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Geomorphological features and seismicity of Bigadiç plain and its immediate vicinity

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Abstract

Bigadiç plain is located in the southeast of Balıkesir, in the south of the Marmara region. The purpose of this study is to determine the geomorphological and seismic features of this plain and its immediate vicinity. To that end, geologic and topographic maps of the area were examined, and information on the processes of geomorphological configuration was obtained. In the meantime, an outline geomorphological map was generated. In addition, earthquakes and their effects on the area were gathered. Field studies were conducted in different time periods; information collected in the field. Data obtained from different sources were integrated, and the results were found. Miocene and Pliocene era volcanic formations have an important effect in the formation of Bigadiç basin. Alluvium belonging to the Quaternary era is the youngest geologic formation in the area. Rivers with parallel and sub parallel dendritic drainage patterns take their sources from high areas in the west and the east of Bigadiç plain, and flow towards Simav stream. These rivers lie along the east-west direction. Faultlines are located along the SE-NW direction, and the study area is seismotectonically situated between the North Anatolian Fault Zone and the Aegean Graben System. Some faults in the area intersect the Pliocene formations. The presence of epigenetic gorges and terraces at different elevations indicates that the area is topographically young and has a polycyclic structure. Bigadiç plain and its immediate vicinity have the characteristics of a tectonic basin and have substantially undergone faulting. This is an outgrowth of the fact that these areas are under the threat of devastating earthquakes. Bigadiç plain and its vicinity have suffered 27 large scale earthquakes in last two millenniums.

Keywords: Balıkesir; Bigadiç plain; geomorphology; seismicity.

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1. Introduction

We can explore the relationship between seismicity and landforms in space and time. Neotectonic activites played important role of shaping Western Anatolia. Some parts of the region were uplifted and some areas subsided. Antecedent of present day drainage system was consequence of these tectonic activities. Geomorphological structure of the area is closely reflected in the topography (Atalay, 1987; Efe, 1994; Efe et al., 2011).

Bigadiç depression is located in the south of Balikesir, which is within south of the Marmara Region. The Sındıgı plateau is in the south of Bigadiç depression while western foothills of Mt. Ulus are in the east of it. The western frontier, which passes the high area in the west of Bigadiç depression, stretches along all the way until the end of the Çağış plateau in the north. The north side is located in the Yeniköy plateau near Balıkesir depression. It loses its characteristics towards north and where Simav stream separates from the Kaleli strait and flows into Balıkesir plain. Marmara transitional climate prevails in the area (Cürebal et al., 2012). Forests consist of oaks observed in the vicinity of the pain. Most of the area is under the cultivation (Efe et al.,2013). The areas without vegetation underwent severe erosion and land degradation (Efe et al., 2008; Efe, 2010).

Miocene and Pliocene volcanic formations have an important role in the structure of Bigadiç basin. Late Cretaceous mélange on the Yeniköy plateau, metasandstones that were formed during the Early Triassic era occur in the west of Değirmenli plain, and limestones belonging to the Permian form the basis under this volcanic coating. Volcanic formations here, particularly in the west and north of the depression, are covered by Late Miocene and Early Pliocene limestone, sandstone, marlstone, and clay deposits. The youngest formation in the area is alluvium belonging to the Quaternary period. These alluvial deposits are especially observed on the lower levels of Bigadiç and Değirmenli depressions and on the valley bottoms of Simav stream and its vicinity. Structure characteristics, including continuous fault lines, thrusts, and steep landforms, constitute a geological mosaic (Ercan et al., 1984)

Bigadiç depression and its vicinity are under the influence of the Mediterranean climate. However, not all characteristics of the Mediterranean climate can be observed. Eventhough winters are rainy as they are in the Mediterranean, average winter temperature is lower, and it snows more here as the area is close to the central Anatolia region. Forests in the area have largely been destroyed as a result of human activities and have turned into park-looking forests.

Rivers with parallel and subparallel dendritic drainage patterns, which take their source from the high areas between the west and east of Bigadiç depression and flow towards Simav stream, lie along the east-west direction. Yet, Kavak stream, Patlak and Höyücek streams on the Çağış plateau, Ayıtlı and Dombay streams, which are in the northwest of the depression, and Emirli stream lie along the NW - SE direction. Savucak and some minor streams flow along the north-south direction. Rivers on the Yarbaşı strait, Değirmenli plain and the Yeniköy plateau stretch along the east-west direction. Rivers in this area flow towards Simav stream.

Faultlines in the area lie along the southeast-northwest direction. This suggests that the study area is seismotectonically situated between the North Anatolian Fault Zone and the Aegean Graben System.

Since there are boron salts and borate deposits in Bigadiç depression and its immediate vicinity, few geological, thermomineral, and hydrogeological studies were conducted (Ketin, 1968; Yılmaz, 1971; Soykan, 1991 and 1994).

The estimated thickness of alluvium ranges between 75 and 100 meters (Esen, 1962). Kaleli and Domboy straits are epigenetic gorges while Yarbaşı strait is a break-through. There are faults and lineaments lying along the NE-SW direction in the west of Bigadiç plain and the north of Değirmenli plain (Erinç et al., 1985).

Some faults in the area cut through the Pliocene formations. The presence of epigenetic gorges and terraces at different elevations indicates that the area is young and has a polycyclic topography (Özoğul, 1987).

2. Geomorphological Features

2.1. Bigadiç Depression and its Immediate Vicinity

It is possible to geomorphologically classify Bigadiç depression into a few groups.

2.1.1. High Area in the West:

This area, surrounding Bigadiç depression in the west and providing passage to the plateaus behind, is cut by deep valleys in some places, and it forms a subsidiary zone where steep slopes appear. The western area has a stepped topography on the lower levels. On the higher levels, however, it looks like a wavy plateau.

There are hanging valleys, monoclinal ridges, and hogbacks at high elevations in the west of Bigadiç depression. Faults and curved small landforms have also played a role in the morphological development of this area.

2.1.2. High Area in the South

There is a high relief in the south of the depression. Passage from the depression base in the north to the high plateau in the south is possible through continuously rising fault scarps. The elevation of the plateau varies between 450 and 600 meters.

2.1.3. High Area in the East

There is a high mass which has an irregular topography and stretches right from the alluvial bottom of Bidagiç depression and rising gradually and rapidly towards east. Lying towards north as a part of the Sındırgı plateau in the south and continuing until Ayıtlı stream, this high area covers lands till Kocadere valley that is located between Özgören and Durasalar villages.

2.1.4. Alluvial Bottom of Bigadiç Depression

Alluvial plain constituting the base of Bigadiç depression begins from the wide edge in the south and stretches for 9 km along the northeast direction towards the west of Avşarbaşı hill. The depression has terraces and its width is about 5 or 5.5 km. The Bigadiç plain covers an area of about 47 km^2. Simav stream flows into this depression from the north and continues to flow by meandering through the pain. The elevation of Bigadiç plain in Simav stream is 130 meters. The elevation increases towards south and reaches 150 meters in the north of Yörücekler village.

There are three hills on the alluvial bottom of Bigadiç depression which attract attention and look like islands. The ones in the southwest and northeast are called Orta hill and Küçükhöyük hill, respectively. Kocahöyük hill, however, is much bigger and has steep slopes rising above the alluvial plain. It looks like a fortress. Braided beds, channel deposits, and back swamps can clearly be seen along Simav stream, which leaves Yörücekler regulator in the south and meanders towards north. It is understood that Bigadiç plain became an alluvial plain in different phases. Indeed, it can easily be spotted particularly along the western edge that alluvium constituting the plain bottom disappears in some places and remains high as terraces. All of these terraces, which are seen at the elevations of 1.5-2 m (Terrace 1), 3-4 m (Terrace 2), and 15-18 m (Terrace 3), slope between 3° and 8°. The thickness of alluvial fill is about 100 meters (Esen, 1962).

2.2. The Northeastern Part of Bigadiç Depression

Ayıtlı stream, which is located right in the northeast of Bigadiç depression and today incorporates Özgören and Çamköy depressions, created a quite narrow and deep valley in the east of Bigadiç depression. Located on a fault line, Ayıtlı stream valley, by cutting through steep landforms in the southwest of İskele village with a right angle, stretches to northwest along the narrow valley it created and reaches Simav stream in the east of Değirmenli plain, which is situated in the north.

2.3. The Northeastern Part: Dombay stream valley

In the northeast of Bigadiç depression lies Dombay stream valley, the upper course of which stretches to Mt Ulus in the south. The river valley widens in some places and lies along 19 km to the northwest. It enters the narrow and deep valley it created beginning from Dereköy in the north and stretches to Kepsut depression, situated outside the study area. It merges again with Simav stream in the north of this depression.

2.4. The Northwestern Part: The Çağış Plateau

The Çağış plateau, the elevation of which ranges between 300 and 400 meters, is located in the area between Bigadiç depression and Balıkesir depression. The plateau is cut down by Höyücek, Patlak, Söğüt, and other streams with narrow and deep valleys. There are inclined structural landforms on the plain, and it constitutes a part of the high southern area of Balıkesir depression. However, the Çağış plateau, a subsidiary area in the northwest of Bigadiç depression, was also incorporated into the study area particularly because it has the same structural features.

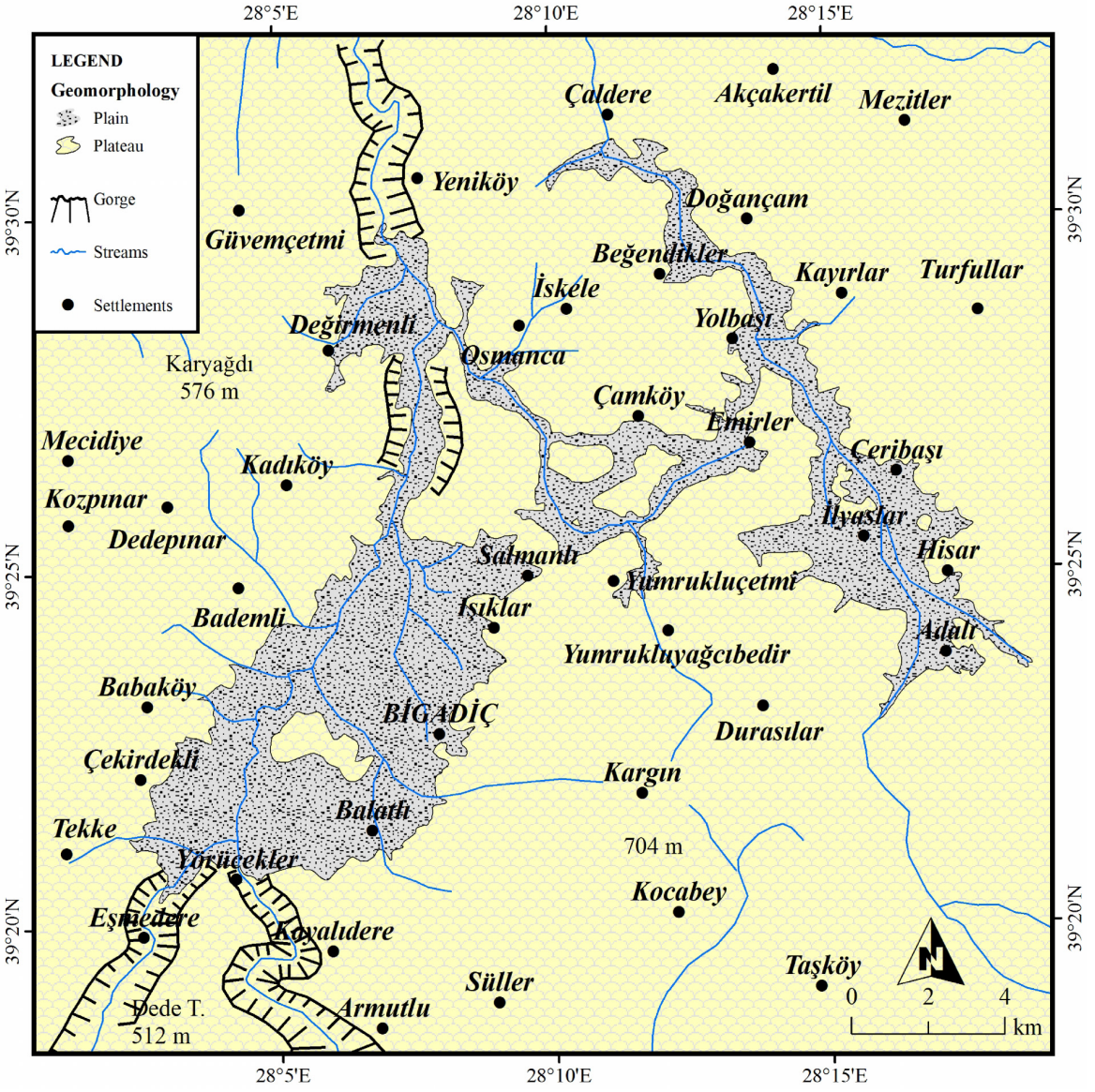

Fig. 1. Geomorphological map of study area

2.5. Passage area to kaleli strait in the north

2.5.1. The Yarbaşı strait

Simav stream flows through the alluvial plain of Bigadiç depression. Then, it flows towards the valley that it cut in order to cross the high threshold area separating this depression from Balıkesir plain in the north. On the northern edge, this valley follows a 400-1000 m wide alluvial bottom until the Kaleli strait in the further north, and it reaches Değirmenli plain, which is a 2 km wide small depression area. This valley is in the 350-400 meters-high area and is called the Yarbaşı strait. The formation of this strait, where the slope inclination is high, is similar to that of the Kaleli strait. In this part, it is understood that while Simav stream continues to flow on Neogene deposits, it is buried on the very spot and loosely splits structural lines during discharge due to epirogenic rising movements. Here, there is an epigenetic gorge formed by Simav stream.

2.5.2. Değirmenli depression

Simav river flows into an area that widens after the Yarbaşı strait. The valley bottom, which widens in the northwest of Degirmenli village, is called Değirmenli plain in this part. The plain has a stepped morphology. The length of the plain along the north-south direction is 3 km while its length along the east-west direction is about 2.5 km.

2.6. The Yeniköy plateau and the Kaleli strait

2.6.1. The Yeniköy plateau

It is located between Değirmenli and Balıkesir plains. It separates these two low areas and sinks into Simav stream. It is a high plateau whose threshold area in the Kaleli strait is about 300-400 meters long.

The eastern part of the Yeniköy plateau begins from the surfaces split by Karapınar stream in the south of Yeniköy. There are faults along the southwest-northeast direction on the deposits here. There are also anticlines and synclines on the deposits where fold axes lie parallel along faults.

The strait has almost the same characteristics of the Yeniköy plateau which is in the east of west. Yet, there are marked heights on the plateau surface here. Among them are Yaylasöğüt hill (421 m) and Fuğla hill (428 m).

2.6.2. The Kaleli strait

The nearly 7 km-long valley of Simav stream is located in the trough that developed in the high threshold between Değirmenli plain in the north of the study area and Balıkesir plain. The strait, created by this stream in the high trough in the north of Değirmenli plain, is the Kaleli strait. This strait was formed on a threshold that looks as if it is broken into pieces by getting split by subsidiaries. This threshold is located in a trough that developed at a elevation of 230-280 meters. In fact, the area where the strait was formed is like a trough compared to the flat and plateau surfaces that are located at an elevation between 300 and 400 meters.

The strait is composed of rocks that have different ages and lithological features. Simav stream cut this old trugh base and loosely split the structure. Today, the course of Simav stream is 140-170 meters deep.

The most striking feature of Simav stream is that it demonstrates incised meanders along the Kaleli strait and that it is almost even made up of incised meanders. There are four incised meanders along the valley.

The Kaleli strait has inconsequential features. It has developed in the high threshold area between Değirmenli and Balıkesir plain, and it does not follow the strait sloping rules. This strait is typically a merge gorge that connects the low two neighboring areas. Before the formation of the low areas here, Simav stream settled consequently on the deposits between Değirmenli and Balıkesir plains. Since the sloping was low in the flowing direction of Simav stream before it meandered. Because of epirogenic rising movements and changes in the base level, it began to cut down without changing its location along with its tributaries. First cutting down began at an elevation of 280 meters and continued until 200-220 meters. Simav stream cuts down at a rapid pace starting from this height, and has formed incised meanders.

Simav stream, along with its tributaries, epigenetically formed narrow and deep valleys on the base which is hard in some places. The area where there are unresisting deposits was eroded and transported. The low area where

Değirmenli plain is located was exposed to such erosion during the development of the valley with incised meanders.

Table 1. Earthquakes (over 4 Mw) in Bigadiç and its vicinity

	Date	Latitude Degree Minutes (N)	Longitude Degree Minutes (E)	Mw	Details
1	04.04.1903	39 00	28 00	5.6	Akhisar, Manisa
2	14.04.1924	39 00	27 48	4.9	Akhisar, Manisa
3	28.10.1942	39 06	27 48	6.0	Kırkağaç, Manisa
4	28.10.1942	39 28	27 48	5.6	Balıkesir
5	28.10.1942	39 16	28 11	5.5	Sındırgı, Balıkesir
6	08.12.1942	39 08	27 38	4.9	Soma, Manisa
7	08.12.1942	39 06	27 42	4.9	Soma, Manisa
8	10.11.1957	39 19	28 12	5.2	Sındırgı, Balıkesir
9	28.04.1963	39 19	27 49	4.9	Savaştepe, Balıkesir
10	23.03.1969	39 18	28 00	4.7	Sındırgı, Balıkesir
11	23.03.1969	39 10	28 19	4.5	Sındırgı, Balıkesir
12	25.03.1969	39 10	28 00	4.5	Akhisar, Manisa
13	26.03.1969	39 02	28 16	4.8	Gördes, Manisa
14	26.03.1969	39 18	28 06	4.4	Sındırgı, Balıkesir
15	26.03.1969	39 18	28 12	4.4	Sındırgı, Balıkesir
16	27.03.1969	39 07	28 12	4.8	Sındırgı, Balıkesir
17	10.07.1969	39 12	28 24	5.2	Sındırgı, Balıkesir
33	13.10.1969	39 10	28 23	4.5	Sındırgı, Balıkesir
18	04.09.1970	39 24	27 54	4.8	Balıkesir
19	09.03.1972	39 10	27 59	4.9	Akhisar, Manisa
20	04.08.1973	39 10	28 23	4.4	Sındırgı, Balıkesir
21	21.06.1977	39 29	27 38	4.4	Bigadiç, Balıkesir
22	12.01.1985	39 17	27 42	4.7	Soma, Manisa
23	06.03.1986	39 28	28 22	4.4	Bigadiç, Balıkesir
24	31.03.1993	39 08	28 02	4.4	Akhisar, Manisa
25	24.07.1999	39 18	27 59	4.6	Sındırgı, Balıkesir
26	25.07.1999	39 20	27 59	5.2	Sındırgı, Balıkesir
27	09.08.2000	39 24	27 40	4.4	Savaştepe, Balıkesir
28	24.05.2001	39 26	27 47	4.4	Savaştepe, Balıkesir
29	22.06.2001	39 18	27 55	4.8	Kırkağaç, Manisa
30	22.06.2003	39 01	28 02	4.5	Akhisar, Manisa
31	12.02.2004	39 16	27 58	4.6	Sındırgı, Balıkesir
32	11.05.2004	39 13	27 43	4.7	Soma, Manisa

3. The Effects of the earthquakes in terms of applied geomorphology

The area is located between the Aegean Region faultlines and North Anatolian fault lines. Bigadiç plain and its immediate vicinity, situated between very active faultlines, have the characteristics of a tectonic basin and have undergone faulting. Thus, it is natural that Bigadiç plain and its immediate vicinity are zones where devastating earthquakes occurred. Bigadiç and its vicinity have suffered 32 earthquakes in two millenniums. The epicenters of the earthquakes that occurred in 1942 and most affected the area (Table 1).

If the fact that the number of earthquakes that were recorded in last 2 millenniums is 24 is taken into notice, one can think that the recording system was not effective in the past. Undoubtedly, the number of earthquakes that occurred in Bigadiç and its vicinity must be many more than the number on the table (Table 1). Though the epicenters of earthquakes develop far away from Bigadiç plain and its immediate vicinity, this area is likely to be significantly affected. For instance, in Gediz, whose distance as the crow flies from the east side of Bigadiç plain is approximately 120 km, a M=7.1 earthquake occurred on March 28th, 1970. In the east of the study area, however, the impact of earthquake was VI M-S (Ergin et al., 1967; 1971). The M=7.4 Gölcük earthquake that occurred on August 17th, 1999 had a VI M-S impact on Bigadiç (Efe, 2001).

The study area is also under the effects of devastating earthquakes occurring around. Besides, this area has some features increasing the intensity of earthquakes. For example, the presence of faultlines in many parts of the basin, creation of thick deposits, high groundwater level, saturation of ground with water between the mid-November and the beginning of April are physical elements that might increase the intensity of earthquakes in the study area.

In addition to these, wrong choice of materials and building types, the use stones and adobe made of mud particularly in walls of old village houses, construction of masonry buildings, opening of roadcuts to built roads, wrong choice of settlement areas are other elements increasing the intensity of earthquakes. Furthermore, the expansion of Bigadiç city towards the plain also enhances the danger of earthquakes.

4. Conclusion

Upper Pliocene erosion surfaces in Bigadiç depression and its vicinity, and Upper Miocene-Lower Pliocene limestones, sandstones, marls, and clay deposits were uplifted. These deposits developed in such a way that they will cover low threshold areas. They have spread over the area by merging with the same type of deposits which fill the basins in the further north and south. Based on the observations, we can say that crust movements occurred in the area after the formation of these deposits and development of the Upper Pliocene erosional surfaces.

These crustal movement lie as wide plains in Bigadiç depression and its vicinity at the end of the Upper Pliocene and during Pliocene and Pleistocene with its slightly rugged topography. The effects of these crustal movements are foldings, dislocations, new faultings, subsidence and uplift along these faults. New sloping conditions emerged as a result of these movements; Simav stream formed its course in accordance with these new inclination conditions.

Large scale uplifts, which led to this last split that enabled the river system and its tributaries to cut down, caused old valleys to be cut deeper, high areas to rise more, and low areas to be flooded by rivers. As a result of these movements, the river system eroded the land over time. Yet, this process has come to standstills at certain times.

A new phase that can be distinguished as a phase in which uplifts led to partial erosion emerged. During these standstills, low surfaces and steps developed due to erosion.

The formation of the Ayıtlı, Dombay, Yarbaşı, and Kaleli straits actually began after this period. Splits, causing considerable changes in Bigadiç depression and its vicinity, led to the scraping of coatings, partial discharge of basins, development of Lower Quaternary zones and river systems. The effects of this tectonic rejuvenation are observed in certain parts of the region as the following:

Subsidiaries on the leveled surfaces in the west and northwest of Bigadiç depression eroded their valleys, and in some places they sank after low-resistance areas. This sinking created a river system that lies parallel along faults that previously emerged in the structure, fold axes, or thrusts. It was observed that the river system in the area mostly lies along the tectonic lines.

The east and southeast of Bigadiç depression was largely affected by tectonic rejuvenation and exposed to a erosion, which formed narrow and deep valleys, by the rivers in this area. As a consequence, the areas where

unresistant formations were warn away, and mildly inclined slopes were formed. Steep slopes emerged on resistant lithologic units.

Ayıtlı and Dombay streams in the northeast cut down their valleys along the tectonic lines and led to the formation of low areas by eroding Neogene deposits.

There are properly formed inclined landforms in İskele town, located in the west of Dombay stream valley and north of Ayıtlı stream. Due to structural faulting, characteristically folded structure relieves occurred in some places. These are monoclinal ridges, which appear on the eroded anticlines, synclines, and on their edges, and epigenetic valleys that cut these ridges.

It can be concluded that Simav river, as the main element of one of its old geomorphologic systems, flows on deposits along the S-N direction, and continues through the threshold between Bigadiç and Balıkesir depression. As a result of geomorphological development that occurred in phases, Simav stream and its tributaries cut down epigenetically. Then, Simav stream eroded basin deposits. Because of this erosion, the river eroded also Upper Cretaceous mélange and volcanic formations that is under the young deposits on the threshold between Bigadiç and Balıkesir depressions. The river formed incised meanders and cut into this threshold. As a result, Çağış and Yeniköy plateaus were developed, and the Yarbaşı and Kaleli straits were epigenetically formed.

The study area is located in a high risk earthquake zone and suffered many earthquakes so far. It is also an area where earthquakes can occur anytime. In addition, it has various physical and human features which might increase the intensity of possible earthquakes. This should be taken into account, and while present dwellings and artworks are renovated, new dwellings should be constructed by taking the seismic features of the area into consideration and following the "*Regulations for the Structures to be Built in Disaster Areas*".

Furthermore, the construction plan of Bigadiç city should be rearranged based on the seismic features. Settling on the alluvial ground should be avoided, and settlements should be moved towards the volcanic terrain in the east of the city.

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