Mineral Res. Expl. Bull.,142, 69-119, 2011

THE GEOLOGY AND GEOCHRONOLOGY OF THE PAN-AFRICAN AND TRIASSIC METAGRANITOIDS IN THE MENDERES MASSIF, WESTERN ANATOLIA, TURKEY

O. Ersin KORALAY*, Osman CANDAN*, Cüneyt AKAL*, O. Özcan DORA*, Fukun CHEN**, Muharrem SATIR*** and Roland OBERHÄNSLI****

ABSTRACT.- The Menderes Massif is a metamorphic complex cropping out on a large region in the Alpine orogenic belt in Western Anatolia. The massif mainly, is made up of a Precambrian basement and the overlying Palaeozoic-Early Tertiary cover series. The basement comprises Late Proterozoic metaclastics composed of paragneiss and high grade micaschists, syn to post-tectonical Pan-African orthogneisses that have intruded into them, and metagabbros which have partly turned into eclogitic form. Cover series unconformably overlying the basement are divided into two units, in Palaeozoic and Mesozoic-Early Tertiary ages. The basement and cover series were influenced by an effective Alpine contractional deformation and a regional metamorphism in Tertiary time. Geological and geochronological data in the Menderes Massif, indicate the presence of three acidic magmatic activities of i) Pan-African, ii) Triassic and iii) Miocene in ages. The acidic magmatics forming the protolithes of Pan-African orthogneisses can be divided into three main types according to their textural and mineralogical compositions as; 1) Biotite orthogneiss, 2) Tourmaline leucocratic orhogneiss and 3) Amphibole orthogneiss. The relations of primary granites of these orthogneisses present a clear intrusive contact relationship among them and with the metaclastics of Late Proterozoic age. The contact relationships show that these orthogneiss types can be ordered as biotite orthogneisses, tourmaline leucocratic orthogneisses and amphibole orthogneisses ranging from old to young, with respect to relative aging. Although there has been some problems originating from the definition of samples dated in previous studies, it is noted that radiometric data mainly show a consistency with this relative relationship (biotite orthogneiss: 550-570 Ma; tourmaline leucocratic orthogneiss: 541-547 Ma and amphibole orthogneiss: 531 Ma). These radiometric data indicate that different orthogneiss types in the Massif are differentiated products of the same Late Proterozoic - Early Cambrian acidic magmatic activity. When the paleogeographical position of the Massif in Early Cambrian and the close temporal relation of the metamorphic stage of cover series and the acidic magmatism are assessed with the geochemical character of orthogneisses, this widespread magmatic activity with an average age of about 550 Ma which is related to the Pan-African orogenesis can be attributed to proccesses of closure of the Mozambique Ocean, collision of East and West Gondwanaland, crustal thickening and partial melting of the lower crust. Triassic leucocratic orthogneisses constitutes the second effective acidic magmatic activity in the Menderes Massif with dimensions of 6-7 km. These plutonic leucocratic orthogneisses in 6-7 km dimensions are exposed in Ödemiş-Kiraz and Demirci-Gördes submassifs. They show well-preserved intrusive contact relationships with Late Proterozoic metaclastics of the Pan-African basement and with metasediments of Late Palaeozoic cover series. Geochemical data show that protolithes of leucocratic orthogneisses are in calc alkaline and S type in character. Based on single zircon Pb/Pb evaporation method, these were radiometrically dated as ranging from 227 to 246 Ma. These ages are interpreted as the age of emplacement of protolithes of orthogneisses in Middle Triassic. The existence of Early-Middle Triassic magmatic activity is widely known not only in the Massif but also at the tectonical zones of the Anatolides, at the Karaburun peninsula, in Cyclades and at the inner Hellenides. When the regional character of Triassic magmatic activities is considered, it is suggested that there is a close genetical relationship between these leucocratic orthogneisses and Triassic magmatics. It is also considered that it can be attributed to the opening of Neothethys Ocean.

Key words: Menderes Massif, Pan-African, Cadomian, Triassic, magmatism, geochronology

* Dokuz Eylül Üniversitesi, Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü, Tınaztepe Yerleşkesi 35160 Buca / İzmir-Türkiye (e-posta: ersin.koralay@deu.edu.tr)

** University of Science and Technology of China, School of Earth and Space Sciences, Hefei, Anhui Provence, 230026, China

*** Eberhard-Karls-Universität Tübingen, Institut für Mineralogie, Petrologie und Geochemie Lehrstuhl für Geochemie, Wilhelmstraße 56, 72074 Tübingen, Germany

**** Institut für Erd- und Umweltwissenschaften, Universität Potsdam, Karl Liebknecht Str. 24, Potsdam 14476, Germany.

INTRODUCTION

The Menderes Massif which is extending in NE-SW direction and presenting strong interior nappes produced by Alpine compressional tectonics, has a great importance in the geological evolution of Western Anatolia. The Menderes Massif is tectonically overlain by the extension of Izmir-Ankara suture zone including also the Bornova Flysch zone in the west and northwest, by the extension of Cycladic complex in Turkey by the Afyon zone containing high pressure/low temperature (HP/LT) metapelite and metacarbonates at the north, and by high pressure metasediments and Lycian nappes with thick ophiolitic slices at the south (Figure 1) (Şengör and Yılmaz, 1981; Okay, 1984; Dora et al., 1995). In previous studies, there is a general acceptance that the Cycladic Complex in Aegean Sea is the eastern extension of the Menderes Massif (Dürr et al., 1978; Jacobshagen, 1986; Candan and Dora, 1998). In recent studies, although there have been many objections in dimension and distribution, it was suggested that, Cyclades were exposed as a tectonic slice in Western Anatolia and present clear differences from the Menderes Massif (Candan et al., 1997; Ring et al., 1999; Gessner et al., 2001; Okay, 2001).

The Menderes Massif is mainly divided into two main rock groups as; i) Pan- African basement and ii) Palaeozoic-Early Tertiary cover series (Figure 2) (Dora et al., 1995). The Pan-African basement is predominantly composed of metaclastic sediments of which the depositional age of protolithes is Late Proterozoic (Koralay et al., 2003). Cover series on the other hand, are divided into two sub groups as; Palaeozoic and Mesozoic-Early Tertiary rocks. Palaeozoic series are dominantly composed of quartzite, phyllite and marbles (Çağlayan et al., 1980; Konak et al., 1987). Mesozoic-Early Tertiary series start with metaconglomeratic schist at the bottom and grade into the platform type thick metacarbonates including emery lenses with a transitional zone. Carbonates are overlain by pelagic marble and the deposition ends with metaolisthostrome (Dürr, 1975; Konak et al., 1987; Dora et al., 1995; Özer et al., 2001).

Metaclastic series made up of partly migmatized paragneiss and micaschists forms the oldest unit of the Pan-African basement of the Menderes Massif. These Late Proterozoic rocks were affected by poly-metamorphism under granulitic, eclogitic and amphibolitic facies conditions related with the Pan-African Orogeny in Precambrian-Cambrian (Dora et al., 1995, Oberhänsli et al., 1997; Candan and Dora 1998; Candan et al., 1994, 2001, 2007). Basement series are cut by widespread acidic/basic magmatics related with the Pan-African Orogeny (Hetzel and Reischmann 1996; Loos and Reischmann 1999; Koralay et al., 2004; Candan, 1996). As a contrast, in recent years, in tectonical studies, especially in the southern part of the Çine submassif, it has been claimed that the most typical rocks belonging to the basement and the Pan-African aged acidic magmatics (orthogneisses) that were obtained by geochronological studies are i) Late Cretaceous (Erdoğan and Güngör, 2004) or ii) Early Tertiary intrusives (Bozkurt et. al., 1995). Geochronological data show that, the main acidic magmatic activity phase forming the protolith of Pan-African orthogneisses has occurred between 520-570 Ma (Late Proterozoic-Cambrian) with a strong emphasis for 550Ma (Hetzel and Reischmann 1996; Loos and Reischmann 1999; Dannat, 1997; Hetzel et al., 1998; Gessner et al., 2001, 2004; Koralay et al., 2004).

Triassic leucocratic orthogneisses form the second prevalent magmatism observed in the Menderes Massif. In eastern part of Ödemiş-Kiraz submassif, at the south of Alaşehir, at the east of Aydın-Köşk, at the southeast of Demirci-Gördes submassif and at the south of Kula, NNE directed leucocratic orthogneiss masses cut Precambrian basement series and Permo-Carboniferous units by intrusive contacts (Akkök, 1983; Candan, 1994; Koralay et al., 2001). From these, by the single zircon Pb/Pb evaporation

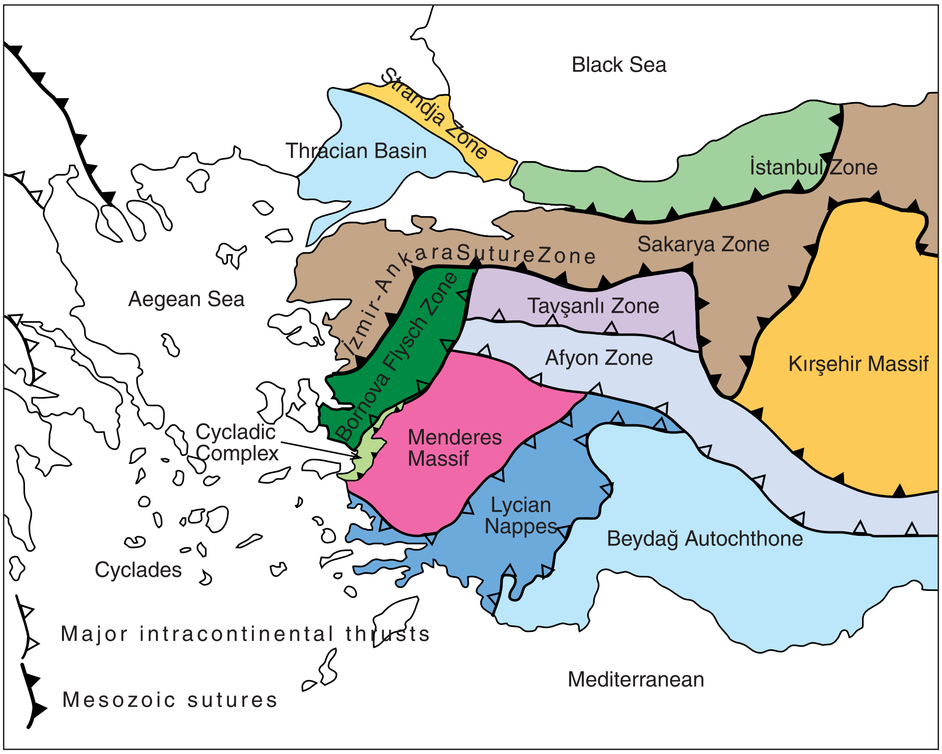


Figure 1- Generalized tectonical map of the Eastern Anatolia and tectonical zones surrounding the Menderes Massif (modified from Okay et al., 1996).

method 230-245 Ma (Early-Middle Triassic) ages have been dated (Dannat, 1997; Dannat and Reischmann 1998; Koralay et al., 2001). Koralay et al. (2001) claimed that these granites were intruded in the period that follows Early Kimmerian metamorphism related with the closure of Paleothethys. Non metamorphic, 12-25 Ma aged granites and Kersantites represent the third magmatic activity (Öztunalı, 1973; Bingöl et al., 1982; Reischmann et al., 1991; Hetzel et al., 1995; Delaloye and Bingöl 2000; Işık and Tekeli 2000; Işık et al., 2004; Lipps et al., 2001; Catlos and Çemen, 2005; Thompson and Ring, 2006; Glodny and Hetzel, 2007).

In the studies published during the last 10 years, there has been a contradiction in the interpretations of geochronological data and field results and on kinematical data regarding the intrusion ages of orthogneisses except for Triassic intrusions. It is considered that, representation of the available data towards the solution of this problem and associating these with geological data will illuminate the future studies. The paper was prepared in this purpose and aims at presenting; i) the geological/petrographical properties and the distributions of orthogneisses, found in the core series, in the Menderes Massif, ii) the geochronological data obtained from these orthogneisses and the association of these data with geological data, iii) the distribution of Triassic leucocratic orthogneisses in the Menderes Massif, iv) the geochronological ages obtained from Triassic aged leucocratic orthogneisses and probable tectonical environments.

ACIDIC MAGMATISM IN THE MENDERES MASSIF

As it has been mentioned briefly above, the geological and geochronological data in the

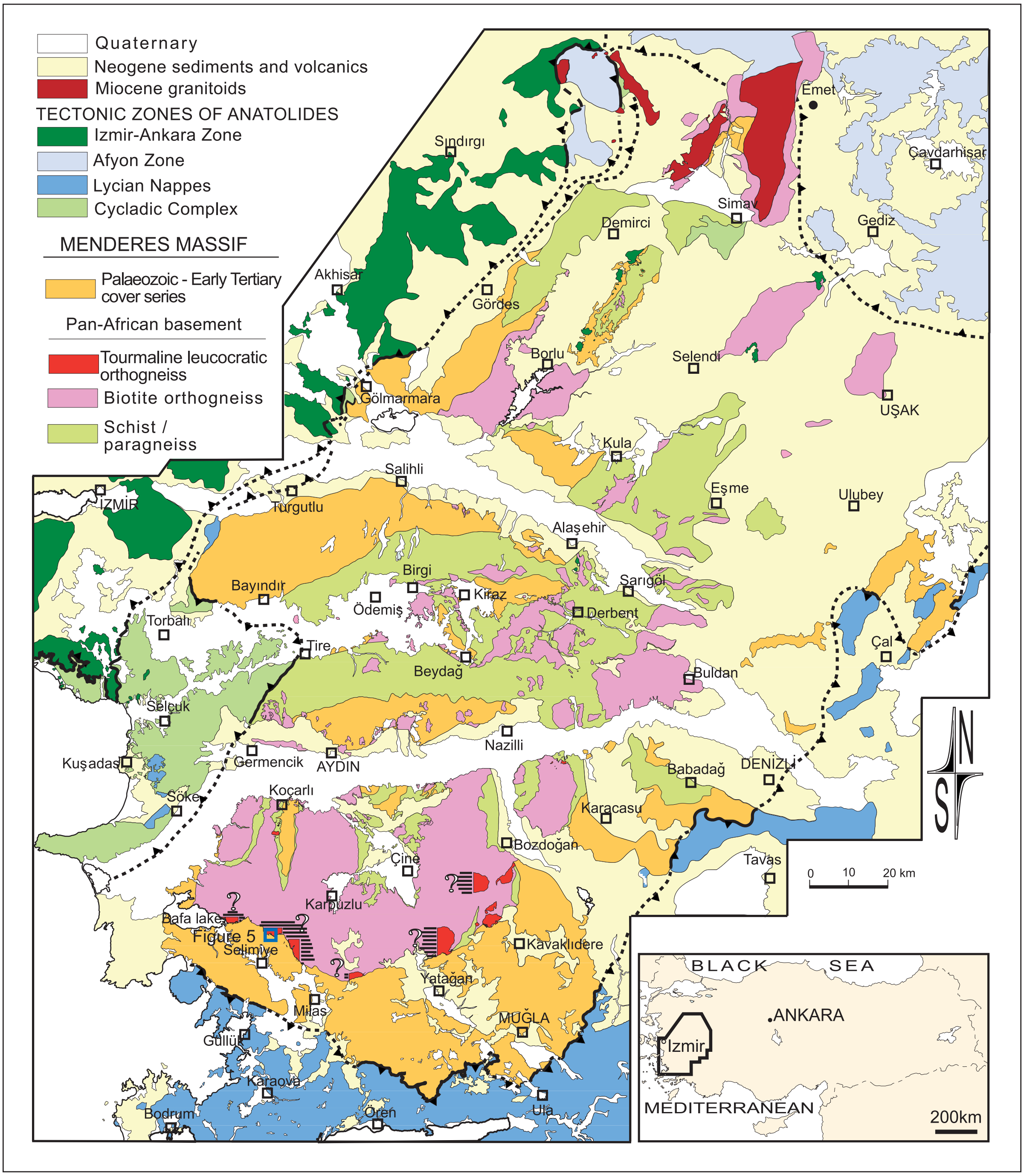


Figure 2- The general distribution of the Pan-African aged acidic magmatics in the Menderes Massif. Areas drawn in horizontal lines represent partly mapped probable extensions of these intrusives around the masses of tourmaline leucocratic orthogneisses (simplified from Candan and Dora, 1998).

Menderes Massif establish the existence of the acidic magmatic activity in three different ages. These are; i) Pan-African (Late Proterozoic-Cambrian), ii) Triassic, and iii) Tertiary rocks. Orthogneisses forming the Pan-African aged acidic magmatism are widely observed in the core series of the Menderes Massif and forms the most characteristic rock type of this basement (Hetzel and Reischman, 1996; Dannat, 1997; Hetzel et al., 1998; Loos and Reischman, 1999; Gessner et al., 2001; Koralay, 2001; Gessner et al., 2004; Koralay et al., 2004). Granitic protolithes of Triassic leucocratic orthogneisses form the second main magmatic activity in the Massif (Dannat 1997; Koralay 2001; Koralay et al., 2001). The Miocene aged third group is the intrusion in post metamorphic character and is observed in the central and in the northern parts of the Massif, in Tavşanlı zone located at north of the Massif, and in Sakarya Zone (Öztunalı, 1973; Bingöl et al., 1982; Reischmann et al., 1991; Hetzel et al., 1995; Delaloye and Bingöl, 2000; Işık and Tekeli, 2000; Işık et al., 2004; Lipps et al., 2001; Catlos and Çemen, 2005; Thompson and Ring, 2006; Glodny and Hetzel, 2007). The reason of these granites are not limited within the Menderes Massif and is genetically associated with the general evolution of northwest Anatolia makes it out of the scope of this paper. The geological and petrographical properties of the Pan-African and Triassic acidic metamagmatics are given below.

PAN-AFRICAN MAGMATISM

The distribution of the Pan-African Magmatism in the Menderes Massif

In recent studies performed in the Menderes Massif, the tectonical structure of this crystalline basement has been shaped by the Precambrian and Alpine contractional deformations and presents a complex internal structure. During the investigations, it was determined that the Pan-African base rocks are tectonically intercalated with Palaeozoic-Early Tertiary cover series in addition to its own intrinsic imbrications (Konak et al., 1994; Partzsch et al., 1998; Ring et al., 1999). The primary stratigraphy of the Massif has almost lost its original structure as a result of this Alpine compressional tectonics. The sequence belonging to Pan-African basement obtained by the correlation of stratigraphies of different tectonic slices is given below.

When the Menderes Massif is generally considered, Late Proterozoic metaclastic series forms the oldest rocks of the Pan-African basement in each of three submassifs. Paragneisses which are the oldest rocks of this series conformably grade into schist unit in upward direction (Dora et al., 2002). In many tectonical slices, paragneiss unit and conformably and transitionally overlying schist unit are observed together. The metaclastic series composed of paragneisses and schists are widely cut by granitoids with acidic composition that were intruded in different periods of the Pan-African Orogeny. When Demirci-Gördes, Ödemiş-Kiraz and Çine submassifs which were made up of many tectonical slices were studied, it was noticed that orthogneisses took place in different tectonical slices. It is assumed that, the orthogneisses acquired their structural and textural properties as a result of the Alpine Orogeny and metamorphism. The orthogneisses named as augen and granitic gneiss in many of the previous studies are divided into two sub groups in recent investigations (Bozkurt, 2004; Dora et al., 2006; Candan et al., 2010). These are the; i) orthogneisses rich in biotite and ii) leucocratic orthogneisses rich in tourmaline. Orthogneisses rich in biotite are remarked as in big plutons of which were intruded into each other, whereas, leucocratic orthogneisses rich in tourmaline are in the form of stocks and veins in various dimensions.

The distribution of the orthogneisses mentioned above, over the Menderes massif is given in figure 2. The tourmaline rich leucocratic orthogneiss masses described so far by the above classification are shown in this map. Areas drawn in horizontal lines show the probable extensions of partly mapped tourmaline rich leucocratic orthogneisses. And the other areas described by orthogneiss in the same map, comprises the all biotite and tourmaline rich leucocratic orthogneisses. The orthogneisses which are seen most widespread in Çine submassif, are exposed in large areas in other submassifs too.

Demirci-Gördes submassif.- It is one of the region in which the all units belonging to the Pan-African basement are observed in clear contacts. The lowest unit in this submassif showing internal nappings is dominantly composed of homogenous micaschists of the Pan-African basement. These rocks having garnet- mica-schist in composition are cut by Pan-African orthogneisses and by amphibolitic metagabbro stocks at the southwest of Eşme and by Triassic leucocratic orthogneissic intrusives at the north-east of Alaşehir. On these, the gigantic ortho-gneisses present at the lowermost part of the slice extending between Alaşehir-Kula were intruded into conformably overlying micaschists (Candan, 1994, Dora et al., 2002). Within orthogneisses, migmatite and paragneiss traps which were partly assimilated, are widely observed in a dimension of 2-3 km. This Pan-African aged slice is overlain by phyllite-quartzite-marble intercalations and by Palaeo-zoic-Mesozoic slice composed of platform type marbles overlapping on these.

Ödemiş-Kiraz submassif.- The stratigraphy of this submassif has been established in more detailed compared to the other submassifs (Partzsch et al., 1998; Ring et al., 1999; Candan et al., 2001; Dora et al., 2002, 2006). The lower-most slice of the metamorphic deposit is made up of Upper Cretaceous marbles defined by the existence of emery deposits and by well pre-served rudist fossils (Koralay, 2001; Özer and Sözbilir, 2003) which are observed in Aydın-Eğrikavak village. The platform type marbles are tectonically overlain by Palaeozoic series along the southern margin of Aydin mountains. Phyllites found in the chlorite-chloritoid bearing series in Aydin Mountains and in staurolite-garnet bearing series in Bozdaglar are cut by Triassic (235 Ma) vein rocks and by leucocratic metagranitic stocks. Palaeozoic series is overlain by three different slices belonging to the Pan-African basement. The lowermost slice is composed of homogenous micaschists which are exposed in large areas in Aydin mountains and Bozdaglar. South of Alaşehir is characterized by the othogneiss that was intruded into medium slice micaschists observed in Derbent and by the Triassic leucocratic orthogneissic intrusives. The paragneiss which was migmatised at lower the parts and the uppermost Pan-African slice made up of conformably overlying micaschists, are cut by the masses of metagabbro. The uppermost layer of the Menderes massif metamorphites is made up of Palaeozoic(?) clastics with the composition of staurolite-phyllite-marble and of the overlying Mesozoic platform type marbles containing emery beds (Koralay et al., 2001). The phyllite-marble community forming the uppermost tectonic unit at south of Derbent is located on the middle tectonic layer with a tec-tonic contact interpreted by a slip fault.

Çine submassif.- The lowermost tectonic unit of the Çine submassif is exposed in eastern and western parts of Çine-Bozdoğan. This slice is dominantly composed of garnet micaschists containing thin paragneiss layers. This clastic series is cut by orthogneissic and metagabbroic intrusives in variable compositions. The tectoni-cal slice overlying this clastic series and present-ing a very large propagation in the middle part of the submassif is dominantly made up of Pan-African granites with different characters that were intruded in periods following one another. Orthogneisses crop out in Yenipazar and Koçarlı at the north, in Karacasu and Bozdoğan at the east, in Bafa Lake at the west and in a large region between Milas and Yatağan at the south (Figure 2). In orthogneisses, there are mig-matised paragneiss and schist traps with a dimension of about 5-6 km. Garnet micaschists observed especially along the southern boundary of the submassif form the country rock of which the orthogneisses were intruded. In this slice, the primary unconformable contact relationship between the Pan-African basement and Palaeozoic cover series can be observed (Konak et al., 1987; Candan et al., 2006, 2007; Dora et al., 2006). The Palaeozoic deposit starting with quartzite which contains metaconglomeratic layers is made up of porphyritic metagranite, tourmaline leucocratic orthogneiss, metaaplite and tourmaline pebbles in channel fillings character. This deposit continues with a series of garnet-chloritoid-phyllite, marble and quartzite intercalations. The Palaeozoic deposit showing imbrication is overlain by metacarbonates produced from Mesozoic- Early Tertiary aged Anatolide-Tauride platform. Red colored pelagic marbles and Paleocene-Eocene aged Na-amphibol bearing blocky series constitute the youngest units of the Çine submassif.

THE CONTACT RELATIONSHIP BETWEEN ORTHOGNEISSES AND PAN-AFRICAN METASEDIMENTS

The contact relationship of orthogneisses (biotite orthogneiss and tourmaline leucocratic orthogneiss) with thick metaclastic deposit forming the country rock presents common properties in each of three submassifs. The primary contact relationship of granitic orthogneisses with metaclastics forming the country rock is in intrusive character in all regions. Late evolution products of protolithes of orthogneisses that were intruded into schists such as pegmatite, aplite and tourmaline belong to Pan-African basement and are widely observed in both units close to contact areas. The contact relationship of orthogneiss/metaclastic well observed in the various regions of Demirci-Gördes, Ödemiş-Kiraz and Çine submassifs is described below in detail.

Candan (1994) stated that, in south of Kula in Demirci-Gördes submassif, the granites of which are the protolithes of orthogneisses revealed an intrusive contact relationship with paragneiss unit. Many apophysis of orthogneisses with dimensions of several kilometers intrude into paragneisses. Besides, gneiss stocks in large and small dimensions are observed in paragneiss, close to gneissic contact. In gneisses close to contact zone, the existence of country rock traps range from a few cm. to a couple of km. and this is another significant data supporting the intrusive contact relationship. Especially, in undeformed orthogneisses, the detection of paragneiss, migmatised paragneiss and calc silicate rocks showing a strong foliation, in the form of partly assimilated traps (Figure 3a,b), indicate that granites of which are the protolithes of orthogneisses has been intruded after the metamorphisms of Pan- African paragneisses.

Ödemiş-Kiraz submassif.- to the south of Derbent of Ödemiş-Kiraz submassif, orthogneisses intrude into schists (Koralay, 2001, Koralay et al., 2004). An intrusive contact relationship between orthogneisses and schists is clearly observed in intermediate slice. Many dikes and sills belonging to orthogneisses are located in schists forming the country rock. It is clearly observed that some of these vein rocks cut the schistosity of schists (Figure 3c). Similar to other regions, schist traps are available in various sizes among orthogneisses, close to schist contacts. The original intrusive contact relationships of orthogneisses with paragneisses in the size of submassif can be detected in almost everywhere and be depicted with similar data. In addition to this, as in the vicinity of Semit and Cevizalan villages, strong ductile deformation evidences can be detected at contacts of paragneisses and orthogneisses that have planar geometry and thickness reaching even 1 km. It is considered that these orthogneiss masses settled into paragneisses in the form of tectonic slices under ductile conditions during the intrinsic imbrication of the units belonging to the Pan-African basement.

Çine submassif is characterized by the existence of gigantic granites in the structure of orthogneiss which represents varieties in composition. The character of orthogneiss/schist contact has been studied by many investigators. It has lateral extend of 100 km and located at the south of the submassif. Field data brings up that, the primary relationship along the contact between the Upper Proterozoic metaclastics forming the country rock and all orthogneiss types is intrusive in character. This relationship is not only limited to this contact but can also easily be detected at northwest of the submassif, south of Koçarlı (Dora et al., 2005). In this region, there is a clear intrusive contact relationship between gigantic sized, biotite rich orthogneiss plutons and tourmaline leucocratic orthogneiss stocks and Late Proterozoic schists. This contact is described especially by the existence of widespread vein rocks (Figure 3d,e,f). It can also be detected that, there is a primary intrusive contact relationship between the orthogneisses and paragneisses, in the form of absorbed traps at the north and southwest of Çine where there is less deformation.

As mentioned above, east of Bafa Lake is one of best places where intrusive relationships of orthogneisses are observed with Late Proterozoic schists forming the country rock. In addition, to Bademyanı point located at the western part of Bucak village, the intrusive relationships of tourmaline leucocratic orthogneisses with Upper Proterozoic schists can clearly be detected at the north of Bucak and Karahayıt villages. At Bademyanı point, there are many vein rocks in schists and near the tourmaline leucocratic orthogneisses widespread schist traps are available. This case complicates the determination of the main contact boundary between the orthogneiss and schist (Figure 4a,b). Although the contact was subjected to ductile deformation, similarly the primary intrusive relationship is observed fairly between schists and orthogneisses around Viranköy and Ekiztaş villages located at the eastern most part of the contact (Figure 5). At the south of Katrancı village, biotite orthogneiss and tourmaline leucocratic orthogneisses present a well preserved intrusive contact relationships with Late Proterozoic schists forming the country rock (Figure 6a). Schist traps in biotite orthogneisses and aplitic vein rocks in those schists are widely observed in this region. Besides, the intrusive contact relationship between biotite orthogneisses and tourmaline leucocratic orthogneisses is also clearly observed which represent two different phases of Pan-African magmatic activity (Figure 6b).

Around Seykel village located at the south of Çine, the primary intrusive contact relationships of biotite orthogneisses and tourmaline leucocratic orthogneisses is well preserved. This relationship type between the orthogneisses and schists belonging to the Pan-African basement which forms the country rock is also clearly detected. This intrusive contact relationship is noticeable in cuts along Yatağan-Çine road. Field data reveal that, granites of which are the protolithes of biotite orthogneisses in the primary stage were intruded into schists. Along contact of these rocks, gneissic veins in schists and schist traps in gneiss are widely remarked (Figure 7a, c). The tourmaline leucocratic orthogneiss mass belonging relatively to a latter stage of the same Pan African magmatic activity shows a clear intrusive contact relationship that can be detected in biotite orthogneisses and schists (Figure 7d). There are many leucocratic vein rocks with a thickness of 1.5 m within schists forming the country rock and in a zone of 200 m (Figure 7e). At contacts of those veins, mica minerals were developed in the form of thin zones as a result of contact metamorphism (Figure 7f). The parts shown by nonexistence of any orientation in mica minerals are the parts protected from the Alpine contractional deformation in which the original contact relationship is observed.

Around Mesken village located at the north of Yatağan, many biotite orthogneisses, tourmaline leucocratic orthogneisses and porphyritic metagranites belonging to poly-phased Pan-African magmatic activity show an intrusive contact relationship conformable with relative age relations (Figure 8a,b). In the region, to the north of Yukarı

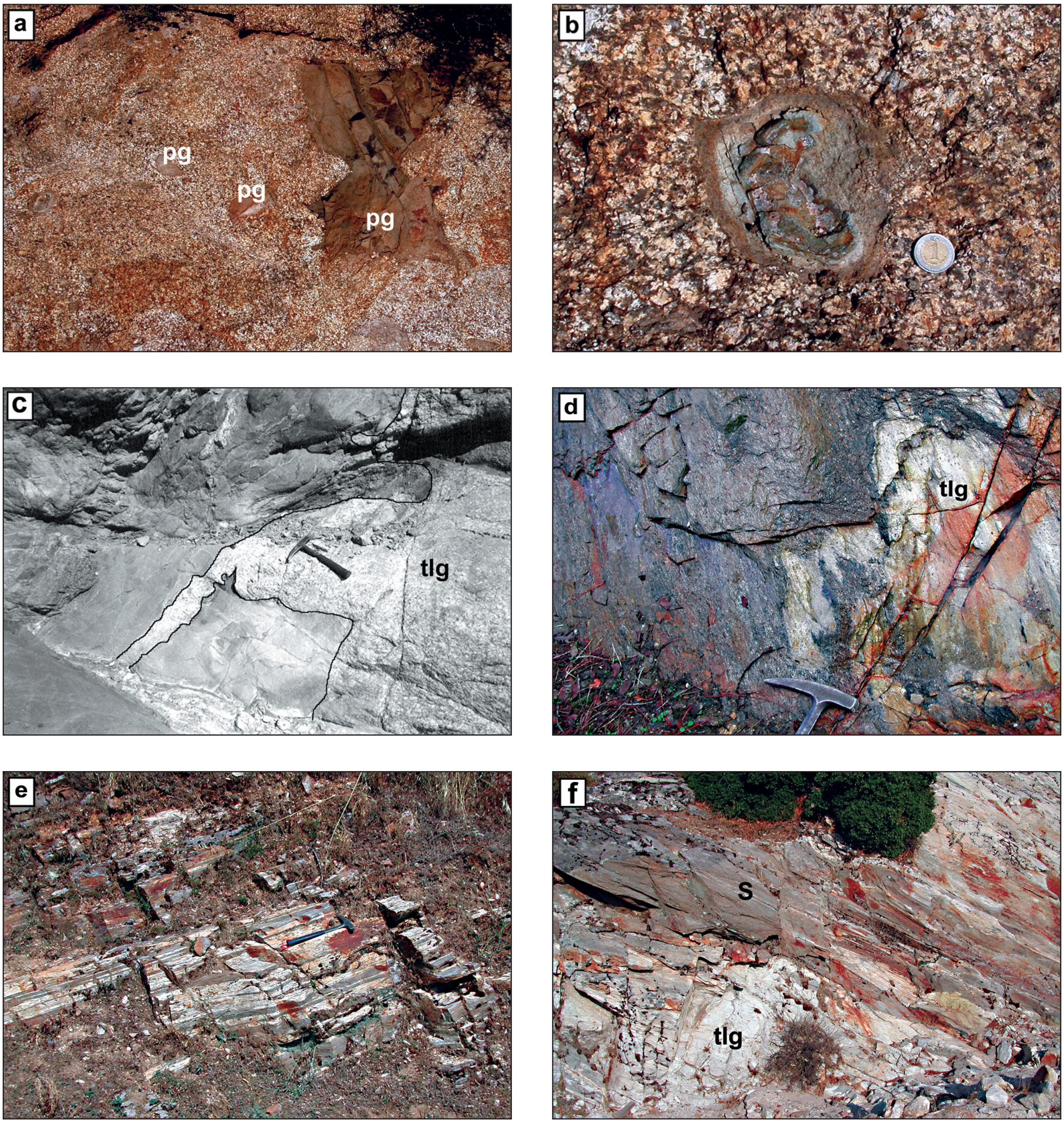


Figure 3- a) Paragneiss showing strong foliation in non oriented biotite orthogneisses, b) country rock traps formed by massif calc silicate rocks, c) the intrusive contact relationship of biotite orthogneisses located in NE Derbent with garnet micaschists forming the country rock, d) the intrusive contact relationship schists belonging to Base series with tourmaline leucocratic orthogneisses, Çulhalar village, e) tourmaline leucocratic veins extending along the foliation planes of schists, f) schist traps observed within tourmaline leucocratic orthogneisses (pg: paragneiss, ks: calc silicate, s: schist, bg: biotite orthogneiss, tlg: tourmaline leucocratic orthogneiss).

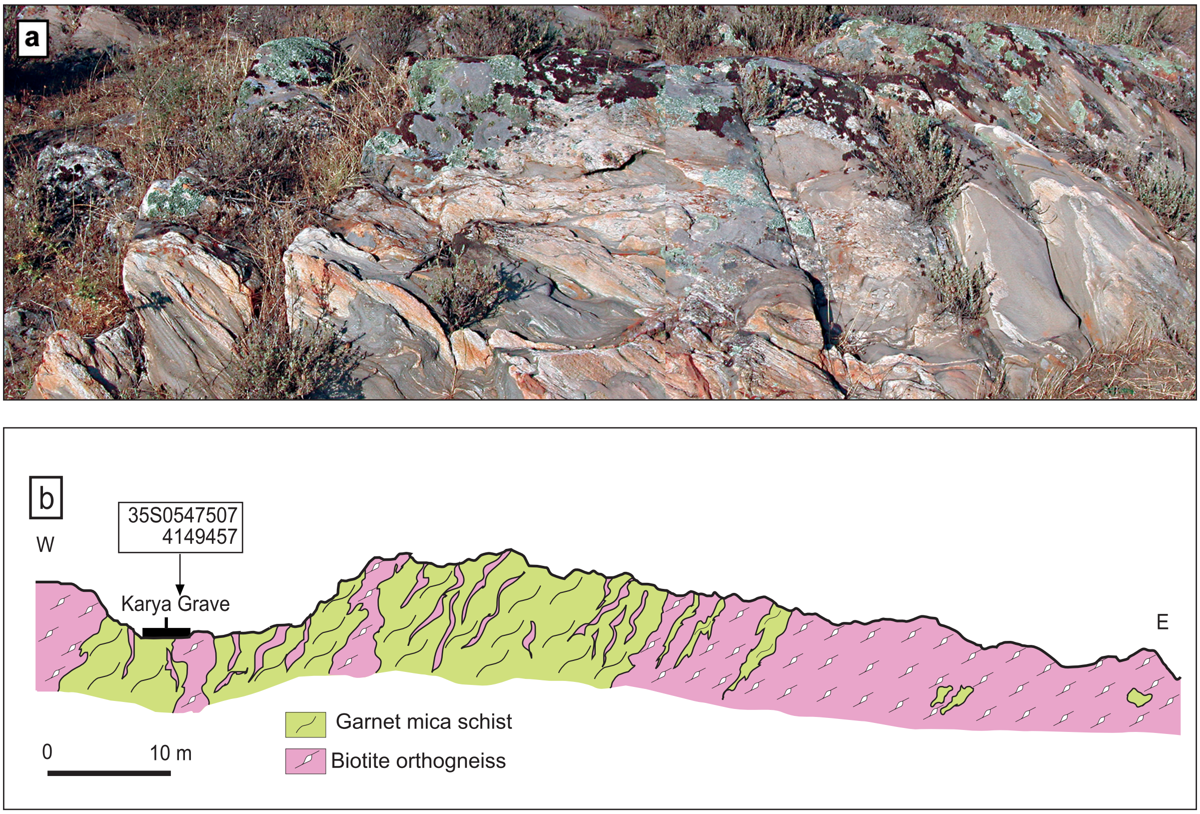


Figure 4- a) Veins formed by biotite orthogneisses and aplites within Late Proterozoic micaschists and garnet micaschist forming the country at Bademyanı foreland, b) the intrusive contact relationship observed between biotite orthogneiss and schists around Bademyanı peninsula near Bafa lake (Dora et al., 2006).

Mesken village, both biotite orthogneisses and tourmaline leucocratic orthogneisses form inter-tongues intruding into Late Proterozoic schist and that reaches several hundreds of meters. Similar to other regions, many country rock traps that are partly assimilated are available in biotite orthogneisses.

MACROSCOPIC AND MICROSCOPIC PROPERTIES OF ORTHOGNEISSES

Orthogneisses in the Menderes Massif were defined typically as augen and/or granitic gneiss by the investigators in previous studies. And, in recent studies, it was determined that it was possible to differentiate the mineralogical composition and textural properties of primary granites of these rocks (Bozkurt, 2004; Dora et al., 2005). These rocks of which are the consecutive products of Pan-African acidic magmatic activity can be divided into three groups based on mafic phase composition and textural properties (Dora et al., 2005). These orthogneiss types and the basic petrographic properties of their primary granites can be described as follows;

Biotite Orthogneisses.- Rich in biotite (± tourmaline), coarse grained crystalline, granite with equally sized and/or in porphyritic texture.

Tourmaline Leucocratic Orthogneisses.- Rich in tourmaline and muscovite (± biotite), light colored (leucocratic), medium to coarse grained, generally equally sized, rarely porphyritic textured granite.

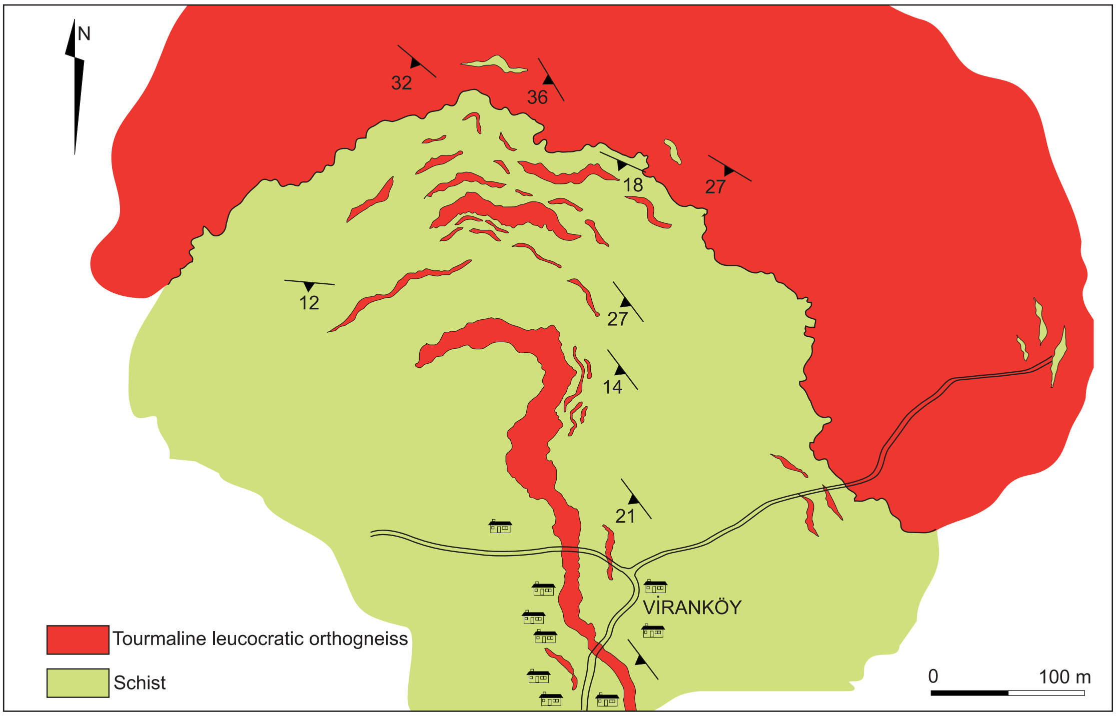


Figure 5- The geological map of the region in which the primary intrusive contact relationship is observed between the Upper Proterozoic schists belonging to the Pan African basement and the tourmaline leucocratic orthogneisses. The primary intrusive property between the two units are well preserved although these were deformed in Alpine metamorphism (Dora et al., 2006). Coordinates of Viran village: Aydın N 19-a2 4146150: 059000.

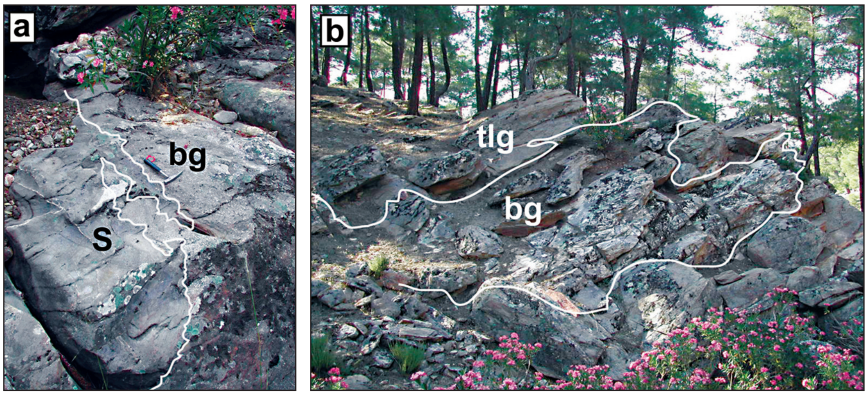


Figure 6- a) The intrusive contact relationship of biotite orthogneisses with schists, b) leucocratic orthogneiss vein cutting biotite orthogneisses by intrusive contacts, south of Katrancı village (s: schist, bg: biotite orthogneiss, tlg: tourmaline leucocratic orthogneiss).

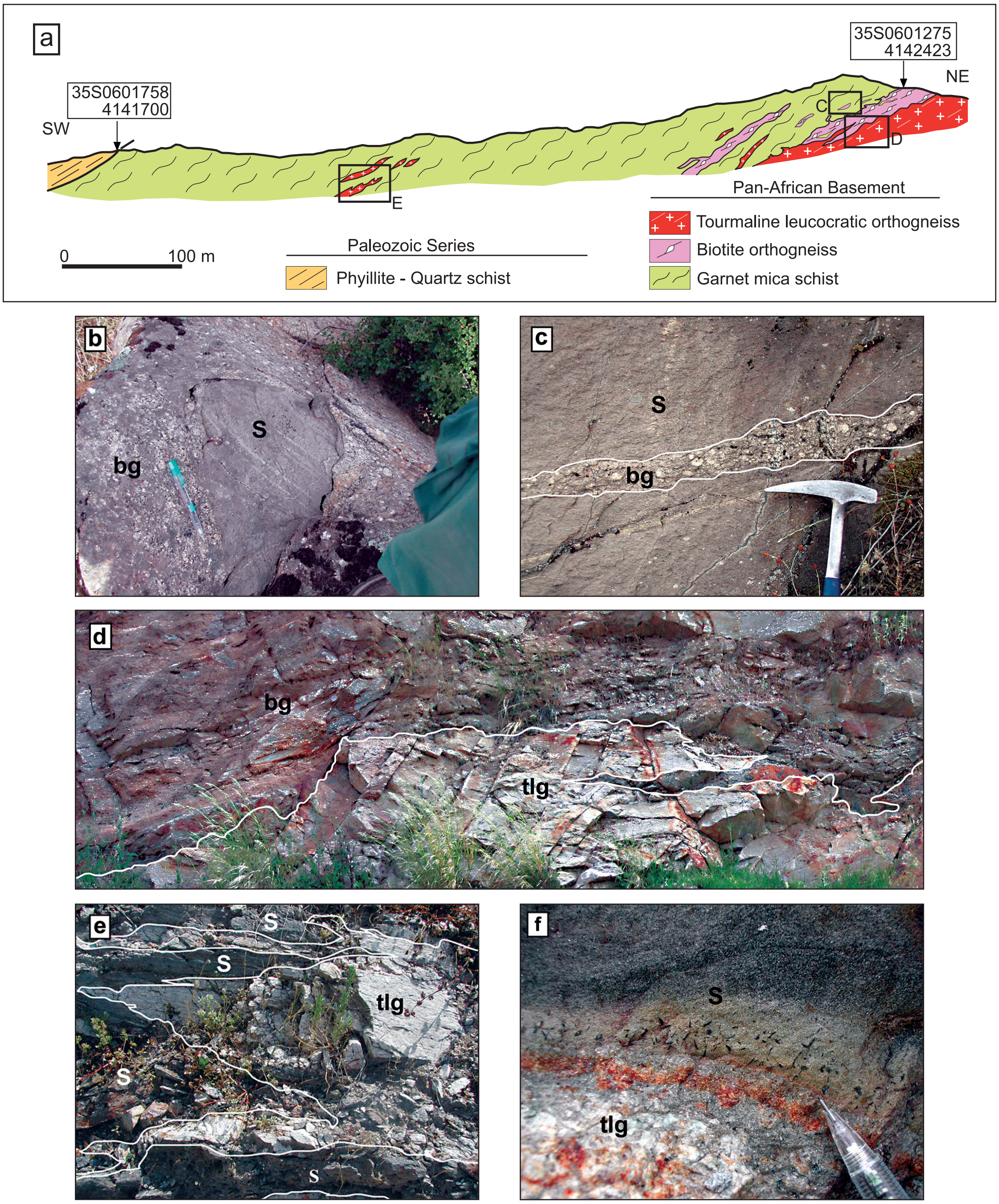


Figure 7- a) Geological cross section observed in Çine-Yatağan road cut and the contact relationships among Pan-African units (Dora et al., 2006), b) schist traps in biotite orthogneisses, c) biotite orthogneiss vein in micaschist forming the country rock, d) the sharp intrusive contact relationship between the biotite orthogneiss and tourmaline leucocratic orthogneiss, e) vein rocks belonging to tourmaline leucocratic orthogneisses in the Upper Proterozoic schist, f) contact metamorphism product preserved from Alpine overlap which is observed in contacts of leucocratic vein rocks with schists, randomly oriented mica crystals (s: schist, bg: biotite orthogneiss, tlg: tourmaline leucocratic orthogneiss).

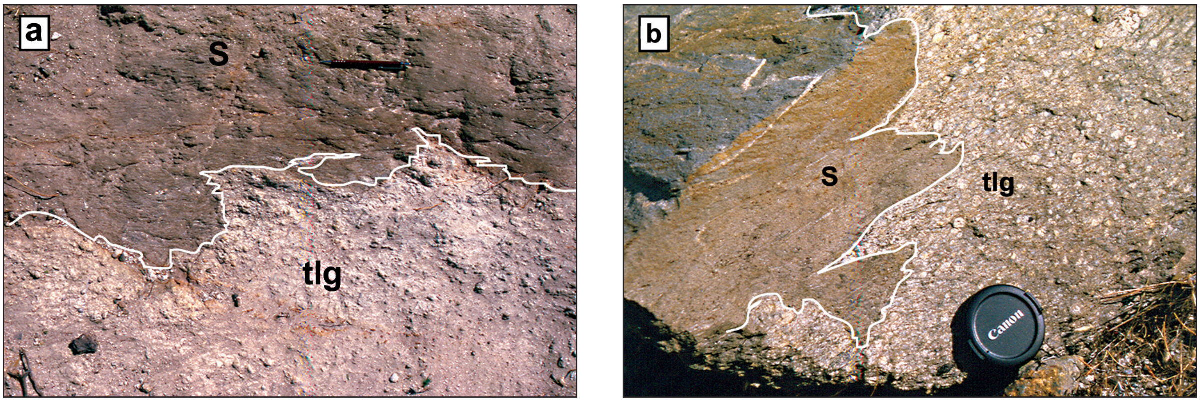


Figure 8- a) Intrusive contact relationship between the tourmaline leucocratic orthogneiss and Upper Proterozoic schist, b) the intrusive contact relationship observed between biotite orthogneisses and Upper Proterozoic schists, Mesken Village (s: schist, bg: biotite orthogneiss, tlg: tourmaline leucocratic orthogneiss).

Amphibolic orthogneiss.- Hornblende bearing (± biotite), fine to medium grained, equally sized holocrystalline textured granite.

1. Biotite Orthogneisses.- These are the most characteristic orthogneiss types that are widely observed in the Menderes Massif. The ratio of biotite mineral in these orthogneisses varies between 15 to 25 %. These are divided into two subgroups based on the primary textural properties in which the sectors were avoided from the deformation of primary granites. Porphyritic granites in phanerocrystalline texture are the most frequent orthogneiss type that is observed. These granites are described as orthoclase crystallines with a less lineation, medium grained, in a groundmass composed of quartz and plagioclase with a size of 8 to 10 cm, in euhedral to subhedral form (Figure 9a). In these rocks, based on the intensity of deformation that develop under ductile conditions, crystal sizes decrease and there occurs a traverse into blasto mylonitic gneiss (Figure 9b), generally named as augen gneiss in previous studies and ultra mylonitic banded gneisses (Figure 9c) which show a strong foliation and lineation.

Equally sized quartz and plagioclase/orthoclase crystals and grano blastic textured coarse grained granites, characterized by randomly distributed, well formed biotite crystals, form the second biotite orthogneiss type (Figure 9d). There is a widespread transformation into banded gneisses of this biotite orthogneiss type also named as granitic gneiss in sections where there occurred ductile deformation.

General mineral composition of biotite orthogneisses were defined as quartz, plagioclase, orthoclase, biotite, muscovite (± microcline, garnet, zircon, tourmaline, sphene, zoisite and opaque mineral). Quartz, plagioclase and orthoclase constitute the main components of biotite orthogneisses. Orthoclases generally cover pertitic structures and are observed in the form of porphyroblasts together with polysynthetic twinned plagioclases. In pertitic orthoclases, microcline transformations are widely observed which is accepted as the deformation product. On the other hand, the secondary twinning which is the deformation product in plagioclases and recrystallization that occur along fractures reflect in similar conditions (Figure 9e). Although coarse grained porphyroclastics originate from orthoclases in gneisses, ductile deformation product in high grade temperature, medium to fine grained feldspar rich layers are made up of microclines and this supports the idea cited above (Figure 9f). Muscovites and biotites depending on the

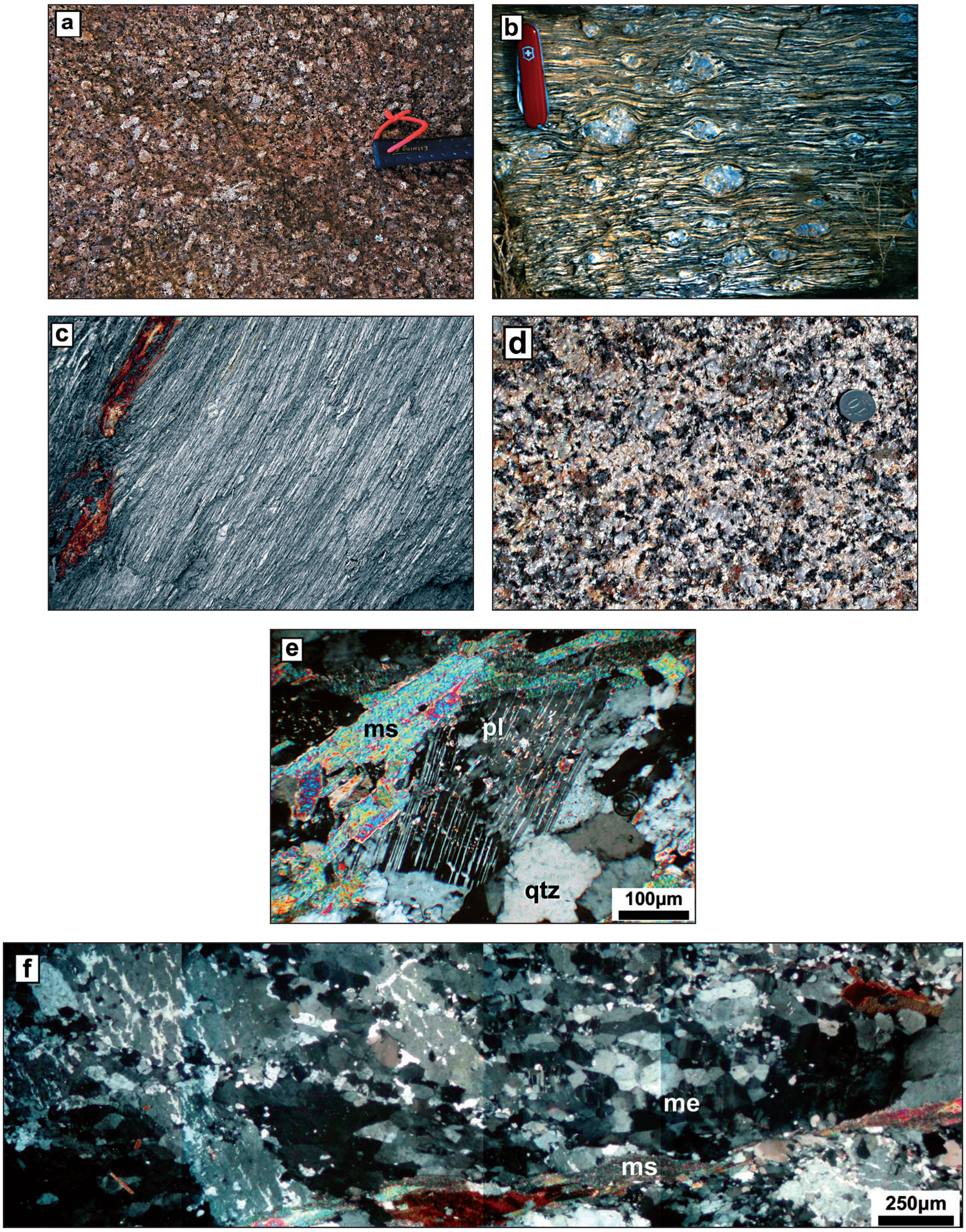


Figure 9- a) Biotite orthogneisses derived from coarse crystallined porphyritic granites where the primary texture was greatly preserved, North of Seykel village, b) the blasto mylonitic texture, product of ductile deformation which is observed in biotite orthogneisses, Dedebelen hill, c) the general view of ultra mylonitic orthogneisses formed by intense ductile deformation of biotite rich porphyritic granites, North of Katrancı, d) massif biotite orthogneisses derived from coarse grained granites with granoblastic texture characterized by equally sized, randomly distributed quartz, plagioclase, orthoclase and biotite crystals, e) cracks developed in plagioclases by deformation and new recrystallizations occurred in these cracks (+nikol), f) microcline crystals produced by the ductile deformation and developed from orthoclase porphyroblasts, ms: muscovite, pl: plagioclase, or: orthoclase, me: microcline.

deformation in rock show a distinct lineation and form foliation planes.

2. Tourmaline Leucocratic Orthogneisses.- These orthogneisses are in dirty white colors, leucocratic in character and contain abundant tourmaline (± biotite) as mafic mineral and are widely observed especially in Çine submassif (Alkanoğlu 1978; Bozkurt 2004; Dora et al., 2005; Bozkurt et al., 2006). This orthogneiss type is encountered in Ödemiş-Kiraz submassif, at south of Kula and at west of Alaşehir. These rocks show a clear intrusive contact relationship with orthogneisses (augen/granitic gneisses) in many regions. Although these rocks are Pan-African aged, these represent a relatively young magmatic stage. The most typical property of these very light gray to white colored rocks is the content of tourmaline in high rates as mafic phase (Figure 10a). Many tourmaline formations were detected in various structures and textures (Bozkurt, 2004; Dora et al., 2006). The most typical tourmaline formations among these are "tourmaline-quartz" formations in nodular structures. In undeformed zones, the aforesaid nodules present a distinctive spherical or ellipsoidal shape. But, in regions where shear zones are effective, these gain a disc or lensoid shape making a parallel elongation to mineral lineation by lengthening and flattening. The most typical examples of tourmaline-quartz nodules are observed along the road of Çine and in Karpuzlu area. The core of nodule is composed of tourmaline and quartz at a percentage of more than 80% and the outer shell is formed by a feldspar and quartz with a thickness of 1-1.5 cm (Figure 10 b,c). The other tourmaline formation in these rocks is in the form of vein, band and amorphous masses and do not represent any lateral continuity. Besides, in this orthogneiss type, homogenously distributed tourmaline crystals in euhedral form and rosette shaped tourmaline formations are widely observed.

According to the structural and textural properties of primary granites and the size and geometry of emplaced masses, these leucocratic rocks show some differences. These tourmaline leucocratic orthogneisses are recognized as in big plutons reaching to tens of kilometers in diameter and interfingered to each other, especially in Çine submassif, between Bafa-Bozdoğan. These masses represent distinctive intrusive contact relationships both with Late Proterozoic schists belonging to core series and with biotite orthogneisses forming the country rock. Furthermore, these leucocratic granites are found in as smaller sized stocks at the south of Koçarlı and north of Karıncalı Mountain in the Çine submassif and at the south of Kula, north of Sarıgöl in the Ödemiş-Kiraz submassif (Figure 2). These large masses in plutonic geometry might illustrate some textural differences depending on primary magmatic facial changes. Orthogneisses having granoblastic texture with coarse grained, equally sized feldspar crystals form the most widely observed leucocratic tourmaline orthogneiss type (Figure 10d). Besides, the porphyritic textured, coarsely crystallined rocks described in a groundmass of coarse orthoclase phenocrystals in gray colored and fine grained quartz-feldspar groundmass form the second common tourmaline leucocratic orthogneiss type (Figure 10 e). It is too difficult to map these granites in detailed which are mainly in leucocratic character, since intervals belonging to these magmatic facies are too narrow.

During field studies, it was observed that these aforesaid gigantic plutons found as in shapeless masses or in the form of lensoid structures with an approximate thickness of 50 to 150 meter were again cut by leucocratic rocks. These rocks are described by the existence of feldspar crystals with a size of 4-5 mm within a relatively fine grained groundmass and are named as "leucocratic metagranite porphyry" based on primary textural properties (Figure 10 f). The excess existence of tourmaline and distinctive leucocratic character shows that those rocks have a common origin with tourmaline leucocratic orthogneisses. In addition, in Çine submassif, leucocratic aplitic veins are widely recognized which cut biotite orthogneiss and tourmaline leucocratic orthogneiss plutons (Figure 10 g). These rocks are white in color,

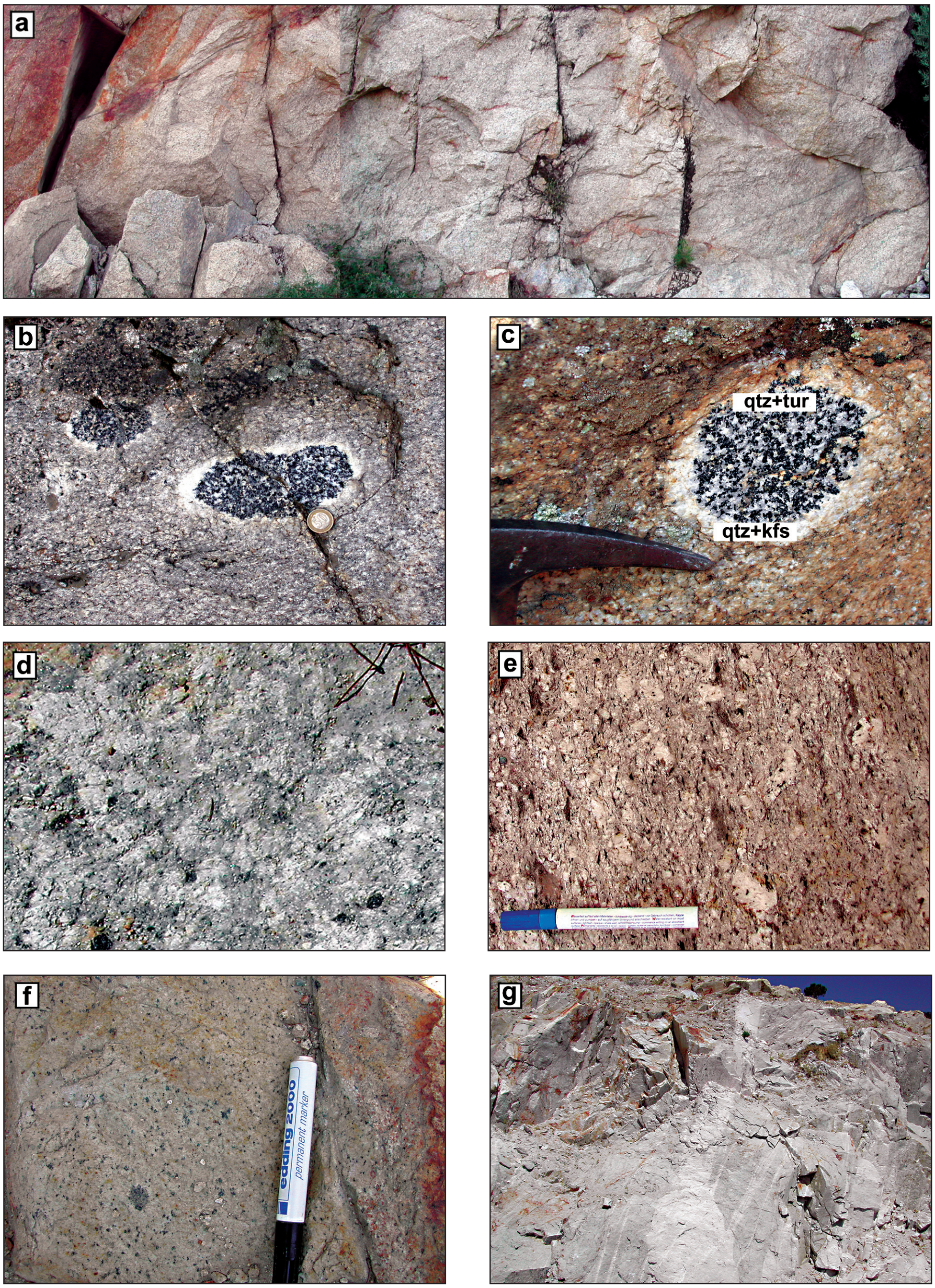


Figure 10- a) General view of tourmaline leucocratic orthogneisses described by its distinctive gray-white colors, North of Viranköy, b-c) tourmalinite nodules showing textural/mineralogical zoning, d) tourmaline leucocratic orthogneisses showing equal sized granoblastic texture, e) tourmaline leucocratic orthogneisses having porphyritic texture, f) fine grained, massive structured, tourmaline rich leucocratic porphyritic metagranites, north of Kale Hill/Mesken village, g) vein rocks fully in leucocratic character which cuts tourmaline leucocratic gneisses, Çomakdağı village (qtz: quartz, tur: tourmaline, kfs: K-feldspar).

very fine grained which are composed of albite and quartz with more than 98% and are processed as albitic deposits. The rocks of which are the last products of leucocratic magmatic activity is characterized by; 1- the constitution of tourmalinite nodules in zonal structure, 2- fine grained formation, 3- distinctive vein characteristics, 4- the presence of rutile and/or sphene rich sections at circumferences of host rock.

Based on petrographical studies, the mineral composition of tourmaline leucocratic orthogneisses were detected as quartz, plagioclase, orthoclase, tourmaline, muscovite (± microcline, sericite, biotite, zircon, opaque). In undeformed and approximately equally sized sections of tourmaline leucocratic orthogneisses, the ratio of quartz, plagioclase and K-feldspar (orthoclase + microcline) may reach 90% that could reflect the leucocratic character of primary granite. On the other hand, textural evidences, such as the platy plagioclase traps in K-feldspars, the graphical texture formed by the growth of K-feldspar and quartz and the process of partially melted plagioclase crystals being trapped during the crystallization of primary magma by K-feldspars which has grown in the following stage are the evidences that support the magmatic origin of mentioned rocks. Quartz of which are the products of the last stage are observed in rocks equally sized, and in anhedral to subhedral crystals. Plagioclases observed in the form of various crystals anhedral to subhedral in form show widespread primary polysynthetic twinning. Orthoclase crystals showing Carlsbad twinning and/or non twinning present strip and patch type perthitifications. Besides, transformations from orthoclases into microclines are widely recognized especially in deformed samples. Involvement of individual tourmaline crystals or the tourmalinite nodules formed by the combination of all these is one of the differentiating properties of orthogneisses in study areas. Anhedral shaped, tourmaline rich core in tourmalinite nodules are surrounded by an outer shell made up of quartz, microcline and orthoclases (Figure 11 a).

In field observations and petrographical studies, it was determined that tourmaline leucocratic orthogneisses has the characteristic of ductile deformation varying between protomylonite to ultramylonite along shear zones although they mainly represent a massive and non oriented structure. Substantially, textural data belonging to each stages of this ductile deformation under amphibolitic conditions, the amphibolite facies that can be defined as the decrease in the crystal size, the recrystallization and acquisition of planar/linear structure can be observed in rocks (Figure 11 b,c,d).

General mineral composition of leucocratic metagranite porphyries is described as quartz, orthoclase, muscovite (± tourmaline, biotite, zircon). The basic property of these rocks is the availability of feldspar crystals of which its euhedral structure has been protected in a fine grained quartz-feldspar groundmass. Feldspar porphyroblasts have highly preserved their euhedral shapes and have different orientations. This shows that this texture was ordered partly by metamorphism and belongs to primary porphyritic texture related to precursor magmatic rock. Relic graphic textures belonging to primary magmatic rock are common in feldspar. Orthoclases representing Carlsbad twinning form the majority of feldspars in the rock (Figure 11 e). Sparse muscovite development is observed along the planes where there is a distinct foliation in rocks where ductile deformation took place. Tourmaline ratios reaching high values reinforce the probability of connection of aforesaid rocks with tourmaline leucocratic orthogneisses in origin.

Leucocratic metaaplites are the last products of the Pan-African magmatic activity and of rocks rich in quartz and plagioclase in vein character. In thin section studies, the mineral composition of these rocks were determined as quartz, albite, rutile (± orthoclase, sphene, zircon). Plagioclases were detected as in fine grained, equally sized crystals. These show polysynthetic twinning and albitic composition (Figure 11 f).

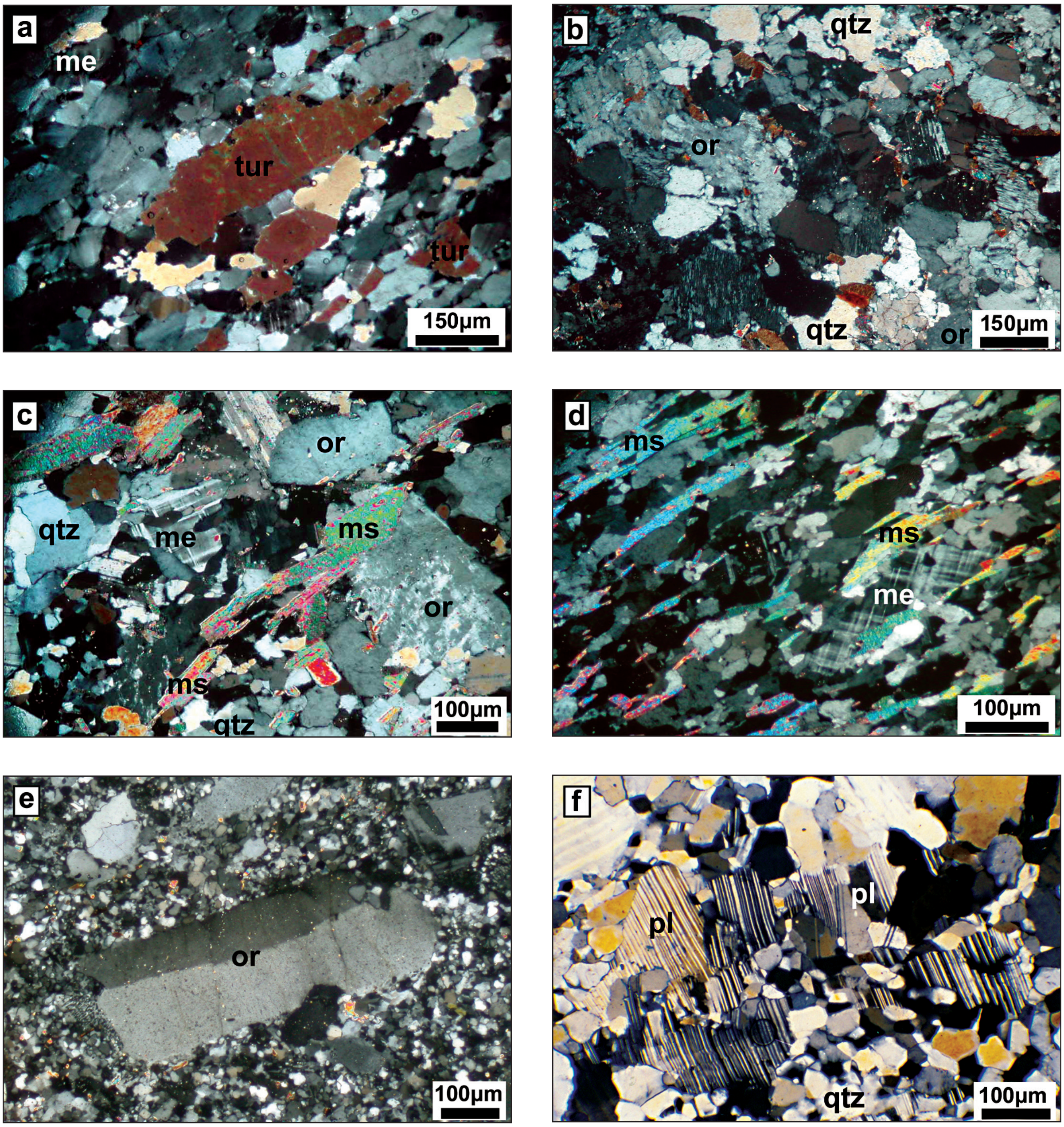


Figure 11- a) core and quartz enriched by tourmaline crystals, tourmalinite nodule made up of a leucocratic exterior zone formed by microcline and orthoclases, b,c,d) textural changes developed in tourmaline leucocratic orthogneisses depending on the intensity of increasing ductile deformation, e) primary orthoclase crystals that has mostly preserved its euhedral shape in a fine grained groundmass of leucocratic metagranitic porphyries, f) microscopic view of metaaplitic rocks composed of albite and quartz (±rutile) me: microcline, tur: tourmaline, or: orthoclase, qtz: quartz, ms: muscovite, pl: plagioclase.

Titanium phases concentrated especially in lateral zones of aplites are made up of rutile and sphene. Rutile and sphene reaching mostly 6% are composed of homogenously distributed small crystals among quartz and albite crystals.

3. Amphibolitic orthogneisses.- These are located only in Karıncalı Mountain and around Buldan area and are described by the existence of hornblende and garnet porphyroblasts, granoblastic in texture and in fine to medium crystallized massif rocks. These masses are observed in the form of small stocks being intruded into biotite orthogneisses and schists which belong to Precambrian basement. Dark green colored, non oriented amphibole crystals with a size of 2 cm present a homogenous distribution in equally sized, granoblastic texture (Figure 12 a,b). At circumferences of the mass and internal shear zones, rocks turned into gray to silver colored ultra mylonitic gneisses that show intensive planar separation property. Partly designed texture belonging to protolithes can be noticed in zones where the intensity of deformation is much less. General mineral composition of amphibolitic orthogneisses was described as orthoclase, plagioclase, quartz, hornblende, biotite, garnet and muscovite (± tourmaline, zircon, sphene, epidote). Amphibolitic porphyroblasts characterizes this type of orthogneisses. Dark green colored amphiboles are in hornblende composition and have a poikilitic texture originated from quartz, feldspar and epidotic inclusions. Garnet porphyroblasts in these gneisses have anhedral crystal forms similar to amphiboles and in some grains, inclusion amount reaches the ratio of major minerals (Figure 12 c,d).

GEOCHRONOLOGY OF THE PAN-AFRICAN VOLCANISM

Zircon Morphology

Basic morphological properties of zircons enriched by biotite and tourmaline rich orthogneisses in the Menderes Massif, features related to internal structures and study methods applied to these are briefly summarized in this part. Koralay (2001), presented detailed descriptions related to these studies. Zircons selected under binocular microscope, were analyzed under Scanning Electron Microscope (SEM) before age determination. SEM and cathode luminesans (CL) photos of zircons were taken in order to classify according to their morphologies and to analyze internal structures. In SEM analysis, it was determined that majority of zircons differentiating from biotite orthogneisses reflected the magmatic origin and has similar morphological features. These are euhedral, sometimes asymmetrical, generally colorless, rarely in pink and brown colors transparent, in short (2:1) or long (3:1, 4:1), prismatic form and sometimes in the form of grains including inclusion and old cores of the former grains (Figure 13). According to Pupin and Turco (1974) classifications, zircons were crystallized dominantly in S6, S7, S11 and S12 types and in less amounts in L1, S2, S13 and S17 types. Depending on these dominant types, the crystallization temperature of primary magma was determined as 700-750 C (Loos and Reischmann, 1999; Koralay, 2001). Pupin (1980) stated that, this type of zircons is typical for two mica granites. Cathode-luminesans studies established that zircons in orthogneisses were magmatic in origin (Figure 14). The crystal faces in zircons which represent a typical zoning peculiar to magmatic rocks make a distinct parallelism to zoning pattern observed in internal parts of the grain. This data show that the whole grain was crystallized in similar conditions. Some zircon grains present textural data related with poly phase growth. While old dendritic cores are not recognized in long, needlelike grains (Figure 14 a,d), one or two old cores in various sizes could be detected in short and thick grains (Figure 14 e). It was also determined that these old grains show magmatic zonation. In order to determine the crystallization ages of primary granites of orthogneisses, nonbearing relic core, thin and long prismatic grains that have magmatic zoning patterns defining the crystallization from a melt

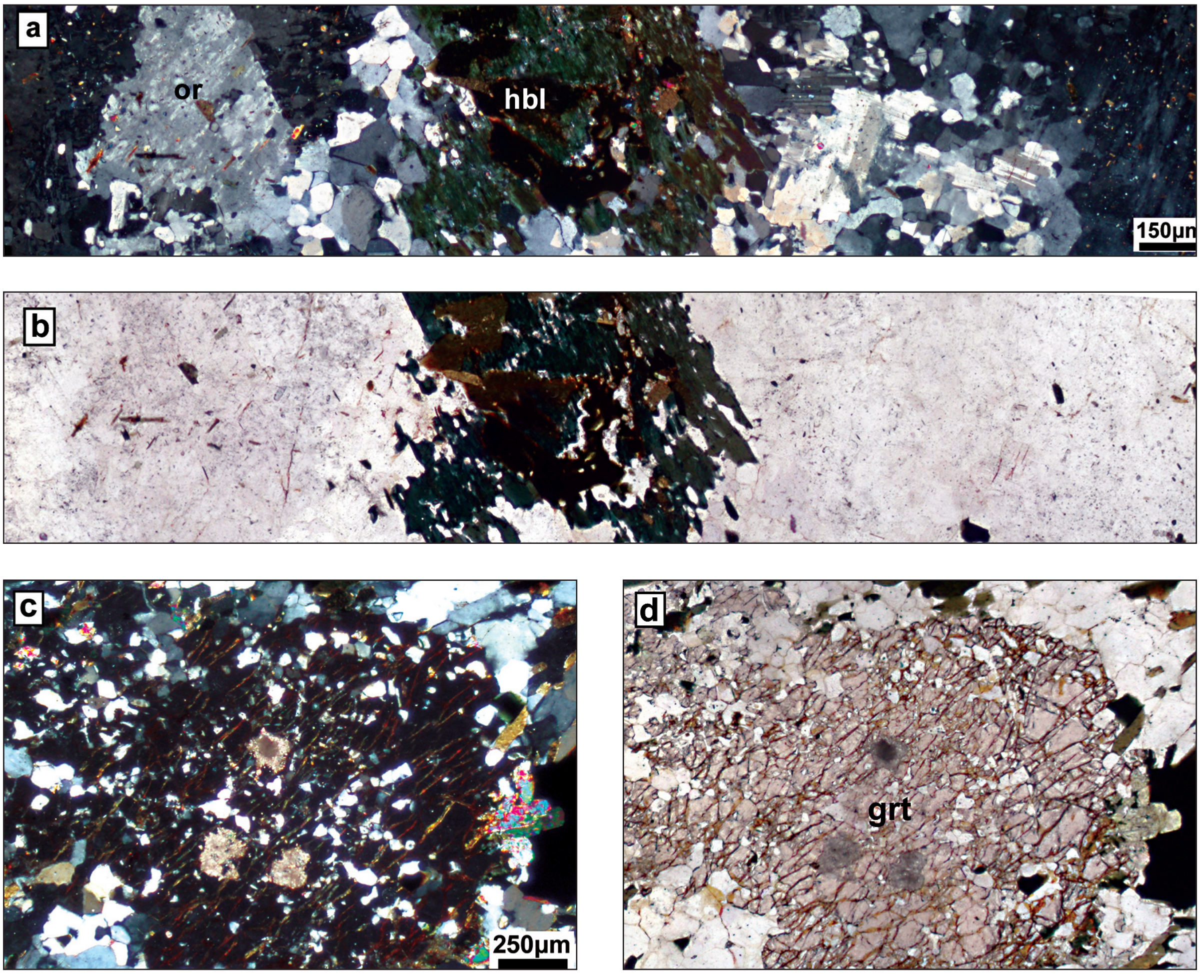


Figure 12- a-b) General view of orthoclase rich amphibole orthogneisses showing granoblastic texture, c-d) anhedral garnet crystal containing much inclusions in amphibole orthogneisses (a-c: cross nicoles, b-d: parallel nicoles) or: orthoclase, hbl: hornblende, grt: garnet.

were selected in age determinations. It is observed that zircons in tourmaline leucocratic orthogneisses are magmatic in origin, similarly.

Ages Obtained

As has been mentioned in former sections, orthogneisses were not differentiated into other types and all gneisses were defined by investigators as augen or granitic gneisses without any distinction in previous studies. Whereas, the evidences acquired in recent years have obviously established the necessity of the classification of gneisses in the Massif according to its mineral composition and rock dating studies should be set on this base. Up to now, majority of geochronological studies performed in the Massif concentrated on orthogneisses cropping out only in Çine submassif. In preliminary geochronological studies, orthogneisses in Çine submassif, south of the Menderes Massif, were dated as 490 ±90 Ma (Dora, 1975, 1976) and 470±9 Ma (Satır and Friedrischsen, 1986) using Rb-Sr method (Table 1). After mid 90's, rock dating studies have accelerated for throughout the

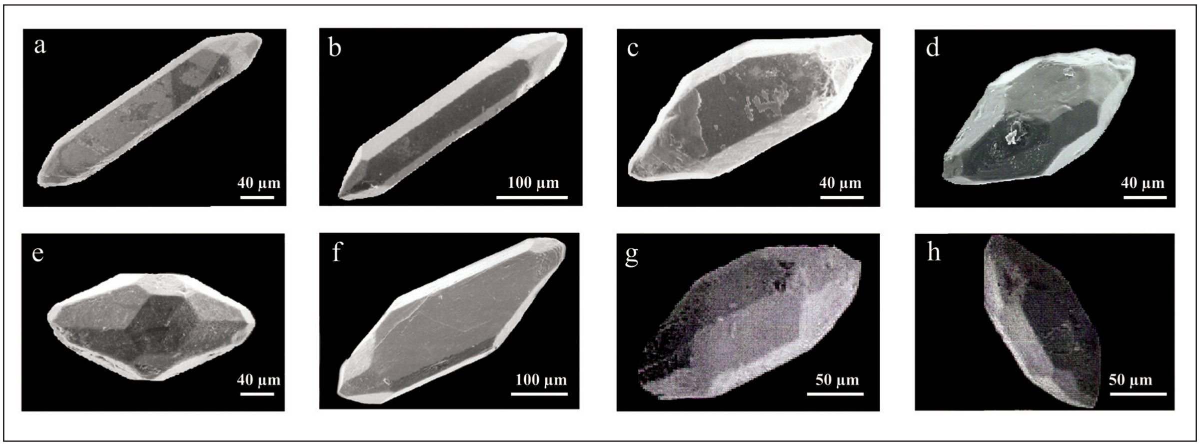


Figure 13- SEM views of typical zircons obtained from biotite orthogneisses (a-f: by Koralay et al., 2004, g-h: by Loos and Reischmann, 1999).

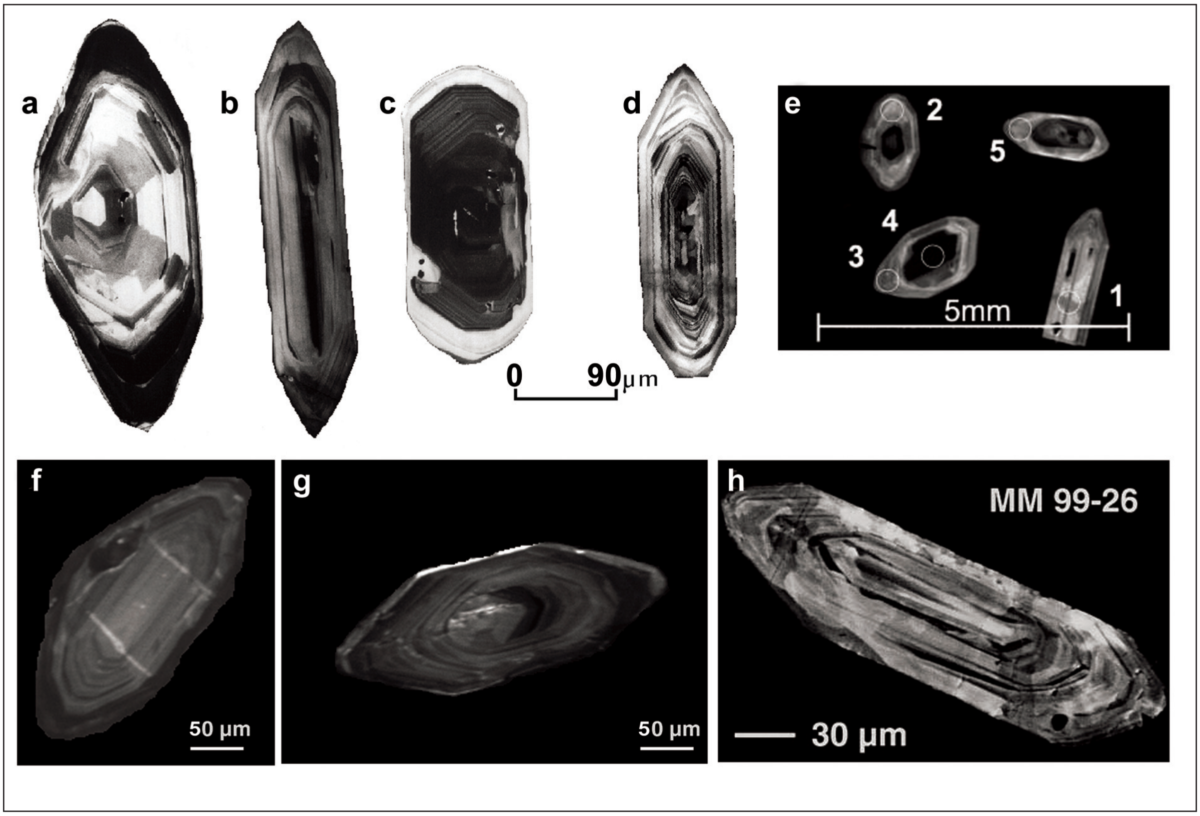


Figure 14- a-e) biotite orthogneiss and f-h) cathode luminance (CL) views of typical long prismatic magmatic zircons in tourmaline leucocratic orthogneisses (a-d-f: by Koralay et al., 2004 e: Gessner et al., 2004, h: Gessner et al., 2001).

Massif. In these studies, new methods have been used and more sensitive ages were determined conformable with geological relationships.

In this paper, it was remained true to the definition of gneisses of the authors of the previous studies. Probable equivalent names of gneisses in our newly proposed classification were given as italic in parentheses. Furthermore; orthogneisses which were dated in our studies have been named based on the criteria defined in previous sections (Table 1). As seen in Table 1 (Dannat, 1997; Dora et al., 2002; Koralay et al., 2004; Dora et al., 2005), while gneisses named as augen/granitic gneiss are equivalent of biotite rich gneisses in the new classification, in many studies (Bozkurt and Park, 1994; Bozkurt et al., 1995; Hetzel and Reishmann, 1996; Loos and Reischmann, 1999; Gessner et al., 2001; Gessner et al., 2004; Erdoğan, 1992; Erdoğan and Güngör, 2004; Bozkurt, 2004; Bozkurt et al., 2006), proposed augen/granitic gneiss and metagranite definitions are given as the equivalent of tourmaline leucocratic orthogneisses. Results of the studies performed about the orthogneiss dating in the Massif are given below.

Demirci-Gördes submassif.- In the Demirci-Gördes submassif, first studies about rock dating were established by Dannat in 1987. The investigator dated 541.4±2.5 Ma from augen gneisses (biotite orthogneiss) samples at southeast of Simav, 537±2.4 Ma at southwest of Demirci, and 544.1±4.3 Ma at the vicinity of Demirköprü dam (Figure 15, Chart 1). These ages were accepted as the intrusion age of protolithes of augen gneisses (biotite orthogneiss), by the investigator. Dora et al. (2002), dated the intrusion age of protolithes of granoblastic textured orthogneisses (biotite orthogneiss) that has intruded into paragneisses as 549.7± 7.6 Ma at south of Kula (Figure 15, Chart 1).

Ödemiş-Kiraz submassif.- There are also rock dating studies on orthogneisses in this submassif. Augen gneiss (biotite orthogneiss) samples were taken from three different regions by Dannat (1997) and dated as 528±4.3 Ma at Northeast of Kuyucak, 528.1±1.6 Ma in the mass located at west of Buldan and 538.1±1.6 Ma in the gneissic mass located at southwest of Kiraz (Figure 15, Table 1). These ages were inferred by the author as the granitic intrusion ages forming the protolithes of augen gneisses (biotite orthogneiss). Koralay (2001) and Koralay et al. (2004) dated 561.5±0.8 Ma and 570.5±2.2 Ma for the intrusion age in augen gneisses (biotite orthogneiss) located at south of Alaşehir (Figure 15, Table 1).

Çine Submassif.- Gneisses in this submassif were geochronologically investigated in detail. Hetzel and Reischmann (1996), dated the intrusion ages of primary granites of the rocks as 546.0±1.6 and 546.4±0.8 Ma named as less deformed and exposing at north of Selimiye. These rocks were defined as leucocratic tourmaline gneisses in the same region by Dora et al. (2005). In the following years, Loos and Reischmann (1999) dated the intrusion ages of gneisses located at the south of Selimiye in a range between 521±8 - 572±7 Ma (Figure 15, Table1).

Gessner et al. (2001) stated that orthogneisses along the road between Eskiçine and Akçova (Southeast of Çine) were cut by metagranites and intrusion ages of relatively younger metagranites were dated as 547.2±1.0 Ma based on single zircon Pb/Pb evaporation method (Figure 15, Chart 1). In recent studies it was detected that metagranites which cut Augen gneisses (biotite gneisses) are equivalent to tourmaline leucocratic orthogneisses (Dora et al., 2005). In the following years, from the samples taken in the same region, by U-Pb SHRIMP method, augen gneisses (biotite gneisses) and tourmaline leucocratic orthogneisses that cut augen gneisses were dated as 566±9 Ma and 541±14 Ma, respectively (Gessner et al., 2004). Along the southern border of Çine submassif, Dora et al. (2005) stated that, field data showed biotite orthogneisses presented granites of the oldest stage and these orthogneisses were cut by the

Table 1- Geochronological and relative ages of orthogneisses suggested in previous studies which are emplaced in the Pan-African basement of the Menderes Massif.

	Location	Reference	Type of Orthogneiss		Method	Age (Ma)
			Original nomenclature	This study		
Geochronological Ages	**Demirci-Gördes Submassif**					
	SE of Simav					541.4±2.5
	SW of Demirci	Dannat (1997)	Augen Gneiss	---	Pb/Pb evapor.	537.2±2.4
	Demirköprü Dam					544.1±4.3
	S of Kula	Dora et al(2002)	Granitic Gneiss	Amphibole Gneiss	Pb/Pb evapor.	549.7±7.6
	Ödemiş-Kiraz Submassif					
	NE of Kuyucak		Augen Gneiss	---		528.0±4.3
	W of Buldan	Dannat (1997)	Augen Gneiss	---	Pb/Pb evapor.	528.1±1.6
	SD of Kiraz		Augen Gneiss	Amphibole Gneiss		538.1±2.6
	S of Alaşehir	Koralay et al (2004)	Ortognays	Amphibole Gneiss	Pb/Pb evapor.	561.5±0.8
						570.5±2.2
	Çine Submassif					
	---	Dora (1975, 1976)	---	---	Rb-Sr tot.rock	490±90
	SW of Çine	Şengör et al (1984); Satır and Friedrichsen (1986)	Metagranite	---	Rb-Sr tot.rock	470±9
	N of Selimiye	Hetzel and Reischmann (1996)	Augen Gneiss	Tourmaline leucocratic orthogneiss	Pb/Pb evapor.	546.0±1.6
						546.4±0.8
	N of Selimiyei	Loos and Reischmann (1999)	Granitic Gneiss	Tourmaline leucocratic orthogneiss	Pb/Pb evapor.	563±3, 536±9
						572±7, 521±8
						556±4, 546±5
						551±5
	SW of Çinei	Gessner et. al. (2001)	Metagranite	Tourmaline leucocratic orthogneiss	Pb/Pb evapor.	547.2±1.0
	N of Yatağan	Gessner et. al. (2004)	Metagranite	Tourmaline leucocratic orthogneiss	U-Pb SHRIMP	541±14
	SW of Çine		Metagranite	Amphibole Gneiss	U-Pb SHRIMP	566±9
	N of Yatağan	Dora et. al. (2006)	Granitic Gneiss	Amphibole Gneiss	Pb/Pb evapor.	552.1±2.4
	NW of Kavaklıdere		Porpyritic Metagranite	Leucocratic Metagranite porphre	Pb/Pb evapor.	551.5±2.9
	N of Yatağan		Tourmaline leucocratic orthogneiss	Tourmaline leucocratic orthogneiss	Pb/Pb evapor.	545.6±2.7
	N of Yatağan		Tourmaline leucocratic orthogneiss	Tourmaline leucocratic orthogneiss	U-Pb isotop dilution	549±26
	NW of Karacasu	Koralay et. al. (2007)	Amphibole Gneiss	Amphibole Gneiss	Pb/Pb evapor.	530.9±5.3
Relative Ages	N of Selimiye	Bozkurt and Park (1994)	Augen Gneiss	Tourmaline leucocratic orthogneiss		Late Oligocene
	N of Selimiye	Bozkurt et. al. (1995)	Augen Gneiss	Tourmaline leucocratic orthogneiss		Late Oligocene / Early Miocene
	N of Yatağan	Erdoğan (1992); Erdoğan and Güngör (1994)	Augen Gneiss	Tourmaline leucocratic orthogneiss		Late Cretaceous/Early Cenozoic
	N of Yatağan	Bozkurt (2004)	Tourmaline leucocratic orthogneiss	Tourmaline leucocratic orthogneiss		Late Oligocene / Early Miocene
	S of Çine submassif	Bozkurt et al (2006)	Tourmaline leucocratic orthogneiss	Tourmaline leucocratic orthogneiss		Tertiary

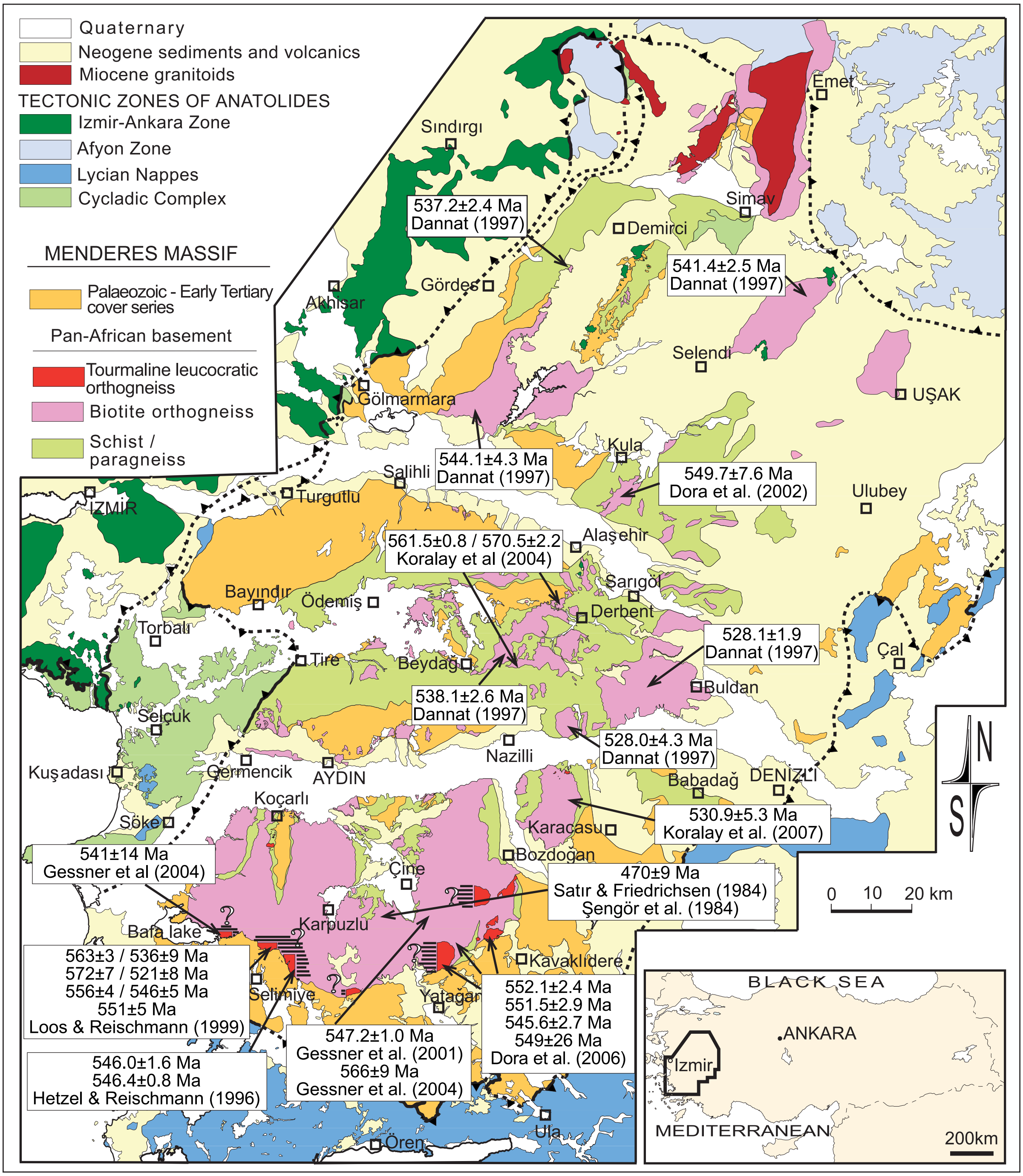


Figure 15- Location and ages of dated orthogneisses emplaced in the Pan-African basement of the Menderes Massif.

other granite types. Geochronological studies also support this fact. The intrusion ages of biotite orthogneisses located at north of Yatağan and north of Kavaklıdere were dated as 552.1±2.4 Ma and 551.5±2.9 Ma, respectively. From tourmaline leucocratic orthogneisses cutting biotite orthogneisses, at north of Yatağan, around Seykel village were dated as 549±29 and 545.6±2.7 Ma defining younger intrusion ages, using U-Pb and single zircon Pb/Pb evaporation method (Dora et al., 2005). In region located at west of Karacasu county in Çine submassif, the intrusion age of amphibolitic orthogneisses observed in small intrusions into Precambrian schists were dated as 530 .9±5.3 Ma (Koralay et al., 2007).

TRIASSIC MAGMATISM

THE DISTRIBUTION OF TRIASSIC MAGMATISM IN THE MENDERES MASSIF

The presence of Middle Triassic granites widely observed in the Menderes Massif demonstrates the second main tectonic activity in the Massif. Triassic leucocratic orthogneisses are seen in various regions along a NE-SW directed zone in the Massif (Şengör et al., 1984), in the Ödemiş-Kiraz submassif, at south of Alaşehir around Derbent and around Demirhan village, north of Atça (Koralay et al., 2001). Besides, these granites are observed in Demirci-Gördes submassif, around Kırcaali village, south of Kula in the form of masses in various sizes (Candan, 1994) (Figure 16).

Around Derbent, leucocratic orthogneisses are located with intrusive contacts within schists and orthogneisses belonging to the Pan-African basement that presents internal nappe structure (Figure 17). There are four tectonic slices in the region. The first three slices belonging to the Pan African basement are overlain by a Palaeozoic aged tectonical slice composed of phyllite, quartzite and marble. The first layer belonging to the Pan-African basement is completely made up of garnet micaschists. Triassic leucocratic orthogneisses located in intermediate slices make an intrusive contact mainly with Precambrian aged garnet-micaschists around Dede Mountain and Derbent (Figure 18 a). The biggest orthogneiss mass located around Sarıpınar village at south cut Precambrian schists and 560-570 Ma aged (Koralay et al., 2004) biotite orthogneisses. In Derbent region, leucocratic orthogneisses located at west of Karacaali village contacts with marble lens, probably in Palaeozoic age. This zone presents distinct signatures of contact metamorphism and has a mineral assemblage of wollastonite, grossular, vesuvianite and epidote (Koralay, 2001). Similar leucocratic orthogneisses in different sizes and its metaaplites are recognized at the north of Alaşehir, the region between Balcılar and Kırcalı villages (Candan, 1994). Triassic leucocratic orthogneisses observed in this region were intruded into schists of basement series and phyllites of Palaeozoic cover series with intrusive contacts (Figure 16). Especially, in marble intercalations the scarn zones were developed made up of epidote and amphibole. The contact metamorphic effects in phyllites are defined by the formations of massif garnet.

Triassic leucocratic orthogneisses are observed around Demirhan village at north of Atça (Aydın) (Figure 19), in the form of small masses within Permo Carboniferous cover series (Koralay et al., 2001). Numerous aplitic veins are also recognized within a couple of meters in thickness related with this magmatism around leucocratic orthogneisses reaching a size of 600 m Dannat (1997), mentions about the existence of rocks in similar ages at north and south of Simav in the Demirci-Gördes submassif. In the investigation made recently, new leucocratic orthogneiss exposures were detected in Palaeozoic cover series in small sized sills in the Kiraz submassif. These orthogneisses are observed around Bayramlık village at southeast of Kemalpaşa and 4 km to the south of Allahdiyen village, south of Salihli (Figure 18b).

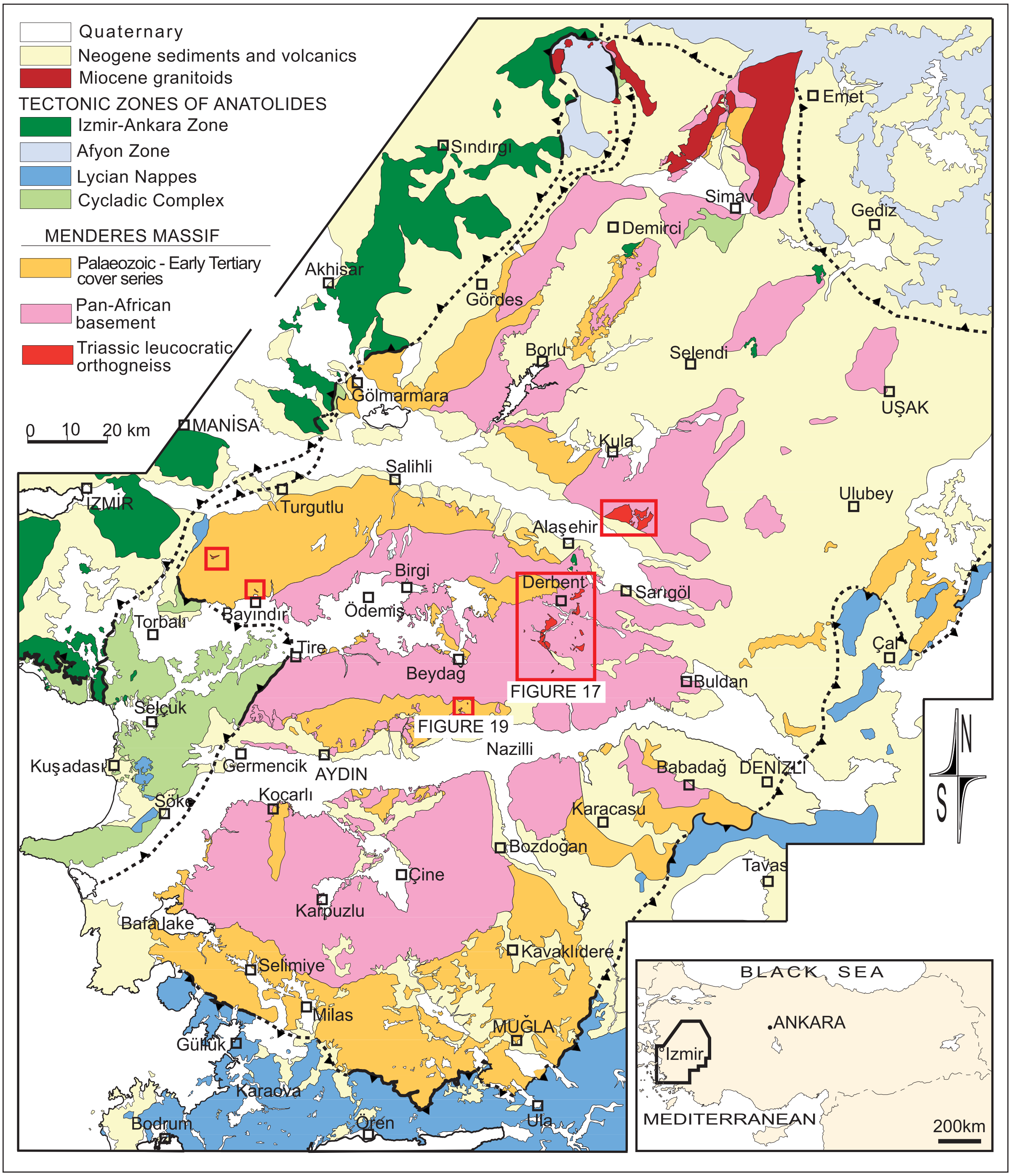


Figure 16- The distribution of Triassic leucocratic orthogneisses in the Menderes Massif.

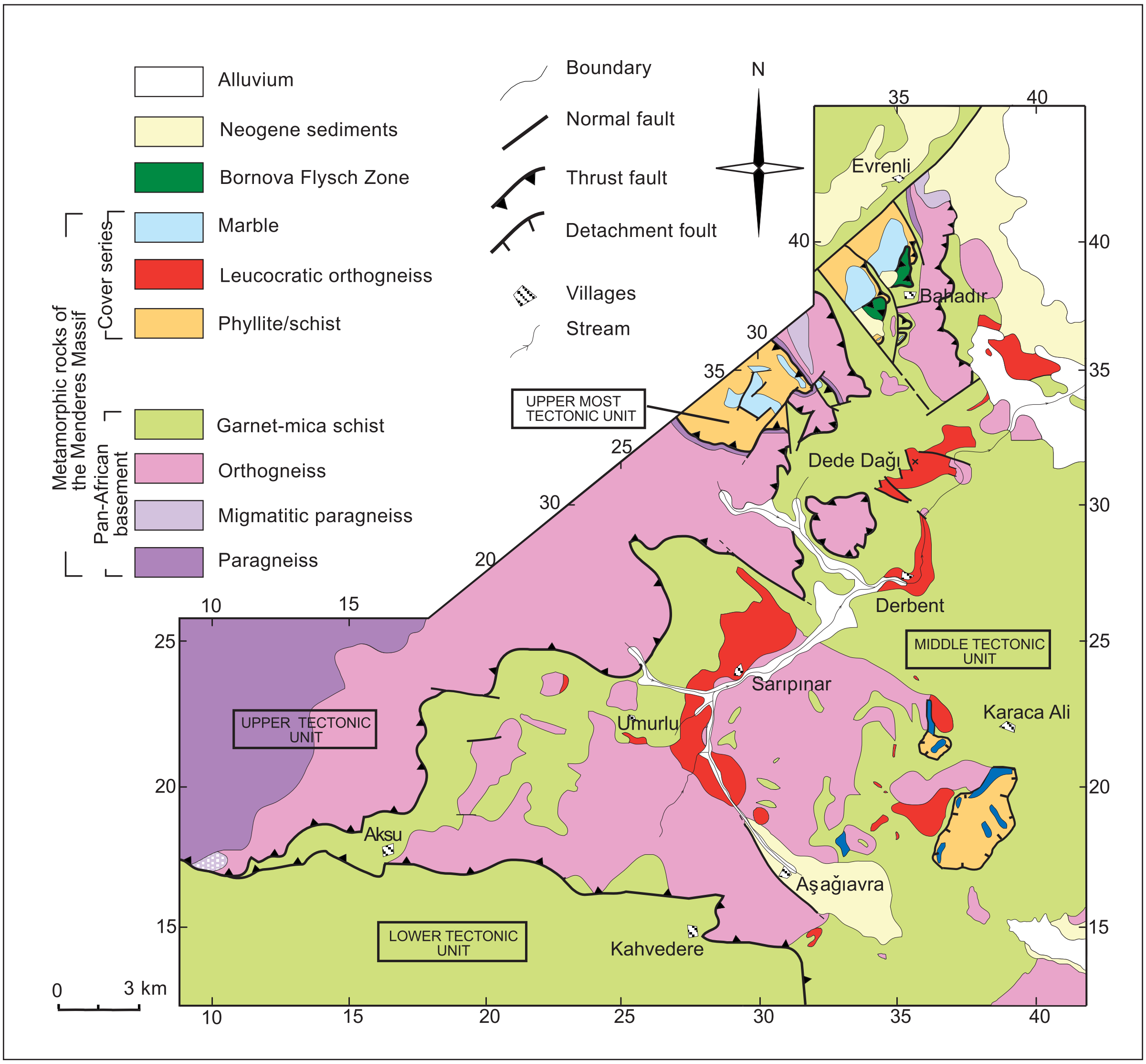
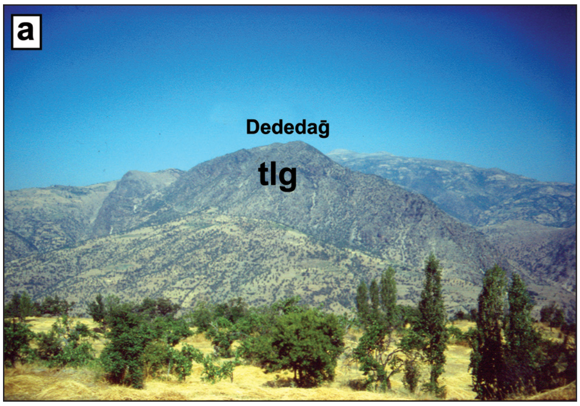


Figure 17- The geological map of Derbent region located in western part of Ödemiş-Kiraz submassif (by Koralay et al., 2001).

MACROSCOPIC AND MICROSCOPIC FEATURES OF LEUCOCRATIC ORTHOGNEISSES

Triassic leucocratic orthogneisses are white to dirty white and greenish white in color, equally sized, fine grained and have a distinct foliation (Figure 20a). Massif structure is observed in undeformed sections. The rock becomes proportionally more in greenish color as the muscovite rate increases. Magnetite bearing orthogneiss types on the other hand are in grayish color (Figure 20b). Muscovites reaching 10-15% in amount determines the foliation planes in the rock. The quartz, plagioclase and orthoclase rates indicating the primary granitic composition reach the percentage of 88-95%.



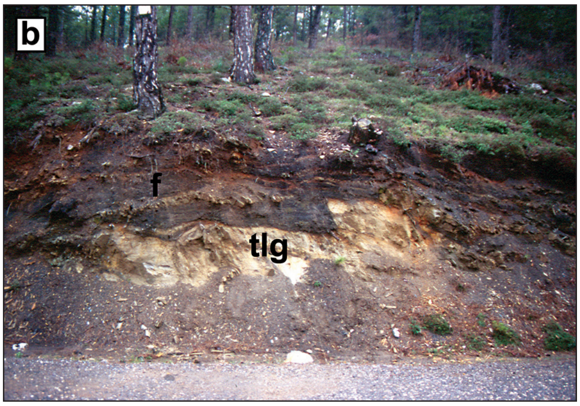


Figure 18- a) Dededağ intrusive made up of Triassic leucocratic orthogneisses that cuts Precambrian schists, south of Derbent, b) Triassic leucocratic orthogneiss vein in Palaeozoic phyllites, Bayramlık village/Kemalpaşa, (tlg: Triassic leucocratic orthogneiss, f: phyllite).

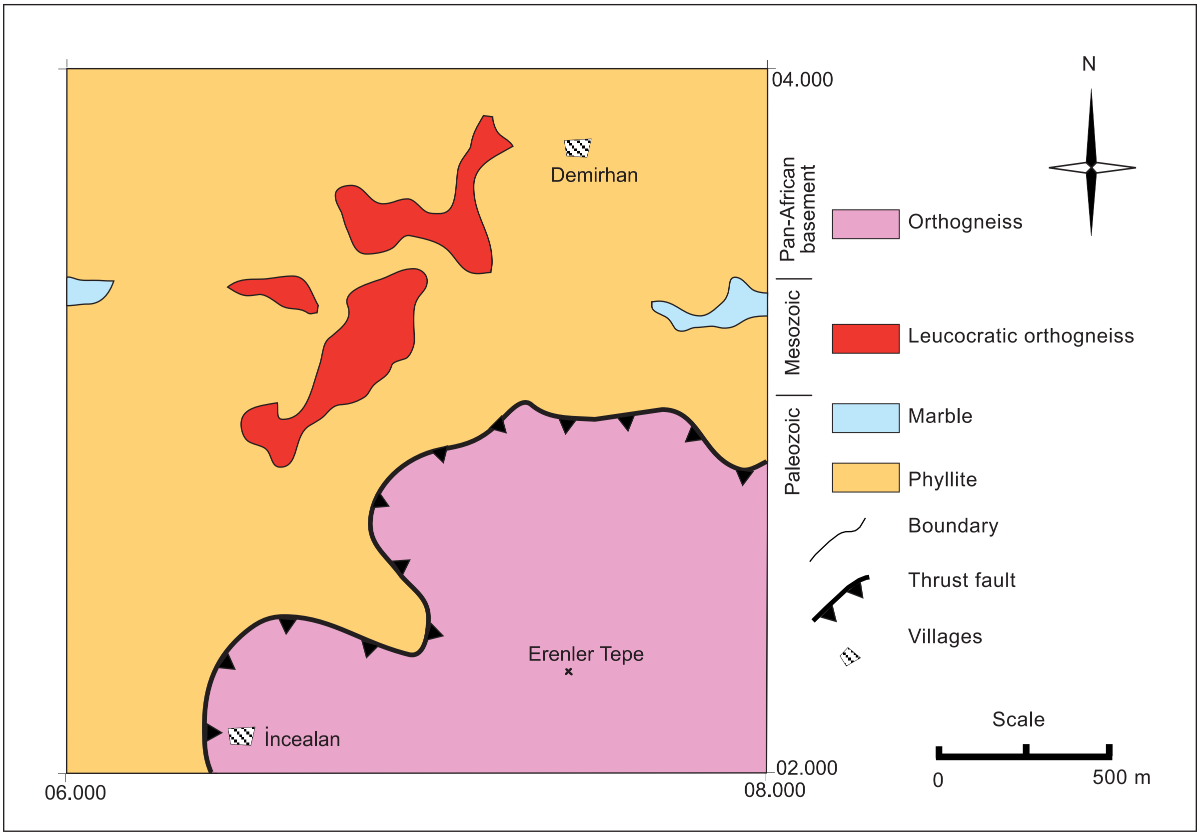


Figure 19- The geological map of Triassic leucocratic orthogneisses located around Demirhan Village/Aydın, south of Ödemiş-Kiraz submassif (Koralay et al., 2001).

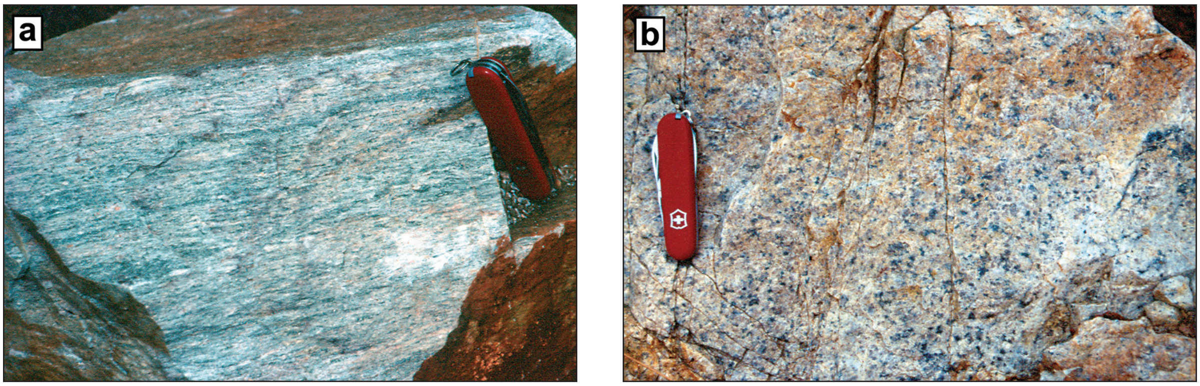


Figure 20- a) Triassic biotite-muscovite leucocratic orthogneisses showing distinct orientation, b) massif structured magnetite leucocratic orthogneisses.

According to mineralogical compositions, Triassic leucocratic orthogneisses are divided into three different groups. These are; i) Biotite-muscovite Leucocratic orthogneiss, ii) Magnetite leucocratic orthogneiss and iii) Biotite leucocratic orthogneiss. The general mineral composition of leucocratic orthogneisses is made up of quartz, orthoclase, plagioclase and muscovite (± biotite, tourmaline, garnet, apatite, zircon, magnetite). Rate of quartz, orthoclase and plagioclase are 42-54%, 10-38% and 6-15%, respectively. K-feldspars (orthoclase and microcline) which is the main component of the rock, is observed in subhedral to anhedral forms and grains reach 6-7 mm in size. Depending on the intensity of deformation in rocks under ductile conditions, crystal sizes decrease and strongly foliated, mylonitic leucocratic orthogneisses are recognized (Figure 21 a,d). Muscovites in masses located at north of Derbent and Alaşehir show a pale green pleochroism at 21%, whereas this decreases below 10% around Demirhan. Magnetite percentage in magnetite leucocratic orthogneisses can even reach up to 15%. Magnetite crystals are observed individually or as in accumulations (Figure 21 e,f).

GEOCHRONOLOGY OF TRIASSIC MAGMATISM

Morphology of Zircon

Zircons differentiating from orthogneisses were examined under SEM before the radiometric rock dating studies. In order to classify zircons according to its morphology and analyze their internal structures SEM and CL photos were taken. As a result of the SEM analysis, it was determined that most of zircons have a similar morphology reflecting the magmatic origin. These are euhedral, generally non transparent, bearing old cores and in the form of grains that have cavities on its plane (Figure 22). Zircons, according to the classification of Pupin and Turco (1974), were crystallized dominantly in types of P3, P4, P5 type and less dominantly in P1, P2, D, S7, S17 types. Based on these dominant types, the crystallization temperature is given as 750-850 C (Koralay, 2001). According to Pupin (1980), zircons in this type are observed as granites in alkaline origin derived from hybrid magmas in subvolcanic and anorogenic complexes.

In CL analysis made, zircons that present a typical magmatic zonation indicates the magmatic origin of these rocks (Figure 22). Old dendritic cores are not observed as in long, spindle shaped grains and in some grains old cores subjected to erosion which reflects the melting from a source rock of sedimentary in origin are recognized. For rock dating long prismatic grains bearing no old cores were selected.

Ages obtained

Although there is not any geochronological data, based on the regional geology, the age of

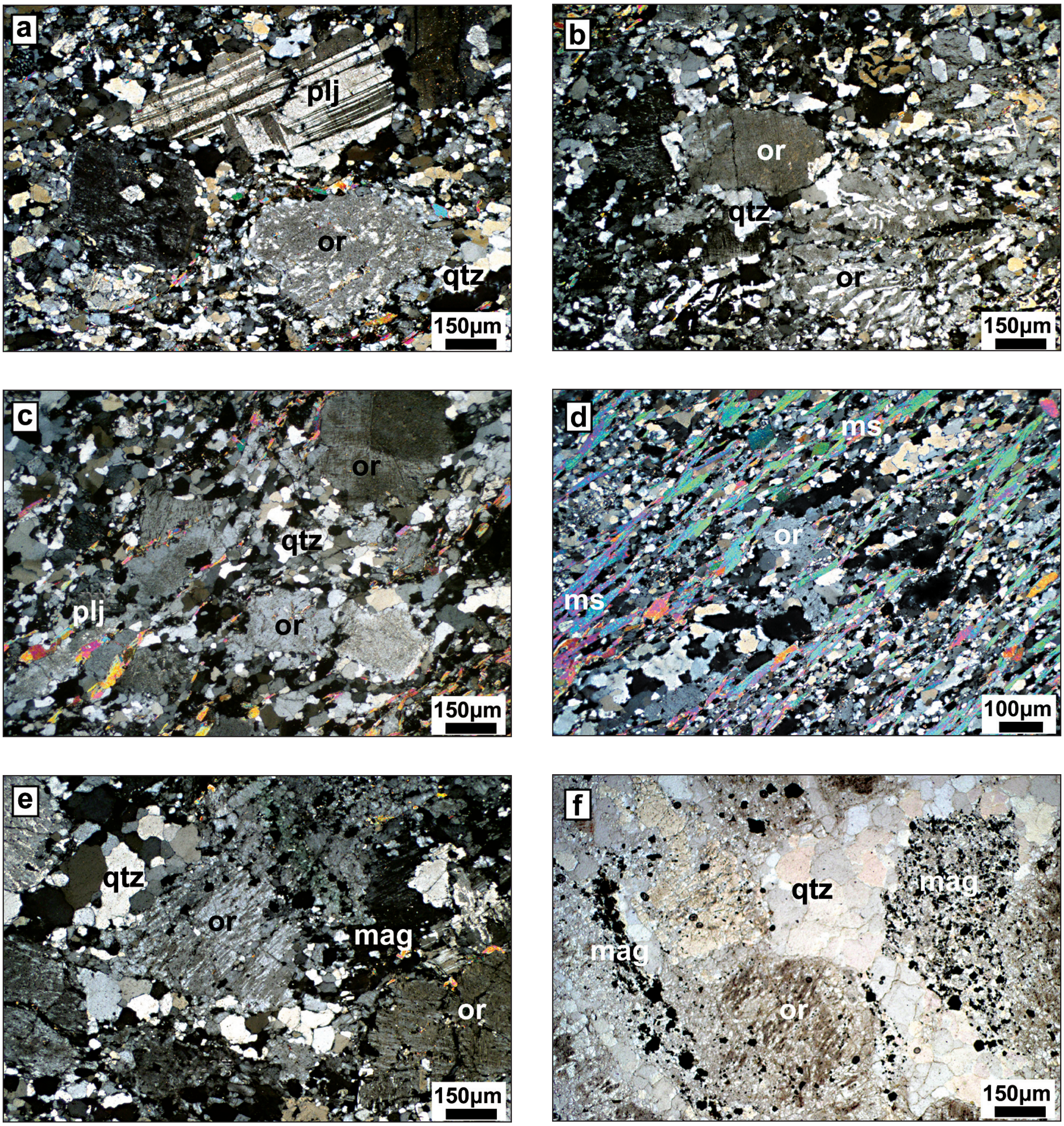


Figure 21- a-d) Textural variations developed in orthogneisses based on the intensity of increasing ductile deformation, e-f) single magnetite crystals and magnetite accretions in magnetite leucocratic orthogneisses, (e: cross nicole, f: parallel Nicole, pl: plagioclase, or: orthoclase, qtz: quartz, ms: muscovite, mag: magnetite).

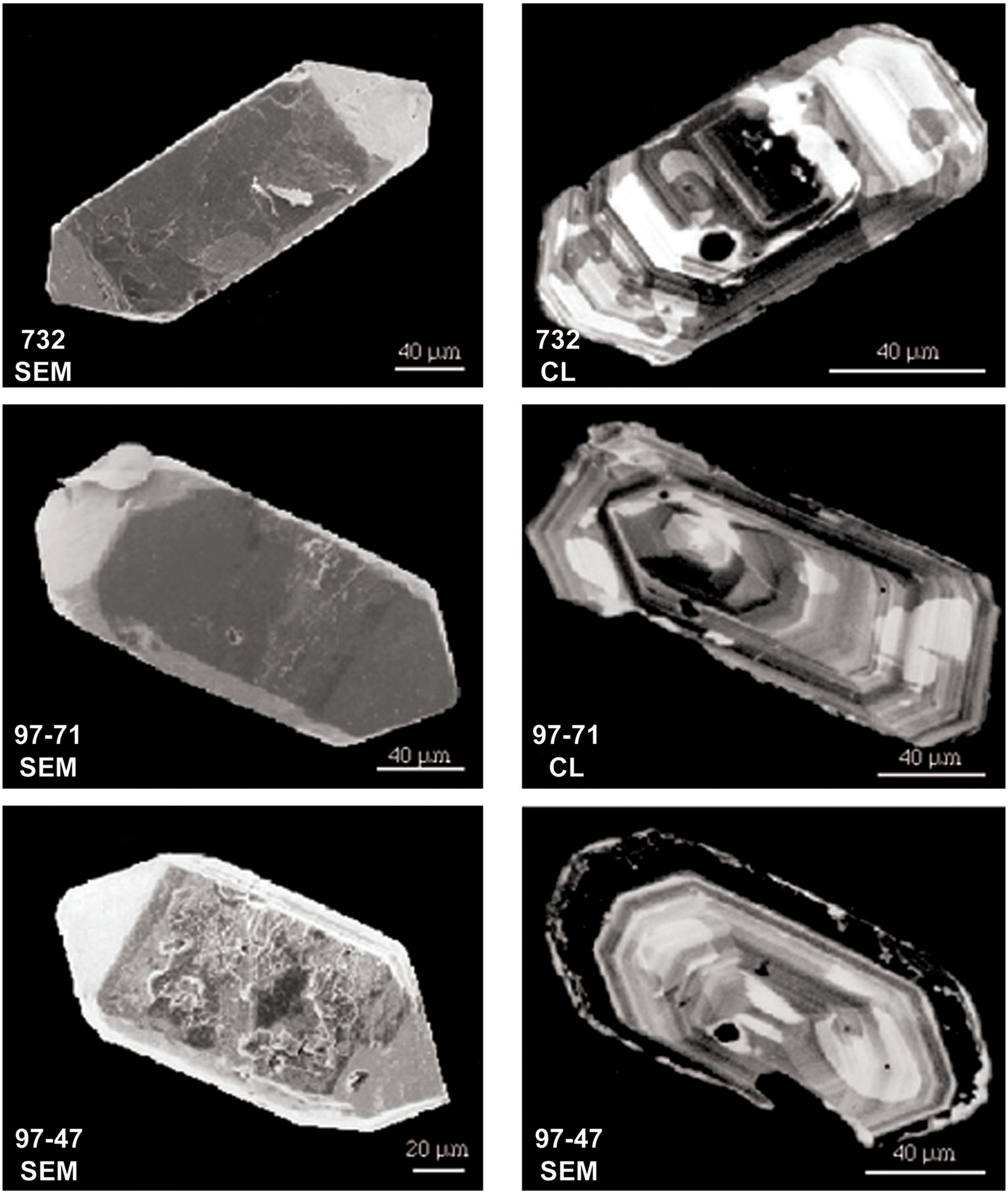


Figure 22- SEM and CL views of zircons belong to Triassic leucocratic orthogneisses (Koralay et al., 2001).

leucocratic orthogneisses until the end of 90's were accepted as Late Triassic and this age was associated with the closure of Karakaya Ocean in Late Triassic (Akkök, 1983, Şengör et al., 1984). After the widespread existence of leucoratic orthogneisses were recognized in the Menderes massif, geological, geochronological and geochemical studies were intensified onto these rocks. Dannat (1997) and Dannat and Reischmann (1998) dated leucocratic orthogneisses in Ödemiş-Kiraz and Gördes submassifs ranging in between 227-240 Ma (Table 2, Figure 22). These ages were interpreted by the authors as the intrusion age of protolithes of orthogneisses. In Ödemiş-Kiraz submassif, leucocratic orthogneisses that cut Precambrian schists around Derbent region were dated and 245.7±4.6 and 241.1±5.2 Ma intrusion ages were obtained by single Zircon Pb/Pb evaporation method. Same investigators determined an intrusion age for the leucocratic orthogneisses as 234.9±5.8 Ma. that cut Palaeozoic cover series located around Demirhan village, north of Atça (Table 2, Figure 23).

DISCUSSION

There have been many opinions about the age and tectonical environments of base rocks for gneisses belonging to two different magmatic activities which are widely observed in the Pan-African basement and Palaeozoic cover series in the Menderes Massif. Main ideas related to these are discussed within the framework of previous evidences and personal data of the author of this paper.

PAN-AFRICAN MAGMATISM

Protolithes of Orthogneisses

Protolithic rocks of the Pan-African orthogneisses forming the oldest magmatic activity in the Menderes Massif have always been controversial so far. Although not expressed exactly, opinions on protolithes of gneisses are grouped in two topics. These are;

i) Sedimentary origin.- Schuilling (1962) stated that orthogneisses were defined as migmatite in general and these were derived from sedimentary rocks as a result of high grade metamorphism by the study made in Çine submassif. Öztürk and Koçyiğit (1983), Akkök et al. (1984), Şengör et al. (1984) and Satır and Friedrichsen (1986) explain that great majority of orthogneisses in the Menderes Massif originated from clastic sedimentary rocks and gained migmatitic character by partial melting. This opinion was widely supported in many of the studies performed in 70's and 80's, as well (Akat et al., 1975; Akdeniz and Konak, 1979; Akkök, 1983). Başarır (1970) claims that rocks defined

Table 2- Radiometric ages obtained from Triassic leucocratic orthogneisses in the Menderes Massif.

	Method	Age (Ma)	Reference
S of Simav NE of Simav	Single Zircon Pb/Pb evaporation	230-240	Dannat (1997) Dannat and Reischmann (1998)
SW of Derbent N of Alaşehit	Single Zircon Pb/Pb evaporation	227-240	Dannat (1997) Dannat and Reischmann (1998)
SW of Derbent N of Derbent (Dededağı) N of Atça (Demirhan Village)	Single Zircon Pb/Pb evaporation	245.7±4.6 241.1±5.2 234.9±5.8	Koralay (2001) Koralay et. al. (2001)

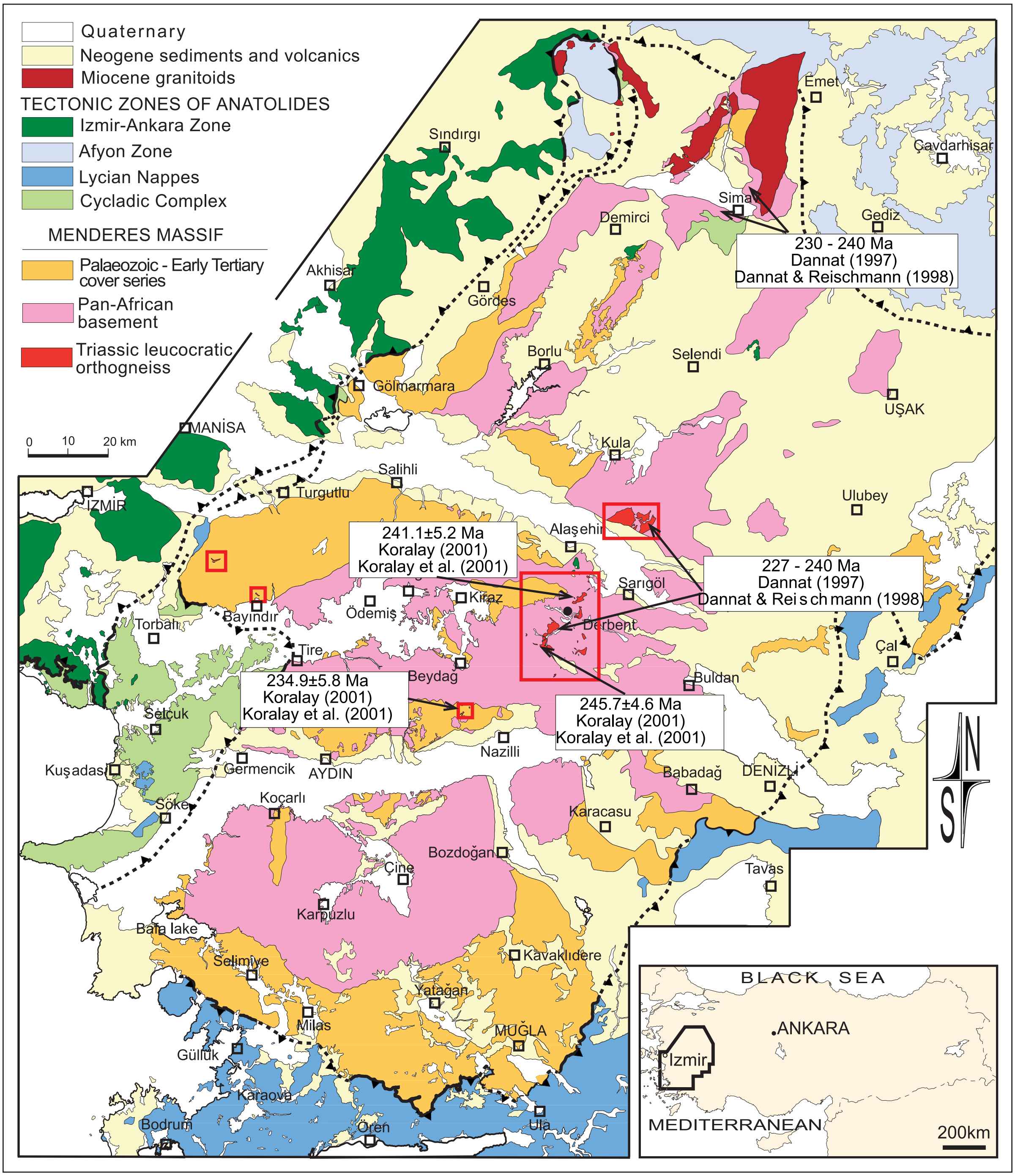


Figure 23- Locations and ages of dated Triassic leucocratic orthogneisses within the Pan-African basement and Palaeozoic cover series in the Menderes Massif.

as in fine grained in Bafa Lake are the sedimentary in origin. This opinion was also supported by Dora et al. (1990) in a study about the evolution of the Menderes Massif.

ii) Magmatic origin.- As an alternative to sedimentary origin, many investigators suggested that gneisses were magmatic in origin (Graciansky, 1965; Başarır, 1970; Konak, 1985; Konak et al, 1987). Great majority of studies made in the Menderes Massif after 1990 has shown that, there has been extremely strong geological, geochemical and geochronological evidences that all gneisses derived from magmatic origin contrarily to the sedimentary origin (Erdoğan, 1992, 1993; Bozkurt et al., 1992, 1993, 1995; Bozkurt, 1994; Bozkurt and Park,1994; Loos, 1995; Dora et al., 1995; Hetzel and Reischmann, 1996; Dannat, 1997; Dannat and Reischmann, 1998; Loos and Reischmann, 1999; Bozkurt, 2004; Gessner et al., 2001, 2004; Erdoğan and Güngör, 1992, 2004; Koralay et al., 2004; Bozkurt et al., 2006). Dora et al. (1994, 2005), suggested that protolithes of orthogneisses with different structures are the granites that have settled down related to Pan-African Orogeny and syn to post-metamorphics. Similar opinion is accepted by many researchers (Hetzel ve Reischmann, 1996; Loos and Reischmann, 1999; Dannat, 1997; Hetzel et al., 1998; Gessner et al., 2004; Koralay et al., 2004). On the other hand, geochemical data indicate that these granites are in calc-alkaline origin, per-aluminuous in character, S-typed and as syn to post-tectonic granite/granodiorite (Bozkurt et al., 1992, 1993, 1995; Dannat, 1997; Koralay and Dora, 1999; Koralay et al., 2004; Bozkurt et al., 2006). In addition to these, morphologies of zircons related to orthogneisses which are investigated intensely in recent years and internal zoning patterns clearly display the magmatic origins of these rocks (Hetzel and Reischmann, 1996; Loos and Reischmann, 1999; Dannat, 1997; Gessner et al., 2004; Koralay et al., 2004; Dora et al., 2005).

As a result, contemporary field data and petrographical, geochemical and geochronological evidences clearly display that protolithes of Pan-African gneisses in the Menderes Massif are deep rocks in character with granitic composition.

Intrusion Ages of Primary Granites of Orthogneisses

When papers published in recent years have been overviewed, it has been clearly observed that big differences in opinions about the intrusive/crystallization ages of the primary granites of orthogneisses had been observed. Opinions about these can be gathered in two main topics. In the first opinion, orthogneisses in the massif is defined as young intrusives (Tertiary/Late Oligocene: Bozkurt et al., 1992, 1993, 1995; Mittwede et al., 1995*a*, 1995*b*, 1997; Bozkurt and Park, 1994, 1997*a*, 1997*b*, 2001; Cretaceous/ Early Senozoic: Erdoğan, 1992, 1993; Erdoğan and Güngör, 2004). Substantially, this opinion is put down to regional geology, field and kinematical data. It is emphasized that zircon ages obtained so far presents a large spectrum. It is also interpreted that these zircons are well preserved in melt and clastics found in sediments where the granites originated from belong to relics grains of Zircon. Although there are some differences in opinions in detail, the judgement which brought investigators to this result mainly depends on five field observations. These are; 1) metaclastic and metacarbonate deposit in the Menderes Massif is Palaeozoic-Early Tertiary, 2) this deposit is continuous and does not have any structural or stratigraphical discontinuity, 3) the primary granites of orthogneisses cut this continuous series extending until Early Tertiary by intrusive contacts, 4) kinematical data related to gneiss and country rocks show that these granites are post metamorphic intrusives according to Alpine metamorphism, 5) transformation of granites into gneiss is related with the cropping out of the Massif in Late Oligocene. Depending on this argument, investigators interprete orthogneisses substantially as the crustal thickening in last stage of Alpine metamorphism and formed by the reason of young acidic intrusives formed by partial melting of high grade clastic sediments.

And in the second opinion, it is suggested that orthogneisses are the granites that are related with the Pan-African Orogeny and intruded into Late Proterozoic gneisses and schists in Late Precambrian-Early Cambrian (Şengör et al., 1984; Satır and Friedrichsen, 1986; Dora et al., 1990; Hetzel and Reischmann, 1996; Danat, 1997; Dannat and Reischmann, 1997; Hetzel et al., 1998; Loos and Reischmann, 1999; Gessner et al., 2001; Okay, 2001; Dora et al., 2002; Gessner et al., 2004; Koralay et al., 2004; Dora et al., 2005). This opinion of the investigators substantially relies upon; 1) the tectonical relationships of Palaeozoic units that belong to cover series of orthogneisses with metaclastics reaching 6 km. in thickness and included into Pan-African basement, and 2) radiometric data obtained from Palaeozoic metaclastic belonging to cover series, metaclastic series forming its the country rocks and orthogneiss.

Country rock.- As previously explained above, the country rocks of the orthogneisses in the Menderes Massif are made up homogenous metaclastics and does not contain carbonaceous levels. In studies performed at the north of Alaşehir around Birgi-Kiraz, it was detected that related metaclastic deposits were formed by paragneiss derived by litarenitic sandstones at the bottom and schist units originated by the intercalation of sub arkosic sandstone-mudstone (Dora et al., 2001, 2002). This clastic series reach a thickness of 6 km, and cut by biotite orthogneisses with a clear contact relationship (Candan, 1994; Dora et al., 2002; Candan et al., 2010). The depositional age of primary sediments of this clastic series ranges between 550-600 Ma (Late Proterozoic) based on the youngest zircon ages in metaclastic series and Pb-Pb zircon evaporation ages obtained by those granites (Dora et al., 2002; Koralay et al., 2005). Petrographical data and field studies show that these metaclastics are widely observed in the Massif. For example, at south of Çine submassif, schists that have intruded into orthogneisses along 100 km long gneiss boundary can be associated with the same schists belonging to Late Proterozoic metaclastic series. Besides, the ages of the clastic zircon obtained from metaclastics extending along this boundary (the youngest clastic zircon age 594 Ma, Dora et al., 2005) and the cutting relationships of orthogneisses clearly show that related rocks are Late Proterozoic schists belonging to the Pan-African basement. However, there is no strong evidence at any place in the Menderes Massif that an orthogneiss extists (except the Triassic leucocratic orthogneisses) which cuts a metaclastic in Palaeozoic age by means of fossil dating or other data. On the contrary, 550-560 Ma clastic zircon ages were obtained showing that source rock is orthogneiss using Palaeozoic aged (?) metaclastics of cover series (Loos, 1995; Dora et al., 2005). On the other hand, Palaeozoic cover series related to this magmatic activity to be sterilized makes an age limitation for intrusives of the primary granites of orthogneisses.

Radiometric data.- Radiometric ages obtained from the Menderes Massif so far are given in table 1. As can be obviously seen, zircons were dated between 570-520 Ma, averaging at 550 Ma. All investigators state that zircons dated describe the crystallization from a melt based on the morphology and zonation pattern and these ages obtained are interpreted as the crystallization/intrusion ages of the primary granites of orthogneisses. According to investigators, ages observed as spread originates from the constitution relic core belonging to sedimentary base rock of some zircon grains that were dated. As clearly emphasized in previous parts of the paper, there are some confusion in the classification and nomenclature of orthogneisses in the Massif. However, the field evidences and petrographical data obtained in recent years indicate that biotite, tourmaline and amphibole orthogneisses based on mineralogical compositions in the Massif can be divided in to three main groups based on mineralogical compositions. Field data and contact relationships show that these gneiss types based on the relative aging can be ordered from oldest to youngest as biotite orthogneisses, tourmaline leucocratic orthogneisses and amphibole orthogneisses. In table 1, although there have been some problems in the nomenclature of samples dated in previous studies, it is observed that radiometric dating values substantially show conformity with this relative relationship. The intrusion ages of biotite orthogneisses show variation between 550-570 Ma, in general (Dora et al., 2002; Koralay et al., 2004; Gessner et al., 2004; Dora et al., 2005). Although tourmaline leucocratic orthogneisses give an age similar to that of biotite orthogneisses throughout the Massif, relatively much younger ages ranging between 541-547 Ma were dated in the sections where clear contact relationships were observed on the field (Hetzel and Reischmann, 1996; Gessner et al., 2001, 2004; Dora et al., 2005). Amphibole orthogneisses were dated as 531 Ma (Koralay et al., 2007) pointing that this granite type indicates a younger magmatic phase. When the information given above is evaluated together, it is noticed that radiometric datings show a general consistency and fits with field data.

As a result, when all geochronological ages, contact relationships and petrographical/mineralogical data are assessed together, it is understood that the metaclastics in which the orthogneisses intrude are Late Proterozoic units that belong to the Pan-African basement. It is also seen that these data define the differentiation product intrusives belonging to stages of the same magmatic activity following one another related with the Pan-African Orogeny of orthogneisses derived from granites of different characters.

TECTONIC ENVIRONMENTS OF THE PRIMARY GRANITES OF ORTHOGNEISSES

Data given above, obviously reveal the presence of a magmatic activity mostly varying between 520-570 Ma, with an approximate date of 550 Ma, throughout Menderes Massif. The other magmatic activities with similar ages in Turkey (except the Menderes Massif) were determined as; 1- Istanbul Zone (Chen et al., 2002; Ustaömer et al., 2005), 2-Sandıklı region (Kröner and Şengör, 1990; Gürsu et al., 2004), 3-Afyon Zone (Gürsu et al., 2005) and 4-Bitlis Massif (Ustaömer et al., 2009) (Figure 23). Besides, the diffuse existence of similar aged magmatic activities in Europe (Neubauer, 2002) and in Africa are clearly observed in regional scale. The magmatic activity in related age range is assocciated with two main orogenies in regional scale. These are; 1- the Cadomian Orogeny and 2- the Pan-African Orogeny. Thoughts related to magmatic activity with an age of approximately 550 Ma in the regions given above and the probable location of magmatic activity in the Menderes Massif under this tectonism is discussed below,

THE MAGMATISM ASSOCCIATED WITH CADOMIAN OROGENY

Around Karadere, located at east of Istanbul Zone, the intrusion ages of granites settling in base rocks were dated varying between 560-590 Ma (Chen et al., 2002) (Figure 24). Investigators, suggest that according to low $^{87}Sr/^{86}Sr$ rates and high εNd values, these granites are the product of an arc magmatism formed by the subduction of an old ocean (Iapetus?) under Gondwanaland. In Bolu Massif, the east of this region, 576±6 and 565±2 Ma. ages were dated for Kapıkaya and Tülükiriş plutonics, respectively (Ustaömer et al., 2005) (Figure 24). Geochemical data reveal that these calc-alcaline and I-type granitoids are the products of Andes type arc magmatism. In recent years, it has been suggested that Palaeozoic basement of West Pontides was the continuity of Cadomian belt observed in West Europe based on these dating values and geochemical data (Ustaömer and Kipman, 1998; Ustaömer and Rogers, 1999; Ustaömer, 1999; Ustaömer et al., 2005). In a similar way, Okay et al. (2008) dated 570 Ma in granitoids, located in west of Armutlu

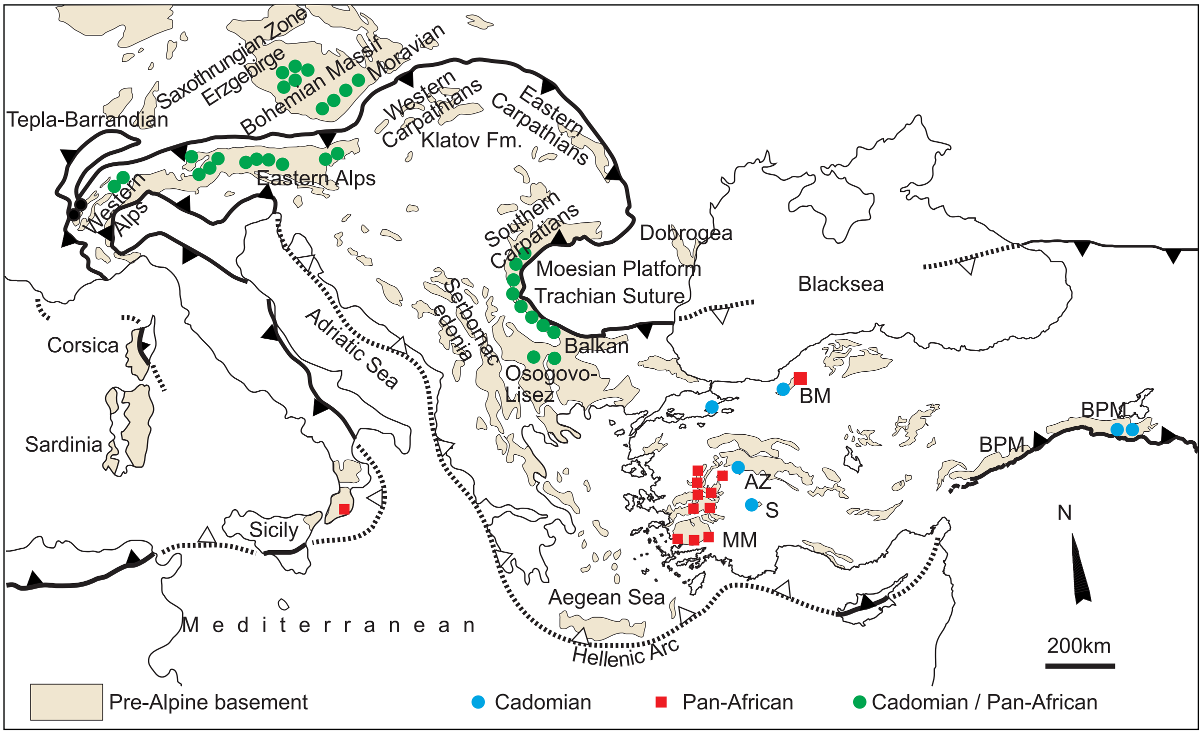


Figure 24- Locations of Pan-African and Cadomian magmatic activities observed in Turkey (modified from Neubauer, 2002). Cadomian location was taken from Kröner and Şengör, (1990), Gürsu and Göncüoğlu (2005), Gürsü et al. (2005), Ustaömer et al. (2005), Okay et al. (2008), Ustaömer et al., (2009); Pan-African locations were taken from Dannat (1997), Hetzel and Reischmann (1996), Loos and Reischmann (1999), Gessner et al. (2001, 2004), Chen et al. (2002), Dora et al. (2002), Koralay et al. (2004), Dora et al. (2006) and Cadomian- Pan-African locations were taken from Neubauer (2002) AZ: Afyon Zone, BM: Bolu Massif, BPM: Bitlis-Pötürge Massif, MM: Menderes Massif, S: Sandıklı.

Peninsula. Investigators include these granitoids into the Cadomian basement of Istanbul Zone.

The intrusion ages of rocks defined as mylonitic granite in Sandıklı Region were dated as 543±7 Ma. by single zircon evaporation method (Kröner and Şengör, 1990) (Figure 24). Gürsu et al. (2004) names these rocks as meta quartz porphyry and defines these are geochemically post orogenic and I-type granites. In recent years, these metaquartz porphyries have been dated as 541±9 Ma similarly, by single zircon evaporation method (Gürsu and Göncüoğlu, 2005). Granite and its accompanying mineral metarhyolites are considered as I-magmatism products associated with extension that has occurred in the evolution following the Pan-African Orogeny. These are observed in Taurides being considered as it is located at north of Africa (Gürsu et al., 2004; Gürsu and Göncüoğlu, 2005, 2006). In the suggested model of investigators, it was stated that, the oceanic plate subducting into the northern margin of Gondwana caused dilation in the northern part of the continent and thus, widespread granitic intrusions along the continental margins covering Taurides and South Europe is between 550-540 Ma. ages have occurred. It is considered that all these metamorphisms and magmatic activities observed in these regions are the products of Cadomian

Orogeny (Bozkaya et al., 2006, Gürsu and Göncüoğlu, 2006).

Similarly, the presence of metaquartz porphyries was determined and dated as 541.1±3.6 Ma. by the single Zircon evaporation method in Afyon zone (Figure 24). These I-typed alkaline magmatic rocks are interpreted as the intrusives developed by the post orogenic crustal expansion in Cadomian Orogeny (Gürsu et al., 2005).

Mutki granite located in Bitlis Massif and the accompanying dikes were dated as 545.5±6.1 Ma and 531.4±3.6 Ma respectively (Ustaömer et al., 2009), and these ages were interpreted as intrusion age of related magmatics (Figure 24). Geochemical and Nd istopic analysis results show that these granites and dikes have originated from mantle and are Arc-type granites associated with subduction zone. By the same authors, all of the Ediacaran-Early Cambrian magmatic activities observed at Bitlis Massif, Menderes Massif and at the Palaeozoic basement of Istanbul Zone are the products of Cadomian arc type magmatism (Ustaömer et al., 2009).

Looking at Europe in general, Cadomian tectonical units (Figure 24), are observed within various regions of Late Neoproterozoic- Early Palaeozoic base units cropping out in Alpine-Mediterranean mountain belt extending from Alpines to Turkey (Neubauer, 2002). Ustaömer et al. 2009, state that Cadomian tectonical units reach up to Iran and India. It is also stated that the easternmost extension of this belt in Europe is defined by the Cadomian magmatic activity dated as between 590-510 Ma in the Iberian Massif (Ochsner, 1993; Bandres et al., 2004, and related references). Cadomian tectonic units are located in Alpine basement constitutes Helvetic, Penninic, Austro Alpine and South Alpine tectonic units (Müller et al., 1995; Neubauer, 2002). The ages of the intrusive rocks in this zone show a variation between 520-570 Ma. Besides, in Erzgebirge, located at north of this zone, in Saxonia and in Bohemian massif 550 Ma, 555 Ma and 567 Ma magmatism ages were dated, respectively (Kröner et al., 1995; Müller et al., 1995; Friedl et al., 2004). At south Carpathians-Balcanians 567-563 Ma and in Sirbian-Macedonian Massif 545-568 Ma aged magmatic intrusives were detected (Neubauer, 2002). Similarly, the existence of 533±9 Ma, 540±10 Ma, 548±9 Ma aged granitoidic intrusives related to Cadomian orogeny are known in Poland and Czech Republic (Zelazniewicz et al., 2004). In recent studies, the intrusion age of gneisses in the Pelagonian Zone have been dated as 546±10 Ma (Anders et al., 2007) (Figure 24).

In summary, majority of granitoids between 520-570 Ma in Europe are associated with Cadomian Orogeny. It is also accepted that at Andes-type continental margin located at north of Gondwana super continent of this orogeny, the granitoids are represented by the products of a calc alkaline, I-type magmatism which were located in subduction-obduction zone towards south (Neubauer, 2002).

Magmatism associated with Pan-African orogeny

In general, the Pan-African Orogeny defines a chain of poly-phase orogenic events which covers the defragmentation of Gondwana Super Continent, subduction, collision and connection periods associated with it and conclude the formation of orogenic belts. The age of Pan-African Orogeny is defined differently by many investigators as; 950 - 450 Ma (Kröner, 1984), 1000-540 Ma (Stern, 1994), 650-550 Ma (Wilson et al., 1997; Veevers, 2004) and 1000-550 Ma (Unrug, 1996). This orogeny is not only limited to African continent, but also covers the whole Gondwana continent and the events occurred at south America, in Madagascar, Sri Lanka, south India, Antarctica and Australia (Kröner and Stern, 2005). There is a general agreement on the separation of East and West Gondwana by a big ocean named as Mozambique Ocean (Dalziel, 1991) in Neoproterozoic (Stern 1994; Wilson et al.,1997). The closure of this ocean formed by the fragmentation of Rodinia continent 800-850 Ma ago, the collision of East and West Gondwana continents caused the formation of N-S extending belt along the eastern margin of today's African continent (Figure 25). This belt is defined as Mozambique belt or East African Orogeny (Stern, 1994; Kröner and Stern, 2005).

During the Pan-African Orogeny, many small plates collisioned and formed different belts. Along these belts, pervasive existence of intrusives showing similar ages and features of orthogneisses in the Menderes Massif is observed (Figure 25). When the paleogeographical position of the Menderes Massif in Late Proterozoic-Early Cambrian is assessed, the Mozambique belt occupies a special place. Stern (1994) states the presence of 540 Ma aged granites in south Somalia. Wilson et al., (1997) claims the presence of S typed granites and granitoids as 500-538 Ma in Tanzania, as 550 Ma in India and Sri Lanca and as 550 Ma in Pyrdz Bay/Antarctica. S typed 560 Ma aged granites in Eastern Ethiopia is known and Teklay et al. (1998) stressed that these granites can be correlated with western Ethiopia and Arabic-Nubian Shield. Furthermore, in southern Ethiopia the existence of post-tectonical granitic and tonalitic intrusions with ages varying between 529-557 Ma were determined by many investigators (Yibas et al., 2002, and the references there in). Magmatic activities with varying ages between 563-611 Ma were reported in northeastern desert of Egypt, one of the closest area to the Menderes massif (Gessner et al., 2004). Kröner and Stern (2005) mentions about the presence of granite derived from the crust of 550 Ma aged in Kaoko belt. In Calabria region, at southern Italy, out of Africa, calc alkaline, post collisional augen gneisses were determined with ages varying between 526-562 Ma (Micheletti et al, 2007). It is considered that these gneisses are the Pan-African post collisonal granites and show big similarities with West African Craton. Goodenough et al. (2010) dated post collisional granitoids as 522-537 Ma which have formed in the stage following the East African Orogeny, north of Madagascar.

TECTONIC ENVIRONMENTS OF ORTHOGNEISSES IN THE MENDERES MASSIF

In the pioneering geochronological studies made in the Menderes Massif, deformation/metamorphism were dated as 500±10 Ma and tonalitic and granitic intrusives were dated as 471±9 Ma (Satır ve Friedrichsen, 1984). Şengör et al. (1984) were suggested an opinion that the magmatic and metamorphic stages of core series in the Menderes Massif can be associated with the Pan-African Orogeny. Investigators suggest a location for the Menderes Massif in the western part of the Arabian Peninsula, at the northernmost part of Mozambique belt during the Early Cambrian continental arrangement. This positioning is also supported with other geological evidences (Late Silurian glaciation, Monod et al., 2003; clastic zircon source rock, Gessner et al., 2004) and the location of the Menderes massif is positioned to the North of Anatolia-Arabian Peninsula in general maps (Stern, 1994; Kröner and Stern, 2005). In the following years Dora et al. (1994) stated that protolithes of orthogneisses observed in the Menderes Massif based on the regional geology were syn to post metamorphic granites intruded by the Pan-African Orogeny. This opinion has been accepted by many researchers as a result of the studies performed in recent years (Hetzel and Reischmann, 1996; Dannat, 1997; Dannat and Reischmann, 1997; Loos and Reischmann, 1999; Hetzel et al., 1998; Gessner et al., 2001; Okay, 2001; Dora et al., 2002, 2006; Gessner et al., 2004; Koralay et al., 2004). Geochemical evidences show that these granites are calc alcaline in origin, per aluminuous in character, S typed, syn/post orogenic granite/granodiorites (Bozkurt et al.,1992, 1993, 1995; Dannat 1997; Koralay and Dora, 1999; Koralay et al., 2004; Bozkurt et al., 2006).

In addition to orthogneisses, many studies have been performed in the Menderes Massif

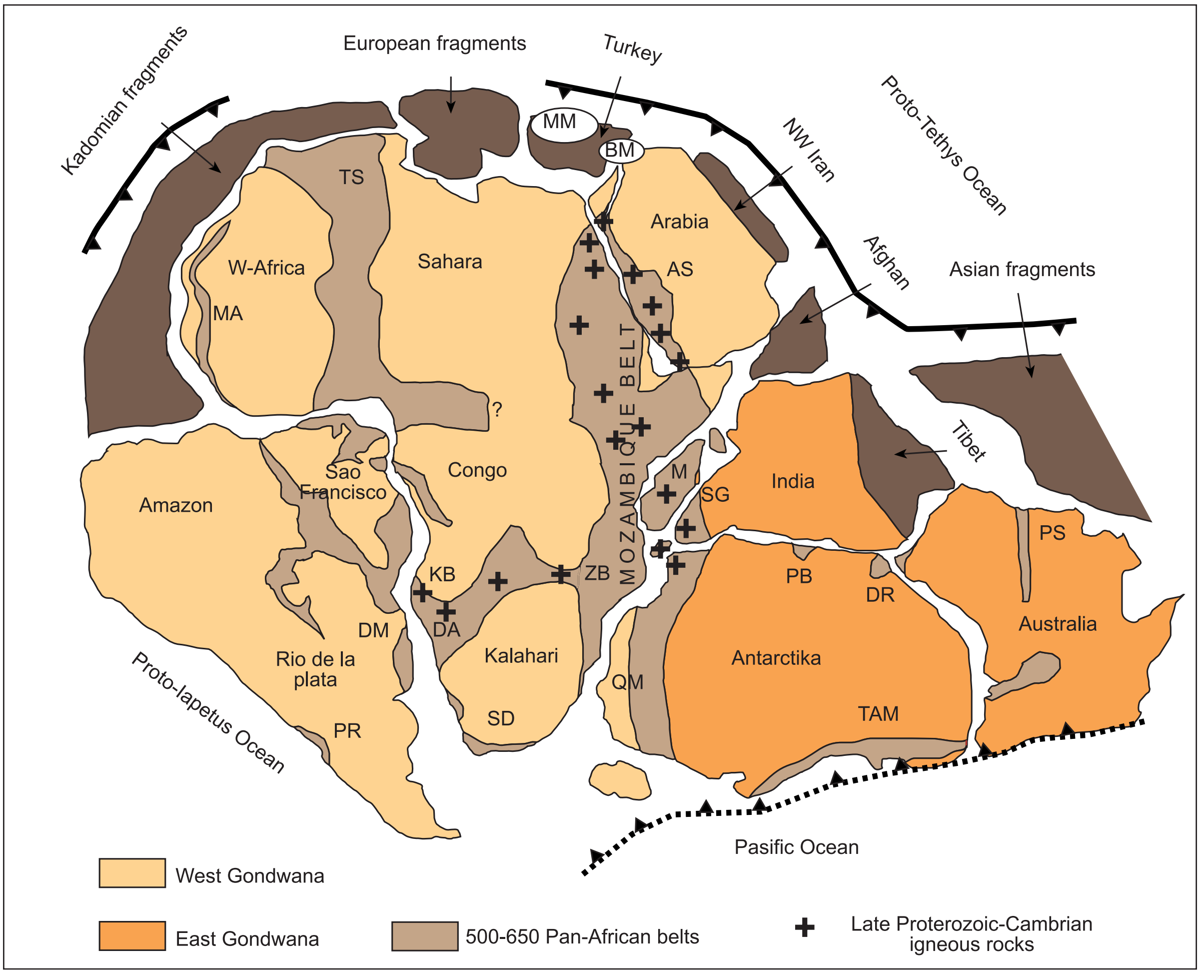


Figure 25- The paleogeographical map of Gondwana super continent in lower Late Neoproterozoic/Early Cambrian (modified from Wilson et al., 1997 and Kröner and Stern, 2005). The locations of the Mozambique belt and Late Neoproterozoic-Cambrian magmatic rocks are shown in the map. AS: Arabian Shield, DA: Damara, DM: Dom Feliciano, DR: Denman Darling, M:Madagaskar, MA: Mauretanides, MM: Menderes Massif, PB: Pryolz Bay, PR: Pampean Ranges, PS: Paterson, QM: Queen Maud Land, SD: Saldania, SG: Southern granulite region, TAM: Trans Antarctic Mountains, TS: Trans Sahara belt, ZB: Zambezi. Magmatic rock locations (from Unrug, 1996; Teklay et al., 1998; Hefferean et al., 2000; Yibas et al., 2002 and Kröner and Stern, 2005).

involving the dissertation of poly-metamorphic stage of core series petrologically and geochronologically in recent years. Petrological studies reveal the presence of a poly-metamorphic stage under granulite, eclogite and upper amphibolite facies conditions in core series (Çetinkaplan, 1995; Candan, 1995; Candan and Dora, 1998; Candan et al., 1994, 2001, 2006; Oberhänsli et al., 1997). In geochronological studies for dating these metamorphisms, metamorphisms of granulite, eclogite and upper amphibolite facies were dated as 583±5.7 Ma (Koralay et al., 2006), 529.9±22 Ma (Oberhänsli et al., 2009) and 551±1.4 Ma (Hetzel et al., 1998), respectively. Radiometric ages and relative textural relationships clearly display these metamorphisms are associated with the stages of an orogenic event following one another. There has not been any metamorphism under granulite and eclogite facies in orogeny involving metamorphic regions since the Cadomian Orogeny has not resulted with a collision of another continent. On the contrary, the stage related with the closure of Mozambique Ocean of the Pan African Orogeny in Late Proterozoic-Early Cambrian are defined by 610-520 Ma (with an average in 550 Ma) aged widespread granulite facies metamorphism (Paquette et al., 1994; Hölzl et al., 1994; Shiraishi et al., 1994; Ayalew and Gichile, 1990; Key et al., 1989) and 530-500 Ma aged eclogite facies metamorphism (Ring et al., 2002). The paleogeographical position of the Menderes Massif in Precambrian and Cambrian times and the stage of core series based on the temporal and spatial similarities of metamorphic evolution of Mozambique Ocean are associated with the closure of Mozambique Ocean and with the collision of East-West Gondwana continents (Candan et al., 2006, Oberhänsli et al., 2009).

The consistency of intrusion ages of orthogneisses varying between 570-520 Ma in the Menderes Massif with poly metamorphic stages of country rocks varying between 580-550 Ma, clearly displays that magmatic stage and the metamorphism is observed within the same orogenic event, genetically. When the paleogeographical position of Menderes Massif in Late Proterozoic- Early Cambrian and close temporal and spatial relationships are assessed with the character of metamorphism and the presentation of orthogneisses have a definite S type, the 570-520 Ma aged acidic magmatic activity in the Massif can be correlated with the closure of the Mozambique Ocean, collision of Gondwana, crustal thickening and the partial melting process occurred in sub crust.

TRIASSIC MAGMATISM

Intrusion age of primary granites of leucocratic orthogneisses

The Triassic magmatic activity in the Menderes Massif constitutes the second biggest magmatic activity observed after the Pan-African magmatism. Leaving aside the amphibolites defining probable Triassic basaltic volcanism located at the base of Mesozoic platform, the Triassic magmatism in the Massif are described by leucocratic orthogneisses. In preliminary studies, although there has been no geochronological evidence the orthogneiss mass cropped out in Dededag, south of Alaşehir was given Triassic age (Akkök, 1983; Şengör et al., 1984). As obviously explained above, detailed radiometric dates were obtained from these orthogneisses in 90's (Dannat, 1997; Dannat and Reischmann, 1998; Koralay, 2001; Koralay et al., 2001). Textural and structural data, contact relationships, ages of the country rock and the radiometric dating values by single Zircon Pb/Pb evaporation method clearly display that these leucoratic masses are magmatic in origin and their intrusion ages vary between 227-247 Ma (Middle Triassic - according to Gradstein et al., 2004).

Tectonic envrionmets of primary granites of leucocratic orthogneisses

As mentioned above, the Triassic magmatism is not only observed in the Menderes Massif (associating the phenomena with a regional tectonism) but also in Lycia belonging to Anatolides, in Afyon and Tavşanlı zones, in Karaburun, in Cyclades and in inner Hellenides.

The middle Carnian aged, inner plate MORB type transition basalts located in Gülbahar Nappe belongs to Lycian nappes and are interpreted as the products of the first formational evolution of the oceanic crust at northern branch of Neothethys (Göncüoğlu et al., 2003). Dacitic and rhyolitic metavolcanites accompanying with coarse clastics and located at the base of Mesozoic cover series of Afyon Zone were dated as 224-243 Ma. (Middle - Late Triassic) (Akal et al., 2007a; Akal et al., 2008). It is considered that these volcanites subducts southward and the Paleothethys ocean characterizes the rifting stage of Neothethys Ocean that was opened as backiarc basin located at the northern margin of Gondwana (Göncüoğlu et al., 2003; Akal et al., 2007*a*). It is known that blueschist metabazite stages and jadeite bearing magmatics are present in Tavşanlı zone, in metaaplites, at lower stages of platform type carbonates (Kulaksız, 1978; Okay and Kelley, 1994; Çetinkaplan et al., 2008). There is not any investigation involving the geochemistry and its tectonical environment of these metabazites in Triassic (?) age. The Triassic magmatism in Karaburun peninsula show similarities with the Menderes Massif. Granodiorites cutting the Devonian-Carboniferous clastic series were dated as 229±3 Ma by single Zircon Pb/Pb evaporation method (Ercan et al., 2000). These are considered as the products of back arc magmatism developed synchronously by the rifting of Neothethys located at northern margin of Gondwana which is related with the Paleothethys subducting southward. The existence of magmatism in similar ages is known as Cyclades which is one of the closest magmatic regions to the Menderes Massif, except Anatolides and at Inner Hellenides at North (Reischmann, 1998; Himmerkus et al., 2009). Granites recognized in Nacsosia island were dated as 233±2 Ma by single Zircon Pb/Pb evaporation method (Reischmann, 1998). Leucocratic granites observed in the Serbo-Macedonia Massif located at inner Hellenides were dated varying between 221±2 Ma. and 241±3 Ma by the single Zircon Pb/Pb evaporation method. The average age is given as 228±6 Ma for this region (Himmerkus et al., 2009). Besides, the existence of Triassic granites at east of Vardar Zone and east of Pelagonian zones is also known (Himmerkus et al., 2009). As can be seen in the abstract, the Triassic magmatism can widely be observed in Turkey and in close tectonic units and is substantially associated with the opening of Neothethys ocean.

In pioneering investigations on Triassic granites in the Menderes Massif, these rocks have been interpreted as plutons that have intruded at the stage of deformation and the metamorphism by which the northern parts of the Massif was affected (Akkök, 1981, 1983; Şengör et al., 1984). This event was suggested as associative with the closure of Paleotehtys subducting southward which was located between Laurasia and Gondwana in Late Triassic (Akkök, 1983; Şengör et al., 1984). This scenario has been appropriated in following studies as well, and these rocks were interpreted as leucocratic orthogneisses that have settled in the stage following the Early Kimmerian Orogeny related with the closure of Paleotethys Ocean (Koralay, 2001; Koralay et al., 2001). However, although there is not detailed geochemical data, when the close relationship of the Menderes Massif with above described tectonic units in Triassic time and origin are considered, it is assumed that associating the Middle Triassic leucocratic granite intrusions with the rifting of northern branch of Neotethys ocean would be more realistic.

CONCLUSIONS

Results related to basic geological features of orthogneisses of which are the Pan-African and Triassic acidic magmatic activity products in the Menderes Massif are given below. These results have been obtained by investigations that have continued more than 50 years.

1. The Pan-African basement of the Menderes Massif is made up of Late Proterozoic metaclastics and by acidic - basic magmatics of which have intruded into. Orthogneisses form the most common rock type.

2. All gneisses in the Menderes Massif are granitic in origin and present well preserved intrusive contact relationships by metaclastics composed of paragneiss and schists that form the country rock. These rocks are in the form of plutons that have intruded one other and reach tens of kilometers, stocks reach in several kilometers and veins reach a few hundreds of meters.

3. The primary rocks of orthogneisses can be divided into three categories based on mineralogical composition and textural properties.

These are; i) biotite orthogneiss, ii) leucocratic orthogneiss and iii) amphibole orthogneisses.

4. Contact relationships relatively define that biotite orthogneisses are the oldest and amphibole orthogneisses are the youngest magmatic stages. Although there are some temporal contradictions, radiometric ages obtained so far support this relative relationship (biotite orthogneiss: 550-570 Ma; tourmaline leucocratic orthogneiss: 540-550 Ma., and amphibole orthogneiss: 530 Ma).

5. When poly metamorphic evolution of the Massif basement, intrusional ages of orthogneisses, geochemical properties of these rocks and the paleogeographical position of Turkey in Late Neoproterozoic-Early Cambrian are assessed altogether, it is noticed that these intrusives can be associated with the closure of Mozambique Ocean in Late Proterozoic and with the Pan- African Orogeny that caused the collision of East-West Gondwanaland.

6. The Triassic leucocratic orthogneisses observed in the Pan-African basement and Palaeozoic cover series are granitic in origin and represent the second effective acidic magmatic activity in the Massif.

7. Gneisses in the form of plutons and vein rocks reaching a 5-6 km in size present well preserved intrusive contact relationships with country rocks.

8. The intrusion ages of these granites were dated as 227-246 Ma (Middle Triassic) by geochronological studies.

9. When the Triassic magmatism in other tectonic zones belonging to Anatolides and the regional tectonism in Triassic are assessed together, the evolution and emplacement of these granites can be associated with the rifting mechanism of northern branch of Neotethys Ocean.

ACKNOWLEDGEMENT

This paper covers the results obtained by the studies that have continued for 20 years in the Massif. We would like to thank to TUBITAK who supported us with 5 projects (TBAG-688 and 937, YDABÇAG-495, 554 and 101Y132), to Volkswagen-Stiftung which helped us with 2 projects both in Turkey and abroad between the years 1994-1998 and 2002-2006 and to the Rectorate of Dokuz Eylül University which have supported us in many projects.

Manuscript received December, 11, 2009

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