Dvurechenskii Mud Volcano – age and temporal variable activity from earthquakes, tsunamis and geological samples

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Geological settings

TTR-6 cruise discovered a "mud pie" MV on the top of a diapiric ridge in the Sorokin Trough on 31 July 1996 (fig. 1, 2). This MV was named Dvurechenskii (Woodside et al., 1998), and it has a crater in the form of an elongated circle ~1 km across and a minimum water depth of 2061 m. The MV has been formed by the local movement of the Tetyaev Rise in N-direction (fig. 2).

The only important difference in the structure of the adjacent MVs is the large offset (~75 m) between N and S seismic reflectors, probably by a large fault zone (Krastel et al., 2003). But high changeable flares on echosounders characterized the DMV as the most active scalable geological object in the basin.

Aims of this study are to evaluate: i) the crater age; ii) the number of eruptions, and their average period; iii) dates for the last 3 eruptions; iv) eruption parameters according to the model of Murton and Biggs, 2003.

Materials

Data from the EC CRIMEA project include swath bathymetry grid with a step of 5 geographical seconds (~154 m in N-S direction — courtesy of J. Greinert, GeoMar) and a gravity core from station CRI03-3-517-BGC-24 (fig. 2A, 3). In addition, other data used refer to: i) tsunamis (44 events starting in 800 BC with maximum and average level rises of 4.5 and 2.1 m (NOAA site); ii) earthquakes (2 650 — regis-

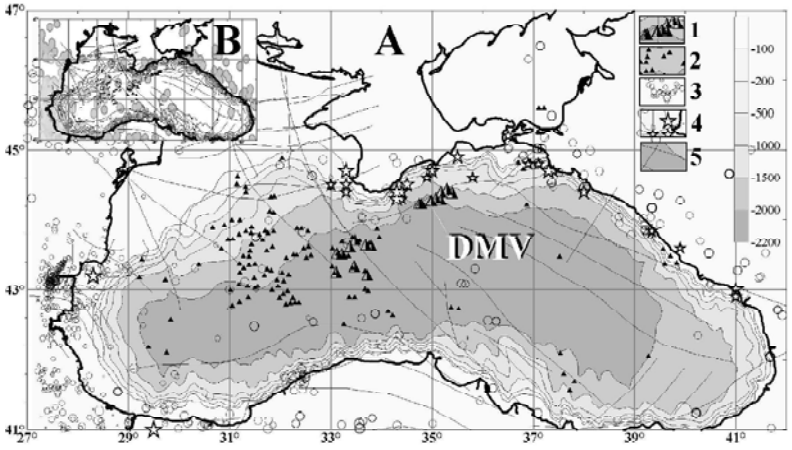

Fig. 1. **A.** MVs, earthquake epicenters and DMV location on the Black Sea bathymetric map. **B.** MVs and areas with boundaries at 20 and 25 km from epicenters. All named and studied MVs are out of 40 km zone. Almost all potential MVs are out of 20 km zone (only 4 potential MVs are closer than 20 km; other 8 are at distances of 20—25 km).
Legend: The isobaths starting from the coast are 50, 100, 200, 500, 1000, 1500, 2000 and 2100 m.
MVs — total 139 objects: 1. Named MVs; 2. Potential MVs; 3. Epicenters of earthquakes registered during the past century; 4. Tsunami related epicenters from historical records; 5. Main fault system.
Note: Epicenter signs' diameter is proportional to earthquake magnitudes: i) registered — 1—6.1 M; i) tsunami — 4.9—7.5 M.

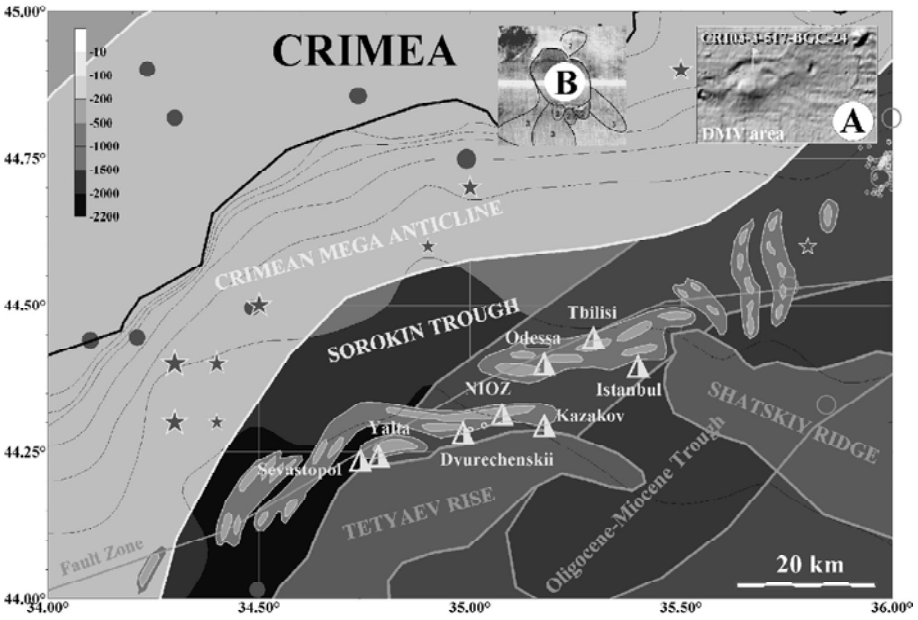

Fig. 2. MVs, earthquake epicenters and general tectonic of the studied area. **A.** Shaded relief map of DMV area from the swath bathymetry (courtesy of J. Greinert). A flag shows location of BGC-24 core. **B.** Side scan sonar record of the DMV crater (after 6) with contours of recent mud outflows.
Legend: See fig. 1.

Fig. 3. Photo of core BGC-24. Layers H_1 andH_2 consist hemipelagic sediments. The rest of core is presented by mud breccia from the last 3 eruptions.

tered between 1900 - 2005); iii) BS bathymetry (GEODAS 2' grid); iv) a side scan sonar record (Krastel et al., 2003); v) main BS faults — 54 lines.

Number of eruptions

The DMV size, shape, and its thinner upper breccia layers show similarity with the model of Murton and Biggs (2003) characterized by a short eruption time and thicker breccia layers in the crater base. According to this model, a 50 m-high MV (the average for the DMV) with a conduit diameter of 10 m and an average eruption time of 10 h is formed by ~20 erupted flows 3.5—0.5 m in thickness.

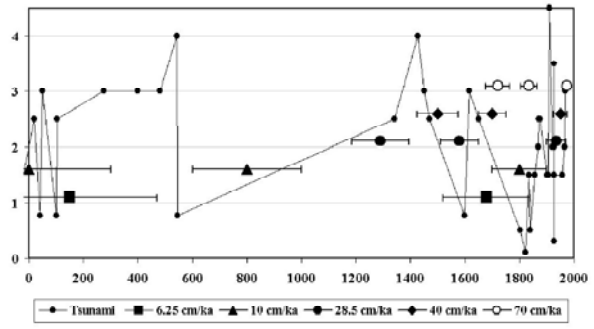

Fig. 4. Five variants of the last 3 eruptions of the DMV and the historical earthquakes and tsunamis in the Black Sea

Last 3 eruptions and the DMV crater age

The most informative core BGC-24 (fig. 2A, 3) consists of 3 generations mud volcanic breccia, separated by 2 undisturbed hemipelagic layers. An additional ~2 cm layer of unconsolidated hemipelagic sediments, covers the bottom on the OFOS photos (Bohrmann, Schenck, 2002). Thus the layers' thicknesses are 2, 44, 10 (H_1 on fig. 3), 66, 8 (H_2) and >17 cm.

Table 1. The DMV: five scenarios of eruptions from published sedimentation rates.
[1] The DMV age is determined from the number of eruptions (20) and the average period; [2] — Eruption interval is partly out of tsunami historical data; [3]? — Eruption — out of tsunami data; [4] Five tsunamis are observed during 1927 (3 in 1 month; 2 in 1 day).

Sedimentation Rate (cm/ka)	Eruption Time				Average Period (yr)
	Last (yr)	Previous (yr)	Before Previous (yr)	First (MV Age[1]) (ka BP)	
6.25	1680	150	-1200	**25.0**	1,210
10	1800	800	0	**18.0**	900
28.5	1935	1580	1290	**6.4**	320
40	1950	1700	1500	**4.5**	225
70	1975	1835	1720	**2.6**	130

Roughly 5 scenarios about the last 3 main eruptions could be dated, based on sedimentation rates in the area: i) 6.25 cm/ka (Shnyukov et al., 2003); ii) 10 cm/ka (Ross, Degens, 1974); iii) 28.5 cm/ka (Wooside et al., 1998); iv) 40 cm/ka (Shnyukov et al., 2003); v) 70 cm/ka (Wooside et al., 1998) — tbl. 1, fig. 4.

Secondary eruptions and activations

Recent mud flows from secondary eruptions, located over older ones, are smaller in volume. A rough estimation (constant mud flow thickness of 0.25 m) shows (fig. 2B): 2 oldest mud flows with volumes of ~100 000 m^3, 1 — 40 000 m^3, 1 — 20 000 m^3 and 3 youngest — 5 000 m^3.

Tongue-shaped mud flows from secondary eruptions shift counter clockwise (fig. 2B). Therefore, geological record in core BGC-24 is possible to include only secondary events. From tbl. 1, the interval between big secondary outflows is 45—420 yr; between small ones — 2.5—25 yr.

Earthquakes and tsunamis

The map of MVs and earthquake epicenters show that MV areas have been aseismic for the last 100 yr (fig. 1). The closest to a MV epicenter for the whole basin is at distance >20 km. Assuming that probably BS MVs have not erupted during the past century and the existence of secondary eruptions, we could name the registered activity stage "snail eruption". It is characterized mainly by strong and variable gas escapes and negligible mud flows. It is important to account for this stage when evaluate the methane contribution from MVs to the atmosphere.

Conclusions

— MVs areas have been aseismic in the course of the last century. A BS MV "protects" from earthquakes an area with a radius >20 km;
— As first approximation, the DMV crater is a result of ~20 abating main eruptions;
— The last main eruption was followed by 7 or more abating secondary activations and mud outflows were generally shifted counter clockwise. It is possible that there were only secondary ones;
— Speculative correlation between the times of eruptions and tsunamis suggest next MV ages, arranged in terms of probability (first — most probable): 6.4, 4.5, 18, 25, 2.6 ka and the next eruption after >0.1 ka.;
— The times between consecutive main, biggest and smallest secondary eruptions with mud outflows appear in the ranges: 130—1 200 yr; 45—120 yr; 2.5—25 yr.

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Кален вулкан Двуреченски – възраст и вариации на активността от данни за земетресения, цунами и седиментни проби

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Абстракт. Мащабни газови емисии характеризират калния вулкан Двуреченски (ДКВ) като един от най-активните гео-обекти в Черно море днес. Според последни изследвания активността на КВи е силно променлива. Тази работа е първа оценка на параметри на активността на ДКВ с най-дълъг период и съответстващите им особености на кратера. Използвани са данни от експедиционни изследвания по проекта на ЕС CRIMEA (2003–2006); регистрираните земетресения; исторически сведения за цунами и опростен модел на коничен кален вулкан.

Сезмичните данни показват, че районите с КВи в Черно море са били асеизмични през последния век. Активността на един „спящ“ КВ предотвратява земетресения с магнитуд над 1 М на площ с радиус 20–40 km. Според модела, геоложкия „запис“ в седиментите и предполагаемата връзка „изригване на КВ – цунами“, кратерът на ДКВ е резултат от ~20 изригвания, започнали след последния ледников максимум (18 ka). Оценени са периодите и мащабите на последните главни и второстепенни изригвания, придружени от кални потоци.