Understanding the in-situ anisotropic stress field for cap-rock integrity

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Abstract

A new method for quantitative characterization of the anisotropic stress field, represented by vertical stress, and minimum and maximum horizontal stresses, is proposed for the cap-rock integrity evaluation. Information from dipole sonic logs, pore pressure data and elastic properties obtained from multicomponent seismic inversion are integrated for this complex approach. This method combines the generalization of Terzaghi's law of effective stresses with the Schoenberg and Sayers linear-slip elastic stiffness matrix, and the anisotropic stress correction estimated from Backus averaging the elastic properties recorded at wells.

For this study, the Clearwater Formation, which is the cap-rock of an oil-sands reservoir in the Athabasca Basin, is characterized by pressures below the normal hydrostatic level which are difficult to resolve using conventional pore-pressure prediction methods. In our method, the pressure is modelled using local pore pressure measurements from 25 wells, and a pore pressure correction estimated from the difference between pressure data and the normal hydrostatic pressure. Having a good estimate of the formation pore pressure allows us to determine not only the total stresses, but also the effective stresses.

In this study area, a high heterogeneity of the modelled stress field is observed, demonstrating the complex relationship between the tectonic stress field and formation pore pressure, lithology variation, micro- and macro-scale rock deformations, and topography variation.

The main results of this study are the following:

1) The estimated minimum horizontal stresses are remarkably supported by findings of five mini-frac tests at six depths within the Clearwater Formation. The average differences are less than 0.2 MPa.

2) The normal-faulting regime indicated by the estimated relative stress magnitudes (vertical stress > maximum horizontal stress > minimum horizontal stress) correlates with the vertical orientation of the mini-frac pressure-induced fractures observed in the analyzed interval.

In conclusion, this new method successfully aids in a deeper understanding of the in-situ anisotropic stress field, which is critically important for the assessment of cap-rock integrity.