Including temperature in the effective stress equation – case study from the deep North Sea basin

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Abstract:

Safe and successful drilling operations in geothermal and petroleum reservoirs with temperatures in the order of 150°C, depend on reliable estimates of the subsurface effective stress. Building on Terzaghi's work from the 1920s, the classical poroelastic theory by Biot describes the effective stress as an equivalent to the resulting strain observed on a rock volume when stressed. The effective stress is from Biot's formulation primarily a function of the total load and pore pressure where Biot's coefficient controls contribution from the latter. The introduction of Biot's coefficient consequently results in the well-known separation from Terzaghi's effective stress formulation. However, where subsurface temperature exceeds an order of 150˚C, the classical definition of effective stress by Biot may require a combination of poro- and thermoelastic theory in order to ensure reliable estimates. Accordingly, e.g. Palciauskas and Domenico (1982) proposed extensions to Biot original poroelasticity to account for thermal expansion/contraction of constituents. Orlander et al. (2020) assessed this combined poro- and thermoelasticity illustrating the complexity related to inversion of thermal strain to thermal stress and visa versa. Staying true the original concept of effective stress as an equivalent to resulting strain, they formulated arguments for boundary conditions allowing thermal strain to stress conversion and added these to the effective stress formulation including non-isothermal conditions.

In order to illustrate the consequences of including boundary conditions proposed by Orlander et al. (2020) for estimation of non-isothermal effective stress, we used a case study of the deeper part of the North Sea basin. We compared estimates of the non-isothermal effective stress with isothermal conditions, including formulations of both Biot and Terzaghi. We found that the effective stress estimated for isothermal conditions by Biot's formulation is presumably too high as compared to the non-isothermal estimates and that it ironically approaches the effective stress estimated by simply subtracting pore pressure from the total load (Terzaghi's formulation). Further, our study indicates that the non-isothermal effective stress becomes neutral (zero) at high depth in this overpressured basin. This modelled condition, depends on mineral properties and degree of overpressure.

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[1] Palciauskas, V.V. and Domenico, P.A. (1982). *Characterization of drained and undrained response of thermally loaded repository rocks*. Water Resources Research, **18**, 281–290

[2] Orlander, T., Andreassen, K.A. and Fabricius, I.L. (2020). *Effect of temperature on stiffness of sandstones from the deep North Sea Basin*. Rock Mechanics and Rock Engineering