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HISTORICAL EVOLUTION OF THE GEOLOGICAL RESEARCHES IN THE MENDERES MASSIF

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ABSTRACT.- The Pan-African basement of Menderes Massif is made up of homogenous paragneiss and schist units (metaclastic sequence) which are intruded by metagabbros and gneisses derived from different types of granites. The basement is unconformably overlain by lower Palaeozoic metaclastic series consisting of quartzite and metaconglomerate at the lowest level. They show a transition into schists, and the Palaeozoic sequence ends with Permo-Carboniferous black marbles of Göktepe formation. Both basement and Palaeozoic sequence are intruded by lower Triassic leucocratic granites which were converted into orthogneisses by Alpine metamorphism. The Mesozoic series of the Menderes Massif begins with upper Triassic meta-sandstone/metaconglomerate intercalation and continues with Jurassic to Cretaceous dolomites and massive marbles. Platform-type massive marbles with metabauxite lenses and well-preserved rudist fossils at the uppermost levels are conformably overlain by late Campanian - late Maastrichtian reddish pelagic marbles. Flysch-type middle Paleocene metaolistostrome forms the uppermost unit of cover series. The protoliths of clastic sediments of the Pan-African basement consisting of paragneiss and conformably overlying schist units were deposited on a passive continental margin. The zircon ages of the granitoids intersecting this clastic sequence are restricted to a time range between 570 and 520 Ma with an average of about 550 Ma. The polyphase metamorphic evolution of the basement under granulite (583 ± 5,7 Ma), eclogite (529,9 ± 22 Ma) and Barrowian-type medium-pressure conditions (average 540 Ma) are related with the Pan-African Orogeny. The isotopic data including the ages of detrital zircons (592-3229 Ma) of paragneiss and schist units, the intrusion ages of granitoids and the age of granulite facies metamorphism constrain an age for the deposition of protoliths of metaclastic sequence between 592-580 Ma, Lower Late Neoproterozoic. In Eocene time, Pan-African basement and cover series were affected by Barrowian-type Alpine metamorphism under greenschist, lower amphibolite facies conditions, traditionally called as the 'Main Menderes Metamorphism. However, new HP/LT evidence found in Mesozoic cover series reveals that this metamorphism is more complex than it was considered. It is generally accepted by many researchers that the exhumation of the Menderes Massif as a core complex is related with the extensional tectonic regime. It is assumed that there is a genetic relation between the intrusion of Eğrigöz - Koyunoba granites and the detachment fault in the northern part of the Menderes Massif. Furthermore; to the South of the Massif, it is suggested that the old thrust fault between the Menderes Massif and Lycian Nappes reworked as a detachment fault during the exhumation. The reason of extension in the region is the thermal weakness in the thickened crust made by the magmatism developed after the the collusion of Anatolide-Tauride platforms and the Sakarya continent. The intrusion ages of Eğrigöz and Koyunoba granitoids are 20-21 Ma and the detachment fault was active during 25-19 Ma. In addition, the symmetric core complex formation in the central submassif was carried out in the middle-late Miocene. Pliocene to recent active graben faults intersect the detachment faults.

Key words: Menderes Massif, Pan-African and Alpine metamorphism, young exhumation.

INTRODUCTION

The Menderes massif, which has an important role during the shaping of geological structure of the western Anatolia, takes place within the main subjects of the geological researches carried out in Anatolia for 150 years. Within this context; the colloquium held in Izmir, between 5th-10th of November 2007 regarding the stratigraphical and tectonical structures, condition of metamorphism, kinematics and ages, latest compressional and extensional tectonical regimes caused to gaining of the recent form of

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the massif that gave the recent outlook to massif, gave chance to the presenting of the latest findings about the massif. In the Colloquium, in which invitational conferences took place, common sides of geological evidences were specified that has been put forward so far in the Menderes Massif and future oriented approaches were exhibited to solve the problems being discussed. Within this paper, which is aimed at presenting the last scene of the researches made in the massif, documents that have been prepared within years and contributed to the geology of the massif will be mentioned first. Later on; which geological problems of the massif have nowadays been solved will be investigated. And in the last section, some proposals about the future geological studies will be presented.

HISTORICAL EVOLUTION OF RESEARCHES IN THE MASSIF

First historical definitions of the rocks of Menderes Massif belong to Hamilton (1841), Tchichatcheff (1867), in the map of Geology of Aegean Region attached to his book named as "Asia Mineure", has approximately localized the NW-SE boundaries of the region, known as the Menderes Massif at present, but has extended the massif to the south of the Sea of Marmara at the north. He defines that the massif consists of micaschist, gneiss, marble, amphibolites, some undefined rocks and less granite. He also points out that the same rocks present in Cyclades (Figure 1). Philipson (1911-1915), uses the name "Lydia Caria" Massif for the region which is named as Menderes Massif at present. He also mentions about the crystalline rocks at the center of the massif and of marbles and semi crystalline limestones towards the western southern regions. In the geological map, a zone is shown at the NW boundary of the massif, which approximately corresponds to the present Izmir-Ankara zone composing of clayey schist, graywacke, serpentine and diabase veins (Figure 2). It is emphasized that the fractures forming the young grabens in the massif might be Late Pliocene-Quaternary. Menderes Massif was first named by Parèjas (1940) and appeared in the 1/1.000.000 scaled geological map of Turkey prepared by Egeran and Yener (1944) as MTA publication. The Menderes Massif is shown as a distinct tectonical unit in Izmir sheet of this map.

Schuiling, who made the first systematic geological-petrographical investigation of the massif in 1962, defines the lithostratigraphical sequence and divides it into two main units as "core" and "cover". With keen eye detection, he also distinguishes the fine grained basic gneisser from classical augen gneisses of the massif which are defined as paragneiss in the recent maps of the "Çine submassif". However, locating the Caledonian Orogeny into core and cover series, aging the uppermost units of the Massif as Permo-Carboniferous and last metamorphism as Hercynien totally disagrees with actual evidences. Graciansky (1965), mentions about the presence of an unconformity between the basement and cover series in Menderes Massif on the basis of lineation, schistosity and inclusion measurements. However, the age of Triassic Milas marbles shown by question marks has been approved as Santonian-Campanian.

Brinkman (1967), extends the southern boundary of the Menderes Massif to the Gulf of Gökova. Whereas, this boundary ends with a unit distinguished as Kazıklı at present, and Kurin, Karaova and Gereme units in the southernmost part of the region are included into the Lycian Nappes. Besides, in recent studies different than Brinkman (1967), Milas, Kızılağaç and Kazıklı units are aged as Santonian-Campanian, Late Campanian-Maastrichtian by fossil content, (Özer et al., 2001).

The first studies aiming the investigation of mineral facies in Bozdağ and in its western parts were made by İzdar (1971) and Evirgen (1979). Evirgen (1979), claims that regional metamorphism has occurred under a pressure of 3,5-6,5 kb and at a temperature of 400-700 °C by basing

Figure 1- Geological map of the Aegean Region (Tchichatcheff, 1867). Explanations: th-m: Tertiary; th: Terrace and diluvian, pl: Marine pliocene, l: Levantine, p: Pontian, s: Sarmatian, m: Marine lower Miocene, e: Eocene; cr-f: Mesozoic, cr: Cretaceous, ti: Titonian, t: Triassic; c-de: Palaeozoic, c: Carboniferous, de: Lower Devonian, x: Metamorphic schist, mica schist, gneiss, marble, amphibolite (granite and non differentiated rocks), g: granite and granulite, sy: Syenite, diorite, Serpentinite, Andesite, trachyte, basalt etc., +: lignite basins, sea depth up to 500 m, sea depth up to 1000 m., Dip and strike of bed and general delineation of folds.

on index minerals in this study, although cataclastic rocks in the southern part of Gediz Graben were mapped, a direct relation of deformation with the north dipping and a low angle detachment fault could not be established.

Dürr 1975 determined the first rudist fossils in Milas marbles which is extending along the southern boundary of Menderes Massif. Based on the fossil content, he defined the age of the platform type marbles belonging to the cover

Figure 2- Geological map of the Western Anatolia (Philippson, 1911). Explanations: 1- Holocene and Pliostecene, n2-Young Tertiary, 3- Tuff bearing Tertiary, 4- Tuff and andesite bearing Tertiary, e5-Lower Tertiary, k6- undated limestone, kk7-Cretaceous formation limestone (partly upper Jurassic), t8- Triassic, ck9-Carboniferous and Permo - Carboniferous calcerous, S10- clayey schist, greywacke, diabase. Partly definite, partly probable Paleozoic, S+D11- clayey schist plenty of diabase and serpentine with veins, gl12- Mica schist and other crystalline schists (very little schistose gneiss), 913- Gneiss (very few micaschist), m14- Marble and semi-marble, B15-Basalt, A16- Andesite, trachyte and rhyolite, T17-Andesitic, trachytic and rhyolitic tuff, AYT18- Andesite and tuff, D,Se19- Diabase, gabbro, porphyrite, green porphyry serpentine, G20-Granite

series of the Menderes massif which was determined as Late Cretaceous, and the overlying unit with the reddish pelagic marbles named as Kızılağaç unit as Early Paleocene. Besides, he located the boundary of Menderes Massif and Lycian Nappes between Kızılağaç and Kurin units as it is in Graciansky's section (Figure 3).

Dora (1976) published the 1/500.000 scaled geological map and the generalized geological map of the whole Menderes Massif based on his observations dividing the Massif into Eğrigöz, Gördes, Ödemiş and Çine submassifs. In the publication, high temperatured metamorphic cores (gneisses and migmatites) were distinguished. Monocline tricline latticework in K-feldspars based on the transformation temperature and index minerals, shows the boundaries between greenschist and almandine amphibolite facies (Figure 4), but these boundaries were subjected to significant changes by new investigations.

Kun and Dora (1984) located leptites (metavolcanites) among the core and cover series, lithostratigraphically. Şengör et al., (1984), interpreted these metavolcanites as volcanics of the Pan-African Orogeny rich in silica, and was thought that this layer might be the continuity of the Pan-African suture belt determined in Karacahisar dome and symbolized the Main Upper Pan-African discontinuity.

Dora et al., (1990), published an evolution scenario shown in schematic figures belonging to the geological history of the Menderes Massif which was prepared on the basis of literature background and their findings (Figure 5a,b). The publication which presents many different interpretations with the recent evidences caused to the increasing interest of the researchers to the geology of the Menderes Massif, and interpretations from location and settlement mechanism points of view.

Erdoğan (1992) and Erdoğan and Güngör (1992) different than the previous researchers, claimed that gneissic granites syntectonically settled at the time of Menderes Main Metamorphism (MMM), and therefore, augen gneisses in the massif originated from Upper Cretaceous-Lower Eocene granitoids. This new hypothesis was later explained on schematic sections by Erdoğan and Güngör (2004). Besides, it is claimed in this study that Lycian Nappes synchronologically thrusted with the main metamorphism of Menderes Massif from south to north and therefore the Menderes platform has been subjected to folding plunged to the north. These papers gave rise to many other investigations from different perspectives for the Massif.

Bozkurt et al., (1993) and Bozkurt and Park (1994), pointed out that, the protolithes of gneisses in the Çine submassif are the granitoides intruded by the extensional collapsing of the thickened crust of the western Anatolia in Late Oligocene which were originated by the partial melting of the greywackes during the Main Menderes Metamorphism (MMM) formed under greenschist-upper amphibolites facies conditions. They also claim that, after the intrusion, granitoids have been rised under ductile conditions along a big shear zone dipping to the north which was the product of an extensional tectonics, and transformed in to gneisses. Therefore, according to these investigators gneiss-schist contact at the south of Çine submassif symbolizes a typical detachement fault. Later, Bozkurt (2004) accepted the presence of two different types of gneisses as leucocratic metagranites much younger than Eocene aged Menderes Main Metamorphism, and Precambrian augen gneisses in the Menderes Massif. They declare that the first interpretation they made in their previous publication is valid for the young leucocratic metagranites, but many investigators claim that gneiss schist contact at the southern margin of Çine submassif does not have any traces of brittle and ductile deformation following one another which is a characteristic for a detachement fault and this contact symbolizes one of the pervasive intrusional contacts belong-

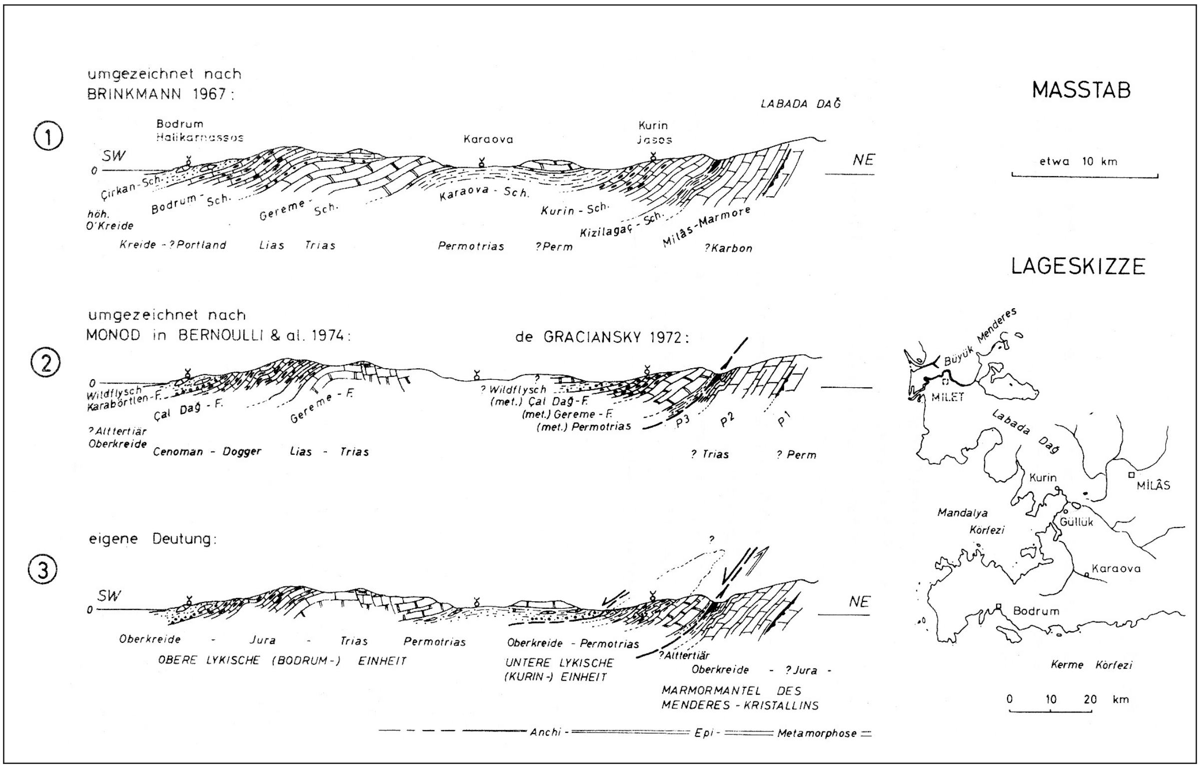

Figure 3- Semi schematic Bodrum-Kulin geological sections of Lycian units, SW Milas (Dürr, 1975). Explanations: 1: Brinkmann (1967), Uppermost Creatceous, Cretaceous-? Portlandian, Liassic, Triassic, Permo - Triassic, ?Permian, ?Carboniferous, 2: Bernoulli et al., (1974), Monod and De Graciansky (1972): Lower Tertiary-Upper Cretaceous, Senomanian-Dogger, Liassic-Triassic; 3: own interpretation; Upper Lycian (Bodrum) unit: Upper Cretaceous-Jurassic- Triassic, Permotriassic; Lower Lycian (Kurin) unit: Upper Triassic-Permo - Triassic; Marble mantle of the Menderes Massif: ?Lower Tertiary, Upper Cretaceous-? Jurassic.

ing to Pan-African granitoids (Candan et al., 2006; Konak et al., 1987).

Candan et al., (1992) illustrated napped structures in the Menderes Massif in Aydın Mountains. Base cover series in this region composed of augen gneiss, leptite and schists take place on different units. Later on, it was understood that some of these klippes, have taken their recent forms by means of detachement faults. Widespread nappe structures in Menderes Massif were defined in many regions after 1994 (Konak et al., 1994; Dora et al., 1994). Dora et al. (1995) have shown some of these structures in his paper as attached maps and schematic sections (Figure 6). This study is interesting in terms of collecting the new evidences discovered so far in the Massif (granulites and eclogites in the Pan - African basement, the first Cambrian ages of the rocks named as leptite gneiss, Early Triassic metagranites and the polyphase metamorphism in the Massif). Granulite and eclogite relics at the Pan-African basement of Menderes Massif were first defined in 1994 by Candan et al., Later on, the formation of these relics, metamorphic conditions and relative ages were established with respect to each other (Oberhänsli et al., 1997; Candan et al., 2001).

Candan and Dora (1998), compiled generalized geological map of the Menderes Massif in 1/750 000 scale and presented it at a workshop

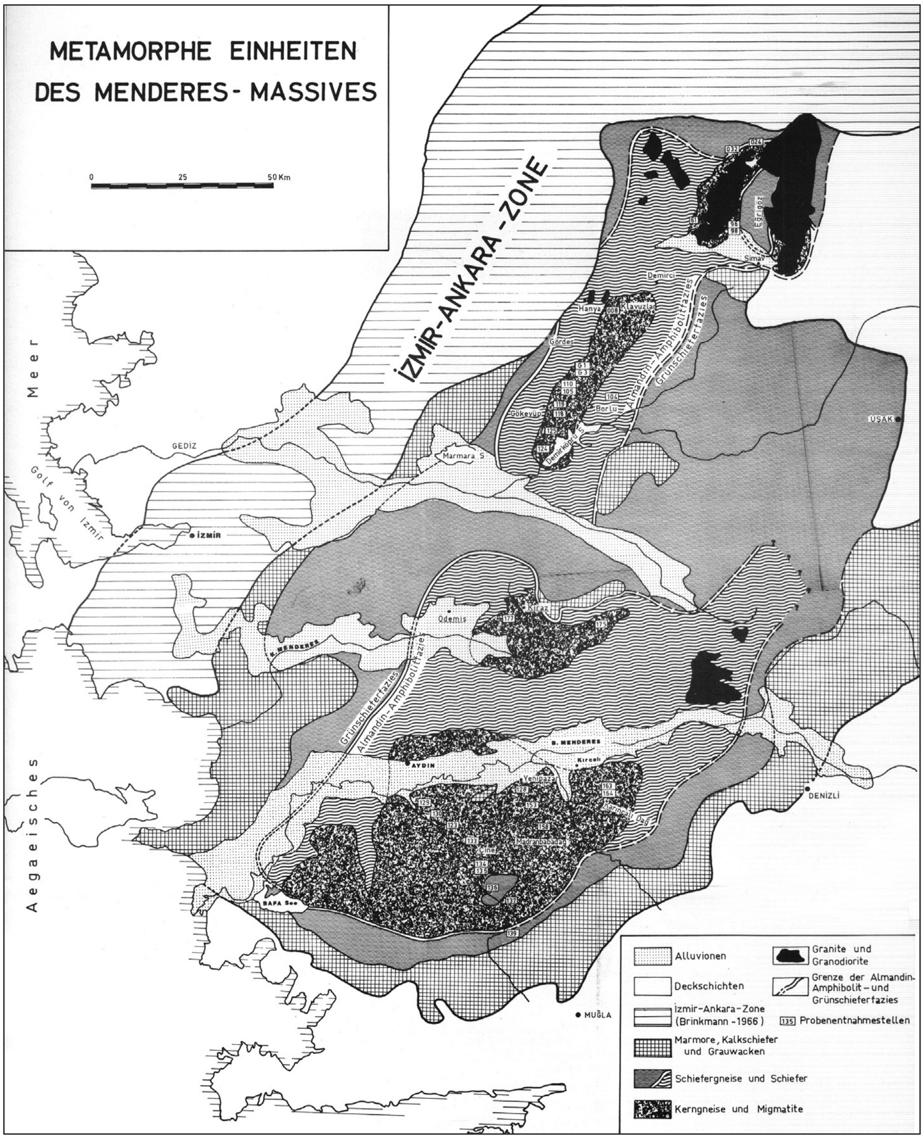

Figure 4- Metamorphic units of the Menderes Masif (Dora, 1976). Explanation: 1-Aluvials; 2-cover series; 3- İzmir-Ankara zone; 4- Marbles, Calcshists and graywackes; 5- Gneissic schists and schists; 6- Core gneisses and migmatites; 7- Granite and granodiorites; 8- The boundary between Almandine, amphibolites and greenschist metamorphism, 9-Sample Locations.

held in Mainz University. However, this map was published at a very less amount but, it still has been used by many investigators. Detailed studies on nappe packages in the Menderes Massif were investigated by Partsch et al., (1998), Ring et al., (1999) and Gessner et al., (2001*a*; 2001*b*). It can be recordet that Ring et al., (1999)'s suggestion about the formation of Dilek peninsula and Selçuk region which are formed by a nappe deposition drifted from Cycladic complex and the Menderes Massif has generally been formed from 4 nappe packages

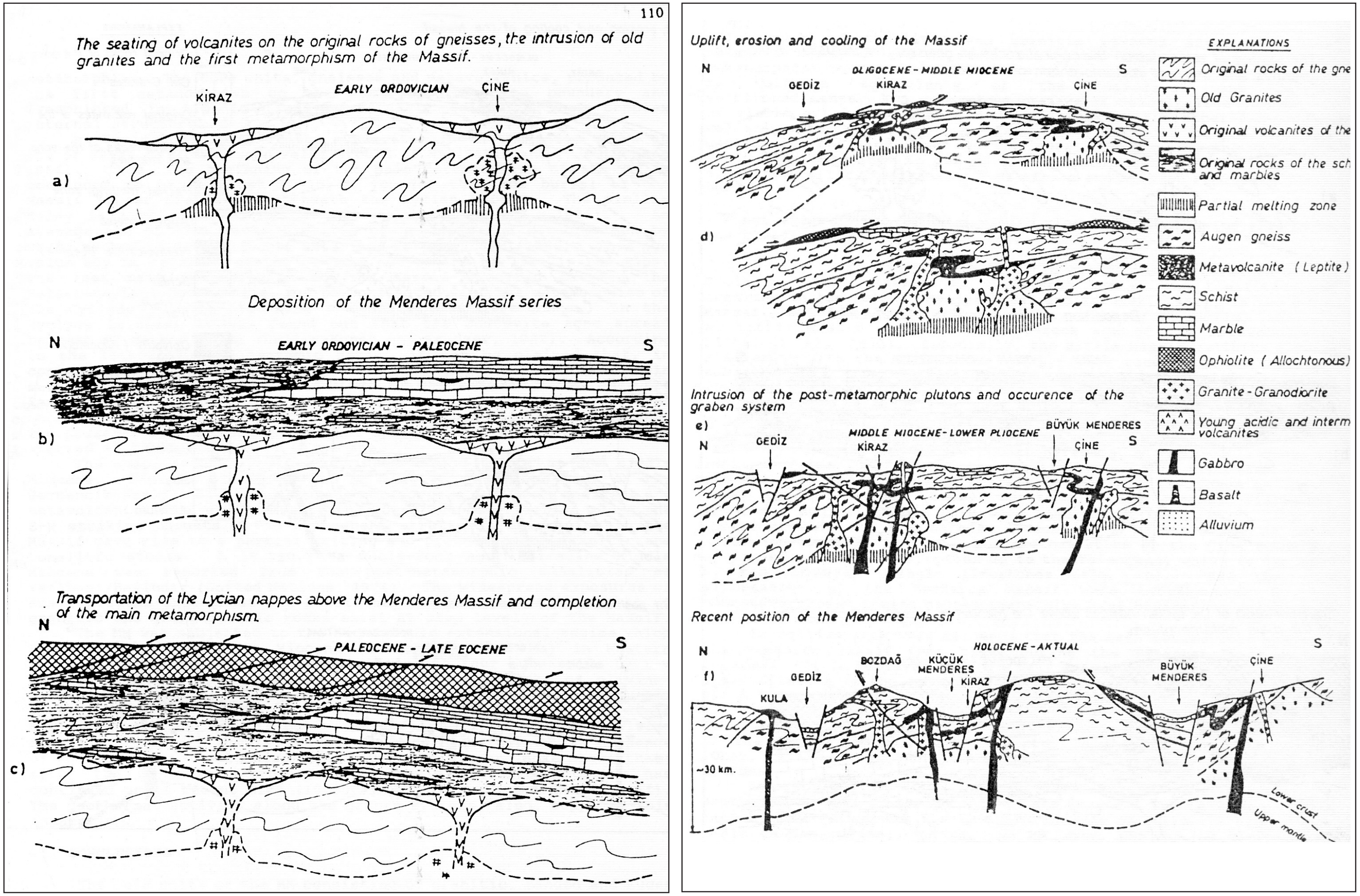

Figure 5ab - Schematic cross sections showing the tectono metamorphicevolution of the Menderes Massif from Devonian to recent a-f (Dora et al., 1990).

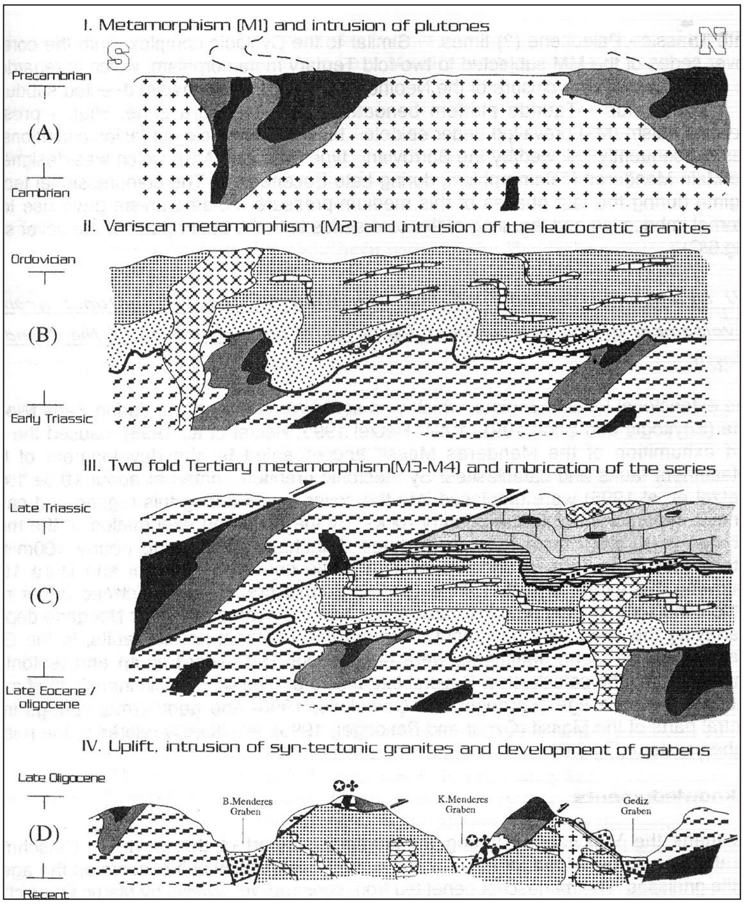

Figure 6- Drafts of the schematic sections of some important stages regarding the geological evolution of the Menderes Massif (Dora et al., 1995).

are the new interpretations. However, extending the shelf series (Dilek Nappe) belonging to Cycladic Complex along the southern margin of the Menderes Massif until Göktepe disagrees with the recent interpretations (Dora et al., 2005). At the bottom of Mesozoic series of the Menderes Massif, Mg-carpholites were detected different than Cycladic complex (Rimmelé et al., 2003). Besides, metaolisthostrome unit forming the uppermost unit of the series does not contain metagabbro and eclogite relics again different than Cycladic Complex (Figure 7).

After 1995, suspects arise about volcanic origins of leptites in the work group in Dokuz Eylül University. Especially, the layers of these rocks have many successions with schists ranging from cm to hundreds of meters in Demirci-Gördes submassif. On the other hand, it was determined that all zircons acquired from these rocks for radiometric dating have lost their primary smooth crystalline forms because of transportation and are highly in rounded shape. Radiometric dating (610-3229 Ma), sedimantological and geochemical studies have revealed that these rocks named as leptite are the paragneisses derived from the metamorphism of sediments alternating with sub arkose mudstone with abundant litarenite belonging to Pan-African basement. Field data show that paragneisses

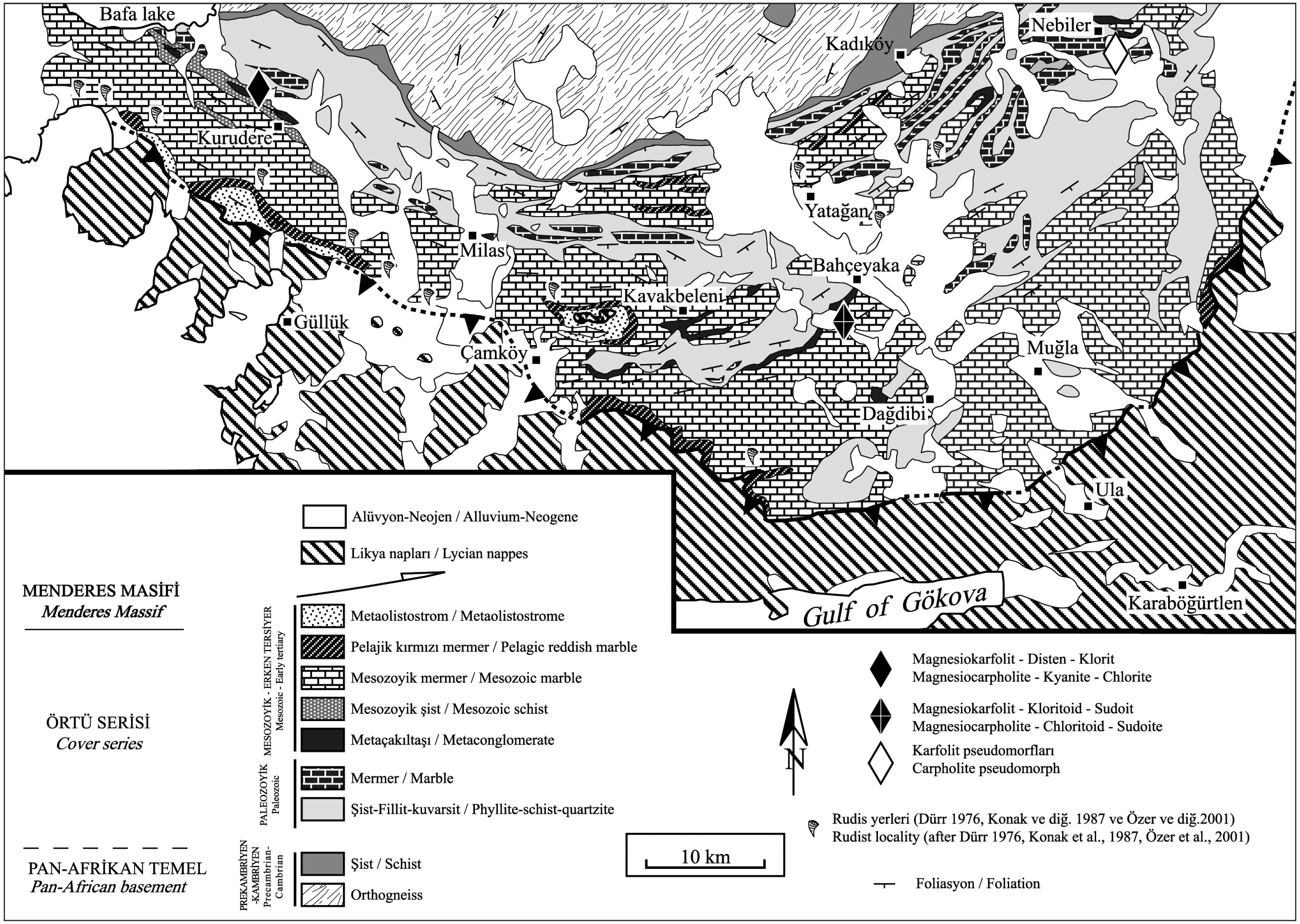

Figure 7- Generalized geological map of the Çine submassif (southern part) and the locations of Alpine HP/LT metamorphism groups (The map was obtained from Çağlayan et al., (1980), in main details. Rudist locations belong to Dürr, 1975, Konak et al., 1978 and Özer et al., 2001, carpholite locations belong to Rimmelé et al., (2003).

are comformably and transitionally overlain by schists. The youngest detrital zircons in these schists were determined as 592 Ma. It is assumed that the protolithes of the series composed of paragneiss and schists are the clastic sediments derived from the source area composing of cratonic crystallines (Dora et al., 2001).

Okay (2001) states that Eocene aged structures in the Menderes Massif could be explained by a northward dipping recumbent fold. Thus, he asserts that the stratigraphical and mineralogical inversion in Bozdağ and Aydın Mountains could be understood easier. He also emphasises that, the Cycladic Metamorphic complex overlies the Menderes Metamorphics along a big thrust zone after the Menderes folding and internal imbricating. This claim which tries to explain the structural position of the Middle Menderes Massif out of nappe packages should also explain some other points with respect to top and bottom relationships of the units in lithostratigraphy.

Dora et al., (2005) stated that the age of all gneiss types in Çine submassif is around 550 Ma by means of radiometric data. These investigators also emphasize that the primary contact between the Pan-African basement and the Palaeozoic cover symbolizes an unconformity plane depending on the metagranite pebble bearing metaconglomerates derived from the Pan-African basement located at the bottom of Palaeozoic series in the Menderes Massif (over Pan- African Unconformity).

Many studies have been established and various models have been created concerning about the cropping out of the Massif after 1995 (Bozkurt and Park, 1997; Işık et al., 2003; Seyitoğlu et al., 2004; Thomson and Ring, 2006).

Many of the publications state that rapid erosion have taken place in the Massif following the uplift along the slip faults in northern and southern boundaries since Early Miocene.

Dating magmatic and metamorphic evolution of the Menderes Massif has rapidly increased in recent years. It has been approved that augen gneisses belong to Pan-African (Hetzel and Reischmann, 1996; Koralay et al., 2002; Gessner et al., 2004) and leucometagranites which cut the Palaeozoic series belong to some parts of the Massif in Lower Triassic (Dannat, 1997; Koralay et al., 2001). There is almost a concensus that, polymetamorphic evolution of core series is related to Pan-African (Hetzel et al., 1998; Oberhänsli et al., 2002; Koralay et al., 2006). It is also stated that Alpine metamorphism affecting the core together with cover series is Eocene (Satır and Friedrichsen, 1986; Hetzel and Reischmann, 1996; Lips et al., 2001).

PICTURE OF TODAY

The geological investigations systematically carried out in the Menderes Massif since 1962 has served a lot to the solution of the problems up to a certain limit, such as the stratigraphy of the Massif, tectonic structure, age of the magmatic activities, conditions and ages of the metamorphisms, cropping out and correlation of neighboring tectonic units. Fine grained paragneisses are observed at the bottom of Pan-African basement in the generalized lithostratigraphical succession of the Menderes Massif. Paragneisses are often successively intercalated with schists then completely grades into schists towards upward. Dora et al., (2005) stated that the ages ranging between 592-3239 Ma were obtained for detrital zircons in these rocks. Due to this fact, it is assumed that these clastic series were deposited at the passive continental margin looking at the northern slope of Gondwanaland in Late Proterozoic. The thickness of the monotonous paragneiss and schist series reach 7-8 meters in Bozdağ region. Both paragneisses and schist series are cut by gabbros and various granitoids of which the crystallization age varies between 570-5212 Ma mainly around 550 Ma (Koralay et al., 2007; Loos and Reischmann, 1999). The whole sequence has first undergone to a granulitic metamorphism, and then is affected by an eclogitic first, and then a Barrowian type, metamorphism under upper amphibolite facies conditions in Upper Proterozoic time. The Pan-African basement of the Massif, although not observed in all regions, is covered with Lower Palaeozoic series presented by an unconformity surface (quartzite and metaconglomerates). The thickness of the clastics in Palaeozoic series in the Menderes Massif reach 2-3 km. and become rich in graphite in upward levels and is intercalated with black marbles. The age of the black marbles was determined as Permocarboniferous (Onay, 1949; Schuiling, 1962). The bottom of the Upper Palaeozoic sequence is overlain by an Upper Triassic purple colored metaconglomerates and metasandstones (Konak and Çakmakoğlu, 2007). The unconformity between Palaeozoic and Mesozoic times is not possibly observable in all parts of the Massif. However, metaconglomerates abundant in quartz components are sparse and comprises typical disthene - chloritoid - Mg - carpholite assemblage. Again, Na-amphibolite relics are observed in metabasics which are located at the bottom. The platform type massive dolomites called as Milas marbles in upper levels of the sequence overlies the metasandstone and metaconglomerates. Emery lenses are observed at lower levels of the Milas formation and rudist fossils are recognized at top levels. Cenomanian age was given to emery levels and Santonian-Campanian age was given to rudistic levels by Özer et al., (2001). Red colored, thin bedded pelaj marbles of the Kızılağaç formation overlies the platform type gray marbles. Due to foraminifers and nanno planktons, the age of these marbles is defined as Late Campanian-Late Maastrichtian (Özer et al., 2001). Kazıklı Formation is the uppermost unit made up of flysch type olistostromal rocks overlying the Kızılağaç formation and the age was given as Paleocene. However, according to Özer et al., (2007), there is also a possibility that the Kazıklı unit unconformably overlies Kızılağaç unit and therefore, Kazıklı unit is included into Lycian Nappes. Na-amphibole relics are also observed in Kazıklı unit including blocks such as marble, serpentinite and etc. On the other hand, the oldest deposits with nonmetamorphic and olisthostromal in character which overlies the Massif is Upper Miocene in age (Konak, 2007).

Today, it is accepted that the Menderes Massif is made up of a nappe package by many investigators. It is possible to trace the nappe packages starting from Demirci - Gördes submassif in the north, to the Çine submassif in the south (Figure 8). In some cases, inner imbrication of cover units and Precambrian basement and in some cases, the overlapping of two main units to each other are observed. Cycladic complex thrusted on the other units of the Massif along its west and northwest margins. According to Gessner et al., 2001*a*, Cycladic Menderes Thrust has occurred after the high pressure/low temperature (HP/LT) metamorphism of the Cycladic blueschists and at a period following the main Alpine metamorphism of the Massif. There are many different opinions about the deformation periods, strike and directions of the compressive tectonic. The Pan-African basement which was subjected to polymetamorphism generally shows very complicated movements in directions. Only in the cover series affected from the Alpine aged metamorphism, the northward lineaments are abundantly developed under high temperature conditions and are directly related with internal imbrication. Southward movements, on the other hand, has been developed under greenschist facies conditions and overlies the structures at the north. At present, all of the investigators agree with the idea that nearly E-W directed grabens in the Menderes Massif formed by the active normal faults since Pliocene.

The most significant magmatic activity in the Menderes Massif develops with the Pan-African Orogeny. The collision type calc alkaline and per alkaline granitoids are intruded (between 570-528 Ma) (Loos and Reischmann, 1999; Koralay et al., 2007). Today, the rocks that come up in two groups named as the augen gneisses and tourmaline leucocratic orthogneiss are the magmatic masses which were developed under the

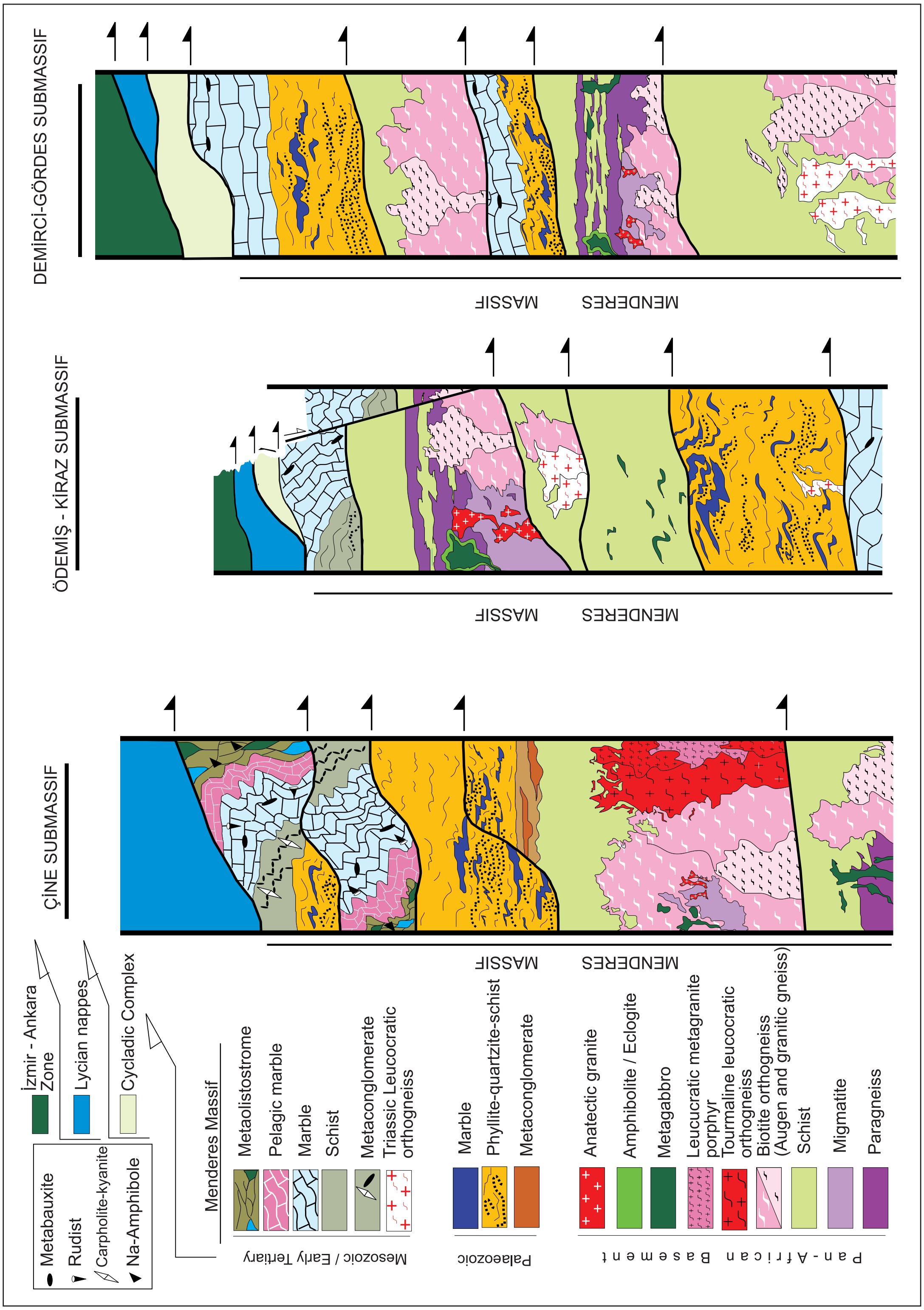

Figure 8- Generalized rock beddings belonging to the submassifs of the Menderes Massif (Dora et al., 2005).

same tectonism, crystallized from one source rock in different partial melting periods and were subjected to crustal contamination in differentrations. Synorogenic granitoids (generally augen gneisses) display less deformation than post orogenic granitoids (leucocratic metagranites and aplites). However, it is not possible to make a distinction among granitoid types with respect to deformation stage. The second big magmatic activity in the Menderes Massif was observed in Lower Triassic time. These leucocratic masses, very light colored and lack in biotite are 235-246 Ma. (Dannat, 1997; Koralay et al., 2001). The magmatism of this period has not yet been associated with a distinct orogenic phase in West Anatolia. However, Akkök (1983) and Koralay et al., (2001) state that these magmatites are related with the closure of Paleotethys. The youngest magmatic activity in the Massif are the young granitoidic intrusions that are mylonitic in character and synchronically uplifted by detachement faults as a product of dilation tectonism. Granitic stocks 21 Ma in age in Simav region and 13 Ma in age in Bozdağ region, which show definite directional traces are closely related with the extension of the Menderes Massif.

Menderes Massif has experienced a polyphased metamorphic evolution. The mineral assemblages defining the granulite, eclogite and amphibolite facies, are respectively observed in Pan African basement. Oelsner et al., (1997) and Koralay et al., (2006), determined the metamorphism age of the granulite facies as 660+61/-63 Ma and as 583±5,7 Ma respectively. As for the metamorphic conditions was estimated 730 °C in temperature and 6 kb in pressure (Dora et al., 2001). Eclogitic metamorphism follows the granulitic metamorphism. It is accepted that this metamorphism of which its effects are observed especially in metagabbros, has occurred 529±22 Ma ago (Oberhänsli et al., 2010) under 644 °C in temperature and in 15 kb pressure. Granulite and eclogite facies assemblages show traces of widespread reverse processes because of the overlying Barrowian type medium pressure metamorphism. Migmatites derive from granulites and amphibolites generate from garnet. Amphibolite facies metamorphism has developed under 628 °C in temperature and 7 kb in pressure (Candan et al., 2007). The age of anatectic granites were defined as derived from paragneisses as 551±1,4 Ma (Hetzel et al., 1998) and as 540 Ma (Dannat ve Reischmann, 1998). The outermost circle of the zircons of granulites that was subjected to recycling gives an age about 560.0±5,6 Ma (Koralay et al., 2006). When the 528-570 Ma aged orthogneisses and polyphase metamorphism of the Pan-African basement are taken in to consider together, it is understood that the granitoids intruded synorogenically during Pan-African Orogeny and partly post orogenically.

The basement and cover series of the Menderes Massif were affected from an Alpine aged regional metamorphism so called as the Main Menderes Metamorphism. There are various opinions about the age of this Barrowian type metamorphism which has occurred under conditions of greenschist of lower amphibolite facies. It is stated that the first non metamorphic sedimentary rocks covering the Massif is Upper Eocene (Konak and Çakmakoğlu, 2007). The Rb/Sr white mica giving an approximate age of 56 ±1 Ma which ranges 63-48 Ma agrees with this geological evidence. The 37 Ma Ar/Ar biotite (Satır and Friedrichsen, 1986) and muscovite approximate ages (Hetzel and Reischmann, 1996) are interpreted as the cooling age. Geological and geochronological data show that the age of the Alpine metamorphism in the Menderes Massif is Upper Paleocene to Middle Eocene. The formation conditions of this metamorphism was estimated as 5-8 kb in pressure and 430-550 °C in temperature (5 kb and 530-550 °C: Ashworth and Evirgen, 1984; 8 kb and 530 °C: Okay, 2001; 6 kb and 430-550 °C: Whitney and Bozkurt, 2002). By finding the carpholite-disthene assemblages in Triassic quartz-metaconglomerates in the Menderes Massif, it was understood that there is an Alpine aged HP/LT metamorphism in cover series of the Massif (Rimmelé et al., 2003). However, the location of the Barrowian type

Alpine metamorphism and this HP/LT metamorphism with respect to each other could not clearly be understood.

Many hypotheses were developed about collection of Anatolide-Tauride tectonic units. Generally, this process is associated with the closure of Northern branch of Neotethys and collision of Anatolide-Tauride platform with Sakarya continent in Paleogene. A schematic model is proposed by a group of investigators including the present author as shown below (Figure 9). Starting from Albian, the Anatolide-Tauride platform subducts northward, below the Sakarya continent along the Izmir-Ankara suture zone. In Campanian, because of low geothermal gradient, the upper series and the lower series of the Tavşanlı Zone reaching to 60 km depth, are affected by a greenschist metamorphism under 5-8 kb pressure, 250-300 °C temperature and 20±2 kb pressure, 430 °C tempeture conditions, respectively. The Afyon zone reaching to a subduction-obduction zone between Early Paleocene-Late Paleocene times undergoes HP/LT metamorphism under 6-9 kb pressure and 350 °C in temperature conditions. And the HP/LT metamorphism of the Menderes Massif has become under 10-12 km pressure and 440 °C in temperature, most probably before Main Alpine Metamorphism in Eocene time. According to data above, the HP/LT metamorphism ages of Anatolides become markedly younger from north to south. K/Ar dating that was estimated as 40 Ma from Na-amphiboles of Dilek Nappe belonging to Cycladic complex (Oberhänsli et al., 1997) show that the HP/LT metamorphism of this unit has become in Lower Eocene too. Lycian nappes which caused the regional metamorphism

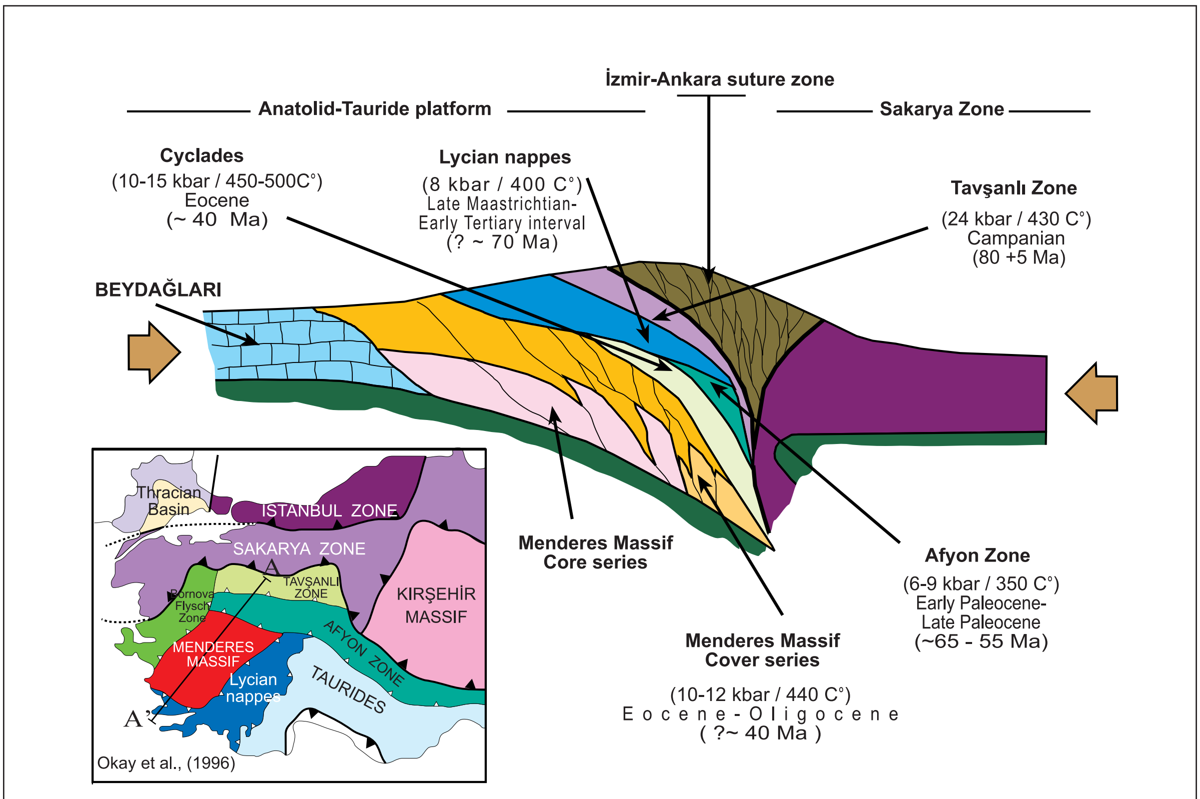

Figure 9- The tectonical environment, age and the condition of the Alpine metamorphism in the Menderes Massif (modified from Rimmelé et al., 2003).

burying the Menderes Massif into deep levels during its passage from North to South has passed its own HP/LT metamorphism (probably in Late Maastrichtian- Eocene times) under of 8 kb pressure and 400 °C temperature conditions.

In West Anatolia, at the beginning of Early Oligocene, various hypotheses were produced about the transformation of the compressional tectonics into the extensional tectonics. These probabilities put forwed mainly by Seyitoğlu and Scott, (1996) are given below:

1) The collapse of the thickened crust as a result of continental collision under gravity (orogenic collapse model); 2) Lithospherical slab break off or break away; 3) Dilatational environment developed as a result of the migration of Hellenic subduction zone to the south (regression and back arc rifting model); 4) The dilatation formed by the movement of Anatolian microcontinent eastward along East and North Anatolian faults as a result of the compressional stage following the continental collision in East Anatolia (tectonic escape model); 5) the combination of some mechanisms mentioned above. There is a common agreement about the beginning of transformation of compressive regime in West Anatolia into extensional regime in NS direction (Bozkurt and Satır, 2000; Gessner et al., 2001*a*; Işık et al., 2003; Ring et al., 2003; Seyitoğlu et al., 2004; Thomson and Ring, 2006).

Many kinematical studies have been made to explain the dilatation and related exhumation of the Menderes Massif along the gently sloping normal faults in West Anatolia in the recent years. All researchers agree that, the kinematic data in the massif define the presence of two movements to the north (old) and to the south (young). However, there are great differences in the idea of meaning of these movements. According to Hetzel et al., (1998), Gessner ve et al., (1998), Bozkurt and Park (1999), Bozkurt and Satır (2000), Rimmelé et al., (2003), the northward movement is the production of the compressional tectonics which is contem poraneous with the Main Menderes Massif metamorphism happened in Eocene time. This deformation has been developed by the back thrust of Lycian Nappes which caused to the internal imbrications of the massif . Ring et al., (1999) and Gessner et al. (2001*a*); interprete that northward movements are pre Alpine which is associated with the internal imbrications of the Pan-African basement of the massif in Precambrian. On the other hand, the same northward movement is interpreted as the structures that belong to dominant deformation observed in the massif and defines the extensional tectonism related with the exhumation of the massif by Seyitoğlu et al., (2004). Similarly, there are great differences in interpretations regarding the northward movements. According to Bozkurt and Park (1994, 1997, 1999), these movements are the production of Oligocene-Early Miocene aged extensional tectonism and are closely related with the exhumation of the massif. As a contradiction to this opinion, Ring et al., (1999), and Gessner et al., (2001*a,b*) interpret the southward movements as the production of a compressional tectonism and make a connection with the internal southward imbrications of the Massif in this stage and the passage of Lycian nappes to south. Seyitoğlu et al., (2004), explain that southward movements are secondary structures related with doming.

Many studies have been made showing that the Massif is a core complex and Oligocene-Miocene aged exhumation has occurred along the normal faults (slip faults) with low angle. At present, there are many different opinions about the location of these slip faults and about the effects of the exhumation of the massif. In preliminary studies, Emre and Sözbilir (1995), suggested that the normal fault with low angle extending between Kemalpaşa - Alaşehir played an important role on this exhumation and the beginning age of extensional tectonism that caused the exhumation of the massif is 19 Ma (Early Miocene) based on syntectonic granitic intrusions Hetzel et al., (1995*a*). Based on the kinematic data obtained from Bozdağ region, it was interpreted as this side of the massif is a symmetrical core complex by Hetzel et al., (1995*b*). In the following years, the presence of a similar type fault has been detected on the southern part of the Aydın Mountains associating with its northern conjugate and suggested that Ödemiş-Kiraz submassif represents a typical symmetrical core complex (Bozkurt, 2001). However, in recent studies, the aforesaid two slip faults developed in the second period are young structures and are associated with the late period exhumation of Ödemiş-Kiraz submassif (Seyitoğlu et al., 2004; Ring and Collins, 2005).

Bozkurt and Park (1994, 1997), Bozkurt and Satır (2000) explained that the gneiss-schist contact extending between Bafa-Yatağan is a tensile shear zone that has played an important role especially on the exhumation of southern part of the Menderes Massif. According to the investigators, Tertiary granites have transformed into gneisses along this shear zone and have exhumed from an approximate depth of 15 km with a continuous period. Hetzel ve Reisschman (1996) suggest that this zone is a shear zone that has been active in Eocene but, this does not have an effective role on the exhumation of the massif. They claim that the exhumation has occurred with passive erosion. On the other hand, Ring et al., (1999) and Regnier et al., (2003) suggest that tectonic zone has no relation with the extension but is a product of compressional tectonism and have the character of a south vergent thrust fault. Bozkurt (2004) revisioned the tectonic model related with the exhumation of this zone and the southern part of the massif. He also stated that, massif was transported to shallow depths along the crustal scaled zone, and the last exhumation occurred by young graben faults. Bozkurt et al., in (2006), again claimed that, this zone is originally a northward thrust and reworked as southward shear zone as dilatational production in the following period.

In recent years, in some tectonic models, it has been suggested that detachement fault in north of Simav had played an important role on the exhumation of the Menderes Massif (Işık and Tekeli, (2001); Işık et al., (2003), 2004; Seyitoğlu et al., (2004); Ring et al., (2003); Ring and Collins, (2005); Thompson and Ring, (2006). Eğriboz and Koyunoba granites have an approximate age of 20-23 Ma and located on the footwall synchronously with the extensional tectonism and undergone ductile deformation along detachement fault. According to Seyitoğlu et al., (2004) Simav slip fault is genetically related with Datça-Kale detachment fault in south and these two faults have accomplished the main exhumation process in two phased exhumation model of the Menderes Massif. Ring et al., (2003), Ring and Collins (2005), Thompson and Ring (2006), claim that, apart from the model briefly mentioned above the old thrust zone between the Menderes Massif and Lycian Nappes in the south worked as a detachement fault during exhumation. The authors also state that while the massif exhumed along this line at the south, exhumed along the Simav slip fault at the north. The reason of the extension in the region is proposed as post collisional magmatism in the area and thermal weakening of the crust caused by the magmatism. As a result of this, the plane of old thrust faults among the main units reactivated as detachement faults. The Simav detachement fault following the thrust plane between the Cycladic units and the Menderes Massif has been active between the ages of 19-25 Ma in a fault character dipping at low angle. Koyunoba and Eğrigöz syntectonic granites were intruded into formerly activated fault plane. The entrance of the granite caused doming and locked and stopped the movement of the detachement fault. The rocks aged 16.4 Ma unconformably deposited on the exposed footwall. The formation of symmetrical core complex core bounded by the Big Menderes detachement faults at the south and Alaşehir at the north in the central Massif, has continued until Middle to Late Miocene (Hetzel et al., 1995*a*; Gessner et al., 2001*a*; Lips et al., 2001).

The normal faults developed in Pliocene and formed the young grabens in the western Anatolia cut all the detachement faults.

RESULTS AND RECOMMENDATIONS

Within the framework of data obtained during the last 40 years, there is a need for the development of the subjects described below for the geology of Menderes Massif and a detailed investigation on the problems of which have not clearly been solved yet,

a. The genetical relation of the polymetamorphic and magmatic evolution of the Pan African basement of the Massif with the integration of Gondwanaland in Late Proterozoic has not clearly been established. It has a great importance for the facies of primary sediments, the age and geochemistry of magmatics, and coeval tectonic period and metamorphism.

b. The relation of acidic magmatics defined with gneiss and metagranites in various compositions in the Pan-African basement of the Menderes Massif with the poly phase Pan-African basement is one of the problems to be investigated in regional scale and should be solved with respect to age and magmatic differentiation.

c. The primary unconformable contact relationship between the base and cover series has been established only in Upper Mesken Village to the southeast of Yatağan. The determination of the primary relationship which should be in regional scale will give rise to the complete solution of one of the main problems. It will also help get a good starting point regarding the evolution of the massif.

d. The evidences about the character of the Palaeozoic and Mesozoic contact in the massif are still in question. Although the bottom of Mesozoic deposit is composed of metaconglomerates in metaclastics and channel fillings character, the unconformable character of the contact could not clearly be established in regional scale. It is necessary to spread out this observation to whole massif and points where certain relations could be observed should be determined.

e. The association of the Early Triassic magmatism in the massif with the oldest magmatism in other tectonic units of West Anatolia and the definition of the meaning of tectonic environment in regional scale will illuminate the geological evolution of Mesozoic time.

f. High pressure mineral assemblages in the Mesozoic series of the Massif require a different interpretation for the Alpine metamorphism in the Menderes Massif rather than it was accepted so far. Besides, to reveal the relationship of the tectonic environment among the Alpine HP/LT metamorphisms of Cycladic Complex and massif and time is another question to be answered.

g. Nappes belonging to Cycladic Complex are located on the western and northwestern sides of the Menderes Massif. The study of the tectonical relationship and metamorphic stage of the massif with Cyclades in regional scale and an establishment of a common stratigraphic, metamorphic and tectonical history will add a great value to the solution of the problems related with the illumination of crustal evolution in Western Anatolia and to the closure of the northern branch of Neotethys.

h. To discuss different tectonical models suggested for the exhumation of the massif and to make these in detail, is another important point which will conclude to develop a common model will be able to answer to all geological questions and considered by all the investigators.

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