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Hydrothermal water-rock interaction of underthrust sediments with seawater – an experimental approach

Andre Hüpers and Achim J. Kopf

MARUM - Center for Marine Environmental Sciences, University of Bremen, P.O. Box 330440, 28334 Bremen, Germany (ahuepers@uni-bremen.de)

At active convergent margins fluids enter as an integral part of the subduction inputs. To a greater extent the fluids are trapped as pore fluids and will be expelled during compaction within 3-4 km of burial depth and may impact ocean geochemistry. The remaining pore water as well as water bound in hydrous minerals will be buried with the sediment to greater depth. During this process the geochemistry of the interstitial water is subsequently affected by processes facilitated by increasing stress and temperature such as mineral dehydration, fluid-mineral exchange reactions, diffusion-advection or pressure solution. For example, mineral dehydration processes can explain fluid freshening anomalies at convergent margins but is also thought to be important for excess pore pressure generation. Thus, a detailed insight on these processes may shed light on the linkage between mechanical, thermal and geochemical processes within the shallow subduction zone.

We conducted heated consolidation tests on sediment samples representing end member mineralogical compositions at the Western Nankai subduction zone (smectite-rich clay and silty illite-rich clay). Expelled fluids were analyzed for pore water geochemistry with the intention to study hydrothermal water-rock interaction in response of increasing temperature (T) and effective stress (P). Burial was mimicked by continuous loading up to effective stresses of up to 70MPa at temperatures of 20°C, 100°C and 150°C up to 150°C. Maximum PT conditions are supposed to equivalent to the onset of the seismogenic zone at the Nankai margin.

Pore water analyses reveal that consolidation has a direct impact on pore water constituents in our experiments. In the low stress regime the beginning of pore water discharge leads to a transient increase of solutes for all samples. At stresses greater than approximately 10MPa depletion in predominantly alkaline and earth alkaline elements is observable for the smectite-rich sample. The high clay content of this sample and in particular the high smectite content suggests that the process is derived by the release of the free pore water followed by the expulsion of the residual water from the overlapping double layer of smectite. Anions will be expelled to a large extent during the expulsion of the free pore water. Thereafter the solutes attached to the double layer will be released, which are depleted in anions. Because of electrical neutrality the expelled water is also depleted in cations. However, we suggest that stress depended observations may have little geological relevance due to the necessary smectite abundance at depth.

The increasing temperature leads to the enrichment of K, Ba and Si and to the depletion of Mg for all tested lithologies. According to the enrichment/depletion in the solution the following retention sequence is proposed with increasing temperature: Mg>Ca for divalent cations and Na>K for monovalent cations. The release/depletion of solutes starts immediately with heating and suggests that long-term diagenetic processes can be neglected for this observation. Thus, the observed change in element concentrations seems to be due to the interaction of the pore water with exchangeable sites at the charged surface of clay minerals. The ion exchange may be relevant for diagenetic processes because K facilitates the smectite-illite conversion and the greater desorption of Si may facilitate the precipitation of quartz cements and veins. Although the observed change in pore water geochemistry may foster diagenetic processes at convergent margin, its geological relevance has to be quantified by further testing.