THE BLACK SEA: CLIMATIC AND SEA LEVEL CHANGES IN THE UPPER QUATERNARY

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New seismology and sedimentology data are discussed from the Upper Quaternary history of the Black Sea.

1. GENERAL SETTING

The Black Sea is one of the largest enclosed seas in the world: its area is about 4.2×10^5 km^2, the maximum water depth – 2,212 m, the total water volume of 534,000 km^3 and the volume of anoxic deep water contaminated with H_2S (below the depth of 150–200 m) 423,000 km^3. The connection of the Black and Mediterranean seas is limited to the Bosphorous-Dardanelles system of straits. The Bosphorous is a rather narrow (0.76–3.6 km large) and shallow strait (presently 32–34 m at the sill) restricting the two-way water exchange between the brackish Black Sea (the salinity of the Black Sea water is about 17‰ at the surface and 22‰ at the bottom) and the very saline Mediterranean Sea (38–39 ‰). The surface outflow of the less saline Black Sea water is estimated at about 600 km^3/yr. (~ 20,000 m^3/s), while the under current of saline Mediterranean water flows towards the Black Sea and supplies it with almost 300 km^3/yr. (~10,000 m^3/s).

Additionally the Black Sea has an enormous drainage basin of more than 2 million km^2, collecting the water from almost all the European countries, except the westernmost ones. A population of about 162 million people is living in the Black Sea drainage basin, which is about twice the population in the Baltic Sea basin.

The north-western Black Sea is characterised by a very large shallow (less than 200 m deep) continental shelf, representing about 30% of the total area of the sea. This part of the sea receives the discharge of two of largest rivers in Europe – the River Danube with a water discharge of about 200 km^3/yr. and the Dniepr contributing with 54 km^3/yr. To this amount the discharges of smaller rivers as Dniestr and Southern Bug are added summing up about 12 km^3/yr.

This north-western part of the sea with its large fresh water inflow and specific wind system is responsible for the structure of the Black Sea water masses and dynamics.

The Black Sea is almost surrounded by high mountain ranges: Pontic mountains to the south, Caucasus to the east, Crimean chains to the north and Balkans and

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Rhodope to the south-west. Only a low platform or deltaic territories border the north-western part of the sea. This clearly demonstrates the eventful geological history of the Black Sea.

The geologists consider it as a result of the back-arc extension associated with the subduction along the southern margin of the Eurasian plate.

Since about 120 million years the area has been a sea basin, with extremely dynamic development and huge sediment accumulation (17 up to 13 km of bottom sediment column) in the central part of the basin. Prior to then the Black Sea area was probably a Jurassic carbonate platform.

2. ENVIRONMENTAL AND SEA LEVEL CHANGES

Large-scale sea level changes and consequently drastic resshaping of land morphology and modifications of environmental settings occurred all along the Black Sea geologic history.

The studies shown that one of the most impressive changes occurred probably 5–6 million years ago when the sea level dropped some 600–800 m. The area of the sea diminished correspondingly by at least 50%, large formerly submerged areas became exposed and all the hydrographic network deeply incised the continental margin zones.

The Quaternary was especially characterised by very spectacular changes, driven by the global glaciations and deglaciations which responded to the Milankovitch cycles of 100 and 20 k.yr. During these changes the behaviour of the Black Sea level was influenced by the restricted connection with the Mediterranean Sea by the Bosphorous-Dardanelles straits. When the general sea level lowered bellow the Bosphorous sill, the further variations of the Black Sea level followed specific regional conditions, without being necessarily coupled to the ocean level changes. One of the main consequences of the lowstands was the interruption of the Mediterranean water into the Black Sea, which became an almost freshwater giant lake.

The changes in the Quaternary have been studied in detail from different points of view: geomorphology of the coastal zones, shelf, slope and deep-zone, sedimentology and sedimentary environments, sediment bodies structure, their geochemistry, fauna and flora assemblages, paleomagnetism and absolute dating, etc. Special attention was drawn to the Upper Quaternary because the more recent changes can be assessed with much more accuracy. Nevertheless after more than a century of studies the picture of the Black Sea environmental changes is not yet sufficiently clear and needs a further assessment. A very short description of existing opinions about the sea-level and environmental changes in the Black Sea during the Upper Quaternary is given below.

According to SCHERBAKOV, 1978, the environmental changes of the sea can be recognised and characterised through the features offered by three main geomorphologic and sedimentary zones: (1) the coastal zone, (2) the continental shelf including the shelf break and (3) the deep-sea zone.

The main glacial periods of Quaternary in Europe (Danube, Günz, Mindel, Riss and Würm) have their correspondence in regressive phases of the Black Sea. Their interpretation and especially of the interglacials differes in certain limits from author to author. The regressions represent, as already said, phases of isolation of the Black Sea from the Mediterranean Sea and World Ocean. Only the connection with the Caspian Sea could sometimes continue through Manytch valley. Correspondingly, during these regressions under fresh water conditions the particularities of fauna assemblages changed every time from marine with Mediterranean influences (during the highstands) to freshwater one with pronounced Caspian character. The altitude of sea-level changes is also difficult to assess and establish because they are very often masked by the up-lift or subsidence movements of the coastal and shelf zones. The marks of lowstands left on the shelf and shelf-break, as paleo-clifs, old submerged beach-ridges, sand dunes etc. are numerous but also difficult to date.

The following two tables present the main characteristiscs and the sucession of the Black Sea development phases and an attempt to correlate these phases with the Mediterranean Sea and the Central Alpine Europe. The first table, reproduced from P.V. FEDOROV, 1978, with insignificant adaptations is dealing with the coastal and the shelf zones of the Black Sea. The second one, from F.A. SCHERBAKOV *et al.*, 1979, also with small modifications, presents the stratigraphy and the correlation for the shelf (inner and outer) and the deep-sea zones. Both reflect a rather "classic" view of the Black Sea development.

3. SHORT DESCRIPTION OF LATE PLEISTOCENE–HOLOCENE PHASES OF THE BLACK SEA

The following description is based on mainly clasical sources and completed with some preliminary results of the Romanian coast and continental shelf survey carried out by GeoEcoMar.

1. The Riss II glacial (Moscovian) was for the Black Sea a regressive phase (down to ~ –100 m)(FEDOROV, 1978) with freshwater Caspian fauna. During this phase the same author consider that the Bosphorous strait was overdeepened to about 100 m.

2. During the Riss-Würmian (Mikulinian) interglacial the glacioeustatic sea level rose up to the Bosphorous sill and the penetration of the saline Mediterranean water changed the environmental characteristics of the Black Sea. This is the Karangatian

Table 1

(after V. FEDOROV, 1978, with insignificant adaptations)

General scale		EUROPE	European Russia	Black Sea region				
				General stratigraphic scale		W and NW Black Sea	Northern Black Sea Crimea, Kertch, Taman	Eastern Black Sea Caucasus
Holocene		Flandrian	Holocene	Black Sea Horizon	Nymphean	Terrace at 2 m; Sands with *Cardium edule* L. etc.	Terrace at 2 m; Sands with *Cardium edule* L. etc.	Terrace at 2 m; Sands with *Cardium edule* L. etc.
					Phanagorian	Regression to - 6÷8 m. Archeological layers V÷I c. BC	Regression to - 6÷8 m. Archeological layers V÷I c. BC	Regression to – 6÷8 m. Archeological layers V÷I c. BC
					New Black Sea	Terrace at 4÷5 m; Sands and shells with *Cardium edule* L., *Chlamys, Ostrea, Mytilus*	Terrace at 4÷5 m; Sands and shells with *Cardium edule* L., *Chlamys, Ostrea, Mytilus*	Terrace at 4÷5 m; Sands and shells with *Cardium edule* L., *Chlamys, Ostrea, Mytilus*
					Old Black Sea	Clayey sands with *Cardium edule* L. etc. at 10÷20 m water depth on shelf	Clayey sands with *Cardium edule* L. etc. at 10÷20 m water depth on shelf	Clayey sands with *Cardium edule* L. etc. at 10÷20 m water depth on shelf
Pleistocene	Upper	Grimaldian – Würm (regression to 100-130 m)	Ostashkovian	Neoeuxinian	Late Neoeuxinian	Würmian loess ; Clays with *Monodacna caspia* Eichw., *Dreissea polymorpha* Pall., at 20÷30 m water depth on shelf	Clays with *Monodacna caspia* Eichw., *Dreissea polymorpha* Pall., at 20÷30 m water depth on shelf	Clays with *Monodacna caspia* Eichw., *Dreissea polymorpha* Pall., at 20÷30 m water depth on shelf
			Mologo-Sheksnian					
			Kalininian		Early Neoeuxinian (Postkarangatian)	Regression to –60÷80 (-130) m. Würmian loess. Deepening of the valleys' incisions.	Loesslike deposits; Alluvial-deltaic sands, deepening of Kertch strait.	Regression ; Deepening of the incisions of the valleys to –60÷80 m.
		Neotyrrhenian (terrace at 2-8 m above SL)	Mykulinian	Karangatian	Upper Karangatian	Terrace at 15÷16 m ; Shells and sands with *Cardium tuberculatum* L., *Paphia senescens* (Coc.) etc.	Terrace at 8÷12 m (4÷8 m Taman); Shells and clays with *Cardium tuberculatum* L., *Paphia senescens* (Coc.), *Aporrhais pespelicani* L. etc. At the base clays with *Paphia senescens* (Coc.), *Cerithium vulgatum* Burg	Terrace at 12÷15 m (Pshady valley). 25÷30 m (in Sochi region); Shells with *Cardium tuberculatum* L., *Paphia senescens* (Coc.), *Aporrhais pespelicani* L., *Cerithium vulgatum* Burg etc.
					Lower Karangatian			
	Middle	Regression (Riss II ?) Deepening of Bosphorous to 100 m	Moskovian	Upper Euxinian-Uzunlarian	Regression	Regression. Clayey loess-like deposits.	Clayey deposits with *Limnaea, Planorbis* ; pebbles with *Viviparus*	Regression. Alluvial pebbles, terminal moraine at Amtcheli.
		Euthyrrenian (Tyrrhenian Ib) (terrace at 10-20 m)	Odyntzovian		Uzunlarian	Terrace at 35÷40 m (Bulgaria) ; Upper Babel layers, sands with *Didacna nalivkini* Wass. etc., Upermost lagoonal clays	Clayey sands with *Cardium edule* L., *Didacna nalivkini* Wass. etc.	Terrace 25÷30 m (Pshady) and 35÷37 m (Pshady valley). Pebbles, sands with *Cardium edule* L., *Mactra stultorum* L., *Soroblcularia*
		Regression (Riss I ?)	Dneprian		Late Paleoeuxinian		Sands and clays with *Didacna nalivkini* Wass., *D.pontocaspia* Pavl., *Viviparus*	Terrace 40÷43 m (Pshady valley). Sands, conglom., limstones with *D.nalivkini* Wass., *D. subpiramidata* Prav., at the base *Balanus*
				Lower Euxinian-Uzunlarian	Regression	Regression	Regression	Regression, Diluvium
		Paleotyrrhenian (Tyrrhenian I-a) (terrace at 18-30 m)	Lykhvinian		Paleouzunlarian	Sands, clays with *Didacna pallasi* Prav., *D.nalivkini* Wass. Lower Babel layers. Lagoonal clays with *Didacna pseudocrassa* Pavl. etc.	Continentsl deposits within the Mandzhil terrace	Terrace 45÷50 m (at Ashe, Makopse, Magri); Pebbles with *C.edule, Paphia* sp., *Chione gallina*
					Early Paleoeuxinian			Terrace 60÷65 m (Dzhubgy); Sands, pebbles wth *Didacna baenorassa* Pavl., *D.pallassi* Prav., *C.edule* L.
	Lower	Mindel (Roman regression)	Okan	Regression		Alluvial sands with *Viviparus* and Tyraspol complex of mammalians	Top deposits with *Archidiscodon sp.*	Regression
		Cromerian – Sicilian 2 Terrace at 60 m	Dnestrian	Tchaudian	Upper Tchaudian		Shells, sands with *Didacna pseudocrassa* Pavl., *D. tschaudae* Andrus., *D.rudis* Nal. ;Terrace « Large tables » (Bolshye stoly)	Terrace 40÷55 m(at Pshady), 100÷105 m (at Pshady valley), ~130 m (at Sochi) ; Congl.,sands with *D.pseudocrassa, D. tschaudae, D.rudis*
		Cromerian – Sicilian 1 Terrace at 100 m			Lower Tchaudian		Clayey continental deposits Sands with *Didacna baenorassa, D.parvula, V.pseudoachatinoides, Fagotia esperi*	Sandy-clayey deposits of Guria with *D. tschaudae, D. tschaudae guriana* Livent., *D.crassa gurienss* Newesk., *D. pleisto-pleura* (Davit), *D.pseudocrassa*
		Günz (regression)		Gurian – Tchaudian	Regression	Sands and clays with *Archidiscodon meridionalis* Nest. (late) within Nogaysk outcrop	Continental deposits with Taman complex of mammalian fauna	Deposits with Gurian-Tschaudian fauna / Break
Eopleistocene		Emilian-Calabrian	Morozovian-Nogayskian	Gurian			Gurian deposits	Clays with *Didacna digressa* Livent. etc.

Table 2

(after Scherbakov F.A. *et al.*, 1979, with small adaptations)

Northern Europe			BLACK SEA									
Stratigraphic subdivisions			Bathymetric zone 0-50 m		Bathymetric zone 50-200 m			Deep-sea zone - northern part		Deep-sea zone - southern zone		
			Layers	Molluscs	Horizon	Molluscs	Diatomaea	Horizon	Diatoms, molluscs	Horizon	Nannoplanktonflagellates	Age
Holocene	Upper	Subatlantic	Dzhemetinian	*Divaricella divaricata* *Gafrarium minimum* *Pitar rudis* *Cardium papillosum*	Phaseolinus muds	*Modiolus phaseolinus*	*Coscinodiscus radiatus* *Thalassiosira excentrica* *Actinocyclus ehrenbergii* *Cyclotella kutzingiana* *Cyclotella aceolata*	Cocholith ooze	*Coscinodiscus radiatus* *Endictia oceanica* *Thalassiosira excentrica* *Asteromphalus robustus* *Rhizosolenia calcar avis*	Cocholith ooze Unit 1	*Emiliania huxlei* *Lingulodinium sp.* *Peridinium sp.*	
	Middle	- 2,800 Sub-boreal - 4,800 Atlantic	Kalamitian	*Chione gallina* *Spisula subtruncata* *Mytilus galloprovincialis*	Mytilus muds	*Mytilus galloprovincialis* *Cardium edule*	*Coscinodiscus radiatus* *Thalassiosira excentrica* *Asteromphalus robustus*	Sapropel-like Muds		Sapropel muds Unit 2	*Braarudosphera bigelovi* *Peridinoum trochoideum*	
			Bugazian-Viteazian	*Cardium edule* *Abra ovata* *Corbula mediterranea* *Mytilaster lineatus* *Monodacna caspia* *Dreissena polymorpha*	6,800 ± 140	*Mytilus galloprovincialis* *Cardium edule* *Monodacna caspia* *Dreissena polymorpha*	*Thalassiosira excentrica* *Stephanodiscus astraea* *Synedra bucculus* *Navicula palpebralis var. semiplena*	Terrigenous-biogenic muds		Terrigenous-Biogenic muds Unit 3		7,090± 180
	Lower	- 7,800 Boreal - 9,400 Pre-boreal - 10,200	Neoeuxin	*Monodacna caspia* *Dreissena polymorpha*	8,550 ± 130	*Monodacna caspia* *Dreissena rostriformit bugensis*	*Stephanodiscus astraea* *Melosira arenaria* *Diploneis domblitensis*	Hydrotroilitic muds	*Stephanodiscus astraea*	Nannofossil-rich terrigenous mud	Reworked Cretaceous, Paleogenous, Neogenous *Cocholiths*	8,600± 200
Upper Pleistocene	Würm (Valdai)	Younger Driass Alleröd Lower Driass Belling Gothiglacial Pomeranian				*Dreissena rostriformis distincta*		Terrigenous broun « oxydated » muds			*Trecatodinium spirifirites*	
				Dreissena polymorpha *Viviparus fasciatus* *Unio sp.*	13,500±1,500	*Dreissena rostriformis distincta*		Clayey muds	*Fragments and young forms of:* *Dreissena rostriformis* *Monodacna caspia*			13,850±200 16,900±270
		Frankfurkian	Karkinitian	*Dreissena polymorpha* *Cardium edule*	17,760 ± 200	*Dreissena rostriformis distincta*			*Micromelania caspia*	Lacustrian phase		
		Brandemburgian	Tarkhankutian	*Cardium edule* *Abra ovata* *Dreissena polymorpha*	~ 22,000 ~ 25,000				*Cardium edule*	Marine phase		22,000
		- 25,000 Paudorf Arcy Gotweig - 40,000	Surozhian									25,000 40,000
			Regression									
			Post-karangatian									
			Karangatian									
	Riss-Würm	Mikulinian interglacial - ~ 65,000 Eemian - ~125,000	Pre-karangatian									

Abbreviations:
M-Sig.= Mologo-Sheksnian interglacial
K.g. =Kalininian glacial

phase or basin which lasted about 60 ka (since 125 ka to ~ 65 ka). The Karangat Sea level exceeded the present day level by 8 to 12 m (FEDOROV, 1978; OSTROVSKIY *et al.*, 1977, CHEPALYGA, 1985). Such a high level opens the conections with the Mediterranean (Tyrrhenian) Sea in the south-west through Bosphorous and, probably with the Caspian Sea in the north-east through the Manych depression. Marine terraces of this age are present all-around the Black Sea basin at altitudes varying from 4÷8 m within Taman peninsula to 30–35 m (neotectonically up-lifted) on the Caucasus coast (FEDOROV, 1978, OSTROVSKIY *et al.*, 1977). Ingressions in lowlands as Kolkhida Depression, Manych Depression and Danube delta are reported. The coastal and shelf zones Karangatian deposits contains marine steno- and euri-haline Mediterranean type fauna. The salinity of the Karangatian Sea was rather high, comparable to the Mediterranean Sea, ranging from 30 to 37‰ (NEVESSKAYA, 1970). During the Karangatian phase anoxic deep water with hydrogene sulfide contamination and sapropel deposits were formed in the deep-sea zone of the basin (NEPROCHNOV, 1980; CHEPALYGA, 1985).

3. After the Karangatian highstand followed the Lower Würmian (Early Valdai, Kalininian) glaciation, which brought a very strong regression of the sea, with a lowering of the level down to –100 ÷ –110 m (OSTROVSKIY *et al.*, 1977; CHEPALYGA, 1985). During this Post-Karangatian (Early-Neoeuxinian, FEDOROV, 1978) phase the Mediterranean connection was interrupted. Consequently the water within the Post-Karangatian basin was brackish-semifresh, completely oxygenated with a salinity of 5–10‰. The characteristic fauna is of Caspian type.

4. In the Middle Würm (Middle Valdai, Mologo-Sheksnian interstade, Bryansk) the sea level rose to a very close to the present-day level (–10 ÷ 0 m). This phase (~40 ÷ ~25 ka) is called Surozhian (POPOV, 1975) and is characterised by saline waters (close to the present-day salinity and, accordingly to OSTROVSKIY *et al.*, 1977, during the maximum of the transgression similar to the Karangatian one), marine endemic fauna with Mediterranean influence. NEPROCHNOV, 1980, suggests the hydrogen sulphide contamination of the deep waters of the Surozhian basin, with sapropel and pyrite formation. Two sub-phases of the Surozhian transgression are reported (OSTROVSKIY *et al.*, 1977): an earlier sub-phase with the sea-level stand at almost –10 m and a later one with the sea-level at the present level or slightly higher. Deposits with Surozhian fauna occur in marine terraces on Caucasian coast, uplifted to +15 ÷ 20 m, as well as in other places in lower stand: Kerch strait, Karkinit bay and peninsula, offshore of them in Golitsin Rise, Shagan lagoon (SHNYUKOV and TRASHCHUK, 1976; TRASHCHUK and BOLTIVETS, 1978) and on the Danube Delta territory (PANIN *et al.*, 1983).

5. The beginning of sea regression (at about 25 ka) is represented by Tarkhankut layers with still marine fauna and Karkinit horizon with brackish fauna and few latest marine elements.

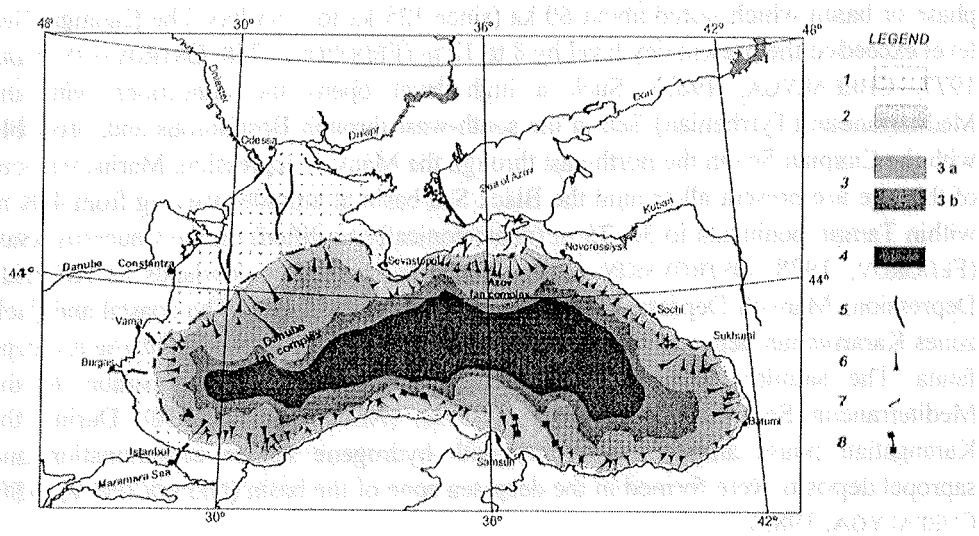

Fig. 1 – The Black Sea: main geomorphologic and sedimentologic provinces (after Panin, Elena and Gabriel Ion, 1993). Legend: 1 – Continental shelf; 2 – Continental slope; 3 – Continental apron: 3a – superior; 3b – inferior; 4 – Deep zone; 5 – Limits among provinces; 6 – The main canyons; 7 – Palaeo- valleys; 8 – Structural elements.

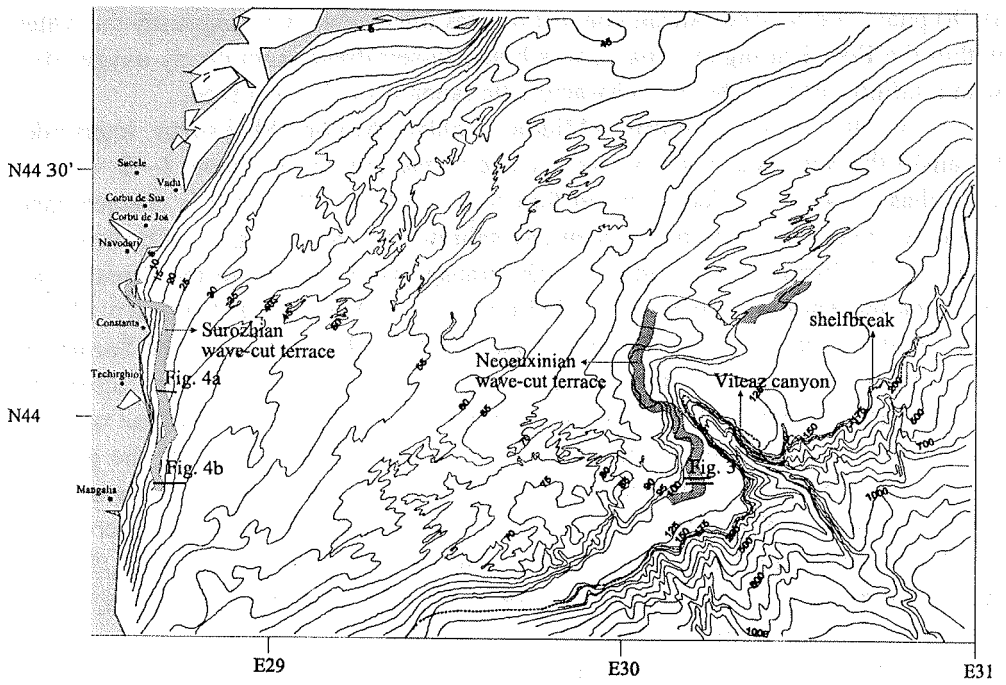

Fig. 2 – Map of the western continental shelf of the Black Sea (Romanian section) showing the bathymetry and the location of the shelf break and the shore lines during the Neoeuxinian and Surozhian.

On the southern Romanian coast, the Surozhian wave-cut notch can be identified at 12–38 m depth (Fig. 1, Fig. 2). Locally, four different terraces appear within this interval, at about 14 m, 22 m, 28 m and 38 m depth (Fig. 1, 3a). This erosional wave-cut zone is overlain by several prograding wedges that developed during the sea-level falling after the Surozhian highstand (Fig. 1, 3b).

The Upper Würmian glaciation (Late Valdai, Ostashkovian) corresponds to the Neoeuxinian phase of the Black Sea. This is a very low-stand phase, down to −110 ÷ −130 m after OSTROVSKIY *et al.*, 1977. More recent studies generally consider a depth between 90–110 m (CHEPALYGA, 1985), around 110 m (RYAN *et al.*, 1997), 100–110 m (DEMIRBAG *et al.*, 1999; GÖRUR *et al.*, 2001). The shoreline moved far away from the present day position, especially in the north-western part of the Black Sea and once again large areas of the continental shelf were exposed. The hydrographic network, especially the large rivers as Paleo-Danube and Paleo-Dniepr once more incised up to 90 m the exposed areas.

The Neoeuxinian basin, during the glacial maximum (~19 ÷ ~16 ka) was, probably completely isolated from the Mediterranean Sea. The water became brackish and fresh (3÷7‰ after NEVESSKAYA, 1965 and even less), well oxygenated, without H_2S contamination. Correspondingly the fauna was brackish to fresh water type, in the deep zone the microflora was of cold-water diatoms with the predominance of a depleted freshwater complex of *Stephanodiscus astraea* (JOUSÉ and MUKHINA, 1980).

At about 16 ÷ 15 ka the postglacial warming and melting of ice-caps melting started. As the supply of the melting water from the glaciers in the Black Sea was very direct (the Dniepr and the Dniestr rivers, as well as the Danube river) and important, consequently the Neoeuxinian sea-level rose very quickly reaching and overpassing at ~ 12 ka BP the Bosphorous sill altitude. The majority of scientists who studied the Black Sea belive that in this phase it was a very large fresh-water outflow through the Bosphorous-Dardanelles straits towards the Mediterranean (Aegean) Sea. KVASOV calculated (1975) that the fresh water outflow discharge was of about 190 km^3/year.

The Neoeuxinian sea-level lowstand can be clearly identified on the Romanian distal shelf. A wave-cut terrace was followed for about 100 km along the shelf edge, at depths between 98 m and 115 m (Fig. 2, 3). This terrace was cut in prograding deposits which are interpreted in similar cases as a shelf-perched lowstand wedge related to forced regressions (POSAMENTIER *et al.*, 1992, BERNÉ *et al.*, 1998). Our preliminary results indicate that the Neoeuxinian shoreline was forming a gulf landward of the Viteaz canyon. As indicated by the main directions of the fluvial incisions on the continental shelf, a large amount of sediment was directed to this gulf, which probably influenced the development of the Viteaz canyon in this special location (POPESCU, in prep.).

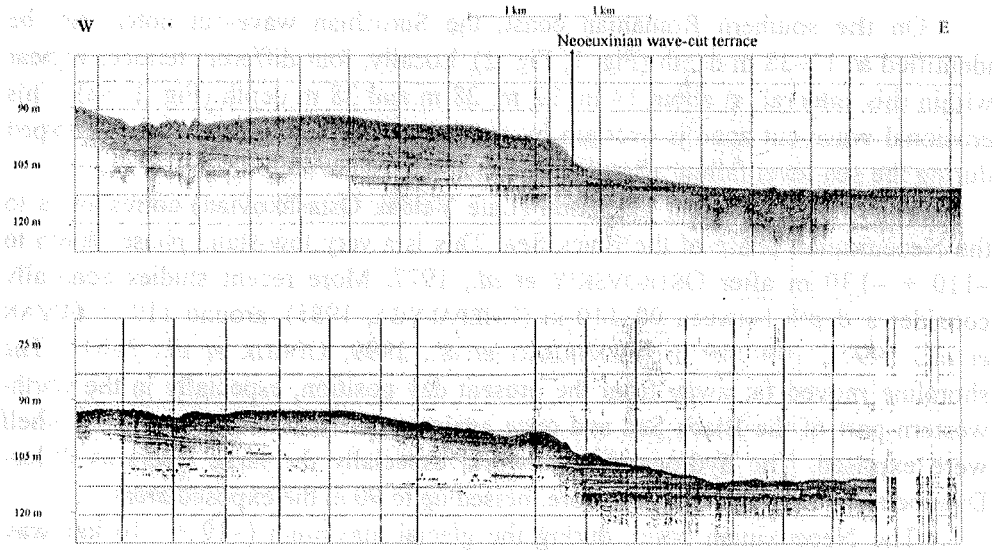

Fig. 3 – Sub-bottom profiles (3.5 kHz) on the distal shelf showing the Neoeuxinian wave-cut terrace (location in Fig. 2).

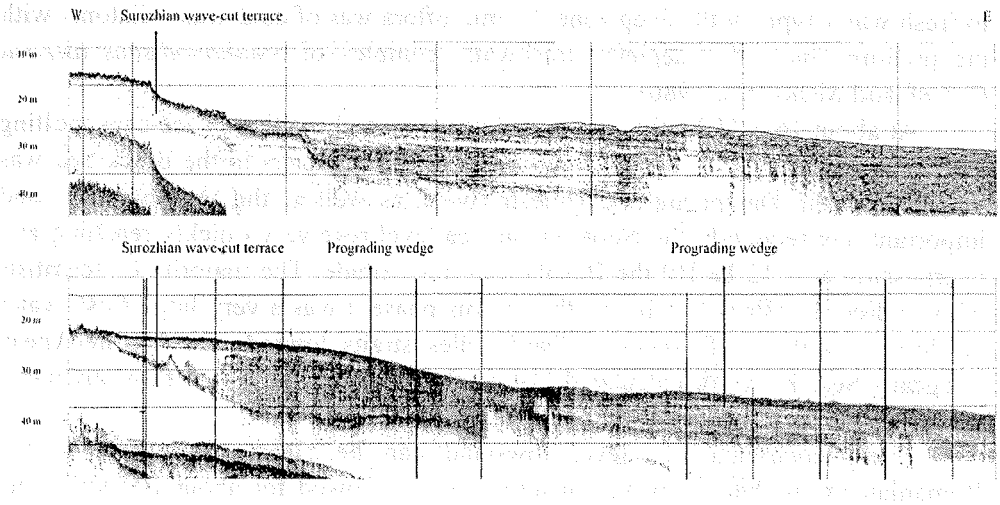

Fig. 4 – Sub-bottom profiles (3.5 kHz) on the proximal shelf showing the Surozhian wave-cut terrace (location in Fig. 2).

6. The Holocene. When the Mediterranean and the Black Seas have reached the same level (close to the present day one), some 9–7.5 ka BP, the two-way water exchange have been established and the process of transformation of the Black Sea in an anoxic brackish sea have started. In FEDOROV's presentation (1978) the maximum rise of the Black Sea up to 3÷5 m above the present-day stand occurred 4÷3.5 ka ago,

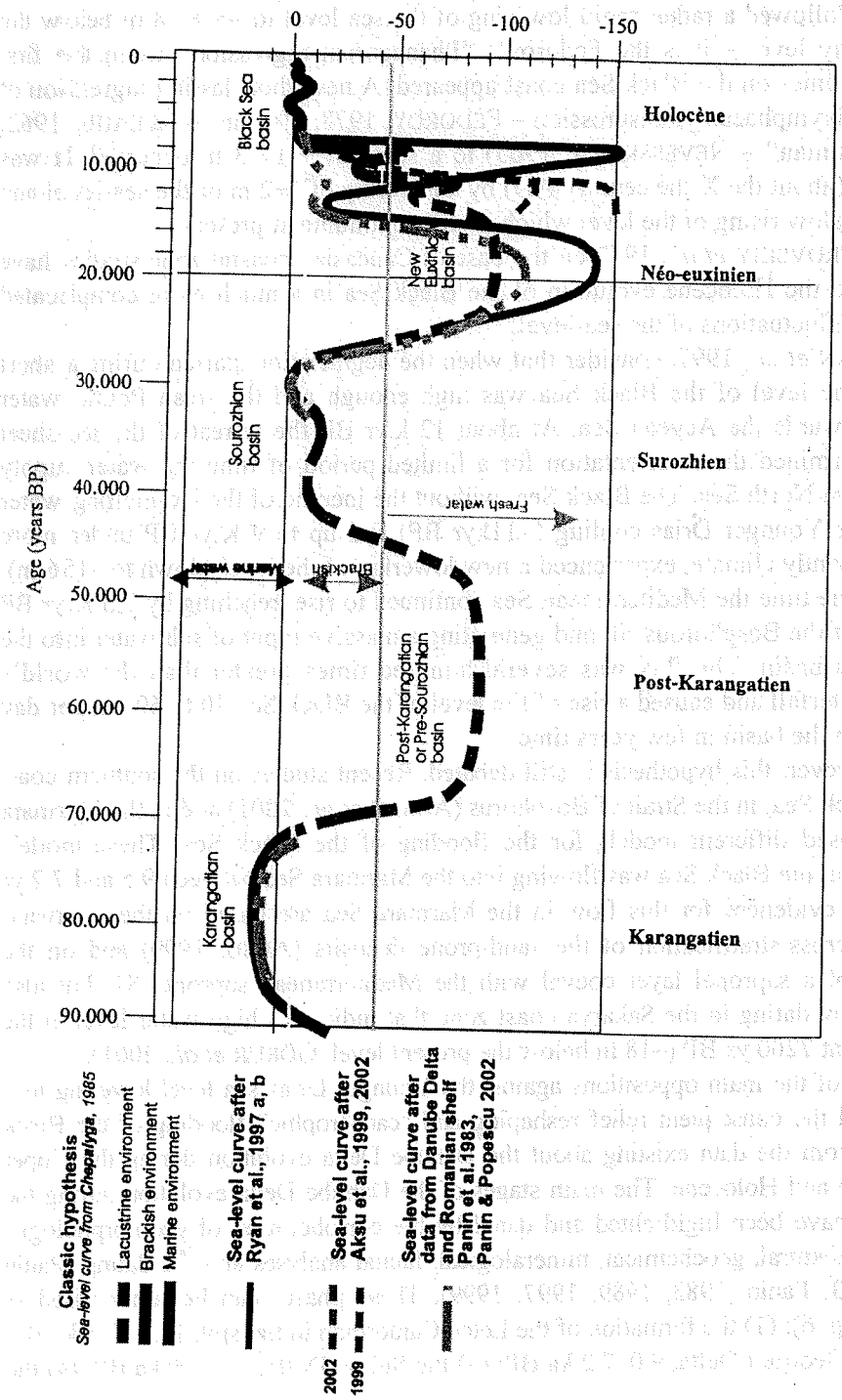

Fig. 5 – Black Sea level variation after different authors.

in Sub-boreal. During this sub-phase the so called "Old Black Sea" terrace was formed. Followed a rather rapid lowering of the sea-level to –5 ÷ –8 m below the present-day level – it is the Fedorov's "Phanagorian regression" when the first Greek colonies on the Black Sea coast appeared. A new short lasting ingression of the sea ("Nymphaean" transgression – FEDOROV, 1978; "Istrian" – BLEAHU, 1962; "Dzhemetinian" – NEVESSKAYA, 1965) to a stand of + 1÷ 3 m occurred. It was followed (about the X-the century AD) by a lowering of 1÷2 m of the sea-level and then by a slow rising of the level which is still continuing at present.

OSTROVSKIY *et al.*, 1977 on the base of Caucasian coastal zone studies have interpreted the Holocene evolution of the Black Sea in a much more complicated pattern of fluctuations of the sea-level.

RYAN *et al.*, 1997, consider that when the deglaciation started during a short episode the level of the Black Sea was high enough and the fresh Pontic water flowed towards the Aegean Sea. At about 12 k.yr BP the retreat of the ice-sheet front determined the re-orientation for a limited period of time the water supply towards the North Sea. The Black Sea, without the income of the ice-melting water during the Younger Drias cooling (~11kyr BP) and up to 9 K.yr BP under more arid and windy climate, experienced a new lowering of the level (down to –156 m). At the same time the Mediterranean Sea continued to rise, reaching by 7.5 K.yr BP the high of the Bosphorous sill and generating a massive input of salt water into the Black Sea basin. The flux was several hundred times greater than the world's largest waterfall and caused a rise of the level of the Black Sea 30 to 60 cm per day topping up the basin in few years time.

However, this hypothesis is still debated. Recent studies on the southern coast of the Black Sea, in the Strait of Bosphorus (ALGAN *et al.*, 2001) and in the Marmara Sea proposed different models for the flooding of the Black Sea. These models indicate that the Black Sea was flowing into the Marmara Sea between 9.5 and 7.2 yr BP. Their evidences for this flow in the Marmara Sea are based on the westward direction cross-stratification of the sand-prone deposits (AKSU, 1999) and on the presence of a sapropel layer coeval with the Mediterranean sapropel S1, but also sustained by dating in the Sakarya coast zone that indicate a high water level in the Black Sea at 7200 ys BP (–18 m below the present level, GÖRUR *et al.*, 2001).

One of the main oppositions against the Younger Drias sea level lowering to –156 m and the consequent relief reshaping and "catastrophic" flooding of the Black Sea rose from the data existing about the Danube Delta evolution during the Upper Pleistocene and Holocene. The main stages of the Danube Delta evolution during the Holocene have been highlighted and dated by the corroboration of geomorphologic, structural, textural, geochemical, mineralogical, faunal analyses and ^{14}C dating (Panin *et al.*, 1983; Panin, 1983, 1989, 1997, 1999). These phases can be summarised as follows (Fig. 6): (1) the formation of the Letea-Caraorman initial spit, 11.7–7. 5 ka BP; (2) the St. George I Delta, 9.0–7.2 ka BP; (3) the Sulina Delta, 7.2–2.0 ka BP; (4) the

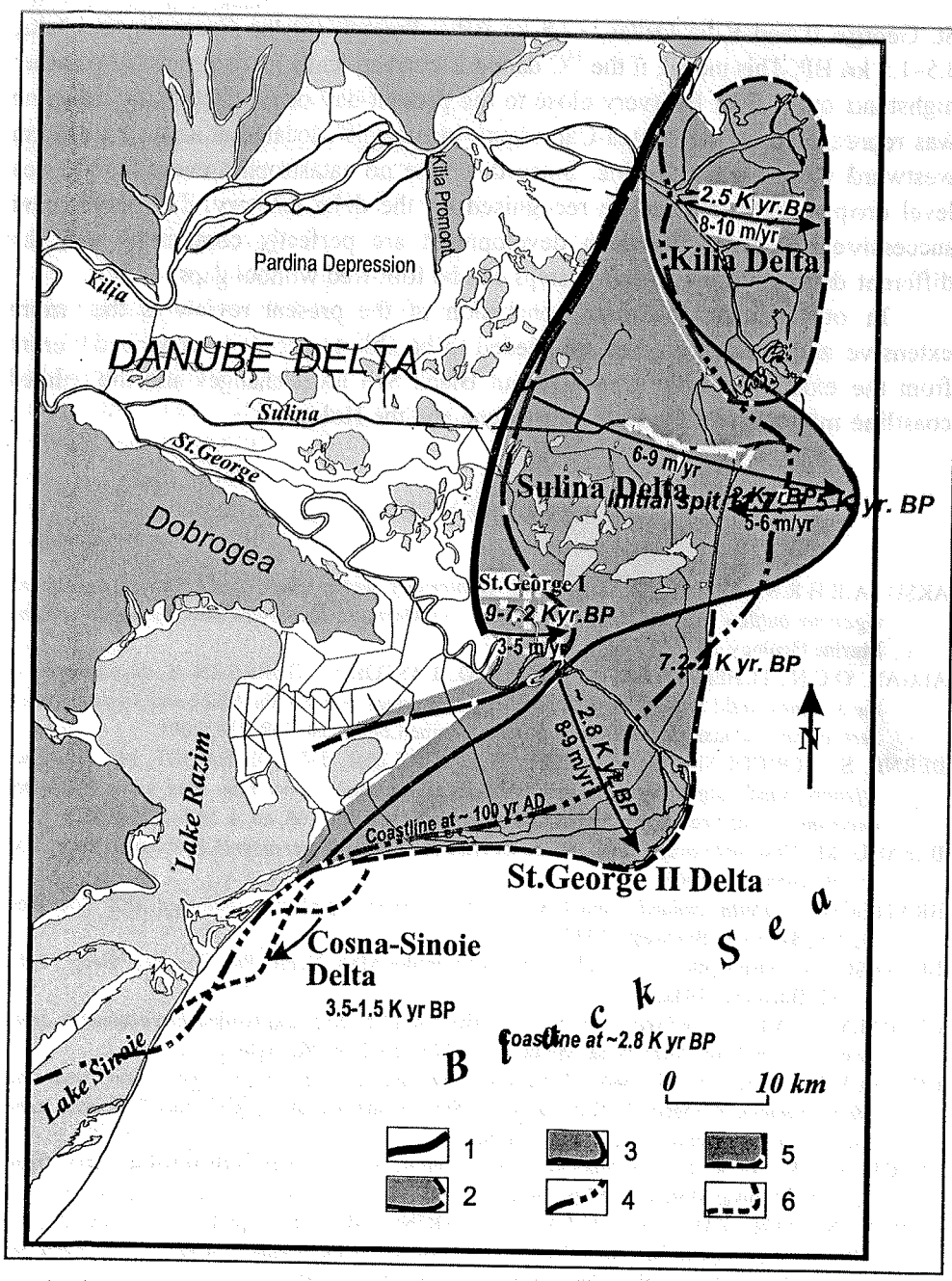

Fig. 6 – The Danube Delta evolution during the Holocene and correspondent coastline position changes (after Panin, 1997): 1. initial split 11.7–7.5 K yr BP; 2. St. George I Delta 9–7.2 Kyr BP; 3. Sulina Delta 7.2–2 K yr BP; 4. Coastline position at ~ 100 yr AD; 5. St. George II Delta and Kilia Delta 2.8 K yr BP – Present; 6. Cosna-Sinoie Delta 3.5–1.5 K yr BP.

St. George II and Kilia Deltas, ~2.8 ka BP – Present; (5) the Cosna-Sinoie Delta, 3.5–1.5 ka BP. This model, if the ^{14}C dating is correct, leads to a scenario of a rather highstand by 11.7 ka BP (very close to the present-day one) as the delta coastline was represented by the "Letea-Caraorman initial spit", located at about 25–30 km westward the present coastline. Since this time no catastrophic event (as the sea level drop to –156 m) can be recognised on the delta territory. The subsequent successive phases of the delta development are perfectly continuous and the different delta lobes progradation steps can be followed without gaps.

In our opinion, the main conclusion of the present review is that more extensive and detailed studies are needed to be able to accept a scenario different from the existing ones at present about Black Sea level changes and the related coastline migration during Late Pleistocene and the Holocene.

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