Geophysical Research Abstracts,
Vol. 11, EGU2009-6836, 2009
EGU General Assembly 2009

Geochemical zonation and characteristics of cold seeps along the Makran continental margin off Pakistan

D. Fischer (1), G. Bohrmann (2), M. Zabel (3), and S. Kasten (4)

(1) DFG Research Center/Cluster of Excellence MARUM "The Ocean in the Earth System", University of Bremen, Germany (david.fischer@awi.de), (2) University of Bremen, Department of Geosciences, Germany (gbohrmann@marum.de), (3) University of Bremen, Department of Geosciences, Germany (mzabel@uni-bremen.de), (4) Alfred Wegener Institute for Polar- and Marine Research, Bremerhaven, Germany (sabine.kasten@awi.de)

Several highly dynamic and spatially extended cold seeps were found and analyzed on the Makran accretionary wedge off Pakistan during R/V Meteor cruise M74-3 in 2007. In water depths of 550m to 2870m along the continental slope nine different gas escape structures were examined some of which are situated within a stable oxygen minimum zone (OMZ) between 150m and 1100m water depth (von Rad et al., 1996, 2000). Echosounder data indicate several gas bubble streams in the water column. The gas seepage presumably originates from squeezing of massive sediment packages being compressed by subduction at the continental margin off Pakistan. Gas- and fluid venting and associated surface-near anaerobic oxidation of methane (AOM) feed several cold seepage systems in the seabed. The seep sites show strong inter- and intraspecific variability of benthic chemosynthetic microhabitats. Singular seeps are often colonized by different chemosynthetic organisms in a concentric fashion. The seep-center, where active bubble ebullition occurs, is often colonized by large hydrogen sulfide-oxidizing bacteria, which are surrounded by a rim inhabited by small chemosynthetic clams and tube worms. These different habitats and the associated sediments show distinct geochemical zonations and gradients. Geochemical analyses of pore water and sediment samples obtained via ROV (push corer) show that concentrations of hydrogen sulfide and alkalinity rapidly increase to >15 mmol/l and >35 mmol/l respectively several cm below the seafloor in the center of the cold seep. In places, sulfate is depleted to concentrations below detection limit at the same depth (ROV push core GeoB 12313-6). Ammonium concentrations in this core on the other hand show a different pattern: In the center of the cold seep, which is colonized by bacterial assemblages, ammonium concentrations fluctuate around 100 μmol/l and peak with 274.4 μmol/l just above the aforementioned sulfide maximum values at 5 cm followed by a rapid decrease to near zero below that depth. A feature of a number of Makran cold seeps within the OMZ is that the central orifice of gas ebullition is solely surrounded by white to rose or yellow colored chemosynthetic bacteria which colonize the seepage spots in concentric rims that are in places elongated towards one direction and hence display a comet tail-like shaped bacterial mat on the sea floor.
In contrast to the cold seep centers, the outer rim around the seep sites, which is colonized by chemosynthetic clams and tubeworms, is characterized by ammonium concentrations that stay below detection limit and hydrogen sulfide and alkalinity concentrations are as well lower here than in the central part with values >8 mmol/l and >25mmol/l respectively at a depth of 13 cm (ROV push core GeoB 12313-12). Sulfate concentrations fluctuate around 15 mmol/l here and hint to lower sulfate reduction rates compared to the central part of the seep. The low contents of ammonium in the pore water of the outer seep sections may originate from processes initially proposed by Tryon et al. (2002): Gas and fluids constantly emanating from a central orifice cause the formation of a small-scale, local fluid-flow system comparable to convectional or belt-like flow dynamics. These convectional fluid-flow characteristics would cause an outflow of the actual gas/fluid composite from the central orifice and an inflow of bottom-near sea water poor in ammonium into the surrounding sediment where it would cause the very low pore water concentrations detected here.

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