3.3.14

Brines from the 4 km deep KTB drillhole in crystalline rocks

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The 4 km deep pilot research drill hole of the German Continental Drilling Project (KTB) has been used to sample fluids from the fracture pore space of the crystalline basement rocks of the continental crust. The open hole and water entry points are located in the section from 3850 m to 4000 m depth. The rocks are predominantly amphibolites and meta-sedimentary gneisses of the Bohemian massif. The Variscian metamorphic sequence is steeply dipping and complexly folded.

The water has been extracted in the context of a pumping test of one year duration, during which water has been pumped with a constant rate of 29 l/min during the first 4 months and subsequently at 57 l/min. The temperature at depth is 120˚C and 42˚C at the wellhead. Drawdown was 255 m after the first period of the pumping test and 570 m after the second period.

The fluid was sampled weekly during the one year lasting test and the composition is essentially constant suggesting that the fluid reservoir is large and homogeneous. The test showed that water in the basement is apparently present in "unlimited" amounts.

The main components of the fluid are Calcium (15.8 g/l), Sodium (6.41 g/l) and Chloride (38.7 g/l). TDS is c. 63 g/l (seawater 35 g/l). Magnesium is surprisingly low. The Cl/Br-ratio (Cl/Br = 75, mg-based) is low, (seawater 288), generally indicating water-rock interaction and salinity derived from the basement. The KTB water is saturated with respect to calcite, gypsum and chlorite, the cause of low Mg-concentrations.

The composition of the fluid is very different from other deep fluids in the Central European crystalline basement that normally have $X_{Ca}<0.1$ (e.g. Black Forest). We suggest that the main reason for the high X_{Ca} of the fluid is the presence of anorthite-rich plagioclase (An_{30} – An_{50}) in the predominantly mafic rocks (amphibolites) of the basement. The Black Forest basement is mainly gneiss and granite with plagioclase < An_{20}. This implies that the principal reaction controlling the X_{Ca} of the fluid is plagioclase alteration.

We propose that the original fluid interacted at 120˚C with andesine-labradorite of the basement amphibolite. The alteration increased the X_{Ca} of the water and excess Na formed new albite. The alteration reaction also produced abundant zeolite coatings on fractures of the crystalline rocks. Zeolite formation acted as an H_2O-sink and as a result the TDS of the fluid increased passively "over the years".

3.3.15

Hydrogeochemical changes before and after a major earthquake

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We report hydrogeochemical changes before and after a magnitude 5.8 earthquake, which occurred within the Tjörnes Fracture Zone, northern Iceland, on September 16, 2002, based on monitoring of ice-age meteoric waters. We report significant Cu, Zn, Mn, Fe and Cr anomalies, which reached our sampling station respectively 1, 2, 5, ≥10 and ≥10 weeks before the earthquake. By comparison with published experimental, geophysical and geochemical studies, we suggest stress-activated source-mixing, with leakage of fluid from an external (hotter) source reservoir, where fluid-rock interaction was more rapid. We report rapid 12-19% increases in the concentrations of B, Ca, K, Li, Mo, Na, Rb, S, Si, Sr, Cl and SO_4 and decreases in Na/Ca, $\delta^{18}O$ and δD shortly after the earthquake. Noting that the rapidity of these changes is consistent with (experimentally-derived) timescales of fault-sealing in response to coupled deformation and fluid flow, we interpret fluid source-switching in response to fault sealing/unsealing. We note that the newly tapped source reservoir contains chemically and isotopically distinct ice-age meteoric water. There is some indication that Na/Ca-variation is sensitive to the changing stress state associated with M >4 earthquakes. We conclude by highlighting the potential relevance of hydrogeochemical change in earthquake prediction studies.