Mud volcanoes of the Azov-Black Sea basin, onshore and offshore

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Introduction

The term "mud volcano" generally is applied to a more or less violent eruption or surface extrusion of watery mud or clay which is almost invariably accompanied by methane gas. Mud volcanism is a geological phenomenon that is widespread on the Earth. The most ancient Early Paleozoic mud volcanoes are known from Decaturville, Missouri, in North America (Zimmermann and Amstutz, 1972). In the Black Sea, Cretaceous mud volcanoes are known in the near-mountain area of the northwestern Caucasus. Numerous traces of mud volcanism are present in Chokrakian, Sarmatian, and Kimmerian deposits of the Kerch-Taman region. The activity of mud volcanoes in Kimmerian time led to the formation of the Azov-Black Sea iron ore province and, connected to this, compensated or compressed geosynclinals.

Study area and material

Since 1990, the Ukrainian-Russian team of scientists headed by the first author of this presentation has performed multidisciplinary research on mud volcano activity in the Azov-Black Sea region over the course of dozens of onshore and offshore expeditions carried out aboard the Ukrainian R/Vs *Mikhail Lomonosov*, *Kiev*, *Professor Vodyanitsky*, and *Vladimir Parshin* (Shnyukov et al., 2005). These expeditions enabled the mapping of mud volcanoes on the sea bottom and on land (Fig. 1), and they have provided some insight into their physical and gasbiogeochemical properties, as well as their origin.

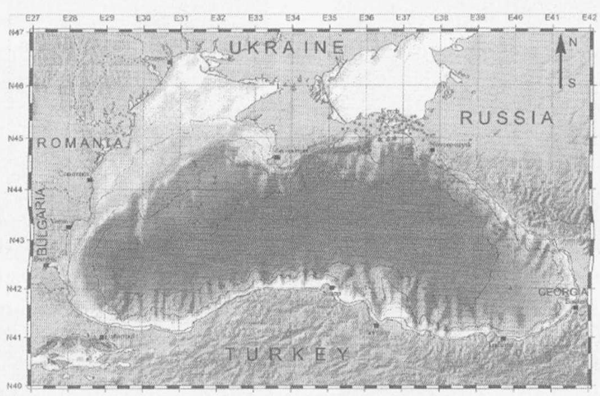


Figure 1. Distribution of onshore and offshore mud volcanoes (marked by red asterixes) in the Azov-Black Sea region.

Results

Spatial distribution

The areas most abundant in mud volcanoes include the northern part of the Western Black Sea, Sorokin trough, Tuapsinskaya trough, Shatskiy arch, and the Kerch downfold (the area south of the Kerch peninsula). At the same time, the southern, Turkish, part of the Black Sea has been insufficiently explored. The exact number of mud volcanoes is unknown, largely due to uncertainty in the primary data; in many cases, the coordinates are inaccurate, and quite often, volcanoes are described by different authors using different names. As of today, the number of known offshore mud volcanoes is close to seventy.

Morphology of mud volcanoes

Offshore mud volcanoes represent positive geological morphostructures with cone-shaped form (Fig. 2).

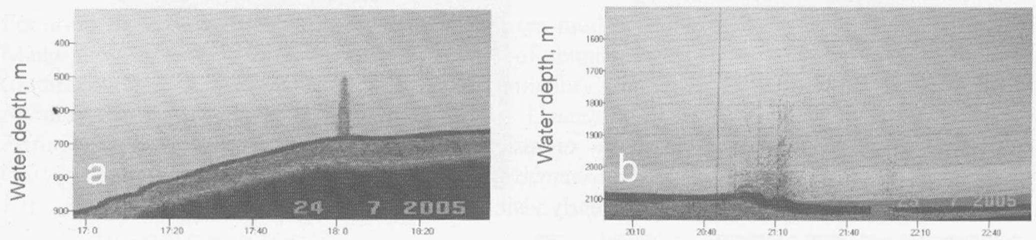


Figure 2. Seismoacoustic profile across mud volcanoes: a = "Mitin" [44°37',897" N, 36°01',058" E; depth 687 m; height of high intensity seep is 200 m]; b = "Sevastopol" [44°16',702" N, 34°52',709" E; depth 2150 m; height of high intensity gas-seep is 300–500 m (after Shnyukov, 2006).

As a rule, they are associated with the axial lines of anticlines and are thus useful for structural mapping of the seafloor. Onshore mud volcanoes often form a series of hills (Fig. 3).

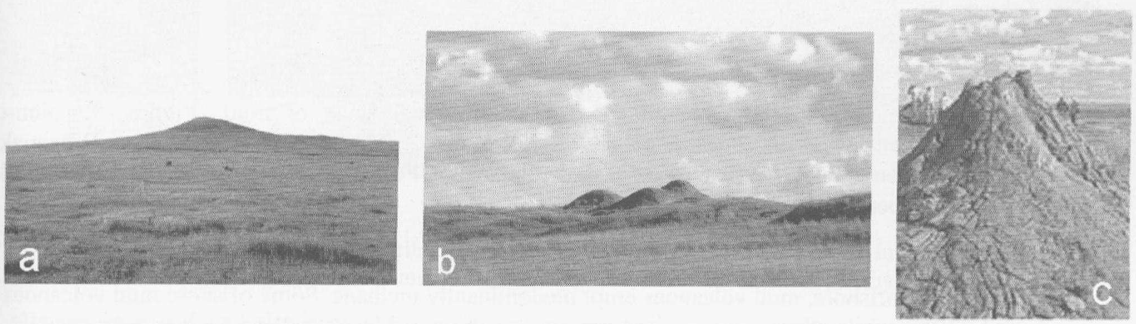


Figure 3. Series of mud volcano hills on: (a) Kerch Peninsula, (b, c) Taman Peninsula.

They demonstrate a wide range of morphologies, ranging from large cones (Fig. 3c) to almost flat structures (Fig. 5) with (Fig. 4a-c) or without (Fig. 5, 9) caldera.

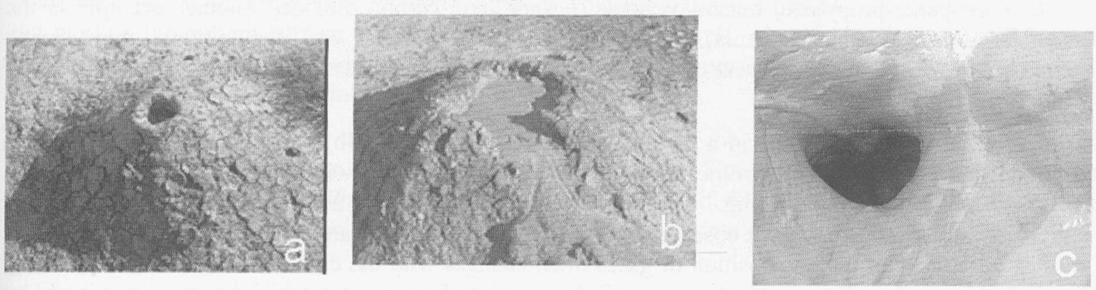
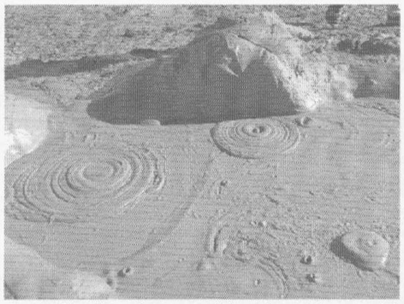


Figure 4. Caldera of a mud volcano: a,c - quiet stage, b - active stage.



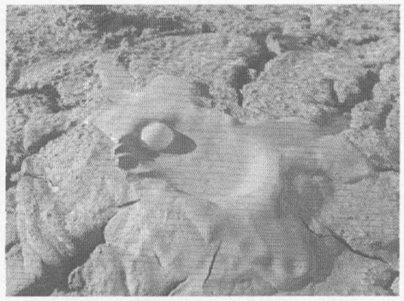


Figure 5. Mud volcano without caldera with clearly visible methane bubbles.

Some mud volcanoes are explosive (Figure 7, 8) while others are eruptive (Fig. 9).

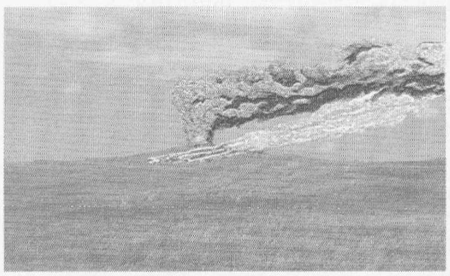


Figure 7. Explosion of mud volcano Dzhu-Tepe in central part of the Kerch Peninsula in vicinity of Volcanovka village (after Shteber, 1915).

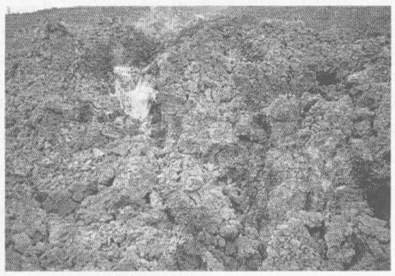


Figure 8. The final stage of mud volcano Western Tsimbali, NW of Taman Peninsula, February, 2002.

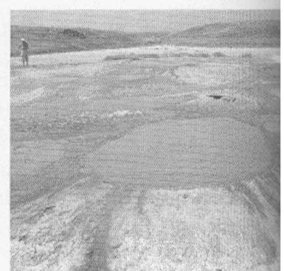


Figure 9. Non-explosive volcano Bulganak in vicin Bondarenkovo village.

Eruptions

Both onshore and offshore, mud volcanoes erupt predominantly methane. Some offshore mud volcanoes erupt gas hydrates while others—oil and iron ore, such as those of Manganari and Neftyanaya mountain, that are located at the vertex of the axis of the Manganari ridge in the Tuapse trough. There, oil is localized in the Neoeuxinian oozes, occupying up to 10% of the rock volume and overlain by Holocene deposits. The oozes contain primarily methane, small amounts of ethane, and insignificant quantities of ethylene, propane, propylene, butane, pentane, hexane, and carbon dioxide. Another example is the Nasyrskaya salse (Kerch peninsula), Neftyanaya mountain (Taman), and Repyevskaya mud-volcano structure (located 25 km southwest of Kerch town). The latter explodes iron ore saturated with oil of Kimmerian age.

In most cases, eruptions occur in a smooth and orderly way (Fig. 4b) and are accompanied by gas bubbling (Fig. 5). However, in some cases, they become violent, spewing out gases and salse breccia (Fig. 7, 8), and often flames (Fig. 8). Prolonged eruptions of gases and salse breccia form peculiar subsidence structures. They were observed on the Kerch peninsula and are named "depressed synclines." It must be noted that the composition of gases often changes with the content of carbon dioxide rising just before an earthquake, as was observed at Bulganak (Kerch peninsula), which has been monitored by us over two years. Similarly, strong eruptions with hundreds of millions of cubic meters of gases (largely methane) occur at offshore mud volcanoes such as Golubitskii and Dvurechenskii in the Azov and Black Sea, respectively.

Gasbiogeochemical characteristics

The distribution of temperature, CH_4, CO_2, ATP, and APA in exemplary cores recovered from the mud volcano at Dvurechenskii shows that the temperature of the sediments drops in those parts of the cores where gas-hydrates are present. There is an increase in methane and a decrease in ATP (adenosine triphosphate) and APA (activity of alkaline monophosphoesterase) in the presence of CO_2 downcore, and there is a synchronous increase in methane and APA downcore. ATP and APA are used as indicators of living substances. The former is a quantitative indicator of biomass for live microorganisms. The latter indicates activity and a tendency of metabolic activity not only in live but dying cells as well.

Source of eruptions

Foraminiferal analysis of geological sequences from mud volcanoes shows that volcanic mud contains a Maikopian foraminiferal assemblage. It consists of abundant benthic species, e.g., *Bolivina* cf. *budensis* (dominant), *Chiloguembellina cubescens* (subdominant), *Guembelina gracillima, Nodosaria spinescens, Robulus* aff. *crassus, Cibicides amphisyliensis, Caucasina schischkinskyae, Uvigerinella majcopica, Trifarina brady, Bolivina* cf. *danvillensis, Brizalina mississippiensis*, and planktonic species, e.g., *Globigerina brevispira* and *Globorotalia* cf. *hexacamerata*. Foraminiferal tests are often pyritized (Fig. 10).

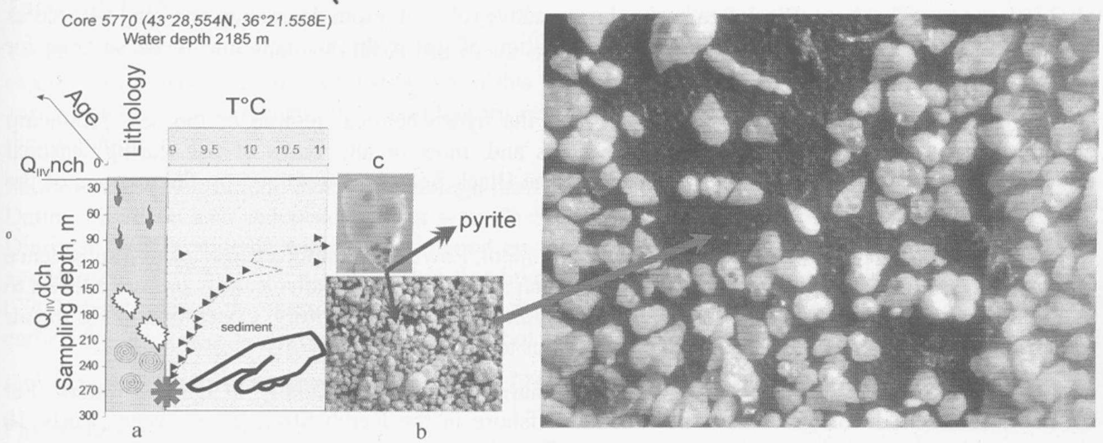


Figure 10. Lithology (Fig. 10a) and distribution of temperature in exemplary Core 5770. In the lower part of the core (represented by light grey volcanic mud), the Maikopian foraminiferal assemblage (Figure 10b) was found.

Discussion and conclusions

There is anomalously high biological activity in the bottom and upper layers of water masses (ATP 2300 and 4770 ng/l, respectively) in mud volcano areas.

Wide areas of the sea bottom are covered by muddy volcanic sediments (mainly silts). They are present not only on the bottom surface but in geological sequences as well, where volcanic clays and breccia have overlain each other since the LGM (ca. 27 ka BP to the present), reflecting the periodicity of volcanic eruptions over a long interval.

Mud volcanoes are related to the Kerch-Taman folded zone of the Alpine fold system, the Sorokin trough, the Abikh and Subbotin structures, as well as the Odessa-Sinop deep fault. Especially intensive seeps occur in the area of the Phoros uplift and Lomonosov massif. Mud volcanoes are often located at the top of geanticlines. Their height ranges between a few meters to a few tens of meters, and their area varies from a few m^2 to 500 m^2.

The source level for the mud volcanoes in the Black Sea and Kerch peninsula are sandy-clay sediments of the Maikopian (Oligocene-Early Miocene) series. The Maikopian series is folded and enriched with water and gases that migrate along tectonic cracks and/or hydrodynamic drainage systems to explode onto the surface. The absolute altitude of the roof of the Maikopian sediments varies. In the Kerch-Taman area and the northwestern shelf, it lies between 300 and 1200 m. In the central part of the Sorokin trough, it is located at a depth of 3000 m. In diapiric structures, the roof of the Maikopian formation is uplifted to 1200–1500 m approximately, e.g., in Core 5770. This formation has its greatest thickness (2500–3000 m) in the troughs, e.g., the Sorokin trough. Their thickness can reach up to 3000 m. The clayey Maikopian sediments contain layers and lenses of water-enriched sands and alevrites bent by neotectonic activity into small folds (clayey diapirs).

The source of a mud volcano can be traced to a substantial subsurface layer or diapir of highly plastic, and probably undercompacted, mud or shale. The motivating force responsible for a mud volcano is, in part, simply the weight of the rock overburden borne by the fluid content of undecompacted shales. However, mud volcanoes all over the world are so invariably associated with quietly or explosively escaping methane gas that it is reasonable to conclude that the presence of methane gas in the subsurface is also an essential feature of the phenomenon.

The activity of a mud volcano is simply a mild surface upwelling of muddy and usually saline water accompanied by gas bubbles. However, highly explosive eruptions where large masses of rock have been violently blown out hundreds of feet into the air and scattered widely over the countryside (Figure 11a) are known as well. These intermittent violent eruptions strongly suggest that the motive force is not produced merely by the weight of the gradually increasing overburden but is due to periodic buildup and release of internal pressure from the generation of methane gas within the shale body or diapir.

Mud volcanoes of the Azov-Black Sea basin play an active role in bottom degassing, and may be used as high-efficiency, low cost indicators for the investigation of gas hydrates, including those suitable for industrial exploration.

Gas outbursts from offshore mud volcanoes affect the hydrochemical regime of the sea, producing currents and acoustics. They also affect ecosystems and, most of all, routes of fish during seasonal migrations. To a certain degree, the entire biota in the Black Sea are determined by fluctuations of the level of hydrogen-sulfide exposure.

Mud volcanoes can cause great damage to the environment. Powerful eruptions cause ground subsidence in nearby areas and, if located within the limits of urban agglomerations, the volcanoes present a threat to such towns, for example, Kerch in Crimea and Temryuk in Krasnodar territory. Contamination of the air with mercury and other elements can also be hazardous to people.

Mud volcanoes can have a significant effect on maritime traffic, especially in narrow waters. For instance, seven mud volcanoes have been found offshore in the Kerch Strait. Every year, nearly 10 thousand ships cleave their way through the strait. There have been cases of ships running aground right in the navigational channel (e.g., *S/S Caesar* in 1914, and some others). The shoal proved to be of mud-volcano nature.

At times, mud volcanoes of the strait have given rise to the formation of small islets. Some researchers propose methane outbursts as the cause of ship loss in the Bermuda Triangle. Accidents of that kind are likely to happen in the Black Sea as well. The probability of such accidents has been shown experimentally.

Mud volcanoes are not just regional prospective indicators, but sometimes they can be used for precise localization of oil traps, as they are good indicators of oil- and gas-bearing provinces. This generality can be used in the future for developing criteria for earthquake forecasting.

In general, mud volcanism in the Black Sea region is an extremely interesting phenomenon of multi-dimensional importance, deserving in-depth study, primarily as an indicator of the earth's oil- and gas-bearing capacity. Today, mud volcano studies are largely focused on scientific, not applied, aspects. No survey of mud volcanoes as indicators of gas hydrates and no calculation of their contribution to total degassing of the seafloor has been performed so far on a basin-wide scale. Likewise, no research on their hazardous role has been conducted. At the same time, mud volcanoes are the seafloor's expression of endogenic processes and a "cheap window" into the deep geosphere; they may be considered valuable tools for industrial needs.

References

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