Cold seeps and mud volcanoes of the Black Sea region: tectonics, lithology, geophysics, and biogeochemistry

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Introduction

Mud volcanoes at the bottom of the Black Sea and Sea of Azov have been studied for more than 20 years. The priority in investigating mud volcanoes belongs to a group of researchers under the guidance of one of the authors, E. Shnyukov. Data on their lithological structure, gēochemistry of deposits, water chemistry, and thermal condition of the deposits are available in many publications (Konyukhov et al., 1990; Shnyukov et al., 2003; Shnyukov and Kobolev, 2004; Stadnitskaya and Belen'kaya, 2000; and others).

Research goal

This research aims at the analysis and generalization of the lithological structure and properties of sediments adjacent to mud volcanoes and seeps at the bottom of the Black and Azov Seas as abiotic components of seafloor ecosystems.

Study area

Thirty profiles have been established that involved dredging in the selected region of the shelf (100–160 m depth; 43°N–46.5° N; 31.6°E–36.6° E), continental slope (1,200–1,900 m), and abyssal plain (2,000–2,300 m) in the northern part of the Black Sea; the southeastern part of the Sea of Azov (water depth 8–10 m); and in the Kerch Strait (22–26 m), where mud volcanoes and high-intensity cold seeps are clearly defined. The sampling was conducted in areas of mud volcanoes and high-intensity cold seeps during the course of several scientific cruises on *R/Vs "Professor Vodianitsky"* (Cruise #s 59 in 2003; 61 in 2004; and 62 in 2005) and *"Vladimir Parshin"* (2006). Regional and local assessment of the subsurface characteristics of mud volcanoes, mapping of the high-intensity gas seep occurrences in the test areas, and characterization of the sources of gas seeps were performed by high-resolution geophysical measurements to define the processes of subsurface gas and fluid formation and migration.

Methods

The field data were obtained using a combination of coring techniques:

- Gravity corer–length of core, 4.5 m; Ø 127 mm, working depth, 2,700 m;
- Grab sampler (grid): working depth, 4,000 m, max mass of deposit, 500;
- Grab sampler (box): working depth, 4,000 m, max mass of deposit, 1,500 kg.

Geophysical, hydro-geochemical, lithological, and paleontological analyses were performed for 150 stations and 30 profiles of grabs.

Results and Discussion

The high-intensity cold seeps can be related to mud volcanoes or ruptures in neotectonic uplifts on the seafloor. The height of these cold seeps varies from 70 to 850 m, and their diameter can reach 400 m. Typically, mud volcanoes are located at the top of geoanticlines. Their height ranges between a few meters and tens of meters; their diameter varies from a few meters to 500 m. Mud volcanoes and a considerable part of seeps are genetically connected with a Maikopian series (Oligocene to Late Miocene), represented by a massive (up to 5,000 m) clay thickness with layers and lenses of water-saturated sand and silt. It is deformed into small folds under the influence of neotectonic oscillatory movements (clay diapirism). Eruptions of mud volcanoes at the bottom of the sea occurred in the Neoeuxinian, Holocene, and some of them at the present time. Alternation of typical marine deposits and eruption products testifies to this activity. In the deepwater part of the Black Sea, the stratigraphy is based on lithological-stratigraphical criteria. The following units are defined: Novochernomorian (New Black Sea) coccolithic mud, Drevnechernomorian (Old Black Sea) sapropel and sapropelic mud, Neoeuxinian hydrotroilitic sediment.

We have analyzed the thermo-physical properties, magnetic susceptibility, specific conductance, density, and water content of the samples. The density and water content of the deposits depends essentially on the maintenance of organic substances: sapropelic mud exhibits the lowest values of density (1.07–1.41 g/sm^3) and water content (19.6–33.9%); the greatest density has been measured in pelitic hydrotroilitic mud (bulk density 1.57–1.77 g/cm^3, water content 59–78%).

The most interesting object of our research was the site of the Dvurechensky mud volcano (Sorokin depression). At station 5780, gas hydrate crystals have been found in the sediments. Here, we also recorded abnormally high sizes of all of the measured gas-biogeochemical indicators, exceeding background values by several times, and a 2–3 order increase in methane, in one horizon of a 1-m-thick deposit.

Highly abnormal biological activity has been observed around the volcanoes. Water weight in the benthic and surficial layers (content of adenosine triphosphate (ATP) and alkali activity *of* phosphoesterase (AAP)) reached 2,300 and 4,770 ng/l, respectively. An abnormal concentration of methane has been also measured in benthic water (3–4 times the characteristic values for these depths). Benthic water is saturated with sulphur (H_2S), methane (CH_4), and carbon dioxide (CO_2), and its biological activity is very high, at times exceeding that of surface water.

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