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THE STRATIGRAPHICAL, GEOCHEMICAL AND GEODYNAMICAL MODELLING OF THE NORTHEAST MARGIN OF MENDERES-TAURUS BLOCK

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Abstract : The area studied about 20 kilometers northwest of Konya is composed of Palaeozoic-Mesozoic metasedimentary and metaigneous rocks. The oldest formation exposed is the Silurian-Lower Permian rocks. The lower part of this unit is mostly of Silurian-Lower Carboniferous metacarbonates having reefal origin. These rocks gradually pass in to Devonian-Lower Permian rocks having continental margin, shallow water and pelagic characteristics. These are cut by different kind of metaigneous rocks. The metatrachyandesite and metadolerite have within plate, and the metabasaltic andesite has characteristics of continental arc lava, and the metahornblende gabbro show MORB like characteristics. All these rocks are covered unconformably by ? Upper Permian-Lower Triassic continental metaclastics. The metaclastics are conformably overlain by Upper Permian-Triassic aged shallow water metaclastic-metacarbonate intercalations. These units conformably pass into the Triassic-Lower Cretaceous metacarbonates and continue up to the Upper Cretaceous aged pelagic metasedimentary rocks. All these rock are overthrusted by Mesozoic ophiolitic rocks. The youngest rock in the area is Miocene-Pliocene aged neo-autochthonous lacustrine-continental sediments and volcanic rocks.

The stratigraphical, lithological and geochemical characteristics of these rocks show presence of an ocean, probably between Menderes-Taurus and Kırsehir block during Devonian time. The oceanic litosphere was subducted under to Menderes-Taurus block during the Middle-Late Carboniferous, and a magmatic arc developed on the continental shelf. Before late Permian-Early Triassic time, the magmatic arc completed its evolution, and the continental shelf repeatedly collapsed and foundered during the Mesozoic time. During the late Cretaceous, the oceanic litosphere subducted under the Kırşehir block and the oceanic rocks obducted to the other rocks. Meanwhile, the region have undergone intense and polyphase deformation, metamorphism during the late Cretaceous.

Keywords: Menderes-Taurus Block, Devonian ocean, magmatic arc, subduction, metamorphism, poly-phase deformation

Menderes-Toros Bloku Kuzeydoğu Kenarının Stratigrafik, Jeokimyasal ve Jeodinamik Modellemesi

Özet : Konya'nın 20 km kuzeybatısındaki inceleme alanında Paleozoyik-Mesozoyik yaşlı metasedimanter ve metamagmatik kayaçlar yüzeylenir. Yörenin en yaşlı topluluğunu Siluriyen-Alt Permiyen yaşlı resifal kompleks niteliğindeki metakarbonatlar, sığ-denizel, kıta-kenarı ve pelajik özellikli kayaçlar ile değişik bileşimli metamagmatitler oluşturur. Metamagmatitlerden metatrakiandezit ve metadoleritler levha içi, metabazaltik andezitler magmatik yay ve metahornblend gabrolar ise okyanus ortası sırtı bazalt (MORB) kökenlidir. Söz konusu kayaçlar ? Üst Permiyen-Kretase yaşlı diğer bir metamorfik topluluk tarafından açılı uyumsuz olarak örtülür. Bu topluluk alttan üste doğru, karasal metaklastikler, sığ-denizel metaklastik-metakarbonat ardalanması, platform tipi kalın metakarbonatlar ve pelajik metasedimanter kayaçlardan oluşmuştur. Tüm bu kayaçlar Mesozoyik yaşlı ofiyolitler tarafından üzerlenmektedir.

Yöredeki kayaçların stratigrafik, litolojik ve kimyasal özellikleri, Devoniyen yaşlı bir okyanusun (olasılıkla Menderes-Toros ve Kırşehir Bloku arasında) varlığını göstermektedir. Orta-Geç Karbonifer'de bu okyanusa ait litosfer Menderes-Toros Bloku (MTB) altına dalmış ve MTB şelfi üzerinde bir magmatik yay gelişmiştir. Erken Triyas (?Geç Permiyen) öncesinde magmatik yay evrimini tamamlamış ve MTB kıtasal şelfi tekrar parçalanmaya/çökmeye başlamıştır. Kretase esnasında okyanusal litosfer bu kez Kırşehir Bloku altına dalmış ve okyanusal kayaçlar Menderes-

Toros Blokunu üzerlemiştir. Bu esnada yöredeki Paleozoyik-Mesozoyik yaşlı kayaçlar metamorfizmaya, şiddetli ve çok evreli deformasyona uğramıştır.

Anahtar kelimeler: Menderes-Toros Bloku, Devoniyen Okyanusu, Magmatik yay, dalma-batma, metamorfizma, çok evreli kıvrımlanma.

INTRODUCTION

The investigation area is located in the Central Anatolia about 20 km north of the Konya (Fig. 1). According to the tectonic subdivision of the Turkey, the area is a part of

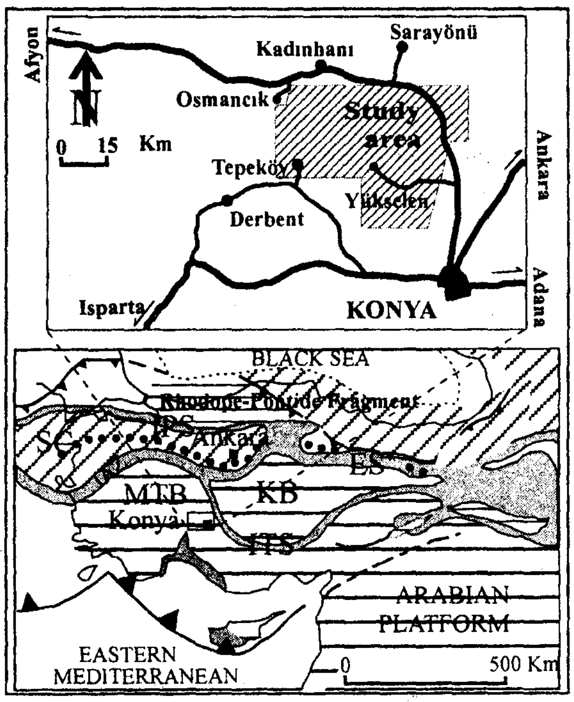


Figure 1. Paleotectonic map of Turkey (Şengör, 1984) and the location of the study area. (MTB:Menderes-Taurus Block, KB:Kırşehir Block, ITS:İnner Tauride Suture, ES:Erzincan Suture, IAZ: İzmir-Ankara Zone, SC:Sakarya Continent, IPS:Intra Pontide Suture).

the Anatolides (Ketin, 1966) and is situated on the central northern margin of the Menderes-Tauride Block (Şengör, 1985). A thick sequence of metamorphosed sedimentary and magmatic rocks ranging in age from early Paleozoic to Cretaceous are exposed in the study area, and are considered to be a part of the Afyon and Tavşanlı Zones of the Okay (1986) or the Kütahya-Bolkardağı Zone of Özcan et al. (1988). Inner Tauride Suture Zone, İzmir-Erzincan Zone, Menderes Massif and Kırşehir Block are situated northeast, north, west and east of the study area, respectively. In the region, Wiesner (1968) and Göger and Kıral (1969) have outlined general stratigraphy of the region. Kaaden (1966) stated that the rocks of the region have undergone blueschist metamorphism due to Variscan orogeny. In the regional studies, especially the Mesozoic geotectonic evolution of the region was discussed by Şengör and Yılmaz (1981). In addition Oktay (1982) explained detailly the Late Mesozoic evolution of the southeast Konya, and Görür et al. (1984) have shown the existence of an oceanic basin near the Tuz Gölü. Özcan et al. (1988, 1990) revealed that the rocks in the north of Konya display different features form the surrounding tectonic units. They also said that the Paleozoic rocks forming the Hercynian basement of the region evolved in the Late Carboniferous back-arc settings. Eren (1993a, 1993b, 1996 a, 1996b and 1996c) studied the stratigraphy and structural features of the region and found out several tectonostratigraphic units, named as Bozdağlar massif. Kurt (1994, 1996, 1997a, 1997b) has investigated in detail the geochemical and petrological features of the area.

The aim of this paper is to explain the stratigraphical, geochemical and geodynamical evolution of the study area, during the Paleozoic and Mesozoic time in the lights of the recent and previous studies.

STRATIGRAPHY

In the study area rocks of the Bozdağlar massif crop out and form the basement. Bozdağlar massif structurally can be divided into three main units, from bottom to top, the autochthonous Upper Permian-Cretaceous Gökçeyurt Group, allochthonous Mesozoic Çayırbağı Ophiolite and allocthonous Silurian-Cretaceous Ladik Metamorphites. The Upper Miocene-Quaternary continental sediments and volcanics constitute the cover of these basement rocks (Figs. 2 and 3).

The autochthonous or parautocthonous Gökçeyut Group cropping out in a half tectonic window southwest of the area, consists mainly of low-grade metamorphic rocks,

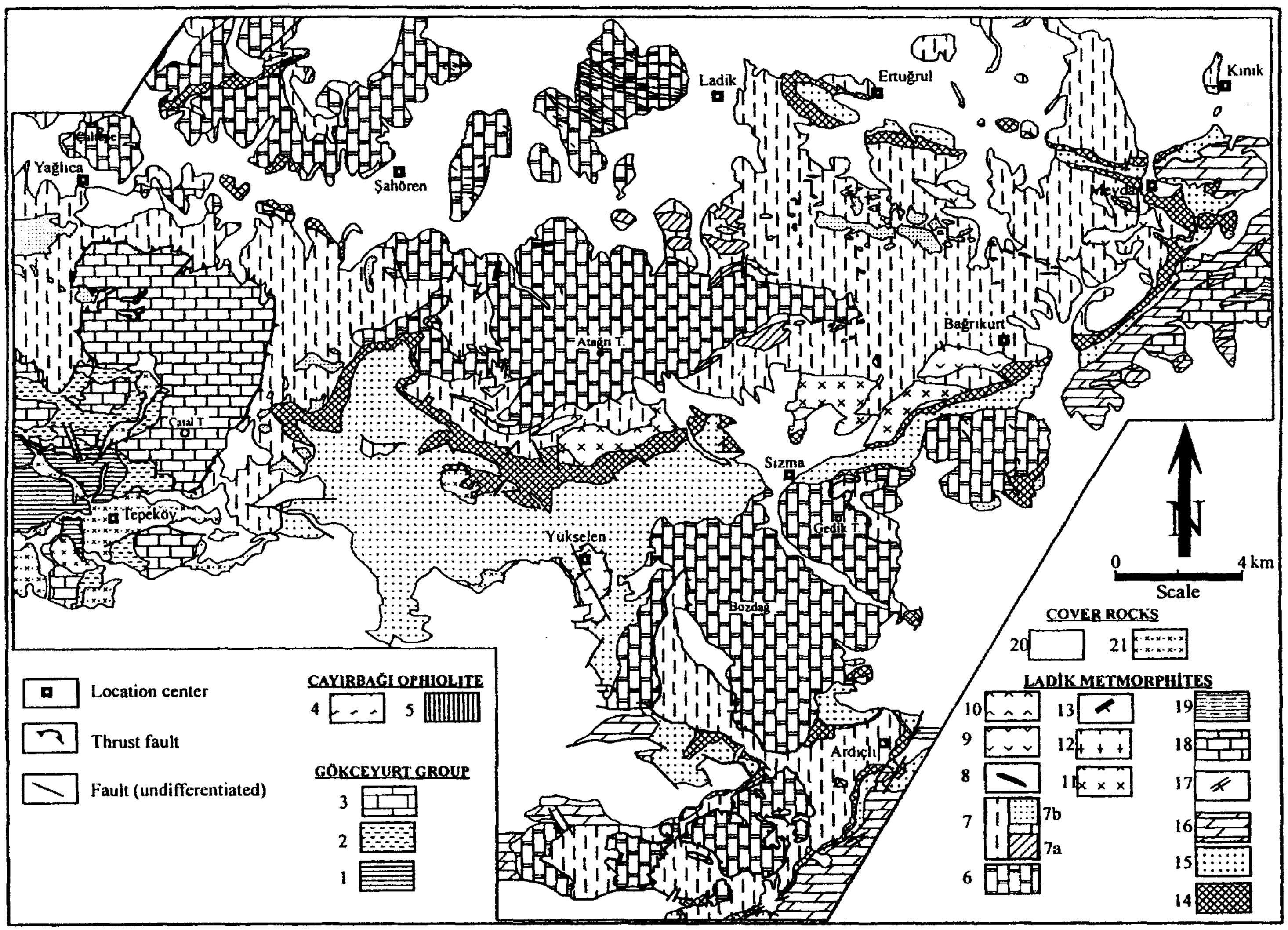


Figure 2. Geological map of the studied area. Gökçeyurt Group (Upper Permian-Cretaceous): 1-Derbent Formation, 2-Aladağ Formation, 3-Lorasdağı Formation; Çayırbağı Ophiolite (Mesozoic): 4-Karşıtepe basalt, 5-Gabbro, Ladik Metamorphites: Sızma Group (Silurian-Lower Permian), 6-Bozdağ Formation, 7-Bağrıkurt Formation, 7a- Ardıçlı member, 7b-Bahçesaray olistolithes; Kadınhanı Metamagmatics (Devonian-Lower Permian): 8-Ayyiles Metagabbro, 9-Karadağ Spilite, 10-Bişiktepe Metabasite, 11-Karatepe Metabasalticandesite, 12-Taşlıtepe Metatrachyandesite, 13-Çeştepe ; etadolerite; Ardıçlı Group: 14-Bahçecik Formation, 15- Ertuğrul Formation, 16-Bademli Formation, 17-Ceylantepe Dolerite 18-Nuras Formation, 19-Karasivri Formation; Cover rocks (Upper Miocene-Quaternary): 20-Sedimentary, 21-Volcanic rocks.

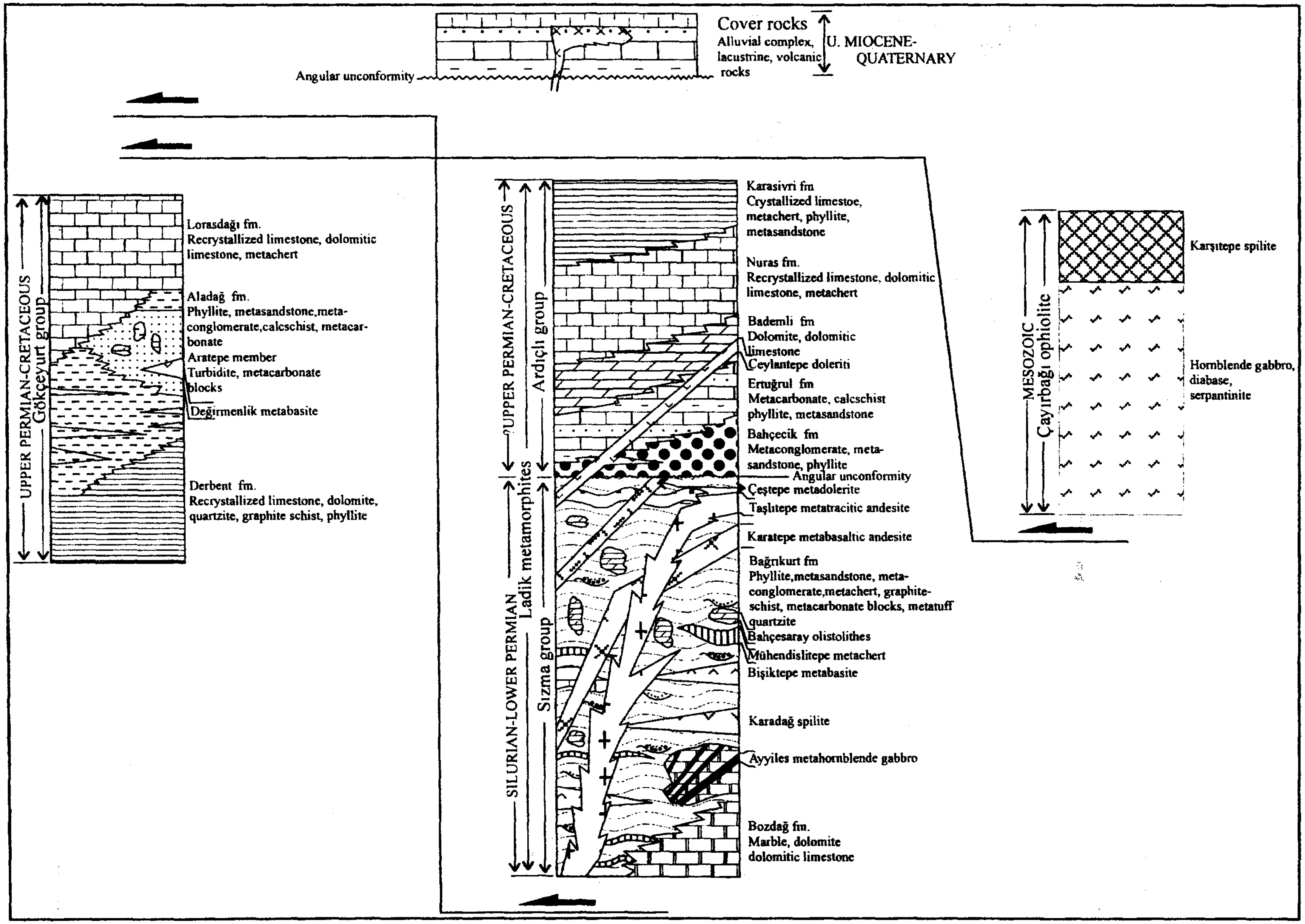


Figure 3. Generalized tectono-stratigraphic section of the sdudied area.

representing originally the shelf sequence. The Group is subdivided into three formations. The Upper Permian Derbent Formation, consists of dark gray-black recrystallized limestone, marble, graphite schist, phyllite and pink-white colored quartzite. The formation is very fossiliferous, containing fusulinid, algae, coral, crinoid and bivalvia. This formation passes gradually into the varicolored rocks of the Upper Permian-Upper Triassic Aladağ Formation. Aladağ Formation mainly consists of purple to violet phyllites, metasandstones, metaconglomerates, yellowish calcschists, and yellow-gray- white colored metacarbonates. At the middle part of the formation, olistostromal facies including metacarbonate blocks of which mainly derived from the Derbent Formation occur. At this level, rare metabasite sills can be observed in the formation. The Aladağ Formation consists rare fusulinid and foraminifers, and is conformably overlain by the Upper Triassic-Cretaceous Lorasdağı Formation which is the youngest unit of the Gökçeyurt Group. The Lorasdağı Formation is made up of platform type thick metacarbonates. The metacarbonates vary from limestone to dolomite. The upper part of the formation have pelagic characteristics (Görmüs, 1984).

The Silurian-Cretaceous aged Ladik Metamorphites overlie tectonically both the Gökçeyurt Group and Mesozoic Çayırbağı Ophiolite. The Ladik Metamorphites includes Silurian-Lower Permian Sızma Group, Devonian-Lower Permian Kadınhanı Metamagmatics and ?Upper Permian-Cretaceous Ardıçlı Group. The rocks of the Ladik Metamorphites are metamorphosed during Alpine events. The oldest unit of the Sızma Group is Silurian-Lower Carboniferous Bozdağ Formation which originally represents reefal complex and occur as seperated bodies or lenses with varying geometry. The Bozdağ Formation consists of light colored marble and dark colored (gray-black) laminated metadolomite and dolomitic limestone (Kurt and Eren, 1998). Dolomite consists of wide spread Amphipora biostromes. Some parts of the formation are very fossiliferous and consist of stromatoporoid, nautiloid, coral, conodont, algae and crinoid (Wiesner, 1968; Eren, 1993; Kurt, 1994). This rocks pass laterally and vertically into the Devonian-Lower Permian Bağrıkurt Formation which is the most widespread unit in the region. The Bağrıkurt Formation is made up of originally shallow marine, continental margin and basinal facies. At the base, it begins with an alternating units of calcschists, phyllites, metasandstones, metaconglomerates and metacherts. In some places metacherts occur at the boundary of the Bozdağ Formation and Bağrıkurt Formation alternating with the lithologies of the both. At this transition zones, metacarbonates which containing widespread crinoid fragments occur as lenses. The middle part of the Bağrıkurt Formation contains the same metaclastic and metachert alternations with the metavolcanics and metacarbonate olistolithes. The metaclastics show turbiditic features and their coarse clastics consist mainly of metachert and phyllite clasts derived from the formation itself. In this part, the Bağrıkurt Formation resembles a typical wild-flysch sequence. The upper part of the formation consists mainly of phyllites, metasandstones, metaconglomerates and quartzites. The metaconglomerates are coarse grained and dominantly consist of quartzite and milky quartz fragments in a cleaved matrix of greenish mud. Locally, the upper part of the formation contains metacarbonate, phyllite, graphiteschist and metasandstone alternation. The metachert horizons are 1 mm to 20 cm thick, and are generally black in color. They are seperated by thinner layers of phyllites or graphiteschists. The metacarbonate blocks or olistolithes are vary in origin. Some of them were derived from the Bozdağ Formation, while others unknown origin. They are mainly shallow-marine metacarbonates consisting of coral, crinoid, nautiloid and brachiopod. Some of the blocks have pelagic characteristics. They are thin bedded and consist of black metachert interbeds, and lengths range from 1m to 3 km. The rocks of the Sızma Group is cut by Devonian-Lower Permian aged Kadınhanı Metamagmatics occuring as dikes, sills and stocks. The Kadınhanı Metamagmatics include Bayamlıdağ Metagabbro, Karadag Spilite, Bişiktepe Metabasite, Çeştepe Metadolerite, Karatepe Metabasalticandesite, and Taşlıtepe Metatrachyandesite. The Sızma Group and Kadınhanı Metamagmatics are overlain by the ? Upper Permian-Cretaceous Ardıclı Group over an angular unconformity. This group is a result of a transgression from bottom to top, it contains five different formations interfingering with each others. Originally continental ?Upper Permian-Lower Triassic Bahçecik Formation is observed at the base of Ardıçlı Group. It is composed of violet to red phyllites, metasandstone and metaconglomerates. The ?Upper Permian-Triassic aged Ertuğrul

Formation formed by alternating units of phyllites, metasandstones, calcschists and yellow-gray and black metacarbonates follows the Bahçecik Formation. The Bahçecik Formation and Ertuğrul Formation are equivalent to the autochthonous Aladağ Formation both in age and in lithology. These rocks pass gradually into gray and black metadolomites of Triassic-Lower Jurassic Bademli Formation. This unit also grades laterally and vertically into the Upper Triassic-Cretaceous Nuras Formation (Karaman, 1986) which is made up a thick sequence of light colored marbles, recrystallized limestones and dolomitic limestones. In places, metacherts can be observed as lenses or intercalations within the metacarbonates. The youngest formation of the Ardıçlı Group is the Upper Cretaceous Karasivri Formation having pelagic, thin bedded metacherts, metacarbonates, phyllites and metasandstones. Bademli, Nuras and Karasivri formations are equivalent to the autochthonous Kızılören, Lorasdağı and Midostepe formations described by Göğer and Kıral (1969), both in age and in lithology, respectively. Upper Miocene-Quaternary sedimentary and volcanic rocks rest on units of the Bozdağlar massif with an angular unconformity (Figs. 2 and 3).

STRUCTURAL GEOLOGY

The metamorphic rocks in the study area have been subjected to at least three phases of deformation and ductile folding (F_1, F_2, F_3) by the Alpine crustal shortening (Eren, 1996a). These intense and polyphase Alpine deformations overprinted and obliterated Hercynian structures of the Sızma group. The first phase of folding (F_1) produced isoclinal, recumbent folds and a penetrative cleavage (S_1) under high-P/low-T metamorphic conditions caused by ophiolite obduction. The S_1 penetrative cleavage has developed axial planar to these folds. The F_2 folds are tight to open and an S_2 crenulation cleavage exists axial planar to F_2 folds. The F_1 and F_2 fold hinges are nearly parallel and superposition of these folds developed Type 3 fold interference pattern (Ramsay, 1967) in mesoscopic scale. F_3 folds are also open and an S_3 crenulation cleavage is recognized axial planar to F_3 folds. The F_2 and F_3 fold hinges are nearly orthogonal. This geometry results in development Type 1 fold interference pattern. Both the F_2 and F_3 phases of folding also developed widespread conjugate kink bands on S_1 surfaces. It is believed that the massif gained its present polyphase deformational history and imbricated structure by syn- and post-metamorphic movements acting during the Late Cretaceous and onwards respectively.

MINERAL CHEMISTRY

Common minerals in the metaigneous rocks are albite + augite + diopsite + crossite + riebeckite + glaucophane +winchite + actinolite + hornblende + chlorite + biotite+ epidote+ pumpelliyite + stilpnomelane + calcite + magnetite + quartz + sphene + sanidine + white mica +hematite and apatite. Metasedimentary rocks are composed of sericite + albite + chlorite + chloritoid + quartz + muscovite + epidote + actinolite + magnesium riebeckite + magnetite + sphene and apatite.

Some minerals are given in Table 1, 2 and in Figure 4 is showing the classification of amphiboles.

GEOCHEMISTRY AND TECTONIC SETTING

Representative major oxides and minor element compositions of the rocks are given in Table 3 and rare earth element compositions of the rocks are given in Table 4.

The psammite and quartzites in the Bağrıkurt Formation have a passive continental margin setting and a quartose sedimentary provenance is deduced (Figs. 5, 6). The REE patterns from the rocks are quite similar to NASC and upper continental crust REE patterns rocks (Fig. 7). These REE characteristics are similar to cratonic sedimentary rocks. The general similarity of the REE patterns in the psammites and quartzites, variable LREE enrichment, Eu depletion and flat HREE reflect the sedimentary province. Some of the cherts in the Bağrıkurt Formation have been deposited in a relatively shallow water environment similar to recent continental shelf slope environment (Fig. 8). The pelitic rocks were originally shales in which the main control in composition was the sheet silicates.

Geochemical data indicate that the meta-igneous rocks are of a sub-alkaline (tholeitic and calc-alkaline) in character (Fig. 9). Immobile element discriminant diagrams show that the metatrachyandesites and the metadolerites have within-plate, and the metabasaltic andesites have continental arc characteristics but the metahornblende gabbro

Table 1. Composition of amphiboles and pyroxenes.

S. No	227	373	373	405	344	344	337	373	373	272	414	414
	Cfg	cr	fw	cfg	fw	cr	Ac	Core	rim		core	Rim
SiO_2	56.00	55.37	53.25	57.56	50.87	51.65	50.89	52.58	51.89	51.15	52.40	50.49
TiO_2	0.96	0.00	0.00	0.02	1.88	0.15	0.35	0.18	0.20	0.24	0.61	1.37
Al_2O_3	3.13	3.00	2.13	2.59	4.11	5.98	3.25	1.27	1.29	2.24	1.65	2.21
FeO	17.90	18.64	20.99	21.28	19.13	22.39	20.90	0.00	0.00	0.00	0.00	0.00
MnO	0.18	0.25	0.33	0.18	0.23	0.20	0.40	9.52	8.99	7.62	8.53	11.08
MgO	9.60	10.60	9.32	5.58	9.00	10.10	11.72	0.28	0.28	0.14	0.21	0.23
CaO	3.63	2.50	7.11	1.03	5.00	1.19	9.62	13.18	13.37	15.98	16.80	14.12
Na_2O	5.61	5.50	3.10	5.86	5.30	5.87	0.86	22.17	22.60	22.12	18.70	19.14
K2O	0.12	0.16	0.11	0.20	0.17	0.04	0.11	0.57	0.54	0.21	0.43	0.37
Total	97.13	96.03	96.23	94.43	95.69	97.57	98.10	99.75	99.19	99.70	99.33	99.01
Recalculated to 23 oxygens for amphiboles, 6 oxygens for pyroxene												
Si	7.67	7.96	7.95	7.76	7.77	7.56	7.51	1.99	1.98	1.88	1.93	1.90
Al^{4+}	0.33	0.03	0.04	0.24	0.23	0.44	0.48	0.00	0.01	0.00	0.00	0.00
AlT	0.53	0.51	0.37	0.45	0.70	1.01	0.56	---	---	---	---	---
Al^{6+}	0.20	0.48	0.33	0.21	0.47	0.57	0.08	0.05	0.05	0.10	0.07	0.10
Ti	0.10	0.00	0.00	0.00	0.21	0.01	0.03	0.00	0.00	0.00	0.02	0.04
Fe^{3+}	0.00	0.98	0.39	0.00	0.12	0.89	0.34	0.04	0.07	0.13	0.04	0.04
*Mg	2.08	2.31	2.07	1.25	1.95	2.16	2.57	0.73	0.74	0.87	0.92	0.79
Fe^{2+}	2.18	1.29	2.22	2.67	2.20	1.79	2.23	0.25	0.21	0.10	0.22	0.31
Mn	0.02	0.03	0.04	0.02	0.02	0.02	0.06	0.00	0.00	0.00	0.01	0.01
FmT	13.10	13.11	13.07	13.08	13.36	13.46	13.34	----	---	---	---	---
Ca	0.56	0.39	1.13	0.16	0.78	0.18	1.52	0.88	0.90	0.87	0.74	0.77
NaM	0.00	1.49	0.79	0.00	1.18	1.34	0.13	---	---	---	---	---
NaT	1.58	1.56	0.90	1.71	1.49	1.64	0.24	---	---	---	---	---
NaA	0.00	0.06	0.10	0.00	0.31	0.29	0.11	---	---	---	---	---
K	0.0	0.048	0.158	0.04	0.04	0.01	0.01	---	---	---	---	---
End member of the clinopyroxene minerals as below												
							wo	46.0	46.7	43.9	38.5	40.2
							En	38.1	38.4	44.1	47.8	41.2
							Fs	15.9	15.0	12.0	14.0	18.6

*Fe^{3+} is calculated by estimation according to Spear and Kimball (1984) for amphibole, by normalization according to Schumacher (1991) for pyroxene.
cr: Crossite, fw: Ferro-winchite, ac: actinolite, cfg: Calcian ferro glaucophane. metatrachyandesite (227, 373), metabasaltic andesite (405, 272), metahornblende gabbro (344, 337) and metadolerite (414).

is MORB like features (Fig. 10). The geochemical characteristics of the metahornblende gabbros are illustrated on N-MORB normalized patterns (Fig. 11) which demonstrate that the gabbros are similar to tholeitic N-MORB but relatively enriched in K,Th, Rb, Ba, Nb and depleted in Ce and Ti.

The metadolerites are enriched in Rb, K, Ba, Th, Ce, P and Nb and depleted in Ti and Y relative to MORB, being calc-alkaline as indicated by enrichment in K, Rb, Ba, Nb, Ce, P, Zr, and Ti compared with the tholeitic metahornblende gabbros as seen on MORB -normalized patterns (Fig. 11). The metatrachyandesite and metabasaltic andesite have closely corresponding REE patterns and N-MORB normalized profiles, strongly suggesting a similar origin (Figs. 11, 12) but the two rocks are not related via crystal fractionation as this conflicts with the REE pattern of the metabasaltic andesite. The metahornblende gabbros have flat REE patterns and compositional data suggesting derivation from sourcesimilar to a mid ocean ridge type parent (Fig. 12).

PETROGENESIS AND METAMORPHISM

The metavolcanics show similarities in chemical composition and tectonic setting, and probably related a subduction zone. They were derived from very similar enriched continental source regions and their incompatible element contents do not imply significant differences in melting as both types show marked enrichment in most incompatible elements (LILE, LREE) compared to N-MORB (Fig. 11). Thus, they form a genetically related comagmatic suite. The geochemistry as a whole indicates that the metavolcanics may have been derived from a subcontinental lithospheric source enriched in LIL and HFS elements. However the

Table 2. Composition of pumpellyite and stilpnomelane.

Sample No	1	2	3	4
SiO_2	36.06	24.01	48.52	68
TiO_2	0.18	0.54	0.11	0.00
Al_2O_3	23.58	39.43	6.27	20.22
FeO*	10.02	25.44	25.91	0.44
MnO	0.34	0.22	0.73	0.05
MgO	2.29	1.99	5.48	0.42
CaO	21.39	0.00	0.73	0.11
NaO	0.00	0.00	0.43	10.86
K_2O	0.00	0.01	1.09	0.68
TOTAL	93.86	91.64	89.27	100.8
Recalculated to 51 for pumpellyites, 8 for stilpnomelane,12 for chloritoids 32 oxygen for plagioclases				
Si	12.31	2.02	2.85	11.8
Ti	0.05	0.00	0.01	0.00
Al	9.49	3.91	0.41	4.12
Fe	2.86	1.79	1.26	0.06
Mn	0.09	0.01	0.03	0.00
Mg	1.16	0.35	0.45	0.10
Ca	7.82	0.00	0.04	0.02
Na	0.00	0.00	0.04	3.64
K	0.00	0.00	0.09	0.15
Total	33.73	8.08	5.07	19.89

Total Fe as FeO*
mineral types of 1 (pumpellyite), 2 (stilpnomelane), 3 (chloritoide) and 4 (Plagioclase).

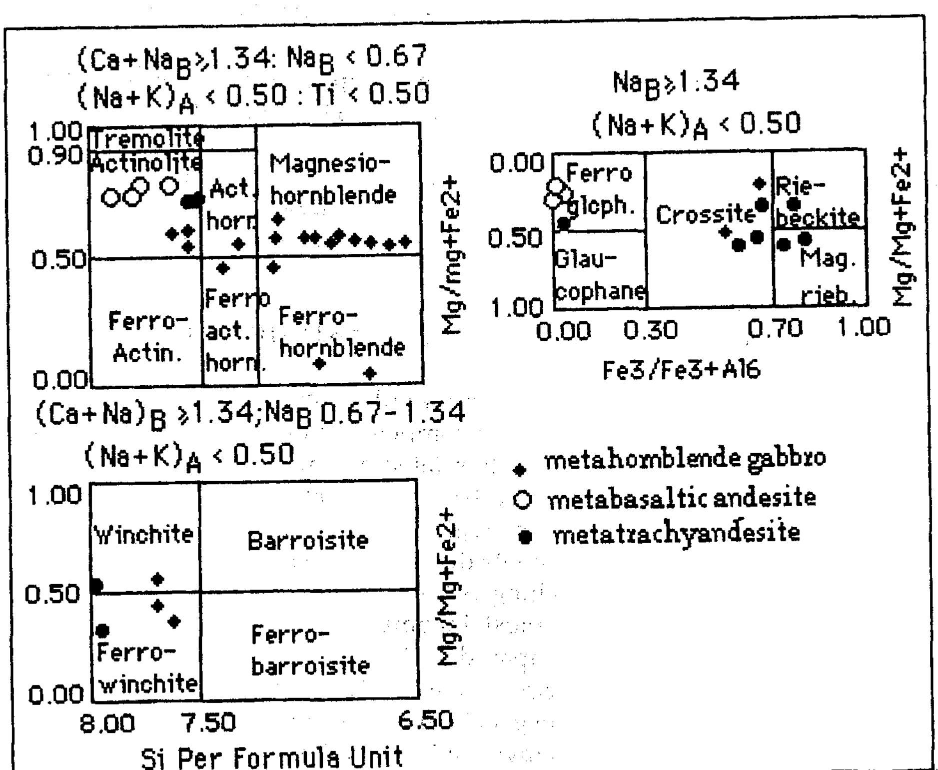


Figure 4. Classification of amphiboles (after Leake, 1978).

Table 3. The average of major oxides and trace elements of each of the rock types.

Sa.No	1	2	3	4	5	6	7	8	9	10
SiO_2	57.4	53.9	52	52.1	55.3	56.19	93.31	82.00	93.08	65.2
TiO_2	0.1	0.7	1.3	1.4	0.51	0.71	0.20	0.38	0.07	0.81
Al_2O_3	15.0	15.4	14.6	15.6	13.5	14.55	1.91	6.60	1.38	16.8
FeO	3.3	4.8	7.0	7.1	3.6	2.04	0.72	0.84	0.26	3.4
Fe_2O_3	3.6	5.4	5.1	2.5	5.4	3.16	0.96	2.82	2.00	4.0
MnO	0.1	0.2	0.2	0.1	0.16	0.09	0.05	0.07	0.02	0.79
MgO	4.3	4.0	5.5	6.5	4.1	1.86	0.20	0.63	0.37	1.59
CaO	4.4	5.2	6.7	5.1	6.6	4.23	0.70	1.10	0.30	0.22
Na_2O	2.6	3.2	3.1	2.9	1.9	0.37	0.60	1.00	0.28	1.05
K_2O	5.1	2.5	1.1	2.4	1.3	9.01	0.70	1.42	0.29	3.04
P_2O_5	0.6	0.3	0.2	0.2	0.2	0.55	0.02	0.05	0.04	0.11
CO_2	0.2	0.4	0.4	0.4	0.5	0.00	0.00	0.60	0.07	0.55
H_2O	2.6	2.8	2.4	2.7	3	6.04	1.49	2.06	0.3	2
TOTAL	99.7	99.0	98.7	98.8	98.3	98.61	98.95	98.90	98.48	98.1
Cr	200	88	103	337	230	165	81	145	100	146
Co	20	22	31	42	29	14	5	9	4	21
Ni	36	13	18	85	69	22	6	18	8	72
Cu	40	94	22	40	117	76	3	14	5	31
Zn	74	120	92	90	67	30	16	39	6	85
Ga	19	16	15	18	14	17	2	8	1	20
Rb	185	51	14	30	26	259	9	76	16	05
Sr	600	193	219	198	308	256	14	52	29	76
Y	19	20	36	21	26	22	12	15	8	30
Zr	256	121	105	111	107	243	155	169	31	189
Ba	2156	973	147	234	162	2659	64	289	285	423
La	27	12	5	5	14	75	14	18	3	30
Ce	1	1	bdl	1	32	158	21	31	13	55
Pb	31	14	4	4	6	16	9	12	13	8
U	53	59	3.7	15	0	9	0	2	2	0
Nb	15	9	7	12						
Th	125	122	9.8	33	5	55	6	7	1	12

Major oxides are in wt %, and trace elements are in ppm, bdl is below the dedection limit.
1. metatrachyandesite, 2. metabasaltic andesite, 3. metahornblende gabbro, 4. metadolerite, 5. metabasites, 6. high-K metatrachyandesite, 7. quartzites, 8. psammites, 9. metacherts, 10. metapelites.

Table 4. Rare earth element data for the metacherts, psammite (160) and quartzite (67).

Sam. No	448	482	449	450	435	478	160	67	227a	323	277	408	337	344	417	414
La	15.4	23.7	7.8	7.5	11.6	14.3	7.4	16.8	53.1	52.0	80.6	36.1	2.9	4.5	18.2	11.9
Ce	16.3	15.4	5.8	4.5	7.7	10.0	33.0	31.8	116.3	134.5	159.6	85.0	7.8	11.8	39.6	27.2
Pr	12.8	14.0	5.4	5.2	6.4	11.5	2.0	4.1	13.9	15.7	17.3	9.4	1.3	1.8	4.8	13.3
Nd	9.9	9.8	4.3	5.0	4.8	8.8	6.9	14.3	52.5	57.0	63.0	37.2	6.3	9.0	19.1	13.7
Sm	9.5	9.2	0.8	3.6	2.5	5.9	1.4	2.8	9.4	9.8	11.9	7.8	2.0	3.3	4.1	3.3
Eu	6.9	7.7	3.1	0.3	1.6	2.7	0.2	0.5	2.0	2.8	3.0	2.5	0.8	3.2	1.5	1.3
Gd	1.0	1.6	0.4	0.4	1.5	0.5	1.2	2.1	7.1	7.6	9.4	6.8	2.6	3.9	4.0	3.7
Tb	5.4	3.6	1.3	1.9	1.1	2.3	0.2	0.2	0.8	0.9	1.1	0.9	0.5	0.6	0.6	0.6
Dy	2.8	2.1	0.6	0.8	0.9	1.2	1.0	0.8	4.4	4.4	5.7	4.4	3.0	4.3	3.3	3.3
Ho	3.7	3.2	3.6	0.9	0.8	1.5	0.2	0.1	0.7	0.7	0.9	0.7	0.6	0.8	0.6	0.6
Er	3.2	2.9	0.7	0.7	0.9	1.2	0.6	0.3	1.9	1.9	2.5	2.0	1.8	2.5	1.4	1.6
Tm	4.0	3.7	0.9	0.6	1.4	1.3	0.1	0.5	0.3	0.2	0.3	0.3	0.3	0.3	0.2	0.2
Yb	4.6	4.1	0.9	0.7	1.0	1.4	0.6	0.3	1.6	1.6	2.1	1.7	1.7	2.2	1.1	1.4
Lu	5.0	4.3	0.9	0.3	1.1	1.6	0.1	0.1	0.2	0.2	0.3	0.2	0.3	0.3	0.1	0.2

Metatrachyandesite (227a, 323), metabasaltic andesite (277, 408), metahornblende gabbro (337, 344), metadolerite (417, 414), quartzites (67), psammites (160) and metacherts (448, 482, 449, 450, 435, 478).

REE are in ppb.

Each number of the grid references of its position

448:	22125 - 24500	227: 33025-32200
482:	27125 – 26625	337:37125-28575
449:	26875 – 25275	323:33050-32300
450:	28500 – 27375	344:40250-27750
435:	30750- 39100	277:33025-32250
478:	29500 – 32000	417:39750-22125
160:	33750- 31825	408:40550-17450
67 :	22625 – 33375	414:38650-22500

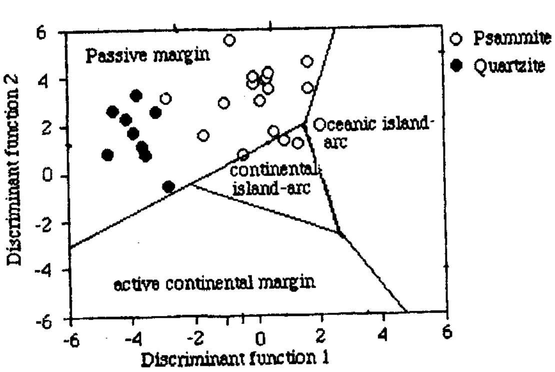


Figure 5. Plot of discriminant functions F1 and F2 (Bhatia, 1983) showing the position of psammites and quartzite.

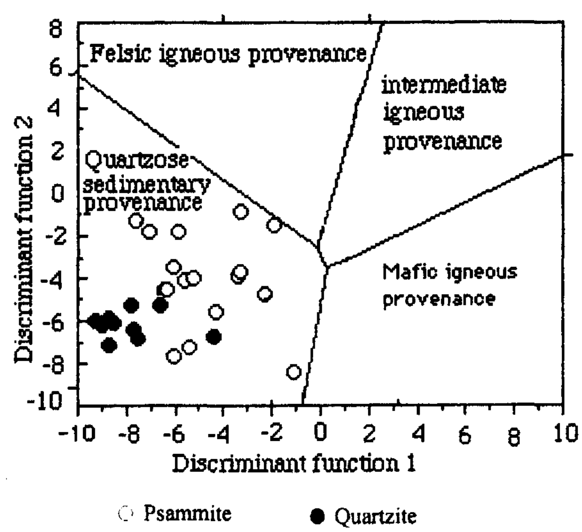


Figure 6. Plot of discriminant function F1 and F2 (Roser and Korsch, 1988) showing the provenance of psammites and quartzite.

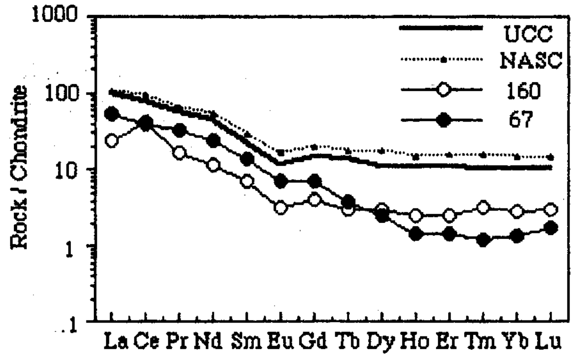


Figure 7. Chondrite normalised REE patters for psammite (160) and quartzite (67) (UUC; upper continental crust, NASC; North American shale composition) (after Boynton, 1984).

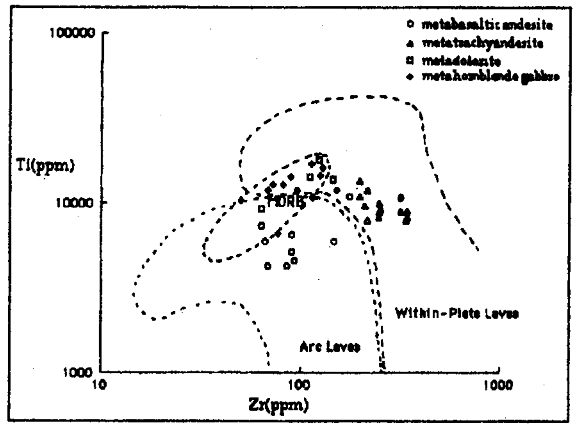


Figure 10. Ti vs. Zr Plot for the meta-igneous rocks of the Kadınhanı area. Field boundaries from Pearce (1982) and Pharaoh and Pearce (1984).

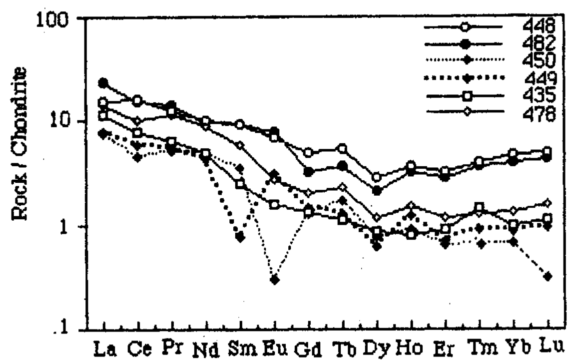


Figure 8. Chondrite -normalised rare earth element distribution patterns for metacherts from the Kadınhanı area. Chondrite normalising values from Boynton (1984).

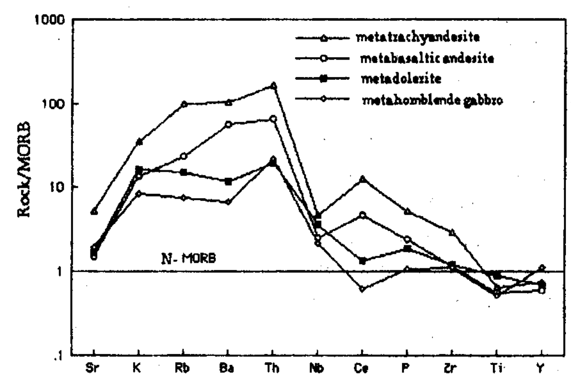


Figure 11. MORB-normalized incompatible element patterns for averages of the meta-igneous rocks. Normalizing values are as cited in Pearce (1982).

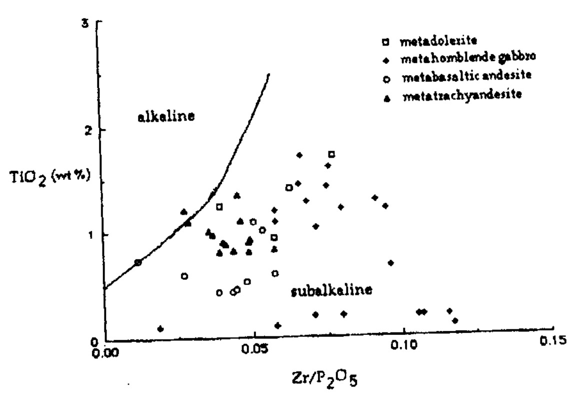


Figure 9. Zr/P_2O_5 versus TiO_2 plot used to reveal the magma type. Field boundaries from Floyd and Winchester (1975) and Winchester and Floyd (1976).

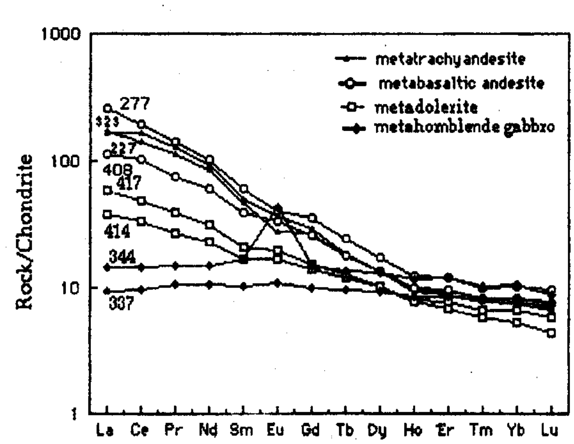


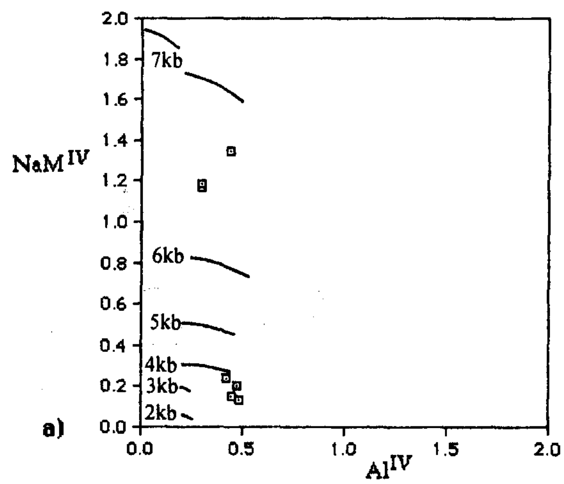
Figure 12. Chondrite - normalized rare earth element patterns for meta-igneous rocks. Chondrite normalizing values are from Boynton (1984).

metadolerites and metahornblende gabbros show that these rocks have probably been derived from different magmatic sources. The metadolerite having higher Ni (56-119 ppm), Cr (150-516 ppm) and mg number (25.6-31.4) compared to the metahornblende gabbros which have low Ni (5- 53 ppm), Cr (0-294 ppm) and mg number (33.3-61.3). The combination of lower Ni+Cr with higher mg is only compatible with two different and unrelated magmas. The low contents of Nb and other elements with high ionic potential in the metahornblende gabbro may be a result of their retention in residual phases stable in a hydrated mantle source region (Kay, 1977; Pearce, 1982). The metadolerite parental magma had a source similar to subduction related lavas in a continental margin environment, involving a mix of subcontinental lithosphere and subductioncomponents.

The normalized incompatible element patterns (Fig. 11) of the calc-alkaline continental metadolerites, are enriched in K, Rb, Ba, Nb, Ce, P, Zr and Ti, compared with the tholeitic oceanic metahornblende gabbros. These characteristics may be due to the involvement of subcontinental lithosphere in magma genesis (Pearce, 1983). Furthermore both upper mantle (sub-continental lithosphere) and subduction components can be identified in incompatible element patterns of metadolerite from continental margin environments (Watters and Pierce, 1987).

The amphibole from actinolite to crossite on the Na M4-Al^{IV} diagram of Brown (1977) for the metahornblende gabbro and crossite on the same diagram for the metatrachyandesite are plotted (Fig. 13a, b). Hornblende and actinolite on the Al^{VI}-Si diagram of Raase (1974) for metabasic schist and metabasaltic andesite are also plotted (Fig. 14 a, b). NaM^{IV} poor calcic amphibole is sequentially replaced first by a deeper green to green blue winchitic amphibole, and then by a blue riebeckite. The extremely low NaM^{IV} content of the actinolite suggests that the metamorphism was initiated with low pressure, greenschist facies conditions and only later became of blueschist facies and the growth of stilpnomelane and pumpellyite. Crossite, glaucophane started and chlorite, white mica, albite and epidote continued to grow and attempted to adjust their compositions to the rapidly changing conditions. The amphiboles display a sequence of changes from actinolite to sodic-calcic variation (e.g. winchite and ferro-winchite) on the greenschist-blueschist boundary to ferroglaucophane phase and magnesio-riebeckite in the blueschist facies.

The temperature obtained from hornblende-plagioclase geothermometers suggest that the temperature during metamorphism was about 521(±75)-482 (±75) °C, and the pressure about 3-6 Kbar for metahornblende gabbro, 431(±75) - 400 (±75) °C and the pressure about 5-7 Kbar for the metabasaltic andesite and 426 (±75)-395 (±75) °C and the pressure about 5-7 Kbar for metabasites. These estimates are based on Blundy and Holland's (1990) plagioclase-hornblende geothermometer.



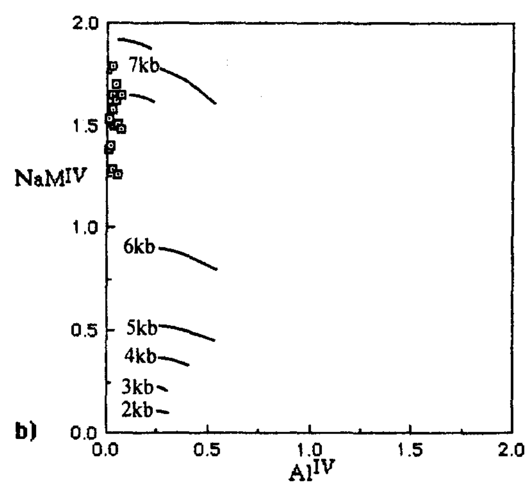


Figure 13. Tentative estimate of the relationship between pressure of metamorphism and NaM^{IV} vs AL^{IV} in the metahornblende gabbro (a) and metatrachyandesite (b) Diagram based on Brown (1977).

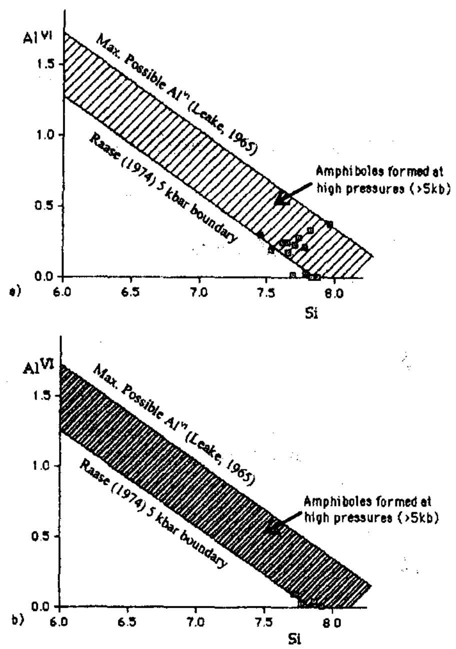


Figure 14. Hornblende analyses plotted on an Al^{VI} against Si diagram (after Raase, 1974), for metabasic schist (a) and metabasaltic andesite (b).

The quartz+muscovite+chlorite+chloritoid mineral assemblages in metasedimentary rocks are indicative of metamorphic conditions in excess of 4-5 Kbar at 380-400 °C and the albite ($Ab_{99\ to\ 95}$) component of the plagioclase is very high, which agrees with low temperatures (Kurt, 1994, 1996, 1997a). In the metatrachyandesite pumpelliyite + chlorite + epidote + actinolite + quartz assemblage indicates metamorphic conditions near the 5-7 Kbar at 380-400 °C.

Geological investigations (Okay, 1986) in the north of the Menderes Massif and the Afyon-Bolkardag Belt suggest that the greenschist and the blueschist metamorphisms seem to have been completed before the late Cretaceous, but the youngest rocks metamorphosed in the study area are Upper Cretaceous in age. Therefore, the age of the metamorphism should be Late Cretaceous or younger in the studied region.

GEOLOGICAL EVOLUTION

The oldest formation in the massif is Bozdağ Formation. Lithological and paleontological features of the Bozdağ Formation show that the formation was deposited as reef complex, icluding reefcore, backreef and forereef facies, during Silurian-Early Carboniferous. The marble of Bozdağ has lenticular shape, and is cut by intrusive rocks having MORB like source. The relations between the Bozdağ Formation and pelagic, continental margin rocks of the Bağrıkurt Formation, show that these reefs were developed as carbonate buildups and/or patch reefs in continental margin and in mid-oceanic highs and ridge (Fig. 15 a). All these findings and geochemical feature of the metahornblende gabbro indicate an Atlantic-type continental margin in the present area during the Late Devonian period.

The middle and upper levels of the Bağrıkurt Formation contain turbiditic sediments and olisthostromal facies and pyroclastic material. All these rocks are cut by intrusive rocks of calc-alkaline and continental arc. Considering all the above data and its position it is proposed that a passive continental margin was turned to the active continental margin. Therefore, before Late Carboniferous, the oceanic litosphere was started to be subducted beneath the Menderes-Taurus block and an evolution of a magmatic arc was initiated by partial melting of oceanic litosphere, over the continental margin (Fig. 15b). High degree metamorphic rock fragments, K-feldispar, plagioclase and volcanic quartz fragments are observed in the metapsammitic rocks in the Bağrıkurt Formation (Eren, 1993a, Kurt 1994). It is proposed that the magmatic arc was grown and rised above the sea level during the Late Carboniferous (Eren, 1996; Kurt and Arslan, 1999) and it was acted as a source of the psammitic rocks in the Bağrıkurt formation (Fig. 15c). The existence of overthrusts in the Sızma Group (Fig. 2, Eren 1996c) suggests that the magmatic arc was probably compressional. While the subduction process was continuing, orogenic activity on the continental margin was in progress and was resulted in the deposition of wild-flysch of the Bağrıkurt Formation. In a following stage, the deposition of the wild-flysch was completed, and in that time, shallow-marine conditions returned (Fig. 15d). Shallow-marine sediments in Bağrıkurt Formation were deposited in these conditions.

Before the Early Triassic period, the magmatic arc completed its evolution and, at this time, subduction was ceased. Subsequently, all the rocks in the Sızma Group was deformed and uplifted. Then, the Late Permian-Early Triassic aged continental coarse clastics of Bahçecik Formation were deposited on the Sızma Group as alluvial fan and fluvial sediments (Fig. 15e). The Ardıçlı Group units laterally interfinger to each other (Özcan et al., 1990; Eren, 1993b) and it suggest that sea environment conditions prevailed in the area and alluvial fan and fluvial sediments passed laterally to shallow sea and the lagoonal sediments. This indicate that post-orogenic continental Bahçecik and shallow-marine environmental Ertuğrul Formation were deposited like classical molasse sediments over the flysch and wild flysch rocks of Bağrıkurt Formation. The position of the Kırşehir block during the Early Triassic (Şengör, 1991), the absence of any data about continental collision during the Permian-Triassic time in the region, as well as the existence of Triassic (Turan, 1990) and Jurassic (Koçyiğit, 1981) pelagic rocks in the Taurides all indicate that there was an ocean possibly between the Menderes-Taurus and Kırşehir blocks in Late Paleozoic, and this ocean survived during the Mesozoic time.

Aladağ Formation which is the equivalent of lower parts of Ardıçlı Group within the Gökçeyurt Group is partly composed of turbidites, metacarbonate blocks, rare metabasite intercalations and dolerite dykes. All these rocks indicating that the continental margin was started to be broken and to be foundering during the Early-Middle Triassic (Fig. 15f). The deposition of clastic sediments within this environment reduced in time and the platform type thick carbonates, belonging to Bademli (Kızılören) and Nuras (Lorasdağı) formations were deposited. Pelagic and turbiditic rocks of Karasivri (Midostepe) Formation were gradually deposited on the continental shelf carbonates, due to continuation of collapsing and foundering of continental margin (Fig.15g). Consequently, the Ardıçlı Group was deposited transgressively during the Mesozoic time. The geological evolution in the region during the Cretaceous and later explained in detail by Oktay (1982) and Özcan et al. (1988 and 1990).

According to the data from Oktay (1982), Görür et al. (1984), Okay (1984), and Aydın and Seymen (1996), there was a subduction under the Kırşehir block and the margin of the Menderes-Taurus block has undergone deformation during the Cretaceous and later. The protolithes of metamorphic rocks indicate that the subduction process was started as a intra-oceanic subduction which mechanisms were described

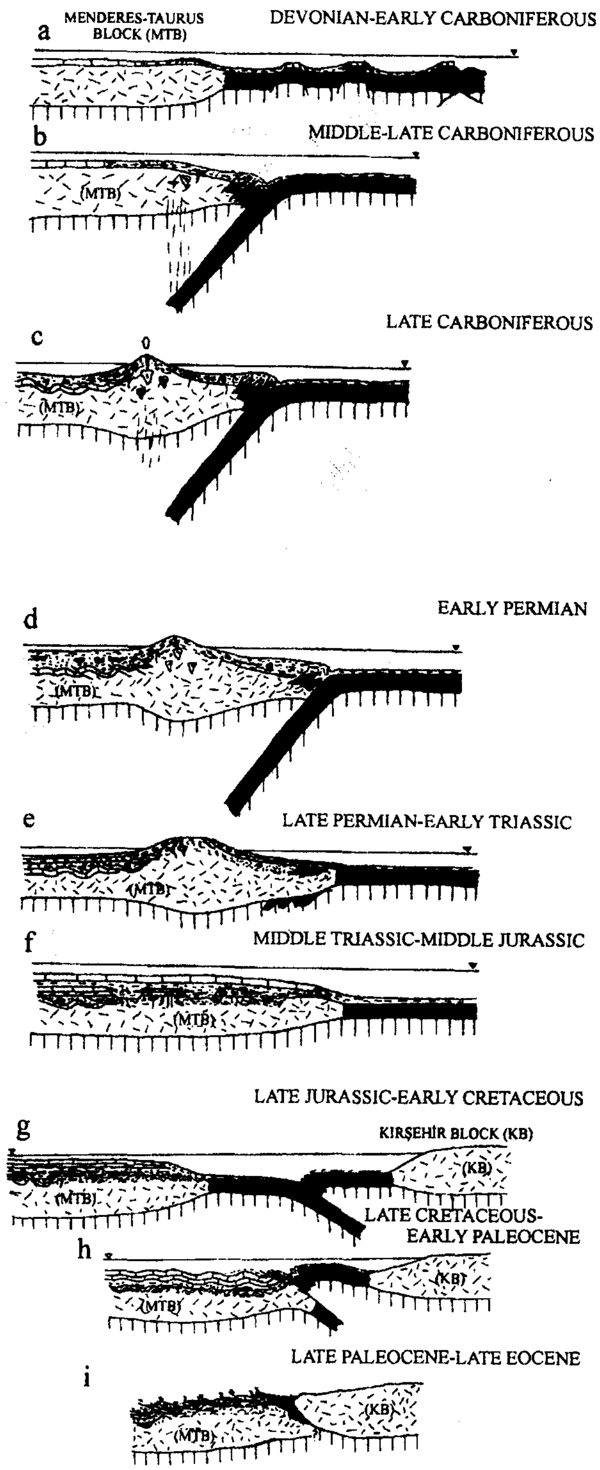


Figure 15. Schematic tectonic evolution of the central northeast margin of Menderes-Taurus block From Devonian to Late Eocene (g, h, i- were modified from Oktay, 1982; Okay, 1984 and Özcan et al., 1990).

by Okay (1984) and Şengör (1990). Subsequently the continental margin of the Menderes-Taurus block was undergone subduction (Fig. 15h). During this time, whole sequence of rocks of the study area have first undergone greenschist metamorphism and later blueschist metamorphism. For a blueschist metamorphism realized under 6-7 Kbar, a subduction depth of 20-30 km is necessary. Therefore it can be said that the continental margin rocks in the study area were subducted about 20-30 km beneath the Kırşehir Block. Later, the ophiolitic melange (Hatip Ophiolitic Melange; Özcan et al., 1988) and the Çayırbağı Ophiolite were obducted on the continental margin, then were sudden-uplifted all together. Finally, Menderes-Taurus and Kırşehir blocks were sutured and the imbrication generated present tectono-stratigraphic framework of the massif (Fig. 15i). There is no data in the study area and surrounding areas on the evolution during Middle Paleocene-Late Miocene times. But around the Afyon-Kütahya region the rocks covered by Upper Paleocene aged post-orogenic rocks (Özcan et al, 1988). According to the Özcan et al. (1990), crustal shortening continued up to Eocene time, and later the region uplifted above the sea level and continental conditions prevailed during the Miocene time and onwards.

CONCLUSIONS

In this paper, stratigraphical, structural, geochemical, and petrological features of the studied area are outlined. Data obtained indicate the existence of an ocean from the Devonian to the Late Mesozoic time, probably between the Menderes-Taurus and Kırşehir blocks. The central northeast margin of Menderes-Taurus block was an Atlantic type passive margin during the Devonian. The subduction of the oceanic litosphere beneath the Menderes-Taurus block, constructed a magmatic arc on this margin during Late Carboniferous. The magmatic arc completed its evolution before Late Permian or Early Triassic time. The oceanic lithosphere begun the subduction under the Kırşehir Block and ophiolite emplaced on to the this margin during the Late Jurassic-Cretaceous. Finally, due to subduction and suturization, the Paleozoic and Mesozoic rocks of the present area have undergone poly-phase deformation and metamorphism during the Late Cretaceous and onwards.

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