Was the Black Sea catastrophically flooded in the Early Holocene – a new perspective from the large scale geological survey of the northwestern shelf

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Introduction

Was the Black Sea catastrophically flooded in the Early Holocene or not? This question has been hotly debated since Ryan et al. (1997) first proposed their hypothesis of a catastrophic inflow of Mediterranean seawater into a Black Sea freshwater lake (locally called the Neoeuxinian Lake) at 7.2 ka BP. This hypothesis claimed that a massive inundation of the Black Sea basin and ensuing large-scale environmental changes drastically impacted early societies in coastal areas, forming the basis for Great Flood legends and other folklore, and accelerating the spread of agriculture into Europe. This scenario (called here the "Flood Hypothesis") was widely publicized and discussed in the general media. In response to criticism, and based on reevaluation of old data as well as new data, the authors of the Flood Hypothesis pushed the date of their inundation back 1200 years to 8.4 ka BP (Ryan et al. 2003). Instead of a single inundation, two lowstands (–120 m at 13.4–11.0 ka BP; and –95 m at 10.0–8.4 ka BP) and two catastrophic floods (sea-level rise from –120 to –30 m at 11.0–10.0 ka BP; and from –95 to –30 m at 8.4 ka BP) were proposed. The second of these two major transgressions was labeled the Great Flood. The initial Flood Hypothesis was based on evidence from seven short (about 1.25 m each), low-resolution sediment cores and 350 km of seismic profiles collected within a fairly restricted area of the Black Sea's NW shelf at water depths between 49 and 140 m during a single mission in 1993.

By 1993, a large-scale (1:200,000, and in certain areas 1:50,000) geological survey of the NW and Caucasian Black Sea shelf was mostly completed; it was conducted to prepare for future underwater industrial infrastructures and mineral exploration. This survey was initiated and supported by the Soviet government and was based on a special methodology for marine geological survey developed by joint efforts of academia, educational institutes, and industries (e.g., Balabanov et al., 1993). Particular attention was given to morphological, lithological, geochemical, and paleontological markers of paleosea level stands and their geochronological control with consideration of a possible influence of neotectonics on paleogeographic reconstructions (e.g., Glebov and Shel'ting, 2007). Most of the authors of the present paper participated in this survey, contributing their results to the Late Quaternary geological history of the region. As part of the survey, thousands of cores, tens of thousands of kilometers of seismic profiles, and hundreds of radiocarbon datings across the Black Sea shelf had been collected and studied in a multi-disciplinary effort (Yanko-Hombach et al., 2007). The NW shelf was studied particularly well, and a massive database described in numerous publications was accumulated. In none of the reports was there any mention of evidence for a catastrophic flooding of the basin in the Late Pleistocene-Early Holocene; none of the classical publications did either (e.g., Arkhangel'sky or Strakhov, 1938).

On the positive side, the Flood Hypothesis encouraged a new round of research in the region, including two ongoing multidisciplinary projects: IGCP 521 and INQUA 501 that both are focused on climate, sea-level change, and coastline migration in the Caspian-Black Sea-Mediterranean corridors during the glacial-interglacial climatic cycles of the past 30,000 years, and the possible influence of these factors in the emergence of complex societies and the early development of agriculture. The Flood Hypothesis is one of the most debated topics in both projects. While some authors have found supportive evidence for the Flood Hypothesis, others were strongly opposed (for more information see Yanko-Hombach et al., 2007; Yanko-Hombach et al., in press). Within this discussion, an intense polemic has developed around the methodology used by eastern scientists for sea-level and salinity reconstructions. Some authors recommend considering "many conclusions of studies [obtained by Eastern scientists]…with a grain of salt" (Giosan, 2007) due to the "uncertainty surrounding the Black Sea level [which] stems from a lack of reconstructions based on reliable sea level markers, a scarcity of radiocarbon ages on in situ materials…as well as ...possible tectonic influences … needed to establish the value of these reconstructions" (Giosan et al., 2009:3). Despite saying that a vast amount of data "collected by Soviet, Russian, Ukrainian, Romanian, or Bulgarian researchers especially over last 50–60 years … point clearly … a lack [of] access to primary data" (Giosan, 2007), these authors proposed their own version of the Flood Hypothesis using evidence from a single drill hole recovered at the Danube Delta and which they believe provides more reliable information than the hundreds of Eastern European studies based on a vast amount of geological data. Their research being widely publicized in the media stated that "In the early Holocene (8660 14-C years BP), immediately before the Black Sea reconnection to the ocean at 8400 14-C years BP … the contemporaneous level of the isolated Black Sea [was] above 40 mbsl." This statement is in a full agreement with previously published conclusions (Balabanov, 2007: 718; Yanko-Hombach, 2007: 173), which should have been at least mentioned in their narrative.

In this paper, we will present our view of whether the Black Sea was catastrophically flooded in the Early Holocene. Catastrophic is defined here as "very rapid (annual-decadal scale), irreversibly destructive events; any large and disastrous event of great significance; a disaster beyond expectations" (Grishin, 2001: 895). We will focus our attention on the lacustrine phase locally named Neoeuxinian Lake in order to show where its level was during the time intervals suggested by the modified Flood Hypothesis. To make it more visible, we will expose the Neoeuxinian deposits by taking away the Holocene sediment cover documented in geological transects performed across the NW shelf. We will also compare 14C dates obtained by the "Bulk" and AMS methods in order to find out whether "Bulk" data are really as unreliable as some authors (e.g., Giosan, 2007) consider. All radiocarbon dates in this paper are in non-calibrated years BP to remain comparable with those of other authors.

Study area

The study area includes the NW shelf of the Black Sea, ranging from the Ukrainian part of the Danube Delta to the NW coast of Crimea. This is a key region because: (1) it is the widest (125–240 km) shelf compared to other parts and encompasses about 25% of the total area of the sea; (2) it is located within stable platform-type structures with a gentle slope (0.001–0.002º), and there are no known expressions of active tectonic movements that would strongly affect reconstruction of shoreline positions in contrast to its southern margins which are tectonically active; (3) it has an excellent geological archive built by extensive sediment input from the Danube, Dniester, Bug, and Dnieper rivers in contrast to the narrow shelves along the Turkish coast, where river input and geological archive is much poorer, resulting in differential sedimentation rate, subsidence, compaction, and erosion (e.g., delta lobe-switching) at different locales; (4) it holds some of the most significant evidence of human prehistory and history in the region; and finally (5) it represents the "cradle" of the Flood Hypothesis in the Black Sea.

Material and methods

Sampling has been continuously performed since 1971 on various R/Vs using seismic profiling, and seafloor sampling by vibra-, gravity coring, and drilling. More than 1573 and 3935 sites were sampled on a grid 2x2 km and 0.5x0.5 km, respectively, and studied in a multidisciplinary effort (Yanko-Hombach, 2007). During the surveys, seabed surface samples were taken by grab samplers, together with measurements of seawater temperature and salinity to link modern faunas and floras with concurrent oceanographic conditions for proper paleogeographic reconstructions. The sampling network is shown in Fig. 1. The classification of Tchepalyga 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‰.

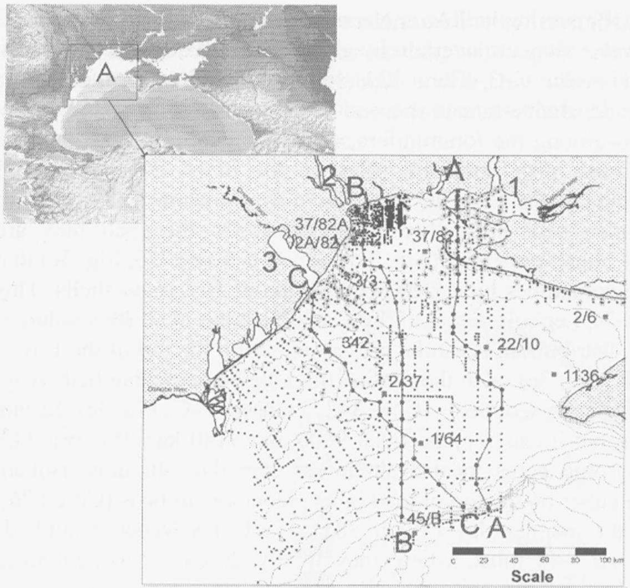

Fig. 1. Study area. In red squares exemplary cores studied by high-resolution microplaeontological studies and supplemented by 14C dating.

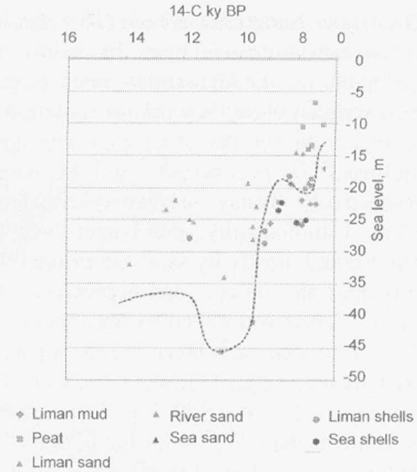

Figure 2. Curve of Neoeuxinian Lake level for time interval 16-7 ky BP.

Results

^{14}C dating

A variety of statistical methods were employed to find out whether "Bulk" and AMS data sets for this particular time interval are really different in their distribution (Null Hypothesis) or, whether some distributional differences can be assigned to random factors (Alternative Hypothesis). Our statistical model is based on the assumption that all observations belong to one entire population (in our case mollusk shells of Neoeuxinian affinity) and are independent. The entire population used for statistical analysis consists of 105 randomly chosen numerical data ranging between 8000 and 18,000. These data represent 14C (uncorrected) years BP obtained on mollusk shells of Neoeuxinian affinity (e.g., D. polymorpha, D. rostriformis, and Monodacna caspia, Turricaspia caspia lincta) in various laboratories and over many years by conventional [β-counting, called here "Bulk"] and AMS methods. Our statistical analysis demonstrates that, while the error of AMS dating is lower compared to that of the "Bulk" method, both methods used for 14C age determination of Neoeuxinian sediments give similar results. As such, there is a large and reliable 14C data set that can be used for paleogeographic reconstructions of the lacustrine stage of the basin, and there is no need to work with only a few numbers to make big conclusions.

Geology

The oldest sediments recovered by coring are represented by Tarkhankutian (=Surozhian) beds (Fig. 3a, Transect A-A, Core 728) below isobath –30 mbsl. They have a ^{14}C age 40–27 ka BP, and contain at least twelve species of Mediterranean benthic foraminifera and mollusks showing that this basin was connected to the Mediterranean Sea. At present, similar assemblages inhabit Odessa Bay, enabling us to conclude that the salinity of the Tarkhankutian Sea was around 11‰.

The Lower Neoeuxinian beds (with the youngest age of 17,400±500, Core 1533, Transect C-C, Fig. 3c) were recovered below isobath –90 m. They do not contain Mediterranean species: neither among foraminifera, nor ostracoda, nor mollusks. Foraminifera are represented by *A. caspica* and *Porosononion martkobi tschaudicus*, and mollusks by *Dreissena polymorpha*. A similar foraminiferal assemblage can be found today in some river deltas that discharge into the Black Sea, indicating semi-fresh (up to 5‰) salinity of the basin. No coastal dune-like sedimentological features were observed.

The Upper Neoeuxinian beds (16.7–8.8 ka BP) overlie the Lower Neoeuxinian beds in the cores located below isobath *ca.* –90 mbsl. In shallower water, they are overlain by alluvial deposits, and occasionally underlain by Tarkhankutian beds (e.g., Transect C-C, Core 723, Fig. 2c). Similar to the Lower Neoeuxinian beds, they do not contain a single Mediterranean species. Instead they are characterized by an increased number of Caspian immigrants among the foraminifera, ostracoda, and mollusks. Among mollusks, *D. polymorpha* and *D. rostriformis* play dominant roles on the inner and outer shelf, respectively. Today, similar assemblages inhabit the Caspian Sea, where they tolerate salinity up to 13‰. Lithologically, the Upper Neoeuxinian beds are rather monotonous. On the shelf they are represented mostly by sand, occasionally by bluish-grey mud (e.g., Transect C-C, Core 723, Fig. 3c) that fills pre-Late Neoeuxinian depressions, and sometimes by a bleached coquina of *Dreissena* shells. This coquina layer was called by Ryan et al. (1997), Lericolais et al. (2007), and Nicholas et al. (this volume) the "*Dreissena* hash layer"; it has a patchy distribution. It can be present either on the top of the Lower Neoeuxinian (e.g., Transect C-C, Core 1633, Fig. 3c) or in the roof of the Late Neoeuxinian beds (e.g., Transect C-C, Core 949, Fig. 2c), or even in liman sediments (Core 342, Transect C-C, Fig. 3c). Its age is younger than 17,400 ka BP (Core 1513), but it can vary between 9600 and 9140 ka BP (Core 342, Transect C-C, Fig. 3c). There is peat in some cores located shallower than the –46 mbsl isobath (Transect C-C, Fig. 3c), which is recovered either on the top of the Upper Neoeuxinian beds (Core 876), or at the bottom (Core 830), or throughout the sediment layer (Core 383). The Upper Neoeuxinian beds dovetail with liman sediments at isobath *ca.* –40 mbsl, where they totally disappear in geological transects.

Discussion

The geological history of the Neoeuxinian basin consists of two major parts. One (older) part corresponds to the LGM (between 27 and 17 ka BP) when the level of the lake stood below isobath –90 mbsl; another (younger) part corresponds to an increase in the lake level up to –40 mbsl due to Caspian transgression via the Manych Spillway sometime between *ca.* 17 and 9 ka BP. The dovetailing of the Lower Neoeuxinian beds with alluvial sediments shows that a large portion of the present shelf was exposed, eroded, and downcut into the basement by the Pre-Danube, Pre-Dnieper, and Pre-Dniester rivers. These rivers had poorly developed deltas, their mouths were relocated 80–100 km seaward, they opened directly into the Early Neoeuxinian basin, into which they brought species of freshwater ostracods as well as freshwater and terrestrial gastropods often filled with soil particles, which are mixed with brackish shallow-water ostracods, foraminifera, and mollusks.

The "Dreissena hash layer" was formed most certainly below isobath –30 mbsl (supported by the presence of muddy particles) and was transported by currents to the deeper part of the Late Neoeuxinian basin as was correctly stated by Arkhangel'sky and Strakhov (1938), who suggested that reworked Dreissena shells were mass-transported from shallow to deeper parts of the lake. We can add that the Caspian transgression via the Manych Outlet contributed significantly to an increase in hydrodynamic activity in the Late Neoeuxinian Lake. In turn, this provided not only transport of the "Dreissena hash layer" but its patchy distribution and numerous Caspian organisms across the present shelf.

The claim of Lericolais et al. (2007b: 177) that the Black Sea shoreline was at –100 m until about 8.5 ka BP based on the dune-like features at that depth does not seem to be correct. It comes from CHIRP sonar profile correlation with a shallower core site >100 m distant, where the Holocene section is only ~0.7 m thick. CHIRP sonar profiles have an optimal vertical resolution of 10–15 cm; at best, this condensed core thickness means that the age of the dune top could be 9500 or older. According to Badyukova (this volume), (1) there are no opportunities for dunes to persist at the sea bottom in any transgressive scenario; (2) transgressive parasequences always occur during the transgression: marine and lagoon deposits accumulate with rising relative sea level during the landward migration of a coastline, so they lie on the coastal plain deposits. Stratigraphic discordance in this case is regular, and it does not indicate erosion during a catastrophic sea-level rise, as Lericolais et al. (2007a,b) consider. Our results seem to be in a full agreement with Badyukova's conclusion. We cannot find any lithological sign of drowned windblown dunes described by Lericolais.

Neither the Early nor Late Neoeuxinan basin was freshwater as was suggested by Soulet et al. (2010) and Lericolas (this volume) based on their study of pore water salinity in a single core located at a water depth of –350 m in the Danube transect. Although this site is located below the halocline, their model treats the situation as if they were dealing with surface water. Moreover, their reconstructions totally ignore a vast amount of paleontological data (for full reference list see Yanko-Hombach, 2007) that contradicts their conclusion and shows that the Neoeuxinian Lake was semi-fresh at the LGM, and then brackish, and in both cases aerobic.

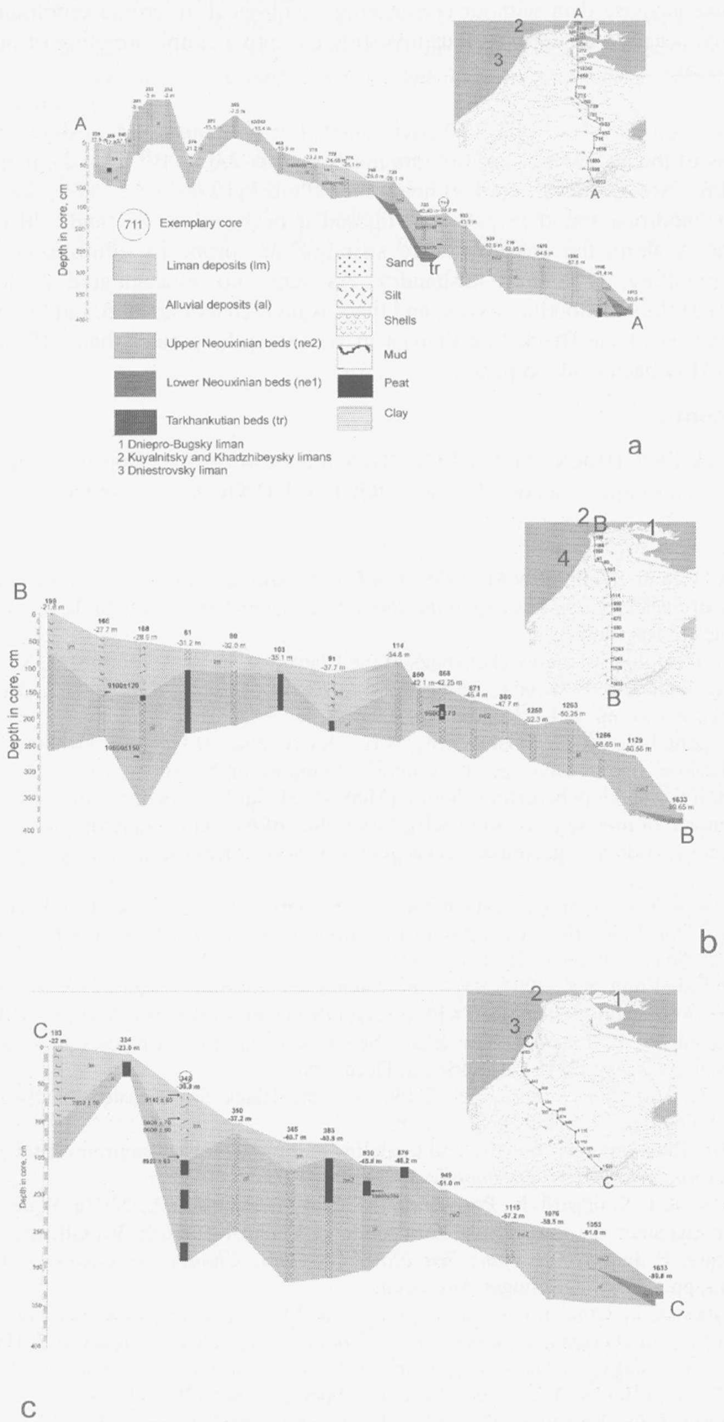

Figure 3. Geological transects across the NW Black Sea shelf. Core water depth is given below core number. Legend is given in Fig. 3a.

Neither our core 342 (Transect C-C, Fig. 3c) nor our cores 721 (Yanko-Hombach, 2007) or 45B (Fig. 1) dated by Nicholas et al. (this volume) demonstrate any evidence for rapid transgression of the Neoeuxinian Lake by Mediterranean-sourced water as suggested by the authors. Their interpretation of isotopic data is given without consideration of the analysis of geologic data in which geologic history is "conserved." Isotopic dating is NOT the only kind, although it is very important and can be a useful instrument. To use isotopic data without considering lithological, micropaleontological, palynological, etc. information can easily transform serious investigation into a simple juggling of numbers that do not make geologic sense.

Conclusions

In reconstructions of the basin level for the time interval 16.0–2.0 ka BP (Fig. 2), it can be seen that the level of the brackish Neoeuxinian Lake was neither –120 mbsl (13.4–11.0 ka BP), nor was it –95 mbsl as suggested by the modified Flood Hypothesis. Instead it occurred at –37 and –20 mbsl, respectively. Exposed shelf areas along the coastline were swampy and prone to salinization, not favorable for arboriculture, agriculture, or animal husbandry. As such, no substantiated geologic evidence for catastrophic Early Holocene flooding exists, and there is no archaeological or palynological evidence for prehistoric occupation of the Black Sea shelves in water depths greater than –10 m near the modern coastline (Yanko-Hombach et al., in press).

Acknowledgments

We sincerely thank PRICHERNOMORGEOLOGIA for use of their coring material as well as archive data for our study. This paper is a contribution to IGCP 521-INQUA 501 project.

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