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An overview of morphotectonic features and seismicity of the vicinity of Biga and Denizkent (NW Turkey)

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Abstract

1. The goal of this study is to determine of the tectonics and seismicity of the Biga region in the northwestern Turkey. Study is based on data collected from different institutions and field observations. Geological maps and 1/25,000 scaled topographical maps were used to determine the faultlines and their effect on landforms and drainage. Historical earthquakes show the activity of the region in terms of tectonics. Several earthquakes occurred larger than M≥ 5 in the historical period in the region. Tectonic activity accelerated during neotectonic period. Earthquakes occurring in the region show the activity of the area.

Keywords: Tectonics; Seismicity; Biga; Turkey.

1. Introduction

Turkey is located in the collisional boundary between several plates such as Euroasia, Arabia and Africa. The present tectonic regime of Turkey follows closure of the Neotethys. We can describe three major structures in Turkey. These are the Hellenic-Cyprus Trench, between the African Plate and the Anatolian Plate, North Anatolian Fault Zone, East Anatolian Fault zone and Western Anatolia fault system (Burchfiel et al., 2003; Burchfiel et al., 2006; Clark et al., 2006). The North Anatolian Fault Zone (NAF) is an active right-lateral strike-slip fault in

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northern Anatolia. It runs along the transform boundary between the Euroasian Plate and the Anatolian Plate. The fault extends westward from a junction with the East Anatolian Fault across northern Turkey and into the Aegean Sea. The North Anatolian Fault zone (NAFZ), one of the most seismoactive faults in the world, is a 1200-km-long and broad arc-shaped (Bozkurt, 2001) dextral strike-slip fault zone (Sengör et al., 1985; Sengör et al., 2005; (Şengör, 1979; Barka & Kadinsky-Cade, 1988). The Faults in the south of Marmara Sea and around Biga are the extensions of North Anatolian Fault Zone (Herece, 1990; Efe 1993; Efe, 1994).

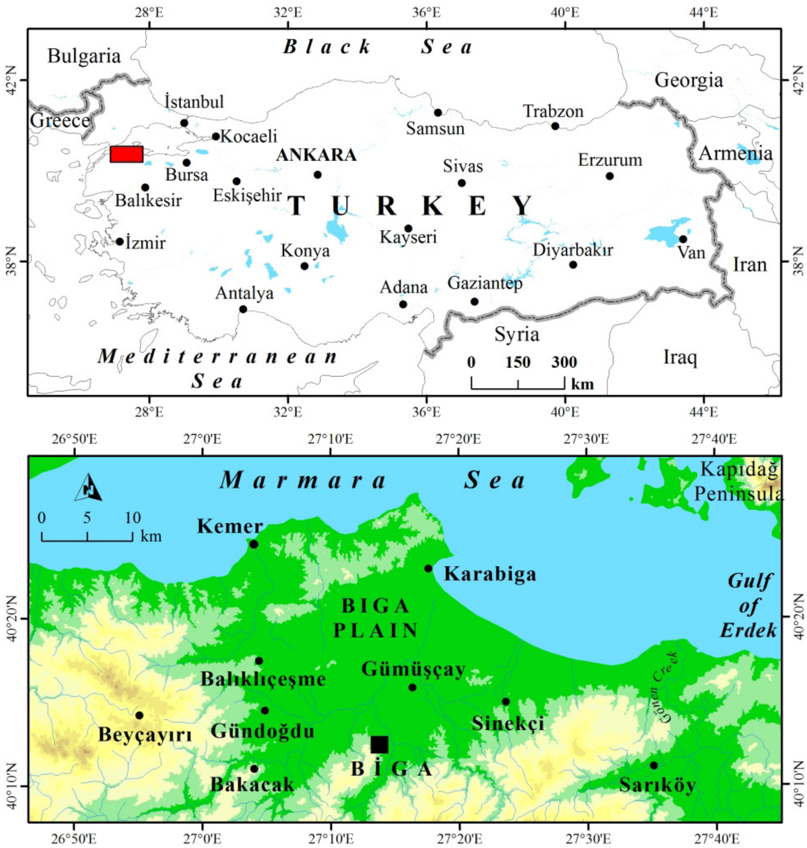

Fig. 1. Location of the study area.

The study area is located in the northwest Turkey in Biga peninsula. Major geomorphological units are the coastal plains in the north, plateaus and mountains in the south. The altitude increases from shores towards the southern areas. Transition from mountainous region in the south to the low coastal plains is with gentle slopes. The role tectonics have very important role in the forming of modern topography. The Marmara transition climate prevails in the region. Two main rivers namely Kocabaş (Biga) and Gönen and tributaries drain the area.

Geological Setting

The study area is composed of rocks that have different lithological features and are mainly formed in various geological periods ranging from the Paleozoic (Permian) to the Holocene Era. Particularly Senozoic formations such as volcanites and detritics surface in a wide area.

The Paleozoic Era: In some parts, metamorphites are incongruously covered with sedimentary and volcanic rocks formed in Middle Eocene or later periods. In the north, the granodiorite mass cuts through Paleozoic metamorphites. Çamlıca Metamorphites and the ophiolitic mélange that forms the Ayvacık-Karabiga Zone are separated by a tectonic contact. Dip faults emerged probably in the Tertiary-aged in this area. The tectonic line lies from Karabiga to the west of the Ayıtdere village. Permian-aged dark grey neritic limestones are seen on the plateau between Biga and the Eybekli village and are cut through by faults.

Mesozoic Formations: The Mesozoic land comprises limestones, detritics (sandstones-claystones), and spilites belonging to the Triassic Era (Gözler et al., 1983). Detritics and spilites surface in a wide area around the Kapanbelen and Havdan villages.

Çetmi Ophiolitic Melange is located within the Biga ophiolitic group. Starting from Karabiga, it surfaces in the west of the Karapürçek, Eskibalıklı, and Ayıtdere villages. It has a length of 35-40 km and a width of 3-4 km (Okay et al., 1990). The Upper Crataceous/Paleocene-aged (Siyako et al., 1989) ophiolitic mélange is in tectonic contact with the Paleozoic Çamlıca Metamorphites and is cut through by a big Late Oligocene-Early Miocene granodiorite mass.

Senozoic Formations: The arrangement formed by Tertiary formations in the study area begins with Middle Eocene neritic limestones and Upper Eocene turbidites, andesite and andesitic tuff intercalated, that cover these limestones accordingly (Okay et al., 1990).

There are formations in the area which are mostly composed of sandstones, shale, and marl that have the features of turbites. These formations are called "Ceylan Formation". They spread towards the Kozçeşme and Asarlı villages in the west, surface between the Çeltik village and Biga in the south, and are the formations which occupy the largest area in the region. The formation is about 500 meters thick, and was eroded on the top by rivers. This arrangement contains two acidic tuff levels and Soğucak limestone olistoliths (Lutetian-Middle Eocene) olistoliths. Fossil samples collected from the Ceylan Formation date back to Upper Eocene. Middle Eocene limestones are present around the Yeniçiftlik village, Kayapınar village, and in the south of Gürçeşme village. Limestones surface in the form of thick layers and blocks (Fig. 2).

Fig. 2. Thick layered limestones in the east of Yeniçiftlik and their disintegration into smaller blocks starting from the surface.

First volcanic activities in the study area, called outcrops, occurred in the Middle Eocene and mainly created andesitic lava, tuff, and agglomerates. These volcanites surface between the Yeniçiftlik and Gürgendere villages, in the southwest of the Bakacak Village, and in the north of the Dışbudak village. Volcanic rocks are covered intercalated partly with fossiliferous Eocene detritics (sandstones) and partly with detritics (Bingöl et al., 1973a). Eocene flysch (sandstones and claystones) formations have a stratified structure over volcanites that from outcrops on the west slope of the Bakacak Dam.

Calcite veins on these stratified structures are striking. The same types of lithological formations are also found on the west slopes of the Biga Stream. Eocene flysch in the outcropping areas here is made up of large gravelled blocks.

The area uplifted at the end of the Oligocene and became a land. While it was becoming continental, Eocene-Oligocene sediments were largely eroded. Therefore, continental, lacustrine, and shallow nautical Miocene deposits and volcanites are present on various units (Siyako et al., 1989).

The second volcanic activity began in the Early Miocene and lasted until the Late Miocene, going through various phases. As a result, formations such as andesite, ryolithic lava, tuff, and agglomerates emerged (Bingöl et al., 1973b). Granodiorites that surface in a large area between Karabiga and the Aksaz village are Late Oligocene-Early Miocene-aged. They are isotopically dated, studied by various researchers, and their ages range between 20 and 31 my (Okay et al., 1990). Whitish and yellowish granodiorites form an arena by getting decomposed into small pieces. In the area between the south of Biga and the Akkayrak village, arrangements composing of gravel and tuff blocks such as andesite, ryolith, tuff, and agglomerates that were formed in the Early-Middle Miocene on the both slopes of the Biga stream outcrops. Middle Eocene-aged and Miocene-aged volcanites look different in terms of their origins.

In the area, there is also a Miocene-Pliocene continental facies. There is sand, clay, gravel and silt on the top layer. Marl and partial limestones are located below. This can be seen around the Hacıhüseyin Highland village and Balıklıçeşme village. The group composed of sand, gravel, and clay is red while limestones and marl are white. The arrangement is usually in a state of a horizontal and loose string (İşcan and Bayır, 1963). Accordingly, red Pliocene continental deposits cover white Miocene lacustrine formations. This also leads to the Miocene/Pliocene transition facies.

Quaternary alluvium is found on river valley bottoms (the Kemer Stream, the Çınar stream, the Biga stream, the Koca stream, and the Şahmelek stream), on river terraces, on the Biga-Koca streams plain bottom, and the area where this extends towards the sea. Sediments composed of sandy, clayey, silty, and loose alluvium carried by rivers by eroding high areas become thinner towards the source of the rivers (Şencan, 2007). They get thicker towards plain bases and areas opening up to the sea. The Biga, Çavuşköy, Çınarköprü, Gündoğdu, and Danışment villages are located on the plain base consisting of Pleistocene base fill. Sand dunes in the south of Karabiga date back to the Holocene.

2. Tectonics

The study area was formed in different lithological periods between the Paleozoic and Quaternary periods and is composed of various lithological units. It is located on a suture zone separating the Sakarya Zone in the south from the Rodop-Istranca Massive (Siyako et al., 1989). The Karakaya orogeny formed in the Triassic Era, the Alp orogeny in the Tertiary Era, and the strike-slip fault formed in the Late Tertiary Period set the main features of the structure.

Data related to the tectonic evolution in the Permo-Triassic Period are limited. This is because ages of most of the units constituting the Karakaya complex were not determined adequately. Another reason is that contracted and strike-slip faults masked the previous tectonism. At the end of the Karakaya orogeny (i.e. in the latest Triassic and Early Lias periods), the area rose and was eroded. Then, it underwent transgression again in the Lias Period (Okay et al., 1990).

The Rodop-Istranca massive and the Sakarya Zone probably collided in the Early Eocene. As a result, the entire area rose and was eroded. Sediments began to deposit due to the transgression starting in the Middle Eocene. Deepening and sediment depositing continued throughout the Late Eocene and turbidites were deposited in a large area. Because of the activation of the North Anatolian Fault (NAF) (Şengör, 1979), a shift from the Paleotectonic Period to the Neotectonic Period occurred, and a new tectonic regime began. Faults lying along the northeast-southwest direction were formed presumably formed in the beginning of the Miocene Period, and their activities have lasted so far.

Even though volcanic activities lost their effect in the Upper Miocene and Pliocene periods, NAF was still in effect. Intense tectonic movements that occurred in the Upper Miocene caused the Lower-Middle Miocene frame, which was the main structure of the study area, to be broken, and they led the topographic structure to incline towards the north and subside. The connection between Tethys and Paratethys was also established in this period (Herece, 1990). In the beginning, rivers were flowing based on the inclination. Due to the effect of young tectonic movements that lasted throughout the Pliocene and Pleistocene periods, the bottom level subsided in phases. As a consequence, rivers were placed on faults and lineaments, and various drainage patterns emerged. Sediments eroded in the high areas were deposited in the lower areas which subsided due to tectonism.

The most important fault in the area is the Biga Fault, a subsidiary of NAF. The Biga Fault lies along the northeast-southwest direction. It leaves the area from the south of the Dikmen village.

The other tectonic extension, which borders the Biga Plain from the south, determines the orographic extension by going through the northwestern section of the Biga-Danapınarı Plateau along the northeast-southwest direction. Controlling the Karabiga-Karahamzalar Plateau from the north, the extension along the northeast-southwest direction led to a significant level difference on the plateau.

The formations, which shaped the morphological features of the study area, are Neotectonic features starting at the end of the Middle Miocene and lasting so far. Young tectonic movements, structural lines with the northeast-southwest, east-west, and north-south directions, horizontal and vertical faulting with northeast-southwest, east-west, and northwest-southeast directions, subsidiary faults, folds and embankments formed by horizontal pressure caused tectonic elevations. They also created a number of morphological marks such as topographic discordance, tectonic chamfer, elbows and translations along rivers, linear valleys, asymmetric ridges and hills, cascaded slopes, epigenic straits, young V-shaped valleys, asymmetric valley, and embedded meanders.

3. Morphotectonic Evolution

The Biga Peninsula has four big tectonic belts lying along the northeast-southwest direction. Beginning from the north, these are Gelibolu, Ezine, Ayvacık-Karabiga and Sakarya zones (Okay et al., 1990). The Biga Peninsula is located on the farthest west point of the Sakarya Zone. The Ayvacık-Karabiga Zone is situated between the Edirne and Sakarya zones, and it is composed of the Ophiolitic Melange which is Late Cretaceous/Pleistocene aged. The area is located on a suture zone represented by the ophiolithic melange which separates the Sakarya Zone from the Rodop-Istranca Massive in the north. The presence of Paleocene pelagic limestones in this ophiolitic melange indicates that the northern side of Neotethyan is partially open towards the end of the Paleocene.

The Rodop-Istranca massive and the Sakarya Zone probably collided in the Early Eocene. As a result, the entire area rose, was eroded, and continental units subsided (Siyako et al., 1989).

Fig. 3. The Çetmi Ophiolitic Mélange and marble layers in the south of Karabiga. Metamorphic rocks (marble) formed under the impact of pressure and folds and embankments on layers, which were deformed due to tectonism.

A significant transgression affecting entire West Anatolia began. Neritic sediments called the 'Soğucak Limestone' were deposited on elevation areas on a large scale.

After the sedimentation of the Soğucak Limestone in the Upper Eocene, the southern shelf on which the Biga Peninsula is located got deeper, the transgression continued, the Ceylan Formation (Ünal, 1967) which is mostly composed of turbidites and spread extensively on the study area subsided. The Soğucak Limestones continued to develop on the elevation areas. The Ceylan Formation is smoothly located on the Soğucak Limestone.

A striking elevation occurred, and an erosion period started on the Biga Peninsula at the end of the Oligocene Era. As a result of this elevation, the Middle Eocene-Oligocene deposits in the south of the Biga Peninsula were totally eroded. Therefore, continental, lacustrine, and shallow nautical Miocene deposits and volcanites are present on various units.

Due to an intense calc-alkaline magmatism on the Biga Peninsula that happened in the Early-Middle Miocene and possibly Late Miocene, continental units also subsided, and a new tectonic regime started. As a result of volcanism, andesite, dacite, rhyolite, and acidic tuffs on the study area largely crops out. As seen in the north of the study area, shallow intrusions of granodiorite occupy the area. In this phase, different lithological units emerged in separate collapse basins, formed due to the activation of the North Anatolian Fault (Şengör, 1979; Şaroğlu 1992). Faults affected by the NAF system and lying along the northeast-southwest direction were formed presumably formed in the beginning of the Miocene Period, and their activities have lasted so far. Miocene volcanites moved 4 km right along the Biga Fault. Aside from right lateral strike slip faults, these faults also have morphologically very distinct vertical stripes in some places. Right lateral strike slip faults along the northeast-southwest direction on the Biga Peninsula constitutes the farthest southwestern part of NAF (Herece, 1990).

Calk-alkaline volcanism losted its effect in the Late Miocene and Pliocene. In that period, NAF maintained its influence and elevated along the pressure ridge of Mount Kaz. This tectonic and sedimentary regime largely continues today (Siyako et al., 1989).

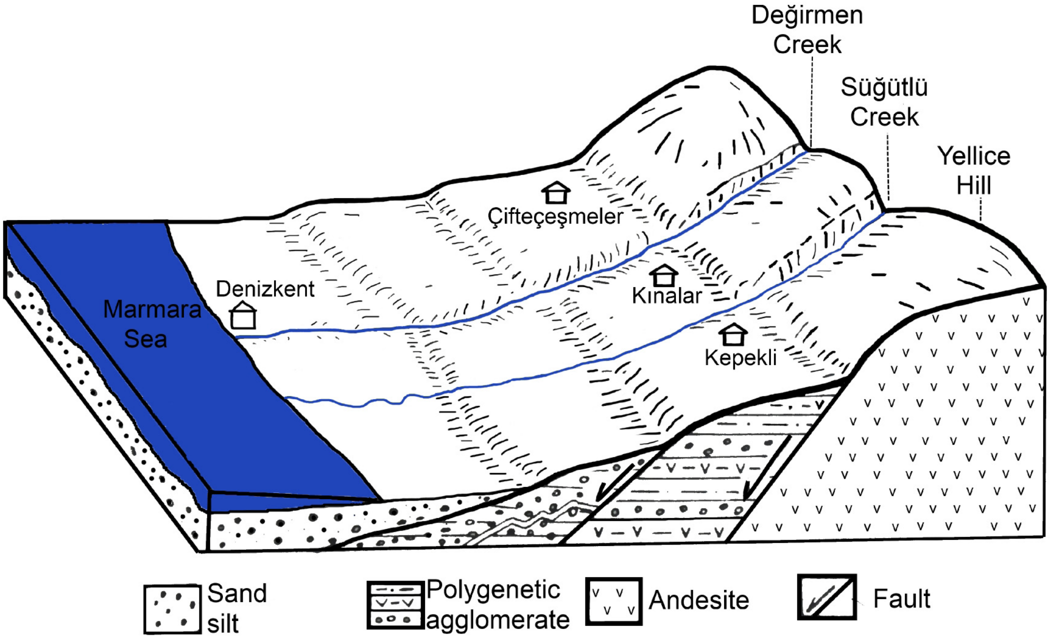

Fig. 4. Fault scarp and "V" shaped Pliocene valleys in the Tortonian gorges in the south of Denizkent.

In the Plio-Quaternary period, fluvial sediments composed of gravel, sandstones, and shale, and lacustrine carbonates settled. Little amount of alkaline basaltic volcanism emerged (Okay et al., 1990). NAF moves towards the west today and it has been active since the Upper Pliocene (Herece, 1990).

4. Results and Discussion

Faults around Biga are an extension of the North Anatolian Fault Zone. Neotectonic faults that affect the Biga Peninsula are the southern part of the North Anatolian Fault System (NAFS), which is right lateral strike slip. Although the directions of the faults in the area are different, most are in the form of listric faults lying along the east-west direction. This fault system is called the “Biga Fault System (BFS)”. Well-developed braided faulting peculiar to strike slip faults, the Biga Peninsula was divided into many blocks that are in various sizes and in the shape of a lens.

Both fault zones and single faults comprising the Biga Fault System cut through rocks that are of different ages and have various facies, pushed them towards the right lateral direction, and tectonically brought these units together among themselves and with the modern basin fill that is of the Plio-Quaternary aged material. According to geological and geomorphological indicators, the amount of right lateral strike slip fault in the Biga Fault System is approximately 40 km.

As shown by historical and recent earthquakes, most of the structural fault segments that make up the Biga Fault System are seismically active. Some active fault segments have the potential to cause earthquakes measuring M=7.0 or more.

Seismicity: The enclosure of the strait between the two continents in the Paleocen-Eocene periods led to the formation of a zone called 'Pontid Suture zone' (Şengör and Yılmaz, 1981, Erdik et al., 2004). This zone creates the weakness zone that controlled the formation of the Marmara Sea.

Between the Euroasian plate in the north and the African plate in the south, the Anatolian plate, this constitutes a large portion of the land on which Turkey is located, uplifted and moved towards the west. North Anatolian Fault (NAF) is approximately 1600 km and makes up the northern border of the Anatolian plate.

Table 1: Earthquakes larger than M≥5.9 occurred in the study area and its vicinity between 460 and 2000.

Year	Latitude	Longtitude	Magnitude (M)	Location
460	40.1	27.6	6.9	Erdek
484	40.5	26.6	7.2	Gelibolu
557	40.9	28.3	6.9	Silivri
740	40.7	28.7	7.1	Marmara Sea
824	40.6	26.8	7.0	Barbaros
860	40.8	28.5	6.8	Marmara Sea
869	40.8	28.7	7.2	Marmara Sea
989	40.8	28.7	7.2	Marmara Sea
1010	40.6	27.0	7.4	Gelibolu
1063	40.8	27.4	7.4	Barbaros
1343	40.7	27.1	6.9	Ganos
1354	40.7	27.0	7.4	Gelibolu
1509	40.9	28.7	7.2	Istanbul
1556	40.6	28.0	7.1	Erdek
1625	40.3	26.0	7.1	Saros Bay
1659	40.5	26.4	7.2	Saros Bay
1737	40.0	27.0	7.2	Biga
1766	40.6	27.0	7.4	Marmara Sea
1809	40.0	27.0	6.1	Gönen
1850	40.1	28.3	6.1	Manyas
1859	40.3	26.1	6.8	Saros
1893	40.5	26.2	6.9	Saros
1901	39.1	26.4	5.9	Ayvalık
1912	40.7	27.2	7.4	Ganos
1935	40.0	27.5	6.4	Erdek-Marmara Island
1944	39.4	27.6	6.8	Edremit-Ayvacık
1953	40.1	27.4	7.2	Gönen
1963	40.2	26.9	6.4	Çınarcık-Yalova
1964	40.1	28.2	6.8	Manyas
1965	40.2	26.1	5.9	Saros
1975	40.4	26.2	6.6	Saros
1983	40.3	27.2	6.1	Biga
1999	40.7	29.9	7.4	Gölcük

The speed of this plate is 2 cm/year towards the west. Because of the plate movements, there is a constant stress accumulation on the fault zone. Stress accumulation triggers fractions on the upper crust and leads to fractions a series of earthquakes on a large part of the fault zone.

Fault systems, formed in the Marmara Region in the last geological periods, have a significant effect on the tectonic structure (Ketin, 1968). The study area is located in the South Marmara Region. It is situated on the Biga Peninsula which is under the influence of the North Anatolian Fault Zone. According to the earthquake zone map of the Ministry of Environment and Urban Planning, this area is within the first-degree seismic zone. An earthquake measuring M≥6 were recorded in the area and its vicinity (Table 1). The NAF Zone is significant in terms of plate tectonics. The North Anatolian earthquake zone is a dislocation strip made up of formations such as faults, pits, and collapse basins. The Ayıtdere, Biga and other fault systems, and tectonic lines bordering the Biga collapse plain are under the impact of NAF. Fault systems that affect the Kırkgeçit stream in the southeast of the Kapanbelen village and in the south of Biga led to the formation of hot springs (Kırkgeçit springs). This suggests that the area has a faulted structure. The Biga Fault lies along the northeast-southwest direction, in parallel with the Sarıköy-İnova Fault which is the western extension of the NAF zone (Herece, 1990). The Biga Fault is under the impact of tectonic fault lines. Stress caused by the relative motion of the plates is charged through the fault in the form of micro earthquakes (Alsan et al., 1984).

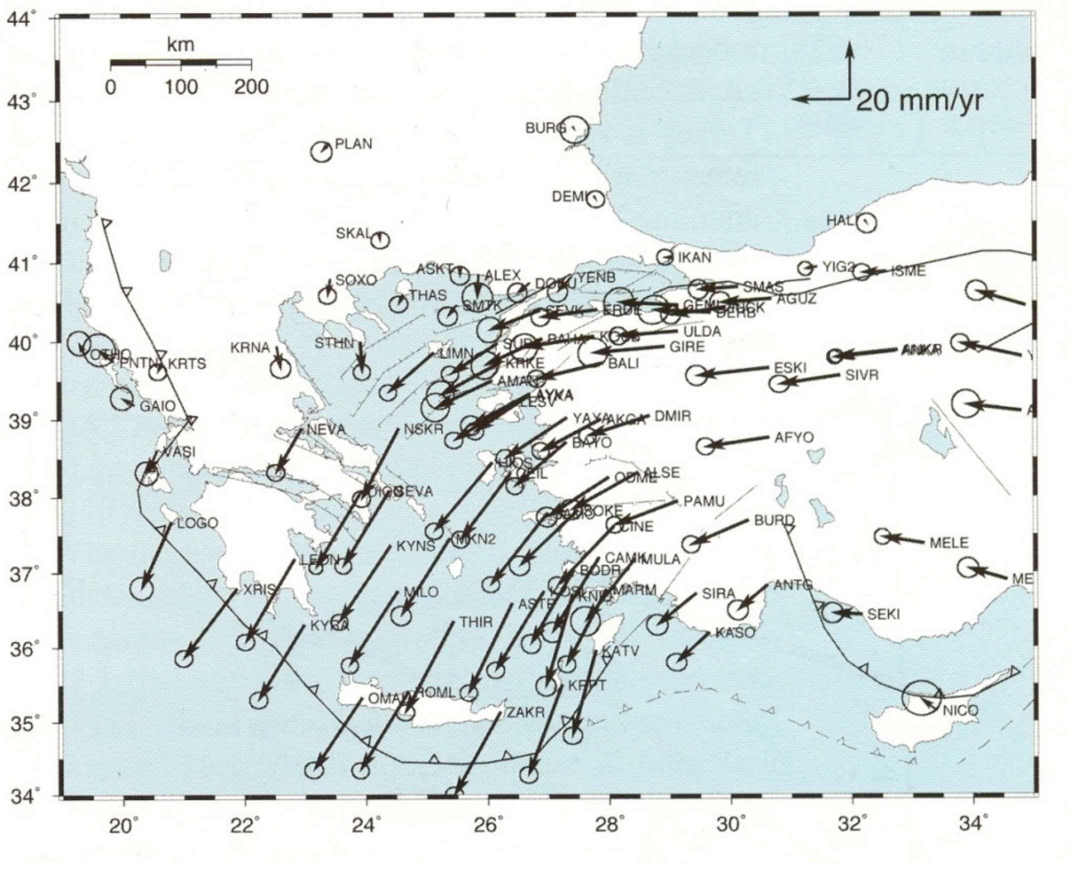

Fig. 5. GPS data of the West Anatolian and Aegean regions (Reilinger and McClusky, 2001)

As explained above, the study area is tectonically active, and massive earthquakes occur in the area. The Biga earthquake (Ms=6.1) which occurred on July 5th, 1983 between Biga and Karabiga was heavily felt and caused loss of life and property. The areas most affected by the earthquake are Çan, Biga, Gümüşçay, Çınarköprü, and Eğridere.

This indicates that eroded material from high areas creates alluvial plains on the Biga Plain, and settlements on these loose grounds are affected by earthquakes to a greater extent.

An analysis of the focus mechanism of the 1983 Biga earthquake and other previous earthquakes in the area reveals that mostly fault along the northeast-southwest direction prevail (Alsan et al., 1984). An examination of the epicentre distributions of Biga aftershocks demonstrates that aftershocks are distributed in the same direction. It must be stated that aftershocks are intense on the Biga alluvial collapse plain, and the area is seismically very active.

Another seismic activity in the study area is the Karabiga seismic activity (Ayhan et al., 1987). It reached its peak after the Biga earthquake on July 5th, 1983. Seismic activity prevails along the tectonic lines of the Marmara Sea, and this indicates that seismicity maintains its effect (Bayrak et al., 2011).

Earthquakes that have occurred since the year 460 larger than M≥ 5.7 in Richter scale listed in the table 1. It is understood that the area and its vicinity have the potential to cause massive earthquakes (Table 1) (Ambraseys, 2002). Intense seismic activities indicate that there are many large and small faults on the ground of the Marmara Sea most of which are active and cause earthquakes.

The fact that no earthquakes other than two important ones happened in the Marmara Sea restricted the explanation of models of the region. However, the earthquake on the Marmara Island (Ms=6.4) in 1935 and the earthquake in Çınarcık (Ms=6.4) in 1963, Ms=7.4 in Gölcük demonstrate that earthquakes of these magnitudes can occur in the Marmara Sea (Efe, 2001). On NAF, there is an intense seismic activity along the fraction which emerged after the Marmara and Düzce earthquakes. In addition, there are intense aftershocks that are observed in the north of the Marmara Island, between the Kapıdağ Peninsula and İmralı, and on the shores of Karabiga-Kemer regions (northern section). This is a quite striking fact. It is necessary to state that the Marmara and Düzce earthquakes had a -VI- scale impact on the study area (Kalafat et al., 2010).

The seismic activity of the region causes a number of problems. When soils are waterlogged (December-April), mass movements that can be caused by earthquakes such as landslides, flood, splits, and collapse particularly on dip slopes might increase in number. As loose alluvial ground covers a large area and ground water is close to the surface at the same time, floods that occur in some years increase the magnitude of an earthquake. The high number of residences on the Biga Plain increases the importance of the subject.

5. Conclusion

Neotectonic movements occurred during the Miocene, the Pliocene and the Pleistocene era formed many landforms around Biga. In the result of these tectonic movements, some surfaces were uplifted, some others tilted and some of them were down faulted. Besides these main landforms many others like listric faults, fault scarps, linear valleys, offset streams were formed. Faults with evidence of active faulting, such as scarps or offset streams were determined in the study area. There is a general relationship between geology and faultings in the vicinity of Biga. Tectonic activities still effective in the south of Marmara Sea including Biga region. Faultlines and vertical activities played important role in geomorphology of the area. The river system was formed in the result of these activities. Neotectonic period has more effect on the present landforms and these activities maintain their effect in the area.

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