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The Holocene Black Sea reconnection to the Mediterranean Sea: New insights from the northeastern Caucasian shelf

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ABSTRACT

Recent findings about the evolution of palaeogeographic conditions of the Black Sea during the Holocene have significantly improved our understanding of the profound environmental changes that took place around 9 ka ago, when the Neoeuxinian Lake reconnected to the global ocean. In contrast to the western and southeastern regions where numerous studies have been recently performed, the northeast region remains relatively under investigated. We carried out the first multi-proxy continuous study of a sediment core (Ak-2575) from the northeastern Black Sea shelf that includes benthic calcareous fossils (ostracods, molluscs and foraminifers), dinoflagellate cysts (dinocysts) and sedimentology, thus providing reconstructions of surface and bottom-water conditions. The age model of the core is based on 10 AMS-^{14}C dates. Calibrated ages are used throughout the manuscript. The first appearance of Mediterranean elements is documented at 9.6 cal. ka BP. Our data provide evidence of sustained cohabitation of benthic species of Caspian and Mediterranean origins, represented by different ontogenetic stages, from at least ~7.8 (or even 8.8) to 6.7 cal. ka BP with the gradual disappearance of brackish species suggesting a gradual increase in salinity and most likely a change in the salt composition. Dinocyst assemblages show species succession that is coherent across the Black Sea basin, with brackish taxa dominating until ~8.5 cal. ka BP and being slowly replaced by euryhaline species. The occurrences of authigenic gypsum crystals, especially abundant at ~7.4 and 6.5 cal. ka BP, suggest the temporal appearance of hydrogen sulphide at the shelf edge which during certain periods appears to reduce the abundance of benthic fauna.

1. Introduction

Palaeoceanographic reconstructions of the semi-enclosed Black Sea basin have proved to be challenging due to complicated sedimentary environments and the scarcity of conventional proxies like planktonic foraminifers and stable isotopes. However, the past two decades have seen an increasing number of studies of both shelf and deep-sea sediments in the Black Sea (e.g. Aksu et al., 2002a,b; Hiscott and Aksu, 2002; Major et al., 2002, 2006; Ryan et al., 2003; Hiscott et al., 2007, 2013; Lericolais et al., 2007; Bahr et al., 2008; Nicholas et al., 2011; Soulet et al., 2011a,b) as well as benthic (ostracods, molluscs, foraminifera) and planktonic (dinocysts, diatoms) fossils, pollen and spores (e.g. Chepalyga, 2002; Mudie et al., 2002, 2004, 2007, 2011; Atanassova, 2005; Hiscott et al., 2007, 2010; Ivanova et al., 2007, 2012; Yanko-Hombach, 2007; Yanko-Hombach et al., 2007, 2014; Marret et al., 2009; Mertens et al., 2009, 2012; Boomer et al., 2010; Bradley et al., 2012; Shumilovskikh et al., 2012, 2013; Filipova-Marinova et al., 2013). These studies have led to contradicting hypotheses with regards to a) the water conditions when the Black Sea was isolated and b) the Holocene environmental changes that have been initiated by the reconnection of the Black Sea to the global ocean system. In addition, several authors argue that the Black Sea experienced well documented significant sea level fluctuations during the early Holocene, with smaller amplitude changes through the mid-to-late Holocene (e.g. Chepalyga, 2002, 2007; Balabanov, 2007, 2009; Konikov et al., 2007; Yanko-Hombach et al., 2007, 2014), whereas others suggest a rather gradual Black Sea level rise corresponding to eustatic rise of the global sea level (Brückner et al., 2010; Esin et al., 2010; Esin and Esin, 2013). Kaplin and Selivanov (2004) demonstrated up to 2–3 m sea level oscillations in the tectonically stable area near the Kuban river delta during the middle-to-late Holocene.

Changes in biotic, sedimentological and geochemical properties through the Holocene have been thoroughly investigated from the western (Atanassova, 2005; Major et al., 2006; Algan et al., 2007;

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Lericolais et al., 2007; Bahr et al., 2008; Coolen et al., 2009; Yanko-Hombach et al., 2014) and southwestern (Mudie et al., 2004, 2007; Filipova-Marinova, 2006; Hiscott et al., 2007; Yanko-Hombach et al, 2007; Bahr et al., 2008; Marret et al., 2009; Verleye et al., 2009; Bradley et al., 2012) parts of the basin, and to a lesser extent, in the south-eastern region (Yanko-Hombach, 2007; Yanko-Hombach et al, 2007; Shumilovskikh et al., 2012, 2013). In contrast only a few sediment records have been studied from the northeastern shelf (Ivanova et al., 2007, 2012, 2014) and no planktonic Holocene records have been published for this region of the basin.

Regardless of the considerable number of regional studies, the views on the timing of the estuarine circulation reopening between the Marmara and Black Seas at ~9.3–9 cal. ka BP (e.g. Bahr et al., 2008; Soulet et al., 2011a,b) or ~9.8–9.5 ^{14}C ka BP (e.g. Grigor'ev et al., 1984; Yanko and Troitskaya, 1987; Mudie et al., 2004, 2007; Yanko-Hombach, 2007; Yanko-Hombach, et al., 2007, 2014) still remain contradictory. Whereas several authors argue for a catastrophic flooding of the Black Sea after the reconnection with the Mediterranean (Ryan et al., 1997, 2003; Lericolais et al., 2007), many others suggest a gradual or step-wise change in sea-surface and bottom salinity (Hiscott et al., 2007, 2010; Ivanova et al., 2007, 2012; Yanko-Hombach, 2007; Yanko-Hombach et al., 2007, 2014; Marret et al., 2009; Bradley et al., 2012; Shumilovskikh et al., 2012, 2013). Faunal and floral assemblages show a slow turn-over of species, with freshwater/brackish taxa disappearing between 8 and 6.5 cal. ka BP depending on local imprints related to the river discharge (Ivanova et al., 2007, 2012; Marret et al., 2009; Shumilovskikh et al., 2013).

To allow basin-wide comparisons of environmental changes during the Holocene, a sedimentary record from the northeastern Caucasian shelf, core Ak-2575, has been analysed using a multi-proxy approach. According to the AMS-^{14}C dates the core recovers the last 9.6 cal. ka.

The sediment lithology was studied to understand changes in the depositional environment at the site. To assess changes in surface conditions, dinoflagellate cysts were analysed for the first time on the NE shelf. To study sea bottom-water conditions, molluscs, ostracods and benthic foraminifers were analysed. The ostracod record from the core Ak-2575 is the most detailed for the Eastern Black Sea shelf.

The paper also focusses on the co-occurrence of species of Caspian and Mediterranean origins found from the same time intervals of core Ak-2575. Although previous studies have documented the upward reworking of the Caspian elements (e.g. Hiscott et al., 2007, 2010; Ivanova et al., 2007, 2012; Yanko-Hombach et al., 2007, 2014), the possibility of their cohabitation with the Mediterranean species in the early Holocene remained questionable. The results of the present multi-proxy study allow us to assess in detail the surface and bottom-water conditions of the northeastern shelf and suggest the possible causes of temporal disappearance of benthic fauna. The AMS-^{14}C dates measured on single species from every dated level and quantitative dinocyst data enable basin-wide comparisons with available well-dated studies from other locations within the Black Sea.

For comparison with previous and other regional studies, the widely used framework by Balabanov (2007, 2009) was applied (see also Ivanova et al., 2012). This is based on the ^{14}C dated succession of the Black Sea transgression phases during the Holocene which are assumed to be separated by short-term low stands of the sea level. The proposed transgression phases include Bugazian (10–8.8 cal. ka BP), Vityazevian (8.8–7.8 cal. ka BP), Kalamitian (7.8–6.9 cal. ka BP), Dzhemetinian (6.9–2.6 cal. ka BP) and Nymphean (2.6–0 cal. ka BP) (Balabanov, 2009). These phases are suggested to be characterized by different salinity conditions in the basin, changing from semi-freshwater with a salinity of 0.5–5 psu (practical salinity units, hereafter unitless) in the Neoeuxinian Lake through brackish (5–12) to semi-marine (12–18) and marine (>18) since the peak of the Kalamitian phase when it reached 18–20 (e.g. Ivanova et al., 2007, 2012; Yanko-Hombach et al., 2007, 2014; Mudie et al., 2011; Shumilovskikh et al., 2013).

2. Oceanographic and physiographic setting

The northeastern (Caucasian) Black Sea shelf is relatively narrow with a maximum width of 25 km. The shelf break occurs at water depths of between 105–120 m (Fig. 1). Surface circulation across the shelf is controlled by the basin-wide counter-clockwise rotating peripheral Rim Current, generally ~750 m in width, and by the anticyclonic submesoscale coastal eddies (Bogatko et al., 1979; Öğuz, 1993; Kostianoy and Kosarev, 2008). A well-ventilated surface water mass occupies the upper 50–90 m of the water column above the strong pycnocline. It is characterized by a low salinity of 17–18 and strong seasonal temperature changes (e.g. Vinogradov et al., 2011). The Caucasian shelf shows the mean-annual salinity of ~20 and temperatures of ~8°C at 100 m water depth (e.g. Shakurova, 2010). A positive fresh-water balance explains the relatively low salinity of the upper water column in the Black Sea (e.g. Simonov and Al'tman, 1991; Latif et al., 1992). Salinity is controlled by a combination of high precipitation, river run-off from the large catchment area, and fresh-water inflow via the Kerch Strait, which in total exceeds evaporation and saline Mediterranean water inflow via the Bosphorus Strait. The water column is well aerated above the northeastern shelf, and the biological productivity is particularly high, which is confirmed by recent satellite data (Lavrova et al., 2011).

A cold intermediate suboxic water mass is distinguished below the pycnocline, at depths of 50 to 100 m (e.g. Murray, 1991; Murray et al., 2007). The deeper part of the Black Sea is composed of warm and saline water of Mediterranean origin entering the basin via the straits of Dardanelles and Bosphorus (Özsoy et al., 1995; Polat and Tuğrul, 1996). The anoxic deep water contains dissolved hydrogen sulphide defined below 100–150 m (Murray et al., 2007), i.e. deeper than the Caucasian shelf break, but in close proximity to. The estuarine circulation in the straits, characterised with an upper layer flow of cooler and fresher waters from the Black Sea to the Marmara Sea, results in isolation and stable anoxia of the Black Sea deep waters.

3. Material and method

3.1. Lithology

The gravity core Ak-2575 (44°13.46′N, 38°38.03′E, water depth 99 m, core length 186 cm) was retrieved from the NE (Caucasian) outer shelf (Fig. 1), during the cruise by RV *Akvanavt* in 2007. The core was described and contiguously sampled in 2 cm thick subsamples. Sub-samples from the 93 levels were taken for dinoflagellate cyst analysis and the remaining sediment was sieved through 63 and 100 μm meshes washing with distilled water just before being dried. Dry fractions >100 μm were sieved through a 2 mm mesh. The coarse fraction (0.1–2 and >2 mm) for each sample was used for benthic fossil analyses and for the sediment classification. The samples containing gypsum crystals in the fraction 0.1–2 mm are documented throughout the core and the digital images of several gypsum microdruses are performed using scanning electron microscopy (SEM). Identification of gypsum is confirmed by the X-ray diffractometry (XRD).

3.2. Dinocyst preparation and identification

A total of 29 sub-samples (enabling a resolution of ~500 years) were prepared for organic-walled dinoflagellate cyst analysis, using the standard preparation outlined in Marret et al. (2009). The samples were not acetolyzed because the procedure has been shown to degrade dinocysts (Marret et al., 2009). Volume of samples was first estimated, followed by the addition of exotic markers (*Lycopodium clavatum*). Samples were then decalcified with cold 10% HCl and rinsed with distilled water. A small amount of cold 40% HF was added and left overnight for removing silicate particles. After a rinse with distilled water, another 10% HCl treatment was performed to eliminate silicate fluoride. The residues were then sieved using a 10 μm mesh with the larger