

STATE OF THE ART GEOMORPHOLOGICAL COASTLINE
CLASSIFICATIONS: GLOBAL STUDIES AND REGIONAL
RESEARCH ALONG THE BULGARIAN-ROMANIAN
BLACK SEA COAST

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The present study is carried out within the framework of a joint Bulgarian-Romanian research project between Institute of Oceanology (Bulgarian Academy of Sciences) and National Institute for Research and Development for Marine Geology and Geo-ecology (GeoEcoMar). The project has been run since 2010 and focused on generation of a common GIS-based coastline geomorphic classification (NSF- MEYS -grant No: DNTS 02/11 in Bulgaria and MEYS - 449-CB and 32130 in Romania).

At present, a number of coastal classifications exist separately for the two coasts as each serves different purposes and methods. This results in a variety of paper/digital maps and different spatial data scales or resolutions. In addition, the existing maps classify the landforms along the Bulgarian and Romanian coasts using different geomorphic schemes, and there is still a lack of a common classification of the entire Western Black Sea coastline. Therefore, one of the first tasks for creation of a common classification should be the performance of scientific analysis on existing regional and global classification schemes. Further comparison between different terminologies and methodologies used for classifying the coastline landforms by both project teams would help building up a common classification scheme for the development of detailed coastline typology of the Western Black Sea coast.

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INTRODUCTION

The needs for understanding coastline formations and influence of human activities on coastal processes has proclaimed that classifications be devised. Most have grouped coastal areas into classes that are similar features because of their developments in similar geological and environmental settings (M o r a n g e t a l., 2002). Since the beginning of the past century a large number of classification schemes at both a regional and global scale have been developed in order to describe and examine coastal landforms. Through various organised classification systems attempts have been made to investigate their origin and dynamic processes, most recently using satellite remote sensing, Light Detection and Ranging (LIDAR), Geographic Information System (GIS) and other modern technologies.

The continuous increase of coastal zone populations requires adequate and reliable information for assessment of coastal risks, as a result of global climate changes and associated impacts of sea level rise and subsequent coastal erosion (M o r t o n, P e t e r s o n, 2005; D i r e c t i v e 2007/60/EC). In this context, the coastal geomorphic classification or typology, including natural morphology and human-induced modifications, forms the primary basis for hazards assessment and highlights the present state of the coastal zone toward the most appropriate decision-making. Numerous types of coastal classifications have been produced in an attempt to characterise coastline features in terms of their physical and/or biological properties, modes of evolution or geographic occurrence (F i n k l, 2004). However, due to the complex variety of coasts worldwide, their geomorphic nomenclature has proved a problematic scientific task. Most coasts are compound representations of overlapping terrestrial and marine processes, both natural and anthropogenic, which produce variety of multifaceted and polygenetic forms. This makes coastal classifications highly interdisciplinary, raising conceptual difficulties and confusing terminology (C o o p e r a n d M c L a u g h l i n, 1988).

Coastlines have been classified on regional and global scale systems as the general categories of phenomena that are studied can be grouped mainly in terms of: (1) processes, (2) materials, (3) forms, (4) age or stage of development, and (5) environments e.g. ecological regions, land systems, morphodynamic zones (F i n k l, 2004). Thus, the geomorphic variation in coastal environments has been described and classified in numerous ways, reflecting the inherent complexity of shorelines and the diversity of applications in which such classifications are applied (S h i p m a n, 2008). The choice of a classification mostly depends on its intended purpose and a single system is unlikely to address all possible concerns, which may range from improved scientific understanding of shoreline changes to management needs (C o o p e r, M c L a u g h l i n, 1998). Classification for a specific, applied, practical purpose is referred to as a technical grouping. In scientific activities the classification system is set up in such a way that each group has as many unique, natural properties as possible and its name and properties relate to it, but separate it from all others. Such systems are commonly named scientific or natural classifications (F i n k l, 2004).

A key part of coastal vulnerability assessment is the identification and mapping of coastal substrates and landforms (i.e., geomorphic types) with sensitivity to potential coastal impacts of climate change and sea level rise, such as erosion and shoreline retreat and other hazards (S h a r p l e s, 2006). The definition and delinea-

tion of landforms depends greatly on the scale of the analysis (landforms are the fundamental geomorphic units, defined by their shape and the processes that form them). Landforms, at any scale are themselves typically combinations of smaller landforms. The topology of landforms varies with the type of feature and the scale of analysis (S h i p m a n, 2008). The problem of classifications in general entails the problem of terminology and nomenclature. Scientific names denote a group or class of objects of concern into classes or categories to which names can be given. Thus, the first purpose of classification is to provide groupings with appropriate names that can substitute for a description of the objects that are classified. Only by use of specific names or categories can researchers communicate effectively (F i n k l, 2004).

In this context, the present study is carried out within the framework of a joint Bulgarian-Romanian research project between Institute of Oceanology (Bulgarian Academy of Sciences) and National Institute for Research and Development for Marine Geology and Geoecology (GeoEcoMar). The project is aimed to establishment of a common GIS-based coastline geomorphic classification for more global risks assessment. At present, a number of coastal classifications exist individually for the two coasts, as each serves different purposes and methods, which results in a variety of paper/digital maps and spatial data scales or resolutions. The availability today of larger coastal datasets by both research institutes dictates the need to formulate an integrated approach towards unified and sufficiently detailed classification to be of practical use (for example in scale 1:25,000 or larger).

EARLIER BROAD-SCALE CLASSIFICATIONS

Perhaps the most commonly used earlier coastal classification scheme is the one introduced by S h e p a r d (1937) and modified in later years (S h e p a r d, 1973). A practical approach to general observations of the coast is to use a hazard assessment scheme. The author modified and elaborated his classification in 1973, but retained its basic structure. It divides the world's coasts into: i) primary ones - formed mostly by non-marine agents; and ii) secondary ones - shaped primarily by marine processes. Further subdivisions occur according to which specific agent, terrestrial or marine, had the greatest influence on coastal development. The advantage of Sheppard's classification is that it is more detailed than others, allowing most of the world's coasts to be incorporated (M o r a n g e t a l., 2002).

Other widely used coastal classifications were introduced by Z e n k o v i c h (1967) and later by B i r d a n d S c h w a r t z (1985), amongst others. According to Z e n k o v i c h (1967) the main criteria for compiling coastal classifications include: involvement of all types and variety of coastal forms; considering all factors responsible for coastal development; identifying the relation between coastal forms and contemporary coastal zone processes; inclusion of wave and non-wave factors, both playing an important role in developing various coastal shapes. Each classification should serve as a theoretical base for a system of classes or categories, needed for the geomorphic mapping of the coasts.

With constantly increasing prevalence of anthropogenic factors in coastal zone, the existing shorelines and coastal environments have been much or less modified by human activities. The major factors that have influenced the development of the modern shoreline are major regional and human controls over landscape formation

(Shipman, 2008). This leads to the description of a hierarchical geomorphic typology of coastal landforms that could relate both natural and anthropogenic processes. Cooper and McLaughlin (1998) reviewed eighteen published accounts of coastal classifications in order to examine the variability and utility of multidisciplinary approaches, as the priority is given to the increased and widespread use of GIS. Some schemes have been designed by adopting coastal vulnerability indices (sea level rise, energetic wave action; coastal erosion rate, sediment transport etc.) used as a management tools to prevent hazard-prone coastal areas. Numerous investigations at regional and local scale have been carried out for subdivision of European coastlines by morphogenetic criteria or segmentation of littoral zone by natural landforms/human structures in cells of different dimensions and characteristics (Anfuso and Martínez, 2005; Chadwick et al., 2005).

Recognition in the early 1990s of variability in physical, ecological and human characteristics of coasts has focused the efforts towards classifying coastline at a world-wide scale under the LOICZ Project (Land-Ocean Interactions in the Coastal Zone, until 2015) of the International Geosphere-Biosphere Programme and the International Human Dimensions Programme on Global Environmental Change. The important task of that project is to establish a global coastal zone “typology” based upon available descriptive and dynamic scientific information. Thus typology, the ‘study or systematic classification of types that have characteristics or traits in common’, has become a commonly used term and technique in coastal zone studies over the past two decades (Buddemeier et al., 2008).

MODERN CLASSIFICATIONS / COASTAL WEB ATLASES

Active elements of modern efforts have been taken both in Europe and outside mainly under the following initiatives:

- CORINE Land Cover project (Coordination of Information on the Environment), with a partnership of European Environment Agency (EEA), has started in mid-1980s and aimed at inventorying and mapping of land cover patterns with a standardised methodology;

- As regional project of LOICZ, the 5th Framework DINAS-COAST project (Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea-Level Rise) developed a GIS database covering the world’s coastline, as 12 148 segments were identified;

- EUROSION project (A European initiative for sustainable coastal erosion management, 2001-2004) generated a database in digital GIS format, with several layers of information (coastline, elevation, boundaries, geology, coastal defence works etc.) in scale 1:100,000;

- MESSINA (Monitoring European Shoreline and Sharing Information on Near-Shore Areas) INTERREG III C initiative (2004-2006), stands for accumulation of knowledge in shoreline management and sharing coastal information;

- 6th Framework ENCORA project (European Network on Coastal Research, 2006-2009), focused on the various aspects of coastal zone, and presents a general classification of the coastline into special features;

- The United States Geological Survey (USGS) National Assessment of Coastal Change Project has generated a broad classification that can be applied to most coast-

al regions in the USA and a Coastal Classification Atlas with basic information for risk assessment has been created (M o r t o n, P e t e r s o n, 2005);

- An indicative map of geomorphic vulnerability to coastal hazards has been prepared for the entire 6,500 kilometers of the Tasmanian coast. It was produced from a GIS line map with attributes providing a uniform coded descriptive classification of coastal landform types at 1:25,000 scale (S h a r p l e s, 2006).

Over the recent years in support to collection and management of various geospatial data and information standards there have been numerous new developments of Internet resources and Web GIS. One class of such resources are being coastal web atlases (CWAs), (<http://www.coastalatlas.net>). A coastal web atlas is a collection of digital maps and datasets with supplementary tables, illustrations and information that systematically illustrate the coast, oftentimes with cartographic and decision-support tools, and all of which are accessible via the Internet (O'D e a e t a l., 2007). In Ireland a Marine Irish Digital Atlas (MIDA) has been developed to display spatial information for their coastline, (<http://mida.ucc.ie>). MIDA offers both digital geospatial data and information, incorporating text and multimedia elements, related to coastal and marine resources in Ireland. The atlas displays data layers from numerous coastal and marine organisations both within Ireland and abroad, thus providing the best single resource for finding and viewing existing Irish coastal and marine data. A similar initiative to the latter is the Coastal Atlas Flanders-Belgium (De KUS-TATLAS), providing both printed and online information on the various activities and themes of Integrated Coastal Zone Management (ICZM), (<http://kustatlas.be>).

In this regard, the International Coastal Atlas Network (ICAN), (<http://ican.science.oregonstate.edu>) has the objective to be a global reference for developing CWAs. A major goal is to help build a functioning digital atlas of the global coast based on the principle of sharing distributed coastal/marine information. One of the new books is the *Handbook of ICAN: Coastal Informatics: Web Atlas Design and Implementation* by W r i g h t e t a l. (2010). The purpose of this book is to present the latest developments in the new field of CWAs and to share best practices and lessons learnt.

SPECIFIC WORKS AND METHODOLOGIES FOR CLASSIFICATIONS/TYOLOGIES OF THE BULGARIAN BLACK SEA COAST – PREVIOUS AND MODERN ATTEMPTS

According to the most recent investigations by S t a n c h e v (2009), the Bulgarian coastline has a length of 412 km. It stretches between cape Sivriburun on the north (to the border with Romania) and Rezovska River mouth on the south (to the border with Republic of Turkey), (Fig. 1 – appendix). The coast has a general eastward exposure and comprises various erosion rocky cliffs, sandy beaches or low-lying parts of firths and lagoons. Coastal erosion, both natural and human-induced is only one of the many hazards threatening the coastline. Flooding in low-lying areas due to extreme sea level rise is another potentially severe risk along the Bulgarian coastline. About 20% (83 km) of the entire coast were projected as areas vulnerable to inundation by extreme sea level rise up to 5 m. Such areas are mostly firths, lagoons, river mouths and wetlands (P a l a z o v e t a l., 2007).

One of the earliest morphological classifications to the Bulgarian coast was introduced by L i l i e n b e r g (1966) using geomorphological criteria. The author divided coast at 5 main districts: Dobrudganska, Varnenska, Staroplaninska, Burgaska, Strandganska, and subdivided 14 regions and 17 subregions. The main districts were defined on the base of morphostructural principle, while for the regions and subregions the geological conditions, morphology and coastal processes were considered.

The second and most commonly used geomorphic division of the Bulgarian coast was performed by P o p o v a n d M i s h e v (1974). It is based on the fact that the formation of coastal relief results from complex interaction between marine erosion/accumulation and the main morphostructural units building the coast. The authors divided Bulgarian coastline at five main geomorphological regions: Dobrudgansko-Frangenski, Dolno-Kamchijski, Staroplaninski, Burgaski and Mednoridski-Strandganski corresponding to the main morphological structures of the Bulgarian coast. It was found that erosion cliffs embrace 59.7% of the entire coastline length, sand beaches (or accumulative coast) - 28% and landslide/erosion coast – 12.3%.

However, the earlier classifications were performed only on the base of coastal (inland) measurements and studies. Since 70s-80s of the past century the Institute of Oceanology (Bulgarian Academy of Sciences) has carried out a number of filed surveys and researches both on the coast and on the underwater part.

The most detailed geomorphologic classification of the Bulgarian Black Sea coast by separate morphodynamical systems was introduced by P e y c h e v (2004) using the following criteria: geological structure and lithological composition of the coast; coastline exposure; coefficient of coastline crenulation and average incline of underwater coastal slope; existing long-shore sediment transport and availability of divergence/convergence zones, which defines the boundaries between each morphodynamical system. Based on these criteria a number of 11 morphodynamical systems (regions) along the Bulgarian coast have been classified (Table 1).

T a b l e 1

Morphodynamical systems identified along the Bulgarian coast (P e y c h e v, 2004)

	Morphodynamical system	Coastline exposure	Coastline length /km/	Crenulation coefficient	Average depth of closure /m/	Long-shore sediment flux
1.	c. Sivriburun-c. Shabla	E	24	1.09	20	Krapetzki
2.	c. Shabla-c. Kaliakra	ESE	26	1.13	24	Kaliakrenski
3.	c. Kaliakra-c. Sv. Georgi	SE	50	1.70	15	Kaliakrenski, Aladgamanastirski
4.	c. Sv. Georgi-c. Galata	ESE	15	1.67	15	Evksinogradski, Asapruhovski
5.	c. Galata - c. Emine	E	61	1.13	25	Kamchiysko-Eminski
6.	c. Emine - Nessebar	SSE	24	1.62	23	Kamchiysko-Eminski, Nessebarski
7.	Nessebar - Pomorie	ESE	22	1.57	20	Aheloyiski, Pomoryiski
8.	Pomorie - Sozopol	E	60	3.88	18	Burgaski
9.	Sozopol – c. Maslen nos	NE	29	2.13	32	
10.	c. Maslen nos-c. Emberler	ENE	21	2.11	30	
11.	c. Emberler-r. Rezovska	NE	46	1.60	35	

Other type of classification was made through distribution of erosion and accumulative processes by extent of activity. The analysis of geomorphodynamical coastal activity was performed via division into areas, as each area was divided in subareas, depending on lithostratigraphical and morphological peculiarities of Bulgarian (K e r e m e d c h i e v, S t a n c h e v a, 2006). It was found that erosion coast is widely occurred and it embraces 42.3 % of the coastline, while the sandy (accumulative) coast is 29.2 %, the erosion-landslide coast constitutes about 16.8 %, and the erosion-accumulative type coast – 11.7 %.

The Bulgarian coast has also been classified by the rate of cliff retreat (P e y c h e v, S t a n c h e v a, 2009). Since 1983 field measurements of coastal erosion rate have constantly been carried out by the Institute of Oceanology, BAS. The coast has been divided into 10 erosion sections on the base of the results for the average erosion rate. At the northernmost part of the Bulgarian coastline, between capes of Sivriburun and Shabla (Fig. 1 – appendix), the erosion coast is built of loess sediments underlied by the Upper Sarmatian limestones. The average rate of erosion in loess sediments is high and up 0.30 m/y. At some sites (e.g. at cape Krapetz and cape Shabla) the erosion rate even reaches to 1.2 – 1.6 m/y. The coast between capes of Shabla and Kaliakra consists of white to cream-colored detrital, biogenic and oolitic Middle Sarmatian limestones. West of cape Kaliakra to the Kavarna town dense shell and oolitic limestones (Karvuna Formation) crop out at the coast. The average erosion rate at this section is 0.05 m/y. Between Kavarna town and sea resort “Albena” the erosion coast is built by Sarmatian limestones or clays, clayey sands and marls, spreading to the cape St. George (Fig. 1). Middle Sarmatian aleurolites, sandstones and clays are predominant lithologies at the coast between resort “Albena” and cape St. George. The next part of the Bulgarian coastline southward includes large Bay of Varna, located between capes St. George and Galata, where the Sarmatian sandstones and Konkian, Karagantian and Chokrakian sandstones and sands crop out. In general, the average rate of erosion varies from 0.13 to 0.16 m/y between Kavarna town and cape St. George, while along the coast of Varna Bay it reaches 0.20 m/y.

Further, between capes of Galata and Emine (Fig. 1 – appendix) the coast consists of Chokrakian sandstones, Sarmatian limestones, Paleogene sandstones, marls and clays, but in the Eastern Stara planina – by Upper Cretaceous sandstones, aleurolites, argillaceous rocks and limestones. The average rate of erosion in these rocks is 0.16 m/y. In the coastal section around the Nessebar Peninsula mostly Lower and Middle Sarmatian limestones from Crimean-Caucasian type are cropped out. Between towns of Nessebar and Pomorie the coast is composed of Sarmatian limestones which built the capes of Nessebar, Akrotiria and Ravda. Coastal erosion rates between cape Emine and cape Pomorie vary from 0.07 to 0.09 m/y. Southward between Pomorie town and cape Foros the erosion coast is built by clays, sandy clays, aleurolites and diatomaceous sandstones (Fig. 1 – appendix). Nowadays, due to the performed coast-protection activities the average rate of erosion ranges from 0.19 to 0.29 m/y. Senonian volcanic rocks (potassium-alkaline trachytes, latites, psammitic and psephitic tuffs, pyroclastic flisch and volcanites, andesite-basalts, basalts) are cropped out along the coast between cape Foros and Rezovska River. These rocks are solid and erosion-stable thereby the average rate of erosion is low: 0.01 m/y.

More recently an indicative segmentation of the Bulgarian Black Sea coast by geomorphologic and engineering criteria (Fig. 2 – appendix) was implemented on

the base of topographic maps in scale 1:25 000 and applying modern GIS approach (Stancheva, 2009). A number of 379 various segments, having a total length of 439 km were identified. All coastal segments indicated were then combined in two main groups of geomorphic types based on different criteria (Fig. 3 and Fig. 4 – appendix):

- Landform coastal segments, identified by geomorphologic criteria:

1. Natural and artificial sandy beaches; Main types of natural beaches are:

Narrow sandy strips (with average width up to 15 m) in front of high erosion cliff or at low coast;

Wide sandy beaches (with average width more than 15 m);

Pocket beaches (formed between erosion promontories);

Artificial sandy beaches (formed between strictures or by beach nourishment projects).

2. Cliffs; Main types of cliffs are:

- Low overgrown type or active erosion type (up to 10 m);

- High overgrown type or active erosion type (with height more than 10 m).

• Technogenous coastal segments (various maritime structures both cross- and long-shore), identified by engineering criteria:

- groins;

- coastal dikes;

- seawalls;

- ports / harbours, marinas and navigational channels.

Both natural and technogenous coastal segments have a total length of 439 km, which exceeds the length of the Bulgarian coastline (412 km) due to the included cross-shore structures such as groins, ports/marinas, port moles/harbour breakwaters and permeable bridges. It is evident from the map of coastline segmentation (Fig. 2) that the cliff types are dominant and embrace almost 61 % or 247 km of the whole Bulgarian shoreline. Whilst the sandy beaches comprise at least 30 % (121 km) from the coast, there is a clear evidence for accelerated human intervention in terms of maritime constructions. As a result the armouring occupies 17 % (71 km) of the entire coastline.

The Institute of Oceanology-BAS has recently joined the ICAN global network with the project for the Bulgarian Black Sea CWA being under ongoing development. The main goal of currently developed Bulgarian Coastal Atlas (BCA) are to foster sharing and using of geographically-linked spatial information on marine and coastal features/resources along the Bulgarian part of the Black Sea coastal zone (Stancheva et al., 2010). Wide range of information has been incorporated in GIS-based BCA project that covers both marine and coastal areas. Some of the main data of already prepared GIS thematic layers for inclusion in the web Atlas are: extreme sea level rise and evaluated flood-prone areas; conductivity, temperature, and depth (CTD) data from field surveys (ship cruises); geomorphic typology/classification of the Bulgarian Black Sea coast (erosion sections /sandy beaches and dunes/ coast-protection structures); population Census data for the 14 Bulgarian Black Sea coastal municipalities over the period 1934-2001; data for shoreline position from different times etc. Images along the Bulgarian coast will also be available for viewing and download from the web Atlas site. The geographical area covered by the BCA includes the Bulgarian Black Sea catchment area, coastline, internal waters,

territorial waters, contiguous zone and exclusive economic zone (EEZ). One of GIS applications to BCA is namely the indicative GIS-based segmentation of the Bulgarian Black Sea coastline for risk assessment under the joint project for generation of web geomorphic classification of the Western Black Sea coast (Bulgaria-Romania). In this context synergies and mutual relations with ICAN will be of relevance to the web GIS framework of the project as well as will help to gain the experiences in developing an online joint Bulgarian-Romanian Coastal Atlas. This would be also one of the first steps to actual implementation of the web BCA.

SPECIFIC WORKS AND METHODOLOGIES FOR CLASSIFICATIONS/TYOLOGIES OF THE ROMANIAN BLACK SEA COAST – PREVIOUS AND MODERN ATTEMPTS

The Romanian Black Sea coast has a length of 243 km from Vama Veche (the Bulgarian border) on the south to Danube Delta on the north. Romanian coastal geology and geomorphology has been a target of research since the early 1970s, when the study of beach morphology and sediment sampling and analysis started. The beach sectors in front of the Danube Delta were measured by the Laboratory of Marine Geology and Sedimentology (transformed in 1993 in National Institute of Marine Geology and Geoecology – GeoEcoMar) of the Institute of Geology and Geophysics in co-operation with the marine geology group of the Faculty of Geology and Geophysics, University of Bucharest. Therefore, a fair amount of information became available on the Romanian shoreline evolution. Erosion, accretion and stable beach sectors were identified in front of the Danube Delta, as well as in the southern part of the coast in several sea resort areas: Cape Midia, Navodari, Mamaia, Agigea (till the early 1990's), Eforie, Costinesti, 2 Mai and Vama Veche (Fig. 5 – appendix).

Meantime, other research organizations and groups started to work on the coastal evolution issue. The Romanian Institute for Marine Research (nowadays National Institute for Marine Research and Development „Grigore Antipa”) has established his own network of measurement along the entire Romanian coastline. The coastal geomorphology group of the Faculty of Geography, University of Bucharest started to work on the Danube delta coastline in the early 1980s, focusing mainly on the Sulina-Sf. Gheorghe sector. Unfortunately there are small number of studies targeted the unstable Romanian loess cliffs, mainly developed by the Faculty of Geography, University of Bucharest.

Only a few attempts were made to classify different sectors of the Romanian shoreline. It is generally accepted that the Romanian coast might be divided into two major sectors, separated by a transitional one (Fig. 5). They are characterized by specific geological setting, as well as by different sedimentological and dynamical features (G a s t e s c u, D r i g a, 1984; P a n i n, 1983, 1992, 2005; U n g u r e a n u, S t a n i c a, 2000, etc.). The northern sector is situated between the Musura Bay at the border with Ukraine and Cape Midia in the south and is a low, accumulative coast (P a n i n, 2005), with a length of 165 km (G a s t e s c u, D r i g a, 1984). The southern one extends, if we include also the transitional sector, for about 80 km from Cape Midia to the border with Bulgaria, but from a geological point of view

the southern limit is arbitrary, since the coast characteristics are the same beyond the political boundary. This sector is considered by P a n i n (2005) as an erosive coast within lowstanding plateaus and plains.

The northern sector is situated in front of the Danube Delta and Razelm-Sinoe lagoon complex and its evolution is tightly connected with the development of these two sedimentary systems. Sediments are dominated by Danube terrigenous material with an organic fraction (modern shells and shell fragments) whose participation increases with the distance from river mouths.

Most studies on the beach geomorphology and evolution were focused on the sector located between the mouths of Sulina and Sfantu Gheorghe distributaries (G a s t e s c u, D r i g a, 1984; V e s p r e m e a n u, 1984a, 1984b; V e s p r e m e a n u e t a l, 1986; V e s p r e m e a n u, S t e f a n e s c u, 1988). Long-shore sediment transport in front of the Danube Delta was investigated by G i o s a n e t a l (1997, 1999). The most recent models of evolution for the entire delta were described by P a n i n (1989, 1996) and modified by G i o s a n e t a l. (2005, 2006, 2007).

V e s p r e m e a n u a n d S t e f a n e s c u (1988) divided the littoral of the Danube Delta into two types according to the geomorphological characteristics of the littoral plain. In fact the two types were separated using their location, in front of the main delta and of the Razelm-Sinoe lagoonar complex. The first category includes the delta plain shore, comprised between the Chilia secondary delta to the north and Perisor to the south. The second category includes the lagoon littoral shore, from Perisor to Chituc in the south. The subdivisions of each shore type (11 and respectively 6) were described in terms of different advance/retreat rates of the shoreline.

No deep insight into the southern cliffed sector beach types has been published until now.

According to their present state, morphodynamics and human influence, Romanian beaches appear like a mosaic of highly variable environments. Although the major classification in lowland accumulative beaches (in the northern part) and cliffed erosion beaches (in the southern part), with a narrow transitional zone in-between is still valid in our opinion, several nuances have to be emphasized. A general picture of the Romanian beach types is presented at Fig. 6 and in Table 2.

The northern sector corresponds to the Danube Delta shoreline, and we include in this category also the lagoon type shore. It is a little bit more unitary from a geomorphologic perspective than the southern littoral. The beach profiles are typical for sandy environments. The backshore is limited in landwards by low coastal dunes, with a series of berms specific for different sea energetic levels and seasonal position of the shoreline. The foreshore comprises a succession of troughs and submerged bars which positions and depths are controlled by storms. Various beach sectors are more or less influenced by human intervention. The key role is played by the construction of the Sulina jetty that started in the second half of the 19th century, afterwards prolonged in several steps till the 1950s, when it reached the present length of 8 km offshore. The jetty changed the long-shore water and sediment circulation, deflecting the long-shore current and creating an anticyclonic eddy to the south (U n - g u r e a n u, S t a n i c a, 2000; S t a n i c a e t a l, 2007). The effect is amplified by the chronic lack of sediments in the Danube mouths area due to upstream river dams and other hydrotechnical works. The changed current pattern in front of Sulina mouth caused the advance of a short segment of the shoreline, situated immediately

southwards to the jetty and strong erosion to the south (Stanica et al, 2007). The sediment starvation induced by this 8 km long construction is extremely visible over a length of about 25 km, in a region where shoreline retreat is very aggressive (up to 20 m/y, with a measured maximal value of 40 m in a small coastal section in 1997). Immediately north of the Sfantu Gheorghe mouth the situation is re-equilibrated and the beach becomes more stable.

The Sakhalin barrier island (Fig. 5 and Fig. 6 – appendix) is a sand spit elongated in southward direction from the Sfantu Gheorghe mouth and suffers processes of retreat, elongation and clockwise rotation (Panin et al, 1994). The erosion has become more and more active since the secondary Sfantu Gheorghe delta filled the gap at the northern tip of the island and the sedimentary load of the Danube depleted. If the present day tendencies continue, the southern tip of the Sakhalin Island will make contact with the mainland gradually transforming Ciotic area into a marsh. A new sand spit will eventually form seawards. In fact the Sakhalin Island is a present day model of how fossil littoral bars were formed within the marine delta plain.

Starting from Perisor and up to Periteasca the beaches are quite stable, fact proven also by the low dipping angle of the transverse profiles (Vespreanu-Stroe et al., 2007; Table 2).

Table 2

Lengths and types of the Romanian beach sectors

	Sector name	Length (km)	Type
Northern sector	Musura	15.30	deltaic beach
	Sulina	10.40	deltaic beach
	Canalul cu Sonda	8.00	deltaic beach
	Casla Vadanei	10.00	deltaic beach
	Sf. Gheorghe	5.70	deltaic beach
	Sahalin	19.32	barrier island
	Ciotic-Zatoane	12.30	deltaic beach
	Perisor	12.00	deltaic beach
	Periteasca	13.00	lagoonar beach
	Portita North	5.64	lagoonar beach
	Gura Portitei	0.74	human structures
	Portita South	4.00	lagoonar beach
	Periboina	10.00	lagoonar beach
	Edighiol	11.00	lagoonar beach
Chituc	16.82	lagoonar beach	
Transitional sector	Vadu	2.28	pocket beach
	Corbu	1.87	pocket beach
	Cap	0.24	cliff
	Midia harbour	6.70	human structures
	Mamaia Bay	12.19	barrier beach

Southern sector	Constanta	6.89	human structures
	Tomis marina - Casino	1.44	human structures
	Constanta harbour	15.14	human structures
	Agigea	1.16	human structures
	Eforie North	2.15	human structures
	Eforie North Belona	1.00	barrier beach
	Techirghiol center	0.25	human structures
	Techirghiol	0.97	barrier beach
	Eforie South	3.90	human structures
	Eforie South-Tuzla	3.39	cliff
	Tuzla	0.20	human structures
	Tuzla-Costinesti	5.16	cliff
	Costinesti North	0.49	barrier beach
	Costinesti	0.68	human structures
	Costinesti South	0.72	cliff
	Frenchman's Bay	1.78	pocket beach
	Southward Costinesti	3.19	cliff
	Tatlageac	0.39	barrier beach
	North Olimp	1.12	cliff
	Olimp	1.71	human structures
	Neptun North	1.14	human structures
	Neptun South	1.19	barrier beach
	Jupiter-Venus	4.62	human structures
	North Saturn	1.42	barrier beach
	Saturn	1.52	human structures
	Mangalia	1.98	human structures
	Mangalia harbour	3.89	human structures
	2 Mai	1.10	pocket beach
	2 Mai - Vama Veche	2.56	cliff
	Vama Veche	1.51	pocket beach
South Vama Veche	0.81	cliff	

From Portita to Chituc the retreat of the shoreline is general. The beaches move toward inland. The main sedimentary process is the overwash. Severe winter storm surges erode the coastal dune front and occasionally pass over the dunes transporting large amounts of sediments on top of the marshes situated beyond the littoral sandy bar. New overwash sandy lobes of several meters in diameter are formed each winter in conjunction with a comparable retreat of the shoreline. Erosive features are common. Up to 1 m high profile scarps and overwash channels in the former dune area are widespread.

The Chituc area, situated in the southern end of the northern sector, is more or less stable from the point of view of the shoreline position, although a minor retreat of up to 5 m was noticed in the last 10 years.

The natural evolution of the littoral bars situated in front of the Razelm-Sinoie lagoon system is locally altered by small scale human-made structures that consist of 20-50 m long groins in Portita, Edighiol and Chituc areas (Fig. 5 and Fig. 6). All of them induce typical effects of beach accretion upstream the littoral current and downstream erosion, but the effects are limited to a few tens to hundreds of meters in each case.

The transitional sector is comprised between the Midia and Singol capes and has a total length of about 16 km (Fig. 5 and Fig. 6 - appendix). Its morphology is typical also for what is encountered southwards. Clifed promontories isolate pocket beaches (Corbu and Vadu) in the north, while broad stacked littoral bars isolated the former Mamaia lagoon which eventually evolved into the fresh water Siutghiol Lake. The transitional aspect comes from the typical terrigenous Danube type sediments that are deposited in southern type environments. The Mamaia beach is probably the most measured and sampled beach on the Romanian littoral. Despite this, very few data were published. It is important also because it marks the northern end of the main touristic area of the Romanian seaside and also experiences the largest anthropogenic impact. The main effect of the building of Midia harbour at the northern end of the Mamaia gulf was a strong erosion of the highly valuable Mamaia beach. Because of the touristic importance southern Mamaia gulf was subject to the first and isolated attempt of beach nourishment on the Romanian littoral, so badly planned and carried on that it had no effects on the beach stabilization.

The southern sector is very different in all aspects from the northern one. From a sedimentological point of view, most of the beach material is made up of shells and shell fragments, associated with detritus grains of terrigenous origin, pebbles and boulders from the neighbouring Sarmatian limestones or from the existing hydraulic structures.

The main types of beaches in the southern sector are (Fig. 7 and Fig. 8 – appendix):

1. *Loess cliffs with narrow strips of sand in front*

The cliffs are made up of Quaternary eolian sediments known as loess. A narrow backshore protects them from the wave action. In places older and tougher rocks - Lower Quaternary red mudstone and Sarmatian limestones - crop out in the base of the cliffs. When this occurs the base of the cliff is not subject to the incoming regular wave energy, therefore the cliff stability increases. Overall, the cliffs retreat at variable rates, sometimes as much as a few meters per year.

2. *Pocket beaches*

When there is enough sand available, it accumulates in the concave shore situated between successive promontories. Some of these beaches were transformed into touristic areas.

3. *Littoral sandy bars*

They separate lakes from the sea and formed in result of accumulation of the sand transported by the longshore currents, eventually blocking sea bays that evolved afterwards into fresh or brackish water lakes.

4. *Anthropogenic beaches*

They are artificially created with the help of hard coastal works. A large variety of groins were built in the late 1970s and early 1980s being in different shapes: straight, T-head, L-head, hockey stick sometimes associated with wavebreakers.

The anthropogenic impact is huge in the southern sector. About half of the littoral length is filled with sea resorts. They include, from north to south: Eforie Nord, Eforie Sud, Costinesti, Olimp, Neptun, Jupiter, Cap Aurora, Venus and Saturn, 2 Mai and Vama Veche. Six of them, from Olimp to Saturn, are situated immediately north of Mangalia and cover a continuous stretch of more than 8 km where most of the hard coastal defence exists. Two large cities (Constanta and Mangalia) are located on the littoral and are important harbours. The jetties protecting them interrupt long-shore circulation and modify current patterns. They induce strong erosion to the south and beaches from Eforie Nord and 2 Mai resorts are in a very poor condition.

The cliffs collapse all along the southern sector sometimes even endangering lives and properties. Attempts were made to stabilize them but the whole current philosophy of protection, which is to create slopes at natural internal friction angle, does not take into consideration the high mobility of loose fine sediments under wet meteorological conditions. For this reason the effect up to now was only to increase the erosion. A better approach would be to drain underground water and to reduce in this way the probability of landslides.

CONCLUSIONS

This multi-institutional paper presents the initial results and outcomes within the framework of the Bulgarian-Romanian joint research project towards generation of a common GIS-based coastline geomorphic classification. The previous and modern existing approaches to global coastal classifications were outlined. Works specific to the Bulgarian and Romanian Black Sea coasts were also reviewed and analyzed. This will allow for the comparison between different methods used and creation of unified geomorphologic criteria to classify the both coasts. The common segmentation framework would also employ/re-organise the existing classification schemes in order to provide a seamless geomorphic typology of the entire Bulgarian-Romanian coastline. In contrast to previous schemes this joint classification will be produced in a spatially detailed scale (1:25,000 and larger) as a web GIS-based CCA to support the quick extraction of a multivariable information needed for coastal zone management and restoration.

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ОБЗОР НА ГЕОМОРФОЛОЖКИТЕ БРЕГОВИ КЛАСИФИКАЦИИ: ГЛОБАЛНИ ИЗСЛЕДВАНИЯ И РЕГИОНАЛНИ КЛАСИФИКАЦИИ НА БЪЛГАРО-РУМЪНСКОТО ЧЕРНОМОРСКО КРАЙБРЕЖИЕ

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(Резюме)

Настоящото изследване е проведено по българо-румънски проект за съвместни научни изследвания между Институт по океанология (БАН) и Национален институт по морска геология и геоекология (ГеоЕкоМар) – Румъния. Проектът стартира през 2010 г. и има за цел разработване на съвместна ГИС-базирана геоморфоложка класификация (НФНИ-МОМН: ДНТС 02/11 в България и MEYS – 449-СВ и 32130 в Румъния). Понастоящем съществуват много класификации поотделно за двете крайбрежия, като всяка е съставена с различна цел и по различна методика. Това води до наличието на различни хартиени/цифрови карти и в различни мащаби или разделителна способност на пространствените данни. Освен това, посредством съществуващите досега карти, еднакви форми по двете крайбрежия се класифицират с различни геоморфоложки схеми и все още липсва единна класификация за целия западен бряг на Черно море. Следователно, една от първите задачи за създаване на обща класификационна схема трябва да бъде извършването на научен анализ на съществуващите глобални и регионални брегови класификационни схеми. Сравняването на терминологиите и методологиите, използвани от двата проектни екипа при описание на бреговите форми, ще спомогне за създаване на общи критерии за класификация при разработването на подробна типология на западния бряг на Черно море.



Fig. 1. The Bulgarian Black Sea coast

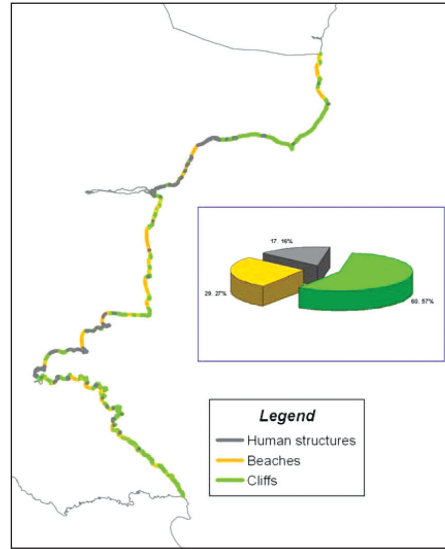


Fig. 2. Map of coastline segmentation for Bulgarian coast



Fig. 3. Landform segment (erosion cliff)



Fig. 4. Technogenous segment (dike)

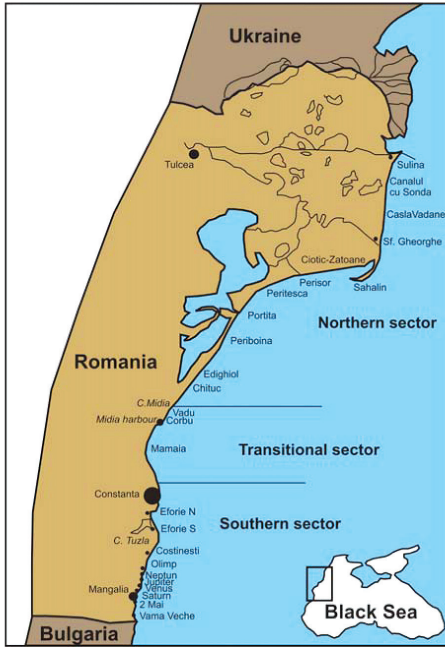


Fig. 5. The Romanian Black Sea coast

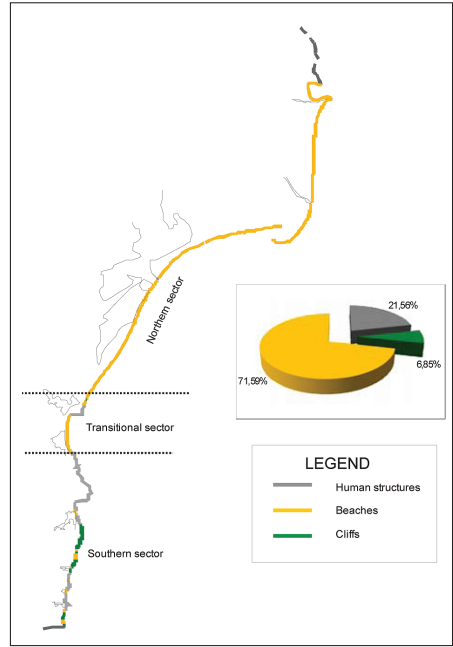


Fig. 6. Map of Romanian coastline segmentation



Fig. 7. Natural sandy beach



Fig. 8. Anthropogenic beach