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Evolution of pore-fluid pressure during folding and basin contraction in overpressured reservoirs assessed by combined fracture analysis and calcite twinning paleopiezometry

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Reconstructing the evolution of paleofluid (over)pressure in sedimentary basins during deformation is a challenging problem, especially when no hydrocarbon-bearing fluid inclusions are available to provide barometric constraints on the fluid system. This contribution reports the application to a natural case (the Bighorn Basin) of recent methodological advance to access fluid (over)pressure level prevailing in strata during sub-seismic fracture development. The fluid pressure evolution in the Mississippian-Permian Madison-Phosphoria carbonate reservoir is tentatively reconstructed from the early Sevier Layer Parallel Shortening to the Laramide folding in two basement-cored folds: the Sheep Mountain Anticline and the Rattlesnake Mountain Anticline, located on both edges of the Bighorn Basin. This reconstruction is based on a combination of stress inversion of fault slip data, calcite twins paleopiezometry and rock mechanics.

Results point out that supra-hydrostatic pressure values prevail in the carbonate reservoir during most of its whole Sevier-Laramide history, and a coeval evolution between fluid overpressure and differential stress build-up is also emphasized. In each fold, a maximum value of 30-35 MPa for overpressure (i.e. above hydrostatic value) is recorded, just before Laramide folding, while minimum values of 0 MPa or 7 MPa are recorded during Sevier foreland flexure/forebulge and Laramide folding, respectively. After normalization to the same depth for both folds of differential stress magnitudes obtained from calcite twins paleopiezometry, the reconstructed values for the two folds can be compared and this comparison provides an image of the evolution fluid pressure levels at the basin scale. Until folding, the evolution of the fluid overpressure during deformation can be interpreted as reflecting large-scale fluid migrations in a laterally connected reservoir. The drop of fluid overpressure recorded in both folds during folding illustrates the enhancement of vertical hydraulic permeability that affect the strata during the curvature-related fracture development.

Another result of our approach is the possible estimate of syn-folding exhumation of strata. The inferred exhumation values range from 0,6 km to 1,3 km at Sheep Mountain and from 0,8 km to 2,0 km at Rattlesnake Mountain. These values are consistent with fold growth models predicting exhumation rates ranging from 0.03 to 0.40 mm/yr and with published exhumation rates from fission track studies in other Laramide uplifts.

This case study illustrates how the combination of stress inversion of fault-slip and calcite twin data with rock mechanics can be used to discuss which are the natural factors that control the pressure evolution in a carbonate reservoir during its large-scale deformation in an orogenic foreland.