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Geology of the Kurucaşile - Cide region, NW Türkiye

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Research Article

Keywords:
İstanbul Zone, Western Black Sea Basin, Ulus Basin, Cide-Kurucaşile, Stratigraphy.

ABSTRACT

The lowest unit of the Cide-Kurucaşile region is the Carboniferous coal-bearing terrestrial sediments. Permian aged terrestrial Çakraz Formation and the Triassic lacustrine Çakrazboz Formation unconformably overlie the Palaeozoic sequence. Dogger-aged Himmetpaşa Formation represents a short-period marine invasion. The transgression started in the Kimmerician has led to the development of a carbonate platform, which has risen and demised after the Berriasian. A second carbonate platform, much more limited than the previous one, developed in the Late Barremian, and then the whole region deepened. The Cenomanian is a period of regional uplift and erosion. The first effective volcanic activity in the region started in the Middle Turonian. During this period, extensional faults coeval with the deposition, and the region gained an irregular topography. In the Middle-Late Santonian, the volcanism became silent for a while, the region rapidly subsided and became a completely deep marine environment. These events indicate that the continental crust of the region was broken up and the oceanic crust began to develop in the Western Black Sea back-arc basin. In the Campanian, the volcanism reactivated, but ceased after a short time, leaving its place to pelagic sediments forming the southern passive continental margin deposits of the Black Sea. In the Maastrichtian, the region was tectonically compressed and uplifted and provided turbiditic material to the Black Sea in the north and the Devrek Basin in the south. Siliciclastic turbidites have been deposited in the region until the Middle Eocene. At the end of the Middle Eocene, following the uplifting of the entire region and the destruction of marine environments, the north-vergent thrusts were developed due to intense compression and the region became a fold-thrust belt.

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1. Introduction

The study area is geographically located in the Western Black Sea region betweeen Çakraz-Kurucaşile-Cide and the Arıt Valley in the south, and geologically on the İstanbul Zone (Okay and Tüysüz, 1999) (Figure 1).

İstanbul Zone, due to the Palaeozoic and Triassic sedimentary deposits at the bottom, has different characteristics from the other tectonic units of Turkey. The İstanbul Palaeozoic sequence differs from the coeval units in the other parts of the Pontides on its stratigraphy and lithology, non-metamorphic nature, and by not being affected by penetrative deformation. The Palaeozoic sequence is unconformably overlain by the Permian and Triassic terrestrial and the Dogger marine sedimentary units peculiar to the İstanbul Zone. All these units are covered by the Late Jurassic-Early Cretaceous platform carbonates. A new transgression in the Late Barremian resulted in the development of a much more limited carbonate platform compared to the previous one, and later a clastic dominant sedimentary sequence. The following regional uplift in the Cenomanian, the deposition that started again

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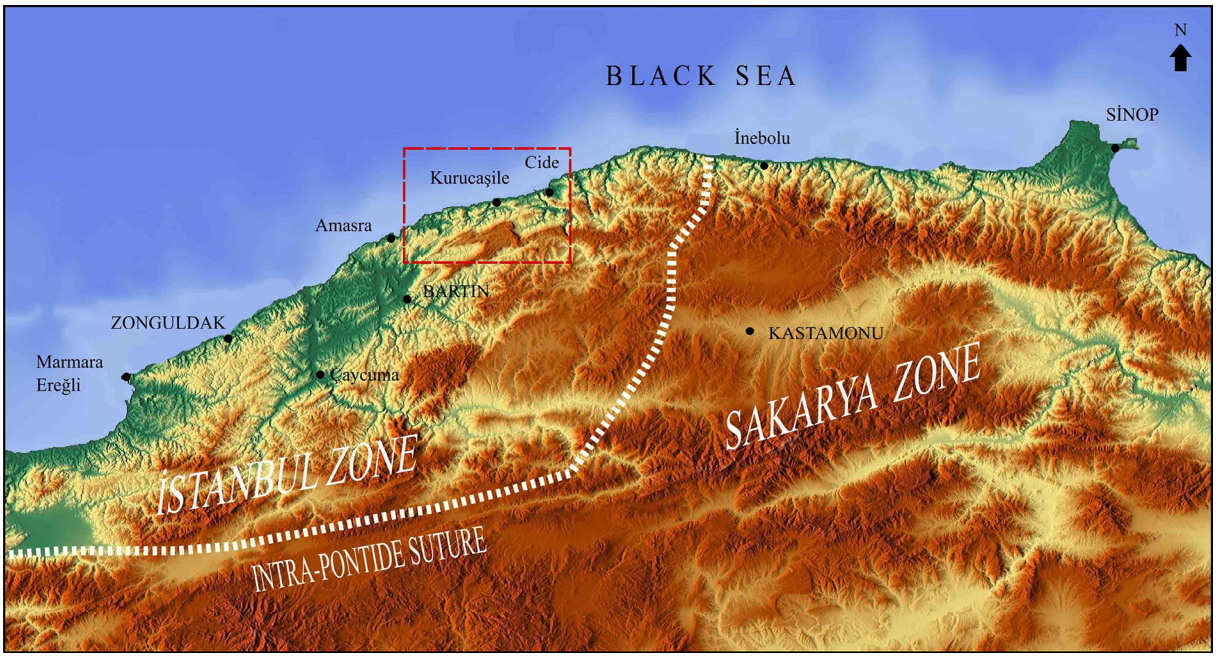

Figure 1- Location map of the study area (red rectangle).

in the Late Cretaceous was accompanied by an intense volcanic activity. This depositional period has continued until the Middle Eocene either continuously or with interruptions in some areas, after ceasing the volcanism.

Stratigraphic and structural elements of all units of the İstanbul Zone from Devonian to recent are best observed in and around the Amasra-Cide region (Figure 2). Although the stratigraphy of the region in the form of a foreland fold/thrust belt (Akyol et al., 1974; Akman, 1992; Tüysüz, 1999; Masse et al., 2009; Tüysüz et al., 2004, 2012; Tüysüz, 2018, Keskin and Tüysüz, 2018) and structural properties (Sunal and Tüysüz, 2002) has been previously published in chapters, it has been aimed in this paper to reveal the stratigraphy and structural elements of the area between Kurucaşile and Cide as a whole and assess their geological meaning. In the nomenclature of stratigraphic units, the terms accepted for the lithostratigraphic units of the Western Black Sea Region by the Stratigraphy Commission of Türkiye are mainly followed (Tüysüz et al., 2004), and the synonyms of the formations have not been accentuated to avoid repetitions and not to increase the volume.

2. Stratigraphy

The study area consists of seven units separated from each other by regional unconformities, ranging from Palaeozoic to Middle Eocene in age. These are; Carboniferous, Permian-Triassic, Dogger, Malm-Neocomian, Barremian-Aptian, Middle Turonian-Santonian and Late Santonian-Middle Eocene units.

2.1. Palaeozoic

2.1.1. Carboniferous

In a generalized columnar stratigraphic section, the İstanbul Palaeozoic sequence, the lowermost sedimentary unit of the Istanbul Zone, represents a transgressive series ranging from Ordovician terrestrial clastics to Devonian platform carbonates and Carboniferous radiolarian cherts (Figure 3). At the topmost part of this series, the regressive Carboniferous clastics, which have wide distribution around İstanbul, are observed (Abdüsselamoğlu, 1977; Önalan, 1982; Görür et al., 1997).

The character of this sequence around İstanbul indicates an environment that has deepened starting from Devonian to the beginning of Carboniferous (Tournasian) and then shallowed. However, the effects of this deepening are not seen around Zonguldak-Cide. This region has become shallower in the Devonian after the deposition of shallow marine carbonates, and deltaic and fluvial units deposited during the Carboniferous. As the Zonguldak Carboniferous

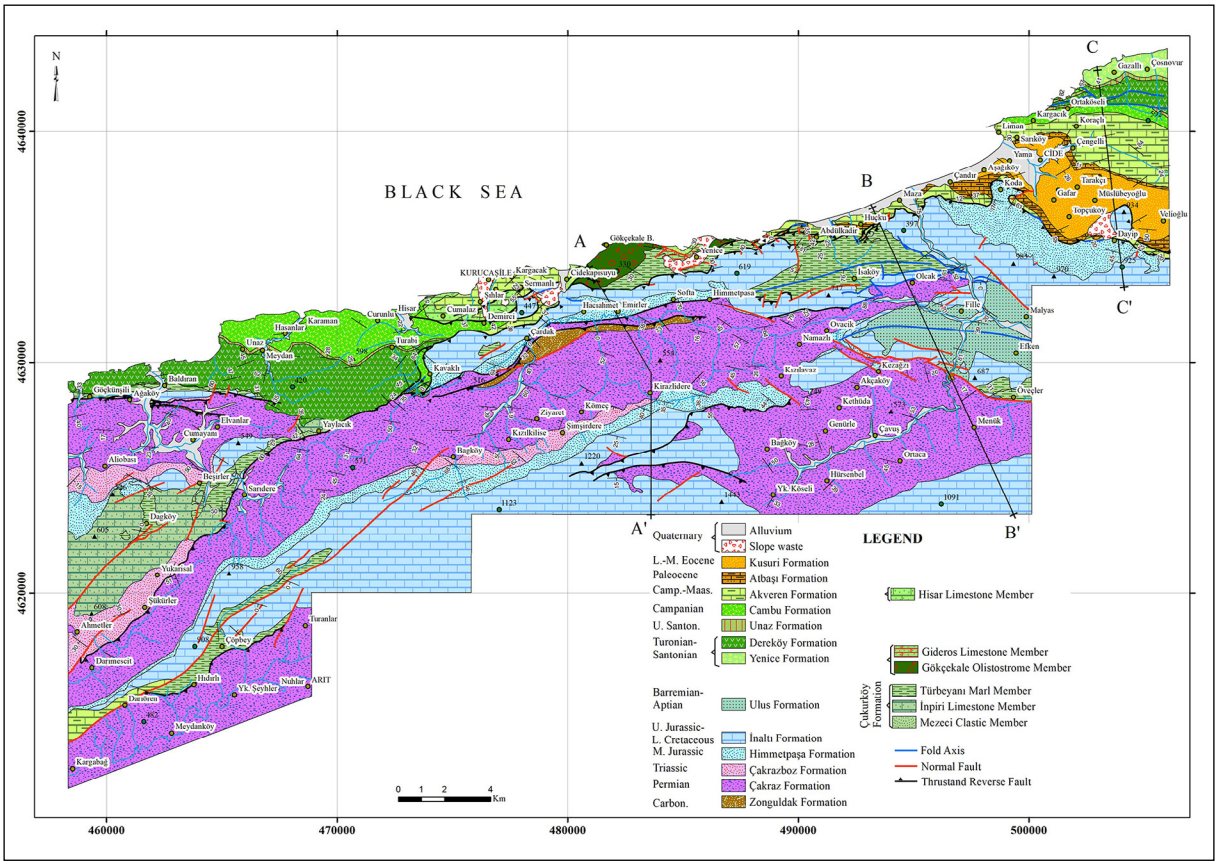

Figure 2- Geological map of the study area.

sequence consists of the only hardcoal basin of Turkey, it has been the subject to various investigations since the late 19th century (Ralli, 1895; Stassinopoulos, 1906, Lucius, 1926; Arni, 1927, 1931, 1936, 1938, 1940, 1941, 1942, 1943; Grancy, 1937, 1938, 1939, 1940; Granigg, 1936, 1938. See Canca, 1994 and Lom et al., 2016 for a broader list of references on this subject).

Devonian carbonates observed in the west of Amasra do not outcrop in the study area. The coal-bearing Carboniferous sediments overlie the Early Devonian-Visean (Tokay, 1954, 1955) neritic limestone, dolomitic limestone, and dolomites with gradual transition, which outcrop around İnkum-Bartın-Amasra region. These units are divided into Namurian Alacaağzı and Westphalian Kozlu and Karadon formations. Alacaağzı Formation is composed of sandstone, siltstone, and claystone alternations with some thin shallow marine limestone horizons. In places where Kozlu and Karadon formations that developed under similar conditions cannot be distinguished, the name of Zonguldak Formation was used as the equivalent of both formations (Akyol et al., 1974; Saner et al., 1979).

Zonguldak Formation: In the study area, the Carboniferous units crop out along an E-trending narrow strip between the Kavaklı village in the south of Kurucaşile in the west and Pelitovası-Nanepınarı coal mine in the east. Another small outcrop is seen around Medüllü village in the Gürendere valley in the east (Figure 2).

The Zonguldak Formation is represented by conglomerate, sandstone, and mudstones alternations (Figure 3). The conglomerates, which are found both as channel fills and as flat beds, are mottled in color, rounded, well sorted, and grain supported. The average diameter of the pebbles is about 1 to 2 cm. Most of the clasts are quartz, and the others are chert and metamorphic rock fragments. The abundance of pebbles belonging to the Devonian limestones indicates that the Devonian sequence was partially uplifted and eroded during the Carboniferous. The sandstones are gray-whitish in color, clasts are

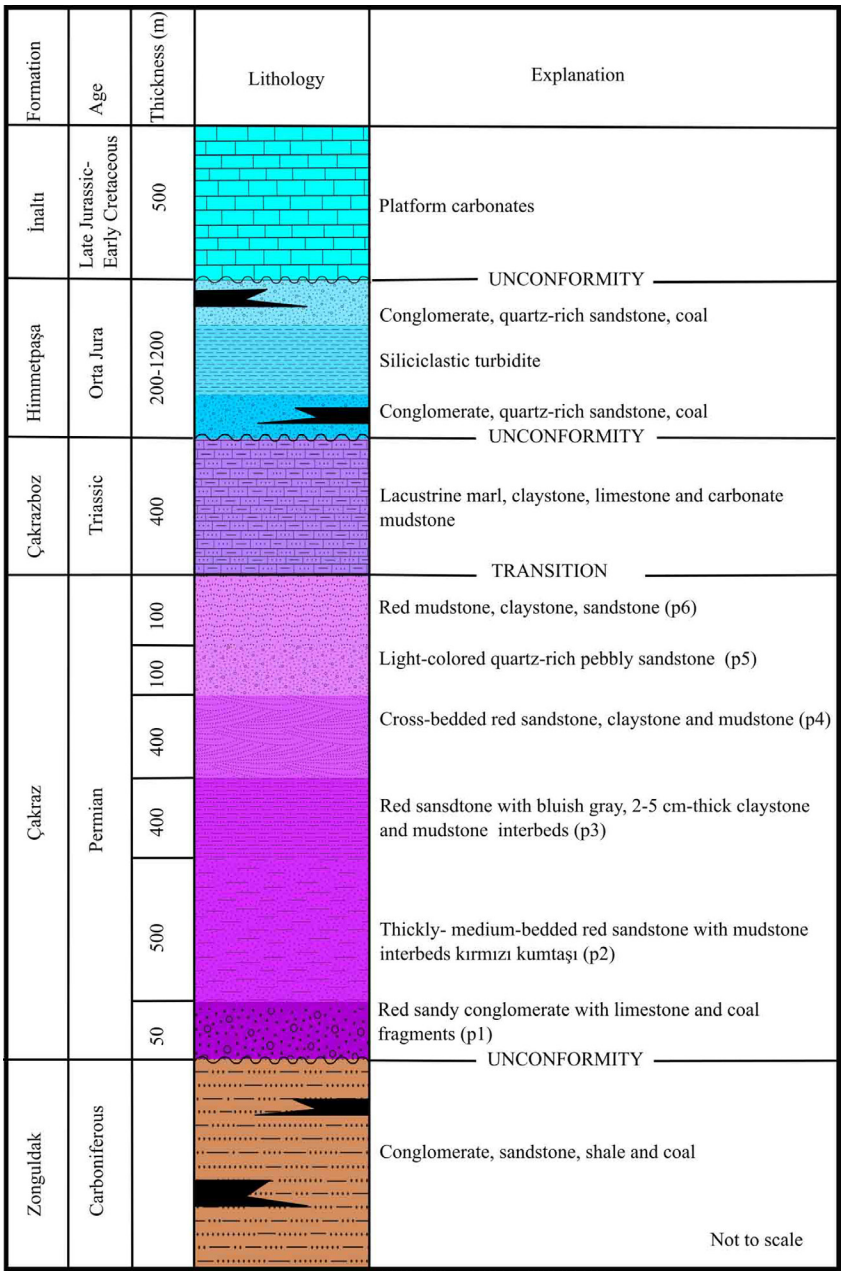

Figure 3- Generalized stratigraphic section of the Jurassic and older units of the study area (formation thicknesses are given as average values).

rounded, almost spherical, well cemented, well sorted, and grain supported. They contain many charred plant fragments. Cross-bedding, wedge- and lenticular-bedding are the most common sedimentary structures in sandstones. The mudstones alternating with sandstones and conglomerates in centimetric levels or seen as residues protected from abrasion during the deposition of these clastics are found in fewer proportions in the sequence compared to the other clastics. Especially in the areas containing coal, blackish-dark gray claystones rich in organic matter are also observed.

The coal seams in the Zonguldak Formation have been mined in Nanepınarı underground mine for many years. In addition, hard coal was produced in several small mines in the Yol and Başköy streams.

The Zonguldak Formation, whose stratigraphic basement cannot be seen in the study area, is

unconformably overlain by the Çakraz Formation in the Yol stream, in the south of Emirler village. In the south of Dikili Cape, in the east of Çakraz Bay, the Çakraz Formation overlies the Carboniferous clastics with an angular unconformity. Akman (1992) suggested that Çakraz and Zonguldak formations were transitional, while Akyol et al. (1974) stated that unconformity separates them.

There is no new finding on the age and depositional environment of the Zonguldak Formation in this study. However, based on previous investigations and its correlation with other coeval successions in the Zonguldak region, it is accepted that this unit deposited in the fluvial and flood plain facies and is of Westphalian B, C and D in age (Canca, 1994 and related references here).

2.1.2. Permian

Çakraz Formation: This unit, which was named as Çakraz sandstone by Akyol et al. (1974), was named as the Çakraz Formation in later studies (Aydın et al., 1987; Yergök et al., 1987).

The Çakraz Formation crops out in three-wide outcrops in the study area (Figures 2 and 3). The first of these starts from the Çakraz Bay in the west and extends towards the east along the villages of Cumayanı, Elvanlar, and Şabanlar. In further south, the second belt starts from Mevren-Ala stream and extends towards the east along with the Başköy, Kızılkilise, Kirazlıdere, Kızılovaz, Ovacık and Develi villages and the Gürendere valley. The third-largest outcrop in the south is seen along the Arıtdere valley.

The Çakraz Formation is completely composed of terrestrial sediments. The unit can easily be recognized even from far distances by its dominant red, and sometimes mottled appearance in places where it generally consists of alternating red, white sandstone, and greenish mudstone levels. The dominant lithologies of the Çakraz Formation are sandstone and mudstone. The conglomerates accompany them in the lower parts of the formation. The conglomerates in the west of Göçkünşili Bay are reddish, mottled, rounded, and poorly sorted. They mainly consist of limestone, dolomitic limestone, quartz, granite, and metamorphic rock pebbles. The pebble sizes vary between 1 and 15 cm, they are grain-supported, and the matrix is often negligible. The clasts are firmly cemented with clay and carbonate cement on occasion. The conglomerates contain greenish-yellowish trough-type cross-bedded pebbly coarse sandstone and mudstone levels. These include quartz, less amount of feldspar, abundant mica flakes, and occasionally transported coal fragments. These fragments, which were eroded from the Carboniferous sequence, sometimes increase and form thin and laterally continuous coal horizons. Based on the sedimentary characteristics, it is interpreted that the conglomerates are deposited in a braided river system.

Towards the upper parts of the Çakraz Formation, the conglomerates gradually decrease, the grain size becomes thinner and the succession turns into an alternation of sandstone, mudstone, and claystone. Up the section, the color changes from mottled to homogenous red, the layers gain more regular character, the channel structures gradually disappear, and some ripple marks start to be seen (Figure 4a).

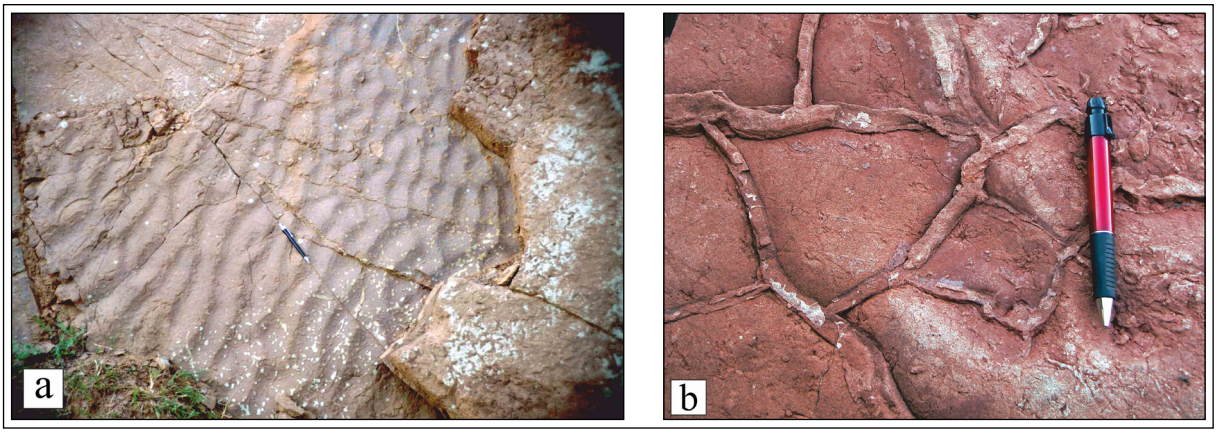

Figure 4- a) Ripple marks in the Çakraz Formation, b) mud cracks in mudstones of the Çakraz Formation.

All these changes indicate a transition from irregularly braided river deposits to more regular meandering river-floodplain deposits. Alternating cross-bedded sandstones and the mudstones with mud cracks and trace fossils indicate that successive humid and dry periods were effective in the deposition, while the red color indicates strong oxidation in this terrestrial environment. (Figure 4b).

In a small area on the western edge of the Çakraz Bay, the unit consists of fine-grained clastics containing red, high-angle wind cross laminae. This uppermost level of the Çakraz Formation, whose lateral distribution is very limited, overlies the fluvial and flood plain deposits of the formation and is overlain by a conformable and transitional contact by the lacustrine clastics and carbonates of the Çakrazboz Formation.

The Çakraz Formation begins with the deposition of conglomerates and red-colored cross- and horizontally laminated sandstones, which unconformably overlie the Carboniferous sequence at the base, and continues with a rather homogeneous mudstone-claystone alternation up to the wind deposits at the top. There are impressive outcrops of this fluvial sequence along the coastline between the Çakraz Bay and Dikili Cape. Along the northern part of this east-trending outcrop, the Çakraz Formation is delimited by high-angle reverse faults. In the Çakraz-I well of Turkish Petroleum Corporation, about 700 m south of these faults, in the north of Kalaycı village, the Carboniferous clastics and Devonian carbonates were drilled below the Çakraz Formation.

In the southern part of the outcrop, starting from the Çakraz Bay and extending towards the east, the Çakraz Formation is conformable and transitional with the overlying Çakrazboz Formation. On the southern slope of the Paşalılar stream the Late Jurassic İnaltı Formation, and at the eastern end of this stream the Mezeci Clastic Member of the Early Cretaceous Çukurköy Formation and the Late Cretaceous Dereköy Formation unconformably overlies the Çakraz Formation (Figure 2).

In the large outcrop between Mevrendere valley and the south of Cide, the Çakraz Formation overlies the Carboniferous clastics with a weak unconformity in the Yoldere valley to the south of Emirler village, and in the Gürendere valley to the northwest of Yeniler village. The Çakraz Formation is unconformably overlain by the Himmetpaşa Formation along the southern slope of the Mevrendere valley. Along the northeast continuation of this contact, around the Darılık locality in the east of Meremler village, the Çakraz Formation grades upward into the Çakrazboz Formation, which is unconformably overlain by the Himmetpaşa Formation. The Himmetpaşa Formation in the west of Apşara village in Daynılakdere valley and the İnaltı Formation in the Avlukaya location, and on both slopes of the Gürendere valley unconformably overlie the Çakraz Formation (Figure 2).

Grancy (1938) distinguished 6 levels ranging from p1 to p6 in the Çakraz Formation (Figure 3). These are conglomerates (p1) deposited in a braided river environment, forming the lowermost part of the formation, the red sandstone and mudstone with *Walchia* traces (p2), the red, green mudstone-dominant fine-grained clastics (p3 and p4), the light-colored quartz-rich conglomeratic sandstones (p5), and the red mudstone and sandstones (p6).

Between the Develi district and the Irmak stream in the east, there are several meters-thick rhyolitic and rhyodacitic dykes intruded into the Çakraz Formation. There is no data about their ages. However, considering that the volcanic activity in the region started in the Late Cretaceous, these intrusions may also be Late Cretaceous in age. To the east of the study area, there is a big rhyolitic dome between Gümeran, Hamitli, and Acına villages. Akyol et al. (1974) stated that this unit, which they mapped as the Hamitli rhyodacite, was of the Precambrian age. According to our observations, the Hamitli rhyodacite intruded into the Çakraz Formation and can be correlated with the small intrusions mentioned above.

While the Çakraz Formation is unconformably overlain by the İnaltı Formation in the south of the Arıtdere valley, it is thrust over Jurassic and Cretaceous units in the north.

Until recently, no age data has been obtained from the Çakraz Formation. However, Gand et al. (2011) found trace fossils in the lower parts of the formation, in the Çakraz Bay. These are the footprints of a tetrapod, *Hyloidichnus* (Figures 5a and 5b), and

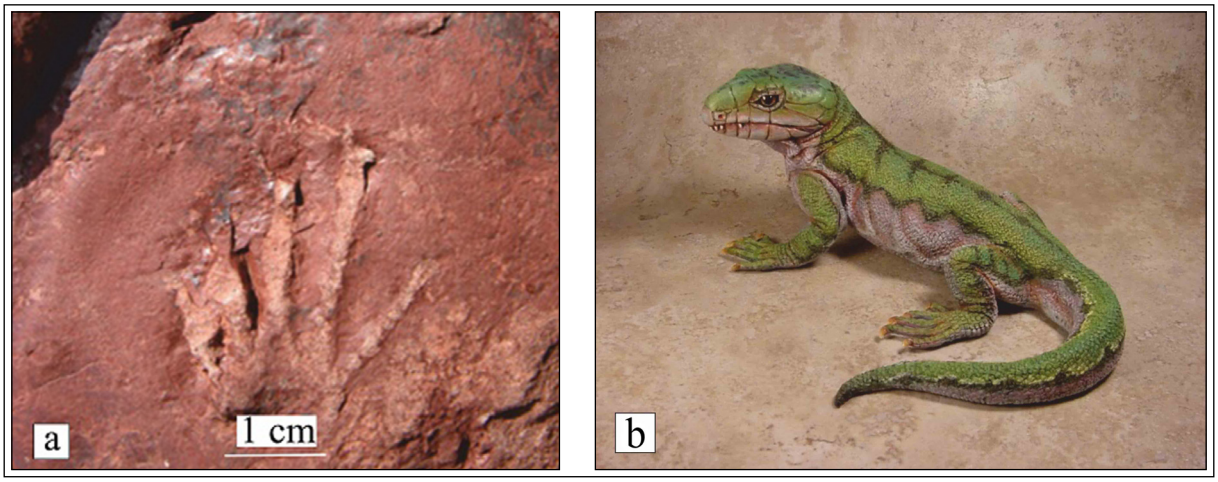

Figure 5- a) Tetrapod (*Hyloidichnus* sp.) footprints found in the red mudstones of the Çakraz Formation in Çakraz Bay (this footprint is also the oldest reptile fossil findings in Turkey), b) an animation of *Hyloidichnus*.

the traces of macrofloral *Annularia* and *Stigmaria*. Similarly, Grancy (1938) mentioned the *Walchia* traces in the sequence. Based on these trace fossils, it was revealed that the lower parts of the Çakraz Formation were deposited during the Cisuralian (Early Permian) period (Gand et al., 2011). Stolle (2016) determined the age of Late Cisuralian-Guadalupian (~ 283-265 Ma) based on palynological data in the outcrops equivalent to the unit around Çamdağ in the west. On the other hand, the Çakrazboz Formation, conformably and transitionally overlying the Çakraz Formation, is Late Triassic in age. This indicates that the Çakraz Formation was deposited in the Early Permian-Late Triassic period, in an approximately 100 million years period. Although this long time interval raises the suspicion that there may be significant erosional periods in the formation, it is impossible to answer this doubt with the field observations and limited fossil data. The actual thickness of the Çakraz Formation could not be measured. Its thickness is predicted to be more than 1500 m.

The red color of the Çakraz Formation, absence of fossils, and sedimentary structures such as the cross-bedding, mud cracks, channel structures, and the traces of waves, raindrops, and living organisms indicate an arid depositional environment (fluvial and flood plain) where the oxidation rate is high. The lenticular conglomerate levels in the lower parts of the sequence and the sections dominated by coarse-medium-grained sandstone indicate a rapidly shifting braided river network. The floodplain deposits with ripple marks and mud cracks, the best examples of which are seen between İlyasgeçidi and Başköy, document the existence of heavy rainy periods between dry seasons. The large-scale wind-type cross-bedding in the upper layers of the sequence indicates that desert conditions dominated in places. In the following periods, large lakes in which the Çakrazboz Formation had been deposited were developed.

Tetrapod (*Hyloidichnus* sp.) footprints found in the Çakraz Formation (Figure 5a and b) by Gand et al. (2011) support the idea that the unit was deposited in a floodplain environment where hot, humid, and long dry periods alternate with each other and the captorhinids, which are one of the earliest reptiles known in the world, had lived. By correlating these fossils, Gand et al. (2011) stated that this terrestrial environment might be a migration route between the Western and Eastern Laurasia, and these small reptiles populated in Asia might have migrated to Asia in this way due to favorable conditions in Laurasia, instead of Gondwana.

2.2. Mesozoic

2.2.1. Triassic

Çakrazboz Formation: The Çakrazboz Formation, named by Varol and Akman (1988), consists of fine-grained lacustrine clastics and carbonates (Figure 3). The formation outcrops around Çakrazboz, Aliobası, and Beşirler villages, south of Çakraz village in the west, and between Başköy and Kirazlıdere villages in the east (Figure 2).

The dominant lithology of the Çakrazboz Formation is a homogeneous alternation of marl and claystone. This alternation is sometimes accompanied occasionally by siltstone and rarely by sandstone and limestone. The marls are generally light gray, greenish, yellowish, and reddish especially in the lower parts of the sequence. The unit is thin to medium bedded and sometimes massive. The lamination is frequently encountered within the layers. In addition, varve structures, typical examples of which are observed in the south of Ahmetler village are exist. Thin levels of charred organic-rich material are also observed in this area.

The claystones, which are common in transitional levels with the Çakraz Formation, are dark yellowish, pale red-burgundy colored. In the sections where claystones alternate with marls, the formation has a green-red mottled appearance. The lamination is the most common sedimentary structure in these clayey, sandy and silty levels. The limestones with conchoidal fractures are rarely seen in the formation, such as around Başköy. They are white-beige-grayish in color, clayey, micritic in texture, and medium- to thickly-bedded. The upper and lower surfaces of the beds, which are mostly 10-40 cm thick, are generally transitional with clayey and silty units. Rarely, nodules and concretions are found.

The gradual transition between the Çakrazboz Formation and the underlying Çakraz Formation is seen almost everywhere, where these two units come together (Figure 6a). The unit is located on wind deposits of the Çakraz Formation around Çakrazboz village and on the flood plain deposits in other regions with a transition zone ranging from a few meters to a few tens of meters in thickness. At the top, the Çakrazboz Formation is unconformably overlain by the Himmetpaşa Formation and younger units. The Himmetpaşa Formation in the southeast of Aliobası overlies the Çakrazboz Formation with a low angle unconformity. A little farther east, the İnaltı Formation overlaps the Himmetpaşa Formation and unconformably overlies the Çakrazboz Formation in the northern slope of Esenlerkayası.

The Çakrazboz Formation, whose thickness varies between 300 and 500 meters, is a typical lacustrine deposit. In previous studies (Rutherford et al., 1992; Alişan and Derman, 1995), palynological data revealed that the unit is Late Triassic in age and indicates a freshwater depositional environment.

The dominating lake sediments in the Late Triassic and the light color of these sediments, unlike the Çakraz Formation document arid conditions in the region, which have been effective since the Early Permian, left their place in the Late Triassic to a less-oxidizing period with abundant rainfall. After that, the region probably has been uplifted and remained as an erosional area for about 20-30 million years, until the Middle Jurassic.

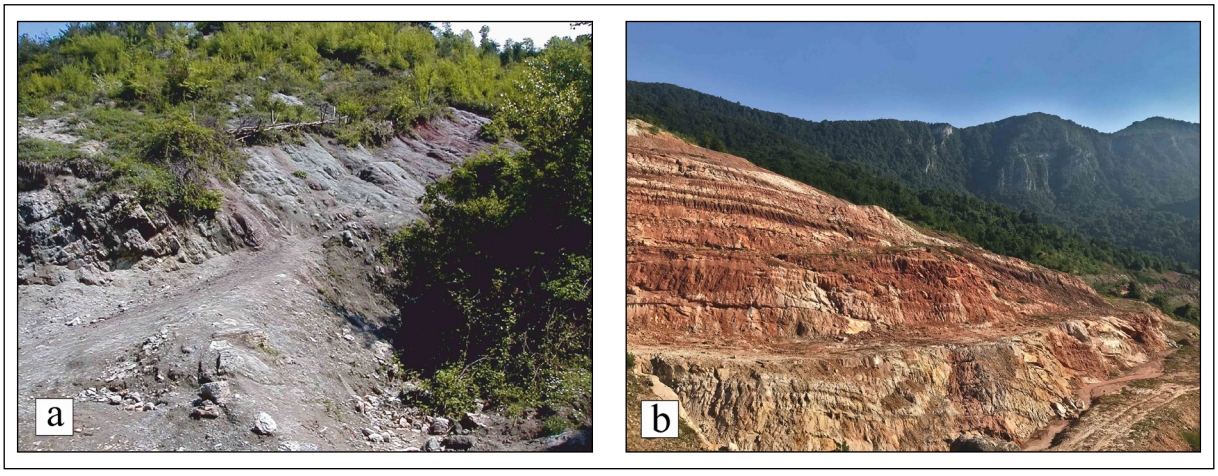

Figure 6- a) The transition zone between the Çakraz and Çakrazboz formations consists of the alternation of burgundy and white carbonated mudstones, b) white-colored beach sandstones in the lower parts of the Himmetpaşa Formation were used as raw materials in the glass industry as they are rich in quartz. Coal and sometimes red mudstone and shales on the sandstones show a deposition in coastal and marsh environments. The unit is unconformably overlain by the İnaltı Formation at the top. Both photos were taken from the vicinity of Başköy.

2.2.2. Jurassic and Lower Cretaceous

Himmetpaşa Formation: This formation consisting of transgressive and following regressive clastics from base to top, was named by Akyol et al. (1974) based on the outcrops around the Himmetpaşa Village in the southwest of Cide. The main outcrops of the unit are located in the south of Aliobası, between Kavaklı-Pelitovası-Himmetpaşa, in the south of Cide, and between the southern slope of Mevrendere valley and Apşara. There are also two small outcrops of the unit around Ovacık and Kezağzı villages (Figure 2).

The basal part of the Himmetpaşa Formation, where it overlies the Çakraz or Çakrazboz formations with a weak angular unconformity, consists of medium-poorly sorted, grain-supported, well-cemented pebbles dominated by red-colored, rounded quartz clasts, and then rapidly grades into sandstones. Thickly-bedded sandstones consisting of clean quartz clasts are light-colored, rounded, well sorted and graded, and sometimes cross-laminated. In outcrops to the south of Kirazlıdere, there are locally gray-colored mudstones and some coal levels which were mined years ago. Up the section, the white, well-sorted, and rounded sandstones begin to alternate with siltstone levels. Siltstones are light gray-leaden and weakly foliated. They consist of plenty of coal fragments. In some places, very thick coal-bearing black shales are also seen on the sandstones. These shales contain various sizes of wood fragments and iron-bearing concretions. In the outcrops around Develi, Yukarıdoğurca, and Kezağzı, the formation starts at the base with black colored swamp shales, with abundant plant fragments. These features indicate that the lower parts of the Himmetpaşa Formation are deposited in coastal and adjacent environments (Figure 6b).

Up the section, khaki-dark gray massive claystone, sandstone, and marls containing abundant ammonite, belemnite, and brachiopod (especially *Rhynconella* sp.) fossils are observed. These fossils indicate a transition from coastal to open sea conditions. Up the sequence, there is an alternation of very thick proximal-intermediate turbiditic sandstone and shale with some turbidite channels filled with coarser clastics. In the uppermost part of the sequence, there are again coal-bearing shales and a few meters thick conglomerate levels alternating with them. Typical outcrops of this uppermost terrestrial unit can be observed around the Apşara village.

The Himmetpaşa Formation generally has an outcrop pattern extending in the form of narrow strips between the underlying Çakraz and Çakrazboz formations and the overlying İnaltı Formation (Figures 2 and 3). In its outcrop between Mervendere and Apşara, the thickness of the formation is about 150-350 meters in the west, but reaches up to 1200 meters in the Daynılak stream.

The unit, which unconformably overlies the Çakraz Formation in the upper parts of the Daynılak stream, is overlain by the Çakraz Formation along a north-vergent reverse fault in the lower parts of the same stream. Around Kavaklı village, the Himmetpaşa Formation thrust over the Dereköy, Unaz and Cambu formations together with the overlying İnaltı Formation. The same unit is tectonically overlain by the Çakraz Formation in the south along a line extending from the south of Kavaklı village to Himmetpaşa village.

The Himmetpaşa Formation was dated as the Liassic-Dogger based on the ammonite fossils (Grancy, 1938; Wedding, 1968; Akyol et al., 1974; Yergök et al., 1987). However, Derman et al. (1995) suggested that the unit doesn't contain Liassic according to palynomorphs and is of Dogger in age. Any dating study covering the whole section of the Himmetpaşa Formation has been conducted. The Himmetpaşa Formation represents a short-lived marine transgression and subsequent regression in the region causing the deposition of shallow marine-terrestrial clastics at the base, ammonite-bearing open marine clastics, and turbidites in the middle, and shallow marine-terrestrial clastics at the top.

İnaltı Formation: This formation, which was named by Ketin and Gümüş (1963) from İnaltı village to the south of Sinop, consists of shallow marine platform limestones. The İnaltı Formation, or the İnaltı Limestone, is represented by a rather monotonous carbonate sequence, excluding its basal part. The unit can easily be confused with similar Early Cretaceous limestones, while can easily be distinguished from the other formations due to its light color, distinct bedding, karstic but resistant structure forming steep hills. The main outcrops of the unit in the study area are seen as east- or northeast-trending strips in the south of Aliobası-Elvanlar, between Kavaklı and Cide, between Çöpbey and Armutluçayır settlements. The Cide-Azdavay road and the Devrekâni stream valley

are also places where the unit is widespread and its features can be well observed (Figures 2, 3, and 7).

The İnaltı Formation generally starts with sandy, clayey, thinly bedded limestones at the base. On the Apşara-Armutluçayır road, this basal part consists of greenish, pinkish, hard, and brittle micritic limestones with very distinct and sharp bedding. At the base of the formation in the Armutluçayır locality, there are yellowish quartz pebbles bearing carbonate cemented, medium-coarse grained sandstones, and alternation of sandstone-claystone-mudstone. In some areas, there are reef build-ups or single corals in the lower parts of the sequence. The upper parts of the sequence are quite homogeneous and generally micritic, and few dolomitic on the occasion and rarely in the form of algae carbonate muds. There are also sparite-cemented intraclastic and oolite-rich levels. The limestones in the upper parts are medium to thick, distinctly bedded, brittle, and fractured with planar surfaces. The karstification is one of the typical features of this unit. Particularly, the outcrops on high hills to the north of

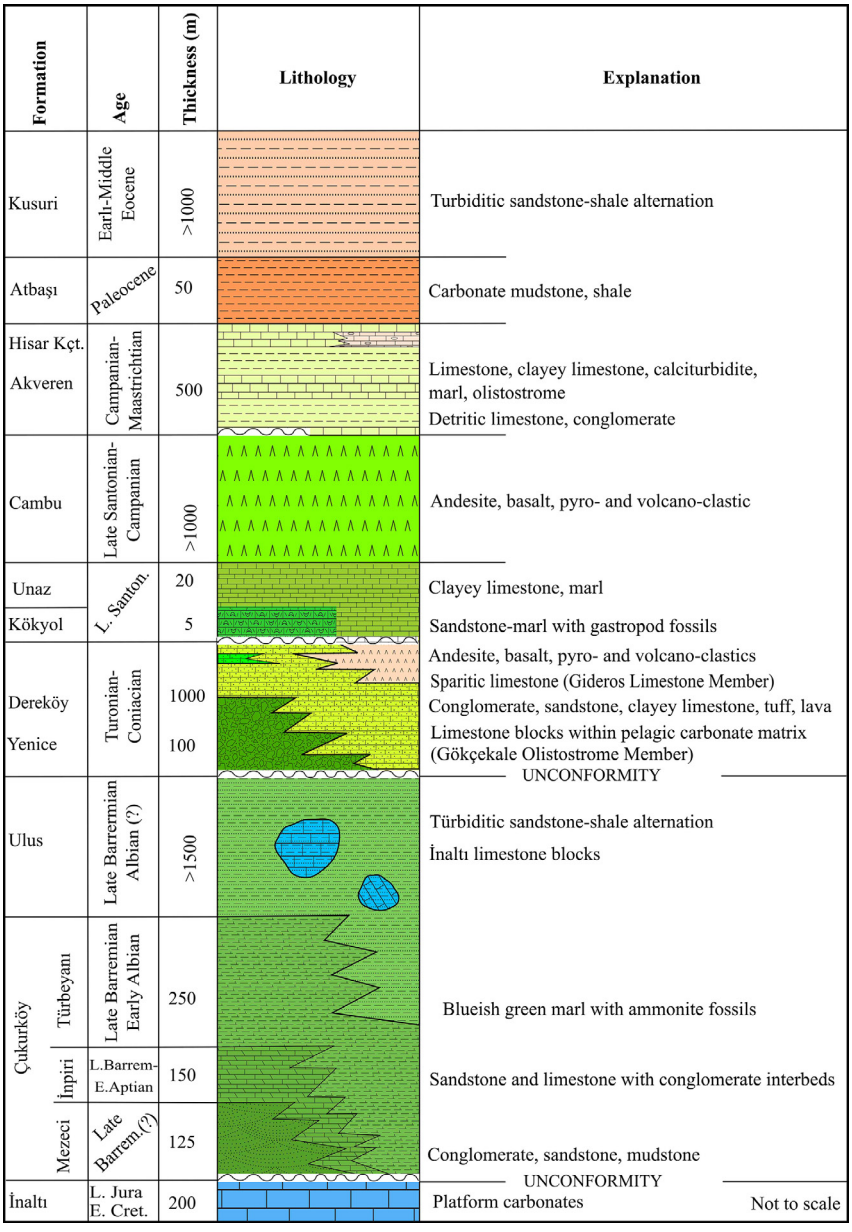

Figure 7- Generalized stratigraphic section of the post-Jurassic units of the study area (formation thicknesses are given as average values).

the Arıt River and the south of Başköy contain funnel- or cone-shaped deep depressions due to karstification and collapsing. There are significant water discharges from these karstic cavities along the bottom of the limestone. The thickness of the İnaltı Formation within the study area reaches up to 500 meters.

The İnaltı Formation unconformably overlies the Çakraz Formation in the south of Başköy, south of Armutluçayır, along the road from Apşara to Armutluçayır and on the Arıkayaları in the east of Apşara (Figures 2 and 8a). The unit, which is located in the south of Aliobası, on the road between Aliobası and Dağköy, disconformably overlies the quartz-rich clastics of the Himmetpaşa Formation and is overlain by the clastic and carbonates of the Early Cretaceous Çukurköy Formation at the top.

The Devrekâni (Irmak) stream valley in the south of Cide-Kumluca is the best place to view the İnaltı Formation. In the old quarry at the entrance of the valley, the İnaltı Formation thrust northward over the Akveren Formation. The İnaltı Formation is disconformably overlain by the Late Cretaceous pelagic red micrites on the path from the Kokurdan district to the Irmak stream canyon. Again, from the same place towards the Okçular district, the Lower Cretaceous marls overlie the İnaltı Formation with an angular unconformity, as can be seen just on the east of the Okçular-Kumluca road. The Lower Cretaceous units near the Fille village in the southern mouth of the Irmak stream canyon unconformably overlie the İnaltı Formation.

The İnaltı Formation is rich in fossils. Especially in the lower parts of the sequence, there are foraminifers that can give an age. Of these, *Alveosepta pouzersi,* and *Alveosepta* sp. indicate the Kimmerician, and *Alveosepta jaccardi* indicates the Late Oxfordian-Early Kimmerician age for the deposition. Derman and Sayılı (1995) and Akman (1992) also stated that the unit is Late Oxfordian-Berriacian in age. Akman (1992) argued that the age of the unit goes up to the Valanginian around Himmetpaşa village.

The İnaltı Formation, which starts transgressively with very shallow marine clastic sediments at the base, is dominantly composed of neritic platform carbonates. These carbonates are sparite cemented and oolitic in parts where deposited under the effect of tidal flat and wave activity, and micritic in parts where deposited in lagoon and protected shelf environments. The lenticular levels of sands and intraclasts with sparitic cement within the micritic levels indicate the tidal flow channels.

Çukurköy Formation: The Lower Cretaceous units in the study area are represented by lithologically different deposits. These coastal deposits collected under the name of Çukurköy Formation include the Mezeci Clastic, the İnpiri Limestone, and the Türbeyanı Marl members showing lateral and vertical transitions to each other (Figures 2 and 7). The turbidites, which are the equivalent of all these three members, seen in the south have been considered under the name of the Ulus Formation.

Mezeci Clastic Member: This red-colored unit, named by Akman (1992), consists of conglomerate, sandstone, and mudstone. The only mappable outcrop of Mezeci Clastic Member is located on the southwestern slopes of the Kayabaşı Hill between Mezeci and Yaylacık villages. This unit is best viewed along the path from Mezeci village to Kayabaşı hill.

The Mezeci Clastic Member overlies the Çakraz Formation with an angular unconformity (Figure 8b). It is quite difficult to recognize this contact on the field, due to the very similar lithological nature of upper and lower units, which were together mapped as the Çakraz Formation in previous studies. In contrast to the Çakraz Formation, the Mezeci Clastic Member consists of pebbles of the İnaltı Formation, and this can be used as a criterion to distinguish these two formations.

The Mezeci Clastic Member starts at the base with quartz-rich, rounded, poorly sorted sandstone. This unit showing irregular and laterally discontinuous bedding reaching up to 2 meters in thickness, has filled the irregular topography of the underlying Çakraz Formation. Up the section, the sandstone starts to alternate with mudstones and conglomerates rich in red quartz sands. Conglomerates are red, burgundy, and poorly sorted. Rounded pebbles are generally supported by a sandy matrix. Grain sizes do not exceed 5 cm. It contains plenty of pebbles sourced from the İnaltı Formation. The grain imbrications and rare cross laminae within the conglomerates reveal that the unit fed from a source area in the northeast. In the upper parts of the sequence, these coarse-grained units are replaced by sandstones that are irregularly alternating

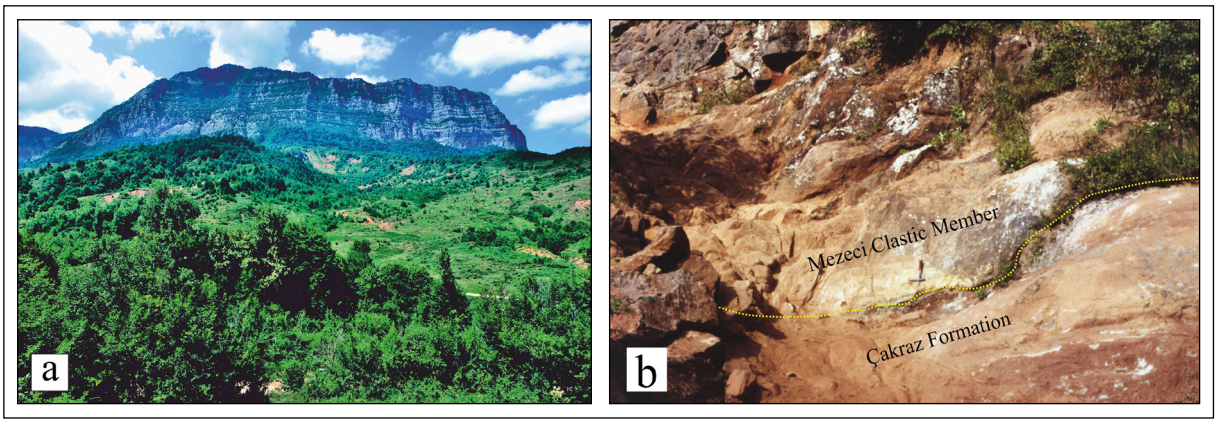

Figure 8- a) Limestones of the İnaltı Formation in the south of Amasra-Kurucaşile road unconformably overlie the Çakraz Formation. There is the Himmetpaşa Formation in the form of a thin strip between these two units, b) the bottom part of the Mezeci Clastic Member is similar to the Çakraz Formation in color and lithology where it overlies this unit. Picture shows the unconformable contact between the two units.

with mudstones. There are scattered angular pebbles at certain levels of the sandstones or sometimes in the form of irregular flooding horizons probably derived from a close source. Up the succession, the appearance of the unit changes rapidly and passes into dolomitic limestones of the İnpiri Limestone Member towards the Kayabaşı hill, and to the khaki-colored marls of the Türbeyanı Marl Member towards the vicinity of Yaylacık.

A few meters thick level underlying khaki-colored marls on the road from Mezeci to Çukurköy consists of beach sands consisting almost entirely of quartz and white spherical quartz pebbles of 1-2 cm in diameter within them. Although the relationship between these thickly bedded, very well-sorted mature clastics, which do not contain any matrix and the red deposits described above cannot directly be seen, their stratigraphic position shows that they are laterally equivalent to each other. These beach deposits laterally pass into sandy carbonates towards Çukurköy to the west.

Although no fossils have been found in the Mezeci Clastic Member, based on its transitional nature with the İnpiri Limestone and Türbeyanı Marl members it is accepted as the Late Barremian-Aptian in age.

Red colored pebbly, mudstone intercalated quartz-grained clastics at the lowest part of the Mezeci Clastic Member was probably deposited in a braided river environment. On the other hand, the clean, white, grain-supported mature quartz sandstones are probably beach deposits. Considering the presence of such beach sand-rich levels, the red color of the unit, and the absence of fossils, the Mezeci Clastic Member is thought to have been deposited on the land and sea border, possibly in a tidal zone. The thickness of the Mezeci Clastic Member varies between 50 and 150 meters.

İnpiri Limestone Member: The İnpiri Limestone Member consists of neritic limestones and dolomites, which contain clastics in places in the lower parts. The unit overlies the Mezeci Clastic Member at the base, laterally and vertically transitional with the Türbeyanı Marl Member, and unconformably overlies the older units in some places. The large outcrops of the unit are located on the Amasra-Çakraz road, around İnpiri village, between Mezeci-Yaylacık villages, in Dağköy and in the north of Arıt valley. The outcrops of the İnpiri Limestone Member are more common around Amasra and Çakraz. In the west of Amasra the unit overlies Devonian, Carboniferous, and Permian deposits with an angular unconformity (Figures 2 and 9a).

The limestone consists of whitish, cream-colored, thickly bedded, sometimes massive, shallow marine limestones and dolomite, often containing abundant fossiliferous and clastic levels. Limestones are more common to the west, and dolomites to the east. The dolomites are light gray and milky brown and generally massive, but much jointed. These limestones are also heavily quarried commercially.

In sections where the İnpiri Limestone unconformably overlies the older units, there are

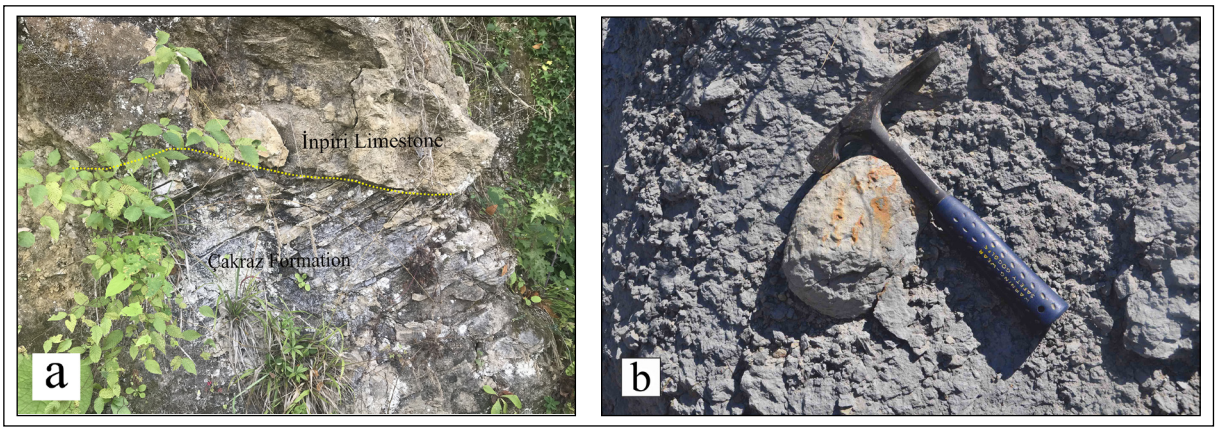

Figure 9- a) İnpiri limestone overlying the Çakraz Formation with an angular unconformity on the road to Tarlaağzı village, in the west of Amasra, b) Ammonite fossil within the Türbeyanı Marl Member.

conglomerates and sandstones intercalating with claystone at the lower levels, the thickness of which sometimes reaches several tens of meters. At the bottom of the unit around Amasra and its east, there are poorly sorted, grain-supported pebbles with rounded grains. This coarse-grained unit first passes into reddish carbonate cemented sandstones with shell fragments and then to the limestone. In the vicinity of İnpiri village, the limestone unconformably overlies the Çakrazboz Formation. Near Mezeci, the limestone is completely dolomitic and rests on the Mezeci Clastic Member.

Lithological characteristics of the İnpiri Limestone Member, which has a limited distribution in the study area, change very frequently. It contains abundant siliciclastics, intra-, and extra-formational carbonate pebbles. The carbonate ratio increases towards Amasra in the west, where the clastic material is seen as thin horizons within limestones. Towards the east, the unit contains more clastics or it is composed entirely of clastics in places. The dolomites are more dominant towards the east. Both these characteristics and fossil content indicate that the İnpiri Limestone is deposited in a high-energy, very shallow marine environment, close to the land. Dolomitic units can be considered to reflect partially closed lacustrine environments separated from the land by sand barriers. The thickness of the İnpiri Limestone member varies between 100 and 200 m.

Masse et al. (2009) stated that the carbonate platform, which presently can be observed for approximately 80 km between Zonguldak and Kurucaşile, was represented by a 10-15 km wide siliciclastic and carbonate mixture in the east and 20-30 km wide horizontally developing Urgonian-type platform in the west, around Zonguldak. The south of this platform was in the form of an uplift providing clastic material to the north and south, and it had a transitional structure with the deep marine basin deposits of the Ulus Basin to the south and southeast. The Western Black Sea Basin was located to the north of this platform, which started to develop in the Late Barremian, demised with the subsidence of the entire region at the end of the Early Aptian, and was replaced first by *Palorbitolina* then ammonite bearing deep marine sediments with marl and glauconite.

Masse et al. (2009) stated the presence of some biostratigraphic markers identified for the first time in Anatolia, such as *Sporolithon phylloideum, Salpingoporella melitae, Acroporella radoiciciae,* and *Pseudoactinoporella fragilis*, and pointed out that the foraminifers such as *Montseciella arabica* and *Rectodictyoconus giganteus* indicate the Late Barremian and Early Aptian period.

Türbeyanı Marl Member: The outcrops of this member, which consists of khaki-colored ammonitic marls, are located in a large area around Dağköy and Çukurköy, around Çöpbey, Çetme villages in the north of Arıt valley, around Göçkün, Dada and Baldıran, and in a large area from Hıdır village in the west to Kokurdan village in the east (Figures 2 and 7).

The khaki-colored marls are generally massive, and often exfoliated at the surface. It contains abundant ammonite fossils in places and limonitized iron-bearing concretions. In addition, it contains rare

sandstone, siltstone and limestone intercalations, and limestone blocks in places. Although the lower stratigraphic contact of the unit is clear in most places, the upper contact is not generally seen due to faulting or erosion.

The İnaltı Formation is unconformably overlain by a carbonate-cemented, thin-bedded, extremely stiff, fine-grained, well-sorted sandstone in the Karadere valley in the north of Çöpbey. This 10-25 m thick unit, which is rarely seen in a few small outcrops in the Karadere valley, rapidly passes into the khaki-colored marls at the top. On the road from the Karadere to Çöpbey, the marls alternate with fine sandstone layers and contain gastropod fossils.

The dominant lithology of the unit is khaki colored marls between Çetme-Hıdırlı-Çöpbey-Ellesköyü. The bottom of the unit here can be best-viewed on the waterfall on the Kara stream about 300 m east of Çöpbey village. The underlying İnaltı Formation has formed giant cauldrons and waterfalls as a result of the fluvial erosion. At the end of the waterfall, sand-rich limestones overlie the İnaltı Formation with an angular unconformity. These thinly bedded, dark gray carbonates rapidly pass into the khaki-colored marls following a transition zone of a few meters towards the top.

The Yukarıtaşça district is the best viewing point for the blocks within the Türbeyanı Marl Member. These limestones, which reach the mappable size in places, are surrounded by a cover with a thickness varying between 10 and 50 cm and consisting entirely of limestone pebbles. These angular, very poorly sorted pebbles have a khaki-colored marl matrix. There are massive marls outside this cover. The limestones forming the blocks are whitish, cream-colored, and massive, and both their lithological characteristics and the fossil content show that the blocks were transported from the İnaltı Formation.

In Çukurköy, the Türbeyanı Marl Member unconformably overlies the İnaltı Formation with a 10-15 m thick basement level consisting of a sandy, oolitic, tabular-bedded limestone, gradually passing upward into the marls. There are also sandstone layers within marls.

In the area between Hıdır district and Gideros Bay, the unit consists of massive, khaki-colored marls overlain by the İnaltı Formation along with a north vergent thrust. In the area between Köçkünköy around Himmetpaşa village in the west and Kokurdan district in the east, there is a wide outcrop of the Türbeyanı Marl Member. Here, the unit outcrops at the core of a syncline, the basement of which is the İnaltı Formation and northern limb of which thrust northward over the Yenice Formation. The northern limb of this syncline is overturned northward and thrust to the north in most places. In the east of Okçular district, the marls unconformably overlying the İnaltı Formation contain ammonites and iron-bearing concretions. Around Abbaslar district, the Türbeyanı Marl Member gradually passes to the Ulus Formation with the inclusion of gradually increasing sandstone intercalations.

In the south of the syncline described above, there is another syncline whose limbs are formed by the İnaltı Formation. At the core of this syncline enlarging towards Malyas, there are Türbeyanı Marl Member and the overlying Ulus Formation. The Türbeyanı Marl Member starts with glauconite sandstones at the base resting unconformably on the İnaltı Formation in the Olcak stream valley and rapidly passes into khaki-colored marls. The thickness of the unit in here is about 50-100 m and passes into the Ulus Formation, which consists of a turbiditic sandstone-shale alternation at the top between Fille village and Honduras district. The thickness of the Türbeyanı Marl Member reaches up to 300 meters.

Based on the fossil assemblage of *Ticinella ragnaudi, Ticinella* cf. *Madecossiana, Ticinella primula*, *Ticinella* spp., *Ticinella* sp., *Lenticulina* sp., *Hedbergella garbachika, Hedbergella* sp., *Modosaria* sp., *Marginula* sp. in the samples taken from the Türbeyanı Marl Member the unit was dated as Early (?) Albian. *Orbitolina* sp., *Neotrocholina* sp., *Miliolidae, Valvulinidae, Pseudocyclommina* sp., *Nezzazata* sp., and *Dasycladaceae* fossils found in samples taken from the carbonated and pebbly levels at the basement of the Türbeyanı Marl Member in the outcrops of the Dağköy syncline indicate the Late Barremian-Aptian period. Masse et al. (2009) reported that the ammonites found in marls (Figure 9b) indicated the *Deshayesites weissi* zone (Early Aptian).

The Türbeyanı Marl Member that gradually overlies the shallow marine İnpiri Limestone Member,

contains glauconite grains and bears ammonite fossils. All these suggest a gradually deepening open marine environment for the deposition of the unit.

Ulus Formation: This siliciclastic turbiditic sequence starting from the south of the study area and spreading further south into the Ulus Basin was named by Akyol et al. (1974).

In the study area, it conformably overlies the Türbeyanı Marl Member within the Malyas syncline, but unconformably overlies the İnaltı Formation in areas where this member is not found (Figures 2 and 7). On the other hand, there is not any overlying stratigraphic unit within the study area, but it is unconformably overlain by the Late Santonian micritic limestones in the north of Azdavay (Tüysüz et al., 2000).

The Ulus Formation begins with the addition of turbiditic sandstone intercalations into the marl in sections where it overlies the Türbeyanı Marl Member, and as these intercalations gradually increase, it becomes a homogeneous thin to medium bedded sandstone-shale alternation. In sections where the İnaltı Formation is overlain, the deposition starts with fan deposits at the base and rapidly passes upward into turbiditic sandstone-shale alternation. Fan deposits are about 50 meters thick and are composed of quartz-rich, light greenish-mottled conglomerate, sandstone, and claystone. In the sections overlying this partly coarse clastic sequence, the claystone-siltstone intercalating with sandstone or the claystone with a higher ratio of sandstone sequence is dominant. In the upper parts of the formation, the sandstone layers are thicker and more abundant.

The sandstones forming the dominant lithology of the Ulus Formation are brownish yellow, milky white in color, and consist mainly of quartz, feldspar, chlorite, muscovite, biotite, carbonate grains, rock fragments, some of which are volcanic, and opaque minerals. Sandstones in the lower levels of the unit are generally fine to medium-grained, while those in the upper levels are medium-coarse grained. The sandstones are turbiditic in character, graded, and laminated with an erosional base. Incomplete Bouma series point out the proximity to the basin margin. The palaeocurrent directions measured in sandstones show that the basin was fed from the north and northwest. The claystones and shales alternating with sandstones are khaki-grayish, horizontal, or convolute laminated. It has been observed that the unit is distal towards the inner part of the Ulus Basin and even contains red radiolarian mudstones and cherts.

There is no fossil data obtained from the Ulus Formation, whose distribution is limited in the study area. The unit was developed on the İnaltı Formation and took pebbles and blocks from it. The Ulus Formation is the lateral equivalent of the Çukurköy Formation. Based on these data, it is accepted that this unit is also of Late Barremian-Aptian in age. Hippolyte et al. (2010) determined that the unit deposited in the Barremian-Late Aptian period was based on nannofossils in the samples from the northern and southern edges of the Ulus Basin. These authors argued that the deposition in the Zonguldak Basin was continuous from the Late Barremian to the beginning of the Late Albian.

The lower parts of the Ulus Formation that unconformably overlies the older units reflect a shallow marine environment. The upper parts of the unit are in the form of a relatively deep marine turbiditic sequence, which includes blocks and olistostromal levels. The unit is thicker than 1500 m within the Ulus Basin.

2.2.3. Upper Cretaceous

Yemişliçay Upper Group: One of the most important geological events experienced in the Late Cretaceous period in the Western Black Sea region is the volcanism that affected the entire Black Sea region. The volcanism (apart from the weak activity in the Eocene) was mainly active between Turonian and Campanian. Units belonging to this period were named as the Yemişliçay Upper Group by Tüysüz et al. (2004), and were separated into the Kurucaşile and Amasra groups.

Kurucaşile Group: The Kurucaşile Group represents the first volcanic dominated unit in the Western Black Sea Region. Tüysüz et al. (1997) defined Kalabaklar, Göldere, Yenice, Meydan and Sarıkaya formations within the Kurucaşile Group, from bottom to top. The Kalabaklar and Sarıkaya formations are not observed in the study area. The Göldere and Meydan formations were not differentiated in this study and will commonly be introduced under the name of the Dereköy Formation. The Kurucaşile Group rocks are

represented by Dereköy and Yenice formations in the study area. Within the Yenice Formation, the Gideros limestone and Gökçekale olistostrome members were distinguished.

Dereköy Formation: The Dereköy Formation consists of clastics, carbonates, lavas, and tuffs. It was noticed by Wedding (1968) that the unit represents the first volcanic period in the region and the unit was distinguished as the Albian-Cenomanian lower volcanic series by this author. Tüysüz et al. (2012) described the unit under the name of the Dereköy Formation. Outcrops of the formation in the west of the study area start from Dikili Cape in the west, continue by widening towards the east, and ends in the south by being thrusted, and in the northeast of Dereköy by being overlain by the Unaz limestone in the north (Figure 2). In the east, it widely outcrops starting from the east of Cide along the İnebolu road.

Dereköy Formation is composed of the alternation of sedimentary rocks, lavas and pyroclastics, whose proportions show significant changes laterally. In general, the volcanites are dominant to the west and the sedimentary rocks to the east. The sandstones in the unit are yellowish, well-rounded and sorted, thick-bedded, and exfoliated. Ta-c and Tc-d type Bouma series are observed in the turbiditic sections of the sequence. The sandstones have an erosional bottom with rare sole structures. The palaeocurrent directions measured in these structures reveal that the unit was fed from the south. Shales are gray-green, laminated, thin- to medium-bedded, and are replaced by carbonates or tuff, marls or siltstones partly. There are also interbedded lithic tuffs. Marls are green, mostly tuffaceous and fragile. The agglomerates, which are common especially in the western parts, consist of volcanogenic sandstone, marl, and lava blocks of various sizes in tuffaceous groundmass. Tuffs consist of bedded lithic tuffs or solid crystal tuffs. The lavas commonly observed between Dikili Cape and Kalaycı beach are holocrystalline porphyritic andesite or basaltic andesite. There are also pillow structures in these places.

Between Yukarıtaşça village and Kıran hill, the Dereköy Formation overlies the Türbeyanı Marl Member with an angular unconformity. The Dereköy Formation starts with a few meters thick carbonate cemented basal conglomerate above this unconformity plane. Most of the pebbles of the conglomerate are the İnaltı and İnpiri limestones. They are highly rounded but very poorly sorted. They are matrix-supported in a calcareous and sandy matrix. With the increase of carbonate ration in the matrix, the unit becomes pebbly limestone in places. There are abundant gastropod and bivalve shells in the matrix of the unit. These are generally poorly preserved and sometimes are found in the form of accretion of shell fragments. All these features reveal that this basement unit was deposited in a shallow, warm, and high-energy marine environment. The fossils taken from this basement unit indicate the Late Barremian to Cenomanian, but most of them have been transported and reworked. This basal conglomerate passes into sandstone with the rapid thinning of grain size in the upper layers. This yellowish, extremely weathered unit is then overlain by highly weathered thin-bedded tuffs.

On the southern slope of Karacakaya hill, north of Göçkünşili (Akkonak) village, the Dereköy Formation begins to deposit with a red, a few meters thick, extremely silicified micrite resting on the Türbeyanı Marl Member and continues with a volcanic succession consisting of greenish, mottled andesites and their pyroclastics. The Dereköy Formation around Dereköy on the road between Kavaklı and Tekkeönü villages presents a different sequence, although it is the lateral continuation of the sections described above. The unit is observed in two tectonic slices in this section. Structurally the upper slice is tectonically overlain by the Zonguldak, Çakraz, and Himmetpaşa formations along with a south-dipping thrust and is completely overturned. The main lithology of this slice is the intercalation of quartz-rich, yellow sandstone and marl, and thin tuff layers that occasionally accompany them. There are also limestone blocks or debris-flow levels containing limestone pebbles. Sizes of the blocks can reach up to 5-10 meters. The debris-flow horizons include rounded İnaltı and İnpiri limestone pebbles as well as the pebbles from the Zonguldak and Çakraz formations. The second, the structurally lower slice is in the form of an antiform. In the northern limb of this antiform, the Unaz Formation unconformably overlies the Dereköy Formation with a distinct contact within the Turabi (Çayaltı) village (Figure 10a). The Dereköy Formation in this section consists of a white, cream, sometimes gray-colored, brittle, conchoidal fractured, thin to very thin sharply-bedded micritic

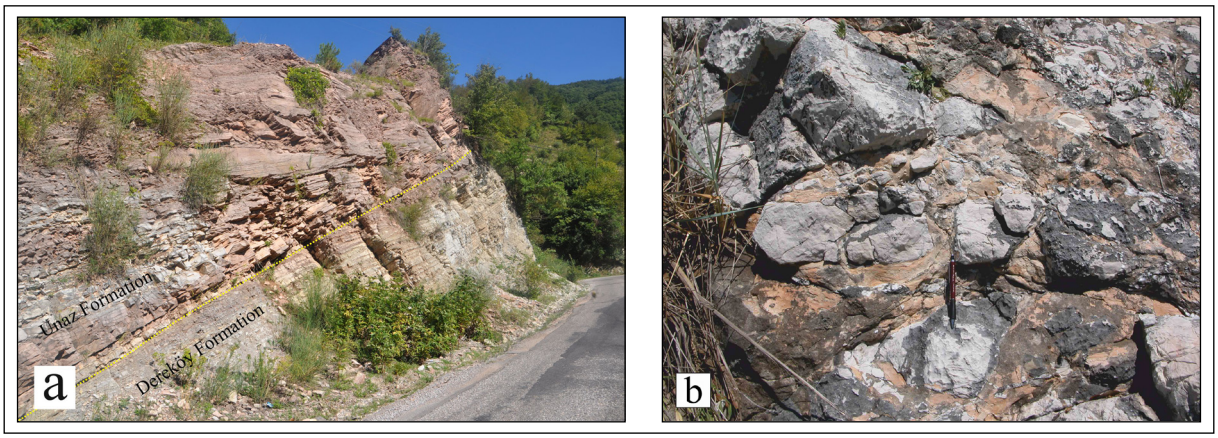

Figure 10- a) Weak angular unconformity between the Dereköy Formation and the overlying Unaz Formation around Turabi (Çayaltı) village, b) Gökçekale Olistostrom: angular pebbles and blocks of İnpiri Limestone in a pelagic sandy carbonate matrix containing the Middle Turonian fossils.

limestone. Globotruncana fossils can be detected by the naked eye in these quite homogenous micrites. The index fossils were found in these levels.

Upwardly clastics become dominant. These are primarily in the form of dark-colored sandstone-shale alterations. In this flyschoidal intercalation, there are occasionally light-colored tuff intercalations. Upwards, the grain size gradually becomes coarser, and the levels of conglomerate and debris-flows are observed partly. The base of conglomerates is generally erosional. Most of the pebbles are limestones while some others are clastics from the Zonguldak and Çakraz formations. The coals eroded from the Zonguldak Formation sometimes form coal-rich horizons. Up the sequence, the grain size becomes thinner again and gradually passes into the alternation of marl and calcareous fine-grained sandstone including light-colored, fine tuff intercalations. This light-colored, marl-dominated section thickens towards the west and overlies the lower section rich in volcanic rocks. The Dereköy Formation is thicker than 1000 meters.

Based on the *Marginotruncana pseudolinneiana, Marginotruncana coronata, Heterohelix* sp., *Hedbergella* sp., and *Globotruncanidae* in samples taken from the micrites of the Dereköy Formation in the south of Turabi village a Middle Turonian-Santonian age was determined. *Marginotruncana pseudolinneiana, Marginotruncana coronata, Marginotruncana* cf. *Renzi, Marginotruncana* cf. *Sehneeansi, Dicarinella imbricata, Dicarinella conaculata, Dicarinella* sp., *Helvetoglobotruncana helvetica, Praeglobotruncana gibba, Praeglobutruncana* sp., *Heterohelix* sp. and *Hedbergella* sp. found in the samples taken from the east of Dereköy indicate (Middle?) Turonian for the deposition. Boehm et al. (2019) showed that the Dereköy Formation had been deposited in a time interval ranging from Turonian (*Dicarinelle concavata* plankton zone and CC13 / UC8-9 nannofossil zones) to Middle-Late Santonian (CC17 / UC13 nannofossil zone).

Yenice Formation: Yenice Formation, which is observed as a narrow strip along the Black Sea coast between Kapısuyu and Kumluca, consists of pelagic limestone, carbonate mudstone, and olistostromal units within them. Tüysüz et al. (1997) determined the Gideros Limestone and the Gökçekale Olistostrome members within this formation.

The Yenice Formation is a pelagic sedimentary sequence. Its typical outcrops begin to be observed on the eastern coast of Kapısuyu Bay. There are well-exposed outcrops of the unit on the Kapısuyu-Cide road and between the eastern coast of Gideros Bay and Okçular. The dominant lithology of the unit is the clayey micritic limestone, pelagic carbonate, mudstone, siltstone, and marls. The micritic limestones are red, burgundy, and pink-colored, thin to very thinly bedded, highly fractured, and contain radiolarian and generally pelagic fossils. Carbonate mudstones and marls are red, pink, white, and bright gray colored. The unit was intensely affected by the tectonic deformations, particularly the carbonate mudstones

and marls were highly deformed and even foliated in most places. The calcareous siltstone and marl are dark gray, cream, or pinkish in color. Especially the siltstones are thick-bedded and massive. The slump structures are common and there are rare sole structures, indicating a source in the south.

The debris-flow horizons and various sizes of olistolites are present in the Yenice Formation (Figure 10b). These were mapped by Tüysüz et al. (1997), in the east of Kapısuyu under the name of Gökçekale Olistostrome. This unit, which constitutes the stratigraphically visible lowest level of the Yenice Formation, consists of pebbles and blocks of various sizes in a pelagic carbonate and clayey matrix. Most of these pebbles and blocks are from the İnpiri Limestone Member, of some from the İnaltı and to a lesser extent from the Çakraz formations. Although the ratio of blocks with respect to matrix varies, the blocks are dominant in general. Even in places where there is no matrix, the unit is observed as a brecciated limestone. The thickness of the unit is around 100 m.

The size of the blocks within the olistostrome is highly variable. Very poorly sorted, angular fragments from a few centimeters to 10-15 meters are randomly embedded in the pelagic matrix (Figure 10b). It is clear that the clasts are transported into the pelagic matrix quickly without any processing. Slump and settlement structures and plastic flow folds are common in the matrix with intra-formational pebbles. The matrix that fills the spaces between the clasts is generally composed of sandstone, siltstone, and claystone, in which tuffites are also observed occasionally. There are globotruncana fossils within these units, although they are not widespread.

Marginotruncana coronata, Marginotruncana pseudolinneiana, Dicarinella canaculata, Helvetoglobotruncana helvetica, Hedbergella flandrin, Marginotruncana spp., *Dicarinella* sp., and *Globotruncanidae* found in the matrix of the Gökçekale Olistostrome indicate the Turonian-Santonian, while the Middle Turonian age was determined based on the occurrence of *Helvetoglobotruncana helvetica, Marginotruncana pseudolinneiana, Marginotruncana coronata, Dicarinella hangi, Marginotruncana* sp. and *Globotruncanidae*.

The massive limestones within the Yenice Formation were named by Tüysüz et al. (1997) as the Gideros Limestone Member. Typical outcrops of the unit are found in the Gideros Harbor, in Samallıkyanı locality in the west of this harbor and around Kalafat, Çalca and Okçular districts to the east. The limestone is yellowish gray, thick-bedded or mostly massive, partly sandy, and pebbly. It contains euhedral pyrite crystals up to 1 cm in size. It is very similar to the İnpiri limestones in terms of its external appearance. However, it differs from the İnpiri limestones with its abundant pyrite content, stratigraphic position, and rare globotruncana fossils in thin sections. The unit rarely reaches a thickness of 100 m.

The Gideros Limestone Member is in the form of a tectonic slice between Türbeyanı Marl Member at the top and the Akveren Formation at the base, between Gideros Harbor and Okçular. Here, the unit alternates with red micrites and marls of the Yenice Formation as can clearly be seen in the west of Kalafat district. *Proeglobutruncana* spp., *Hedbergella* spp., *Heterohelix* spp., *Melobesoidae,* and *Valvulinidae* fossils found in the Gideros Limestone Member indicate the Late Albian-Turonian age.

The stratigraphic base and the top of the Yenice Formation cannot be seen in the study area. The Gökçekale Olistostrome constitutes the lowest visible stratigraphic level of the unit. At the eastern exit of Kapısuyu Bay, where the best outcrops of the Yenice Formation can be observed, the formation is overlain by the İnaltı Formation along a north-vergent thrust. Many secondary thrusts and duplex structures were also developed within the Yenice Formation, parallel to this main thrust.

In Kokurdan district, south of Cide, the Yenice Formation unconformably overlies the İnaltı Formation and is tectonically overlain by the Türbeyanı Marl Member. The Yenice Formation in the east of Gideros Bay is in the form of a thin tectonic slice between the Akveren Formation at the base and İnaltı and Türbeyanı formations at the top. Although the whole section cannot be observed due to this high tectonic imbrication in both outcrops, it was determined that the Yenice Formation had started on the Gökçekale Olistostrome at the base and the deposition had continued in a pelagic environment, but in quieter tectonic conditions in the following period. Rare tuff levels within the formation around Kapısuyu indicate the presence of weak volcanism in a distant area.

The pelagic deposits of the Yenice Formation are rich in foraminifers. *Helvetoglobotruncana helvetica, Marginotruncana schneegansi, Marginotruncana pseudolinneiana, Marginotruncana coronata, Dicarinella* sp., *Marginotruncana* spp. fossils in the samples taken from the east of Gideros Harbor indicates the Middle Turonian age. *Marginotruncana coronata, Marginotruncana pseudolinneiana, Dicarinella flandrin, Dicarinella* sp., *Hedbergella* sp., *Heterohelix* sp., *Globotruncanidae* obtained from the samples taken from a bit further south give the Middle Turonian-Early Santonian age.

Dereköy and Yenice formations are important units in terms of understanding the geology of the region since they contain the first products of the Late Cretaceous volcanism. The fact that these units unconformably overlie both the Lower Cretaceous and Triassic deposits, indicates that the region has been eroded before and the older units have been uplifted with tectonic movements. The olistoliths and debris flow sourced from the older units indicate that the deposition took place under tectonic effects. On the other hand, the paleocurrents in the Dereköy Formation and the overlying units are northward, while the palaeocurrent directions in the older units are southward.

Amasra Group: The Amasra Group, one of the two groups that make up the Yemişliçay Upper Group, shows different relations with the underlying Kurucaşile Group. It begins with a transgressive sedimentary sequence resting unconformably on the Early Cretaceous and/or older units, especially around Çakraz and to the west, without the Kurucaşile Group beneath. In these regions, the sequence begins with a thin shallow marine clastic unit (Kökyol Formation), or with pelagic micritic limestones (Unaz Formation) that conformably overlie this clastic sequence or directly resting on the older units with a distinct contact, and ends with a thick volcanic sequence (Cambu Formation). At the bottom of the Amasra Group, east of Çakraz, the Kökyol Formation is absent. The Amasra Group starts here with pelagic limestones of the Unaz Formation and continues with volcanites. In this region, a disconformity unconformity or a corresponding very thin conglomeratic level is observed at the base of the Unaz Formation, though it is not as distinctive as in the west.

Kökyol Formation: The Kökyol Formation, which constitutes the lowest member of the Amasra Group, consists of a few meters thick sandstone, a rare conglomerate, and limestone. The unit, which is generally too thin to be mapped (generally around 5-6 m), was mapped with the overlying Unaz Formation in most places. Typical outcrops of the Kökyol Formation are seen around Ahatlı village in the east of Amasra and around Kökyol, Saraydüzü and Doğaşı villages in the south.

The Kökyol Formation generally consists of light yellowish, grayish sandstone, clayey sandstone and conglomerate, and rare clayey sandy limestone, which generally shows poor bedding. There are large and thick-shelled gastropod and bivalve fossils in the unit. The presence of these fossils indicates that the unit was deposited in a shallow and warm marine environment.

The Kökyol Formation overlies the Türbeyanı Marls and İnpiri Limestone in the east of Amasra with an angular unconformity (Figure 11a). To the west of Amasra, this unit rests unconformably on the Palaeozoic sequence. It is conformably overlain by micrites of the Unaz Formation along with a sharp contact. There is no age data obtained from the unit in this study, but it is accepted to be Late (?) Santonian; it is conformable with the overlying Unaz Formation. The fossils described by Hippolyte et al. (2010), on the other hand, indicate the Coniacian-Santonian time interval.

Unaz Formation: The Unaz Formation extends in the form of a narrow strip starting from Gökyar Bay in the west and along with Unaz and Çengel districts, Daldoruğu hill and Turabi (Çaybaşı) village towards the east (Figure 2). It can be traced on the field as a marker horizon with its red-pink color, thin, but very distinct and regularly bedded nature, forming a resistant level with a thickness between 10 and 30 m that does not change much.

The base of the Unaz Formation consists of clayey and abundant silty marls. This light green, gray, and pink colored unit pass into clayey limestone with an increase in the carbonate amount. Red, pink and cream colored, thin and distinctively bedded clayey limestones with smooth fractures also contain calciturbiditic carbonate mudstone intercalations in the upper levels. There are also tuffaceous horizons

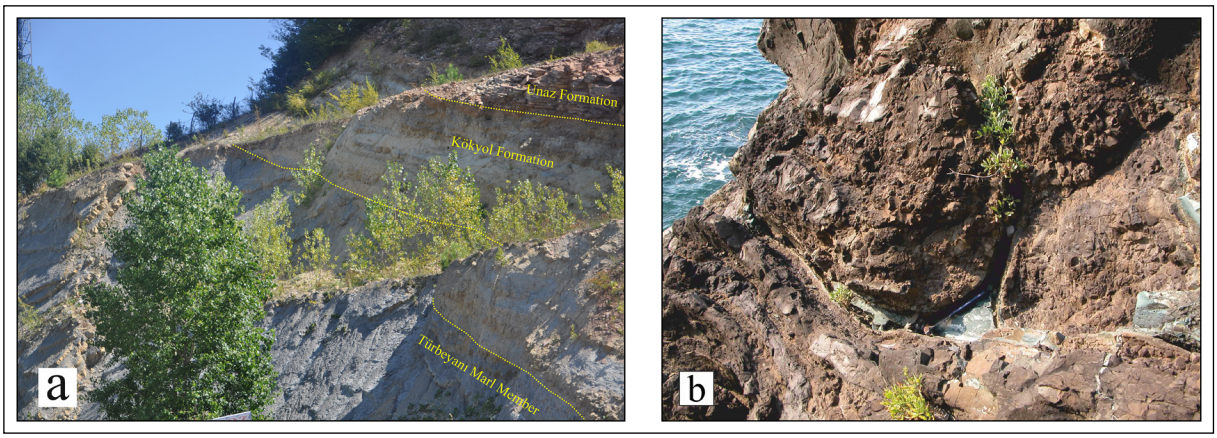

Figure 11- a) At the eastern exit of Amasra, the Kökyol Formation overlies the Türbeyanı Marl Member with an angular unconformity, and it is conformably overlain with a sharp contact by pink pelagic micrites of the Unaz Formation, b) pillow lavas within the Cambu Formation and green pelagonitic tuff levels developed in the spaces between them.

towards the top of the unit and pass into the Cambu Formation with the increasing of these tuffaceous levels (Figure 7).

The contact relationships of the Unaz Formation with the units above and below are clearly seen. The Unaz Formation, which covers the Dereköy Formation with a weak angular unconformity on the road cut passing through Turabi village (Figure 10a) is about 10 m thick and the volcanics of the Cambu Formation are observed on it. The presence of *Lucianorhabdus* and *Braarudosphaera* as well as the dense burrows observed along the unconformity plane indicate that the depositional conditions of the Dereköy Formation have become shallow marine just before the deposition of the Unaz Formation.

On the Cide-İnebolu road, marl and clayey limestones belonging to the Unaz Formation unconformably overlie the Dereköy Formation. Here, the approximately 1 m thick coarse conglomerate with pelagic carbonate matrix located at the bottom of the Unaz Formation indicates this disconformity.

Dicarinella conaliculata, Dicarinella concavata, Dicarinella asymetrica, Heterohelix sp., *Hedbergella* sp., *Globotruncanit* spp., *Globotruncana* sp. in the samples collected from the Şar district point to the Late Santonian-Campanian age. *Dicarinella asymetrica, Dicarinella concavata, Globotruncanita stuartiformis, Hedbergella flandrin, Globotruncana* cf. *elevata* and, *Radiolaria* in limestone samples taken just at the top of the unconformity plane in the Turabi village indicate the Late Santonian age. Tüysüz et al. (2012) examined the Unaz Formation in a wide area and gave a long list of fossils. They stated that the formation commonly and suddenly covered all regions that were both shallow or deep marine depositional and erosional areas before the deposition of the Unaz Formation during the Late Santonian. Boehm et al. (2019) defined the *Dicarinelle asymetrica* zone (UC 13), which indicated the Late Santonian age for the Unaz Formation. The Unaz Formation represents the end of the first period of magmatic activity, which started with the deposition of the Dereköy Formation, in addition to a sudden deepening. The absence of any clastics within the Unaz Formation throughout the wide-spreading area indicates that this deepening in the Late Santonian was effective enough to cover the whole region.

Deposition of the Unaz Formation on very different units indicates that an irregular topography has developed in the region until the deposition of the Unaz Formation and that subsidence and transgression are effective enough to cover all these topographic irregularities during the Late Santonian. In the period following this sudden subsidence, the volcanism has restarted more intensely in a way to cover a wider area.

Cambu Formation: This unit consisting of lava and pyroclastics and accompanying volcanogenic sediments, was distinguished by Akyol et al. (1974) as the Cambu agglomerate-lava member of the Kurucaşile Formation.

The outcrops of the unit within the mapping area start from Gökyar Bay in the west and extend

to the east towards Yenciköy, Cambu Bay, Hasanlar, Karaman, Tekkeönü, and Demirci. The section of the Cide-Amasra road between Tekkeönü and Karaman provides the best outcrops (Figure 2). The unit is conformable and transitional with the underlying Unaz Formation and with the overlying Akveren Formation (Figure 7).

The lavas, which have an important volume in the Cambu Formation, are dark green, dark gray-brown, and black colored, having pillow structures and cooling fractures in places. Dark green-copper green tuff and marls fill in the pillow spaces. Lavas are mostly composed of basalt, basaltic andesite, and andesite. Euhedral plagioclase and pyroxene phenocrysts can be seen with the naked eye. In addition to these; olivine, biotite, amphibole, and opaque minerals are seen in thin sections. These phenocrysts are embedded in an intersertal matrix formed by glass and plagioclase microliths.

The agglomerates are in various colors and sizes between gravel and blocks, poorly sorted, mostly angular clasts in a tuff matrix. There are also sedimentary materials such as marl and limestone in places. Most of these are intra-formational fragments. Tuffs are in the form of white, thin to thick, regular bedded lithic or in the form of thick, massive, tightly crystalline tuff packages in which the lava fragments and glassy levels are added. Sandstones and siltstones are green, yellowish-brown, gray-colored, medium-poorly sorted with volcanic materials, angular grained, and with tuff intercalations in places. The exfoliation is one of the main weathering features of these units. In parts where the volcanic material partially decreases, lithic arenites showing gradation and lamination alternates with siltstone and marl. Turbiditic structures are observed on this occasion. The marls are light and dark green, gray-green and beige in color, well-bedded, laminated, and jointed with calcite infilling, and mostly consists of tuff-tuffite and silt.

The Cambu Formation rests conformably and transitionally on the Unaz Formation. This transition zone is usually 1 to 2 meters thick. The unit gradually passes upward into the Akveren Formation with the ceasing of volcanics and increasing marls.

There is no fossil finding obtained from the Cambu Formation in this research. However, the fact that it is transitional with the underlying Late Santonian Unaz Formation and transitional with the overlying Maastrichtian Akveren Formation, indicates that the unit can be considered as Campanian in age. Boehm et al. (2019) identified fossils from the unit indicating the Early-Middle Campanian. The thickness of the unit varies between 300 and 1200 meters.

Akveren Formation: The name Akveren Formation was used by Gayle (1959) as the Akveran layers for the clayey limestones in the south of Ayancık, and later it was named as the Akveren Formation by Ketin and Gümüş (1963). The unit consists of clayey limestone, marl, and calcareous mudstones, and calciturbidites. The clastic limestones in the lower parts of the sequence are distinguished as the Hisar Limestone Member, where it can be mapped.

The Akveren Formation is seen in two regions in the study area. One is between Tekkeönü Bay and Cide on the Black Sea coast. Here, the unit extends between Dipli Cape-Konpos on the east coast of Tekkeönü beach to the west and Kurucaşile, Demirci and Kapısuyu in the east. The formation also crops out on the eastern coast of the Gideros Harbor in the further east and on both limbs of the Cide syncline. The second locality where the Akveren Formation crops out is around Darıören, Çetme, Çöpbey, and Turanlar, in the northern part of the Arıt valley (Figure 2). The thickness of the formation varies between 100 and 600 meters.

Hisar Limestone Member: The Hisar Limestone Member, which takes its name from Hisar village in the Tekkeönü Bay, is seen in Dipli Cape, Doğancıköy Harbor in the west of Kurucaşile and around Cumalaz. The unit consists of white-cream colored, thickly-bedded limestones and calciturbidites. Limestones are sparitic in nature and contain abundant intra- and extra-clastic materials. These clasts, sand, and pebble in size, are mainly intraformational. The orbitoid-rich horizons, which are very tightly cemented with white carbonate, are remarkable. Sole marks are quite common, all of which show palaeocurrent directions from south to north.

The Hisar Limestone Member, whose thickness varies between 50 and 200 m, gradually passes into the alternation of thin-bedded claystone, marl, clayey limestone, which are the dominant lithology of the Akveren Formation, both in upward and lateral directions. In this alternation, there are also limestone

intercalations similar to those of the Hisar Limestone. The best outcrops of this type of marl, clayey limestone, and calciturbidite alternation are seen in the western part of Kapısuyu beach (Figure 12a).

The Akveren Formation is represented by the alternation of red, khaki, gray, and white-colored limestone, marl, claystone, and rare sandstone. These units are laminated and thin- to medium-bedded. In general, they are well foliated and intensely fractured. The carbonates prevailing in the lower parts of the unit decrease towards the top and the fine clastics become dominant. Thus, the formation consisting of micritic limestone, marl, and claystone at the bottom becomes a unit dominated by marl and claystone, and the siltstones alternating with them. One of the localities where this change in the sequence can be seen is Doğancıköy Harbor at the western exit of Kurucaşile.

The Akveren Formation was affected by intense tectonic deformation in its outcrops along the Black Sea coast. Due to intense northward imbrication, many north-vergent thrusts of varying scales and duplex structures developed along the contacts and within the unit, and the lithologies underwent penetrative deformation in most places. The western coast of Kapısuyu beach provides a very good example to examine the internal structure and partial stratigraphy of the Akveren Formation (Figure 12a). The lowest unit of the sequence seen here is red-pink marl. In this unit, the debris-flow levels, of which the majority of the clasts are formed by İnaltı and İnpiri limestones, have an important place. The limestone clasts generally reach 5-10 cm and are rarely 30-50 cm in size. These originally spherical and rounded clasts rotated, deformed and gained an elongated boudin shape as a result of the intense deformation. The marl matrix covering the clasts has gained a foliated structure. The calciturbiditic levels on top of the sequence alternate with marls. They are up to one meter in thickness and partly contain highly reworked orbitoid-rich masses. Up the section, the unit becomes more regular and the fine-grained lithologies dominate the sequence with the increase in marl content.

The Akveren Formation grades upward into the Atbaşı Formation between Gideros and Cide, on the other hand, the Yenice Formation and structurally overlying İnaltı Formation thrust over the Akveren Formation between the east of Gideros Harbor and Cide.

The outcrop of the Akveren Formation in the north of Arıt valley has very different characteristics compared to the outcrops on the Black Sea coast in the north. Here, the unit transgressively overlies the older rocks. There are mottled, pinkish, rounded, mostly grain-supported conglomerates at the bottom. The pebbles are tightly cemented by a pink carbonate matrix. In places, they grade into a micritic limestone with the decrease or disappearance of pebbles. Although the thickness of the conglomerate is variable, it is mostly around 50m. This unit grades upward into an alternation of white micrite and marl.

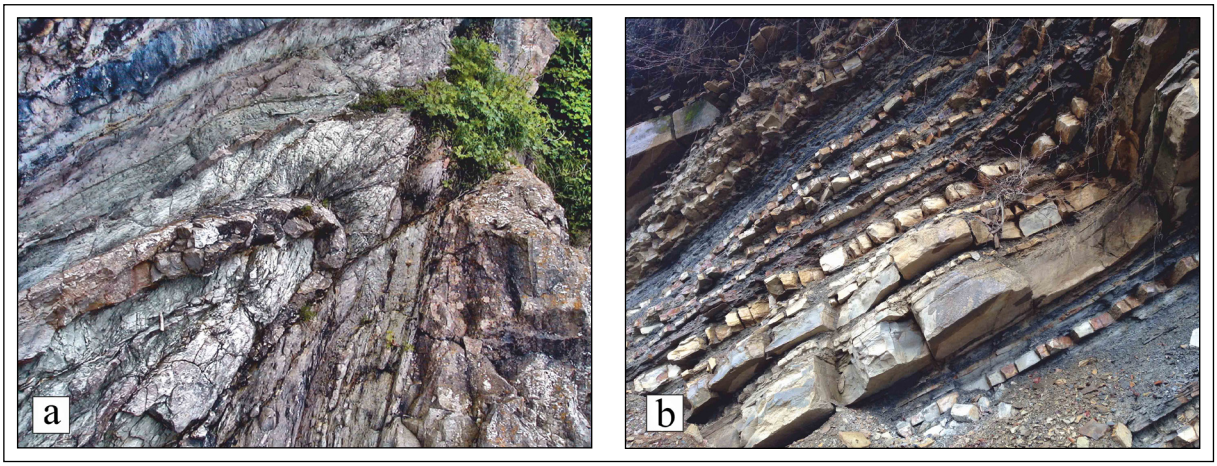

Figure 12- a) Akveren Formation is located at structurally lower horizons as it is tectonically overlain by the older units. Therefore, it has been affected by a severe deformation. The picture taken from the Kapısuyu beach shows the overturned and imbricated structure of the turbiditic limestone and marls and the development of severe cleavage, b) turbidites of the Kusuri Formation.

The Akveren Formation is rich in fossils. Based on *Rugoglobigerina penyi, Rugoglobigerina hexacamerata, Rugoglobigerina rugosa, Globotruncanelli* sp., *Globatruncan arca, Globatruncana mariei, Contusotruncana plummerae, Rugoglobigerina* cf. *Mimamensis, Globotruncana ventricosa, Rugoglobigerina* spp., *Globatruncana* spp., *Heterohelix* spp. found in samples taken near Demirci, which represent the lower parts of the formation indicate Early Maastrichtian age. Boehm et al. (2019) stated that the Akveren Formation started to deposit diachronically with the Cambu Formation in the Campanian and the deposition continued until the Late Maastrichtian. Özer (2014) near Bartın and Gedik et al. (2005) in the northwest of İstanbul described fossils dating to Selandian, and Sarıgül et al. (2017) around İzmit dating to the Thanetian

2.3. Cenozoic

In the study area, Cenozoic is represented by Paleocene Atbaşı and Eocene Kusuri formations.

2.3.1. Paleocene

Atbaşı Formation: The red, pink Paleocene marl and carbonate mudstone sequence overlying the Akveren Formation (Figure 7) was named as the Atbaşı Formation by comparing it with its equivalents in the Central Pontides (Ketin and Gümüş, 1963; Aydın et al., 1986). The outcrops of the unit are located between Huçku and Gebeş districts and further east within the Cide syncline (Figure 2).

The Atbaşı Formation is a rather homogeneous unit. The marl and carbonate mudstones, which are the main lithology of the formation, are red, pink-colored, and thin to medium-bedded. The layer boundaries are gradationally transitional. Marls rich in carbonate are in the form of more resistive layers compared to carbonate mudstones. These units, most of which are close to tectonic contacts, have been intensely and penetratively deformed.

The Atbaşı Formation, which reaches up to 50 m thickness, is gradually transitional with the Akveren Formation at the base (Figure 7). There is not any sharp contact between the two units due to the similar lithologies. Siliciclastic turbidites of the Kusuri Formation conformably overlie the Atbaşı Formation.

Based on the occurrence of *Morozovella conincotruncana, Morozovella angulata, Morozovella aequa, Planorotalites capmani, Planorotalites psedomenardii, Globigerina triloculinoides, Morozovella* spp., *Planorotalites* sp., *Globigerina* spp., *Melobesoideae* and *Fasciculithus tympaniformis, Curuciplacalithus tenuis, Coccolithus* sp. nannofossils in the samples taken from the south of Irmak village, the Atbaşı Formation was dated as the Middle-Late Paleocene. This unit, which is conformable with the Akveren Formation, probably covers the entire Paleocene.

2.3.2. Eocene

Kusuri Formation: The Kusuri Formation crops out at the core of the Cide syncline (Figure 2) and is composed of a turbiditic sandstone-shale alternation. It was compared with the similar sequences in the Central Pontides (Ketin and Gümüş, 1963; Aydın et al., 1986), and investigated under the name of Kusuri Formation.

The thin-bedded claystone-marl alternation in the lower parts of the Kusuri Formation contains sandstone intercalations that gradually increase towards the top and thus turn into sandstone-shale alternation (Figure 12b). Sandstones are gray, khaki-colored, hard, tabular-bedded, and rich in quartz and lithic grains. At the bottom of the turbiditic sandstones, erosional structures such as flute and load casts are observed. The bottom of the sandstones is sharp and erosional but grades upward into thinner clastics. The convolute and parallel laminae are observed in fine-grained sections. The Bouma series indicate the intermediate to the distal characteristic of the unit, and the sole marks indicate the palaeocurrent direction from south to north.

Globigerina eoceana, Globigerina cryptomphala, Globigetherinelca index, *Acarinina* cf. *Bullbrooki, Globigetherinelca* sp., *Globigerina* spp., and *Hodosoridae* in the samples taken from Uzunoğlu and Kolo districts indicate the Middle Eocene age. Hippolyte et al. (2010) also gave the Early-Middle Eocene age based on the nannofossils.

The Kusuri Formation is a typical flysch succession with a thickness exceeding 1000 m. The unit was deposited in a regressive environment fed from the south. This flysch sequence, which was deposited

following the Akveren and Atbaşı formations, is the last sedimentary sequence known in the region (Figure 7). The uplift, which was developed in the southern areas synchronous with the deposition of the Akveren Formation, was more progressed in the Eocene and propagated towards the north.

3. Structural Geology

The study area is in the form of a north-vergent fold and thrust belt. All units described above thrust over each other from south to north (the term of thrust is used here for all reverse faults regardless of the amount of dip of the faults). The thrusts in the study area can be divided into three main belts running approximately parallel to the Black Sea coast. In the southernmost zone, the Zonguldak and Çakraz formations thrust over the İnaltı Formation. The dip of these thrusts is about 70°. In the middle belt, the Zonguldak and Çakraz formations thrust over the İnaltı and Ulus formations along the faults dipping approximately 50°-70°. The northern belt, on the other hand, lies close to the Black Sea coast, and possibly under the waters of the Black Sea, and dips between 10° and 50°. Along these faults, the İnaltı and Ulus formations thrust over the Late Cretaceous and younger units, and these relatively younger units have gained a much more intensely imbricated structure compared to the ones described above. In addition to the north vergent thrusts; less frequently, north-south trending strike-slip transfer faults are also observed. The amounts of measured lateral offset along these faults, which are associated with the low angle thrusts in the northern belt, vary between 25 and 300 m. Three geological cross-sections taken from the study area are given in Figure 13.

The major folds in the study area are anticlines and related synclines associated with the faults. These are clearly observed particularly in the middle and northern belts. The Çakraz and Zonguldak formations take place at the core of the anticlines located in the south of the study area and the Ulus Formation at the synclinal cores. Contrary to the southern belt, the Late Cretaceous and younger units crop out in the axes of both anticlines and synclines in the northern belt. The overturned and recumbent folds and thrusts, ramp

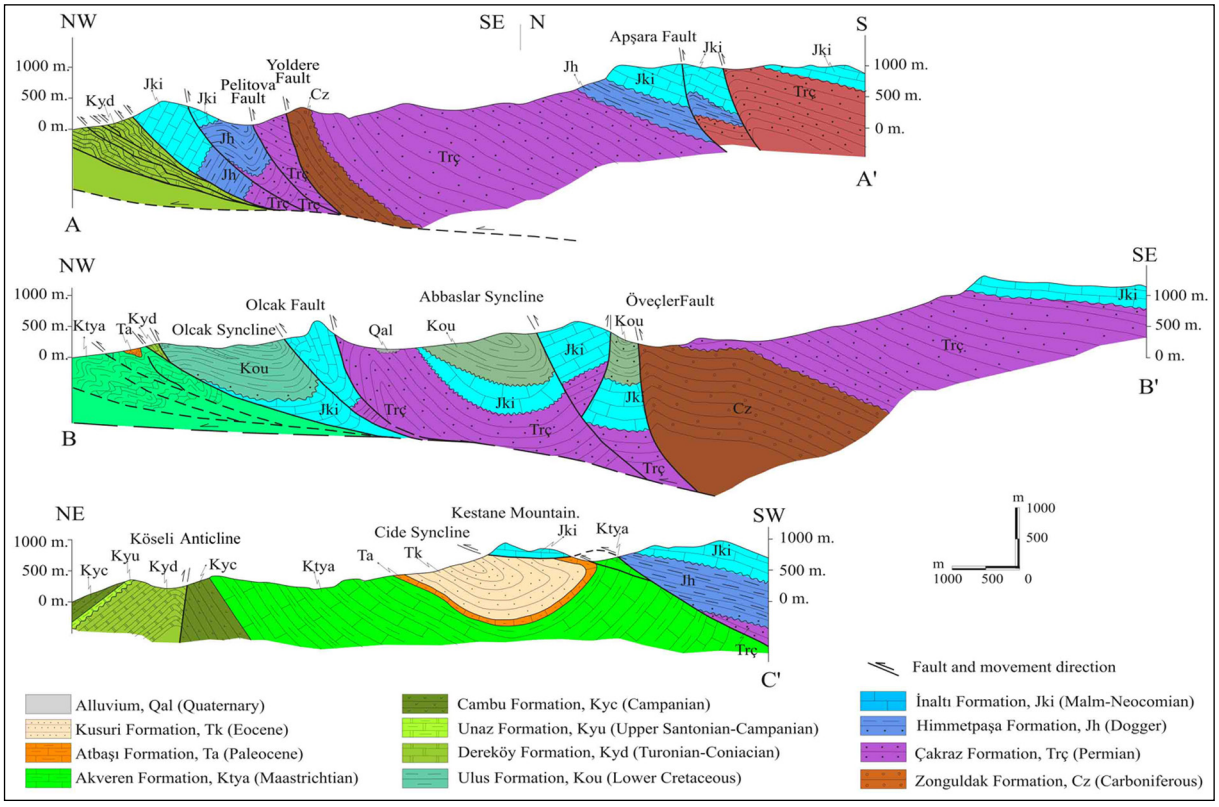

Figure 13- Geological cross-sections showing the imbricated structure of the study area (Sunal and Tüysüz (2002), see the geology map in Figure 2 for section locations).

folds due to duplex structures, and fan-shaped thrust series are common in this belt.

The folds observed in the study area are asymmetrical, semi-cylindrical, and approximately E-W trending, slightly plunging, north-verging, overturned, and rarely recumbent anticlines and synclines, with generally southerly inclined axial planes. Folds are mostly of zigzag type in the Ulus Formation. The limb angles rarely exceed 50°. The axes are mostly parallel to fault orientations.

Sunal and Tüysüz (2002) investigated the small-scale structures developed especially in the Akveren Formation and partially in the Atbaşı and Dereköy formations in the study area. Accordingly, the stress directions that develop thrusts in the study area are; 4.6°/156.6° for σ_1, 6.4°/66.1° for σ_2 and 83.2°/261.9° for σ_3. The authors argued that, based on the structural characteristics of this foreland fold belt in the region, the regional shortening exceeded 50% and that the main shortening probably occurred along a deep detachment fault, and that the thrust faults could turn into oblique and even strike-slip character in time.

The north-vergent thrusts in the study area have affected all Middle Eocene and older units, so it is certain that this compressional regime is younger than the Middle Eocene or has continued until post-Middle Eocene. However, the data obtained from the Central Pontides show that the Oligocene Cemalettin Formation (Tüysüz, 1990) in the Boyabat Basin was also affected by this deformation (Gedik and Korkmaz, 1984; Aydın et al., 1986; Tüysüz, 1990, 1993, and 1999).

4. Geological Evolution

The Carboniferous and Permo-Triassic units are represented by terrestrial sediments. The depositional environment of the Carboniferous, extremely rich in organic material, was replaced by a terrestrial/desert regime in which conditions of life had been limited during the Permian, and this environment, which had been covered by floods from time to time, caused the development of red-colored, highly oxidized deposits. However, a humid regime prevailed and the region was covered by large lakes in which the carbonate-rich sediments were deposited at the end of the Triassic.

After a short-term sea invasion in Dogger, a new transgression in the Late Jurassic covered the areas approximately to the east of Marmara Ereğli and caused the deposition of a neritic carbonate platform probably lasting until the Valanginian in some areas.

The Carboniferous and Permian, Triassic and Dogger, Dogger and Upper Jurassic units were separated from each other by unconformities. However, characteristics of these unconformities show that no significant deformational/erosional phase had been experienced in any of these periods. The penetrative deformation and the strongly folded structure of the Carboniferous deposits around İstanbul in the west were not observed in the study area. The unconformities between these units are close to parallel or at low angles, and there is no difference between the units above and below the unconformity planes in terms of deformation style. This situation shows that the study area has not been affected by a significant tectonic deformation during the period from Carboniferous, or even before, to the Late Barremian. In other words, our study area was in a distant position away from the plate margin events of that period. The correlation of both Permian (Gand et al., 2011) and Lower Cretaceous deposits (Masse et al., 2009) also indicates that the İstanbul Zone, on which the study area is located, was a continuation of Europe during these periods. However, this calm tectonic regime was replaced by an active period since the Late Barremian.

Late Barremian is the development period of a new transgression and deposition of an Urgonian-type carbonate platform, though it has a limited extent. This short-lived platform, which was extending as a narrow archipelago between the Western Black Sea in the north and the Ulus basins in the south, was replaced by deep marine clastics with the opening and deepening of these basins. This platform contains more carbonates towards the Zonguldak region in the west and more clastics in the east. The debris-flow horizons and the olistoliths within clastics upper parts of the section can be attributed to an active tectonic regime accompanying the sedimentation. The region, which deepened in the Late Barremian-Aptian interval, was considerably uplifted in the Albian and became an erosional area. This uplift should probably be created by a continental collisions that occurred in the south of the İstanbul Zone. Okay et al. (2013) defined the regional metamorphism that developed 105 million years ago (Albian) as a result of the collision of the Istanbul Zone with the Sakarya and

Domuzdağ continental fragments in the south. The Albian deposition, which is not seen in the southern areas, must have continued until the impact of this collision and the regional uplift in the south reached the Zonguldak Basin (Hippolyte et al., 2010). The entire İstanbul Zone was uplifted and eroded during the Cenomanian.

The marine deposition started again in the region since Turonian, but there is no clear data on the exact timing of this transgression. Although Tüysüz et al. (2000) stated that there is a thick coarse clastic succession at the base of the Turonian sediments in the north of Şenpazar and their age could be down to Cenomanian, but there is no age data from this clastics. Significant changes have begun to develop since Turonian, and the region has been covered by a rapidly deepening sea. In the Middle Turonian, the pelagic micrites were deposited in the lower parts of the Dereköy and Yenice formations. This situation shows that the region was rapidly subsided and covered by a deep-sea in Turonian. In the following period, intense volcanic activity began in the region. This volcanic activity is representative of the arc magmatism covering the entire southern Black Sea belt. Since the geochemical character of volcanism was introduced by Keskin and Tüysüz (2018) in detail, it will not be discussed here. Considering the characteristics of the units developing synchronously with volcanism, it implies that an important normal faulting phase was also experienced in the region in this period. The debris-flows and blocks with angular grains in the Yenice Formation were interpreted as colluvial wedge deposits deposited in front of fault scarps, transported without being processed from a source close to a deep marine environment. The lithological character of this unit, which frequently changes laterally, and the thickness differences are also indicators of faulting. Considering the stratigraphy and geographical distributions of the units that have developed between Turonian-Santonian, the landscape seen in Figure 14 comes out of the region. Turonian-Santonian units are absent in Amasra and in the west of it. This area has probably been uplifted following the deposition of the Türbeyanı Marl Member and remained as an erosional area until the deposition of the Kökyol and Unaz formations.

Hippolyte et al. (2010) defined the Cenomanian-Santonian period as a region-wide stratigraphic gap, probably due to insufficient data. However, for example, the Göçkünşili-Çakraz area was a deep marine depression where volcanic activity was active in it, and the Dereköy area was a marine area where only pyroclastics could reach in this period. The presence of materials derived from Carboniferous and the overlying units within Dereköy and Yenice formations, and the unconformable contact between

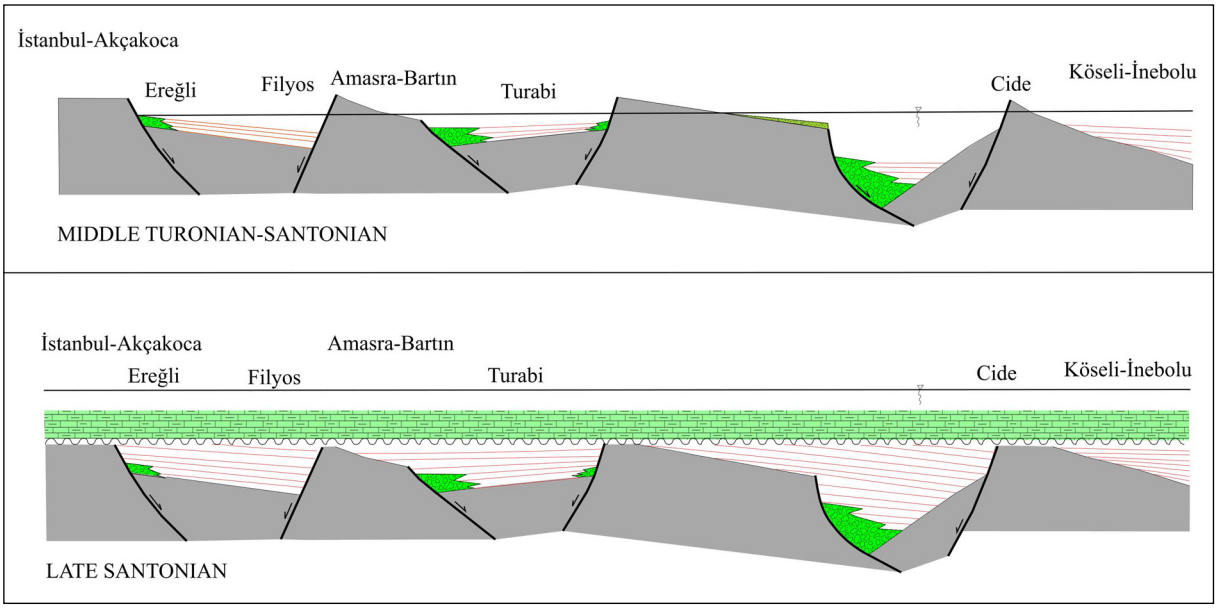

Figure 14- Cartoon showing the structure between Marmara Ereğlisi and İnebolu in Turonian-Early Santonian and Late Santonian periods (after Tüysüz et al., 2012).

these units and older units indicate that a part of the area emerged and the provided clastic material and olistostromes to the sediments depositing in deep marine environments. The Santonian pelagic carbonates directly overlying the İnaltı limestones in the south of Cide indicate that this region that remained as an erosional area until that time has also subsided rapidly during this period.

The shallow marine sandstones of the Kökyol Formation were deposited on the Türbeyanı marls and on the older units in the west of Amasra. The fact that the Unaz Formation stands on this unit with a sharp contact indicates that this region, which remained in the form of a horst until then, was rapidly subsided and covered by a deep-sea in the Late Santonian. The areas in the Çakraz and its east where the marine deposition took place in the Turonian also subsided rapidly in this period, and the Unaz Formation was almost deposited in the form of a thin cover over the entire region. This subsidence also points to a period in which the volcanism has become inactive. As Görür et al. (1993) and Tüysüz (1999) stated with some temporal differences that this period probably corresponds to the time when the continental crust of the Black Sea was broken up and the oceanic crust began to spread.

Following the deposition of the Unaz Formation, the volcanism was intensified and lasted until the end of the Campanian. This second phase of the volcanism is much higher in volume and more severe than the first phase. Keskin and Tüysüz (2018) showed that these two phases of volcanism had different geochemical characteristics and that the asthenospheric mantle component joined the arc component of the first phase in the second phase. These data indicate that the arc magmatism in the Western Black Sea Basin started in the Turonian, the arc was broken by normal faults and the Western Black Sea was opened as a back-arc basin in the Turonian-Santonian interval. The sudden subsidence defined in the Late Santonian probably documents the period when the continental crust was ruptured and the oceanic spreading began in the Western Black Sea Basin. Towards the end of the Campanian, the arc magmatism ceased and a turbiditic sequence facing the Black Sea including the Akveren, Atbaşı, and Kusuri formations in the north started to deposit and form the southern passive continental margin sedimentary sequence of the Black Sea.

The olistostromal levels sourced from the south in the lower parts of the Akveren Formation indicate that a high area was formed in the south. This high area probably separated the Western Black Sea Basin in the north and the Devrek Basin in the south at that time. The Akveren Formation seen in the north of the Arıt valley consists of the neritic limestones that unconformably overlie the İnaltı Formation, unlike the calciturbidites in the north. This situation shows that the compression providing the regional uplift probably began in the Campanian in the south and progressed northward. Thus, the uplifted southern areas have provided clasts to the sediments on the Black Sea coast in the north until the Middle Eocene. This compressional regime, which is the product of the closure of the Tethys Ocean and the continental collision in the south, has continued after the Middle Eocene and caused the region to be imbricated by north vergent thrusts. This compressional tectonic regime probably continues effectively today, as demonstrated by the 1968 Bartın earthquake, and the steep and deeply deformed morphology that indicates that the Black Sea region is actively uplifting.

5. Results

The Carboniferous Zonguldak, Permo-Triassic Çakraz and Çakrazboz, Dogger Himmetpaşa and Late Jurassic-Early Cretaceous İnaltı formations, which are stratigraphically the oldest units of the study area separated from each other by unconformities, have not been affected by an important deformation phase until the Early Cretaceous. Early Cretaceous is an extensional tectonic period resulting in the opening of the Ulus Basin in the south and Western Black Sea Basin in the north and filling these basins with clastics eroded from the uplifting areas. The arc magmatism, which is the result of the northward subduction of the Tethys Ocean in the south, started in the Turonian. During the Turonian-Coniacian period, horst-graben topography was developed in the region with the effect of normal faults, and the oceanic spreading began to develop in the Late Santonian with the breaking up the continental crust in the Western Black Sea Basin. While the violent arc magmatism in Campanian left its place to the passive continental margin deposits of the Black Sea in the north, the uplifts that had developed since Campanian in the south provided material for these deposits in the north. The deposition in the region has continued until the Middle Eocene. During

the Campanian-Oligocene period, the compressional tectonic regime affecting the region has caused the study area to acquire a north-vergent foreland fold and thrust structure, like the entire Pontide belt. The general structural style is an imbricated system propagating northward. This structure has caused the study area to narrow more than 50% in the north-south direction since the Late Cretaceous.

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