DISCOVERING ACTIVE MUD VOLCANOES IN THE ALBORAN SEA (WESTERN MEDITERRANEAN)

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The high-resolution survey carried out by TTR-12 Leg 3 (MARSIBAL-1 cruise; R/V *Prof. Logachev*, 2002) in the Alboran Sea has revealed the existence of recent active mud volcanism in both, the Spanish and Moroccan margins of the West Alboran Basin (WAB) (Fig. 1). The occurrence of mud volcanoes in the West Mediterranean (southern WAB) was first documented by TTR-9 (1999). TTR-12 Leg 3 was planned to complete the study of the southern WAB volcano field and to explore on mud volcano existence in the northern WAB. The Leg successfully accomplished to discover a volcano field in the Spanish margin and two new volcanoes in the Moroccan margin.

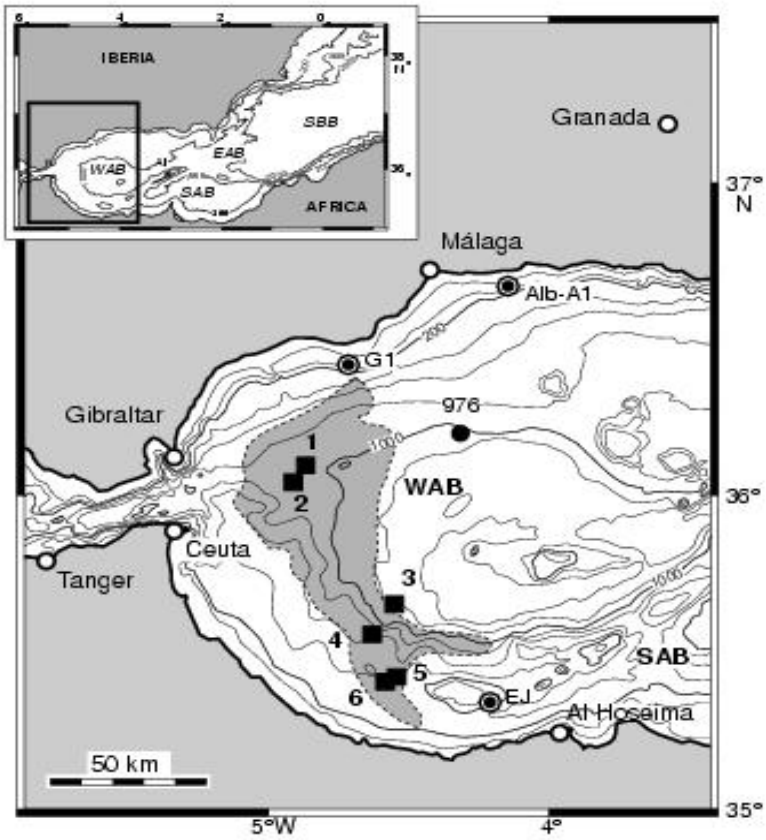

Fig. 1. Location map of the mud volcanoes in the West Alboran Basin (WAB) evidenced by TTR-9 and TTR-12 cruises. Mud volcanoes (black squares): 1= Perejil; 2= Kalinin; 3= Marrakech; 4= Granada; 5= Dhaka; 6= Mulhacen.The mud diapir province in the WAB is also shown in shading. Bathymetry contour interval is 200 m. Inset map shows the location of the surveyed area in the westernmost Mediterranean. AI: Alboran Island; EAB: East Alboran Basin; SAB: South Alboran Basin; SBB: South Balearic Basin. Commercial and scientific wells: Alb-A1= Alboran A1; G1= Andalucia G1; EJ= El-Jebha; 976= ODP Leg 161 Site 976.

Studies from the southern WAB volcanoes in the Moroccan margin have established ages and lithology in the volcano material (mud breccias), and argument the morphology, structure, and evolution of these volcanoes (Comas et al., 2000; Sautkin et al., in press; Talukder et al., in press).

TTR-12 Leg 3 survey in the WAB acquired high-resolution seismic profiles and concurrent OKEAN sidescan sonar images (9 kHz) to investigate on possible new volcano incidence. High-resolution sidescan sonar (MAK-1; 30kHz) and concurrent 5 kHz bottom profiles were deployed on specific mud volcanoes to better depict the volcano edifices. The extruded material was also sampled in and around volcano craters by gravity coring, grabbing, and dredging.

Mud volcanoes build on from the mud diapir province of the WAB and are connected to the deep diapiric structures founded in the major sedimentary depocenter of the basin (up to 7 km

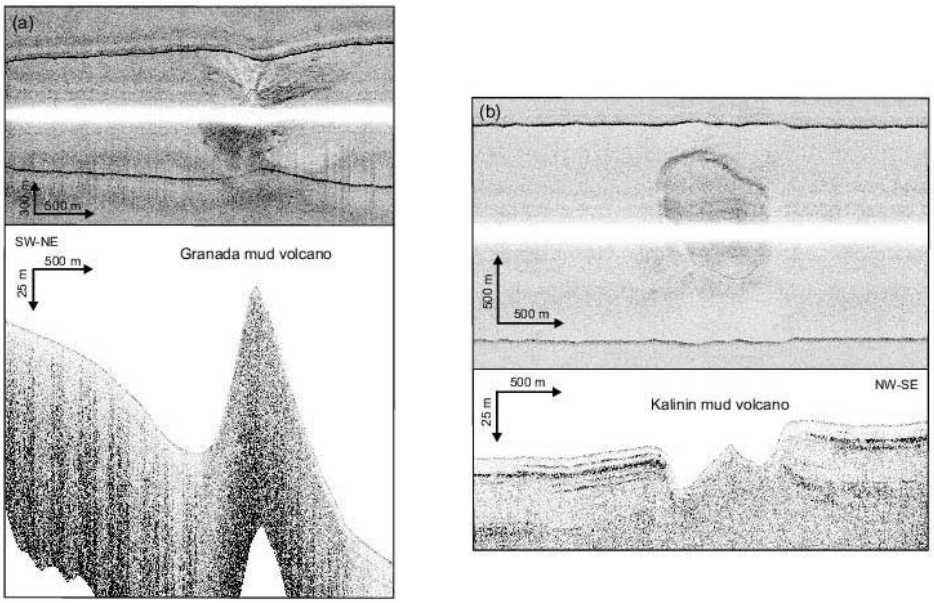

Fig. 2. MAK-1 sidescan image (30 kHz) and corresponding sea-bottom profile (5 kHz) of the (a) Granada (Profile MAK-66ms) and (b) Kalinin (Profile MAK-64ms) mud volcanoes in the WAB. For location of these mud volcanoes see Fig. 1.

in sediment thickness) (Fig. 1). The mud diapir province is formed of under compacted shale and olitostromes from the lowermost marine sedimentary sequences, early to middle Miocene in age, which overlie the metamorphic basement of the WAB. During basin extension (16 to 9 Ma) normal faulting triggered the mud diapirism, and later on, it evolved in a tectonic setting in which the basin undergone sub-meridian contraction and roughly E-W transtension (9 Ma to Holocene) (Comas et al., 1999). Regional seismic- profile correlation indicates that mud volcanism started mainly from the late Miocene, and was well developed during the Pliocene and Quaternary until Present.

The four new TTR-12 discovered mud volcanoes, are named Kalinin and Perejil, and Mulhacen and Dhaka, and are located in the northern and southern WAB, respectively (Fig.1). The high-resolution MAK-1 images and sampling from these four mud volcanoes, and the re-sampling in the Granada volcano provide an impressive amount of new information about the mud volcanism in the WAB.

The Alboran mud volcanoes are conical edifices with occasional caldera collapse structures, showing multiple erosive features in the slopes from running of extensive mud fluxes (Fig. 2a). Volcano relief elevations are from 25 m to 150 m high. Mud volcano perimeters vary from elliptical (e. g. Kalinin) to roughly circular (e. g. Perejil and Granada) shapes. The volcanic cones, with gentle lateral slopes ($\approx 2.6^{o}$), have dimensions between 1.2 km (e.g. Kalinin) and 1.6 km (e.g. Perejil and Dhaka) in diameter. Volcano craters and calderas are between 350 m (Perejil) to about 1600 m (Dhaka) in diameter. Feeder channels are cylindrical to cone-shaped showing transparent to chaotic seismic facies in the high-resolution profiles. Caldera structures show recent conical vents inside, revealing multiple events of extrusion and degasification through the feeder channel (Fig. 2b) in recent times. High-resolution seismic profiles indicate that distinct episodes of volcano collapse also occurred from the Pliocene.

Gravity cores in the craters of Perejil, Granada, and Dhaka, sampled mud breccias on the top of the volcanoes, and high gas content was revealed by a typical smell in some cores. Nevertheless, cores from Kalinin show pelagic drapes up to 1.5 m thick overlaying the mud breccias. Chemosynthetic communities of Pogonophora were found in Kalinin, beneath few cm of

pelagic drape. Few Hydrozoa and coral branches were also encountered in the Granada mud volcano. Grab and dredge sampling in Granada mud volcano evidence that the extruded material contains blocks (up to 45 cm) and clasts, boulders-to-pebble sized, from different sedimentary rocks. The extruded blocks and clasts belongs to rock-units, of very different ages, involved in the olistostromes encountered in the basal early Miocene sedimentary unit of the Alboran Basin (Comas el al., 1999). In consequence, TTR-12 Leg 3 proves that the Alboran mud volcanoes brought up material form the older and deeper sediments in the basin from more than 5 km depth, in addition to drive out mud-breccias, fluids, and gas. Multi-channel seismic reflection data across the Dhaka mud volcano show that its feeder channel reaches down to 4 s (t.w.t.), supporting that volcanic material came from very deep levels in the basin.

The absence of a pelagic drape on the top of some volcano craters together with the occurrence of Pogonophora, suggest that mud volcanoes were recently active or are still active at present.

Available data indicate that mud volcanoes developed as a consequence of fluidized sediments (fluid and gas) migration and rise through faults and fractures connected with the top of deeper mud diapirs (e.g. Kalinin, Perejil), or build on the flank of some diapir highs (e.g. Marrakesh).

Mud volcanic processes confirm the postulated gas-prone character of the Alboran Basin. Gas-rich layers inside sediments around the volcano craters (Fig. 2b) and the widespread occurrence of pock-marks in the seafloor is also indicative of the high gas content and the hydrocarbon potential of the West Alboran Basin.

Mud-volcano features in the Alboran Sea are comparable to those shown in the Gulf of Cadiz and in the Mediterranean Ridge, but illustrate occurrence and evolution in a different tectonic setting. Mud volcanism in the western Mediterranean Sea represents a case of active sediment-and-fluid flows in a back-arc basin instead of in active accretionary prism domains.

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