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Observations of stable high-pressure gradients in clay-rich materials; implications for the concept of effective stress applied to unconventional hydrocarbons

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The concept of effective stress is a well established relationship where the stress acting on a rock can be viewed as the total stress minus the pore water pressure. In clay-rich rocks this relationship has been seen to be imperfect and a Biot coefficient is added to account for the material properties of the clay matrix.

Recent experimental results seen during the flow testing (both gas and water) of several rocks (Callovo-Oxfordian Claystone, Opalinus Clay, Boom Clay) and geomaterials (Bentonite, Kaolinite) has given evidence for stable high pressure gradients.

The experimental geometry used at BGS has an injection and back-pressure filter at either end of a sample. Guard-rings are used at both ends to discount by-pass flow along the sample/jacket interface, with 12 mm between filter and guard-rings. This geometry yields four measurements of pore pressure, which commonly is observed to be heterogeneous.

During aqueous flow testing of Callovo-Oxfordian Claystone pore-pressure differences of 4.5 MPa were observed between injection filter and guard-ring. During gas testing this pressure difference exceeded 5 MPa. Therefore for water and gas testing a pressure gradient in excess of 400 MPa/m or 40 km of head is measured. These anomalously high pressure gradients have been seen in several experimental geometries (including shear tests) and also in the large-scale gas injection test (Lasgit), demonstrating that these gradients may be seen in depositional scenarios.

The observed stable high pressure gradients and heterogeneous pore pressure distribution makes the describing of stress states in terms of effective stress complex. It is clear that highly localised pore pressures can be sustained by argillaceous materials and that concepts of evenly distributed pore pressures throughout the sample, i.e. conventional effective stress, do not fit many clay-rich rocks. These observations have implications for modelling experiments and the applicability of available mathematical codes.