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THE GEOLOGY OF THE SOUTH OF MANYAS (BALIKESİR) AND TECTONIC SIGNIFICANCE OF BLUESCHISTS

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ABSTRACT.- The study area comprises mainly Karakaya complex units of Sakarya zone, a granodioritic pluton which cuts the Karakaya complex and unconformably overlying Neogene sedimentary and volcanic rocks. Apart from these, a small blueschist klippe rests on the Karakaya complex. The Karakaya complex in the area studied is made up of Nilüfer unit and tectonically overlying Triassic detritics (Hodul unit and Orhanlar greywacke). Nilüfer unit consists of metabasite-metapelite-marble intercalation at the base and monotonous marbles at the top. Nilüfer unit has undergone greenschist fades metamorphism probably during Late Triassic. Nilüfer unit is in tectonic contact with detritic rocks bearing neritic limestone blocks of Carboniferous-Permian age and rare spilite blocks. A blueschist klippe, which consists of metabasites, is observed on the Nilüfer unit and on the Triassic detritics to the south of Manyas. The metamorphic age of the blueschist is Late Cretaceous as reported from south of Mustafakemalpaşa. The exhumation of blueschists mainly occurred during the latest Cretaceous. Thus, the thrusting of blueschist onto Karakaya complex units took place probably during the Paleocene continent-continent collision. Main blueschist belt is located to the south of klippe which indicates a northward vergence. This shows that back-thrusting occurred during continent-continent collision in the western Anatolia.

INTRODUCTION

Western Anatolia comprises different tectonic units which came together as a result of continent-continent collisions during the Tertiary (Fig.1, Şengör and Yılmaz, 1981; Okay et al., 1996). These continental fragments are separated by suture zones. Izmir-Ankara suture is one of the most important suture, which separates Pontides to the north from the Anatolidae Tauride units in the south. Tavşanlı zone, which consists of ophiolite, ophiolitic melange and blueschist, formed during the northward subduction of Neo-Tethys ocean, is observed to the south of the Izmir-Ankara suture between Bursa and Ankara (Okay, 1984), while Sakarya zone is located to the north of the suture (Fig. 1). The Sakarya zone is made up of Permo-Triassic arc-trench rocks named as Karakaya complex (Tekeli, 1981; Okay et al., 1990, 1996; Akyüz and Okay, 1996) that formed during the closing of Paleo-Tethys and unconformably overlying Jifrassic-Cretaceous sediments (Fig. 2). Izmir-Ankara suture, which constitutes the boundary between Sakarya and Tavşanlı zones, is represented by a strike-slip fault between Bursa and Eskişehir, which was active even after the Miocene (Harris et al., 1994). The area to the south of Manyas is important as shows the pre-Miocene relation between the Tavşanlı zone and Sakarya zone. In this area, blueschists lie on the Karakaya complex as a horizontal klippe. For these reasons, the region south of Manyas was studied and mapped in detail (Akyüz, 1995). This paper comprises the main results of this study.

In the study area there are only very few previous studies. The most important is a published geological map in the scale of 1:100.000 and its explanations, which comprises the eastern part of the study area (Ergül at al., 1986); another study is related to general geology and Tertiary volcanism of the area (Ercan et al., 1990). Moreover, there are some MTA reports which constitute the base to these publications.

There are three main units in the study area. These are Permo-Triassic Karakaya complex units, which cover nearly half of the study area, a small blueschist klippe and Neogene magmatic and sedimentary rocks, which unconformably cover or cut the older units (Fig. 3).

KARAKAYA COMPLEX

The major part of the study area is made up of Karakaya complex units (Fig. 3). The previous studies in the Biga peninsula have indicated that Karakaya complex is composed of four tectono-stratigraphic units. Permo-Triassic Nilüfer unit is made up of metabasite, marble and phyllite which is undergone

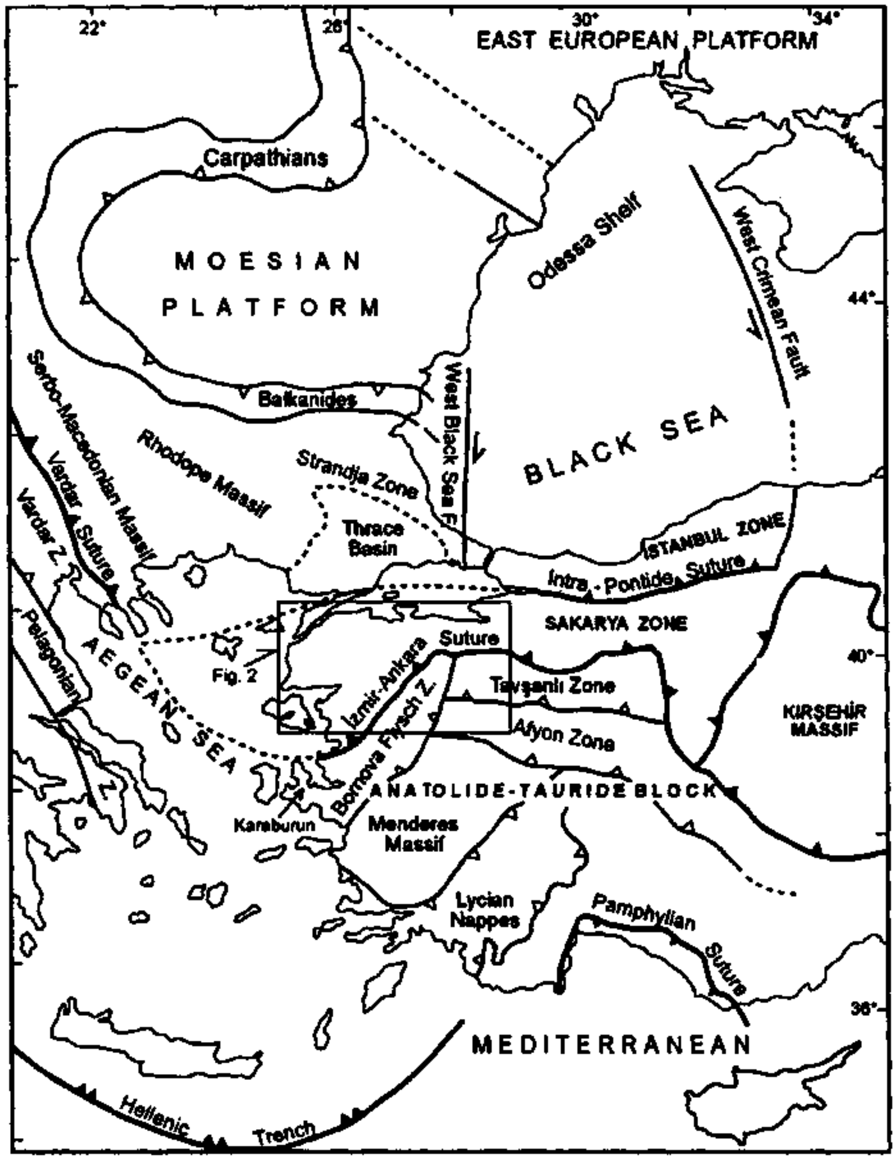

Fig. 1- Tectonic map of western Turkey and the surrounding area. The thick barbed lines show the Mesozoic sutures with their primary subduction polarities. The thinner lines with open triangle indicate major intra-continental thrusts (after Okay et al., 1996).

greenschist facies metamorphism, tectonically overlying clastic rocks with Permian limestone blocks (Hodul unit and Orhanlar greywacke) and Permo-Triassic Çal unit, which is composed of basic volcanic rock, greywacke and pyroclastic rock (Okay et al., 1990). All Karakaya complex units except Çal unit exist in the study area.

Nilüfer unit

This unit was named as Fazlıkonağı formation by Ergül et al., (1986) and Ercan et al., (1990) and in the absence of paleontological data was considered as Upper Paleozoic. This unit is similar to Nilüfer unit

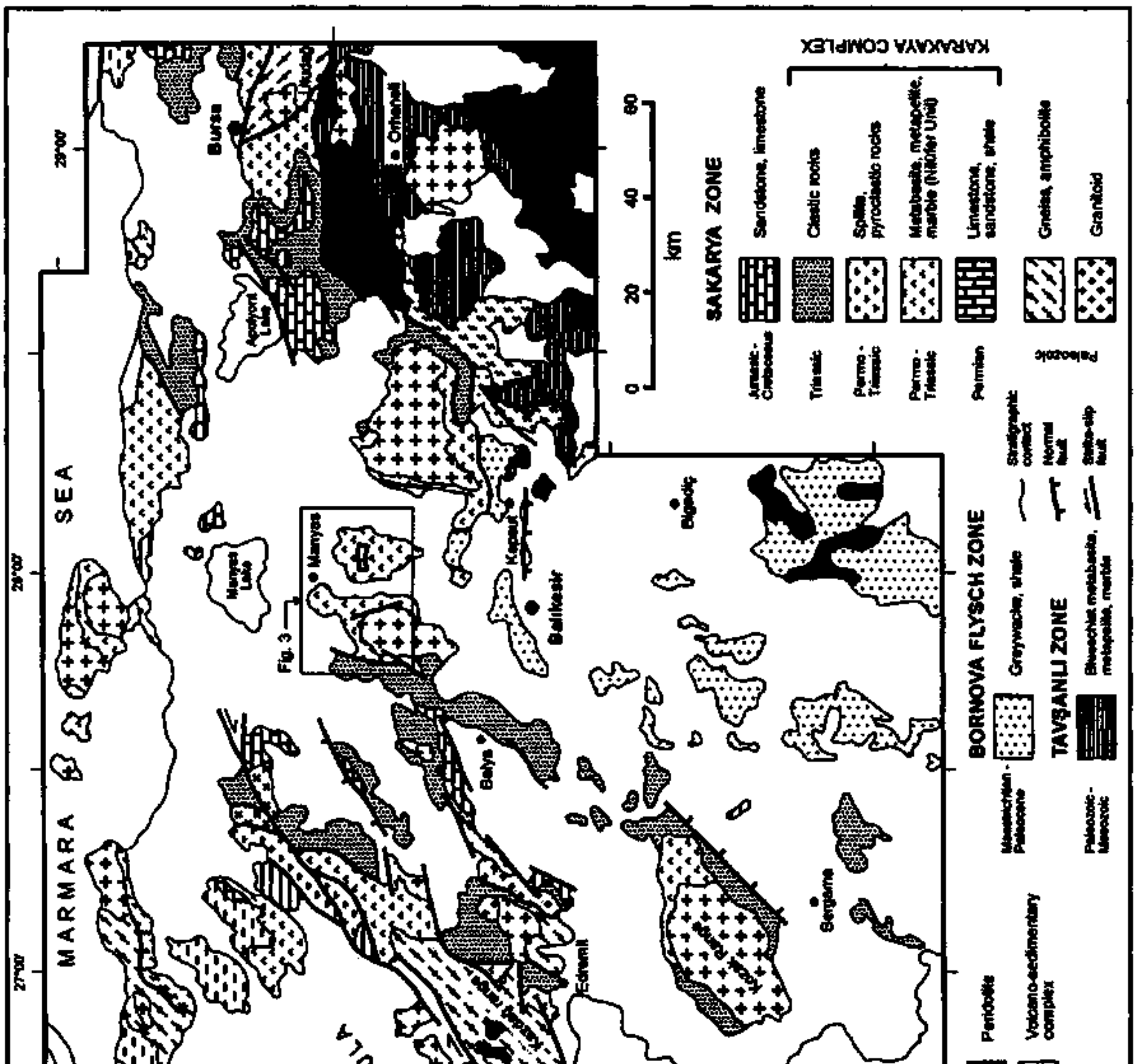

Fig. 2- Simplified geological map of northwestern Turkey (modified after Okay et al., 1996).

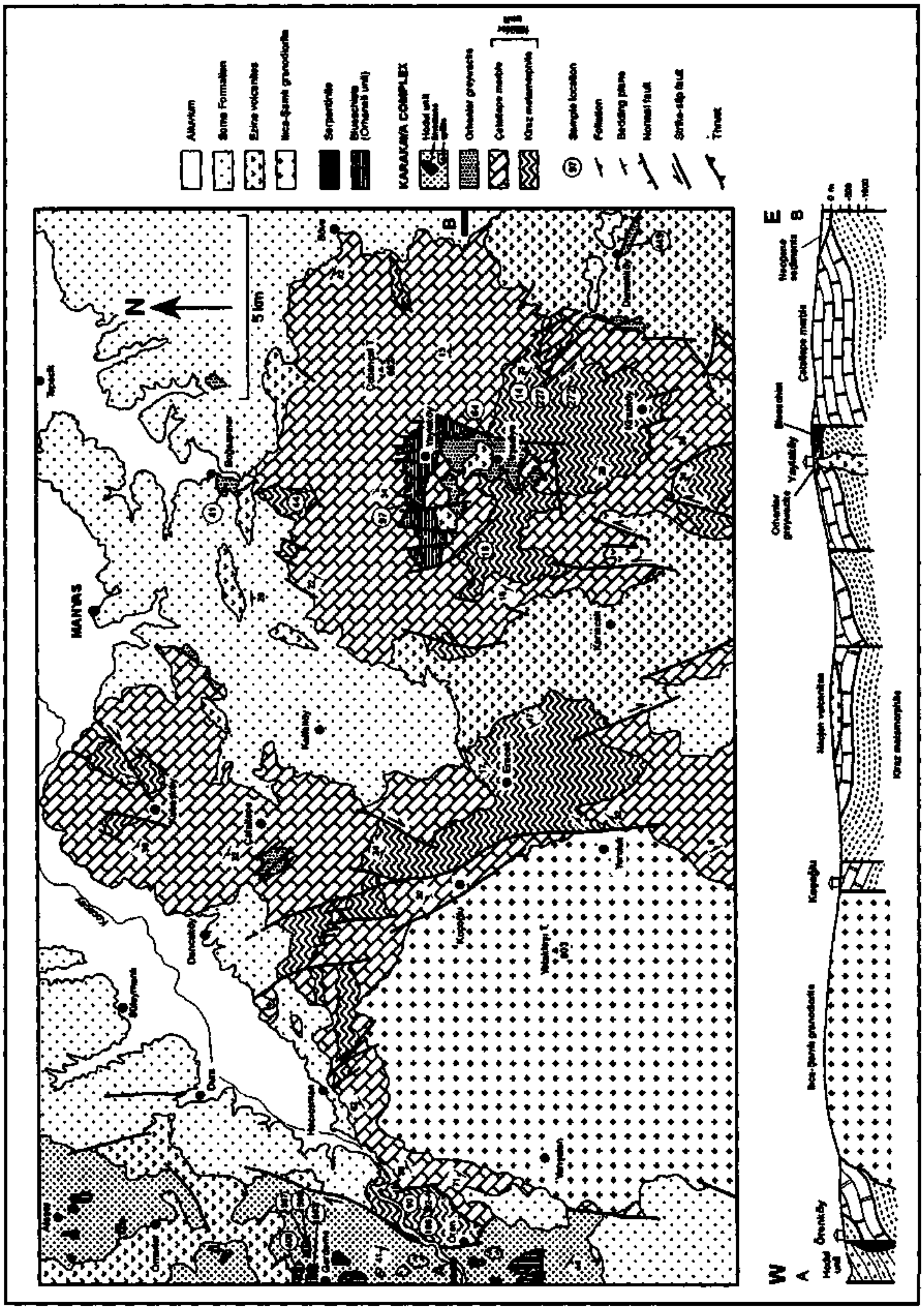

Fig. 3- Geological map and section of the Manyas region. For location see Fig. 2.

lithologically and stratigraphically that crops out extensively in NW Anatolia. Moreover, the name of Fazlıkonağı formation is also used for Upper Cretaceous blueschists (Ergül et al., 1986). Thus, the Nilüfer unit was used in this study.

Nilüfer unit was divided into two formations. These are Kiraz metamorphite at the base, composed of volcano-sedimentary rocks, and Çataltepe marble at the top (Fig. 3 and 4).

Kiraz metamorphite. - It consists of mainly metabasite and metapelite and rarely quartzschist and calcschist. The best outcrops are around Erecek and north of Kirazköy (Fig. 3). All outcrops have a foliation and locally formed preferred mineral orientation. Kiraz metamorphite is in tectonic contact with Hodul unit to the west of the study area. The thickness of the Kiraz metamorphite in the study area is about 1500 m.

Metabasite constitutes %50-60 of Kiraz metamorphite. The common mineral assemble of metabasite is calcic amphibole + albite/oligoclase + epidote + chlorite + sphene ± calcite ± quartz ± opaque. Calcic amphibole locally shows strong zoning. Two samples from metabasite were analysed with electron microprobe and mineral analyses were given in Table 1. In zoned amphibole, actinolitic composition is found in the core while tschermakitic composition occurs in rim (Table 1; Fig. 5). Plagioclase is either oligoclase or albite in composition. In some samples they occur together. Five samples (samples 18, 44, 90, 92-A and 106) are analysed geochemically (Table 2) to understand the origin and tectonic setting of metabasites of Kiraz metamorphite. Si ratios range between %48-56 and Al %13-16. The results are concentrated on basalt area on Le Maitre (1989) diagram. These samples represent island arc tholeite in Mullen (1983) diagram.

Micaschists constitute %25-30 of Kiraz metamorphite. Their common mineral assemblage is muscovite + biotite + quartz + chlorite + plagioclase ± epidote ± calcite ± opaque. One sample (sample 14), which is composed of muscovite, biotite, quartz and plagioclase, was analysed under the electron microprobe (Table 1). Quartzschist and calcschist are seen as interbeds of 5-30 m in thickness or as lenses and comprise %5-10 of Kiraz metamorphite. These lithologies are intercalated with each other. Mineral paragenesis of metabasite and metapelite indicate that Kiraz metamorphite has undergone upper greenschist facies metamorphism.

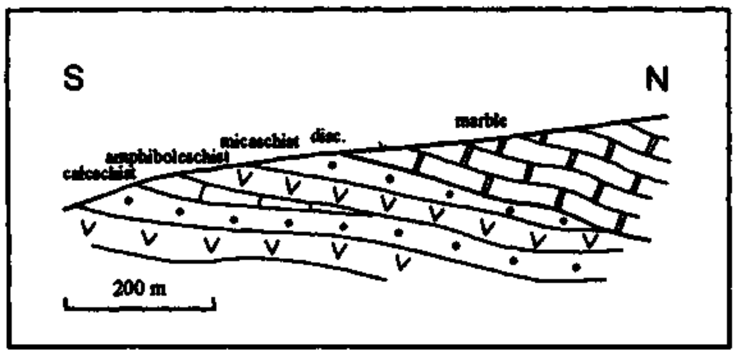

Fig. 4- Sketch section showing the relation between Kiraz metamorphite and Çataltepe marble to the north of Kirazköy.

Çataltepe marble. - Kiraz metamorphite is overlain by marble around Kirazköy and Erecek. In these areas, marbles are underlain by metabasite, micaschist and quartzschist in short distances. This probably indicates that there was an unconformity between them before regional metamorphism. Kiraz metamorphite was thrust on Çataltepe marble around Örenköy to the west of the study area. Çataltepe marble is tectonically overlain by blueschist and Omanlar greywacke around Yaylaköy (Fig. 3 and 4).

Table 1- Chemical compositions of some index minerals from metabasite of Kiraz metamorphite.

	amphibole				epidote		chlorite		plagioclase	
	227		272		227	272	227	272	272	14
	core	rim	core	rim						
SiO_2	53.34	45.00	54.09	44.05	37.36	37.73	27.98	27.47	65.07	62.43
TiO_2	0.07	0.45	0.09	0.41	0.08	0.12	0.08	0.07	0.01	0.11
Al_2O_3	3.58	11.87	3.47	13.19	22.62	22.96	21.85	21.89	23.02	24.71
Cr_2O_3	0.25	0.04	0.06	0.07	0.02	0.02	0.12	0.08	0.01	---
Fe_2O_3	8.78	12.86	8.58	13.72	12.15	11.92	13.62	14.26	0.11	0.16
MgO	16.93	12.21	17.95	11.60	0.01	0.02	21.99	22.29	0.01	0.00
MnO	0.23	0.23	0.18	0.22	0.11	0.08	0.15	0.16	0.00	---
CaO	12.43	11.53	12.30	11.42	23.61	23.54	0.16	0.26	4.23	3.88
Na_2O	0.56	1.70	0.43	1.81	0.05	0.02	0.00	0.02	6.75	8.42
K_2O	0.12	0.09	0.09	0.29	0.01	0.01	0.02	0.06	0.06	0.28
Total	96.29	95.98	97.24	96.78	96.02	96.42	85.97	86.56	99.27	100.00
Structural formula based on:										
	23 O	23 O	23 O	23 O	25 O	25 O	28 O	28 O	8 O	8 O
Si	7.61	6.47	7.62	6.29	3.23	3.24	5.62	5.51	2.86	2.76
Ti	0.01	0.05	0.01	0.05	0.01	0.01	0.01	0.01	0.00	0.00
Al^{IV}	0.39	1.53	0.38	1.71						
Al^{VI}	0.21	0.49	0.20	0.52	Al_t 2.30	2.32	5.18	5.18	1.19	1.28
Cr	0.03	0.01	0.01	0.01	0.00	0.00	0.02	0.01	0.00	---
Fe^{3+}	0.04	0.49	0.33	0.60						
Fe^{2+}	1.01	1.06	0.68	1.04	Fe_t 0.88	0.86	2.29	2.39	0.00	0.01
Mg	3.60	2.62	3.77	2.47	0.00	0.00	6.59	6.67	0.00	0.00
Mn	0.03	0.03	0.02	0.03	0.01	0.01	0.03	0.03	0.00	---
Ca	1.90	1.78	1.86	1.75	2.19	2.17	0.03	0.06	0.20	0.18
Na	0.16	0.47	0.12	0.50	0.01	0.00	0.00	0.01	0.58	0.72
K	0.02	0.02	0.02	0.05	0.00	0.00	0.01	0.02	0.00	0.02
Total	15.01	15.02	15.02	15.02	8.63	8.61	19.80	19.89	4.83	4.97
									alb 74.0	78.4
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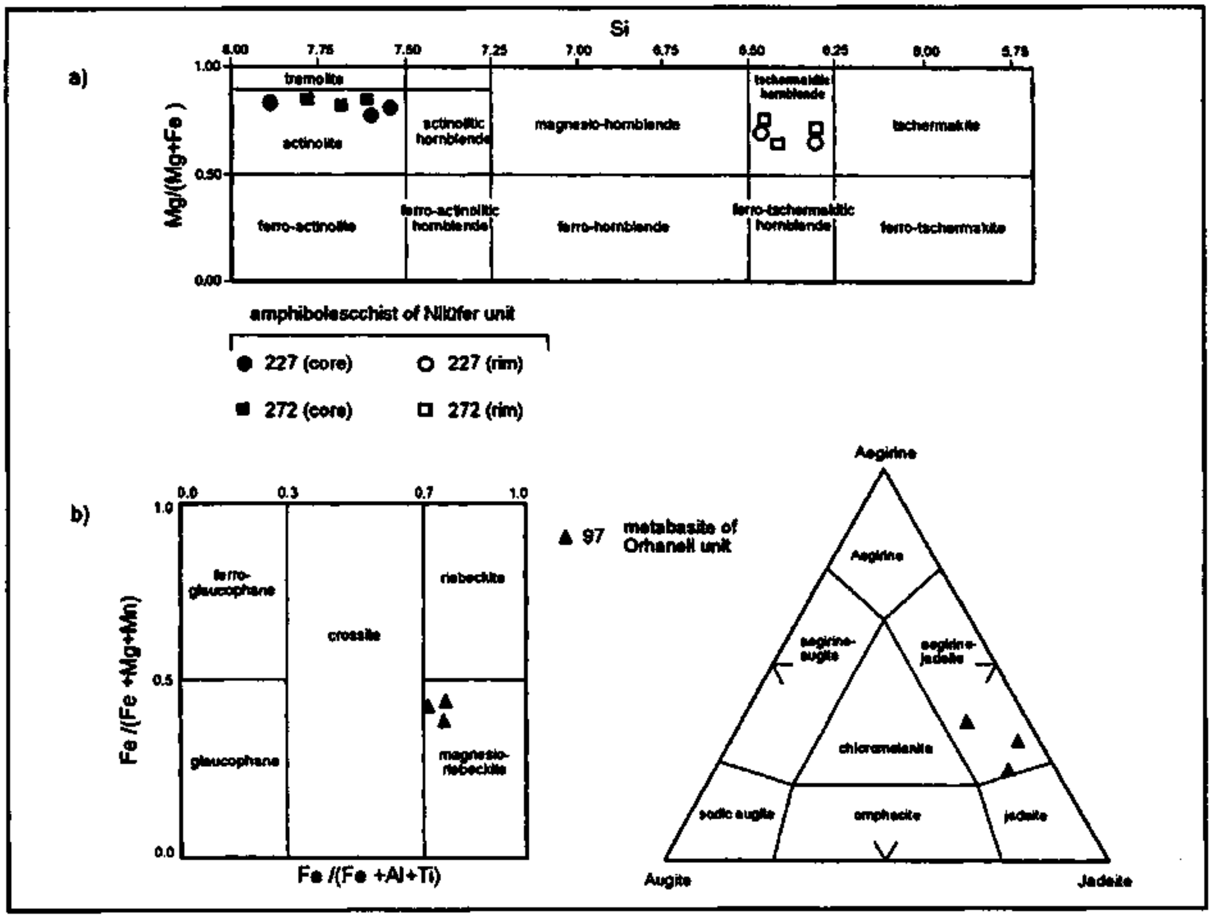

Fig. 5- Amphibole and pyroxene compositions from metabasites of Nilüfer (a) and Orhaneli (b) units.

Çataltepe marble is white-grey, holocrystaline and forms a homogenous sequence. Rare siliceous bands, whose thickness ranges from several cm to 4 cm, are seen within the marble. It is observed that marbles locally preserved primary bedding on the roadway between Manyas-Darıcaköy and that they have middle to thick bedding. This data indicates that marbles are deposited in shallow marine environment. The thickness of the marble is more than 700 m.

The age and tectonic environment of the Nilüfer unit. - No fossils have been found in the Nilüfer unit within the study area. However, Kaya and Mostler (1992) reported Middle Triassic conodonts in carbonate interbeds intercalated with metabasites from the Kozak range in northwest Anatolia. Moreover, it is known from different parts of NW Anatolia that Nilüfer unit is unconformably overlain by Liassic sediments (Okay et al., 1990), thus, the depositional age of the Nilüfer unit is Triassic and metamorphic age is Late Triassic.

Nilüfer unit covers large areas throughout the Sakarya zone extending from Biga peninsula to eastern Black Sea area (Okay et al., 1990,. 1996). Such thick and extensive volcano-sedimentary successions represent basins which is adjacent to active island-arc (Dickinson and Seelly, 1979). Similar volcano-sedimentary successions were reported from New Zealand (Houghton and Landis, 1989) and from present-day Fiji volcanic arc (Hathway, 1994).

Table 2- Geochemical analyses of metabasites in Kiraz metamorphite.

Sample	18	44	90	92-A	106
SiO_2	56.40	54.03	48.68	50.06	48.97
TiO_2	1.65	1.30	1.13	0.87	1.07
Al_2O_3	15.25	13.05	16.10	12.93	15.88
Fe_2O_3*	10.27	12.28	11.18	13.33	11.63
MgO	3.61	6.37	6.72	7.64	6.46
MnO	0.19	0.20	0.17	0.22	0.17
CaO	7.13	8.24	11.89	10.54	11.69
Na_2O	3.97	3.38	3.03	3.11	3.14
K_2O	0.11	0.22	0.10	0.22	0.22
P_2O_5	0.45	0.14	0.07	0.10	0.11
LOI**	0.46	0.62	1.48	0.68	0.16
Total	99.49	99.82	100.65	99.70	99.51
Cr	26.8	33.8	---	370.3	487.4
Ni	11.4	32.5	---	115.8	100.6
Co	27.6	42.0	---	47.6	33.3
V	289.0	477.7	---	353.4	257.3
K	913.0	1826.0	---	1826.0	1826.0
Rb	2.4	6.6	---	2.6	4.4
Ba	9.0	6.6	---	22.8	12.1
Sr	282.4	114.0	---	176.6	172.0
Ga	20.7	13.7	---	10.7	13.4
Nb	2.7	1.9	---	4.2	2.2
Zr	54.3	68.4	---	48.5	62.3
Ti	9892.0	7793.0	---	5261.0	6415.0
Y	20.9	20.7	---	18.1	21.6

* Fe_2O_3 represents total Fe ($FeO+Fe_2O_3$)
** LOI: Lost of ignition

Orhanlar greywacke

This unit is composed of greywacke and shale with limestone and rare spilite blocks. Ercan et al., (1990) defined this unit together with Late Cretaceous units and called them Yayla Melange. However, the lithological characteristics of this unit and the fact that it contains Permian limestone blocks indicate that it belongs to the Orhanlar greywacke which was described in the Biga peninsula. The Orhanlar greywacke technically overlies Nilüfer unit in area to the west of Çataltepe village and around İrşadiye, while it is covered by Neogene sedimentary rocks (Fig. 3 and 6).

The sandstone of Orhanlar greywacke is made up of semi-angular, medium to poorly sorted quartz, feldspar, lithic fragments, mica, chert and opaque grains within, a clay matrix of % 16-20. Quartz is mostly polycrystalline and rarely monocrystalline. K- feldspar-plagioclase ratio is nearly equal. Lithic fragments were derived mostly volcanic and rarely metamorphic and sedimentary rocks. Rare, grey-brownish shale interlayers changing from several cm to 3 m Were observed within greywackes. The matrix of Orhanlar greywacke is intensely sheared and its primary structures have been destroyed. It is.hard to understand the stratigraphic features and thickness of the Orhanlar greywacke due to intense shearing, its homogenous features and absence of a stratigraphic basement.

Grey-bluish, middle bedded limestone and rare spilite blocks are important components of the Orhanlar greywacke. Limestone blocks are seen around Dumanköy and Boğazpınar and between İrşadiye-yayla. Their size range from 0.5 to 150 m. Spilite blocks are rare and their sizes are less than 20 m.

While, there is no paleontological data from the matrix of Orhanlar greywacke, the limestone blocks in the Orhanlar greywacke are highly fossiliferous. Samples collected from Boğazpınar, İrşadiye and Dumanköy have the following fossils: Schwagerinidae, *Schubertella* sp., *Deckerella* sp., *Paleotextularia* sp. (Permian, sample no: 41); *Globivalvulinasp., Tetrataxissp.,* (Carboniferous-Permian, sample no: 64); *Climacammina* sp., *Cribrogenerina* sp., *Eotuberitina* sp., *Glomospira* sp. (Upper Permian, sample no: 449). Orhanlar greywacke is unconformably overlain by Liassic sediments as well as other Karakaya complex units (e.g. Aygen, 1956; Okay et al., 1990), thus, its age is constrained as Permian-Triassic.

The blocky and intensely sheared structure of Orhanlar greywacke points out that it was formed in a tectonically active environment. Similar sequences were reported from present-day trench zones (e.g. Peru-Chile: Thornburgh and Kulm, 1987; Middle America: McMillen et al., 1982; Aleutian: Underwood, 1986; Cascadia: Schweller and Kulm, 1978; Japan: Boggs, 1984; Hellenic trench: Stanley and Maldonado, 1981), thus, Orhanlar greywacke is accepted as trench deposit.

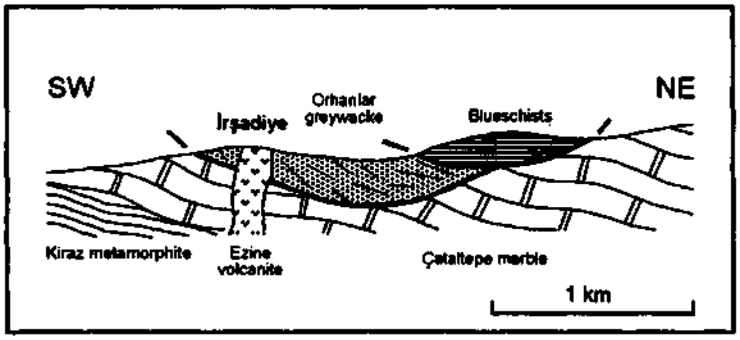

Fig. 6- Sketch section showing the relations among Nilüfer unit, Orhanlar greywacke and blueschist around Yaylaköy.

Hodul unit

Hodul unit is composed of grey-yellowish white arkosic sandstone and dark shale with Permian limestone and spilite blocks. It crops out to the west of Örenköy and around Ömerler to the NW of the study area (Fig. 3). These outcrops form the northern end of a belt trending NNE-SSW, 8-10 km in width and 80 km in length extending from İvrindi to Manyas (Fig. 2, Okay et. al., 1990, 1996). This unit is also defined as Karakaya complex by Ercan et. al,, (1990).

Hodul unit is in subvertical tectonic contact With the Nilüfer unit in the east and is covered by Neogene volcanic and sedimentary rocks in the north and south (Fig. 3). Hodul unit has a monoclinal structure younging westward in the study area. The bottom part of the sequence in the study area starts with middle bedded sandstone intercalated with rare shale and micritic limestone (Fig. 7). Small and rare limestone and spilite blocks are seen upward. Sandstone gets dirty in this part due to increasing amount of the matrix and lithic fragments while shale interbeds thicken. The upper part of the sequence has a olistostromal character with limestone blocks (Fig. 7 and 8). The presence of a sheared zone and plastic deformation of several cm around limestone blocks indicates that the limestone blocks have slid into the detritics during the sedimentation. The thickness of Hodul unit in the study area is 1200 m. The Hodul unit shows no regional metamorphism in the study area.

Arkosic sandstone of Hodul unit is made up of semi-angular, well-sorted quartz, feldspar, mica, chert and lithic fragments in clay matrix of %6-10. Quartz are both mono- and polycrystalline. K-feldspar is represented by microcline and its amount is relatively more than plagioclase. The presence of microcline shows that sandstone took the material from a granitic source. Lithic fragments increase towards the top of the sequence which have mostly volcanic and rarely sedimentary rock origin.

The amount and size of limestone blocks increases towards the top of the unit. These grey-bluish blocks are sparitic and mostly middle to thick bedded and rarely massive. The size of blocks range from several cm to 600 m. The samples taken from the blocks gave Upper Carboniferous to Upper Permian ages. Two samples (no: 1503 and 1568) from just east of Gerdeme village contain fusulinid and small forams giving a Moscovian age: *Eostaffella* sp., *Pseudoendothyra* sp., *Verella* sp., *Profusulinella latispiralis* Safonova, *Profusulinella* aff. parva (Lee and Chen), *Eotuberitina* sp., *Tuberitina* sp., *Diplosphaerina* sp., *Endothyra* sp., *Globivalvulina* sp., *Monotaxinoides* sp., *Glomospira* sp. (Leven and Okay, 1996). Another sample (no:1499) from west of Gerdeme village has a rich fusulinid and small foram fauna giving Upper Permian age: *Nankinella* sp., *Schubertella* sp.; *Verbeekina* sp., *Eotuberitina sp., Tuberitina sp., Diplosphaerina sp., Globivalvulina* sp., *Glomospira* sp., *Nodosaria* sp., *Pachyphloia* sp., *Climacammina* sp., *Lasiodiscus* sp. In a limestone block to the north of Gerdeme (no:409), *Glomospira*

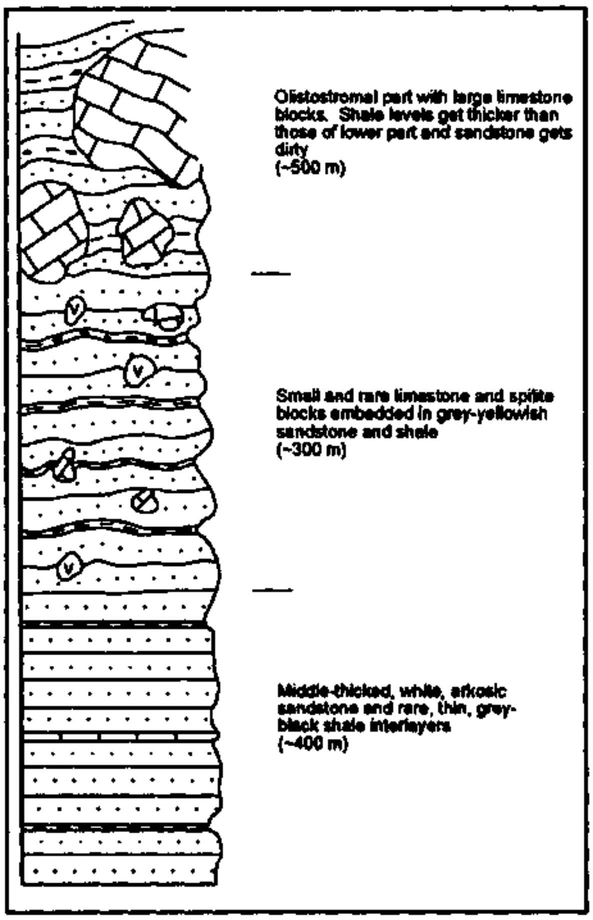

Fig. 7- Generalized columnar section of Hodul unit to the north of Ören.

sp., *Dunbarula* sp., *Paleotextularia* sp. giving Upper Permian age has been determined. Moreover, limestone pebbles in a debris flow which lies under limestone block have Upper Permian fossils: *Eopolydiexodina* sp., *Tuberitina* sp.

A few spilite blocks are present within the Hodul unit. They have amygdaloidal texture and are composed of feldspar microliths and phenocrysts, monoclinic pyroxene and chlorite in vitrophyric groundmass. Amygdales were filled by mostly chlorite and rarely quartz.

There are no paleontological data within the detritic matrix of Hodul unit in the study area. The youngest age determined from limestone blocks is Upper Permian (Murgabian-Midian). However, Norian macrofossils were reported in shale and siltstones which are equivalent to the upper part of Hodul unit in the Balya and İvrindi areas in the southern continuation of this olistostromal belt (Aygen, 1956; Leven and Okay, 1996). Hodul unit is covered by Liassic sediments outside the study area (e.g. Aygen, 1956; Genç, 1986; Okay et al., 1990). These data show that the age of the Hodul unit is Late Triassic. The presence of abundant feldspar indicates that Hodul unit was rapidly deposited in a fault-controlled basin. Okay et al., (1990, 1996) proposed that Hodul unit represents a fore-land environment.

BLUESCHISTS

Blueschists cover a large area between Orhaneli, Tavşanlı, Eskişehir and Sivrihisar in NW Anatolia (Okay, 1984, 1986). This belt, which was named as Tavşanlı zone by Okay (1984), consists of regionally metamorphosed, thick and regular sequence of blueschists (Orhaneli unit) at the base, and tectonically overlying ophiolitic melange and peridotite. Orhaneli unit is composed of metapelitic rocks bearing jadeite, glaucophane, chloritoid and lawsonite (Okay and Kelley, 1994) at the base with more than 1 km in thickness. They are conformably overlain by a thick homogenous marble sequence. At the top of the Orhaneli unit, there are metabasites, metacherts and metashales (Okay, 1981). The basement of the blueschist sequence is not observed in the Tavşanlı zone. According to Ar/Ar dating on phengite and sodic amphibole in blueschist, the age of HP/LT metamorphism is late Cretaceous (Okay and Kelley, 1994; Harris et al., 1994). Orhaneli unit represents the passive northern margin of Anatolide- Tauride platform. This passive margin was subducted in an intra-oceanic subduction zone following the consumption of Neo-Tethyan oceanic lithosphere and underwent blueschist fades metamorphism (Okay et al., 1984,1986) similar to the case in Oman (e.g. Goffe et al., 1988; Searle et al., 1994; Michard et al., 1994).

The most significant feature of the area studied is the exposure of the basal tectonic contact of the blueschist. A small blueschist klippe rests on marbles of Nilüfer unit around Yaylaköy, 10 km south of Manyas (Fig. 6). Thrust plane is marked by serpentinite

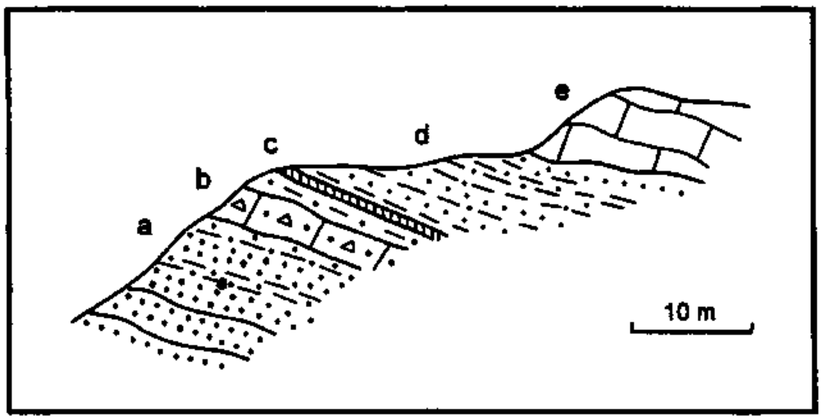

Fig. 8- The transition from arkosic sandstones to limestone olistoliths in the Hodul unit (northeast of Gerdeme village, locality 1568). a- arkosic, white sandstone, b- debris flow with limestone pebbles of 10-15 cm of size, c- black chert, d- brown-greenish brown micaceous sandstone, siltstone, shale, e- Middle Carboniferous (Moskovian) limestone olistolith; the determined fusulinid and small forams: *Eostaffella* sp., *Pseudoendothyra* sp., *Verella* sp., *Profusulinella* aff. parva (Lee and Chen), *Profusulinella latispiralis* Safonova, *Tuberitina* sp., *Diplosphaerina* sp., *Endothyra* sp., *Eotuberitina* sp., *Globivalvulina* sp., *Monotaxinoides* sp.

slices. Serpentinites become dominant westward. Metabasites have a bluish color'due to common presence of sodic amphibole. Metamorphic mineral paragenesis in the metabasite is sodic amphibole + lawsonite + sodic pyroxene + chlorite + sphene ± quartz. Sodic amphibole and lawsonite comprise %70-80 of rock. Sodic pyroxene has formed during the first stage of metamorphism and substitutes igneous augite. Relic igneous augite is preserved in some massive metabasites. The mineral paragenesis and petrographic characteristics of these blueschists are similar to blueschists reported from Tavşanlı zone (Okay, 1980, 1981). One metabasite sample (no: 97) was analysed under the electron microprobe. In this sample, sodic amphibole is magnesio-riebeckite and sodic pyroxene is aegirine-jadeite and contain %65 of jadeite (Table 3; Fig. 5). P-T conditions of metamorphism based on 65 % jadeite, content of sodic pyroxene, and the presence of lawsonite are temperatures less than 450 °C and pressures more than 9 kbar. Okay and Kelley (1994), who analysed blueschist metapelite to the south of Mustafakemalpaşa, reported that the condition of blueschist metamorphism was 430 ± 30 °C and 20 ± 2 kbar based on chlorite-glaucophane jadeite paragenesis in metapelites.

NEOGENE MAGMATIC AND SEDIMENTARY ROCKS

Ilıca-Şamlı granodiorite

Ilıca-Şamlı granodiorite is a large leucocratic pluton located to the SW of the study area. The petrology and petrography of the pluton was studied by Bürküt (1966). The age of the pluton was determined as 23-25 Ma based on K/Ar method on orthoclase and hornblende (Ataman, 1973) and 20-23 Ma based on Rb/Sr method on biotite (Bingöl et al., 1982). Thus, the age of the pluton is Late Oligocene-Early Miocene.

Ilıca-Şamlı granodiorite cuts the Nilüfer and resulted in contact metamorphism. Aplite, quartz and rare pegmatite dykes and veins cut both granodiorite and country rocks. Ilıca-Şamlı granodiorite is made up of quartz, plagioclase, K-feldspar, rare biotite, hornblende, and accessory epidote, sphene, tourmaline, zircon, ilmenite and apatite. This pluton is granodiorite in the Le Bas and Streckeisen (1991) classification.

Ilıca-Şamlı granodiorite is surrounded by marble. Especially to the northern contact of pluton, a contact metamorphic zone is seen represented by idocrase-garnet bearing skarn zone with 0.5-2 km in width. The porphyritic texture of the Ilıca-Şamlı granodiorite and its sharp contact with country rocks point out to shallow level emplacement of the pluton.

Table 3- Representative mineral analyses from metabasites of Orhaneli unit (no: 97).

	sodic amphibole	sodic pyroxene	lawsonite	chlorite
SiO_2	55.33	57.28	40.83	27.57
TiO_2	0.09	0.06	0.34	0.04
Al_2O_3	3.03	15.94	31.57	15.85
Cr_2O_3	0.01	0.01	0.04	0.02
Fe_2O_3	21.92	7.56	1.80	23.64
MgO	8.46	1.98	0.09	18.73
MnO	0.30	0.09	0.03	0.69
CaO	0.64	3.73	16.98	0.27
Na_2O	7.02	13.00	0.03	0.04
K_2O	0.04	0.01	0.01	0.02
Total	96.84	99.66	91.72	86.87
Structural formula based on:				
	23 O	6 O	8 O	28 O
Si	7.94	2.00	2.07	5.80
Ti	0.01	0.00	0.01	0.01
Al^{IV}	0.06	0.00	0.00	2.20
Al^{VI}	0.46	0.65	1.89	1.74
Cr	0.00	0.00	0.00	0.00
Fe^{3+}	1.54	0.22	0.08	0.44
Fe^{2+}	1.09	0.00	---	3.72
Mg	1.77	0.10	0.01	5.88
Mn	0.04	0.00	0.00	0.13
Ca	0.10	0.14	0.92	0.06
Na	1.95	0.88	0.00	0.02
K	0.01	0.00	0.00	0.01
Total	14.97	3.99	4.98	20.01
		jad. 065		
		aeg. 0.23		
		aug. 0.12		

Volcanic and sedimentary rocks

Volcanic succession of Lower to Middle Miocene composed of volcanic breccia, massive lava and rare tuff and volcanogenic clay was named as Ezine volcanites. These rocks were studied by Ercan et al., (1990) in detail. Dacitic-andesitic lavas of Ezine volcanite are common around Boğazpınar while volcanic breccias are seen around Ömerler, Karıncalı and Dumanköy (Fig. 3). There is no radiomefric data within the study area but the age of volcanic rocks from neighbouring areas were reported as 17-21 Ma (e.g. Borsi et al., 1972; Benda et al., 1974; Gündoğdu, 1984; Ercan et al., 1990, 1995).

Volcanic activity was interrupted in the Middle Miocene and terrigenous sediments were deposited in river and lacustrine environment. The age of this formation is accepted as Middle Miocene-Pliocene from mammal fossils around Sünnük village to the east of the study area (Fig. 2) determined by Bemor and Tobien (1990) and pollen analysis and lacustral gastropods reported by Ercan et al., (1990).

DISCUSSION

The most important feature of the study area is that blueschists lie technically on the Permo-Triassic Karakaya complex units as a klippe. The main blueschist belt occurs to the south of this klippe (Fig. 2), then it means the vergence of the blueschist was north- northwestward. This vergence is contrary to the general southward vergence of Alpid orogen in western Anatolia and points out that northward back-thrusting developed along the suture as the case in the western Alps.

There is no direct data on the time of northward thrusting of blueschist within the study area, however, there is no doubt that this event occurred after blueschist facies metamorphism. The age of blueschist metamorphism is isotopically determined by Okay and Kelley (1994) as 80-90 Ma (Turonian-Santonian) in the region south of Mustafakemalpaşa (Fig. 2). The fact, that blueschist grains and pebbles were found in Upper Senonian-Paleocene clastic rocks of Sakarya zone (Norman and Rad, 1971; Batman, 1978) indicates that blueschists which metamorphosed in 50-60 km depth during Turonian-Santonian were partly exhumed during Maastrichtian to Paleocene. Moreover, blueschist blocks were reported within Upper Maastrichtian-Lower Paleocene wild-flysch deposited to the south of Tavşanlı zone (Göncüoğlu et al., 1992).

The continent-continent collision between Sakarya zone and Anatolid-Tauride platform occurred probably during the Paleocene. The evidence of this opinion is the passing from flysch deposition to molasse deposition in Sakarya, zone during Paleocene followed by thrusting in the Sakarya zone (Saner, 1980). Thus, the exhumation of blueschists occurred during the Latest Cretaceous before continent-continent collision. Blueschists, which were partly exhumed, were thrust northward over the Sakarya zone during continental collision.

CONCLUSION

A small blueschist klippe lies on Permo-Triassic Karakaya complex units with a low angle tectonic contact. The age of thrusting is post-Late Cretaceous (probably Paleocene) and has occurred during the continent-continent collision. Blueschists were thrust northward onto Sakarya zone during this collision. This indicates that back- thrusting occurred along the Izmir-Ankara suture such as the case in western Alps.

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