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Mud volcanism and mounds on the Moroccan margin: origin and growth

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Giant submarine mud volcanoes on the Moroccan continental margin have been studied with high resolution seismics in order to analyse their origin and activity in a spatial and a temporal framework. The El Arraiche mud volcano field, discovered in 2002 during the CADIPOR cruise onboard R/V Belgica, boasts 8 mud volcanoes of which some are without equal in size and height. Orthogonal grids of narrow spacing high resolution seismic profiles over three large mud volcanoes have allowed for the first time to analyse the activity history of mud volcanoes in detail. The three grids were connected by seismic lines in order to correlate the mud flows of the different mud volcanoes.

The occurrence of the mud volcanoes is related to extensional tectonics. The top of the accretionary wedge is subject to extension, resulting in large rotated blocks bound by lystric faults. The crests of the rotated blocks are expressed as anticlinal ridges at or near the seafloor. Most ridges show evidence of collapse of the ridge crest where the mud volcanoes are located, in response to the created subsurface mass deficit. This is expressed by downward bending reflections of the basement and oldest unit, sometimes accompanied by small normal faults.

Regional tectonic events are controlling the long-term eruptive history of mud volcanoes, as inferred from seismic data. Based on small unconformities in the seismic profiles, a seismic stratigraphic framework was built, with 3 major units and multiple subunits. Although synchronized activity of the different mud volcanoes was not observed by analysis of extruded mudflows, units with many outflows could be discriminated from barren units. All three studied mud volcanoes activated in a short time frame, during the Pliocene, and remained active for the same period, contemporane-

ous to basin subsidence. A successive period of no mud volcano activity and absence of subsidence is followed by a recent pulse of high mud volcanic activity again. This suggests that regional tectonic events control the long-term eruptive history of the mud volcanoes, although the short-scale timing seems random.

Two mud volcanoes boast an enigmatic but coherent reflection under its surface at a waterdepth of $\sim$350 m. Its acoustic and morphological (3D) properties lead to the hypothesis of shallow gas hydrate presence. A stability model using thermogenic gas compositions and calculation of the thermal gradient and heat flow pattern confirmed our interpretation. The high inferred heat flow (over $1\ \mathrm{W\ m^{-2}}$) in the crater of the mud volcano confirms the focused flow of warm fluids. It shows that in areas of thermogenic gas production, gas hydrates can occur at very shallow water depths, even in areas with high heat flow.

In the El Arraiche mud volcano field, biogenic carbonate mounds are present on the Pen Duick Escarpment, a fault-bounded cliff. In addition to all existing models for growth and origin, we want to propose a new model. A scarp or hill on the seabed subject to rather strong currents will develop zones of high pressure at the lows of the slopes and low pressure areas at or near the summit, triggering a fluid flow towards the summit of the structure. An enhanced migration of reduced chemical compounds at an uncolonized scarp or hill towards the surface could promote cementation of the sediments leading to hardground formation, suitable for subsequent settling. Fluid rise also could result in cementation of a coral rubble framework for existing mounds, leading to stabilization. It can also enhance the food supply for microbial communities. This in turn can boost species diversity, both mega- and microfauna. So, in this view, the pumping of fluids in carbonate mound systems, driven by external currents, is responsible for different processes. Numerical modelling of this process to assess the impact of pressure fields is ongoing.