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SEDIMENTOLOGICAL- STRATIGRAPHICAL EVALUATION OF TERTIARY CARBONATES (SOĞUCAK FORMATION) OF THRACE BASIN (BOZCAADA - KIYIKÖY)

Baki VAROL*, Meltem BAYKAL** and Turhan AYYILDIZ*

ABSTRACT.- Soğucak formation which crops out in Thrace Basin has characteristics of reefal limestones and is one of the target levels in oil exploration studies in the basin. While this unit directly and unconformably overlies the basement rocks in some areas, it is transitive to siliciclastic-dominated units (Koyunbaba formation) in other areas. The Soğucak formation is comprised of carbonates of reefal-shore complex which was deposited in a shelf environment as a consequence of a transgression which lasted between Early-Middle Eocene and Early Oligocene. The rocks of the lower limit of the age interval of the formation, the Lower Eocene, crops out in Bozcaada only and is transitive to Fıçıtepe formation. In general, the unit was deposited in SE of the basin between Middle-Late Eocene, and between Late Eocene and Early Oligocene in NE of the basin. Sedimentological features and age data indicate that Soğucak formation was deposited under the control of antecedent topography and it is the product of a time-transitive transgression together with coastal morphology and sea level changes.

Key words: Thrace Basin, Soğucak formation, sedimentology, stratigraphy

INTRODUCTION

Because of its rich coal, natural gas and quartz sand resources, the Thrace Basin has been studied in detail by various oil companies, MTA and University researchers for long years. The Tertiary units of Thrace are in general comprised of clastics and include carbonates in shelf areas (Figure 1). TPAO conducts detailed surface and subsurface (seismics, well log and test-development wells) studies because of the natural gas explored in the region. Among the researches conducted in the area, mainly Kopp et al., (1969) and Turgut et al., (1983, 1991) can be cited. The most significant documents for the stratigraphic definiton of the Thrace basin are the 1:100 000 scale geological maps published by the MTA (İmik, 1998; Çağlayan and Yurtseveri 1998; Şentürk and Karaköse, 1998). The Tertiary sequence which begins to cropping out at the southern foothills of the Strandja Mountains and covers almost the whole Thrace basin, reaches up to a thickness of 900 m (Kopp et al., 1969; Turgut et al., 1983, 1991; Görür and Okay, 1996; Turgut and Eseller, 2000; Siyako, 2006). The Eocene-Oligocene units are covered by Miocene and younger units in the Central and Northern Thrace. İslamoğlu et al., (2008) revealed the Oligocene paleogeography of the northern part of the Thrace basin.

Detailed description and various age data of the Soğucak and Ceylan formations of the Thrace Basin was studied by Siyako (2006). Researches conducted until today indicate that Soğucak formation is comprised of carbonates deposited in shelf environment. Besides, it was deposited in patchy reefal facies around Pınarhisar while the subsurface data show that it has characteristic features of pelagic clayey limestone (Siyako, 2006). Although different ages were attributed to the formation in different researches conducted in the basin, the generally accepted age for the Soğucak formation is the Middle Eocene – Early Oligocene (Siyako, 2006).

During this research, facies characteristics and age of the formation, based on fosil content, were studied in detail. According to the data acquired, the age of the carbonates of the Soğucak formation was revised; consequently the position and the place of the formation in the basin chronostratigraphy were reevaluated.

MATERIAL AND METHOD

Carbonates from the Soğucak formation are the materials used in this research. The samples from carbonates were collected along 15 measured stratigraphic sections where the Soğu-

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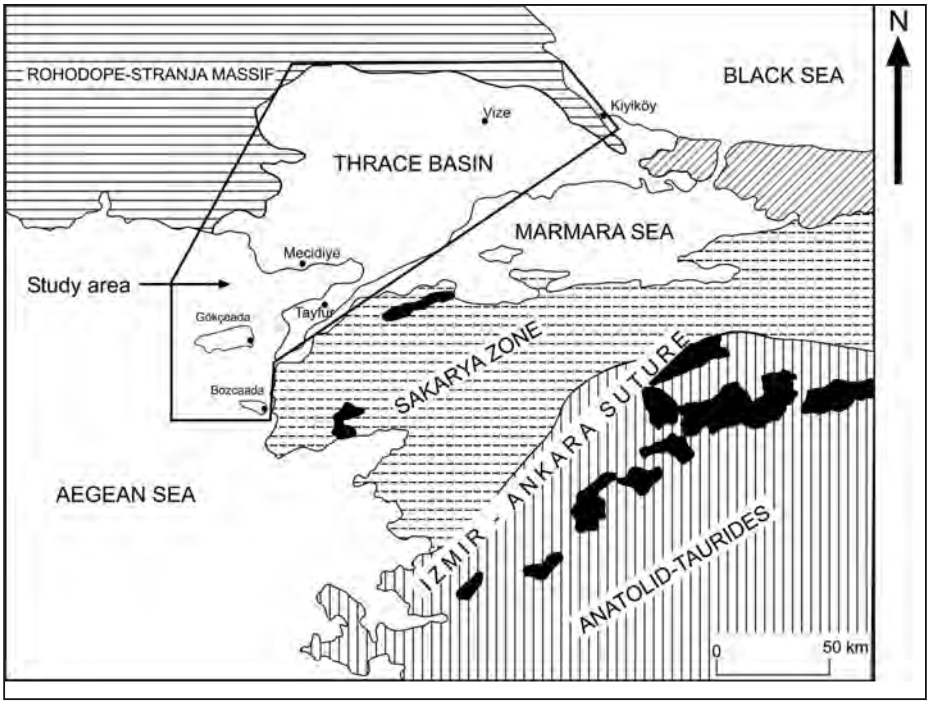

Figure 1- Location map of the study area (modified from Okay and Tansel, 1992).

cak formation is observed typically. These are Gökçeada, Bozcaada, Mecidiye, Süloğlu, Dolhan, Tekedere, Erenler, Soğucak, Poyralı, Okçular, Akören-Pınarhisar, Manastırdere, north of Vize, Kıyıköy1, Kıyıköy 1a, Kıyıköy 2 and Kıyıköy 2a sections. Besides where no good outcrops were observed, point samples were collected. From these limestone samples collected along the sections and the points, 350 thin sections were prepared in TPAO Research Center. Petrographic and paleontological study of the thin sections were conducted both in Petrography Laboratory of the Ankara University Department of Geological Engineering and Department of Geological Research of MTA. Leica DMEP Polarising microscobe and Nikon E5400 Coolpix (5.1 MG pixel) were used to study and to take photographs of the thin sections, respectively.

STRATIGRAPHY

Stratigraphy of the Thrace Basin was studied in detail during many researches until today (Keskin, 1974; Siyako, 2006; Siyako and Huvaz, 2007). Previous studies, in general, indicate that Middle Eocene-Early Miocene units unconformably overlie the Paleozoic-Mesozoic basement in the northern parts of the basin (Esso Standart, 1960; Holmes, 1961; Keskin, 1974; Kasar et al., 1983). The clastic sequence overlying the basement rocks were defined as the Koyunbaba Member in these studies, and the age attributed to this member is Middle Eocene (Siyako et al., 1989). Later on Keskin (1974) defined this member as Koyunbaba formation. Soğucak formation which overlies the Koyunbaba formation is of Middle-Late Eocene age in southern Thrace, namely in the Gelibolu peninsula, Bozcaada, Gökçeada and Biga peninsula (Kasar et al., 1983; Sümengen et al., 1987; Temel and Çiftçi, 2002; Siyako et al., 1989). The age of the outcrops of the formation, at the foothills of the Strandja Mountains and in the northern Thrace, was in general determined as Late Eocene (Erenler, 1985; Batı et al., 1993). Besides, Önal (1985, 2002) differentiated the Early Eocene carbonates below the Karaağaç formation in the Gelibolu Peninsula as Başoğlu member. On contrary, in Kuleli-Babaeski paleo-rise area located in the northwest of Thrace, the age of this formation was determined as Early Oligocene based on the well data (Keskin, 1974; Siyako, 2006). Ceylan formation which is observed to overlie these units is assumed to be conformable in general on the Soğucak formation. However, in the south, in Bozcaada, the Soğucak and Ceylan formations (Kesgin and Varol, 2003) and in the north, around Karaburun, Soğucak and Karaburun formations (Early Oligocene) were observed to have unconformable relations (Sakınç, 1994). On these rocks, Late Eocene-Early Miocene Mezardere, Osmancık, Danişmen (Taşlısekban, Pınarhisar and Armutburnu members) and Çantaköy formations of Yenimuhacir Group take place. These units also are covered by Pliocene unconformably.

Soğucak formation which is the subject of this research is quite widespread in the northern parts of the Thrace Basin, and in general, the age of the unit is accepted as Middle-Late Eocene as cited above. Besides, the upper section of the Soğucak formation in the north of the basin (around Dolhan village) was dated as Oligocene (Sirel and Gündüz, 1976).

In this study, based on descriptions made along the measured stratigraphic sections which are given below in detail, the age of the Soğucak formation is determined to be as Early (?)-Late Eocene – Early Oligocene.

MEASURED STRATIGRAPHIC SECTIONS

The limestones of the Soğucak formation crop out as blocks (their size varying between a few m and a 100 m) along approximately east-west lying lines in the north of the basin. The measured stratigraphic sections (MSS) are located in the north of the basin, beginning in the west from Süloğlu village to Dolhan, Tekederesi, Kaynarca, Pınarhisar, Erenler, Soğucak, Vize, Okçular and around Kıyıköy in the easternmost. In the south, stratigraphic sections were measured on the outcrops in Bozcaada, Gökçeada; Tayfur and Mecidiyeköy. The rock samples and fossils collected along these sections were used to evaluate the age data of the formation (Figures 2, 3, 4 and 5).

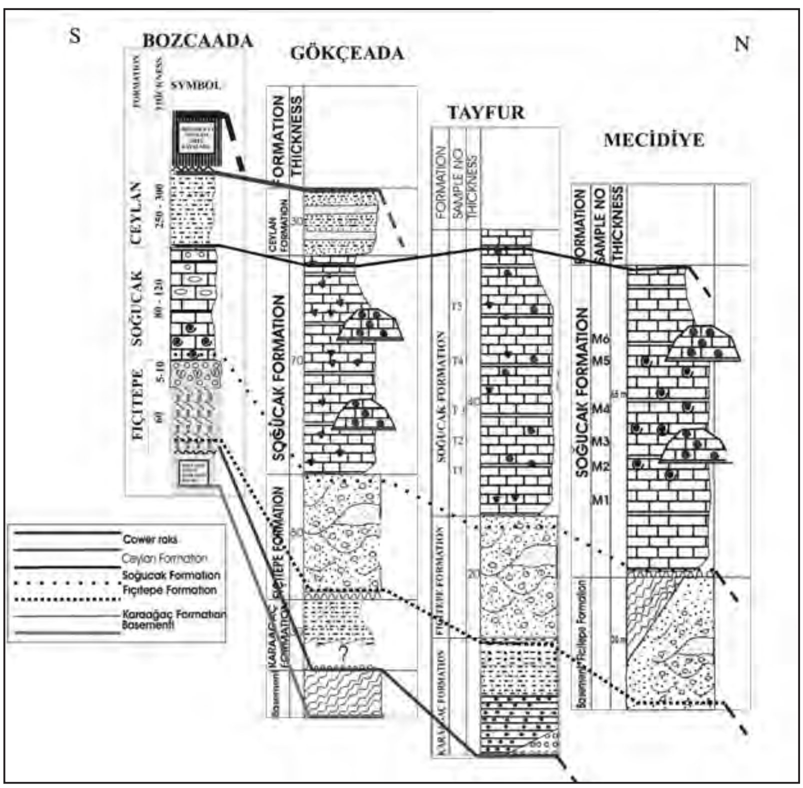

Figure 2- Correlation of the formations of the measured stratigraphic sections in south of the Thrace Basin.

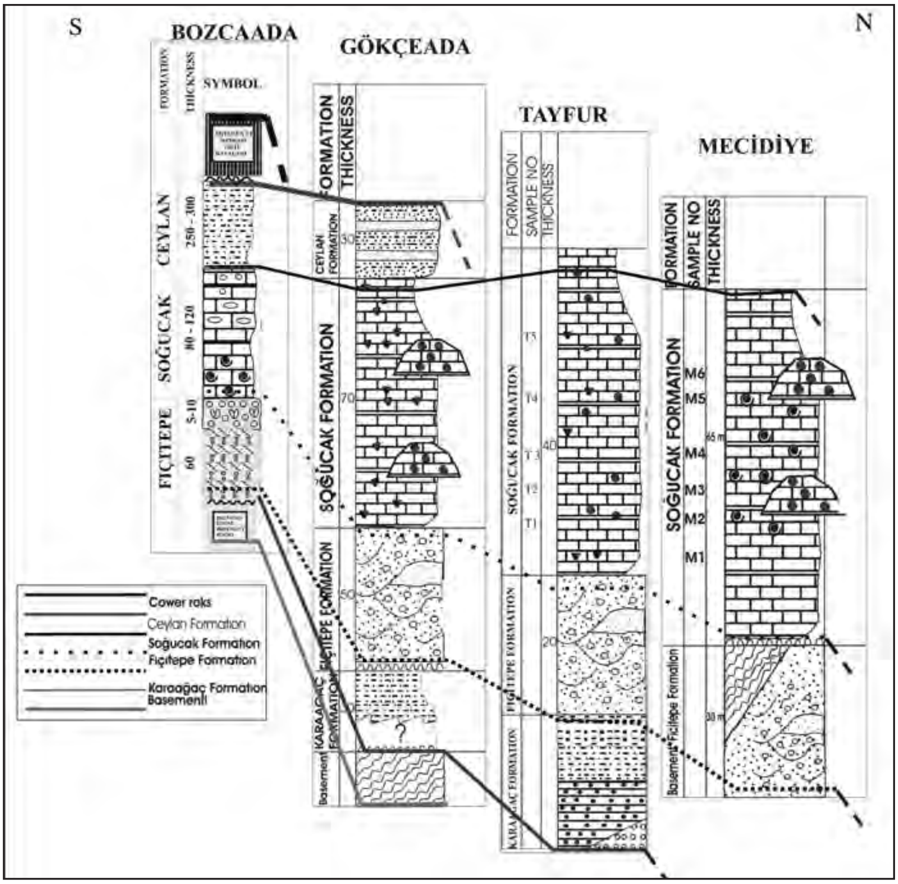

Figure 3- Chroronostratigraphic correlation of the measured stratigraphic sections in south of the Thrace Basin.

Southern Sector of the Thrace Basin(Bozcaada, Gökçeada, Mecidiye, Tayfur)

The previous studies in the Bozcaada point out that Soğucak formation unconformably overlies the terrestrial Fıçıtepe formation and the age of the of the formation is Middle Eocene (Temel and Çiftçi, 2002; Kesgin and Varol, 2003). During this study, in pebblestone units of the Fıçıtepe Formation small scale individual reef developments were observed; this levels were observed to transite to Soğucak formation by sandstones, algae spreads and limestones with ostrea (Figure 6). Paleontological data acquired from this transitive levels indicate Early Eocene (Varol et al., 2007). However, the relation of these two units are reported to be unconformable in Mecidiye and Tayfur regions (Siyako, 2006). Besides, Önal (1985) differentiated the levels as Başoğlu Member which could assumed to be equivalents of the Early Eocene limestones. In this situation, it was found necessary to study the this unit which crops out in the Bozcaada in detail.

In Gökçeada-Kolbaşı hill the Soğucak formation is represented by typical patchy reefs and the surrounding reefs. As seen in paleontological evaluations in table 1, Late Eocene-Early oligocene age is attributed and its upper contact is transitive to the Ceylan formation (Figure 2).

Another section was measured around Mecidiye in the south of the basin. Here, Soğucak formation begins with algae oncoid bearing banks and passes into coral reefs upwards. The

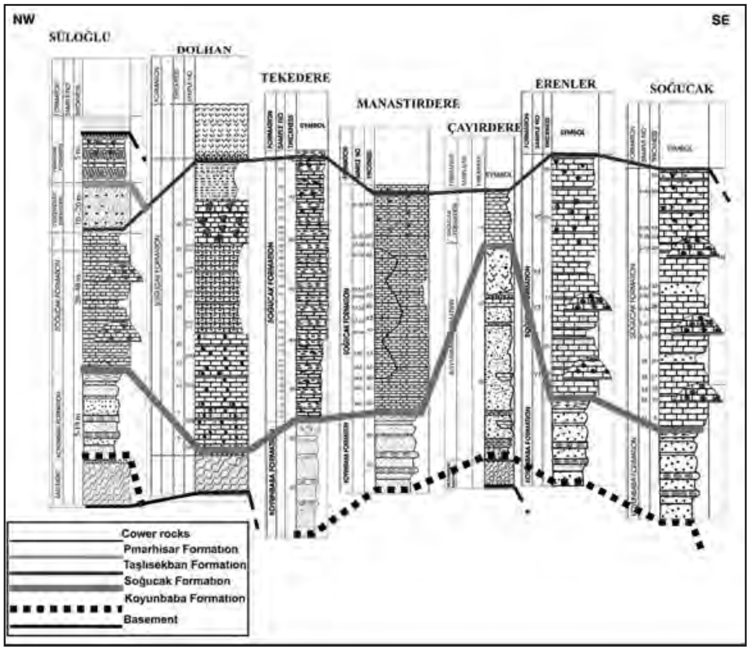

Figure 4a- Formations correlation of the measured stratigraphic sections within the northern part of the Thrace Basin

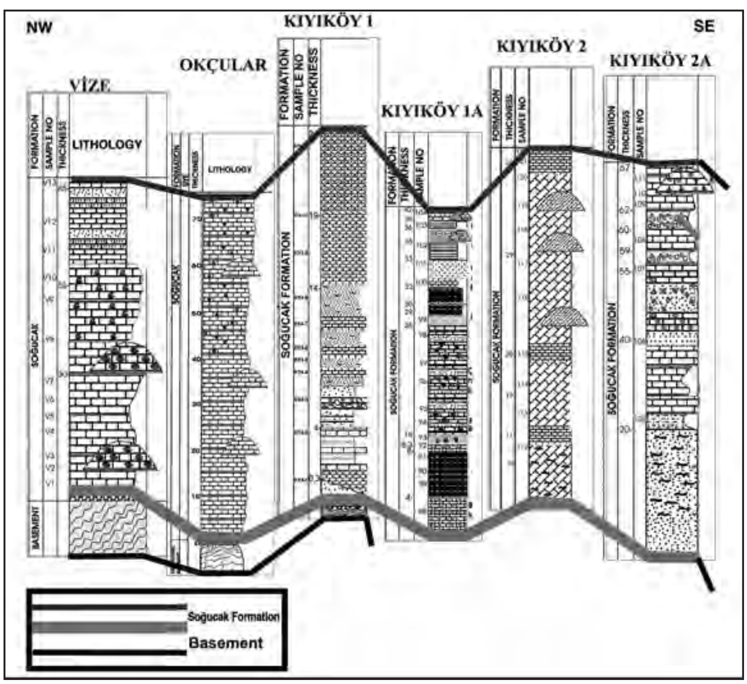

Figure 4b- Correlation graphic of the meassured stratigraphic sections belonging to the Soğucak formation within the northern part of the Thrace Basin facies surroundings of the reef is represented by bioclastic limestones. Here, Soğucak limestone unconformably overlies the basement rocks in the Fıçıtepe formation in some places (Siyako and Huvaz, 2007).

The last section representing the Gelibolu Peninsula was measured in the north of the Tayfur village. The approximately 10-15 m thick limestones are comprised of lenticular Nummulites banks and the age of the unit is Late Middle-late Eocene (Figure 3). At the basement, it has unconformable relation with the Fıçıtepe formation.

Northern Sectodr of the Thrace Basin
(between Süloğlu – Kıyıköy)

During the study conducted in Thrace Basin, the places where the Soğucak formation is directly time-transgressive onto the basement are Süloğlu, Dolhan, Vize and Okçular sections. On contrary, in Tekedere, Manastırdere, Erenler, Soğucak and Poyralı sections it is transitive to Koyunbaba formation at the basement. The age determined in these sections is Late Eocene-Early Oligocene (Table 1) (Figure 5).

Along the Süloğlu section, Soğucak formation is unconformable on the matamorphic basement, along some other sections it is transitive to a very thin (3-4 m, comprised of quartz sandstones) Koyunbaba formation. The lower levels are transitive to *Nummulites* banks from backreef environment; at the top this carbonate assemblage passes to coastal sandstones with 10-20 m thin mudstone bands. This unit was defined and mapped as Taşlısekban member in previous studies (Siyako and Kasar, 1985). Later on, the sequence ends up with a few metres thick *Congeria*-bearing limestone levels (Figure 7). These limestones crop out at some distinct regions of the Thrace Basin (Kaynarca – Erenler) and are differentiated as Pınarhisar formation (Keskin, 1966; Umut et al., 1983; Umut et al., 1984). Along Dolhan section carbonates of the Soğucak formation directly and unconformably rest on the basement. The lower levels of the sequence begin with bank type limestones bearing abundant *Nummulites* and continues with mudstone dominated, cross bedded sandstone which deposited in lagoon-beach environment. It ends up with gastropoda bearing limestones which represent brackish water at the top. The samples collected here which include abundant *Nummulites* yield Late Eocene-Early Oligocene age which harmonize with the dating in Sirel and Gündüz (1976) (Figure 4, 5).

The Tekederesi section begins with the clastics which unconformably rest on the basement. The sandy limestones of the Soğucak formation with abundant bioturbation and ostrea are transitive to the clastic levels of the Koyunbaba formation (Figure 8). The levels, in general represent the lagoonal enviroment, are followed by *Nummulites* banks. In this period, based on the fast sea level changes, back-bank and fore-bank facies were developed very well. This bank-type deposition passes upwards into patchy reefs where the coral assemblages are dominant. In this section, the age of the *Nummulites* banks which form the lower-middle parts was given as Middle Eocene in previous studies (Baykal et al., 2007), however, according to latest paleontological data, age of this reefal assemblage is revised as Late Eocene-Early Oligocene (Figure 4). This indicates a relative sea level increase in this area by the end of the Eocene and beginning of Early Oligocene (Figures 4, 5).

Along the Manastırdere section, Soğucak formation rests on the Koyunbaba formation transitively. The first levels of the section is comprised of reef-backreef (lagoon) assemblages. The reef assemblage that developed in later stages around Kaynarca village form the massive reefal core of 50-60 m thick where the corals are dominant. In the SW direction thin bedded forereef facies with pelagic intercalations take place. This reefal assemblage ends up with limestones bearing *Congeria* near the junction of Kaynarca-Manastır road (Figure 9).

The section measured in Soğucak village which is reported as the typical section of the Soğucak formation in the Thrace Basin (Holmes, 1961) massive limestone deposition developed

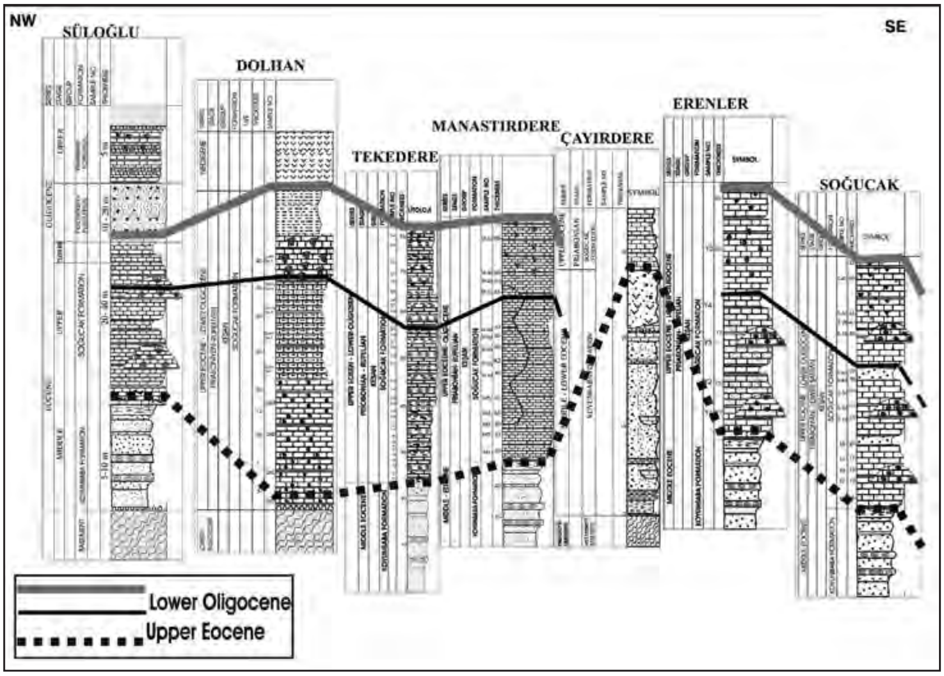

Figure 5a-Chronostratigraphic correlation graphic of the measured stratigraphic sections within the northern part of the Thrace Basin

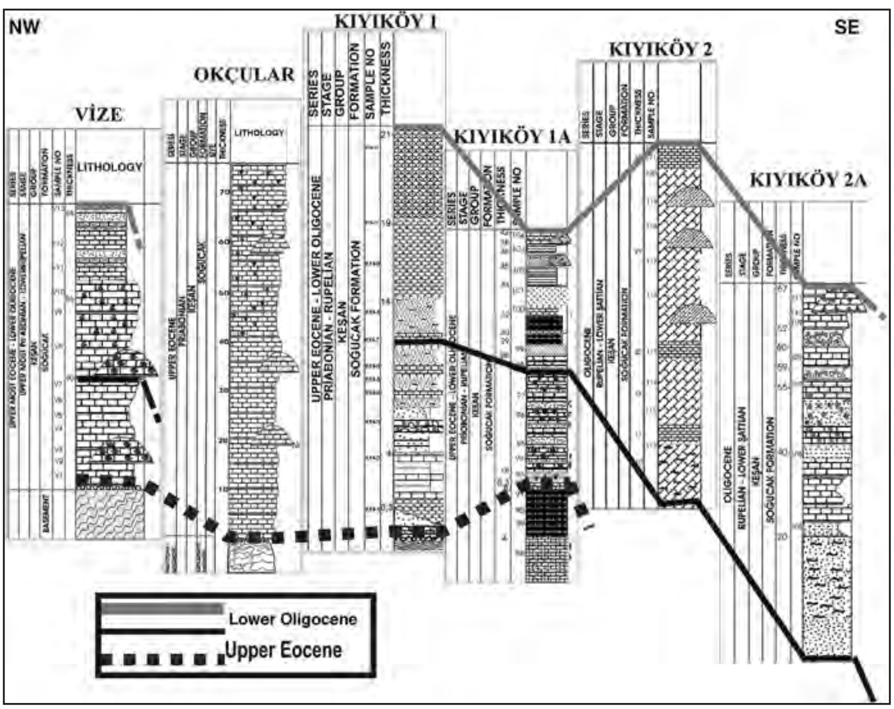

Figure 5b- Chronostratigraphic correlation graphic of the measured stratigraphic sections belonging to the Soğucak formation within the northern part of the Thrace Basin

Table 1- The age intervals of the Soğucak formation determined in measured stratigraphic sections in the investigated region.

MEASURED SECTION LOCATION	FOSSIL CONTENT	AGE INTERVAL IN THIS STUDY
BOZCAADA	*Bryozoa, Alveolina* sp. *Nummulites* sp. *Milliolidae, Cuvvilerina* sp., *Discocyclina* sp., *Assilina* sp., *Opertorbitolites douvivillei, Alveolina* aff.*cemali* (n.s.p).	EARLY EOCENE
GÖKÇEADA	*Spharegypsina, Gypsina, Famiania cassis/ Gyroidinella* sp. Rotalidae., *Asterocyclina* sp., *Discocyclina* sp. Globigerapsis sp. *Alveolina* sp., *Asterigerina* sp., *Nummulites perfatus, Nummulites ptukhiani., Nummulites* cf *incrassatus, Assilina* sp.,	MOST EOCENE - OLIGOCENE
MECİDİYE	*Fabiania, Spiroclypeus* sp., *Discocyclina* sp., *Nummulites* sp., *Gyroidinella magna*	LATE EOCENE
TAYFUR	*Gyroidinella maga.,Fabiania cassis,Heterostegina* sp., *Halksyardia minima., Discocyclina* sp., *Nummulites* sp., *Alveolina* sp., *Orbitolites* sp. , *Acervulina* sp.,	LATE MIDDLE - LATA EOCENE
SÜLOĞLU	*Congeria* sp., Gastropoda, Coral, Red alg Bryozoa, *Nummulites* sp.,	LATE EOCENE - EARLY OLIGOCENE
DOLHAN	*Nummulites intermedius, Nummulites ficteli, Nummulites vascus, Asterigerina* sp., *Operculina* sp., *Rotalia* sp., *Nummulites fabianii., Fabiania cassis.,*	LATE EOCENE - EARLY OLIGOCENE
TEKEDERE	*Fabiania cassis, Gyroidinella cf-magna., Acervulina.* sp, Miliolidae., *Spiroclypeus* sp., *Nummulites* cf., *vascus Planispira* sp., *Textularia* sp., Bryozoa, Kırmızı alg	LATE EOCENE - EARLY OLIGOCENE
MANASTIRDERE	*Red algea, Nummulites* sp., Miliolidae, Pelecypoda *Asterigarina* cf *rotula* Textularidae, *Nummulites vascus Rotalia* cf *armata* Ostrokoda, Pelecypoda	LATE EOCENE - EARLY OLIGOCENE
ERENLER	*Nummulites* sp., *Nummulites* cf. *yascus Nummulites* cf., *fichteli,* Red algea, Bryozoa *Nummulites* sp.	LATE EOCENE - EARLY OLIGOCENE
SOĞUCAK	Red algea, Ekinit, *Nummulites* sp., Miliolidae, Pelecypoda, Mercan Amhisteginid, Rotalidae., *Sphaerogypsina* sp., *Nummulites* cf. *vascus, Nummulites* sp.,	LATE EOCENE - EARLY OLIGOCENE
VİZE	*Gyroidinella magna, Acervulina.,* Miliolidae, *Orbitolites* sp, *Asterigerina* sp., *Rotalia* sp., *Nummulites* cf., *vascus Gyroidinella* sp., *Asterigerina rotula, Spiroclypeus Chapmanina gassinensis, Alveolinidae, Fabiania* sp.,	LATE MOST EOCENE - EARLY OLIGOCENE
OKÇULAR	*Nummulites* cf, *fabiani, Asterigerina* sp. *Discocyelina* sp. *Orbitolites* sp., *Heterostegina* sp., Rotalidae, Miiolidae, Ostracoda, *Nummulites* sp.,	LATE EOCENE
BALKAYA	Red algea, *Nummulites* sp., Amphisteginid, Miliolidae,	LATE EOCENE
KIYIKÖY 1	Red algea, *Nummulites* sp., Coral., Bryzoa, Pelecypoda, *Nummulites* cf. *Vascus Cytheridae* cf. *pernota, Costa tricostata Paijenborchella* sp.,	LATE EOCENE - EARLY OLIGOCENE
KIYIKÖY 2	*Nummulites* sp., *vascus Operculina?* sp. *Operculia* cf. *Complanata* Amphisteginid, *Krithe* cf., *bartonensis, Cytheretta tenuistriata Costa tricostata, Ruggieria* sp., Cytheridae	OLIGOCENE
KIYIKÖY 3	*Neorotalia lithothamnica, Nummulites fichteli, Nummulites vascus,Nummulites* sp., Ekinit, Pelecypoda., Red algea	OLIGOCENE
KIYIKÖY 4	*Neorotalia lithothamnica, Nummulites* cf. *vascus Oeprculina?* sp. *Operculia* cf. *complanata,* Amphisteginid *Krithe* cf. *bartonensis, Cytheretta tenuistriata, Cytheridae Cytheretta tenuipunctata, Costa tricostata, Ruggieria* sp.	LATE EOCENE - EARLY OLIGOCENE

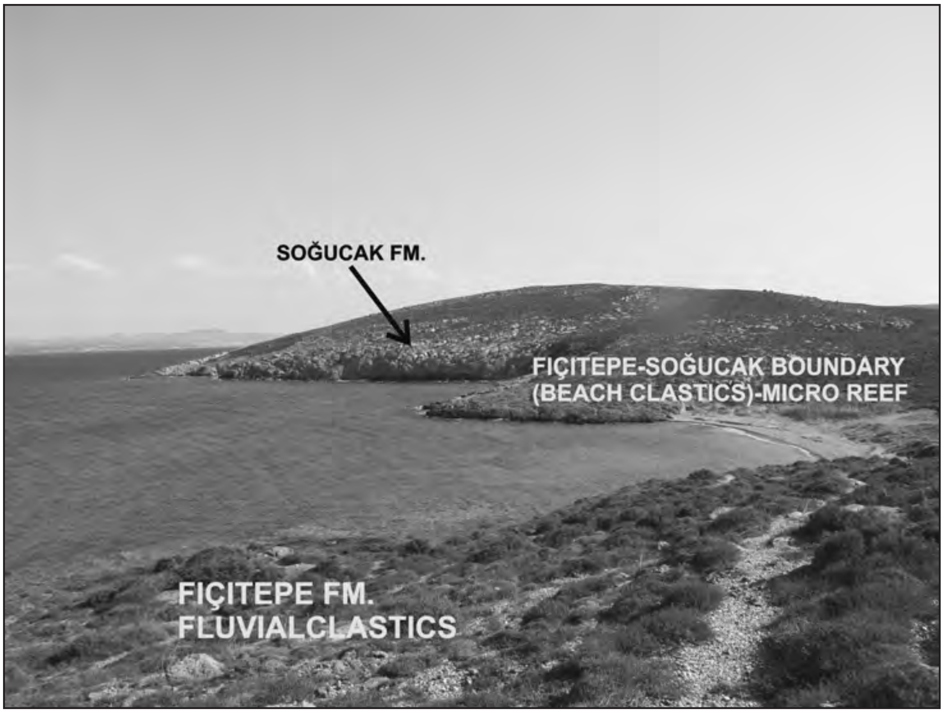

Figure 6- Transition of Fıçıtepe – Soğucak formations in south of Bozcaada – Poyraz port.

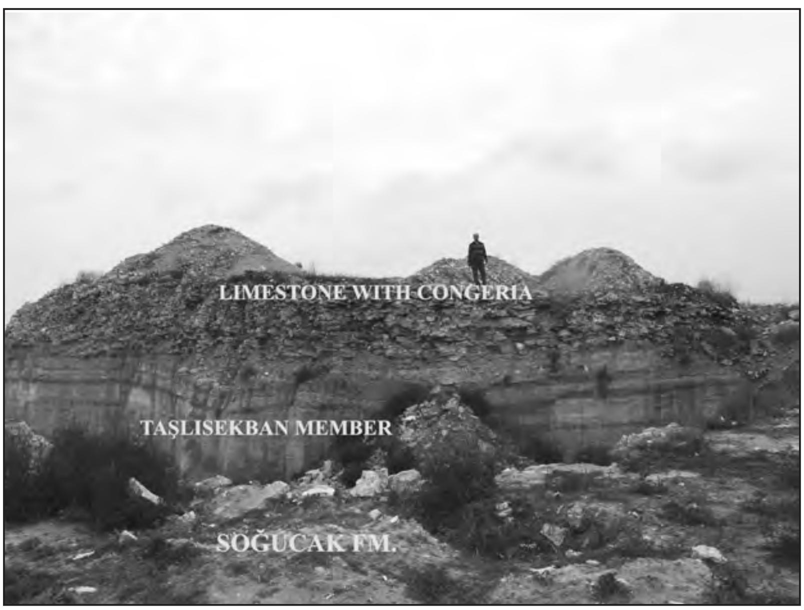

Figure 7- Transition of Soğucak formation – Taşlısekban Member in (north of) Süloğlu.

in form of bank-reef complex is observed. Around this assemblage, back-reef and fore-reef facies spread out in wide areas. In this area, onlaps and offlap sets which indicate fast sea level changes overlie each other angularly. Dating from the samples collected from the entire sequence indicate Late Eocene-Early Oligocene (Table 1). Along the Erenler section which is located at the southeastern extension of this section, this reefal assemblage is covered by 5-7 m thick cross bedded ooliitic limestones. The transgressive layering observed in oolites which represent the carbonate shoal indicate the changes in the coast line based on the sea level changes. The Congeria sp. bearing limestones which form the uppermost level of the section represent a brackish water facies that developed in the platform where the Soğucak formation was deposited; its stratigraphical position is interpreted as the upper section of the formation.

Paleontological determinations indicate that age of the unit is Late Eocene-Early Oligocene (Figure 5, Table 1).

In the north of Vize, the Soğucak formation unconformably overlies the basement rocks. In this section which displays examples of a a typical bank formation, the E-W trending massive bank and the surrounding facies represented by thin to medium limestones are observed (Figure 8). The back-bank facies deposited during the regressional periods are in general thin bedded and include carbonaceous mudstone intercalations and abundant bioturbations (Figure 10). The age interval of the formation, different from the previous studies (Baykal et al., 2007: Middle Eo-

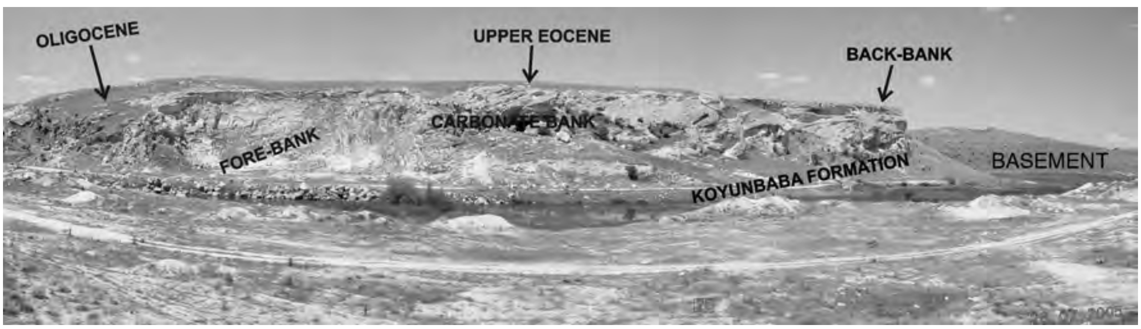

Figure 8- The facies and stratigraphic relation of the Soğucak formation with the other units in the Tekederesi section.

Figure 9- Transition from reefal Soğucak limestone to *Congeria* bearing limestone in the Manastır section (north of the Kaynarca village).

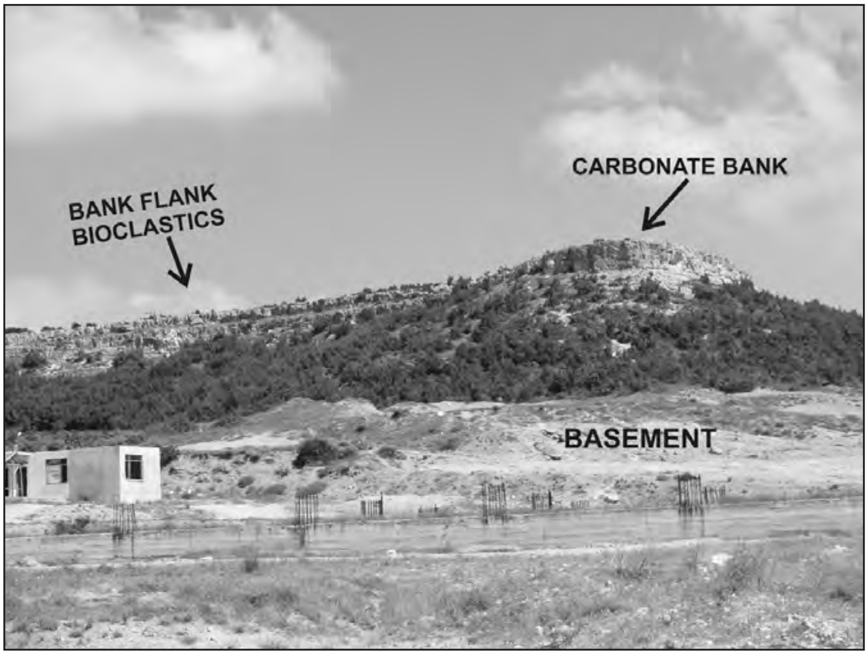

Figure 10- Facies assamblages of the Soğucak formation in the north of the Vize

cene) but conformable with the other sections, was determined as Late Eocene – Early Oligocene (Figures 4, 5) (Table 1).

The Soğucak formation which can be observed in the easternmost part of the study area crops out around the Kıyıköy and was investigated by sections measured on both flanks of an anticline observed on the coast. The sequence unconformably rests on the basement rocks and there is a thin siliciclastic-dominant level at the base of the formation. In the overlying coast sandstones (5-10 m thick) with bioturbation, mudstones including mud intraclasts and flame structures representing tide conditions take place. This level passes upwards into cross bedded clastic limestones (Figure 4). This clastic section is 10-15 m thick and includes a few meter thick individual coral reefs. The sequence ends up with levels bearing *Ostrea* and gastropoda deposited along a retreading coast line. This way, the levels including mudstone intercalations pass into the Ceylan formation through a tuffaceous level (Figure 11).

Section (2, 2a) represents the southern flank of the syncline. Sandy limestone with bioturbation is located at the base similarly (10 - 15 m). This level passes upwards massive bioclastic sand and sandstone with coral fragments. At these levels many soft deformation structures and brecciation and nodules are observed. In this section which is about 50 m thick channels fills with pebbles, cross bedding and local interbands with echinoid lineaments can be observed. The sequence in general is of set sand complex nature. In the back-set abundant pelecypod, *Ostrea* and gastropoda bearing bioturbated sandy limestone and carbonate mudstones were deposited. The most typical examples of bioclastic dominated Soğucak formation is revealed in this section. Along the coast, NW-SE trending limestones with huge cross beds most probably mark the megaripples active along the coast line (Figure 4).

The age interval which is valid fort he whole Kıyıköy section is determined as Late Eocene (Priabonian) –Oligocene (Rupelian – Early Chattian) (Baykal et al., 2009) (Table 1) (Figure 5).

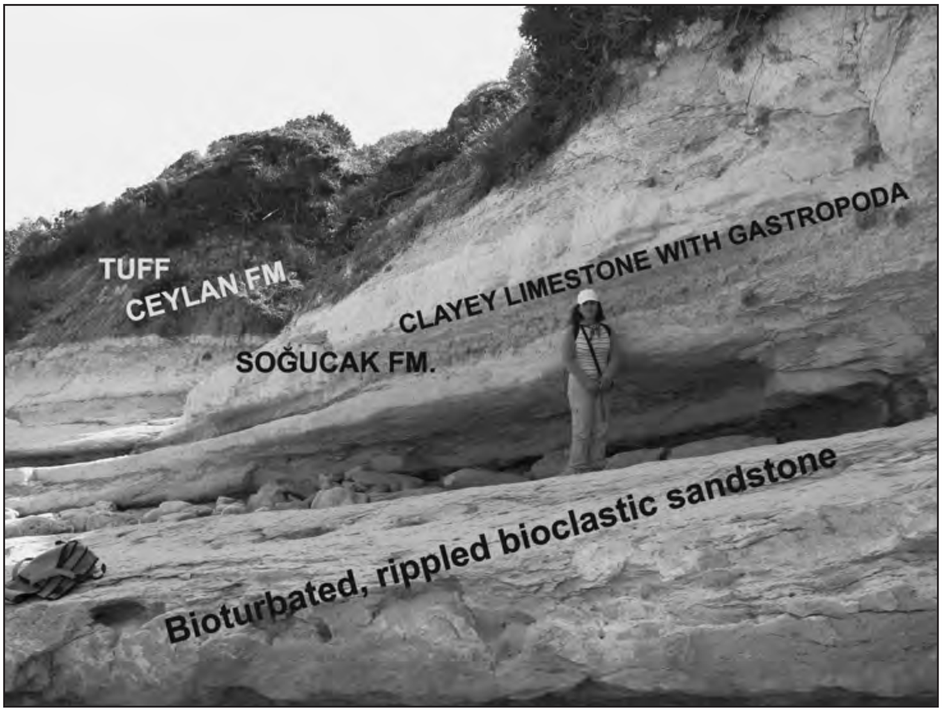

Figure 11- Facies assemblages representing the transition of the Soğucak – Ceylan formations in the Kıyıköy.

COMPARISON OF THE MEASURED STRATIGRAPHIC SECTIONS

Southern Sector: In this sector, the Bozcaada, Gökçeada, Tayfur (in Gelibolu Beninsula) sections and Mecidiye section (Gulf of Saros) were measured. The most different section here is the Bozcaada section; abundant *Alveolina canavari*, *Alveolina pasticillate*, *Alveolina* aff. *pisiformis*, *Alveolina avellena*, *Alveolina cemali*, *Alveolina* sp., and *Nummulites* sp., (Table1) fossils are dominant throughout the bank-type limestones in the unit which was determined to be Middle Eocene Soğucak formation previously. However the above mentioned fossils indicate Early Eocene (Figure 3). Another different point is about the lower boundary of the Soğucak formation. In previous studies, Fıçıtepe formation is defined as aterrestrial formation in the region. In this study, it was observed that the upper boundary of the formation is composed of beach pebblestones-micro reefal assemblage, and it is transitive with the Soğucak formation (Varol et al., 2007). Although in the Gökçeada, Mecidiye and Tayfur sections Fıçıtepe formation is unconformably located at the lower boundary of the Soğucak formation, especially in the Mecidiye section, it can directly overlie the basement rocks as a result of time transgression. Age of the unit defined in these sections is Middle-Late Eocene. In all the sections, Ceylan formation conformably take place at the upper boundaries of these sections (Table 1) (Figures 2-3).

Northern Sector: When a west to east ordering was made here, the first group is represented by the Süloğlu, Dolhan and Tekedere sections. The age interval determined as Late Eocene – Early Oligocene (Figure 5). In these sections the Early Oligocene (?) Soğucak formation (Late Eocene in Dolhan stream) unconformably overlies the basement. However, along the other sections, clastics of the Koyunbaba formation are transitively located at the base. The upper contact of the formation is variabe in this region. In the Süloğlu, in a limited area, quartz sandstone and mudstone which are the products of a siliciclastic coastal development overlie the platform limestone (Taşlısekban formation) and this is overlain by *Congeria* bearing limestones (Pınarhisar formation). Extensions of these two formations which overlie the Soğucak formation are not observed in this position along the other sections. Only in the Dolhan stream a formation similar to the Pınarhisar is observed to overlie the Soğucak formation (Table 1). In the Tekedere stream this upper section is missing (Figure 4).

Northeastward, along the Manastırdere, Çayırdere, Erenler and Soğucak sections the Koyunbaba formation is observed at the base. Along Okçular section, Soğucak formation is observed to overlap the basement. Age of the Soğucak formation determined here is in general Late Eocene – Early Oligocene, however, along the Okçular section it is Late Eocene. Erenler section has a difference in this group (Figure 4). The oolitic facies and the *Congeria* bearing limestone in the section are not observed along the other sections. In previous studies these facies assemblage is mapped as the Pınarhisar (Keskin, 1966).

Along the Vize and Kıyıköy sections which are located at the easternmost part of the study area Soğucak formation is unconformable on the basement, however, along the section Kıyıköy 1a, a thin (3-5 m) siliciclastic level behind the Soğucak formation can be correlated to the Koyunbaba formation with its stratigraphic position. The age interval obtained from these sections is Late Eocene – Early Oligocene (Table 1, Figure 5). A significant matter that should be mentioned here is that Kıyıköy facies is quite different than the other facies assemblages in the areas of the other section with respect to the facies types and environments (shore, back-shore, beach, lagoon). The upper limit of the Soğucak formation passes by a thin tuffaceous level in lagoon facies to the Ceylan formation in Kıyıköy (Figure 11).

DISCUSSIONS AND RESULTS

Soğucak formation which crops out in the Thrace was deposited as reefal facies in general between Middle Eocene – Early Oligocene. The *Nummulites* banks, from the point of facies development, dominantly characterizes the Middle – Late Eocene. The dominant coral patchy reefs were deposited during Late Eocene – Early Oligocene. The facies around reefs have formed different deposition environments based on the sea level changes. These can be differentiated as back-reef – lagoon, tidal flat, oolite shoals and fore-reefs.

Soğucak formation was deposited in Early Eocene in the Bozcaada section. If this time interval is taken as a beginning point, it can be said that the Eocene transgression in the Thrace basin has advanced on an irregular topography time transgressively from south to north. For this reason, in the Kıyıköy which is the distant point of the transgression, a thick Oligocene sequence was deposited. The depositional features and age limits of the Soğucak formation pointed out in this study emphasize the necessity to deal with the following subjects:

1- The Early Eocene limestones cropping out in the Bozcaada were included in Soğucak formation, however, this unit must be studied in detail and its position in the Eocene must be clarified.

2- Interpretation of oolite and *Congeria* bearing limestones which were assumed to be a distinct facies group in the Soğucak formation in the Kaynarca-Erenler section as a different facies assemblage deposited in the platform where the Soğucak formation was deposited, and consequently its redefinition as a single formation (Soğucak Fm); this redefinition shall facilitate the correlation of Early Oligocene units which crop out widespreadly in the Soğucak formation.

3- The units which rest on the basement in the Kıyıköy are quite different than the facies defined in the Soğucak formation. In the region which is represented by high energy clastic carbonate depocenters (set island – beach complex, megaripples, etc.) detailed sedimentological studies are required.

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NANNOPLANKTON BIOSTRATIGRAPHY OF THE SELANDIAN-YPRESIAN GÜNEY FORMATION (ULUKIŞLA BASIN) AND SEA-WATER TEMPERATURE CHANGES IN THIS PERIOD

Manolya SINACI* and Vedia TOKER**

ABSTRACT.- In this research, nannoplankton flora of Selandian-Ypresian Güney formation which is comprised of sandstone-shale intercalation and cropping out in Ereğli – Ulukışla basin was studied. 44 species of 16 nannoplankton taxons were determined in 50 samples collected from Güney measured stratigraphic section. Flora of five nannoplancton zone [*(Fasciculithus tympaniformis* Zone (late Selandian), *Heliolithus kleinpellii* Zone (late Selandian – early Thanetian, *Heliolithus ridelii* Zone (Thanetian), *Discoaster multiradiatus* Zone (Thanetian), Tribrachiatus contortus Zone (Ypresian)] were determined. Of the nannoplancton species which are sensitive to temperature changes, *Coccolithus eopelagicus* indicate mild – cool water and *Discoaster* and *Sphenolith* indicate mild-warm water environments; based on this information, we suggest that the sea water during the Selandian was mild to warm, during the Thanetian, the sea water was mild to cool and during the Ypresian, again the mild to warm sea water conditions prevailed.

Key words: Nannoplankton, Güney formation, Ereğli-Ulukışla Basin, Selandian, Ypresian.

INTRODUCTION

Ereğli-Ulukışla Basin is located 100 km NW of the Adana city (Figure 1). Güney formation which forms part of the basin spreads out in Ulukışla (Niğde), Çamardı, Pozantı and Ereğli (Konya) (Figure 1).

The basin is delimited by Aladağlar mountains and Ecemiş fault in the east, by Niğde massif in the west and by Bolkar mountains in the south (Demirtaşlı et al., 1973) (Figure 1).

Geological studies for different purposes were carried out in the study area and surroundings (Ketin and Akarsu (1965), Demirtaşlı et al.,1973; Oktay, 1982; Dellaloğlu and Aksu, 1986; Pampal and Meriç; 1990; Sonel and Sarı, 2004; Dursun, 2006). This study aims to reveal the *nannoplankton* biostratigraphy of the study area in detail.

In study area and its surroundings an ophiolitic emplacement is observed in Late Cretaceous; following this a sedimentary sequence were deposited in Late Cretaceous – Miocene time interval. The units filling the basin are clastic deposits, volcanosedimentary units, carbonates and evaporites. There are vertical and horizontal transitions and lithofacies changes among the Ulukışla, Halkapınar, Hasangazi and Güney formations (Figure 2). These units are shown in flysch character and they include many channel filling structures (Sonel and Sarı, 2004). By the end of the Middle Eocene, as a result of tectonic movements, the region has gained its structural position as shown today.

In this study, nannoplanktons in 50 samples collected from a measured stratigraphic section in Güney formation were studied and taxons of 5 biozone were determined (Figure 3). These data indicate that age of the formation is Selandian – Ypresian (Paleocene – early Eocene).

MATERIAL AND METHOD

50 samples collected from the Güney formation along a measured stratigraphic section are the materials used in this study. Slides were prepared from the samples by stripping method. Abundance of zone fossils from the samples collected were counted in 200 areas (Wei, 1988) and revealed. Accordingly, following evaluation

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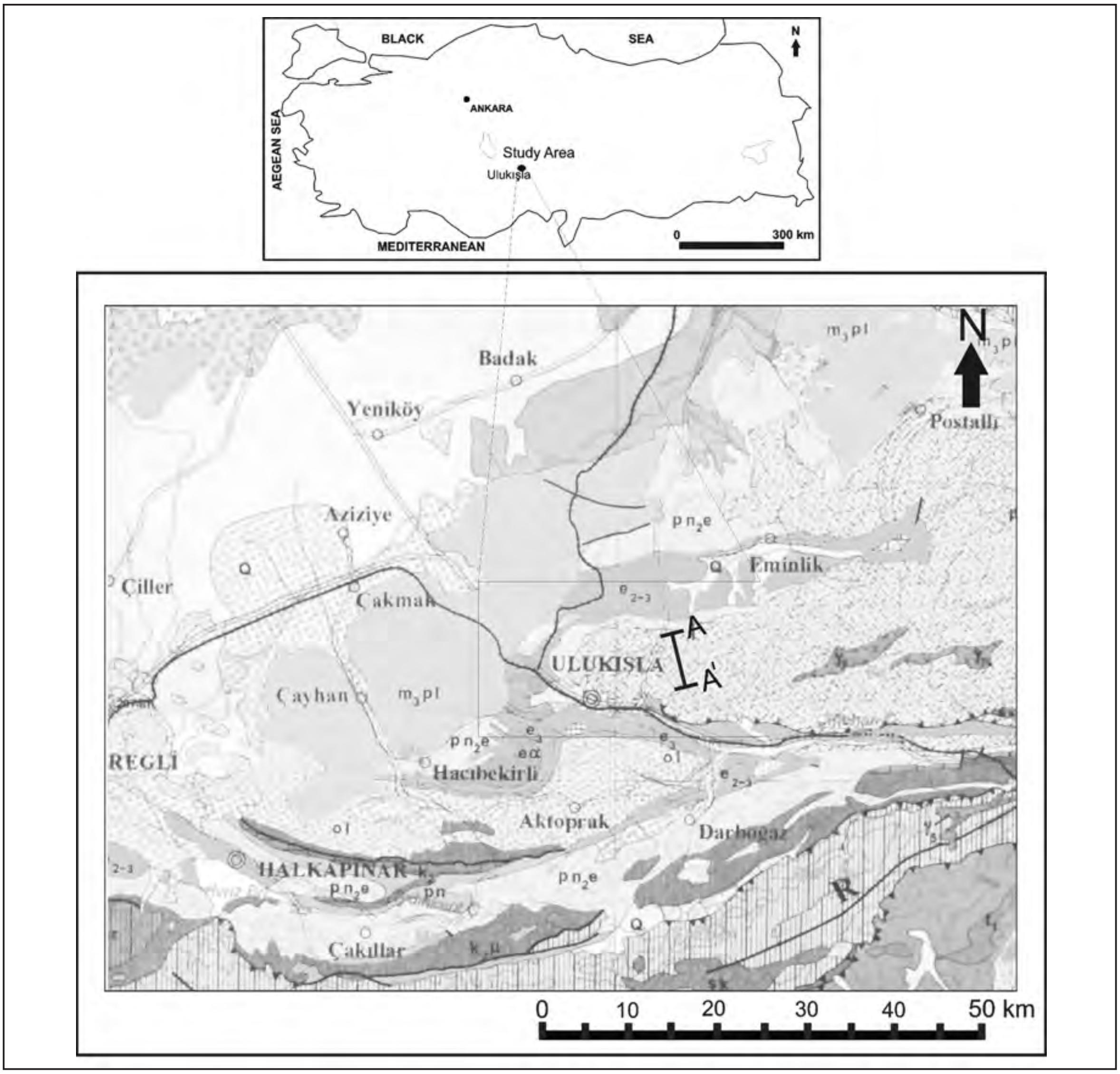

Figure 1- Location map of the study area (MTA, 2002)

was made for the species: one or many species in an area as “Abundant = B”; one species in 2 - 10 areas as “Widespread = Y”, and one species in 11 – 50 areas as “ Few (Little) = A” and one from each species in 51 – 200 areas as “Rare = N” (Table 1).

LITHOSTRATIGRAPHY

Güney formation which crops out in study area is comprised of an intercalation of sandstone and shale, however, red lenticular mudstones and thin to medium bedded lenticular sandstones and mudstones are also included. Pillow lavas of 1 – 15.5 m thick are also observed in the

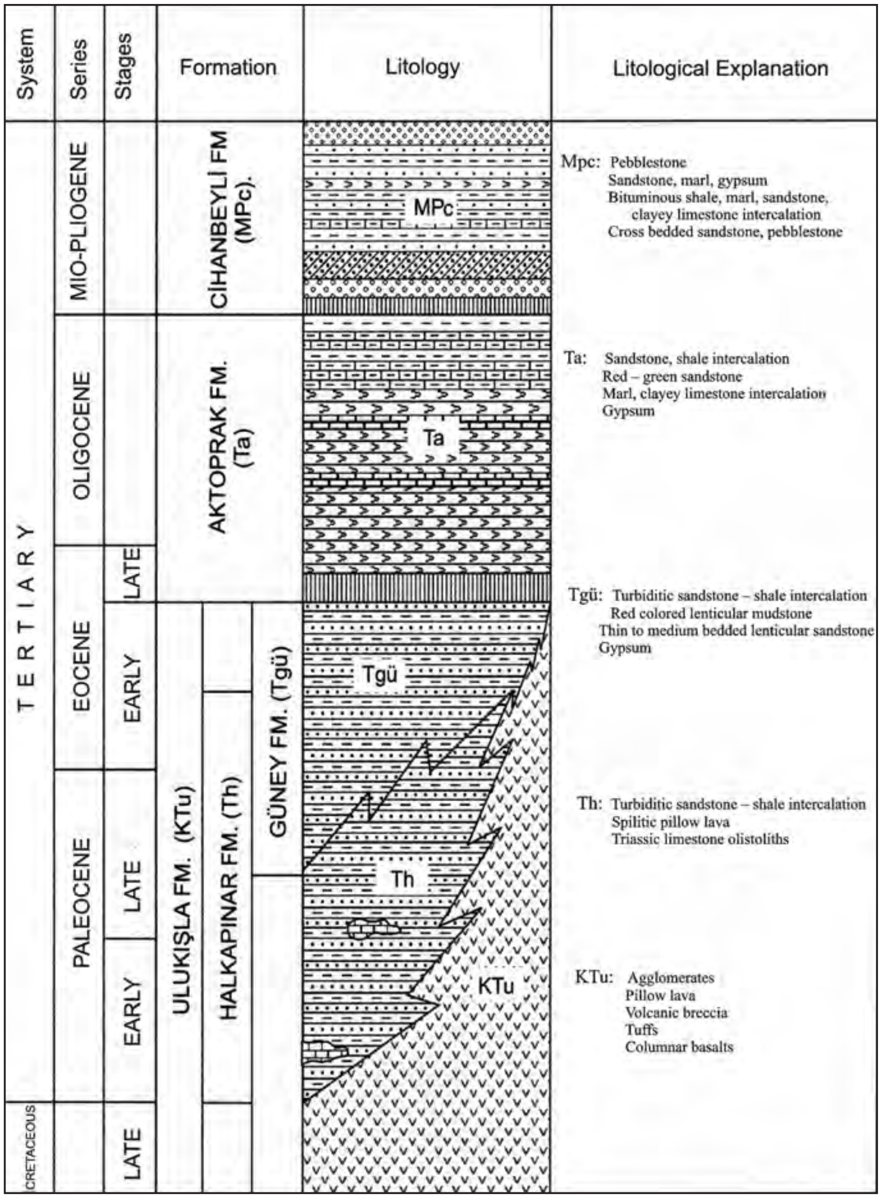

Figure 2- Generalized stratigraphic columnar section of the Ereğli-Ulukışla Basin(Dursun, 2006).

unit. At the top of the unit widespread lenticular channel fills displaying graded bedding, slump deposits and intercalations of turbiditic sandstone are observed.

Güney formation is represented very well around Ulukışla – Güney village. It was developed time regressive from north to south; therefore it has different facies and ages around its typical locality and southwest of Ulukışla (Oktay, 1982).

Güney formation was deposited in general below the wave base and by turbiditic currents.

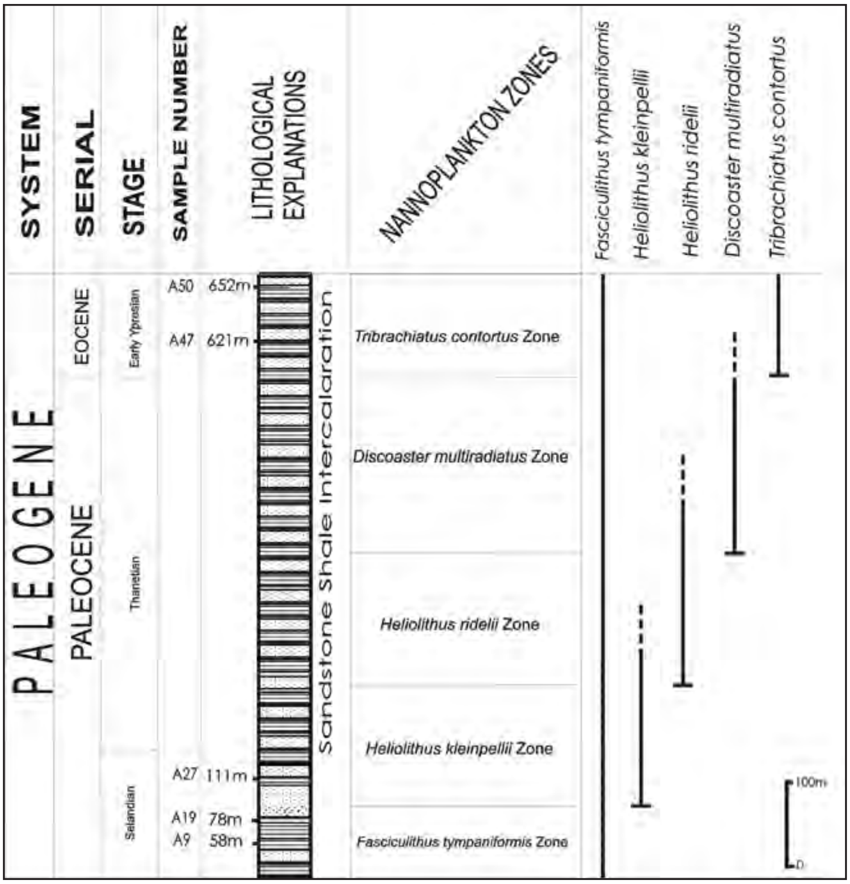

Figure 3- Generalized view ıof Güney formation (north of Bekçitepe).

The lower levels of the sequence include channel fills and sandstones are dominant in these levels, therefore they display characteristics of proximal turbidites. Northward in the study area, the shale and sandstone dominance become equal; in these regions channel fills are observed at the upper sections and sandstones become dominant with coarse grains while the dominance of the shales decrease. For this reason, the upper levels are observed in proximal turbiditic character.

The unit was developed in general as grey, coarse sandstone and shale intercalation. It is 800 m thick.

Güney formation is vertically and horizontally transitive to Ulukuşla and Halkapınar formations in the study area. It is not observed south of Ulukışla, but here Hasangazi formation which has the same age with the Ululışla formation was deposited. Aktoprak formation is vertically and horizontally transitive to Hasangazi and Güney formations and overlies these two formations. Miocene – Pliocene Cihanbeyli formation unconformably overlies the Aktoprak formation in south, and Güney formation in the north of the study area.

Along the 652 m thick Güney stratigraphic section which is comprised of sandstone – shale intercalation, between 58 – 78 m the amount

Table1- Abundance of Güney formation nannoplankton zone species

ZONES	SAMP. NUM. / SPECIES	F.tympaniformis	S.spiniger	S.anarrhopus	F.involutus	E.robusta	E.ovalis	E.cava	Thracosphaera sp.	T.tovae	C.eopelagicus	Z.bijugatus	D.barbadiensis	S.radians	S.editus	D.elegans	C.tenuis	D.bifax	H.kleinpellii	T.eminens	D.diastypus	D.binodosus	C.solithus	N.junctus	P.plana	C.danicus	B.sparsus	M.crenulatus	S.primus	D.saipanensis	H.ridelii	S.conspicuus	D.multiradiatus	E.formosa	D.aster	T.orthostylus	D.lodoensis	C.reticulatum	D.tani nodifer	D.tani	D.salisburgensis	B.bigelowi	S.conspicuus	N.eoseapes	D.pacificus	D.deflandrei	D.gemmeus	M.inversus	T.contortus
T.CONTORTUS ZONE	50	R				R					R																		R	R			R		R												R		
	49																																															R
	48	R					R	R	R	R	R			R	R														R					R	R	R													R
D.MULTIRADIATUS ZONE	47	F		R				R	R		F			F	R														R				R	R	R	R													
	46	F		R			R	R	R	R	F	R		F	R										R				R	R			R	R		R												R	
	45	R					R	R	R		F			R	R	R	R										R			R			R	F	R	R	R	R	R		R			R	R	R	R		
	44	R								R	F	R	R	F	R										R					R			R	F	R	F	R			R	R	R	R						
	43	F		R			F			F				R	R															R				R		R												
	42	F		R				R	R	R	F			F	R														R	R	R			F	R	R	R	R	R										
	41	F		R		R		R	R	R	R			F	R														R																			
	40	F		R		R		R		R	R			R	R														R																			
	39	F		R							R			F	R									R					R																			
	38	F								R	R	R		F	R														R																			
	37	F				R				F	R	R		F	R														R																			
	36																																															
	35	F		R		R	R	R		R	R			F	R																																		
	34	F		R		R		R	R	F	F	R		F	F														R																			
	33	R		R		R				R	R	R		R	R														R			R	R																
	32	F		R		R				R	R	R		F	R														R																			
	31	F		F						F	F	R		R	R																																		
	30	F		F		R		R		F	F			R	F														R				R																
	29	F		R						F	F	R		R	R																																		
	28	F		R		R		R	R	R	R			R	R														R				R																
H.RİDELII ZONE	27	R		R			R		R	R	R				R																																		
	26	R									R				R																																		
	25																																															
	24	F		F		R	R	R		F	F	R		R	R														R																			
	23	C		R		R	R			F	F	R		F																		R																	
	22	F		R		R	F		R	F	F	R		R										R					R																			
	21	F		F		R	R	R		F	F	R		R									R						R																			
	20	A		F		R	R	R		F	A	R		R	R											R			R		R																		
H.KLEINPELLII ZONE	19	F		R		R	R			R	F	R	R	R													R																						
	18	C		R			F	R		F	A	F		F	R			R										R	R	R																			
	17	F		R		R			R	F	F	R																																					
	16	A		R		R		R	R	F	F	R																																					
	15	F		R		R	R		R	F	F																																						
	14	A		F		R	F	R	R	C	A	R	R	R	R							R	R		R	R	R																						
	13	F		R		R		R	R	F	R																																						
	12	A		F		R	F	F		C	A	R	R						R	R	R	R	R	R																									
	11	F		R		R	R			R	R		R																																				
	10	F					R	R		R	R		R		R				R																														
F.TYMPANIFORMIS ZONE	9	C	R			R		R		F	F	R	R	R																																			
	8	F				R	R	R		R	R							R																															
	7																																															
	6	R					R			R	R		R																																				
	5	F		R		R	R	R		R	F																																						
	4	A		R		R	R	R	R	C	C	R																																					
	3	A		R	R	R	F	R		F	C	R		R		R	R																																
	2	F	R	R		R		R	R	F	R	R	R																																				
	1	F	R	F	R	R	F	R	R	F	F	R	R																																				

A: Abundant C: Common F: Few R: Rare

of sandstone decreases while the shales increase. Between 78 – 111 m, the thickness of sandstones is more than that of the shale (Figure 3).

BIOSTRATIGRAPHY

16 genus and 44 species were determined along 652 m thick stratigraphic section in Güney formation, and 5 biozones were defined (Figure 3). In the first 58 m, *Fasciculithus tympaniformis* Zone ranging between the first appearance of *Fasciculithus tympaniformis* Hay and Mohler and the first appearance of *Heliolithus kleinpellii* Sullivan; between 58-78 m *Heliolithus kleinpellii* Zone ranging between the first appearance of *Heliolithus kleinpellii* Sullivan and Discoaster gemmeus Stradner; and between 78-111 m *Heliolithus rideli* Zone ranging between the first appearance of *Heliolithus ridelii* Bramlette and Sullivan or *Dicoaster nobilis* Martini and *Discoaster multiradiatus Bramlette* and Riedel; between 111-621 m *Discoaster multiradiatus* Zone ranging between the first appearance of *Discoaster multiradiatus* Bramlette and Riedel and *Tribrachiatus contortus* Stradner, between 621-652 m *Tribrachiatus contortus* Zone ranging between the first and last appearance of *Tribrachiatus contortus* Stradner were determined (Figure 4, Table 1.2). As for the previous studies related to the biostratigraphic zoning of nannoplanktons we can cite Hay and Mohler (1967), Bukry (1969), Martini (1971), Okada and Bukry (1980) and, Perch and Nielsen (1985 a, b). This study is based on the standard zoning of Perch and Nielsen (1985 a, b) (Table 1,2).

Fasciculithus Tympaniformis Zone

Description: Zone was formed during the interval between the first appearance *Fasciculithus tympaniformis* Hay and Mohler and the first appearance of *Heliolithus kleinpellii* Sullivan of (Plate I, Figure 6).

Author: Hay and Mohler (1967)

Category: Concurrent range zone

Stratigraphic level: Selandian

Fossil Assemblage: *Biantolithus sparsus* (Bramlette and Martini), *Coccolithus eopelagicus* (Bramlette and Riedel), *Discoaster barbadiensis* (Tan Sin Hok), *Ericsonia cava* (Hay and Mohler), *Ericsonia ovalis* (Black), *Ericsonia robusta* (Bramlette and Sullivan), *Fasciculithus tympaniformis* (Hay and Mohler), *Fasciculithus involotus* (Bramlette and Sullivan), *Sphanolithus radians* (Deflandre), *Sphenolithus anarrhopus* (Burky and Bramlette), *Toweius tovae* (Perch and Nielsen), *Thracosphaera* sp. (Kamptner) and *Zygrhablithus bijugatus* (Deflandre).

Comparison and Interpretations: Hay and Mohler (1967), Martini (1971), Perch and Nielsen (1972,1985a), Toker (1977), Okada and Bukry (1980), Aköz (1981), Meriç et al. (1987), Lang and Wise (1987), Wise and Pospichal (1990), Aydın (2005) defined this zone at the same stratigraphic level during their studies. During this study, *Fasciculithus tympaniformis* Zone is determined in Selandian (Table 2).

Heliolithus Kleinpellii Zone

Description: *Heliolithus kleinpellii* Zone was formed during the first appearance of Sullivan and *Discoaster gemmeus* Stradner (Plate I, Figure 2).

Author: Hay and Mohler (1967)

Category: Concurrent range zone

Stratigraphic level: Upper level of late Selandian – lower level of early Thanetian

Fossil Assemblage: *Coccolithus eopelagicus* (Bramlette and Riedel), *Discoaster barbadiensis* (Tan Sin Hok), *Ericsonia cava* (Hay and Mohler), *Ericsonia ovalis* (Black), *Ericsonia robusta* (Bramlette and Sullivan), *Fasciculithus tympaniformis* (Hay and Mohler), *Heliolithus kleinpellii* (Sullivan), *Sphenolithus anarrhopus* (Burky and Bramlette), *Toweius tovae* (Perch and Nielsen).

Comparison and interpretation: Hay and Mohler (1967), Bukry (1969), Martini (1971), Perch and Nielsen (1972,1985a), Toker (1977), Okada and Bukry (1980), Aköz (1981), Lang and Wise (1987), Wise and Pospichal (1990), Aydın (2005) defined this zone during their studies. On the other hand, Decima et al. (1975) defined this zone as *Markalius inversus* Zone. Meriç et al. (1987) could not determine this zone during their study. In this study *Heliolithus kleinpellii* Zone was determined in late Selandian-early Thanetian based on the findings and the study of Bukry (1969) (Table 2).

Heliolithus Ridelii Zone

Description: *Heliolithus ridelii* Zone was formed between the first appearance of *Heliolithus ridelii* Bramlette and Sullivan or *Dicoaster nobilis* Martini and the first appearance of *Discoaster multiradiatus* Bramlette and Riedel (Plate I, Figure 3).

Author: Bramlette and Sullivan (1961), Perch-Nielsen (1972)

Category: Concurrent range zone

Stratigraphic level: Thanetian

Fossil Assemblage: *Coccolithus eopelagicus* (Bramlette and Riedel), *Cribrocentum reticulatum* (Gartner and Smith) Perch and Nielsen, *Discoaster aster* (Bramlette and Riedel), *Ericsonia formousa* (Kamptner), *Ericsonia ovalis* (Black), *Fasciculithus tympaniformis* (Hay and Mohler), *Heliolithus ridelii* (Bramlette and Sullivan), *Sphenolithus anarrhopus* (Burky and Bramlette), *Sphenolithus editus* (Perch-Nielsen), *Sphenolithus primus* (Perch and Nielsen), *Sphenolithus radians* (Deflandre), *Toweius tovae* (Perch and Nielsen), *Tribrachiatus orthostylus* (Shamrai) and *Thracosphaera* sp.

Comparison and interpretation: Hay and Mohler (1967), Bukry (1969), Martini (1971), Decima et al. (1975), Perch and Nielsen (1985a), Wise-Pospichal (1990), Aydın (2005) defined this zone during their studies. On the other hand, this zone was defined as *Discoaster gemmeus* Zone by Toker (1977) and Aköz (1981). Perch and Nielsen (1972), Okada and Bukry (1980), Lang and Wise (1987) defined this zone as *Discoaster nobilis* Zone. Meriç et al. (1987) determined the fosil assemblage of this zone durng their study. In this study, *Heliolithus ridelii* Zone is determined as Thanetian based on the findings and the study of Bukry (1969) (Table 2).

Discoaster Multiradiatus Zone

Description: Zone was formed between the first appearance of *Discoaster multiradiatus* Bramlette and Riedel and first appearance of *Tribrachiatus contortus* (Stradner) (Plate, Figure D).

Author: Bramlette and Sullivan (1961), Martini (1971)

Category: Concurrent range zone

Stratigraphic level: Upper level of Late Thanetian

Fossil Assemblage: *Biantolithus sparsus* (Bramlette and Martini), *Braarudosphaera bigelowi* (Gran and Braarud), *Coccolithus eopelagicus* (Bramlette and Riedel), *Chiasmolithus danicus* (Brotzen), *Chiasmolithus solithus* (Bramlette and Sullivan), *Cribrocentum reticulatum* (Gartner, 1967), *Cruciplacolithus tenius* (Stradner) Hay and Mohler, *Discoaster aster* (Bramlette and Riedel), *Discoaster barbadiensis* (Tan Sin Hok), *Discoaster deflandrei* (Bramlette and Riedel), *Discoaster diastypus* (Bramlette and Sullivan), *Discoaster elegans* (Bramlette and Sullivan), *Discoaster gemmeus* (Stradner), *Discoaster multiradiatus* (Bramlette and Riedel), *Discoaster pacificus* (Haq), *Discoaster salisburgensis* (Stradner), *Ericsonia cava* (Hay and Mohler), *Ericsonia formosa* (Kamptner), *Ericsonia robusta* (Bramlette and Sullivan), *Ericsonia ovalis* (Black), *Fasciculithus involotus* (Bramlette and Sullivan), *Fasciculithus tympaniformis* (Hay and Mohler), *Heliolithus kleinpelli* (Sullivan), *Heliolithus ridelii* (Bramlette and Sullivan), *Micrantolithus crenulatus* (Bramlette and Sullivan), *Markalius inversus* (Deflandre), *Neochiastozygus eoseapes* (Perch and Nielsen), *Neochiastozygus*

Table 2- General comparison of Paleocene – Early Eocene nannoplankton zones.

Series	Stages	Hay and Mohler 1967 France	Bukry 1969 NW Pacific Ocean	Martini 1971 Genel Zonlar	Perch and Nielsen 1972 Atlantic	Decima et al. 1975 Italy	Toker 1977 Haymana	Okada and Bukry 1980 General Zones	Aköz 1981 SE Turkey	Perch and Nielsen 1985 General Zones	Meriç et al. 1987 Adıyaman	Lang and Wise 1987 Atlas Ocean	Wise and Ropacha 1990 Antartica	Aydın 2005 İzmit	This Study 2006
EARLY EOCENE	YPRESIAN		*Discoaster lodoensis* & *Marthasterites contortus*	*Discoaster binodosus*		*Discoaster binodosus*	*Discoaster binodosus*	*Discoaster diastypus*	*Marthasterites tribrachiatus*	*Discoaster binodosus*	?	*Discoaster diastypus*	*Tribrachiatus bramlettei*	*Discoaster binodosus*	
			Marthasterites contortus & *Discoaster diastypus*	*Marthasterites contortus*		*Tribrachiatus contortus*	*Marthasterites contortus*			*Marthasterites contortus*	*Tribrachiatus contortus*			*Tribrachiatus contortus*	*Tribrachiatus contortus*
PALEOCENE	THANETIAN	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*	*Discoaster multiradiatus*
		Heliolithus ridelii	*Heliolithus ridelii*	*Heliolithus ridelii*	*Discoaster nobilis*	*Heliolithus ridelii*	*Discoaster gemmeus*	*Discoaster nobilis*	*Discoaster gemmeus*	*Heliolithus ridelii*	?	*Discoaster nobilis*	*Heliolithus ridelii*	*Heliolithus ridelii*	*Heliolithus ridelii*
		Discoaster gemmeus		*Discoaster gemmeus*	*Discoaster gemmeus*	*Cruciplacolithus tenuis*		*Discoaster mohleri*		*Discoaster mohleri*		*Discoaster mohleri*	*Discoaster mohleri*	*Discoaster gemmeus*	
		Heliolithus kleinpelli	*Heliolithus kleinpellii*	*Heliolithus kleinpelli*	*Heliolithus kleinpelli*	*Markalius inversus*	*Heliolithus kleinpelli*	*Heliolithus kleinpelli*	*Heliolithus kleinpelli*	*Heliolithus kleinpelli*		*Heliolithus kleinpelli*	*Heliolithus kleinpelli*	*Heliolithus kleinpelli*	*Heliolithus kleinpelli*
	SELANDIAN	*Fasciculithus tympaniformis*		*Fasciculithus tympaniformis*	*Fasciculithus tympaniformis*		*Fasciculithus tympaniformis*	*Fasciculithus tympaniformis*	*Fasciculithus tympaniformis*	*Fasciculithus tympaniformis*	*Fasciculithus tympaniformis*	*Fasciculithus tympaniformis*	*Fasciculithus tympaniformis*	*Fasciculithus tympaniformis*	*Fasciculithus tympaniformis*

junctus (Bramlette and Sullivan), *Pontosphaera plana* (Bramlette and Sullivan), *Sphenolithus anarrhopus* (Burky and Bramlette), *Sphenolithus conspicuus* (Martini), *Sphenolithus editus* (Perch and Nielsen), *Sphenolithus primus* (Perch and Nielsen), *Sphenolithus radians* (Deflandre), *Toweius tovae* (Perch and Nielsen), *Thracosphaera* sp., *Toweius eminens* (Bramlette and Sullivan), *Tribrachiatus orthostylus* (Shamrai) and Zygrhablithus bijugatus (Deflandre).

Comparison and interpretation: Hay and Mohler (1967), Bukry (1969), Martini (1971), Perch and Nielsen (1972,1985*a*), Decima et al. (1975), Toker (1977), Okada and Bukry (1980), Aköz (1981), Meriç et al. (1987), Lang and Wise (1987), Wise and Pospichal (1990), Aydın (2005) defined this zone at the same stratigraphic level during their studies. In this study, *Discoaster multiradiatus* Zone is defined in the upper level of Thanetian (Table 2).

Tribrachiatus Contortus Zone

Description: *Tribrachiatus contortus* Zone was formed between the first and last appearance of *Tribrachiatus contortus* (Stradner) (Plate, Figure A).

Author: Hay (1964) and Bukry (1973)

Category: Range zone

Stratigraphic level: Early Ypresian

Fossil Assemblage: *Coccolithus eopelagicus* (Bramlette and Riedel), *Discoaster barbadiensis* (Tan Sin Hok), *Ericsonia ovalis* (Black), *Fasciculithus tympaniformis* (Hay and Mohler), *Toweius tovae* (Perch-Nielsen) and *Tribrachiatus contortus* (Stradner).

Comparison and interpretation: Meriç et al. (1987), Decima et al. (1975), Aydın (2005) defined this zone during their studies. Martini (1971), Toker (1977), Perch and Nielsen (1985a) defined this zone as *Marthasterites contortus* Zone, on the other hand, Okada and Bukry (1980) and Lang and Wise (1987) defined it as *Discoaster diastypus* Zone, Aköz (1981) as Marthasterites tribrachiatus Zone, Wise-Pospichal (1990) as *Tribrachiatus bramlettei* Zone, and Bukry (1969) as *Marthasterites contortus* and *Discoaster diastypus* Zone. Perch and Nielsen (1972) did not encounter this zone during their study. In this study *Tribrachiatus contortus* Zone is defined in early Ypresian (Table 2).

TEMPERATURE CHANGE OF SEA WATER

In the graphical evaluations based on the nannoplankton species, changes in temperature of sea water were determined depending on the amount of the nannoplankton species which indicate the environments of hot and cold water. According to previous researchers, the number of *Coccolithus eopelagicus* is much in moderate sea water (Hay et al., 1967; McIntre et al., 1967,1970; Wei and Wise, 1989; Tantawy, 2003; Villa et al., 2005). *Discoaster* ve *Sphenolithus* species are represented abundant in moderate-warm water areas (Wei and Wise, 1989; Wise and Pospichal, 1990; Edwards and Perch-Nielsen,1975).

As a result of the study, it was determined that abundance of *Discoaster* and *Sphenolith* is inversely proportional to abundance of *Coccolithus* eoplelagicus.

While the individual number of *Coccolithus* eopelagicus in the samples in Selandian is 40, that of *Sphenolith* ve *Discoaster* is only 3. Towards the end of Selandian the number of Coccolithus eoplelagicus decreases, while the number of *Sphenolith* and *Discoaster* increases, depending on the increasing temperature of the sea water. The number of *Coccolithus eoplelagicus* increases first to 100 and then to 140 towards the middle Thanetian while the number of *Sphenolith* and *Discoaster* decreased to 3 and then 2. These data show that the temperature of the sea level decreased. Towards the end of Thanetian the individual number of Coccolithus eoplelagicus decreased again to 45 and the number of *Sphenolith* and *Discoaster* increased to 38; suggesting that the temperature of the sea water increased again. Individual number of *Coccolithus eopelagicus* decreased during Ypresian and became 30 in middle Ypresian and 5 at the end of the Ypresian. On the other hand, the number of *Sphenolith* and *Discoaster* increased and became 42 in middle Ypresian and 43 at the end of the Ypresian. This indicates that the temperature of the sea water increased (Figure 4).

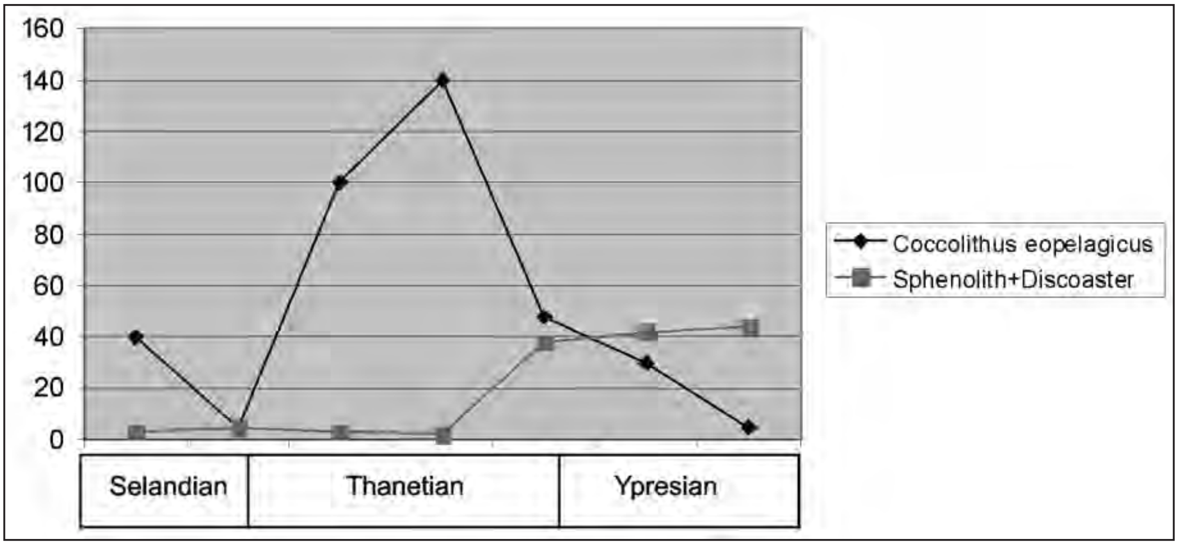

Figure 4- Nannoplankton zones determined along the Güney stratigraphic section in the study area.

RESULTS

As a result of the nannoplankton biostratigraphy research on Güney stratigraphic section in Ereğli-Ulukışla Basin, five zones, such as *Fasciculithus tympaniformis* Zone, *Heliolithus kleinpellii* Zone, *Heliolithus ridelii* Zone, *Discoaster multiradiatus* Zone ve *Tribrachiatus contortus* Zone were determined. Accordingly, it was also determined that the deep sea deposition represented by turbiditic sequence in the basin occurred between Selandian-Ypresian.

According to the analyses based on the individual numbers of the nannofossils, it was determined that temperature of the sea level decreased from moderate to warm in Selandian and became cooler in early – middle Thanetian. Between late Thanetian to Ypresian the temperature again increased and changed from moderate to warm.

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PLATE

PLATE - I

Figure 1- Fasciculithus tympaniformis Hay and Mohler; Sample Number: A 3

Figure 2- *Heliolithus kleinpellii* Sullivan; Sample Number: A 10

Figure 3*a-b-* *Heliolithus ridelii* Bramlette and Sullivan; Sample Number: A 20

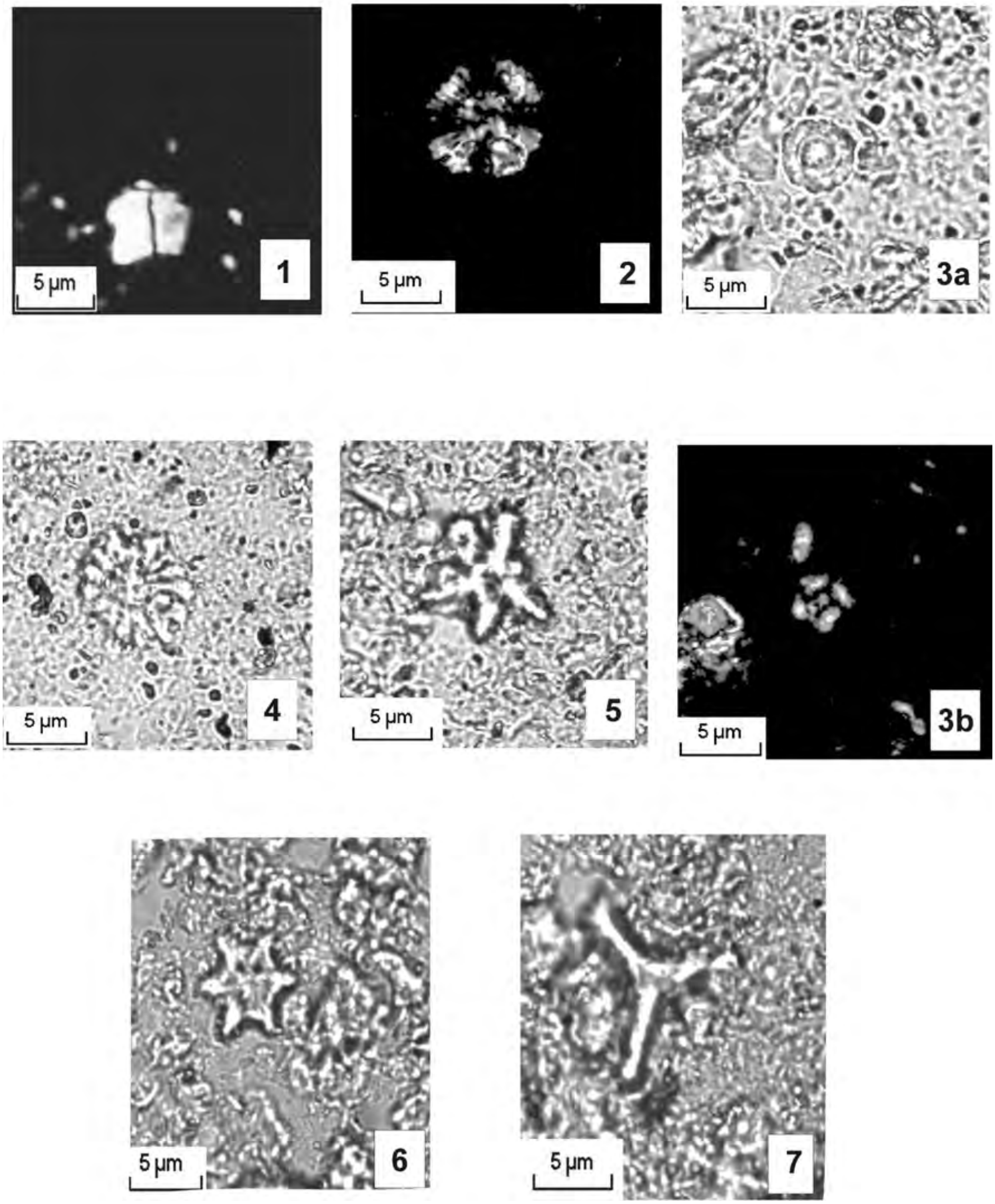
Figure 4- *Discoaster multiradiatus* Bramlette and Riedel; Sample Number: A 33

Figure 5- *Tribrachiatus contortus* Stradner; Sample Number: A 48

Figure 6- *Discoaster saipanensis* Bramlette and Riedel; Sample Number: A 46

Figure 7- *Tribrachiatus orthostylus* Bramlette ve Riedel; Sample Number: A 42

PLATE - I



Mineral Res. Exp. Bull., 139, 33-49, 2009

PETROGRAPHICAL AND GEOCHEMICAL PROPERTIES OF PLAGIOGRANITES AND GABBROS IN GULEMAN OPHIOLITE

* Ayşe Didem KILIÇ

ABSTRACT.- Petrographical and geochemical properties of gabbros and plagiogranites of Guleman ophiolite are determined. It was concluded that gabbros can be basic rocks on subduction zone and plagioclase rich leucocratic rocks (plagiogranite) are differentiation products of fractional crystallization of a basic magma in the magma chamber.

Key words: Neotethys, supra-subduction zone, plagiogranite, gabbros, Taurides.

INTRODUCTION

Study area is located in a 200 km^2 area surrounding the Hazar village (Maden town) in Eastern Taurus orogenic belt (Figure 1).

When tectonic framework of Turkey is considered, it is located in northeast – southwest trending East Anatolian Fault zone passing from south of Elazığ, and south of Lake Hazar. Guleman ophiolite was formed after the closure

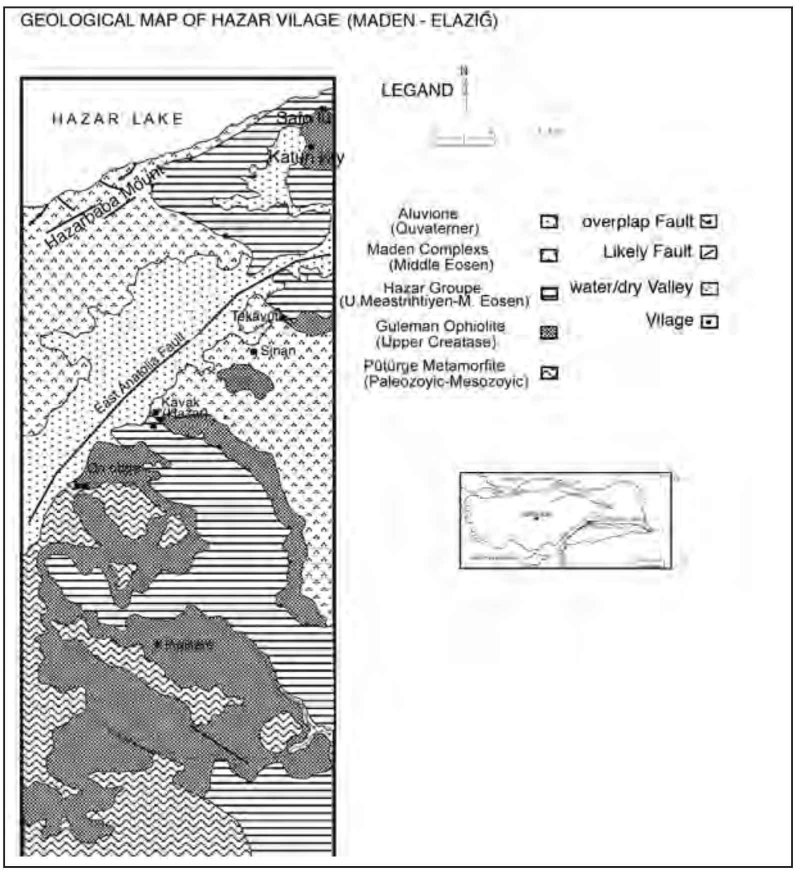


Figure 1- Geoylogic map of studied area (Kılıç, 2005)

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of the Neotethyan ocean as supra-subduction zone ophiolites (Açıkbaş and Baştuğ, 1974; Aktaş and Robertson, 1984; Lytwyn and Casey, 1993; Beyarslan and Bingöl, 2000; Parlak et al., 2008; Robertson, 2002; Kılıç, 2005).

The ophiolites have emplaced in five different zones in Turkey; these are, from south to north, 1) Pontide ophiolites, 2) Anatolide ophiolitic belt, 3) Tauride ophiolite belt, 4) Southeast Anatolian ophiolites, 5) Peri-Arabian ophiolites (Figure 2). All of these ophiolites are the products of subduction zone (Robertson, 2002; Göncüoğlu and Turhan, 1984; Floyd et al., 2000).

There are many researches on the geology, petrography, petrology and ore formations of the Guleman ophiolite (Perinçek 1979b; Perinçek and Özkaya, 1981; Özkan,1982; Erdoğan,1982; Özkan, 1984; Bingöl, 1984; Özkan and Öztunalı,1984; Sungurlu et al., 1985; Yazgan and Chessex, 1991; Kılıç, 2005). The acidic magmatic rocks (trondheimite, tonalite, diorite, etc.) that take place at the plutonic level of the ophiolites or at the sheeted dyke complex provide significant data on the position and origin of the ophiolites (Hebert and Laurent,1990; Floyd et al., 2000). Formations which do not have volcanic units such as Guleman ophiolite have great significance to understand the tectonic positions of the ophiolites. Plagiogranites are the most significant indicators of the arc environments (Floyd et al., 2000). As for the formation of the plagiogranites there are different opinions. It was proposed that, plagiogranites were formed by the differentiation of a tholeiitic magma in the Mid-Oceanic Ridge (Coleman and Peterman,1975; Coleman and Donato, 1979; Pallister and Knight, 1981; Floyd et al., 2000), by partial melting of gabbros (Gerlach et al.,1981; Spulber and Rutherford, 1983; Floyd et al.,2000), and by presence of immiscible liquids found together with mafic solutions (Phillpotts, 1976; Dixon and Rutherford, 1979; Floyd et al., (2000).

This paper aims to examine the petrogenesis, geochemistry and tectonic position of the plagiogranites in Guleman ophiolite, and compare their relation to the gabbros. Defining these properties is significant for revealing the properties of felsic magmatism.

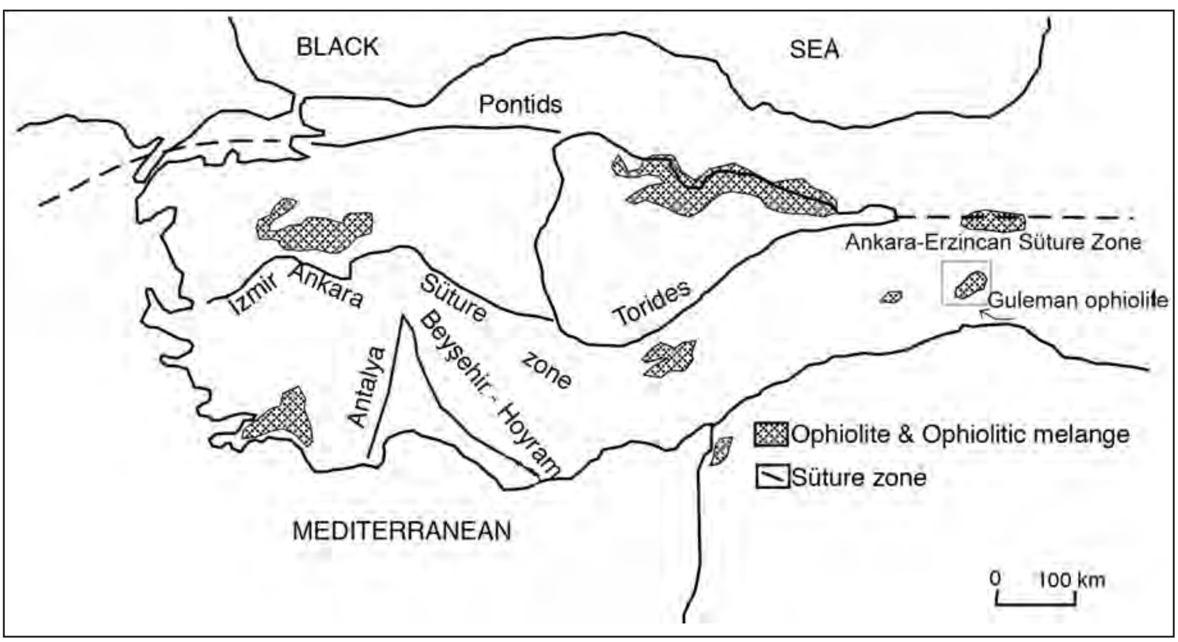

Figure 2- Tectonic units of Turkey and ophiolitic masiffes (changed from Robertson, 2002).

GEOLOGICAL SETTING

An intensive tectonic activity is observed in the study area due to presence of big faults such as the East Anatolian fault and Hazar fault (Figure 1). As for the relation between the lithological units, we observe that Guleman ophiolite is thrusted over the Hazar Group, and Pütürge Metamorphics is thrusted over the Guleman ophiolite and Maden Complex. Hazar Group is thrusted over the Maden Complex as well.

From bottom to top, the following units are observed in the study area (Figure 3): 1) Pütürge Metamorphics, 2) Guleman ophiolite, 3) Hazar Group, 4) Maden Complex, 5) Holocene alluviums (Kılıç, 2005).

Pütürge Metamorphics is composed of Paleozoic-Mesozoic muscovite schists, phyllite, quartzite, calc schist and marbles.

Upper Cretaceous Guleman ophiolite (Erdoğan, 1977; Perinçek and Çelikdemir, 1979) is composed of two main groups, namely tectonites and ultramafic-mafic cumulates. Tectonites are comprised of harzburgite, dunite and podiform chromites in harzburgites. The ultramafic cumulates which have gradual contact with tectonites are represented by dunites with banded or disseminated chromites, wehrlite and clinopyroxenes. A thick layered gabbro level takes place on these rocks. It is possible to differentiate the gabbros as isotope gabbros or as normal gabbros. Isotropic gabros display a equigranular structure in meso and micro investigations whereas the normal gabbros have larger crystals in size. At the upper sections of the isotropic gabbros plagiogranite levels are observed. Ophiolitic units are cut by isolated diabase dykes. Since sheeted dyke complex is not presented in Guleman ophiolite, it is defined as a dismembered ophiolite. Lack of volcanic levels may be explained by tectonic stripping or by a later erosion (Parlak et al. 2008). According to Özkan and Öztunalı (1984), volcanic rocks of Guleman ophiolite is Caferi Volcanics which are

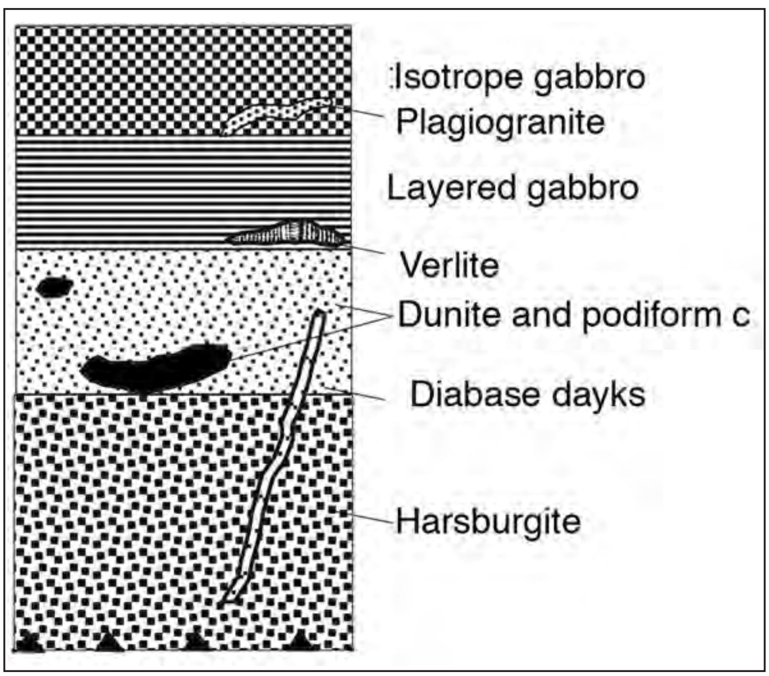

Figure 3- Colon section of The Guleman ophiolite (Kılıç, 2005).

stripped tectonically from ophiolite and rested on Maden Complex. Thickness of diabase dykes which cut the ophiolitic units at different levels is 1 – 1.5 m on average.

Maastrichtian – Lower Eocene Hazar Group (Aktaş and Robertson, 1984) is comprised of an intercalation of conglomerate, sandstone-shale, clayey limestone units.

Middle Eocene Maden Complex is represented by volcanic Karadere Formation (Baştuğ, 1976; Sugurlu et al., 1985; Erdoğan, 1977, 1982) and sedimentary Melefan Formation (Açıkbaş and Baştuğ, 1974; Sungurlu et al., 1985) in the study area. Karadere Formation is composed of agglomerate, tuff, volcanic sandstone, andesite intercalated with mudstone and pillow lava while Melafan formation is composed of marl, mudstone, sandstone and grey limestone.

This study aims to study the petrographical and geochemical properties of gabbros and especially the plagiogranites of Guleman ophiolite and to reveal the character of arc magmatism.

PETROGRAPHY OF GULEMAN OPHIOLITE

Dominant lithology of the Guleman ophiolite is harzburgite. The other rocks are the the mantle tectonites comprised of podiform chromite located in harzburgites and dunites, ultramafic cumulates, gabbros and isolated diabase dykes. The ultramafic cumulates are comprised of wehrlite, dunite and disseminated or banded chromites in dunites. On the cumulate level thick gabbro (isotope gabbro, layered gabbro) is located. Between the two gabbroic level plagiogranites are observed. Isolated diabase dykes cut the whole succession of Guleman ophiolite at different levels.

Harzburgites constitute 40% of the whole ophiolitic rocks. They are serpentinized at tectonic levels and appear as greenish, bright rocks in the field. The main minerals of the harzburgite are olivine (50-60%), enstatite (50-40%) and chromite (less than 1%). Structural and textural features such as recrystallization, partial melting and plastic deformation were preserved in tectonites (harzburgites and dunites) (Özkan and Öztunalı, 1984).

Harzburgites and dunites are laterally transitive. Dunites display fabric texture and/or granular texture. Their modal mineralogical components are olivine (90-97%), clinopyroxene (5-2%) and magnetite (5%).

Thick cumulates are observed on the tectonite level. The ultramafic cumulates and tectonites are laterally transitive. The rocks which much more affected by alteration are wehrlite and clinopyroxene. Wehrlite has mesocumulate texture and forms clinopyroxene (augite) and plagioclase cumulus minerals; on the other hand, olivine forms intercumulus minerals. Intercrystal deformations such as kink banding and plastic flow are not observed. The thick gabbro layer which overlie the cumulate level is represented by isotope gabbro, normal gabbro and plagiogranites at the upper levels.

Layering in gabbros are defined by the change of rate of olivine, plagioclase and pyroxene in layered gabbros. Isotrope gabbros or equigranular gabbros are the upper section of the gabbro level and they have subophitic texture. They are comprised of clinopyroxene (30-35%), olivine (30%) and plagioclase (40-45%). On the other hand, normal gabbros have mesocumulate texture. The most significant property that differs isotope gabbros from layered gabbros is the anorthite content in plagioclases, besides the textural difference (Beccaluva et al., 1994). As a result of microscopic study, the anorthite content of plagioclases is found as 10%.

Plagiogranites are located between the isotope gabbros and normal gabbros. These light colored acidic rocks can easily be observed ingabbros in macroscopic scale. These rocks which display fine granular texture have a modal mineralogical composition of plagioclase (An20-25) (60-65%), quartz (>20%) and biotite (10-15%) (changed into chlorite) and magnetite. Zoning is observed in the euhedral and subeuhedral plagioclases in plagiogranites.

Thickness of isolated diabase dykes whch cut the ophiolitic rocks at different levels is 0.5-1m. They display intersertal texture. Modal mineralogical composition of unaltered diabases is plagioclase (60-80%), clinopyroxene (20-40%) and secondary minerals. Plagioclases have prismatic shapes. They display albite, albite-carlsbad twinning.

GEOCHEMISTRY

Main oxide and trace element (including rare earth elements) analyses of gabbros (7 samples) and plagiogranites (3 samples) of Guleman ophiolites were conducted in ACME Analytic Laboratories in Canada. Total amount of major oxide and minor elements were analysed by ICP-MS method and by acid digestion and lithium metaborate/tetraborate fusion method on 0.2 gr samples. The results are shown in table 1.

When the results of analyses of the gabbros and plagiogranites of Guleman ophiolites were studied in table 1, it was observed that the gabbros have 48.33-54.88 SiO_2, 5.73-11.84 MgO, and the plagiogranites have 60.21-69.19 SiO_2 and 1.22-2.34 MgO values. LOI values of these rocks are between 1.0 – 4.5 and the rocks display hydrothermal alteration in less amounts.

Gabbros have affected from this alteration even if less and in mafic element chemistry this effect is observed. Due to alteration the Na_2O+K_2O value is 1.52-4.90%. K_2O value is less than that of Na2O. Enrichment of Na might be due to spilitization of mafic rocks as a result of low gade hydrothermal ocean floor metamorphism.

In AFM diagrams it is observed that some gabbros fall into an area of non-cumulate gabbro related to arc (Figure 4). This indicates the formation of the primary fraction of solutions in depleted mantle which typicaly occurs at the

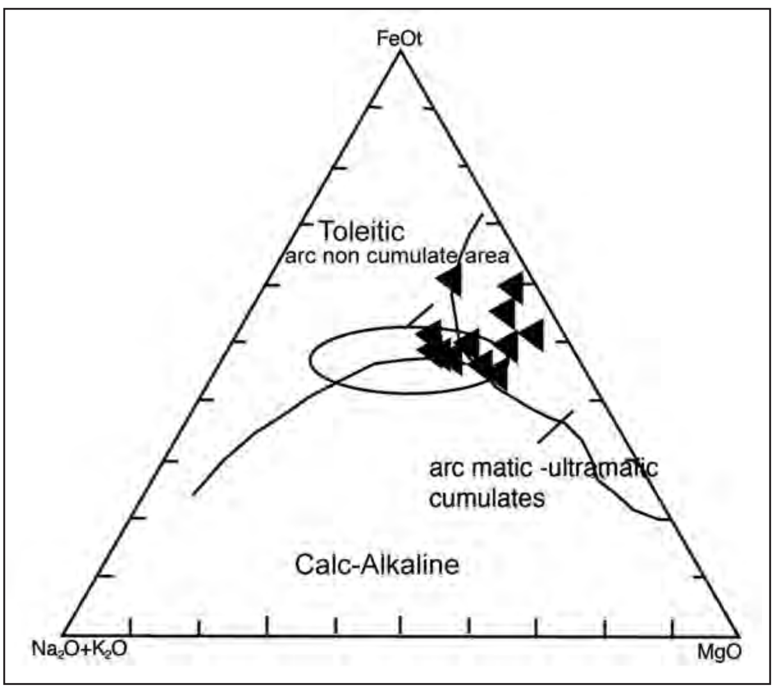

Figure 4- AFM diagrams of gabbros (Beard, 1986).

Table 1-Major and trace element analysis of the gabbros and plagiogranites of Guleman ophiolite.

Lihology	*Plagiogranite*			*Gabbro*						
Sample No	**Pl-1**	**Pl-4**	**Pl-12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
SiO_2	60.21	69.19	62.52	49.30	53.40	54.88	52.17	48.33	53.77	51.29
Al_2O_3	12.84	13.57	15.56	9.63	14.60	11.56	15.85	12.23	12.56	7.8
TiO_2	0.71	0.38	1.23	0.70	1.37	1.05	0.46	0.60	1.51	0.47
Fe_2O_3	6.19	3.81	8.24	13.76	9.92	8.42	8.98	12.76	8.24	15.09
MnO	0.09	0.08	0.04	0.26	0.13	0.13	0.14	0.16	0.15	0.23
MgO	2.34	1.22	1.48	11.66	5.73	6.74	7.22	11.26	6.48	11.84
CaO	13.46	3.35	6.03	11.78	6.64	10.84	9.75	11.18	10.42	9.98
Na_2O	0.19	4.51	3.92	1.46	4.86	3.15	2.85	2.47	3.61	0.51
K_2O	0.03	0.23	0.34	0.06	0.04	0.66	0.20	0.04	0.06	0.03
P_2O_5	0.07	0.08	0.07	0.07	0.15	0.15	0.04	0.08	0.14	0.07
LOI	3.7	3.4	1.0	1.0	2.8	4.1	2.0	1.7	2.9	2.3
Total	99.88	99.84	99.43	99.68	99.64	99.92	99.66	99.77	99.81	99.61
Mg#	56	55	57	59	49	57	57	54	58	55
Rb	0.4	2.6	1.3	<5	1.1	8.2	3.3	3.8	0.5	1
Sr	310	166	193	134	115	166	176	122	155	141
Y	19	26	30	33.5	32	25.2	15.7	31	27	16.8
Zr	45	26	39	18.6	92.7	66.0	25.5	19	51	83.7
Nb	1.1	2.8	2.1	0.7	2.1	1.5	0.5	1	1.7	1.4
Ba	12	62	73	7	26	69	28	45	32	56
Hf	1	1.9	1.3	0.7	2.4	1.8	0.8	1.6	0.9	2.1
Ta	0.1	0.2	<0.1	0.1	0.1	<0.1	<0.1	0.1	<0.1	<0.1
Pb	0.7	2.6	1.8	0.4	0.3	0.5	0.5	0.3	0.4	0.3
Th	0.2	1.1	0.12	1.1	0.7	0.2	0.3	0.6	0.2	0.7
U	0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
La	3.9	4.4	3.83	2.0	2.5	2.3	1.4	2.1	4.1	1.8
Yb	1.8	2.61	1.73	0.08	0.13	0.16	0.49	1.01	0.52	2.01
Eu/Eu*	0.89	1.13	1.08	0.02	0.02	0.02	0.07	0.02	0.07	0.02
$(La)_N/(Sm)_N$	0.90	0.95	0.92	0.52	0.78	0.95	0.8	0.75	0.94	0.91
$(La)_N/(Yb)_N$	**1.04**	**0.97**	**1.03**	**0.46**	**1**	**1.14**	**5.40**	**1.13**	**3.28**	**1.1**

floor of the magma chamber of mafic cumulate gabbros (Hopson et al., 1981). Plagiogranites are accepted as a product of a later differentiation of such a magma (Hopson et al., 1981).

TiO_2 value of the gabbros are between 0.46-1.37 and their Ti content is between 4000-8000 ppm which is consistent with the 5000 ppm Ti content of the island arc tholeiites as indicated by Pearce and Gale (1977). Low trace element values such as Nb, Y, Zr besides Ti, low Nb/Y amount indicate a subalkaline environment (Floyd and Winchester, 1975, Figure 5).

Clustering of rock samples in Ti/V (<20) area in Ti/1000-V diagram which is one of the discriminant diagrams of tectonic environment indicate an island arc tholeiite environment (Figure 6). Similar low Zr amount and low Zr/Y rate (0.5-2.94 in gabbros and 1.0-2.36 in plagiogranites) is typical for island arc (IAT) (Beccaluva et al., 1994; Spulber et al., 1983). When the samples are in studied in Nb/Th-Y diagram similarly, it is observed that the rock sampes fall in island arc area (Figure 7).

The effects of metamorphism observed as a result of petrographic and chemical analyses, the samples variable in MORB-normalized multi-element spider diagrams and the gabbros variable in respect to LILE (Sr, K, Rb, Ba) (Figure 8) reflect ocean flor metamorphism. The most reliable indicator element in LILE which is affected by alteration is Th, which indicates enrichment. Th enrichment is an indicator of emplacement of subduction zone (Wood et al., 1979; Pearce et al., 1990). In (Nb/Zr)n-Zr diagram, it was observed from the distribution of gabbros and plagiogranites that they take place in subduction zone area (Figure 9), and some samples located out of the area indicate the presence of processes of contamination in evolution of magmas (Jenner et al., 1991).

The Th/Y rate, which is the indicator of enrichment of magma with the solutions separated from the subductiong plate (Pearce et al., 1990; Edwards et al., 1991) is 0.04-0.012 and this value is more than MORB (0.03). The low Ti and Zr rates of the samples point out a low melting. Low melting also indicates low crustal thick-

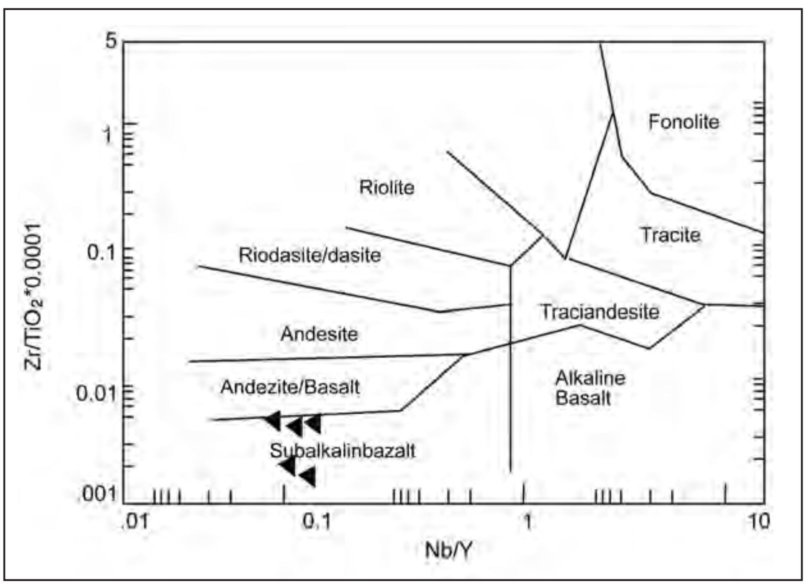

Figure 5- Nb/Y-Zr/TO2*0.0001 diagrams of gabbro (Winchester and Floyd, 1975).

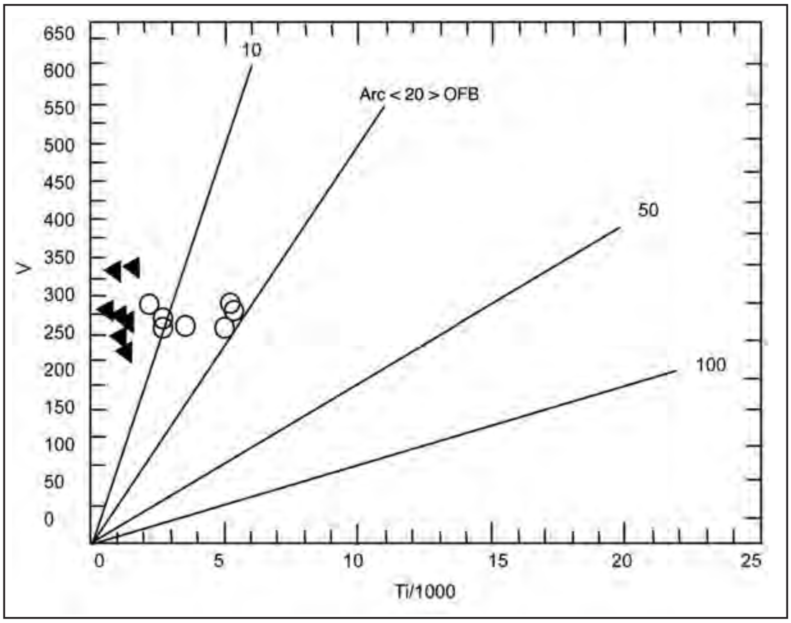

Figure 6- Tectonic diagrams of Plajiogranites (circle) and gabbros (triangle) (Floyd and Winchester, 10975). OFB: Oceanic Floor Basalts

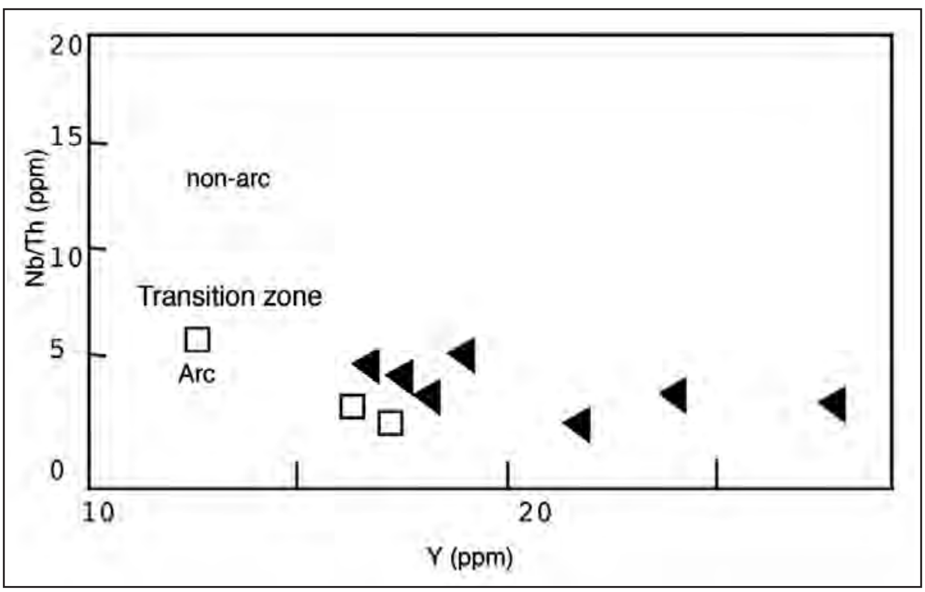

Figure 7- Nb/Th-Y diagram of gabbro and plagiogranites (Jenner et al., 1991 partly changed from). Gabbro (triangle), plagiogranite (square).

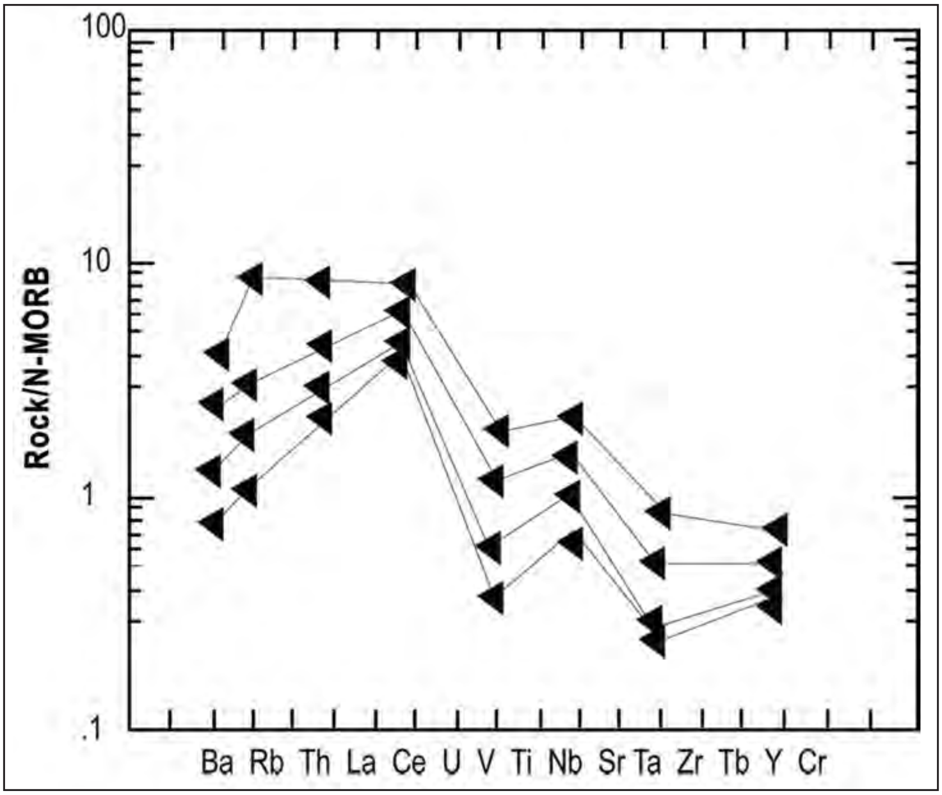

Figure 8- N-MORB normalized diagram of gabbros.

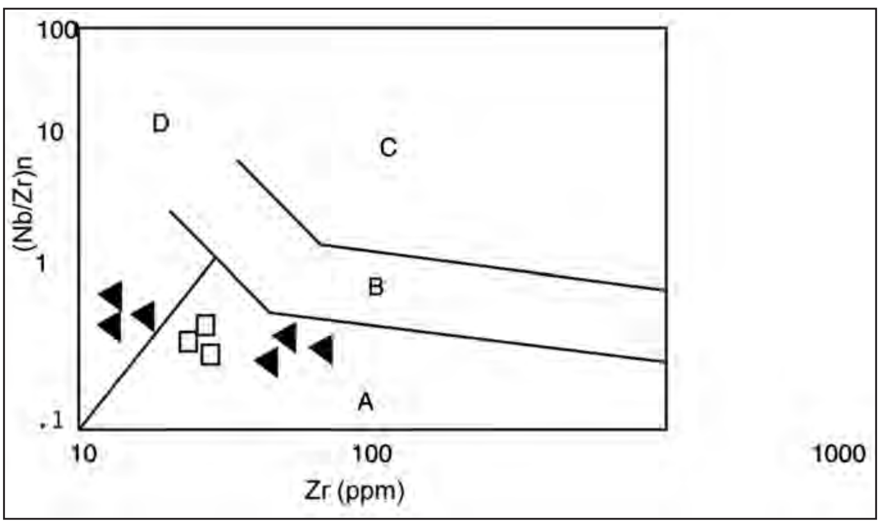

Figure 9- (Nb/Zr) n-Zr diyagrams of gabbros (triangle) and plagiogranites (sqare). A: Subduction zone volcanic and plutonic area, B: Continent-continent corossion area. C: Plate interior plutone and lava area, D: Continent-continent collosion peralümina rocks (Jenner et al., 1991)

ness (Rheid and Jackson, 1981) and change in composition of magma is related to interaction of subducting plate and mantle, composition of subducting plate, enrichment by components coming from the mantle, and depletion rate of mantle. Low concentration of elements coming from the mantle such as Nb, Ti, Y and Yb indicate a depleted mantle resource.

When trace element contents of the plagiogranites observed at the upper levels of the gabbros the most conspicuous property is their low Rb contents. On Rb/Sr diagram, the whole samples are below the line which defines the 0.1 ratio. This ratio is used by Pedersen and Malpas (1984) for discrimination of the plagiogranites formed by partial melting and the plagiogranites formed by fractional crystallization (Figure 10). In all plagiogranites which were assumed to have formed by differentiation of basic magma the Rb/Sr is less than 0.1 (Göncüoğlu and Türeli, 1993).

When the rock/chondrite diagram of the gabbros and plagiogranites of the Guleman ophiolite was studied, it is seen that the plagiogranites are richer in Rare Earth Elements (REE) compared to gabbros (Figure 11). Observing the gabbros along a rather flat curve compared to plagiogranites can be explained by rather less decomposition of the hornblend and/or opaque minerals (Rao et al., 2004).

In ORG (ocean ridge granites)-normalized diagram of plagiogranites (Figure 12) it is observed that the Nb and Ta values are negative. Besides Nb and Ta, negative values of Eu indicate subduction zone (Schilling et al., 1984; McCullough and Gamble, 1991). It is observed that these rocks have been depleted by high

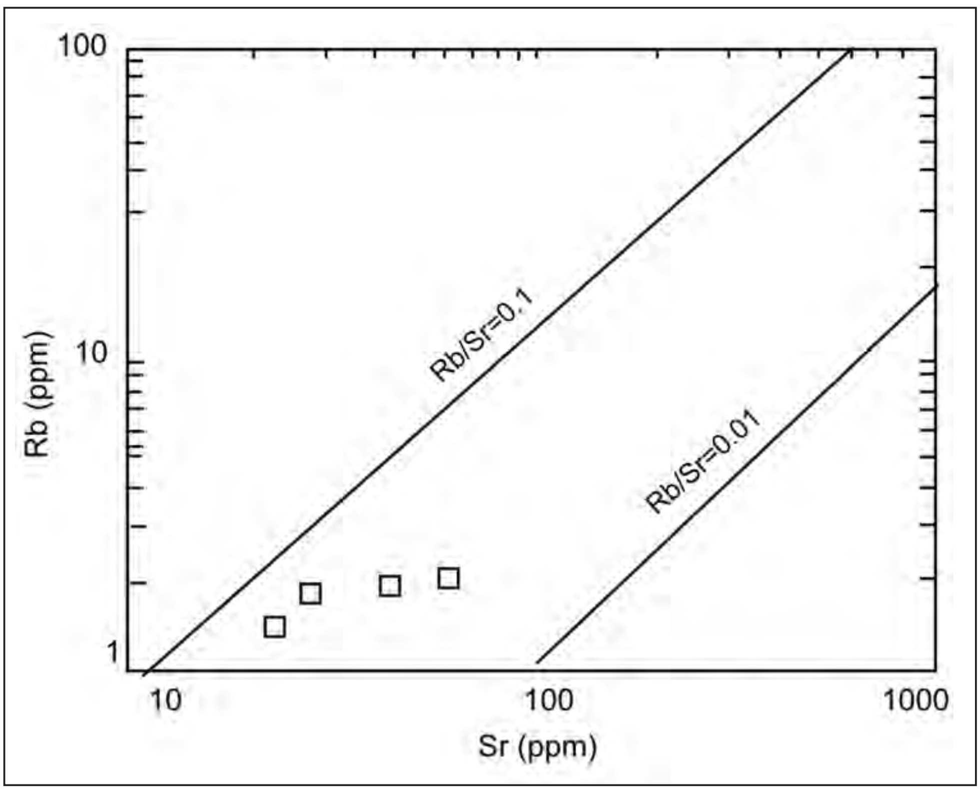

Figure 10- Rb-Sr diagrams of plagiogranites (Pedersen and Malpas, 1984).

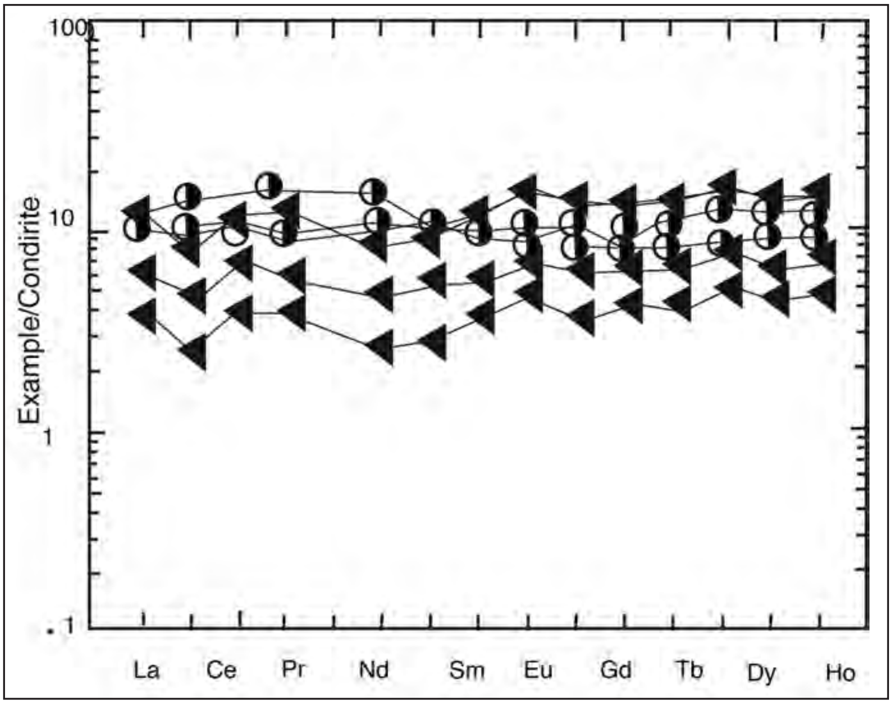

Figure 11- Normalized diagrams of gabbros (triangle) and plagiogranites (circle). (Sun and McDonough, 1989).

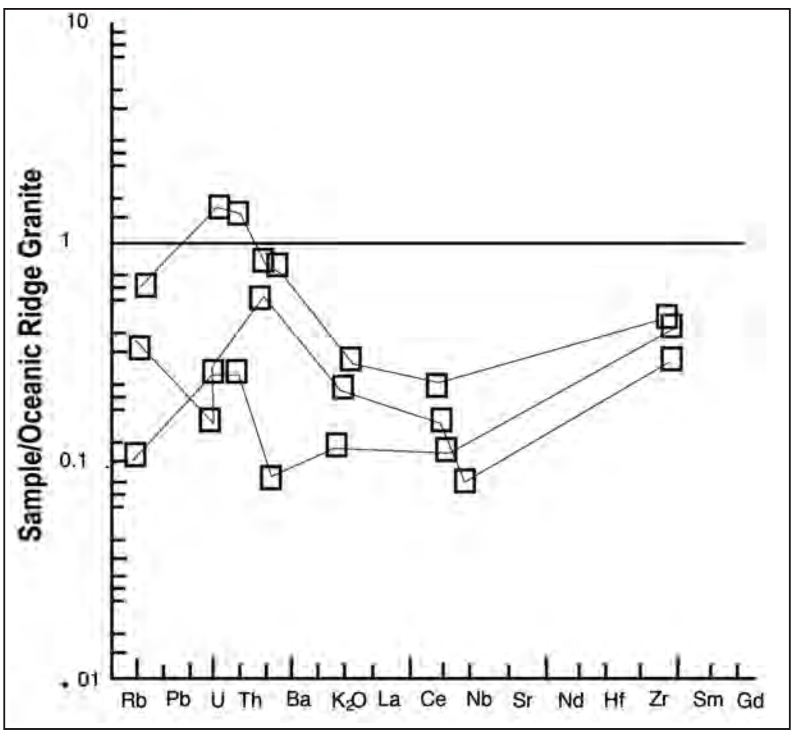

Figure 12- Incompatible elements according to occean ridge granites (from Pearce, 1982).

fastness elements (HFSE) and enriched in large ion radius elements (LILE). This depletion and enrichment is interpreted as a consequence of subduction by Pearce (1982) and Hawkesworth et al. (1977). Another possibility for LILE enrichment is the process of contamination (Wilson, 1989). Zr/Nb-Y/Nb and Rb/Y-Nb/Y diagrams (Figure 13) define the contamination processes. These data indicate the addition of crust components to the solution to separated from the subducting slab. Because the negative Eu anomali also indicate the contamination (Pearce and Parkinson, 1993).

In the Rb-Y+Nb diagram prepared for acidic origin rocks by Pearce (1982) (Figure 14) the plagiogranites take place in volcanic arc granite (VAG) area. The structural position of the gabbros in the Guleman ophiolite and acidic rocks which are collected under the name of plagiogranite, and the Rare Earth element (REE) content show that they have formed by partial melting of some basic rocks located at the upper levels of the subduction zone below the island arc with the effect of the solutions separated from the subducted slab and water (Luchitskaya et al., 2005; Li et al., 1997). The most significant

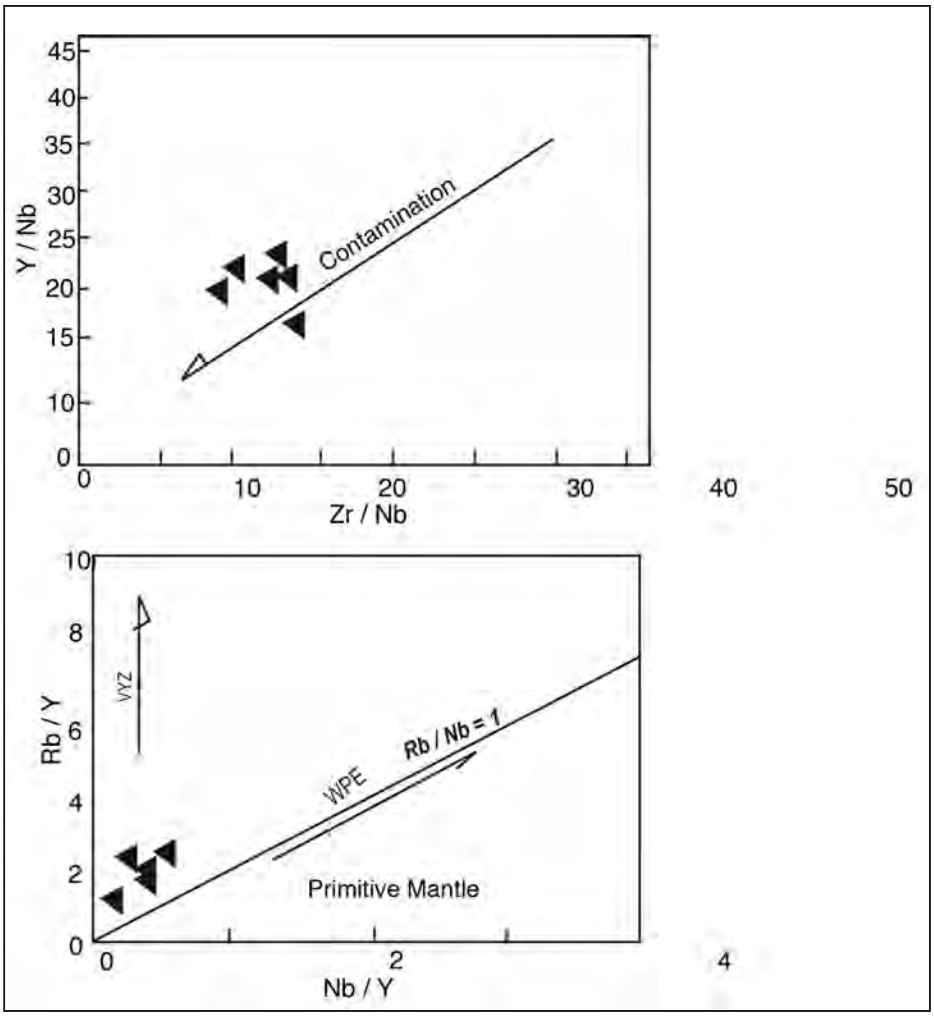

Figure 13- Gabbros of The Guleman ophiolite. Zr/Nb-Y//Nb (changed from Edwards et al., 1991) and Nb/2-Zr-Y (Mechede, 1986). Plate iunterior mid-plate enrichment ((WPE), are enrichment (VYZ.)

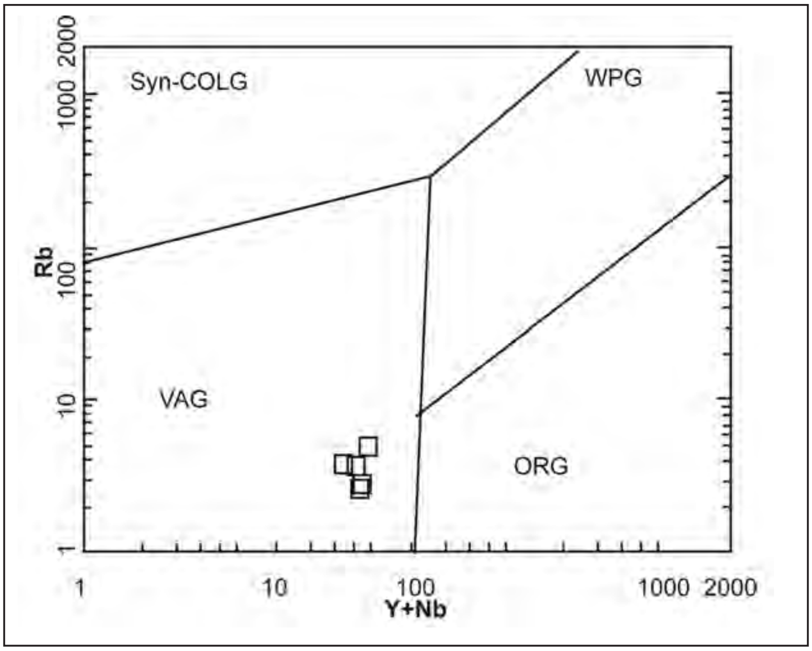

Figure 14- Tectonic environment examine diagrasof plagiogranites (interior spare square) (Pearce ve diğerleri, 1984). ORG: oceanic ridge granite, VAG: volcanic are granite, WPG: plate interior granite, syn-SCOLG: collision granite

evidences for the formation by partial melting of the basaltic rocks are the depletion of these rocks by Rare Earth Elements (REE), high La/Yb and Sr values and low Y value.

Therefore, when all the geochemical data were studied, it is seen that the REE concentrations of the gabbros of the Guleman ophiolite is 2-9x chondrite and that of the plagiogranites is 6-75x chondrite; and they have high REE values. As in Semail (Oman) and Troodos ophiolites, based on the similarity in REE distribution, it is possible to say these two rock types are cogenetic.

DISCUSSION AND RESULTS

The study area is located in tectonically most active region in Turkey. The region has undergone many changes by tectonic movements that have occurred since the Upper Triassic. The most significant and relevant to this work is the subduction process that began with the closure of the Neotethys (Şengör and Yılmaz, 1981; Tüysüz, 1993) and formation of a wide ophiolitic basin that began to open between the Keban and Pütürge massifs (Yazgan, 1984; Yazgan and Chessex, 1991). According to these researchers, the Guleman and Kömürhan ophiolites were formed in this basin and these ophiolites were thrusted over the Arabian platform during Campanian. Some researchers indicate that the ophiolite formation in the region can not be explained only by a an oceanic opening (Perinçek and Özkaya, 1981; Şengör and Yılmaz, 1981; Aktaş and Robertson, 1984; Turan and Bingöl, 1991). These researchers claim that these ophiolites might have formed in two different subduction zones. While the Guleman ophiolite has formed in a small ocean opened between Keban and Pütürge Metamorphics, the other ophiolites (e.g. Koçali ophiolite) have formed on the oceanic crust located between Pütürge and Arabian platform.

Bingöl (1984) states that Guleman, Kömürhan and İspendere ophiolites, since the Upper Triassic, have formed on an oceanic floor that has opened between Bitlis-Pütürge massifs with a high rate and, since the Upper Cretaceous this oceanic floor has first broke up to form a subduction northward and as a consequence of this subduction Baskil granitoid was formed and by the end of the Upper Cretaceous, Baskil granitoids and the ophiolites emplaced on the Bitlis-Pütürge massifs southward. Yılmaz et al. (1992) claims that these Late Cretaceous ophiolites (Göksun, Kömürhan, İspendere, Guleman, etc.) are similar in age, lithology and metamorphism and they all formed by the gradual extinction of the south branch of the Neotethys on the oceanic subduction zone dipping northward. Şengör and Yılmaz (1981), Yılmaz et al. (1992), Parlak et al. (2008), Robertson et al. (2007) state that, although these ophiolites display differences in metamorphism grades, distributions, existence or inexistence of sheeted dyke complexes and volcanic rocks, they all have formed as consequences of thrusts during the orogenic movements between Late Cretaceous and Late Miocene.

Rocks related to Late Cretaceous arca re the basic, neutral and acidic extrusive and intrusive rocks. While the extrusive rocks were defined as "Elazığ unit" by Robertson et al. (2007) the intrusive rocks were defined as "Baskil Magmatic Rocks" by Aktaş and Robertson (1984) and Yazgan (1984) and as"Elazığ Volcanic Complex" by Hempton (1984, 1985) and as "Elazığ Granitoid" by Turan and Bingöl (1991) and Beyarslan and Bingöl (2000). The intrusive rocks known as Baskil granitoid are the I-type calcalkaline rocks that cut the Taurid platform, ophiolites and the extrusive rocks in the north. These rocks are And type active continental margin rocks (Yazgan, 1984; Yazgan and Chessex,1991; Beyarslan and Bingöl, 2000; Robertson et al., 2007). The gabbros in the study area are the extensions of the opholitic series, their mineralogical and geochemical features indicate that these gabbros do not belong to Baskil granitoid.

Presence of harzburgites as mantle rocks in Guleman ophiolite and, presence of thick gabbros with different textural and mineralogical composition, the geochemical features, indicate that this ophiolite is of "Harxburgitic Type Ophiolite" which is one of the supra-subduction zone ophiolites which developed based on the opening of the upper section of the crust as a result of the subduction.

As a result of the petrographical and geochemical study of the plagioclase-rich leucocratic rocks located at the upper levels of the gabbros and isotrope gabbros of the Guleman ophiolite, it was found out that these rocks are products of island arc magmatism related to subduction zone. Besides, presence of acidic rocks and location of the samples in volcanic arc granitic area (VAG) (Figure 14) indicate island arc activity.

The leucocratic rocks we define under the name of plagiogranite are interpreted to have formed as a result of the activity in the upper levels of the magma chamber (Floyd et al., 2000). Plagiogranites may form by the partial melting (5-15%) of the gabbroic source rocks or by fractional crystallization (Floyd et al., 2000).

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COASTAL SALT WEATHERING OF QUATERNARY EOLIANITE (BOZCAADA ISLAND) AND EOCENE SANDSTONE (GELİBOLU PENINSULA): THE CONTRIBUTION OF MICROANALYTICAL DATA

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ABSTRACT.- In this paper, factors controlling the diverse dissolution of Quaternary eolianite and Eocene sandstone in two different coastal environments in northwest Turkey were investigated by means of Energy Dispersive X-Ray Spectroscopy (EDX) coupled with Scanning Electron Microscopy (SEM), X-Ray Diffractometry (XRD), X-Ray Fluorescence Spectroscopy (XRF) analyses and thin section interpretations. With regard to governing agents of the weathering process, petrographic attributes, salt crystallization and biological impacts appear to be important. The weathered forms were found to be distinctive in size, shape and the degree of weathering owing to different mineral compositions of the host rocks and combined effects of sodium chloride (halite) and calcium sulphide (gypsum) crystallisation during the dry summer period when evaporation conditions dominate.

Key words: Eolianite, salt weathering, microanalysis, Bozcaada Island, Gelibolu Peninsula, Turkey.

INTRODUCTION

In coastal areas, sandstone weathering is controlled by a wide range of factors, such as petrography of the host rock, wind erosion, exfoliation, frost and thaw, biological activities and salt weathering. The impacts of crystallized sea salt on cavity development have been emphasized by several researchers (Evans, 1970; Mustoe, 1982; Mc Greevy, 1985). As an indurated coastal dune deposit, formed as a result of carbonate cementation, eolianite is also a kind of sandstone in petrographic composition and its mechanism of dissolution and resultant forms bear comparison with the weathered cavities that develop on coastal outcrops of various sandstones. However, compared to the numerous studies on weathering of coastal sandstone outcrops, our knowledge of the weathering of eolianite remains relatively limited.

In this paper, (a) we present two case studies from NW Turkey that shed light on factors controlling disintegration of Quaternary eolianite, located on the south coast of Bozcaada Island (lat. 39°48'51'' N to 39°48'42'' N, long. 26°00'12'' E to 26°00'26'' E) and (b) Eocene sandstones outcropping on the west coast of Gelibolu Peninsula (lat. 40°19'00'' N to 40°18'58'' N, long. 26°12'54'' E to 26°13'10'' E) to contribute to the discussions on coastal weathering of sandstones (Figure 1a). For both types of rock, we discuss the effects of physical disintegration induced by crystallization of sea salt, petrographic composition, and structural weaknesses based on field data, thin section interpretations and several analytical studies.

SITE DESCRIPTIONS

CAPE ZUNGUMA

Bozcaada Island is located 4 km west of the Biga Peninsula (western Turkey) and shows close geologic and geomorphologic relationships with that region. The geology of the island, as described by several authors (Erguvanlı, 1955; Kalafatçıoğlu, 1963; Saltık and Saka, 1972), consists of several lithologic units that range in age from Palaeozoic to Holocene. Palaeozoic metamorphic rocks (marble and schist) and underlying serpentine form the visible basement and are unconformably overlain by conglomerate, limestone and flysch of

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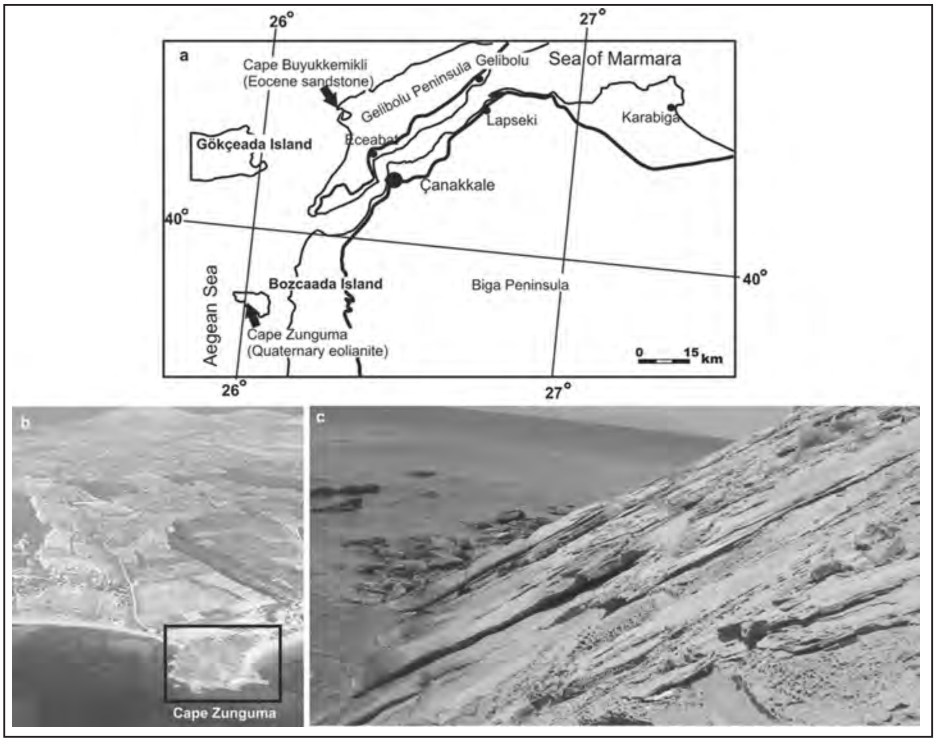

Figure 1- (a) Locations of the study sites; (b) oblique aerial photograph of the Cape Zunguma comprising Quaternary eolianite; (c) Eocene sandstones with honeycomb cavities at Cape Büyükkemikli.

Eocene age. Upper Miocene formations consist of conglomerate, sandstone, claystone, limestone and andesite. The western part of the island is occupied by recent coastal dunes. In previous publications, Cape Zunguma (Figure 1b), however, was not mapped in detail and was erroneously depicted as composed of Miocene deposits. A recent study, however, demonstrated that these outcrops consist of eolianite units of Late Pleistocene age, based on luminescence data (Kiyak and Erginal, 2009).

According to climatic data recorded at Bozcaada meteorological station (Geographical coordinate: 39°50' N and 26°04'E) for the period between 1975 and 2003, the area receives annual average precipitation of 462.5 mm. Maximum and minimum precipitations occur in winter (December: 89.4 mm) and summer (August: 5.5 mm) seasons. The average temperature is 15.4 °C. The coldest and the warmest months are February (8.3 °C) and July (23 °C). The island is one of the windiest areas in Turkey. The prevailing wind activity is from northeast. The number of stormy and strong windy days is 86.5 and 156.5, respectively.

CAPE BÜYÜKKEMİKLİ

Eocene sandstone crops out at the western end of the SW-NE-trending Gelibolu Peninsula in the northwestern part of Turkey (Figure 1c). Honeycomb cavities most commonly occur on the south-facing slope of Cape Büyükkemikli. The geology of the area and its surroundings has been previously studied by Önem (1974) and Sümengen and Terlemez (1991). The Eocene sandstones with honeycomb cavities crop out along the 3.3 km-long coastline of Cape Büyükkemikli. Elevations range from sea level to 15-20 m at the top of cliffs. Wave-cut platforms that can be observed about 30 m offshore to the south are conspicuously developed on seaward-inclined surfaces of sandstone ledges (Erginal et al., 2007).

In the absence of a meteorological station in the area studied, data obtained from the Gökçeada Meteorological Station (located 14 km west of the study area) indicates that the area receives an average precipitation of 737.9 mm per year. Maximum precipitation occurs in November, December and January. The amount of monthly average precipitation varies between 100 and 140 mm in these months. The area receives the lowest rainfall in the period from June to August, between 11 and 17 mm. The average temperature is 15.1 ºC. The yearly temperature range is from 24.6 ºC to 6.7 ºC in summer and winter periods, respectively. The frequency distribution and velocity of wind activity is predominantly from NE and SW.

METHODS

Several field surveys were carried out to note geo-environmental characteristics of the sites studied and to collect samples for analytical examination. Petrography of samples was determined by microscopic examination of thin sections. Energy Dispersive X-Ray Spectroscopy (EDX) and X-ray diffractometry (XRD) were used for major, minor and trace element characterization of samples collected. Scanning electron microscopy (SEM) was performed to characterize micro-porosity, micro-fractures and traces of microscale weathering on cavity walls. These analyses were performed in the mineralogy, petrography and technology laboratories of General Directorate of Mineral Research and Exploration, Turkey. To determine chloride ion concentration, the Mohr method (Skoog et al., 2000) was utilized. Ca, K, Mg and Na concentrations were determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES, Varian Axial Libery II Series).

RESULTS AND DISCUSIONS

MORPHOLOGIC CHARACTERISTICS OF WEATHERING FEATURES

Quaternary Eolianite

The eolianite, located on Bozcaada Island, comprises the N30E-aligned Cape Zunguma with a total area of 32120 m^2, constituting a promontory some 220 m long, backed by sandstone and limestone of Miocene age (Figure 1b). Several diagnostic features of this rock, such as foresets having angles between 15° and 20° and abundant content of rhizoliths as organo-sedimentary structures, reveal its eolian origin (Kiyak and Erginal, 2009).

Morphologically, the northern coast of the cape is dominated by 2-5 m-high sea-cliffs. Its western and southern parts are, however, formed by wave-cut platforms with elevations between 0 and 2 m, where weathered features occur (Erginal, 2008).

Weathered forms are represented mainly by dissolution cavities that display variable physical dimensions and shapes. In many places, these cavities are completely or partly occupied by sea water, thick salt accumulations within them are very common. From the wave splash zone to nearly horizontal surfaces, cavities occur preferentially on wave-cut platforms (Figure 2 a and b). Because of intensive dissolution, the surface of these platforms is quite irregular and marked by the presence of elongated cavities and irregular-shape connected pits, which are widespread along structural weaknesses that allow the penetration of sea water. Both diameters and depths of the weathered cavities range from a few cm up to over 1 metre. Honeycomb-like forms are absent.

Eocene sandstone

Weathering forms on the Eocene sandstones are characterized by the common presence of honeycomb cells (Figure 1c). Along the wave-splash zone (0-1 m) on the surface of dipping

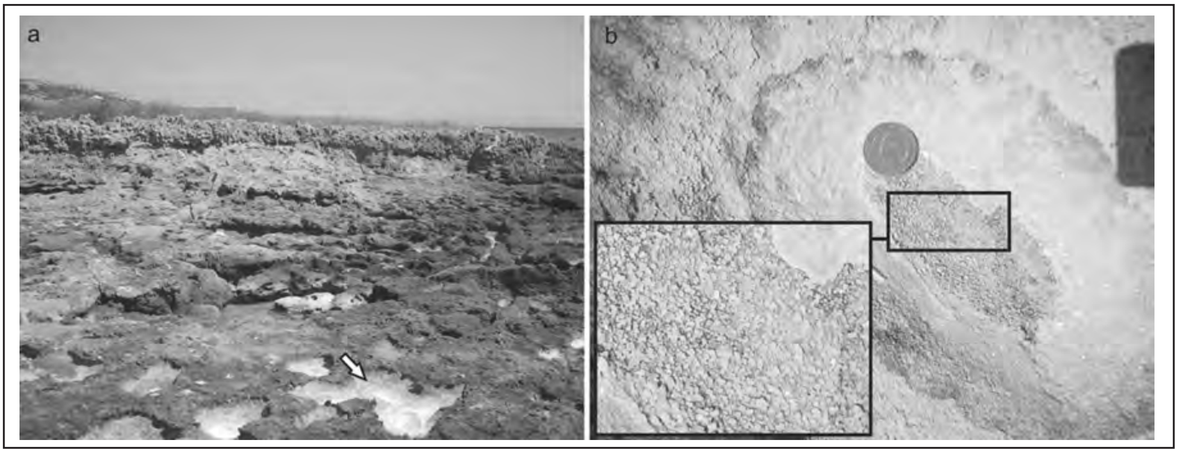

Figure 2- (a) View of numerous weathered cavities on wave-cut platforms; (b) a closer view of a cavity occupied by sea salt precipitates.

planes with N60°E trend and 37° dip, the lengths of honeycomb cells range from 15 to 65 mm, widths from 15 to 50 mm, and depths from 10 to 45 mm (Erginal et al., 2007). Although they have circular or joint-controlled ellipsoidal shapes in general, the walls of cells are partly irregular due to the activities of rock barnacles, such as Semibalanus balanoides (Linnaeus 1758) and the gastropod Littorina neritoides (Linnaeus 1758).

In some places, larger cell sizes (length: 3.5 cm-10 cm, width: 2.5 cm-8 cm, and depth: 1.5 cm-6 cm) are present, likely related to the more abundant presence of rock barnacles. These bioeroders, especially Balanus populations, settled on southwest faces or in the bottoms of cavities conforming to east-west trending fractures. Closely spaced cells with sharp wall boundaries are well developed as a result of the enlargement of cavities through bioerosion of cavity walls. SEM analysis demonstrates that Balanus plays a significant biologic role in the weathering of the rock. Figure 3a shows evidence of this bio-erosion by the abundance of rock fragments surrounding the organism. It was also observed that the surfaces inhabited by Balanus are marked by shallow holes where traces of both chemical weathering and physical disintegration are present (Figure 3b).

MICRO-ANALYTICAL RESULTS RELATING TO SALT WEATHERING

Quaternary Eolianite

Thin section analyses show that the studied eolianite is lithic arenite in composition according to the classification of Pettijohn et al. (1987). The rock consists mainly of fragments of quartz, plagioclase, orthoclase, and, in lesser amounts, microcline, epidote, chloride and leucoxene. These mineral fragments constitute 40% of the petrographic composition. Several angular rock fragments such as quartzite, schist, micritic limestone, various magmatic rocks and microfossils are also found that make up the other 60%. Limestone fragments are predominant. All these components are found together by sparitic calcite and meniscus cements.

XRD data (Figure 4a) also demonstrated the widespread presence of calcite and quartz within the rock. The weathering residue deposited within cavity bottoms yields main peaks of quartz, calcite and, to a lesser amount, other accessory minerals such as rutile (Figure 4b). However, other minerals detected in thin sections were not identified in the XRD diffractograms, which reveal that the weathering of the rock is widely associated with dissolution of Ca.

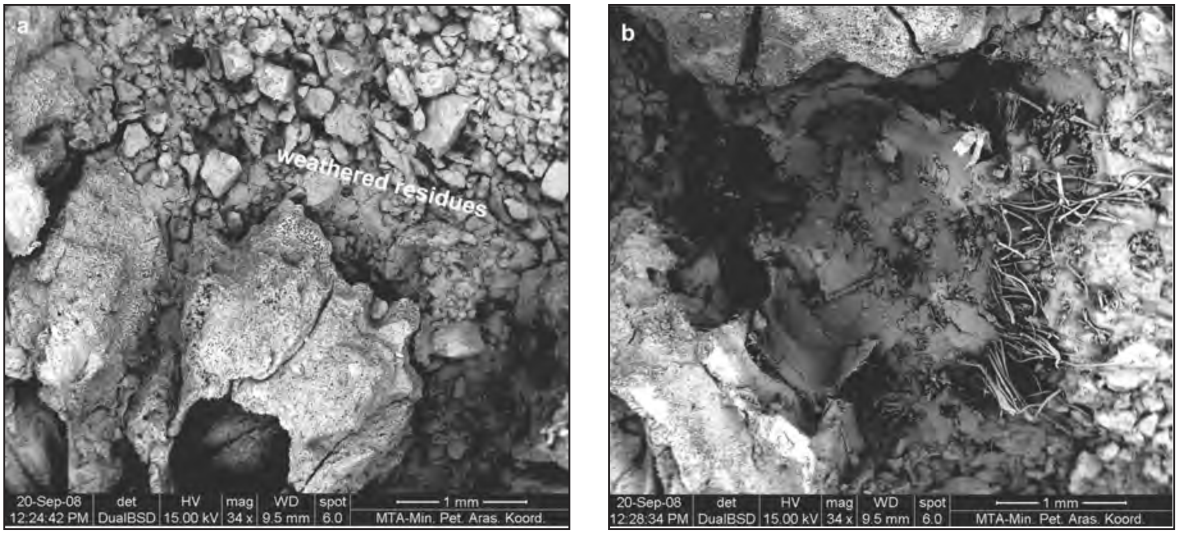

Figure 3- SEM images of Eocene sandstones; (a) weathered residues around, and (b) underneath a cavity caused by the rock barnacle Semibalanus balanoides.

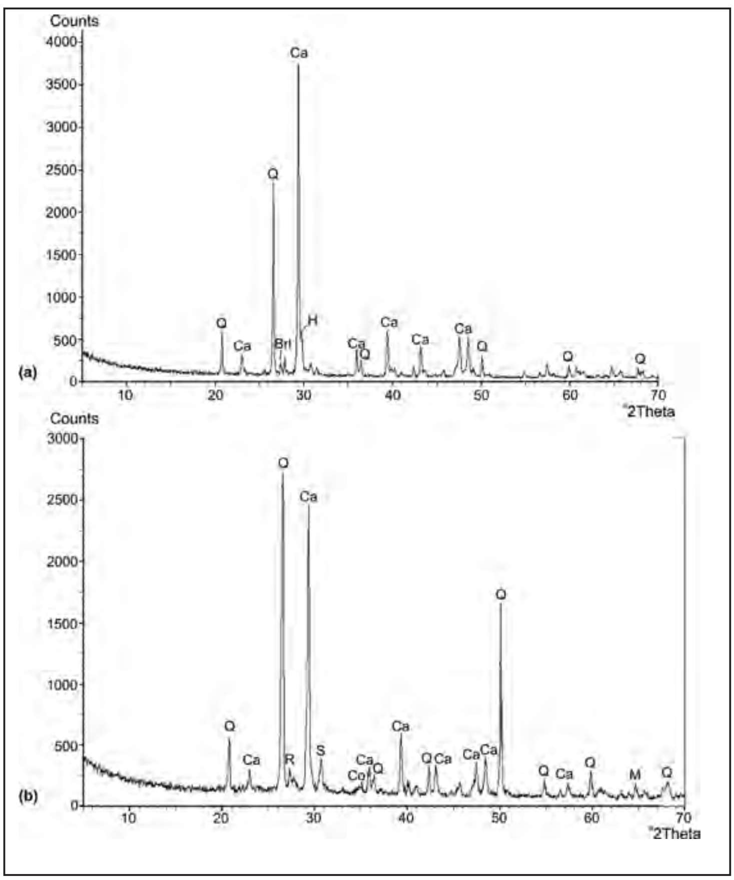

Figure 4- XRD diffractograms of eolianite (a) and its weathered product (b).

According to ICP-AES analysis, salt samples extracted from cavity bottoms contain Ca (3.546 ppm), K (12.450 ppm), Mg (7.942 ppm), Na (358.607 ppm). The Mohr method (Skoog et al., 2000), used to determine chloride ion concentration, revealed that Cl is found in an amount of 570 ppm. Based on these values, the analyzed salt is composed of NaCl (91 %), KCl (2.4 %), $CaCl_2$ (0.98 %) and $MgCl_2$ (3.3 %). The predominance of halite (NaCl) is confirmed by the EDX data, which also showed the existence of gypsum ($CaSO_4.2H_2O$). Thus, physical disintegration of eolianite is closely associated with the combination of halite and gypsum, as confirmed by SEM images (Figure 5a and b), showing a precipitated thick (max. 1 mm) salt crust over the rock surface and within micro-cavities. These observations indicate that the combined effects of halite and gypsum precipitated by the evaporation of sea water play an important role on the physical disintegration of eolianite in the study area, as previously emphasized elsewhere by Goudie et al., (1997), Goudie and Viles (1997) and Robinson and Williams (2000).

Eocene sandstones

To make a comparison with eolianite weathering, salt weathering on the surface of sandstone beds exposed on the Gelibolu coast was studied. The sandstone unit, underlain by siltstones with thin or laminated bedding features, is a yellow, fine-grained, calcite-cemented, moderately-sorted sub-greywacke according to Folk et al. (1970) classification. It is made up of predominantly quartz and plagioclase with trace amounts of biotite and muscovite. Lithoclasts of serpentine, chert and metamorphic rocks are also abundant. Beds are generally a few cm to 50 cm thick and dip from 30° to 50° toward the southeast. Honeycomb type of weathering is predominant (Erginal et al., 2007).

Salt crystallization induced by wind-enhanced evaporation of saline solutions deposited by sea spray is significant in development of honeycomb weathering in the coastal environment, as pointed out by several researchers (Mustoe, 1982; Matsukura and Matsuoka, 1991; Rodrigues-Navarro et al., 1999; McBride and Picard,

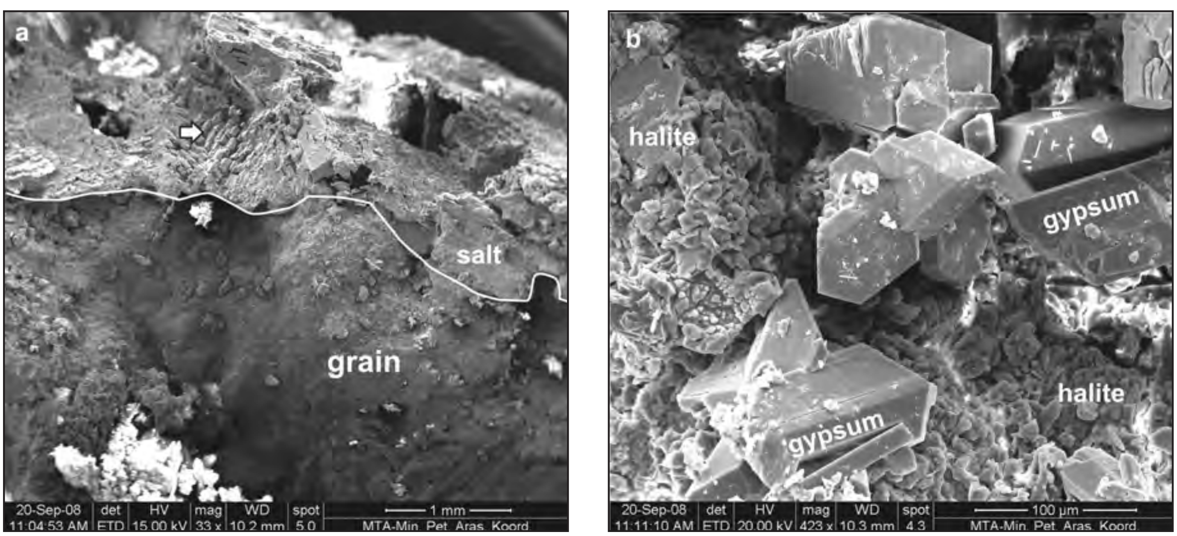

Figure 5- SEM images of eolianite; (a) the interface between salt crust and eolianite; (b) halite and gypsum crystals occupying micropores.

2004). EDX analyses carried out on salt samples collected from the honeycomb cells in August 2008, the driest period in this study area, demonstrated Na and Cl as the main constituents of the composition with total amounts of 39.31 % and 60.69 %, respectively. However, another sample yielded a more complex mixture comprising O (47.24%), Na (1.04%), S (22.46%), Cl (0.73%) and Ca (28.53%), suggesting the composition of gypsum ($CaSO_4.2H_2O$). Thus, it can be stated that salt precipitations involve both halite and gypsum, similar to those seen in the weathered eolianite.

SEM images (Figures 6 a and b) demonstrate the shapes and dimensions of halite and gypsum crystals. The salt encrustations with maximum thickness of 100Ìm were composed of cubic crystals of halite with sizes between 10 Ìm and 30 Ìm (Figure 6a). The interfaces between salt encrustations and the sandstone body are commonly voided and most of the voids are occupied by salt crystals. The cube-shaped crystals of halite are also covered with prismatic gypsum crystals, connected to each other with thin filament-like forms. The chain– shaped circular structures formed by halite crystals (Figure 6b) appear to coat the walls of weathering cells, which suggests that physical disintegration caused by pressure of crystallized salt within the micro-pores of the host rock is the most common mechanism of salt weathering (Evans, 1970; Bradley et al., 1978; Mustoe, 1982; Mc Greevy, 1985).

CONCLUSIONS

This study demonstrates that the Quaternary eolianites and Eocene sandstones from the study area exhibit significantly different coastal weathering features. In particular, the Eocene units are characterized by honeycomb weathering cells whereas the Quaternary eolianites lack honeycomb cells but display abundant, larger but more heterogeneous dissolution cavities, many of which have exploited structural weaknesses within the rock.

Precipitation of halite and gypsum from penetrating salt-spray appears to be the principal agent of destructive weathering in both types of deposit but physical bioerosion by molluscs

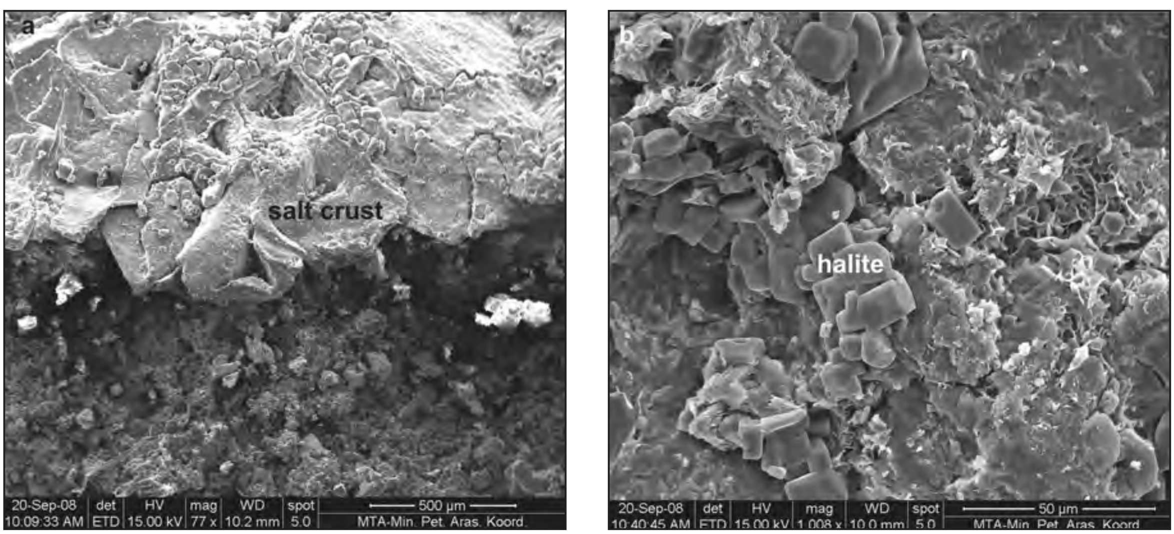

Figure 6- SEM images showing coastal salt weathering on Eocene sandstones; (a) the interface between salt crust (top) and sandstone; (b) arcuate arrangement of halite crystals on the wall of a honeycomb cell developed in micropores within sandstone.

(barnacles and gastropods) is also important in enlarging chemically formed cells, especially in the Eocene sandstones. In contrast, the close-spaced strata and cross-bed planes that characterize the eolianites favour leeward-drainage of impacting sea-water and saline spray. This feature, together with the higher carbonate content of the eolianites, leads to large-scale dissolution and rapid enlargement of weathering cavities in these Quaternary units.

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We thank Dr. Yusuf Dilgin for his help with determination of chloride ion concentration using the Mohr method. Dr. Okan Zimitlioğlu is thanked for painstaking efforts in thin section studies and EDX/SEM analyses. This paper was supported by Çanakkale Onsekiz Mart University Research Foundation (Project number: 2008/32).

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MINERALOGICAL AND TECHNOLOGICAL PROPERTIES OF THE ZEOLITES FROM FOÇA (İZMİR), BİGADİÇ (BALIKESİR) AND GÖRDES (MANİSA)

Günnur ULUSOY* and Mustafa ALBAYRAK**

ABSTRACT.- Technological analyses of zeolites are important for their areas of use. Zeolite samples were collected from different regions (İzmir-Foça, Balıkesir-Bigadiç, Manisa-Gördes) for this study.

First mineralogical and chemical analyses of the samples were conducted in the study. Later on, technological tests of the samples were made for their utilizing in ceramic industry (pre- technological), in paper industry (filling and coating) and as cat litter. Finally the results were evaluated.

It was concluded that some samples can be used in baked ceramics in ceramic industry; they have high whitening properties to be used in paper industry. As for cement additives, their flexural strength is observed in a range between 0,94 - 12,85 kgf/cm^2 while their compressive strength is between 2,08 - 51,20 kgf/cm^2. Porosity of some samples are above 40% which means they meet the criteria to be used as soil conditioners.

Key words: Zeolite, Foça, Bigadiç, Gördes

INTRODUCTION

Zeolites which are defined as hydrous aliminium silicates with alkaline and earth alkaline elements are among significant industrial raw materials because of their physical and chemical properties.

In this study the zeolite samples collected from İzmir (Foça), Balıkesir (Bigadiç) and Manisa (Gördes) regions were investigated for their mineralogical and technological properties to define their areas of usage (Figure 1).

For this reason, thin sections of the samples were prepared and their mineralogical determinations, XRD and XRF analyses were performed. By thin sections and XRD analyses types of zeolites were determined. As for the technological properties, pre-technological investigation methods, water and oil absorption capacities, cat litter test, whiteness and abrasion tests, porosity and pozzolanic tests were applied to reach to the results of the areas of usage. Experiments and tests were conducted in the laboratories of the Department of MAT of MTA.

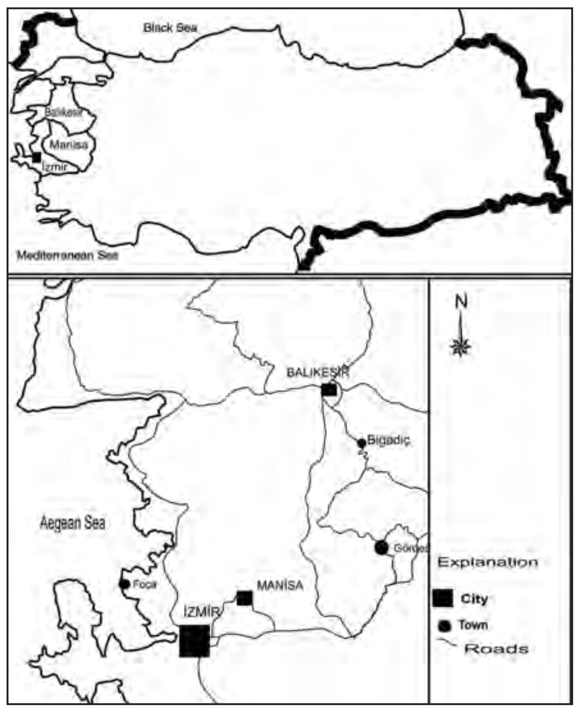

Figure 1- Location map of the study area (Foça,Bigadiç and Gördes)

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Literally the word “ZEOLITE” means “boiling rock”. The name was given to the rock since it explodes and decomposes when heated. In general, the natural zeolites are used as light building rocks and light aggregates in construction industry and as additives in paper industry and as soil conditioner and additive for fertilizers in agriculture industry (Yücel, 1987).

Zeolite minerals include empty spaces and channels in their structures. Since they can lose the water in these empty spaces and channels without changing their structures under high temperatures, based on their loose skeletal structures, they have replaceable cations. For this reason, they are succesfully used in adsorbtion, ion Exchange and dehydration areas.

Öner et al., (2000) have studied different aspects of the zeolites collected from Manisa-Gördes area in course of their project titled “Geological, mineralogical and chemical properties of zeolitic tuffs and their areas of usage in industry”.

Albayrak et al., (2001) have used zeolite (clinoptilolite) instead of quartzite to produce gas concrete during their Project titled “Production of light building Stones from zeolites”.

Kalafatoğlu et al., (2002) prepared “Bibliography of Zeolite Research” in TÜBİTAK Marmara Research Center in which, researches on zeolites in Turkey based on earthsciences; researches on characterization of zeolites in Turkey; application-oriented researches on zeolites, synthetic zeolites and zeolitic borophosphates were discussed.

GEOLOGY

MANİSA GÖRDES REGİON

The volcanosedimentary formations known as Gördes zeolites were formed by flowing and deposition of rhyolitic, rhyo - dacitic eruptions of Kobaklar Volcanism (Göktaş et al., 1996) located in the north of Gördes into the Lake Gördes which was a sedimentation basin in that period.

In Gördes and the surrounding area, metamorphic rocks (gneiss, migmatite, micaschist, quartzite) of Menderes massif are located at the basement (Figure 2).

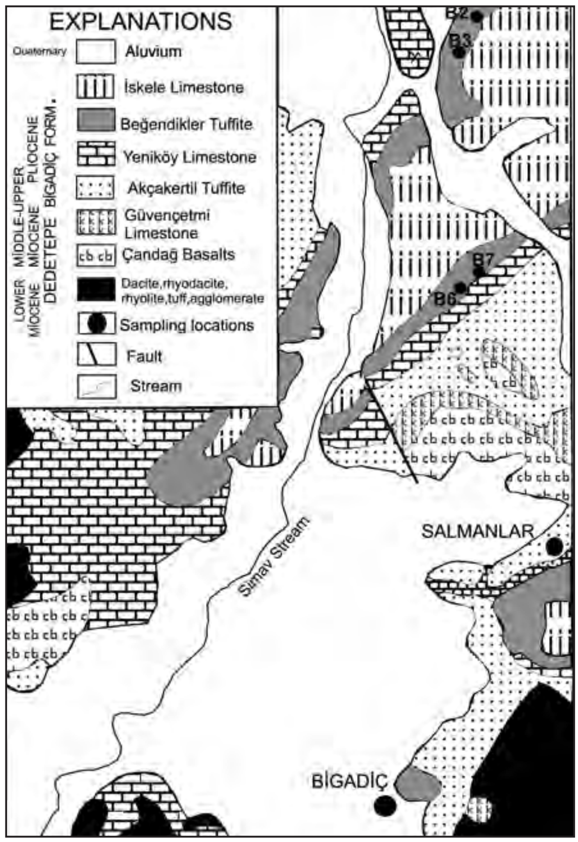

Figure 2- Geological map of Bigadiç and its surroundings and sampling locations (modified from Ercan et al., 1984).

Lower Miocene Kürtköyü, Yeniköy and Çıtak formations unconformably overlie the Menderes massif. Kürtköyü formation is dominantly composed of boulderstone, coarse conglomerate, conglomerate and sandstones. It is unconformably overlain by Yeniköy formation which is comprised dominantly of conglomerate, sandstone and mudstones which includes lignite levels. There are algal limestone interbeds at the upper levels of this formation.

Küçükderbent formation conformably and transitively overlies the Yeniköy formation. It is dominantly comprised of clayey limestone, shale, mudstone, sandstone, tuff and less bituminous shales which reflect a lacustrine environment. This unit is unconformably overlain by Gökyar formation which is made up of rhyolitic tuffs. In Manisa-Gördes region mostly clinoptilolite minerals and less hoylandite and analcime bearing levels are observed (Vural and Albayrak, 2005). Calcalkaline volcanism comprised of lava and tuffs of dacitic, rhyodacitic composition which activated in Early Upper Miocene ends the Küçükderbent lacustrine deposition. These volcanics were defined as Karaboldere Volcanics (Ercan, 1983). All these units were unconformably overlain by Upper Miocene-Pliocene sedimentary sequence.

BALIKESİR (BİGADİÇ) REGION

The sequences cropping out in Balıkesir-Bigadiç region were compiled from Ercan et al., (1984a, b) (Figure 3).

Figure 3- Geological columnar section of Gördes and the surrounding area (modified from Göktaş, 1966).

The Lower Miocene Dedetepe formation is comprised of dacite, rhyodacite, rhyolite, tuff and agglomerate. At the lower levels of the formation brown, pink, grey colored, locally altered dacite, rhyolite and agglomerates take place, on the other hand, at the upper levels tuffs are dominant. The Çandağ basalt which is located on the unit is comprised of basalt, trachy - basalt, agglomerate and tuffs, from bottom to top. The fresh surfaces of the rocks are black colored while the altered parts are red-brown. The unit is quite hard and irregular. Flow structures and hexagonal cooling (columnar jointings) structures are observed in the lavas. On these volcanic rocks unconformable lacustrine deposits known as Bigadiç formation are observed. This formation is comprised of five members. These are: Güvemçetmi Limestone Member, Akçakertil tuffite member, Yeniköy limestone member, Beğendikler tuffite member, İskele Limestone Member. Bigadiç formation is probably of Upper Miocene-Lower Pliocene age. Akçakertil tuffite member which conformably overlies the Güvemçetmi limestone member in the study area is quite widespread, its tuffite levels are light grey, white, yellowish in color and they are dacitic and rhyodacitic in composition. It is locally calcite and silicium cemented. Tuffs are also observed in Akçakertil tuffite member. The tuffs which are intercalated with tuffs have various grain size, they are glassy and irregularly distributed. Ataman (1977) determined zeolite formations in these tuffs. Beğendikler tuffite member is coarse grained in general, however fine grains also can be observed. It is formed by deposition of rhyolitic glassy tuffs in a lacustrine environment. The coarse grained and porous, thick tuffites are located at lower levels but fine grained glassy tuffites are observed in the upper levels. These levels also include zeolite (clinoptylolite) formations as Akçakertil tuffite member does. The youngest units in the study area are unconsolidated or less consolidated alluviums. Alluviums are mostly observed along Simav stream and in Bigadiç plain.

FOÇA-İZMİR REGION

In Foça region Miocene and younger units crop out. Stratigraphically andesite, basalt, rhyolite, dacite, tuff and agglomerates overlie conglomerate, sandstone, siltstone, claystone and marly sequence. At the upper levels dirty white, beige colored limestones take place. Alluviums are mostly in form of loosely consolidated blocks, pebbles, sand, silt and clay intercalations (Lengeranlı et al., 1998).

In Foça-İzmir region, the apparent + probable reserve with high clinoptilolite content is about 120 million tons (Esenli, 2002).

During the research carried out by MTA, besides clinoptilolite, presence of hoylandite and mordenite minerals were determined (Albayrak, 2008).

EXPERIMENTAL STUDIES

During the research, experimental studies were carried out on the areas of usage for the zeolites (clinoptilolite) collected from Foça, Bigadiç and Gördes regions. First, the chemical and mineralogical analyses of the samples were conducted. Second, pre-technological tests (original position and color, baking condition and color, reaction with dilute acid, dispersion in water, plasticity) and tests for usage in paper industry as filling and coating materials, and usage in cement industry and cat litter were performed.

TESTS APPLIED AND APPLICATION STAGES

1. Drying.- This is the process of drying of the samples at 105 °C in drying ovens before weigh bridge.

2. Grinding.- This is the process of grinding of the samples in ball mill until the desired grain size is reached.

3. Pre-Technology Observation Tests as Ceramic Raw Material

a- Original color and condition.- Expresses the original color and condition of the sample (crushed or as particles).

b- Dispersion in water.- Shows whether a part of the material is dispersed or not in the water.

c- Plasticity.- A small part of the crushed material is mixed with water and plasticity is examined by hand.

d- Reaction with dilute acid.- 10% dilute HCl is dripped on the sample to see whether the sample foams or not. If foaming is observed, ths is due to presence of carbonaceous material.

e- Baking condition and color.- Baking conditions and colors are observed at 1150 °C, 1300 °C, 1430 °C.

4. Water Absorption (for samples as particles) Test.- This test is conducted according to “TS699 January 1987” standard.

5. Oil Absorption Test.- This test is conducted according to “TS 2583 EN ISO 787 – 5 / December 1997” standard.

6. Cat Litter Test.- This test is conducted according to “TS 12131 / February 1997” standard.

7. Whiteness Test.- This test is conducted according to “TS 12131 / February 1997” Standard under Canadian Research Institute, Model CG – 166 reflectometer using green fitler.

8. Abrasion Test: - This test is conducted according to “TS 10521 / December 1992” standard using the “Voith Allis Valley Laboratory Equipment” at 6000 revolution.

9. Porosity Test.- This test is conducted according to “TS 699 January 1987” standard.

10. Pozzolanic Cement Test.- This test is conducted according to “TS 25 / April 1975” standard.

Tests were conducted at laboratories of Department of MAT. Mineralogical determinations of the samples were carried out in Mineralogy and Petrography Unit. Chemical properties of the samples were determined at Analytical Chemistry Unit. Thechnological properties, on the other hand, were determined in the laboratories of the Industrial Raw Materials and Ceramic Materials Research Unit.

Sample numbers, sampling locations, coordinates, 1: 100 000 scale topographical map numbers are given in table 1.

Table 1- Sampling locations, coordinates and sample numbers.

İzmir (Foça)			Balıkesir (Bigadiç)			Manisa (Gördes)		
Sample No.	Map Sheet No.	Coordinates	Sample No.	Map Sheet No.	Coordinates	Sample No.	Map Sheet No.	Coordinates
FO-17	K18	X:286 Y:345	B2	J20	X:71952 Y:98052	KIR-3	K20	X:14170 Y:10225
FO-20	K18	X:356 Y:520	B-3	J20	X:71725 Y:97977	KIR-7	K20	X:11875 Y:13168
FO-23	K18	X:728 Y:958	B-6	J20	X:68442 Y:97868	KAL-1	K20	X:4762 Y:9449
Fo-35	K17	X:79465 Y:82707	B-7	J20	X:68846 Y:98338	KAL-4	K20	X:6447 Y:8311
						KAY-9	K20	X:11169 Y:3264
						KAY-14	K20	X:14228 Y:7505
						SA-2	K20	X:8585 Y:11227

MINERALOGY

XRD analyses results of the samples are given in table 2. According to these results, it is observed that the samples in general include clinoptilolite and hoylandite minerals as well as glassy materials, quartz, opal and illite and smectite group clay minerals. Minerals are given in table 2 according to abundance in the rock.

It was observed also that, the dominant minerals in the samples from İzmir-Foça region are hoylandite, in contrast, the samples collected from Balıkesir-Bigadiç and Manisa-Gördes clinoptilolite mineral is more dominant.

GEOCHEMISTRY

Results of the chemical analyses of the samples collected from Balıkesir, İzmir and Manisa regions and their density values are given in table 3. It is observed that SiO_2 values of the samples are equal to or higher than 70% and Al_2O_3 values are higher than 10% for all the samples. Density values of the samples vary between 1.98 and 2.40, and fire loss values are between 3.40 and 9.65.

Table 2- Mineralogical descriptions of the samples based on XRD analyses.

Sampling Location	Code of the Sample	Mineralogical Description
İzmir (Foça)	FO-17	Hoylandite, Amorphous substance
	FO-20	Hoylandite, Quartz, Mica, Feldspar, Smectite group clay mineral
	FO-23	Hoylandite,
	FO-35	Opal CT, Hoylandite, Quartz, Feldspar
Balıkesir (Bigadiç)	B2 (Tülü Quarry)	Clinoptilolite, Amorph substance
	B3 (Tülü Quarry)	Amorphous substance , İllite
	B6 (Simav Quarry)	Clinoptilolite, Quartz, Amorphous substance
	B8 (Simav Quarry)	Clinoptilolite, Amorphous substance , Quartz, İllite
Manisa (Gördes)	KIR-3 (KIRANKÖY)	Clinoptilolite, Amorphous substance
	KIR-7 (KIRANKÖY)	Clinoptilolite, Amorphous substance
	KAL-1	Clinoptilolite, Opal CT, Smectite group clay mineral, Mica, Amorphous substance
	KAL-4	Clinoptilolite, Mica, Amorph substance
	KAY-9	Clinoptilolite, Amorph substance
	KAY-14	Clinoptilolite, Amorphous substance
	SA-2	Clinoptilolite, Mica, Smectite group clay mineral, Amorphous substance

Table 3- Results of chemical analyses of the samples and their density values

Samling Location	Code of Sample	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	NaO %	K_2O %	P_2O_5 %	A.Z %	Density. g/cm^3
İzmir (Foça)	FO-17	70,6	0,1	11,6	1,3	0,1	0,6	2,4	0,3	5,0	K˙0,1	8,23	2,01
	FO-20	72,2	0,1	11,8	0,3	K˙0,1	0,6	3,0	0,2	4,2	K˙0,1	7,60	2,13
	FO-23	72,0	0,2	11,5	0,9	K˙0,1	0,8	3,5	0,5	2,0	K˙0,1	8,70	2,20
	FO-35	77,3	0,1	11,5	0,5	K˙0,1	0,3	0,9	0,3	6,0	K˙0,1	3,40	2,13
Balıkesir (Bigadiç)	B-2	70,5	0,1	11,6	0,9	0,1	0,9	3,2	0,3	3,8	K˙0,1	9,26	2,01
	B-3	70,6	0,1	11,5	0,9	K˙0,1	0,9	3,0	0,4	3,9	K˙0,1	9,65	1,98
	B-6	72,5	0,1	12,1	0,8	K˙0,1	0,7	2,1	0,2	5,5	K˙0,1	5,88	2,31
	B-7	72,5	0,1	11,8	0,9	0,1	0,8	2,3	0,1	5,2	K˙0,1	6,65	2,31
Manisa (Gördes)	KIR-3	73,0	0,1	11,8	1,0	K˙0,1	0,5	2,1	0,5	4,0	K˙0,1	7,39	2,00
	KIR-7	73,5	0,1	13,5	1,2	K˙0,1	0,3	1,8	1,8	4,0	K˙0,1	3,51	2,25
	KAL-1	74,5	0,1	11,5	1,4	K˙0,1	0,8	2,8	0,1	1,3	K˙0,1	7,65	2,06
	KAL-4	73,0	0,1	11,0	1,1	K˙0,1	1,0	3,0	0,2	2,0	K˙0,1	8,98	2,30
	KAY-9	74,0	0,1	10,8	0,8	K˙0,1	0,8	3,0	0,3	2,0	K˙0,1	8,62	1,99
	KAY-14	74,0	0,1	11,6	0,3	K˙0,1	0,8	2,0	0,6	3,4	K˙0,1	7,83	2,03
	SA-2	70,5	0,1	12,3	0,7	K˙0,1	0,7	6,0	0,7	2,4	0,1	6,79	2,40

DETERMINATION OF AREAS OF USAGE OF ZEOLITE

RESULTS OF PRE-TECHNOLOGY TESTS AS RAW MATERIAL

Pre-technological examination of the samples for ceramic were carried out and the results are given in table 4. Water disperssion test of the samples is the control whether a small part of the sample disperses in the water or not. The behaviour of the sampe gives an idea about the grain size and decreases the grinding cost of a sample which can easily disperse in the water. However, no dispersion in the samples were observed (Table 4).

The crushed samples were mixed with some water and plasticity is examined by hand. After the test, it was observed that the plasticity is very little or none for the samples. Therefore, they can be used after mixing with some materials with high plasticity. The acid reaction of the samples is made by pouring some dilute acid drips on the sample and carbonate content of the samples is observed consequently.

Presence of carbonate causes cracks during and after baking. Fort his reason, materials containing carbonates are not good for ceramics. The results of the tests carried out by 10% HCl is given in table 4.

During the baking tests, the materials were baked at 1150 °C -1300 °C -1430 °C to see their colors. Figure 4 shows the colors of the samples after baking test and table 4 shows the colors and conditions after the test.

According to the results of the chemical analyses (Table 3), the Al_2O_3 content is too low to be used in ceramic industry, however, the percentage of the color providing oxides, Fe_2O_3 and TiO_2 are between the limits according to TS 5396/December 1987 standards.

Consequently, these zeolites can be taken into consideration to be used in ceramic industry at certain percentages together with kaolin.

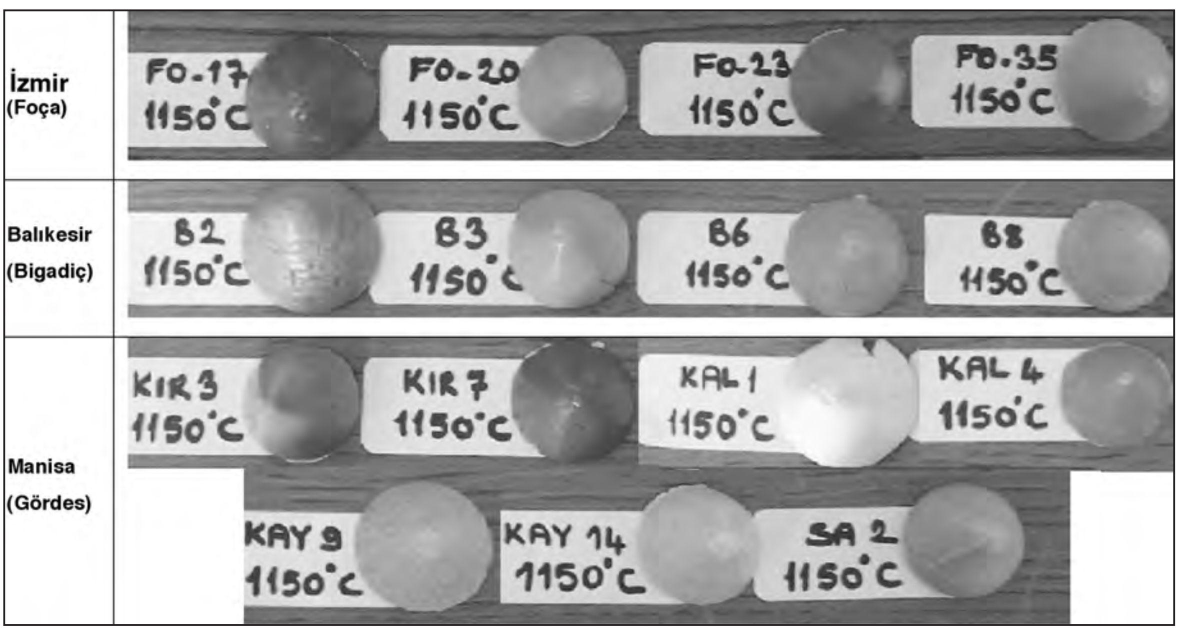

Figure 4- Baking conditions and colors of the samples (1150 °C).

Table 4- Ceiramic pre-technological evaluation of the samples

Sampling Location	Code of Sample	Original Position and Color	Dispersion in Water	Plasticity	Reaction in Acid	Baking Condition / Color		
						1150 °C	1300 °C	1430 °C
İZMİR (FOÇA)	FO-17	Coarse particles – yellowish cream	no	no	no	Light red brown / melting		
	FO-20	Coarse particles – yellowish cream	no	less	no	Greyish white / melting		
	FO-23	Coarse particles – yellowish cream	no	no	no	Dark brown / melting		
	FO-35	Coarse particles – greenish cream	no	no	no	Cream / melting		
BALIKESİR (BIGADİÇ)	B-2	Coarse particles – dark green	no	no	no	Grey spotted Brown / melting		
	B-3	Coarse particles – dark green	no	no	no	Milky brown / melting		
	B-6	Coarse particles – yellowish green	no	no	no	Light brown / melting		
	B-7	Coarse particles – black spotted cream	no	less	no	Light brown / melting		
MANİSA (GÖRDES)	KIR-3	Coarse particles – cream	no	less	no	Brown / melting		
	KIR-7	Coarse particles – light green	no	no	no	Light red brown / melting		
	KAL-1	Coarse particles – greenish cream	no	plastic	no	Yellowish white / baking	Greenish cream sinter	Melting / light green
	KAL-4	Coarse particles – greenish cream	no	less	no	Milky white / beginning of melting	Light gren / melting	
	KAY-9	Coarse particles – yellowish green	no	no	no	Grey spotted Brown / baking		
	KAY-14	Coarse particles – cream	no	no	no	Dirty white / melting		
	SA-2	Coarse particles – grey spotted	no	no	no	Dark cream / melting		

WATER ABSORPTION TEST AS PARTICLES

Water absorption tests of the samples were conducted according to "TS 699 January 1987 Natural Building Stones Inspection and Test Methods" and the results are given in table 5.

CAT LITTER TEST

The prerequisite for the samples to be used as cat litter is to define mudding in the samples. An amount of the sampe is left in the still water. In case the sample is dispersed in the water, the water absorption test is not conducted and the sample is recorded as not suitable to be used as cat litter. If no mudding is observed, water absorption test is applied. When the results are evaluated according to table 6, since the water absorption value is low, we can think that the samples can anly be used after being mixed some highly absorbent materials.

WHITENESS, ABRASION AND OIL ABSORPTION TESTS

In paper production, many industrial raw materials, mainly calcite and zeolite are being

Table 5- Water absorption values of the samples.

Sampling Locattion	Code of Sample	Water Absorption under Atmospheric Pressure	
		By Mass(%)	By Volume (%)
İzmir (Foça)	FO-17	33	39
	FO-20	31	39
	FO-23	24	31
	FO-35	8,8	16
Balıkesir (Bigadiç)	B-2	17	25
	B-3	20	28
	B-6	24	38
	B-7	19	28
Manisa (Gördes)	KIR-3	21	30
	KIR-7	23	32
	KAL-1	Dispersed in water	
	KAL-4	22	30
	KAY-9	14	21
	KAY-14	20	29
	SA-2	18	26

Tablo 6- Cat litter water absorption values.

Sampling Location	Code of Sample	% Water Absorption
İzmir (Foça)	FO-17	43,4
	FO-20	49,0
	FO-23	40,2
	FO-35	29,3
Balıkesir (Bigadiç)	B-2	33
	B-3	32
	B-6	32
	B-7	36
Manisa (Gördes)	KIR-3	37
	KIR-7	40
	KAL-1	Dispersed
	KAL-4	40
	KAY-9	37
	KAY-14	36
	SA-2	40

used. These materials are also being used as filling and coating materials.

The minerals used as filling materials are used to increase the opacity and softness of the paper, and when added to whitened paper, they are useful in increasing the whiteness of the paper, and absorption of the ink in the paper and consequently to increase the printing quality. Therefore, among the features expected from an ideal filling material, higher whiteness, grain distribution, high immersion in the pulp, non-dispersion in the water, low hardness (abrasion) and cheapness from economical point of view can be counted. For this reason, abrasion, whiteness and oil absorption tests were made to see the usage of the samples in paper industry, (Table 7).

Table 7- Whiteness / abrasion values according to TS 10521 and TS11653 standard

Standard	Class	Whiteness % (Minimum)	Abrasion (mg/100g) (Maximum)
TS 10521	Class I (for coating)	90,2	6
	Class II (for filling)	80	
TS11653	Class I (for coating)	90	10
	Class II (for filling)	85	15

When we evaluate the results of the whiteness and abrasion tests of the samples, we see that, when the values indicated in (TS10521, TS11653) standards, the whiteness values of the samples FO-20, FO-35 and KIR-3 are observed to be at usable limits. In this case, the sample FO-20 can be used for filling purposes according to TS 10521 and TS 11653 and the sample FO-35 can be used as filling material according to TS 10531 and as filling material according to TS 10521.

The abrasion values are above the values indicated in the standards, therefore the samples are considered as not suitable.

In general, as a result of the examination for the purposes of paper industry, the whiteness percentage of the samples FO-35 and KIR-3 are suitable to be used as filling material. The high abrasion index requires low additives with respect to the paper quality used for filling.

According to table 8, in order to make an evaluation for oil absorption characteristics, it must be compared with another material of which oil absorption value is known.

POROSITY TESTS

For porosity tests, the samples were dried until fixed weighing at 105±5 °C and then their porosities and unit voluminar weights were determined accordding to TS 699 January 1987 standards (Table 9). The porosity values of the samples are observed to be high.

According to the regulations published in “official newspaper” dated and numbered of 04.05.2004, 25452 about the Production, Exportation, Importation and market supply of the Organic, Organomineral Soil Conditioners including special microbial and enzymes, the porosity value must be 40% minimum to use as soil conditioner.

Table 8- Whiteness – abrasion – oil absorption values of the samples.

Sampling Location	Code of Sample	Whiteness	Abrasion (mg/100g)	Oil Absorption cm^3 /100gr
İzmir (Foça)	FO-17	66,4	142	60
	FO-20	85,6	-	60
	FO-23	76,1	85	60
	FO-35	82,0	96	40
Balıkesir (Bigadiç)	B-2	64,2	71	45
	B-3	64,5	70	65
	B-6	71,3	194	48
	B-7	67,8	151	50
Manisa (Gördes)	KIR-3	80,2	77	55
	KIR-7	66,3	161	55
	KAL-1	76,6	52	65
	KAL-4	72,5	39	50
	KAY-9	73,0	120	48
	KAY-14	75,9	237	50
	SA-2	68,0	167	55

Table 9- Unit voluminar weight and porosity percentage of the samples.

Sampling Location	Code of Sample	Unit voluminar weight (U.V.W) (gr/cm^3)	Porosity (%)
İzmir (Foça)	FO-17	1,26	37,3
	FO-20	1,33	37,5
	FO-23	1,36	38,1
	FO-35	1,88	11,7
Balıkesir (Bigadiç)	B-2	1,60	20,4
	B-3	1,48	25,2
	B-6	1,29	44,1
	B-7	1,59	31,1
Manisa (Gördes)	KIR-3	1,48	26,0
	KIR-7	1,53	32,0
	KAL-1	Dispersed in water	
	KAL-4	1,42	38,2
	KAY-9	1,62	18,5
	KAY-14	1,39	31,5
	SA-2	1,51	36,6

The research conducted by us is based on this regulation, and the porosity test results show that the sample B-6 complies with the requirements of the above mentioned regulation and can be used as soil conditioner.

PUZZOLANIC CEMENT (TRASS) TESTS

The natural zeolites are potential cement additives due to their SiO_2 and Al_2O_3 contents. They have puzzolanic features which can be defined as, because of their high SiO_2 and Al_2O_3 contents, they can form binding products when reacted with dead lime ($Ca(OH)_2$) and water. So, they can be used as puzzolans in cements and concrete systems. Addition of puzzolans to cements and concrete systems increase the permeability and workability of the concrete and similarly increase the resistance to external factors such as alkali silica reaction and sulphate effect (Uzal et al., 2003).

In puzzolanic activity tests, crushed tras (this is a silica and alumino-silica bearing tuff, a natural puzzolanic material, and it does not have any hydrolic property when it is used alone, but when crushed in to small particles, in aquaeous mediums and with calcium hydroxide under normal temperature, it starts chemical reaactions and displays hydraulic properties), dead lime mixture and standard sand is used.

The tests for it to be used as cement-additive materials are conducted according to "TS 25 – April 1975 Trass" standard. For it to be used as cement additive, the preliminary conditions are as follows:

Total % SiO_2+Al_2O_3+Fe_2O_3 must be higher than 70%,

% MgO must be 5.0 % maximum,

% SO_3 must be 3.0 % maximum, and,

% A.Z. must be 5.0 % maximum.

Puzzolanic activity of the samples were calculated according to “TS 25 April 1975” standard. According to TS 25 the flexural strength and compressive strength must be at least 10 kgf/cm^2 and 40 kgf/cm^2, respectively.

The tests to evaluate zeolite as cement additive material were started acccording to the suitability of the results of the density and chemical analyses. According to the standard (TS 25), the requested minimum 7 days compressional strength must be 40 kgf/cm^2, and 7 days flexural strength must be at least 10 kgf/cm^2.

Accordingly, when the table 10 is studied, we see that the samples FO-35 and B-2 can be used as cement additive materials.

Table 10- Results of flexural and compressive strength tests of the samples.

Sampling Location	Code of the Sample	Flexural Strength (kgf/cm^2)	Compressive Strength (kgf/cm^2)
İzmir (Foça)	FO-17	2,50	7,29
	FO-20	0,94	2,08
	FO-23	2,81	7,94
	FO-35	12,85	51,20
Balıkesir (Bigadiç)	B-2	10,45	43,20
	B-3	4,26	13,98
	B-6	5,06	16,17
	B-7	2,75	10,39
Manisa (Gördes)	KIR-3	2,68	15,62
	KIR-7	3,25	23,64
	KAL-1	1,09	8,23
	KAL-4	0,74	3,33
	KAY-9	3,78	14,38
	KAY-14	3,28	11,98
	SA-2	4.37	15.73

RESULTS AND DISCUSSIONS

Technological and mineralogical research was conducted to determine the areas of usage of the zeolites collected from İzmir-Foça, Balıkesir-Bigadiç and Manisa-Gördes regions.

The minerals determined after thin section studies and XRD analyses and the results of XRF analyses of the samples collected from the study areas were given as tables.

In this study which aims to determine the areas of usage of zeolite, research was conducted to see whether they can be used in ceramic, paper industries and as cat litter and cement additives. Some samples were found to be suitable to be used in ceramic, paper and cement industries.

As a result of the mineralogical and technological analyses the samples FO-35 and B-2 were found suitable to be used as cement additives. The sample B-6 ca be used as soil conditioner according to the regulations published in the Official Gazzette dated 04.05.2004 and numbered 25452. It was shown that the samples FO-20, FO-35 and KIR-3 displayed whiteness values which indicate they can be used as filling materials in paper industry, however, since this sample has high abrasion index, its percentage amount must be decreased depending on the type of the paper being produced.

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