Coupled pore fluid pressure oscillation and natural fracture opening in tight-gas sandstone reservoirs: Piceance Basin, Colorado, USA

Fall, András*, Eichhubl, Peter*, Laubach, Stephen E.* and Bodnar, Robert J.**

*Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, Austin TX 78713, USA
**Department of Geosciences, Virginia Tech, Blacksburg, VA 24061, USA

Continuous gas charge of low-permeability tight-gas sandstones in the Piceance Basin, Colorado, creates a dynamic system where pore pressure increases locally and temporarily to near lithostatic pressures, and fractures the rocks. The natural opening-mode fractures are partially cemented with crack-seal quartz cement bridges that precipitate synkinematically with fracture opening. Coexisting aqueous and hydrocarbon gas fluid inclusions trapped in crack-seal cement increments record pressure, temperature, and fluid composition (P-T-X) conditions during subsequent fracture opening and cementation. Methane concentrations of the aqueous fluid inclusions can be used as proxy to determine the pore pressure variations during fracture opening. Combining homogenization temperatures with burial history models allows determining the timing of fracture opening and cementation in these systems.

The Upper Cretaceous Mesaverde Group in the Piceance Basin is considered a basin-centred continuous gas accumulation where gas charge of the low-permeability sandstone occurs during peak gas generation at maximum burial conditions. This model contrasts with other low-permeability gas reservoirs where gas accumulates in conventional traps prior to maximum burial and significant permeability reduction. We tested aspects of the basin-centred gas model as it applies to the Piceance Basin by determining the timing of fracture growth and associated temperature, pressure, and fluid composition conditions using microthermometry and Raman microspectrometry of fluid inclusions. Trapping temperatures of methane-saturated aqueous fluid inclusions record systematic temperature trends that increase from ~140 °C to 185 °C and then decrease to 158 °C over time, indicative of fracture growth during maximum burial conditions. The CH_4 Raman symmetric stretching (ν_1) peak position of the vapour bubble was used to determine the pressure of the aqueous inclusions at room temperature (Lin et al., 2007). Based on microthermometry, fluid pressure at room temperature, and equation of state modelling, the pressures at trapping were calculated for the observed inclusions (Becker et al., 2010). Pore fluid pressures for methane-rich inclusions of 55-110 MPa indicate fracture growth under near-lithostatic pressure conditions consistent with fracture growth during active gas maturation and charge. Lack of systematic pore pressure trends over time (Fig. 1) suggests dynamic pressure conditions and is consistent with episodic gas charge from deeper source rocks along connected fracture and fault systems (Cumella and Scheevel, 2008). The natural fracture network creates pathways that allow upward gas migration in high-pressure cells to form a continuous gas-saturation interval in the absence of a top seal in the deep-central parts of the Piceance Basin.

Comparison of trapping temperatures with burial and thermal maturity models suggests that gas generation, active gas charge in high-pressure cells, and natural fracture growth lasted for 33 Ma., and ended at ~8 Ma in the Piceance Basin.

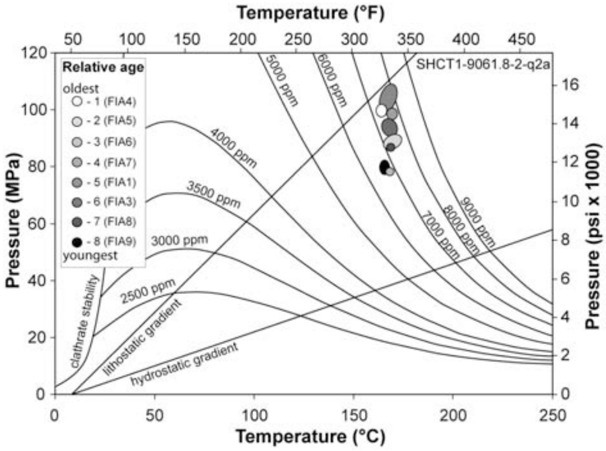

Fig. 1. P-T diagram illustrating trapping pressure oscillation of aqueous fluid inclusions in a single quartz bridge cement of a natural opening-mode fracture in the southern Piceance Basin, Colorado. Methane concentrations of the FIAs range from ~6500 ppm to 8000 ppm corresponding to trapping pressures from ~75 MPa to 110 MPa. Also shown are isopleths of methane concentrations in the H_2O-NaCl-CH_4 system for the 2 mass % NaCl-CH_4 pseudobinary (Duan and Mao, 2006), and thermobaric gradients representing a geothermal gradient of 43 °C/km over the hydrostatic and lithostatic gradients of 9.9 MPa/km, and 24.8 MPa/km, respectively.

REFERENCES

Becker, S. P., Eichhubl, P., Laubach, S. E., Reed, R. M., Lander, R. H., Bodnar, R. J. (2010) *GSA Bulletin* 122: 1081-1093.

Cumella, S. P., J. Scheevel (2008) *in* S. P. Cumella, K. W. Shanley, W. K. Camp, eds., *AAPG Hedberg Series* 3: 137 – 155.

Duan, Z., Mao, S. (2006) *Geochim. Cosmochim. Acta* 70: 3369-3386.

Lin, F., Bodnar, R. J., Becker, S. P. (2007) *Geochim. Cosmochim. Acta* 71: 3746 - 3756.