The Journal of Archaeomythology

Spring 2006 Volume 2, Number 1

Late Quaternary Sea-level and Environmental Changes in the Black Sea: A Brief Review of Published Data

Nicolae Panin and Claudia Strechie

General setting

The Black Sea is one of the largest enclosed seas in the world, covering an area of about 4.2 x 10^5 km^2. The maximum depth is 2,212 m and the total volume of the water 534,000 km^3. Most of this water, below a depth of 150-200 m, is anoxic and contaminated with H_2S (about 423,000 km^3) **(Figure 1).**

The Bosphorus and Dardanelles Straits provide the sole connection between the Black and Mediterranean Seas. The Bosphorus is narrow (0.76-3.6 km) and shallow (presently 32-34 m at the sill). It restricts the two-way water exchange between the very saline Mediterranean Sea (with a salinity of 38-39‰) and the more brackish Black Sea (about 17‰ at the surface and 22‰ at the bottom). The surface discharge of Black Sea water has been estimated at about 600 $km^3.yr^{-1}$ (~20,000 $m^3.s^{-1}$), while the heavier Mediterranean undercurrent streams into the Black Sea, resupplying it with about half its outflow, ~300 $km^3.yr^{-1}$ (~10,000 $m.s^{-1}$) (Özsoy *et al.* 1995).

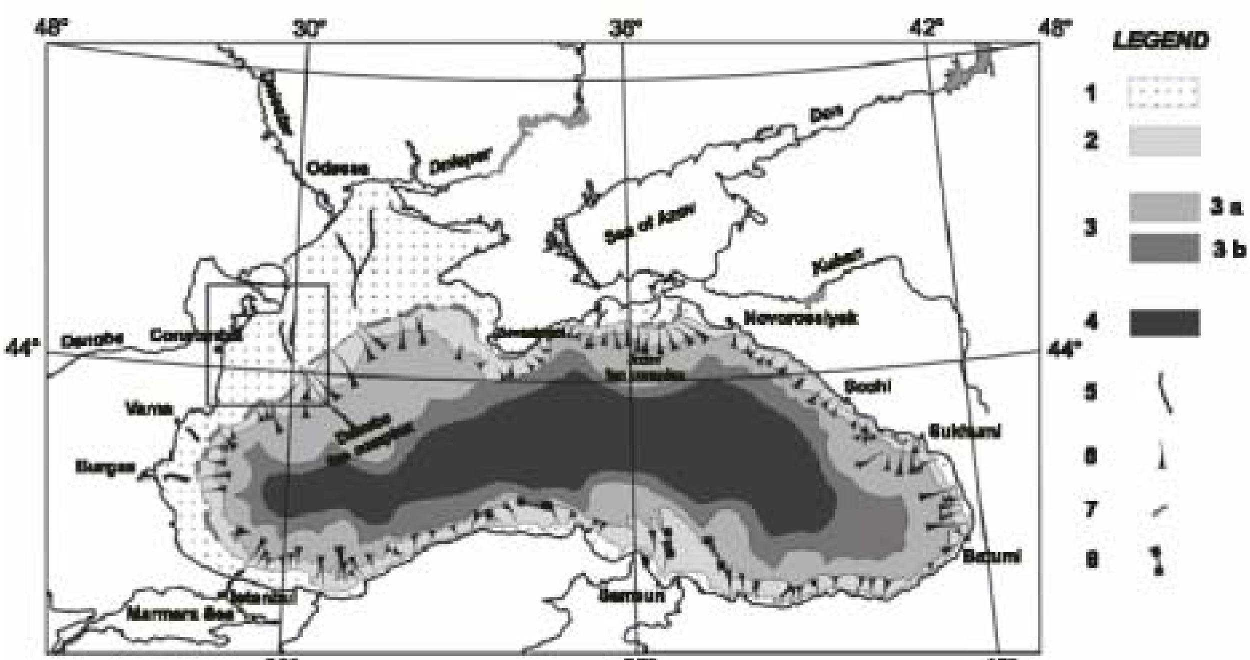

Figure 1: The Black Sea: main geomorphologic and sedimentogenetic provinces (after Panin *et a*l. 1997). (1) Continental shelf; (2) Continental slope; (3) Continental apron; (3a) superior; (3b) inferior; (4) Deep zone; (5) Limits among provinces; (6) Main canyons; (7) Paleo-valleys; (8) Structural elements.

The Black Sea has a very large drainage basin, over 2 million km^2, and a very important fresh water inflow by river runoff, summing over 372 km^3 yr^{-1} **(Table 1).** From a geological point of view the Black Sea is a large marginal sea surrounded by a system of Alpine orogenic chains, including the Balkanides and Pontides to the southwest and south, the Caucasus to the east and northeast, Crimea to the north, and North Dobrogean orogene to the northwest, as well as by the adjacent platforms—East European, Scythian to the north, and Moesian to the west (Dinu *et al*. 2005).

The Black Sea basin represents a backarc basin that opened during the Early Cretaceous–the Early Paleogene northward subduction of the Neo-Tethys below the Balcanides–Pontides volcanic arc (Letouzey *et al*. 1977; Zonenshain and Le Pichon 1986; Nikishin et al. 2001). More detailed deep reflection seismic studies (Finetti *et al*. 1988) indicate two extensional sub-basins separated by a large continental uplifted block, the Andrusov or Mid-Black Sea Ridge (Finetti et al. 1988). The Western Black Sea Basin opened by a rifting phase in Late Barremian–Early Albian, followed by a major subsidence and emplacement of oceanic crust in Cenomanian to Maastrichtian (Finetti et al. 1988; Görür 1988; Artyushkov 1992). The Eastern Black Sea Basin formed by Late Paleocene rifting, followed by Middle Eocene emplacement of oceanic crust (Robinson et al. 1996).

Evolution of the Black Sea investigation

Large-scale sea level changes and consequently drastic reshaping of land morphology and modifications of environmental settings occurred all along the Black Sea geologic history. Very spectacular changes are reported in the Quaternary being driven by the global glaciations and deglaciations, which responded mainly to Milankovitch cycles of 100 and 20 ka.

Changes in the behavior of Black Sea water level were influenced by the restricted connection with the Mediterranean Sea by the Bosphorus–Dardanelles straits (Bosphorus sill at ~34 m depth). When the general sea level lowered below the Bosphorous sill,

Rivers	Length (Km)	Drainage basin Area (Km^2)	Water discharge (Km^3/yr.)	Sediment discharge (Mt/yr.)
I. North-Western Black Sea				
• Danube	2,860	817,000	190.7	51.70**
• Dniestr	1,360	72,100	9.8	2.50*
• Dniepr	2,285	503,000	52.6	2.12*
• Southern Bug	806	63,700	2.6	0.53*
Sub-total I:		*1,455,800*	*255.7*	*56.85*
II. Sea of Azov				
• Don	1,870	442,500	29.5	6.40*
• Kuban	870	57,900	13.4	8.40*
Sub-total II:		*500,400*	*42.9*	*14.80*
III. Caucasian coast rivers			*41.0**	*29.00**
IV. Anatolian coast rivers			*29.7*	*51.00**
V. Bulgarian coast rivers			*3.0**	*0.50**
T O T A L :			*372.3*	*152.15*

Table 1. Fluvial water and sediment discharge into the Black Sea (*data from Balkas *et al.*, 1990; ** multiannual mean discharge before damming the River Danube after Bondar, 1991; Panin, 1996).

further variations of the Black Sea level and environmental changes followed specific regional conditions, without being necessarily related to changes in ocean levels.

One of the most important consequences of these lowstands was the interruption of Mediterranean inflow into the Black Sea, which, lacking any saline contribution, gradually became a giant brackish to freshwater lake

Quaternary environmental changes in the Black Sea have been studied in detail from different perspectives, including geomorphology (of the coastal, shelf, slope, and bathyal zones), sedimentology (sedimentary environment, sediment architecture, and geochemistry), faunal and floral assemblages, paleomagnetism, absolute age dating, $^{18/16}O$ ratio in the carbonates, and archaeology.

The environmental changes of the sea can be recognised and characterised through the sometimes contradictory features of the three main geomorphologic and sedimentary zones (Scherbakov 1978): (1) the coastal zone; (2) the continental shelf including the shelf break, and (3) the deep-sea zone.

First phase of scientific studies in the Black Sea

Andrusov was among the first scientists to carry out oceanographic and geologic investigations in the Black Sea (on gun-boats "Tchernomoryetz" in 1890, "Donetz" and "Zaporozhetz" in 1891). He carried out oceanographic studies, described the near-surface sediments and fauna assemblages within the sediments, first determined the greatest depth of the sea (2,244 m) and found that the deep water of the Black Sea (below 200 m) is contaminated by H_2S formed by decomposition of organic matter (1892, 1893). Later, in 1926, he established a set of paleo-geographical maps of the Black Sea region.

In other riparian countries there were also investigations initiated by the end of the nineteenth century: e.g., in Romania, in 1898–1899, A. Cãtuneanu drew a bathymetrical map of the Romanian coastal sea with information about bottom sediments. At the beginning of the twentieth century the Russian Hydrographical General Directorate began a systematic oceanographical assessment of the Black Sea. Several extensive oceanographic studies were made in 1923–1928 by Shokalskyi (onboard the vessels "Ingul," "Dunay," and "Hydrographer"), and after 1928 by Snezhinskyi. Basic studies on the lithology and stratigraphy of the Upper Quaternary deposits, sedimentary processes and geological history of the Black Sea have been performed by Arkhangelskiy (1927, 1928) and Arkhangelskiy and Strakhov (1932, 1938). Arkhangelskiy and Strakhov first established a chronology of the Black Sea sediments and Shokalskyi drew a general morphological map of the sea. During this period, oceanographic and geologic studies were also performed in Romania (Ciocârdel 1936-1937), Turkey, and Bulgaria (Petrbok 1925, 1926, 1927, 1935; Yaranov 1939, 1940; and Ivanov 1925, 1927). Studies on the Danube Delta were carried out by different researchers (Antipa 1915, 1941; Bratescu 1922, 1942; and Vâlsan 1934).

After the Second World War, intensive studies were carried out by the Institute of Oceanology (Academy of Sciences, USSR). Strakhov (1947, 1954, 1961, 1963) studied the sediments in cores over 11 m long, while Goncharov (1958) drew the first bathymetrical map of the entire sea using modern acoustic technology.

Important studies concerning the changes of the Black Sea water level in Quaternary were performed by a Romanian geographer, Brãtescu, in 1942. The general oceanography and biology of the Black sea were studied by Antipa in 1941. Studies of the Danube Delta evolution connected with the Black Sea geological history continued (Lepsi 1942, etc.).

More detailed studies were performed in the 1950s and 1960s by Muratov (1951, 1967, etc.), Barkovskaya (1961), Nevesskiy (1961, 1967, etc.), Fedorov (1963), Nevesskaya (1958, 1965, 1970, etc.), Emelianov and Shimkus (1962), Bleahu (1963), and many others. Neprochnov (1958, 1960, 1962), Goncharov et al. (1960, 1972), Malovitskiy et al. (1966, 1969, 1972), Moskalenko et al. (1974) and others studied the deep structure of the Black Sea bottom and found that in the central part of the sea there are two areas (in the eastern and in the western parts) where the "ocean type crust" directly underlies very thick sedimentary series. Geological, geophysical and oceanographic studies have been done in all riparian countries. These investigations were directed mainly to the mineral resources of the sea (especially to oil and gas perspectives). All the studies mentioned above led to a realistic perception of the geological evolution of the Black Sea and of the main changes in its environmental conditions, in the structure and functioning of ecosystems.

The following tables summarize the Quaternary evolutionary phases of the Black Sea and provide correlations with the Mediterranean and Central Alpine Europe. **Table 2**, reproduced from Fedorov (1978) with a few modifications, involves the Black Sea coastal and shelf zones. **Table 3**, slightly modified from Shcherbakov et al. (1979), provides stratigraphy and correlations between the Black Sea's inner and outer shelves and the bathyal zone. All tables reflect a "classic" view of Black Sea development.

The second phase of scientific studies in the Black Sea

Starting with late 1960s, the Black Sea was opened to international co-operative studies. One of the first international oceanographic expeditions was the 1969 R/V "Atlantis II" cruise that made it possible for Degens and Ross (1970) to notice dramatic changes in organic carbon and nitrogen values along the core taken from the deep part of the sea. They linked these changes to modifications of the physical and chemical conditions of the Black Sea and found (considering the $\delta^{13}C$ ratio) that before 7,000 yrs BP, the earliest organic matter was composed of fresh water organisms and, in contrast, the organic matter deposited during the last 3,000 yrs was typically marine. They also furnished the first radiocarbon dating of the recent sediments: 2,900 ± 140 and 7,140±180 yrs BP.

Deuser (1972) showed that the Black Sea, between 17,000 and 9,000 yrs BP, was a fresh or brackish basin (by measuring $\delta^{18}O$ and $\delta^{13}C$ ratios in the carbonates and organic matter in the sediments). For Deuser, the shift in the $?^{18}O$ of the carbonate around 9,000 yrs BP suggests a rather sudden increase of the Black Sea salinity at 9,000–8,000 yrs BP. From 9,000 to 3,000 yrs BP a radical change in the sedimentary regime occurred, as well as a gradual increase in salinity.

At c. 3,000 yrs BP, present conditions were reached in the Black Sea basin. Consequently one can suppose that around 9,000 yrs BP the first influx of salted water from the Mediterranean Sea began (after the Last Glacial Maximum occurred) and the setting of anoxic conditions were initiated at the Black Sea bottom.

Ross and Degens (1974) have described the succession of the upper sediment layers in the deep basin calling these layers:

Unit 1 – coccolith ooze (0-3,000 yrs BP): micro laminated carbonated sediment with *Emiliana huxleyi*;
Unit 2 – sapropel beds (3,000-7,000 yrs BP): micro laminated sediment very rich in organic matter (sapropel);
Unit 3 – banded lutite (7,000-25,000 yrs BP): banded lutites ± turbidites.

These units correspond approximately to Arkhangelskiy and Strakhov's (1938) stratigraphic units: (1) recent deposits (New Black Sea beds); (2) Old Black Sea beds; and (3) Neoeuxinian deposits.

Ross and Degens found that 22,000 yrs ago in the Black Sea there were freshwater conditions with oxygenate water column. The water level 25,000 yrs BP was ~ 30 m bellow the present sea level.

Between 9,000 and 7,000 yrs BP, occasional marine water spills through the Bosphorus towards the Black Sea changed the oxygenated environment of fresh water into a stagnant marine environment. At around 7,000 yrs BP in the deep basin (at ~ 2,000 m) the H_2S zone started to form and the deposition of Unit 2 began.

Manheim and Chan (1974) studied the interstitial water in the Black Sea sediments and found that considerable salinity gradients occur in these interstitial waters in many cores from the Black Sea. Between 20,000 and 8,000 yrs BP the salinity in the Black Sea was roughly constant at 3.5 ‰; the density stratification was probably absent in the water column and the bottom waters were probably aerated.

Stanley and Blanpied (1980) studied the Sea of

Table 2 - Stratigraphy and correlations of Upper Quaternary phases for the coastal and inner shelf zones (after Fedorov, 1978, with insignificant adaptations).

<table>
<tr><th colspan="2" rowspan="2">General scale</th><th colspan="2" rowspan="2">Europe</th><th rowspan="2">European Russia</th><th colspan="6">Black Sea region</th></tr>
<tr><th colspan="2">General stratigraphic scale</th><th>W and NW Black Sea</th><th>Northern Black Sea
Crimea, Kertch, Taman</th><th colspan="2">Eastern Black Sea Caucasus</th></tr>
<tr><td colspan="2" rowspan="4">Holocene</td><td colspan="2" rowspan="4">Flandrian</td><td rowspan="4">Holocene</td><td rowspan="4">Black Sea Horizon</td><td>Nymphean</td><td>Terrace at 2 m; sands with *Cardium edule* L. etc.</td><td>Terrace at 2 m; Sands with *Cardium edule* L. etc.</td><td colspan="2">Terrace at 2 m; sands with *Cardium edule* L. etc.</td></tr>
<tr><td>Phanagorian</td><td>Regression to – 6 – 8 m.
Archeological layers V÷I c. BC</td><td>Regression to – 6 – 8 m. Archeological layers V÷I c. BC</td><td colspan="2">Regression to – 6 - 8 m. Archeological layers V÷I c. BC</td></tr>
<tr><td>New Black Sea</td><td>Terrace at +4 +5 m;
sands and shells with *Cardium edule* L., *Chlamys, Ostrea, Mytilus*</td><td>Terrace at +4 +5 m; sands and shells with *Cardium edule* L., *Chlamys, Ostrea, Mytilus*</td><td colspan="2">Terrace at +4 +5 m; sands and shells with *Cardium edule* L., *Chlamys, Ostrea, Mytilus*</td></tr>
<tr><td>Old Black Sea</td><td>Clayey sands with *Cardium edule* L. etc. at –10 –20 m water depth on shelf</td><td>Clayey sands with *Cardium edule* L. etc. at -10 -20 m water depth on shelf</td><td colspan="2">Clayey sands with *Cardium edule* L. etc. at -10 -20 m water depth on shelf</td></tr>
<tr><td rowspan="16">P l e i s t o c e n e</td><td rowspan="5">Upper</td><td colspan="2" rowspan="3">Grimaldian – Wűrm
(regression to
-100 -130 m)</td><td>Ostashkovian</td><td rowspan="3">Neoeuxinian</td><td>Late Neoeuxinian</td><td>Wűrmian loess ; clays with *Monodacna caspia* Eichw., *Dreissea polymorpha* Pall.,at –20 –30 m water depth on shelf</td><td>Clays with *Monodacna caspia* Eichw., *Dreissea polymorpha* Pall., at –20 –30 m water depth on shelf</td><td colspan="2">Clays with *Monodacna caspia* Eichw., *Dreissea polymorpha* Pall., at –20 –30 m water depth on shelf</td></tr>
<tr><td>Mologo-Sheksnian</td><td rowspan="2">Early Neoeuxinian (Postkarangatian)</td><td rowspan="2">Regression to –60 – 80 (-130) m.
Wűrmian loess. Deepening of the valleys incisions</td><td rowspan="2">Loesslike deposits; alluvial-deltaic sands, deepening of Kertch strait.</td><td colspan="2" rowspan="2">Regression ; deepening of the valleys incisions to –60 –80 m.</td></tr>
<tr><td>Kalininian</td></tr>
<tr><td colspan="2" rowspan="2">Neotyrrhenian
(terrace at 2-8 m above SL)</td><td rowspan="2">Mykulinian</td><td rowspan="2">Karangatian</td><td>Upper Karangatian</td><td rowspan="2">Terrace at +15 +16 m
Shells and sands with *Cardium tuberculatum* L., *Paphia senescens* (Coc.) etc.</td><td rowspan="2">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.</td><td colspan="2" rowspan="2">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.</td></tr>
<tr><td>Lower Karangatian</td></tr>
<tr><td rowspan="6">Middle</td><td colspan="2">Regression (Riss II ?)
Deepening of Bosporus to
- 100 m</td><td>Moskovian</td><td rowspan="3">Upper Euxinian-Uzunlarian</td><td>Regression</td><td>Regression.
Clayey loess-like deposits.</td><td>Clayey deposits with *Limneea, Planorbis* ; pebbles with *Viviparus*</td><td colspan="2">Regression. Alluvial pebbles, terminal moraine at Amtkheli.</td></tr>
<tr><td colspan="2">Eutyrrhenian (Tyrrhenian Ib)
(terrace at 10-20 m)</td><td>Odyntzovian</td><td>Uzunlarian</td><td rowspan="2">Terrace at +35 +40 m (Bulgaria)
Upper Babel layers, sands with *Didacna nalivkini* Wass. etc., Uppermost lagoonal clays</td><td>Clayey sands with *Cardium edule* L., *Didacna nalivkini* Wass. etc.</td><td colspan="2">Terrace at +25 +30 m (Pshady) and
+35 +37m (Pshady valley); pebbles, sands with *Cardium edule* L., *Mactra stultorum* L., *Scrobicularia*</td></tr>
<tr><td colspan="2" rowspan="2">Regression (Riss I ?)</td><td rowspan="2">Dneprian</td><td>Late Paleoeuxinian</td><td>Sands and clays with *Didacna nalivkini* Wass., *D.pontocaspia* Pavl., *Viviparus*</td><td colspan="2">Terrace at 40÷43 m (Pshady valley);
Sands, conglom., limstones with *D.nalivkini* Wass., *D. subpiramidata* Prav., at the base *Balanus*</td></tr>
<tr><td rowspan="3">Lower Euxinian-Uzunlarian</td><td>Regression</td><td>Regression</td><td>Regression</td><td colspan="2">Regression, Dilluvium</td></tr>
<tr><td colspan="2" rowspan="2">Paleotyrrhenian
(Tyrrhenian I-a)
(terrace at 18-30 m)</td><td rowspan="2">Lykhvinian</td><td>Paleouzunlarian</td><td rowspan="2">Sands, clays with *Didacna pallasi* Prav., *D.nalivkini* Wass.
Lower Babel layers.
Lagoonal clays with *Didacna pseudocrassa* Pavl. etc.</td><td rowspan="2">Continental deposits within the Mandzhil terrace</td><td colspan="2">Terrace at +45 +50 m (at Ashe, Makopse, Magri); pebbles with *C.edule, Paphia* sp., *Chione gallina*</td></tr>
<tr><td>Early Paleoeuxinian</td><td colspan="2">Terrace at +60 +65 m (Dzhubgy); sands, pebbles with *Didacna baericrassa* Pavl., *D.pallassi* Prav., *C.edule* L.</td></tr>
<tr><td rowspan="5">Lower</td><td colspan="2">Mindel
(Roman regression)</td><td>Okan</td><td colspan="2">Regression</td><td>Alluvial sands with *Viviparus* and Tyraspol complex of mammalians</td><td>Top deposits with *Archidiscodon sp.*</td><td colspan="2">Regression</td></tr>
<tr><td rowspan="3">Cromerian</td><td>Sicilian 2
Terrace at
60 m</td><td rowspan="4">Dnestrian</td><td rowspan="2">Tchaudian</td><td>Upper Tchaudian</td><td rowspan="3"></td><td>Shells, sands with *Didacna pseudocrassa* Pavl., *D. tschaudae* Andrus., *D.rudis* Nal. ;Terrace « Large tables » (Bolshye stoly)</td><td colspan="2">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*</td></tr>
<tr><td rowspan="2">Sicilian 1
Terrace at
100 m</td><td rowspan="2">Lower Tchaudian</td><td rowspan="2">*Clayey continental deposits*
Sands with *Didacna baericrassa, D.parvula, V.pseudoachatinoides, Fagotia esperi*</td><td colspan="2" rowspan="2">Sandy-clayey deposits of Guria with *D. tschaudae, D. tschaudae guriana* Livent., *D.crassa guriensis* Newesk., *D. pleisto-pleura* (Davit), *D.pseudocrassa*</td></tr>
<tr><td rowspan="2">Gurian –
Tchaudian</td></tr>
<tr><td colspan="2">Gűnz (regression)</td><td>Regression</td><td>Sands and clays with *Archidiscodon meridionalis* Nest. (late) within Nogaysk outcrop</td><td>Continental deposits with Taman complex of mammalian fauna</td><td>Deposits with Gurian-Tschaudian fauna</td><td>Break</td></tr>
<tr><td colspan="2">Eopleistocene</td><td colspan="2">Emilian-Calabrian</td><td>Morozovian-Nogayskian</td><td colspan="2">Gurian</td><td></td><td>Gurian deposits</td><td colspan="2">Clays with *Didacna digressa* Livent. etc.</td></tr>
</table>

Table 3- Stratigraphy and correlations of Upper Quaternary phases for shelf and bathyal zones (After Scherbakov *et al.*, 1979, with slight adaptations)

Northern Europe					BLACK SEA										
Stratigraphic subdivisions					Bathymetric zone 0-50 m		Bathymetric zone 50-200 m			Bathyal zone - northern part		Bathyal zone - southern part			
					Layers	Molluscs	Horizon	Molluscs	Diatomaea	Horizon	Diatoms, molluscs	Horizon	Nannopl,dinoflagelates	Age	
Holocene		Upper		Subatlantic - 2,800	Dzhemetinian	*Divaricella divaricata* *Gafrarium minimum* *Pitar rudis* *Cardium papillosum*	Phaseolinus muds	*Modiolus phaseolinus*	*Coscinodiscus radiatus* *Thalassiosira excentrica* *Actinocyclus ehrenbergii* *Cyclotella kutzingiana* *Cyclotella aceolata*	Cocolith ooze	*Coscinodiscus radiatus* *Endictia oceanica* *Thalassiosira excentrica* *Asteromphalus robustus* *Rhizosolenia calcar avis*	Cocolith ooze Unit 1	*Emiliania huxlei* *Lingulodinium sp.* *Peridinium sp.*		
Holocene		Middle		Sub-boreal - 4,800	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*		
Holocene		Middle		Atlantic - 7,800	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 buculus* *Navicula palpebralis var. semiplena*	Terrigenous-biogenic muds		Terrigenous-biogenic muds Unit 3		7,090± 180	
Holocene		Lower		Boreal - 9,400 Pre-boreal - 10,200	Neoeuxin	*Monodacna caspia* *Dreissena polymorpha*	8,550 ± 130	*Monodacna caspia* *Dreissena rostriformis bugensis*	*Stephanodiscus astraea* *Melosira arenaria* *Diploneis domblitensis*	Hydrotroilitic muds	*Stephanodiscus astraea*	Nannofossil-rich terrigenous mud	Reworked Cretaceous. Paleogen, Neoge *Cocoliths*	8,600± 200	
Upper Pleistocene	Würm (Valdai)	Upper	Ostashkovian glaciation	Younger Dryas Allerød Lower Dryass Bølling	Neoeuxin			*Dreissena rostriformis distincta*		Terrigenous brown « oxydated » muds			*Tectatodinium spirifirites*		
Upper Pleistocene	Würm (Valdai)	Upper	Ostashkovian glaciation	Gothiglacial Pomeranian	Neoeuxin	*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	
Upper Pleistocene	Würm (Valdai)	Upper	Ostashkovian glaciation	Frankfurtian	Karkinitian	*Dreissena polymorpha* *Cardium edule*	17,760 ± 200	*Dreissena rostriformis distincta*			*Micromelania caspia*	Lacustrian phase			
Upper Pleistocene	Würm (Valdai)	Upper	Ostashkovian glaciation	Brandenburgian - 25,000	Tarkhankutian	*Cardium edule* *Abra ovata* *Dreissena polymorpha*	~ 22,000 ~ 25,000				*Cardium edule*	Marine phase		22,000 25,000	
Upper Pleistocene	Würm (Valdai)	Middle	M-S.ig.	Paudorf Arcy Gotweig - 40,000	Surozhian									40,000	
Upper Pleistocene	Würm (Valdai)	Lower	K.g		Regression										
Upper Pleistocene	Würm (Valdai)	Lower		- ~ 65,000	Post-Karangatian										
Upper Pleistocene	Riss-Würm		Mikulinian interglacial	Eemian - ~125,000	Karangatian										
Upper Pleistocene	Riss-Würm		Mikulinian interglacial		Pre-Karangatian										

<u>Abbreviations</u> :
M-S.ig. = Mologo-Sheksnian interglacial
K.g. = Kalininian glacial

Marmara and came to the following conclusions:

(a) The maximum eustatic lowstand occurred before 12,000 yrs BP when the Black Sea, the Marmara and the Mediterranean were totally separated; (b) from 12,000 to 9,500 yrs BP, Black Sea fresh water spilled into Marmara and Aegean seas. The Black Sea received a maximum quantity of melt-water from the rivers and possibly from the Caspian Sea; (c) from 9,500 to 7,000 yrs BP minor amounts of salt water from the Mediterranean spilled into the Black Sea; the freshwater outflow from the Black Sea led to the formation of Sapropel 1 into the Eastern Mediterranean; (d) between 7,000 to 3,000 yrs BP: the two way flow from and into the Black Sea was established and the sapropel started to form in the Black Sea, where the bottom waters became anoxic and contaminated with H_2S; (e) from 3,000 yrs BP to the Present the two way flow from and into the Black Sea continued and the present day conditions were consolidated in the Black Sea.

There are a very large number of publications that have contributed to an understanding of the Black Sea geological and environmental evolution during the Quaternary. We selected a few of them in order to highlight the most important steps in the progress of our knowledge until the late 1990s when new and revolutionary hypotheses were presented.

Late Quaternary Environmental Changes in the Black Sea

The following overview of Late Pleistocene and Holocene environmental changes in the Black Sea is based on sources in the literature mainly already discussed above.

Riss-Würm interglacial – Karangatian phase

The Riss-Würm interglacial (Mikulinian) corresponds to the Karangatian phase in the Back Sea. The Karangatian phase lasted about 60 ky (from ~125 to ~ 65 ky BP). Eustatic rise in sea level allowed saline Mediterranean water to penetrate the Pontic basin through the Bosphorus and Dardanelles and consequently the Karangatian basin had marine conditions. Connections with the Caspian Sea through the Manych Depression existed as well. The Karangatian sea level exceeded that of the present day by 8 to 12 m (Fedorov 1978; Ostrovsky *et al.* 1977; Chepalyga 1984). Marine terraces of this age have been found around the Black Sea basin at elevations of 4-8 m on the Taman Peninsula and 30-35 m along the Caucasus coast depending on the neotectonic uplift (Fedorov 1978; Ostrovsky et al. 1977). The salinity during the Karangatian phase ranged from 30 to 37‰ (Nevesskaya 1970) **(Figure 2).** Anoxic deep water with hydrogen sulphide and sapropel deposits formed during the Karangatian phase (Neprochnov 1980; Chepalyga 1984).

Lower Würm glacial - Post-Karangatian

The Karangatian highstand was succeeded by the Lower Würm glaciation (Early Valdai, Kalininian), which lowered sea level significantly to between -100 and -110 m (Ostrovsky et al. 1977; Chepalyga 1984). This post-Karangatian phase (Early Neoeuxinian according to Fedorov, 1978) interrupted the Mediterranean connection again and transformed the sea back to a brackish, semi-fresh condition, completely oxygenated, and with a salinity of 5-10‰. The characteristic fauna was once more of Caspian type.

Middle Würm interstade – Surozhian

In the Middle Würm (Middle Valdai, Mologo-Sheksnian interstade, Bryansk interstade), sea level rose to a level very close to that of the present day (between -10 and 0 m). This phase in the Black Sea is called Surozhian phase and it occurred between c. 40 and 25 ky BP (Popov 1975) and brought saline waters into the Pontic basin accompanied by marine endemic fauna with Mediterranean associations.

According to Ostrovsky *et al.* (1977) salinity was comparable to that of the present Black Sea as well as the previous Karangatian highstand during its maximum transgression. Neprochnov (1980) suggests that the deep waters of the Surozhian basin achieved a high hydrogen sulphide concentration, with sapropel and pyrite formation.

Deposits with Surozhian fauna outcrop in marine terraces along the Caucasian coast at +15 to +20 m. Elsewhere, they occur at lower elevations: the Kerch strait, Karkinit Bay and peninsula, offshore on the Gallitzin Rise, in the Shagan lagoon (Shnyukov and Trashchuk 1976; Trashchuk and Boltivets 1978), and in the Danube Delta (Panin et al. 1983).

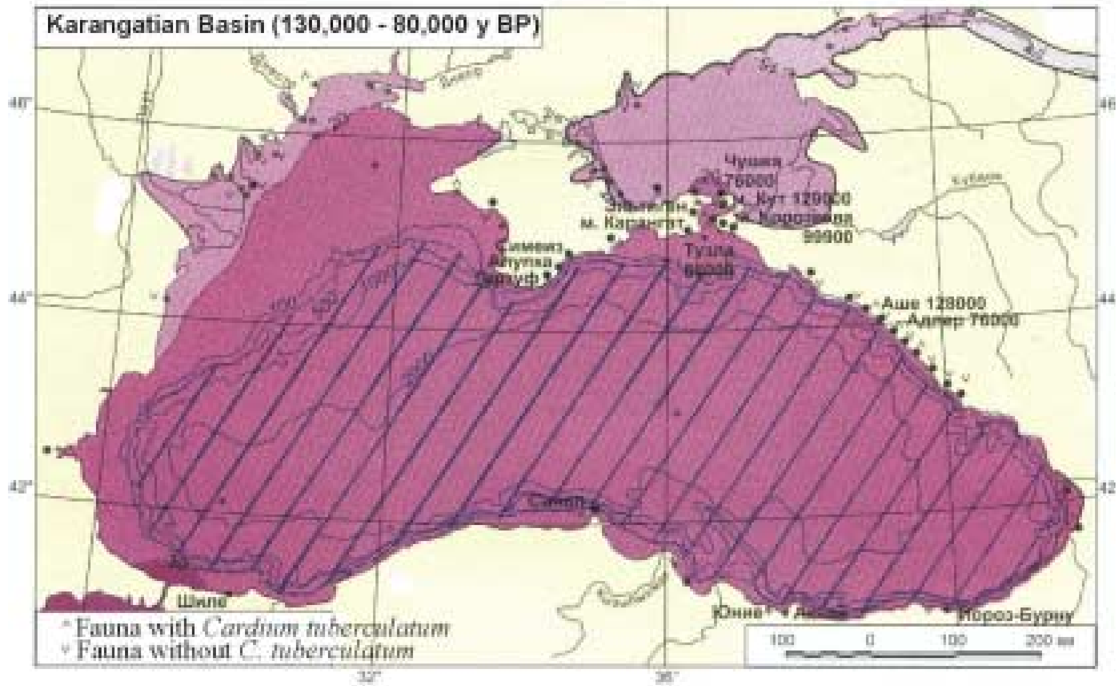

Figure 2: The extension of the Karangatian Basin (~ 125–65 ky BP). The water level was at ~ +8 - +12 m and the salinity between 20 and 30 ‰ (Velichko 2002).

On the southern Romanian coast, a Surozhian wave-cut cliff or bench was identified at 12-38 m depth. Locally, four different terraces appear within this depth interval at about -14, -22, -28, and -38 m. These erosional, wave-cut features are overlain by several prograding wedges that developed during the sea-level fall after the Surozhian highstand (Panin and Popescu 2005).

Upper Würm glacial – Neoeuxinian

The beginning of the subsequent regression at about 25 ky BP is represented by the Tarkhankut layers, which still contain marine fauna, and the Karkinit horizon, which reveals brackish fauna and few late marine remnants.

The Upper Würm glaciation (Late Valdai, Ostashkovian) corresponds to the Neoeuxinian phase of the Black Sea. This extreme lowstand witnessed a dramatic water-level drawdown to depths variously estimated by researchers: -110 to -130 m (Ostrovsky et al. 1977), -90 to -110 m (Chepalyga 1984), around -140 m (Ryan *et al*. 1997), and -100 to -110 m (Demirbag et al.1999; and Görür et al. 2001). The shoreline receded far from its present position, especially in the northwest, where much of the wide continental shelf was exposed. Tributary rivers, especially the Paleo-Danube and the Paleo-Dnieper, incised sharply into the newly exposed areas, cutting to a depth of 90 m on the outer shelf. During the last glacial maximum (~19 to ~16 ky BP), the Neoeuxinian basin was probably completely isolated from the Mediterranean Sea. Water became brackish, then fresh—3-7‰ salinity or less according to Nevesskaya (1965)—well-oxygenated, and free of H2S (**Figure 3).** The faunal record contains species of brackish to freshwater type, and in the bathyal zone, the microflora consisted of cold-water diatoms dominated by a depleted freshwater complex of *Stephanodiscus astraea* (Zhuze and Mukhina 1980).

At about 16-15 ky BP, post-glacial warming and ice cap melting began. The supply of meltwater from the glaciers to the Pontic basin was direct and plentiful (via the Dnieper, Dniester, and Danube

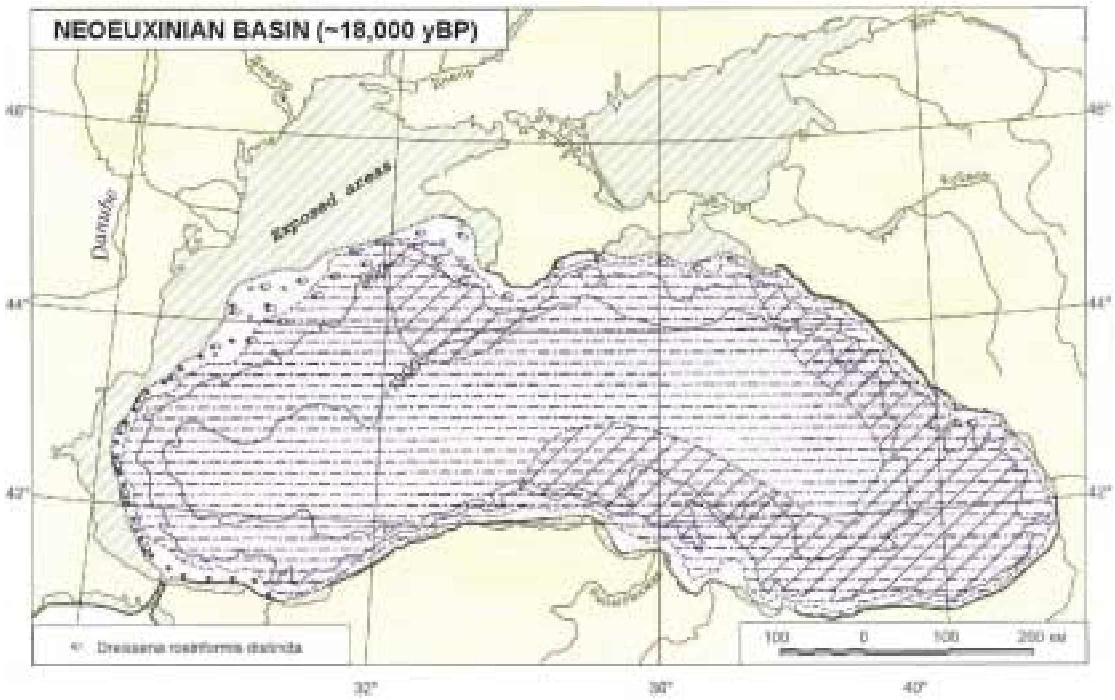

Figure 3: The extension of the Neoeuxinian Basin during the Last Glacial Maximum; the water level was at ~ -100 m and consequently the continental shelf was exposed (Velichko 2002).

Rivers), and as a consequence, the Neoeuxinian water level rose very quickly, reaching and surpassing the Bosphorus sill level by ~12 ky BP. It is now generally believed that, during this phase, there was substantial freshwater outflow from the Neoeuxinian lake into the Aegean Sea through the Bosphorus and Dardanelles Straits. This fresh water discharge has been estimated at about 190 km3/year (Kvasov 1975).

The Neoeuxinian lowstand is marked on the distal edge of the Romanian shelf by a wave-cut terrace that can be followed for about 100 km along the shelf edge at depths between 98 and 115 m **(Figures 3 and 4).** This terrace was cut into prograding deposits that are interpreted as a shelf-perched lowstand wedge formed during a forced regression (Posamentier et al. 1992; Berné et al. 1998).

Our preliminary results indicate that the Neoeuxinian shoreline formed a gulf landward of the Viteaz Canyon. Fluvial incisions on the continental shelf suggest that a large amount of sediment was transported into this gulf, probably controlling the development of the Viteaz Canyon (Winguth *et al.* 2000; Popescu et al. 2001, 2004).

Holocene

When the Mediterranean and Black Seas reached the same level (close to the present-day situation) between 9 and 7.5 ky BP, a two-way water exchange was established, and the transformation of the Neoeuxinian lake back into an anoxic brackish sea began. The maximum rise in the Black Sea (3-5 m above current level) occurred 4-3.5 ky ago during the Sub-boreal (Fedorov 1978). At this time, the so-called “Old Black Sea” terrace was formed. A rapid lowering of the water level to -5 to -8 m followed, and this phase corresponds to Fedorov’s “Phanagorian regression,” coeval with the first Greek colonization of the Black Sea coast. A new, short-lived ingression of the sea to a stand of +1 to +3 m then occurred; this transgression has been called the “Nymphaean” by Fedorov (1978), the

"Istrian" by Bleahu (1963), and the "Dzhemetinian" by Nevesskaya (1965).

By about the 10th century AD, the level of the Black Sea experienced a decline of 1-2 m, then a slow rise, which continues today. Based on studies of the Caucasian coastal zone, Ostrovsky et al. (1977) reconstructed a much more complicated pattern of water-level fluctuations for the Black Sea. In our opinion, however, data from other areas of the Black Sea are not consistent with their results.

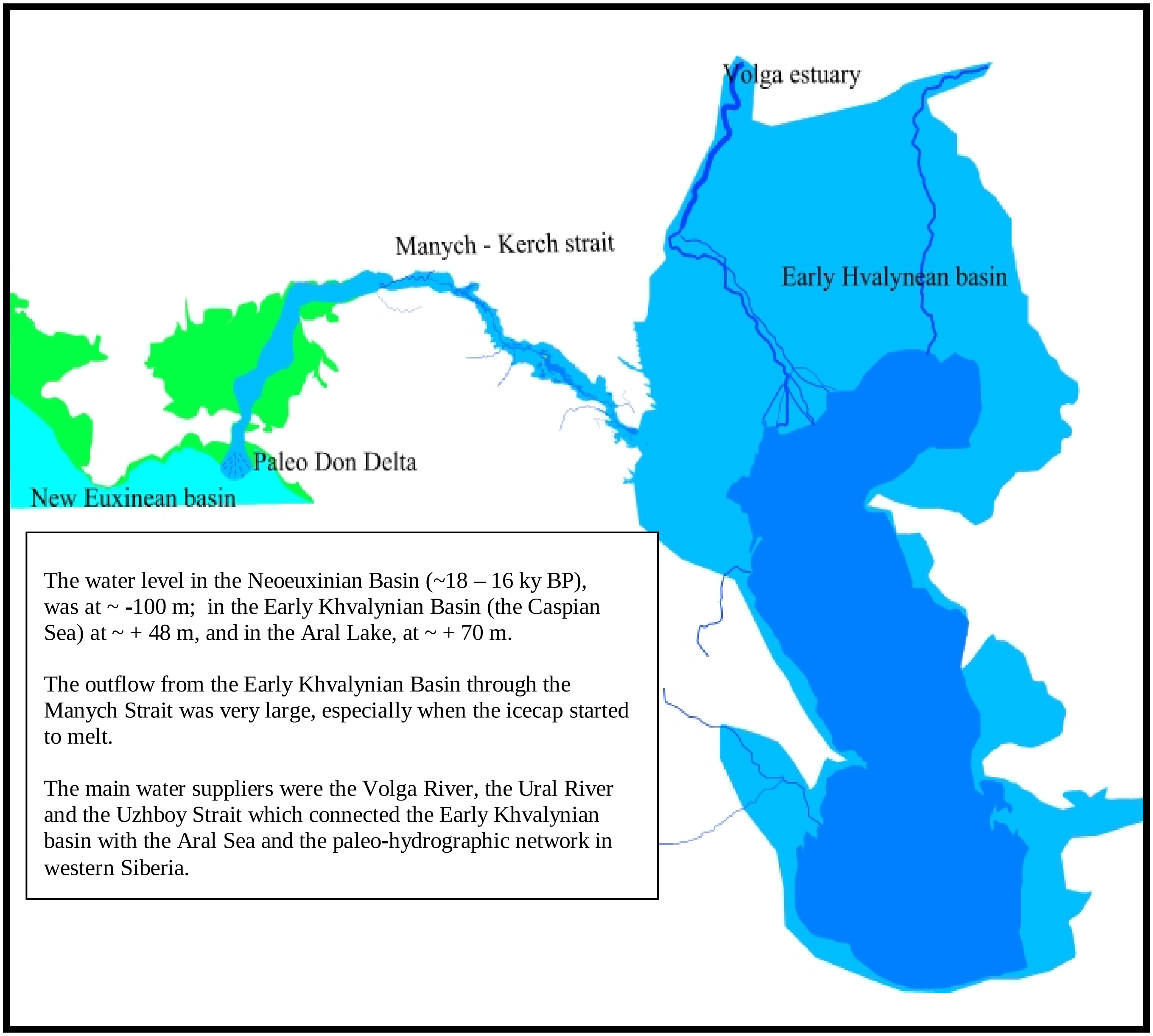

Figure 4: The extension of the Caspian Sea—the Early Khvalynian Basin (~18 – 16 ky BP)—and the location of the Manych –Kerch couloir allowing a large outflow from the Caspian towards the Black Sea, the Neoeuxinian Basin (after Chepalyga, 2003).

The third, present-day phase of scientific studies in the Black Sea

We can now consider the present-day phase of Black Sea studies since the revolutionary hypothesis of Ryan and Pittman was proposed in 1997. This new hypothesis sustained that a rapid and catastrophic marine flooding of the Black Sea by Mediterranean water took place at about 7.5 ky BP (Ryan et al. 1997a, b). According to the authors, the level of the Black Sea was high enough during initial deglaciation for allowing fresh Pontic water to enter the Aegean Sea. By about 12 ky BP, retreat of the ice sheet led to a temporary redirecting of meltwater into the North Sea. Deprived of this incoming meltwater during the cool Younger Dryas beginning

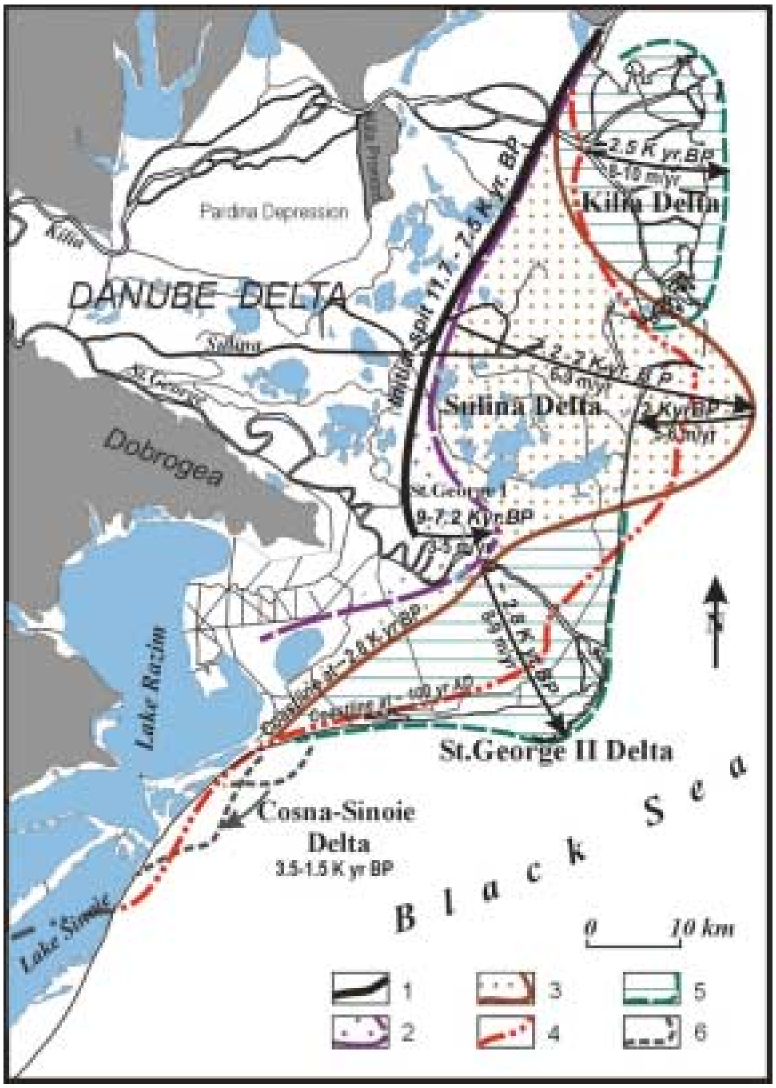

Figure 5: Evolution of the Danube Delta during the Holocene and corresponding coastline changes (after Panin 1997). (1) Initial formation of the Letea-Caraorman spit at 11.7-7.5 ky BP; (2) St. George I Delta, 9.0-7.2 ky BP; (3) Sulina Delta, 7.2-2.0 ky BP; (4) coastline at 100 AD; (5) St. George II and Kilia Deltas, ~2.8 ky BP to the present; and (6) Cosna-Sinoie Delta, 3.5-1.5 ky BP.

~11 ky BP, and under the influences of a drier and windier climate that lasted until 9 ky BP, the Black Sea experienced a new regression to -156 m. At the same time, Mediterranean sea level continued to rise in step with the global ocean. This progressive increase finally reached the height of the Bosphorus sill by 7.15 ky BP and broke through, generating a massive torrent of salt water into the Black Sea basin. In the opinion of Ryan and Pitman (1998:234), the input rate was 200 times greater than the falls at Niagara and produced a surge in the level of the Black Sea approaching 30 to 60 cm per day that filled up the basin in a few years.

Later (Ryan et al. 2003) the flooding moment was shifted to 8,400 y BP based on $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ measurements.

The flood hypothesis has strong arguments, the most important of them being: (1) the presence of an unconformity between the lacustrine and marine deposits (on the northern shelf); (2) ^{14}C dating of the fauna found above this unconformity gave a mean values of 7,150-7,500 yrs BP; (3) below the unconformity, ^{14}C data on shells of Caspian freshwater mollusks *Dreissena rostriformis* extend from 14,700 ±65 to 10,400 ±55 yrs BP.

A deeper Bosphorus sill (~ – 80-85 m), however, might have led to an earlier reconnection with the Mediterranean and a different scenario of Black and Mediterranean Seas water mixing (Major et al. 2002; Ryan et al. 2003). In this scenario the Black Sea water level changes in accordance with the level of the Sea of Marmara, and the Black Sea outflow would remain almost continuous. In the second scenario, with a shallower sill (<-35 m), the Black Sea water level change would depend of the regional water budget being decoupled from the world sea level. This hypothesis is still debated, however.

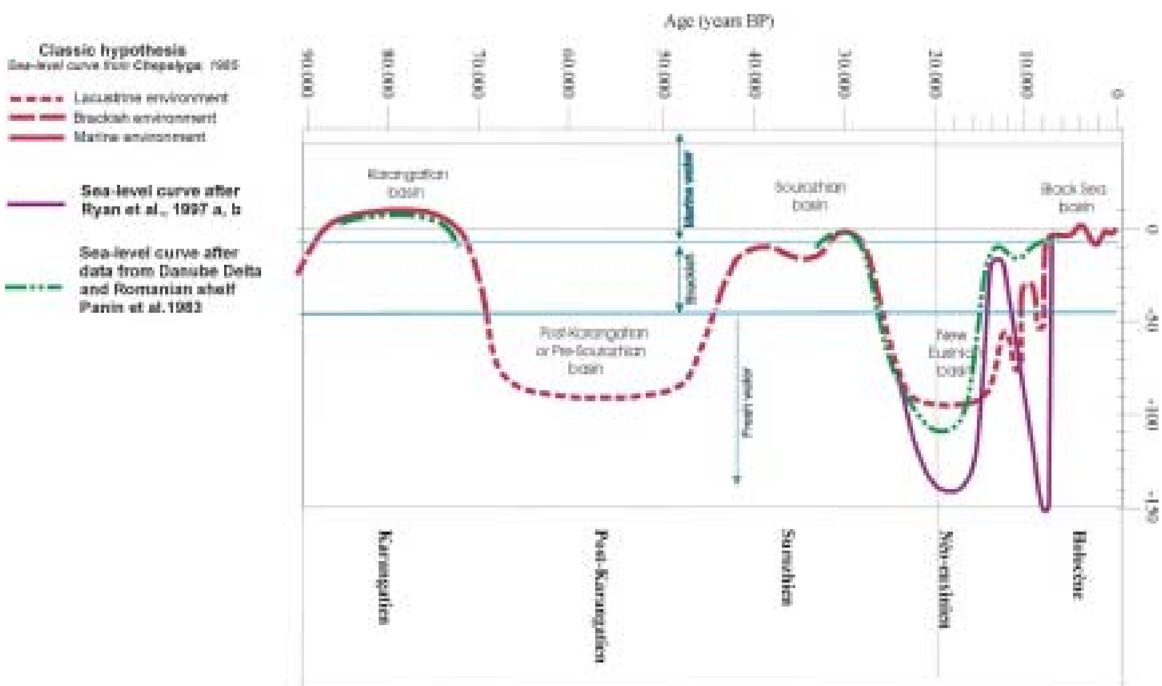

Figure 6: Black Sea level variation according to different authors.

Recent studies conducted on the southern coast of the Black Sea, in the Bosphorus Strait and in the Marmara Sea have led several scientists to propose that the Black Sea was flowing into the Marmara Sea between 9.5 and 7.2 ky BP.

According to Aksu et al. (1999, 2002a, b), there is evidence for a persistent Holocene outflow from the Black Sea to the Eastern Mediterranean, and for a progressive reconnection over the past 12,000 yrs. This outflow into the Marmara is shown by a westward oriented climbing delta on the middle shelf south of the Bosphorus exit, active only from ~10-9,000 yrs BP. At 10-11 ky BP low surface salinities have been recorded in the Marmara Sea and northern Aegean Sea and there is evidence of a sapropel layer forming in the Marmara by 7 ky BP.

The sedimentary evolution of the Danube Delta seems to give strong evidence that argues against both a -156 m lowstand in the Black Sea during the early Holocene and a subsequent catastrophic flooding of the Pontic basin. The main stages of deltaic growth during the Holocene have been identified and dated by corroborating studies in geomorphology, geochemistry, mineralogy, structural and textural analysis, faunal analysis, and ^{14}C dating (Panin et al. 1983; Panin 1983, 1989, 1997, 1999). The phases are identified geographically in **Figure 5**. If the ^{14}C dating is correct, this model suggests a highstand (very close to present day level) by 11.7 ky BP, when the deltaic coastline was represented by the "Letea-Caraorman spit," now located about 25-30 km west of the present shore. From this point onward, no catastrophic event, including a sea-level drop to -156 m, can be recognized within the delta's sedimentary record. The subsequent phases of deltaic growth are fully continuous, and no gaps have been found between the successive stages of lobe progradation (**Figure 6**). New data collected during recent German-Romanian and French-Romanian BLASON projects as well as within the European project ASSEMBLAGE seem to support, at least in part, a reconnection of the two seas after 9 ky BP.

The present review reveals that more extensive studies are needed to fill the remaining gaps in our knowledge before the uncertainties about Late Pleistocene and Holocene sea-level changes and related coastline migration in the Black Sea can be eliminated and the ideas contained within the existing hypotheses can be decisively evaluated.

References

Andrusov, N.I. 1890. "Preliminary report concerning the participation in the 1980 Black Sea deep water expedition." *Comm. Russian Geographical Soc.* 26, 2-5: 398-409 (in Russian).

Andrusov, N.I. 1892. "Some results of the expedition of 'Tchernomoryetz': About the genesis of the hydrogene sulphide in the Black Sea waters." *Comm. Russian Geographical Soc.* 28, 5: 89-94 (in Russian).

____1926. "Paleogeographical maps of the Black Sea region in the Upper Pliocene, Pontic, Tchaudian and in the Euxinian Lake epoch." *Bull. MOIP, Sect. Geology* 4, 3-4: 35-46 (in Russian).

Antipa, Gr. 1915. "Wissenschaftliche und wirtschaftliche Probleme des Donaudeltas." *Anuarul Institutului Geologic al României* VII, 1: 88. Bucuresti.

____1941. *Marea Neagrã. Vol. 1: Oceanografia, bionomia si biologia generalã a Mãrii Negre (La Mer Noire. Vol.1 : Océanographie, bionomie et biologie générale de la Mer Noire).* Publicatia Fondului Vasile Adamachi, T.X, LV: 313. Acad. Românã, Bucuresti.

Arkhangelskyi, A. D. 1927. "On the Black sea sediments and their importance in the knowledge of sedimentary deposits." *Bull MOIP, Sect. Geology* 5, 3-4: 199-264 (in Russian).

____1928. "The Black Sea map and cross-sections in the sediments of the sea." *Bull MOIP, Sect. Geology* 6, 1: 77-108 (in Russian).

Arkhangelskyi, A.D., and N. M. Strakhov. 1932. "The geological structure of the Black Sea." *Bull MOIP, Sect. Geology* 10, 1: 3-104 (in Russian).

____1938. *The geological structure of the Black Sea and its evolution.* Moscow-Leningrad: Ed. Acad. Sc. USSR (in Russian).

Artyushkov, E.V. 1992. "Role of crustal stretching on subsidence of continental crust." *Tectonophysics,* 215, 187–207.

Balkas, T., G. Dechev, R. Mihnea, O. Serbanescu, and U. Unlüata. 1990. "State of marine environment in the Black Sea region." *UNEP Regional Seas Report and Studies* 124, UNEP.

Barkovskaya, M.G. 1961. "Regularities in the distribution of bottom sediments on the shelf of the Soviet shores of the Black Sea." *Trudy Inst. Oceanology Acad. Sc. USSR* 53, 123-148 (in Russian).

Berné, S., G. Lericolais, T. Marsset, J.-F. Bourillet, and M. De Batist. 1998. "Erosional offshore sand ridges and lowstand shorefaces: examples from tide- and wave-dominated environments of France." *Journal of Sedimentary Research* 68: 4, 540-555.

Bleahu, M. 1963. "Observatii asupra evolutiei zonei Histria în ultimile trei milenii." *Probleme Geogr.* IX: 45-56. Bucuresti (in Romanian).

Bondar, C., I. State, D. Cernea, and E. Harabagiu. 1991. "Water flow and sediment transport o the Danube at its outlet into the Black Sea." *Meteorology and Hydrology* 21: 21-25. Bucharest.

Brãtescu, C. 1922. Delta Dunãrii (geneza si evolutia ei morfologicã). *Bul. Soc. Rom. Geogr.* 41 (in Romanian).

____1942. "Oscilatiile de nivel ale apelor si bazinului Mãrii Negre în Cuaternar." *Bul. Soc. Rom. Geogr.*61: 1-112 (in Romanian).

Chepalyga, A. L. 1984. "Inland Sea Basins." In: *Late Quaternary Environments of the Soviet Union*, A. A. Velichko, ed., 229-247. Minneapolis: University of Minnesota Press.

____2003. "Late glacial Great Flood in the Black Sea and Caspian Sea." GSA Annual Meeting and Exposition, November 2-5, 2003, Seattle, USA, p. 460.

____2006. "Late Glacial great flood in the Ponto-Caspian basin." In *The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement.* Edited by V. Yanko-Hombach, A. S. Gilbert, N. Panin, and P. M. Dolukhanov. Springer, in press.

Ciocârdel, R. 1937. "Influence des vents sur l'évolution du Delta du Danube." *C. R. Acad. Sc. Roum.* 1, 5-6 : 422-425.

____1937. "La circulation générale des eaux de la Mer Noire." *Bull. Soc. Rom. Geogr.* 56 : 216-229.

Demirbag, E., E. Gökasan, F. Y. Oktay, M. Simsek, and H. Yuce. 1999. "The last sea level changes in the Black Sea: evidence from the seismic data." *Marine Geology* 157: 249-265.

Deuser, W. G. 1972. "Late Pleistocene and Holocene history of the Black Sea as indicated by stable-isotope studies." *Jour. Geophys. Res.* 77: 6, 1071-1077.

Dinu, C., H. K. Wong, D. Tambrea, and L. Matenco. 2005. "Stratigraphic and structural characteristics of the Romanian Black Sea shelf." In *Tectonophysics* Amsterdam: The Netherlands.

Emelianov, E. M., and K. M. Shimkus. 1962. "To the problem of variability of deep-water sediments in the Black Sea." *Okeanologiya Acad. Sc. USSR* 2, 6, 1041-1049 (in Russian).

Fedorov, P. V. 1978. "The Pleistocene of the Ponto-Caspian Region." *Trudy Geol. Inst. Acad. Sc. USSR* 168. Moscow: Nauka, Moscow (in Russian).

Finetti, I., G. Bricchi, A. Del Ben, M. Papin, and Z. Xuan. 1988. "Geophysical study of the Black Sea area." *Bull. Geofis. Teor. Appl.* 30: 117–118, 197–234.

Goncharov V. P. 1958. "New data on the Black Sea bottom relief." *Dokl. Acad. Sc USSR* 121: 5, 830-833 (in Russian).

Görür, N., 1988. "Timing of opening of the Black Sea basin." *Tectonophysics* 147: 242– 262.

Görür N., M. N. C., O. Emre, B. Alpar, M. Sakinç, Y. Islamoglu, Algan, O. Erkal, M. Keçer, R. Akkok, and G. Karlik. 2001. "Is the abrupt drowning of the Black Sea shelf at 7150 yr BP a myth?" *Marine Geology* 176: 65-73.

Ivanov, S. N. 1927. "Surface currents in the Black Sea." *Morski sgovor.* 4: 4, 8-10 (in Bulgarian).

____1927. "Underwater currents in the Black Sea" *Morski sgovor.* 4: 5, 7-10 (in Bulgarian).

Kvasov, D. D. 1975. *The Late Quaternary History of the Large Lakes and Inland Seas of the Eastern Europe*, 278. Moscow: Nauka (in Russian).

Lepsi, I. 1942. "Materiale pentru studiul Deltei Dunãrii. Partea I-a." *Buletinul Muzeului Regional Bassarabia* 10: 94-325. Chisinãu (in Romanian).

Letouzey, J., B. Biju-Duval, A. Dorkel, R. Gonnard, K. Krischev, L. Montadert, and O. Sungurlu. 1977. "The Black Sea: a marginal basin: geophysical and geological data." In *Structural History of the Mediterranean Basins.* B. Biju-Duval, and L. Montadert, eds., 363– 376. Paris: L. Editions Technip.

Major, C., W. Ryan, G. Lericolais, and I. Hajdas. 2002. "Constraints on Black Sea outflow to the Sea of Marmara during the last glacial-interglacial transition." *Marine Geology* 190, 1-2: 19-34.

Malovitskiy Ya. P., and Yu. P Neprochnov. 1966. "Comparison of the seismic and gravimetric data on the crustal structure of the Black sea basin." In *Structure of the Black Sea Basin.* V.A. Magnitskyi, *et al.*, eds., 5-16. Mosow: Nauka.

Malovitskiy Ya. P., Yu. P., Neprochnov, I. A. Garkalenko, E. A. Starskinov, K.G. Milashina, Ya. Momornaiam, L.N. Ryunov, B.V. Klolopov, and V. V. Sedov. 1969. "Structure of the Earth's crust in the western part of the Black Sea." *Dokl. Acad. Sc. USSR* 186: 4, 905-907 (in Russian).

Malovitskiy Ya. P., and Yu. P. Neprochnov, eds. 1972. *Structure of the western part of the Black Sea depression.* Moscow: Nauka (in Russian).

Manheim, F. T., and K. M. Chan. 1974. "Interstitial waters of the Black Sea Sediments." In *The Black Sea: Geology, Chemistry, and Biology.* E.T Degens, and D.A. Ross, eds. AAPG Memoir 20: 155-182.

Moskalenko V. N., and Ya. P. Malovitskyi. 1974. "Results of deep seismic investigations on a trans-meridional cross-section through the Sea of Azov and the Black Sea." *Izv. Acad. Sc. USSR* 9: 23-31 (in Russian).

Muratov, M.V. 1951. "History of the Black Sea basin in relation to the development of surrounding areas." *Bull. MOIP, Section Geology,* NS 26: 1, 7-34 (in Russian).

Muratov, M.V., and Yu. P Neprochnov, 1967. "Structure of the Black Sea depression and its origin." *Bull. MOIP, Section Geol.* 42: 5, 40-49 (in Russian).

Neprochnov, Yu. P. 1958. "The results of seismic investigation in the Black sea in the neighborhood of Anapa." *Dokl. Acad. Sc. USSR* 121: 6, 1001-1004 (in Russian).

____1960. "The deep structure of Earth crust bellow the Black Sea based on seismic data." *Bull. MOIP., Section Geol.* 35: 4, 30-36 (in Russian).

____1980. *Geological history of the Black Sea reconstructed from deep-sea drilling data*. Moscow: Nauka (in Russian).

Nevesskaya, L. A. 1965. *Late Qaternary Molluscs of the Black Sea, thei Systematics and Ecology*. Trudy Inst. Paleontology, Acad. Sc., T. 105. Moscow: Nauka (in Russian).

____1970. "On the classification of enclosed and semi-enclosed basins based on their fauna characteristics." In *Modern Problems of the Paleontology,* D. B. Obruchev and V. N. Shimanskiy., eds., 258-278. Moscow: Nauka (in Russian).

Nevesskiy, E. N. 1961. "Postglacial transgressions of the Black Sea." *Dokl. Acad. Sc. USSR* 137: 3, 667-670 (in Russian).

_____1967. *Processes of sediment formation in the near-shore zone of the sea*. Moscow: Nauka (in Russian).

Nikishin, A. M., P.A. Ziegler, D.I. Panov, B.P Nazarevich, M. F. Brunet, R.A. Stephenson, S.N. Bolotov, M.V. Korotaev, and P.L. Tikhomirov. 2001. "Mesozoic and Cainozoic evolution of the Scythian Platform–Black Sea–Caucasus domain." In *Peri-Tethyan Rift/Wrench Basins and Passive Margins*. H. K. Ziegler, W. Cavazza, A. F. Robertson, and S. Crasquin, eds. Peri-Tethys Memoir 6: 295–346. Paris: Mem. Mus. Natl. Hist.

Ostrovskiy, A. B., Ya. A. Izmailov, and A. P. Shcheglov. 1977. "New data on stratigraphy and geochronology of Pleistocene marine terraces of the Caucasian Black Sea coast and of the Kerch-Taman region." In *Paleogeography and the Deposits of Southern Seas of the USSR*, 61-68. Moscow: Nauka.(in Russian).

Özsoy, E., M. A. Latif, S. Tuğrul, and Ü. Ünlüata. 1995. "Exchanges with the Mediterranean, fluxes and boundary mixing processes in the Black Sea." In *Mediterranean Tributary Seas* F. Briand, ed. Bulletin de l'Institut Océanographique Monaco, Special No. 15, CIESM Science Series 1: 1-25.

Panin N. 1983. "Black Sea coastline changes in the last 10,000 years. A new attempt at identifying the Danube mouth as described by the ancients." *Dacia*, N.S., XXVII: 1-2, 175-184. Bucuresti.

_____1989. "Danube Delta Genesis, evolution, sedimentology." *Rev. Roumaine Géol. Géophys. Géogr., Serie Géographie* 33, 25-36. Bucuresti.

____1996. Danube Delta. "Genesis, evolution geological setting and sedimentology." *Geo-Eco-Marina* 1: 7-23, Bucharest.

____1999. *Danube Delta, Geology, Sedimentology, Evolution.* Paris : Association des Sédimentologistes Français, Maison de la Géologie.

Panin, N., S. Panin, N. Herz, and J. E. Noakes. 1983. "Radiocarbon dating of Danube Delta deposits." *Quaternary Research* 19: 249-255.Washington.

Popescu, I., G. Lericolais, N. Panin, H. K. Wong, and L. Droz. 2001. "Late Quaternary channel avulsions on the Danube deep-sea fan, Black Sea." *Marine Geology* 179: 25-37.

Popov, G. I. 1975. *The Pleistocene of the Black Sea. Caspian straits*. Moscow: Nauka (in Russian).

Posamentier, H. W., G. P. Allen, D. P. James, and M. Tesson. 1992. "Forced regressions in a sequence stratigraphic framework: concepts, examples and exploration significance." *AAPG Bull.* 76: 1687-1709.

Robinson, A.G., J. H. Rudat, C. J. Banks, and R.L.F. Wiles. 1996. "Petroleum geology of the Black Sea. Mar." *Pet. Geol*. 13: 195–223.

Ross, D. A., and E.T. Degens. 1974. "Recent sediments of the Black Sea." In *The Black Sea: Geology, Chemistry, and Biology,* E. T. Degens, and D. A. Ross, eds. AAPG Memoir 20: 183-199.

Ryan, W. B. F., W.C. Pitman, C.O. Major, K. Shimkus, V. Moskalenko, G. A. Jones, P. Dimitrov, N. Gorur, M. Sakinç, and H. Yuce. 1997. "An abrupt drowning of the Black Sea shelf." *Marine Geology* 138: 119-126.

Ryan, W. B. F., W. C. Pitman, C. O. Major, K. Shimkus, V. Moskalenko, G. A. Jones, P. Dimitrov, N. Gorur, M. Sakinç, and H. I. Seyir. 1997. "An abrupt drowning of the Black Sea shelf at 7,5 kyr BP." *Geo-Eco-Marina* 2: 115-126.

Ryan, W. B. F., C.O. Major, G. Lericolais, and S. L. Goldstein. 2003. "Catastrophic flooding of the Black Sea." *Annu. Rev. Earth Planet. Sci.* 31, 525-554.

Shcherbakov, F.A., P. N. Kuprin, L. I. Potapova, A. S. Polyakov, E. K. Zabelina, and V. M. Sorokin 1978. *Sedimentation on the continental shelf of the Black Sea*. Moscow: Nauka (in Russian).

Shcherbakov, F.A., E. V. Koreneva, and E. K. Zabelina. 1979. "Late Quaternary Stratigraphy of the Black Sea." In *Late Quaternary History and sedimentogenesis of Marginal and Inland seas*. Moscow: Nauka (in Russian).

Shokalskyi, Yu. M. 1928. “General description of the Black Sea relief on the base of research carried out by oceanographic expeditions in 1924 1927.” *Proceed. 2-nd Congress of Hydrology of USSR*, 337-340. Leningrad (in Russian).

Shnyukov, E. F., and N. N. Trashchuk. 1976. “Karangatian deposits on the southeastern slope of the Kerch Peninsula.” *Dokl. Acad. Sc. Ukrainian SSR*, Ser. B, 12: 1077-1080 (in Russian).

Stanley D. J., and Ch. Blanpied. 1980. “Late Quaternary water exchange between the eastern Mediterranean and Black Sea.” *Nature* 285: 537 541.

____1981. “The Sea of Marmara, late Quaternary lithofacies and palaeoceanographic exchange between eastern Mediterranean and the Black Sea.” *Marine geology and geophysics*. Rapp. 27th Congress of CIESM 27: 8, 57.

Strakhov, N. M. 1954. “Sedimentogenesis in the Black Sea.” In *Genesis of sediments in modern basins*, 81-136. Moscow: Academy of Sc. USSR (in Russian).

_____1963. “Some characteristics of diagenesis of the Black Sea deposits.” *Lithology and mineral resources* 1: 3-21 (in Russian).

Trashchuk, N. N., and V. A. Bolivets. 1978. “New area of occurrence of Karangatian deposits on the northwestern Black Sea coasts.” *Dokl. Acad. Sc. Ukrainian SSR*, Ser. B, 8: 699-702 (in Russian).

Yaranov, D. 1939. “Correlation of the Quaternary of the Balcan peninsula, the Black Sea, of the Mediterranean Sea and of the Atlantic coasts of the Euro-African bloc.” *God. SU.* 35: 187-204.

Zonenshain, L. P., and X. Le Pichon. 1986. “Deep basins of the Black Sea and Caspian Sea as remnants of Mesozoic back-arc basins.” *Tectonophysics* 123: 181–212.

Zhuze, A. P., and V. V. Mukhina. 1980. “Stratigraphy of the Upper Cenozoic sediments.” In *The Geologic History of the Black Sea based on Results of Deep-ocean Drilling*, 62-64. Moscow: Nauka (in Russian).

Wong, H. K., N. Panin, C. Dinu, P. Georgescu, and C. Rahn. 1994. “Morphology and post-Chaudian (Late Pleistocene) evolution of the submarine Danube fan complex.” *Terra Nova* 6, 5: 502–511.

Winguth, C., H. K. Wong, N. Panin, C. Dinu, P. Georgescu, G. Ungureanu, V. V. Krugliakov, and V., Podshuveit. 2000. “Upper Quaternary sea level history and sedimentation in the northwestern Black Sea.” *Marine Geology* 167, 1-2: 127-146.

Nicolae Panin is a specialist in Marine Geology and Sedimentology who earned his Ph.D. at the University of Paris VI in 1974. His research on the Danube Delta and the Black Sea focuses on coastline changes during Upper Pleistocene and Holocene. Prof. Panin is Director General and Corresponding Member of the Romanian Academy, and is President of the Romanian Committee of IAPSO (International Association of Physical Sciences of the Oceans). Honors for his work include “Officier of Palmes Académiques”; Cavalier of Romanian Order “Honest Service”; and the “Grigore Cobalcescu” prize of the Romanian Academy. He is a board member of the Romanian Society of Geologists, and is an active member of the National IGBP Committee in Romania; the National focal point for LOICZ Core Project; the National Committee of Geophysics and Geodesy; the Romanian Ecological Society, and the National Committee for the Coastal Zone. He is the author of more than eighty-five publications and one hundred fifty geological studies and reports.

Claudia Strechie is a geologist at the National Institute of Marine Geology and Geo-ecology *GEOECOMAR* in Bucharest, Romania, and is a Ph.D. student at Université de Paris-Sud XI, Orsay, France. Her Ph.D. thesis focuses on the north-western Black Sea and deals with organic matter in sediments, magnetic mineralogy and environmental changes during the last 30 k yr. She is the author of six scientific papers.