# THE GEOMORPHOLOGICAL EVOLUTION OF RAZIM - SINOIE LITTORAL BAR DURING THE HISTORICAL PERIODS

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*Der Lagunenkomplex Razim-Sinoie ist der größte lakustrische Komplex auf dem Gebiet Rumäniens (96,950 Hektare). Die Nehrung, die das Schwarze Meer von der Lagune Razim-Sinoie abtrennt, ist von sandiger Herkunft und hat eine variable Breite: von etwa zig Meter neben den Seen Leahova und bis zu 5 Km in der Zone des hohen Ufergeländes Chituc. Das Alter dieser Nehrung wird auf etwa 2.000 Jahren eingeschätzt und derer Herkunft ergibt sich aus den von dem nördlichen Sektor des Delta transportierten Sedimenten. Der Aufbau der Nehrung begann als das dreieckige Delta von Sulina (Typus „Tibrus") enthauptet wurde. Nach der Konsolidierung der Nehrung verschwanden die Häfen der Festungen Histria und Enisala (Heraclea). Die Strände dieser Nehrung sind relativ schwach entwickelt, da auf seinem Alignament ein Abhobelungsphänomen vorhanden ist (60-70%), während die Progradation sich auf einer relativ eingeschränkten Länge (30-40%) abspielt und nur für das hohe Ufergelände Chituc typisch ist. In der Umgebung des Leuchtturms Portiţa verzeichnete die Breite der Nehrung eine Regression von 75 Metern in 20 Jahren, was eine einer Durchschnittsrate von 3,75 m/Jahr entspricht. Infolge der horizontalen und senkrechten Erosion ergibt sich eine Verminderung der sedimentären Ablagerung von etwa 70 m³/Laufmeter. Die bedeutendste Anhäufungsrate in der Nähe des hohen Ufergeländes Chituc erreichte in den letzten zwanzig Jahren einen Maximalwert von 23-24 m, mit einer sedimentären Ablagerung von etwa 25 m³/Laufmeter. Der Küste entlang entstanden die Vordünen, manchenorts mit psammophiler Vegetation bedeckt. Die natürlichen Öffnungen, die in der Nehrung vorhanden sind, heißen „periboine" (rum.) (Bruchstellen der Küste, wodurch Wasser ausgetauscht wird) oder „buhazuri" (rum.). Zurzeit gibt es nur zwei solche natürlichen Öffnungen, die zum großen Teil vom Menschen kontrolliert werden. Gura Portiţei wurde 1960 geschlossen und Gura Peribоinei wird mit Hilfe eines Stauwerks kontrolliert. Der Strand der Nehrung ist „pfeilförmig": lang, ununterbrochen und schmal. Sie umfasst zwei unterschiedliche Teile: den niedrigen Strand und den hohen Strand. Das Profil des Strandes verändert sich stetig infolge der hydrodynamischen*

*Bedingungen durch das Phänomen der Selbstadjustierung. Wenn es schönes Wetter gibt, findet der Prozess der Anhäufung statt und während des Gewitters, tritt die Erosion auf. Die Rate des terrigenen und organogenen (T/O) Materials vor der Nehrung hat einen Wert von 50/50. Diese Rate hat den Wert von 90/10 im Sektor Sulina-Sahalin, 60/40 in Sahalin-Zatoane, 80/20 in Perişor usw. Die Zonen, welche von einem relativen Gleichgewicht oder von einer Progradation gekennzeichnet sind, weisen zwei Bermen auf. Im Gegensatz dazu, gibt es keine solchen Formen in den Zonen wo das Phänomen der Abhobelung vorhanden ist. In den Zonen mit einem relativen Gleichgewicht sind die Vordünen bei einem 12-15 m Abstand von dem Strand weit entfernt, während diejenigen in den abgehobelten Zonen bei einem 8-10m Abstand von dem Strand entfernt sind. Ein besonderer Fall ist die Existenz einer muscheligen Düne mit einer Länge von 250 m und einer Breite von 20-25 m. Der Nehrung entlang ist eine Serie von Durchgängen (Korridoren) spürbar, die das Phänomen der Deflation gestatten (Delten infolge der Stürme). Die Seen, welche sich hinter der Nehrung befinden (kleine Seen und stark sedimentiert infolge der Windablagerung und der biologischen Anhäufung), haben der Grund viel höher als das Durchschnittsniveau des Schwarzen Meeres.*

## Introduction

The Razim-Sinoie lagoon complex is situated in the south-eastern sector of Romania, in the north-eastern part of Dobrudja (Fig. 1). Its western and northern limit is represented by the lands of Northern Dobrudja; the north eastern limit is represented by the Danube Delta, and the eastern limit, by the Black Sea. Its limits are: 44$^0$21'30'' N lat. (Midia Cape), 45$^0$02'30'' N lat. (Agighiol), 28$^0$32'40'' E long. (Tasaul), 29$^0$08'30'' E long. (Gura Dranov) (Fig. 2).

The area of the Razim-Sinoie lagoon complex (waters, swamps, levees) has progressively increased, from 76,949 hectares in 1835, to 93,156 hectares in 1883, 96,950 hectares in 2005 (including the swampy areas around it)[1].

The Razim-Sinoie lagoon complex is the largest lake complex in Romania, and it represents an association of three genetic types of cuvettes[2]:

- marine lagoons with one shore representing actually the old maritime cliff, fossilised at present (the four large lagoons: Razim, Goloviţa, Zmeica and Sinoie);
- marine limane coasts that occupy the river mouths in the former golf (Calica, Agighiol, Babadag etc);
- lakes between levees, belonging to the group of marine barrier spits situated between the Razim-Sinoie complex and the Black Sea (Cosna, Periteasca, Pahane Ranec, Leahova Mare, Leahova Mica, Edighiolurile etc).

The Razim-Sinoie lagoon complex is situated on an abrasion basement, with wavy appearance, over which the marine or lacustrine-swampy formations were deposited, following the sinking and the water raising period. The Dobrudjan abrasion basement can be found at depth of 14.5 m at Jurilovca, 40 m in the area of Portiţa-Periboina levee, and 52m next to the Dranov lake. Therefore, the abrasion basement is inclined from west to east and from south-west to north-east, towards the deltaic complex.

[1] ROMANESCU 1996a; ROMANESCU 2005; ROMANESCU 2006.
[2] GÂSTESCU 1971; BREIER 1976.

The origin of the Razim-Sinoie lagoon complex is somehow identical to that of the Danube Delta. The genesis of the lake is therefore a copy, on a smaller scale, of the genesis of the Danube Delta:

- the golf stage (Halmyris);
- the lagoon stage;
- the delta stage (or deltaic plain) – the next stage.

The depth of the lake is relatively reduced, around 1.5 – 2 m, sometimes even less; very seldom depths reach 3m (only in the southern part). An important characteristic is represented by the fact that inside the lake several remainders of the predeltaic land can be found, they are of inselberg type, with pediments, and they are extended much below the water level: Popina (49m), Grădiştea, Popinetu (Triassic) and Bisericuţa (9 m – Cretaceous)[3] (Fig. 3).

The sedimentary continental material that is brought in the lagoon complex comes from the Danube Della (through the above mentioned canals), or from the brooks tributary to the lakes. Another part comes from the surface erosion produced on the loess type friable material, specific to the Dobrudjan land.

The sediments are made up of calcareous mud, organic mud and calcareous sand with a thickness of 0.3-1.20 m. Usually, the sand is coarse and the clay can exceed the value of 15%. A larger proportion of the clay is found in the north-eastern sector of the Razim, due to the contribution of the Danube (through the canals linking the arms of the delta). The largest quantities of whole shells, or shells in different breaking stages, can be found next to the Dobrudjan shore[4]). The quantity and type of sediments depend on the agitation degree of water.

**Methods, techniques, materials, study area**

In this study we have tried to point out the types of the barrier spit, the classification of the dunes, of the beaches, of the linking passages between the lagoon and the Black Sea. In this respect, a series of information from the literature in the field has been used[5].

The detailed measurements (height, length) have been made in order to point out the differences existing between the shore dominated by progradation processes and the shore with abrasive processes. They showed the difference between the level of the lagoon water and the sea level.

The measurements have been taken during a longer period of time, and they were compared with several topographical maps printed by the Military Topographical Service[6].

For comparisons, sand samples have been taken both from the typical barrier spits of the Danube Delta, as well as from the barrier spits that close the Razim-Sinoie lagoon complex. Besides particle size analysis (that makes the subject of another study), the terrigene/organogene ratio has been analysed in order to point out its provenience.

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[3] ROMANESCU 2006.

[4] ROMANESCU1997, p. 1-13; ROMANESCU 2000, p. 169-176; ROMANESCU 2001, p. 115-123; ROMANESCU 2006.

[5] BIRD 1969; BIRD 1985; PASKOFF 1998; PIRAZZOLI 1993.

[6] *Military topographical service* 1952; *Military topographical service* 1971-1972.

For the morphology, modern digital accurate theodolite have been used, in order to point out any details. The measurements have been reported to the local average see level. As accessories, tape measures and rulers have been used.

In order to recognise the plants growing on the barrier spit the Romania's flora determination has been used.

The first problem risen during the sand collecting was the identification and the establishing of the characteristic points of the samples that were to be taken out from. The samples were taken out from four littoral segments considered as characteristic for the progradation and abrasion models. For each segment several sand samples were taken out and an average was made.

The sand samples have been taken out from the line of wave breaking (0 m).

Besides the particle size analysis, from each sample, the proportion between the terrigen and the organic material has been established.

The intensity of the morphological processes was estimated through measurements between fixed landmarks and the water line. All the elements of the landmark base are used to obtine a data set relative to the shore and beach dimensions in cross placed at a 1km distance from one another. The precise location is ensured by the identification of the coordinates x and y within STEREO/70 system as well as of the z.m. marks within the Black Sea Constanta system.

**The genesis of the lagoon complex and of the Razim-Sinoie barrier spit**

From a genetically and an altitudinal point of view, the Romanian littoral is divided into two distinct sectors:

- an accumulation northern sector, deltaic, situated between the Musura arm mouth (N) and the Midia Cape (S);
- a high, abrasion sector, between the Midia Cape (N) and Vama Veche (or the state boundary with Bulgaria, in the south).

The deltaic (accumulation) sector is 166 km long and represents 68% of the total length of the Romanian littoral[7].

The formation of the lagoon complex is directly related to the genesis of the Danube Delta. The two morpho-hydrographical units have had a relatively independent evolution, but the factors that have contributed to their appearance have been the same.

The genesis of the barrier spit, and implicitly of the lagoon, has to be associated with the formation and evolution of the Danube Delta. The data obtained so far reveal a Holocene age for the Danube Delta[8]. The problem of sequence in time is hard to establish.

With all the hypotheses issued so far, it seems that in the Altantic period (the climatic optimum, 5,000-6,000 years ago) the level of the Planetary Ocean raised to a certain level that favoured an intense accumulation of sand on the slope of certain shores. During that period (Fanagorian Transgression?) the level of the

[7] ROMANESCU 1999; ROMANESCU 2004; ROMANESCU 2005.

[8] LITEANU, PRICAJAN 1961, p. 103-125; LITEANU, PRICAJAN 1963; MIHĂILESCU 1989, p. 45-80; PANIN 1972; PANIN 1983, p. 25-43; PANIN 1989, p. 25-36; ROMANESCU 1995; ROMANESCU 1996a; ROMANESCU 1996b, p. 267-295; ROMANESCU 2006.

Black Sea raise with 3-5 m and the first barrier spit, separating the present golf occupied by the Danube Delta, was formed (the Jibrieni, Letea, Caraorman alignment). The deltas studied by Panin indicate an age of 11,000 BC. After that, secondary delta appeared: Sf.Gheorghe I, Sulina, Sf.Gheorghe II and Chilia, Cosna and Sinoie (next to the lagoon complex Razim-Sinoie).

The Razim-Sinoie barrier spit (Cosna and Sinoie deltas) appeared as a result of the decapitation of the triangular delta of Sulina (of „tibru" type). The sediments that the Sf.Gheorghe II delta and the Razim-Sinoie barrier spit are made up of, come from the erosion of the Sulina Delta in the „scissors" system.

The littoral deposits in front of the Razim-Sinoie lagoon complex are not older than 2000 years. After this complex appeared, the ports-fortresses of Histria and Enisala practically disappeared (Fig. 4).

**The geomorphology of the barrier spit**

From a morphologic and hydrologic point of view, the lagoons can be classified in several types. One of the simplest classifications considers the opposite processes occurring here, which have, as a result, either the closing up of the lagoons, or the maintenance of a communication with the sea (one or several breaks)[9]. In this case the factors involved include a sedimentary littoral transfer, the existent marine currents and the river water discharge. As a result the these factors four large categories of lagoons can be differentiated: estuarian; open; semi-closed; closed. According to this classification, the Razim-Sinoie lagoon is a semi-closed lagoon, communicating to the sea only through two inlets: Periboina (active) (Fig. 5) and Portita (anthropically closed).

The Razim-Sinoie barrier spit cannot be older than 2,000 years. In the beginning it had the character of an arrow with the end sticked to the southern sector of the Danube. It is older in the northern sector and younger in the southern sector. Its width varies from one place to another, according to the conditions existing in that perimeter. In those sectors affected by progradation (Perisor, Chituc) they are more developed, while in those sectors affected by abrasion (Portita) they are less developed.

In a cross section, the barrier spit is relatively symmetrical from one side to the other. On that part exposed to the sea, the slope is higher as compared to that part exposed to the lagoon, where the slope is smoother.

The sediments that make up the barrier spit are of Danubian origin (most of them) and marine origin (of bioconstructional nature, coming from the breaking of the shells). The materials are transported by means of the shore drift and the waves and wind deposit them.

The sedimentary accumulation is caused by the waves and currents as well as by the human activities, which are still very reduced in this case. This sedimentary accumulation is realised by the longitudinal littoral transfer (drift, shore drift, littoral transfer), by the reconstruction of the summer equilibrium profile (of calm weather) and by coastal hydrothechnical constructions.

The sedimentary loses are caused by the same factors (waves, currents and human activities) and they are realised by means of the shore drift, by the

[9] NICHOLS, ALLEN 1981.

transport offshore of the material, during storms, and as a result of the coastal constructions that cause the abrasion phenomenon[10]. The industrial exploitation and even the handiwork exploitation of sand in this sector is absent.

The Razim-Sinoie barrier spit has known several evolution stages in the last 2,000 years, as a result of the changeable local conditions that existed next to the deltaic shore. Besides the present transgression that is present on a general level, with values of 1-2 mm/year next to the Romanian shore, other forces that have to be considered are: sedimentary accumulation processes, the slope of the avant-shore, the factors that contribute either to the abrasion or to the progradation etc. Although the transgressive phenomenon is present on the whole area of the barrier spit, some sectors are slightly eroded (Portiţa), others are slightly progradated (Chituc-Midia Cape) and in the rest of the sectors a precarious relative equilibrium occurs (Periboina, Periteasca) (Fig. 6). The two opposite phenomena appear as a result of a shortage of sedimentary material that occurs in the Portita sector (as a result of the closing of the Portita Inlet, the accumulation of sedimentary materials coming from the lagoon ceased and the high intensity wind have a north to south and a north-east to south-west direction).

In our case, the terrigen material/organogene material ratio (T/O) is 50/50 on all the barrier spit, in comparison with 90/10 for the Sulina-Sahalin sector, 60/40 for Sahalin-Zatoane, 80/20 for Perişor (Fig. 7). The reduced turbidity of the water in the sector of the Razim-Sinoie barrier spit causes a rich development of the shell fauna that represents the raw material of beach sediments. The organogene material represents the $CaCO_3$ accumulation. The aeolian activity, by means waves and wind, causes the breaking up of the shells and their transformation in sandy particles. The gradual decrease of the terrigene accumulation is caused by the distance between this sector and the Danube river mouths. Only the very fine particles are transported, in a reduced a quantity.

The accumulation shore (of deltaic type) has been divided into several sectors, according to the morphological characteristics. The Razim-Sinoie barrier spit includes three morphological sectors:

- Perişor – Portiţa (Periteasca – in the north);
- Portiţa – Chituc (Portiţa – in the centre);
- Chituc – Midia Cape (Chituc – in the south).

The Perişor – Portiţa sector includes a dune bar behind which small size lakes are found, greatly fragmented and in an advance clogging process.

The Portiţa – Chituc sector is the most interesting and it's the most specific example of a barrier spit partially closing a lagoon. It had two natural inlets, popularly known as „portite", „periboine" or „buhazuri" („buazuri", „bugazuri" – in Turkish, means a channel); in reality they represent openings (*grau* or *passe* in French, *inlet* in English) through which the communication between the lagoon and the sea is ensured. Their genesis can be different (in the case of the Black Sea where tides are not significant):

- they can be created by the passage of the marine currents over the barrier spit, during strong storms, when the waves can exceed 6-10 m:
- they can be generated by the water surplus in the lagoon;

[10] ROMANESCU 1999; ROMANESCU 2005.

- a previous interruption in the sedimentation in the barrier spit can also be the cause.

Unfortunately, both passages have undertaken modifications:

- in 1960-1974 Portiţa Inlet was completely closed, and now its evolution is controlled[11];

- Periboina Inlet has a lock that controls the water flow through the canal.

The features of these inlets are still typical for such a form, its orientation is slightly deviated to the south as a result of the north-south direction of the shore drift. The shape of the inlet is a result of the fact that the shore drift is predominating on a certain direction.

It is possible that the groins (shelter dams) built next to the Portiţa tourist complex caused the stagnation of important quantities of sediments that were supposed to be deposited in southern sectors. The most obvious withdrawal is manifested in the sector of the Portiţa Inlet (southern sector – Portiţa Lighthouse), because an accumulation with sediments from Razim is absent, but also from the north (Periteasca, Perişor) where there is not any Danube tributary to feed the barrier spit.

In the sector of Portiţa Lighthouse, the barrier spit has reduced with 75 m in 20 years, with an average of 3.75 to 4 m per year, respectively. The erosion occurred horizontally as well as vertically, the latter one had as a result the diminishing of the sedimentary storage with 70$m^3$/ml (linear meter).

On the barrier spit, in the period 1982-2004 we have 6 measurement:

-the accumulation shore in Perişor sector, at an average rate of +3 - +11 m/year;

-shore of moderate erosion between Perişor and Portiţa sectors, at an average rate of -1 - -6 m/year;

-lagoon barrier in parallel retreat in Portiţa sector, at an average rate of -5 - -10 m/year;

-barrier in translation in Periboina sector, at an average rate of -5 - -10 m/year;

-erosion shore between Periboina and Chituc sectors, at an average rate of -5 – 8 m/year;

-accumulation shore in Chituc sector, at an average rate of +5 - +7 m/year (Fig. 8).

The volume of solid material transported to the south of the Periboina Inlet is higher than that transported to the north, as, besides the proper quantity, the solid materials transported by the lagoon current inside the lacustrine complex are added. As a result of the closing of the Portiţa Inlet, the solid discharge through the Periboina Inlet increased. This material has been used to build up the Chituc barrier spit.

The Chituc – Midia Cape sector is much better represented, and it is the only that clearly reveals the progradation phenomena. It is made up of two sub-sectors:

- a northern one, with lakes (of „edighiol" type) situated between the secondary barrier spits, with prolonged shape, with north east to south west

[11] I.R.C.M. 1999.

direction;

- a southern one, with a well developed typical accumulation barrier spit, where the width can exceed 5km.

In this sector the highest accumulation rate is recorded, that reaches, in certain places, a maximum value of 23.2 m in the last 15 years, that is a sedimentation storage of 25.3 $m^3$/ml.

Abrasion is predominant on the Razim-Sinoie barrier spit (on more than 60-70% of the area), while accumulation represents only 30-40%. The hydro-dynamic factors, in natural regime, have a large contribution to the modification of this barrier spit. The anthropic constructions are very rare (shelter dams at Portiţa, - groings and the lock of Periboina) and they do not influence too much the activity of the natural factors on the shore line.

The *beach* represents the most important element of the barrier spit. The beach accompanies all the shore line of the barrier spit and it has distinct characteristics depending on the natural conditions characterising those sectors. The beaches are formed when the quantity of available materials exceeds the volume of the sediments that the waves and shore drift are capable of transporting. The beaches are dynamic, as they are made up of mobile material. The beaches correspond to the shores where the deposited sediments have higher size than the muds (fine to coarse sands). Those materials are not cementated.

The beach of the Razim-Sinoie lagoon complex is of „arrow" type („arrow" type barrier spit). The arrows are only particular beaches, as they are not superposed, on all the length of the barrier spit, with rocky outcrops. Their existence is caused by the shore drift, well fed with materials (in the present case we refer to a very recent past). The above mentioned beach is long, continuous and straight. The orientation of the shore line tends to be perpendicular to the predominant swell.

The width and slope of the beach depend on the quantity of available materials and by the energy of the waves and of the currents that are capable of to transport them[12]. The beach on the Razim-Sinoie barrier spit is poorly developed, and it contains only one single row of prolonged dunes. When the shore is well fed with sedimentary materials and its evolution is long, coastal dune field or prolonged successions of dunes can appear. The interior dunes are older than those closer to the shore.

The low beach of the Razim-Sinoie barrier spit is very extended because it is part of a typical accumulation sector. Subaqueous bars and troughs appear on her surface. The high beach includes one or two berms and a row of prolonged dunes known as avant-dunes. Sometimes, small waves of shells appear (under different degrees of destruction). Due to the present transgression of the Black Sea, the present shore is continuously withdrawing on almost its entire length (except the northern and southern sector). Erosion and accumulation take place in accordance with Bruun's law.

The accumulation or erosion of the beaches is caused by the action of the wind, waves and shore drift. Depending on the incidence angle with which the waves hit the shore, the sedimentary materials are transported either on back and

[12] PIRAZZOLI 1993.

forth direction, as a result of the rip-currents, or longitudinally, along the shore, as a result of the shore drift. The back and forth movement of the waves select the material of the beaches and give a characteristic aspect to them. The sand particles are blunted, glossy, with lots of traces of the shock (visible on microscope). The sand and the finer materials (clay) are transported towards the sea by means of retour currents (rip type currents). Therefore, the general movement direction of the materials on the beach, by means of the shore drift, depends on the type of beach and on the predominant winds.

The profile of the beach is continuously changing as it has to adjust itself to the hydro-dynamical conditions that are continuously changing too. The beach lowers down, when the sedimentary storage diminishes, as a result of erosion caused by the storm winds, and it raises up, as a result of the accumulation produced in the periods of relatively calm weather with wind. The beach undertakes an annual cycle of accumulation and erosion. An objective tendency of the beach (stability, progradation, abrasion) can be predicted only when long term observations are made.

During stormy weather, the waves also surf on the beach, and coarse materials are thrown on the high beach. The finer sediments are recarried and transported to the low beach, and they are accumulated under the form of submerse bars. The bars themselves force the waves to break next to the shore, to a certain distance from the separation line between water and land; in this way, their force is lower and erosion is lower too (as a self defence reaction of the beach).

During the warm period of the year (May-September) the wind are weaker and the less cabrated waves are constructive. They surf next to the shore and the beach jet has a higher power than the withdrawal water. Therefore the material migrates from the avant-beach to the beach; the submerse bars tend to uniformise themselves, and the profile get back to normal in such a way that the action of the withdrawal water compensates the beach jet: a new temporary equilibrium is created. The repeated erosion and accumulation alternances generate oblique stratification on the beach deposits, creating multiple crossings.

Unfortunately, the general rule of the Razim-Sinoie beach is represented by the withdrawal. In reality, this beach is included in the average statistics in the world (70% abrasion, 20% relative equilibrium, 10% progradation[13]). The diminution of the total quantity of sediments transported by the Danube (81 mil.t/year in 1894[14]; 58.7 mil.t/year[15]; 22 mil.t/year[16]) the raising of the general level of the Black Sea with 1-2 mm/year, the intensification of the destructive power of winds etc. are the causes that generate a precarious state of the Razim-Sinoie beach.

In order to preserve the beach that is continuously withdrawing, certain hydrotechnical works can be done. In order to complete the existent alluvionary

[13] BIRD 1985.

[14] Commission Européenne du Danube, 1932.

[15] GÂSTESCU, DRIGA 1982, p. 77-91; BONDAR 1983, p. 23-28.

[16] DUMA 1988, p. 3342; ROMANESCU 1996a; ROMANESCU 1999; ROMANESCU 2005; ROMANESCU 2006.

shortage in the sector of the Razim-Sinoie barrier spit, the waters of the Sf. Gheorghe arm could be deviated to the south of the Sahalin island complex through the Buhaz-Zaton, Crasnicol and Dranov Canals, or through the Turkish Brook, in order to feed the beach of the Zatoane, Melelei Sahalin complexes, and of the Razim-Sinoie complex, implicitly.

The beach can be fed also artificially, but this procedure is very expensive and laborious. The material used in such a case should have closer size and nature as the material existent on the beach. If the material is too fine, there is the risk of being dispersed very easily by the waves. The material can be taken out from the dunes or from the avant-coast, by dredging; in this latter case the sand is to be taken from depths of 20 m, so that the beach should not be disturbed. The extracted material can be diffused at a lower depth, upstream the chosen place, in order to be transported by the shore drift; in this case, the accumulation on the beach is realised naturally. The dredged material can be brought to the shore also by means of reffulation pipes (floating or submerse).

The genesis of the *littoral dunes* depends on the abundance of the sand on the low beach, on the existence of strong winds with sea to land direction and on the installation of psamophyle vegetation. The incipient mounds that appear on the beach join together until they build up a bordier dune, parallel to the shore, with variable dimensions. The aeolian accumulation implies the existence, nearby, of a shore where sand can be taken of from. For the particles of quarts, 0.2-0.3 mm in diameter, to be transported, the wind velocity should reach at least the values of 5-6 m/s). A coast dune is not fixed. If the beach withdraws, the dune replies. The coastal dune represents a useful sand reserve for the dynamic equilibrium of the beaches[17].

The sedimentological features of the littoral dunes emphasise the selective characteristics of the wind action. The pioneer vegetation installed on the sandy surfaces diminishes the wind velocity and increases the rugosity of the dune surfaces. They are psamophyle plants that need a sandy support in order to develop and they are adapted to the dune substratum: some of them have rhizomes, others have roots. Sometimes, the roots are vertical and deeply thrust in the sand in order to reach the phreatic water; others are superficial and they are developed on large area in order to collect as much water as possible from the surface. They contribute to the edification of the alignments, known under the name of avant-dunes.

The dunes in the first line corresponds to the bordier dunes. The small sand accumulations are born during the warm season, on the high beach, where the remainders of different annual halonitrophic plants represent obstacles for the wind. Their existence is often ephemeral, as they can be swept by the waves of the first storm. The only plants that last, are those that are formed above the highest sea waters, behind the perennial psamophyle plants. They get the appearance of low mounds, several decimetres in height, known under the name of *nebkas*. These have the tendency to dispose themselves in a more or less continuous alignment (Fig. 9).

[17] PIRAZZOLI 1993; PASKOFF 1998.

By the uplifting and reunion of several nebkas an avant-dune is created, which has the appearance of a levee parallel to the shore. The altitude varies depending on the general state of the sea. When winds and seiches occur, the sea level can vary with over 1 m (more or less). This dune has an almost symmetrical profile, and presents heights of several meters (2-3 m). It is present along the whole lagoon barrier spit (Periteasca – Midia Cape). From place to place this dune is fragmented by deflation corridors (storm corridors) prolonged in the dominant direction of wind. The aspect of these dunes depend a lot on the degree of vegetation coverage. In the sectors where the storm waves reach the basis of the avant-dune the beach terassettes are created („scarps" or improperly called „cliffs").

The avant dunes on the Razim-Sinoie barrier spit are clearly represented and they have special characteristics in accordance with their position in the barrier spit and against the factors that contribute to their evolution. The campaign of measurement of these dunes was held in the period July 2000 and July 2004. Complex observations have been made on the form, altitude, vegetation cover degree, level of the phreatic water, existence or inexistence of berms, of the shell waves, of the abrasion sectors, of the progradation sectors, of the anthropization degree (hydrotechnical works) etc.

One can notice that the dunes in the sectors with a relative equilibrium, or with a certain tendency of accumulation, are situated at a longer distance from the shore (8-10 m – Portiţa). The slope of the avant-dunes in the abrasion sector is higher and often the dunes present terassettes on the beach, with altitudes frequently reaching 1m.

The avant-dunes with relative equilibrium present one or two berms while in the abrasion sectors, these are absent. The psamophyle vegetation installed on these avant-dunes is a pioneer vegetation and it is absent in the areas where shells are predominant (Fig. 10).

It is to be mentioned the existence of a dune made up exclusively of shells in different destruction stages. It has a length of 250m and an average width of 20-25m. It is situated 9km north of Portita Inlet and it is limited from the southern and northern alignment (with dominant shells) by deflation corridors (storm corridors). The dune was recently formed, as inside it, around 20-30 cm deep, still green plants were formed. Such a shell dune is very seldom noticed and that is why it represents a unique phenomenon on the Romania accumulation shore.

For the three sectors (Periteasca, Portiţa, Periboina) ideal profiles of the Razim-Sinoie barrier spit have been created (Fig. 11). The back of the dune, in the Portiţa sector, is short, as small size and low depth lakes are found nearby, and they are covered with vegetation (Fig. 12). Their clogging is advanced and their bottom is situated at an altitude superior to the general level of the Black Sea. In the Periteasca sector the back of the dune is very extended, and it turns practically into a sandy area, covered with psamophyle vegetation, and with *Euphorbia helioscopia.* The summits of the avant-dunes contain a large quantity of shells. The barrier spit has a single berm. The Periboina sector, with two berms, extends a lot behind the avant-dune and its end is situated in lacustrine depressions, strongly clogging (they are usually swamps).

The clogging phenomenon behind the avant-dunes is accelerated also by the fact that a protection dam has been built, separating the beach sector and the lagoon complex (Fig. 13). On this dam the high road linking Constanţa and Sulina should have passed. The sand swept away by the wind is carried to the lacustrine depressions situated between avant-dune and the dam, and due to this phenomenon the lakes are strongly clogging. The process is speeded up also by the fact that the reef vegetation and the rush vegetation is well developed. On the edge of the lakes, as a result of the saraturation phenomenon, halophyle vegetation is frequently developed (*Salicornia herbaceea* and *Sueda maritima*).

The western sector of the barrier spit knows an accelerated evolution of progradation towards the lagoon complex, as the vegetation develops very well and facilitates the clogging. The clogging is faster due to the fact that the sand swept away by the wind is kept by the reed vegetation and by the fact that this vegetation contributes, with a large quantity of organic matter to the agraddation of the lagoon bottom. After the closing of the Portiţa Inlet (1960-1974) the chemical concentration of water has changed, from a value of 6-10 g/l before the closing, to less than 2 g/l today. As a result of the sweetening of the water in the lagoon, the areas covered with reed vegetation extended a lot. If the previous situation occurred, these areas would diminish (Fig. 14).

After digging up the canals (Dunavăţ, Dranov, Lipovenilor and Mustaca) that link the Sf. Gheorghe arm with the Razim-Sinoie lagoon complex, the water level raised with more than 30cm. The highest level is met in the Razim lagoon. The water level in the Sinoie lake was modified too, but only after the cutting of the V Canal, that allowed the transfer of the drinking water from Goloviţa to the south. As a result of the fact that the drinking water has a lower density than the salt water from the Black Sea, but also of the fact that the water level in the lagoon complex is higher, a water transfer by means of the phreatic water takes place, from the lagoon to the sea (Fig. 15). Theoretically, a slow transfer of sandy and clay sediments that make up the barrier spit could also take place.

The avant-dunes play the role of barrier against the strong waves. They protect the lagoon sectors against the floggings produced by the marine waters. As a result, the avant-dune is considered to be a natural protection wall that should be very carefully protected.

In the case when an avant-dune is destroyed, it is advisable that it should be recreated in the same place where it was degraded, to rebuild it in the place where it was affected and to protect it where it is still intact.

In order to re-establish an avant-dune several psamophyle species can be planted, especially *Ammophila arenaria*, which is a very good sandy fixator. This procedure is very cheap and efficient and it is very adequate to the Romanian littoral. The bushes are arranged perpendicular to the predominant wind, and their density should be higher on the maritime side in order to contribute to a better spreading of the sand on the whole dune area. For these bushes to grow faster, fodders can be administrated.

If an avant-dune is restaurated it is very important that it regained the previous natural morphology that represents the result of an equilibrium with the associated beach. It is essential that the avant-dune to preserve the same mobility,

as its location changes in time, as a result of the changing of the meteo-marine conditions. The anthropic interventions on the avant-dunes should be led carefully in order to preserve the fragility of the natural equilibrium.

**Discussions**

Among the lagoons of the Romanian littoral, the Razim-Sinoie lagoon occupies the depresionary zones of the land and it is caused by the negative epirogenetic movements and by the positive eustatic movements.

In the genetical history of the lake three main stages are present: the golf stage, the lagoon stage and the clogging stage (or disappearance stage). The present evolution stage of the Razim-Sinoie lagoon complex is the second one, but, as a result of digging up several canals that link the Sf. Gheorghe arm from the Danube Delta to the lagoon, the latter one has known an intense clogging process.

The alluvionary material existing in the barrier spit come from the north, and they are brought by the shore drift. It is practically similar to the one in the Danube Delta, but the proportion of terrigene material is lower as a result of the distance from the Danube arms.

From a typological point of view, under the present conditions, the Razim-Sinoie lagoon is a semi-closed lagoon. Nevertheless, as a result of the anthropic interventions (the Portiţa Inlet is anthropically closed since 1960; Periboina Inlet is controlled by a water lock), this lagoon could be included in the category of the closed ones.

The hydro-dynamic factors that contribute to the modelling of this barrier spit are diverse and they generate different geomorphologic processes on the entire littoral segment: progradation in the south; abrasion in the centre, relative equilibrium with a progradation tendency, in the north. There are sectors where the abrasive processes reach the value of 4 m/year; similar phenomena occur on the littoral of the Danube Delta.

As compared to the Danube Delta where two or three dune alignments are found, the dunes in the Razim-Sinoie barrier spit are arranged under the form of a single alignment (avant-dune) generated as a result of the joining of several nebkas.

The dunes have maximum heights between 2 and 3 m and they are farther or closer to the shore depending on the hydro-dynamic conditions that have generated and modelled them.

**Conclusions**

As a result of the fact that the Razim-Sinoie lagoon copies, on a smaller scale, the genesis and other features of the Danube Delta, it should be included in this morpho-hydrographic unit. Actually, it is included in the Danube Delta Biosphere Reserve.

The Razim-Sinoie lagoon complex occupies the old territory of the Halmyris Golf. This golf was blocked 2,000 years ago by a barrier spit of „arrow" type. The materials that make up the barrier spit were transported by the shore drift with north to south direction. They are of Danubian origin. The genesis of the barrier

spit was also facilitated by the decapitation of the Sulina delta (of „tibru" type).

The sediments of the lagoon complex are made up of calcareous mud, organic mud and calcareous sand, in layers 0.3 to 1.2 m thick, and even thicker.

The barrier spit is penetrated only by two openings called „portiţe", „periboine" or „buhazuri" („bugazuri", „buazuri" – in Turkish, means a canal): Portiţa Inlet (artificially closed in 1960-1974) and Periboina Inlet (controlled by means of a water lock).

The terrigene material/organic material ratio (T/O) next to the barrier spit is of 50/50.

The Razim-Sinoie barrier spit includes three sub-sectors: Perişor-Portiţa (Periteasca), in a state of relative equilibrium: Perişor-Portiţa (Portiţa), with significant abrasive phenomena; Portiţa-Chituc (Chituc), in a state of relative equilibrium with clear progradation sectors. The maximum abrasion is recorded in the point of Portiţa Lighthouse and it has the value of 4.5 m/year.

Along all the barrier spit, the abrasion is predominant (60-70%), while the accumulation sector represents only 30-40%.

The beach of the barrier spit is of „arrow" type, it is long, continuous, straight. It has two distinct parts: the low beach and the high beach. The profile of the beach is continuously changing as it has to adjust to the hydrodynamic conditions that are continuously changing. On good weather accumulation takes place: during storms erosion occurs.

The incipient dunes, formed behind the pioneer psamophyle vegetation, are of nebkas type. Through their coalescence the avant-dunes are formed. The littoral dunes in the Razim-Sinoie barrier spit are of avant-dune type and they get the appearance of a levee parallel to the shore. The avant-dunes have an almost symmetrical profile, and they have heights of 2-3 m. They are sporadically fragmented by deflation corridors (storm corridors). The avant-dunes in the sector with relative equilibrium are situated at a longer distance from the shore (12-15 m) as compared to those situated in the abrasive sector (8-10 m), The shore of the sector with a relative equilibrium has one or two berms, while the abrasive shore does not have such forms, and it is limited by beach terassettes (scarps) with heights up to 1m. They are covered with pioneer psamophyle vegetation. The coastal dune (avant-dune) represents a useful sand reserve for the dynamic equilibrium of the beaches.

Towards the lagoon complex, the lacustrine depressions are intensely clogging with deflation materials and with organic remainders deposited by the hygrophile vegetation developed abundantly as a result of the sweetening of waters*.

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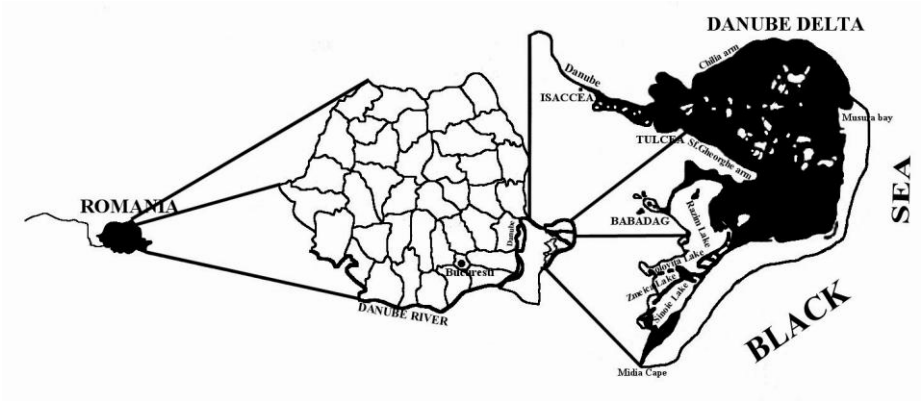


**Fig. 1 - The geographical location of the Razim - Sinoie lagoon complex and Danube Delta in Romania.**


**Fig. 2 - The geographical location of the Razim - Sinoie lagoon complex.**

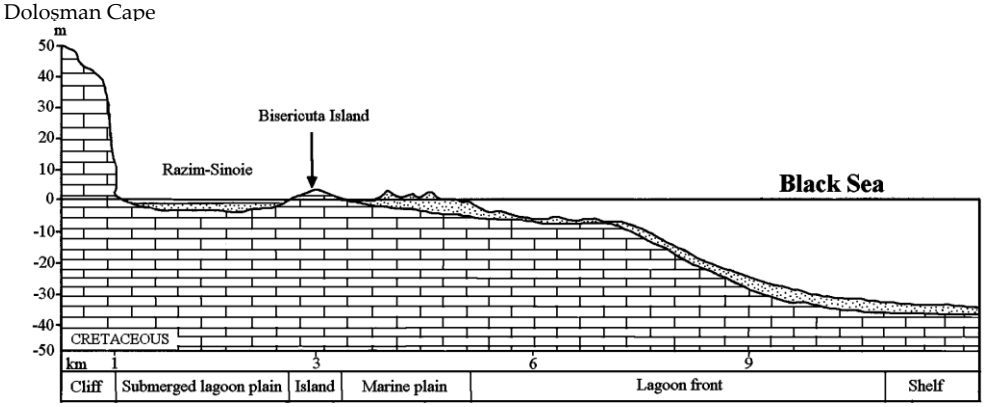


**Fig. 3 - Cross section profile between Doloşman Cape and Black Sea.**

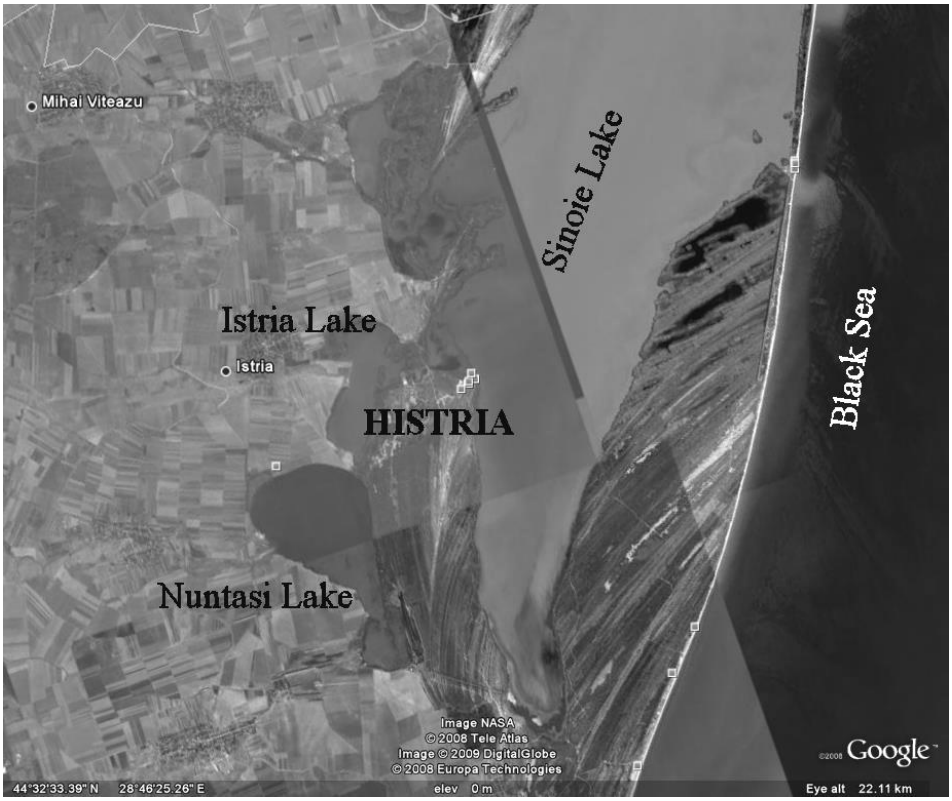


**Fig. 4 - The geographical location of the port-fortresse Histria.**

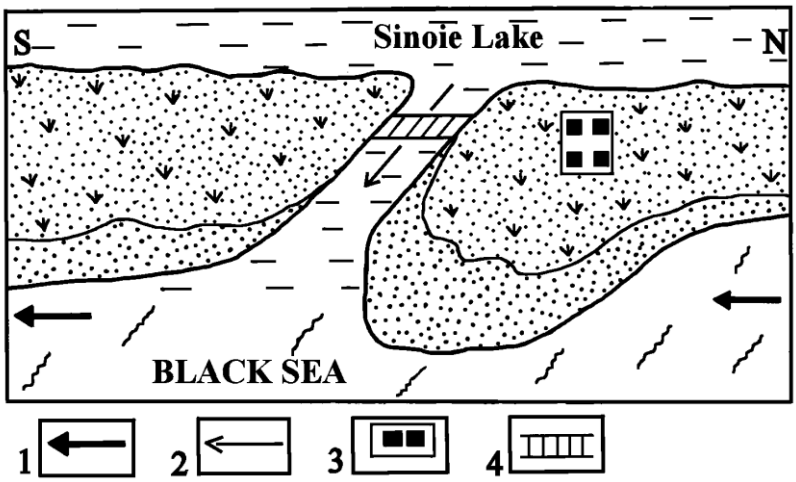


**Fig. 5 - Morphology of Periboina mouth 1. Shore drift; 2. Lagoon current; 3. Hydro-technical works; 4. Lock and Bridge.**

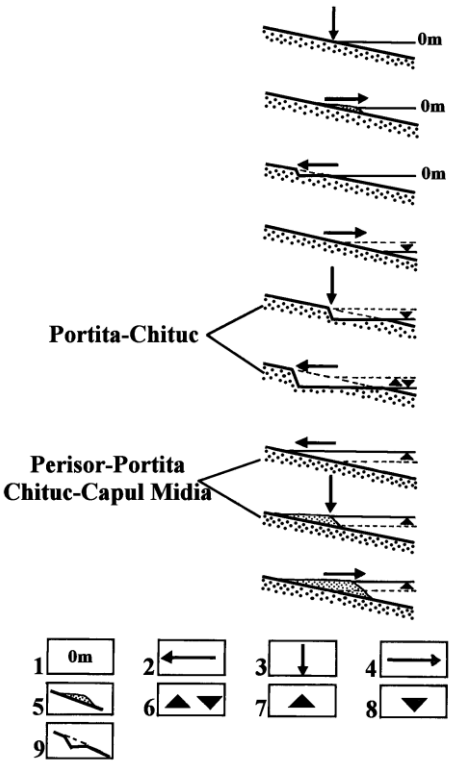


**Fig. 6 - The dynamics of the shore line, the sea level and the morphogenetic action of the littoral processes.**

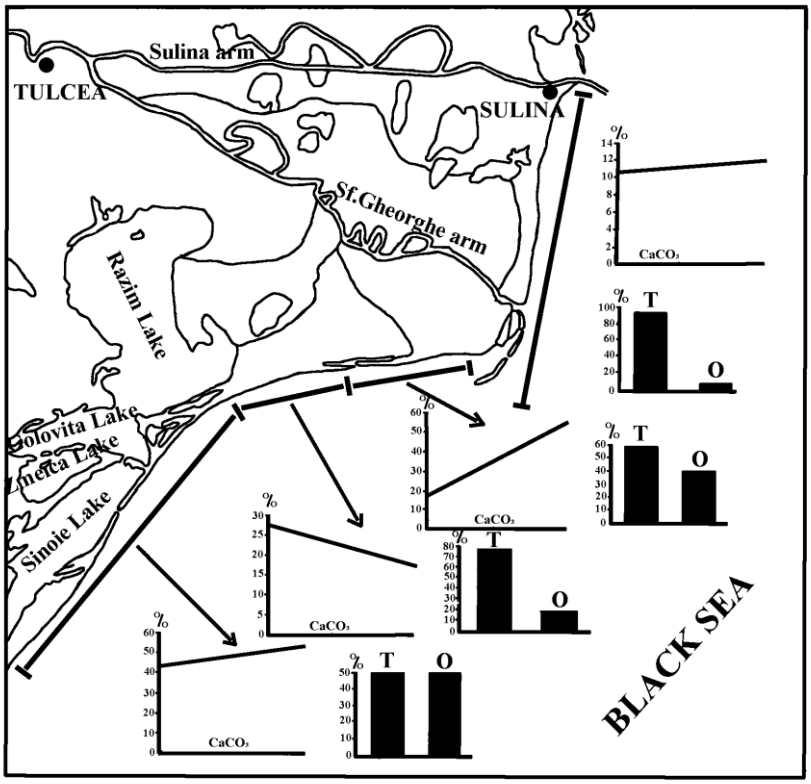


**Fig. 7 - The percentage of the terrigene/organogene material (T/O) and the tendency of the biogene material accumulation (CaCO3) on the deltaic shore.**

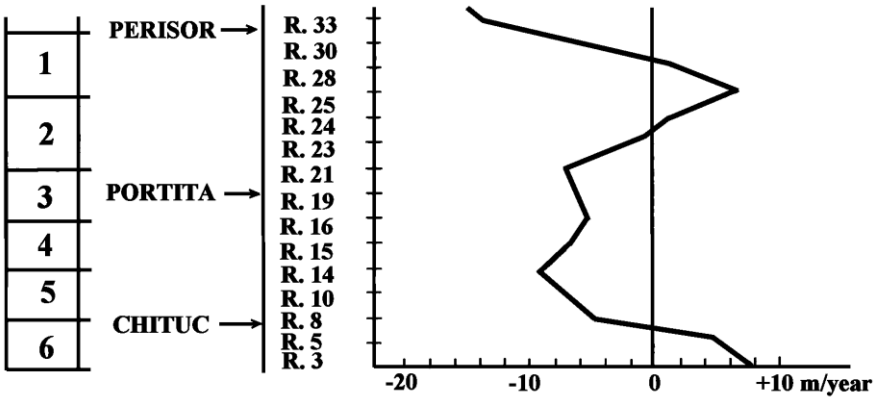


**Fig. 8 - Behavior of the water line on the barrier spit along of the Razim - Sinoie lagoon.**

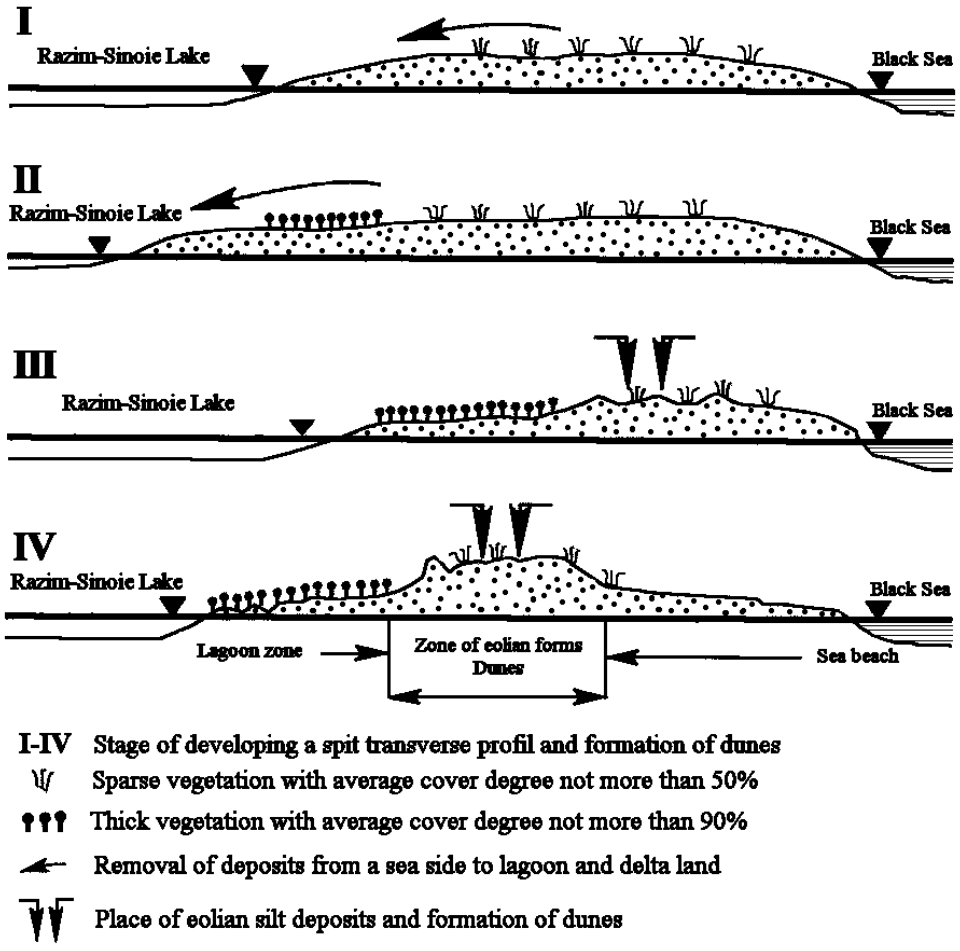


**Fig. 9 - Schema of dune formation in the Razim-Sinoie barrier spit**

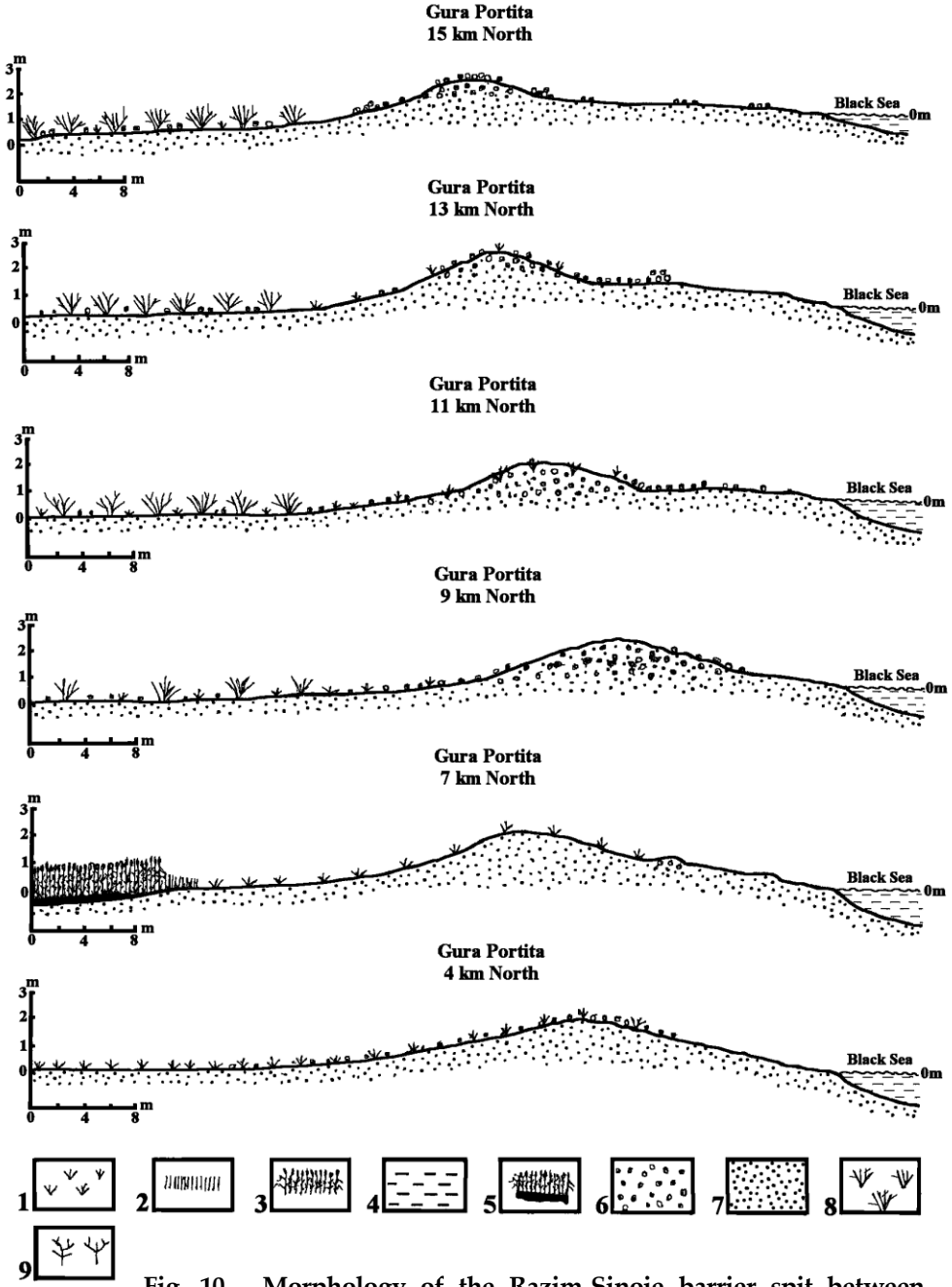


**Fig. 10 - Morphology of the Razim-Sinoie barrier spit between Periteasca – Portița 1. Psamophyle vegetation; 2. Rush; 3. Reed; 4. Lakes; 5. Swamps; 6. Shells; 7. Sand; 8. *Euphorbia helioscopia*; 9. Arbustive vegetation.**

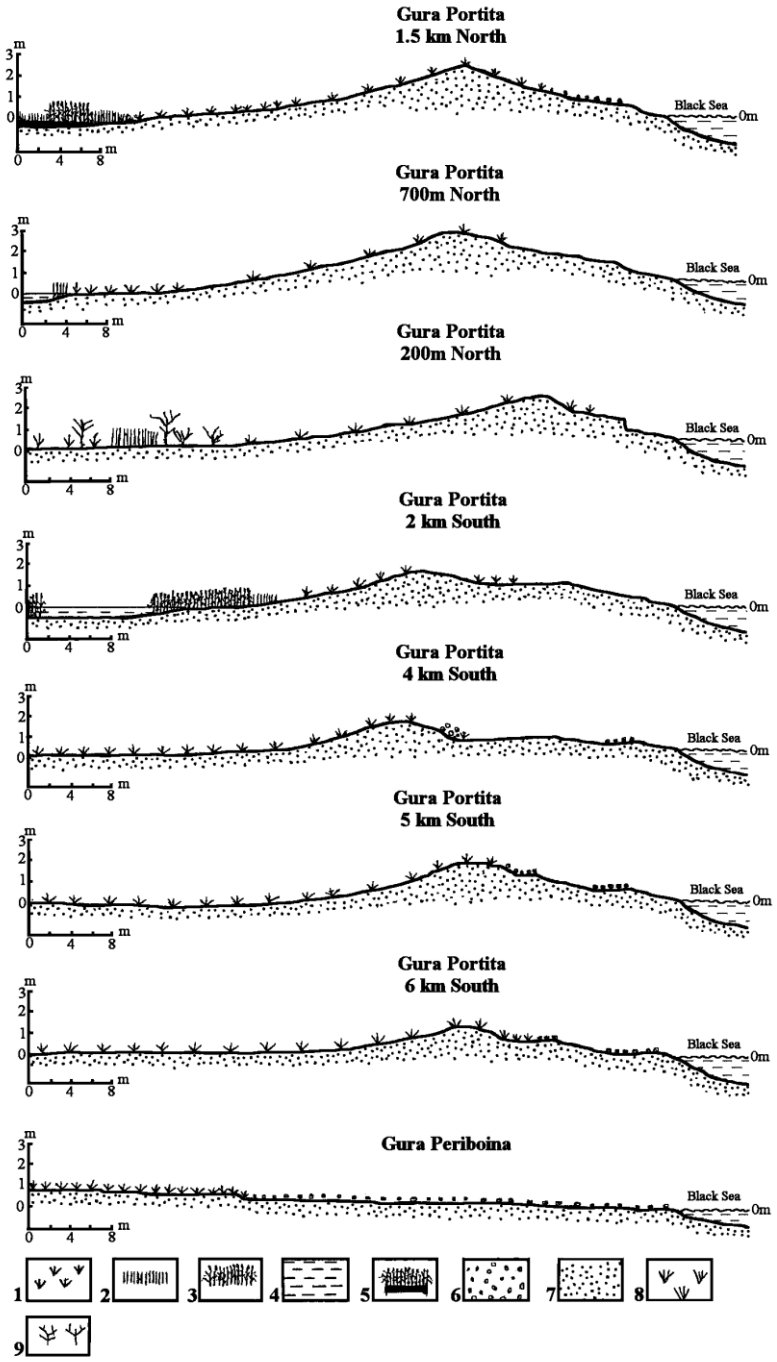


**Fig. 11 - Morphology of the barrier spit between Portița and Periboina. 1. Psamophyle vegetation; 2. Rush; 3. Reed; 4. Lakes; 5. Swamps;6. Shells; 7. Sand; 8. *Euphorbia helioscopia*; 9. Arbustive vegetation.**

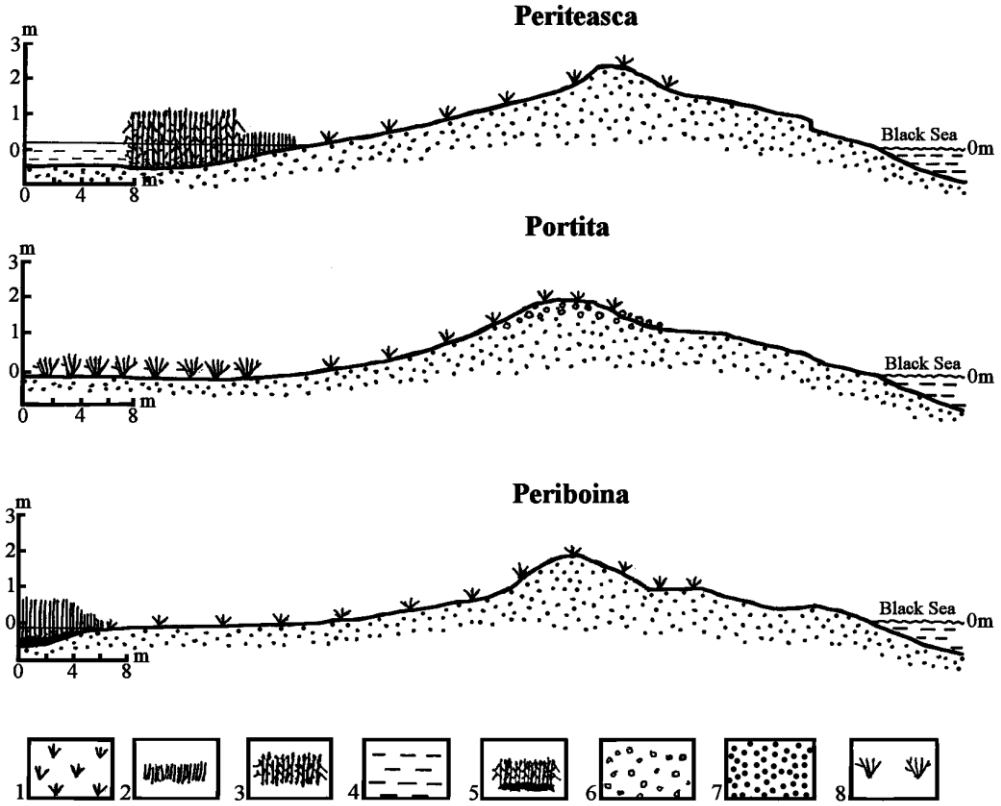


**Fig. 12 - Synthetic profiles in the Razim - Sinoie barrier spit (Periteasca, Portiţa, Periboina) 1. Psamophyle vegetation; 2. Rush; 3. Reed; 4. Lakes; 5. Swamps; 6. Shells; 7. Sand; 8. *Euphorbia helioscopia*.**

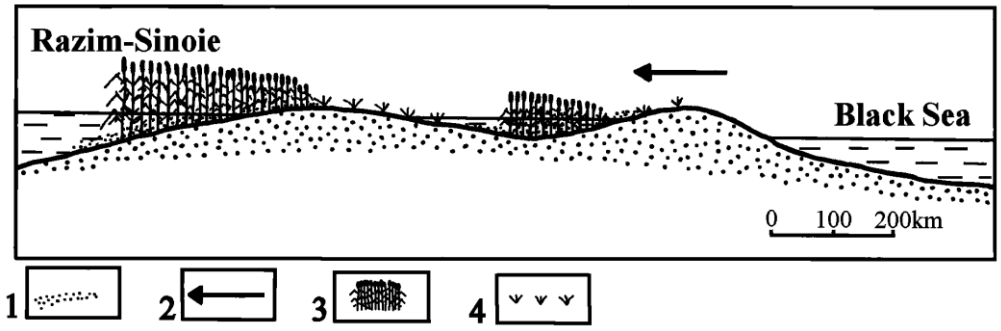


**Fig. 13 - Clogging of the inter-dune lakes and of the Razim – Sinoie lagoon 1. Sand; 2. Direction of the wind; 3. Reed; 4. Psamophyle vegetation.**

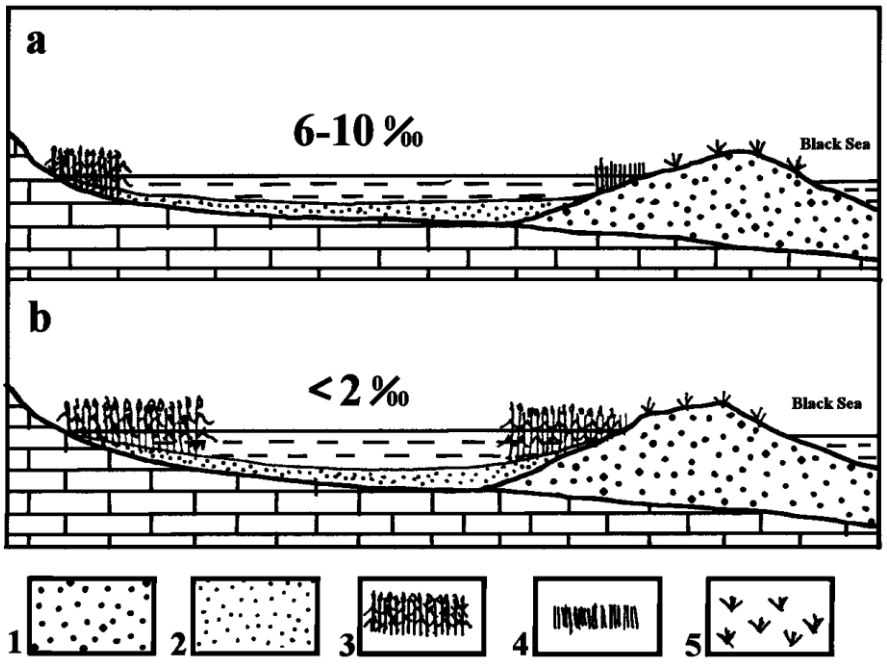


**Fig. 14 - Extension of the reed vegetation as a result of the sweetening of the lagoon waters 1. Sand; 2. Lacustrine sedimentary deposits; 3. Reed; 4. Rush; 5. Psamophyle vegetation.**

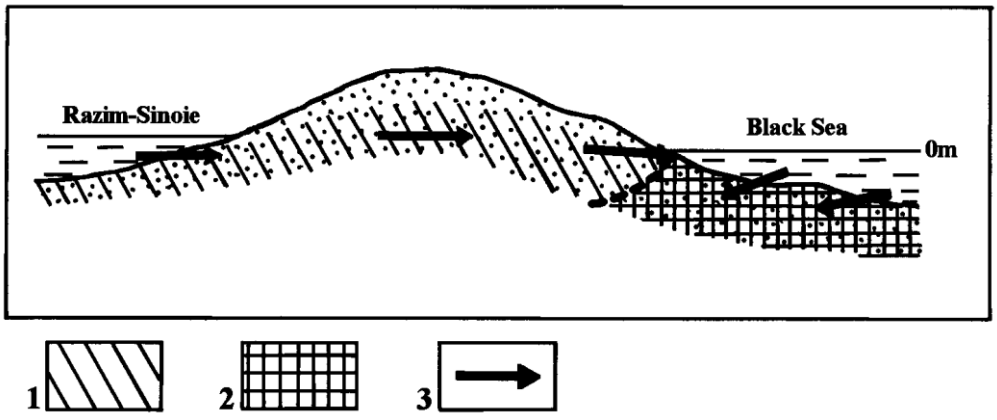


**Fig. 15 - The underground movement of the lagoon waters in the Black Sea. 1. Lagoon phreatic waters (sweet); 2. Marine phreatic waters (salty); 3. Phreatic waters movement direction.**