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Research Article

Effects of Geological and Petrographic Factors on Landslide Development in the North of Biga Peninsula, NW Turkey

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Abstract

The study includes landslide movements that occurred on Eocene and Middle-Upper Miocene terrestrial and marine sedimentary units in the Biga Peninsula. In this study, three active landslide areas in Ambaroba, Şevketiye and Adatepevillages located on the northern coastof the Biga Peninsula were investigated. Geological studies ofthe Ambaroba landslide show the integrity of the Bayramiç formation and the Şapcıvolcanics in this area were influentialin the Miocene period. The sandstones in the Bayramiç formation are not very well consolidated, and are yellow, dirty yellow and gray in color. The sliding surface units in the moving masses consist of unconsolidated, very large blocky, pebbly and loosely cemented pebbles. In the Şevketiye and Adatepe landslides, sliding movement occurred on sandstone and conglomerate units with yellowish brown colors in the Fıçıtepe formation. The sandstones in these landslide areas are massive and well cemented. Conglomerates are weaker than sandstones with a gray-beige colorand no consolidation. Precipitation data and Global Positioning System measurements of the landslide areas were evaluated together with the lithological properties of the rocks. Loose sandstones and pebbles in the entire landslide areas can easily move due to seasonal precipitation. This movement was mostly seen in the Şevketiye landslide area and then in the Adatepe and Ambaroba areas, respectively. Although their effectiveness has decreased, movements will continue as the lithological features will not change in these areas. As a result, the measures specified in this study should be considered in order to eliminate the destructive effects of landslides.

Keywords: Landslide, Geology, Petrography, Biga Peninsula

Introduction

Landslide is one of the most common natural disaster types in many parts of the world and in Turkey. Geological, geomorphological, meteorological and anthropogenic causes are among theleading factors affecting landslides. Until recently, many studies were performed about landslide types, development mechanisms and measures to be taken against landslides. (Varnes, 1978; 1984; Rib and Liang, 1978; Ildır, 1995; CrudenandVarnes, 1996; Hungret al., 2001; Hutchinson, 1968; AleottiandChowdhurry, 1999; Carrara et al., 1991).

Biga Peninsula, located in northwestern Anatolia, contains metamorphic, magmatic and sedimentary rock units. In addition, it has been under a compression regime with NW-SE direction since the Middle-Late Miocene, the onsetof the neotectonicperiod in Turkey. Today, it continues to be shaped by right-lateral strike-slip faults that developed under this compressional regime and earthquakes occurring on these faults. The basementof the peninsula isformed by metamorphic rocks of the Sakarya Belt (Okay et al., 1990). Following the collision of the Sakarya continent and Tauride-Anatolide platforms, plutonic and volcanic products of magmatism, which were active in different periods from Eocene to Pliocene, are found together and widespread in the peninsula. In the northern part, sedimentary rocks begin with lagoon faciesafter the Middle Eocene. Early-Middle Miocene sediments are observed in the inner and southern parts of the Biga Peninsula, while Late Miocene and Plio-Quaternary sedimentary formations are observed along the coast of Çanakkale Strait. Considering the geological characteristics of Biga Peninsula, the landslide risk potential is high (Yiğitbaş et al., 2005; Türkeş et al., 2011; Erginalet al., 2009; Bekler et al., 2011; Duman and Ateş, 2012; Ekinci et al., 2013; Erenoğluet al., 2015a; Yiğitbaş, 2016; Perinçek, 2018; Erenoğlu and Yüceses, 2019).

This study discusses landslide movements on the Middle-Upper Miocene terrestrial and marine sedimentary rocks in the Çanakkale basin in the Biga Peninsula. Active slope failures within these sediments in the region formedthe Amboraba landslide, the Şevketiye landslide and the Adatepe landslide, from east to west, along the northern part of the Biga Peninsula. Many studies were carried out in these landslide areas previously, which attracted the attention of many researchers. Türkeş et al. (2008 and 2011) discussed the geomorphological, geophysical and climatological features of mass movements in Ambaroba and its surroundings in detail. Seismic refraction studies were carried out for the visualization of landslide structures in Lapseki and Şevketiye regions using seismic reflection techniques for visualizing surface structures together with Global Positioning System (GPS) data (Erginal et al., 2009; Bekler et al., 2011; Erenoğlu et al., 2013; Erenoğlu and Erenoğlu, 2018). In this study, landslides located in the northern part of the Biga Peninsula, geological factors and other triggering factors are discussed. Rock units in which the landslides occurred, especially, which were not dealt with in previous studies, were petrographically examined and their effects on the landslides were revealed together with precipitation data forthe region.

Study Area

The studied landslidesare in Ambaroba, Şevketiye and Adatepe villages in the northern part of Biga Peninsula in northwest Anatolia (Figure 1).

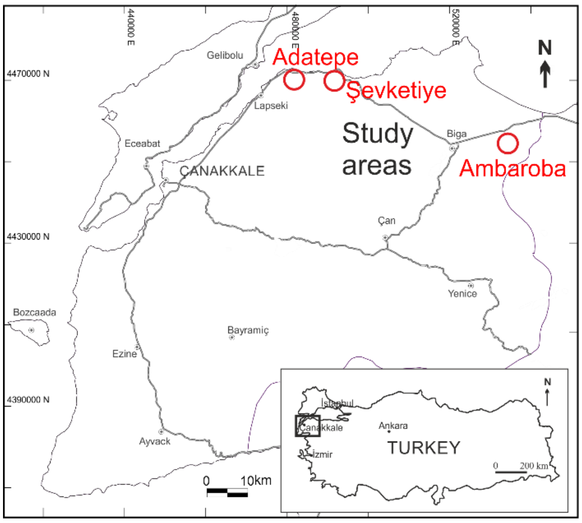

Fig. 1. Location map showing landslide areas.

Materials and Methods

In the first stage, within the scope of field studies carried out in the landslide areas, 1/25,000 scale geological mapping studies were carried out. Simultaneously with mapping, lithological sampling was performed and tectonic and geomorphological observations were carried out.

From the 30 rock samples collected as a result of field studies, thin sections were prepared for petrographic studies of samples that best represent different rock units in the study area. The thin sections were examined under a polarizing microscope, their mineralogical composition was determined, and information about the texture, naming and classification of the rocks was obtained from petrographic examinations. Important textures and minerals identified in thin section studies were photographed and scaled. In addition, the ages of the units were verified with the help of paleontological data from thin section samples containing fossils taken from some sedimentary units. According to the data obtained from the meteorology stations of the Turkish State Meteorological Service (MGM) in Biga and Lapseki, precipitation was investigated regarding the lithological development of the landslide areas.

Geological and Petrographical Properties of Landslides

Ambaroba Landslide

The Ambaroba Landslide formed around Ambaroba Village in the Biga district of Çanakkale province. Ongoing small-scale landslide movements in the region were significantly effective between 1992 and 2006 and caused the destruction of houses, barns and workplaces in the village.

The main geological formations are Şapçı volcanic comprising andesitic volcanism (Dönmez et al., 2005), and the Bayramiç Formation (Siyako et al., 1989) deposited in the Pliocene period (Figure 2). The Bayramiç Formation was deposited in the form of fluvial sediments consisting of pebble, sandstone and shale and lacustrine carbonates, and rests conformably on older units. Volcanics cropping out in higher areas have a compact structure and therefore, are not prone to mass movements. The landslide movements in the region occur in the slide-prone sedimentary deposits of the Bayramiç Formation.

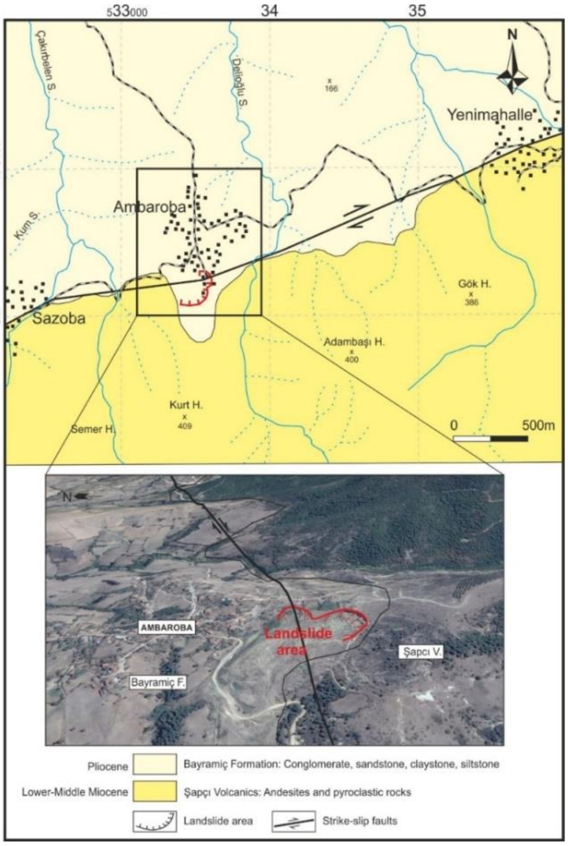

Fig. 2. Geological map of Ambaroba village and its surroundings.

Conglomerates and sandstones belonging to the Bayramiç Formation are common in and around Ambaroba village. However, in the area to the south of the village where the landslide occurred, the sandstones are almost absent, and the blocky conglomeratic level is present where the gravel sizes vary between 1-50 cm. Conglomerates are bonded with sandy and gravelly cement that is not well hardened (Figure 3). Although the locations of the conglomerates are EW/15N, they are not clearly seen. In the samples collected from gravel and blocks, it was observed that these mostly represent volcanic rock fragments in the environment. Blocks of different colors and sizes have the feature of breaking and dispersing immediately. Therefore, this conglomeratic unit observed south of Ambaroba village can easily move as a result of seasonal rainfall. The continuity of this movement will probably continue until the boundary with the Bayramiç formation, where very strong volcanic rocks in the region are located.

When the outcrops of the Bayramiç formation are examined in the Ambaroba landslide area, generally yellowish, beige sandstone and conglomerate lithologies cover large areas. Sandstones are yellowish, dirty yellow, and gray in color and not well cemented. They do not present clear bedding in their outcrops. However, they are oriented towards N45W/14NE in an area where regular alternations with conglomerates is observed (Figure 4).

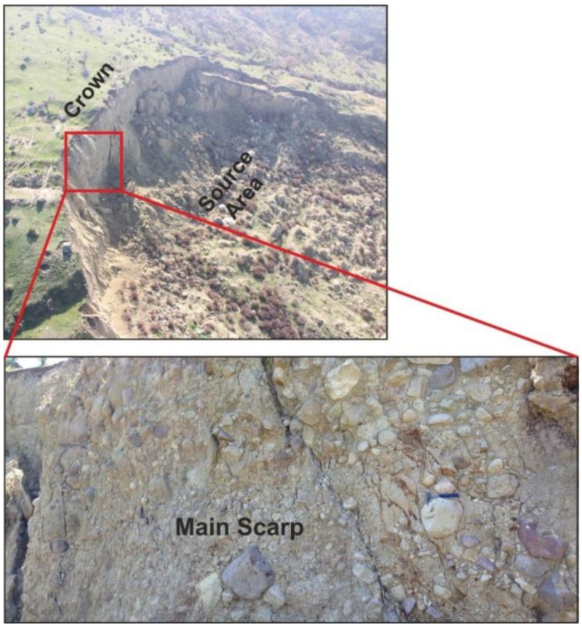

Fig. 3. Gravel and block fragments of the Bayramiç formation observed on the sliding surface in the Ambaroba landslide (UTM Zone 35: 433504 E, 4452146 N).

Medium-coarse-grained quartz and plagioclase minerals are mostly encountered in petrographic examinations of sandstones belonging to the Bayramiç Formation. Apart from these minerals, alkaline feldspar and biotite minerals are rarer (Figure 5). Quartz minerals are found as anhedral and coarse grains. Plagioclase minerals are subhedral and have polysynthetic twinning. Alkali feldspar minerals can be distinguished from quartz by their gray interference colors and faint cleavage marks. As mica minerals, muscovites are mostly in the form of micro crystals, while biotite minerals from volcanic sources in the region are observed to have medium-grained and rod-like shapes. They can be easily distinguished from other minerals with yellowish-brown interference colors, high relief and brown-colored pleochroism. There are cavities in the entire rock. These voids are important for porosity and permeability of the rock.


Fig. 4. Sandstone and conglomerate alternations in the Bayramiç formation observed in Ambaroba village (UTM Zone 35: 433653 E, 4452486 N)

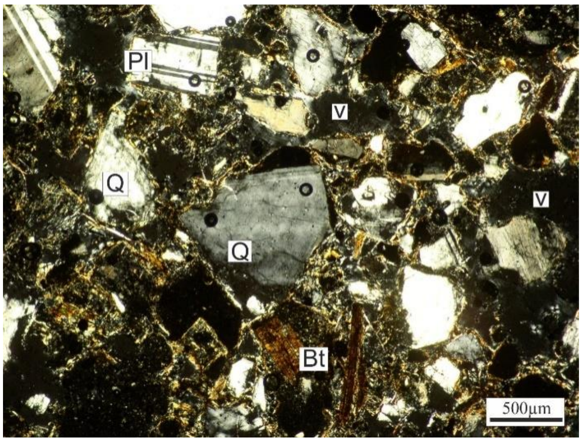

Fig. 5. Thin section view of volcanogenic sandstone belonging to the Bayramiç formation (XPL=cross polarized light. Q: Quartz, Pl: Plagioclase, Bt: Biotite, V: Void)

The landslide area in Ambaroba village is close to the Biga fault included on the Active Fault Map of Turkey, or Sinekçi fault included on the updated Active Fault Map of Turkey (MTA, 2012). This fault corresponds to the western tip of the southern strand of the North Anatolian fault zone (Emre et al., 2013). In the period when the landslide was active and in modern times, there was no earthquake on this fault line and there is not much information about historical period earthquakes. However, the imperceptible movement effect along this fault zone may cause slope instability in the area vulnerable to mass movements.

Şevketiye Landslide

Eocene sediments are common in the Şevketiye region located in the north of the Biga Peninsula (Figure6). The Eocene units were first defined in the Gelibolu Peninsula by Sfondrini (1961) as the Fıçıtepe unit; then Siyako et al. (1989) named their outcrops in the Biga Peninsula as the Fıçıtepe formation.

The sliding movements in the Şevketiye region occurred on the yellowish brown colored sandstone and conglomerate units of the Fıçıtepe formation. Sandstones are massive and well cemented. Pebble stones, on the other hand, havegray-beige colorsand are not strengthened and hardened compared to sandstones. The sandstone and conglomerate units are observed alternately (Figure 7a). The size of the pebbles is larger than those in the Adatepe region and varies between 1-15 cm (Figure 7b). Some of the large pebble samples mostly represent quartz, claystone and volcanic fragments. A very clear layer plane was not encountered within the unit in the landslide area. However, the direction of N75W/52NE was measured from an area where alternations of sandstone and conglomerate with a certain sequence were observed. The slope of these layers is the same as the movement direction of the landslide.

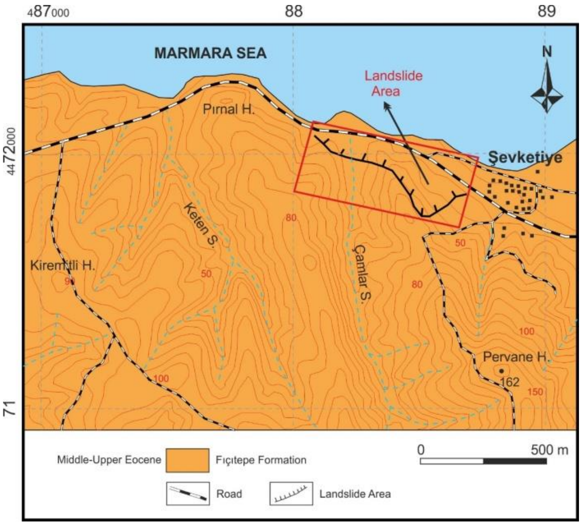

Fig. 6. The geological map of the Şevketiye landslide area and its surroundings.

In the region where sandstones and pebbles are intercalated, thin sections could not be obtained from weak and unhardened pebbles. In the thin section studies carried out in sandstones, they are mostly volcanogenic and lithic sandstones rather than fossiliferous sandstones as in Adatepe (Figure 8a and 8b). As a result of the determination of minerals in thin section, the main components that make up the rock are medium-grained quartz and rock fragments. In addition to hollow rocks, there are small crystals of muscovite and chlorite minerals, and plagioclase crystals are found in some sections. Plagioclase minerals are generally seen as angular grains.

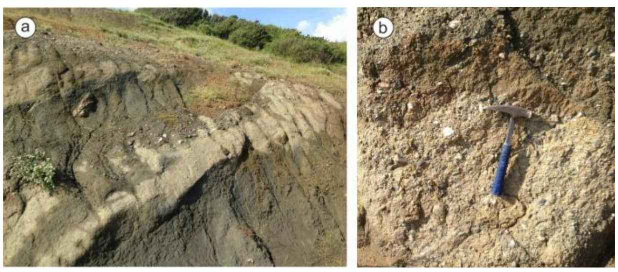

Fig. 7. a) Sandstone-conglomerate alternation in the Fıçıtepe formation, b) Poorly cemented conglomerate unit (UTMZone 35: 488541 E, 4471955 N).

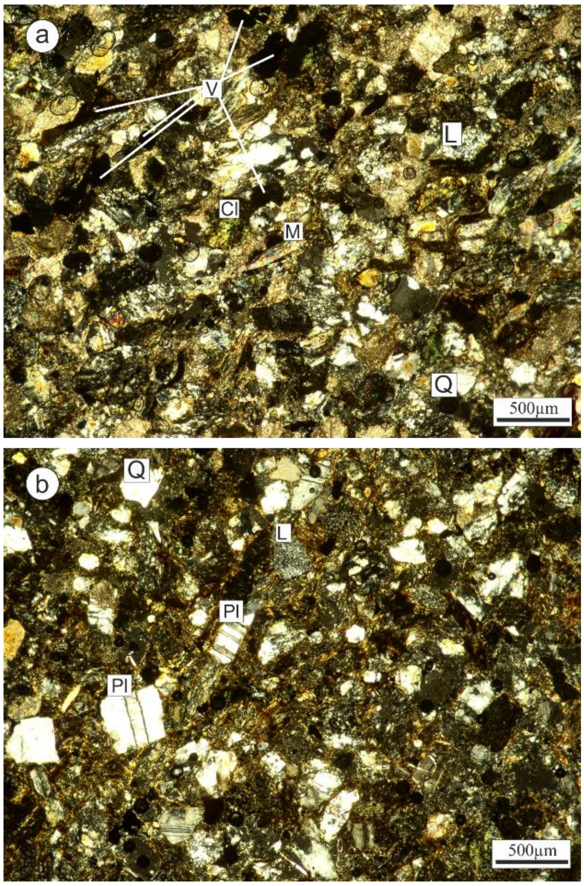

Fig. 8. a-b) Thin section views of lithic sandstone belonging to the Fıçıtepe formation (XPL, Q: Quartz, L: Lithic fragment, Cl: Chlorite, M: Muscovite, Pl: Plagioclase).

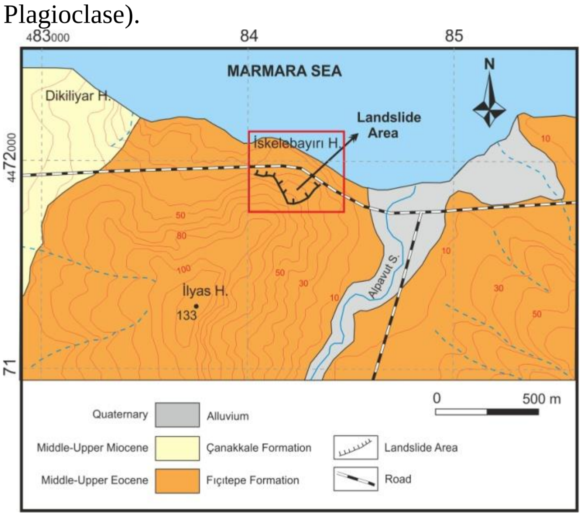

Fig. 9. The geological map of the Adatepe landslide area and its surroundings.

The presence of plagioclase is suggestive ofderivation from the surrounding volcanic rocks. It was observed that rock fragments consist of carbonate fragments formed from calcite minerals with micrite size and micro quartz. The cement of the rock consists of carbonate.

Adatepe Landslide

The sliding movements in the Adatepe region occur on the yellowish brown colored sandstone and conglomerate units of the Fıçıtepe formation, as in the Şevketiye region (Figure 9). The distance between these two landslide zones is approximately 6-7 km. A distinct change in the lithology of sandstones is not observed along this distance.

In the sandstone and conglomerate units of these sediments, which are named the Fıçıtepe formation, there were quite a lot of sliding movements over a period of approximately 6-7 years (Figure 10).

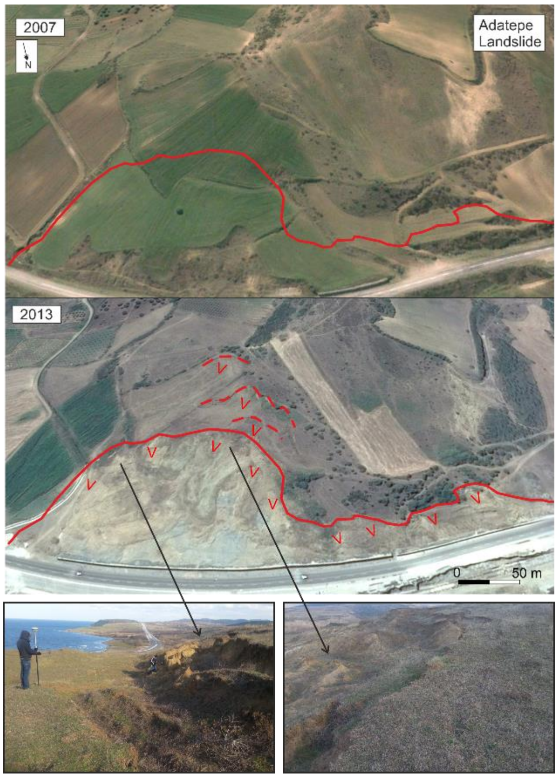

Fig. 10. Satellite imagery of the Adatepe landslide area and surface movements observed in the region.

In the area where sliding movements are observed, the units belonging to the Fıçıtepe formation are mostly composed of micaceous sandstone, pebble stone and fossiliferous carbonate sandstones. Muscovite, one of the abundant mica minerals, is observed in yellowish-brown colored sandstones. It is medium grained, well hardened and massive in appearance. It is also possible to see graycolored, carbonated sandy limestone and white colored clay levels within the sandstones. Micaceous sandstones are intercalated with conglomerates. Pebbles have yellowish brown color, are not well cemented, easily dispersible, and abundantly cracked. Gravel sizes vary between 2-15 mm. On top of the conglomerate-sandstone alternation, there are light graycolored, highly dispersible, fine to medium grained carbonate sandstones. Abundant macro fossils were found in these sandstones. Macro fossils described as Globularia (Globularia) vapincana (d'Orbigny) indicate Middle Eocene age for this unit.

Thin sections could not be obtained due to the pebble stones in the region being poorly cemented and easily dispersible. Because of petrographic studies carried out on sandstones, the main component consists of medium-grained quartz minerals (Figure 11a). In addition, rock fragments in which a large number of micro-quartz minerals are located together constitute the lithic material. Muscovites are dispersed in sandstones as microcrystalline flakes rather than platy and rod-like shapes. Sparitic calcite cement fills between the grains. Microfossils reflecting the Eocene period were encountered in almost all of the thin sections obtained. These fossils are Operculina sp., Nummulites sp., Assilina sp. and Discocyclina sp. (Figure 11b). Calcite is represented bysparitic cement and carbonate rock fragments within these rocks. There is not much void ratio in these sandstones.

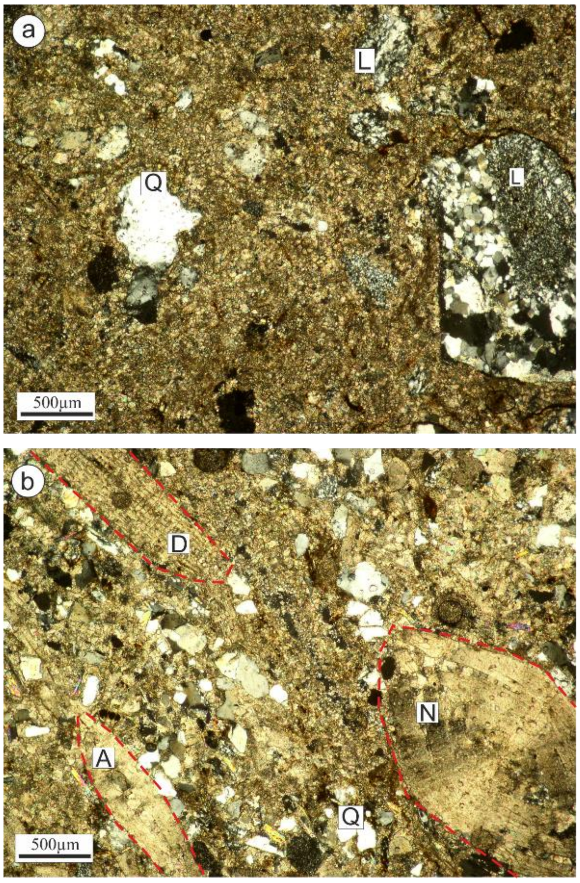

Fig. 11. Thin section views of fossiliferous sandstones belonging to the Fıçıtepe formation (XPL, Q: Quartz, L: Lithic fragment, D: Discocyclina sp., N: Nummulites sp., A: Assilina sp.).

Therefore, when considered for active landslide action, it can be concluded that the strength of sandstones in this texture and composition is actually high. However, with the clay levels and unconsolid pebbles in the unit, the movement capability gains in this unit.

Relationship between Lithology and Rainfall

Landslides usually occur during periods when it is rainy and the ground is wet and damp. During these rainy periods, the water above the bedrock or the ground penetrates the bedrock and the soil becomes saturated, which facilitates slipping. In general, landslides occur more frequently in rainy or wet seasons.

Biga Peninsula has the characteristics of a Mediterranean precipitation regime, where the highest rainfall is recorded in winter and the lowest in summer (Türkeş, 1996, 1998). Geographically, it is classified as "semi-humid Marmara transition climate" (Türkeş, 2011). In this regard, in order to determine the relationship between lithologies where landslides occur in the north of Biga Peninsula and rainy months, average monthly total precipitation data for landslide regions between 2013 and 2017 was obtained from Çanakkale Meteorology Station Directorate. In the precipitation data, the data from Lapseki district were used to evaluate the precipitation characteristics for the Ambaroba landslide area, with data from Biga district used for Şevketiye and Adatepe landslide areas (Figures 12 and 13). The reason for choosing the data for this period is that GPS data were also recorded in the landslide areas in the same period. Therefore, the average GPS velocity vectors in these years and the effect of precipitation on lithological units were evaluated together (Table 1).

According to the climate classification for Ambaroba village and its surroundings, a semi-humid, second degree mesothermal (moderately hot) climate with severe water loss in summer and marine climate is dominant (Türkeş et al., 2008). When the total monthly precipitation graph obtained from Biga Station between 2013 and 2017 is evaluated, the year 2014 has the highest average value with 71.4 mm of precipitation. The average value of five years is 53.5 mm. In 2017, the highest precipitation occurred in January and October.

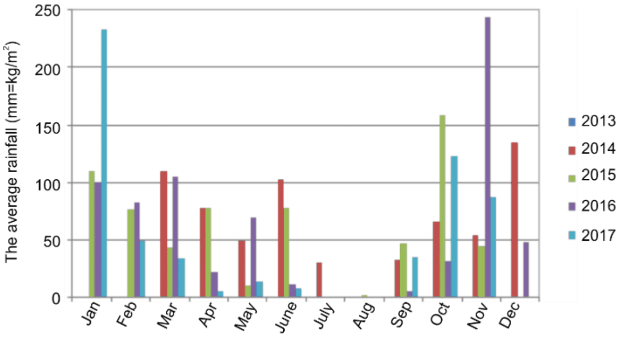

Fig. 13. Average monthly total rainfall graph for Çanakkale / Lapseki district between 2013 and 2017.

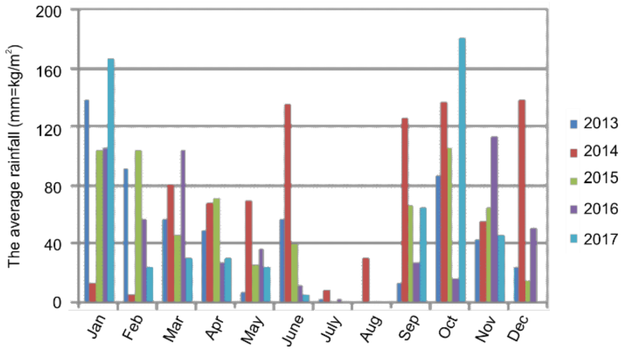

Fig. 12. Average monthly total rainfall graph of Çanakkale / Biga district between 2013 and 2017.

In the data for Lapseki district, there is nodata for the first 10 months of 2013 because this station is a recently established station. When the monthly total precipitation values between 2013 and 2017 are evaluated, the years 2015-2016 had the highest rainfall with the rates of 59.5 mm. The average of the five years is 46.0 mm. The highest rainfall in the region occurs in November 2016. The other high rainfall is in January 2017. For all three-landslide areas, there is almost no rainfall in the summer months. GPS technique is widely used to monitor landslide movement, both as a complement to traditional surveying methods and as a valid alternative. Monitoring the horizontal and vertical displacement in the landslide area is the most basic form of modeling the kinematics of a landslide. In addition to the landslide risk analysis using GPS monitoring data, it is aimed to estimate the shock time of the landslide. GPS measurements were carried out periodically on a sufficient number of sites representing the landslide movement. Then, the high accurate coordinates of the sites were computed using research software developed (Dach et al., 2015). Based on appropriate differentiation techniques, the horizontal and vertical velocity vectors of the points representing the kinematics of the landslide area were estimated. In this way, according to GPS data obtained between 2013 and 2017, the average horizontal and vertical velocity data forthe Ambaroba landslide are 1.42 cm and 0.59 cm, respectively; the horizontal and vertical velocities of the Adatepe landslide are 1.07 cm and 1.38 cm, respectively; and the horizontal and vertical velocity data of the Şevketiye landslide were determined as 2.28 cm and 2.08 cm, respectively (Erenoğlu et al. 2013, 2015b, 2015c).

Table 1. Average horizontal and vertical velocity results of landslide areas according to GPS data for 2013-2017.

	Horizontal velocity (cm)	Vertical velocity (cm)
Ambaroba Land.	1.42	0.59
Şevketiye Land.	2.28	2.08
Adatepe Land.	1.07	1,38

Landslides developing on areas with different lithological characteristics during winters with higher rain than normal are affected differently and sometimes cause serious damage. Heavy and continuous rains or melting of snow cause more water to leak into the bedrock or the cover on the ground. Considering this situation for the rock units in the landslide areas, it will not take long for the blocky and pebbly ground to become saturated with water, and the landslide formation will accelerate as the weight of the cover increases. In the landslides in Şevketiye and Adatepe areas, clayey and hollow sandstones that are not well anchored will absorb water and become slippery as they get wet. This will increase the risk of landslides in the region and affect the frequency of occurrence. It was observed that the topography in all three regions does not consist of very steep slopes. Despite this, this weakness in the lithology could not prevent landslide movements.

Discussion and Conclusion

The geological structures of the landslide regions and their reactions to precipitation are different from each other. Therefore, when studying the effects of precipitation on landslides, it is very important to know the structure of the rocks in the region as well as the precipitation.

The physical properties of the landslide areas studied are summarized in Table 2. The Ambaroba Landslide involves sedimentary sediments belonging to the Bayramiç formation. These sediments are not well cemented. There are conglomerates and sandstones in the region, these are fragile and can easily be activated by the effect of heavy rainfall. Although it is not active, it is clear that the landslide area being located near a fault line is a triggering factor in addition to lithological features.

Table 2. Physical characteristics of the studied landslides.

Landslide characteristics	*Ambaroba Landslide*	*Şevketiye Landslide*	*Adatepe Landslide*
*Type of slide	Rotational landslide	Shallow planar slide-earthflow	Shallow planar slide-earthflow
Lithology	Conglomerate (Blockandgravelsized, poorly anchored material)	Sandstone (hollow), conglomerate (pebbly and clayey)	Sandstone (hollow), conglomerate (pebblyandclayey)
Topography	Slope medium	Slope medium, layer locations in the same direction as the landslide	Slope high
Activity	Main scarp	Slide body	Slide body
Triggering Factors	Lithology, faultline and heavy rainfall	Lithology, highway construction and heavy rainfall	Lithology, highway construction and heavy rainfall

**Taking into account the definitions of CrudenandVarnes (1996) and Hungr et al. (2014).*

Şevketiye and Adatepe landslides, which are close to each other, are similar in terms of geological features. In Adatepe, there are micaceous sandstone, conglomerate, carbonate sandstone and Eocene sediments. Since these are not well cemented, they have a cracked structure that can easily break up. Water seeping through cracks during rainy periods is effective in breaking down these rocks easily and forming landslides. Pebbles in the Şevketiye area are larger than Adatepe, and poorly cemented sandstones reflect the geology of the region. Elements with fractured and fragile structures, as in Adatepe, are vulnerable to precipitation and are effective on landslides. In addition, the layer positions measured on the existing sediments are the same asthe movement direction of the landslide. This situation can ultimately affect the speed of the landslide movement.

When the lithological features, precipitation data and the motion of the estimated GPS velocity vectors in the landslide regions are evaluated together, the highest movement in both horizontal and vertical directions is in the Şevketiye landslide area. In Adatepe, on the other hand, the vertical velocity is higher than the horizontal velocity. It is thought that the highway construction carried out in this area between 2013 and 2017 also affected these movements. In addition, it is possible to say that the effectiveness of the Ambaroba landslide area, which will cause great damage, has decreased, but small movements continue to be observed in the unit.

As a result of the geological studies carried out in landslide areas; It can be concluded that the presence of unstable sedimentary units is one of the main factors for all landslide areas. Within the scope of GPS monitoring studies, similar geometric responses were given to the loads acting on the points in the landslide zones. Although the horizontal and vertical velocities generally tend to have similar directions, they occur in different magnitudes. For landslides with a highway right next to it, the horizontal mass movements of the landslides generally occurred perpendicular to the highway. In addition, another reason for the deformations in Ambaroba and Şevketiye Landslides is the accumulation of existing surface and underground waters in this region and the slope of the landslide areas.

In order to solve the main problem in all landslide areas discussed in this study, it is recommended to make underground drainage and improve the infrastructure, remove the surface waters that may affect the landslide area with the help of hill ditches before they reach the crown of the landslide, and prevent the surface waters from draining into the ground in the landslide zone. In addition, the landslide mechanism should be analyzed and necessary measures should be taken before engineering structures such as roads, bridges and viaducts are built. To do it, temporal and spatial monitoring, modeling and interpretation should be made in areas with landslide risk, especially in the Biga Peninsula and Marmara Region, taking into account all the factors that will affect the landslide.

Acknowledgements

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