MARITIME SPATIAL PLAN OF THE REPUBLIC OF BULGARIA 2021-2035

GEOLOGY AND GEOMORPHOLOGY

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BAS	Bulgarian Academy of Sciences
BBSC	Bulgarian Black Sea coast
BCS	Bulgarian continental shelf
BGS	Bulgaria Geodetic System
BN	Bulgarian Navy
BSHS	Black Sea Height System
DEM	Digital Elevation Models
EU	European Union
EVRS	European Vertical Reference System
GCCA	Geodesy, Cartography and Cadastre Agency
GDC	Gas distribution company
ICOMOS	International Council on Monuments and Sites
IGGG	Institute of Geophysics, Geodesy and Geography
IO	Institute of Oceanology — BAS
MEW	Ministry of Environment and Water
MRDPW	Ministry of Regional Development and Public Works
MSFD	Marine Strategy Framework Directive
SG	State Gazette
UELN	United European Levelling Network
UN	The United Nations
WFD	Water Framework Directive

GEOLOGY AND GEOMORPHOLOGY

1. Coastal Area

1.1. Coastline and sea level

The line which delineates the transition between the land and the sea is defined as ***coastline***. It is a baseline in cartographic representation and is the territorial border of the country's land. It extends from Cape Sivriburun to the north (the border with the Republic of Romania) to the estuary of Rezovo River to the south (the border with the Republic of Turkey). Notwithstanding its importance as a basic geographic element, no data of targeted measurement of the coastline length is available to date neither official, uniform digital version of the coastline is available for map-making at different scales.

The earliest information on the coastline length is provided by Popov and Mishev (1974). The length measured by them is 378 km based on own field measurement and topographic maps with a scale of 1 : 5 000. This value is quoted in the subsequent targeted research until 2010. *(Krastev and Mihova, 1990; Krastev, 1993; Peychev, 2004; Kozhuharov, et al., 2010, etc.).* Targeted surveys to determine the coastline length have been carried out by the research associates of the Institute of Oceanology at the Bulgarian Academy of Sciences (IO-BAS). On the basis of digitalising the waterline from orthophoto images, current as of the period 2011—2012, they determined the total coastline length at **498.33 km**, adding the technogenic type of coast consisting of ports, groynes, shore protection facilities, permanent bridges, etc. to the natural shore. (*Stanchev, et al., 2011; Stanchev, et al., 2013*). The natural length of the coastline is determined to be **432.35 km**. As of January 2020, the coastline length shown by district on the website of the Geodesy, Cartography and Cadastre Agency (GCCA) in the Bulgarian Geodetic System (BGS) 2005 is **475.34 km**, and in the Cadastral Coordinate System (CCS) 2005[1] it is **503.75 km**.

The ongoing anthropogenic changes and the increasing technogenic load of the Black Sea coastal area are the basic problem for the accurate parametrisation of the coastline. Larger-scale changes, such as building of ports, shore-protection and shore-consolidation elements play an essential role for the outline of the modern coastal morphology and have a significant impact on the ratio of technogenic to natural coast. Such changes cannot be forecast, as currently only one of all the 14 seaside municipalities boasts a current, approved Master Plan of the municipality (MPM). In addition, the information in these plans quite often does not fully correspond to the parameters of the changes to the subsequently developed Detailed Land-use Plans and the implemented investment intentions.

The initial comparative analysis of the set of orthophoto images of the campaigns from the period 2011—2014 and the current free access data of the Google Maps and Google Earth Internet Platforms show the changes in the coastline, mostly in urbanised and tourist areas within the Bulgarian Black Sea coast (BBSC), as it has increased significantly in the recent years. For the purpose of updating the current coast status, the waterline was digitalised based on a series of orthophoto mosaics of the coast with resolution 0.5 m, current as of 2014. In some places high resolution raster orthophoto mosaics — a product of research associates of the IO—BAS — were made by an unmanned aerial vehicle system

[1] https://kais.cadastre.bg/bg/Map

to enable the most current parametrisation possible of the coastline. To date, the total length of the digitalised Bulgarian Black Sea coastline, as determined by the team of the IO—BAS, is **517.13 km**.

The coastline is determined by the **sea level**. This is a notion directly related to altitude. Bulgaria has adopted as sea level the multi-annual average level of the Black Sea, known as the Black Sea Height System. The Black Sea Height System 1930 (BSHS) is defined by the average sea level determined in the period between July 1928 and January 1931 by continuous records of the sea level at a tide-gauge station in Varna. The estimated average sea level which serves as a starting point ("zero") of the National Geodetic Network, First-Order, completed in 1931 corresponds to mark 68.17 cm of the mareograph tide gauge, installed at the Varna Port (Figure 1). This starting point serves as a reference point to determine the altitude of the benchmarks in the territory of the country, which are used in all construction and mapping related activities. In connection to upgrading of the geodetic network in 2003, the starting point ("zero") of the average sea level as per the mareograph gauge rod at the Varna Port was estimated to correspond to mark 79.00 cm.

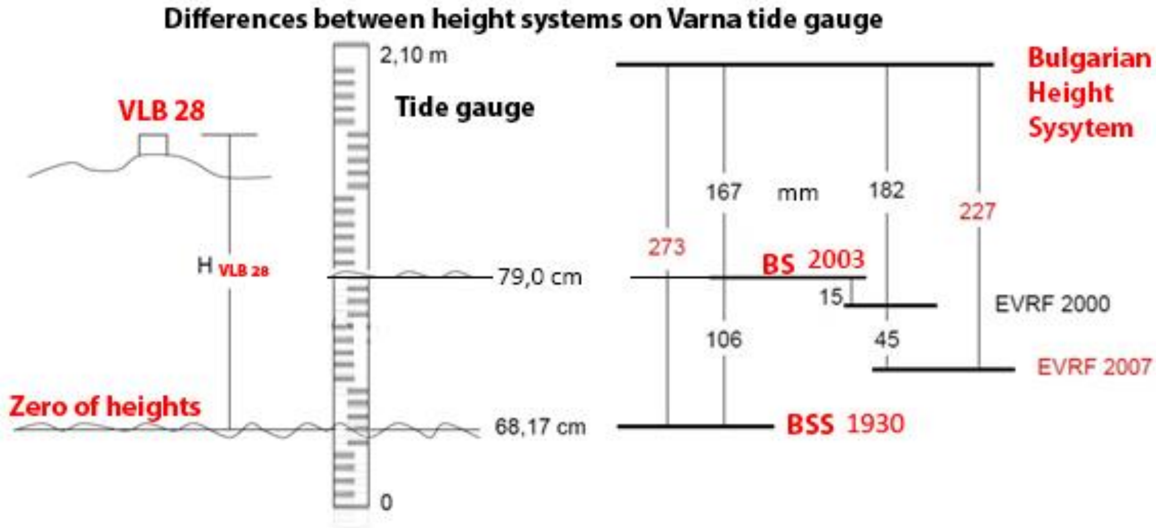
In 1958, as part of the unification of geodetic networks in the former socialist countries, the Baltic Height System (BHS) was introduced; in it the starting point is the average sea level of the Baltic Sea determined by the Kronstadt mareograph (Russia). The average level estimated according to the Kronstadt mareograph tide gauge is higher than the average level at Varna. The differences in altitudes of benchmarks estimated in the Black Sea and the Baltic Sea Height Systems are 273 mm at the Varna mareograph and 238 mm at the Burgas mareograph. Therefore, the records of sea level by the Bulgarian mareographic stations lost their initial purpose for determining the starting point of the Bulgarian Geodetic System. Daily, monthly, annual and multi-annual average levels continue to be used mainly in making marine maps by the Naval Hydrographic Service for navigation and research purposes — for research of sea level trends, which is a particularly topical issue in relation to the rising global sea levels due to global warming, for research of geodynamic phenomena in the coastal areas.

In 2010, as an EU Member State Bulgaria implemented the European Vertical Reference System (EVRS) thus ensuring geo-spatial compatibility of all activities, not only geodetic one, on European scale[2]. EVRS is a kinematical height reference system based on the United European Levelling Network (UELN) with starting benchmark ("zero") of the Amsterdam mareograph and it is a zero-tide system, i.e. it eliminates of the permanent tide effect in compliance with the IAG Resolutions of 1983. Bulgaria uses the latest version of the EVRS — EVRF2007 — which is based on a combination of three basic elements: network (EUVN), vertical datum and its changes over time.

Due to differences in the Geoid Model of the country at the time of transition from the Baltic height system to the United European Levelling Network, the BGStrans 4.5 software adopted by GCCA is in use. For transition to the Black Sea Height System, the differences between the "zero" of the nearest mareographic station in the Baltic or the European Levelling System and the respective mareograph readings for the respective period are taken (Figure 1).

[2] Regulation No 2 of 30 July 2010 on defining, implementation and maintenance of the Bulgarian Geodetic System, published in SG No 62/10.08.2010

Figure 1: Relation of “zero heights” in various height systems adopted in Bulgaria.



VLB – Varna Leveling Benchmark; BSS – Black Sea System; BS – Black Sea

Source: L. Dimitrov, T. Lambev (MSPRB, 2020)

According to Article 4 of Regulation No 2 of 30 July 2010, the unified geodetic control network in the territory of the Republic of Bulgaria also includes the network of tide-gauge stations. The latter comprises four tide-gauge stations for sea level monitoring — at Varna, Irakly, Burgas and Ahtopol. The Varna tide-gauge station built in 1928 is the main tide-gauge station on the Bulgarian coast. At the beginning of 2013, modern radar tide gauges Vega Plus type were installed at Burgas and Varna. They ensure continuous recording and transmitting of water level in real time. The tide-gauge stations at Irakly and Ahtopol have been in operation since 1970. However, due to lack of funds, they discontinued their observations in 2001 (Ahtopol) and in 2006 (Irakly). Since the beginning of 2019, the Burgas tide-gauge station is not operational due to privatisation of the land on which it is installed. At present, specialists of the IO—BAS jointly with their colleagues from the GCCA are making efforts to resume its operation.

The average sea level estimated by tide-gauge measurements is used for defining of height systems and it is an important component in defining the Geoid, also for defining local and regional changes of the sea level. The analysis of the monthly sea level values from measurements for the period 1928—2013 shows continuous rising of the Black Sea level with a trend of 1.2 —1.4 mm per year for the Varna tide-gauge station and 1.6—1.7 mm per year for the Burgas one (Ivanov, 2017).

Being an enclosed sea basin isolated from the World Ocean, the Black Sea is a “tideless” sea. High and low tides are insignificant, their amplitude being about 7.0 cm (Ivanov, 2017). It should be emphasised that despite the negligible high-low tide movements, non-periodic fluctuations of the sea level are considerable and are not rear along the Bulgarian coast. They usually are generated by atmospheric phenomena, such as rapid change of baric pressure.

As observations show, the sharpest level variations are due to wind-induced level fluctuations. Thus, for instance, on 7 May 2007 the water level of the Black Sea at Balchik dropped by 80 cm for a few hours, and water receded by 15 m. Lowering of water level by about 70 cm was registered in the Varna Bay, at Kavarna, by about 50 cm, and levels were restored in 7—8 hours. Such fluctuations of the sea result from sudden sharp changes in the atmospheric pressure and are called “seiches”. Other, more dangerous phenomena include rising of the level due to continuous, severe and prolonged wind (longer than 2—3 days) from the east and north-east. Sea level rising by more than 2 m is registered under such meteorological conditions: in February 1979 at Burgas by 251 cm, at Irakly by 218 cm, at Ahtopol by 253 cm; in July 2006 at Irakly by 248 cm, at Burgas by 231 cm (Kostochkova et al., 2001, Trifonova, 2007). Accompanied by heavy rain, such extreme sea level rises have caused disastrous floods.

This shows that sea level monitoring should be an essential element of the overall marine environment monitoring system.

The brief analysis above identifies the following needs:

- up-to-date measurement of the coastline according to an approved methodology and its maintenance by designated bodies of the Ministry of Defence and the Ministry of Regional Development and Public Works (said updating should be carried out within a reasonable period, e.g. 5 years), as well as establishing a single unified digital version of the Bulgarian coastline for the purposes of map-making at various scales and introducing it in the global maritime databases;
- restoring and expanding the network of tide-gauge stations along the Bulgarian coast and combining them with monitoring of horizontal and vertical movements of the earth crust; maintaining the network by real-time data feeds and free access for third parties.

1.2. Coastal Area

Most frequently the **coastal area** is defined as the area of the boundary between land and sea, where the sea impacts the land and vice versa. The coastal area boundaries vary depending on physical and bio-geographical conditions, the combination of available uses and legal regulations. There is no strict definition of coastal area in the Bulgarian legislation, however, the Black Sea Coast Development Act (BSCDA)[3] defines the notion of **“Black Sea coast”** which, according to the Act, may extend to more than 2 km into the land.

The same Act defines the term “**sea shore**” as a narrow strip of land where land meets sea and where they interact: it consists of underwater and land parts and is characterised by various transverse profiles developed close by the coastline, in the water and on the land. A “**Zone A**” is defined thereinafter for spatial development protection, which covers a 200 m wide area seaward from the coast line, measured from the line of the lowest tide; the beach strip; sand dunes; and part of the land falling within a 100 m measured along the horizontal line from the boundaries of the sea shore or the sea beaches, as well as the islands in the internal sea waters and the territorial sea. Experience shows that **“Zone A”**, as defined in the Act, completely coincides with the definition of “**coastal area**”.

The modern dynamic outline of the Bulgarian Black Sea coast is determined by geological conditions and strictly specific local geomorphological features. The whole range of complex interactions

[3] SG No 48/15.06.2007, amended and supplemented in SG No 60/30.07.2019

between tectonic and non-tectonic movements of the earth crust and exogenic processes, such as abrasion, erosion and accumulation, have shaped a diverse landscape — long and wide sand beaches, dunes, lagoons, estuary, dense forests, cliffs, coastal lakes with rare flora and fauna and abundance of natural resources. At the same time, an ever increasing anthropogenicity is observed, which results in gradual destruction of natural assets.

The basic geomorphological types of shores and adjacent landforms which are observed along the BBSC are as follows:

A. Natural shore formed by local geological and tectonic impacts and shaped by the action of endogenic and exogenic processes. Most significant for the appearance of the forms in the coastal area are the selective abrasion and accumulation processes, which formed the following:

- ***Flat denudation surfaces.*** Being among the oldest landforms, their importance in terms of modern-day dynamical processes is secondary, as their hypsometric position is normally in the range 80-400 m above the contemporary sea level – well above the geo- and morphodynamically active sectors of the coastal zone. These landforms are widely present in the inner coastal areas, and dated to be of Sarmato-Pontian (Middle-Late Miocene), Pontian (Late Miocene) and Levantine (Late Miocene) age (Popov and Mishev 1974; Baltakov 2000; Keremedhiev 2004).
- ***Marine Terraces.*** The accurate dating of these relic landforms for subsequent analyses of the marine transgressional and regressional phases remains an open issue. This fact implies the necessity of further underwater investigations and surveys, as the interpretative correlations of the terrestrial and submarine relief holds the key to accurate paleogeographic reconstructions of the Black Sea evolution. Several authors (e.g., Baltakov, 2000; 2003; Baltakov and Kenderova 2003; Peychev, 2004; Peychev and Peev 2006; etc.) question the existence of marine terraces of Tschaudinian, Paleoeuxinian and Uzunlarian age along the Bulgarian coast. Nevertheless, marine terraces and/or their fragments of the following ages are claimed by authors to have been preserved: Early Pleistocene - Early Tschaudinian (110-120 m a.s.l.) and Late Tschaudinian (85-100 m a.s.l.) stages; Middle Pleistocene - Paleoeuxinian (50-60 m a.s.l.) and Euxino-Uzunlarian (35-45 m a.s.l.) stages; Late Pleistocene - Early Karangatian (20-25 m a.s.l.) and Late Karangatian stages (8-15 m a.s.l.); Early Holocene - Starochernomorski stage (4-5 m a.s.l.) (Keremedchiev 2002; Baltakov 2003; Peychev 2004; etc.)
- ***Erosional gullies and ravine systems.*** Various factors determine the generation of these forms. The predominant opinion is that vertical movements of the coastal morphotectonic blocks and the lithostratigraphic structure are the main factors for the formation of gullies and ravines along the Bulgarian coast. An important feature of these landforms is the erosion-prone properties, especially when formed in loess, sandy and gravelly sediments, being of major importance to the natural beach nourishment (Popov and Mishev, 1974; Stancheva, 2013; Kotsev, 2014; Prodanov, 2017).
- ***Landslides*****.** The natural processes facilitating the manifestation of landslide activity can be grouped into two categories: endogenous (epeirogenic movements of the Earth's crust and earthquakes) and exogenous (wave-induced cliff erosion, surface erosion and ground water

discharge) (Frangov et al. 1998). The majority of the landslides along the Bulgarian coast are caused by exogenous processes, acting together with several human-induced factors (Kochev 1998; Varbanov et al. 1998). Most susceptible to landslides are coastal segments whose lithology represents an alternation of unconsolidated with solid strata (i.e., limestones with interbeds of clayish materials, marls and conglomerates), also characterized with active ground water discharge and presence of micro-faults (Popov and Mishev 1974; Varbanov et al. 1998). Different studies provide data on the aggregate length of the erosional/abrasional-landslide type of coast, varying from 12.3 % (Popov and Mishev 1974) to 16.8 % (Keremedchiev 2001; Keremedchiev and Stancheva 2007). The latest data describe 79 landslides with a total length of 45 km (Peychev et al 2014).

- ***Erosion-denudation slopes.*** Their formation implies prevalence of subaerial morphostructure processes in the superstructure of already described erosion landforms in slopes steeper than 5° (Blagoeva, 1980);
- ***Karst formations.*** These formations are typical for the Northern Bulgarian Black Sea coast. Geological and lithological conditions (Sarmatian limestone and calcareous sandstone) along the Dobrudzha coast have predetermined specific processes of karstification, shaping various types of forms — naked karst plateau (local name “kayriatsi”), karst valleys, sea arches, caves, and klippes (Popov and Mishev, 1974; Popov and Stefanov, 1980; Petrov, 2010; Prodanov et al., 2019b);
- ***Limans and lagoons.*** They are widespread forms along the BBSC. Presumably, given the conditions of the Bulgarian coast, limans are “submerged” former river estuaries (there are 28 limans), while lagoons are considerably less in number (5) (Popov and Mishev, 1974; Kanev, 1989; Kotsev et al., 2019);
- ***Bulgarian Black Sea islands.*** There are 5 rocky islands in the Bulgarian maritime spaces, that are situated along the southern Bulgarian coast, namely: St. Anastasia (Burgas Bay), St. Kirik (nowadays, part of the port facilities of the town of Sozopol), St. Ivan and St. Petar (Sozopol Bay) and St. Toma (situated to the northwest of Cape Maslen Nos). Kanev (1989) describes them as continental type of island formations, that is they have geological and geomorphological characteristics similar to their adjacent coast.
- ***Cliffs and related landforms.*** Cliff coast is most widespread along the Bulgarian coast and covers 213 km (49.3 %) of the Bulgarian Black Sea coast (Stanchev et al., 2013). Over the years, on the basis of various topographic maps or on-site measurements, a number of authors have proved statistically that the cliff coast is considerably longer than the accumulation one and the technogenic one. Alongside erosional cliffs, other classical landforms widely observed are headlands, wave-cut platforms and ramps, nips and cliff-base (abrasional) notches, rockfalls, sea stacks, skerries, rocky islets, geos, etc.
- ***Beaches and dunes*** are typical accumulation landforms. They represent the most common landforms formed in depositional coastal environments and valuable recreational resources, whose preservation is of topmost importance. The number of beaches on the Bulgarian coast exceeds 70, with an overall length of 121 km, while the aggregate number of beach-dune

systems is 28 (Stancheva et al. 2015). Along the Bulgarian Black Sea shore, the sandy substrata for their formation are predominantly of terrigenous origin. Once eroded from the nearby coastal source provinces, they are subsequently transported by rivers and surface streams, and eventually deposited and redistributed in the littoral zone. Accordingly, the spatial distribution of beach-dune systems is primarily associated with the occurrence of gullies and ravines, estuaries, lagoons, inlets and bays. Beach-dune systems are characterized by rather intensive spatio-temporal changes due to related specifics of the coastal morphodynamics (sand strips) and the aeolian transport (Popov and Mishev, 1974; Daneva and Mishev, 1979; Kenderova et al., 1999; Keremedchiev & Cherneva, 2003; Keremedchiev, 2005; Peychev and Dimitrova, 2012; Stancheva, 2013; Stanchev et al., 2013; Valchev, 2015; Prodanov et al., 2019; Kotsev et al., 2019). Their condition and environmental status are a major contributory factor to maritime tourism.

B. Technogenic type of coast. Over the years, various natural factors, such as geological hazards in the susceptible areas and the industrialisation of the Black Sea coast, required building-up of port infrastructure which needs strengthening and protection against flooding, damages and loss. Building of breakwater walls and short groynes along the coastline, as well as construction of port infrastructure resulted in concreting of the coastline and currently 16.2 % (i.e. 70 km) of the Bulgarian coast is transformed into technogenic coast (Kotsev et al., 2019). The latest anthropogenic influence and impact data identify an extremely high degree of technogenic load between Balchik and Cape Galata (Stancheva, 2009; Stancheva et al., 2011; Prodanov et al., 2013; Stanchev et al., 2013).

The ***circalittoral zone*** (nearshore underwater zone) is situated along the current coastline and covers the underwater shore slope and submerged relict terraces. The 20-metre isobath is provisionally considered as the seaward boundary of this zone (Dimitrov, 1979). The seaward boundary of our coastal zone is currently debatable, however most of the studies express the common opinion that the seaward boundary is situated along the 23—25 m isobath, to the point where any impact of wave processes on the bottom may be found. (Keremedchiev, 2001a; 2001b; Ignatov, 2008; Trifonova, 2014; Prodanov and Dimitrov, 2015; Prodanov, 2017b). The most essential feature is that it is subject to active wave-induced impact, thus two processes—abrasion and accumulation—take place concurrently (Keremedchiev and Cherneva, 2001). Its shape is influenced to a great extent by the geomorphological features of adjacent land and large areas of intensive abrasion with a cliff coast, complicated in many places by landslide processes, which are interrupted by small coves with intensive accumulation, and, vice versa, lengthy beach strips alternate with isolated abrasion capes (Popov and Mishev, 1974; Keremedchiev, 2001, 2002; Peychev, 2004; Keremedchiev & Stancheva, 2006; Keremedchiev & Stancheva, 2007; Kotsev 2014; Prodanov et al., 2017; Prodanov et al., 2019a; 2019d; Dimitrov et al., 2019). The diverse and complicated lay of the terrace complex in the active coast zone is associated with differences in the genesis of abrasion and abrasion-accumulation forms as a result of selective abrasion of rock formations with a different degree of resistance to wave impact (Keremedchiev & Cherneva, 2001; Keremedchiev, 2002).

Over the years, the Institute of Oceanology at the Bulgarian Academy of Sciences (IO—BAS) conducted significant bathymetric and lithologic research in the coastal zone. The acquisition of new data with high horizontal and vertical accuracy and high density, obtained by advanced research facilities, enabled the available archived morpho-lithologic map developments and parametrisation of the bottom type in the circalittoral area to be drawn up in detail in line with the considerably changed coastline and sea bottom in the recent years. Large-scale morphologic classification and defining of forms types at the sea bottom in the circalittoral zone was made based on the ongoing abrasion and accumulation processes (Table 1).

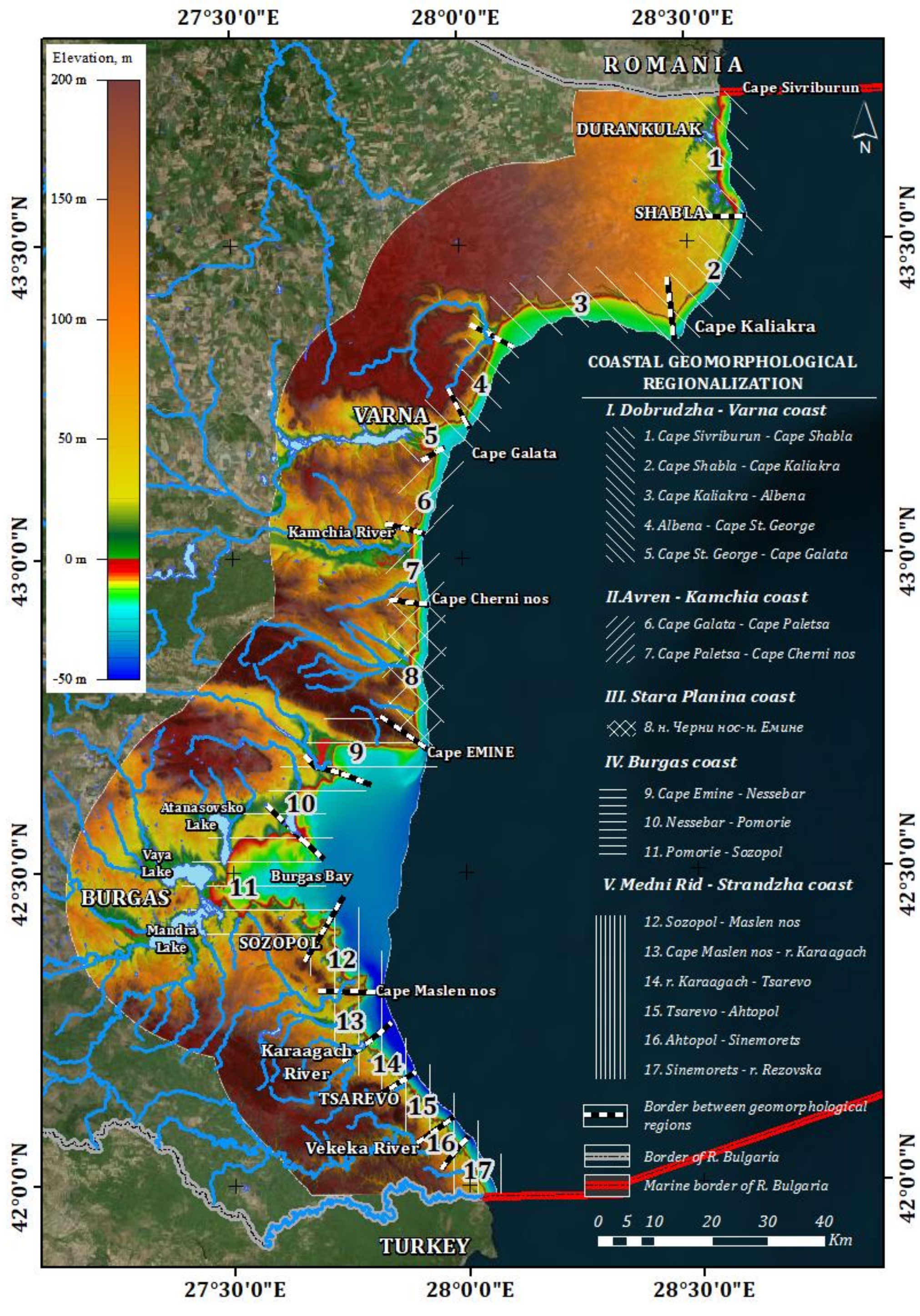
Table 1: Types of underwater morphologic forms in the circalittoral zone of the Bulgarian Black Sea

Code	**Type of morphological form**	**Morphological form**
	With mapping in a scale ≥ 1 : 25 000	With mapping in a scale > 1 : 25 000
A	**Abrasion-structural morphology**	
A1		Coast slope
A2		Contemporary structural terrace *(bench)*
A3		Structural terrace levels
A4		Structural slope
A5		Rocky Reef
A6		Paleoshoreline
B	**Abrasion-accumulation morphology**	
B1		Abrasion-accumulation slope
B2		Abrasion-accumulation terraces
C	**Accumulation morphology**	
C1		Beach slope
C2		Accumulation levels (terraces)
C3		Accumulation slope
C4		Wave sandbar
D	**Landslide morphology**	
D1		Landslide-structural slope
E	**Structural morphology**	
E1		Structural slope
E2		Terrace levels
E3		Structural depression
E4		Paleoshoreline
F	**Structural-accumulation morphology**	
F1		Structural-accumulation terrace levels

Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

The morphologic landscape of the Bulgarian Black Sea coast is closely related to its constituent basic geomorphological units: the eastern part of the Moesian Plate, the Lower Kamchia Graben Fault Block, the circalittoral part of the megastructure of the Balkan Mountains, the Burgas synclinorium and the Mednorid—Strandzha mega-anticlinorium. On the basis of these geomorpho-structural units, the Bulgarian coast is divided by Popov and Mishev (1974) into five geomorphological areas: Dobrudzha—Frangen covering 30.4 % of the coastline length, Lower Kamchian — 8.9 %, Balkan Mountains — 7.6 %, Burgas — 28.3 %, and Mednorid—Strandzha — 24.8 %.

Figure 2: Geomorphological zoning of the Bulgarian Black Sea coast



Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

1.3. Zoning of the Bulgarian Black Sea coast

Depending on the lithostratigraphic varieties and tectonic faulting processes in the coastal area, on the one hand, and the morphographical peculiarities, on the other hand, 17 sub-zones have been identified (Figure 2). The BBSC zoning in accordance with various criteria, such as morpho-stratigraphic characteristics (Lilienberg, 1966), morphostructural conditions (Popov and Mishev, 1974), morphometric parameters (Keremedchiev, 2001a), morphodynamic activity (Keremedchiev & Stancheva, 2006; Keremedchiev & Stancheva, 2007), follow the zoning on Figure 2, to which this analysis of the coastal area adheres.

Area I. Dobrudzha—Frangen Area. The local morphostructures of Krapets, Tyulenovo and the Vranil-Balchik block, the Batovo sunken block and the Frangen block, the Varna sunken block, and the northern part of the horst Avren block determine the morphologic structure of the Dobrudzha—Frangen coast. Sub-meridional fault ruptures, positive and negative movements of the earth crust, the geo-lithologic composition, diverse exposure of the coast (ranging from protected to extremely exposed) to waves, separate the Dobrudzha part (to the north of the estuary of Batova River and the Frangen—Avren part (to the south of Batova River) — Figure 2.

The coastline in the Dobrudzha—Frangen area between Cape Sivriburun and Cape Galata is 158.79 km long. As a consequence of the morphologic expression of the above-mentioned blocks, cliff coast with an overall length of 57.89 km (36.46%) considerably prevails over accumulation one — 50.45 km (31.77 %). There is notable anthropogenisation of the coast, and in addition to the water areas of the ports of Varna, Balchik and Kavarna, the technogenic coast (sea walls, groynes and shore-consolidation facilities) has increased to 31.77 % (50.45 km) — Figure 3.

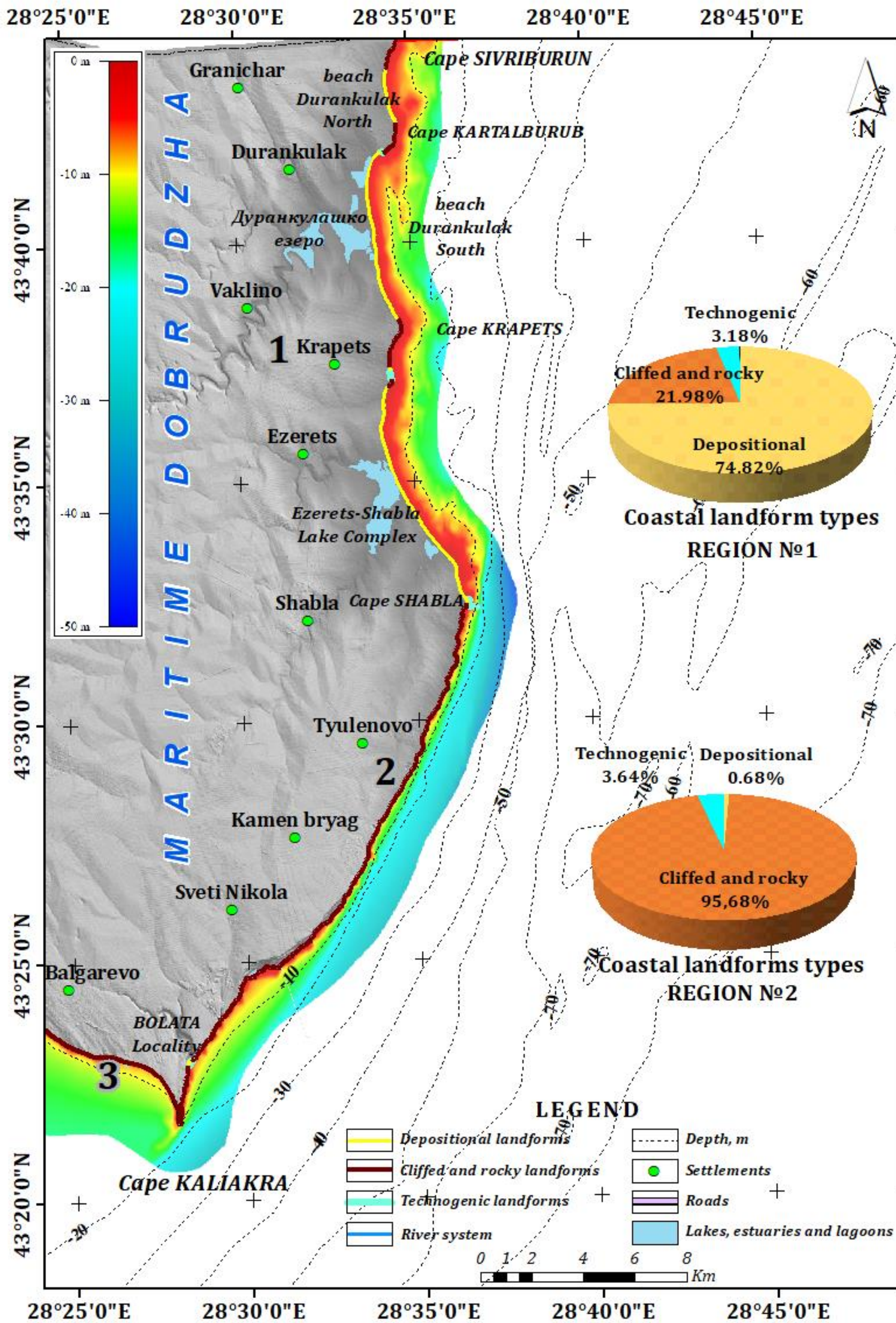
Sub-area I.1 covers the coastal area from Cape Sivriburun to Cape Shabla. The northernmost section of the BBSC is a typical example of a low abrasion-accumulation coast with prevailing accumulation forms (74.28 %; 18.80 km). The sub-area along the coastline is 25.12 km long and the remaining part is a cliff section (5.52 km; 21.98 %). The coast is preserved from anthropogenic influence and the technogenic coast is limited to 3 % (800 m) — Figure 3.

Accumulation coast comprises well-defined long beach strips, in some places turning into sand and dune systems: Durankulak—North, Durankulak—South, Krapets—North, Krapets—Central, Krapets—South, Shabla, and Dobrudzha camping site. Loess cliffs with a height of 19 m near the Romanian border get lower down to 9.5—12 m near Krapets and to 12.5 m and 10.6 m north of the lighthouse at Cape Shabla.

The cliffs in the sub-area are moderately to highly susceptible to erosion, and observations show that in the period 1972—2011 the land loss rate reached 0.47 m per annum (Stanchev et al., 2013; 2018). The present appearance of the coast is directly influenced by natural limans and lagoons: Baltata Lake, Durankulak Lake, Ezeretsko Lake and Shablenska Tuzla, which are important wetlands along the Bulgarian Black See coast.

The underwater morphology in the sub-area does not differ in terms of genesis of the forms. The beach and dune systems continue in the form of low gradient (> 0.64°) sand slopes with abrasion-accumulation features. At 8 m depth, they change into a smooth, almost flat, accumulation slope. At depths of 1.5—2.0 m the abrasion capes in their shallow part form contemporary benches with clearly expressed abrasion-structure, which form rock abrasion-structural slopes with a 0.45° gradient as the depth increases to more than 20 m.

Figure 3: Types of shore forms along the Dobrudzha coast



Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

Sub-area I.2 extends from Cape Shabla to Cape Kaliakra. This sub-area shows “the other face” of the Dobrudzha coast. To the south of Cape Shabla the rock and cliff coast dominates and beach and dune forms account for only 0.6 % of the coast. The intensive abrasion processes have formed many underwater and surface klippes and shallow caves. The height of the plateau smoothly increases from north to south and in some places reaches up to 73 m (at Yailata locality); then it smoothly decreases in the direction to Bolata Cove and Cape Kaliakra down to an altitude between 52 m and 55 m. The abrasion and landslide systems Yailata and Taukliman and the landslide system Naneva Tuzla are interesting in geomorphological terms. The typical karst morphology of the platform forms a picturesque karst valley at Bolata cove, where a combination of denudation and erosion-denudation forms can be seen in the cliff superstructure *(Prodanov et al., 2019b)*.

Figure 4: Photorealistic model of Bolata cove and the karst valley which formed it.

Source: B. Prodanov (MSPRB, 2020)

The underwater morphology is influenced by neotectonic movements. The resultant inclined terrace can be seen down to 30 m depth. A well-defined steep abrasion-accumulation coastal slope (with abrasion-landslide characteristics at places) with an average gradient over 1° is identified immediately next to the vertical cliffs, which are often almost vertical. Only the sea bottom of the Bolata Cove is an exception which, due to its defence purpose in the past, features a well consolidated shore and has formed a sand accumulation slope (Figure 4). Before Cape Kaliakra, bathymetric profiling shows the presence of an accumulation sandbank with about 1 km length, extending in SE-SW direction. Its crest rises 8—12 m higher than the adjacent flat bottom, and to the south it smoothly merges with the flat shelf.

Sub-area I.3 from Cape Kaliakra to Albena Resort (the estuary of Batova River). This part of the Dobrudzha coast is different from the northern areas; it is E-W oriented (87°), which defines the coast as protected and moderately exposed to waves. Sub-area 3 is 47.85 km long, and accumulation forms have a relatively small share — 12.16 % (5.82 km), while landslide and abrasion relief are dominated by extremely high cliffs reaching more than 200 m — 220 m (Figure 5). The lithostratigraphic structure of alternating Sarmatian limestones and sandstones and dynamic landslide processes account for suspended valleys, typical for the area.

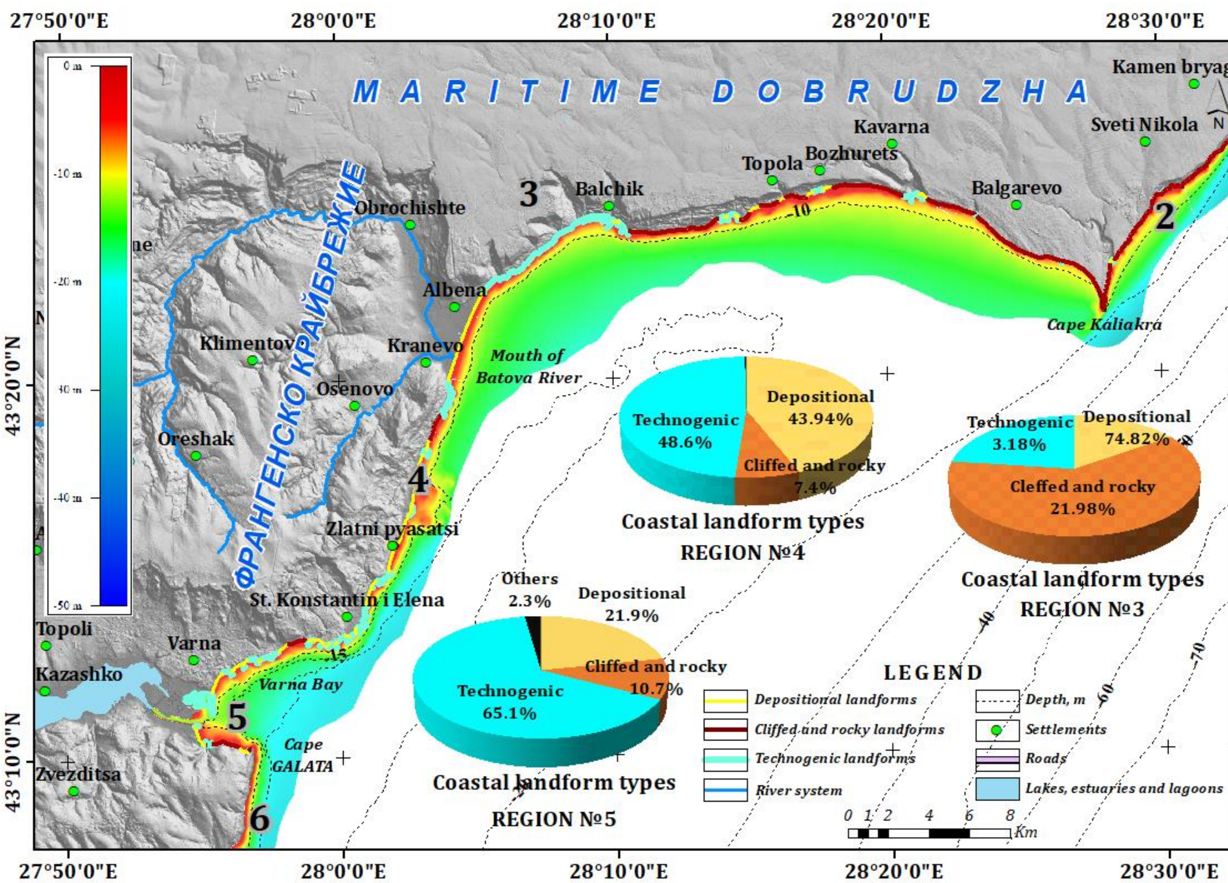
The landslide lake Balchishka Tuzla is interesting from a geomorphological point of view. It is among Bulgaria’s most important assets, as owing to the unique mineral and sediment composition of the bottom it is a balneotherapy centre. Tuzlata and the lower parts of Ikantalaka resort are situated on the lowest landslide bench within the hypsometric range of 3 m—10 m.

To the south of the town of Balchik, the cliffs are deeply cut by erosion-denudation gullies (up to 125 m height difference between the cliff edge and the midstream of the gully, featuring a high degree of dynamism (Kotsev, 2014). The end of landslide-abrasion morphology is marked by the canyon-like Batova depression where the dense forest along Batova River (Baltata nature reserve) is situated.

The high percentage of technogenic coast in this sub-area is a result of the shore consolidation dike between the town of Balchik and Albena resort, and the well-developed port facilities of Balchik, including its adjacent shore consolidation facilities and the shore-protection facilities in the Kavarna Bay.

The underwater slope adjoins immediately next to the waterline and seldom exceeds a gradient of 1°, however with a clear boundary at approximately 10 m depth where it changes into an accumulation slope with an insignificant gradient. The lithological varieties of the coast between Cape Kaliakra and Balchik are determined mostly by landslide morphology, and the eroded and processed rock material in the sections open to the wave impact reaches a depth of almost to 6 m. The bottom substrate is of diverse and sandy sediments alternating with larger-grain ones.

Figure 5: Types of shore forms along the Dobrudzha—Frangen coast



Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

Sub-area I.4 covers the coastal area from Albena resort (the estuary of Batova River) to Cape Saint Georgy (Euxinograd Palace). This sub-area is part of the Frangen coast, dominated by the Frangen Plateau which played a main role in the formation of the coastal landforms. The Frangen landslide system has a long history of development related to the morphological evolution of this part of the Bulgarian Black Sea coast, with prevalent macro- and meso-landslide benches. Stoyanov (1960) divided the eastern slope of the plateau into three large fault zones, and exploration drilling proved that the landslides included Middle Sarmatian sediments. The age of the highest landslide benches is assumed to be Upper Pliocene and Pleistocene, and the lowest ones are of Holocene age (Popov and Mishev, 1974). According to data of the System reporting the current status of landslides at MRDPW — "Geozashtita Varna", the coast section features active landslides and this visibly affects the coast picture.

The sub-area boasts a highly developed tourist industry with large resorts: Kranevo, Riviera, Golden Sands, St.St. Constantine and Elena, and Kabakum. In combination with hazardous geological processes, they are the main reason why almost half of the coast length (48.63 % — 23 km) is covered by technogenic shore consolidation and port facilities. The natural coast is shared between the beach strips of Kranevo, Golden Sands resort, Kabakum, and St.St. Constantine and Elena (43.94 %). The sediments of accumulation strips in the area consist of medium to fine sands of low carbonate content.

The morphology of the sea bottom, by analogy, follows the principles of geomorphological conditions of the land, and is of prevailingly landslide-accumulation nature. The small beaches to the south of Kabakum resort are an exception, where an accumulation slope goes down to a depth of 3—5 m. Outside the centre of the Golden Sands resort, the attractive "Aladzha Bank" accommodates rich biodiversity and geological phenomena — natural gas underwater springs.

Figure 6: Orthophoto image of the new fishing port under construction in Karantinata location, current as of December 2019

Source: B. Prodanov (MSPRB, 2020)

Sub-area I.5 Cape Saint Georgi — Cape Galata. The plateaus of Franga and Avren blocks which have similar tectonic structural composition (Figure 5) are identified in the superstructure of the Varna Paleogene-Neogene depression. In geotectonic and geomorphological terms, this sub-area is dominated by the Varna depression where the Varna—Beloslav lake system which separates the Franga Plateau from the Avren Horst is identified. Despite the relative lithostratigraphic similarity of the two structures, they differ significantly in the inclinations of the northern Franga and the southern Avren slopes. The northern slopes of the Avren Plateau differ by their average gradient (7.4°) from the considerably less inclined south-eastern slope (4.97°) of the Franga Plateau. This is why the town of Varna is situated on several different terraced slopes: 50—60 m; 40—45 m; 30—35 m; 18—25 m and 8—12 m (Popov and Mishev, 1974). The Varna Lake, an altered former firth, is currently one of the areas along our Black Sea coast most severely affected by anthropogenicity. This sub-area and sub-areas No 3 and No 11 are characterised by a coast that is most severely affected by anthropogenicity (Stancheva et al., 2011, 2013; Stancheva, 2009). To the north of Cape Galata, there are 111 maritime and hydro-engineering facilities of various types. Another important factor contributing to the extreme technogenic burden on the coast is the Varna quay, equipped with strong protection against wave impact, with a length of about 1 km from the adjacent South Beach. Currently, the technogenic coast within the sea waters of the Varna Bay is assessed to account for 67.56 % (18.57 km), and will further increase with the new fishing port under construction in the Karantinata location at the south-eastern end of the Asparuhovo beach (Figure 5).

The public beaches of Varna and the Asparuhovo take 30 % of the accumulation shore in the area. Regretfully, the hydro-engineering facilities (groynes 101, 102 and 103), in addition to their coast protection role, also impact adversely the sediment balance in the active zone.

The underwater slope in the area is in direct relation with the morphology of the coast, the character of rock layer bedding, the lithostratigraphic structure and the local fault structural movements of the earth crust. The formation of submerged terrace levels is developed during the regressive Holocene phases *(Prodanov et al., 2017; 2019)*. Depending on the degree of intensity of morpho-dynamic processes, the coastal zone of the Varna Bay is divided into three sub-zones: A) active shore sub-zone down to 5—6 m depth (150—400 m from the coastline). It is distinguished by considerably higher slopes of the underwater relief (from 1.15° to 2.9°); B) less active sub-zone which extends from 6 m to 12—15 m depth, is 300 m to 800 m wide, and is considerably low inclined to the bottom — 0.23° to 0.72°; C) inactive zone represented by a slightly inclined accumulation plain-like flat bottom with inclination of the slope from 0.057° to 0.37°. Geologically, the wave processes contribute to “instantaneous” processing of the underground relief, while eustatic fluctuations of the sea bottom (regressive-transgressive cycles) lead to slow, simultaneous, or rhythmic changes of the coastal zone. The complex combination of eustatic changes of the sea level with tectonic movements of the earth crust determines the historic development of the coast. The active hydrodynamics of the sub-area is determined by a diverse and complicated relief due to different degrees of resistance of rock systems to wave impact. The southern boundary of the Frangen—Avren coast is occupied by the abrasion-landslide system of Cape Galata, extending to a depth of 7—8 m (Prodanov et al., 2017; 2019).

Area II. Lower Kamchia Area

In morphostructural terms, the Lower Kamchia coast is formed by similar contemporaneous vertical movements of the Bliznashki Block, Lower Kamchia Graben, Shkorpilovtsi Block and Fandakly Depression. Southward to Cape Cherni Nos, the area borders on the Samotino Block. The area is situated between Cape Galata and Cape Cherni Nos to the south. It is 29.20 km long and slightly indented (indentation coefficient 1.08). The coast lies in the SW-NE direction (17°) and is exposed to wave impact from the east, which classifies it as “highly exposed”, WE1 (Wave impact exposure…, 2013; Valchev et al., 2014). According to the geomorphological zoning of the Bulgarian Black Sea coast by Popov and Mishev (1974), the area is divided into two sub-areas with radically different morpho-sculpture and morphologic outline (Figure 7).

Sub-area II.6 from Cape Galata to Cape Paletsa. The current landscape of the coastal morphology is formed at the end of Early Holocene (the new Black Sea) transgression, when erosion processes prevailed. The irregular positive tectonic movements manifested actively after the Pleistocene sedimentation process, and the lithostratigraphic structure have significantly impacted the height of the erosion basis, the dynamics and intensity of the slope processes (Mihova, 1998).

The best preserved of the structural-denudation flats is the Upper Pliocene (Levantine) one, situated between the 105 m and 150 m isohypses, with a surface slightly inclined to the southeast. Of the Upper Pleistocene terrace-structural system, the Chaudian terrace (hypsometric level 85—95 m) and the Paleoeuxine terrace (55—60 m) are preserved and can be seen along the valleys of Sakama Dere and Pasha Dere. The Holocene terrace system is represented by Euxine-Uzunlar (35—40 m) and Karangat terraces which can be seen in the estuary sections of the river valleys (Popov and Mishev, 1974; Keremedchiev, 2004).

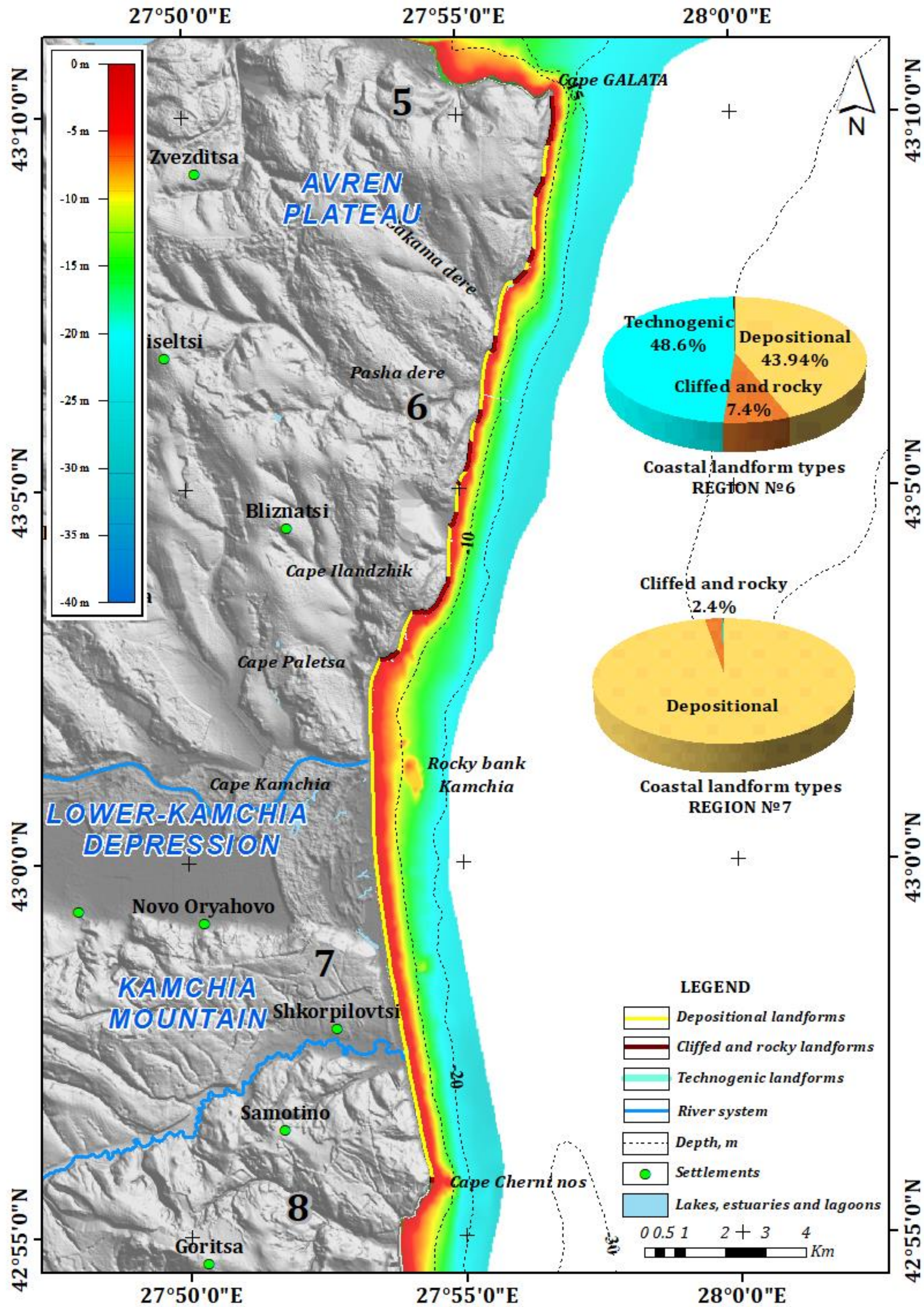
The leading factors for occurrence of landslide and slump processes include the post-Sarmatian tectonic fault processes, irregular positive movements, and seismic processes. The absence of urbanisation in the lower parts of Pasha Dere and Sakama Dere, the sediment inflow from the gullies, and abrasion and landslide component have resulted in prevalence of accumulation forms (74.82 %), while the cliffs account for 6.68 km (24.18 %).

The underwater slope is characterised by a three-slope structural bench relief, conditional on the lithostratigraphic structure, active landslide meridional fault and slump processes, which took place during the Holocene, and the hydrodynamic activity at different sea levels. According to morphometric characteristics, two landslide cycles are differentiated which vary in terms of scope and time of acting. The first landslide cycle is localised at depths from -7 m down to -17.5 m. The second landslide cycle covers the contemporary active shore zone which extends up to 7—8 m depth (Prodanov and Dimitrov, 2015).

The following underwater morpho-structural elements can be seen in front of the abrasion coast: contemporary bench-like structural system which extends from 1 m height on land to -2.5 m, with a width of separate benches from 15—20 m to 40 m. Next come abrasion structural terraces at a depth down to -4 m and a width up to 50 m, delineating the boundaries of the slumped rock masses of the second cycle. Presumably, this landslide and slump system outlines a submerged shoreline, formed during the regressive Phanagorian phase of the sea level (from -4, -5 to -10 m depth) (Keremedchiev, 2004).

There are various morphological elements in front of the shore accumulation forms. A beach front with a slope of up to 0.1° consisting of sands of medium grain size to coarse grain-size comes first. Next comes a contemporary accumulation bench at a depth down to -3 m. In the depth, there is an accumulation slope covered predominantly with fine sands, with a slope gradient from 0.03° to 0.04°. In some places there are terraces of structural origin covered with a sand layer with thickness $\leq$ 0.5 m, ending with a rocky bank delineating the boundary between the first and the second slump cycles. There is a structurally determined terrace in the zone with little hydrodynamic activity which is covered with large grain-size detrital material formed at a lower sea level. Tapering off southwards is a characteristic morphological feature of this area, reaching to -22.5 m depth.

Figure 7: Types of shore forms within the Lower Kamchia Area



Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

Sub-area II.7. Cape Paletsa — Cape Cherni Nos. To the north this sub-area borders at the end of the last height of the Avren Block — Boaza, which carves into the valley of Kamchia River (average gradient 5.12°). In morphometrical terms, the low-lying estuary sections of Kamchia River and Fandakliyska River are clearly expressed, with average gradients of the relief 1.72° and 1.54°, respectively, which separate from the Achamlaka anticlinal section.

The longest beach along the Bulgarian Black Sea Coast (nearly 13 km) Kamchia-Skorpilovtsi beach, is located in the Lower Kamchia depression. The beach is provisionally divided by the estuaries of Kamchia River and Fandakliyska River. A stable dune system is formed at the back side of the beach, and in addition to grey dunes, over the recent years there has been a considerable growth of maritime pine *(Pinus Pinaster*). The low topography and the impact of Kamchia River are conductive to the existence of wetlands, such as Lessen Azmak, Maznia Azmak, etc. There are stable afforested dunes at the back side of the dunes. The beach-dune complex width varies from 160 m to 240 m.

The southern part differs considerably, as at its back part the strip is limited by the eastern slopes of the Karaach Heights. In some places, the beach strip is also accompanied by dune forms at 3—4 m above the sea level. With the exception of sections near Cape Paletsa and Cape Cherni Nos, where cliff forms exist (0.06 %), the remaining coast is represented by accumulation forms (13.35 km; 97.39 %).

The underwater slope is three-sided (1.5°; 0.76°; 0.47°), mostly of accumulation type, and goes down to a 25 m depth. Similarly, to the surface morphology, the underwater abrasion structural forms encircle Cape Paletsa and Cape Cherni Nos. Fragmentary rock reefs can be seen in front of the estuary of Kamchia River and 500 m east of Cape Cherni, namely the Kamchia rock bank and Cape Cherni Nos bank, which are less explored and their genesis is not clear.

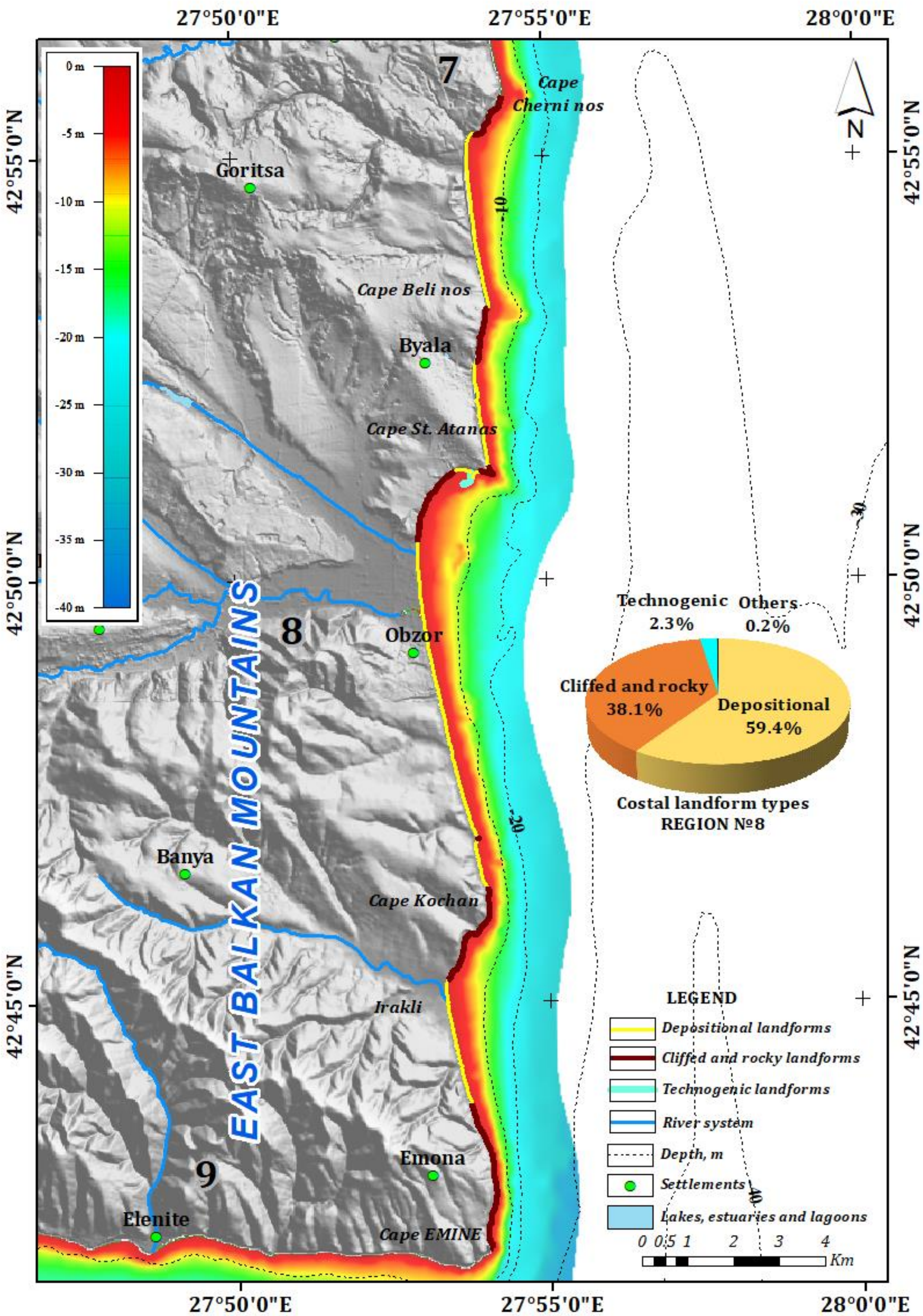
Area III. (*III.8*) Balkan Mountains area

This area covers the eastern parts of the Balkan Mountains coast, between Cape Cherni and Cape Emine. It features a diverse, structural-block structure that includes: Belenska anticline (Samotinski and Belenski blocks); Dyulino depression; Irakli anticline (Obsor and Irakly blocks); Banensko depression and Emona block (Keremedchiev, 2001). Fault and displacement processes in the past are the main cause for that, thus forming the estuaries of Kara Dere, Dvoynitsa River and Vaya River along the eastern Balkan Mountains Area. Popov and Mishev (1974) describe it as a predominantly abrasion section. Modern morphological analyses of the coastline show that at the foot of the cliff sections, clearly visible beaches have formed (59.58 %; 17.03 km). The larger of them are beaches of Kara Dere, Byala, Irakly and Obsor. The area is almost completely exposed to the east, resulting to its extreme exposure to wave impacts (Valchev et al., 2014).

Submerged slump tongues formed in front of the shore slump protrusion sections are a typical morphologic form. They include a shore slope with a gradient of up to 0.13º, a flat structural bench, a depression and an upper structural slope which delineates the boundary of the second slump cycle. Next comes a structural terrace, a depression and a washed away structural bench covered with coarse shell materials with thickness > 0.5 m. At depths of -8.5 m to -13 m, there is a structural terrace which delineates the boundary of a second slump cycle (Prodanov et al., 2017).

The underwater morphology down to the depth of 20 m is represented by a comparatively flat, accumulation slope. To the north of the towns of Byala and Obsor, the slope is with an unchanging gradient of 0.8°, and to the south, after Kara Dere, the bottom becomes steeper (2.78°) and at 20 m depth it changes into an abrasion and accumulation terrace. The abrasion-structural morphology is developed near to the shore, in front of Cape Cherni Nos, Cape Beli, Cape Kochan and Cape Emine.

Figure 8: Types of shore forms within the Balkan Mountains Area

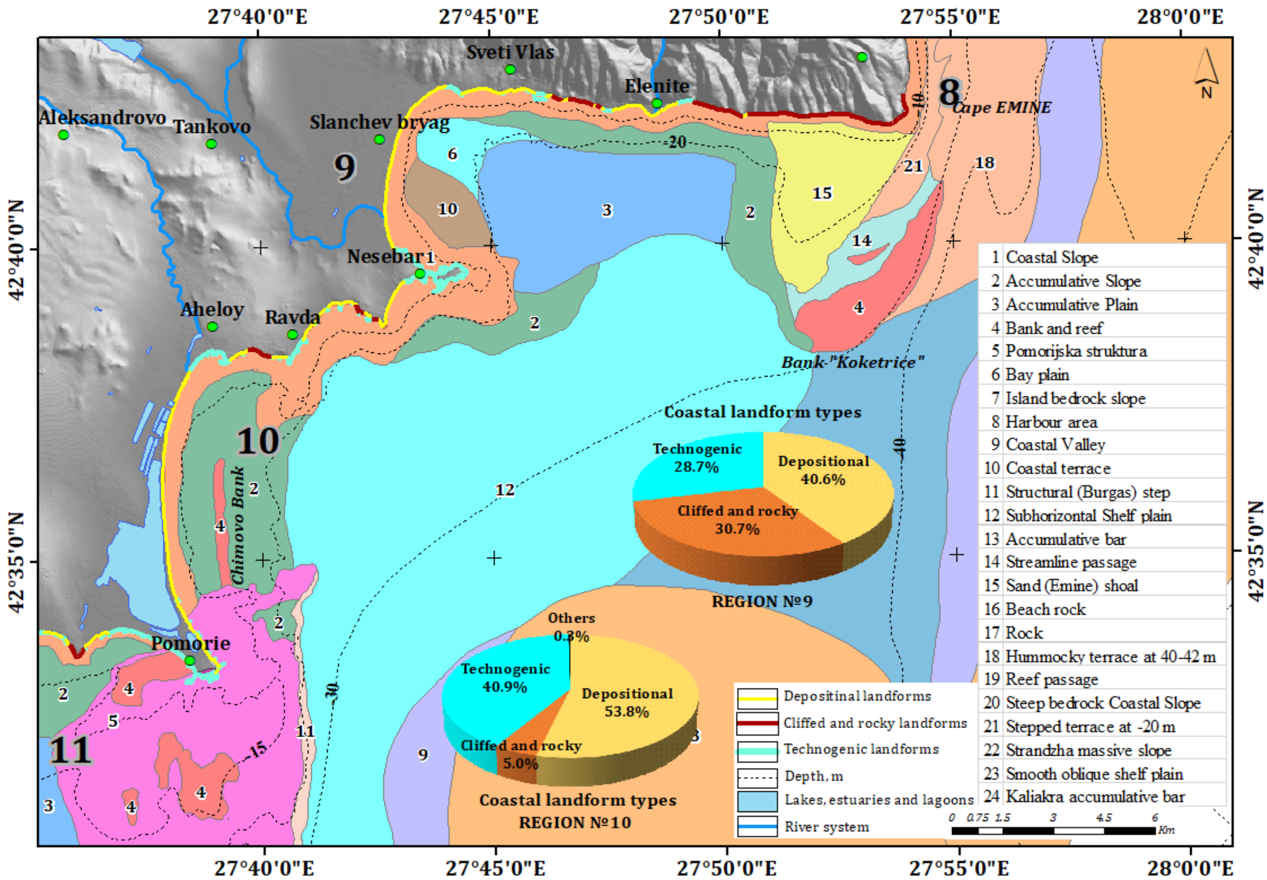


Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

Area IV. Burgas Area

The Burgas area is the most highly indented part of the Bulgarian Black Sea coast (Figures 9 and 10). It includes the coastline between Cape Emine and town of Sozopol, and is 163 km long. The northern and southern parts of the Burgas syncline accommodate the Prosenishki Asymmetric Graben and the Burgas Graben-like Valley, which are superimposed Quaternary depressions with emphasised manifestation of Quaternary and contemporary negative tectonic deformations that determine the low lay and the firth character of the coastal zone. Shore exposure to wave impact varies from high to protected. The coastline is mostly of technogenic nature (42 %), while the natural coast is represented by 34.7 % beach strips and 22.4 % cliff sections.

Figure 9: Types of shore forms within the Northern Burgas area (Cape Emine — town of Pomorie)



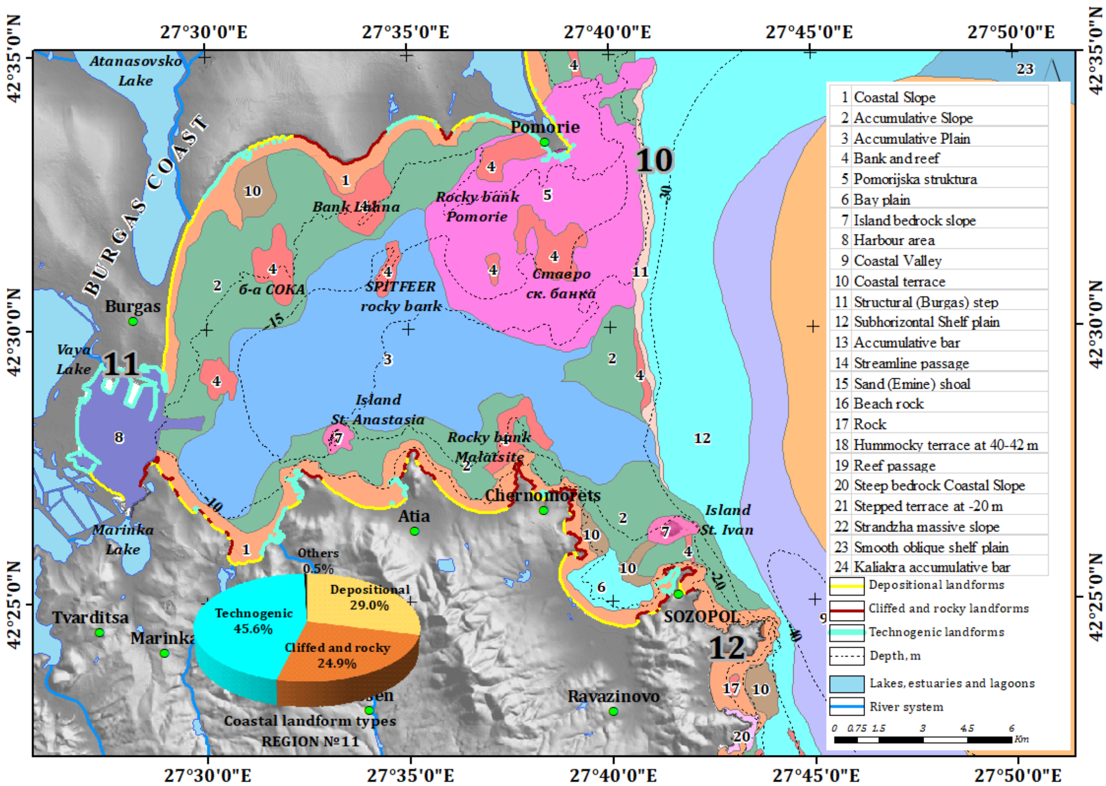
Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

Sub-area IV.9. The area from Cape Emine to the town of Nesebar is composed of the northern parts of the Emona anticline, Prosenishko depression and the anticlinal Nesebar Block. Cliff forms is cut by many small gullies and gorges covering the coast west of Cape Emine to Elenite resort. The western part of the area is closed by the firth of Hadzhiyska River with an area of 19.2 km^2 and a width of 4.9 km (Figure 9). The beach between Slanchev Bryag resort and Nesebar is fully facing east; its length is 5.6 km. Stable dune fields are located at the back parts and have been mostly destroyed by the aggressive construction since the early 1990s.

Depending on the coastal exposure (eastern or southern), the type of substrate and the sediment inflow, the sea bottom within the Nesebar Bay is composed of a shore slope, accumulation slope, sandspit and the clearly morphologically outlined lithified Cockatrise Bank. The shore slope is comparatively steep (1.68°—1.70°) from both north and east and reaches 8—10 m depth. A clearly shaped flat (0.04°) accumulation terrace is in the western part at a depth from 13 to 15 m, and changes into an accumulation slope (0.08°).

The Nesebar Bay falls in the rearmost southern part of the Kamchia—Emine alluvial flow (Dacheva & Cherneva, 1979). Following the sharp change of shore direction from N-S to E-W in the direction to Elenite resort and St. Vlas resort, the flow intensity is considerably reduced, resulting in quiet accumulation within the Bay. The strong shielding role of the Balkan Mountains shore for protection against the prevailing north-eastern winds contributes to the build-up of the Emine sandpit, reaching up to 15 m depth. The Cockatrise bank is located at approximately 5 km to the south of Cape Emine.

Figure 10: Types of shore forms within the Burgas area (town of Pomorie — town of Sozopol)



Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

Sub-area IV.10. from the town of Pomorie to the town of Sozopol. The diagram of the proportion of shore types within the sub-area is radically different from that of the adjacent sub-area 9 to the north of it. Accumulation forms exceed cliff shore and urbanised fortified sections, namely: accumulation forms (53.8 %), technogenic forms (40.9 %) and cliffs (30.7 %). When approaching the Burgas lowland proper, one passes through two peninsulas — Nesebar and Pomorie peninsulas. To the south of Nesebar, the shore is formed by Sarmatian limestones (Popov and Mishev, 1974), which are more resistant to abrasion. The Nesebar—Pomorie coast, in its northern part, is formed of alternating low cliffs facing south and narrow beaches among linear groynes.

To the south of the estuary of Aheloiska River, the low topography is a prerequisite for the formation of a lagoon — the Pomorie Lake with an area of 6 100 m^2. The lake system falls in a NATURA’2000 protected area (BG000620 Pomorie) and this has allowed its natural environment to be protected against anthropogenic impacts. The lake is separated from the sea by a 6.9 km long sandspit. There is a well-differentiated tourist beach eastern coast in the urbanised zone of Pomorie. Ten closely situated line groynes have contributed to the natural formation of small beaches.

The underwater morphology in the shallow part of the sub-area is made up of the two-sided profile of the underwater shore slope. The southern part of the Nesebar Peninsula is dominated by structural-abrasion morphology at a depth down to 10 m. With the gradual increase in depth to the south-east, the structural slope changes over into a flat accumulation plain with an inclination below 0.25°.

The shore slope which faces the Pomorie liman features different morphometric parameters. It is considerably steeper (1.15°) and at 7 m depth changes into an accumulation plain. The Chimovo Bank is interesting from a geological point of view. It is a narrow, linear bank with its long axis in parallel with the Pomorie sandspit. It starts from 14 m depth and rises 5—6 m above the surrounding flat bottom. Supposedly, the rock bank is an ancient, partially lithified sandspit of Phanagorian age (Khrischev et al., 1980). The southmost part of the sub-area is occupied by an abrasion-accumulation bottom with a gradient of 0.25°, limited by the Burgas structural bench at a depth of 26 m (Figure 10).

Sub-area IV.11. from the town of Pomorie to the town of Sozopol. In morpho-structural terms, the area is formed within the boundaries of the Nesebar, Pomorie and Burgas anticlines. The convex shore sections are composed of abrasion-resistant Lower and Middle Sarmatian organogenic limestones, descending to the southeast into Pliocene fine sand and clay materials. The negative Pomoriyska and Atanovska structures and the Poda depression are determined to the southwest by fault displacements which border on the positive Nesebar, Ravda, Sarafovo and Burgas morpho-structural blocks. Some Miocene fine sand and clay materials at Cape Lahna are located highly above the sea level, which confirms the presence of a tectonic displacement that created the depression between the Pomorie block anticline and the Sarafovo block (Popov& Mishev, 1974; Keremedchiev, 2005). The southern coast of the Burgas Bay is formed by the coastal part of the Strandzha anticline.

The coastline of this sub-area is 163 km long. In 1974 Popov and Mishev calculated that the length of the beach strip between Pomorie and the Mandrensko Lake mouth was 12.8 km. In the past 45 years urbanisation and the technogenic burden have reduced this accumulation beach strip by nearly 30 % and it is currently 9.2 km long. Over the years, considerable industrialisation (the ports of Pomorie, Sarafovo, Burgas, Rosenets, Atia, Chernomorets and Sozopol) and the shore consolidation were the main cause for the technogenic component to increase to 45.6 % (49.6 km) of the overall shore length.

Three large lakes—Atanasovsko, Burgasko and Mandrensko—are situated around the coast of Burgas Bay. In the past their nature of low accumulation limans separated them from the sea, however, at present only the Mandrensko Lake has preserved its natural connection with the sea. Beaches facing north-east, with moderate exposure to wave impacts, separated by Cape Chukalya, Cape Atia, Cape Talaskra and Cape Chervenka which are projecting into the sea, alternate along the Mednorid coast (Figure 10).

Underwater morphology. The Burgas Bay is enclosed between the towns of Pomorie and Sozopol and is the largest bay along the Bulgarian Black Sea coast with an area of 210 km^2. Its central part is 19 km long and 11 km wide. The tendency of slanting, horizontally less indented land relief continues also under the water (Keremedchiev, 2001). The Burgas structural bench marks the seaward boundary of the bay at a depth from 26 to 32 m. It is a clearly shaped rock base connecting the Pomorie volcanic structure and the Sozopol Bay, open to the NE. In comparison to the Varna Bay (average seabed gradient of 0.93°), the seabed of the Burgas Bay is even less inclined and descends to the south at an average gradient of 0.47°. This is a combination of a smooth accumulation seabed (between Sarafovo and Mandra lake) and accumulation and abrasion-accumulation southern shore slope reaching 10 m depth (Poda, Chengene Skele, Atia, Vromos coves). The exceptions are the rock banks (Spitfire, Soka, Lahna and Stavro), the Pomoie volcanic structure and the bedrock substructures of St. Anastasia, St. Ivan and St. Petar islands.

Area V. Mednorid—Strandzha Area

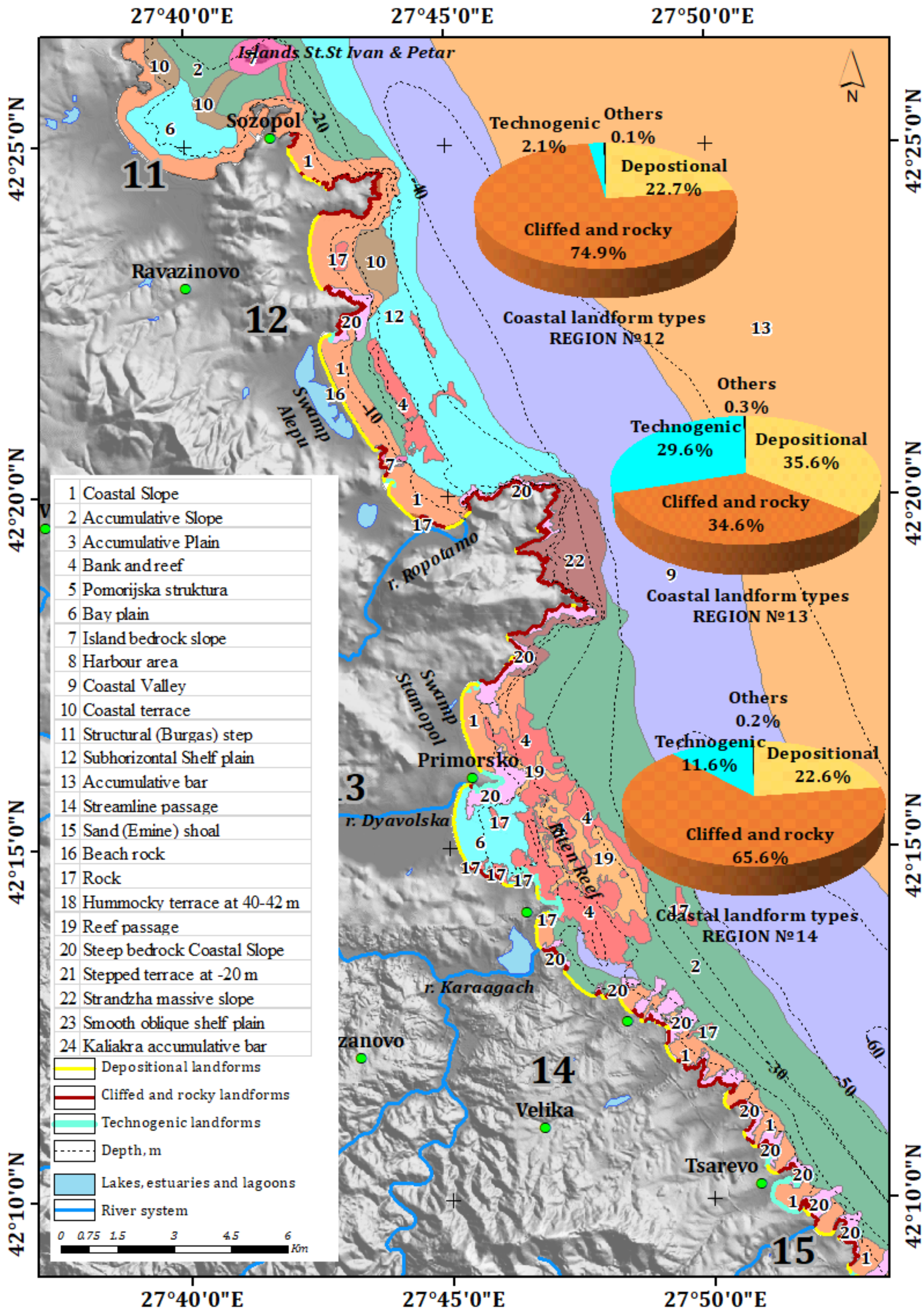
The Southern Bulgarian Black Sea coast was formed in the easternmost parts of the Mednorid and the Strandzha anticlines. Their shores are composed of a typical Upper Cretaceous (Senonian) volcanogenic-sediment system consisting of effusive rocks, such as andesites, andesite tuffs, basalts with interlayers of marine sediments. In some places along the southern coast, the geological composition shows intrusive rocks, such as monzonites, monzodiorites, syenites, monzosyenites, etc. (Petrova et al., 1992; Zhelev., 2006).

The coastline between the Port of Sozopol and the estuary of Rezovska River (the border with the Republic of Turkey) is 137.5 km long. Cliff forms are the most widespread forms — 70.1 % (96 km) in this area, while the accumulation shore of 20 separated beaches is 29.2 km long (21.32 %). The most famous among the larger beaches include Harmanite, Kavatsite, Duni, Arkutino, Ropotamo, Stomoplo, Atliman, Kiten, Koral, Oasis, Arapya, Nestinarka, Ahtopol, Silistar, etc. The technogenic coast is 8.3 % (11 km), formed mostly within Port of Tsarevo, Ahtopol Bay and the port and shore consolidation facilities of Primorsko and Kiten (Figures 11 and 12).

The Mednorid—Strandzha section is characterised by the highest indentation of the coastline — coefficient 1.76 (Keremedchiev, 2001). This comparatively high indentation is created by numerous small peninsulas ending with steep, rocky capes (Cape Kolokita, Cape St. Agalina, Cape Korakya, Cape Maslen Nos) accompanied by huge rock blocks collapsed in front of them (klippes). Faults in the firm volcanic rocks have contributed to their shaping, and abrasion has carved picturesque corridors and caves. Beach strips are shaped in the backshores of small coves, and there are small lagoons (Alepu, Arkutino, Stomoplo) behind some of them. The near-estuary parts of the rivers are typical firths, filled-in with river and marine depositions (Petrova et al. 1992). Well-protected dune systems, predominantly spread in the backshore of the beaches, are a characteristic feature of the Southern Bulgarian Black Sea coast, including: Harmanite, Kavatsite, Duni, Arkutino, Ropotamo, Stomoplo, Atliman, Kiten, Koral, Oasis, Arapya, Nestinarka, Ahtopol, Silistar.

The Strandzha coast covers the area south of the estuary of the Karaagach River and reaches to that of the Rezovska River. It is oriented from north-west to south-east and is extremely exposed to wave impacts. Abrasion shores with deep abrasion-structural underwater profiles and gently inclined accumulation slope are predominant. They are formed near shores with strongly expressed fault tectonics and block-tectonic composition, consisting of abrasion-resistant volcanogenic systems. To the south, an abrasion shore with deep abrasion-structural underwater profiles and gently inclined accumulation slope predominates in shores, featuring clearly manifested micro-tectonic processes, contemporary negative movements, and active selective wave abrasion (Keremedchiev, 2001).

Figure 11: Coast form types within the Mednorid – Strandzh Area (town of Sozopol to town of Tsarevo)



Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

The abrasion morphology is clearly expressed in highly serrated shoreline, small coves, and short and rocky capes, e.g.: Atliman, Arapya, Tsarevo, Ahtopol (Sub-areas Nos 14, 15, 16, 17) (Figure 11 and Figure 12), etc. Small, beautiful beach strips are formed in its concave little coves. The cliff shore accounts for 76 % of the shoreline along the coast. The system of sea terraces reaching 3—4 km in width contribute to the general appearance of the coastal strip. Near-estuary parts of the rivers Dyavolska, Karaagach, Poturnashka, Veleka and Resovska are typical limans, silted with marine and river alluvium, separated from the sea by beach strips. The liman of the Veleka River is a typical example — a swampy terrace with dense forest growth, separated from the sea by a sandspit up to 3.2 m high.

The Mednorid—Strandzha area is provisionally divided (on account of high similarity of the coast in morphostructural terms) into 6 sub-areas because of the diverse morphological composition of the underwater shore slope. The basic difference in the morphologic composition of the Southern Bulgarian coast comes from the alternating abrasion-structural, abrasion-accumulation forms, and purely accumulative landforms.

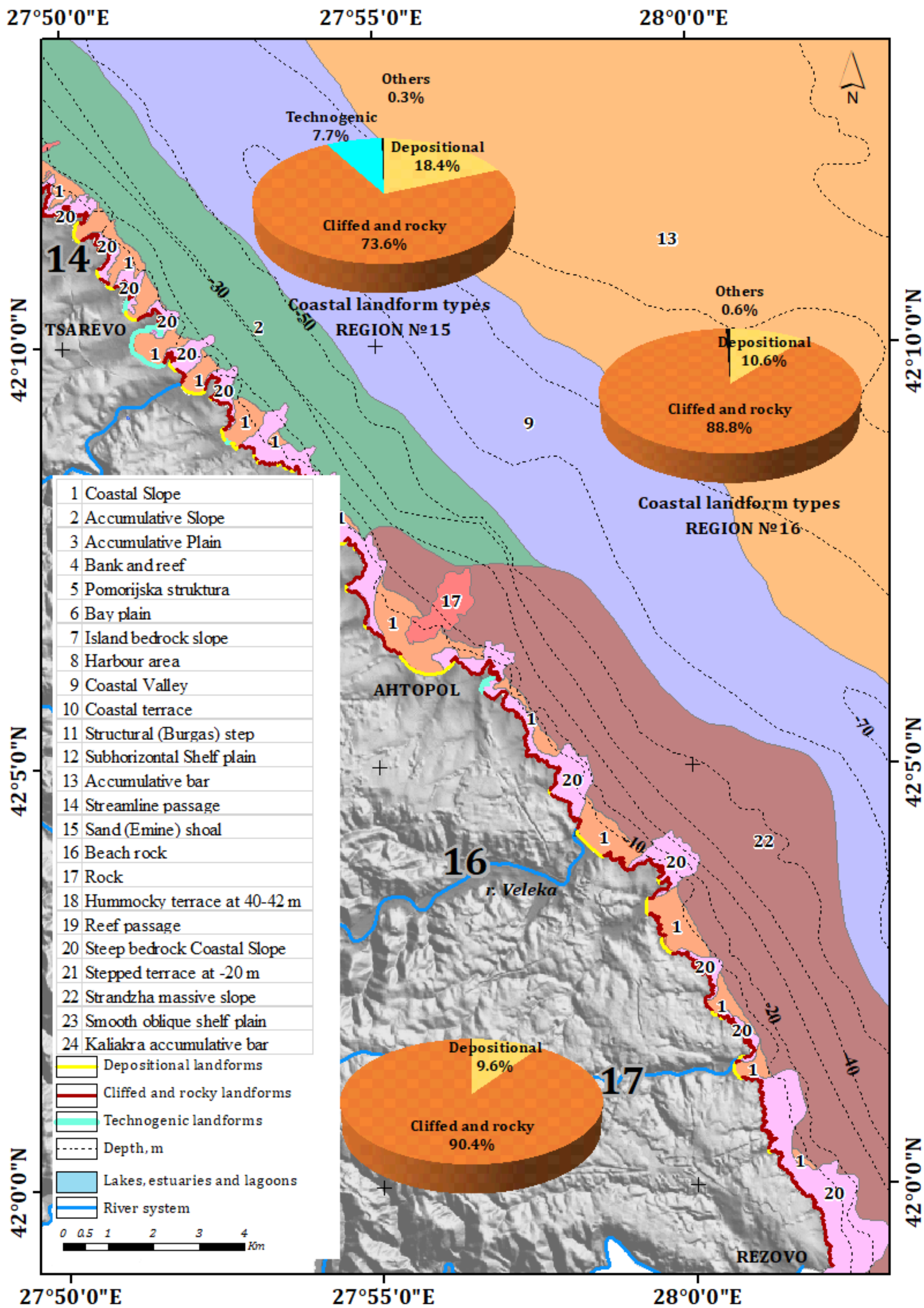
Sub-area No 12 features a shore slope of relatively unruffled nature. The exception includes the abrasion-structural slopes of capes Kolokita and St. Agalina. They can be observed up to 26 m depth in front of the Budzhaka Peninsula and up to 16 m in front of Cape St. Agalina, respectively, to the south of Kavatsite and Smokinya camping sites. The flat accumulation seabed continues to the Ropotamo Bay. The sand seabed is disturbed by a lengthy rock reef (-13 m to -18 m depth) along the direction of the long NW-SE axis (153°), and by occasional rock banks. An abrasion-accumulation slope with a gradient 1.12° covered with slimy sediments encircles Cape Korakya and Cape Maslen Nos.

To the south of Cape Maslen Nos, a clearly expressed block composition, in combination with abrasion-resistant rock foundation, allow for significantly more diverse morphological and lithologic picture of the seabed sediment. The shore slope in front of the Stomoplo Lagoon is a flat sand seabed with a small gradient (less than 1.5°), while the limans of Dyavolska River and Karaagach River are swampy terraces crossed by coastal depressions (valleys), probably paleo-beds of the adjacent rivers.

In sub-area No 13, the Kiten reef is situated in the marine space in front of Primorsko, Kiten and to the south of Lozenets. As a separate morphological form with an area of 8.5 km^2, it is strictly typical only for the northern part of the Strandzha coast. The reef is a natural underwater extension of Cape Konnik and Cape Urodoviza, and its last rock features are at 38 m depth. In some places the reef rises between 8 m and 10 m above the surrounding seabed. Given the background of the surrounding sand seabed (Dimitrov et al., 2019), there is a contrast with the sharp variations of its gradients, reaching up to 23°, which, in some places are almost vertical. The reef is rich in biodiversity.

Sub-areas Nos 14, 15 and 16. The jagged, abrasion-resistant shore plays the main role in the composition of the underwater slope. Alternating small coves with flat sand seabed and abrasion-structural slopes of cape protrusions in the sea is typical for the shores between Kiten and Sinemorets. In the hydrodynamically less active zone beyond the depth of 15 m, the seabed is a shallow sand and slime accumulation slope with a 1.60° gradient. To the south of Ahtopol, the shore slope changes beyond the depth of 10 m into a Strandzha abrasion accumulation slope where strong underwater currents have denuded the primary rocks thus forming numerous rock banks.

Figure 12: Types of shore forms within the Mednorid—Strandzha area (town of Tsarevo — estuary of Zezovska River)



Source: L. Dimitrov, B. Prodanov (MSPRB, 2020)

From an engineering and geological perspective, all cliff areas in the sub-areas within the Dobrudzha—Frangen, Lower Kamchia and Balkan Mountains areas along the Black Sea coast are most heavily affected by landslide, abrasion, and erosion processes. Depending on the specific conditions of a shore section, including also the underwater shore slope, these shore destruction processes are more intensive and destructive, e.g. at Cape Kaliakra, Cape Galata, in the sections between the towns of Kavarna and Balchik, between the village of Kranevo and the Golden Sands resort, etc.

While the divisions of MRDPW maintain a proper register of landslides[4] in accordance with Regulation No RD-02-20-1 of 19.06.2014, it is difficult to find accessible and current data of erosion and abrasion along the Black Sea coast. The General Scheme of Coast Protection along the Bulgarian Black Sea Coast is also not accessible. The Programme developed in 2015— "National programme for preventing and containment of landslides on the territory of the Republic of Bulgaria, erosion and abrasion along the Danube riverside and the Black Sea coast 2015—2020"— remains of optional nature although it states that "resolving the issues involving erosion, abrasion and landslides in Bulgaria will be lasting throughout the whole XXI century due to a great number of landslide, erosion and abrasion sections"[5].

The analysis imposes the general conclusion that the knowledge of the coast inland area is more than satisfactory, while knowledge of the sea water area is fragmentary and incomplete. Therefore, it is imperative to make systematic efforts to bridge in the gaps in our knowledge of this active, intensively exploited richest in biodiversity area. A positive step in this direction will be to restore the suspended monitoring under Descriptor D7 — Changes to hydrographical conditions (under the WFD (Water Framework Directive) and the MSFD (Marine Strategy Framework Directive)), and to resume monitoring of erosion and abrasion processes along the Black Sea coast. It is necessary to unify the terminology and to harmonise the regulations in order to impose clear obligations, responsibilities and control functions on the competent institutions.

2. Continental shelf and deep-water sea

Since 1987, the maritime spaces of the Republic of Bulgaria have been regulated, initially in the Maritime Space Act, and since the 2000 — in the Maritime Space, Inland Waterways and Ports of the Republic of Bulgaria Act (MSIWPRBA)[6]. In accordance with the Act, the Bulgarian maritime spaces cover five legal categories: internal sea waters, territorial sea, contiguous zone, continental shelf and exclusive economic zone (Figure 13).

The internal sea waters are defined by so called "base line" as early as in the Act of 1987 which is determined by coastline and five straight lines (the straight lines connect Cape Kaliakra with Cape Tuzla, Cape Tuzla with Cape Ekrene and Cape St. Constantine with Cape Ilandzhik to the south of

[4] http://gz-varna.mrrb.government.bg/map/
[5] https://www.mrrb.bg/bg/nacionalna-programa-za-prevenciya-i-ogranichavane-na-svlachistata-na-teritoriyata-na-republika-bulgariya-eroziyata-i-abraziyata-po-dunavskoto-i-chernomorskoto-krajbrejie-2015-2020-g-i-dopulnenie-kum-neya-s-novovuzniknali-77199/
[6] SG No 12/11.02.2000, amended and supplemented in SG No 28/29.03.2018

Galata, Cape Emine with Cape Maslen Nos, and Cape Maslen Nos with Cape Rohy to the north of Tsarevo). The internal sea waters of the Republic of Bulgaria are located to the north and west of these lines, along the coastline. The total area of the internal sea waters is 971.871 km^2. These straight lines and the connecting coastline between them are the so-called baseline from which the other four maritime spaces are measured in the direction of open sea.

The territorial sea of the Republic of Bulgaria comprises the 12 nautical miles wide stretch of sea adjacent to the coast and the internal sea waters, measured from the baselines. It is part of the territory of the Republic of Bulgaria, and so are the air space above it, its seabed and its subsoil on which Bulgaria exercises its state sovereignty. The sea waters of the territorial sea cover a total area of 5 336.42 km^2.

The contiguous zone of the Republic of Bulgaria is the belt of sea adjacent to the territorial sea and extending to 24 nautical miles from the baselines.

The United Nations Convention on the Law of the Sea grants the right to every state with access to the sea to regulate its continental shelf and the exclusive economic zone (EEZ) in the maritime space within 200 nautical miles (370 km) measured from its baselines. In this zone, the state does not exercise sovereignty but sovereign rights. The most important sovereign right is that no exploitation of living and non-living resources of the sea waters and seabed is permitted without special authorisation by the owner state.

Bulgaria has not declared its continental shelf due to lack of data of its external border – so called “shelf break”. If new data and knowledge are gained, this border may be duly mapped.

Due to the limited size and specific shape of the Black Sea, none of the Black Sea states is able to establish an EEZ of 200 nautical miles for itself. The 2000 Act provides that “the EEZ of the Republic of Bulgaria extends beyond the limits of the territorial sea to a distance of up to 200 nautical miles from the baselines, from which the breadth of the territorial sea is measured” and that “the external boundaries of the EEZ shall be established by an agreement with the neighbouring adjacent and opposite-lying states in accordance with international law in order to achieve an equitable solution”.

The southern boundary of the marine spaces of Bulgaria is laid down in the Agreement between Bulgaria and Turkey of 4 December 1999 on determination of the boundary in the area of the estuary of Rezovska River/Mutludere and delimitation of the maritime spaces between the two states in the Black Sea. Delimitation of the maritime boundary between Bulgaria and Romania is still under negotiations, without final agreement, although the two states committed themselves to determine boundaries of their maritime spaces by consensus upon their accession to the European Union. The easternmost point of the country’s EEZ is located at about 120 nautical miles (220 km) from the Bulgarian coast, almost in the middle of the Western Black Sea Basin, with coordinates 43º26’40.00”N – 31º20’43”E, as determined by the Agreement between the Republic of Bulgaria and the Republic of Turkey.

It should be underlined that our maritime border with the Republic of Romania, as included in the Global Maritime Boundaries Database (GMBD)[7] and probably registered by the authorised bodies of

[7] Maritime Boundaries Geodatabase, http://www.marineregions.org/gazetteer.php?p=details&id=5672

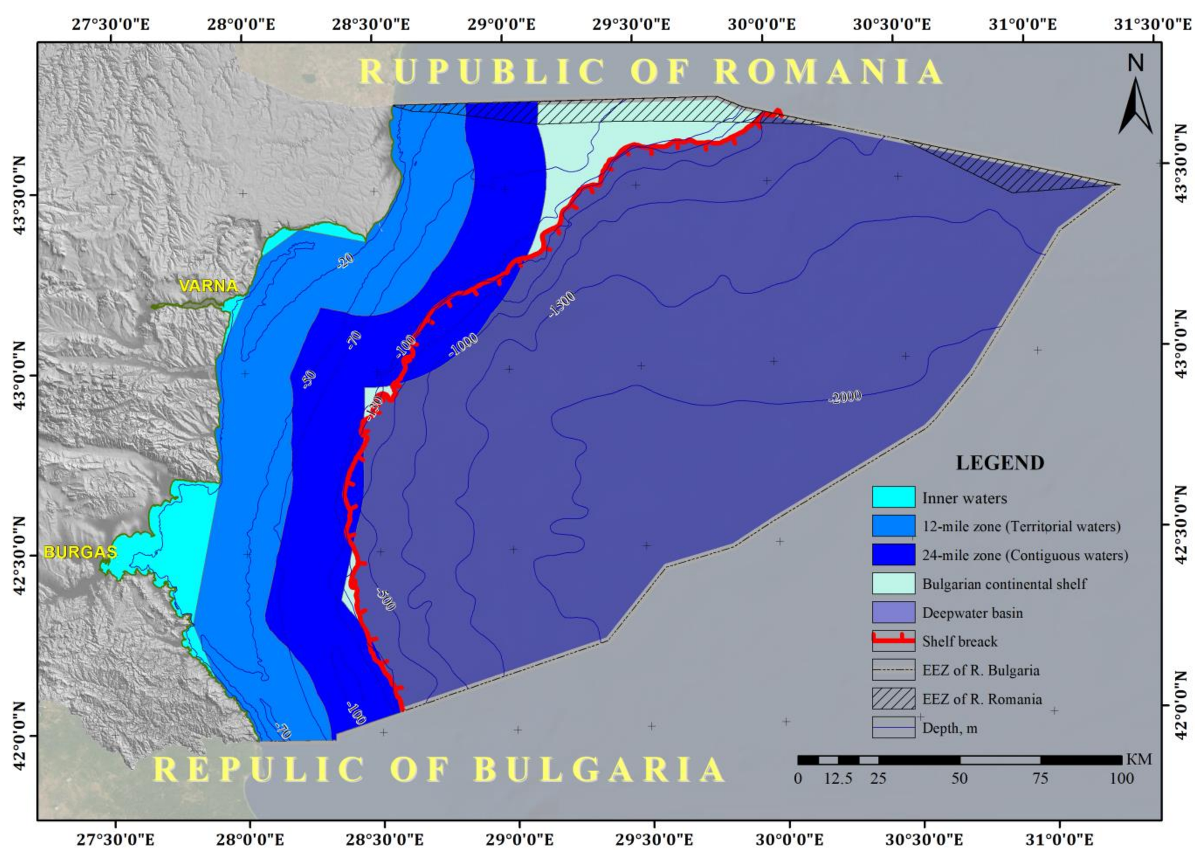
the Republic of Romania, differs essentially from the one adopted by the Bulgarian authorities and is to the detriment of Bulgaria, depriving it of more than 1 000 km^2 (Figure 13).

The total area of sea waters in the Black Sea under the jurisdiction of the Republic of Bulgaria is 32 271 km^2.

In geological and tectonic terms, the region of the Black Sea falls within the Anatolian sector of the Alpine-Himalayan orogenic system and is located between the Eurasian plate (to the north) and the African and Arabian plates (to the south). Supposedly, the Black Sea is a remnant of the ancient Tethys Sea and many authors believe that the basin formation took place in the Late Cretaceous period to Paleogene (Tugolesov et al., 1985; Finetti et al., 1988; Nikishin et al., 2003; Georgiev, 2011).

In terms of earth crust structure, the Black Sea Basin consists of a Western and an Eastern sediment basins divided by the Middle Black Sea Heights (Andrusov—Arhangelski ridge). The Bulgarian EEZ falls fully within the boundaries of the Western Black Sea Basin (WBSB) lying on oceanic and sub-oceanic crust. Therein, four principal geomorphological zones are differentiated, bathymetrically limited at different levels: 1) continental shelf — from the coastal zone down to a depth of 130—140 m; 2) continental slope — down to a depth of about 1 200 m; 3) continental rise — down to a depth of about 1 800 m; and 4) abyssal plain which reaches down to a maximum depth of 2 120 m in the Bulgarian EEZ.

Figure 13: Maritime Space of the Republic of Bulgaria



Source: L. Dimitrov (MSPRB, 2020)

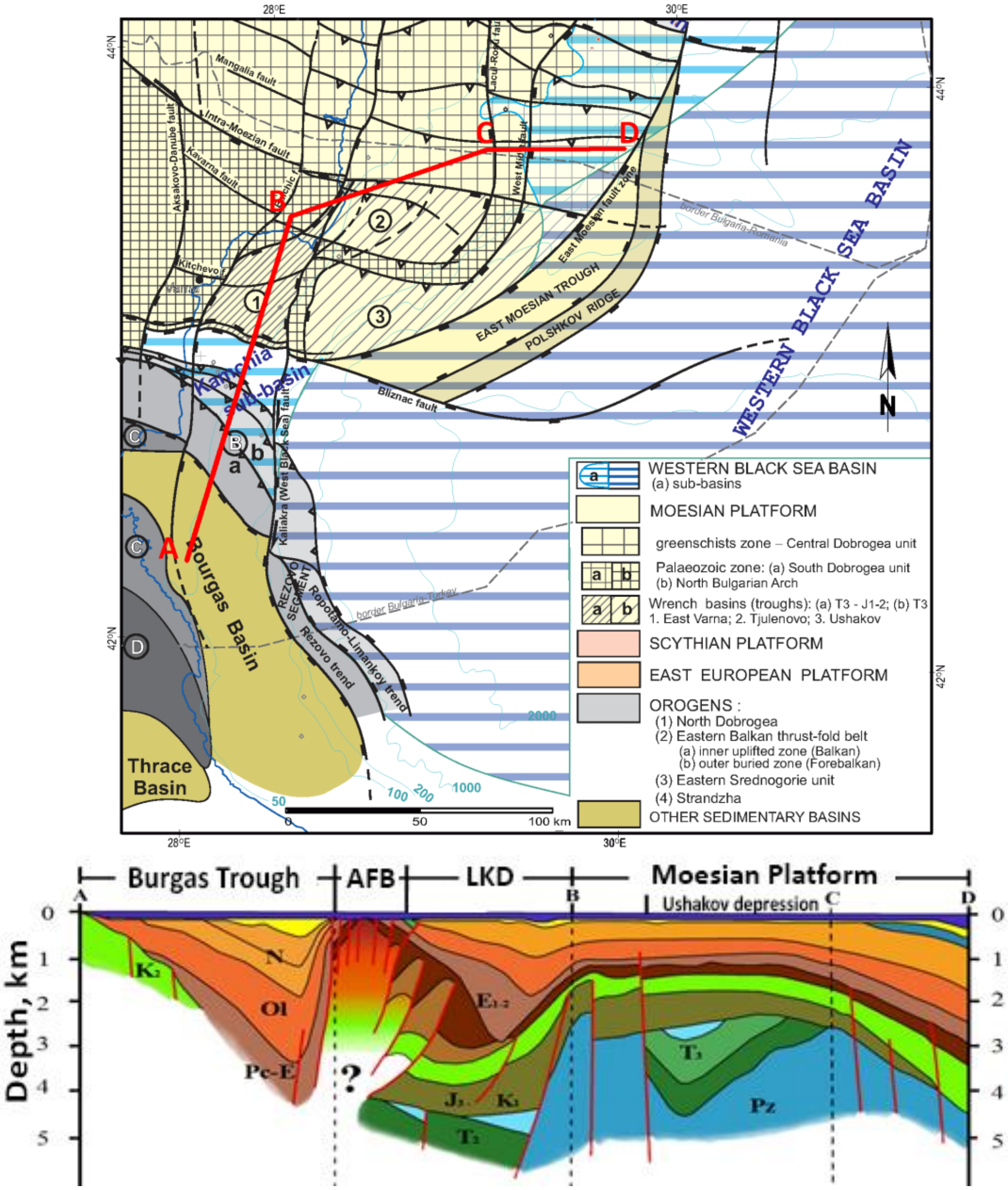
The main tectonic elements on the Bulgarian continental shelf (BCSh) traced from the north to the south include: eastern part of the Moesian platform, Lower Kamchia depression, Eastern Balkan Mountains zone and Srednogorska tectonic zone, the latter being represented by the Burgas depression and the Strandzha Anticlinorium (Krastev and Mihova, 1990; Krastev, 1993; Dimitrov, 2003; Peychev, 2004).

The eastern part of the Moesian platform covers the northern part of the Bulgarian Black Sea coast and extends between the state border with Romania to the north and the valley of the Kamchia River to the south. The lithology of the coast is marked by a Miocene sedimentary system, including limestones, sandstones, marls, clays, etc. The most distinctive feature of the coast within the range of the Dobrudzha Plateau between Cape Sivriburun and Cape Shabla is the loess cover formed in the Quaternary, which in some places exceeds 15 km thickness (Cheshitev et al., 1989). With the exception of the above-mentioned area, the geological composition of the remaining part of Seaside Dobrudzha consists of Sarmatian sediments, which, together with the Miocene sediments, also dominate the lithology of the Frangen Plateau (Popov and Mishev, 1974). To the south, the above Miocene lithostratigraphic elements prevail in the composition of the Avren Plateau (Popov and Mishev, 1974; Cheshitev et al., 1989; Keremedchiev, 2004). The continuation of the Moesian platform is traced along the whole northern shelf and covers a small part of the continental slope (Krastev and Zafirov, 1981; Krastev, 1993; Dimitrov, 2003). It is assigned to pre-Black Sea geological structures which precede the formation of the contemporary Black Sea basin (Krastev, 1993). The natural southern boundary is along the front northern strip of the Fore-Balkan, which is assumed to have developed on the southern descending edge of the Moesian Platform (Bonchev, 1971).

The Lower Kamchia depression is located to the south of the Varna depression where the valleys of Kamchia River and Fandakliyska River are formed. In terms of geotectonics, the Lower Kamchia depression is a transitional zone sharing the Balkan Mountains early folded Alpian system on its eastern part. It is a specific negative tectonic element with characteristic features of a peripheral depression, generated on the southern periphery of the Moesian platform, most likely at the boundary between the Lower and the Middle Eocene (Bonchev, 1986; Dachev et al., 1988; Georgiev, etc. 2004; Georgiev, 2004). It gradually expands to the east and enters the Western Black Sea Basin. It is composed of Valanginian to Upper Cretaceous sediments, topped by thick Neozoic layers. The surface Quaternary sediments are dominated mostly by gravel, sand or clay alluvium and the sediment in the littoral zone is a product of selective erosion and abrasion (Peychev and Dimitrov, 2012).

The eastern nearshore part of the Balkan Mountains early folded megastructure is a system of Upper Cretaceous and Paleogenic sediments, represented by the flysch of Emine suite, sandstones, marls, conglomerates, limestones, etc. (Cheshitev et al., 1989). Bonchev (1975) describes the eastern part of the Balkanides as formed by the Belenska, Lyulinska, Iraklievska, Banyanska and Eminska anticlines. The latter can be traced along the seaside eastern Balkan Mountains area. Modern geological and physical research shows that immediately with its entry into the shelf area the Balkan Mountains structure descends and sharply changes its direction — from W-E to NW-SE towards the Bosporus, and is traced along the shelf edge to the Western Pontides (Bonchev, 1986; Krastev and Mihova, 1990; Nachev, 2002 Krastev, 1993). Its boundaries are marked by regional deep faults — the Fore-Balkan one from the north and the Sub-Balkan one from the south.

Figure 14: Geotectonic composition of the Bulgarian continental shelf and deep sea waters with cross-section according to seismic data



AFB – Alpine Folded Belt; LKD – Lower Kamchian Depression

Source: Georgiev, 2014, with changes

The southern part of the shelf between the coast and the Southwest pericline of the East Balkan Mountains is taken by the Burgas Paleogene-Neogene depression. To the north the depression comes into contact with the Balkan Mountain tectonic zone through the Sub-Balkan deep fault, while to the south it borders on the Strandzha orogenic zone (Bonchev, 1971; Dachev, 1977, Krastev, 1986; Kuprin, 1988). From the direction of the coast it borders a knee-like flexure of the Strandzha anticlinorium marked in the littoral area by Upper Cretaceous volcanogenic rocks (Kuprin, 1988; Vassilev & Dimitrov, 2003; Georgiev, 2011). In terms of tectonics, the Burgas depression belongs to the Srednogorie movable belt (Dachev et al., 1988) and is superimposed on part of the northeastern wing of the Burgas synclinorium (Krastev et al., 1980; Krastev, 1986).

The southern coastal zone is situated in the coastal sections of the Burgas lowland and the alternating anticlines and synclines of the nearshore parts of Medni Rid and Strandzha. The zone itself is linear Meso-Alpine arc orogenic zone laid in the Upper Cretaceous to the south of the Balkanides (Gochev, 1991). Dislocated volcanogenic sedimentary Senonian rocks, covered by thin assise of earlier Upper Cretaceous sandy limestones are underlying the Burgas depression. The rocks of the two series are laid bare on the coast and can be traced along the shore strip to the south of the city of Burgas. Their top sharply declines from the shore to the E-NE, reaching depths of about 3.5—4 km in the axial zone of the depression. The sedimentary space, thus formed, is filled with diverse series of Eocene to Quaternary sedimentary rocks with overall thickness varying from tens of metres to more than 3.5 km in its deepest south-eastern part. Paleogenic sediments account for more than half of that thickness (Dimitrov, 2003).

The combination of the continental slope and the continental rise is due to their evolutionary character which is explained as a “late Black Sea” structural-geomorphological element of the subaqueous part of the continental margin (Krastev, 1993). The seaward peripheries of the Moesian Plate (East Moesian Monocline), the Lower Kamchia Depression and the eastern wing of the Balkanides continue beyond the boundaries of the shelf, covering a larger part of the continental slope. Paleogene-Quaternary sediments of various tectonic elements feature a similar structure. Characteristic features include flexural folding in the beginning, not very deep disintegration benches in the lower parts of the cross-section, and wedge-shaped filling typical of non-compensated basins.

The thickness of the Paleogene-Quaternary system varies at the beginning of the continental slope from less than 1 km in the area of the Moesian Plate and the Balkanides up to 3—4 km in the area of the Lower Kamchia depression. Downwards along the slope, its thickness increases gradually to become equal at its foothill to up to about 7—8 km. It exceeds 12 km in the Western Black Sea deep sea water basin, and Paleogene sediments account for more than half of this thickness, while the thickness of the Quaternary sediments exceeds 600 m (Melnik et al., 1990). The entire sedimentary system is composed of deep-sea, hemipelagic sediments with uniform lithological composition but with significant variations in the content of organic matter influenced by different Paleo-climatic conditions (Sorikin et al., 1990). These are mostly siderite and carbonate clays with isolated thin lenses and interlayers of alternating aleurilites, fine sands of likely turbidite nature (Dimitrov, 2003).

Despite of the great variety of heterogeneous, heterochronous and multi-ordinal geological and tectonic elements which compose the subsoils of the Bulgarian continental shelf, they have no reflection in its contemporary relief, with the exception of the few active faults in the form of structural benches on the seabed, mainly in the southern shelf and along its periphery. The contemporary lay of the Bulgarian continental shelf is formed, first of all, by the impact of hydrodynamic processes, mostly during the Holocene, after its connection with the World Ocean was restored, and some relict landforms formed during the low sea level stand of the last Glacial Age (the dune field in the shelf periphery).

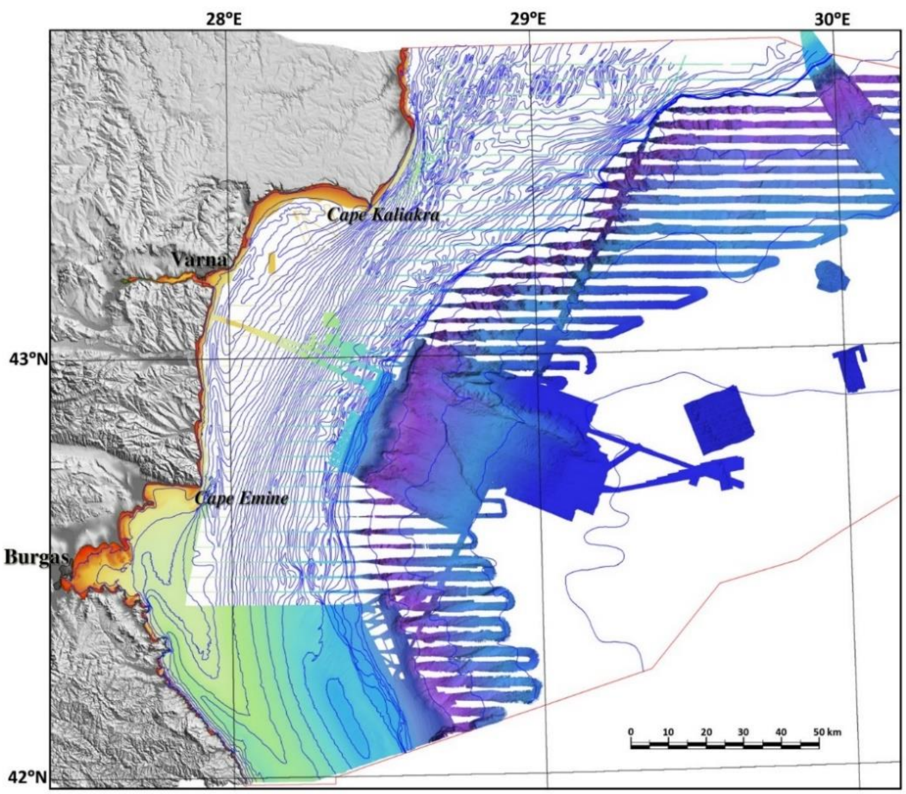
The geomorphology of the Bulgarian continental shelf was subject of intensive exploration in the period 1975—1990 by Bulgarian and Soviet specialists (Geology and Hydrology of the Western Part of the Black Sea, 1979; Sorokin et al., 1980; Sorokin, 1984; Kuprin et al., 1980; Popov and Mishev, 1984(b); Krishnev & Shopov, 1987; Mihova, 1989; Krastev and Mihova, 1990). The geomorphological mapping of the Bulgarian continental shelf started (Fedorov, 1963; Lilienberg et al., 1964; Parlichev and Markov, 1971, 1972; Parlichev and Petrov, 1974; Lilienberg, 1966, 1970; Mishev et al., 1971), and the geomorphological maps of Parlichev (1987) with a scale of 1 : 200 000 and Krastev (1992) with a scale of 1 : 500 000 were their top achievement. Some of the main morphological forms in these maps were described and mapped surprisingly truthfully, such as the two accumulation bars in the shelf central zone, the Kaliakra and Emine bars and their adjacent nearshore valleys. Others, such as the peripheral ridges and a number of hypsometrically positioned terraces with “unclear genesis” and “submerged cliffs”, were wrongly outlined in terms of both the morphology and the spatial range and a wrong interpretation of their genesis was provided. Some forms were fully omitted, basically due to insufficient data or lack thereof, such as the whole coastal area, which was marked as “nearshore slope” without type classification. The Burgas Bay is not separated as an independent morphological structural element and its connection with the shelf terrace is not shown.

A new geomorphological map of the Bulgarian continental shelf with a scale of 1 : 100 000 was made in the period 2017—2019 by a team of the IO—BAS within the framework of Work Project 4, Quaternary Geology and Morphology Project, of the European Marine Observation and Data Network — Lot 2 Geology (EMODnet Geology). The boundaries of the main morphological forms, such as the two accumulation bars in the central shelf area, the Kaliakra and Emine bars and their adjacent nearshore valleys were outlined. New zones and forms were defined and duly mapped instead of other zones and forms which were completely wrong in terms of both outlining their morphology and their spatial range and of the interpretation of their genesis. The lack of data of the coastal zone and the Burgas Bay was resolved by adding detailed geomorphological mapping. The shelf — continental slope boundary was determined in greater detail. New morphological elements, such as the Kaliakra barrier bank, gas pockmarks at the entrance of the Burgas Bay and some elongated depressions in the upper part of the continental slope, were discovered and described. The morphology of the Cockatrise bank was mapped in detail.

Composite digital terrain models (DTM) of the seabed landscape drawn up according to data of multibeam echo sounding systems have been used as basis for geomorphological mapping. DTMs feature resolution 14 m and better, cover the entire coastal area down to depth of about 20 m, the Southern Bulgarian shelf and parts of the Central and Northern shelf, as well as a series of bathymetric lines crossing the shelf from the west to the east and running along a regular network at 4 km interval (Figure 2.2 —15). DTMs were made by IO experts in fulfilment of arrangements under the EMODnet Bathymetry Project (Thematic Lot 1). To ensure a better characterisation of separate morphological zones, bathymetric contours have been interpolated and digitalised at 2 m interval from the shore (zero line) down to 130 m depth on the basis of a set of navigation maps with various scales. The morphometric analysis includes analysis of the slopes and their direction, spatial localisation of the forms, their continuity, flat or hilly nature etc.

The morphology of the Bulgarian continental shelf is described below on the basis of a new geomorphological map with a scale of 1 : 100 000. It is characterised as a comparatively shallow part of the seabed (average depth about 130 m), and in separate sections it reaches up to 200 m; it is low-fragmented abrasion-accumulation flat situated between the shoreline and the boundary of the continental slope (Krastev, 1993; Dimitrov, et al., 2013(a). The Bulgarian continental shelf is a marine space gradually narrowing from north to south with a width along the parallel of 90—100 km to the north along the maritime boundary with the Republic of Romania, 60—70 km in its central parts at the parallel of the town of Varna, and 45—50 km opposite the mouth of the Rezovska River to the south. Its area within these boundaries is 12 194 km^2. The end of the shelf and the beginning of the slope are expressed either in a clear knee-shaped shelf break, or by a sloping convex shape, but always by a definite change in the seabed gradient — from the comparatively low regional gradient of the shelf plane (within the range of 0.1—0.3°) up to 3-5° and even tens of degrees of the continental slope gradient. The boundary between geomorphological elements can be observed along the underwater front edge of the peripheral shelf terrace at depths of 130—170 m, nonetheless, at greater depths sharper bends may occur in the seabed landscape. The continental slope is situated arc-wise to the east of this boundary (Figure 16).

Figure 15: Bathymetric model of the Bulgarian Exclusive Economic Zone in the Black Sea. The colour grid includes composite DTMs and area surveys by multibeam echo sounding system. The red line shows the boundary of the Bulgarian EEZ in the Black Sea

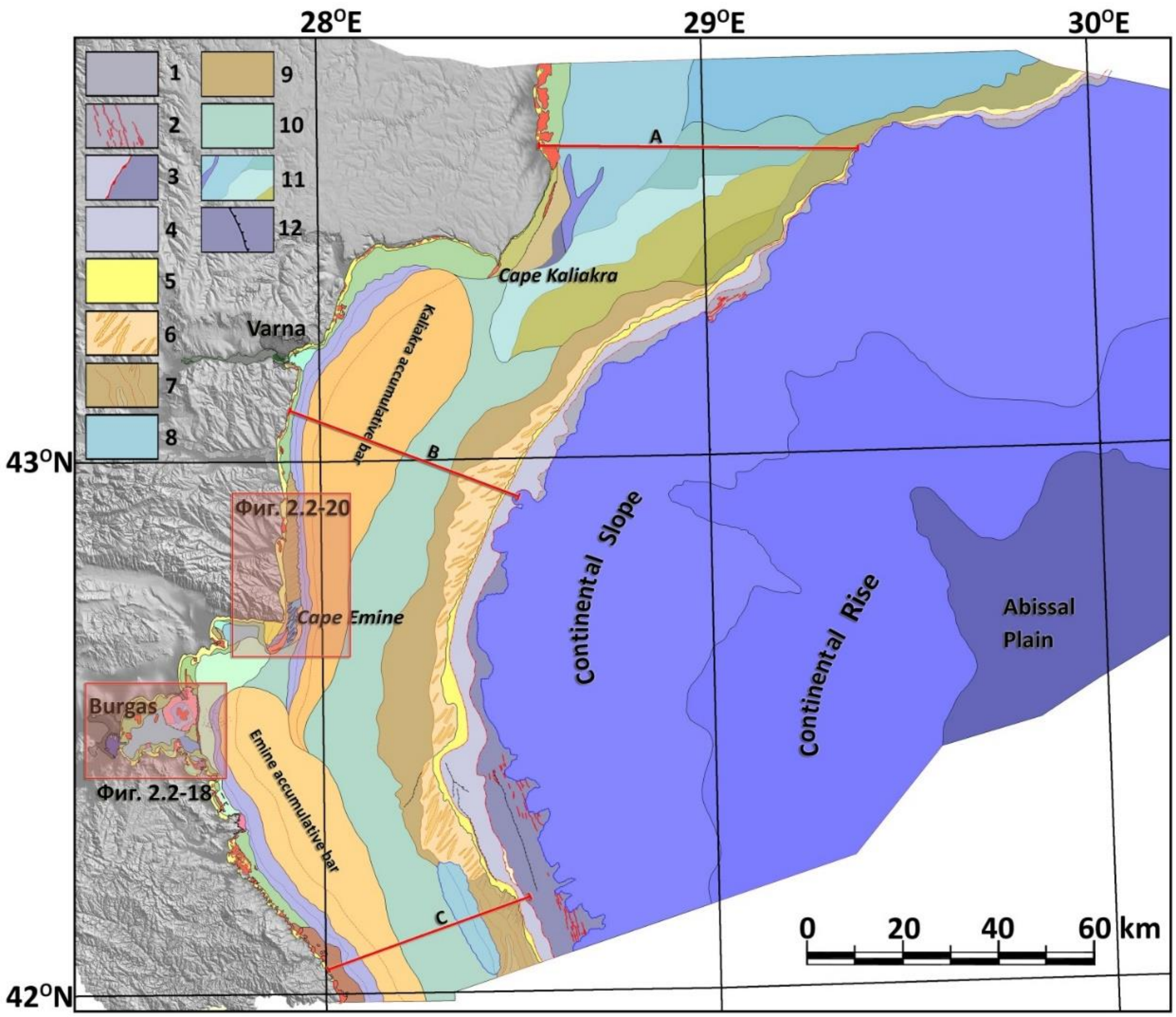


Source: L. Dimitrov (MSPRB, 2020)

In geomorphological terms, three main areas are differentiated within the shelf: **nearshore, central and peripheral** (Figures 2.2—16), each having its own peculiarities (Krastev et al., 1984). The main distinctive feature between the zones comes from the different hydrodynamic environment, as well as from different occurrence of abrasion and accumulation processes, i.e. the specific morphology and geological pattern of the seabed is most directly dependent on contemporary sedimentation and mass movement processes taking place in various shelf zones (Dimitrov, 2003; Kozhuharov et al., 2010; Dimitrov et al., 2013).

The meridional zoning of the shelf is determined by hydrological conditions along the coast; the following zones are differentiated: northern shelf — from the border with the Republic of Romania to the north to the Varna parallel to the south, with prevailing abrasion processes, and southern shelf — to the border with the Republic of Turkey, with prevailing accumulation forms of the seabed landscape.

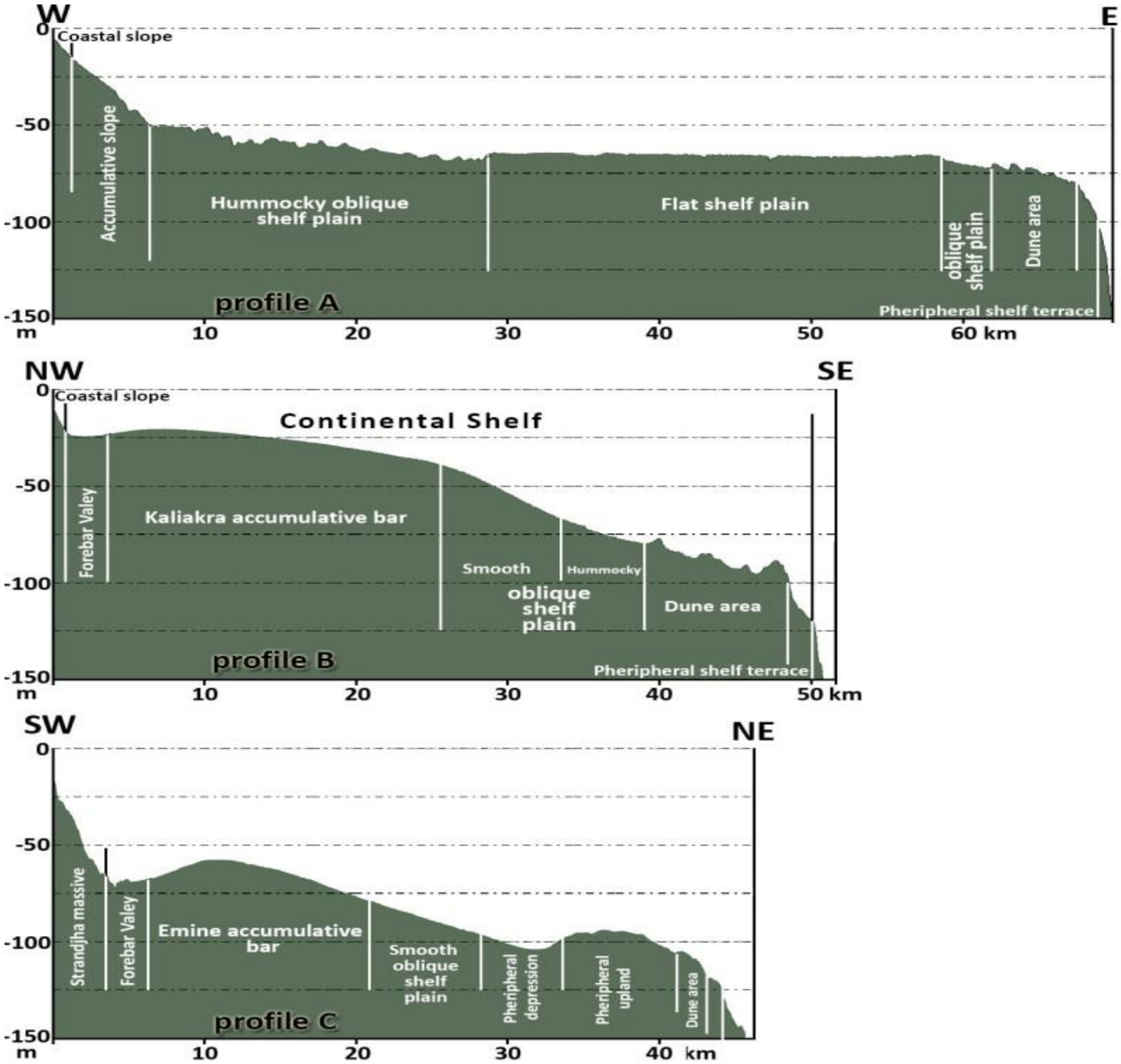
Figure 16: Geomorphological map of the Bulgarian Black Sea shelf



Legend: *Geomorphological elements (from deep sea to the shore):*
1. Even sloping flat at the onset of the continental slope with landslide ditches; **2.** Shelf — continental slope boundary; **3.** Peripheral shelf terrace; **4.** Underwater paleoshore zone; **5.** Area with relict dunes and individual dunes; **6.** Peripheral rising with identified ridge axes, a valley and dunes; **7.** Peripheral shelf depression; **8.** Uneven sloping shelf flat; **9.** Even sloping shelf flat; **10.** Various morphological elements of the Northern shelf; **11.** Active faults (projected on the seabed). *The other symbols are the same as on* Figure 18 *and* Figure 20.

Source: L. Dimitrov (MSPRB, 2020)

Figure 17: Characteristic profiles of the seabed landscape in the Northern (upper side), Central (in the middle) and Southern shelf (bottom side)

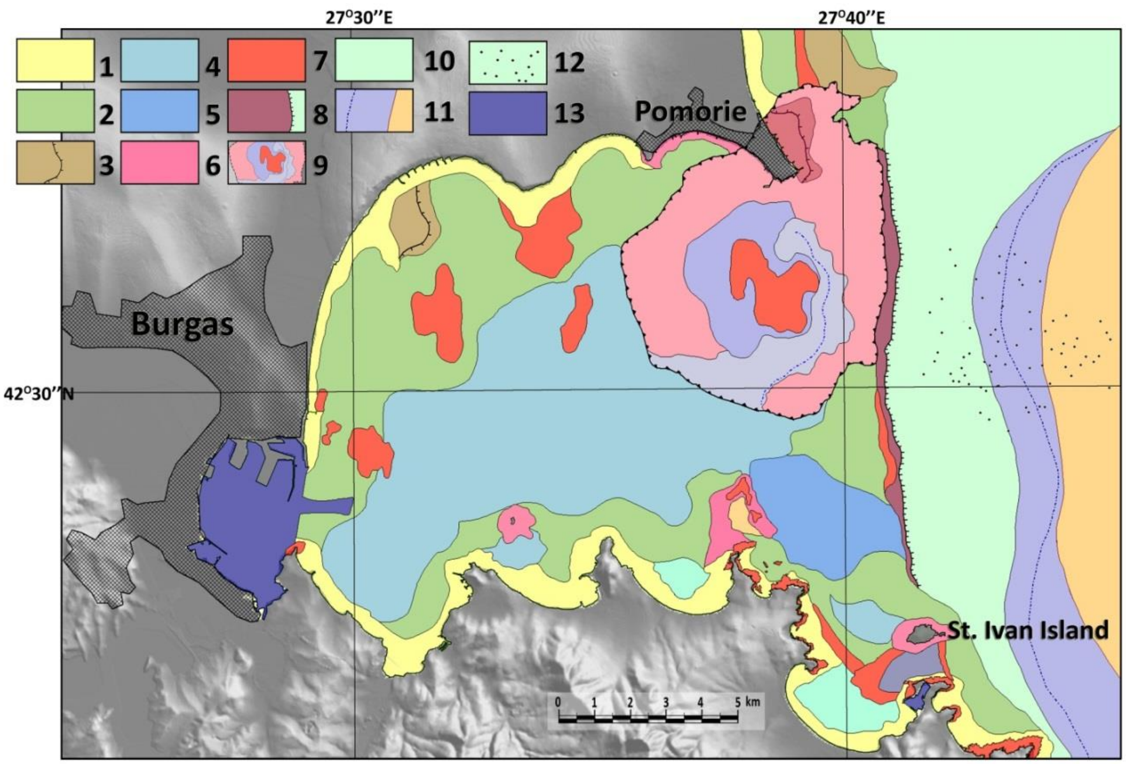


Note: The location of the profiles is shown on Figure 16. The characteristic reduction of the shelf length from north to south and the radically different morphology of the Northern shelf can be clearly discerned.

Source: L. Dimitrov (MSPRB, 2020)

The Burgas Bay takes a special place in the geomorphology of the Bulgarian continental shelf. It is situated between the towns of Pomorie and Sozopol and is the largest bay along the Bulgarian Black Sea coast with an area of 210 km^2. The latest studies indicate that in terms of its geomorphological features its range is larger, with its eastern boundary passing along the meridian of Sozopol. It is marked by a steep structural bench (the Burgas structural bench) at depth from 26 m to 32 m, probably of tectonic origin, extending in the direction north–south and with a difference in height levels of 6—8 m in its central parts and more than 20 m in the area of Pomorie (Figures 18 and 19). It has a clearly shaped rock base connecting the Pomorie volcanic structure to the north and the Sozopol Bay which is open to the northeast. In many places in its upper part the bench is complicated by comparatively low (3—5 m) linear rock banks. The bench is a structural boundary of primary importance, separating the Burgas Bay from the central shelf plain, and defines the bay as an independent element of the morphological structure.

Figure 18: Geomorphological map of the Burgas Bay



Legend:

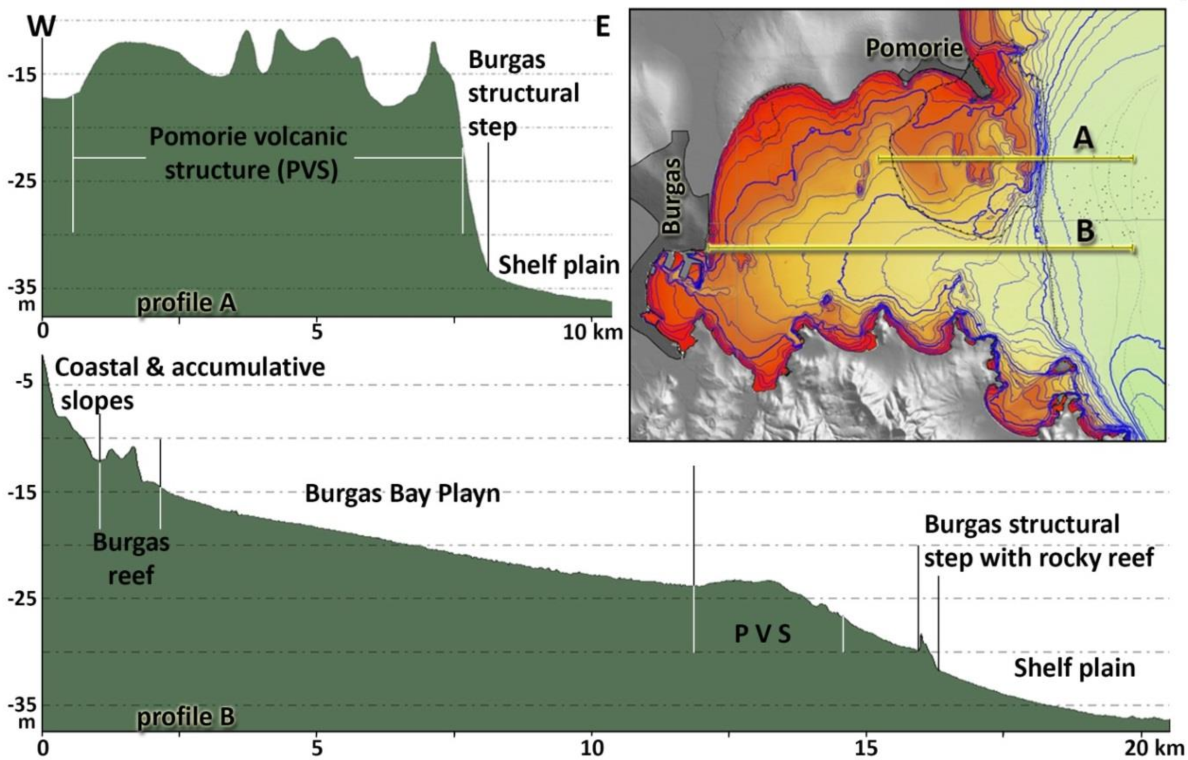
Geomorphological elements:

1. Shore slope; **2.** Accumulation slope; **3.** Nearshore flat terraces; **4.** Sloped accumulation flats of the Burgas Bay; **5.** Bevelled flats; **6.** Base rock slopes; **7.** Rock reefs and banks; **8.** Burgas structural bench; **9.** Pomorie volcanic structure; **10.** Even shelf flat; **11.** Accumulation ridge (Emine ridge) and a fore-ridge valley; **12.** Pockmarks; **13.** Port zone.

Source: L. Dimitrov (MSPRB, 2020)

The tendency of slanting, low indented land relief continues also under the water. In comparison to the Varna Bay (average seabed gradient of 0.93°), the seabed of the Burgas Bay is even less inclined and descends to the south at an average gradient of 0.47°. It features many not very well explored rock banks with unclear genesis (Burgas reef, Spitfire, Soka, Lahna and Stavro, etc.). The seabed of the Burgas Bay may be described as a combination of smooth accumulation seabed and accumulation and abrasion-accumulation southern shore slope, reaching 10 m depth. The exception are the rock banks, the abrasion-accumulation Pomorie volcanic structure, and the bedrock substructure of the islands St. Anastasia, St. Ivan and St. Petar.

Figure 19: Seabed landscape by profile



Note: Profile **A** (Pomorie volcanic structure) and profile **B** (Burgas Bay) Locations are shown in the top right-hand corner of the bathymetric map of the Burgas Bay.

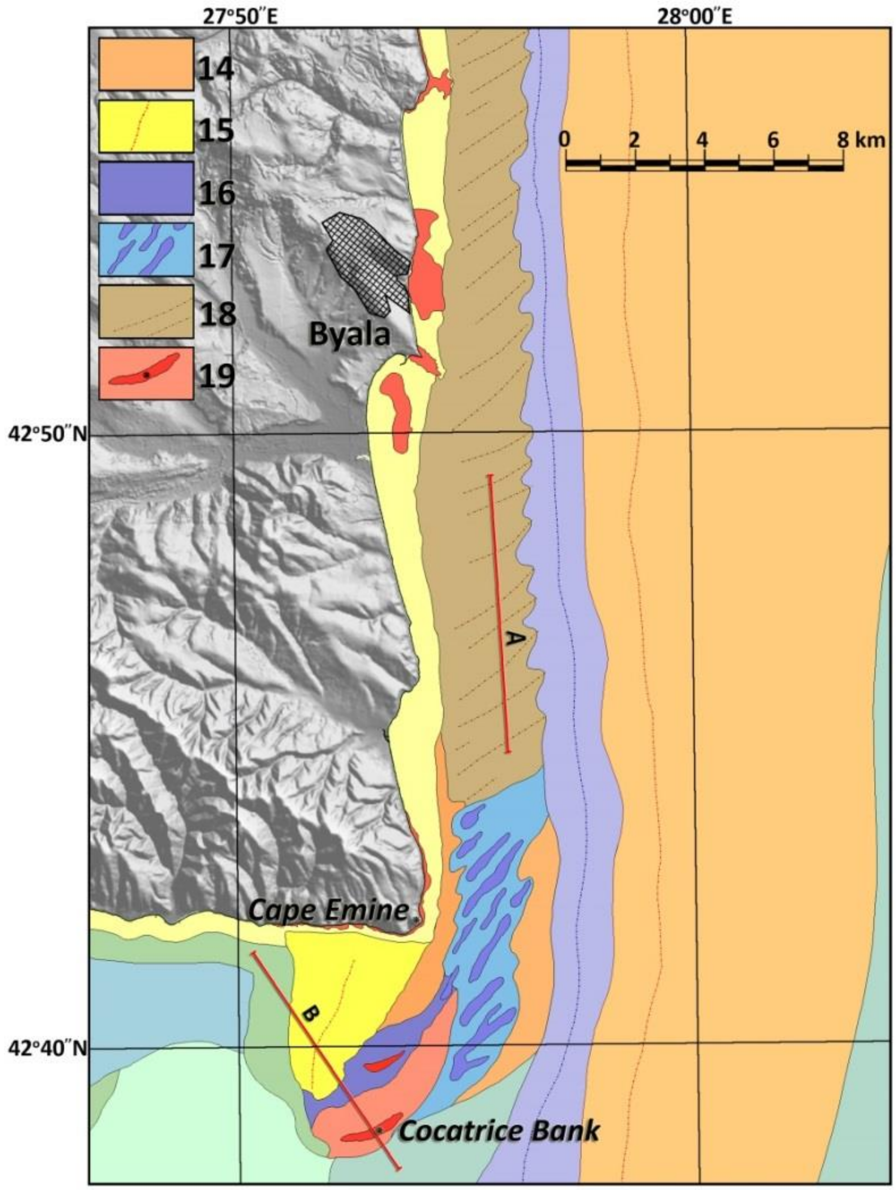
Source: L. Dimitrov (MSPRB, 2020)

Pomorie volcanic structure is situated immediately to the south of the town of Pomorie and covers the entire Pomorie Peninsula (Figures 18 and 19). It has a typical conical shape with a well outlined caldera with a central rise which marks the main magma outflow (Figures 18 and 19). An internal valley is located to the southwest of the central rise. It opens the caldera in the central parts of the Burgas Bay and through it lava probably ran out, thus forming a rock apron.

A typical accumulation form—the Emine sandspit—is shaped to the south of the steep slopes of Cape Emine due to the sharp change in the coastline direction from N-NE to almost E-W. Its axis is directed from northeast to northwest, and it is 5 km long and 3.5 km wide at its biggest width (Figures 20 and 21). It is composed mostly of fine to coarse sands and was formed in the latest 3.5—4 thousand years. Koketrays bank, composed completely of Holocene sediments, is situated to the south of it (Shopov, V. 1983). It features a very steep southeastern slope and its depth ranges from 40—42 m at its base to 12—15 m depth at its crest. The top of the bank erodes continuously, changing from 9.15 m depth when it was discovered in 1987 to 16.2 m registered in 2010 during the 2010 area measurements.

A zone of development of sediment waves, indicating an intensive near-bottom current, is located in the area from the Kamchia estuary to the Cockatrise bank next to the shore slope (Figure 20). Its profile is typical, undulating and with less slanting northern and steep southern slope, therefore a conclusion may be made about the current direction — from north to south.

Figure 20: Geomorphological map of the area from the town of Byala to Cape Emine



Legend
Geomorphological elements:
14. Levelled terraces at depths of 20—21 m and 39—41 m
15. Emine sandspit
16. Passage valley between Emine sandspit and Koketrays bank
17. Zone with ditches carved by intensive near-bottom current
18. Sediment waves zone with marked ridges
19. Koketrays bank with a marked ridge

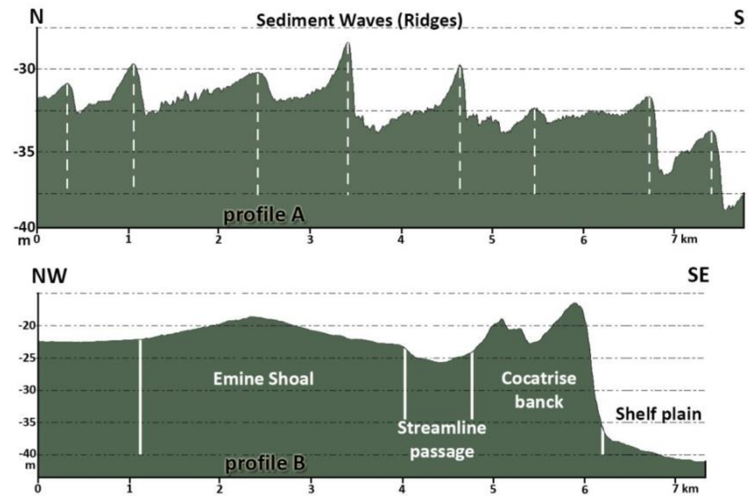
Source: L. Dimitrov (MSPRB, 2020)

Figure 21 clearly shows the undulating (saw-tooth shaped) sediment waves and the steep southeastern slope of the Cockatrise bank.

The following elements can be differentiated when entering the central zone of the Southern shelf: fore-ridge depression; accumulation bars; inclined flat shelf and peripheral shelf zone.

The fore-ridge depression consists of two independent valleys which vary in their width (Figure 16). The northern one begins from the Balchik Bay and can be traced southwards to the parallel of Pomorie at depths of 42—44 m. The southern one is formed immediately in front of the Burgas structural bench and continues to the south in the maritime space of the Republic of Turkey, where its fairway reaches sea depth of 75 m. A sprawly, U-shape form in the beginning that changes into a sharp V-shape at the centre and further on is characteristic for the two fore-ridge depressions.

Figure 21: Seabed landscape by profile



Profile **A** (Sediment waves)

Profile **B** (Emine shoal and Cockatrise bank)

See Figure 20 for location

Source: L. Dimitrov (MSPRB, 2020)

Kilometres-large accumulation bars are located to the east of the fore-ridge depressions: the Kaliakra one (to the south of Cape Kaliakra); the Emine one (to the south of Cape Emine), covering fully the central shelf areas. These large accumulation forms were generated during the Holocene by the main Black Sea current carrying sediments, mostly, from the delta of the Danube. Thickness in their central parts reaches 40 m in the Kaliakra bar and more than 20 m in the Emine one. To the north of Cape Kaliakra such ridges are completely absent. The Kaliakra bar begins from the Balchik Bay and joins the Emine bar in front of the Burgas Bay. Its length is more than 100 km; its width is 4—12 km. Southward, the Emine bar continues along the Turkish coast, and in the Bulgarian part it is 72 km long, 6—12 km wide and 4—18 m high. A specific structural feature of the two ridges is that they have an asymmetric cross profile — a steep western slope and an even, shallow eastern slope. Their survey by geophysical means is difficult because the two structures contain gas-saturated sediments, Roquefort type, which create acoustic shade and screen all underlying horizons.

The eastern slopes of the two ridges smoothly change into slanting flat shelf, the landscape of which in the adjacent zone was levelled by the same sedimentation processes that formed the accumulation ridges, but with less intensity. In seaward direction, the processes of intensive sedimentation are abating and the seabed relief at 75—85 m depth is uneven, hilly, seemingly as a legacy from pre-Holocene landscape. This is clearly seen in the zone of the peripheral dune field where the dunes formed by the low sea level stand of -120 m in the latest Ice Age are only draped by contemporary sediments with thickness less than 0—5 m.

The so-called peripheral shelf depression spreads in the most southeastern part of the Bulgarian shelf (Figure 16). It is a closed oval valley with a length of 26 km and an almost unchanging width of 5.5 km. Its maximum depth reaches 12 m. The end of the shelf is marked by the Peripheral Shelf Terrace which goes along its whole length and whose eastern part delineates the boundary between the continental shelf and the continental slope.

The continental slope reaches sea depths of 1 400—1 600 m. The relief of the slope features complex morphology owing to being heavily horizontally and vertically indented. A specific feature is the existence of numerous underwater valleys with varying indentation depth which most often form systems converging in the direction of the abyssal seabed: Danubian, Babadag, Tuzla, Shabla, Varna, etc. systems (Krystev, Melnik, Yordanov, 1990). These valley systems are 100 to 150 km long. The demarcation divides between the valley systems give to geomorphologists grounds to largely divide the continental shelf into several segments: Danubian, Shabla, Tyulenovo, Varna, Kamchia, etc. segments (Malovitskiy et al., 1979; Krystev, Melnik, Yordanov, 1990).

The continental rise situates at depths ranging from 1 400 to 1 800 m and is an enormous accumulation form. The relief is slightly sloping to undulating to flat. This is the part where the network of often merging underwater canyons transforms into cones with seepage of sediment material through their mouths. The abyssal seabed is the deepest even part of the seafloor. In geological terms, this is part of the basin with a sub-oceanic type of crust.

Similarly, to the geologo-tectonic and geomorphological research, the lithostratigraphy of the Quaternary sediments was studied in detail before 1990 by teams of Bulgarian and Soviet scientists. Works that are of fundamental importance for the research of the sediments in the continental shelf and the creation of a chronostratigraphic diagram are those of Shopov (1983), Dimitrov et al. (1984), Khrishev & Shopov (1987), Hrischev et al. (1988) and Hrischev et al. (1989).

As an intra-continental basin in the humid temperate climate zone, the Black Sea is characterised by a wide water catchment area which accounts for active terrigenous sedimentation. The Quaternary system features significant thickness that grows from south to north to the fore delta of the Danube where the greater part of the terrigenous material comes from.

Areas of contrasting sedimentological trends are in place of Bulgarian sector of the Black Sea. The spatial distribution of the rate of sedimentation in the contemporary stage is also controlled by several hydrodynamic factors, the entirety of which determines a diverse picture of sedimentogenesis.

In the shelf zone, there is a pronounced meridional distribution of genetic sediment types. To the north of the parallel of Cape Kaliakra, there is a large developed zone of transit movement of terrigenous material, the sediments being represented mainly by shell-based accumulations. Thus, in the conditions of by-passing detrital material, a zone of shallow carbonate biogenic sedimentation is settled. To the south of this zone starts the unloading of the terrigenous material from the Danube River, with prevailing terrigenous aleuritic and aleuropelitic silts. There is also a change to the south of Cape Emine where the coastal configuration also changes abruptly. Homogenisation of the sediment material and formation of a horizontal accumulative flat is discerned there. The gradual inclusion of local feeding sources along the course of the water masses to the south is deduced from the terrigenous mineralogical association of the Sredna Gora distributive province.

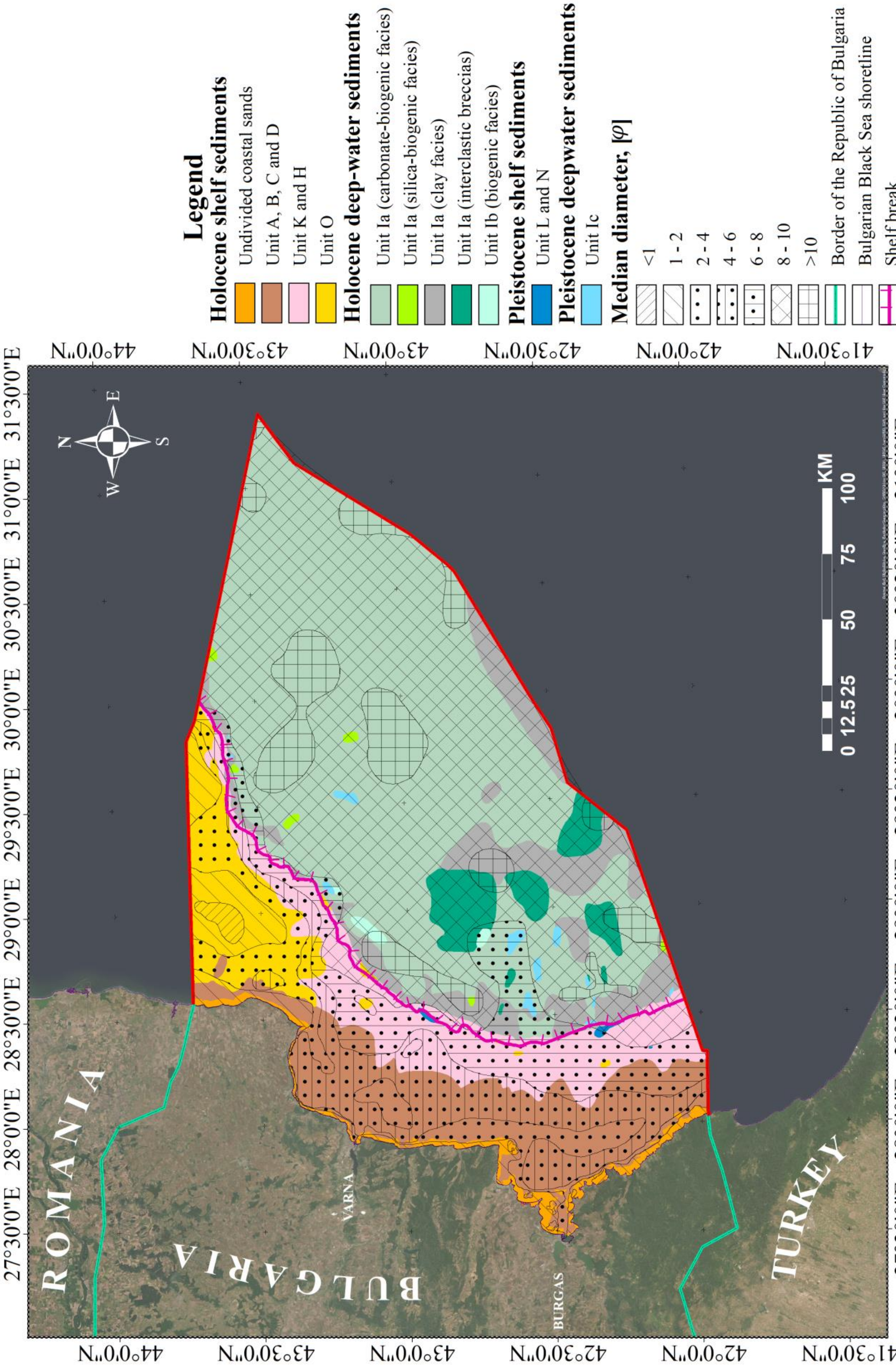


Figure 22: Sediment map of the Bulgarian section of the Black Sea with a scale of 1 :500 000 (based on Kozhuharov et al., 2010)

In the central shelf areas, two main groups of sediments are differentiated by their structural characteristics — shell sediment per unit O and terrigenous silts of the main lithostratigraphic units — A, B, C, H and D (Kozhuharov et al., 2010; Peichev and Dimitrov, 2012b; Hristova, 2015; Hristova, 2015) — Figure 22. Terrigenous silts have built the fundamental mass of the cross-sections in the Bulgarian shelf. In all lithostratigraphic units here, clay or aleuropelitic and sand silts are equally represented. In the northern shelf areas a deterioration in grading is observed owing both to variations in the terrigenous plastic material and to the increased participation of organogenic shell detritus, distributed in strata or dispersed across the basic silt mass (Kozhuharov et al., 2010).

In the outer peripheral shelf area, the grey aleuropelitic silts of lithostratigraphic unit L are prevailing. These are soft plastic silts with a quantity of unevenly dispersed organogenic shell detritus (Kozhuharov et al., 2010; Hristova, 2015). The quantity of the biogenic component is significant in places, represented by Dreissena whole shells and detritus (Dimitrov, 1984). Their carbonate content varies in very wide range, and the increased quantity is a sign of gradual transition to Lumashell deposits per unit N (Kozhuharov et al., 2010).

In the peripheral shelf area north of Cape Kaliakra, the quantity of the sand-aleurite component is increased, and at places individual layers of silt and fine-grain sands are differentiated. These sediments correspond to the silt-type substratum. In addition to the silt ones per unit L, phaseoline silts per unit O (typical for the northern shelf area) are dispersed in splotches in the peripheral shelf area, as well as olive green soft plastic silts of unit K (Hristova, 2015). The latter are usually displayed as liquid plastic silts (variety K1) with sand aleurite, Dreissena shells and fragments (Kozhuharov et al., 2010; Hristova, 2015). In addition to the bio-detritus and detrital material, the sediments also contain a significant quantity of mollusc shells, differentiated in layers or dispersed in the olive green silt material. The silts are heterogeneous, with varying structural characteristics, even within one cross-section. The grain size distribution curves are a proof of poor grading with a maximum in the aleurite or psammite range. These sediments contain a large quantity of mollusc shells, dispersed or in layers, and to a certain extent correspond to the phaseoline type of substrate (Kozhuharov et al., 2010).

3. Conclusions and Recommendations

The main conclusion from the analysis of the geological and geomorphological characteristics of the coastal zone and the continental shelf shows that the knowledge about the coastal zone from the land is more than satisfactory, but those about the aquatory are fragmentary and incomplete. This is one of the reasons for the uncertainty in the forecasts and in the adequacy and effectiveness of measures to improve the marine environment. Systematic efforts are needed to fill the knowledge gaps for this active, intensively exploited, and richest in biodiversity area. A positive step in this direction could be the resumption of the interrupted monitoring under Descriptor D7 - Changes in the hydrographic conditions (under the WFD and MSFD), as well as resumption of the monitoring of the coastal erosion.

A targeted measurement of the coastline according to and approved methodology is needed as well as the approval of a unified digital version for Bulgaria coastline for mapping on various scales and presentation in world databases. The update of this measurements should be done within a reasonable time (e.g. 5 years).

An urgent need is the restoration and expansion of the network of tide gauge stations along the Bulgarian coast and their combination with observations of the horizontal and vertical movements of the earth's crust, maintenance and submission of data in real time and free access by authorized bodies.

The total area of the Black Sea under the jurisdiction of the Republic of Bulgaria amounts to 32,271 km^2 (of which 972 km^2 is inland waters and 5,336 km^2 is the territorial sea), of which only 17% is properly (swath) mapped. There are four principal zones, bathymetrically limited at different levels: 1) continental shelf - from the coastal zone to depths of 130-140 m; 2) continental slope - to depths of about 1,200 m; 3) continental foothills - to depths of about 1,800 m; and 4) abyssal bottom, the maximum depth of which, in the Bulgarian EEZ, reaches 2 120 m. These are unexplored waters, seafloor and geological space with great expectations.

Bulgaria has not declared its continental shelf due to lack of data on its external border – the shelf break, so it is necessary to make targeted efforts to be able to properly map this border.

While our knowledge of the deep geology of the Bulgarian EEZ in the Black Sea is more than satisfactory, that of the modern seabed and the Quaternary is fragmentary and incomplete. Efforts need to be made to gain full knowledge of the geological resources in the Bulgarian marine areas, with a systematic and comprehensive study of the environment, including hydro- and lithodynamic regime, feeding provinces, sediment transport and modeling of environmental changes in possible extraction.

The possibility of conducting independent research in licensing blocks in the Black Sea for prospecting and exploration should be ensured to obtain a full knowledge of the resources in the water body and the seabed.

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