Diagenetic Fluid Circulation through Fractures: a Case Study from the Barrandian Basin (Lower Paloeozoic), Czech Republic

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In sedimentary rocks, joints may propagate at different times during a tectonic cycle including burial, diagenesis, tectonic compression, uplift, and erosion. In this study, a natural example of the interplay between fracture propagation and fluid composition and circulation has been examined by deciphering vein and fracture sequence in Silurian and Devonian limestones and shales at the Kosov Quarry, the Barrandian Basin. The relative age of joints was determined from the structural relationships of the various joints within the exposures over the quarry. Fluid inclusion homogenization measurement on calcite and quartz cements from pre-, syn-, and post-kinematic structural settings were used to constrain the temperature ranges at which the fractures propagated. In addition, representative samples of vein cements were subjected to gas chromatography-mass spectrometric (GC-MS) analysis to reveal the chemical composition of fluid for each period of fracturing.

The earliest veins, that propagated prior to folding, were *fibrous "beef" calcite veins*, found parallel to the bedding of some shales. The veins range up to a few centimetres in thickness, and consist of calcite crystals arranged perpendicular to the plane of the vein. Abundant brightly fluorescing hydrocarbon inclusions within the vein cements which posses T_{hom} values between 58-65°C indicate that the "beef" was formed during deeper burial. The mode of opening of the veins is indicative of hydrofractures that may have originated due to overpressure generated during compaction of shale sequences.

E-W-striking, mineralized tensile veins propagated relatively later during burial, probably prior and/or during early stages of Variscan folding. The veins are a few millimetres wide, rather straight, and oriented semi-vertically to the bedding plane. Vein-filling minerals include milky calcite, quartz and residues of hardened or waxy bitumen. Vein quartz contains a number of two-phase primary hydrocarbon inclusions, 10 to 200 µm in size, with consistent liquid to vapor ratios (of about 10 vol. % of vapor phase). Larger inclusions occur rarely, mostly with variable LVR, some containing immiscible yellowish waxy substance. No aqueous inclusions have been found in this quartz type. At room temperature, most hydrocarbon inclusions contain a colourless to light yellow-brown liquid and a vapor bubble. When examined under long wavelength ultraviolet light (365 nm peak of Hg), the liquid phase of fluid inclusions fluoresces a deep blue, light blue and light blue-green which is characteristic for light oils and condensates (40–50° API gravity). Many quartz crystals exhibit a distinct geographic pattern of fluorescence: inclusions with light blue fluorescence tend to be concentrated near the crystal core, whereas dull blue and blue-green fluorescent inclusions occur along the margins of the crystals. Temperatures of homogenization vary from 51 to 101 °C with two peaks at 80-90 °C for crystal cores and at 60-70 °C for marginal growth zones. GC-MS analysis of fluid extracted from the crystals shows that they are composed of multicomponent mixtures of hydrocarbons including n-alkanes C_{10} – C_{23}. Carbon Preference Index (CPI) of the fluid (0.91) is characteristic of thermally matured petroleum.

Subvertical *shear fractures forming a diagonal set striking NNE to NNW* apparently represent the relatively youngest stage of fracturing that followed Variscan folding. The fractures exhibit distinctive straight plumes (the chevron type) on joint surface that is typical of high-energy, fast-running fracture opening. At some outcrops, the joint surfaces are coated with a number of flat, 0.4 mm or less thick, quartz crystals that range 5-8 mm in length. Under the microscope, the crystals reveal regular growth zoning which is due to the alternation of both solid and liquid organic inclusions. Besides particles of black non-fluorescent bituminous substance, numerous small (5-20 µm in diameter) two-phase inclusions of liquid hydrocarbons with about 10 vol. % of vapour phase were recognized in crystal cores that fluoresce dull blue to deep blue-violet. Brightly yellow and orange fluorescent inclusions composed of heavier oils tend to concentrate in crystal rims. Temperatures of homogenization of the inclusions range between 55 and 80 °C for crystal cores and between 36-50 °C for crystal rims. At present, the interpretation and timing of this fracture system remains uncertain. Indirect structural evidence and on-going measurement of vein bitumen reflectivity suggest that the N-S-striking fractures could belong to a large system of regional seismotectonic lineaments that cut across the Bohemian Massif. These lineaments appear to correspond to deep faults and fractures repeatedly reactivated during Tertiary and Quaternary times to provide the conduits for warm mineralized fluids.