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Time scales and potential controls of focused fluid flow deciphered in microbially mediated carbonates

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Focused gas and fluid flow of cold seep ecosystems is often characterized by carbonate precipitation processes fueled by hydrocarbon-rich fluids and microbial activity. In various geological settings the seabed leakage is methane dominated and accompanied by the formation of long-lasting hard substrates and open channels. These fluid pathways are connecting deeper levels of the sediment column with the bottom water, bridging the diffusive processes at the sediment/water-interface.

Understanding and quantifying feedback mechanisms between hydrocarbon-sources, ocean chemistry, and climate requires detailed data about the dynamics of seafloor methane emanation throughout geological time.
Authigenic carbonates from these ecosystems represent in many cases unique archives of marine methane emanation by their geobiological, geochemical, mineralogical, and structural inventory. Precise and high resolution geochronology of these archives provides new insights into the rate and duration of precipitation processes, the related microbial activity and a base for the reconstruction of paleoactivity of natural seepage.

The actual data set of our compilatory study is spanning a wide range in space and time. It covers circum-Pacific settings (South China Sea, Costa Rica & Nicaragua, New Zealand), including more than 200 thousand years old archives (Hydrate Ridge, off Oregon), and almost recent methane-related carbonates from Black Sea and Mediterranean Sea.

Special emphasis is actually given to new insights into growth structures, emplacement processes, mineralogy and high resolution geochemistry of mud mound and escarpment related carbonates from the Central American Forearc.
Carbonate drill cores decipher the late stage evolution of mound growth and related methane enriched fluid emanation during the last 70 000 years. As a complex case study a broad range in δ13C from -22 to -36‰ (mounds) and -43 to -56‰ (escarpment) is covered, reflecting different hydrocarbon sources and/or varying fluid/seawater-ratios. Whereas the δ18O signatures indicate a systematic variation between 3.8 - 5.3‰ (mounds) and 4.2 - 5.1‰ (escarpment) in close correlation with their age (U-Th geochronology [1]) and the record of seawater evolution.

Combining high resolution observations of growth structures (fluorescence microscopy) and analyses of Cl-S-C distribution pattern (electron microprobe) decipher multiple phases of carbonate precipitation separated by micrometer scaled layers of residual organic matter (e.g. 50 alternations on 3 mm). The latter are interpreted to be attached onto crystal surfaces during phases of rather stagnant or low fluid flow, respectively.

On long time scales, the circum-Pacific data set indicates sea level decrease as an important enhancement factor for focused fluid flow via increasing pore water buoyancy, destabilization of gas hydrates and related fluxes from underlying free gas deposits upon hydraulic pressure release.
Data from tectonically highly active settings imply structural changes as major control on initiation and position of cold seeps and their activation on short time scales [2,3].

[1] Hammerich et al. (2007) Terra Nostra. [2] Kutterolf et al. (2008) Geology, doi: 10.1130/G24806A [3] Liebetrau et al. (2010) MG, doi:10.1016/j.margeo.2010.01.003.