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Compositional trends through the Holocene mud succession of the southwestern Black Sea shelf: Implications for sedimentary provenance and water-level history

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ABSTRACT

Cores MAR02-45 and MAR05-03 were raised from 68–69 m water depth on the SW Black Sea shelf and indicate transgression and submergence beneath several tens of metres of water before 11.0 cal ka. Those who postulate a Black Sea lowstand below −100 m until the approximately 9.1 cal ka reconnection with the world ocean have suggested that sites like MAR02-45 and MAR05-03 must have been located in perched lakes on what is now the modern shelf. However, the silt- and clay-fraction mineralogy of samples from MAR02-45 provides no evidence for a shift in provenance at 9.1 cal ka, with earlier input from local rivers and later input from a broader region. Sedimentary abundances of Sc, Fe, Co, Ce, La, Th and Y also show no significant downcore trends. These elements likely reside in aluminosilicate mineral grains shed from terrestrial sources, so negligible downcore variation suggests long-term continuity in the composition of the detrital supply. More critically, the volume of pre-9.1 cal ka sediment around the MAR02-45 and MAR05-03 sites is >25 times the expected yield from local rivers over a 5000 year period, so other more substantial sources are required. The predominant silt size of the recovered sediments, the configuration of late Holocene currents in the western Black Sea, and analogies with dispersal systems elsewhere suggest that the bulk of the fine-grained muds at these sites likely came from the Danube and Kamchiya drainage basins where thick deposits of unconsolidated Pleistocene loess have been strongly dissected. To reach core sites on the SW Black Sea shelf, this material must have been advected from the Danube and Kamchiya deltas by unobstructed marine currents. Only thin event beds (tempestites) of fine sand and silt in the lower part of cores MAR02-45 and MAR05-03 are interpreted to have a local source in the Strandja Mountains of Thrace. Comparison of the palynology of surface samples from the Danube Delta and its associated coastal lagoons with the pre-9.1 cal ka sediments of core MAR02-45 confirms that the hypothesis of deposition in a perched ancient lake is untenable.

1. Introduction

Almost two decades have passed since the proposal by Ryan et al. (1997) and Ryan and Pitman (1999) that the Black Sea was catastrophically inundated by Mediterranean waters when global sea level rose above the floor of the Bosphorus Strait (~ −40 m elevation 'relative to modern sea level', hereafter rmsl). This proposed flooding event is most recently dated by Ryan et al. (2003) at 8400 conventional radiocarbon years before present (^{14}C yr BP; uncalibrated to calendar years and with no marine reservoir correction), equivalent to ~9.1 cal ka using the Marine09 calibration curve and $\Delta R = -105$ years (reservoir age ~300 years) consistent with Soulet et al. (2011) and Mertens et al.(2012). Immediately prior to the inundation, adherants to the scenario of a catastrophic flood propose that the level of the Black Sea was below −100 m rmsl (Ballard et al., 2000; Ryan et al., 2003; Lericolais et al., 2007; Nicholas et al., 2011), implying a large deficit of river runoff and precipitation relative to evaporation, unlike today (Özsoy et al., 1995).

Other researchers have argued that the pre-reconnection level of the Black Sea was near or above the level of the floor of the Bosphorus Strait by the time that the first Mediterranean waters penetrated into the Black Sea (Hiscott et al., 2007a, 2007b; Yanko-Hombach, 2007; Giosan et al., 2009; Yanko-Hombach et al., 2013; Mudie et al., 2014). A critical piston core that has provided support for this view is MAR02-45, raised from a water depth of −69 m rmsl on the southwestern Black Sea shelf near the border between Turkey and Bulgaria (41° 41.17′N, 28° 19.08′E; Fig. 1). This core is 9.5 m long with a continuous, high-resolution sedimentary record in its lower 6.8 m, spanning 10.3–5.5 cal ka (Mertens et al., 2012) and, thus, the entire time of the reconnection between the Black Sea and the world ocean. In many other parts of the

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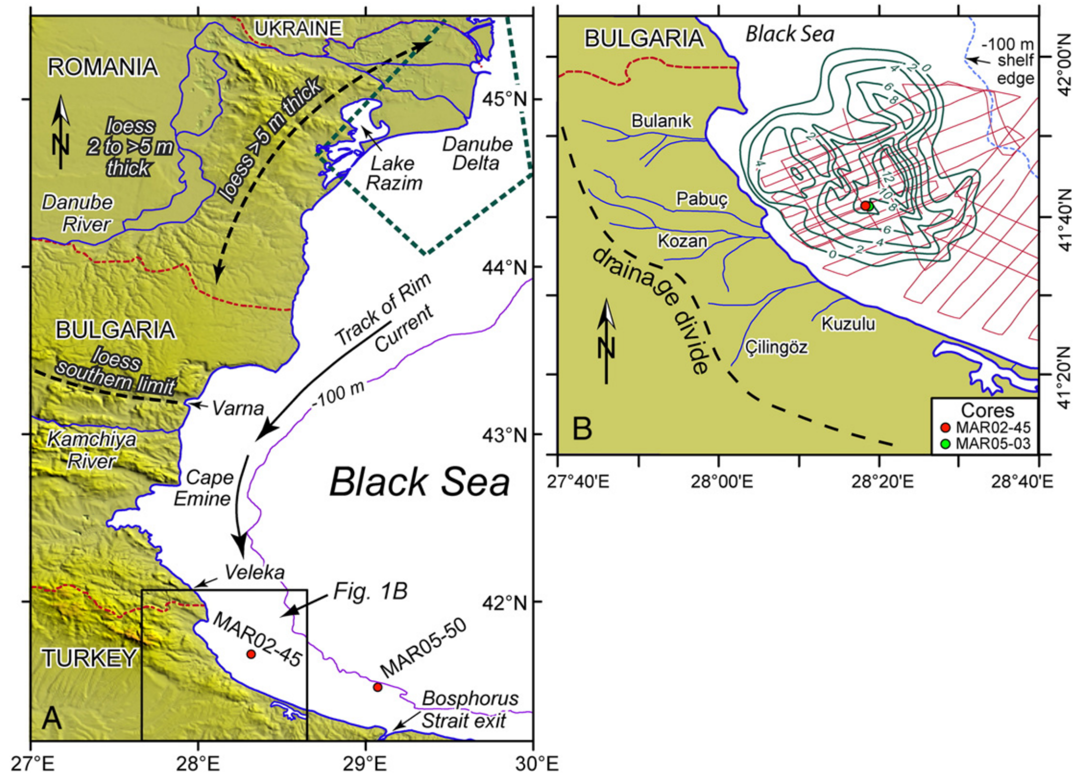

Fig. 1. (A) Location map of western Black Sea extending from Danube Delta to Bosphorus Strait. Sun-shaded topography of land areas from Ryan et al. (2009). Loess thicknesses and approximate southern limit from Haase et al. (2007). Lower box shows location of part B. Upper dashed polygon encloses palynology sampling sites of Frail-Gauthier and Mudie (2014) around the Danube Delta. North arrow is 50 km long. (B) Location map showing seismic tracks (i.e., the grid of mostly parallel lines) around the MAR02-45 and MAR05-03 core sites. Isopach contours (in milliseconds of two-way travel time) for seismic unit 1B (equivalent to lithologic Unit C of Hiscott et al., 2007a) were determined from seismic profiles, except northwest of the seismic grid where contours were closed in a conservative manner consistent with the shape of the main "bulls-eye" near the core sites. The contours were closed to enable volume calculation; the conservative extrapolation shown here minimizes the calculated volume of seismic unit 1B on this part of the shelf. Also shown are local small rivers north of the drainage divide (Okay and Okay, 2002) in the Strandja Mountains of NW Thrace. North arrow is 20 km long.

southwestern shelf, there is a subtle erosional unconformity called α1 (Aksu et al., 2002) which, ~5.25 m below the seafloor (mbsf) at the MAR02-45 site (Hiscott et al., 2007a; Fig. 2A), flattens around this core site into a conformable surface with age ~8.0 cal ka. The α1 level separates lowermost lithologic Unit C in the core from Unit B. A second, shallower unconformity (α2 of Aksu et al., 2002) is present 2.70 mbsf at the MAR02-45 site (Fig. 2A), and represents a hiatus from 2050–5465 cal yr BP (Mertens et al., 2012). α2 defines the top of lithologic Unit B and the base of the uppermost Unit A (Hiscott et al., 2007a). α2, and α1 where it is an unconformity, are both interpreted as submarine erosional surfaces that formed beneath strong shelf currents, presumably when sediment supply was insufficient to maintain accumulation. A comparable and analogous modern erosional surface has developed on a portion of the seabed north of the Bosphorus Strait (Flood et al., 2009).

Unit A is comprised of subtly colour-banded bioturbated silty mud with silt laminae and several molluscs of Mediterranean affinity. Unit B consists of alternating beds of silty mud and shelly mud. Molluscs (e.g., *Truncatella subcylindrica*, *Mytilus galloprovincialis*, *Parvicardium exiguum*) and bioclastic sand locally exceed 20 wt.% (Fig. 2B). Unit C consists of burrowed silty mud with graded beds of silt and fine sand. Molluscs include *T. subcylindrica*, *Monodacna pontica*, *Didacna* spp., *Dreissena polymorpha* and *D. rostiformis* (Hiscott et al., 2007a, 2010). In pre-reconnection (older than 9.1 cal ka) sediments of Unit C, the presence of thin beds of silt and very fine sand devoid of any evidence of wave reworking suggests that the water depth at the MAR02-45 site was of the order of some tens of metres (Hiscott et al., 2007a), and therefore the elevation of the local sea surface could not have been below approximately −40 m to −50 m rmsl (calculated, in metres, as −69-9.5 + [30 to 40]).

A second piston core, MAR05-03 (41°40.92′N, 28°18.99′E), was collected within ~500 m of the MAR02-45 site in an attempt to reach the transgressive unconformity, α (Aksu et al., 2002). Because the strata in this area have little dip or lateral thickness change (Hiscott and Aksu, 2002, their Fig. 16), the age–depth curve and facies of this core closely match the middle to lower Holocene stratigraphy of core MAR02-45, but the recovery extends ~75 cm deeper to 10.2 m below the seafloor (mbsf) and reaches gravel draping the α unconformity. A *Dreissena* sp. shell 5 cm from the base of core MAR05-03 and immediately above the basal muddy gravel is dated to 11.9 cal ka (Reynolds, 2012), constraining the start of the transgression across this portion of the modern shelf.

If the pre-9.1 cal ka Black Sea had an elevation below −100 m rmsl (Ballard et al., 2000; Ryan et al., 2003; Lericolais et al., 2007; Nicholas et al., 2011), then the water covering the MAR02-45 and MAR05-03 sites could have been tens of metres deep only if the sites were isolated in a perched lagoon or lake on what is now the modern shelf. This possibility has been suggested by Ryan (2007) for shallow-water sites in the Sea of Azov and on the Romanian shelf which have yielded pre-9.1 cal ka dates; he has interpreted these settings as "saline ponds or limans that were located landward of the shoreline of the Neoeuxinian lake" (Ryan, 2007, p. 72). The term 'liman' is used in the Black Sea area for isolated to semi-isolated water bodies (lakes and lagoons) in the coastal zone, usually in the vicinity of river deltas (Shuisky, 1982). Sediment supply to a perched coastal lake, higher in its level than the nearby receiving basin, can only come from local watersheds, implying a local bedrock provenance and a deposit volume controlled by the sediment yields of streams entering the lake. On the Turkish coast adjacent to the MAR02-45 and MAR05-03 sites, there are five small rivers and streams that might account for such local sediment supply (Aksu