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Technologies for monitoring the activity of exogenous and endogenous processes of the black seacoast within the Krasnodar territory using the method of photographic analysis

Tecnologías para monitorear la actividad de los procesos exógenos y endógenos de la costa negra dentro del territorio de Krasnodar utilizando el método de análisis fotográfico

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ABSTRACT

Morphometric, morphographic, and structural analysis should be combined since orographic features directly reflect the tectonic structure of the territory. In the study, the authors supplemented these types of analysis with the photograph analysis method which allowed them to study the relief of the coastline better. The results of the analysis showed that the close contact of the Caucasus mountain system with the Black Sea and the high dissection of the relief predetermined the intensity of economic activity on the coast. This makes it necessary to constantly monitor the activity of exogenous and endogenous processes, in particular, seismic activity, to prevent their adverse manifestations.

Keywords: tectonic structure, economic activity, seismic activity.

RESUMEN

Se debe combinar el análisis morfométrico, morfográfico y estructural ya que las características orográficas reflejan directamente la estructura tectónica del territorio. En el estudio, los autores complementaron este tipo de análisis con el método de análisis de fotografías que les permitió estudiar mejor el relieve de la línea de costa. Los resultados del análisis mostraron que el estrecho contacto del sistema montañoso del Cáucaso con el Mar Negro y la alta disección del relieve predeterminaron la intensidad de la actividad económica en la costa. Esto hace necesario monitorear constantemente la actividad de los procesos exógenos y endógenos, en particular, la actividad sísmica, para prevenir sus manifestaciones adversas.

Palabras claves: estructura tectónica, actividad económica, actividad sísmica.

1. INTRODUCTION

The main orographic units of the territory of the Black Sea coast are the local ridges of the Main Caucasian Range and the Southern Lateral Ridge, interconnected with each other by bridges and cut by numerous erosive forms: gorges, canyons, and cracks, as well as larger valleys of the Mezyb, Vulan, Shapsukho, Psebe, Psezuapse, Shakhe, Sochi, and Mzymta rivers (Nesmeyanov, 1992). The territory is characterized by a general increase in elevation in the eastern direction. Roughness is also increasing. A characteristic feature of the morphostructures of the coastal zone is clustering, which can be traced in several places (Krivorotov et al., 2021; Antipceva et al., 2019).

In general, one can mostly note such structures as horsts and grabens, isolated by hade faults, as well as brachyfolds and flexures. The coastal zone is a complex of accumulative forms in the form of artificial beaches belonging to the main resorts (Volkova et al., 2022). Accumulative areas alternate with active abrasive ones. The shore has been transformed throughout by passive hydraulic structures for its stabilization (sea walls, breakwaters, wave cutters, wing dams, rockfill blankets). The composition of the beaches is mainly macrofragmental (with gravel and pebbles), except for sand and shelly ground in the Anapa area.

2. METHODOLOGY

The study was conducted on a part of the Black Sea coastline from the Kerch Strait to the southern border of the Krasnodar Territory, Russia in 2021 (figure 1).

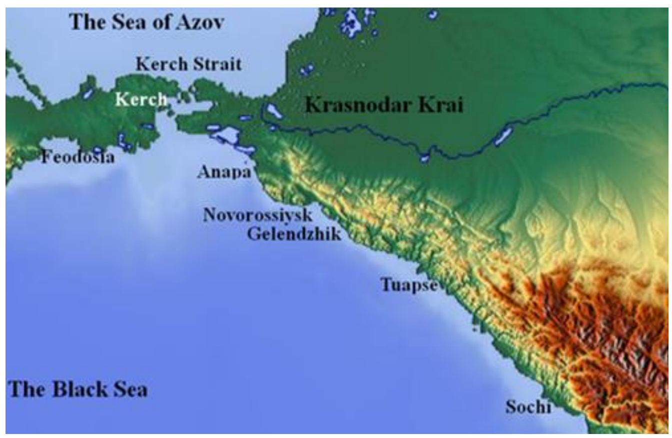
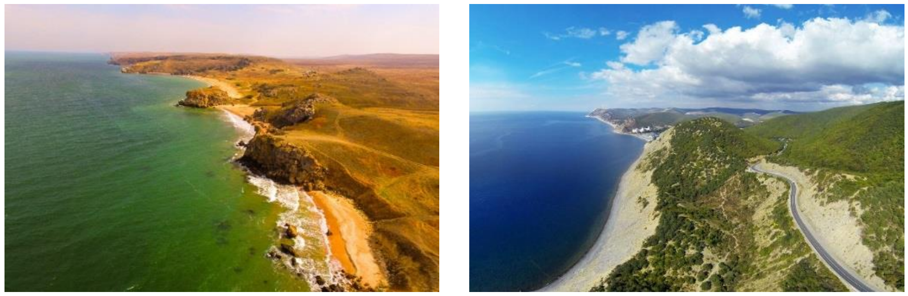


Figure 1. Studied territory of a coastline from the Kerch Strait to the southern border of the Krasnodar Territory

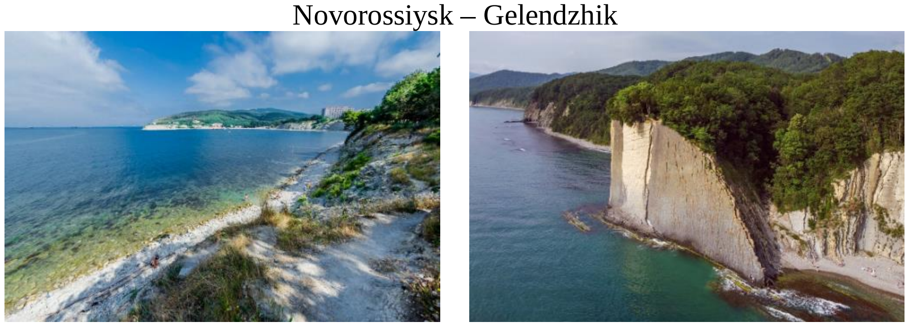
To characterize the Black Sea coast, the main methods we used were the general scientific methods of description, comparison, and analysis and some special ones. These methods helped us to get a holistic view of the morphology of the territory. To visualize the results of the textual material, we used the cartographic method which implies drawing up an orographic scheme of the territory. To do this, the territory was analyzed according to the main hypsometric indicators (maximum, minimum, average height), the excess of watersheds over valleys, etc. We determined the orographic units of the highest rank (mountain ranges, massifs, intermountain valleys), their elevations, direction, stretch, and linear dimensions, as well as the complexity of morphometry, in particular, the shape and nature of the slopes and their steepness. All these features were mapped with mandatory reference to residential places.

In the study, we used the photograph analysis method (Vagizov et al., 2017). Using the photo viewing window, the user selected the area on which the terrain relief had to be determined. To increase the clarity of the image, filters were applied to highlight the contours. Next, the image was segmented, that is, the areas that were similar in some way were selected. After that, we created a database of standards for each segment. To do this, a sample of 124 reference images with a size of 32×32 pixels from the studied image was created. The recognition algorithm was written in JavaScript, and a MySQL database was used to store the standards and recognized objects. For the algorithm to work, the operator set the critical value of the coincidence coefficient. The efficiency of the algorithm was affected by the following parameters: image size, the size of the reference image matrix, and the detail and resolution of the image. Therefore, based on these parameters, a critical value had to be selected rationally.

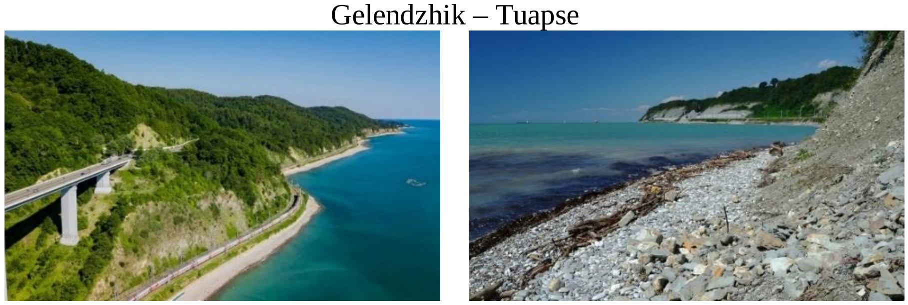


Kerch Strait – Anapa　　Anapa – Novorossiysk

Novorossiysk – Gelendzhik



Gelendzhik – Tuapse



Tuapse – southern border of the region

Figure 2. Studiued relief of the coastal zone

Studying the relief of the coastal zone helped us to make an assumption on which path development was taking place. When analyzing the data obtained, we analyzed the coastal forms in the studied areas. The study of the Black Sea coast allowed us to observe the complexity of abrasion processes, draw conclusions about their intensity, and trace the history of basin development by analyzing sea terraces.

3. RESULTS AND DISCUSSION

The shores of the Black Sea are subject to abrasion almost throughout, except for local areas (Table 1).

Table 1. Typification of the shores of the Black Sea within the Krasnodar Territory

Segment of the coastal strip	Type of beaches	Type of shores	Shoreline length
Kerch Strait – Anapa	Pebble (from cape Panagia to cape Zhelezny Rog) Sand and shell (along the Kuziltash group of estuaries) Sandy (near Anapa)	Mostly flat, at cape Zhelezny Rog rocky, precipitous	133.2 km
Anapa to Novorossiysk	Sandy, pebbly	Abrasive and landslide-prone with shore stabilization structures	68 km
Novorossiysk to Gelendzhik	Gravel and pebbles	In Novorossiysk Bay, there are abrasive and landslide-prone shores with shore protection structures, after that rocky ones, and near Gelendzhik steep	38.8 km
Gelendzhik to Tuapse	Gravel and pebbles, sandy near the village of Dzhubga	Rocky with sections of boulder-block heaping (before the village Dzhanhot and on the segment from Arkhipo-Osipovka to Olginka), otherwise rocky	111.2 km
Tuapse to the southern border of the region	Gravel and pebbles	Abrasive with shore stabilization structures (largely man-made)	145 km

The beaches of Anapa stretch in a continuous strip for almost 40 km, and their width reaches 200 m. They are unique in their constituent material (mainly due to the smallest fragments of seashells). Along the Black Sea coast, the beaches have an average width of 5-7 m. The material is usually represented by a heterogeneous mixture of stone fragments. Relatively wide beaches have become widespread only in the concavities of the coast. Surface wash is represented here by more rounded and sorted material. The only stretch of quartz sand beach is located in Pesochnaya Bay to the southeast of Dzhubga. The presence of large masses of this material here is associated with the destruction of powerful sandstone layers in the coastal cliff and at the bottom (around the Orlenok camp). Between Anapa and Tsemesskaya Bay, there is a relatively large ledge in the form of the Abrau Peninsula with high cliffs and a densely dissected coastline. The erosion gives a relatively large amount of detrital material, from which beaches up to 20-25 m wide are formed. There is a pebble beach in the area, which has a length of about 600 m. The underwater slope in the form of a ridge bench is blocked by large blocks and low-power accumulations of gray sand and shell fragments. At the island of Bolshoy Utrish, a strip of gravel and pebble 12-15 m wide beach appears. The Krinitsa Resort has a total coastline length of 1.2 km. The average width of the pebble and sand beach is 30-35 m, the maximum is about 50 m on the southeastern flank. The underwater slope in the central part of the bay is shallow. The beach pebbles sink under the water to a depth of 3 m, and then a gentle sandy slope begins. Betta Bay is 2 km from Krinitsa. It has a 35-40 m wide pebble beach. The mouth of the Betta River is blocked most of the year by a powerful shingle rampart. The bay of Arkhipo-Osipovka has a total length of sand and pebble beach of about 1 km. The Dzhubga Bay is one of the largest ones on the coast. The distance between adjacent capes is about 1.5 km with a cut depth of 0.5 km. The north-western wing of the bay is composed of stable flysch rocks and has a view from which the cliff is up to 30 m high. The Dzhubga River carries pebbles and sand into the sea, from which a beach with an average width of 25-30 m is formed. Along the coast from Dzhubga to Tuapse, a high cliff of limestones, marls, and sandstones of Upper Cretaceous age stretches for almost 38 km. There are Lermontovskaya, Novomikhailovskaya, and

Olginskaya bays with wide sand and pebble beaches. Olginka Bay has a shore length of about 1.2 km with a pebble beach with a width of about 25 m in the central part. The city of Tuapse is located behind Cape Kadosh. The only natural beach is located south of the mouth of the Tuapsinka River. Now the southern city beach has an average width of about 35 m and is very popular with locals and vacationers. The beaches of Greater Sochi stretch along the edge of the Black Sea for 146 km. The coastline of the municipal district (MD) of the resort city of Sochi is subject to abrasion almost throughout (Kataeva et al., 2019). The line between the shore and the underwater coastal slope, although slowly, but continuously, is changing in some places, the coast is destroyed, and the bottom may become shallow, or vice versa, deepen (Nagalevskii et al., 2015).

The main ridge, despite its axial position, is not uniform throughout. It originates from the Gostagaevskaya village MD of the resort city of Anapa. In many places, it is crossed by rivers of both the northern and southern slopes. On the southern slope of the Greater Caucasus, the Main Range is also crossed by rivers in several places, and therefore the main watershed shifts to the Side Ridge at the sources of the rivers Pshada and Shapsukho. The southern slope of the Greater Caucasus is much shorter than the northern one, but it breaks off very steeply to the south. Its width in the western part is 20-30 km. The chain of local ridges that make up the Southern Lateral Ridge is observed here. Within the region, it extends from the valley of the Gostagayka river. The average height of the ridge is 2,440 m. The highest point is located at Laila mountain (4,008 m).

For a considerable distance, the Southern Side Ridge is not a single ridge but consists of several ridges of various lengths separated by river valleys flowing into the Black Sea. They are connected to the Main Range by short bridges. The height of the bridges is always 500-1,000 m less than the ridge and includes private ridges located mainly parallel to the Main Range, the biggest of which is located in the Krasnodar Territory: Markotkhsky, Pshada, Mezetsu, Psekhetuk, Autl, Bzych, Achishkho, Aibga, and Agepsta (Table 2). The latter is characterized by modern glaciation with typical forms. To the west of the Aibga Ridge, the relief of the Southern Side Ridge is mainly mid-mountain, and in most cases, the ridges are completely forested. The length of most ridges does not exceed 50 km.

Table 2. Morphometric characteristics of the ridges of the Southern Lateral Ridge within the Krasnodar Territory

Name of the ridge	Location on the watershed of rivers	Stretch direction	Length, km	Height, m	
				average	highest point
Markothsky	Adegoy-Pshada	SE	72	560	787, Mikhailovka
Pshada	Pshada-Dzhubga	SE	27	510	629, Ostraya
Plaho	Dzhubga-Psebs	SE	18	400	618, Plyaho
Novomikhailovsky	Psebps-Tuapse	SE	27	700	820, Lysaya
Mezetsu	Tuapse-Malaya Naji	SE	17	580	763, Mezetsu
Psekhetuk	Malaya Naji-Psezuapse	SE	18	1,020	1,280, Psekhetuk
Autl	Psezuapse-Shakhe	SE	20	1,260	1,855, Autl
Bzych	Shakhe-Sochi	E	21	1,600	2,250, Bolshaya Chura
Achishho	Sochi-Mzymta	SE	21	1,920	2,391, Achishho
Aibga-Agepsta	Mzymta-Lashipse	SE	47	2,450	3,256, Agepsta

There are also several ridges of various sizes, which are spurs of the Main Range and Southern Lateral Range (Oblego, Gebeus, Kotsekhur, etc.) ridges. The main rivers (Pshada, Vulan, Tuapse, Sochi, Mzymta) in most cases consist of long longitudinal segments and short transverse ones that cut through the ridges of the southern slope of the Greater Caucasus (Table 3).

Table 3. Morphometric characteristics of local ridges of the southern slope of the Greater Caucasus within the Krasnodar Territory

Name of the ridge	Watershed of rivers	Stretch direction	Length, km	Height, m	
				average	highest point
Navagir	Durso-Sukko	E	15	410	548, Orel
Oblego	Pshada-Vulan	SSW	25	390	747, Oblego
Gebeus	Vulan-Dzhubga-Shapsuho	SSW	27	350	735, Gebeus
Shapsukhsky	Shapsuho-Nechepsuho	SSW	22	390	628, Goryachaya
Ostry	Nechepsuho-Nebug-Kazachya	SSW	24	430	821, Lysaya
Kokoth	Agoi-Tuapse	S	22	460	888, Bukepka
Kiheth	Asche-Psezuapse	SW	32	730	924, Muzzoauku
Yehosh	Sochi-Mzymta	SSW	23	1,700	1,837, Pyat Yegosh
Alek-Ahtsu	Sochi-Mzymta	SE	24	850	1,116, Ahtsu
Kotsekhur	Mzymta-Psou	SW	30	1,240	1,880, Krasnaya skala

The lowest part of the studied territory from the point of view of hypsometry is located in the Temryuk district. Within the Black Sea coast, it lies in the extreme west, occupying the southern part of the Taman Peninsula, and geographically extends to the Kiziltash group of estuaries. The terrain relief of the territory is a low-lying plain. The absolute heights in the coastal zone do not exceed 100 m, on average fluctuating at 23-30 m. The orographic features directly reflect the structural plan of the territory, which is a combination of ridges of depressions: in the relief, ridges and depressions are associated with brachyfolds.

The coastal territories of the MD of the resort city of Anapa are characterized by low hypsometric marks, increasing from west to east. Thus, in the area of Nizhny Dzhemete, the marks barely exceed 100 m, and the maximum height is the Lysaya mountain (319.8 m) located in near the village of Supseh.

In the area of Novorossiysk, heights are increasing at the Orel peak (548.5 m) of the Navagir ridge. The northern border on the Novorossiysk to Tuapse segment is the zigzag watershed line of the Main Caucasian Range. The orography here is complex and is determined by natural conditions conducive to sufficiently intense deep breakdown with an amplitude of several hundred meters. The most important conditions include the latest tectonic movements that change the position of the erosion basis, with the formation of a complex of the sea and river terraces near the coastal strip, a large steepness of the slopes, a wide spread of unstable rocks, and a large amount of precipitation, especially in the cold season of the year (Finogenov, Popov, 2019).

In the eastern part of the Novorossiysk municipal area, the heights continue to increase, e. g., the Sakharnaya Golova mountain (558.0 m) and unnamed peaks with marks of 564.5 m and 591.2 m. The main orographic unit is the Markoth ridge with such peaks as Kvashin bugor (696.4 m), Sovkhoznaya (717.6 m), and Bezumnaya (638.4 m).

In the area of the village of Divnomorskoye, the heights acquire a stable character, about 700 m above sea level. There are ridges of the general Caucasian stretch (the Lysye Mountains) and an almost submeridional direction (the Middle Range). Small erosive forms (cracks) represented by narrow, steep-walled valleys with large height differences between the bottom and the top parts have received great development.

The hydrographic network is quite dense (Martirosyan et al., 2022). The largest watercourses include the rivers Pshada, Vulan, Nebug, Tuapse, Ashe, etc. In summer, the valley rivers are shallow, but with heavy precipitation, they can become turbulent. The slopes of the mountains are sometimes exposed, sometimes covered with grass and forest. Along the southern slope of the Caucasian Range, within the limits of the development of the flisha, a large number of springs flow out of the gorges. The hypsometry of the relief acquires values characteristic of low mountains such as the Lysaya mountain (821 m) and the Bolshoe Pseushkho mountain (1,100 m).

In the Sochi area, the relief is even more contrasting. The ridges cut through by numerous gorges are characterized by medium altitude marks, such as the Dzyhra mountain (1,277.1 m), the Sapun mountain (1,373.3 m), etc. The area of the Krasnaya Polyana village is characterized by a typical high-mountain relief (the Kamenny Stolb mountain of the Aibga ridge, 2,509.0 m), with relict glacial forms and modern glacial cover. The rivers in these places flow in deep-cut erosion gorges that look like canyons with steep walls, sometimes reaching hundreds of meters in height. Especially large canyons are observed along the valleys of the Bzyb and Mzymta rivers (the Akhtsu gorge).

The studied territory lies within the Western (more precisely, North-Western) segment of the Greater Caucasus. Structurally, it corresponds to the southern edge area. Within the Western segment of the megafold, longitudinal structures have the greatest vertical amplitude and differentiation. Transverse structures are mainly represented by wide zones of complex crushing (Bondarenko et al., 2021). A comparison of orogenic structures with more geosynclinal ones indicates a significant difference in their structural plans. The newest structures do not inherit many overlaps and overturned folds, which are widely developed among the older ones (Janteliyev et al., 2022).

The western end of the megafold is characterized by the appearance of sinuous low-amplitude structures framed by slight flexures. These are weakly differentiated (with an amplitude of tens and the first hundreds of meters) folded-block structures united in brachyfolds and complicated by grabens. In the Anapa region, the megafold is separated from the Kerch-Taman region by the West Caucasian flexure zone, which arose during the formation of the early orogenic Kerch-Taman trough filled with deposits of the Maikop series. Along the Black Sea coast along the border of the megafold with the Tuapse downfold, an even larger flexure is observed, complicated by discontinuous and connected dislocations.

The southern edge zone is divided by the Tuapse transverse hade fault shift into the western Dzhankhot subzone and the eastern subzone of Greater Sochi.

The Dzhankhot subzone, in turn, is divided by the Anapa-Rayevsky and Novorossiysk grabens into the Abrau uplift and the Dzhubga block system. Kujalnice deposits of the Pliocene age are recorded in the bottom of the western one of these grabens. In the north, the mentioned uplift is limited by the Supsekh flexure and the Severguzok hade fault, in the northeast by the Borisov hade fault and complicated by the Abraudyursinsky and Sukkinsky grabens. In the west, the Abrau fold is bounded by the Zapadnoutrish hade fault. To the east of the Novorossiysk graben, there is a trapezoidal Dobsky ridge, bounded on the west by the Kabardian and the east by the Yashmabai hade faults. The lowered wing of the latter is the Gelendzhik graben. The Mezyb hade fault separates it from the Janhotsky uplift, which includes the Idukopassky block, the Thachehochuksky horst, and the Hotateysky horst. The Idokopasskaya and Hotateyskaya structural terraces are separated by the Krasnoshelsky hade fault, displacing the Middle Pleistocene sea terraces. To the east, the Ararat Mountain joins the Khotateysky horst, separated by the Ustvulansky hade fault from the Dzhubga block. The latter includes the Shepelevsky mountain, the Dzhubginsky terrace, and the Lermontovsky terrace. The Nizhneshapsug hade fault separates the Dzhubga block from the Lermontov-Tuapse system of structural terraces in the north-western direction. In the northwest is the Tengin terrace, to the south of which lie the lowered Chaikinskaya and Novomikhailovskaya terraces. From the east, the

Kuibyshev rectangular step rises above the latter, bordering on the east with the Messazhay step. To the south of these structures are the narrow winding Olginskaya and even lower Kadoshskaya steps.

The following separate structures are represented in the Greater Sochi subzone: the Dagomys system of transverse blocks, delimiting the Adler Depression located in the southeast, and the Golovinsky system of blocks located in the northwest. The Golovin system consists of three groups of blocks, namely, Tuapse-Ashei, Ashei-Shahei, and Shahei-Loos, separated by Ashei and Shahei hade faults. On the southeastern wings of these hade faults, the elements of the brachyfold zone are wedged out of the Southern Side Zone.

The Tuapse-Ashei group of blocks includes the following structures (from the northeast to the southwest): the graben of the Cold Spring, the Berry Ridge, the Maikopsin, Dederkoy, and Magrin steps, successively descending to the sea. The latter is joined with the Lazarev terrace, which belongs to the Ashei-Shahei group of blocks. The structures of the Tuapse-Ashei group are divided by the Bogomolnensky, Tamyurderinsky, Vishnevsky, and Kiparisovy hade faults, respectively.

The Ashei-Shahei group of blocks is more complex in its structure. It includes in the north-west the Asheysko-Lazarevskaya subgroup of the Alekseevsky graben, the Asheysky horst, and the mentioned Lazarevskaya terrace, separated by the Yuzhnoalekseyevsky and Lazarevsky hade faults. To the east, the listed blocks are cut off by the Vinogradny hade fault located in front of them. Further to the southeast, the Shahei heterogeneous subgroup of blocks is located. The Shaitakh structural terraces are located on the stretch of the structures of the Ashey-Lazarev subgroup. Together with the Lazarevskaya step, they are cut off by the sublatitudinal Soloniksky hade fault. Between the latter and Shakhinsky hade faults, there is a system of blocks, diagonal to the Southern instrument area. The following grabens are located along the edges: in the north, the Soloniksky, and in the south the Kichmaysky, to which the lower course of the Shakhe River is confined. The middle part of the system is formed by the Upper- and Middle Chemit terraces. Between the Solonik graben and the sea is the Volkonsky ridge, to which the horst-like part of the Srednechimitskaya structural terrace adjoins. The southwestern part of the Kichmai graben, within which the estuary segment of the Shakhe River is located, is relatively lowered, forming the Ustshakhey graben. It cuts off from the north the structures of the Shahei-Loos group of blocks following to the southeast.

The Shahei-Looo group of blocks is a typical "keyboard" system. The orographically pronounced Golovinsky graben stretches along its northeastern edge. Its northeastern side is formed by the Berandinsky hade fault ledge, along which one can note shatters of fresh landslides. The southwestern side has a distinct bend in the relief. The Khobzinsky graben opens towards the sea and is joined through the Vardaninsky flexure with the Vardaninsky ridge, separated, in turn, by the Loos hade fault from the Loos graben, which also opens towards the sea. The entire "keyboard" group is facially assigned to the Uchderinsky horst, which belongs to the Dagomys system of transverse blocks. The Dagomys graben also belongs to it. These elements have a complex internal structure. In the south, the Dagomys system of transverse blocks borders on the Mamai system of longitudinal blocks, which are connected in a terraced manner from the south to the Shahei-Loos system of longitudinal blocks. The Mamai system includes the Mamai block, the Yuzhnodagomyssky horst, the Ustmamay graben, and the Zapadnosochinsky uplift. From the east, it is bounded by the Sochi hade fault, passing into the flexure of the same name, which serves as the western limit of the Adler depression.

The Adler depression is a typical early orogenic downfold made by sandy and silty analogs of the Maikop series which experienced uplift at the late orogenic terrace.

The coastal zone of the Black Sea includes several unique and typical objects of interest from the point of view of lithological, tectonic, and geomorphological features.

Some of them have the status of protected areas, others are popular as objects of tourist display (Tien et al., 2021; Shishanova et al., 2020). These include geological and geomorphological natural monuments, the exposure of the Agoi Pass, flyshes (geological deposits), Kiselyov rocks, and the Odinokaya, Monakh, and Parus rocks (Afanasieva et al., 2022).

The larger objects, the territory of which includes geological and geomorphological unique objects subject to protection, include the Utrish state reserve, such natural parks as Anapa bay bar, Markoth, Abraussky Nature Reserve, the Anapa seaside coastal natural complex, and the natural attraction site Prikladunye.

These and other objects and natural complexes potentially have characteristic features and properties based on which they can be classified and assigned to a certain group of notable natural objects.

5. CONCLUSION

The Black Sea coast is interesting in terms of relief and structures. The southern macroslope of the Greater Caucasus is in contact with the Black Sea basin throughout, which causes a complex combination of genetically diverse landforms and tectonic structures. Erosion processes prevail throughout the coastline. The relief of the coastal zone was formed as a result of the interaction of marine and subaerial processes, as well as man-made transformation. The inherent shortage of surface wash contributed to the features of relief formation. Due to this, the coast is being actively stabilized, primarily by bringing in the sand for new beaches, as well as through the construction of protective walls and the installation of hydraulic structures.

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