SYNTHESIS OF THE IGCP 610 RESULTS: SOME CONTROVERSIES AND PARADOXES

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Introduction

As a result of many years of work in the framework of successive projects, including IGCP 521 and 610, a large set of multidisciplinary data has been accumulated. It is a time to synthesize these data. By doing this, one can see at least one fundamental problem, namely, the earth science data do not correspond to empirical ones. This may be related to logical errors in the construction of arguments and judgments, imperfection of currently available scientific methods, or insufficient accuracy of the instruments used, as well as the inadequacy of the adopted idealization, that is, an incorrect theory axiomatization. This can also be a result of the fact that some aspects of science are picked up by investigators individually despite of all efforts made by the management of IGCP 521 and 610 to integrate different areas of research. For example, geological and paleontological records indicate that during last 20 ka the Black Sea level fluctuated in a gradual but oscillating manner (Balabanov, 2007; Yanko-Hombach, 2007; Yanko-Hombach et al., 2014) while mathematical modeling shows that such fluctuations were not possible (Esin and Esin, 2014). The existence of these contradictions, called by us paradoxes, is discussed in the present paper, which encourages a new round of research that could lead to a deeper understanding of climate change theory.

Methodology

Two methodologies were used in our investigations. The first one included geological and paleontological investigations of coastal outcrops (mainly stratotypes) and bottom sediments for reconstruction of the climate and hydrological regime of the Caspian and the Black seas. The second one applied different mathematical techniques (simple models and Earth system models) for the same purposes (Kislov et al., 2014; Kislov, 2016). The results obtained hardly if never corresponded to each other.

Results, discussion, and conclusions

Paradox no. 1. According to geological data, there were several epochs, such as the Late Khvalynian one, when the Caspian Sea level was so high that its water spilled into the Black Sea. It is clearly indicated by the presence of Caspian fauna in the form of mollusks (Yanina, 2012) and foraminifera (Yanko, 1990) in the Black Sea. It is not clear what source of additional water could have filled up the basin. For realization of an event such as the Late Khvalynian transgression, inflow of approximately ~300-1000 km^3/year (several additional Volga Rivers) would be required. This paradox puts forward the contradiction between full-flowing rivers, the fact of transgression, and at the same time the presence of spillover into the Black Sea, all of which lacks an explanation for the origin of the water source.

Paradox no. 2. According to geological data, there were rather large and irregular fluctuations (secular-scale, decade-scale) of both the Caspian and Black sea levels. Sometimes, they can be correlated with climate events (Martin and Yanko-Hombach, 2011) but more often not; they appear to be self-generating events. We can assume that this paradox will eventually be resolved somehow by a logical (quantitative) explanation based on the concept of accumulation of small random fluctuations leading to the slow variations in the volume of the seas (the principle of Brownian motion) (Kislov, 2016).

Paradox no. 3. Some authors (Aksu et al., 2016) claim a large water discharge from the Black Sea into the Sea of Marmara via the Bosphorus Strait at the beginning of the Holocene while others (Balabanov, 2007; Yanko-Hombach, 2007; Martin and Yanko-Hombach, 2011; Yanko-Hombach et al., 2014) insist on the fluctuating character of the Black Sea level at the same time interval. These hypotheses contradict each other because, from a mathematical point of view, they could not co-exist simultaneously.

All three paradoxes will be discussed in the presentation. It will be shown that Paradox no. 2 can be explained somehow, while Paradoxes no. 1 and no. 3 are much more difficult to explain, although some preconditions for the solution of these problems do exist. These preconditions will be addressed by the authors.

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THE KARANGATIAN EPOCH (MIS 5E) IN THE BLACK SEA BASIN

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Introduction

Black Sea Quaternary history shows an alternation of transgressive and regressive stages that are related to global climate change; they appear pronounced due to semi-isolation from the World Ocean. In warm periods, the Black Sea was connected to the Mediterranean Sea (i.e., World Ocean) via connecting seas and straits. In cold periods, it became isolated or connected to the Caspian Sea via the Manych outlet. During transgressions, sea level rose as did salinity. During regressions, when it dropped below the Bosphorus sill, the basin was transformed into an isolated lake. During transgressions, organisms migrated into the Black Sea from either the Mediterranean or Caspian. Such migrations affected assemblage structure and increased the number of species, especially in the case of Mediterranean transgressions. During regressive stages, the number of species dropped, and only some holeuryhaline Mediterranean species could survive the lowering of salinity (Yanko-Hombach, 2007).

The first Quaternary penetration of Mediterranean water into the Pontic basin occurred at the end of Chaudian (Karadenizian) time, ca. 580-505 ka BP. Penetrations were repeated again and again in the Late Oldeuxinian (ca. 287.0-292.6 ka BP), Middle and Late Uzunlarian (ca. 235.6-198.7 ka BP), Karangatian (ca. 122.9-73.7 ka BP), Tarkhankutian (ca. 40-27 ka BP), and Holocene (9.4 ka BP-present) times.

Sediments with abundant Mediterranean mollusk shells were initially described by N.I. Andrusov in 1925 on Cape Karangat, Kerch peninsula, in the early XX century. He called them Tyrrhenian, as they were similar to those in the Tyrrhenian beds that form a coastal terrace in the Mediterranean. This similarity enabled him to conclude that the Mediterranean and Black Sea basins were connected to each other. Later, the Tyrrhenian beds were renamed Karangatian by A.D. Arkhangel'sky and N.M. Strakhov (1938) and were studied by numerous scientists including the present authors.

The purpose of the present study is to provide detailed stratigraphy and reconstruction of the sea level and salinity changes of the Black Sea during the course of the Karangatian transgression using foraminifera and lithological properties of the sediments as the main tools. As such, this presentation describes in detail the Karangatian transgression that was the most prominent compared to all others, increasing salinity in the Pontic basin to at least 30 psu, which is 1.5 times higher than the average salinity in the Black Sea today. Clear traces of this transgression are preserved in coastal outcrops exposed in tectonically elevated terraces of the Kerch and Taman peninsulas, and in the Caucasus. They are also found in numerous cores and drill holes recovered from the Black Sea bottom.

Materials and methods

Material has been continuously collected since 1971. In the Black Sea, 112 Pleistocene outcrops (including all Eo- and Neopleistocene stratotypes) located on elevated terraces of the Kerch-Taman Peninsula and Caucasus (Fig. 1) (Yanko, 1990; Yanko et al., 1990) as well as

56 boreholes (Yanko and Gramova, 1990) and ~4000 gravity/vibracores on the shelf, were studied (Figs. 1, 2).

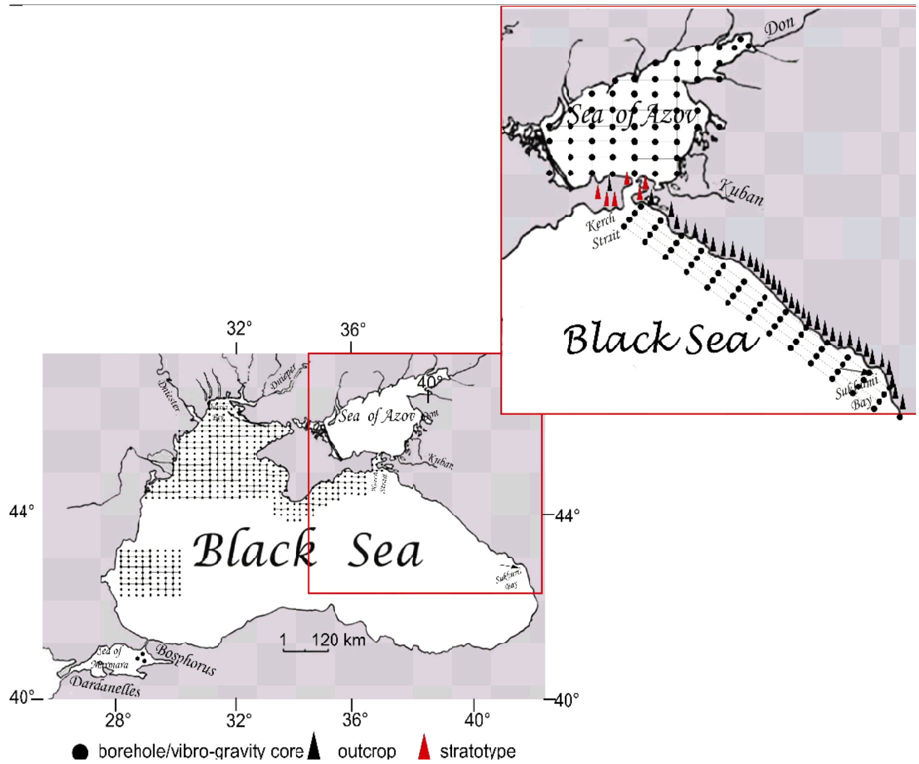

Figure 1. Studied area with schematic location of outcrops, drill-holes, gravity and vibrocores.

In addition, eighteen boreholes from the Bosphorus Strait, Sea of Marmara, Izmit Gulf, and Sakarya were investigated (Meric et al., 1995). The Eastern Mediterranean foraminifera were studied in the course of the EU AVICENNE project (Yanko et al., 1998).

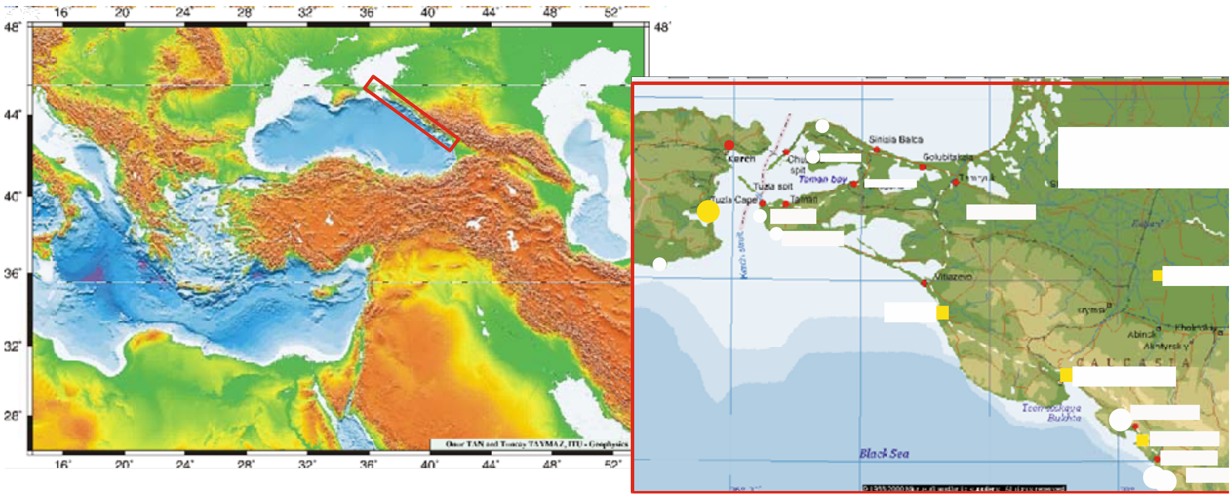

Figure 2. A - Caspian-Black Sea-Mediterranean Corridors, B - study area with Karangatian outcrops (marked by circles).

Materials from the Eastern Mediterranean, the Sea of Marmara, and the Caspian Sea were used as supporting evidence for the origin of the Black Sea foraminifera as described in Yanko-Hombach (2007). Representative collections of foraminifera from studied basins are now stored in the Museum of Natural History, Paris; the Paleontological Museum of Odessa at I.I. Mechnikov National University, Odessa, Ukraine; and at the Avalon Institute of Applied Science, Winnipeg, Canada. At present, 350 species are on file.

The foramifera 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% = frequent, 9-1% = rare, and <1% = trace. According to their ecological preferences, foraminifera are divided into oligohaline (1-5 psu), strictoeuryhaline (11-26 psu), polyhaline (18-26 psu), euryhaline (1-26 psu), shallow (0-30 m), relatively deep (31-70 m), and deep (71-220 m) species (Yanko-Hombach, 2007: Table 1).

Our ecostratigraphic technique is largely based on the 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.

The most complete marine sequence of the Karangatian transgression is found in the Eltigen section on the Kerch peninsula, in a cliff 3-4 km long on the western coast of the Kerch Strait (Yanko et al., 1990; Dodonov et al., 2001). The Karangatian marine deposits, 20-25 m thick, overlie Sarmatian Clays (Late Miocene) and are overlain by Late Pleistocene loesses, 7-8 m thick, with one or two weakly developed paleosols. The composition of the Karangatian deposits in Eltigen shows nine sedimentary units corresponding to six cycles of sea-level and salinity change.

Unit 1 reveals a lagoonal facies formed in isolation from the sea, such as bluish clays with one oligohaline foraminiferal species: *Mayrella brotzkajae*. The closest recent assemblage (D) inhabits the Danube delta today Yanko-Hombach, 2007, Table 1). The paleosalinity was 2-3 psu; the paleowater depth <3 m. U/Th dating (LU-4202) yielded 127±8.9 ka (Dodonov et al., 2000).

Unit 2 contains clayey silt interbedded with sand and clay. It was deposited during a transition from continental to marine conditions, and it is subdivided into subunits 2a and 2b. The foraminiferal assemblage includes 8 species. The closest recent assemblages to Units 2a and 2b inhabit today the Berezansky (B) and Khadzhibeisky (Kh) limans, respectively. The paleosalinity increases upwards from 2 psu to 12 psu. The paleowater depth was >5 m. The U/Th dates (LU-4203) yielded 107±7.7 ka (Dodonov et al., 2000).

Unit 3 represents an open lagoon facies consisting of bioturbated greenish-gray sands and clays. The number of foraminiferal species increases from 7 to 12 in subunits 3a and 3b, respectively. Similar assemblages inhabit today the Khadzibeisky liman (Kh) and Odessa Bay (Od-1), respectively, indicating an increase in paleosalinity from 11 psu to 19 psu, and a paleodepth >12 m.

Unit 4 comprises fluvial and sandy clays; it overlies Unit 3 and is marked by an unconformity that formed in the open bay surf area (subunit 4a). In subunit 4b, it changes to cross-bedded sands and then (to the north) to clays. A similar assemblage is found in the Sea of Azov (A) today. The number of foraminiferal species increases from 6 (subunit 4a) to 9 (subunit 4b) indicating an increase in paleosalinity from 12 psu to 15 psu, respectively. The paleowater depth was >12 m.

Unit 5 incorporated cross-bedded gravel, sand, and sandy limestone formed in the surf area (subunit 5a), and horizontal, non-layered, poorly- or well-sorted deposits formed in a lagoon. The number of foraminiferal species is three. Similar assemblages today inhabit the limans permanently connected to the sea and having insignificant river input, such as Berezansky (B) and Golovitsa (G). Paleosalinty varies between 2 psu and 7 psu, paleowater depth is >9 m. While clays show a lagoonal genesis, the sands were formed under lacustrine conditions.

Unit 6 is composed of coarse- to fine-grained bioclastic sands; it overlies Unit 5 with an unconformity enriched in bivalve shells, and gravelites with gentle and steep bedding. The foraminiferal assemblage includes 45 species, most of which do not live in the Black Sea today but are widely distributed in the Aegean Sea (A). Genetically, they were formed in coastal areas with medium hydrodynamic activity, and long shore currents that sometimes change their direction. *Cardium tuberculatum* appears among the mollusks, together with other Mediterranean mollusks (23 species). All of them have large, thick, and well ornamented shells. They form bioherms. There is no similar foraminiferal assemblage in the Black Sea today. The closest one in existence today inhabits the Aegean Sea at water depths up to 80 m and salinity of 32.6 psu. Bioherms are indicators of shallow warm water, an absence of turbidity, and a medium hydrodynamic regime formed under salinity at least 25 psu. The U/Th dates yield 80-100 ka (Dodonov et al., 2000).

Unit 7 is represented by limestones, bioherms, and bioclastic sands overlying the lower unit with an unconformity. In the middle part of Unit 7, there is a clay diapir of Sarmatian age. Bioherms consist of *Ostrea*, *Serpula*, algal, and Bryozoan limestones. The foraminiferal assemblage includes 44 species (subunit 7a).

Unit 8 contains pink sands and shelly gravelites that were formed in a coastal zone. The number of foraminiferal species is 11. The closest example among recent assemblages today inhabits the Sea of Azov (A). The paleosalinity was about 13 psu and paleodepth >15 m.

Unit 9 is represented by loams with two to three horizons of fossil soil indicating continental conditions of sedimentogenesis. No foraminifera are present.

In summary, there is clear stratification of the outcrop revealing six transgression-regression cycles in the levels and salinity changes. Progressive distribution of bioherms to the north the transgression was developing from the south to south-east. In the course of the transgression, the salinity increased from 0.2 to 30 psu, and then dropped to 12 psu. An increase in salinity indicates that the Black and Mediterranean seas were connected to each other. A decrease in salinity indicates restricted connection between the basins and even their isolation from each other. In other outcrops of Karangatian sediments, the above-mentioned development cannot be traced in all its completeness. As a rule, it is possible to trace some stages and correlate them to each other.

Conclusions

The Karangatian transgression raised the Black Sea level to at least the present elevation. This transgression was not gradual but oscillating in nature. It occurred during the Mikulino (MIS 5e) interglacial, corresponding to the central European Eemian interglacial, and it is usually compared with the Alpine Riss-Würm interglacial.

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