

MAKRAN, PAKISTAN: ACTIVE MUD VOLCANISM IN A CONVERGENT MARGIN SETTING

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The source, activity and evolution of mud volcanism in the Arabian Sea offshore Pakistan and in the coastal regions of the Makran Desert have been studied during two marine surveys (1993 and 1998) with the German research vessel R.V. SONNE and during two land expeditions to mud volcano fields onshore (1998 and 1999). Transects from the abyssal plain to the coast cross an on average 50 km wide accretionary prism with several well developed upthrust ridges and a 50 km wide shallow shelf sector. The wedge is build by the approaching Indo-Arabian plate, which subducts with a velocity of about 4 cm/year and along a very shallow angle of 3° under the Eurasian Plate. The approaching plate is covered with a sediment thickness in excess of 7 km due to high sedimentation rates (0.2-1 m/1000 years).

Only inactive mud volcanoes were found in the abyssal plain seawards of the deformation front. They are probably the result of episodic and localized vigorous mud diapirism. Unlike with other accretionary prisms in the world oceans, no evidence was found by our surveys for elevated heat flow or enhanced fluid expulsion near the accretionary front or near faults bounding the upthrust ridges of the prism. The lower slope of the prism is characterized by a thick (locally in excess of 700 m) gas hydrate layer, through which no fluid flow was detectable except at one location, where a deeply incised canyon cuts almost completely through the gas hydrate zone. The presence of *Calyptogenia sp.* colonies and an elevated gas content in the bottom waters only at this position point to local fluid expulsion. Detailed bathymetric mapping of the lower slope did not produce evidence for active or inactive mud diapirism.

Elevated gas content in bottom waters, indicative of elevated fluid expulsion from the sea floor and many gas seeps were observed at water depths of less than 800 m. The 800 m water depth line is identical with the termination of the gas hydrate stability zone. Back in 1993, first evidence of an extensive gas plume (bacterial methane) extending laterally over 20 km at water depths between 500 m to 1000 m was detected. The concentration of trace gases, and in particular methane, in the water column of the Arabian Sea was remeasured in 1998 along three additional profiles over the accretionary prism. Gas plumes extending laterally over 10 km to 25 km were detected along all profiles in water depths between 300 m to 800 m. The apparent origin of the gas plumes in water depths of less than 800 m suggests to us that the gas hydrate layer acts as a cap rock to fluids at depth. Fluids are deflected to the shallow water section, where they are suspected to feed the abundant number of gas seeps. The lateral deflection of the fluid flow by the gas hydrate layer appears to be the key reason for the lack of mud volcanoes on the lower slope of the accretionary prism.

Mud diapirism occurs again close to the shore in episodic fashion. The sudden eruption of three mud volcanoes in 1945 near the coastline of the Makran Desert in connection with a large earthquake and their destruction by wave action within months is documented in the literature. In March of 1999 a sudden eruption of a mud volcano, apparently in identical position with one of the in 1945 erupted mud volcanoes, offered the opportunity of a more detailed study. An echo sounder record conducted in November 1999 over the remnants of the new mud volcano (called Malan Island) identified two closely spaced eruption centers, from which approximately 160 000 m³ mud had extruded to form a temporary island, only to be washed again by wave action within three months.

The position of former Malan Island lines up along a straight line in SE-NE-orientation with the position of well known mud volcano fields on land (Gebel u-Gurab field; Chandragup volcanoes, Khandewari mud volcano). This line is parallel to the long axis of a well exposed anticline suggesting a structural control of the position of the mud volcanoes.

The Chandragup volcano field consists of two active edifices, one inactive and one apparent ruin of a former mud volcano. The highest volcano (Chandragup I) raises 100 m over the plain and is known from literature to exist at least since 1840 with an almost unchanged shape. The volcano has probably been permanently active since then. Gas bubbles rise from the 16.5 m wide mud lake in the crater. The mud enters the 25 m deep lake from a N-S oriented fracture at the lake bottom. The vigor of gas exhalation appears to vary systematically on a daily basis. Mud overflow from the crater is infrequent.

Chandragup II, an about 40 m high adjacent edifice raises about 1 km to the east of Chandragup I. He features a double crater, now filled with a lake, from which only minor gas exhalation was observed in 1998, but vigorous gas flow in 1999. If and with which periodicity gas escapes to the atmosphere from this position is unknown. Gas exhaled from both volcanoes is predominantly of bacterial origin.

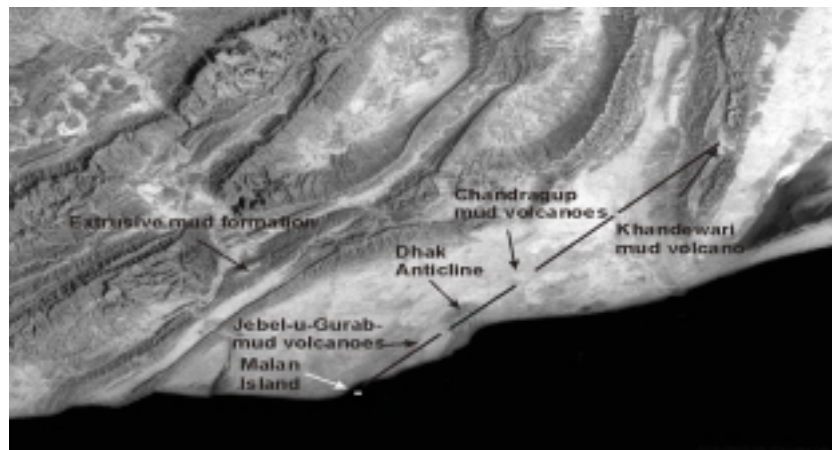


Figure: Position of various mud volcanoes along the coast of the Makran Desert, Pakistan