LANDSLIDES ALONG THE NORTHERN BLACK SEA COAST BETWEEN VARNA CITY AND KAVARNA TOWN (BULGARIA)

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Abstract. The landslides along the Northern Black Sea coast, between the Varna City and Kavarna town, may be divided in the following six regions, according to their geological structure, geomorphological and engineering geological settings: I – Varna city – Golden Sands resort; II – Golden Sands resort – Kranevo village; III – Batova River valley; IV – Batova River – Balchik town; V – Balchik town – Topola village; VI – Topola Dere –Kavarna town and northward of it. The results of the new engineering geological investigations, made mainly in regions II, III and V, are discussed in the paper. They include geological and engineering geological mapping, photo surveying of the terrain by a helicopter, geodetic surveys, re-interpretation of data from old drilling, considerable number of new boreholes and resistivity survey (RS), slope stability analyses, and engineering geological zoning. The main result of these investigations is the elaboration of a new geological model with tiered landslide steps, where the sliding surfaces are not connected between them. In the previous studies, the presence of an unified rupture surface from the plateau till the sea cost has been accepted. The separate landslides, their lithology and stratigraphy, geomorphology and engineering geology are also described. Several marine terraces are established and dated. Based on this, the age of landslides is determined.

The major factors for the origin of the studied landslides are: the eustatic fluctuations of the sea during the Pliocene and Pleistocene, the constant uplifting of the dry land, the relatively high slope inclination, the high seismicity (IX degree, according to the MSK scale), and the anthropogenic activity at present. The lithological-stratigraphic structure of the Sarmatian sediments is an important prerequisite for the slope instability.

Key words: Black Sea coast, landslides, lithology, stratigraphy, geomorphology, engineering geology, geodynamic evolution.

1. STATE-OF-THE-ART OF THE PROBLEM

The landslides between the Varna City and Kavarna town are among the biggest landslides in Bulgaria. The town of Balchik, the northern quarters of Varna, parts of the "Golden Sands" and "Albena" resort complexes, as well as other smaller resort settlements fall within the considered area. Over the last 60 years, scientific research and engineering geological explorations related to the deformations and destruction of buildings and infrastructural facilities, coast stabilization, as well as elucidation of the possibilities of using new terrains for resort construction were carried out.

These landslides may be divided into the following six regions, according to their geological structure, geomorphological and engineering geological settings (Fig. 1):

I – Varna city – Golden Sands resort;

II – Golden Sands resort – Kranevo village;

III – Batova River valley;

IV – Batova River – Balchik town;

V – Balchik town – Topola village;

VI – Topola Dere – Kavarna town and northwards of it.

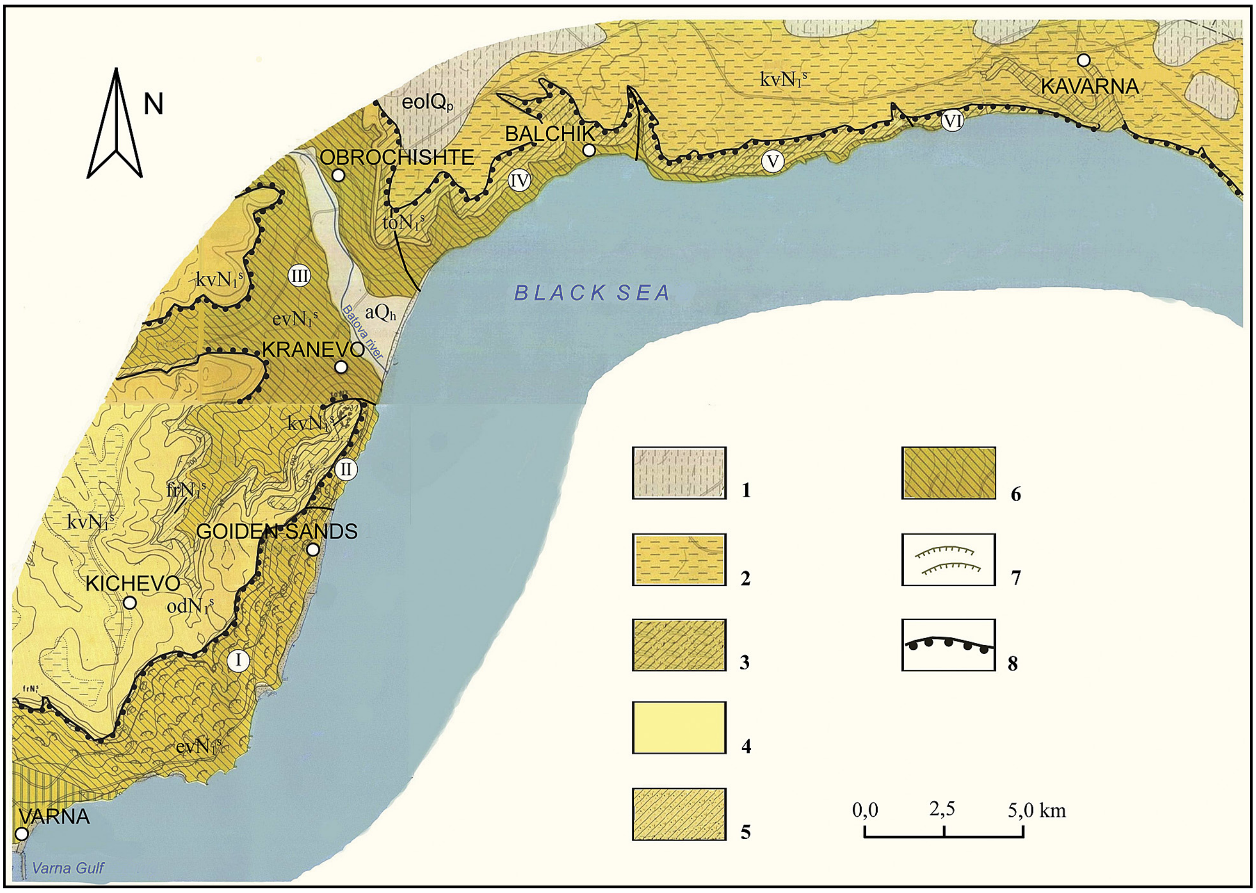


Fig. 1. Geological map with the landslides along the northern Black Sea coast (Cheshitev *et al.*, 1991,1992 – map sheets Balchik – Shabla, Varna-Zlatni piasatsi, scale 1:100 000). **I** – region Varna city – Golden Sands resort; **II** – region Golden Sands resort – Kranevo village; **III** – region Batova River valley; **IV** – region Batova River valley – Balchik town; **V** –region Balchik town – Topola village; **VI** – region Topola Dere – Kavarna town and to the north of it; **1** – loess complex (eolQ$_p$); **2** – limestones of the Karvuna Formation (kvN$_1^s$); **3** – aragonite clays with limestone intercalations, Topola Formation (toN$_1^s$); **4** – limestones with sand intercalations, Odar Formation (odN$_1^s$); **5** – sands, Frangen Formation (frN$_1^s$); **6** – diatomaceous clays of the Euxinograd Formation (evN$_1^{kg-s}$); **7** – delapsium; **8** – oldest landslide scarp.

The landslides were explored and studied by the Geological Institute of BAS, the Anti-landslide Station in Varna (at present, Geo-protection Ltd.) and a number of other organizations and companies. The results are described in numerous reports and publications.

Iliev and Tzvetkov (1971) described one of the most destructive landslides that occurred 2 km to the south of the Kranevo village and provoked the demolition of dozens of buildings. They consider that the landslide was caused by abrasion and technogenic rising of groundwater level.

Kamenov *et al*. (1972, 1973a, 1973b) analyze the landslides between the Batova River and Kavarna town (regions IV, V and VI; Fig. 1). They are taking into consideration the geological-tectonic conditions of the region, the structure and manifestation of landslides, as well as the factors that have provoked them.

Iliev (1973) discusses the impact of historical and contemporary earthquakes on the origin and activation of landslides in the regions investigated by Kamenov *et al*. (1972). Popov and Mishev (1974) made an attempt to date the landslides on the base of data for the Black Sea terraces.

Stoykov (1979) studied the landslides between Varna and Kranevo (regions I and II). The author believes that the old block slides occurring along faults have now been more or less stabilized and their current activation in the lower part of the slope is due to abrasion and technogenic impacts.

Stoykov and Evstatiev (1983) explore the big landslides near the Panorama camping, which took place in 1978 causing great damages to the buildings and infrastructure.

Evstatiev and Rizzo (1984) consider the geomorphologic development and mechanism of the landslide in Balchik from a geohistorical viewpoint, using, besides historical data, old engravings with views of the town. The later comparison with contemporary photos allowed inferences about the relief changes in the last centuries. The authors consider that the detachment of large blocks from the plateau, which is typical for this landslide, is due to strong earthquakes and its present activation is provoked by marine erosion and rising of the groundwater level.

Stakev *et al*. (1984) analyze the landslide in the Kranevo villa zone, described by Iliev and Tzvetkov (1971), and Stoykov (1979), in connection with its stabilization.Varbanov *et al*. (1997) analyze the reasons for landslide activation in the region of Golden Sands during the 1950s.

The landslides along the northern Black Sea coast are also described in the explanatory text to the map "The Geological Hazard in Bulgaria" (Iliev-Bruchev, Resp. ed., 1994). Their activation is explained by soil over-moistening, marine erosion, slope cutting and seismic impacts.

The quoted authors assume that the investigated landslides were formed along a deep sliding surface, beginning from the plateau and continuing to the sea. The surface is initially rather steep, with a circular-cylindrical form, subsequently transformed in a plain surface with a slight inclination towards the sea. The landslides are considered to be delapsive, possessing one landslide body, composed of large packages. At present, the lowermost part of this body is usually activated, mainly, under the impact of marine abrasion and technogenic factors. The movements are assumed to gradually spread to the upper parts of the slope, now in a provisionally stabilized state. The analyses and conclusions of the cited publications use the ideas concerning the tectonic and lithological-stratigraphic structure of the sixties of the past century, which have undergone serious development in the 1980s and 1990s (Popov *et al*., 1986; Popov& Kojumdgieva, 1987; Cheshitev *et al*., 1992; Koleva-Rekalova, 1994; Koleva-Rekalova, 1997; Mandev& Nachev, 1981; Bokov *et al*., 1987). The following more important results of these works are considered in this paper:

- The lower part of the landslide slopes is built from laminated, lithified to a different extent, mainly, diatomaceous clays of the Euxinograd Formation (evN_1^s) – called in the older publications "lower marl-clayey group" (Fig. 1);
- According to information from Prof. Kristalina Stoykova, the explorations at sea have shown that horizontal intercalations of organic clay are observed in the diatomaceous clay layers. These intercalations are encountered at different levels along the marine slope in the considered regions, and when crossed by the borehole profiles they may be erroneously united as an integral sliding surface;
- To the north of the Golden Sands resort (regions II to VI), the aragonite sediments of the Topola Formation (toN_1^s) – called earlier "middle calcareous-marl group"- are embedded on top of the clays of the Euxinograd Formation. Southward from the Golden Sands resort (region I), the Euxinograd Formation is covered by the sands of the Frangen Formation (frN_1^s);
- To the north of the Golden Sands resort, the uppermost part of the slope is built from limestones and calcareous sediments of the Karvuna Formation (kvN_1^s) – named before the "upper limestone group" - while southward is formed by the limestones of the Odar Formation (odN_1^s);
- The explored slopes fall within the Varna monocline, which is the eastern part of the North Bulgarian uplifting. The surface of the Euxinograd Formation dips to the east and northeast by about 60 m from region I to region V. The traces of intensive block tectonics are old. During the Neogene and the Quaternary, the tectonic movements were predominantly vertical and positive and were not accompanied by big faulting.

These conceptions about the tectonics and stratigraphy of the studied area were used in the new explorations of the landslides in regions II, III and V, conducted by the Geological Institute of BAS, in the period 2005–2011 (Evstatiev& Petrova, 2006; Evstatiev& Evlogiev, 2007; Evlogiev, 2010; Evstatiev *et al*., 2010a; Evstatiev *et al*., 2010b; Evlogiev& Evstatiev, 2012; Evlogiev& Evstatiev, 2013).

2. BASIC EXPLORATION RESULTS IN THE 2005-2011 INTERVAL

These explorations covered the southernmost part of region I (the northern quarters of Varna city), regions II, III and the landslides near the Topola village in region V. They included geological and engineering geological mapping, photo surveying of the terrain by a helicopter, geodetic surveys, re-interpretation of data from old drilling, a considerable number of new motor boreholes and geophysical boreholes (resistivity survey/RS), slope stability analyses, and engineering geological zoning. The explorations were financially supported, mainly, by the owners of the terrains, the Bulgarian Academy of Sciences and Varna municipality. They provided new geomorphological, engineering geological and hydrogeological information for unexplored or not sufficiently explored terrains.

2.1. Landslides in region II (Golden sands resort – Kranevo village)

The Region II is of high interest from the viewpoint of resort extension. It has been studied as a whole (Stoykov, 1979) and in its individual parts, in connection with large landslides and stabilization works (Iliev& Tzvetkov, 1971; Stoykov& Evstatiev, 1983; Stakev *et al*., 1984). As a result of the new investigations, a new geological model has been proposed (Evlogiev& Evstatiev, 2012), according to which the landslide is a three-storey one with independent sliding surfaces (Figs. 2 and 3). The highest landslide storey is of the block-type, while the lower ones are ordinary delapsive landslides. Similar three-storey landslides are observed along the Ukrainian Black Sea coast, too (Zelinskii, Ed., 1993).

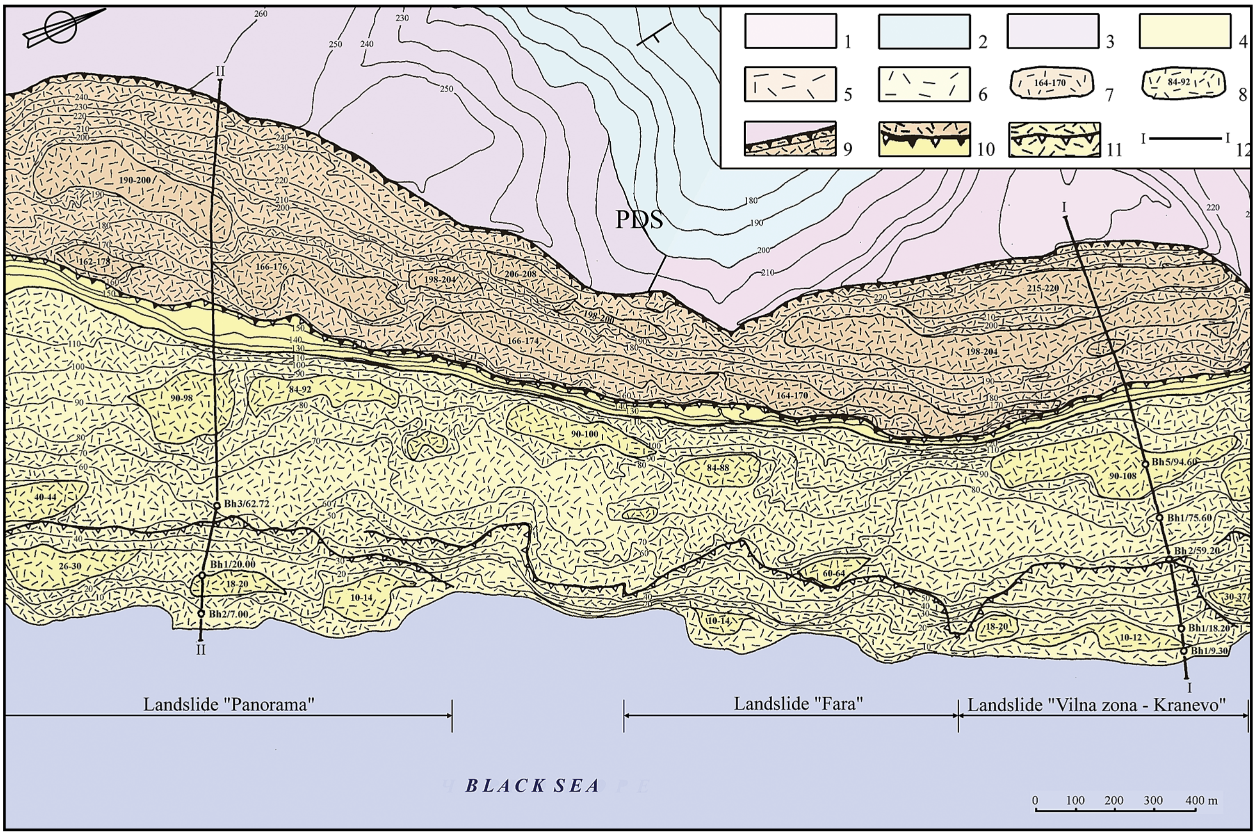


Fig. 2. Geological-geomorphological map of the region II (Panorama camping – Kranevo village). **1** –limestones of Karvuna Formation (kvN$_1^s$); **2** – aragonite sandy or silty clays with limestone intercalations, Topola Formation (toN$_1^s$); **3** – detritus, shelly and oolithic limestones with sandy intercalations, Odar Formation (odN$_1^s$); **4** – diatomaceous silty clays, thinly lithified, Euxinograd Formation (evN$_1^{kg-s}$); **5** – landslide blocks and delapsium of the Pliocene landslide (third storey); **6** – delapsium of the Early Middle Pleistocene (second storey) and Late Middle Pleistocene-contemporary landslide (low storey); **7** – Pliocene terraces; **8** – Pleistocene terraces; **9** – oldest landslide scarp (Early Pliocene); **10** – intermediate landslide scarp (Early Middle Pleistocene); **11** – low landslide scarp, changing since the Late Middle Pleistocene till now; **12** – profile line; Other designations: **PDS** – Pliocene denudation surface, **90-100** – absolute elevation of the terraces, m; **Bh1/75,60** – motor borehole No / terrain elevation, m.

This model was elaborated by analyzing the geological, paleogeographical and geomorphological settings. Neogene and Quaternary sediments are outcropped in the region (Figs. 1 and 2). The Sarmatian is represented by the Euxinograd Formation, building the slope base, and by the Frangen, Odar, Topola and Karvuna Formations, building the slope and the plateau (Fig. 3).

An unified aquifer horizon is found in the delapsive materials. The diatomaceous clays of the Euxinograd Formation are the main aquitard. The groundwater is recharged from the plateau and from precipitations. The technogenic water has a substantial contribution in some areas, being the main cause of the landslides near the Panorama camping and the Kranevo villa zone (Iliev& Tzvetkov, 1971; Stoykov & Evstatiev, 1983). The groundwater is drained at three levels: at the highest landslide scarp under the Frangen plateau, between isohypses of 60 and 80 m and at the seacoast.

The landslides occurred during the sea transgressions, when the marine terraces were formed.

Evlogiev and Evstatiev (2012) describe the location, age and structure of the main geomorphological forms: the Pliocene denudation surface (*i.e.*, the Frangen plateau), the slope and the marine terraces. The slope width increases from north to south – from 900 m at the Kranevo villa zone to 1300-1400 m at the Panorama camping. The overall inclination, in the same direction, decreases from 20 º -26º to 12 º -14º.

The marine terraces, formed on old landslides, are situated one above the other along the slope (Fig. 2). The oldest Pliocene terraces, under the highest slope from elevation 190 to 215-220 m (with probable Dacian age), were formed on the sliding blocks and on the delapsium. The lower terraces, from 164 to 178 m, are of Lower Romanian age. The terraces with elevations from 84 to 108 m, 60-64 m, 26-30 m, 18-20 m and 10-14 m are of Pleistocene age.

Based on terrace age the highest landslide storey was active during the Dacian-Early Romanian. Now, this level is stabilized. The middle landslide storey was formed in the Early Middle Pleistocene. It is assumed to be provisionally stabi-

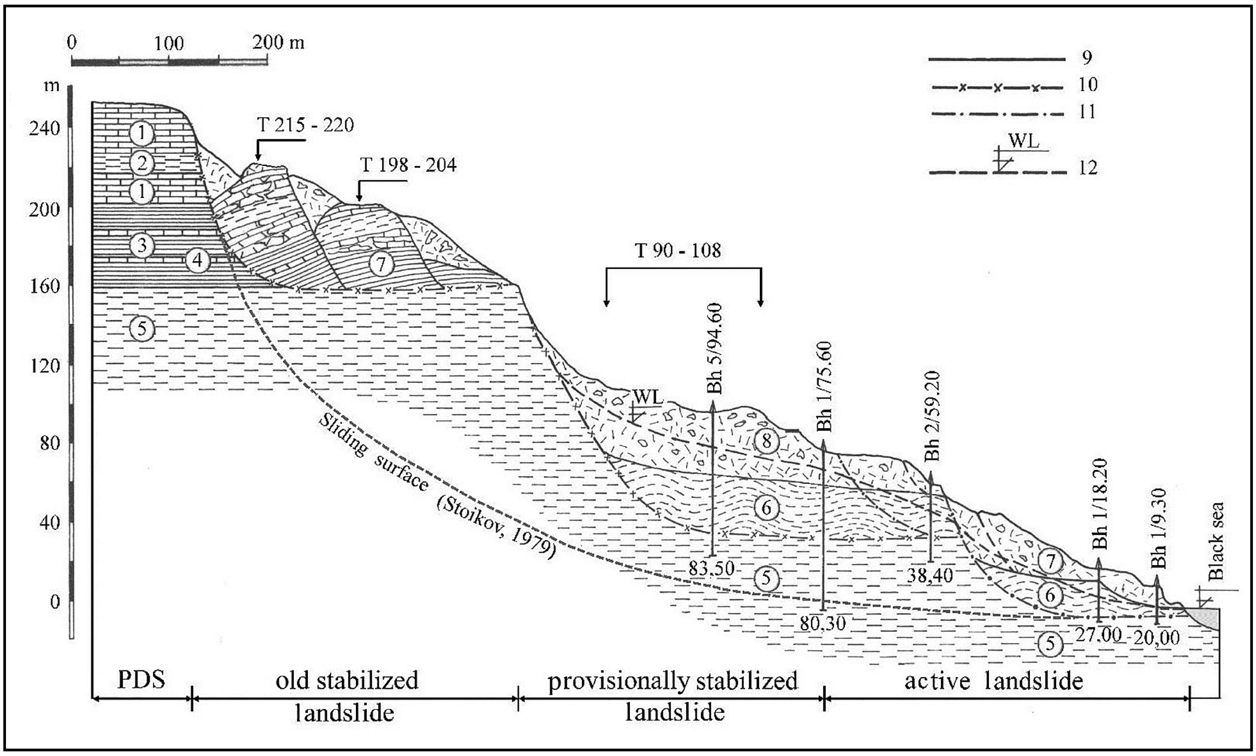


Fig. 3. Engineering geological profile I-I across the landslide in the Kranevo villa zone. Engineering geological varieties from 1 to 8: **1** – limestones of Karvuna Formation (kvN$_1^s$); **2** – silty clays of the Karvuna Formation; **3** – aragonite sandy or silty clays, Topola Formation (toN$_1^s$); **4** – limestone intercalations in the aragonite clays of the Topola Formation; **5** – diatomaceous clays of the Euxinograd Formation (evN$_1^{kg-s}$); **6** – sediments of the Euxinograd Formation with undulated structure, formed by the weight of the slid blocks; **7** – landslide blocks; **8** – delapsium of silty clays with limestone fragments; Other designations: **9** – lithological boundary; **10** – rupture surface of an old stabilized and provisionally stabilized landslide; **11** – rupture surface of an active landslide; **12** – water level; **PDS** – Pliocene denudation surface; **T$_{90-108}$** – marine terraces/absolute elevation, m; **Bh1/75,60** – motor borehole No / terrain elevation, m.

lized. The low landslide storey was formed in the Late Middle Pleistocene. Since that time up to now, it has been subjected to cyclic activation by marine erosion, which affected new parts of the Early Middle Pleistocene landslides.

The main landslide circuses at the Panorama camping, the Fara locality – activated on 13.10.2012, and the Kranevo villa zone, are described by Evstatiev and Evlogiev (2012).

After additional engineering geological explorations it will be possible to prove that the third and second landslide storeys may turn out to be suitable for construction. Preventive measures against groundwater level rising should be taken in these areas to avoid activation and broadening of the landslide range in the lowermost part of the slope.

2.2. Landslides in Region III (Batova River valley)

The coastal part of the Batova River valley is of high economic importance. Located here are the big resort of Albena and other smaller resort settlements. New explorations were carried out in connection with the extension of these resorts. The geomorphological conditions and the origin of the valley are described by Evlogiev (2010) and Evstatiev *et al*. (2010b).

Diatomaceous clays (Euxinograd Formation) are embedded in the base of the valley. On top of them follow aragonite clays with limestone intercalations (Topola Formation). The slopes begin with a steep limestone rock crown (Karvuna Formation) from the edge of the plateau (Fig. 4).

Landslides of the block-type occurred along the slopes (Evstatiev *et al*., 2010a). The space between the blocks was filled with redeposited aragonite clays (Fig. 5). The greater part of the landslides is provisionally stabilized with local revival due to high groundwater level. The main landslide surface passes along the top surface of the clays of the Euxinograd Formation.

Critical sections, where landslide activation is possible, have been established by the slope stability analysis along representative profile lines, taking into account the seismic forces and eventual rising of groundwater level. In 1971, a landslide emerged in one of them, destroying a 150-m long road section to the Golden Sands resort, south of Kranevo (Fig. 4) (Stoykov, 1979). The event was provoked by a failure in the pipeline supplying drinking water. Thereafter, both the road and pipeline were abandoned. Stabilization

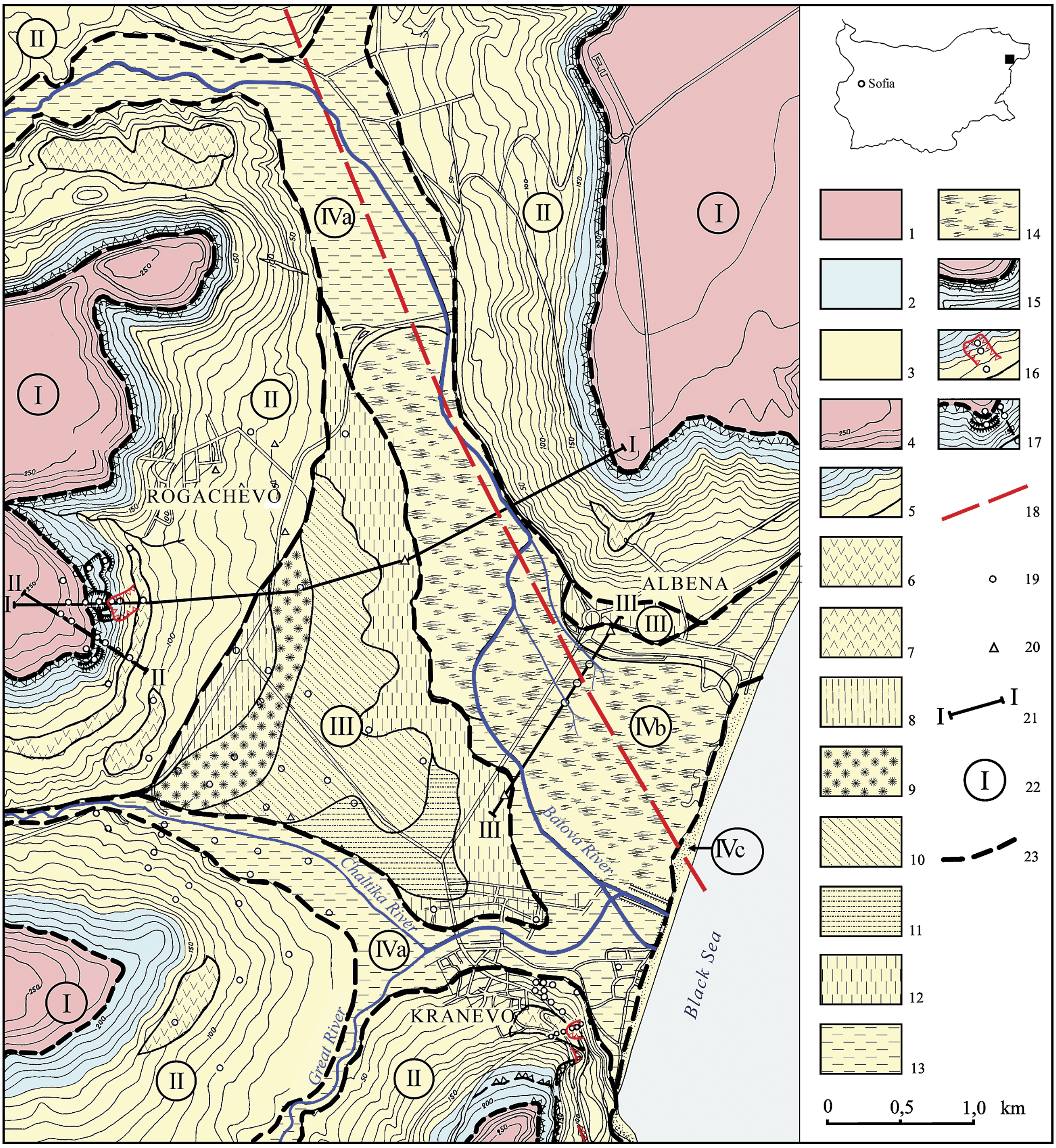


Fig. 4. Engineering geological map of region III (coastal part of the Batova River valley). **1** –limestones of Karvuna Formation (kvN_1^s); **2** – aragonite sandy or silty clays with limestone intercalations, Topola Formation (toN_1^s); **3** – diatomaceous silty clays, thinly lithified, Euxinograd Formation (evN_1^{kg-s}); **4** – Pliocene denudation surface (PDS); **5** – slope; **6** – terrace $T_{120-130m}$; **7** – terrace $T_{84-92\ m}$; **8** – terrace $T_{53-61\ m}$; **9** – terrace $T_{44-46\ m}$; **10** – terrace $T_{33-37\ m}$; **11** – terrace $T_{20-27\ m}$; **12** – terrace $T_{10-12\ m}$; **13** – terrace $T_{2-5\ m}$; **14** – marshland terrain; **15** – oldest scarp; **16** – active landslide; **17** – landslide circus and steps; **18** – presumable fault of Pre-Neogene activity; **19** – borehole; **20** – resistivity survey point -RSP); **21** – profile line; **22** – site; **23** – contour of the site.

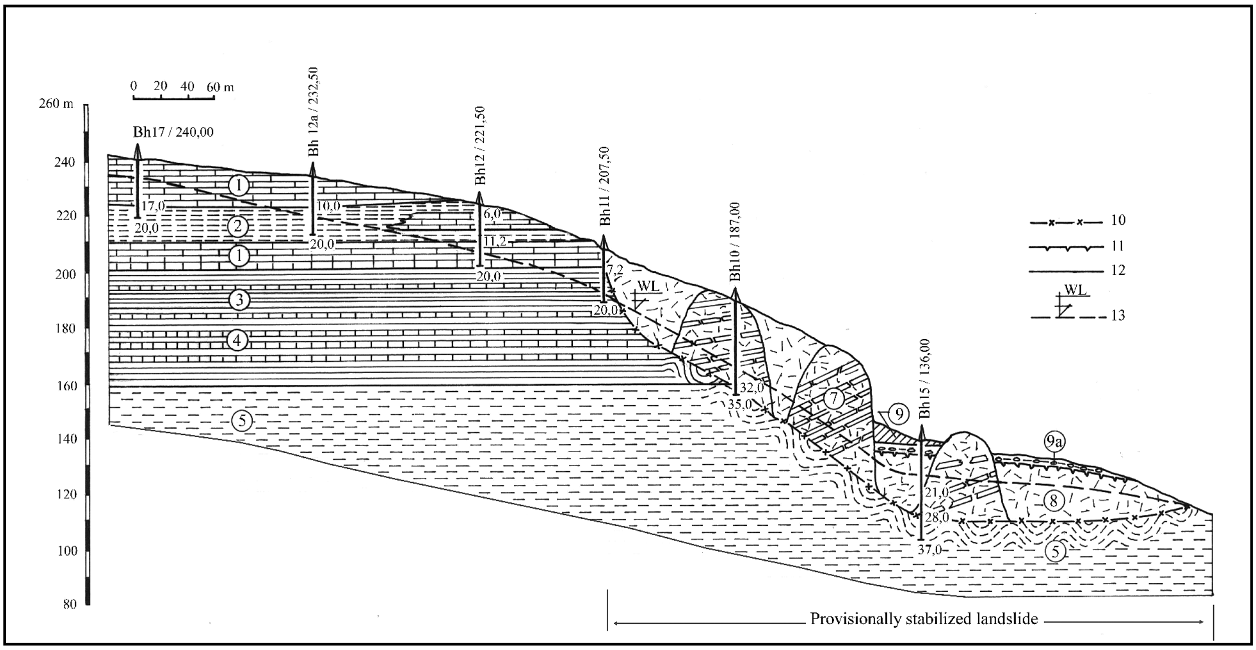


Fig. 5. Engineering geological profile II-II in the western slope of the Batova River valley. Engineering geological varieties from **1** to **8**: Their description is the same as that in Fig. 3. **9** – silty clays, slope embankment; **9a** – alluvial sandy clays with gravel fragments; **10** – sliding surface of an old landslide; **11** – abrasion surface; **12** – lithological boundary; **13** – water level; **Bh** – motor borehole.

was carried out, which included deep drainage, encircling the landslide from the slope side, terracing of the landslide body, removing the sliding masses under the road and their replacement with a well compacted embankment.

The conclusion from the exploration is that the greater part of the landslides are old and stabilized, permitting construction on their slopes after detailed feasibility studies and undertaking of protective measures, the most important of them being to prevent rise of groundwater level.

2.3. Landslides in Topola village area (Region V)

These landslides were divided into 5 sections, named Topola 1 to Topola 5, with an individual report dealing with each terrain (Geological Institute of BAS, 2006[1,2,3]).

A geomorphological map (Fig. 6) and profiles for each section were drawn up. The results of the explorations are summarized in a special study (Evlogiev& Evstatiev, 2013, in print).

[1] Geological Institute of BAS. 2006. Engineering geological report for the preliminary spatial plan of the land estates on terrain 1 of Litex Komers AD near the Topola village, Dobrich district.

[2] Geological Institute of BAS. 2006. Engineering geological report for the preliminary spatial plan of the land estates on terrain 2 of Litex Komers AD near the Topola village, Dobrich district.

[3] Geological Institute of BAS. 2006. Engineering geological report for the preliminary spatial plan of the land estates on terrains 3, 4 and 5 of Litex Komers AD near the Topola village, Kavarna municipality, Dobrich district.

2.3.1. Lower Romanian Level (LRL)

A well pronounced level (plateau) with an absolute height of 155 – 168 m has been formed. The Lower Romanian Level (LRL) has been determined according to geomorphological features and comparative studies (Evlogiev, 2006). The LRL represents the initial relief, where the landslide circuses are formed and the erosion gullies are incised, one of them being the Topola gully.

The surface of the plateau is made up of sediments of the Karvuna Formation – limestones, intercalated with clay. The water level in LRL is found at a depth of 7-8 m from the surface. The aquifer horizon is formed on the clayey intercalation in Karvuna Formation. It is recharged by infiltrated precipitation water. The drainage is in the slope towards the sea and in the Topola gully, where springs with relatively constant flow rate are found.

Compared with other sections the LRL offers the best conditions for construction of buildings and facilities.

2.3.2. Topola 1 Section

This section is located southward of the Topola village and includes the banks of the Topola gully and the remnants of an old marine terrace (Fig. 6). The Topola gully drains the water of a vast catchment area.

Landslides of detrusive type can be observed in the upper end of the steep slopes of the Topola gully. They develop entirely in the Topola Formation, the sliding surface being situated above the erosion basis. Traces of contemporary activity

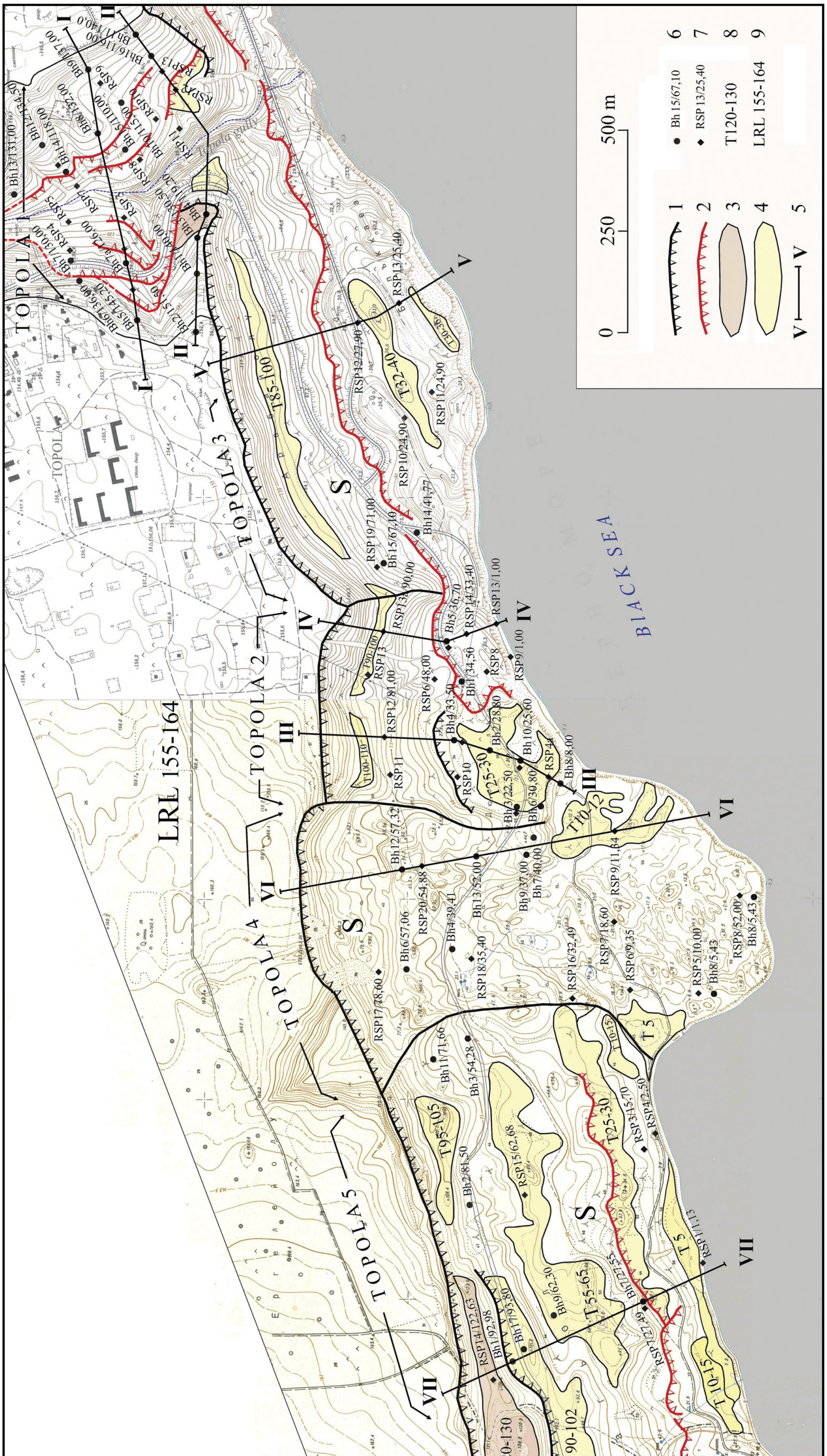


Fig. 6. Geomorphologic map of the landslides in Topola village area (Region V). 1 – high and medium scarp of a provisionally stabilized landslide; 2 – low scarp of an active landslide; 3 – Upper Romanian – Lower Pleistocene terrace level; 4 – Pleistocene terraces; 5 – profile line; 6 – motor borehole No/terrain elevation, m; 7 – resistivity survey point No/terrain elevation, m. Other designations: $T_{120\text{-}130}$ – terrace with an absolute elevation, m; $LRL_{155\text{-}164}$ – Lower Romanian Level with an absolute elevation, m.

can be seen on the terrain surface: fresh landslide slopes and steps, long cracks parallel to the edge of the gully, trees tilted in the direction of sliding, *etc*. Several well outlined landslide steps are seen.

2.3.3. Topola 2 Section

This section comprises a landslide circus with well outlined flanks and a scarp with a height of up to 10 m at the Lower Romanian Level (Fig. 7, Pl. I, Fig. 1).

After the scarp under LRL, the inclination of the slope gradually decreases and relatively well expressed terraces can be observed along it: T_{90-100} and $T_{100–110}$. In its lower part, the slope passes on a plane area, 220 m wide and 450 m long, inclined towards the sea (Pl. I, Fig. 1). Terrace T_{25-30} was formed on the coastal flat area. Several low hills are also observed, which are parallel to the coastline. The slope was made by slid blocks of the Topola Formation and the plane area – on delapsium. These forms are incised by several gullies. The coast is high (up to 40 m) and steep, with a narrow beach, and is strongly affected by marine erosion activity.

In its present outlook, the landslide in Site 2 is a two-storey one (Fig. 7). The sliding surface in the lower part of the circus runs through the sediments of the Euxinograd Formation. At the sea coast, the elevation is -2 to -3 m, and reaches 7 to 10 m at the end of the plain area. Its inclination is 2-3° towards the sea. From here to the upper part of the circus (the high storey), it passes along the top part of the Euxinograd Formation and then crosses the sediments of the Topola Formation.

The slope part of the circus is of interest for resort construction due to its location and existing terrace flat areas, but the exploration data are not sufficient to guarantee its stability (Geological Institute of BAS, 2006[2]).

The slanted plain area in the middle part of the circus has an altitude of up to 47 m at the top of the slope, decreasing to 25-30 m at its lowest part. Most of this flat area includes an old, provisionally stabilized landslide, which shows prominent features of contemporary activity only in its southeastern end (Pl. I, Fig.1).

The plane area is built of delapsive redeposited materials of the Topola Formation, with the sediments of the Euxinograd Formation embedded underneath (Fig. 7). A layer with undulated structure is observed at the boundary between the two formations, formed as a result of the weight of the blocks moving towards the sea.

An aquifer horizon was formed (at a depth of 15-16 m) on the plateau, along the top part of the Topola Formation, its water being discharged in the upper part of the slope. During exploration, a constant aquifer horizon has been identified only in the lower part of the landslide, at a depth from 15 to 22 m. Diatomaceous and marl-like clays are the aquitard of this horizon, which is drained in the sea.

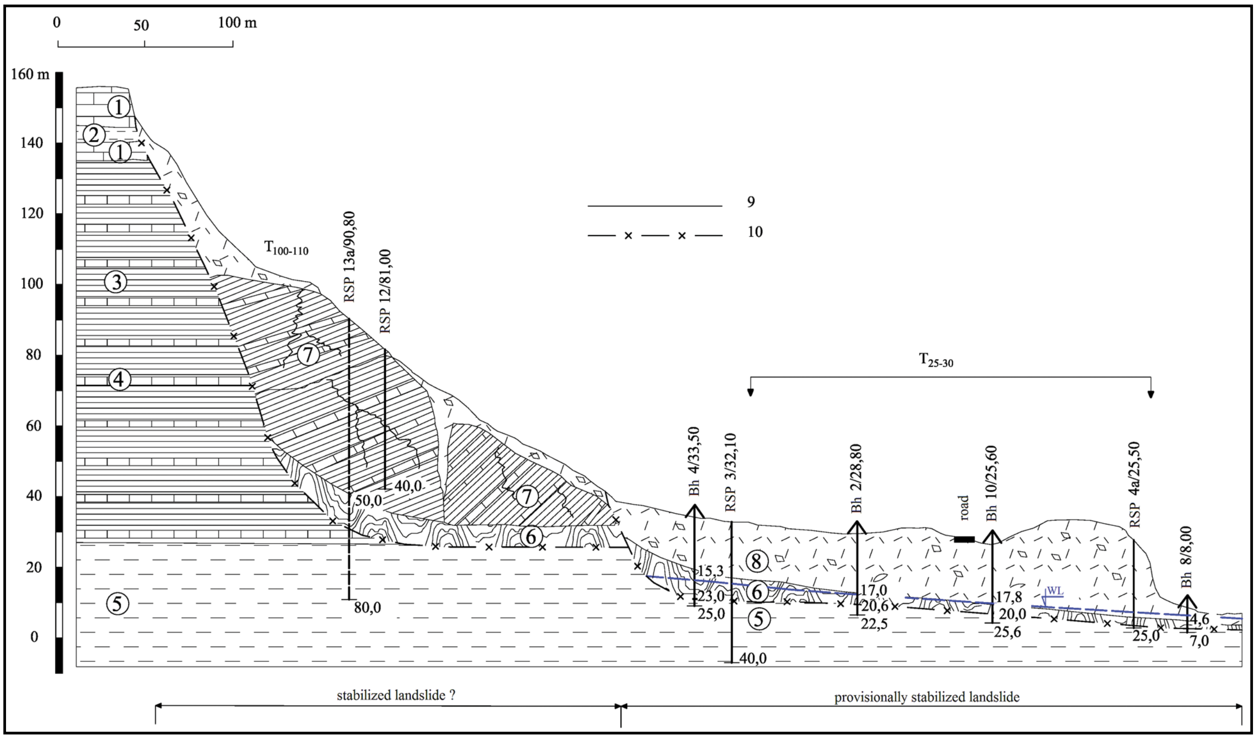
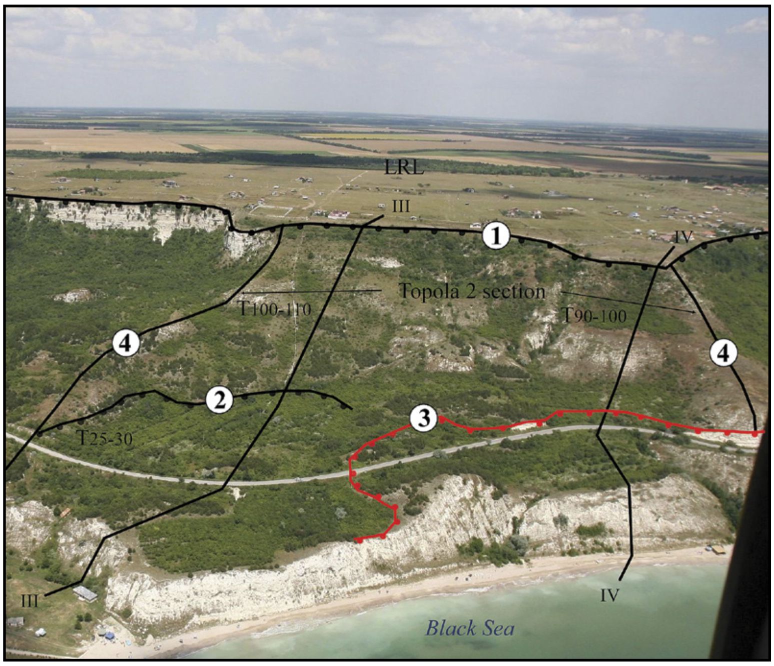


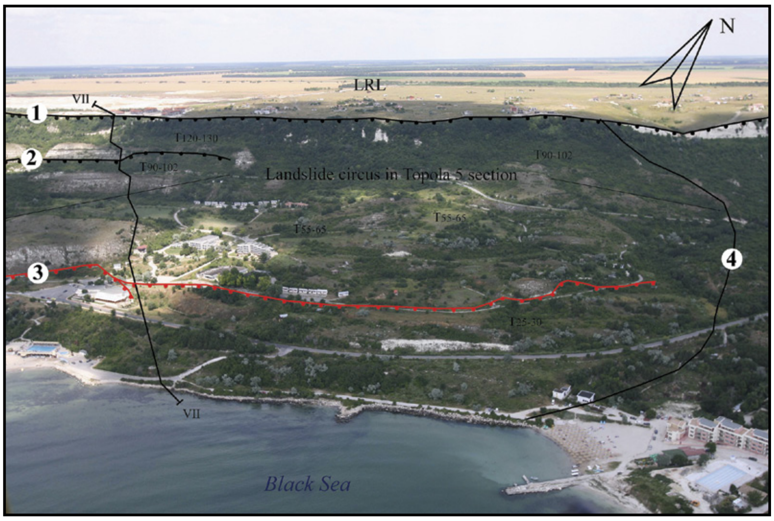
Fig. 7. Engineering geological profile III-III across the Topola 2 section. Engineering-geological varieties from **1** to **8**: Their description is the same as that in Fig. 3. Other designations: **9** – lithological boundary; **10** –rupture surface; **WL** – water level; $\mathbf{T}_{100-110}$ – terrace level at an absolute elevation, m; **Bh2/28,80** – motor borehole No/terrain elevation, m; **RSP 4a/25,50** – resistivity survey point No/terrain elevation, m.

PLATE I



Pl. I, Fig. 1. View of the Topola 2 section: **LRL** – Lower Romanian Level; **1** and **2** – high and low landslide scarp of a provisionally stabilized two-storey landslide; **3** – landslide scarp of an active landslide; **4** – flanks of the landslide; **III-III** – profile line; **T**$_{90\text{-}100}$ – terrace level at an absolute elevation, m.

Pl. I, Fig 2. View of the Topola 3 section: **LRL** – Lower Romanian Level; **1** – high scarp of a provisionally stabilized two-storey landslide; **2** – low landslide scarp of an active landslide; **3** – flanks of the landslide; **V-V** – profile line; **T**$_{85\text{-}100}$ – terrace at an absolute elevation, m.



Pl. I, Fig. 3. View of the Topola 5 section: **LRL** – Lower Romanian Level; **1** and **2** – high and middle landslide scarps of a provisionally stabilized landslide; **3** – low landslide scarp of an active landslide; **4** – eastern flank; **T**$_{120\text{-}130}$ – terrace at an absolute elevation, m; **VII-VII** – profile line.

Conditions for construction in the plain part of Topola 2

As already mentioned, the plain part of the circus represents an old, provisionally stabilized landslide, which has been activated in the southeastern end. This part was divided into two sites: site 1, occupying most of the plain area, where no active landslides occur, and site 2 – with clearly expressed contemporary landslides.

Flat areas similar to site 1 can be observed in other landslides terrains, along the Northern Black Sea coast, and construction has been done on some of them. Due to the unceasing marine abrasion, the landslide processes have not completely faded and are manifested in slow deformation (creep), causing single cracks on building walls.

Stability analyses for the Topola 2 site are carried out along two profiles. The first profile runs across the middle of the site and the second, in its eastern end, across the active landslide. The analyses for the first profile were made according to the method of Shahunyants, and for the second, using the GEOSLOPE software (Geological Institute of BAS, 2006[2]). The analysis along the second profile has shown that the coefficient of slope stability is very low – K_s=0.60.

The analysis for the first profile is made according to two models: Model 1 – assuming activation of the landslide along a unified sliding surface, from the sea to the highest landslide scarp; Model 2 – assuming activation of the landslide only in the coastal flat area.

The main result of stability calculations according to Model 1 is that the slope is in unstable state, taking into account the seismic forces – K_s= 0.78.

If Model 2 is valid (accepting two storied landslide), K_s= 1.25 taking into account the seismic forces and ground water level is raised with 5 m.

We presume that the following considerations should be added to the results of the stability analyses using the two models:

- The geomorphological data excludes the activation of the whole slope along a deep sliding surface, because no traces of activation are observed along the terraces T_{90-100} and $T_{100-110}$, formed on the landslide in the Early Middle Pleistocene;
- The active landslide in the southeastern corner of the circus has a local character and has not provoked horizontal displacements along the slope above it;
- There are data for activation of only one landslide during the big earthquake in 1901 – the Momchil Rid near Balchik. However, it is characterized by hydrogeological conditions rather different from the conditions in the considered circus. The Momchil Rid landslide was revived again in the mid of the 1990s, when a small lake was formed on its uppermost step, *i.e.* in the near-slope part. The displacements were stopped after the water was removed by draining.

The stated facts and considerations provide the grounds to infer that in the present case the more reliable model is the one assuming the formation of a two-storey landslide in the respective circus, with subsequent stabilization of the upper step. Landslide activation could be expected only in its coastal part, mostly under the impact of marine erosion. Slow creep in the flat part of the circus commences under the effect of abrasion. This is evidenced by the flexures along the longitudinal axis of the road in the vicinity of the two borders of the circus.

2.3.4. Section Topola 3

The section comprises the first circus, situated to the west of the Topola Dere gully (Fig. 6, Pl. I, Fig. 2). The circus has well expressed left and right flanks, and is 1000 m wide and 600 m long. To the south, the landslide body enters the sea in the form of a peninsula, its width being reduced by marine erosion.

The slope of the circus has an irregular inclination. It starts from the LRL with a steep gradient from 37° to 45°. Here, the landslide scarp is not well expressed as in the adjacent circus situated to the west. The terrace T_{85-100}, 50 to 100 m wide and with inclination in the range of 10º-15º, follows under the steep part of the slope. After the terrace, the slope becomes steep again.

The coastal plane area represents the low step of the landslide. Narrow strips of terrace levels T_{32-40} and T_{30-38} are established on in it. A well expressed valley-like lowering, probably formed by an old marine arm, can be observed between the flat area and the slope, incised in the landslide sediments up to 25 m elevation. Two rows of steep hills, representing preserved landslide blocks and made of the sediments of the Topola Formation rise between the lowering and the sea (Fig. 8, Pl. I, Fig. 2).

The seacoast is high up to 12 m and is very steep to vertical. The beach is narrow and covered by blockage and gravels, formed by the more stable limestone intercalations of the Topola Formation and the strong limestones of the Karvuna Formation. The coast is subjected to intensive erosion, provoking continuous collapse of earth masses.

The preliminary stability analysis, based on the assumption of a rupture surface from the plateau to the sea, yielded an unsatisfactory stability coefficient K_s, taking under consideration the seismic forces. For this reason, the Section 3 was not recommended for construction.

On the basis of the additional studies, a new work model, assuming that the landslide is a two-storey one, with steps, has been proposed.

The highest landslide scarp had inherited the older one, processing and deepening it. As a result it is not well shaped – it is sub-vertical in the upper 15 m and steep in the follow-

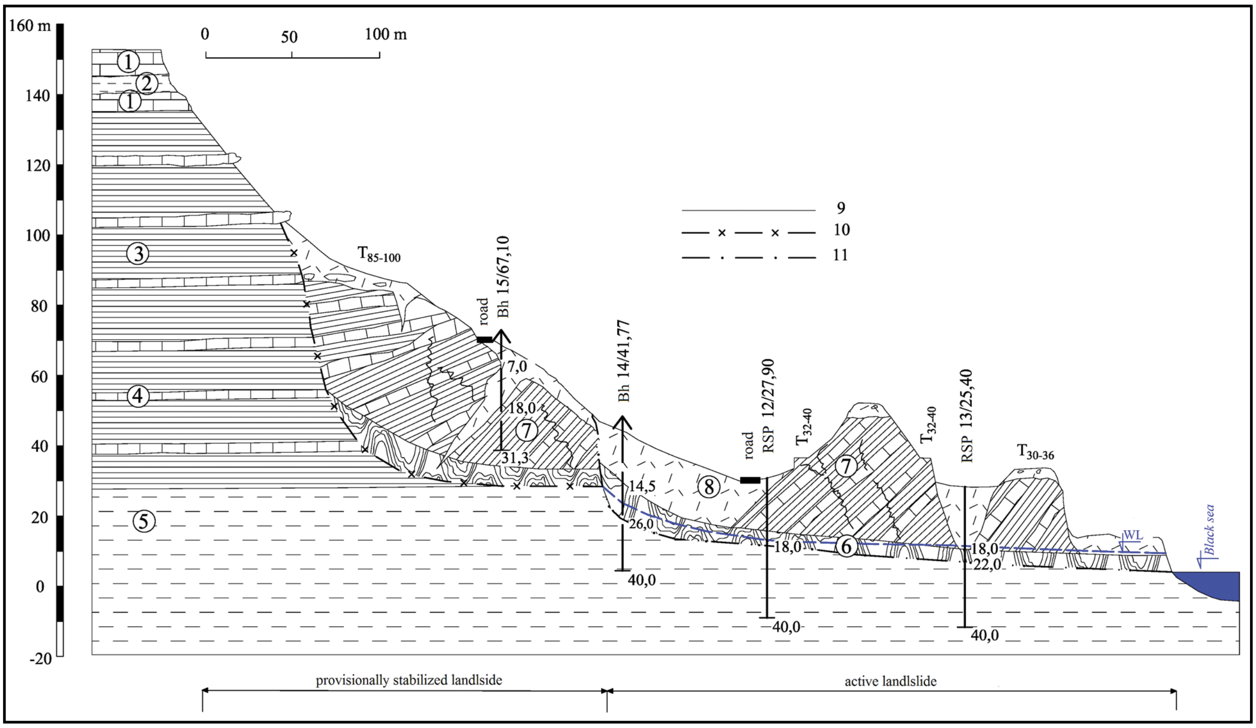


Fig. 8. Engineering geological profile V-V across the Topola 3 section. Engineering-geological varieties from **1** to **8**: Their description is the same as that in Fig. 3. Other designations: **9** – lithological boundary; **10** –rupture surface of a provisionally stabilized landslide; **11** – rupture surface of an active landslide; **WL** – water level; T_{85-100} – terrace level at an absolute elevation, m; **Mb14/41,77** – motor borehole No/terrain elevation, m; **RSP13/25,40** – resistivity survey point No/terrain elevation, m.

ing 40 m. It is outlined in the sediments of the Karvuna and Topola Formations. The sliding surface of the high landslide step starts in the terrace T_{85-100}, and crosses the sediments of the Topola Formation along a rotational surface. Its horizontal section reaches the top part of the Euxinograd Formation at an elevation of 27 m (Fig. 8). The high step is built of slid blocks separated by delapsium, formed by the Topola Formation and clays with a disturbed structure. No traces of contemporary activity are observed on this step. The terrace T_{85-100}, formed on the landslide block, is spatially homogeneous and has been preserved since the Early Middle Pleistocene till now, without visible deformations, providing evidence to consider the landslide as being provisionally stabilized.

The low landslide step includes the terrain of the coastal flat area. Its landslide scarp in the eastern part of the section forms slopes with an amplitude from 2-3 m to 5 m, at the level of contour line 35-40 m (Fig. 8). Its elevation is higher in the western part– 45 m. The sliding surface starts from the scarp and is rapidly transformed from rotational into a horizontal surface inclined towards the sea. It is developed on the Euxinograd Formation, at an absolute elevation from 10 m at the scarp to -5 m at the seacoast. The landslide step is built of preserved slid blocks of the Topola Formation, forming steep hills (Fig.8, Pl. I, Fig. 2). The broad interstitial block spaces are filled with delapsium. This low step appeared in the Late Middle Pleistocene and it is contemporary active due to the intensive marine abrasion.

The terrain of both steps is well drained. The groundwater level is within the sliding zone. The aquifer horizon with low water abundance is recharged mainly from precipitation water along the slope, and the drainage is at the seacoast. The water is captured at some places in the steep cliff base.

More data are necessary to confirm the proposed work model, which is of high interest from the viewpoint of utilizing new terrains. In this context, the following should be pointed out:

The coastal plain area of the landslide is currently active due to intensive marine erosion. If there is one unified rupture surface from the edge of the LRW to the sea, in case of a detrusive landslide, its upper part should be activated, too. Since the latter does not move, the existence of a two-storey landslide with a provisionally stabilized upper storey is more reliable.

The territory of the Topola 3 section was divided into two sites coinciding with the main geomorphological forms. The steep part of the slope to the elevation of 100 m and the coastal flat area are unsuitable for construction. The latter comprises the low step of the two-storey landslide, which exhibits features of contemporary activity. The principal reason for the landslide activation is the intensive marine erosion. It is possible to utilize the coastal flat area for the construction of parks, golf playgrounds and other sport facilities, road infrastructure, *etc*.

2.3.5. Section Topola 4

The third landslide circus (Fig. 6) is known as the Ikantalaka locality. Its geomorphologic specific features, as well as the history of the homonymous landslide, are considered by Evstatiev and Evlogiev (2007). They are presented here in a concise form.

The width of the circus in its upper part is 750 m and the length is 1200 m. In the middle the circus narrows to 500 m, afterwards broadening in a fan-like manner and entering the sea in the form of a peninsula, with larger dimensions in the past. The following geomorphologic forms are observed in Topola 4 site:

- The Ikantalaka landslide is a seismic-gravitational landslide-torrent, developed on the background of an older block landslide. The landslide has a unified sliding surface and is considered to be a provisionally stabilized one;
- *The slope* comprises the zone from the edge of the rock crown to the contour line 15-20 m (Fig. 9). The main scarp is almost vertical with a height up to 50 m. The slope is steep from the rock crown base to contour line 80-90 m, then it is steep to slanting at some places to contour line 60 m, and thereafter it has an inclination of 8-12° to contour line 20 m. The surface is uneven, with irregularly distributed hills of various heights, with valley-like lowering between them. A dense network of gullies and ravines is formed between the hills, along which surface runoff occurs;
- *The coastal hilly flat area* includes the fan-like low part of the circus and the peninsula formed by the landslide. The inclination of its surface is about 5-6°. Small hillocks are scattered in the area – remnants of slid blocks, the levels between them being filled with delapsium. The terrain here was leveled during the contemporary construction works and the natural valley network, draining the surface runoff, was annihilated. A Karangatian 10-12 m high terrace is outlined in the eastern end of the coastal flat area;
- *The seacoast* at the Ikantalaka peninsula has no beach and is interspersed with limestone fragments, remnants from the landslide subjected to marine erosion. The slope at the seacoast exhibits blocks and fragments of the Topola and Euxinograd Formations, the interstitial spaces between them being filled with aragonite clays.

The exploration provides evidence that the main rupture surface (zone) crosses the Topola Formation along a rotational surface, passes along the top part of the Euxinograd Formation, entering it near the sea at an elevation of -9 m. In the upper part of the circus, it is situated at a depth of 40.0 m from the surface and at 15.0-20.0 m in the lower part. As in the other sections, the sliding zone is built of clay with undulated structure. Its thickness in the high part of the landslide is 18-20 m. This thick smashed zone was formed by the passing massive blocks, broken off the plateau, which, under the conditions of a "landslide-torrent", reached the peninsula and far inside the sea, and were crushed into smaller blocks and fragments.

The landslide body has a complex structure. Apart from the basic sliding surface, more shallow sliding surfaces are observed in some of the boreholes, which cross the slid materials of the Topola Formation.

In the eastern part of the terrain, the groundwater level is in layer 6, and, in the middle and western part, it is above layer 6. Its depth is variable due to the uneven surface of the terrain, fluctuating between 15 and 30 m. Water was pumped from borehole Mb4 (Fig. 6) with a flow rate q=10 l/min for 35

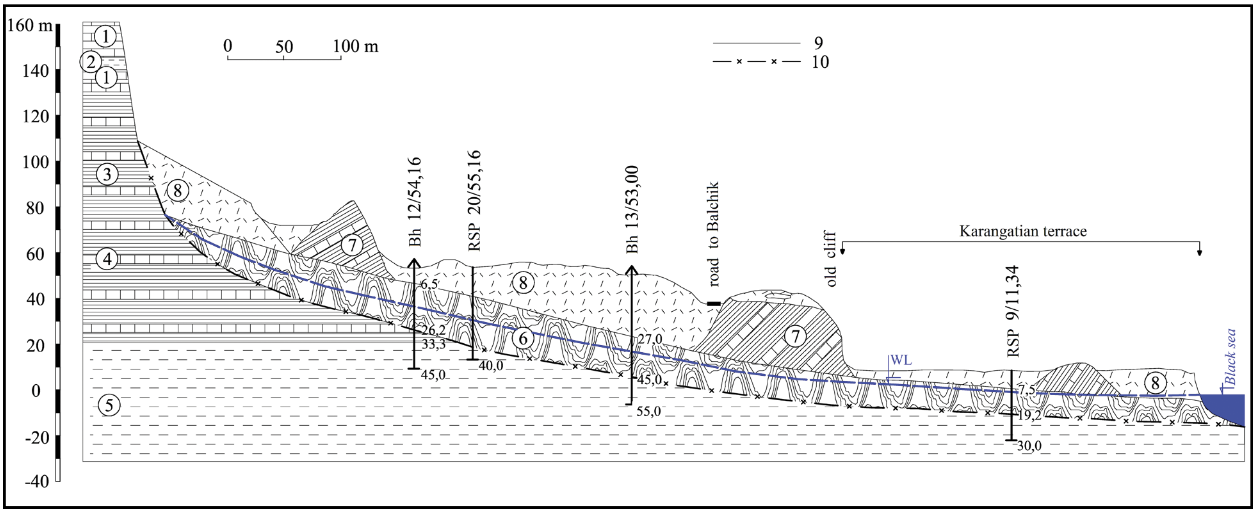


Fig. 9. Engineering geological profile VI-VI across the Topola 4 section. Engineering-geological varieties from **1** to **8**: Their description is the same as that in Fig. 3. Other designations: **9** – lithological boundary; **10** – rupture surface; BH – WL; $\mathbf{T}_{10\text{-}12}$ – terrace level at an absolute elevation, m; **Bh13/53,00** – motor borehole No/terrain elevation, m; **RSP 9/11,34** – resistivity survey point No/terrain elevation, m.

min, and the water level descended with 3.5 m, *i.e.*, it changed from 16.50 m to 20.00 m. The borehole diameter was ϕ127 mm. These data show that the aquifer horizon has low water abundance and low filtration coefficient.

The following inferences can be made for the engineering geological conditions in the Topola 4 site:

- The landslide potential of the lower plain part of the circus (below the contour line 15-20 m, with inclination of up to 5-6°) has been exhausted to a significant extent. The building of groins played an important role for halting marine erosion;
- The issue of predicting the stability of the steep terrain above the road to Balchik above the 60 m contour line (Fig. 9), where the relief forms exhibit features of recent landslide activity, is more complicated;
- The geological model of the considered landslide terrain is in a process of development. Deformations of the pavement can be observed along the road to Balchik in the immediate proximity of the left and right flanks, which indicate probable creeping of the landslide body towards the sea. The extent of this creep and its dependence on the groundwater level can be determined using geodetic benchmarks and measurements in piezometric wells, but for the time being there has been no financial support for these activities.

Engineering geological zoning was made and two sites were specified – a slope and a coastal flat area. Certain zones were identified in the slope, where, after additional explorations, it could be possible to carry out low-rise and infrastructural construction. The coastal flat area offers better conditions, and numerous hotels and other resort facilities have been already built here.

2.3.6. Section Topola 5

This section also comprises a landslide circus. Its western flank is not shown in the geomorphological map (Fig. 6). The circus at the highest landslide scarp has a significant width, reaching up to 1800 m and a length of 600-700 m (Fig. 6, Pl. I, Fig. 3). Four big step-wise landslide packs are observed in the western half, built of the sediments of the Topola Formation. Flat areas with features of marine terraces are situated on the steps. A three-storey landslide is formed in the circus.

The high part of the slope includes the uppermost scarp, the terrace $T_{120-130}$ and the steep slope to the next terrace (Fig. 10). They belong to the high step of the landslide, built of slid blocks of the Karvuna and Topola Formations. The middle part of the slope is formed by landslide blocks and plain areas between them, building the middle landslide step. Two marine terraces are distinguished here. The higher terrace T_{90-102} forms a strip with a length of 600 m and width of 100 m, in the western part, which narrows to the east, and after a break forms a small spot (Figs. 6 and 10, Pl I, Fig. 3). The next terrace T_{55-65} can be observed in the middle and western part of the site. It has an irregular shape, with 50-150 m width and 870 m length. The middle step of the landslide emerged during the Early Middle Pleistocene (according to dating of the Chaudian terrace T_{90-102}).

The low landslide step starts from the lower landslide scarp, formed at an elevation of 30-35 m. It is built of slid blocks and delapsium. The terraces T_{25-30} and T_{5-10} are also cut into the landslide slope (Fig. 6). The first one is spatially more homogeneous, 50-80 m wide and 650 m long. The next terrace forms small spots in the lower part of the slope.

The seacoast has a narrow beach, above which is the Holocene terrace T_5.

The drainage of surface water in the site occurs *via* several shallow gullies.

The geological and geomorphological structure of the western half of the terrain is rather different from the eastern one (Fig. 6, Pl. I, Fig. 3), a difference reflected in its engineering geological conditions. Here, the movement of the big blocks, observed in the upper part of the slope, is not so pronounced as on the other terrains. The cause is probably the smaller influx of groundwater from the high slope. The water table is at a depth exceeding 36 m from the surface.

The three-stories landslide has well expressed high, middle and low scarps. The sliding surface of the high step crosses the Topola Formation along a rotational surface, which is at an elevation of 70 m in its horizontal section.

The middle step occupies the largest area. Its sliding zone has the same geometry as that of the higher step, but the horizontal section is considerably longer and penetrates in the top part of the Euxinograd Formation to an elevation of 10 m. The water level, between the landslide blocks, in the delapsium, is at a depth of 22 m.

The upper two landslide steps are assumed to be stabilized or provisionally stabilized. Contemporary movements have been registered in the low step, its landslide scarp starting from the contour line 30-35 m. Its sliding surface at the seacoast reaches the Euxinograd Formation, at an elevation -5 to -7 m (Fig. 10).

Engineering geological zoning and preliminary stability analyses were made for that slope (Geological Institute of BAS. 2006[3], Evstatiev& Petrova, 2006). The combined influence of groundwater level rising and of the different degrees of seismic intensity was studied. It has been established that at present the slope is in an equilibrium state, which can be altered by the rise of the groundwater level and/or seismic impacts.

Except for the results of the stability calculations, the assessment of the suitability of the considered section for construction takes into account the following geomorphological and engineering geological conditions:

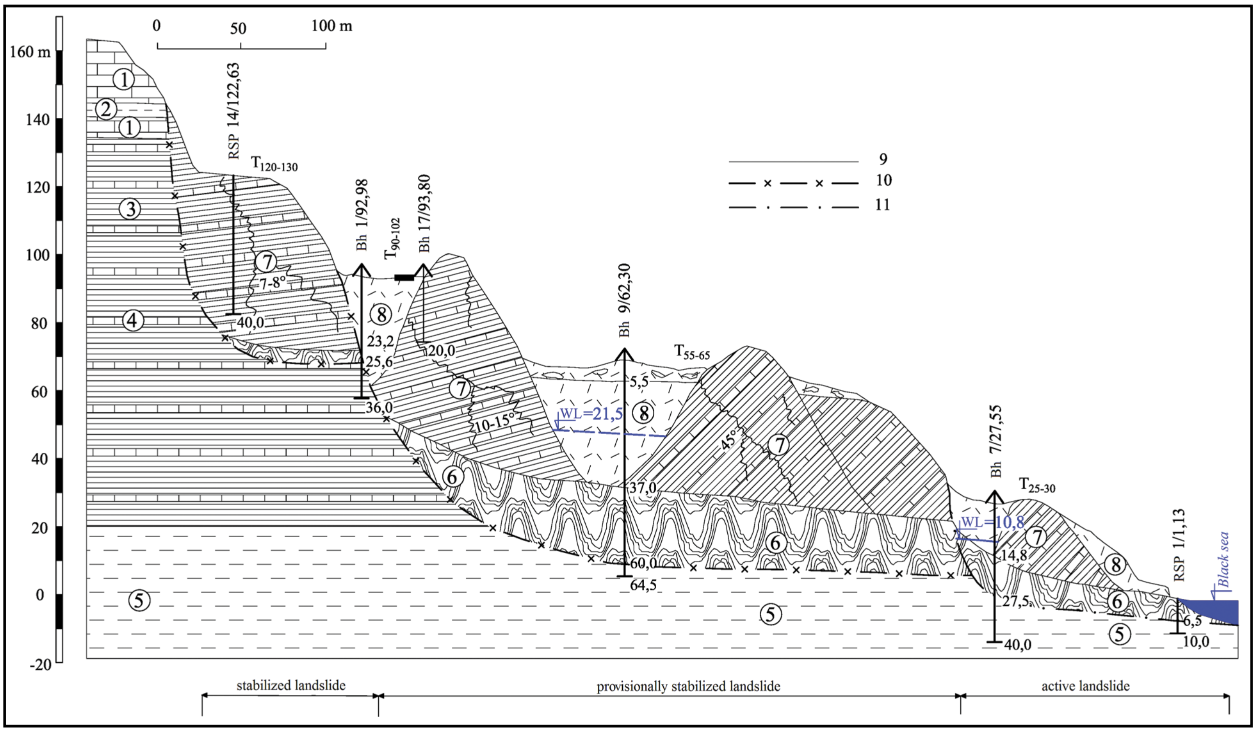


Fig. 10. Engineering geological profile VII-VII across the Topola 5 section. Engineering-geological varieties from **1** to **8**: Their description is the same as that in Fig. 3. Other designations: **9** – lithological boundary; **10** – rupture surface of a stabilized and provisionally stabilized landslide; **11** – rupture surface of an active landslide; **WL** – water level; **T_{25-30}** – terrace level at an absolute elevation, m; **Bh9/62,30** – motor borehole No/ terrain elevation, m; **RSP14/122,63** – resistivity survey point No/terrain elevation, m.

- The existence for hundreds of thousands of years of the above mentioned old marine terraces, formed on the middle and high landslide steps, permits to assume that these steps belong to old stabilized landslides;
- The high landslide step has been preserved in the studied section. Only here it has three storeys, while in the neighbouring circus the high storey had been processed by the following landslide cycle during the Early Middle Pleistocene, and hence two-storey landslides were formed. The landslide blocks in the Topola 5 section remained in the upper part of the slope, which proves that its stability is relatively higher here;
- The sliding surfaces of the three steps (storeys) are at different levels and, according to the data on our disposal, seem to have no connection with each other. The stabilization of the seacoast with groins (Pl. I, Fig.3) had contributed to the increase of the stability coefficient of the low step, whose equilibrium was disturbed by the active marine abrasion. Hotels and other facilities were built above it and no deformations due to horizontal displacements were observed in them.

3. PHYSICAL AND MECHANICAL PARAMETERS OF THE SOIL VARIETIES

The most typical feature of the lithological structure of the considered regions is their vertical inhomogeneity. Frequent alternations have been observed on both macro and micro level of layers, along with intercalations of hard limestone rocks, soft limestones, sands or special soils as, for example, the rarely encountered aragonite and diatomaceous clays. All this hampers field and laboratory research and, especially, the development of the models for slope stability calculation. These difficulties were largely overcome in the studies by applying precise documentation in the *in situ* explorations, by drilling dozens of boreholes, investigating hundreds of samples and back analysis based on data for high vertical slopes.

Boreholes logging and the physical and mechanical parameters of the soil varieties have been described in the cited reports and papers. Here, a brief soil mechanical characterization will be given only for the varieties 3 – aragonite clays, 5 – diatomaceous clays, and 6 – the smashed zone between Topola and Euxinograd formations, which are the most important from the landslide point of view.

Variety 3. The aragonite clays of the Topola Formation are embedded under the Karvuna Formation. Their thickness varies from 30-40 m in regions III and IV to 110 m in region V.

The clays are silty and consist mainly in whitish thin-stripped aragonite clays with laminations of grey fine-layered clay (Pl. II, Fig. 1). The clays are intercalated with strong carbonate stacks, with a thickness of up to 1 m, at a distance of 5-10 m between each other. The water content *w* of the aragonite clays is very high – between 40 and 60%. They have

PLATE II

Pl. II, Fig. 1. Drill-core of aragonite clay: The fine horizontal lamination is clearly seen.

Pl. II, Fig 2. Drill-core from the diatomaceous clay of Euxinograd Formation.

Pl. II, Fig. 3. Smashed clay with undulated structure from the main rupture zone predominantly a firm consistency, but single, isolated layers, with soft consistency, appear, too. It should be noted that the outlook of the aragonite clay drill-core seems dry, but it becomes softer when manually vibrated, with water appearing at the surface. This is an indication that this clay is prone to liquefaction under dynamic impact that could be provoked by seismic forces.

The aragonite clay is characterized by low density – dry density ρ_d = 1.25 g/cm^3, void ratio e = 1.24, degree of water saturation Sr = 0.98, and the following shear strength parameters: cohesion (peak value) c^I = 29.0 kPa; angle of internal friction (peak value) φ_I = 16.5°; cohesion (residual) c_r = 17.1 kPa; angle of internal friction (residual) φ_r = 12.8°.

Since the shear strength of the whole massif, unaffected by sliding, depends not only on the aragonite clays, but also on the carbonate stacks reinforcing them, back analysis has been applied for its determination. The yielded results have been c^I = 71.00 kPa for cohesion, and φ^I = 25.00° for the angle of internal friction.

Variety 5. It is represented by the sediments of the Euxinograd Formation. Within the range of the Pliocene plane area and the Lower Romanian level, the surface of variety 5 has an inclination of 2°-3° towards the sea. Its thickness reaches up to 100 m. The base of this variety is built of slightly cemented grey sandstones with thin clayey intercalations. Higher up the sandstones gradually turn to diatomaceous clays with fine sand layers. The diatomaceous clays have a typical fine laminated texture, in which lighter and darker strips can be distinguished (Pl.II, Fig. 2). The lighter strips represent clayey sand cemented with calcareous substance, and the darker ones are marl-like clays, with a high amount of skeleton remains from diatomites and spongolites.

The diatomaceous clays are characterized by ρ_d = 1.37 g/cm^3, w = 34-35%, and e = 0.99. They have stiff consistency. Their shear strength is rather variable in depth because their top part is weathered. The samples are tested in direction parallel or perpendicular to their lamination surfaces. The following shear strength parameters are used in the stability analyses: cohesion – c^I = 149 kPa; c_r = 13 kPa; φ^I = 23,20°; j_r = 15.90°. The average compressive strength of samples from the drill-core is R_c = 2.05 MPa.

As already mentioned, layers of grey-black organic clay with almost unnoticeable horizontal stratification are encountered in the Euxinograd Formation . Their thickness varies from several tens of centimeters to 5 m. These strata have firm consistency and are weaker than the layers of diatomaceous clay below and above them: dry density ρ_d = 1.26 g/cm^3, void ratio e = 1.17; c^I =32,2 kPa; c_r = 12.1 kPa; φ^I = 23.8°; j_r = 17.8°.

Variety 6. It represents the rupture zone formed of smashed clay with undulated structure (Pl.II, Fig. 3), which is result of the pressure of the blocks of Topola Formation (height up to 100 m) sliding onto the surface of the Euxinograd Formation. Its thickness is between 3-4 and 38 m. The ground water level is very often present in this zone. It has the next soil mechanics parameters: ρ_d = 1.33 g/cm^3 ; w = 39.9 %; Sr = 0.97 and e = 1.12; c^I = 48.2 kPa; c_r = 22.3 kPa; φ^I = 21.4°; j_r = 17.3°.

4. CONCLUSIONS. GEODYNAMIC DEVELOPMENT OF THE REGION AND ORIGIN OF LANDSLIDES

The contemporary aspect of the Black Sea coast in the studied area was shaped by a number of processes and events during the Pliocene and the Quaternary, which had destructive (marine erosion, landslide formation) and creative (terrace formation and deposition) effects.

The cited more recent investigations cover the history of landslide formation in the region and present a new model for regions II and V, including the presence of stored landslides. Here, an attempt will be made to explain this phenomenon with the paleogeographical evolution of the basin.

Paleogeographical circumstances

The cyclic climate changes during the Pliocene-Quaternary provoked the alternation of regressions and transgressions in the Black Sea basin. The Black Sea had been repeatedly isolated from the Mediterranean Sea and connected with the Caspian Sea, which had caused the periodic interchange of the molluscan faunas (Caspian brackish water with Mediterranean-halophilic; Shopov, 1991). The first marks the regressive phases in the Black Sea, and the latter – the transgressive one, with the inrush of Mediterranean water *via* the Bosphorus.

During the regressive sea level, the coastline was subjected to erosion, the gullies became deeper, the relief was strongly dismembered and the groundwater level descended. The subsequent transgression exerted pressure on groundwater and its level rapidly ascended. Under these conditions, gravitational landslides occurred in some sections along the dismembered relief. A large part of them were subaqueous, for example the landslide in the Ikantalaka locality (Evstatiev&Evlogiev, 2007). Their formation was enhanced by the existence of the Miocene sediments, easily washed away. This process has been occurring in a cyclic manner since the Pliocene to date, the older landslides being often reprocessed by the younger ones.

During the maximum of transgressions, the Black Sea level was close to the contemporary one. The coastal terrace levels (Pliocene and Pleistocene) were formed on top of the delapsium at that time. They rose to the present high elevations as a result of terrain uplifting.

Main landslide stages

Four main landslide stages have been established in the regions I to VI as a result of dating the marine terraces: Dacian

– Early Romanian; Late Romanian – Early Pleistocene; Early Middle Pleistocene; Late Middle Pleistocene till now.

Each of these landslide stages has manifested under conditions of sea level rising (after regression), the landslides probably occurred under water, and maybe under seismic impacts, too, modeling the respective landslide step. They are at the present height as a result of terrain uplifting. The highest/top storey is usually of the block-type.

The next storey was developed at a lower level, under similar conditions. Four landslide steps could emerge in this way, but often some of them reprocessed the older ones.

Relation between the initial relief and the number of landslide storeys

The number of landslide storeys depends on the age of the initial relief, in which they were formed. Four landslide storeys could develop only in the massif of the Pliocene denudation surface – during the whole Pliocene and Quaternary. Within the range of the Lower Romanian level the maximum number of landslide steps could be three. They have been formed since the Late Romanian to date. The geological chronicle of the events is not always complete in nature. Often one or two landslide steps are missing due to their reprocessing by the subsequent landslide process.

In region II (Kranevo-Panorama), the Pliocene denudation surface was the initial relief for landslide formation. Investigations (Evlogiev& Evstatiev, 2012) proved the existence of three preserved landslide storeys, formed during the Dacian - Early Romanian, Early Middle Pleistocene and Late Middle Pleistocene stages to present. The landslide steps have separate sliding surfaces and not a common sliding surface as presumed earlier.

The landslide near the Rogachevo village, from the mouth of the Batova River valley (region III), was also developed in the massif of the Pliocene denudation surface. A Black Sea bay existed there, which retreated towards the present-day coastline during the Pleistocene. The landslide has only one storey (Late Romanian - Early Pleistocene), because of the attenuating marine erosion during the Pleistocene. The higher storey was reprocessed.

In region V (Topola village), four landslide circuses were formed in the massif of the Lower Romanian level. In the westernmost circus, the landslide is with three storeys (Late Romanian - Early Pleistocene, Early Middle Pleistocene and Late Middle Pleistocene to date). The landslides in the other circus have two storeys, the highest one being reprocessed during the subsequent landslide stage.

Further evidence of the validity of the new geological model

The new geological model presented for the storey-character of the landslides is confirmed by the following additional arguments:

- In region II, the sediments of the Euxinograd Formation, with well pronounced horizontal stratification, have been outcropped in the second landslide scarp, located to the west of the Golden Sands – Kranevo road. The top part of the formation is at an elevation of 160 m, as along the slopes of the Batova River valley (region III). This proves that in this case no landslide block with a deep sliding surface exists, but a natural terrain, which is broken off from the landslide scarp of the Early Middle Pleistocene landslide;
- Another evidence for the absence of a deep united sliding surface is the existence of stabilized old landslides (third storey), provisionally stabilized (second storey) and currently active (lower storey) landslides. If a deep sliding surface did exist, with the continuous marine erosion, all of these landslides would have become active to a greater or lesser extent. The activity of the landslides has been well explained by the presence of individual surfaces, not connected with each other, only in the coastal zone;
- The type of the landslides provides another evidence of the stage character of their development. The Pliocene stabilized landslide is of the block-type. The blocks had not been destroyed by later landslide events. The landslides of the middle and low storey are delapsive – the blocks of older landslides have been reprocessed.

In conclusion, the major factors for the origin of landslides are: the eustatic fluctuations of the sea during the Pliocene and Pleistocene, the constant uplifting of the dry land, the relatively high slope inclination, the high seismicity (IX degree according to the MSK scale), and the actual anthropogenic activity. The lithological-stratigraphic structure of the Sarmatian sediments is an important prerequisite for the slope instability.

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