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Fluid migration in sedimentary basins - a case study from the Central European Basin

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Core samples from the cap rock of an Upper Permian dolomitic limestone from the Zechstein formation (Stassfurt carbonate sequence, Ca2) in the Central European Basin were studied for a better understanding of the tectonic control on fluid migration during the burial and uplift of CO_2-rich gas reservoirs. Petrographical investigations were carried out by means of optical transmission and cathodoluminescence microscopy. A heating-freezing stage was applied for fluid inclusion analysis; gas compositions were measured by Laser-Raman spectroscopy. The study focuses on the quantification of paleo pressures, temperatures and compositions of diagenetic fluids trapped as inclusions in dolomite, anhydrite, calcite, and fluorite, as well as in postdiagenetic fluorite in mineralized fractures.

Limestone matrix mainly consists of early diagenetic, euhedral dolomite with few hydrocarbon-bearing inclusions. Offset veins originating from fine-grained inclusion-free anhydrite nodules consist of coarse-grained recrystallized anhydrite containing primary aqueous CaCl2-rich inclusions. Late calcite cement fills remnant pores between the dolomite rhombs and contains H_2O-NaCl-CaCl2 fluid inclusions. Subsequently, the dolomitic limestones were affected by pressure solution due to burial, followed by basin inversion (uplift) starting in Upper Cretaceous. Pressure solution generated carbonate rich fluids, which resulted in dolomite and calcite veinlets. Simultaneously, a first clearly zoned and brown coloured generation of fluorite (I) accumulated in nodules together with sulfides and organic matter. This fluorite (I) contains mostly H_2O-NaCl-CaCl2 fluid inclusions with relatively high salinity (17.8 wt% NaCl, 8.9 wt% CaCl2). Colourless fluorite (II) is the latest observable (post-) diagenetic mineral phase filling veinlets in dolomitic limestone that crosscut pressure solution features. Fluorite (II) replaces fluorite (I) within the nodules as well. Carbonic inclusions together with CH4 and N2 are only found in fluorite (II).

These results reveal almost no change in the composition of aqueous fluids during basin burial and uplift (H_2O-NaCl-CaCl2, with only small variations in concentration). From the presence of hydrocarbons in the recrystallized dolomite and the recrystallization temperatures of anhydrite (Th ca. 125°C), mean temperatures during early diagenesis can be estimated. The calcite cement indicates a slightly higher temperature (Th ca. 147°C), followed by the early fluorite (I) phase (Th 152°C). The fact that CO_2 was trapped only in type (II) fluorite (Th ca. 156°C/185°C) ascertains a late episode of gas trapping during the migration of gas rich fluids along fractures. Besides, co-existing fluid inclusions (H_2O/CO_2) in fluorite (II) veinlets reveal exact P-T conditions during trapping of CO_2 and therefore provide an important data set for calibrating numerical basin models.