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Some criteria used in determining paleoshorelines, examples from Turkey and Rhodes Island

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Research Article

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ABSTRACT

Shorelines are important boundaries separating the erosional and the depositional areas. Determining the location of the shorelines in geological time sand how it changes by the time is one of the major problems of geology. The most accurate estimate of the location of the shoreline, which is a dynamic structure, in the period when it was exist is very important in palaeogeographic studies. The determination of coastal changes by the time provides valuable information on active tectonic sand climate, and the relationships between these two. The most basic approach to determine the paleoshoreline is to estimate the geological events on the sea and land sidesand thus to estimate the location of it indirectly. For this purpose, if the physical, chemical and biological conditions of the depositional environments from land to shore and from there to the basin and which land part and how fed this environment can be revealed, the location of the shoreline can be estimated. Incontrast, some field observations provide direct and much more precise data for identifying the paleoshorelines. In this paper, it will be introduced how somerock-boring organisms, wave-cut feature sand coastal sediments can be used to estimate the paleoshorelines based on two examples of Quaternary sediments in Hatay and Rhodes Island along th Mediterranean coastand on some Eocen esediments in the vicinity of Çorum, Central Anatolia.

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1. Introduction

Although determining a "moment of time" is often not possible for the past geological events, the shortest possible "time slice" is considered as the "moment of time" and the geological events that occurred in this period are interpreted as if they occurred at this moment. For example, while preparing a paleogeographic map for the Santonian period (85.8 to 83.5 million years ago), this period of 2.3 million years is considered as a single "moment of time". The shorter the "period of time" in question to be kept to the extent of possibilities, the greater the sensitivity of the study and the value of the interpretations. One of the oldest and most reliable methods of determining time limits in geology is to reveal local or regional unconformities or discontinuities in deposition. The unconformity plane represents a wide period of time between the erosional and depositional periods. However, if the age and depositional conditions of the first sediments above the unconformity can be determined precisely, these data provide valuable information on both the location and the environmental characteristics of both the erosional and the new depositional periods.

A coast is shaped by interactive events occurring in the atmosphere, on the sea (or ocean), on the land and by their responses to these events (Davidson-

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Arnott, 2010; Absalonsen and Dean, 2011). The coasts are affected very quickly by climatic, tectonic and marine changes, the dynamics between them and even the biological activity, and they quickly change their shape as a response (McFadden et al., 2007). For this reason, when and where the paleo-shorelines were and how they changed by the time in terms of physical and chemical conditions provide valuable information about the regional conditions of that period. The main factors controlling a shoreline and causing its changes are; eustaticsea-level changes and climate; tectonic uplift and subsidence; relative erosion, transportation and precipitation rates; topography; wave activity; coastal geology; coastal fauna and flora, and weathering. In this respect, the determination of the locations and the ages of the paleo-shorelines provide valuable information about all these factors and their evolutions. This article will focus on some criteria for determination of paleo-shorelines and their evolution, with some examples from the Quaternary shores of Hatay and Rhodes Island in the Mediterranean, as well as an older example from Central Anatolia.

2. Some Criteria Used in Determining the Paleoshorelines

2.1. Bioerosion: Rock-boring and Sticky Organisms (Barrows, 1917)

A certain number of sea organisms live within the cavities they bore. Burrowing organisms live within the unconsolidated or partially consolidated sediments such as clay and sand depositing on the sea floor. The fossils of these organisms can be found at any level of a sedimentary a sequence, and they provide information about the age and depositional conditions of that level if they can be dated by any method. In contrast to the burrowing ones, the rock-boring organisms live only within the indurated rocks, usually the carbonates or coral reefs that form the sea floor or shore. In other words, rock-boring organisms live on an older solid rock substratumat the beginning of a transgressive depositional period. These organisms live at the interface of the erosional surface and sediments depositing on this erosional surface. Therefore, the information provided by burrowing and rock-boring organisms are different. Since the rock-boring organisms live along the interface between an unconformity or non-depositional surface and the marine environment, they will provide information about the age of the beginning of the deposition and the environmental conditions during the beginning of this depositional period. Perkins (1966) states that the fossils of these organisms, which have existed since Ordovician, and become widespread especially in Jurassic, Cretaceous and Tertiary, provide valuable information not only about unconformity surfaces but also non-depositional periods that developed as a result of uplifting-shallowing, and subsiding-deepening events in the stratigraphic record. On the other hand, since the rock-boring organisms live in shallow and clear waters facing the open sea, they also provide information about the characteristics of the depositional environment. Although fossils of sticky organisms, such as barnacles, are also useful, their preservation is less frequent compared to rock-boring organisms.

The bioerosion, which is a result of the mechanical and chemical functions of the rock-boring organisms, is an important part of marine deposition and benthic ecology, and is also one of the factors of long-term shaping of the shores. Rock-boring organisms are considered to be biological sea level markers indicating the paleo-shoreline (Barrows, 1917; Warme, 1975; Taylor and Wilson, 2003; Ricci et al., 2015; Smith and Ross., 2018). Although the rock-boring organisms generally prefer to live in carbonate rocks, Bolotov et al. (2018) found holes in Myanmar, which were bored by *Lignopholas fluminalis* on a siliceous foundation in freshwater environment. However, almost all rock-borers in marine environment bore into the carbonate rocks.

Rock-boring organisms form a large taxonomic group that includes bivalves, gastropods, annelids, sponges, sea urchins and others. Among these, the most common rock-borers seen in marine environments are the species belonging to Pholadidae and Mytilidae families (Photo 1). Since biological and paleontological classes of these organisms are outside the purpose of this article, all the rock-borers will hereinafter be referred to as "pholade” or "rock borer", regardless of the species and genus. More than 70 genera of the pholadidaefamily, also known as the angel wings, and more than 250 genera of the mytilidae family are among the most common ones.

In one of the valves of rock-borers, there are teeth used to grinding away the hole, which they live in. The organism enlarges the hole in the rock both by grinding

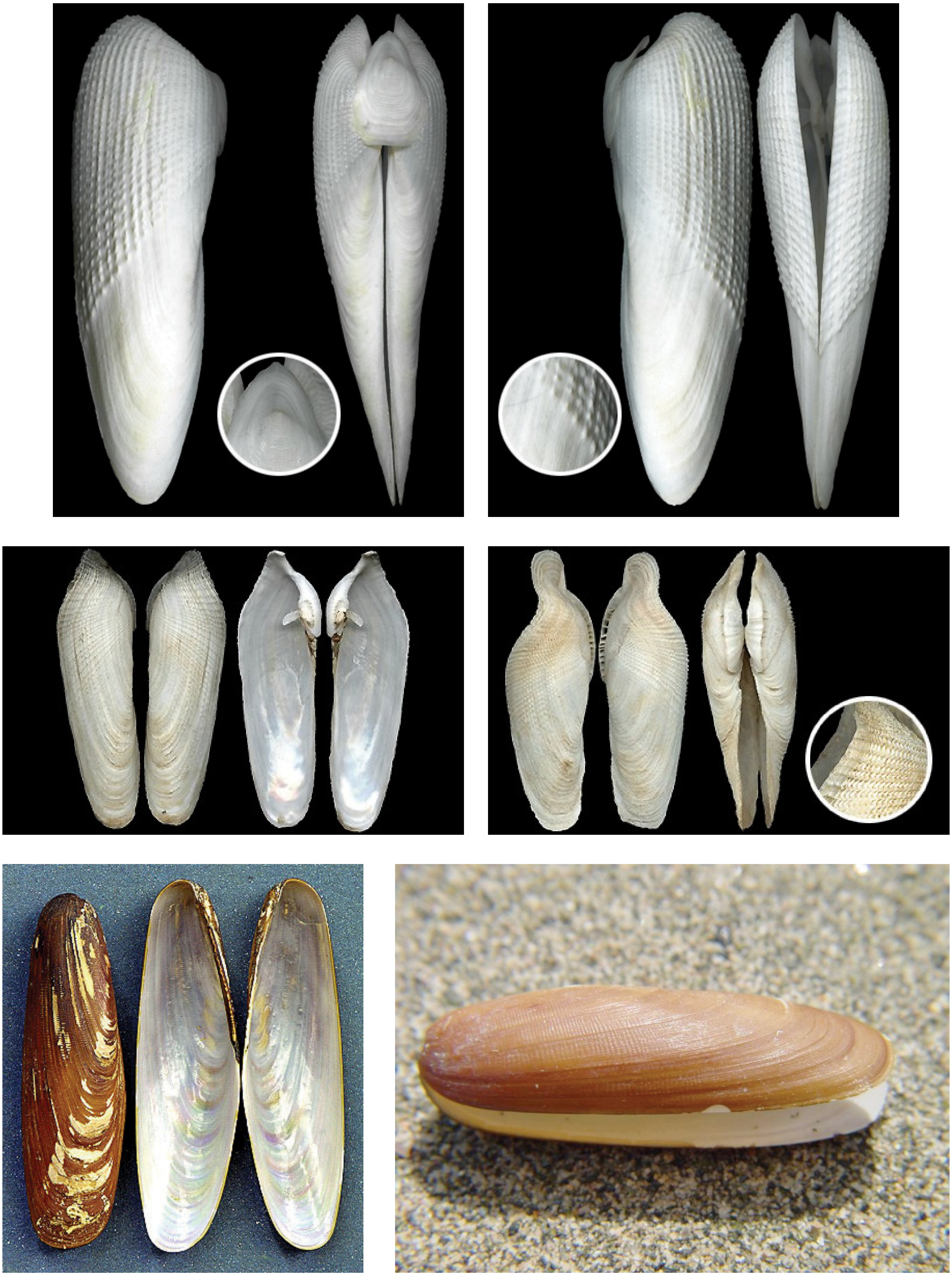

Photo 1- *Pholas*and *Litophaga* fossils: *Pholas orientalis* Gmelin at the top, *Pholas dactylus* Linnaeus in the middle, and *Litophaga* Linnaeus at the bottom. (http://www.idscaro.net/sci/01_coll/plates/bival/pl_pholadidae_1.htm, http://www.apneamagazine.com/ibf/index.php?showtopic=80937).

away and chemical decomposing. While some genera such as *Adula* and *Lithodomus* chemically decompose the rock and form a hole by emitting some kind of solvent, some other genera such as *Parapholas* open and expand the hole mechanically by using their shells. The organism expands and deepens the oval shape of the hole parallel to its growing, and stays there all along its life. Only the siphon, which is used to filter the waterand take food throughout its lifetime remains outside. A rock-borerlives approximately 8 years and the other organisms occupy and fill this natural refuge after its death. The second owners of these hole scan be sticky organisms, bryozoa and pelecypods such as, *Tapes, Cumingia, Kellia, Diplodonta, Entodesma* and *Mytilus*. If the sediments, which fill the hole, are not cemented in a short time, then the shell of the dead organism is broken, erodesand the hole becomes empty. The size of the rock-borers is usually around a few cm, but it even sizes up to 18 cm. The shells are usually white or pinkish in color.

Most of the rock boring organisms live on shores facing the open sea today. This is probably due to the abundance of plankton, high oxygen content in the water, and lack of silt size suspension material in the water. On the other hand, the rock-borers are not found very often at the edge of bays or lagoons protected against the waves, which are relatively poor in fresh plankton and low in oxygen and rich in suspension material. For this reason, the rock-borers provide information not only about the location of the shore but also its physical and biological conditions. On the other hand, any sudden change in marine conditions affects the organisms significantly, and in such changes, they all can leave the environment. However, the rock-boring organisms remain in the environment and provide valuable information as they are trapped in their bores.

Dating the fossils of rock-boring organisms provides sensitive data about the location and timing of evolution of a paleoshoreline. If the organism's shell is preserved in the bore, it can be dated by the methods such as ESR (Electro Spin Resonance) or AAR (Amino Acid Racemization). In cases when there are no or negligible methodological errors in dating, the place where the *in-situ* fossil exists can safely be interpreted as the paleoshoreline. In the case that there are fossils lived within the bore after the death of the original rock boring organism, this can also be accepted as the reliable data considering the geological time, although it is relatively less reliable compare to the original one.

2.2. Marine Terraces

Marine terraces, which are one of important data sources in determining the paleoshores, are the coastal deposits preserved on shores that relatively raised due to tectonic or eustatic reasons. These deposits usually contain beach sands, beach stones or cliff debris. Although they consist of abundant fossils, most of these fossils are occasionally eroded and reworked from previous terrace deposits due to repeating relative sea level changes. For this reason, it is necessary to be careful in dating the terraces based on fossils, as the reworked fossils can be misleading. One method that can be used here is to make the age determinations on different fossils from the same stratigraphic level and use the youngest age found, if it can be determined, provided that it accepts a certain margin of error. The same applies for well cemented beach stones. Without *in-situ* fossils, it is necessary to be skeptical in aging of the terraces.

Marine terrace deposits have been often developed on an abrasion platform that marks the wave base. This platform is generally horizontal or gentle, and it is also inclined if affected by tectonic deformations. Although nature of terrace deposits vary depending on the coastal morphology, they generally develop by leaning on steep slopes on land side. Terrace deposits, which developed in a beach environment, can submerge or raise due to tectonic movements or eustatic sea level changes. The repetition of tectonic uplifting events causes the development of a step like morphology, the oldest terrace is at the top and the youngest terrace is at the bottom. If the age ofeach level can be determined, then the sea level changes and tectonic movements and their mutual effects can be determined (Keller and Pinter, 2002). However, it should be emphasized once again that the ages of marine terraces are often difficult to determine without *in-situ* fossils. Terraced older than Quaternary are rarely preserved due to erosion and become impossible to determine.

C^{14} method is widely used for dating Holocene marine terraces. In this method, the carbon-rich materials in coastal deposits can be used in addition to fossil shells. The fact that the 35, 000 years reliable age limit half-life of C^{14} isotope is the weakest aspect of this method. Although some other methods such as Th_{230}/U_{234} ratio can be used for dating in some cases, the clastic contamination or low uranium concentration in open systems reduce the reliability of this method. The marine terraces dated by paleomagnetism and OSL (Optic Simulating Luminescence) methods are quite limited. However, the terrestrial cosmogenic nuclide methods, especially like Be^{10} and Al^{26}, have started to be used in recent years. In this way, the periods when marine terraces come to the surface and begin to be exposed to cosmic rays can be determined. On the other hand, the methods such as ESR and AAR have also been used for dating marine terraces. Although many methods have been used to date the marine terraces, it is also possible to encounter with the reworking problem apart from the error margins of each method as it is very difficult to find *in-situ* material in marine terraces, as mentioned above.

Marine terrace deposits are one of the most important data sources to determine the paleo-shores. However, difficulties in dating, destruction of their internal structures due to repeated erosions and depositions and being temporary structures due to their easily erodible nature can create problems to the use of this data source.

2.3. Wave Notches

Horizontal erosion that occur bychemical, physical and biological agents lead to the formation of wave notches located at an average sea level on relatively high-slope coasts. Wave notches (coastal notches or tidal notches) are morphological structures that result from the erosion of rocks along the shore with the strength to bear the upper load. Wave notches are generally considered as the indicators of paleo-shorelines (Pirazzoli et al., 1982*a*, *b*, 1989, 1991; Laborel et al., 1999; Kershaw and Guo, 2001; Evelpidou et al., 2011*a*, *b,* 2012*a*, *b*). The use of wave notches to determine the paleosea levels and paleo-shores possess significant difficulties due to their short living nature, high wave or tidal height in mid latitudes and tidal areas, and the differences in the resistance of rocks they erode. Detailed information about the development and classification of wave notches are given by Trenhaile (2015).

Wave notches are erosional structures located at the bottom of cliffs with depth and height ranging from centimeters to meters (Trenhaile, 2015). Wave notches are generally developed on shores that are composed of steep and resistant rocks, which are poor in terms of material carried from the shore and not affected by surficial weathering. Factors such as salt ratio of water, time and temperature differences between wetting and drying of rocks and biological erosion are also effective in the development of wave notch.

The wave notch located between the abrasion platform and paleocliff is an important element showing the maximum level transgression has reached, and therefore the paleo-shoreline. Therefore, the morphological factors are important, as well as terrace deposits, in determining the paleo-shoreline. The functions of the development and protection of the wave notches are given in figure 1.

The wave notches have extensively been used for the determination of eustatic sea level changes and tectonic movements in the Quaternary (Trenhalie 2015 and references here). In areas where the waves not very strong, such as the Mediterranean, and the areas with limited tidal events, the wave notches developed in resistive rocks such as limestones are considered as sensitive markers of the paleo sea level (Pirazzoli and Evelpidou, 2013). There are also some difficulties in using wave notches in tidal areas to determine the paleo sea level, because there are observed wave notches that developed at high tide level in some areas (Wentworth, 1939; Guilcher, 1953; Newell, 1956; Verstappen, 1960; Christiansen, 1963; Takenaga, 1968; Hills, 1971; Tricart, 1972; Trenhaile et al., 2015), below the average tide level in some areas (Schneider, 1976; Torunski, 1979) and at the average tide level in some other areas (Guilcher, 1958; Hodgkin, 1964; Fairbridge, 1968; Debrat, 1974; Trudgill, 1976; Bird et al., 1979; Woodroffeet al., 1983; Tjia, 2013). In the Mediterranean, V- or U-shaped notch profile, which indicates the high wave and high tide levels, is encountered, and the apex of this shape is accepted as the average sea level (Pirazzoli and Evelpidou, 2013). Schneiderwind et al. (2017) investigated the development of wave notches in the Mediterranean environment and developed a numerical model for the development and classification of wave notches.

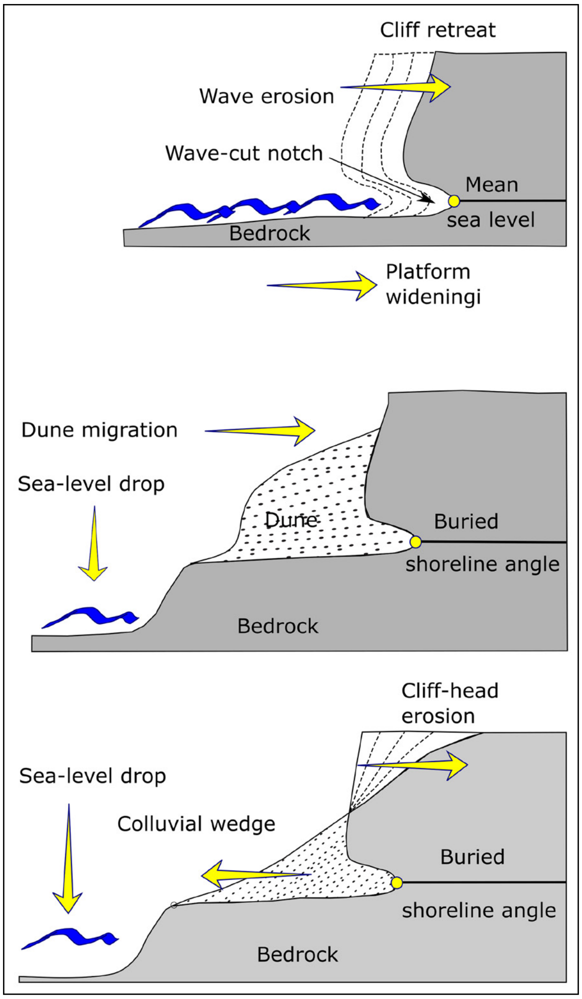

Figure 1- Processes associated with the generation of shoreline angles and their preservation. Wave-cut platforms result from the effects of wave erosion leading to cliff retreat during sea-level highstands. Wave erosion may generate a wave-cut tidal notch that marks the position of mean sea level. (Above) During sea-level lowstands, the shoreline angle may be covered by sediments transported along the beach, such as during the formation of dunes. (Middle) Shoreline angles may be covered by colluvium, or they may be eroded by the effects of fluvial incision. (Below) Geomorphic markers can be identified by using high resolution topography maps and numerical models (for example; TerraceM®, Jara-Muñoz et al. 2016) to determine the height of the marine terrace. (taken from Jara-Muñoz et al., 2016).

Although wave show the paleo-shorelines very precisely and the sea level changes in environments where tidal events are negligible and the height of the wave does not change much, it is very difficult to date them, especially for paleo-shorelines. On the other hand, some other reasons such as intense biological erosion, constant wetting and drying effect, salt abrasion may also lead to the development of similar notches.

3. Examples from Turkey and Mediterranean

Three main criteria used in determining the paleoshorelines given above will be discussed with examples from Hatay, Rhodes Island and Çorum.

3.1. Marine Terraces Alongthe Shores of Samandağ, Hatay

Along the shore of Samandağ District of Hatay, SE Turkey, where the Asi River meets the Mediterranean, the indicators of paleoshorelines such as raised marine terraces and wave notches, standing elevations from the present sea level up to 180 m, are observed between Meydan village in the south and Çevlik village in the north (Figure 2). The properties of these structures have been investigated in detail and the age determinations have been made using different methods (Erol, 1963; Pirazzoli et al., 1991; Doğan et al., 2012; Tüysüz et al., 2012; Tarı et al., 2013, 2018; Florentin et al., 2014). The stratigraphy of marine terraces generally consists of a bottom section that changes depending on the nature of the basement on which the sediments deposited, and an upper section consisting mainly of cross-bedded loose sands and pebbles. In areas, which are fed by an ophioliticsource, these sands are green as they are rich in pyroxene and olivine.

The terraces developed on the relatively resistant late Miocene aged limestones are generally observed in south of the Asi River. Here, the deposition begins with large blocky and pebbly sediments that have a chaotic internal structure at the bottom, then grades into the crossbedded, well sorted loose beach sands. There are large limestone blocks perforated extensively by rock-borers within the chaotic lower part or within homogenous marine sands in the upper part (Photo 2).

Limestones, which are seen as blocks within sediments of terrace deposits, are surrounded by pebbles or sands. Some of the holes that are observed intensely on the blocks are empty while some of them are filled with sand. Shells of the original organism are rarely found in the holes, but usually the later settled gastropod or small and mostly broken bivalve shells are seen. The dimensions of limestone blocks generally range from a few 10 cm's to just over one meter. Most of the blocks are rounded and spherical in shape indicating that they were processed in high-

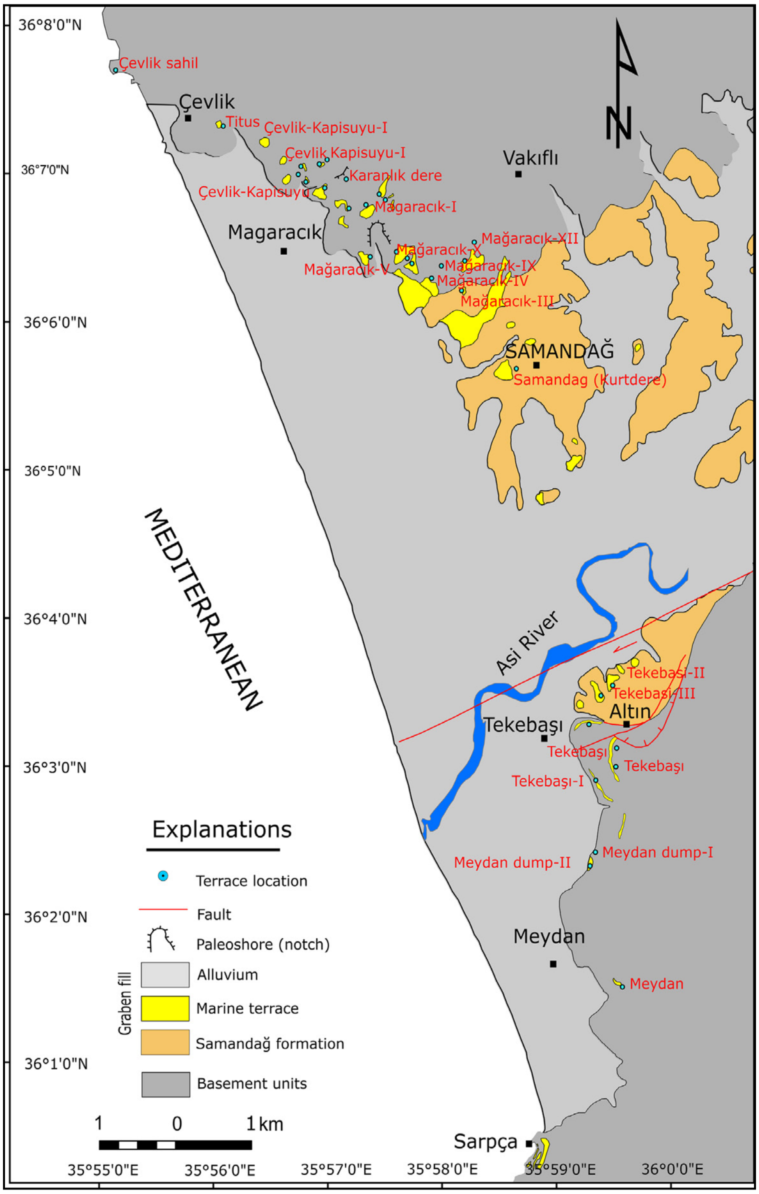

Figure 2- The map showing the distribution of sediments of the marine terraces observed in the north and south of the Asi River on the Samandağ coast (Tüysüz et al., 2012).

energy environment for a long time, and the presence of angular pebble and blocks between them was deposited in the same environment. In the light of these data, it was interpreted that the units in question were deposited in front of a cliff. These blocky unit deposited on a limestone substratum that were also dug by rock-borers and is overlain by very well sorted and cross-bedded beach sands at the top. This indicates that limestones in which these living organisms live on the coast have been rolled down from the cliff due to wave actions or gravity and some of them have been processed and rounded for a long time by the waves.

Hole sare commonly observed both in chaotic cliff front sediments and limestones located at the bottom of thick beach sands. Although most of them are empty or filled by gray-greenish colored, fine to medium sands rich in serpentinite or ultramafic rockclasts, some others have rarely preserved shells with rounded or oval sections. These structures are widely encountered both at the bottom and inside the terrace sediments standing at altitudes of 3 to 180 meters above the sea level, especially; around the Tekebaşı and Meydan villages and in their topographically higher parts. It is noteworthy that limestones are almost full of

Photo 2- Limestone block containing pholade holes in the chaotic clastic unit at the bottom of marine terrace (left.) Presence of angular grains together with rounded blocks indicates a high-energy environment (cliff front) where clastics with different reworking degrees come together. Pholade holes in the big limestone block, which sits at the bottom of marine terrace (red line) deposits that deposited on the Pliocene claystones (right).

bores while there is not any bores inserpentines at the bottom of terrace sediments at 50 m elevation to the east of Meydan district (Photo 3). Tarı et al. (2018) demonstrated that these terraces resting on different elevations were developed in different stages from bottom to top nearly between 8.3 and 214kyr (Figure 3).

Terraces in north of the Asi River, on the other hand, deposited on more easily erodible lithologies such as the Pliocene claystones and marls. Here, the terrace deposits generally consist of thick crossbedded medium to coarse grained loose sands. Chaotic deposits described in the south are not observed here, except for some large random blocks (Photo 2). This indicates that this part of the shore was an abrasion platform. However, it is possible to see the terrace deposits on a horizontal and flat surface, raised to different levels around Mağaracık village (see Doğan et al., 2012; Tarı et al., 2013 and 2018 for details of these terraces).

Terrace deposits rest on the Pliocene marls and claystones (Samandağ formation, Tarı et al., 2013) in the east of Mağaracık village, basal elevation of which is 33.5 m. This outcrop is destroyed today by the farmers who replaced the highly permeable terrace sands with fertile agricultural soil. There are abundant *Litophagus* sp. fossils within bores in marls and claystones along very flat and planar unconformity plane. These fossils, which are 1-3 cm in diameter and 3-7 cm in length, are filled with hard clays so that their molds are largely preserved, however their shells

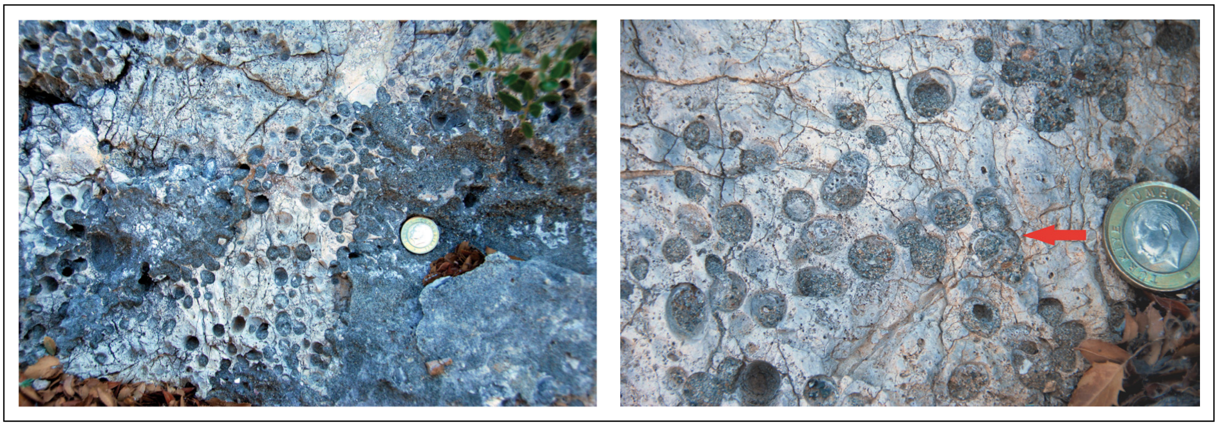

Photo 3- Pholade bores observed in lime stones around Meydan vilalge. Fossil shells (red arrow) are observed inthe bores filled with sand.

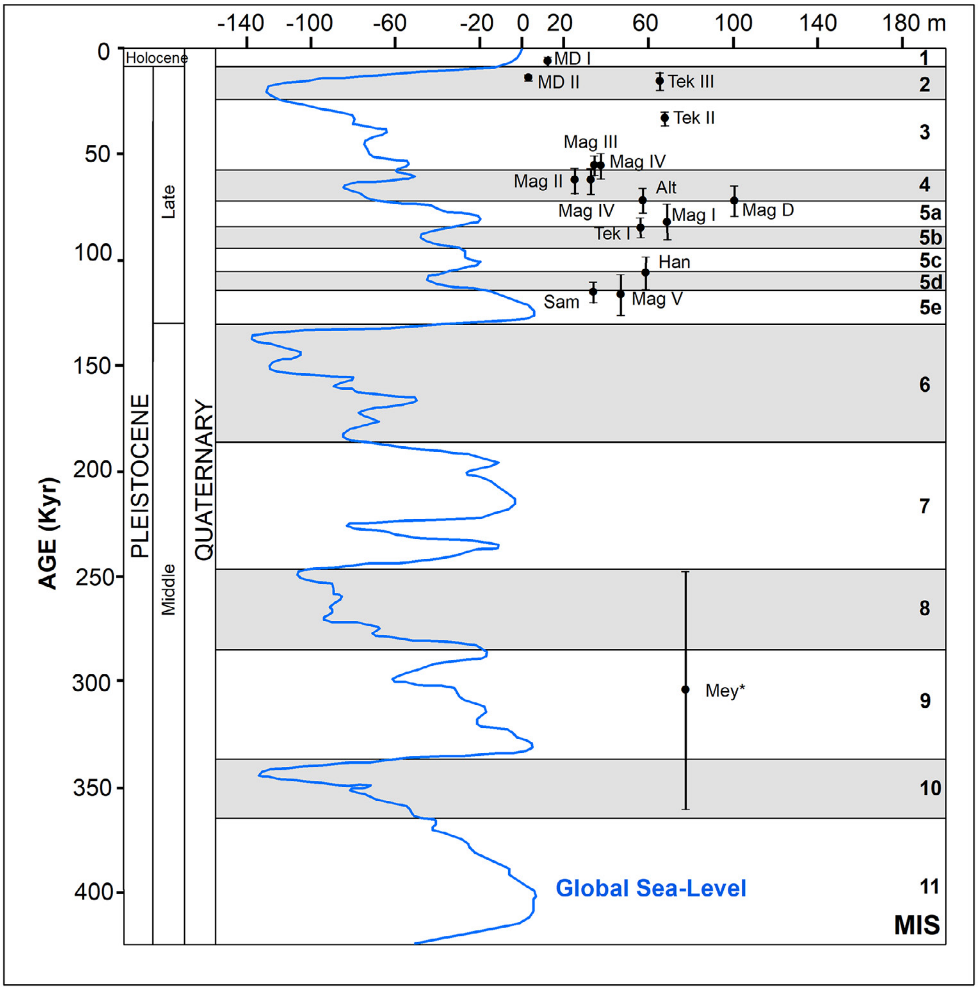

Figure 3- Correlation of the marine terraces on the shores of Samandağ, Hatay and the global sea level curve. Gray shaded areas indicate MIS (Marine Isotopic Stages) or the substages. Locations with measured marine terraces deposits: Mag- Mağaracık village, MagD Mağaracık village dump site, MD-Meydan village dump site, Tek- Tekebaşı village, Mey- Meydan village, Sam- Samandağ town, Alt- Altındistrict and Han- Hancağız district. The ages of terraces marked with * symbol may be younger than shown here as their age is not based on in-situ fossils (taken from Tari et al., 2018, it is recommended to refer to this article for details).

are usually weathered and chalked. In addition to the fossils, fine sands also fill the bores (Photo 4).

Mağaracık section has been interpreted as deposited on an abrasion plain and a bit far from the shore considering the flat geometry of the basal plane, the presence of boring organisms and homogeneous stratigraphy of the terrace sediments. Based on ESR age determinations on *Litophagus*shells, Tarı et al. (2018) stated that this terrace, which began to deposit 63.2 ± 5.6 kyr, possibly in the late MIS 4 phase and tectonically uplifted to its present elevation, 33.5 m above present sea level.

Another important paleoshore markers on the Samandağ coast are the wave notches and abrasion platforms. Such structures are observed along the Çevlik-Mağaracık beach as well as on the steep limestone slopes of Keldağ, facing the Mediterranean (Photo 5). It is very difficult to date wave notches. If there is a Vermes or *Dendropoma* like fossil, which are coral or gastropod species living on the wave notch, and they are synchronous with the development of the notch, then the age determination can be made within previously mentioned limitations using methods such as U-Th, AAR or ESR. On the other hand, wave notches can be filled with marine sediments in some

Photo 4- In-situ *Litophagus* sp. fossils located at the bottom of the sands of the marine terraces in the Mağaracık terrace. White colored fossil shells are seen in the holes bored in the claystones (upper left). The claystone level is directly overlain by well sorted marine sands (upper right). *Lithophagus* sp fossils in their original position inside the bore (lower left), *Lithophagus* sp, fossils recovered from the holes (lower right).

cases (Photo 5). Although there are fossils suitable for the age determination within these sediments, it should be noted that they are more likely to be reworked due to high energy depositional environment.

The tilted abrasion platform located at the southern most edge of the Samandağ shore is one of the important morphological structure of paleoshorelines (Photo 5).

3.2. Terrace and Wave Notches on the Coasts of Rhodes Island

It is possible to see the traces of paleoshore along the beaches on Rhodes Island, as in most Aegean-Mediterranean islands. In particular, the coastline between Lindos and Faliraki along the southeast shores of the island offers beautiful examples of paleoshore traces in this respect. Howell et al. (2015) dated the traces of paleoshores on Rhodes Island carrying out AMS radiocarbon analyses of *Litophaga* and coral fossils. They interpreted that these Holocene terraces were formed as a result of tectonic uplifting of the island due to a single big earthquake (M> 7.7) originated from the Hellenic subduction zone between the years of 2000-200 BC Cornée et al. (2006) studied the sedimentological and paleontological features of the late Pliocene-Middle Pleistosen deposits along these coasts and interpreted tectonic and climatic conditions during their deposition.

Although sedimentary and morphological traces of many paleoshores can be seen along the southwest coasts of Rhodes Island, one of best is seen on the southern slopes of the Prophitis Elias (Prophet Elijah) in south of Archangelos village and on the northern edge of Agathibeach. Prophitis Elias hill is formed by Triassic-Cretaceous limestones (Lekkas et al., 2007). Limestones are cut by normal faults trending approximately in N-S direction. Due to these faults, the Prophitis Elias Hill covers a graben and its shoulders (Figure 4).

Photo 5- Raised coastal traces at the Samandağ-Çevlik beach. The paleo wave notch that stands 1 m above the present sea level on the upper left. Coral and *Dendropoma* fossils, which have been grown on the raised wave notch on the upper right. Wave sediments that filled a raised wave notch in the lower left. There are gastropod fossils in these sediments. Raised wave cut platform (limestone) in the lower right.

Morphological elements in the form of a stepped terrace, which stands horizontally along the slopes of Prophitis Elias hill facing southward and eastward, draw attention (Figure 4). Cornée et al. (2006) assessed these flat areas, which developed on limestone, as abrasion platforms and 24 different levels of paleo coastal traces (abrasion platform) standing on the slopes of this 591 m high hill from the current sea level were determined. Cornée et al. (2006) stated that these terraces had burrows dug by the rock-boring organisms on limestones and that the Pliocene calcarenites were deposited on some of these rocks at higher levels. Although there is not any age data on all those 24 levels mentioned above, it is clear that these are related to sea level changes in the Mediterranean and tectonic uplifting on the Hellenic subduction zone between the Pliocene and recent.

The Agathi beach, located to the south of the Prophitis Elias hill, also offers beautiful examples of the recent coastal uplift. The bedrock on the northern edge of the moon-shaped beach is again limestones. These limestones were perforated very intensely by the rock-boring organisms. Most of the bores are emptied, and some of them were eroded by waves and karstic dissolving. Nevertheless, it is observed that some bores, especially the ones overlain by the sedimentary cover, are preserved, filled with fine sands, and there are some fossils within them even if some are not fully preserved. These limestones with extensive bores of mollusks are overlain by beach sediments rich in fine sands and coarse clastics (Photo 6). In beach sediments, there are rounded, spherical shaped limestone pebbles and blocks that have been reworked for a long time due to the wave effect, and the bores are preserved even partially on large limestone blocks.

Sequences, similar to those of the Agathi beach are located at different levels along the entire coast between Rhodes and Lindos settlements on the southwest coast of Rhodes Island. In addition, there are also

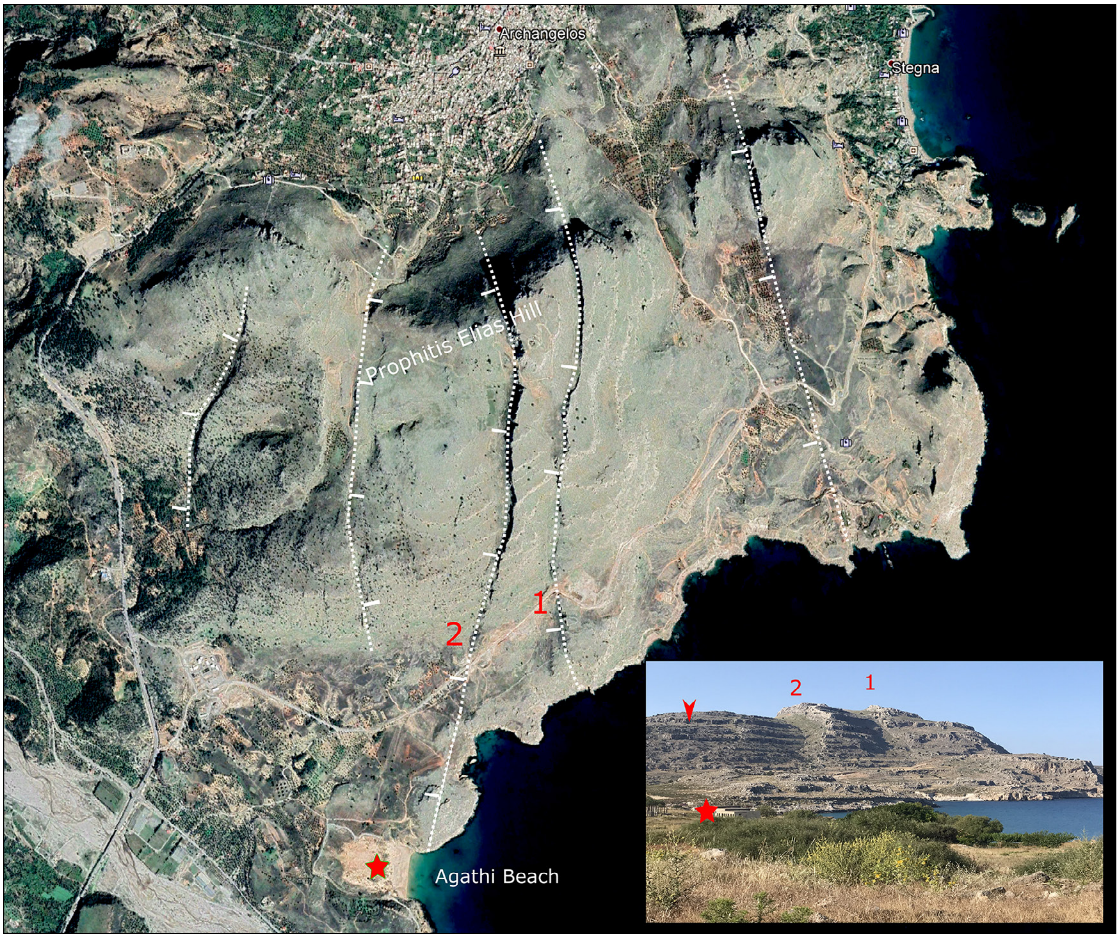

Figure 4- Satellite (Google Earth) image of the Prophitis Elias Hill. White dotted lines indicate the faults and white teeth on them indicate the slip direction. The levels, of which the only one is marked with a red arrow, show the paleo wave notches. View of Prophitis Elias hill from south in lower right: Red stars on the photo and map point the same place. Two steep slopes numbered as 1 and 2 on the photograph were created by the normal faults dipping west. These faults are shown with the same numbers on the map. Stair-like horizontal flats are wave notches and abrasion platforms that point to the paleoshorelines. Only one of them is marked with a red arrow.

well preserved wave notches and abrasion platforms along the entire coast in resistant rocks, especially in limestones (Pirazzoli et al., 1982*b*; Pirazzoli et al., 1989). The height of these wave notches above the current sea level reaches a height of 3.8 meters near the northeast end of the island, but decreases towards southwest. Kontogianni et al. (2002) also identified coastal notches that stand at heights of 4.2 and 5.2 m, higher than 3.8 m, but stated that they were developed during the pre-Holocene period. It is suggested to refer to Pirazzoli (1986, 1989), Kontogianni et al. (2002) and references herein on the age of these coastal notches and their relationship with active tectonic sea level change.

3.3. Bores of Pholades at the Base of Çorum Eocene Sediments

Some examples of physical and biological markers observed on shores of Hatay and Rhodes Island, though not limited with them, were given above. Could these functions their resulting markers, which are especially encountered in the Mediterranean Sea in the Pliocene-recent time interval also help us to understand the location and physical conditions of paleo-shores?

Tokat Massif[1] located in north of the Ankara-Erzincan suture belt in the Central Anatolia is a

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[1] Although the term "massive" is used in literature for different purposes, it is used here in the sense of the region where metamorphic rocks are predominant

Photo 6- Pholadebores observed on the northern edge of the Agathi Beach in the upper left. A close-up view of them in the upper right. In the lower left, the marine terraces deposited on the limestones with pholade holes on the northern shore of the Agathi beach. Wave notches observed along the beach to the south of Lindos in the lower right.

region where the Permo-Triassic Karakaya Complex rocks (Bingöl et al., 1973), forming the basement of the Sakarya Unit (Okay and Tüysüz, 1999) crops out extensively. This group, which is divided into different formations around Çorum-Amasya (Tüysüz, 1996), consists of the intercalations of metapelites, metabasites and marble blocks within them. Sizes of these blocks range from a few meters to hundreds of meters. The Late Jurassic-Early Cretaceous aged neritic limestones (Bilecik limestone, Altınlı, 1973) unconformably overlie this basement. These limestones, which are oolitic in lower parts and micritic in upper parts, pass into the Early Cretaceous aged pelagic limestones in south (Soğukçam formation, Altınlı, 1973). The Upper Cretaceous ophiolites or chaotic rocks with ophiolitic blocks were imbricated with these units and thus a south-vergent fold and thrust belt was developed in the region (Tüysüz, 1996). It is accepted that this belt was developed due to continental collision of the Sakarya Unit with the Kırşehir Continental Block. Following this collision, the Tokat Massif was uplifted and all Massif, except for the Çankırı Basin and the southern borders of the Massif, remained as an erosional area during the Paleocene (Tüysüz, 1993, 1996; Tüysüz and Dellaoğlu, 1992; Yılmaz et al., 1997).

Lutetian deposits of the Tokat Massif around Amasya and Çorum unconformably overlie the metamorphic rocks that form the Massif, the Jurassic-Cretaceous deposits overlying these metamorphites, the Upper Cretaceous ophiolitic units and the all contacts between these units imbricated together. In contrast to the folded and thrusted structures of the units below the unconformity, the Lutetian deposits are quite thin and they are in the form of a flat cover, not affected from deformation. The characteristic of these units, which are obviously developed on a peneplain surface, changes towards the Ankara-Erzincan Ophiolitic Belt, which limits the Tokat Massif in south and west, and the basins in front of this belt. They gradually passes into flyschoidal units and begin to consist of volcanic rocks. In addition to this lithological change, it is observed that Eocene sediments join the folded and thrusted structure towards these areas. Based on these features, different Eocene units were distinguished in the region (Tüysüz, 1996). The Neogene units in the region are represented by terrigenous clastic and evaporites which unconformably overlie the older rocks.

The Eocene sedimentary rocks around Çorum and Amasya were named as the Dereağıl formation by Tüysüz (1996). The dominant lithologies of this formation are sandstones, siltstones and carbonaceous sandstones. The shallow marine limestones in this formation were named as the Ballı limestone member. The bottom of the Dereağıl formation usually consists of the red-yellowish, poorly cemented quartz-rich conglomerates and sandstones. These clastics at the lower part of the sequence pass upward into yellow, carbonate cemented, thin and irregularly layered sandstones with abundant nummulite fossils. Gastropods, brachiopods and echinoid fossils in addition to nummulites, and partly coalified plant fragments are also observed in the rocks which cover the underlying units. In the north of Amasya, there are thick lignite seams in the middle Eocene deposits known as the Çeltek formation around Suluova. Atalay (2001) distinguished meandering river, lake, flood plain and marsh sediments in the Çeltek formation, which overlies the alluvial fan deposits at the bottom and conformably grades into shallow marine deposits at the top. This terrestrial sequence, which is peculiar to the Suluova-Merzifon area, is not observed in most parts of the Tokat Massif. The marine sediments located on the continental sequence in Suluova directly overlie the older units in most places.

The east of Çorum is one of the places where the basal parts of this transgressive marine sequence are best seen (Tüysüz ve Sakınç, 1992). The Eocene sequence, around Palabıyık village to the south of Çorum-Amasya highway and in the west of area between Kuşsaray and Elvançelebi villages, unconformably overlies the Late Jurassic-Early Cretaceous aged Bilecik limestones and the Triassic schists (the Karakaya Complex) that thrust over these limestones (Figure 5). The sequenceis usually represented by yellowish sands with carbonate cement

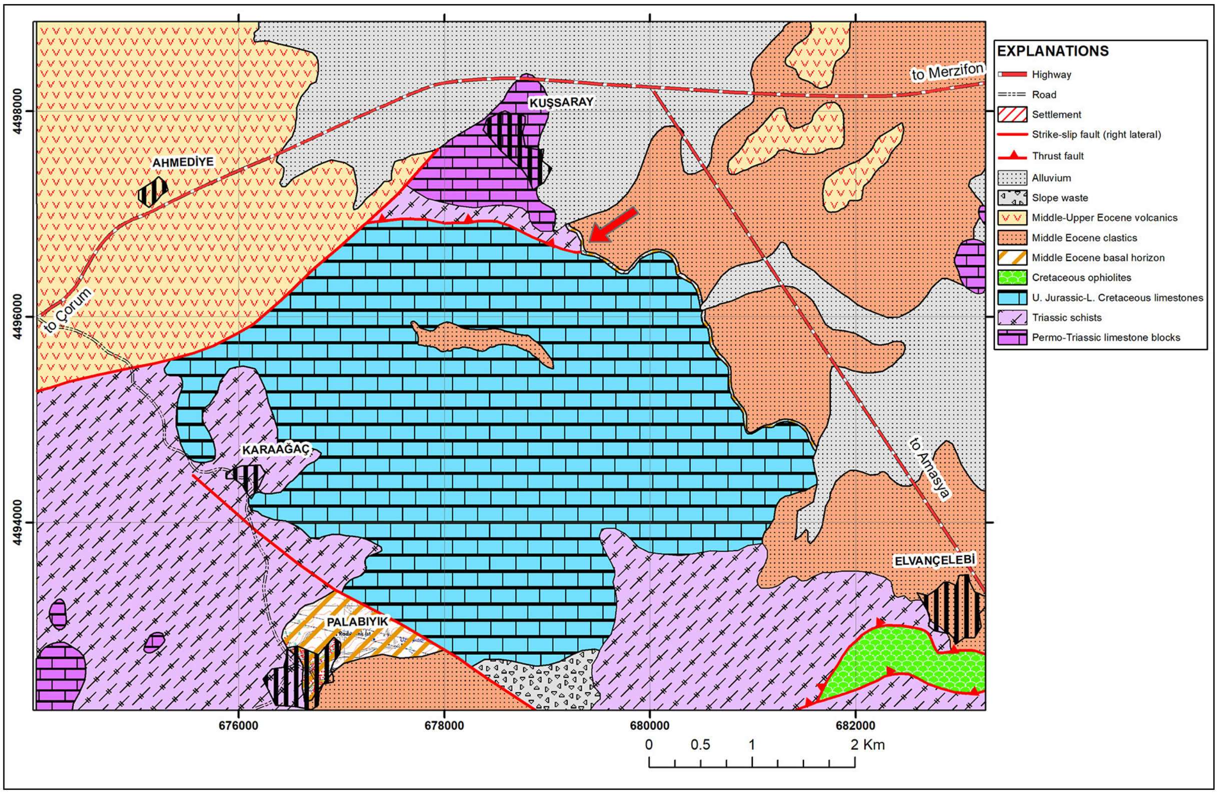

Figure 5- Geological map of Kuşsaray village and its vicinity located about 15 km NE of Çorum. Red arrow indicates the place where pholadebores are best seen at the base of Eocene sequence.

and is grades upward into volcanic rocks. Massive limestone intercalations and lenses are also exist within the sequence. The thickness of the formation is only a few meters in some places and may reach 150 meters in places protected from erosion.

There are abundant holes bored by rock-boring organisms on the Late Jurassic-Early Cretaceous aged Bilecik limestones, which are unconformably overlain by the Dereağıl formation around Kuşsaray and Palabıyık villages in the east of Çorum and the Dereağıl village in the north of Amasya. As these bores are quite common along the stream in south of the Palabıyık village, where the limestone is at the surface, this stream is called as the Deliklikayalar (rocks with holes) stream referring to those holes. *Lithodomus* sp. fossils have been found within these bores, which have not yet been completely eroded due to overlying Eocene deposits. They stand in a way that their valves would face downward in their cylindrical holes as bored perpendicular to the limestone surface (to the bottom of the unconformity plane). The long axes of the burrows are between 1-2 cm and 6-7 cm (Photo 7). They are filled with *Nummulites* sp. in addition to *Lithodomus* fossils and cemented with yellow sandy carbonates. The presence of *Lithodomus* shells together with the nummulite fossils shows that *Nummulites* lived in the holes after the death of *Lithodomus*.

Similar structure is also observed in the north of Amasya, in the Ballı stream to the west of Dereağıl village and in the stream to the west of it, at the base of the Dereağıl formation (Photo 8). Here, the white-cream colored, hard, brittle, medium to thick-bedded oolitic or bioclastic textured Ballı limestone member directly overlies the Bilecik limestone, and the bores under this unconformity plane are noteworthy. On the other hand, there are coral fossils in growing stage in the outcrops to the northeast of Çorum, and they point out that the sedimentation continues in warm climatic conditions and shallow marine environment.

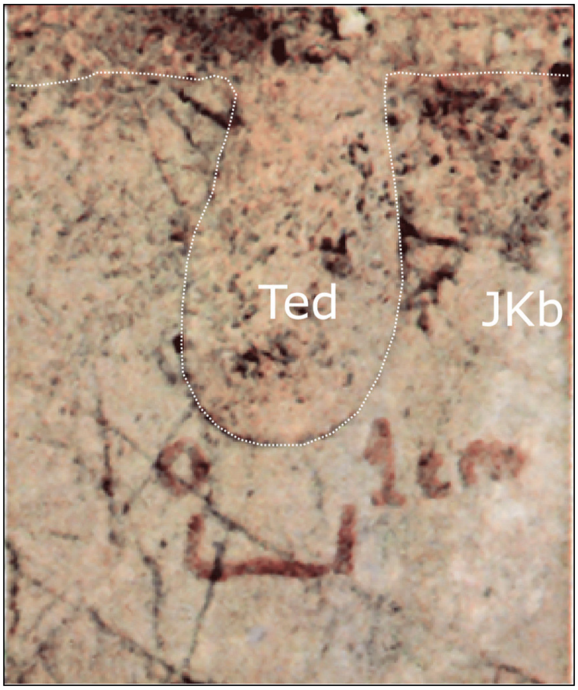

Photo 7- Pholade bore located in the Late Jurassic-Early Cretaceous limestone (JKb) filled with Eocene sandy limestone (Ted) in the section normal to the unconformity plane.

Photo 8- Holes opened by the rock-boring organisms during the Eocene period in the Late Jurassic-Early Cretaceous aged limestones and sandy limestones in the Delikli kayalar stream (upper) to the south of the Palabıyık village, Çorum and around Dereağıl village, Amasya (lower). In some holes, the shells have been preserved (lower), while some of them have been destroyed by karstic melting and erosion.

4. Results

In this study, the examples of some features that had formed along the coastal areas from Pliocene to recent are given from two different parts of the Mediterranean, Samandağ, Hatay and Rhodes Island. In addition, it was emphasized that these similar events that caused development of these features might occur also in paleo coastal sediments and provides information on locations of the shorelines in geological periods and on the characteristics of the depositional environments close to the coast.

One of the important markers of coastal line formed by limestones and facing to the open marine, is the rock-boring organisms. The fossils of these organisms can be used as the markers of paleo-shorelines as well as the unconformity planes. Considering that these organisms live on open and clean shores today, it can be said that their fossils reflect the same conditions for the past periods. Tracking of holes of the rock-boring organisms along the unconformity planes will allow precise determination of shorelines on site, which is an important element in determining the depositional and erosional areas. The structures such as wave notches and abrasion platforms, which are important elements of the coastal morphology, can also be identified within paleo sediments and can provide important information about paleocoastal forms.

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