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Shallow gas transport and reservoirs in the vicinity of deeply rooted mud volcanoes in the central Black Sea

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ABSTRACT

The principal objective of this paper is to understand the gas migration process and the structures of mud volcanoes in the central Black Sea. Multichannel seismic lines were acquired across 6 mud volcanoes in the central Black Sea: MSU, Yuzhmorgeologiya, Malyshev, Kornev, Goncharov and Vassoevitch. Based on a high resolution seismic processing, we analyzed acoustic anomalies and studied near-surface sediment structures of these mud volcanoes. Four types of pathways for gas and fluid migration and three types of gas reservoirs were recognized. A regional "Bottom Simulating Reflection" (BSR) seems to be absent in most parts of the study area, however a clear BSR was observed in one of the seismic profiles. The free gas migrating upwards along these pathways were sealed by gas hydrates or fine-grained sediments in the gas hydrate stability zone. Four seismic units were separated according to a suggested age model and identified seismic facies. Combining with the possible sedimentary processes of the central Black Sea, we try to reveal the active mechanism of these mud volcanoes. These mud volcanoes reveal two to three major active stages. These active stages might be related to distinct sea level falls, which seem to be one of the main trigger factors of the mud volcano eruptions in the central Black Sea. A structural model for the MSU mud volcano was presented with respect to mechanisms of gas migration and the origin of the gas.

1. Introduction

Mud volcanoes are important geological sedimentary structures associated with the expulsion of fluid, gas and sediment to the Earth's surface or the seafloor, which reveal positive morphology (e.g., Dimitrov, 2002; Judd and Hovland, 2007). The gas emitted by the mud volcanoes are dominated by methane gas, which is the famous greenhouse gas that has a great relevance to the carbon budget and climatic change (e.g., Milkov, 2000). Mud volcanoes occur in many parts of the world, on land as well as offshore (Milkov, 2000; Dimitrov, 2002; Kopf, 2002). The number of mud volcanoes reaches about 1000 onshore, 500 on the continental shelves, and 5000 in deep waters; however, the offshore estimates are very speculative (Judd and Hovland, 2007). The research on offshore mud volcanoes just began ~40 years ago (Dimitrov and Woodside, 2003). There are some well-known mud volcano areas, like the Black Sea and the Caspian Sea (Ginsburg and Soloviev, 1994; Ivanov et al., 1996; Limonov et al., 1997), the Norwegian Sea (e.g., Hovland and Judd, 1988), the Gulf of Mexico (Kohl and Roberts, 1994), the Mediterranean Ridge (Ivanov et al., 1996; Woodside et al., 1997), etc. The principal controlling factors for mud volcanoes formation has been intensively discussed. Dimitrov (2002) summarized these factors including: 1. recent tectonic activity, particularly compressional activity; 2. sedimentary or tectonic loading due to rapid sedimentation, accreting or overthrusting; 3. continuous active hydrocarbon generation; 4. the existence of thick, fine-grained, soft, plastic sediments deep in the sedimentary succession. Furthermore, the important sea-level falls may also constitute a factor to explain episodic reactivations of mud volcanoes (e.g. Gay et al., 2007; Somoza et al., 2012). Pérez-García et al. (2011) proposed that the episodic reactivation of Cádiz MVs was related to major sea-level lowstands, which could alter the neutral buoyancy conditions of the overburden above the shale units.

Thick sedimentary sequences in the Black Sea with high organic matter content favor the development of mud volcanism, as e.g., in the central part of the Black Sea (Ivanov et al., 1996; Limonov et al., 1997) and in the Sorokin Trough (Ginsburg et al., 1990; Woodside et al., 1997; Krastel et al., 2003). Generally, deep water mud volcanoes are associated with gas hydrate occurrences (Woodside et al., 1997), and gas discharge in the central Black Sea is commonly associated with mud volcanism. A high resolution multichannel seismic survey has therefore been performed in the central Black Sea south of the Crimean Peninsula (Fig. 1) by the University of Bremen during R/V Meteor Cruise M52/1 in January 2002 to acquire 11 seismic Lines GeoB02-026 through GeoB02-036 to investigate main features associated with six previously identified mud volcanoes (Ivanov et al., 1989): MSU,

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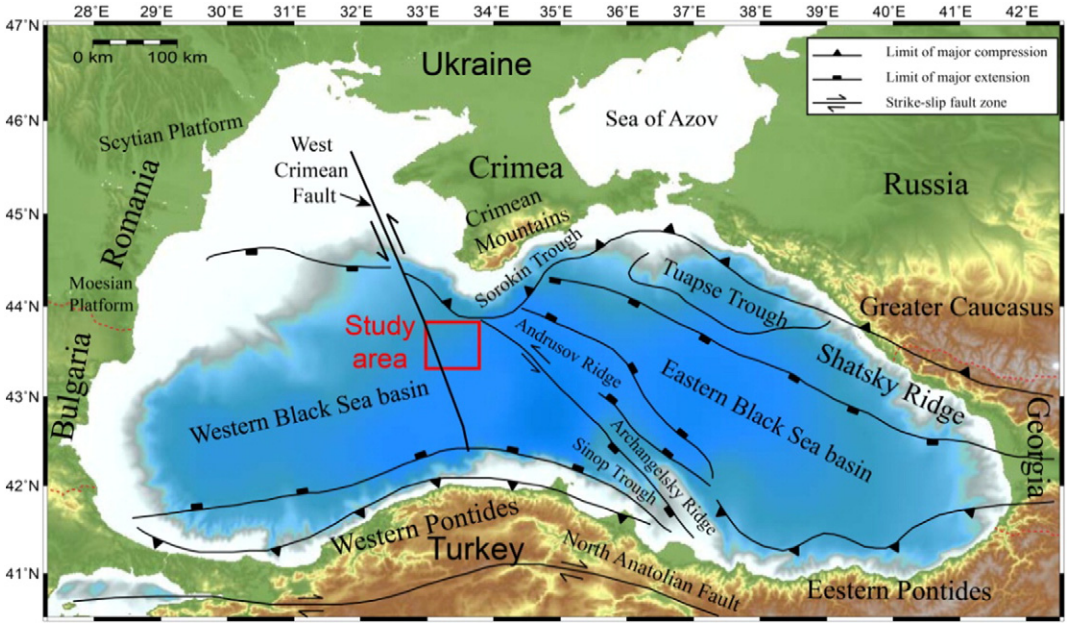

Fig. 1. Bathymetric map of the Black Sea and the surroundings showing the major tectonic units, morphological structures (modified after Robinson et al., 1996, Gebco 1-min grid). The location of the study areas is marked as red rectangle.
Location of West Crimean Fault is from Slack et al. (1998).

Yuzhmorgeologiya, Malyshev, Kornev, Goncharov and Vassoevitch (Fig. 2). While these mud volcanoes have been first seismically imaged during the TTR-1 Cruise in 1991 (Ivanov et al., 1996), our new seismic data reveal a higher vertical and lateral resolution, which shall further elucidate the relation of gas/gas hydrate accumulations and gas/fluid migration pathways in their vicinity. The main objectives of this study

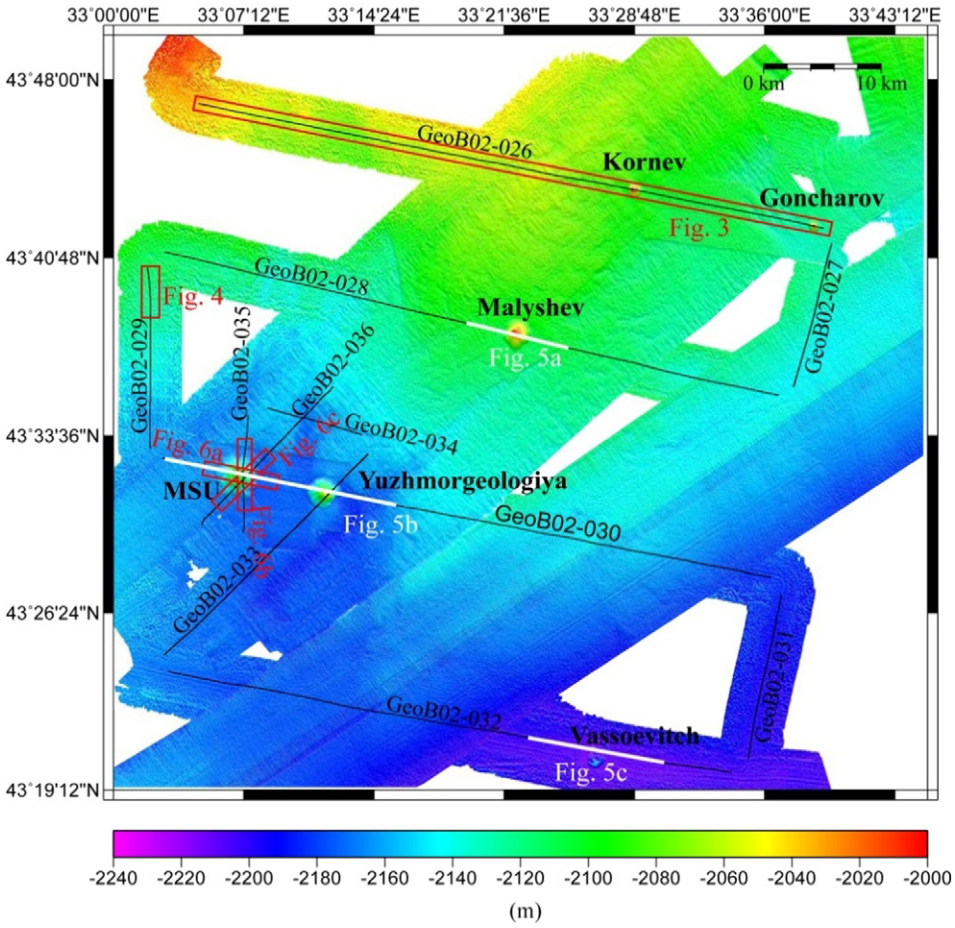

Fig. 2. Bathymetry of the area of investigation in the central Black Sea together with the seismic lines (bathymetric data from Cruises TTR6, M52-1, M72-3, MSM15-2 and M84-2). Six mud volcanoes were mapped.