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Black Sea “Lake” reservoir age evolution since the Last Glacial — Hydrologic and climatic implications

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ABSTRACT

Chronologies of sediments that document the last glacial history of the Black Sea “Lake” are hampered by issues relating to reservoir age. Regulated by basin hydrology, reservoir ages represent a tool that could potentially be used to better understand the response of Black Sea “Lake” hydrology to climate change. Therefore, deciphering reservoir age evolution is crucial both for better constraining the basin chronological framework and for providing new insights into our understanding of Black Sea “Lake” hydrology.

By tuning a meaningful new high-resolution geochemical dataset (obtained from core MD04-2790) to a climate reference record, here, we propose a reliable chronology spanning the last 32 kyr BP. The chronology is compared to a large AMS radiocarbon dataset ($n = 51$). Pairs of calendar and radiocarbon ages allowed us to compute reservoir ages, and to, then, reconstruct a high-resolution quantitative reservoir age record for the last glacial history of the Black Sea “Lake”.

The main factor controlling reservoir ages in lakes is the Hard Water Effect (HWE), which is regulated by basin hydrology. Therefore, changes in the reconstructed reservoir age record have been qualitatively interpreted in terms of the hydrologic responses of the Black Sea “Lake” to climate change. Our results allowed us to determine periods of complete isolation or outflow for the Black Sea “Lake”. During Heinrich Event 2 (HE2) and during the Last Glacial Maximum (LGM) the basin was strictly isolated, whereas prior to HE2 and during HE1 it outflowed into the Marmara Sea. Following the onset of the Bølling–Allerød, factors other than the HWE are thought to have influenced the reservoir age, preventing conclusive interpretations. We also determined an undocumented, to date, phase of Black Sea “Lake” stratification during the full glacial (HE2 and LGM). Our results indicate that reservoir age is a powerful tool for investigating and better understanding past hydrologic changes in lakes and inland seas.

1. Introduction

During the last global lowstand and for much of deglacial ocean level rise, the Black Sea was disconnected from the global ocean and evolved as a giant lake with its water level controlled by regional climate (e.g. Ross et al., 1970; Schrader, 1979; Stoffers et al., 1978). The last reconnection of the Black Sea “Lake” to the global ocean occurred at 9000 yr BP (Ryan, 2007; Soulet et al., 2011). The previous prevalent hypothesis of a smooth reconnection (e.g. Fedorov, 1971; Ross et al., 1970) was challenged when Ryan et al. (1997) proposed that Mediterranean waters breached the Bosphorus sill leading to a catastrophic refilling of the Black Sea basin. Attendant flooding of the vast emerged continental shelf would have led to a massive migration of Neolithic farmers, imprinting collective memory through culturally-widespread deluge myths (Ryan and Pitman, 1998). In a decade, the “Flood hypothesis”, as well as its possible cultural consequences, has been a matter of debate (e.g. Aksu et al., 2002a; Hiscott et al., 2007; Ryan, 2007; Ryan et al., 2003; Yanko-Hombach et al., 2007).

The lack of reliable Black Sea “Lake” level markers (Giosan et al., 2006; Pirazzoli, 1991), the scarcity of radiocarbon ages on in situ materials, and the difficulty in constraining basin reservoir ages (Giosan, 2007; Kwiecien et al., 2008; Ryan, 2007) mainly explain uncertainties surrounding the last reconnection. Since Black Sea “Lake” level is directly linked to the basin water budget, disentangling the last reconnection mystery also relies on a better understanding of the response of Black Sea “Lake” hydrology to glacial and deglacial climate changes. Recently, several high-resolution geochemical studies (Bahr et al., 2005, 2006, 2008; Kwiecien et al., 2008, 2009; Major et al., 2002, 2006) have considerably increased our knowledge

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regarding Black Sea "Lake" hydrologic responses to climate change. However, meaningful interpretations in terms of Black Sea "Lake" paleohydrology must rely upon robust chronologies, a limiting factor for most studies, due to poorly-constrained basin reservoir ages.

The reservoir age of a water body is the difference between the radiocarbon ages of the water body and the contemporary atmosphere (Arnold and Anderson, 1957; Bard, 1988; Craig, 1957; Stuiver and Polach, 1977; Stuiver et al., 1986; Suess and Revelle, 1957). Reservoir age changes throughout time are directly linked to changes in reservoir parameters (e.g. water input and output, exchange with the atmosphere, the size of the carbon pool, etc.) and in atmospheric $\Delta^{14}C$. As a consequence, reservoir ages represent a powerful tool for reconstructing the response of the reservoir to climate change (e.g. Bard, 1988; Bard et al., 1994; Bondevik et al., 2006; Mangerud, 1972; Siani et al., 2001; Stuiver et al., 1986).

Closed basins (lakes, inland seas) are extremely sensitive to climate change. As a result, lake reservoir ages vary markedly (e.g. Stein et al., 2004; Zhou et al., 2009). The strong sensitivity of the Black Sea "Lake" to climate change is now well established (Bahr et al., 2005, 2006, 2008; Kwiecien et al., 2008, 2009; Major et al., 2002, 2006). First attempts to decipher Black Sea "Lake" reservoir ages were performed using rough comparisons between Black Sea "Lake" geochemical records and Greenland ice core records (Kwiecien et al., 2008; Ryan, 2007). Although these pioneering results provided important insight into our understanding of Black Sea "Lake" reservoir age variability, they only represented rough estimations. To date, a single reservoir age has been quantitatively reported (1450 ± 400 ^{14}C yr; Kwiecien et al., 2008). Providing a quantitative reservoir age record throughout last glacial Black Sea "Lake" history is critical for properly calibrating radiocarbon ages obtained from biota grown within the basin and for better constraining the hydrologic response of this former lake to climate change.

Based upon new high-resolution geochemical records, obtained from a sedimentary sequence from the Black Sea tuned to ^{230}Th-dated Hulu Cave climate records (Wang et al., 2001), here, we propose a calendar chronology for glacial to deglacial sediment of the Black Sea "Lake". The obtained calendar chronology is then compared to a previously published dataset of AMS radiocarbon ages (Bahr et al., 2005; Kwiecien et al., 2008; Major et al., 2002), as well as to numerous original dates. For this study, we developed a statistical method for computing reservoir ages, and provide a quantitative high-resolution reservoir age record of the Black Sea "Lake" spanning the last 32 yr BP. We also qualitatively interpret large and abrupt reservoir age changes in terms of the hydrologic responses of the Black Sea "Lake" to climate change.

2. Materials and methods

2.1. Material

Piston core MD04-2790 was recovered in the upper slope of the NW Black Sea (44°12.8′N, 30°59.6′E; 352 m water depth), in the direct axis of the Danube River (Fig. 1) during the ASSEMBLAGE 1 cruise, aboard *Marion Dufresne*. From the top to a depth of 1.24 m, the core revealed the typical marine stratigraphic Units I and II (Ross and Degens, 1974). The lowermost limnic unit, Unit III (Ross and Degens, 1974), was found at a depth of 1.24 m to the core base. The base of Unit III was not reached. A careful inspection of MD04-2790 core sediments revealed neither a turbiditic sequence nor a visible unconformity.

2.2. Methods

2.2.1. High-resolution geochemical records (XRF profiles, $CaCO_3$, and TOC)

The bulk intensity of numerous major elements was determined using an Avaatech XRF-core scanner (Jansen et al., 1998). Measurements were performed on every millimeter on the split core at Ifremer (Brest, France) by setting the voltage to 10 kV and the intensity to 1000 mA. The acquisition time was 20 s. Here, we present XRF profiles useful to build the chronology of MD04-2790 sedimentary sequence: the Ca-intensity (calcium) and the Ti/Ca-ratio (titanium vs. calcium ratio) profiles.

The carbonate content ($CaCO_3$) and the Total Organic Carbon (TOC) content were measured at CEREGE (Aix en Provence, France) with a FISONS NA 1500 elemental analyzer, as described in Pailler and Bard (2002). Sediment samples were freeze-dried, crushed, and homogenized in an agate ball mill. Both the Total Carbon (TC) and the TOC contents of each sample were determined in two separate

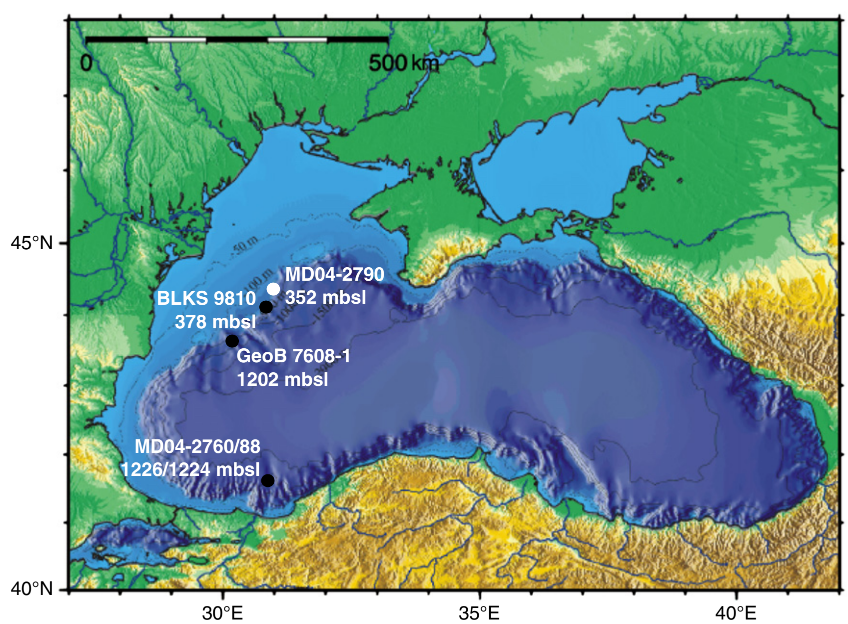

Fig. 1. The Black Sea area. The white dot indicates the location of the MD04-2790 coring site (44°12.8′N, 30°59.6′E). Black dots represent the coring locations for previously published cores, as follows: BLKS-9810 (Major et al., 2002), GeoB 7608–1 (Bahr et al., 2005), and MD04-2760 and MD04-2788 (Kwiecien et al., 2008). The coring depths, in meters below sea level (mbsl), are indicated below the coring sites.