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The Black Sea Flood Question
Changes in Coastline, Climate and Human Settlement

Stimulated by “Noah’s Flood Hypothesis” proposed by W. Ryan and W. Pitman in which a catastrophic inundation of the Pontic basin was linked to the biblical story, leading experts in Black Sea research (including oceanography, marine geology, paleoclimate, paleoenvironment, archaeology, and linguistic spread) provide overviews of their data and interpretations obtained through empirical scientific approaches. Among the contributors are many East European scientists whose work has rarely been published outside of Cyrillic. Each of the 35 papers marshals its own evidence for or against the flood hypothesis. No summary or overall resolution to the flood question is presented, but instead access is provided to a broad range of interdisciplinary information that crosses previously impenetrable language barriers so that new work in the region can proceed with the benefit of a wider frame of reference. The three fundamental scenarios describing the late glacial to Holocene rise in the level of the Black Sea—catastrophic, gradual, and oscillating—are presented in the early pages, with the succeeding papers organized by geographic sector: northern (Ukraine), western (Moldova, Romania, and Bulgaria), southern (Turkey), and eastern (Georgia and Russia), as well as three papers on the Mediterranean. The volume thus brings together eastern and western scholarship to share research findings and perspectives on a controversial subject. In addition, appendices are included containing some 600 radiocarbon dates from the Pontic region obtained by USSR and western laboratories.

Audience

Scientists, researchers and students in geology, climatology, archeology, oceanography, linguistics, history, geography as well as Black Sea specialists.

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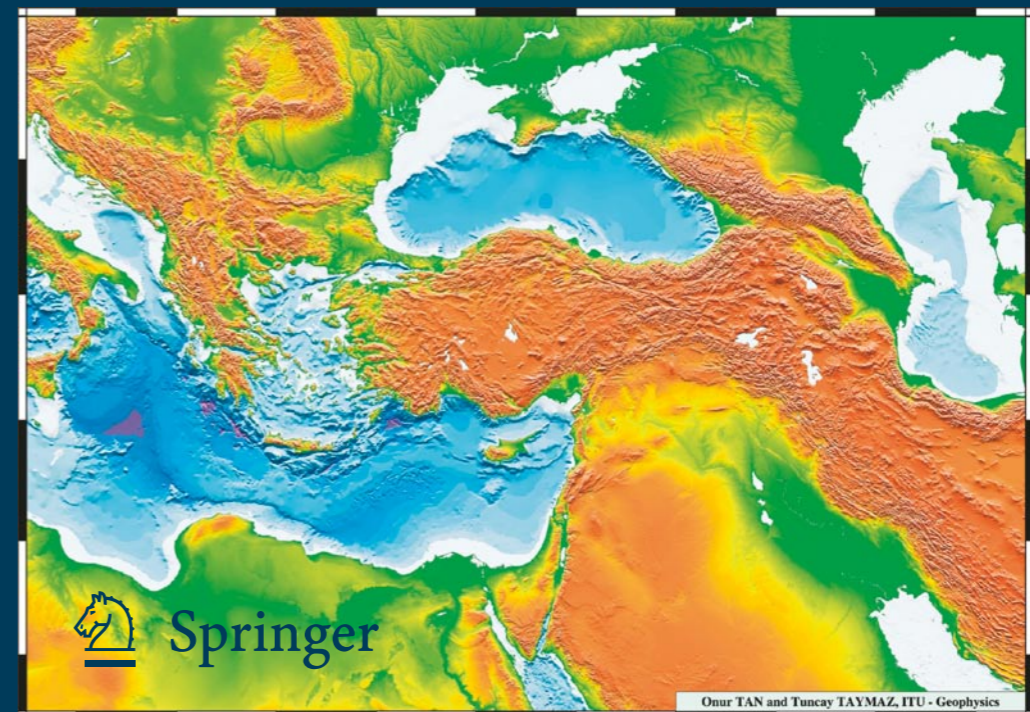


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*Changes in Coastline, Climate
and Human Settlement*



Onur TAN and Tuncay TAYMAZ, ITU - Geophysics

CONTROVERSY OVER NOAH'S FLOOD IN THE BLACK SEA: GEOLOGICAL AND FORAMINIFERAL EVIDENCE FROM THE SHELF

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Abstract:

This paper reviews the geological and foraminiferal evidence collected during the course of extensive paleoceanographic and geological studies in the Black Sea, conducted largely by Eastern European scientists since 1970. Though this research has a long history, its most recent focus has been examining the “Noah’s Flood” Hypothesis proposed by William Ryan and Walter Pitman, which proposes an abrupt and catastrophic flooding of the Pontic basin in the early Holocene. Specifically, the hypothesis states that the Black Sea was a freshwater lake with a surface about 140 m below present sea level between 14.7 and 10 ky BP, while at 7.2 ky BP (initial hypothesis) or 8.4 ky BP (modified hypothesis), the lake was rapidly inundated by Mediterranean water flowing through the Bosphorus, which forced the dispersion of early Neolithic people into the interior of Europe. The hypothesis further suggests that the event formed the historical basis for the biblical legend of Noah’s Flood. This paper considers the period between 28 and 7 ky BP, and three crucial points are discussed: (1) the level and salinity of the Neoeuxinian lake; (2) the re-colonization of the Black Sea by Mediterranean immigrants—and by implication sea level and salinity changes due to connection/isolation between adjacent basins; and (3) an alternative to the Bosphorus as an inter-basin conduit. It will be shown that, prior to the moderately warm Würm Paudorf (Middle Weichselian) Pleniglacial (prior to *ca.* 27 ky BP), a brackish Tarkhankutian basin was connected with the Sea of Marmara. At the Last Glacial Maximum (LGM), this connection was interrupted, and the level of the Tarkhankutian basin dropped to about –100 m, transforming this basin into a closed Early Neoeuxinian lake. In the warming climate of *ca.* 17 ky BP, a massive water discharge originating most likely from the Caspian Sea and arriving via the Manych Spillway increased the level of the Late Neoeuxinian lake to about –20 m. Excess semi-fresh to brackish water must have spilled into the Sea of Marmara and from there into the Mediterranean. During the short climatic cooling episode of the Younger Dryas, the level of the lake dropped from –20 to –43 m and then rose again to about –20 m. After *ca.* 10

ky BP, the level of the Black Sea never again dropped below the –40 m isobath, nor exhibited a maximum amplitude of fluctuation greater than approximately 20 m. At *ca.* 9.5 ky BP, the water level reached –20 m again and Mediterranean water with its inhabiting organisms entered the Late Neoeuxinian lake. This re-colonization of the Black Sea occurred in an oscillating manner. It was slow at the beginning, becoming most prominent by 7.0 ky BP. The connection between adjacent basins was probably not through the Bosphorus Strait but via an alternative route, e.g., that following Izmit Bay–Sapanca Lake–Sakarya River. On average, sea level rose gradually, but in an oscillating manner, to its present level, and perhaps slightly higher, averaging 3 cm per 100 years but certainly not 15 cm per day (almost 55 m per year) as postulated by the “Noah’s Flood” hypothesis. A rate of sea-level increase of 3 cm per 100 years would not be noticed by local inhabitants and would not have accelerated their dispersion into the interior of Europe. This brings us to the conclusion that “Noah’s Flood” in the Black Sea is a contemporary legend.

Key words: Black Sea, Late Pleistocene, Holocene, sea level, flood, salinity, benthic foraminifera, re-colonization

1. INTRODUCTION

Whether it is referred to as Noah’s Flood or the Great Flood, this disastrous event is so deeply rooted in the collective memory of humankind that it is reported in the Epic of Gilgamesh (Keller 1981) and other similarly ancient texts—e.g., the Epic of Atrahasis (Lambert and Millard 1969) and the Epic of Ziusudra (Best 1999)—and it is reflected in several world religions. It comes as no surprise that scientists have a strong interest in the historical reality, if any, behind the story of Noah’s Flood.

Although the story likely originated in Mesopotamia, and the Epic of Gilgamesh was recorded at the northwestern end of the Persian Gulf (King 1918; Magnusson 1977; Keller 1981), Ryan *et al.* (1997) locate the Great Flood in the region of the Black Sea, quite far from Mesopotamia, on the other side of a large mountain chain. Based upon 350 km of high-resolution seismic profiles, a few short sediment cores obtained at water depths of –49 to –140 m within a fairly restricted area of the Black Sea’s northwestern shelf, and ¹⁴C dates on *Dreissena* shells (all radiocarbon ages in this paper are uncorrected), they concluded that the Black Sea was a freshwater Neoeuxinian lake with a level 140 m below present between 14.7 and 10.0 ky BP. According to their Flood Hypothesis, in the course of the post-glacial transgression, at 7.2 ky BP (dates based on *Mytilus galloprovincialis*), saltwater broke through a barrier within the narrow Bosphorus Strait and funneled through this channel at a speed of 50 mph, hitting the Black Sea at 200 times the force of Niagara Falls, thereby rapidly refilling

the lake and increasing its salinity. A single, structureless and uniform layer of jelly-like sapropel was formed, draping the undulating surface of the Neoeuxinian unconformity. At a rate of 15 cm per day, the sea level rose 100 m within two years, catastrophically submerging more than 100,000 km² of exposed shelf and flooding coastal farms. This catastrophe accelerated the dispersion of early Neolithic foragers and farmers into the interior of Europe, forming the historical basis for the biblical story of Noah's Flood (Ryan and Pitman 1998).

This Flood Hypothesis spurred tremendous interest by the public, the scientific community, and the media—e.g., BBC (1996); *New Scientist* (Mestel 1997; Hecht 2003); *New York Times* (Wilford 1999, 2001); *Scientific American* (Morrison and Morrison 1999); *Washington Post* (Gugliotta 1999, 2000); *Der Spiegel* (2000); *National Geographic* (Ballard 2001); *GSA Today* (Aksu *et al.* 2002a); *Frankfurter Allgemeine Zeitung* (2003)—encouraging a new wave of research in the Black Sea-Mediterranean Corridor.

In support of the Flood Hypothesis, Ballard *et al.* (2000), Lericolais (2001, 2003, 2004), Lericolais *et al.* (this volume), and Algan *et al.* (2003, this volume) described a submerged coastline with wave-cut terraces, coastal dunes, and drowned beaches, enriched with *Dreissena* at various depths, and ranging from –90 m at the Romanian shelf to –155 m at the Turkish shelf near Sinop. This coastline was overlapped by a uniform drape of mud containing *Mytilus galloprovincialis*. The age of the *Dreissena* samples ranges between 24.2 and 7.9 BP (Major 2002), in particular, 11.8–7.9 ky BP (Algan *et al.* this volume), 10.2–8.6 ky BP (Lericolais *et al.*, this volume), and 15.5–7.4 ky BP (Ballard *et al.* 2000). The age of *M. galloprovincialis* varies between 7.8 and 4.0 ky BP, in particular, 7.8–6.6 ky BP (Lericolais *et al.*, this volume), 7.5–4.0 ky BP (Ballard *et al.* 2000), and 7.4–5.9 ky BP (Algan *et al.*, this volume).

Görür *et al.* (2001) posed a contradiction to the Flood Hypothesis. After studying the coastal plain and offshore sedimentary successions on the southern Black Sea coast around the mouth of the Sakarya River, about 130 km east of the Bosphorus, they suggested that the water level of the lake rose gradually from some time prior to 8.0 ky BP to 7.2 ky BP, when it attained a surface level of –18 m, and the most recent influx of Mediterranean water began. Further evidence for a higher level within the Black Sea in the early Holocene has been proposed by Aksu *et al.* (1999, 2002a, b), who suggested that the Black Sea was higher than the Sea of Marmara and has been flowing out into the world ocean unabated since 10.5 ky BP. In so doing, it prevented the establishment of a two-way flow in the Bosphorus Strait and delayed the salination of the Black Sea and the immigration of Mediterranean organisms northward until 8.5 ky BP (the Outflow Hypothesis of Aksu *et al.* 2002a, b). This interpretation is based on physical sedimentological evidence from bedform asymmetry and, directly south of the Bosphorus exit, a climbing mid-shelf delta in the Sea of Marmara that was

formed by the Bosphorus outflow (Aksu *et al.* 1999; Aksu *et al.* 2002a; Hiscott *et al.* 2002). Similarly, Çağatay *et al.* (2000) proposed that the formation of a sapropel layer in the deep Marmara Sea during the period 10.6–6.4 ky BP reflects water column stratification and seafloor anoxia, which they attribute to prolonged freshwater influx from a Black Sea whose surface at that time must have been at or above the Bosphorus sill depth of –35 m.

To address these arguments, the Flood Hypothesis was eventually modified. The initially formulated lowstand of –140 m at 14.7–10.0 ky BP and the abrupt drowning of the Black Sea shelf at 7.2 ky BP were replaced by two lowstands and two floods (Ryan *et al.* 2003). The first lowstand at –120 m occurred between 13.4 and 11 ky BP and was followed by the first flooding event, which increased the level of the Neoeuxinian lake from –120 m to –30 m at 11.0–10.0 ky BP (i.e., the Younger Dryas), when the surface of the lake rose well above that of the contemporaneous global ocean (Siddall *et al.* 2003). The level of the Neoeuxinian lake during the Younger Dryas was explained by decoupling the lake from the world ocean by a shallow (less than 30 m) sill in the Bosphorus under moist climatic conditions. The second lowstand (–95 m) of the Neoeuxinian lake occurred at 10–8.4 ky BP due to evaporation of the isolated lake under arid conditions. At 8.4 ky BP, Mediterranean water topped the Bosphorus sill and flooded the Neoeuxinian lake. Simultaneously with the world sea-level rise, the second flood raised the surface level from –95 to –30 m and replaced the relict Caspian biota with Mediterranean organisms. The mid-shelf climbing delta at the southern Bosphorus exit was attributed to a small stream, the Kurbağalıdere River (Ryan *et al.* 2004, this volume).

Hiscott *et al.* (this volume) criticized this modified Flood Hypothesis, arguing that modern sediment discharge from the Kurbağalıdere River is so small that it would take about 100,000 years to construct the delta, a time span clearly at odds with the duration of delta progradation (about 1000 years from *ca.* 10–9 ky BP). They insist that the Black Sea has been at or above the Bosphorus sill depth and flowing into the world ocean uninterrupted since 10.5 ky BP, making flooding of the basin impossible.

As an alternative to both hypotheses, Kerey *et al.* (2004), and Yanko-Hombach *et al.* (2004) argue that the Bosphorus Strait is too young to have played a cataclysmic role in water exchange before *ca.* 5.5 ky BP, and an alternative route between the basins must be considered.

The western scientists have based their hypotheses largely on material obtained outside the Black Sea (e.g., Aksu *et al.* 2002a, b) or on limited data from the outer shelf (e.g., Ryan *et al.* 1997). The abundant scientific data recovered directly from the Black Sea by USSR and Former Eastern Bloc scientists (among them, Andrusov 1918; Arkhangel'sky and Strakhov 1938; Nevesskaya and Nevessky 1961; Nevesskaya 1963, 1965; Il'ina 1966; Nevessky 1967; Semenenko and Kovalyukh 1973; Tsereteli 1975; Shilik 1977; Fedorov

1978; Shcherbakov *et al.* 1978; Dimitrov *et al.* 1979; Komarov *et al.* 1979; Malovitsky *et al.* 1979; Kuprin *et al.* 1980; Balabanov *et al.* 1981; Shnyukov 1981, 1982; Popov 1983; Shcherbakov 1983; Shnyukov 1983, 1984a, b; Kuprin *et al.* 1985; Shnyukov 1985, 1987; Gozhik *et al.* 1987; Yanko and Troitskaya 1987; Balabanov and Izmailov 1988; Panin 1989; Yanko 1989, 1990a; Yanko and Gramova 1990; Khrishev and Georgiev 1991; Gorshkov *et al.* 1993; Glebov *et al.* 1996; Mel'nik 1997; Shilik 1997; Stanko 1997; Kuprin 2002) have unfortunately been largely ignored in the global scientific debate, apparently due to language barriers and the lack of west-east scientific dialogue.

By 1997, a large (1:500,000 to 1:10,000) marine geological survey of the Black Sea shelf had been nearly completed (e.g., Kuprin *et al.* 1980; Balabanov *et al.* 1981; Panin 1983; Shnyukov 1981, 1982, 1983, 1984a, b, 1985; Esin *et al.* 1985; Shnyukov 1987; Dmitrienko *et al.* 1988; Yanko-Hombach 2003). As part of these projects, thousands of cores and tens of thousands of kilometers of high-resolution seismic profiles across the Black Sea shelf from the northern exit of the Bosphorus Strait on the west to the city of Batumi on the east (Figure 1) had been collected and studied in a multi-disciplinary effort.

A methodology for the Black Sea shelf investigation had been developed (Shnyukov 1982), and the paleoclimatic (e.g., Komarov *et al.* 1979), tectonic (e.g., Shnyukov 1985), and sedimentary (e.g., Fedorov 1978; Kuprin *et al.* 1980) history of the basin had been investigated. A high-resolution Quaternary biostratigraphy based upon molluscs (Nevesskaya 1965; Fedorov 1978) and foraminifera (Yanko 1989, 1990; Yanko and Gramova 1990), all supported by hundreds of radiocarbon assays (Appendices 1 and 2, this volume), had been established, and sea-level dynamics had been reconstructed (e.g., Tsereteli 1975; Shilik 1977; Balabanov *et al.* 1981; Shilik 1997; Balabanov, this volume; Chepalyga, this volume).

This paper focuses on the reconstruction of sea level and salinity in the Black Sea since the Last Glacial Maximum (LGM) using benthic foraminifera as the main tool. These organisms, ubiquitous in marine environments, are well known as reliable paleoenvironmental indicators. Their tremendous taxonomic diversity allows for a wide range of biological reactions to varied environmental factors, including many species-specific responses to ecological conditions (Fursenko 1978), which adds to their potential as index species for monitoring sea-level and salinity changes. They have very short reproductive cycles—six months to one year (Boltovskoy 1964)—and rapid growth (Walton 1964), making even their community structure particularly responsive to environmental change. Their tests are readily preserved and can record evidence of environmental variability through time, thus providing historical baseline data even in the absence of background studies. They are small and abundant compared to other larger, hard-shelled taxa (such as molluscs), which makes them particularly easy to recover in statistically significant numbers (Yanko *et al.* 1999a).

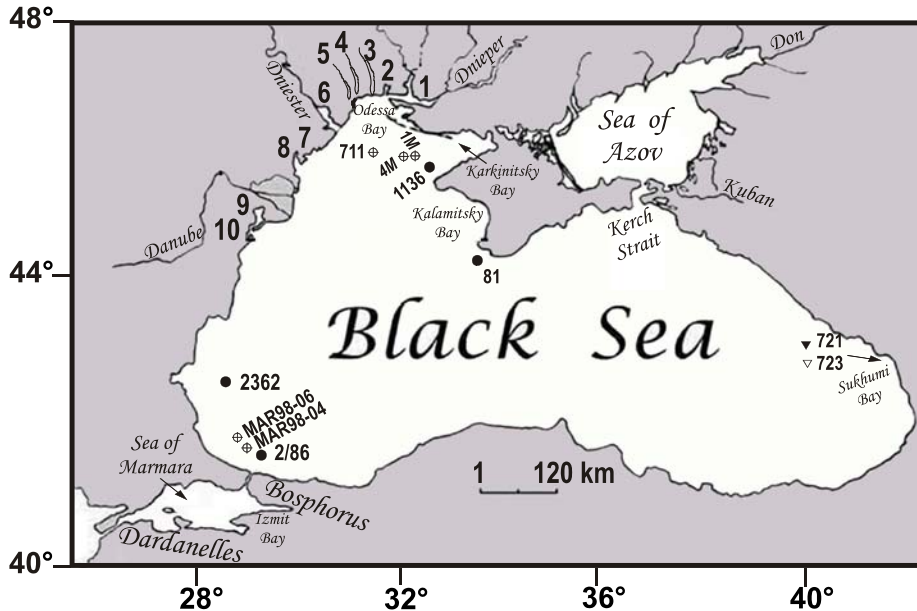


Figure 1. Map showing location of sample cores in the Black Sea. **Key:** Solid circles = gravity cores; solid triangles = boreholes; cross within circles and hollow triangles = cores and boreholes, respectively, dated by ^{14}C from the literature: Core 4M and 1M (Balandin and Mel'nik 1987); Core 723 (Kvavadze and Dzeiranshvili 1989); Core 711 (Gozhik *et al.* 1987); Cores MAR98-04 and MAR98-06 (Aksu *et al.* 2002b); 1 to 10 = limans/lagoons: 1 – Dnieper-Bugsy, 2 – Berezansky, 3 – Tiligulsky, 4 – Kuyalnitky, 5 – Khadzhibeysky, 6 – Dniestrovsky, 7 – Alibey, 8 – Sasyk, 9 – Razelm, 10 – Golovitsa, Sinoe, Nuntash.

In examining the flood hypotheses, this paper emphasizes the interval of 28–7 ky BP, and three crucial points are discussed: (1) level and salinity of the Neoeuxinian lake; (2) re-colonization of the Black Sea by Mediterranean immigrants, and, by implication, sea-level and salinity changes due to connection/isolation between adjacent basins; and (3) an “alternative” to the Bosphorus connection between adjacent basins.

It will be shown that the increase in the level of the Black Sea was not catastrophic, nor was it gradual. It occurred in an oscillating manner from its lowest point at about –100 m during the LGM (27–18 ky BP) to –20 m at *ca.* 10 ky BP. After this date, it never again dropped below the –40 m isobath, nor did it exhibit a maximum amplitude of fluctuation greater than about 20 m. During the last 10,000 years, sea level rose in a steady, oscillating manner to its present level, averaging only 3 cm/100 years, not enough to force human groups into the interior of Europe between 8.4 and 7.2 ky BP. The re-colonization of the Black Sea by Mediterranean immigrants began at 9.5 ky BP, and by 7.2 ky BP, the shelf was completely re-colonized. This evidence contradicts the “Noah’s Flood” Hypothesis, suggesting that it is a contemporary legend.

2. MATERIALS AND METHODS

2.1 Data Collection

The data were collected since 1971 over the course of a large-scale geological survey of the Black Sea shelf (e.g., Malovitsky *et al.* 1979; Yanko 1979; Dmitrienko *et al.* 1988; Yanko 1989, 1990a; Yanko and Gramova 1990). Materials from the Eastern Mediterranean (Basso *et al.* 1994; Yanko *et al.* 1998; Basso and Spezzaferri 2000; Koral *et al.* 2001), the Sea of Marmara (Yanko *et al.* 1998), and the Caspian Sea (Yanko 1989, 1990a) were used as supporting evidence for the origin of the Black Sea foraminifera.

In the Black Sea, approximately 30,000 samples from 1325 grabs, 4000 gravity/piston cores, and 56 boreholes were investigated. The cores were obtained in limans, lagoons, river deltas, the Kerch Strait, the Sea of Azov, and across the shelf. In the Caspian Sea, the Sea of Marmara, and the Eastern Mediterranean, 302, 73, and 512 sediment samples, respectively, were studied. The location maps of studied materials are provided in Yanko (1989, 1990a), Basso *et al.* (1994), and Yanko *et al.* (1998).

Locations of six exemplary cores discussed in this paper appear in Figure 1. They were chosen because they represent the larger population of cores particularly well. The working half of the sediment column was examined at 2 cm intervals within the gravity cores (max. length 5 m), and in the uppermost 2 cm of each 10 cm interval within boreholes (max. length 28 m).

2.2 Grain Size Analysis

Grain size analysis of the sediments was performed at Odessa State University in Ukraine, Tel Aviv University in Israel, and Istanbul University in Turkey. Sediments were divided into clay (<0.0039 mm), silt (0.0039–0.0625 mm), sand (0.0625–2.0 mm), and gravel (>2 mm) fractions, and the methods used included wet sieving for sediments with a grain size greater than 63 μm , and pipette analyses for clay and silt fractions as described in Folk (1974).

2.3 Radiocarbon Dating

Conventional radiocarbon dating of peat, wood, and mollusc shells was performed at various USSR (Appendices 1 and 2, this volume) and foreign (Appendix 2, this volume) laboratories. Throughout this text, ^{14}C data are expressed as uncorrected years BP in order to remain comparable with worldwide Pleistocene/Holocene chronology and sea-level curves (e.g., Fairbanks 1989).

2.4 Foraminifera

Live (Rose Bengal stained) and fossil foraminifera were investigated separately as described in Yanko *et al.* (1998) and Yanko and Troitskaya (1987), respectively. Samples were soaked and washed in distilled water, and passed through 63 μm mesh sieve. Live foraminifera were counted in wet samples equivalent to 50 g (Black Sea) and 5 g (Eastern Mediterranean) of dry sediment mass. Fossil foraminifera were studied in samples that were dried at room temperature to avoid destruction of agglutinated species. Dried samples were split with a microsplits to avoid sample bias; about 300 fossil foraminifera were picked by hand (flotation in CCl_4 was sometimes used) and counted for population statistics. The total number of foraminifera was calculated in dry samples of 50 g (Black Sea) and 5 g (Sea of Marmara, Eastern Mediterranean).

All species were morphologically examined, taxonomically identified, and SEM pictures were taken. In our taxonomic work, we followed the suprageneric classification in *Osnovi Paleontologii* (Rauzer-Chernousova and Fursenko 1959), in combination with the generic classification of Loeblich and Tappan (1987). All identified taxa were systemized as belonging to Protozoa (Class Sarcodina, Subclass Foraminifera). Direct comparison with the original collections of d'Orbigny, Schlumberger, and Le Calvez in the Museum of Natural History, Paris, was used for most of the species.

The collection of Black Sea, Caspian Sea, and Sea of Azov foraminifera (155 species) is stored in the Paleontological Museum of Odessa National University, Ukraine. The original collection of foraminifera (~ 500 species) from the Eastern Mediterranean and Sea of Marmara is stored at the Avalon Institute of Applied Science. A partial (Israeli shelf) duplicate of the collection is kept at University College London, UK, and at the Museum of Natural History, Paris.

The foraminifera were divided into dominant (<50% of a given population) and accessory species. Species that occur at 50% of all studied locations are considered to be widely distributed, 49–10% are considered frequent, 9–1% rare, and <1% trace. According to their ecological preferences (Table 1), foraminifera are divided into oligohaline (1–5‰), strictoeuryhaline (11–26‰), polyhaline (18–26‰), euryhaline (1–26‰), shallow (0–30 m), relatively deep (31–70 m), and deep (71–220 m) species (Yanko and Troitskaya 1987; Yanko 1989, 1990a).

2.5 Ecostratigraphic Techniques

Ecostratigraphy is the biostratigraphic application of ecological and paleoecological principles to develop an understanding of the global external forcing agents that drive ecological change. The ecostratigraphy of the Black

Sea addresses biotic responses to isolation from and connection to the neighboring Sea of Marmara and Caspian Sea, and to related sea-level changes and salinity oscillations.

Our ecostratigraphic technique is based largely on alternation of foraminiferal assemblages and their ecological characteristics in geological sections, supported by ^{14}C and palynological assays. An increase in the number of Mediterranean immigrants, especially strictoeuryhaline and polyhaline species, in sediment sequences indicates an increase of Mediterranean influence and salinity, and *vice versa*. The complete replacement of Mediterranean immigrants by oligohaline Caspian species shows separation between the Black Sea and Mediterranean, followed by desalination of the Black Sea. This conclusion is based on a generally accepted observation, fully supported by our ecological study (Yanko 1989, 1990a, b), that foraminifera are not well adapted to freshwater environments (Sen Gupta 1999). The classification of Tchepalyga [also spelled as Chepalyga] (1984) is used to describe paleobasin salinity: fresh <0.5‰, semi-fresh 0.5–5‰, brackish 5–12‰, semi-marine 12–30‰, and marine 30–40‰.

3. RESULTS AND INTERPRETATION: ECO-STRATIGRAPHY AND PALEOENVIRONMENTAL RECONSTRUCTIONS

3.1 Live and Fossil Foraminifera

Planktonic foraminifera do not live in the Ponto-Caspian basins—the Black Sea, the Sea of Azov, and the Caspian Sea (Yanko 1989, 1990a; Yanko and Vorob'eva 1990, 1991)—while they abound in the neighboring Sea of Marmara (Alavi 1988; Kaminski *et al.* 2002) and the Mediterranean Sea (Cimerman and Langer 1991).

Benthic foraminifera live on the shelf to a maximum depth of 220 m in the Black Sea and 70 m in the Caspian Sea. In the Black Sea, they are represented by 101 species: 19 Black Sea endemics, 5 Paratethys relics, 5 Caspian, and 72 Mediterranean immigrants (Figure 2). In the shallow (maximum depth 13 m) Sea of Azov, they are represented by 24 Black Sea immigrants. In

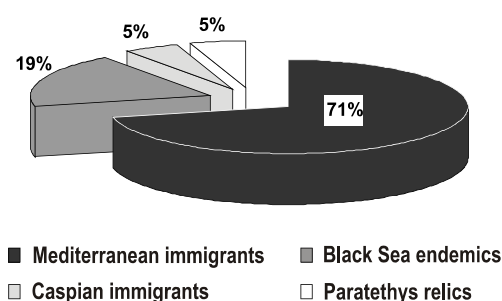


Figure 2. Origin of the Black Sea foraminifera.

the Caspian Sea, only 27 (mostly endemic) species were found (Yanko 1989, 1990a).

Taxonomic diversity in Black Sea benthic foraminifera is low compared to that of the Eastern and Western Mediterranean, where 250 and 400 species have been identified, respectively (Cimerman and Langer 1991; Sgarrella and Moncharmont Zei 1993; AVICENNE Annual Report 1995, 1996; Basso and Spezzaferri 2000). The Black Sea average salinity (17‰) is only half that of the Eastern (39‰) and Western (34‰) Mediterranean, and the maximum salinity of the Sea of Azov and Caspian Sea is almost the same, about 13‰. However, the Caspian Sea has a continental type of salinity with a dominance of Ca^{2+} and SO_4^{2-} ions (Bruevich 1952).

In the Black Sea, the number of species and their abundance decreases progressively with decreasing salinity (Figure 3, Table 1), and no live foraminifera exist in salinities below 1‰.

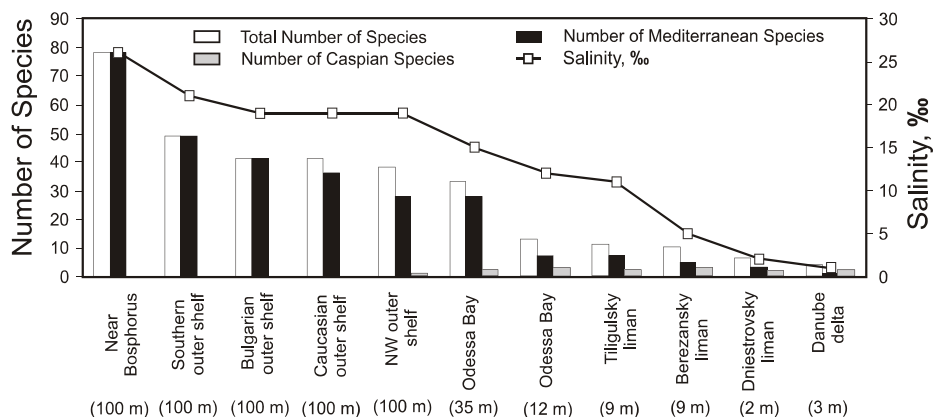


Figure 3. Decrease in the number of foraminiferal species with decreasing salinity in various areas of the Black Sea (average depths of sampling areas shown in parentheses).

Black Sea foraminifera are dominated by 10 species of *Ammonia* (Yanko 1989, 1990a, b). The Black Sea endemic *A. novoeuxinica* together with Caspian endemics *Mayerella brotskajae* and *Elphidium caspicum caspicum* inhabit river deltas. Together with other Caspian endemics *A. caspica* and *Porosonion martkobi tschaudicus*, they indicate a semi-fresh regime for the Black Sea. The euryhaline Mediterranean species *A. tepida* lives everywhere on the shelf, while the polyhaline *A. compacta* and *A. ammoniformis* dominate on the outer shelf where salinity is >18‰. Together with the other Mediterranean species, *A. beccarii*, *A. parkinsoniana*, and *A. agoiensis*, they indicate a semi-marine and marine regime within the Black Sea.

There is strong variation in the taxonomy and diversity of foraminiferal assemblages across the Black Sea shelf. The western assemblages differ from

the northwestern ones in having low numbers of *Haynesina anglica*, miliolids, and a total absence of *E. caspicum caspicum*. The eastern assemblages are distinguished by the presence of *Canalifera nigarensis*. The outer shelf assemblages differ from those of the inner shelf by having a greater number of Mediterranean immigrants of Lagenida, Buliminida, *Acervulina*, *Gavelinopsis*, *Planorbulina*, *Pateoris*, and *Pyrgo*, which are especially abundant near the Bosphorus (Yanko and Troitskaya 1987; Yanko 1989, 1990a, b; Yanko and Vorob'eva 1991). In general, diversity among foraminifera increases from the northwest toward the east and west, reaching maximum values near the Bosphorus. The main foraminiferal assemblages in the Black and Caspian Seas are given in Tables 1 and 2, at the end of this paper.

3.3 Late Pleistocene Ecostratigraphy

3.3.1 Tarkhankutian Beds (40–27 ky BP)

In the cores, the Late Pleistocene is represented by Tarkhankutian and Neoeuxinian beds. The Tarkhankutian beds were recovered in Core 2362 (Bed 1, dated 27,295 BP) on the Bulgarian shelf at a water depth of –103 m (28°24'2" N by 42°12'6" E). They are represented by dark-grey terrigenous silt and clay (Figure 4A) with CaCO₃ at 18–32%, C_{org} at 0.3–0.7% (Malovitsky *et al.* 1979), and a monospecific (*Dreissena rostriformis distincta*) mollusc assemblage. While no Mediterranean species are found among the molluscs (Govberg *et al.* 1979), they are present among foraminifera, represented by 12 species and 74 specimens (Figure 4B). Mediterranean holeuryhaline *A. tepida* dominates (Figure 4C), while strictoeuryhaline *Nonion matagordanus* and *Elphidium ponticum* play an accessory role (Figure 4D). At present, the closest foraminiferal assemblage, Od-2, with elements of NW-1 inhabits Odessa Bay (Table 1), indicating that the paleosalinity and paleodepth of the basin during the accumulation of Bed 1 was around 11‰ and >35 m, respectively.

Neveeskaya and Neveesky (1961) first reported Tarkhankutian sediments with a mixture of Caspian and Mediterranean molluscs from Karkinitzky Bay, on the northwestern shelf, at water depths of 30–35 m. Later, they were discovered in many places in the Pontic region, e.g., the Colchis Plain (Georgia) where they are overlain by subaerial peats dated *ca.* 31 ky BP at sampling depth –60 m (Dzhanelidze and Mikadze 1975). Popov and Zubakov (1975) and Popov (1983) recognized similar sediments as Surozhian. Svitoch *et al.* (1998) considered Tarkhankutian and Surozhian sediments as coeval, with an age of 40–25 ky BP. The Tarkhankutian transgression at 31,330±719 ky BP (Chepalyga 2002a, b) brought Mediterranean waters and organisms (Figure 4) into the Black Sea and increased salinity to about 8–11‰ (Neveeskaya 1965; Yanko 1989, 1990a). The submerged accumulative coastal bars of synchronous age are lo-

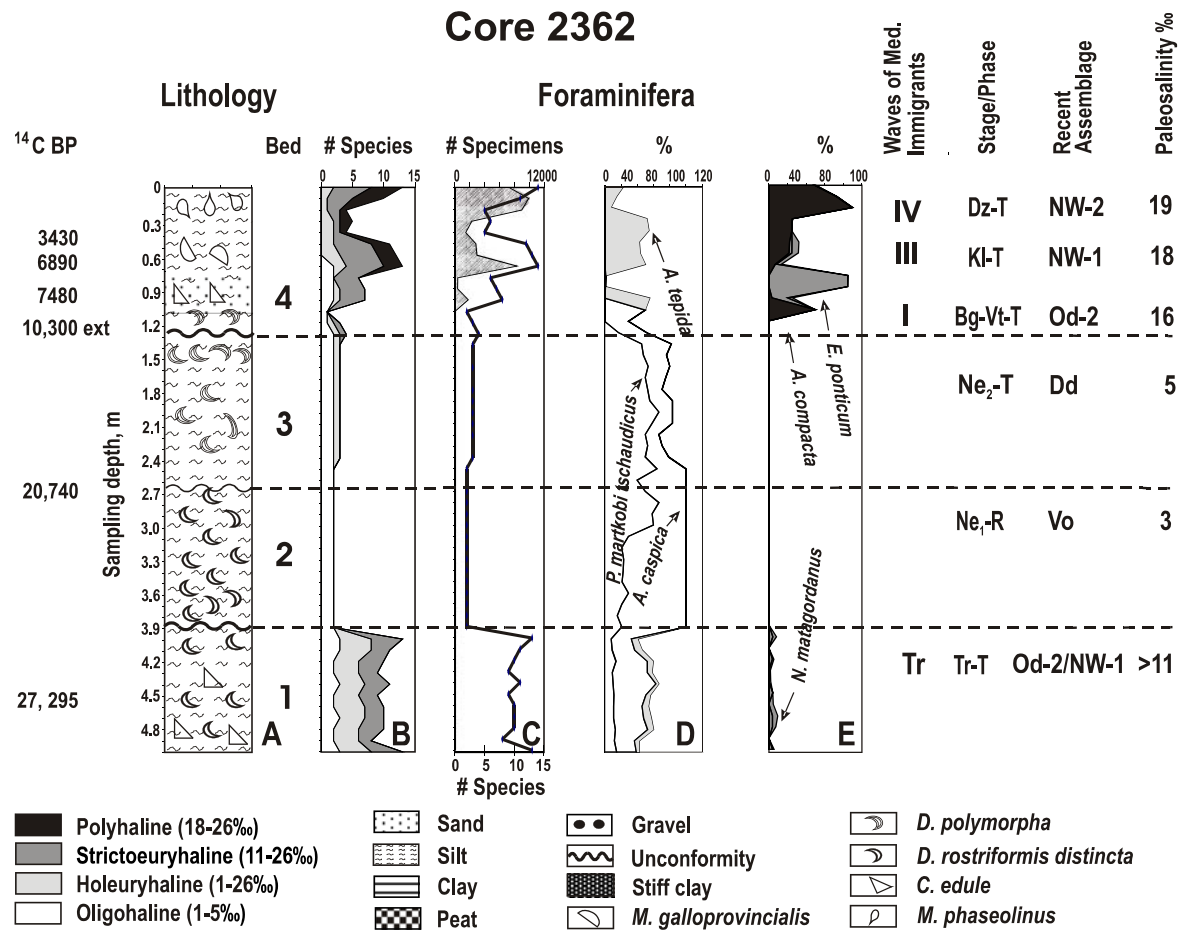


Figure 4. Diagrams for Core 2362 (Bulgarian shelf, 42°12'6" E by 28°24'2" N, water depth -103 m) showing down-core changes in lithology and foraminifera. Dotted lines indicate boundaries between the stratigraphic units. For explanations of recent assemblages, see Tables 1 and 2. Identification of the phases will be found in the caption to Figure 8.

cated at water depths of –22 to –30 m on the northwestern (Chepalyga *et al.* 1989; Chepalyga 2002a, b) and Romanian (Caraiivan *et al.* 1989) shelf, indicating that Tarkhankutian sea level was about –30 m compared to the present. Temporally, the Tarkhankutian sediments correspond to Unit 3 (Çağatay 2003) in the Sea of Marmara. This unit contains some marine molluscs and benthic foraminifera indicating a weak Mediterranean marine incursion during the early part of MIS-3.

Interestingly, no similar sediments have yet been found in the Bosphorus. Instead, they have been recovered in Izmit Bay and the Sakarya Valley (Meriç *et al.* 1995; Yanko-Hombach *et al.* 2004).

The palynological diagrams are dominated by arboreal *Pinus* (subgenus *Diploxyton*) but contain broad-leaved *Quercus*, *Acer*, *Carpinus*, and grassy *Artemisia*, as well as Compositae, e.g., Bed 1, Core 2362 (Komarov *et al.* 1979). In the view of this author, they are similar to the palynological diagrams of the Schtilfrid soil in Austria (Frenzel 1964), which are typical of the moderately warm Würm Paudorf (Middle Weichselian) Pleniglacial, dated 27,990–28,120 BP (Fink 1962). This period of increased Eastern Mediterranean pluviality together with northwestern European permafrost degradation and climatic warming is associated with increased fluvial discharges (Huijzer and Vandenberghe 1998) and must have been accompanied by a noticeable increase in river discharge flowing into the Black Sea (Aksu *et al.* 2002b). By implication, the level of the Black Sea must have been high (Çağatay *et al.* 2000), and the Black Sea should have been connected to the Marmara via a south-flowing river (Aksu *et al.* 2002a, b). The presence of Mediterranean species in the Tarkhankutian sediments indicates northward flow from the Sea of Marmara as well.

3.3.2 Lower Neoeuxinian beds (27–17 ky BP)

In the cores recovered below isobath –100 m, the Tarkhankutian beds are separated from the overlying Lower Neoeuxinian beds (27–17 ky BP; Figure 5D) by an erosional unconformity (Figure 4A). According to Ross and Degens (1974), the Black Sea was in the process of evolving from a marine basin to a more freshwater environment by about 23 ky BP. Our data show that this process started earlier at *ca.* 27 ky BP, during the accumulation of the Lower Neoeuxinian beds. The latter are represented by alternations of grey silt and grey striped clays enriched with hydrotriolite, sand (minor), and shells of *D. rostriformis distincta* (e.g., Bed 2, Core 2362, Figure 4A; Bed 1, Core 2/86, Figure 6; Bed 1, Core 81, Figure 7A); CaCO₃ is about 50% and C_{org} >1% (Malovitsky *et al.* 1979). The foraminiferal assemblage consists of *A. caspica* and *P. markobi tschaudicus* (Figure 4B, D; 6, 7D). The number of specimens is low (12–29, Figure 4C, 7C). A similar assemblage, Dd (Table 1), inhabits

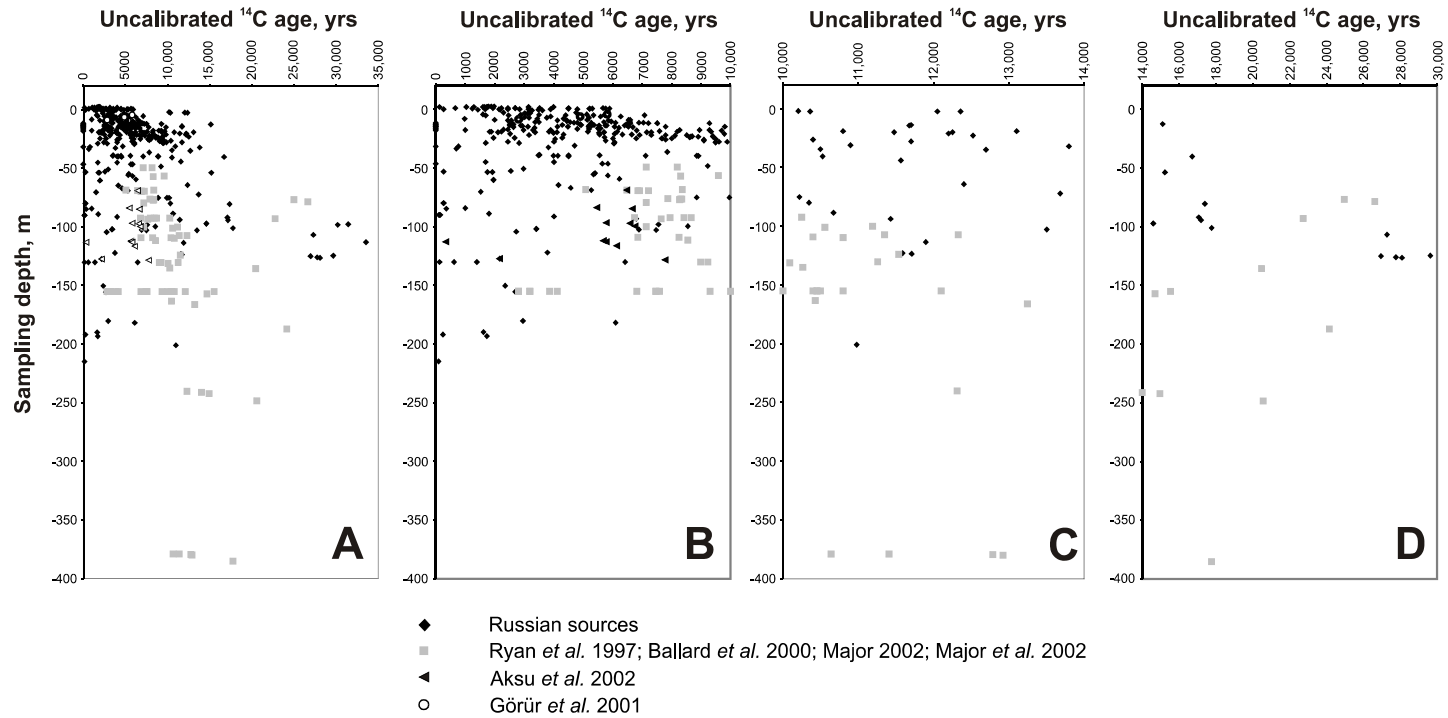


Figure 5. Scatter diagrams compiled from Appendices 1 and 2 showing uncalibrated ^{14}C records for the time intervals (A) 0–35 ky BP, (B) 0–10 ky BP, (C) 10–14 ky BP, and (D) 14–30 ky BP. Only age determinations obtained from mollusc shells are considered. For the time interval 35–10 ky BP, ^{14}C analysis was performed on *Dreissena* and occasionally *Monodacna* and *Viviparus*. For the time interval 10–0 ky BP, other mollusc shells, e.g., *Cardium edule*, *C. exiguum*, *Mytilus galloprovincialis*, and some others (see Appendices 1 and 2) were used in addition to *Dreissena*. The total data set consists of 424 radiocarbon records obtained by conventional (Russian sources) and AMS (western sources) methods.

Core 2/86

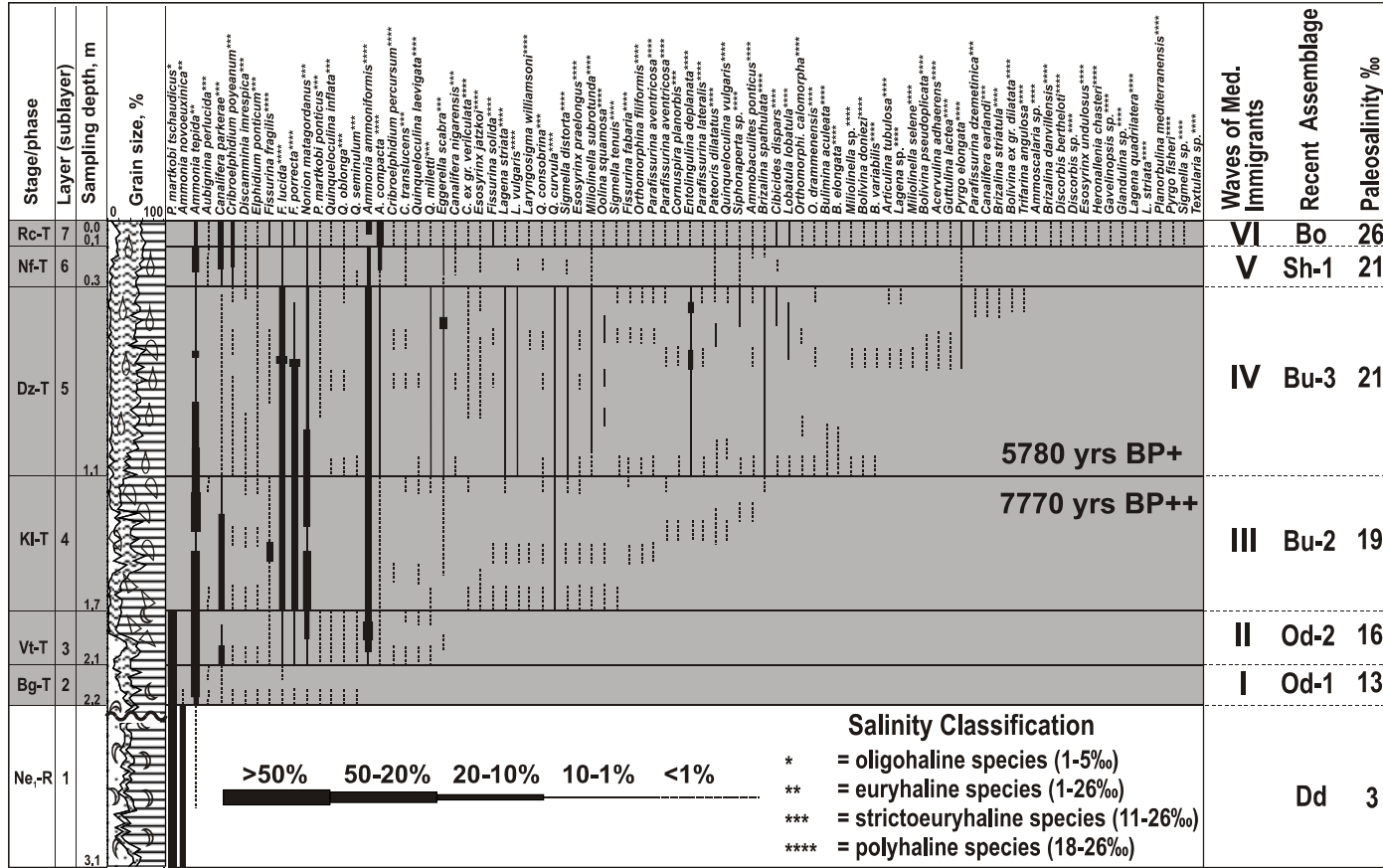


Figure 6. (Previous page) Diagram for Core 2/86 (Northern Bosphorus exit, 41°31'30" N by 28°59'32" E, water depth –103 m). The sediment column is subdivided into seven beds showing downcore changes in grain size and percentage of foraminiferal species. ^{14}C on *Mytilus* from cores MAR98-04 (+) and MAR98-06 (++) (Aksu *et al.* 2002b). For an explanation of the recent assemblages, see Table 1. Identification of the phases appears in the caption to Figure 8. For further explanations, see Figure 4.

present-day river deltas, indicating a shallow, semi-fresh paleoenvironment during the accumulation of the Lower Neoeuxinian beds. There are no Mediterranean species among the foraminifera, ostracoda (Yanko and Gramova 1990), and molluscs (Nevevskaya 1965). Similarly, there are no Mediterranean species in synchronous sediments of the Sea of Marmara (Unit 2, Çağatay 2003), indicating that they were deposited in a fresh/brackish environment (salinity <6‰), corresponding to the late part of MIS-3 and MIS-2. During the deposition of Unit 2, the water level was at –85 m, and the shelf areas were subaerially exposed or occupied by small, isolated lakes (Çağatay 2003). The Bosphorus was a freshwater lake (26–5.3 ky BP) with a sandy bottom containing freshwater molluscs of Black Sea Neoeuxinian affinity—*D. rostriformis*, *D. polymorpha*, *Monodacna pontica* (Algan *et al.* 2001). The level of the Aegean Sea, –115 m (Aksu *et al.* 1987), and the Sea of Marmara, –100 m (Smith *et al.* 1995) was about the same as the level of the Black Sea, assuming a lack of connection between the basins during early Neoeuxinian times (Svitoch *et al.* 1998).

The Early Neoeuxinian basin was semi-fresh, aerobic (Degens and Ross 1974), and heavily populated by benthic organisms, in particular by those with calcareous shells (CaCO_3 in sediments: $\geq 50\%$), e.g., molluscs, ostracoda, and on a much smaller scale, by foraminifera.

The Early Neoeuxinian palynological diagrams are dominated by *Artemisia*, Chenopodiaceae, *Adonis*, and *Thalictrum* (e.g., Bed 2, Core 2362). They are similar to those of the dry pine forest of Romania (Komarov *et al.* 1979; Pop 1957), the pine/birch forest and xerophyte steppe in southern Ukraine and Moldova (Artyushchenko *et al.* 1972; Kyrvel *et al.* 1976), and the steppe and forest-steppe on the Balkan Peninsula (Bottema 1974), all indicating a cold and dry climate (Nikonov and Pakhomov 1993). By implication, the river discharge into the Early Neoeuxinian lake must have decreased, causing a dramatic drawdown of the water level below the –100 m isobath (Kvasov 1975; Skiba *et al.* 1975; Fedorov 1977, 1978; Shcherbakov *et al.* 1978, Abashin *et al.* 1982; Shcherbakov 1983; Shnyukov *et al.* 1985; Fedorov 1988; Svitoch *et al.* 1998). A large portion of the present shelf was exposed, eroded, downcut some 40 m into the basement by the Pre-Danube, Pre-Dnieper and Pre-Dniester Rivers, and covered by subaerial loams (e.g., Shcherbakov *et al.* 1978; Shcherbakov 1983; Inozemtsev *et al.* 1984; Fedorov 1988). The river mouths were relocated 80–100 km seaward (Gozhik 1984b; Shnyukov *et al.* 1985), where they possessed poorly developed deltas and opened directly into the canyons on the continental

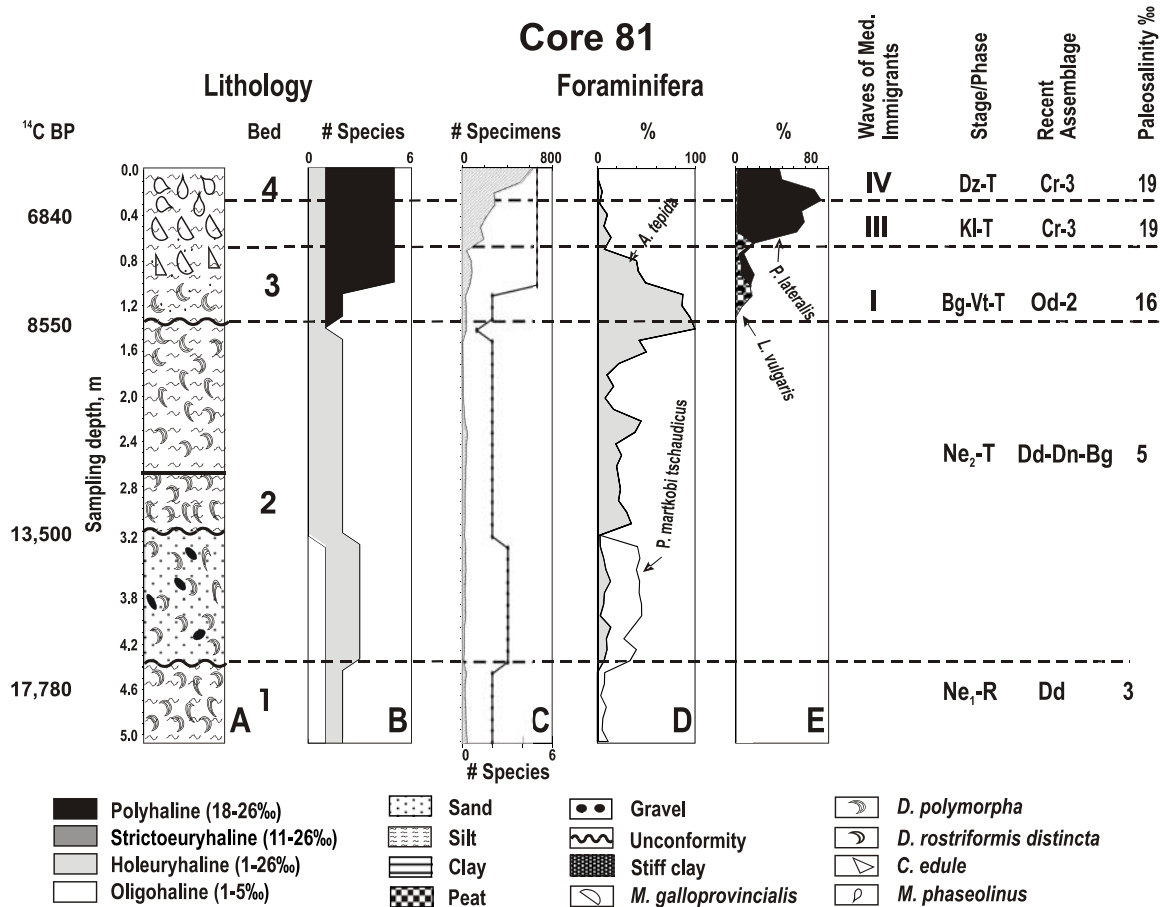
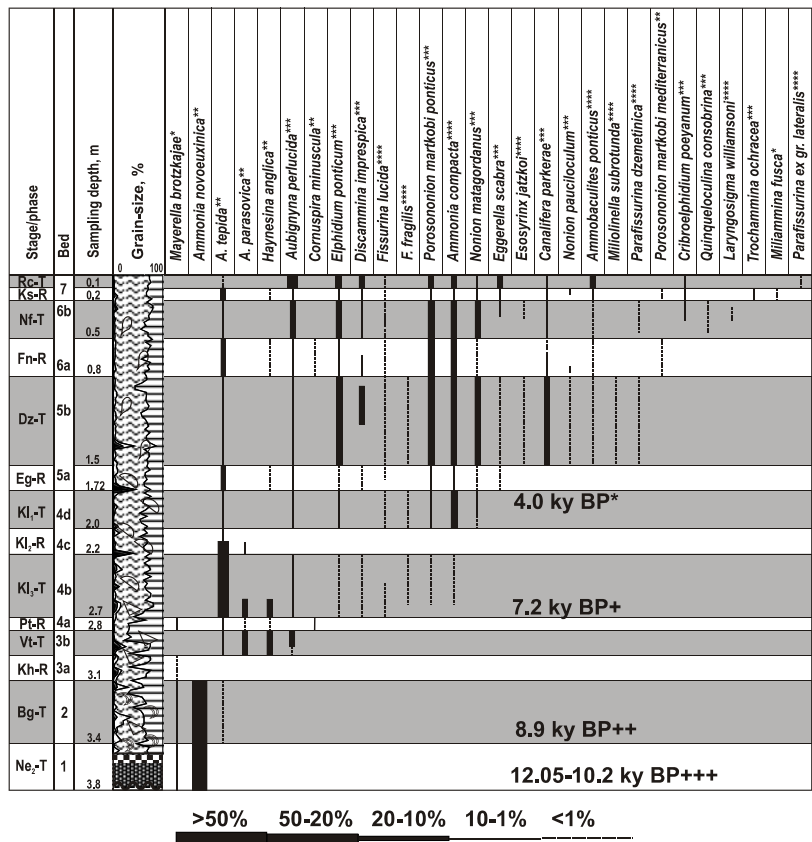


Figure 7. Diagrams for Core 81 (Crimean shelf, 44°24' N by 33°28'40" E, water depth -100 m). The sediment column is subdivided into four beds that show the downcore changes in lithology and number of foraminiferal species, specimens, and percentage of dominant species. Dotted lines indicate boundaries between stratigraphic units. For an explanation of the recent assemblages, see Table 1. Identification of the phases appears in the caption to Figure 8. For further explanations, see Figure 4.

Core 1136



Waves of Mediterranean Immigration

VI	Kr-1	18
V	Od-2	15
	NW-2	19
	NW-1	18
IV	Bu-2	19
	Od-2	15
	NW-1	18
III	Od-1	12
	Od-2	15
II	Bz	5
	Kz	>12
	Bz	5
I	Dn-Bg	9
	Dd	5

Recent Assemblage

Paleosalinity, %

Figure 8. Diagrams for Core 1136 (Northwestern shelf, Karkinitzky Bay, 45°35'02" N by 32°25'07" E, water depth -31 m) showing downcore changes in grain size and percentage of species. ¹⁴C on *Mytilus* (+), *Cardium* (++) and *Viviparus/Dreissena* (+++) from cores 4M, 1M (Balandin and Mel'nik 1987) and 711 (Gozhik *et al.* 1987) located in close vicinity to Core 1136 (for location, see Figure 1). For an explanation of the recent assemblages, see Table 1. For further explanations, see Figure 4. Transgressive (T, in grey) and regressive (R) phases: Tr = Tarkhankutian, Ne1 = early (lower) Neoeuxinian; Ne2 = late (upper) Neoeuxinian, Bg = Bugazian, Kh = Kolkhidian, Vt = Vityazevian, Pt = Pontian, Kl = Kalamitian, Eg = Eggrisian, Dz = Dzhemetinian, Fn = Phanagorean, Nf = Nymphaean, Ks = Korsunian, Rc = Recent.

slope (Konikov, this volume: his Figure 12). The river valleys and canyons were filled with thick (22–40 m) alluvial sediments (Kuprin and Sorokin, this volume) of the Ant age (22,800–16,900 BP) containing 27 freshwater and 14 brackish water shallow ostracods dominated by *Cyprideis littoralis* and *Ilyocypris bradyi* (Gozhik 1984c).

3.4.2 Late Neoeuxinian (17–10 ky BP)

Above isobath –100 m, the Lower Neoeuxinian beds are often overlapped by subaerial loams and further on by aquatic sediments with ostracoda *Candona*, *Candoniella*, and foraminifera *A. novoeuxinica*. This change indicates transformation of the bottom from an erosional to a subaquatic accumulative phase at the beginning of the Late Neoeuxinian transgression (Gozhik 1984b; Shnyukov 1985).

The Upper Neoeuxinian beds (e.g., Bed 3, Core 2362, Figure 4A; Bed 1, Core 1136, Figure 8A; Bed 1, Core 711, Figure 9A) cover the Black Sea floor below isobath –20 m almost everywhere: –18 m on the Turkish shelf (Görür *et al.* 2001), –30 m on the Bulgarian shelf (Filipova-Marinova, this volume), –20 m on the northwestern shelf (Gozhik *et al.* 1987; Konikov, this volume), –30 m on the Crimean shelf (Shnyukov 1985), –30 m on the Caucasian shelf (Balabanov *et al.* 1981; Yanko and Gramova 1990), and –11 m in the Kerch Strait (Put' 1981). In some places (e.g., the western part of the Golitsin Uplift located at the mouth of Karkinitsky Bay, see Figure 1 for location), they are exposed on the seafloor (Tkachenko *et al.* 1970; Ishchenko 1974; Tkachenko 1974; Yanko 1974, 1975, 1989). Their thickness varies up to 25 m (Put' 1981).

Lithologically, the Upper Neoeuxinian beds on the shelf are rather monotonous. They are represented by light grey sandy coquina and/or bluish-grey stiff clays that fill pre-Neoeuxinian depressions and paleoriver valleys (e.g., Arkhangel'sky and Strakhov 1938; Nevesskaya 1965; Semenenko and Kovalyukh 1973; Ostrovsky *et al.* 1977; Malovitsky *et al.* 1979; Balabanov *et al.* 1981; Skryabina 1981; Yanko 1982; Gozhik 1984a, b, d; Voskoboinikov *et al.* 1985; Shnyukov *et al.* 1985; Fedorov 1988; Gozhik *et al.* 1987; Yanko 1989, 1990a; Yanko and Gramova 1990; Glebov *et al.* 1996). The stiff clay has a massive structure, high density (about 2.7 g/cm³), and low water content. The interstitial water salinity is 7‰ (Konikov, this volume: his Figures 3 and 4).

Molluscs are dominated by *D. polymorpha* and *D. rostriformis* on the inner and outer shelf, respectively. Other Caspian molluscs, such as *M. caspia*, are also abundant (Figure 9F). The foraminiferal assemblage is rather uniform, being dominated by oligohaline Caspian *M. brotzkajae* and *E. caspicum*, and holeuryhaline Black Sea endemic *A. novoeuxinica*. The number of specimens was found to be >100 (Figure 4B–D, 6, 7, 8B–D, 9B–D, 10B–D). Today, a similar foraminiferal assemblage, Dd, with elements of the Dn-Bg assemblage,

Core 711

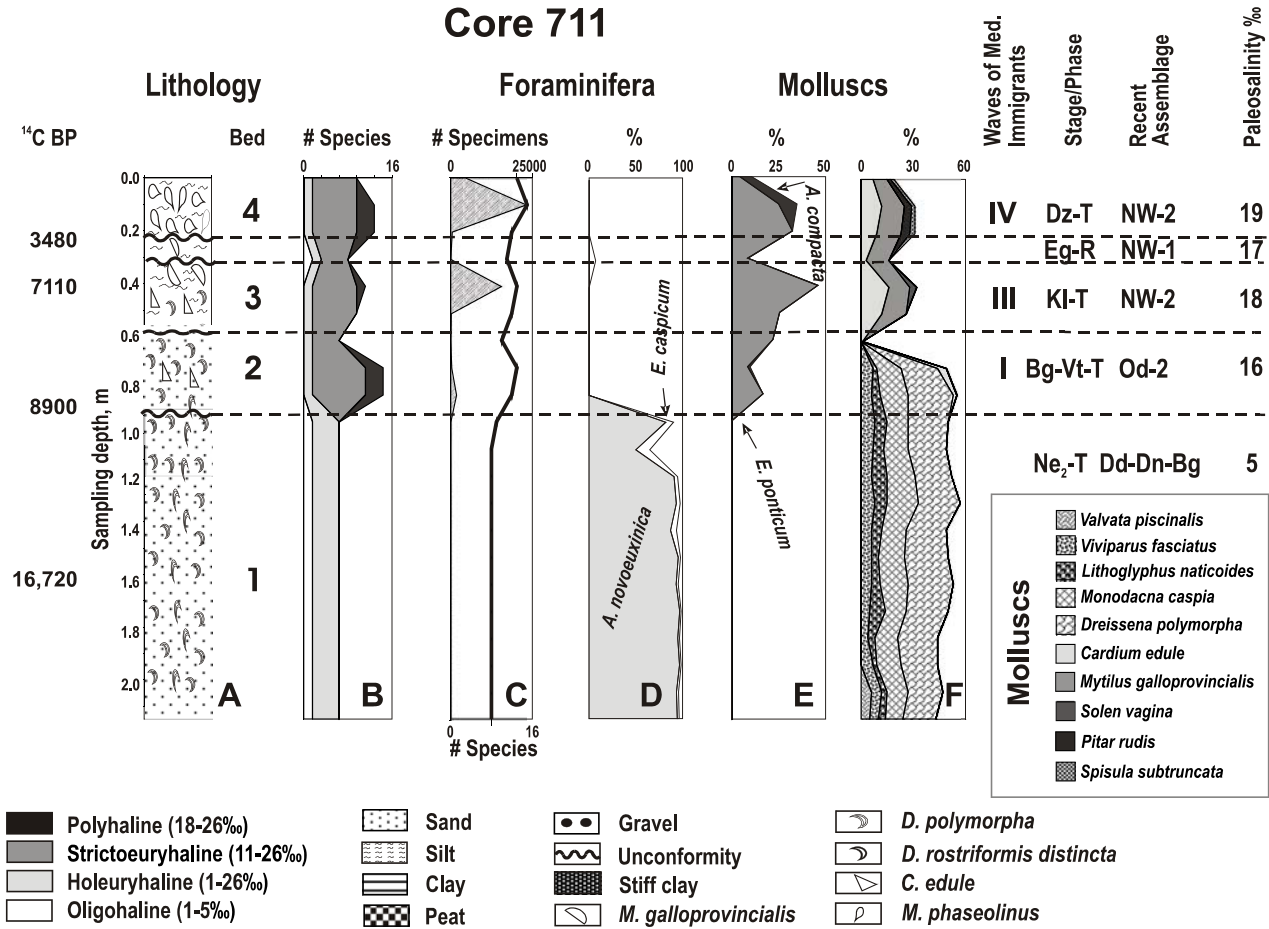


Figure 9. (Facing page) Diagrams showing downcore changes in lithology, number of species, specimens, and percentage of dominant foraminiferal and molluscan species for Core 711. For an explanation of the recent assemblages, see Table 1. Identification of phases appears in the caption to Figure 8. For further explanations, see Figure 4.

inhabits river deltas and semi-fresh limans (Tables 1 and 2), indicating a paleosalinity for the Late Neoeuxinian lake of about 5‰ in the shallow area; it could have reached 7‰, which is typical of interstitial salinity (Manheim and Chan 1974), and even 11‰ (Neveeskaya 1965) in deeper parts of the basin. Despite a relatively high salinity, no Mediterranean species are present. Instead, Caspian immigrants are abundant. The Late Neoeuxinian lake was aerobic and heavily populated by organisms with carbonate shells. The Upper Neoeuxinian sediments seem to be partially synchronous with the upper part of Unit 2 (Çağatay 2003) of the Sea of Marmara sediment column. The level of the Late Neoeuxinian lake was much higher (~ -20 m) than that of the Sea of Marmara (~ -85 m), and by implication, the Late Neoeuxinian lake discharged its waters into the Sea of Marmara. The Bosphorus continued to be a semi-fresh lake and might have served as a channel for southward water discharge from the Neoeuxinian lake. However, this discharge could have occurred through the Izmit Gulf-Sakarya Valley, as indicated by the presence of fresh/brackish facies with an age of 14.6 ky BP in borehole KS2 (Kerey *et al.* 2004).

Late Neoeuxinian palynological diagrams are dominated by *Quercus*, *Carpinus*, *Ulmus*, *Salix*, and *Betula*, with decreased concentration of *Pinus* and grass (Komarov *et al.* 1979; Kvavadze and Dzeiranshvili 1989). They are similar to the late glacial diagrams of the Balkan Peninsula (Bozilova 1973, 1975) and the Prichernomorian soil horizon (Veklich and Sirenko 1976) formed before 10.5 ky BP (Ivanova 1966). The climate warmed during Late Neoeuxinian times, which is indicated by the replacement of pine by broad-leaved forests.

In many places, the Upper Neoeuxinian beds are overlapped by peats (Figures 8 and 10A) of *ca.* 10 ky BP: 10,600–9900 BP (Inozemtsev *et al.* 1984); 10,550 BP (Kind 1976); 10,130 BP (Balabanov *et al.* 1981); 9580 BP (Yanko and Troitskaya 1987), and/or very coarse sediments (Figure 10A). The maximum sampling depth (water depth plus depth in the core) of the peats is about 50 m. They were formed at the end of the Younger Dryas (*ca.* 10.2 ky BP) when the level of the lake dropped to about -50 m (Figure 5C and Balabanov, this volume: his Figure 3).

3.4.3 Holocene (*ca.* 10 ky BP–present)

The Late Neoeuxinian beds, often with erosional unconformity, are overlapped by Bugazian beds containing the first Mediterranean immigrants. Bugazian sediments are widely distributed below the -17 m isobath. Their

Core 721

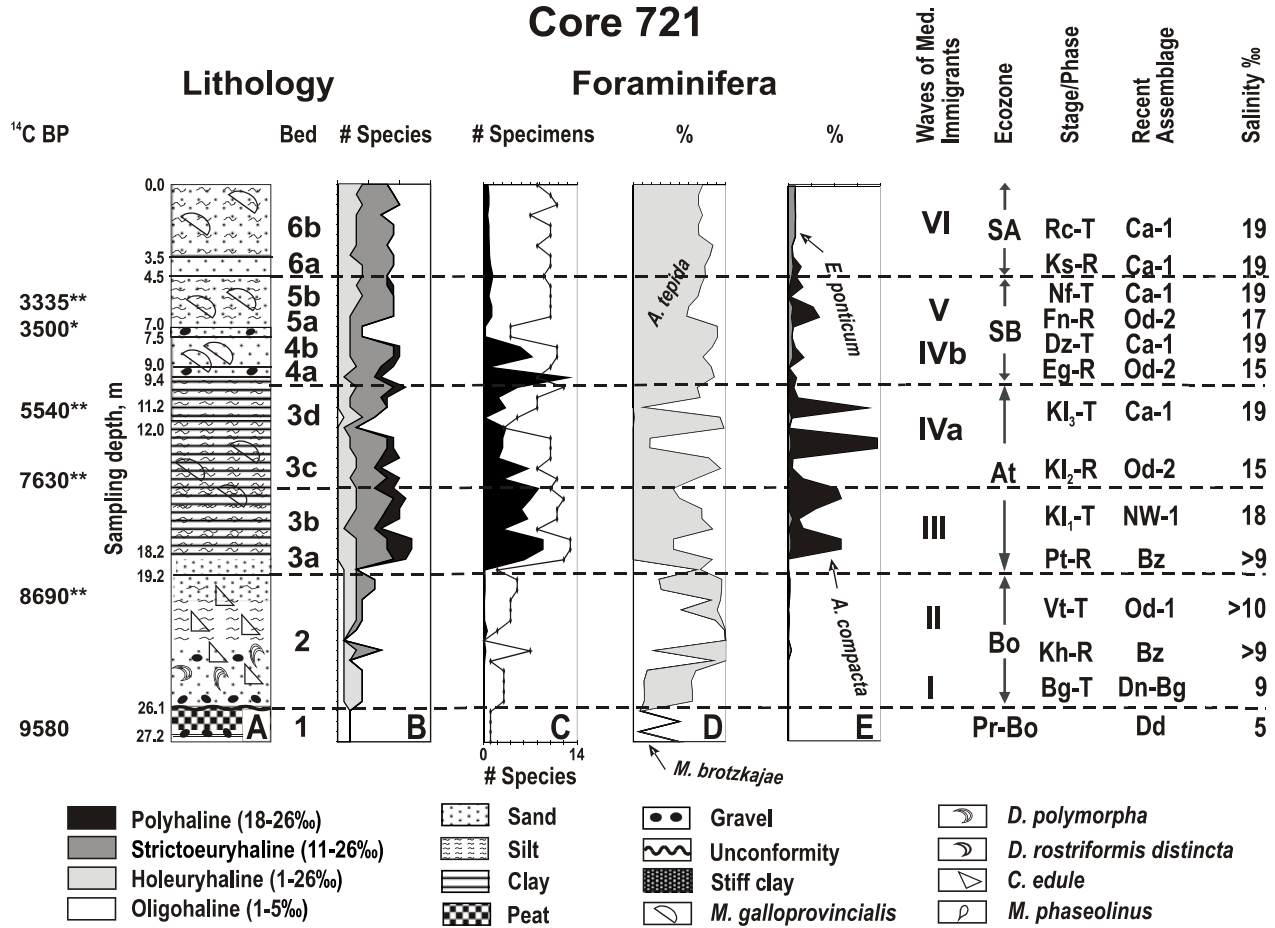


Figure 10. (Facing page) Diagrams showing downcore changes in lithology, number of species, specimens, and percentage of dominant foraminiferal species for Core 721. * = ^{14}C from archaeological source; ** = ^{14}C from Core 723 (Figure 1). For recent assemblages, see Table 1. For phases, see caption to Figure 8. For further explanations, see Figure 4.

thickness increases from 0.03–0.2 m on the slopes of submerged river valleys to 2.5 m on their bottom. They are represented by light grey or greenish-grey fine sand (Bed 2, Core 711, Figure 9A; Bed 2, Core 721, Figure 10A) or bluish-grey clayey silt (Bed 2, Core 1136, Figure 8) or silty clays (Bed 2, Core 2/86, Figure 6) with CaCO_3 at 31–36% and C_{org} at 0.5–1.1%. The sediments have rudimentary lamination expressed as alternating light grey and dark grey microlayers of 1–2 mm thickness (Konikov, this volume: his Figure 3).

The Bugazian palynological diagrams are characterized by a sharp decrease in grassy elements (e.g., wormwood, goosefoot) and conifers (*Pinus*, *Picea*, *Juniperus*). Instead, broadleaf *Quercus*, *Corylus*, *Ulmus*, *Betula*, and even beech become dominant, indicating moderate climate conditions typical of the Boreal Ecozone (Komarov *et al.* 1979). A similar palynological diagram of the deep sediments of the Black Sea and peats of the Ril mountain massif in Bulgaria have ^{14}C ages of $10,737 \pm 315$ BP (Shimkus *et al.* 1977) and $10,035 \pm 65$ BP (Bozilova 1973), respectively, which is close to the extrapolated ^{14}C age (10,300 BP) of Bugazian beds in Core 2362 (Figure 4A). A summary of the palynological data from lakes in a wide area west and south of the Black Sea shows that oak-pistacio (*Quercus-Pistacia*) forests were present over most of the region by 10 ky BP, although local desert-steppe vegetation persisted until about 7 ky BP in the southeast, from Lake Van (Eastern Turkey) to the Caspian Sea (Mudie *et al.* 2002). These forests indicate the early establishment of mesic climatic conditions characterized by >600 mm/year of precipitation in excess of evapotranspiration, as is presently found in most of central and western Europe (Hiscott *et al.*, this volume).

On the inner shelf, Bugazian mollusc assemblages are dominated by *D. polymorpha*, but rare *C. edule* are present as well. The foraminiferal assemblage includes *M. brotzkajae*, *A. novoeuxinica*, and *A. tepida* (up to 30 specimens per sample in total) and resembles the recent Dn-Bg assemblage distributed at depths >9 m and salinities of about 14.0‰. The interstitial water salinity is 15‰ (Konikov, this volume: his Figures 3 and 4). On the outer shelf, below isobath –40 m, Bugazian mollusc assemblages are dominated by *D. rostriformis distincta* (Govberg 1979), but rare *C. edule* are also present. The number of foraminiferal species and specimens increases to 13 and 7000, respectively (Figure 6, Bed 2). The euryhaline Mediterranean *A. tepida* dominates. The similar foraminiferal assemblage Od-1 lives today in Odessa Bay under a salinity of 13‰, indicating a brackish/semi-marine regime within the Black Sea during the accumulation of the Bugazian beds.

The Bugazian beds overlap the Upper Neoeuxinian beds with an erosional unconformity (Figure 10A) corresponding to a drop in sea level from –20 to –53 m below present (Balabanov, this volume: his Figure 3). The boundary between the two is clearly marked by the appearance of the first Mediterranean immigrants among the foraminifera (Figure 4E), molluscs (Figure 9F) and ostracoda (Yanko and Gramova 1990) in the Bugazian beds. This indicates the beginning of a Mediterranean transgression that transformed the semi-fresh Late Neoeuxinian lake into the semi-marine Black Sea. This transgression started *ca.* 9.8 ky BP (Grigor'ev *et al.* 1984) or 9.5 ky BP (Yanko and Troitskaya 1987), when sea level and salinity were about –42 m (Balabanov, this volume: his Figure 3) and 7‰, respectively. The increase in sea level and salinity was neither rapid nor catastrophic. Rather, it was gradual and occurred in a fluctuating manner (Balabanov *et al.* 1981; Yanko 1989, 1990a; Chepalyga 2002a, b; Balabanov, this volume: his Figure 3). A series of low amplitude transgressive and regressive (**in bold**) phases is clearly manifested on the inner shelf of the Black Sea (Figures 8 and 10). Neveeskaya (1965), Fedorov (1978), and Tsereteli (1978) named them Bugazian (9.4–8.1 ky BP), **Kolkhidian** (8.1–7.9 ky BP), Vityazevian (7.9–7.4 ky BP), **Pontian** (7.3–7.0 ky BP), Kalamitian (7.0–6.4 ky BP), **Eggrisian** (6.4–6.0 ky BP), Dzhemetinian (6.0–2.8 ky BP), **Phanagorian** (2.8–2.4 ky BP), Nymphaean (2.4–1.6 ky BP), **Korsunian** (1.6–1.2 ky BP), and Recent (1.2 ky BP–present). Due to the low amplitude of the regressive phases, they cannot be traced in cores recovered from a depth of more than 50 m (Figures 6 and 7), thus giving an impression of a gradual increase in sea level and salinity.

The first wave of Mediterranean immigration was poor. It slowed and even stopped during the Kolkhidian regression (Figures 8 and 10A, B, D). The re-colonization became more or less prominent during Vityazevian times, reaching its maximum in the course of the Kalamitian transgression (the third wave of Mediterranean immigration). On the inner shelf, the Kalamitian beds are represented by silt and sand with predominantly obliquely and horizontally stratified structure and $C_{org} < 2.6\%$ (Bed 4b, Core 1136, Figure 10A). On the outer shelf, they form a single structureless and uniform bed of jelly-like sapropel that drapes all of the undulations of the unconformity surface as was correctly noted by Ryan *et al.* (1997). Among the molluscs, *D. polymorpha* disappears and *C. edule* becomes rare. Instead, *M. galloprovincialis* takes on a dominant role, being widely distributed across the shelf. Foraminifera, molluscs, and ostracoda indicate an increase in salinity to approximately 19‰, in full agreement with data on interstitial water salinity of the sediments (Konikov, this volume: his Figures 3 and 4). The Kalamitian pollen diagrams are dominated by mixed broadleaf trees—*Quercus*, *Corylus*, *Ulmus*, beech, lime, nutwood, and alder—with a small component of coniferous and herbaceous trees, indicating a Holocene climatic optimum corresponding to the Atlantic Climatic Ecozone of

about 7.4 ky BP (Shimkus *et al.* 1977; Komarov *et al.* 1979).

4. DISCUSSION

4.1 Level of the Neoeuxinian Lake

During the extensive studies conducted by Soviet and Eastern Bloc researchers, no evidence for a catastrophic flooding of the Neoeuxinian lake by Mediterranean waters was ever discovered. This writer stated at the 2003 annual meeting of the Geological Society of America (and cited by Ryan, this volume), “It is next to impossible that that such an event could have been missed by decades of Soviet research” (Yanko 2003). The “event” in question was the rapid flooding of the Neoeuxinian lake; it was not, as presented by Ryan, the lowstand shoreline or down-cutting of coastal river valleys that indicate a major water-level drop in the Black Sea’s ice-age lake. These latter features were well known to Soviet geologists since at least the time of Arkhangel’sky and Strakhov (1938) and cannot under any circumstances be used by themselves as support for catastrophic flooding of the Neoeuxinian lake as presented by Ryan (this volume). The details are as follows.

Shallow foraminiferal assemblages in sediments of 27–17 ky BP distributed below the –100 m isobath demonstrate that the level of the Early Neoeuxinian lake stood at approximately that elevation, –100 m (Figure 5D). They also show that the water level reached approximately –20 m at about 10 ky BP (Figure 5B-C). If the level of the Neoeuxinian lake had been –120 m below present between 13.4 and 11 ky BP, or –95 m between 10 and 8.4 ky BP, no sediments with the foraminiferal and molluscan assemblages of these periods would have been recovered above these depths. However, such sediments cover most of the shelf up to the –20 m isobath (Figure 5B; Balabanov, this volume: his Figure 3; Konikov, this volume: his Figure 2; Kuprin and Sorokin, this volume: their Figure 5). These results preclude the first flooding event of the modified Flood Hypothesis (Ryan *et al.* 2003) that allegedly raised the level of the lake from –120 to –30 m during the Younger Dryas. Instead, the level of the lake dropped from –20 to approximately –50 m (Figure 5C; Balabanov, this volume: his Figure 3), as indicated by peats in numerous cores.

Subsequently, the lake level rose again to approximately –20 m by 9.5 ky BP owing to the warmer, post-Younger Dryas climate, coinciding with the first wave of Mediterranean immigrants into the Black Sea (Figure 10). After about 10 ky BP, the level of the Black Sea never again dropped below the –40 m isobath (Figure 5C; Balabanov, this volume: his Figure 3), nor exhibited a maximum amplitude of fluctuation greater than about 20 m, leaving no room for

the second lowstand (–95 m) and flooding event described by Ryan *et al.* (2003) in the modified Flood Hypothesis.

The age of the submerged coastline at about –100 m was obtained on shells of *D. polymorpha* and/or *D. rostriformis* (Ryan *et al.* 2003; Lericolais *et al.*, this volume; Algan *et al.*, this volume). These species, however, are not exclusively Neoeuxinian indicators as suggested by Ryan *et al.* (1997, 2003), Major (2002), Algan *et al.* (2002), and Lericolais *et al.* (2004). In fact, their stratigraphic distribution is much wider, as they are present in all semi-fresh to brackish facies of the Pontic region from the Neogene (Meotis, *D. polymorpha*) and Pliocene (Apsheron, *D. rostriformis distincta*) (Nevevskaya 1965; Il'ina *et al.* 1976) to about 7 ky BP. They can also be found together with Mediterranean species (Figure 11). The AMS radiocarbon age of *Dreissena* varies, e.g., between 24.2 and 7.9 ky BP (Major 2002). Thus, *Dreissena* is not a reliable age-marker for the submerged coastline.

Molluscs	Phase ¹⁴ C age	Salinity, ‰
<i>M. phaseolinus</i>	Dzhemetinian 6.0-2.8 ky BP	19
<i>M. galloprovincialis</i>	Kalamitian 7.0-6.4 ky BP	18
<i>C. edule</i>	Vityazevian 7.9-7.4 ky BP	11-12
<i>D. polymorpha</i> , <i>D. rostriformis distincta</i>	Bugazian 9.4-8.1 ky BP	9-10
<i>Monodacna caspia</i>	Neoeuxinian 28.0-9.4 ky BP	7 5

Figure 11. Stratigraphic distribution of key molluscs in the Late Pleistocene - Holocene sediments of the Black Sea (modified after Nevevskaya 1965; Grigor'ev *et al.* 1984). **Key:** white = semi-fresh, grey = semi-marine, white and grey = brackish water body. Thickness of the black vertical lines is proportional to abundance of the species.

Dreissena is also not a reliable paleobathymetric indicator because the distribution of fossil *Dreissena* is much wider than that of its living specimens. The difference between the two distributions becomes wider with increasing distance from shore, and it reaches its maximum on the continental slope due to reworking (Arkhangel'sky and Strakhov 1938). The alternation of transgressive and regressive phases intensifies reworking, leading to the mixing of paleontological material of different ages and ecological affinities (Shnyukov *et al.* 1985; Yanko and Gramova 1990). For example, the gravel-pebble beach sediments described by Ballard *et al.* (2000) as relics of the Neoeuxinian paleoshoreline at a water depth of –155 m contain a mixture of Caspian (*Dreissena*, *Turricaspia*) and Mediterranean (e.g., *Modiolus phaseolinus*) molluscs (see their Table 1). *M. phaseolinus* immigrated into the Black Sea at about 3 ky BP, however. Today, it lives at a water depths of 40–120 m under

salinities $\leq 18\text{‰}$ (Nevesskaya 1965). Consequently, these two molluscs do not indicate the same environment. Either one or both of them must be reworked, e.g., transported down to the bottom together with coarse material by underwater currents (Kuprin and Sorokin, this volume). A similar phenomenon was observed on the Crimean (Arkhangel'sky and Strakhov 1938) and Caucasian continental slopes in the canyons of the Kodori and Bzyb' Rivers (Kuprin *et al.* 1985; Solov'eva and Sorokin 1993).

In defending his dating of the lowstand and its accompanying arid landscape to the late Neoeuxinian (14–11 ky BP) based on radiocarbon dating of associated shells, Ryan (this volume) explains that both Kuprin *et al.* (1974) and Shcherbakov *et al.* (1978) had already drawn attention to the submerged shoreline. Based on more than 250 sediment cores containing shallow, brackish water foraminifera, ostracoda, and molluscs of Caspian affinity (e.g., Govberg *et al.* 1979; Yanko 1990a; Yanko and Gramova 1990; Yanko-Hombach 2003, 2004) without the appearance of a single Mediterranean species, however, Shcherbakov *et al.* (1978) attributed this lowstand to the LGM (20–18 ky BP). Indeed, Russian geologists did not miss or ignore the occurrence of a major regression within the Pontic basin. They simply assumed that it was earlier in date and that the subsequent transgression was neither abrupt nor catastrophic.

Foraminifera serve as a more powerful tool for paleoenvironmental reconstructions than molluscs, as demonstrated herein for the Tarkhankutian beds. However, their use still requires caution. For example, it is methodologically wrong to use *Ammonia* as indicating a shallow and low salinity paleoenvironment as was done by Kaminski *et al.* (2002). There are at least 10 species of *Ammonia* in the Black Sea, each of which has its own ecological preferences, which vary from oligohaline to polyhaline conditions (Yanko 1990b).

Following the second scenario of the Flood Hypothesis, one would expect that the older (13.4–11 ky BP) submerged coastline lies at a water depth of about –120 m, while the younger (10–8.4 ky BP) would be located at a water depth of about –95 m. However, the water depth and age of the submerged shorelines vary:

- Turkish shelf (near Sinop): –155 m, 7.5–6.8 ky BP (Ballard *et al.* 2000);
- Turkish shelf (near Sakarya Valley): –90 m, 11.8 ky BP (Algan *et al.*, this volume);
- Romanian shelf: –95 m, 10.2–8.6 ky BP (Lericolais *et al.*, this volume);
- Romanian shelf: –100 m, Last Glacial Maximum, MIS-2 (Winguth *et al.* 2000);
- Romanian shelf: –120 m, 13.4–11 ky BP (Ryan 2003);
- Northwestern shelf (between Karkinitsky and Kalamitsky Bays: –140 m, 14.7–10.0 ky BP (Ryan *et al.* 1997);
- Crimean shelf: –100 m, 20–18 ky BP (Shcherbakov *et al.* 1978);

Bulgarian shelf: –100 m, Chaudinian* (Krystev *et al.* 1990; Yanko-Hombach *et al.* 2004) [*age of Chaudinian beds is *ca.* 800 ky BP];
Caucasian, Bulgarian, and Kerch shelf: –147 to –70 (Skiba *et al.* 1975; Esin *et al.* 1980; Goncharov and Evsyukov 1985; Glebov 1987; Glebov *et al.* 1996; Glebov and Shel'ting, this volume).

Abashin *et al.* (1982) show that the depth of the outer edge of the Early Neoeuxinian terrace (with coastal bars constituted by shallow lacustrine facies) changes from east to west from –110 m in the vicinity of the Kerch Strait to –90 m in the central part of the southern shelf of Crimea, and from –160 to –200 m in the western part.

Most probably, variations in the water depths of submerged coastlines relate to neotectonic processes that have caused differential uplift/subsidence of different blocks of the seafloor (Tkachenko *et al.* 1970; Tkachenko 1974; Abashin *et al.* 1982; Tkachenko, personal communication, January 5, 2005), vertical movements similar to those that were noticed recently in Izmit Bay (Sea of Marmara) during the 1999 earthquake (Öztürk *et al.* 2000). The displacement of the shelf break and development of submerged staircase terraces and off-shore cliffs and bars that cluster at certain bathymetric levels (Glebov and Shel'ting, this volume) support this conclusion. Variations in age are likely related to reworking of the mollusc shells used for radiocarbon dating.

At the beginning of the Late Neoeuxinian transgression, the level of the lake must have risen rather rapidly from –100 m at 17 ky BP to –40 m at 12 ky BP (12 mm per year); for comparison, the recent rate of sea-level rise is 2 mm per year (Tushingham and Peltier 1991). Under climate warming, the melting of the Scandinavian Ice Sheet and massive river discharge increased the level of the Caspian Sea to +50 m. Such a large amount of water could not be retained in the Caspian depression and was discharged into the Neoeuxinian lake through the Manych-Kerch Outlet (Mamedov 1997; Chepalyga 2003, this volume).

Such a relatively rapid increase in the Late Neoeuxinian lake level prevented the stabilization of the shoreline and the development of accumulative coastal bars (Mel'nik 1997). Therefore, the coastal dunes of Ryan *et al.* (1997) and Lericolais *et al.* (this volume) must be older than *ca.* 17 ky BP.

4.2 Salinity of the Neoeuxinian Lake

Foraminifera are not adapted to freshwater. As a rule, the boundary between brackish and freshwater environments is marked by their disappearance, with the exception of the organic-walled Allogromiida (Sen Gupta 1999). For this reason, the presence of relatively diverse calcareous foraminifera implies that the Neoeuxinian basin could not be fresh.

However, the advocates of the Flood Hypothesis (Ryan *et al.* 2003;

Lericolais *et al.*, this volume) insist that the Neoeuxinian lake was fresh due to drainage from the melting of the ice cap after Melt Water Pulse 1A. This assumption is based on the belief that *D. polymorpha* and *D. rostriformis* may serve as freshwater indicators (Ryan *et al.* 1997; Ryan and Pitman 1998; Ballard *et al.* 2000; Major *et al.* 2002; Filipova-Marinova *et al.* 2004; Lericolais *et al.* 2004, this volume; Algan *et al.*, this volume; Ryan, this volume).

Nevevskaya (1963, 1965), Il'ina (1966), and Yanko-Hombach (2004) argue that the Neoeuxinian basin was semi-fresh to brackish. This difference of opinion results from an erroneous interpretation of the salinity requirements for *D. polymorpha* and *D. rostriformis*. In the Caspian Sea today, these molluscs tolerate salinity up to 13‰, similar to other molluscs (*M. caspia*), ostracoda (*Leptocythere bacuana*, *Loxococoncha lepida*) and foraminifera (*E. caspicum*, *M. brotzkajae*) that coexist with *Dreissena* species in sedimentological sequences (Davitashvili and Merklin *et al.* 1966; Shornikov 1972; Yanko and Gramova 1990).

Paleontological and geochemical data are in full agreement. The Neoeuxinian salinity of the interstitial water is 4.0‰ (Bruevich 1952; Glagol'eva 1961), about 5.0‰ (Markov 1965), 6.0‰ (Manheim and Chan 1974), 6.8‰ (Shishkina 1962), and even 10-12‰ (Konikov, this volume: his Figures 3 and 4). Whatever reasonable set of assumptions one uses, it is impossible to equate salinity patterns in the interstitial waters with a totally fresh Neoeuxinian lake (Manheim and Chan 1974). Thus, the Neoeuxinian lake was brackish with a continental type of salinity where Ca^{2+} and SO_4^{2-} dominate over K^+ and Cl^- , respectively (Nevevskaya 1970). This is probably a consequence of the Caspian flood described by Chepalyga (this volume).

No oxygen depletion has been found in the Neoeuxinian sediments, thus signifying that the lake was aerobic (Arkhangel'sky and Strakhov 1938; Nevevskaya 1965; Degens and Ross 1974; Fedorov 1978). Our data are in full agreement with this conclusion.

4.3 Sea Level and Salinity in the Holocene

If there had not been northward inflow from the Sea of Marmara prior to 7.2 or 8.4 ky BP (as required under the first and second flood scenarios), then no Mediterranean immigrants would be present in the sediments of about 10 ky BP. However, the first Holocene wave of Mediterranean immigrants appears in the sediment sequences at about 10 ky BP (e.g., Figure 4). If re-colonization of the Neoeuxinian lake by Mediterranean organisms had been as rapid as is proposed by the advocates of the Flood Hypothesis (Ryan *et al.* 1997, 2003), we would observe a dramatic increase of foraminiferal species and specimens in Bugazian sediments. However, their diversity and abundance are low. Moreover, upcore variation leads to almost complete disappearance during the Kolkhidian

regression, which is counterindicative of the alternative gradual re-colonization of the Black Sea by Mediterranean organisms suggested by the opponents of the Flood Hypothesis (Kaminski *et al.* 2002). Indeed, there are six major waves of re-colonization reflecting the fluctuating character of the Holocene Mediterranean transgression. A strong shift of the Sr isotope signature toward marine values at 8.4 ky BP (Major 2002) most likely indicates progressive salination of the Black Sea by increasing Mediterranean inflow during the Vityazevian transgression, but not at the time of the Black Sea–Sea of Marmara reconnection. The prominent foraminiferal re-colonization occurred at about 7.0 ky BP and coincides with a massive immigration of *M. galloprovincialis* when salinity increased to its present value. It was, however, still not high enough to support an immigration of planktonic foraminifera.

Thus, the immigration was neither rapid nor catastrophic, and so, neither the sea-level nor the salinity increase was catastrophic. Instead, the change occurred in a fluctuating manner that can be seen only above the –50 m isobath due to the low amplitude of the regressive phases. A high-resolution micropaleontological study with detailed knowledge of the ecological preferences of each foraminiferal species is needed to reconstruct the low amplitude fluctuations of sea level.

4.4 Alternative to the Bosphorus Connection Between Adjacent Basins

If the Upper Neoeuxinian sediments are found at water depths of about –20 m prior to 10 ky BP, then one must assume that the level of the lake was higher than the level of the world ocean at that time: –60 m (Fairbanks 1989). If so, the Neoeuxinian lake should have discharged an excess of brackish water into the Sea of Marmara, as was correctly pointed out by many authors (e.g., Fedorov 1978; Aksu *et al.* 2002a, b). If this persistent outflow occurred through the Bosphorus Strait (Aksu *et al.* 2002a, b), it should have prevented migration of Mediterranean organisms northward. Their presence in the Black Sea sediments, however, suggests that an alternative connection between the Black Sea and Sea of Marmara could have existed at about 9.5 ky BP (Yanko-Hombach *et al.* 2004).

If Mediterranean immigrants with an age of about 10 ky BP are present in the Black Sea, one would expect to find them in the Bosphorus, however, no Mediterranean immigrants younger than 5.3 ky BP have been found to date. The Bosphorus was a freshwater lake between 26 and 5.3 ky BP when the first euryhaline Mediterranean molluscs entered its sediments (Algan *et al.* 2001). Deposition of coarse *Mytilus*-bank and *Ostrea*-bank units suggests that the establishment of the present dual-flow regime in the Bosphorus occurred at 4.4

ky BP. A clear stratification of the water in the Bosphorus is apparent from about 4 ky BP (Yanko *et al.* 1999b). Thus, the Bosphorus seems not to have been the main link between adjacent basins prior 5.3 ky BP

It can be argued that the record of the Bosphorus Strait boreholes is incomplete and/or marine sediments in the strait were eroded. However, the paleotopographic relief in the strait, at least below the mid-Holocene unconformity disclosed by geophysical profiles, contradicts this interpretation (Kerey *et al.* 2004). At the same time, marine sediments with an age of about 30 ky BP (Tarkhankutian?) and about 8 ky BP (Vityazevian?) are found in Izmit Bay and the Sakarya Valley, suggesting an alternative route between the Black Sea and Sea of Marmara (Meriç 1995; Kerey *et al.* 2004; Yanko-Hombach *et al.* 2004).

5. CONCLUSIONS

During the moderately warm Würm Paudorf (Middle Weichselian) Pleniglacial (prior to *ca.* 27 ky BP), there was a brackish Tarkhankutian basin connected with the Sea of Marmara. At the LGM, this connection was interrupted, and the level of the Tarkhankutian basin dropped to about –100 m, transforming it into the Early Neoeuxinian lake. The lake did not have a connection with the Caspian Sea.

In the warming climate of about 17 ky BP, a massive water discharge, most likely from the Caspian Sea via the Manych Spillway, increased the level of the Late Neoeuxinian lake to about –20 m. The latter must have overflowed, pouring its excess semi-fresh to brackish water into the Sea of Marmara and from there into the Mediterranean. During the short climatic cooling episode occurring at the Younger Dryas, the level of the lake dropped from –20 to about –50 m and then rose again to about –20 m. After *ca.* 10 ky BP, the level of the Black Sea never again dropped below the –40 m isobath, nor exhibited a maximum amplitude of fluctuation greater than 20 m.

At *ca.* 10 ky BP, the lake level reached –20 m again, allowing Mediterranean water and organisms to enter the Late Neoeuxinian basin. This re-colonization of the Black Sea occurred in an oscillating manner. It was slow at the beginning, becoming most prominent at about 7.0 ky BP. The connection between adjacent basins was probably not through the Bosphorus Strait, but via an alternative route, e.g., Izmit Bay–Sapanca Lake–Sakarya River.

On average, sea level rose gradually, but in an oscillating manner, to its present level, and perhaps slightly higher, averaging 3 cm per 100 years but certainly not 15 cm per day (almost 55 m per year) as postulated by the Noah's Flood Hypothesis. An increase in sea level of 3 cm per 100 years would not be noticed by the region's inhabitants and would not have accelerated their

dispersion into the interior of Europe, bringing us to conclude that “Noah’s Flood” in the Black Sea is a contemporary legend.

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Table 1. Live foraminiferal assemblages of the Black Sea and Sea of Azov. Locations appear in Figure 1.

Connection with the Black Sea	River Discharge	Area	Depth, m	Salinity, ‰	No. of Stations	No. of Species	Dominant Species, max %	Accessory Species	Assemblage Index
Permanent	Strong	Danube delta	>5	1–5 (avg 1)	28	4	<i>A. novoeuxinica</i> , 76 <i>A. tepida</i> , 16	<i>Ma. brotzkajae</i> , <i>Ma. kolchidica</i>	Dd
		Dniestrovsky liman	>9	0.03–9 (avg 2)	10	6	<i>A. novoeuxinica</i> , 70 <i>A. tepida</i> , 17 <i>H. anglica</i> , 12	<i>M. fusca</i> , <i>H. anglica</i>	Dn
		Dniepro-Bugsky liman	>9	0.1–14.3 (avg 2.5)	10	6	<i>A. novoeuxinica</i> , 70 <i>A. tepida</i> , 17 <i>H. anglica</i> , 12	<i>M. fusca</i> , <i>H. anglica</i>	Dn-Bg
	Weak	Golovitsa liman	>9	5	20	5	<i>A. novoeuxinica</i> , 76 <i>A. tepida</i> , 19 <i>H. anglica</i> , 14	<i>M. fusca</i> , <i>H. anglica</i>	Gv
		Berezansky liman	>9	1–14 (avg 5)	10	10	<i>A. novoeuxinica</i> , 76 <i>A. tepida</i> , 18 <i>H. anglica</i> , 4	<i>M. fusca</i> , <i>H. anglica</i>	Bz
Absent	Sinoe liman	>2	5–18 (avg 5)	13	6	<i>A. tepida</i> , 86 <i>H. anglica</i> , 10	<i>J. polystoma dacica</i>	Si	
Restricted	Temporary (season-dependent)	Tiligulsky liman	>19	1–76 (avg 11)	10	11	<i>A. tepida</i> , 47 <i>H. anglica</i> , 41	<i>A. novoeuxinica</i>	Tl
		Khadzhibeysky liman	>14	2–63.5 (avg 12)	6	11	<i>A. tepida</i> , 47 <i>H. anglica</i> , 41	<i>A. novoeuxinica</i>	Kz
		Nuntash lagoon	?	21	9?	6	<i>A. tepida</i> , 63 <i>N. matagordanus</i> , 20 <i>P. martkobi ponticus</i> , 16	<i>Q. seminulum</i>	Nu
Absent	Absent	Alibey lagoon	>2.5	1–140 (avg 27.4)	10	14	<i>H. anglica</i> , 50 <i>A. tepida</i> , 40	<i>E. caspicum azovicum</i> , <i>A. parasovica</i> , <i>Au. perlucida</i>	Al
		Techirghiol lagoon	>1	75	5	7	<i>A. tepida</i> , 30 <i>T. aguajoi</i> , 30 <i>J. polystoma dacica</i> , 30	<i>M. fusca</i>	Tg

Free	Strong	Odessa Bay	>10	3–14 (avg 12)	100	13	<i>A. novoeuxinica</i> , 55 <i>H. anglica</i> , 20 <i>A. tepida</i> , 14	<i>E. caspicum azovicum</i>	Od-1
	Significant	Odessa Bay	11–25	11–16 (avg 15)	200	33	<i>A. tepida</i> , 48 <i>H. anglica</i> , 19 <i>P. martkobi ponticus</i> , 12	<i>Au. perlucida</i> , <i>E. ponticum</i> , <i>A. parasovica</i>	Od-2
	Absent	Karkinitzky Bay	>35	18.2–19 (avg 18.6)	50	40	<i>A. tepida</i> , 31 <i>A. caucasica</i> , 10 <i>Q. seminulum</i> , 11	<i>Q. laevigata</i> , <i>Q. bicornis</i>	Kn
		Kalamitsky Bay	>35	18.3	20	39	<i>A. tepida</i> , 20 <i>E. scabra</i> , 15 <i>A. caucasica</i> , 10	<i>M. secans</i> , <i>Ab. ponticus</i>	Kl
Open shelf	Absent	NW and Crimean (western) outer shelf	36–70	18.3	200	38	<i>A. compacta</i> , 29 <i>E. ponticum</i> , 20 <i>C. parkerae</i> , 9 <i>Cr. poeyanum</i> , 12	<i>N. matagordanus</i>	NW-1
		NW and Crimean (western) outer shelf	71–150	19	160	33	<i>A. compacta</i> , 27 <i>P. martkobi ponticus</i> , 12 <i>N. matagordanus</i> , 9 <i>P. dzemetinica</i> , 6	<i>L. vulgaris</i> , <i>Es. jatzkoi</i> , <i>E. deplanata</i> , <i>Lr. williamsoni</i>	NW-2
		Crimean (eastern) inner shelf	>35	18	10	37	<i>A. tepida</i> , 43 <i>E. scabra</i> , 13 <i>P. martkobi ponticus</i> , 10	<i>C. nigarensis</i>	Kr-1
		Crimean (eastern) outer shelf	36–70	19–20	10	40	<i>A. compacta</i> , 29 <i>C. parkerae</i> , 16 <i>Cr. poeyanum</i> , 13	<i>N. matagordanus</i>	Kr-2
		Crimean (eastern) outer shelf	71–200	20–21	10	32	<i>A. compacta</i> , 34 <i>N. matagordanus</i> , 12 <i>F. lucida</i> , 10	<i>L. vulgaris</i> , <i>Lr. williamsoni</i> , <i>Es. yatzkoi</i>	Kr-3
Restricted	Absent	Kerch Strait (central part)	>10	14–15	10	17	<i>A. parasovica</i> , 34 <i>A. tepida</i> , 22	<i>H. anglica</i> , <i>Au. perlucida</i>	Ke-1
		Kerch Strait (southern part)	>10	17.1–17.5	10	17	<i>A. tepida</i> , 30 <i>A. parasovica</i> , 25	<i>H. anglica</i> , <i>P. martkobi ponticus</i>	Ke-2
	Moderate	Sea of Azov (southern part)	>12	12–13	20	17	<i>A. parasovica</i> , 40 <i>A. tepida</i> , 23	<i>E. caspicum azovicum</i> , <i>H. anglica</i>	Az-1
		Sea of Azov (central part)	>12	11–12	20	17	<i>A. parasovica</i> , 45 <i>A. tepida</i> , 16 <i>A. novoeuxinica</i> , 10	<i>E. caspicum azovicum</i> , <i>H. anglica</i>	Az-2

Connection with the Black Sea	River Discharge	Area	Depth, m	Salinity, ‰	No. of Stations	No. of Species	Dominant Species, max %	Accessory Species	Assemblage Index
Restricted	Strong	Taganrogsky Bay (southern part)	>7	7–9	10	11	<i>A. novoeuxinica</i> , 79 <i>A. tepida</i> , 10	<i>E. caspicum azovicum</i> , <i>H. anglica</i>	Tg-1
		Taganrogsky Bay (northeastern part)	>2	4.3	10	9	<i>A. novoeuxinica</i> , 82 <i>A. tepida</i> , 9	<i>M. brotzkajae</i>	Tg-2
Open shelf	Minor	Caucasian inner shelf	>35	18–19	80	42	<i>A. compacta</i> , 30 <i>P. markobi ponticus</i> , 22	<i>A. caucasica</i> , <i>E. scabra</i>	Ca-1
	Absent	Caucasian outer shelf	36–70	19–20	65	41	<i>A. compacta</i> , 46 <i>P. markobi ponticus</i> , 18 <i>N. matagordanus</i> , 12	<i>A. ammoniformis</i> , <i>E. scabra</i>	Ca-2
		Caucasian outer shelf	71–220	20–21	75	34	<i>A. compacta</i> , 57 <i>F. solida</i> , 13	<i>A. ammoniformis</i> , <i>N. matagordanus</i> , <i>E. scabra</i>	Ca-3
Open shelf	Moderate	Bulgarian inner shelf	8–35	17–19	14	38	<i>A. tepida</i> , 40 <i>A. compacta</i> , 14 <i>A. ammoniformis</i> , 13	<i>A. caucasica</i> , <i>Cr. poeyanum</i> , <i>Au. perlucida</i>	Bu-1
		Absent	Bulgarian outer shelf	36–70	19–19.6	30	41	<i>A. ammoniformis</i> , 35 <i>A. compacta</i> , 21 <i>C. parkerae</i> , 12	<i>A. tepida</i> , <i>P. markobi ponticus</i> , <i>Au. perlucida</i>
	Bulgarian outer shelf		71–220	21–22	60	43	<i>A. compacta</i> , 30 <i>A. ammoniformis</i> , 15 <i>Lagenida</i> , 18	<i>N. matagordanus</i> , <i>Pa. dzemetinica</i> , <i>F. lucida</i>	Bu-3
	Southern shelf		71–220	21–23	20	49	<i>A. ammoniformis</i> , 32 <i>A. compacta</i> , 28 <i>Lagenida</i> , 25	<i>Py. elongata</i> , <i>N. matagordanus</i> , <i>Cr. poeyanum</i>	Sh-1
	Northern Bosphorus exit	100–120	26.2	10	79	<i>A. ammoniformis</i> , 32 <i>A. compacta</i> , 28 <i>Lagenida</i> , 13	<i>Bolivina</i> , <i>Brizalina</i> , <i>Pyrgo</i>	Bo	

Table 2. Live foraminiferal assemblages of the Caspian Sea.

Part of Caspian Sea	Connection with Caspian Sea	River Discharge	Area	Depth, m	Salinity, ‰	No. of Stations	No. of Species	Dominant Species, max %	Accessory Species	Assemblage Index
Northern	Free	Very strong	Volga River delta	>3	0.1–7.5 (avg 2.3)	10	3	<i>A. caspica</i> , 96	<i>Ma. brotzkajae</i> , <i>M. fusca</i>	Vo
		Strong	Northeastern inner shelf	>17	7–9	11	9	<i>A. caspica</i> , 73 <i>Am. verae</i> , 17	<i>Ma. brotzkajae</i>	NC-1
		Weak	Northwestern inner shelf	>22	9–12	11	9	<i>A. caspica</i> , 66 <i>Am. verae</i> , 19	<i>E. caspicum caspicum</i> , <i>M. fusca</i>	NC-2
Central	Free	Strong	Western inner shelf	>35	11–12.5	11	11	<i>Am. verae</i> , 31 <i>A. caspica</i> , 23	<i>C. minuscula</i>	CC-1
		Weak	Western outer shelf	36–70	12.4–12.9	11	3	<i>A. caspica</i> , 88	<i>M. fusca</i> , <i>C. minuscula</i>	CC-2
		Absent	Eastern inner shelf	>35	12.7–13	11	14	<i>A. caspica</i> , 50	<i>E. caspicum caspicum</i>	CC-3
	Eastern outer shelf		36–70	12.7–13	11	3	<i>A. caspica</i> , 89	<i>M. fusca</i> , <i>C. minuscula</i>	CC-4	
	Restricted in 1968 Absent in 1981 Free in 1968	Absent	Krasnovodsky Bay	>5	14–15	11	17	<i>Am. verae</i> , 55	<i>S. perexilis</i>	Kr
			Kara-Bogaz–Gol Bay	>2	13–14	11	13	<i>A. caspica</i> , 54 <i>B. macrostoma</i> , 28	<i>T. aguajoi</i>	KBG-1
			Kara-Bogaz–Gol Bay	>2	60–65	11	4	<i>T. aguajoi</i> , 80	<i>B. macrostoma</i>	KBG-2
Kara-Bogaz–Gol Strait	>2	12.2–13.3	11	12	<i>A. caspica</i> , 43	<i>Am. verae</i>	KBG-s			
Southern	Free	Very strong	Kura delta	>10	>3	6	3	<i>A. caspica</i> , 97	<i>Ma. brotzkajae</i>	Kd
		Absent	Western inner shelf	>35	12.2	11	18	<i>E. caspicum caspicum</i> , 20	<i>E. shohinae</i>	SC-1
			Western outer shelf	36–70	12.8	11	3	<i>A. caspica</i> , 91	<i>M. fusca</i>	SC-2
		Weak	Turkmensky Bay	>35	12.6–13.2	11	12	<i>A. caspica</i> , 70	<i>E. caspicum caspicum</i>	Tu
		Absent	Eastern inner shelf	>35	13	11	18	<i>A. caspica</i> , 66 <i>E. caspicum caspicum</i> , 22	<i>E. shohinae</i>	SC-3
Eastern outer shelf	36–70		13.1–13.8	11	3	<i>A. caspica</i> , 58	<i>M. fusca</i>	SC-4		

Addendum: Faunal reference list of benthic foraminiferal species included in the text and Tables 1 and 2 (in alphabetical order).

- Ammobaculites ponticus* **Mikhalevich** (1968:15, pl. I, fig. 4). Yanko (1979: pl. 24A, fig. 6; 1982: pl. V, fig. 3; 1989:8–10, pl. 1, figs 7, 8). Yanko and Troitskaya (1987:14, pl. 1, fig. 1).
- Ammonia ammoniformis* (**d'Orbigny**) = *Rotalia* (turbinuline) *ammoniformis* d'Orbigny (1826:174, pl. 12, fig. 149). Yanko and Troitskaya (1987:42, pl. X, figs 1–10). Yanko (1989:169–177, pl. XXVII, figs 1–12; pl. XXVIII, figs 1–9; pl. XXIX, figs 1–5).
- Ammonia agoiensis* **Yanko** (1990b:24, pl. I, fig. 1; pl. II, fig. 1; 1989:167–169, pl. XXIX, fig. 6).
- Ammonia caspica* **Shchedrina** = *Ammonia beccarii caspica* Mayer (1968:28, fig. 48) = *Ammonia neobeccarii caspica* Shchedrina (Shchedrina and Mayer 1975:255, figs 1–8). Yanko (1989:177–179, pl. XXX, figs 1–9).
- Ammonia caucasica* **Yanko** (1990b:25, pl. I, figs 2, 3; pl. II, fig. 5; 1989:179, pl. XXXI, figs 1–6; pl. XXXII, figs 1–12).
- Ammonia compacta* (**Hofker**) = *Streblus compactus* Hofker (1969:99, figs 242, 243) = *Ammonia neobeccarii pontica* Yanko (1979:82, pl. 24B, fig. 2). Yanko and Troitskaya (1987:44, pl. XI, figs 1–10). Yanko (1989:182–185, pl. XXXIII, figs 1–9).
- Ammonia novoexinitica* **Yanko** (1979: pl. 24B, fig. 1; 1990b: pl. 2, fig. 7; 1989:185–187, pl. XXXIV, figs 1–11). Yanko and Troitskaya (1987:46, pl. XII, figs 1–3).
- Ammonia parasovica* **Shchedrina and Mayer** (1975:255, pl. 2, figs 4–6). Yanko and Troitskaya (1987:47, pl. XII, figs 4–6). Yanko (1989:187, 188, pl. XXXV, figs 1–10; pl. XXXVI, figs 1–9).
- Ammonia tepida* (**Cushman**) = *Rotalia beccarii* (Linnaeus) var. *tepida* Cushman (1928:79, pl. 1). Yanko and Troitskaya (1987:48, pl. 12, figs 7–12). Yanko (1989:192–195, pl. XXXVIII, figs 1–9; pl. XXXIX, figs 1–9).
- Ammoscalaria verae* (**Mayer**) = *Ammotium* (?) *verae* Mayer (1968:21, fig. 40). Yanko (1989:12, 13, pl. II, fig. 3).
- Aubignyna perlucida* (**Herron-Alen and Earland**) = *Rotalia perlucida* Herron-Alen and Earland (1913:139, pl. 13, figs 7–9). Yanko (1979: pl. 24B, fig. 5; 1982: pl. 4, fig. 1; 1989:226–229, pl. XLVIII, fig. 3; pl. XLIX, figs 1–4). Yanko and Troitskaya (1987:36, pl. VII, figs 6–9; pl. VIII, fig. 1).
- Birsteinia macrostoma* **Mayer** (1974:25, fig. 19). Yanko (1989:17–19, pl. III, fig. 1).
- Canalifera nigarensis* (**Cushman**) = *Elphidium nigarensis* Cushman (1939:63, pl. 17, fig. 19). Yanko and Troitskaya (1987:50, pl. XIII, figs 1–5). Yanko (1989:197–200, pl. XL, figs 6–8; pl. XLI, figs 1–3).
- Canalifera parkerae* (**Yanko**) = *Criboelphidium parkeri* Yanko (1974:24, pl. I, fig. 1) = *Nonion* sp. B (Parker 1958:191, pl. 1, figs 40, 41). Yanko and Troitskaya (1987:51, pl. XIV, figs 1–6). Yanko (1989: 201–204, pl. XLII, figs 1–9; pl. XLIII, fig. 1).
- Cornuspira minuscula* (**Mayer**) = *Cyclogyra minuscula* Mayer (1972:33, fig. 5). Yanko (1982: pl. 5, fig. 5; 1989:25, 26, pl. IV, fig. 1).
- Criboelphidium poeyanum* (**d'Orbigny**) = *Polystomella poeyana* d'Orbigny (1839:55, pl. 6, figs 25, 26). Yanko (1979:84, pl. 24F, fig. 2; 1982: pl. 1, fig. 4; 1989:262, pl. LXI, figs 1–6; pl. LXII, fig. 1). Yanko and Troitskaya (1987:58, pl. XXI, figs 4–6). Yanko *et al.* (1998: pl. 1, fig. 15).
- Eggerella scabra* (**Williamson**), 1858 = *Bulimina scabra* Williamson (1858:604–605, pl. 5, figs 136, 137). Yanko (1989:22–24, pl. III, figs 5–7).
- Elphidium caspicum azovicum* **Yanko** (Yanko 1989:243–246, pl. LIII, figs 3–7; pl. LIV, figs 1–4).
- Elphidium caspicum caspicum* **Yanko** (1989:242–243, pl. LIII, figs 1, 2) = *Elphidium littorale caspicum* Mayer (1968:31, fig. 50) = *Elphidium caspicum* (Yanko and Troitskaya 1987:55, pl. XV, fig. 4).
- Elphidium ponticum* (**Dolgopol'skaya and Pauli**) = *Elphidium advenum* var. *pontica* Dolgopol'skaya and Pauli (1931:36, pl. III, fig. 14) = *Elphidium ponticum* (Mikhalevich 1968:19, pl. 6, fig. 2). Yanko (1979: pl. 24F, fig. 1; 1982: pl. 1, fig. 1; 1989:254–257, pl. LVII, figs 1–4; pl. LVIII, figs 1–4). Yanko and Troitskaya (1987:56, pl. XVI, fig. 3; pl. XVII, fig. 1–3).
- Elphidium shohinae* **Mayer** (1968:32, fig. 51; 1974:34, fig. 26). Yanko (1989:257–258, pl. LIX, figs 4, 5).
- Entolingulina deplanata* **Yanko** (1979: pl. 24A, fig. 4; 1982:130, pl. III, fig. 5; 1989:113–114, pl. XV, figs 5–7). Yanko and Troitskaya (1987:27, pl. IV, figs 7, 8).
- Eosyrinx jatzkoi* **Yanko** (1974:28, fig. 3; 1979: pl. 24A, fig. 7; 1989:107–108, pl. XIV, figs 4–6). Yanko and Troitskaya (1987:26, pl. IV, figs 3, 4).
- Fissurina lucida* (**Williamson**) = *Entosolenia marginata* (Montagu) var. *lucida* Williamson (1858:17, pl. 2, fig. 17). Voorthuysen (1973:46, pl. 5, fig. 9). Yanko and Troitskaya (1987:30, pl. V, figs 1–12). Yanko (1989: 122–125, pl. XVI, figs 6–17).
- Fissurina solida* **Seguenza** (1862:56, pl. 1, fig. 42) = *Fissurina* ex gr. *solida* (Yanko and Troitskaya 1987:33, pl. VI, figs 6–9). Yanko (1989:128–129, pl. XVII, figs 3–10).
- Haynesina anglica* (**Murray**) = *Protelphidium anglicum* Murray (1965:149, pl. 25, figs 1–5). Yanko and Troitskaya (1987:54, pl. XX, figs 1–3). Yanko (1989:232–235, pl. L, figs 1–7; pl. LI, figs 1–6).
- Jadammina polystoma dacica* **Tufescu** (1973:28, pl. I, fig. 2a-b).
- Lagena vulgaris* **Williamson** (1858:3, pl. 1, fig. 5). Yanko (1979: pl. 24A, fig. 2; 1982: pl. 3, fig. 6; 1989:101–103, pl. XIII, figs 12–14). Yanko and Troitskaya (1987:25, pl. III, figs 13, 14).
- Laryngosigma williamsoni* (**Terquem**) = *Polymorphina lactea* var. *oblonga* d'Orbigny (Williamson 1958:71, pl. 6, fig. 149) = *Polymorphina williamsoni* Terquem (1878:37). Mikhalevich (1968:18, pl. V, fig. 3). Yanko (1982: pl. III, fig. 7; 1989:111–113, pl. XV, figs 3, 4). Yanko and Troitskaya (1987:27, pl. IV, figs 5, 6).
- Massilina secans* (**d'Orbigny**) = *Quinqueloculina secans* d'Orbigny (1826:303, pl. 43, fig. 96). Yanko (1982: pl. 3, fig. 2; 1989:65–68, pl. X, fig. 5). Yanko and Troitskaya (1987:22, pl. II, fig. 9).
- Mayerella brotzkajae* (**Mayer**) = *Elphidiella* (?) *brotzkajae* Mayer (1968:33, fig. 52; 1974:35, fig. 28). Yanko and Troitskaya (1987:60, pl. XXII, figs 1–3; pl. XXIII, figs 1–4). Yanko (1989:272–274, pl. LXIV, figs 2–4; pl. LXV, figs 1–4; pl. LXVI, fig. 2).

- Mayerella kolchidica* Yanko (1989:274–275, pl. LXVI, fig. 3) = *Mayerella* ex gr. *brotzkajae* (Yanko and Troitskaya 1987:61, pl. XXIV, fig. 2).
- Miliammina fusca* (Brady) = *Quinqueloculina fusca* Brady (1870:286, pl. XI, figs 2, 3). Mayer (1968:23, fig. 41; 1974:23, fig. 18). Yanko (1989:15–17, pl. II, fig. 5).
- Nonion matagordanus* Kornfeld = *Nonion depressulus* (Walker and Jacob) var. *matagordana* Kornfeld (Cushman 1939:21, pl. 5, figs 23–25). Yanko (1979: pl. 24B, fig. 4; 1982: pl. IV, fig. 2; 1989:154–157, pl. XXIV, figs 1–5). Yanko and Troitskaya (1987:40, pl. 9, figs 7–9).
- Parafissurina dzemetinica* Yanko (1979: pl. 24A, fig. 3, 1982:130, pl. 5, fig. 7; 1989:132–134, pl. XIX, figs 6–13). Yanko and Troitskaya (1987:34, pl. VII, figs 6–12).
- Parafissurina lateralis* Cushman = *Parafissurina* ex gr. *lateralis* Cushman (Yanko and Troitskaya 1987:35, pl. VI, figs 13–15). Yanko (1989:134–137, pl. XIX, figs 14–16).
- Porosonion martkobi ponticus* Yanko (1989:210–214, pl. XLIV, figs 1–4) = *Nonion martkobi* Bogdanovich (1947:30, pl. IV, fig. 4a-c) = *Nonion stelligerum* Dolgopol'skaya and Pauli (1931:31, pl. 3, fig. 12a, b) = *Porosonion martkobi* (Yanko and Troitskaya 1987:52, pl. 18, figs 1–4) = *Protelphidium martkobi* (Yanko 1979: fig. 24F, fig. 3; 1982: pl. 2, fig. 2) = *Criboelphidium martkobi* (Mikhalevich 1968:20, pl. 7, fig. 1).
- Porosonion martkobi tshaudicus* Yanko (1989:215–218, pl. XLV, figs 1, 2).
- Pyrgo elongata* (d'Orbigny) = *Biloculina elongata* d'Orbigny (1826:298, fig. 4). Yanko and Troitskaya (1987:21, pl. 2, figs 5, 6). Yanko (1989:70–72, pl. XI, figs 1, 2).
- Quinqueloculina bicornis* (Walker and Jacob) = *Serpula bicornis* Walker and Jacob (1978:633, pl. 14) = *Quinqueloculina* ex gr. *bicornis* (Yanko and Troitskaya 1987:17, pl. 1, fig. 9). Yanko (1982: pl. III, fig. 4; 1989:3–34, pl. IV, figs 5–10).
- Quinqueloculina laevigata* (d'Orbigny) = *Triloculina laevigata* d'Orbigny (1826:134, pl. IV, fig. 1) = *Quinqueloculina laevigata* (Cushman 1922:65, pl. 13, fig. 2). Mikhalevich (1968:17, pl. III, fig. 2). Yanko and Troitskaya (1987:18, pl. 1, fig. 10). Yanko (1989:42–45, pl. VI, figs 6–9; pl. VII, figs 1, 2).
- Quinqueloculina seminulum* (Linnaeus) = *Serpula seminulum* Linné (1767:1264, fig. 1) = *Quinqueloculina seminulum* (Williamson 1858:86, pl. 7, figs 183–185) = *Quinqueloculina pseudoseminula* (Mikhalevich 1968:17, pl. 4, fig. 1). Yanko (1979: pl. 24A, fig. 1; 1982: pl. 3, fig. 1). Yanko and Troitskaya (1987:20, pl. 2, figs 3, 4). Yanko (1989:55–57, pl. VIII, figs 5–9).
- Spiroplectinata perexilis* Mayer (Mayer 1968:24, fig. 44). Yanko (1989:21–22, pl. III, fig. 4).
- Trichyalus aguajoi* (Bermúdez) = *Discorbis aguajoi* Bermúdez (1935:204, pl. 15, figs 10–14) = *Discorbis instans* Mayer (1968:26, fig. 46). Tufescu (1974: pl. IV, fig. 19). Yanko (1989:163–165, pl. XXVI, figs 5, 6).

