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Dynamics of slow suspension flows on the Black Sea abyssal plain

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ABSTRACT

This paper aims to develop a theoretical hydromechanical model designed to explain slow motion of thin sediment suspension layer over the Black Sea abyssal plain. The suspension flows are regarded as a new lateral deep sea sediment transport mechanism differing from turbidity currents and other gravity flows in minor mass scale and velocity. The suspension can flow as a heavy liquid denser than the surrounding clear sea water if its upper surface has an inclination to the horizontal plane. Estimated kinematic viscosity coefficient of the suspension is about $3 \cdot 10^{-4}$ m^2/sec. Laboratory measurements showed that the suspension has properties of a viscous incompressible fluid. Its motion can be described by the Navier-Stokes equations if the suspension density is less than 1.32 g/cm^3. According to box corer and multicorer sampling, a suspension layer, up to 20 cm thick, exists above the sediment surface on the Eastern Black Sea abyssal plain. It can move over the abyssal plain as a near-bottom gravity driven suspension current, several tens of centimeters thick or less, with velocities from several meters up to several kilometers per day, depositing a millimeter-scale terrigenous mud lamina on the way. Our study was focused on the Eastern Black Sea basin where the flat slightly inclined abyssal plain provides favorable conditions for suspension flows motion and lateral deposition of laminated sequences from these flows out of turbidite sequences which dominate in the. Western basin with the Danube turbidite system. Rather weak near-bottom suspension flows are generated here on the shelf from rather small Caucasian rivers discharge plumes and move downslope to the abyssal plane through numerous submarine canyons.

1. Introduction

A new lateral sediment transport mechanism in the Black Sea basin is described here in terms of hydromechanics, based on data obtained during the multidisciplinary research carried out within the International IAEA RER/2/003 Project (2004) where the first author participated (Esin, 2003). The primary materials including deep sea sediment samples for measurements and experiments have been collected from the eastern abyssal plain of the Black Sea and are later supplemented by new data from the Caucasus shelf and continental slope (e.g. Esin, 2003; Khvoroshch et al., 2012; Yakubenko, 2011; Zavialov et al., 2014).

Two abyssal plains of the deep Black Sea basin, eastern and western, representing shallower analogues of oceanic abyssal plains, differ considerably in their morphology and modern sedimentation processes. The eastern plain mainly considered in this paper represents a flat almost horizontal surface with the maximum depth of the sea in its western part, covered with soft fine-grained sediments overlain by a stable thin suspension layer. We hypothesize that this suspension mainly derived from river discharge, is responsible for deposition of varve-like laminated sequences widespread among the recent sediments (Degens et al., 1978; Oaie et al., 2003-2004).

Sedimentation in the Western deep basin complicated by the huge Danube fan and other sedimentary features, is studied in detail by Lericolais et al. (2013), Constantinescu et al. (2015) and many other authors. We believe that slow suspension flows described by our theoretical model also contribute to the laminated sedimentary structure formation here, but are masked by other processes of lateral sedimentation.

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2. Geomorphological, hydrological, and sedimentological setting

The deep Black Sea basin is subdivided into Eastern and Western basins by the system of low topographic highs, called Hills and Ridge in Russian literature. The Eastern Basin floor with maximum depth of 2200 m represents an abyssal plain, a shallower analogue of more than 3000 m deep oceanic abyssal plains. Bottom topography of the Western Basin is complicated by the huge Danube fan and other sedimentary or tectonic features, but a flat abyssal plain also occurs around its depocenter.

Recent sedimentation on the western abyssal plain does not principally differ from that on the eastern plain. On both plains, varve-laminated organic rich coccolith ooze is described from the uppermost hemipelagic unit. However, that from the Western Basin is thought to be directly related to turbidite systems, whereas laminated successions from the Eastern Basin likely deposited independently (Constantinescu et al., 2015; Lericolais et al., 2013; Oaie et al., 2003-2004). Very fine-grained surface sediments from the eastern abyssal plain suggest still-water bottom conditions which is on line with direct measurements. Absence of macrobenthos owing to anoxic (euxinic) environment prevents from bioturbation of sediments hence promoting preservation of the laminated sedimentary structure.

The abyssal plain is approximately constrained by the contour of 2000 m (Fig. 1). Inclination of the eastern Black Sea abyssal plain surface decreases from $5 \cdot 10^{-2}$ at the periphery of the basin to $3 \cdot 10^{-4}$ at its center (Goncharov et al., 1972). Generalised bathymetric profiles off the Caucasian and Crimean coasts (Fig. 2) demonstrate gradual transition from the abyssal plain to the continental slope without any continental rise, hence indicating restricted sediment accumulation by turbidity currents at the slope base aside of canyon fans. The concave shape of profiles supports this suggestion.

Numerous submarine canyons cut the Caucasian continental slope (Fig. 3) serving as pathways for any gravity driven sediment transport from the shelf, including the suspension flows considered in this study. The seismic profile along the canyon bed (Fig. 4) show eroded bottom from steep slope and slump bodies from gentler steps (Khvoroshch et al., 2012) Sochi report.

The continental slope is bathed by the hydrogen sulphide polluted, higher salinity deep water almost up to the shelf brake. This results in black color of recent sediments owing to staining by authigenic iron sulphide (hydrotroilite) even if their organic carbon (TOC) content does not exceed 1.5–2%, i.e. much lower than that in sapropelic mud. We recovered a coretop layer, up to 75 cm thick, of such black semi-liquid mud (with the water content of 28% and wet density as low as 1.2 g/cm^3) from the thalveg of a canyon. (Moskalenko et al., 2006). These semi liquid sediments are apparently unstable and may easily flow down-slope as a suspension flow.

Small rivers discharge their particulate material load to the NE Black Sea shelf forming suspension plumes adjacent to their mouths well discriminated in satellite images (Fig. 5). Instrumentally measured concentration of fine-grained particulate material in these plumes reaches 60 g per liter and they extend up to a distance of several kilometers from the river mouths (Zavialov et al., 2014). Sinking to the bottom, the suspension behaves as a heavy liquid. Being gravity forced, it moves toward the shelf edge and further down-slope in canyons, with increasing velocity (up to 5 m/s) as a suspension flow.

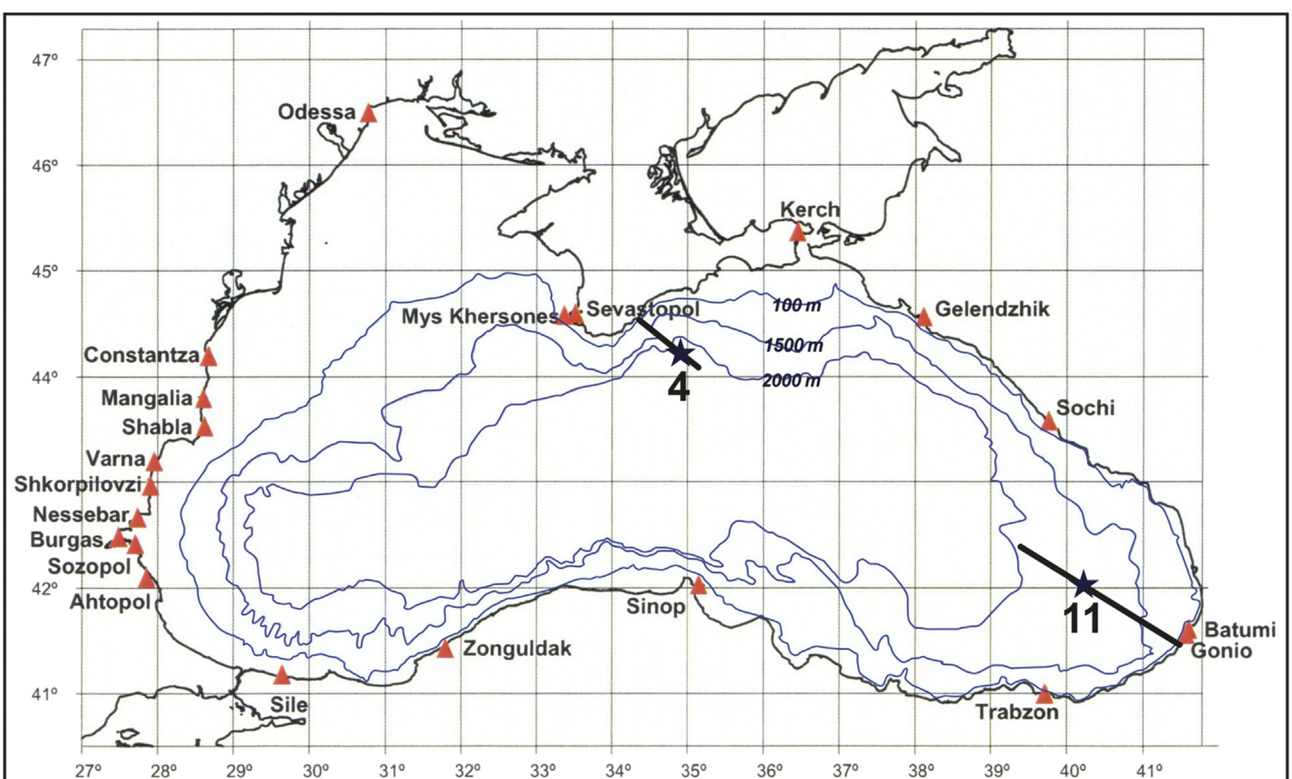

Fig. 1. Bathymetric map of the Black Sea with location of box corer sampling sites 4 and 11(asterisks) for the RER/2/003 Project (Marine Environmental Assessment of the Black Sea) and profiles shown in Fig. 2.