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# How was the Anatolian side of Istanbul formed? A geomorphologic assessment (NW Turkey)

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**Abstract**

This study investigates the Geomorphological evolution of Anatolian side of Istanbul. This area is one of the most problematic and most discussed areas in the Near East geography. There is no detailed contemporary geological study undertaken in the area although there are various publications regarding the study area in terms of geomorphology. Current study aims to explicated the geomorphologic features of the study area. In addition to examining the related literature in terms of subject and field, topography maps scaled 1/25.000 were utilized in the study as main materials. Geological characteristics were compiled from geological maps with various scales and reports generated by different researchers. Mapping phase of the study was undertaken with the help of Geographical Information Systems (GIS) software ArcGIS/ArcMAP 10 package program. Obtained data were checked in situ via field surveys and missing points were completed. It was observed that Anatolian side of Istanbul was a product of elements and processes that completely developed in the new tectonic period. The field was observed to be the product of various morphological transformations, different developments and different elements and processes with a topography which has various landforms and polycyclic features due to a lengthy and discontinuous process. Time concept which started with the first lithological storage in Lower Ordovician continued with the deformation related to the right lateral heave around the Marmara Sea and with the clockwise rotation of the study area in Middle-Upper Miocene. The distortion caused by relief inversion during the geomorphologic development caused the formation of embedded valleys in places as a result of drainage gaining a new energy. The study area has obtained its contemporary geomorphologic form.


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*Keywords*: Geomorphological Features; Geographical Information Systems (GIS); Geomorphologic Cycle; Istanbul; NW Turkey.

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## 1. Introduction

One of the most problematic and most pondered discussion areas about Near East geography since the mythological ages (Şengör, 2011) is the region where Istanbul is located. Geological characteristics of this region have attracted the attention of many national and international scientists (VonHoff, 1822; Hochstatter, 1870; Phillipson, 1898; Andrussow, 1900; Cvijic, 1908; Penck, 1919; Pamir, 1938; Yalçınlar, 1949; 1985; 1996; Ardel & İnandık, 1957; Ardel, 1960; Ardos, 1971; 1979; Ertek, 1995; 2010; Gökaşan et al., 2006; Hoşgören, 2010; Erinç, 2010; Ak, 2010; Şengör, 2011; Özşahin, 2013). Current study aims to explain the geomorphologic features of the Anatolian side of Istanbul.

## 2. Material and Method

Study area is located between 28° 59' 28" – 29° 58' 28" eastern longitudes and 40° 47' 46" – 41° 15' 40" northern latitudes in the northwestern corner of Turkey (Fig. 1). The average elevation of the study area with a surface area of 1893.46 km² is 116.41 m and the highest point is Aydos Mountain with 538 m (Fig. 1).

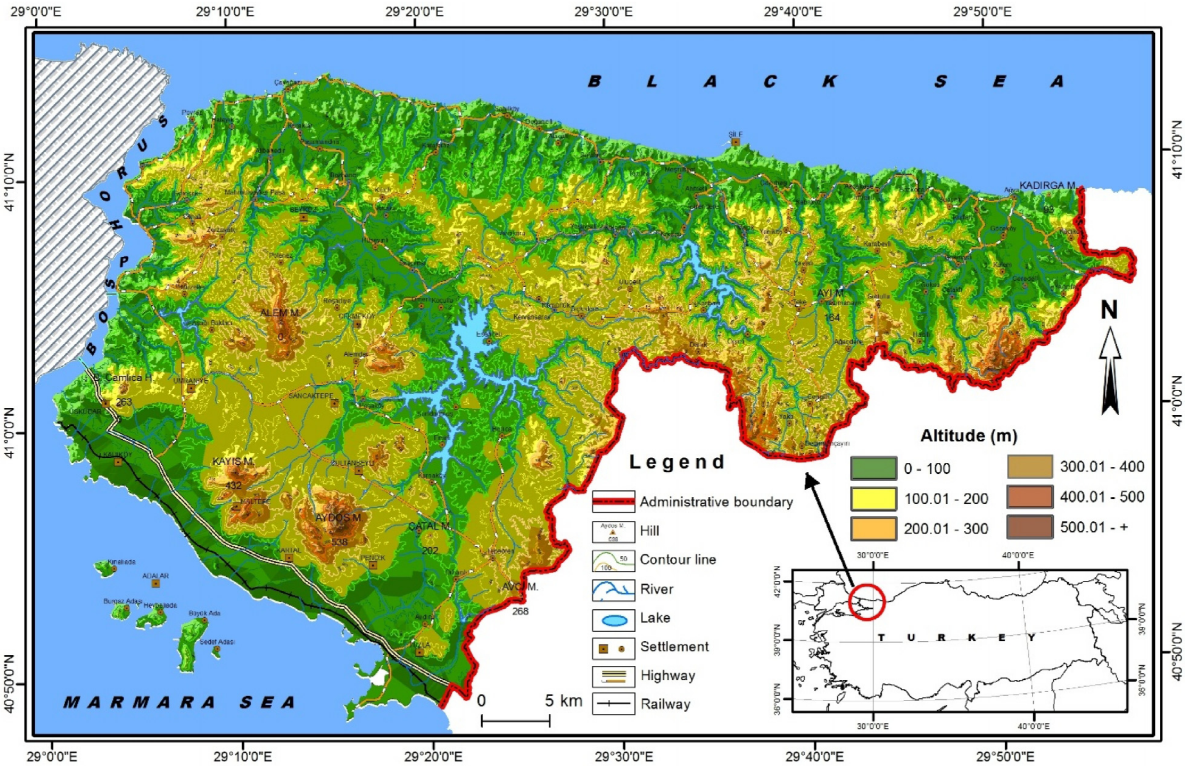


Fig. 1. Location map of study area

The study area is located in a key area that is different from almost all parts of Turkey geologically, that is rather important and that can assist in understanding the geological past of Europe. When general geological characteristics are taken into consideration, the area presents various diversities in terms of geological structure since it carries the traces of at least three Wilson cycles (cyclical opening and closing of ocean basins) (Şengör & Özgül, 2010; Şengör, 2011), it covers many rock units developed in a large range from the Lower Ordovician to the current date, it possesses the signs of very complex structural movements and it is situated in an area where current active tectonic movements are observed.

The field meandered, broke and sloped as a result of tectonic movements experienced during the processes of orogenesis. The meanderings structures in the study area played a critical role in the development of reliefs and the later faulting was effective in shaping the current morphology. Especially the land that formed the base in the study area was affected from Upper Paleozoic (Upper Carboniferous?-Permian) orogenesis and later was severely deformed in the Alpid orogenesis however was not metamorphosed.

The study area with various landforms was created in the characteristic of the erosion surfaces during its geomorphologic development process. All main landforms such as mountain, plateau and plain are found in the study area. In addition to these main landforms, elementary landforms such as terrace, fluvial-karstic area, and marine cliff can also be found.

The preparation stage of the study conducted in three phases in terms of geomorphologic research methods included the review of related literature regarding the field and the topic. Later main materials necessary to produce the thematic maps used in the study were collected. In this context, topography maps scaled 1/25.000 prepared by the General Command of Mapping were utilized. Elevation and hydrograph layers of these sheets were obtained digitally in UTM projection, WGS-84 datum and Arc Info Covarage formats from General Command of Mapping. These data were later converted to vector format. In addition to this, The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) data produced by the Ministry of Economy, Trade and Industry (METI) Earth Remote Sensing Data Analysis Center (ERSDAC) in Japan were used in the analysis and mapping of topographic features. Geological features were compiled from geological map sheets scaled 1/50.000 (Gedik, Duru, Pehlivan, & Timur, 2005) and reports (MTA, 2011) which were published by General Directorate of Mineral Research and Exploration. Mapping phase of the study was undertaken with the help of Geographical Information Systems (GIS) software ArcGIS/ArcMAP 10 package program. The second stage of the study, the observation phase, was realized with field trips taken in various dates. Several measurements were taken during the work, data obtained during the preparation phase were checked in situ via field surveys and missing points were completed. The last stage of the study included rigorously reporting the data obtained from both literature review and field trips in the light of the current geomorphologic studies to answer the research questions. Some current problems were associated with the geomorphologic findings and some suggestions were offered. The study was designed around geomorphologic features and finalized in this vein.

## 3. Discussion

### *3.1. General Geological Properties*

Study area contains rock stratigraphy units (Fig. 2) that represent a large geological time period that include Early Paleozoic (Ordovician)-Quaternary range (Okay & Tüysüz, 2005; Özgül et al., 2005). Therefore, Paleozoic and Mesozoic units that surfaced in the study area show allochtonous characteristics whereas Cenozoic units have semi-autochthonous and autochthonous characteristics.

The base of the lithological stacking in the field and the oldest of the rock groups are formed with various Paleozoic (Şengör & Özgül, 2010; Şengör, 2011) formations collected under the name of Polonezköy group. However, the Paleozoic land in the field is represented by two different units as Istanbul and Çınarlıdere Paleozoic stacks (Gedik *et al*., 2005; Akyüz, 2010). These geologic units that belong to Paleozoic were more affected by tectonic movements, were deformed and obtained a non-continuous characteristic (Gedik et al., 2005). The Mesozoic stack, called Gebze Group which meandered and sliced as a result of embankments and drifting, was settled on this main land with angular discordance (Zapcı, 2010; Şengör, 2011). All these lithological units were cut by Cenozoic stack with angular discordance.

The study area is located on one of the most active parts of the earth's crust in the regional scale (Yalçınlar, 2002; Şengör, 2006). Also, it carries the deep traces of important tectonic movements in the geological times (Şengör, 2000; Efe, 2000; Efe 2001; Okay & Tüysüz, 2005; Özgül *et a*l., 2005; Efe & Cürebal 2011). Therefore, it has significant tectonic structures such as many active fault systems (Hoşgören, 2000).

As a result of the experienced tectonic movements, structural elements were meandered and gained slope in the study area which has various rocks and formations. The meandering structures in the field played a crucial role in the development of the relief and the consequent faulting was effective in the development of the current morphology. Especially the land that formed the base in the study area was affected from Upper Paleozoic (Upper Carboniferous?-Permian) orogenesis and later was severely deformed in the Alpid orogenesis however was not metamorphosed. The study area obtained its current appearance with Post-Alpine movements.

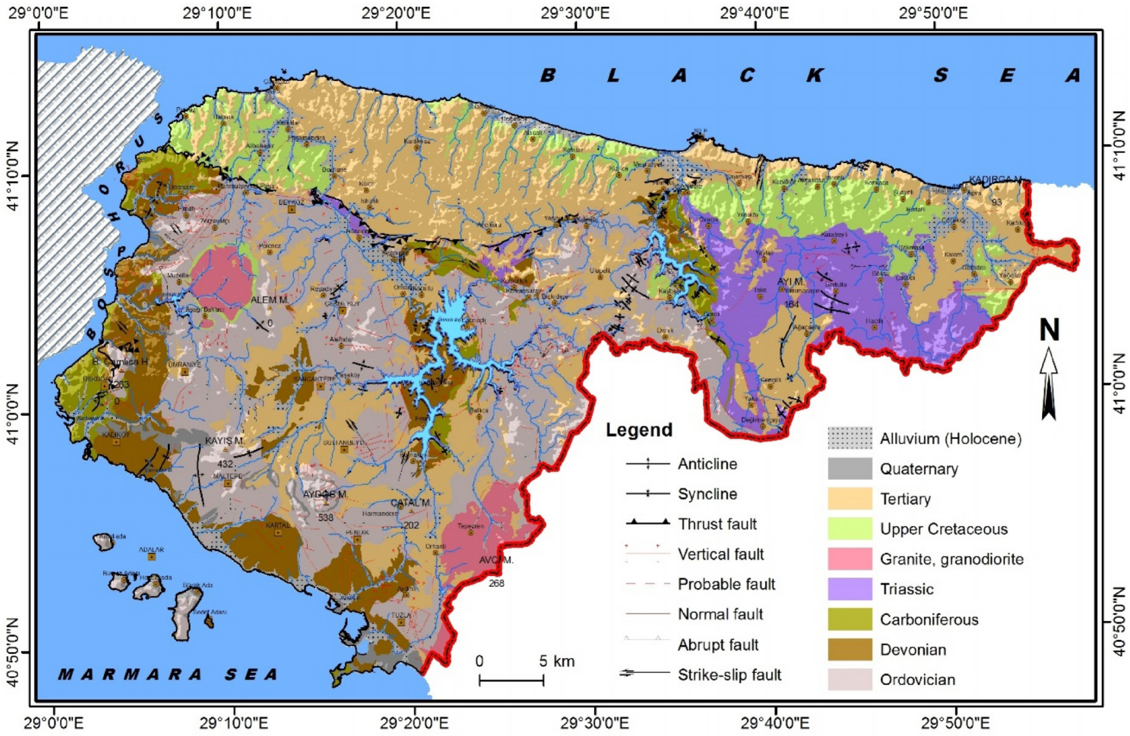


Fig. 2. Geological map of study area

### 3.2. General Geomorphological Properties

Study area located on Kocaeli Peninsula presents differences as the reflection of geological characteristics in terms of landforms. The field which developed as an erosion surface in the beginning was affected by various elements and processes in its geological and geomorphologic past. While the morphology shaped as a result of these elements and processes, it was also completed with the help of geological stacking and its current structure was obtained. This geomorphologic development experienced in the history of geology was also reflected in the topography characteristics and caused the development of different landforms in different characteristics which give the topography its current outlook. These landforms are formed of main landforms such as mountain, plateau and plain (Fig. 3; 4) as well as elementary landforms such as slope and terrace (Özşahin, 2013). These landforms have obtained very different characteristics since their geological past goes long way back and they were shaped by more than one element and process.

The area corresponds to a part of a landforms developed as an erosion surface identified as Kocaeli Plateau (Yalçınlar, 1949; 1985; 1996; Ardel & İnandık, 1957; Ardel, 1960; Ardos, 1971; 1979; Ertek, 1995; 2010; Gökaşan, Tur, Ecevitoğlu, Görüm *et al*., 2006; Hoşgören, 2010; Erinç, 2010; Ak, 2010; Şengör, 2011; Fig. 3). Also, the other fundamental landforms such as mountain and plain areas do not show typical characteristics as well (Ertek, 2010).

The highest point in the study area is the Aydos Mountain with 538 m and the lowers point is the sea level. Therefore, difference in elevation is 538 m (Fig. 3). Other main elevations from the highest to lowest are Aydos Mountain (538 m), Kayış Mountain (438 m) and Alem Mountain (409 m).

The elementary landforms in the study area are classified in 4 genetically as belonging to river, coast, karst and volcanic topography. The dominant landforms in the study area located in fluvial morphogenetic area belong to fluvial topography (Özşahin, 2013).

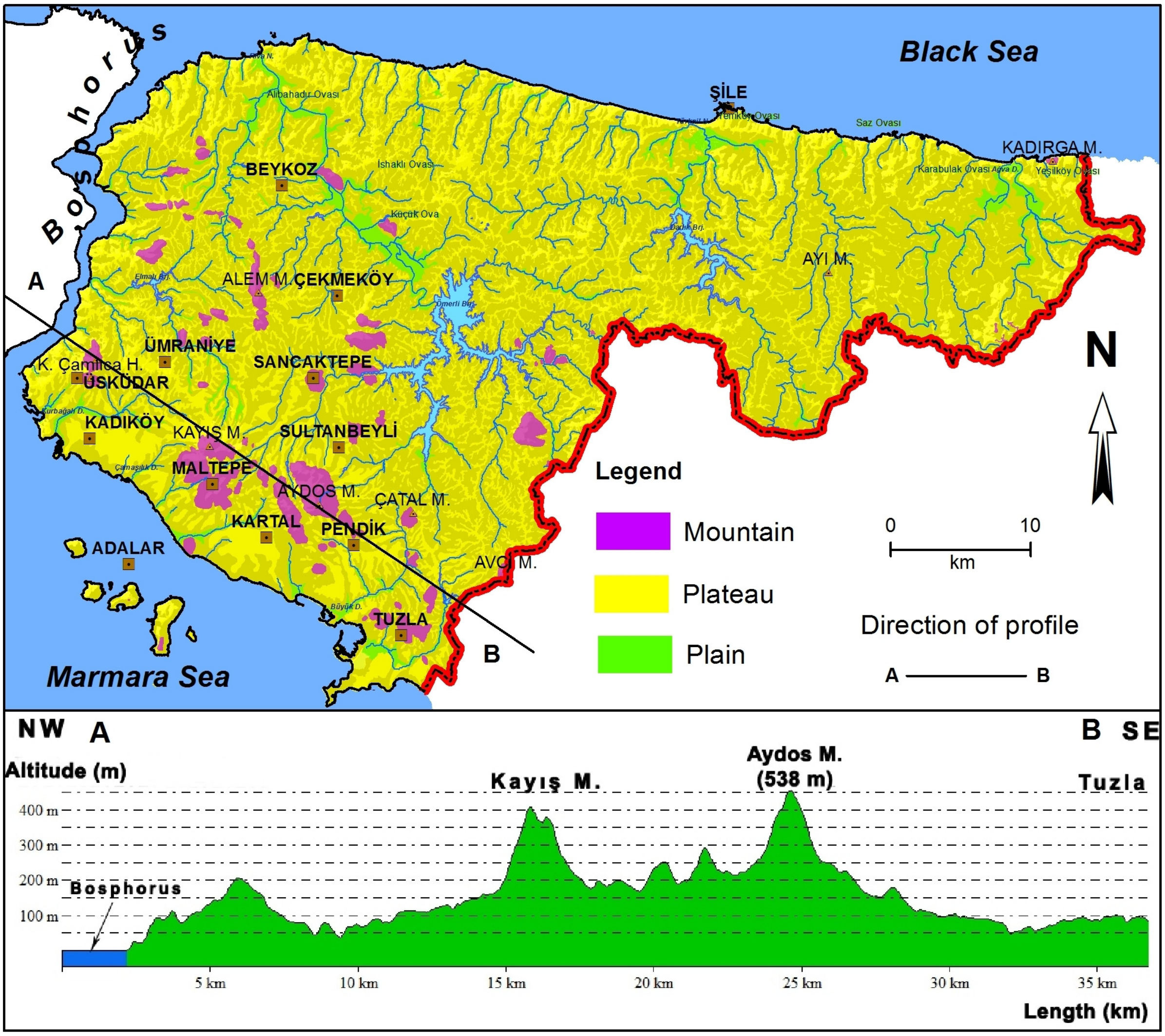


Fig. 3. Geomorphological map of study area

### *3.3. Geomorphological Evolution*

Almost all geomorphologic processes that provided the study area with its current morphology were created as a result of new tectonic movements (Neotectonic). Actually, the process for the area to obtain its final geomorphologic shape started about 2 million years ago with the distortion of Miocene- Pleistocene (?) erosion surface (Trakya-Kocaeli or Çatalca-Kocaeli) and the formation of embedded valleys as a result of the drainage gaining a new energy (Şengör, 2011). This situation was confirmed with the help of various geomorphologic studies (Pamir, 1938; Yalçınlar, 1968; Ardos, 1996; Erinç, 2010; Özşahin, 2013). However, the basis for this distortion started about ± 11 million years ago with the distortion related to the right lateral heave that started with the formation of Northern Anatolian Fault Zone around the Marmara Sea in (Tortonien) Middle-Upper Miocene. While this distortion developed, the structures that were formed earlier started to turn clockwise in a manner appropriate to the character of the distortion (Oktay *et al*., 2002; Yılmaz, 2002; Oktay, 2010; Şengör, 2011; Özşahin, 2013). In time, the small faults were combined in the distorted area to produce a single fault with a lateral heave. With this faulting, Northern Anatolia Fault reached the south of the study area about 20.000 years ago. Therefore, the last phase that represented the formation of the fault with a single main lateral heave that completely cut the fault zone in the Marmara Sea was reached. The fact that the lateral heave extricated itself from the secondary structures and created a fault caused possible traces on the geomorphology of the prior structure that developed with the lateral heave in the north of the fault (Şengör, 2011). The geomorphologic findings from previous studies (Göney, 1963-1964; Hoşgören, 1995; Bargu, 1996; Tarı & Tüysüz, 2001; 2008; Tarı, 2007; Özşahin, 2013) and from seismic reflection (Bargu, 1996; Barka & Kuşçu, 1996; Özhan & Bayrak, 1998; Tarı, 2007) confirm this situation (Şengör, 2011).

After the formation of the Northern Anatolian Fault (Pliocene-Pleistocene), the northern shoulder of Cınarcık Basin rose and caused the distortion of Kocaeli Peninsula to the north (by having the study area rotate around a horizontal axis clock wise when observed from the east) (Şengör, 2011). This distortion movement was a result of Northern Anatolia Fault Zone that laid in the Marmara Sea in the south in Middle-Upper Miocene and slip faults in the direction of Northern Boundary Fault (NBF) that laid in the east-west direction in the Black Sea in the north. This event was termed relief inversion in terms of geomorphologic development (Şengör, 2011) and was supported with studies undertaken in this framework (Ardos, 1996; Oktay, 2010; Özşahin, 2013). Also the movement of rotation caused by the distortion resulted in the acquisition of horst structure by Koceli Plateau (Fig. 4; Yılmaz, 2007; Yılmaz et al., 2010) as well as opening of the Istanbul Strait (Şengör, 2011).

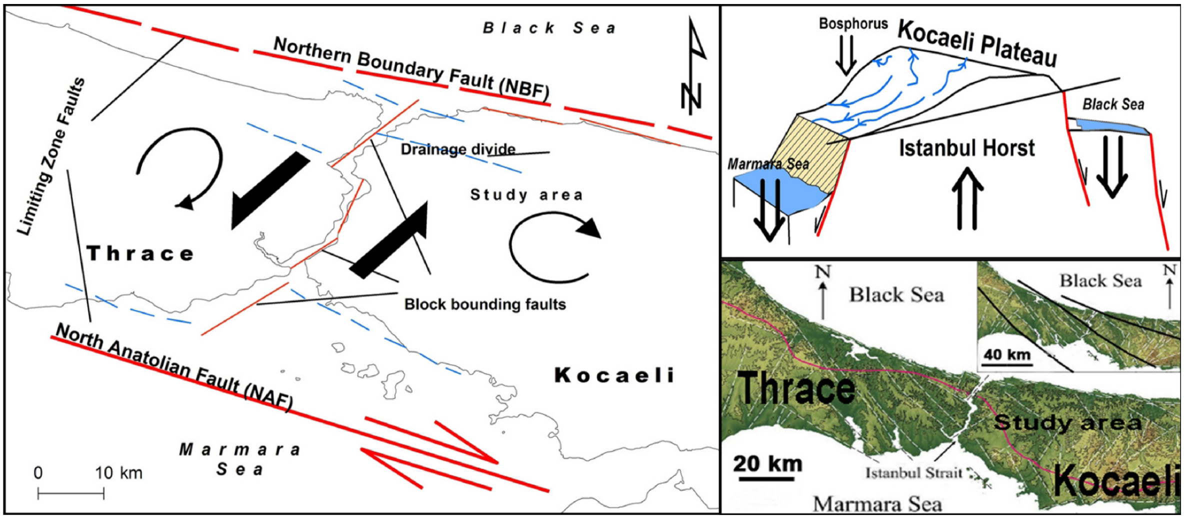


Fig. 4. Tectonic evolution of study area

Erosion surface formed by Oligo-Miocene buttes between 226–538 m and 340–500 m elevation levels in Midle-Upper Miocene when the study area largely started to be shaped (Fig. 3). The sediments formed by the eroding of these erosion surfaces as a result of continuous erosion processes started to be collected in lower ground. This collection process caused the necessary conditions for the development of Kayalıtepe and Mesetepe formations generally represented by river alluvium.

The morpho-tectonic development in the Upper Miocene caused a specific Upper Miocene sedimentation in the basins and therefore created an effective erosion process in higher areas (Erol, 1989). From this period on, colder and more arid climate conditions started to be reign (Şengör, 2011). In this period, Oligo-Miocene erosion surfaces were fragmented by rivers and Upper Miocene high plateau surfaces that can be defined today between 200-300 m elevation range and which developed at the expense of these surfaces were developed (Fig. 3). The continuing effect of these erosion surfaces resulted in the collection of Cekmece group (Çukurçeşme, Güngören and Bakırkoy formations) river alluvium that are the same age as Upper Miocene erosion surfaces (Gedik, Duru, Pehlivan, & Timur, 2005). The fact that this collection is not observed in the study area but in its close vicinity is related to the level of effect of the erosion surfaces that took place afterwards (Özşahin, 2013).

The river network that is effective today was formed at the end of Miocene and at the beginning of Pliocene. Climate generally started to get cooler in the period that corresponds with the end of Miocene period and gained a more humid character in Upper Miocene (Erol, 1983; 1989).

Following the renewed tectonic movements at the end of the Pliocene period, the erosion elements and processes that were effective on the Pliocene covering caused the Upper Pliocene erosion surfaces that consisted of the low plateau areas that can be observed between 50-200 m elevation levels today (Fig. 3). The Pliocene depots that correlated with these surfaces were collected in the neighboring low areas. The layers of the depots are sloped and fragmented and wept at places (Hoşgören, 1995). These characteristics of the Pliocene depots were interpreted that the area was under the effect of epirogenic and/or cratogenic Post-Alpine tectonic movements and was exposed to large scale faulting and therefore block basin structures were mostly formed during the phase that followed the formation of Upper Pliocene surfaces (Hoşgören, 1995). Since the Upper Pliocene, scraped surfaces that belong to prior erosion period and that can be observed between 20-130 m today were developed in some areas where the Pliocene cover in the north was eroded and the old foundations were exposed (Kurter, 1957; Ertek, 1995) (Fig. 3).

In this time frame Upper Pliocene-Lower Pleistocene stacks in the lithology of sandstone, pebble stone, siltstone, claystone and mudstone (Gedik *et al*., 2005) that covered the Upper Oligocene-Lower Miocene units were formed. Bedding characteristics of the unit represented by river and fan deposits (Gedik, Duru, Pehlivan, & Timur, 2005) documents the existence of anoxic marine and deep and shallow brackish water environment in the Upper Pliocene and Lower Pleistocene respectively (Emre *et al*., 1998; Meriç, 1995). It is probable that at the end of Pliocene the distribution of vegetation and climate types obtained a similar structure to those of today and the new prod of Pleistocene started with the oncoming cooling process at the end of this period.

Significant climate changes in the global scale were observed in Pleistocene, the first part of the Quaternary that lasted the longest, and glacial and interglacial periods (Hoşgören, 1995) were experienced successively. While aridity decreased during the interglacial periods, the most arid process was experienced during the glacial periods (The most severe stage of the Wurmian glaciations around the vicinity of the Black Sea is a local exception to this situation). In line with this condition, connections were formed between the Black Sea and the Mediterranean during the interglacial periods in the study area however this connection was severed during the glacial periods. Studies confirm that the first connection between the Black Sea and the Mediterranean was formed during the Uzunlar phase of the Tyrrhenian (Erinç, 1953, 1954; 2001).

In addition to that, the isostatic collapse of the continent caused by the inlandsis (Eurpean inlandsis) that occurred in Eastern Europe in the north of Turkey during the last glacial period (Wurmian) (Erinç, 2001) changed the slope conditions in the north of the Black Sea and the big rivers that normally flowed into this sea started to flow into the inlandsis and were directed towards the northwest (Şengör, 2011). The Black Sea, deprived of its own water resources due to both aridity and the change of slope conditions, became unable to feed through the waters of the Mediterranean due to the drop in world sea levels below 85 meters (the threshold depth of Çanakkale Strait) and the levels of Black Sea water dropped down to -150 meters (Ryan et al,, 1997a; 1997b; Ryan et al., 2003; Ryan, 2007; Şengör, 2011). These changes that took place in the coastline cause the formation of differing terrace levels in various elevation steps (Erinç, 1953-1954; Eriş & Çağatay, 2008).

The lengths of rivers became longer and the depth of riverbeds gained importance with the renewal of erosion when floor levels dropped in drainage systems that obtained their primary characteristics in the study area in the Quaternary period. In the same vein, as a result of the sea level changes caused by negative and positive eustatic movements that occurred during this period, transgression and regression activities were experienced in the coasts. Terraces were formed in the coasts and riversides in varying elevation levels based on the changes that were experienced in the floor levels (Hoşgören, 1995; Erinç, 2010).

The results of dating processes undertaken in order to more clearly explicate the geomorphologic formation and development in the near geological past of the study area also documented that the terraces aged 11.7 thousand years located in the varying steps from the sea level were formed in Holocene and the older terraces were formed in

Pleistocene (Özşahin, 2013). Comparison of the dating results with the changes in the global sea levels shows that the sea level was -50 m below approximately 30-35 thousand years ago, -110 m 14.81 thousand years ago, -45 m 10.21 thousand years ago and -38 m 9.73 thousand years ago (Özşahin, 2013). The dating results also confirm the hypotheses that watershed in the Quaternary in the strait was between Büyükdere and Beykoz and that the study area was formed as a result of the torsion caused by the clockwise rotation mechanism for 2 million years (Şengör, 2011).

The reflection of the weak zones observed in the study area on the morphology, irregularities in the young geomorphologic units (terraces etc.), shifting in the river network and recent earthquakes (Sancaklı, 2004) prove that he area is located in a zone that is still tectonically active (Özşahin, 2013).

When all these events experienced in the geomorphologic past of the study area were assessed in total, the impossibility of explaining the current topography formations with only the current environmental conditions is clear. However, the geomorphologic formation and development process in the study area is still ongoing. Evaluation of the factors o this process is important since it will assist in predicting how and in which manner the current geomorphology will develop.

## 4. Conclusion

The geological and geomorphologic formation and development that started with the collection of the first lithological stack in the Lower Ordovician continued with the deformation related to the right lateral heave around the Marmara Sea and with the clockwise rotation of the study area and the distortion to the north in Middle-Upper Miocene. The situation that can be identified as relief inversion started with the distortion of Miocene- Pleistocene (?) erosion surface (Trakya-Kocaeli or Catalca-Kocaeli Plateau) and the formation of embedded valleys as a result of the drainage gaining a new energy. The study area gained its current geomorphologic formation in this manner.

Changes experienced in the elements and processes during the geomorphologic formation and development of the study area were effective in the development of orogenicy character in Paleo-tectonic period and epirogenic character in Neo-tectonic period. This case can be regarded as a tectonic style with a polygenic character. The role of fluvial processes as the main element is significant in the development of topography. Apart from these, the effects of other processes such as living beings, waves wind and he underground waters can be felt. In this context, the study field has a polygenic topography.

The fact that the study area is the product of a rather complex and long geological formation resulted in the development of more than one cycle both in the formation and the development of the geomorphologic structure. In this respect, the study area has a polycyclic topography.

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