Fracture sealing in limestones, a microstructural and mineralogical study *Vortrag*

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Introduction

Fractures significantly enhance the flow rate in rocks, if fracture density is high (Taylor 1999, Cox et al. 2001). This leads to rapid flux along a hydraulic gradient from high to low pressure reservoirs, and is represented in rocks as veins. Veins are precipitates from supersaturated fluid, and are formed by a change in pressure, temperature or geochemistry. The solubility of vein forming minerals such as quartz, calcite or halite is generally low and thus large (and sometimes unreasonable) fluid volumes are required to account for the precipitated mass. Rapid ascent of solution may explain the high supersaturation needed to seal fractures, either by fluid flow along deep reaching faults due to seismic ruptures, or mobile hydrofractures driven by pressure gradients in fluid filled fractured at deeper crustal sections (Bons 2001, Miller 2002). The vein microstructure is a unique tool to unravel the fracture sealing process. The most indicative microstructures are fractured minerals, which were sealed by a fluid of different composition. The repeated presence of fluid and solid host rock inclusions in fibrous, stretched crystal type veins (minerals which extend across the vein and into the host rock) also indicate repeated fracture-sealing processes (Ramsay 1980), although their presence is not a sufficient criteria (Hilgers 2005). In this study, we outline the different fault sealing processes associated in a still seismic zone. The faults are located in Carboniferous limestones, and thus present an analogue for fault sealing processes in hydrocarbon reservoirs and an in-depth study of seismogenic faults.

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Geological Setting

We studied lower Carboniferous limestones, which are truncated by subvertical, dm-wide calcite veins. These platform limestones are located on the NE-limb of the Stavelot-Venn Anticline, which is part of the Variscan fold and thrust belt. Our study area is the quarry Hastenrath, which is located app. 50 m SW of the seismogenic Sandgewand normal fault. Calcite veins locally contain lead- and zinc-sulfide ores and strike NW-SE parallel to the normal fault. We compare our results of core data derived from the deep drilling project RWTH–1, a 2543 m deep well drilled in 2004 in the city centre of Aachen. The core contains 20 m of intensely deformed upper Devonian limestones at 1420 m depth. These limestones also contain different sets of calcite veins, but are devoid of ore mineralization.

Microstructure and mineralogy

Hastenrath

The Hastenrath quarry exposes several approx. 20 cm wide subvertical veins in limestone with some first localised dolomitisation. Macroscopically, the veins show three to four different, symmetrically arranged cements.

#1 is close to the host rock, a pink hydrothermal dolomite precipitated next to the host rock. The dolomite is a tectonic dilational breccia, which is cemented with calcite. The cathodoluminescence shows fragments of euhedral calcite crystals outlined by different colours, and large areas where grains do not match with the variations in luminescence. Such calcite grains consist of subangular fragments of dark and orange luminescence. Calcite twin morphology indicates temperatures of app 250°C. Dolomite is overgrown by euhedral ankerite. Euhedral to subhedral galena crystals up to 1 cm in diameter indicate a later timing of growth. Euhedral quartz has a solid inclusion rich rounded centre and is present in all phases of zone #1.

The intermediate zone # 2 shows up to 2 cm twinned calcite grains of twin type II which indicate a temperature of 150–300°C. The cathodoluminescence shows a pattern which does not correspond to calcite grain boundaries. The central zone #3 is sealed with small twinned calcite crystals with a thin sphalerite vein. The sphalerite shows zones with high cadmium content. Both zone #1 and #3 contains chalcopyrite within and around galena and sphalerite. Locally, organic material em-

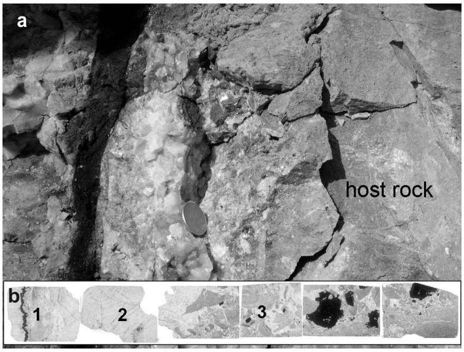

Figure 1: (a). A calcite vein with Pb-Zn mineralization, Hastenrath Quarry. The rim of the vein shows fragments of hydrothermal dolomite and euhedral galena crystals. The central part of the vein is filled with organic material (36% C). (b). Horizontal section of the vein shows three fluid generations.

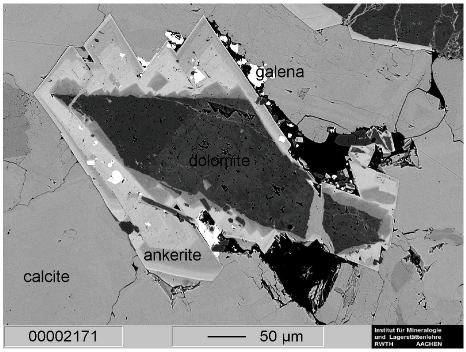

Figure 2: Microprobe image of a broken fragment of dolomite with an ankerite seam. Galena is also present in the patchwork calcite matrix.

placed in the central part of the vein. Vitrinite reflectance gives <150°C.

RWTH Aachen

The core material from the RWTH-1 well contains up to 0.3 cm thick veins in dolomite. The host rock indicates a late diagenetic dolomitisation with zoned Fe-rich seams around dolomite crystals. Two different quartz phases precipitates in the pores, as indicated by a blue luminescence (restricted to the host rock) and a later brown luminescence in veins and host rock. Pyrite crystals growth in the pores of the host rock as bacterial degradation in reduced milieus. The vein consists of dolomite of dark brown luminescence, transected and surrounded by bright orange calcite. Euhedral quartz crystals (brown luminescence) are present in dolomite, calcite and are enriched along the vein wall interface.

Conclusions

The sealed fractures show similar fluid events and -sequences in upper Devonian (RWTH–1) and lower Carboniferous (Hastenrath) limestones with an early dolomite vein, fractured and resealed by calcite and late euhedral quartz. The veins in Hastenrath show an even more complex sealing history because they contain beside brecciated dolomite and calcite, euhedral ankerite overgrowth, galena (approx. 150°C), euhedral quartz, calcite, sphalerite (approx. 150°C) and calcite, later filled with organic material <150°C. Galena and sphalerite are associated with chalcopyrite. The geochemistry of the dolomite is different in both localities, indicating either a different fluid systems or strong influence of the host rock. Similar fluid types at both localities may suggest a homogeneous fluid system. However, marked differences exist between hydrothermal mineral products of both localities. The complex fluid system in Hastenrath shows that the same fracture was sealed during different fluid events, possibly associated with normal faulting.

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