ON THE GEOMORPHOLOGIC AND GEOLOGIC EVOLUTION OF THE RIVER DANUBE - BLACK SEA INTERACTION ZONE

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Abstract. The present paper aims at describing of the evolution of the mouth zones of three main distributaries of the Danube Delta system: the northern branch - Chilia, a median one - Sulina and a southern branch - St. George (Sf.Gheorghe). These main distributaries are responsible for the formation and the development of different stages of the Danube Delta. The description is based on the complex study of the entire Danube Delta edifice by aerophotogrammetric, geomorphologic, sedimentologic-geologic, biostratigraphic means, as well as by ^{14}C datation of deltaic deposits. The main stages of development through which the Danube Delta reached the present day aspect include: (1) the Danube Gulf and the "Danube Blocked Delta" - ~12-11 k.yr.B.P.; (2) Initial Letea-Caraorman Spit, 11,700 -9,800 yr.B.P.; (3) St.George I Delta, 9,000-7,200 yr.B.P.; (4) Sulina Delta, 7,200-2,000 yr.B.P.;(5) St.George II Delta and Chilia Delta, 2,800 yr.B.P.-present; (6) Secondary Cosna-Sinoie Delta, 3,550-2,500 yr.B.P. Detailed description of the succesive phases of development of the mentioned stages is given.

Key words: geomorphologic and geologic evolution, deltaic deposits, phases of development, ^{14}C datation, Danube Delta system.

INTRODUCTION

The river-sea interaction zones have very complex dynamic, depositional, biogeo-chemical and eco-structural characteristics. Geomorphologically these zones are represented mostly by estuaries and deltas.

One of the most interesting and complex of the European deltas is the River Danube Delta. The Danube Delta is situated in the North-western part of the Black Sea, between 44°25' and 45°30' northern latitude and between 28°45' and 29°46' eastern longitude, being bordered by the Bugeac Plateau to the North and by the Dobrogea Unit to the South.

The main phases of development through which the Danube Delta reached the present day aspect include: (1) Initial Letea-Caraorman Spit, 11,700 -9,800 yr.B.P.; (2) St.George I Delta, 9,000-7,200 yr.B.P.; (3) Sulina Delta, 7,200-2,000 yr.B.P.;(4) St.George II Delta and Chilia Delta, 2,800 yr.B.P.-present; (5) Secondary Cosna-Sinoie Delta, 3,550-2,500 yr.B.P.

The Danube Delta has three main distributaries: a northern branch – Chilia, a median one – Sulina and a southern branch – St.George (Sf.Gheorghe). These main distributaries are responsible for the formation and the development of different stages of the Danube Delta.

The present paper aims at describing the evolution of the mouth zones of these three main distributaries of the Danube Delta system. The description is based on the complex study of the entire Danube Delta edifice by aerophotogrammetric, geomorphologic, sedimentologic-geologic, biostratigraphic means, as well as by ^{14}C datation of deltaic deposits.

THE "BLOCKED DANUBE DELTA"

In the period 12-11 k.y. BP, when the level of the Black Sea had reached the present level or, probably, had even exceeded it with few meters, the present area of the Danube Delta was transformed into a large gulf – the Danube Gulf. All the tributary valleys coming from the plateau Bugeac-Kitai, Catlabug, Ialpug, Kahul etc. had been partially invaded by the sea and changed in limans by forming spits at their mouths. In this period the Northern shore of the Danube Gulf presented some promontories in the present day area of the delta, of which the most important being Jebriany, Chilia and Izmail-Bugeac. There were also some reliefs, probably exposed, situated in the areas Letea, Caraorman and Stipoc. These reliefs might have represented the supporting, hanging points for the spits which had started forming under the action of the littoral drift of sediments. ***"The Initial Jebriany - Letea - Caraorman Spit"*** was formed by the sediment littoral drift fed by the Ukrainian rivers at the mouth of the Danube Gulf, closing almost entirely the access into the Gulf (Fig.1). The Stipoc lacustrian spit formed within the gulf having the starting point the Izmail promontory, supporting point Stipoc relief and the "tail" towards the Chilia promontory.

Thus, the Chilia promontory together with the Stipoc paleorelief and the lacustrian spit Stipoc have closed a large depressionary area – the Pardina Depression, where, as it had been described by the ancients at the beginning of our era, there was the lake Thiagola. The lake might have comprised the whole Pardina Depression and the present day lakes (limans) Sofian, Catlabug

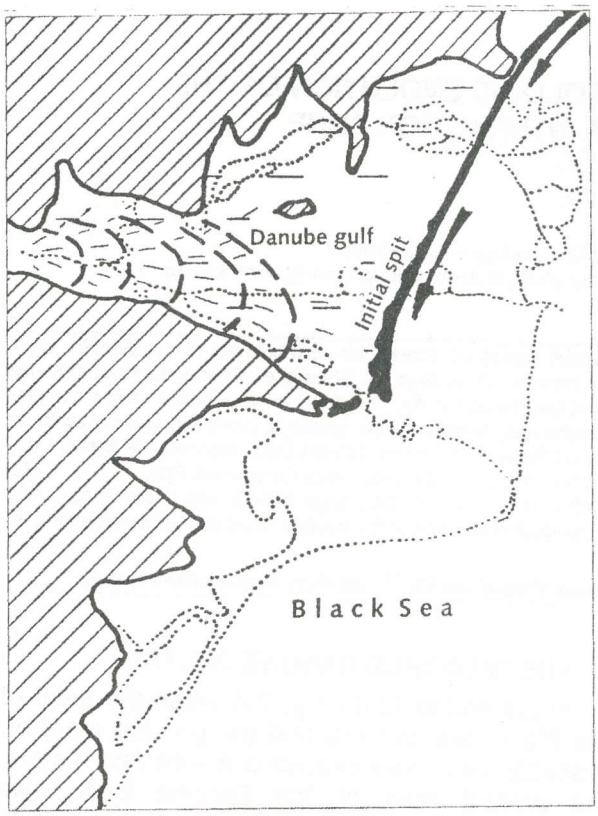

Fig.1 First stage of the Danube Delta evolution (11700-7500 BP) (after Panin, 1996a)

and Kitai.

During the existence of the Danube Gulf, almost the whole solid discharge of the River Danube was settled inside the gulf, forming there a real delta, so one could speak about the ***"Blocked Danube Delta" phase*** (Fig.1). The Initial Spit represents the limit between the two main units of the Danube Deltaic Plain: the Fluvial Delta Plain, westward the spit and the Marine Delta Plain, eastward of it.

As regards the evolution of the Blocked Delta (the fluvial one), the existing data are limited, the researches being still under way. That is why we shall be able to present below only a hypothesis regarding the genesis and the evolution of the Danube distributary system within the Danube Gulf area and the Fluvial Delta.

It is difficult to say for sure when and how the main bifurcations appeared along the Danube at Ceatal Izmail and Ceatal St.George. The forking at Ceatal Izmail (Mile 44 upstream from the present day Sulina Distributary mouth) might have occurred when the front of the Danube Blocked Delta reached this area.

The southern branch Paleo-Tulcea was joined with the firm land of Northern Dobrodgea under the Coriolis force action. One can notice a remarkable constancy of the distances (7-10 km) between the places in which the southern branch course comes into touch with the Dobrodgean "wall" and it is reflected North-eastward, and then is brought back by the Coriolis force to the same "wall". These points are Tulcea, Nufaru (Preslav or Periaslavet), Carasuhat, Mahmudia. After the "hit" at Preslav, the Paleo-Tulcea branch divided into Paleo-St.George and Paleo-Sulina distributaries. However, the same Coriolis force must have determined the Paleo-St.George branch to have been the most important and active distributary for a long time, being responsible for the appearance of the first Danube Delta - St. George I Delta. At a certain time the Paleo-St.George distributary was clogged and the Paleo-Sulina branch took the main role within the deltaic system of water and sediment pathways. The Sulina distributary built up the next Danube Delta - the Sulina Delta.

In the Blocked Delta phase, the Paleo-Chilia distributary seems to have had less importance and a smaller discharge than Paleo-Tulcea branch. On a certain distance the Chilia distributary was flowing Northward, up to hitting the Bugeac Plateau in the Izmail area, where it was changing its direction Eastward, directing probably along the approximately present day course of Sontea channel and joining with Paleo-Sulina distributary in Mile 25-Mile 24 area on its so called Old Danube (Dunãrea Veche) section. The flowing of Paleo-Chilia into the Thiagola Lake (Pardina Depression) is difficult to be explained as a hydrological phenomenon and to be appreciated in time. This flowing might have been the result of the relative water level variations of the Danube Gulf and of Thiagola Lake, variations which determined the Stipoc lacustrine spit breaking not far from Izmail Promontory (at the "foot" of the spit) and of Chilia Promontory in the place where this was narrower. The breakings played then a part of natural capture: the first captured the flowing of Paleo-Chilia distributary deriving it to the Pardina Depression, and the second one had a part of discharging the whole amount of water which was flowing into the Depression (the cumulated water discharges of Paleo-Chilia distributary and of the Kitai and Catlabug tributaries).

On the eastern side of the Chilia Promontory, within the lagoon behind the Initial Spit, which might have been discontinue and thin enough in this area, a lacustrian (lagoonal) spit was formed (called Rosca-Suez), delimiting southward the available space for braiding of the new branch formed by the breakings described above. It is difficult to precise these processes in time but Chilia branch might have reached the shape resembling the nowadays course 3000-3500 years BP. The distributary might have found a way out to the sea through the Initial Spit in almost the same period of time.

From this moment on the Chilia distributary will start introducing into the littoral area an increasing quantity of sediments and building up its own delta – the Chilia Delta.

SAINT GEORGE DISTRIBUTARY MOUTH ZONE EVOLUTION

The St. George distributary had the most complex evolution of all the Danube Delta distributaries. Within the structure and evolution of the Danube Delta, two phases entirely related to the development and the activity of the St. George distributary could be pointed out (Panin et al., 1983; Panin, 1989). These phases are the following:

I. During the period 9,000-7,200 yr.B.P., at the mouth zone of the St. George distributary, the first Danube Delta - the "St. George I Delta" had been formed. In about two thousand years the St. George I Delta prograded by almost 10 Km, the average rate of progradation of its coastal zone being of ca. 5 m/year. This phase could be characterised by a very reduced Danube borne sediment supply. The progradation of the delta occurred under the influence of the littoral drift of sediments from the mouth zones of Ukrainian rivers - the Dniepr, the Southern Bug and the Dniestr.

II. After a period of almost five thousand years when the main distributary within the deltaic system was the Sulina branch, which has built up during this time its own delta - the "Sulina Delta", 7,200-2,000 yr.B.P., the St. George distributary reactivated itself and started to form the "St. George II Delta". The development of this delta took place in the last 2,000-2,800 years and was simultaneous with the erosion of the Sulina Delta, as well as with the Chilia Delta formation.

The "Saint George I Delta"

As said just above, the St. George I Delta is the first Danube Delta formed in the period 9,000-7,200 yr.B.P., at the mouth zone of the Paleo-St.George distributary, at the southern end of the Initial Spit which had closed the Danube Gulf. At present, one could observe only the northern wing of this delta. This flank is formed exclusively by the Ukrainian rivers sandy sediments transported along the sea shore by littoral drifting (Fig.3), being represented by the Littoral Accumulative Formation Caraorman, built up by juxtaposition of an impressive number of beach ridges.

Four phases of St.George I Delta development could be evidenced (Fig.2):

- ***The Initial Spit*** - the oldest geologic and geomorphologic element of the Danube Delta - formed 12-10 k.yr. B.P.;
- ***The Erenciuc phase***, materialised by the Erenciuc set of fossil beach ridges, having a Southward slightly divergent structure as the St.George I Delta had began its progradation;
- ***The Caraorman-pãdure phase*** continued the following up the progradation of the Paleo-St.George mouth zone;
- ***The Caraorman-sat phase*** represents the last stage of the St.George I Delta development and progradation. Finally, the overall progradation of this delta was of about 10 km during a period of time of two thousand years.

The Caraorman Formation consists of some more sets of fossil beach ridges as (Fig.1): Jacob, Puiulet I and Puiulet II, Lumina I and Lumina II, Rosu, Rosulet and finally Ivancea which represent evolution phases of the next delta - Sulina Delta and formed its southern wing. These sets correspond to the sets forming the northern flank of the Sulina Delta (Letea Littoral Formation) and will be described below.

The "Saint George II Delta"

The formation and the development of the "St. George II Delta" took place in the last 2,000-2,800 years.

The St. George II Delta northern wing is represented by the Littoral Accumulative Formation Sărăturile, while its southern wing is composed of an important number of fossil beach ridges and beach ridges sets, showing the successive steps of the delta shore line progradation.

The northern wing of the St. George I Delta is characterised by a divergent (fan like) structure of the Sărăturile littoral accumulative formation. The main beach-ridge sets composing the formation are Câsla Vădanei, Iepurilor, Morilor, Lung, Câsla and St. George. The divergent structure is due to the retreatment of the coast line in the North, the Sulina Delta being continuously eroded, while in the South, the coast was prograding with the development of the St. George II Delta. The Sărăturile Formation is composed of sediments eroded from the Sulina Delta, most of which were supplied by the Paleo-Sulina distributary especially as bed-load.

The southern wing of the "St. George II Delta" is formed, as mentioned before, of multiple fossil beach ridges and beach ridges sets, pointing out successive steps of this delta development and progradation. There are very evident correspondences between the northern wing beach ridges sets and those of the southern wing.

The main sets of beach ridge within the southern wing are (from the oldest to the youngest) (Fig.2): the set Crasnicol, the set Frasin, the beach ridge Grindac, the set Plopilor, the set Uncu and Strajina, the set Palade-Cretu, the set Chiruscova-Cruhlic, the set Tigănus-Crucea-Călugăru, the set Buhaz and the arcuated lateral mouth beach ridge Sakhalin (Island Sakhalin). These sets are evidencing the main phases of the St. George II Delta development during the last ca.2,800 yr.B.P., the ages of different phases being determined by ^{14}C.

Apparently, the progradation of the St. George II Delta was not uniform in time. The oldest beach ridges set within this delta is the set Crasnicol, formed about 2,800 yr.B.P.. At the beginning the progradation was very slow: 1.0-1.5 Km in ca.800 years. Then, the progradation became faster - about 6 Km in ca. 1,000 years, after what the delta front advancement went on even faster - more than 10 Km in the last 800 years. The average rate of progradation is of 8-9 m/year.

The beach ridges and the sets of beach ridges making up the southern wing of the St.George II Delta and showing the steps of development of this delta, had a very similar genesis and evolution to the Sakhalin Island arcuate lateral bar. The ends of these fossil beach ridges were floating to their joining with a former already stabilised shore line. The same evolution will have the end of the Sakhalin Island, which is advancing towards WSW and will join the present day coast line in the Zătoane section.

The St.George II Delta evolution phases

The Crasnicol phase. As already mentioned, the oldest beach ridges set in the St.George II Delta is the Crasnicol set, which was marking the coastal line at 2,800 yr.B.P. (Fig.2).

The Crasnicol set has a complex structure, being made up of numerous fossil beach ridges. In the primary period of its evolution, the set was corresponding to the Ivancea set marking the maximal development of the Sulina Delta. During this phase, the St.George distributary had a very reduced water and sediment discharge, so the progradation of the distributary mouth zone was slow. This progradation is evidenced by the sub-sets Crasnicol-Belciug (1), Crasnicol-Popilor (2) and Crasnicol-Plopilor (3). The sub-set Crasnicol-Belciug is made up of 4-5 fossil beach ridges converging south-westward, joining themselves into one single fascicle cut by the following sub-set Crasnicol-Popilor. In its turn, this sub-set is also cut by the next sub-set Crasnicol-Plopilor. In this way the Crasnicol set has a complex structure and was corresponding to a quite long period of time (about 800 years), when the shore line remained almost unchanged, except the closely neighbouring with the distributary mouth section where a very slow progradation could be pointed out (average rate of progradation 1.0-1.5 m/year). To be noticed the heterochronous age of the Crasnicol set.

The Frasin - Sterepova phase represents the first phase of a faster advancing of the Sf. Gheorghe II Delta, being contemporary to the beginning of the Chilia Delta progradation and of the Sulina Delta erosion.

The Grindac and Plopilor phases are successive phases when the Sf. Gheorghe II Delta front prograded about 6 km.

During the ***Plopilor and Uncu phases*** that followed, the front of the St. George II Delta prograded ca. 3.0 more km. The Plopilor set has a structure diverging to the SW , direction in which, after a lower area of an insufficient supply of detritic material for forming an entirely developed beach ridges, the set rises and juxtaposes to the Crasnicol set. Three subsets - (*Uncu 1, Uncu 2 and Uncu 3*) are to be distinguished in the Uncu set. The last sub-set (*Uncu 3*) is continued by the Starpuluc beach ridge and farther on by Strajina set, which, in its final end intersects the Crasnicol set cutting it off. The Strajina set is made up of 4-5 beach strands, of which the most recent ones cut successively off the older ones.

The Palade - Cretu phase is represented by an important beach ridges set : Palade near by the Sf. Gheorghe branch, continuing farther South-westward by some Gâscă beach ridges and then, by Cretu ridge. Corresponding to this set within the Sărăturile accumulative formation (the northern flank of Sf. Gheorghe II Delta) is Morilor set.

Chiruscova - Cruhlic phase is represen-ted by a very complex and structurally complicated beach ridges set, the main one being Chiruscova. This phase preceded a period of time when Sf. Gheorghe distributary has divided in several distributaries (at least two) and created a small lobated secondary delta (which we called "St.George secondary delta A"), resembling the secondary delta existing nowadays at the mouth of the river branch. According to C^{14} dating, the Chiruscova-Cruhlic set corresponds to the beginning of our era, being contemporary with the time when the ancients gave their geographical descriptions of the Pontus Euxinus and the River Danube.

Tigănus phase, with the beach ridges set having the same name, corresponds to the maximum development of the ***first lobated secondary delta "A"*** of the St.George distributary (Fig.2). Towards the west the Tigănus set joins the previous Chiruscova-Cruhlic set.

There follows ***Buhaz phase*** representing the


L. KOTLABUH
IZMAIL
Chilia
Chilia
VILCOV
Jibrieni
CHILIA DELTA
Stipoc
Sfistofca Vest 2
Sfistofca Vest
Sfistofca Est
Rosetti Est
Rosetti Vest
Letea
Letea Sud
Cardon Vest
Cardon Est
Sulina
Uje
Cherhanoi
Pocora - Sinehradca
Sulina
TULCEA
SULINA
SULINA DELTA
Erenciuc
Sf. Gheorghe
SF. GHEORGHE I DELTA
Rosu
Ivancea
Cisla Vădanei
Sulina
Popina I.

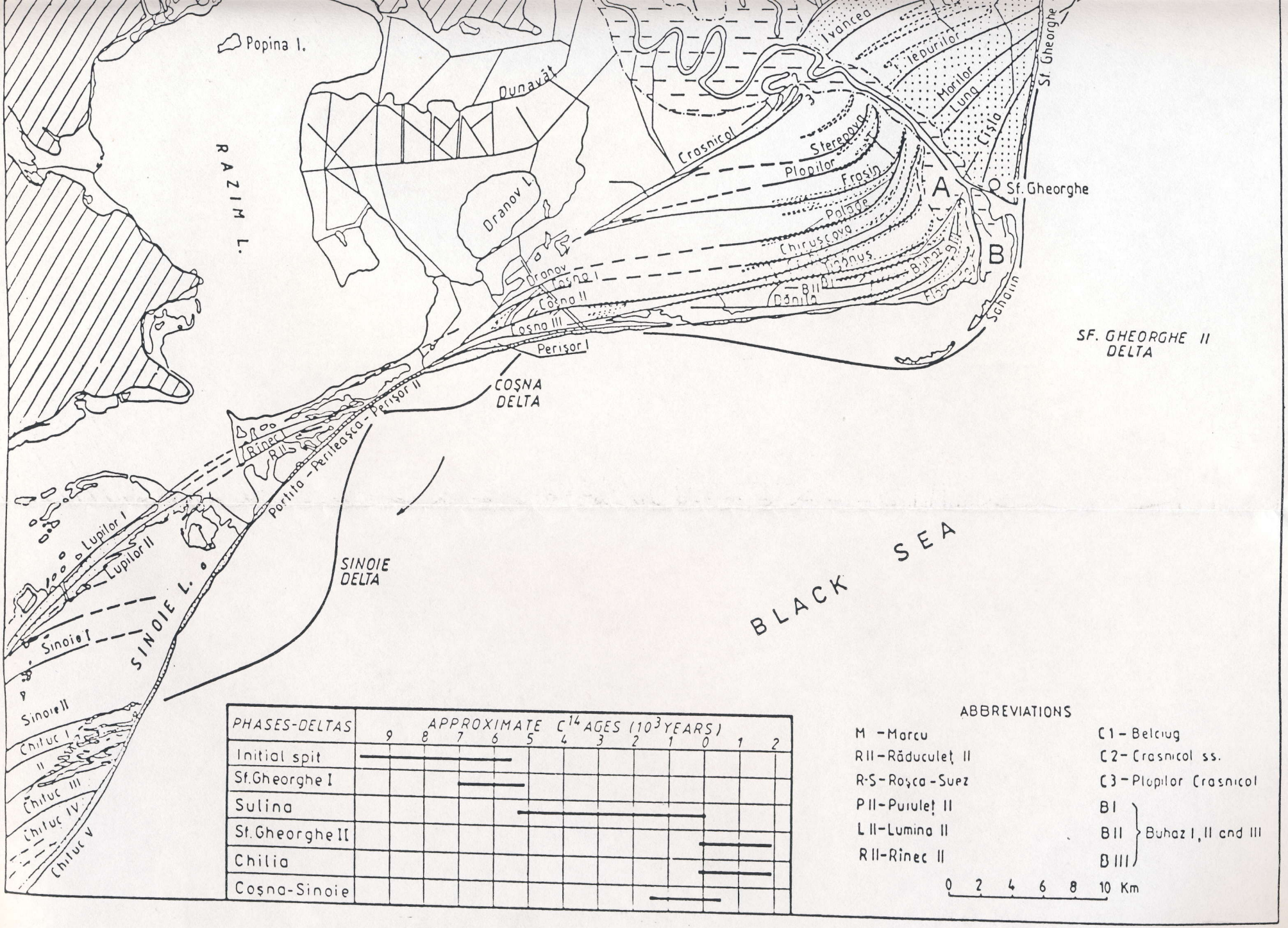

Fig. 2 The Danube Delta geomorphological-sedimentological structure
The map outlines the main sets of beach ridges and the phases of delta evolution during Holocene

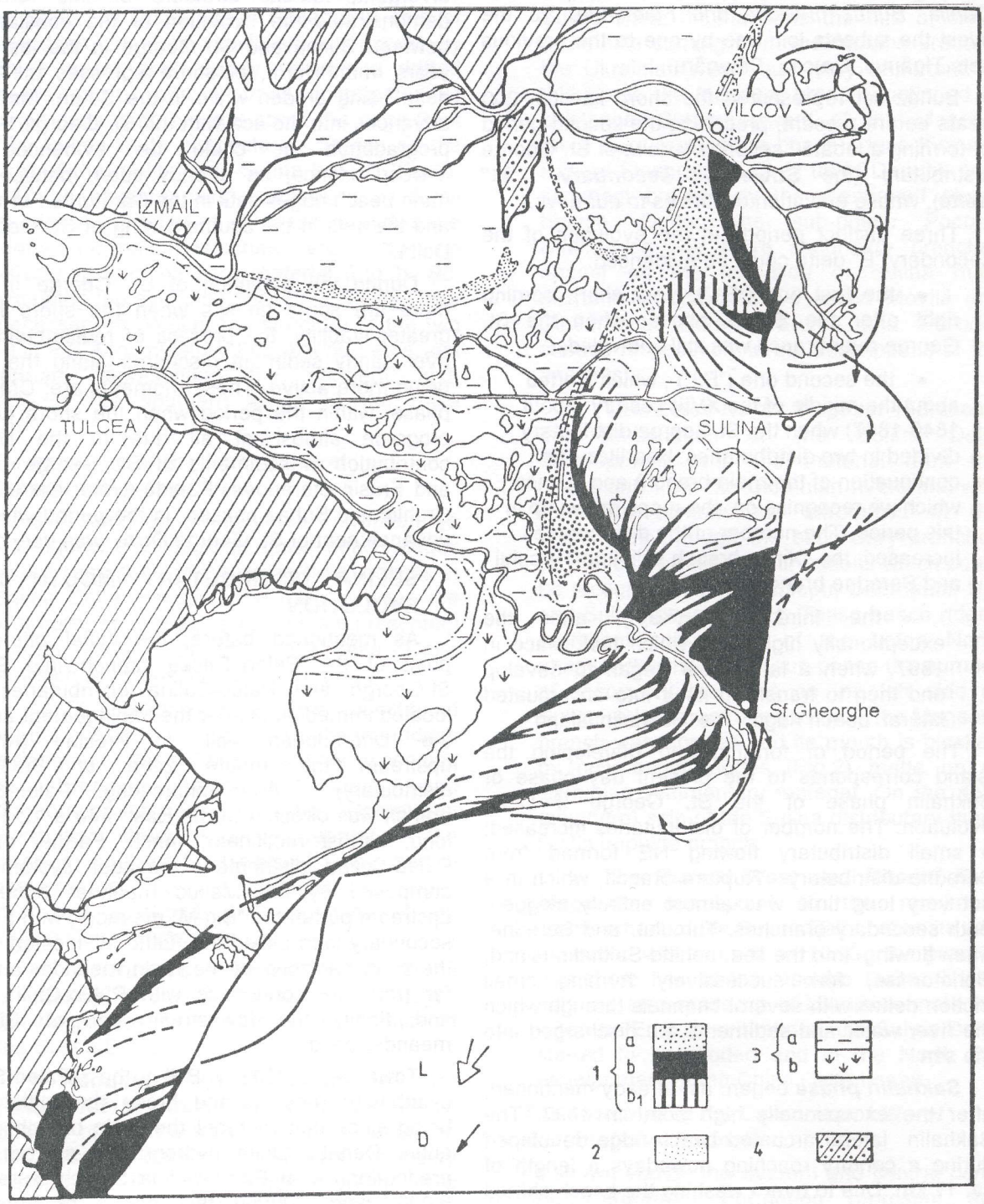

Fig.3 Areal distribution of the main types of littoral deposits within the Danube Delta territory. Legend: 1.Marine littoral deposits: type "a", formed by the litoral drift from the North, from the rivers Dniestr, Dnieper and Southern Bug; type "b", of Danubian origin; type "b_1", of littoral diffusion, marked by mixing types "a" and "b"; 2. Lacustrine littoral deposits; 3. Fluvial deposits: a-meander belt deposits; b-interdistributaries depression deposits; 4. Loess like deposits; L – Direction of the littoral sediment drift; D – Main sediment supplies.

end of the secondary delta "A". The Buhaz set has a very complex structure being made up of a number of subsets. Among these, mention should be made of *: Buhaz I (Vasile), Buhaz II (Crasotki)-Dănilă, Buhaz III-Ciotic and Flămânda*. To the West the subsets join one by one to the previous sets Tigănus, Crucea, Călugăru.

Buhaz set represented the shore line ca. 200 years before present, preceding the second period of forming a lobated secondary delta of St. George distributary (the ***St.George secondary "B" delta***), whose evolution continues to our days.

Three distinct periods in the evolution of the secondary "B" delta could be evidenced:

- the first one ("B1"), very short, coming right after the Buhaz phase, when the St. George river branch was still undivided:
- the second one ("B2") , which started about the middle of the XVIII century (about 1840-1857) when the St.George distributary divided in two distributaries: Kedrilles (the continuation of the main branch) and Olinca , which we recognise on the maps drawn up in this period. The number of the distributaries increased: the Olinca branch split into Turcului and Seredne branches;
- the third one (***"B_3"***), after the exceptionally high flood which took place in 1897, when a lateral bar began to develop and then to transform itself into an arcuated lateral beach ridge - the Sakhalin Island.

The period of forming and developing the island corresponds to the present day phase or Sakhalin phase of the St. George II Delta evolution. The number of distributaries increased: a small distributary flowing NE formed from Seredne distributary - Ruptura branch, which in a not very long time was almost entirely clogged. Both secondary branches, Turcului and Seredne, when flowing into the sea, behind Sakhalin Island, dichotomise, fork successively forming small friction deltas with several channels through which the river water and sediments are discharged into the sea.

Sakhalin phase began, as already mentioned, after the exceptionally high flood in 1897. The Sakhalin lateral arcuated beach ridge developed during a century reaching nowadays a length of ca. 17 km. Due to over - washing the beach shifted inward, while the front of the secondary "B" delta of St. George distributary prograded being sheltered by the island, so that in the `80's the island joined the front of the secondary delta near by the mouth of Seredne branch. The south-western end of the island is still floating having the tendency of approaching the shore in the area Ciotic-Zătoane of the Danube Delta coast.

The northern flank of St. George II Delta is represented as mentioned before, by the

Sărăturile littoral accumulative formation. The divergent, fan-like structure of this formation demonstrates the evolution of the coastal area between Sulina and St. George in the last 2000 years. In the North, the shore regresses, the Sulina delta being eroded while in the South, the shore advances into the sea with the St. George II Delta progradation. It could be evidenced the correspondence, as already seen, between the main beach ridges sets in the Sărăturile Formation and the sets in the southern wing of St. George II Delta.

During the evolution of St. George II Delta there are some phases when the shore had a greater stability, the process of redistributing the river sandy sediment discharge along the coast being more active. These moments are: Crasnicol phase, within the period when the shore did not prograde almost at all due to the smaller contribution in sediments of St. George branch and Frasin-Sterepova, Palade-Cretu, Chiruscova-Cruhlic and Buhaz phases in the period when the advancement of St. George Delta was very quick.

SULINA DISTRIBUTARY MOUTH ZONE EVOLUTION

As mentioned before, the initial bifurcation point of the Paleo-Tulcea branch into Paleo-St.George and Paleo-Sulina distributaries was located immediately after the impingement against the "Dobrodgean wall" at Preslav (Km.104 upstream the mouth zone of St.George distributary). After bifurcating, Paleo-Sulina branch was directed to the East, into a 12-13 Km long, almost rectilinear, reach. Farther on the Paleo-Sulina distributary meander system was composed by the Maliuc meander bend, the upstream part of the "Big M" meander, with a small secondary loop called the "Little M" located within the point bar zone of the main meander and not far from the confluence with Paleo-Chilia arm, and, finally, the downstream part of "Big M" meander bend.

Towards 7,200 yr.B.P. the Paleo-Sulina distributary reached and broke the Initial Spit, being since that moment the main branch of the entire Danube Delta hydrographic system. The predominance of Paleo-Sulina branch lasted ca. 5,000 years. During this period of time the distributary built up a very large delta - the Sulina Delta, which prograded more than 30 Km passing from a cuspate to a lobate delta as the Sulina sediment supply overpassed the wave power regime of the delta coastal zone.

The Sulina Delta evolution phases

The Sulina Delta consists of two very distinct flanks: **(1)** the northern one, represented by the Letea Accumulative Formation, built up of a very large number of fossil beach ridges and sets of beach ridges, most of which are composed by Ukrainian rivers born sandy sediments drifted along the shore, with a small contribution of Danubian sediments brought about the delta front zone by Sulina Delta distributaries flowing on the left side of the main Paleo-Sulina branch (Fig.3), and **(2)** the southern wing, composed by fossil beach ridges, a number of which taking part of the Caraorman Formation structure and built up exclusively of Danube born material (Fig.3). So, for describing the evolution phases of Sulina Delta it is necessary to present the structure of the two main Littoral Accumulative Formations Letea and Caraorman, representing the northern and, respectively the southern wings of the delta (Fig.2).

The structure of the Letea Littoral Accumulative Formation

In the building up of the Letea Formation we can distinguish the following fossil beach ridges sets which represent, at the same time, phases in the Sulina Delta evolution. To these phases are added a number of beach ridges sets representing steps in the development of the next delta - Delta Chilia, which will be described below (Fig.2).

- ***The Răducu set or phase,*** constituted in the western part of some beach ridges belonging to the Initial Spit and corresponding to Erenciuc, Caraorman-pădure and Caraorman-sat sets in the Caraorman Formation structure, which represents the northern flank of St. George I Delta, and in the eastern part a number of ridges representing already the beginning of the Sulina Delta advancing;

- ***The Hudacova Set*** presents trough the orientation of the constitutive beach ridges the beginning of the quite quick advance of the Sulina Delta;

- ***Răduculet I, Răduculet II and Răduculet III Sets*** represent successive phases of the Sulina Delta progradation. In this phase of developing the first secondary distributary of Sulina-Magearu branch was formed. To the east of Magearu branch, between it and the main course of Sulina, the Căpătână-Chirilă beach ridge was formed of Danubian sedimentary material discharged in the shore area by the mentioned branch. Southward the main distributary of Sulina, a secondary branch - Împutita - was formed during this phase, branch which, later on was to be called Naracu Stoma by the ancients.

- ***The Letea-South Megaset*** represents a phase of a very quick advancing of the Sulina Delta. In that time the flux of shore sediments coming from the mouths areas of the Ukrainian rivers was very important. In this phase the Magearu branch continued its existence. South-eastward of the Magearu there were formed the beach ridges Ifim and Pocora-Sinehradca, made up of Danube born sediment brought by the mentioned above branch. During the sub-phase Pocora-Sinehradca two more secondary branches appear on the left side of Sulina main distributary, branches we called Movilă and Sinedrahca (Boreion Stoma and Pseudo-stomos respectively in the descriptions of the ancients);

- ***The Letea-North Megaset*** represents the continuation of the Sulina Delta development, with the material from the littoral drift from the Ukrainian rivers and with Danubian contributions introduced in the shore area through the secondary branches on the left of Sulina, contributions which could be recognised in the Schiopu, Cherhanoi, Uje and Sulina beach ridges. These beach ridges represent sub-phases of the Letea North phase. After the Sulina sub-phase the number of secondary branches on the left side of Sulina reduce from three to two - the Magearu branch was clogged and its mouth is blocked by new beach ridges (Fig.2) made up of Ukrainian sedimentary material. On the right (southern) side of the Sulina distributary there is still Împutita branch.

- ***The Rosetti West and Rosetti East Magasets*** correspond to the maximum development of the Sulina Delta, when its end exceeded with more than 10 Km the present day shore line of the Danube Delta. These sets are also made up of Ukrainian material. After the East Rosetti phase, the Sulina Delta started to be eroded and in the North the development of the Chilia Delta began.

The structure of the Caraorman Littoral Accumulative Formation

As shown above, the western and central parts of the Caraorman Formation represent the northern flank of the St.George I Delta and the four first (western) sets (the sets belonging to the Initial Spit, Erenciuc set, Caraorman-pădure and Caraorman-sat sets) are evidencing the phases of development of this delta. The eastern part of the Caraorman Formation consists of some more sets of fossil beach ridges as: Iacob, Puiulet I and

Puiulet II, Lumina I and Lumina II, Rosu, Rosulet and finally Ivancea and represents evolution phases of the next delta - Sulina Delta, forming, at the same time, its southern wing (Fig.2). These sets and phases will be described below.

- ***Iacob set and phase*** corresponds to the beginning of Sulina Delta formation and progradation. The set has a slightly Northward divergent structure, consisting of three subsets: Iacob A, Iacob B and Iacob C separated one from the other by elongated lakes occupying the inter-ridge depressions;
- ***Puiulet I and Puiulet II sets*** are successive phases of Sulina Delta front progradation. As at that time the preceding delta St.George I became eroded, the Puiulet I sets are cutting off the ridges constituting the Iacob set, and the Puiulet II are cutting the ridges of Puiulet I, Iacob and the last ridges of Caraorman-sat sets.
- ***Lumina I and Lumina II sets*** are showing a very rapid progradation of the Sulina Delta. The erosion of the St.George I Delta continued: the Lumina I set is cutting the Puiulet II ridges and the Lumina II set is cutting, at its turn, the sets Lumina I, Puiulet II, Caraorman-sat and partially Caraorman-pădure sets.
- ***Rosu and Rosulet sets*** evidence the continuation of the rapid progradation of the Sulina Delta. The Rosu phase could be divided in two subphases A and B. The Rosu set, at its southern end is cutting the ridges of Lumina II set, while the Rosulet set cuts off the Rosu, Lumina II and Caraorman-pădure sets.
- ***Ivancea set*** represents the maximal progradation phase of the Sulina Delta, which occurred approximately 3,000-2,800 yr.B.P. The Ivancea set is cutting off the Rosulet and Caraorman-pădure sets. The following table shows the Sulina Delta development phases and characteristics as they could be evidenced by making the correspondence of the two delta wings main beach ridges sets described above.

Table 1. Sulina Delta evolution phases and geomorphologic characteristics

Evol. phases	Main sets of fossil beach ridges		Age ^{14}C yr.B.P.	Geomorphologic characteristics
	Northern wing	Southern wing		
I	Răducu	Iacob	7,200	cuspate delta, 1 distributary
II	Hudacova	Puiulet I		cuspate delta, 1 distributary
III	Răduculet I	Puiulet II		cuspate delta, 1 distributary
IV	Răduculet III + Căpătână-Chirilă	Lumina I	6,000	lobate delta, 3 distributaries
V	Letea South + Pocora-Sinehradca	Rosu A		lobate delta, 5 distributaries
VI	Letea North + Schiopu-Movilă	Rosu B	4,900	lobate delta, 5 distributaries
VII	Letea North + Sulina	Rosulet		lobate delta, 5 distributaries
VIII	Rosetti East	Ivancea	2,800-2,500	cuspate delta, 4 distributaries

CHILIA DISTRIBUTARY MOUTH ZONE EVOLUTION

The Chilia Delta

Since the period of time when the Chilia distributary reached and broke the Initial Spit (see Chapter 2 of the present paper), a new delta began to form and grow - the Chilia Delta (Fig.2).

The Chilia Delta is situated North and East of the Letea Littoral Accumulative Formation, whose west side represents, as described above, the northern wing of the Sulina Delta and the eastern part corresponds to the Chilia Delta formation and developing.

The phases of the Chilia Delta evolution:

- ***The Sfistofca West I set*** has a slightly divergent structure to the North, the beach ridges making it up following the beginnings of the Chilia Delta progradation. The beach ridges are made especially of Danubian material and, subordinatelly, of Ukrainian material brought about by the littoral drift from NE (Fig.3). The phase could be placed in the period 3000-2500 years BP;
- ***The Sfistofca West II set*** follows on the progradation of the Chilia Delta, corresponding to its development in between 2500-1000 years B.P. In this period the delta got a lobated shape, which demonstrates the fact that the Chilia distributary became the

main distributary of the deltaic system, with a very important water and sediment discharge. Starting with the Sfistofca West II Phase, the constitutive material of the beach ridges making up the following sets is exclusively Danube borne, the material from the Ukrainian rivers stopping North of the Chilia Delta, forming the beach ridges of the Jebriany Formation. In the South, the Sulina Delta is eroded on and this fact is materialised by the cutting off the previously formed Rosetti East and Sfistofca West I sets by the Sfistofca West II set of beach ridges;

- ***The Sfistofca East set*** is strongly divergent to the north-east, corresponding to a quick advancement of the Chilia Delta in between 1000-500 years B.P. The southern part of this set cuts off successively the beach ridges of the Sfistofca West II, Sfistofca West I, Rosetti East sets as well as the last ridges of the Rosetti West set;
- ***The Cardon West set*** follows on the ever quicker progradation of the Chilia lobated delta. The set cuts off the beach ridges of the Sfistofca East, Rosetti West and Letea sets;
- ***The Cardon East set*** developed probably in the 16th-17th centuries. It cut off the beach ridges of the Cardon West and Letea sets. After the formation of the Cardon East set, the Chilia Delta prograded so quickly that covered entirely the beach ridges which had been previously formed.

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