"The impact of Skempton's A on overburden pore pressure response above a depleting reservoir"

Marcin Duda[a], Rune M. Holt [a] and Jørn Stenebråten [b]

[a] *Norwegian University of Science and Technology*

[b] *SINTEF Industry*

Contact email: marcin.duda@ntnu.no

Introduction

Depletion or inflation of a reservoir introduce stress changes in the reservoir itself as well as in its surroundings. As the cap rock is assumed to have very low permeability, negligible fluid movement and hence no pore pressure equilibration is expected between the reservoir and the overburden within a typical reservoir lifetime. However, alteration of the stress state of a porous impermeable cap rock, caused by pore pressure changes in the reservoir, can lead to undrained pore pressure changes around it. According to Skempton (1954), pore pressure changes in the undrained conditions are governed by two parameters, as shown in equation (1):

$$\Delta p_f = B_S\big(\Delta\sigma_3 + A_S(\Delta\sigma_1 - \Delta\sigma_3)\big) \tag{1}$$

where: p_f − pore pressure, σ_1 − maximum principle stress, σ_3 − minimum principle stress.

Skempton's parameter B_S depends on rock and fluid compressibility, and Skempton's A_S is sensitive to elastic anisotropy and non-elastic characteristics of the rock, as reported by Holt et al. (2018).

The parameter B_S, capturing the influence of the mean stress, is frequently measured and used in geomechanical modelling. The parameter A_S, describing pore pressure response to shear stress, is usually assumed to be 1/3, which is the expected value for a linearly poroelastic isotropic medium. Experimental results obtained with typical overburden shales (Holt et al., 2018) show that both elastic anisotropy and nonelastic behavior strongly affect the values of the Skempton parameters. Further, both parameters may have a significant impact on pore pressure changes in the field. In extreme cases of a near-critical state of the overburden, undrained pore pressure changes could lead to cap rock failure. Figure 1 shows a fictitious case, where Geertsma's nucleus of strain approach (Geertsma, 1973) has been used to calculate overburden stresses above the centre and near the edge of the reservoir. While Geertsma's model predicts constant mean stress and hence no pore pressure change in the overburden, the consequence of making $A \neq 1/3$ are significant changes, in particular near the edge of the reservoir, where depletion leads to pore pressure increase if $A > 1/3$. Above the reservoir centre the situation is opposite, and pore pressure may increase by depletion if $A < 1/3$.

The undrained pore pressure response may also modify the effective stress field in the overburden sufficiently to be detected with the use of time-shifts extracted from 4D seismic datasets. This has motivated an experimental study combining measurements of the Skempton parameters and ultrasonic wave velocities under stress paths representative for overburden shales.

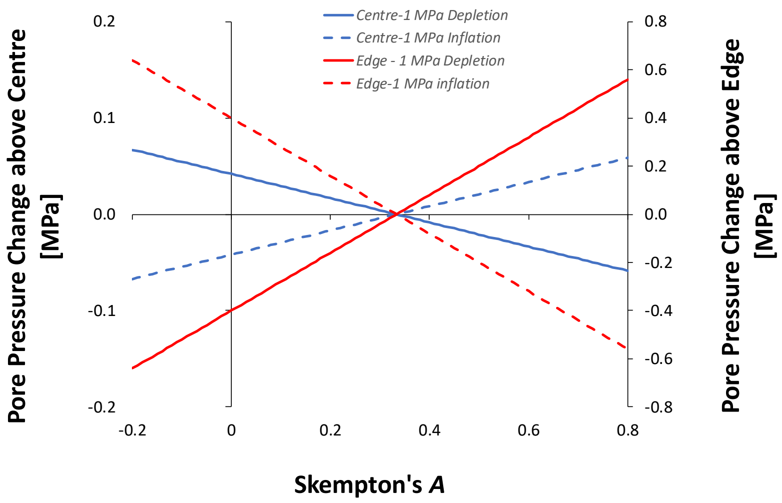

Figure 1: Undrained pore pressure change in the overburden above a disk-shaped reservoir with aspect ratio 0.1, assuming Geertsma's solution for the total stresses. Note that Geertsma's model is isotropic and linear elastic, so by default A = 1/3, and the pore pressure change would then be zero. The graph shows the consequences if A has a different value, without imposing anisotropy nor non-elasticity in the stress calculation itself. Poisson's ratio = 0.25, Biot's α = 1.

Experimental methodology

Laboratory tests are carried out within a triaxial cell, using a core material from an overburden shale. The samples are cut normal to bedding, confined with a fluid of composition and properties matching those of the pore fluid (determined by pore fluid extraction and physicochemical analysis), loaded to in-situ stresses and further tested in undrained conditions. Testing procedure consists of multiple loading cycles of varying amplitude and stress paths (see Holt et al., 2018 for examples). Stresses, strains and pore pressure are recorded, and stress path dependent ultrasonic velocities are measured with pulse transmission. Both Skempton parameters are determined from the pore pressure response during different stress paths.

Data analysis

The collected data will be used to assess overburden pore pressure response in fictitious field cases like that illustrated in Figure 1. The data will also be used with geomechanically modelled stress changes above a depleting reservoir, comparing the traditional approach of not including Skempton's A (i.e. A = 1/3) with an approach using the measured A from the laboratory tests. Further, based on this, we will discuss to what extent overburden pore pressure change can be detected with 4D seismic.

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References

Geertsma, J. (1973) A basic theory of subsidence due to reservoir compaction: The homogeneous case. Verh. Koninklijk Nederlands Geol. Mijnbouw. Genotschaap, 28, 43-62.

Holt, R.M., Bakk, A., Stenebråten, J.F, Fjær, E. (2018) Skempton's A – A key to man-induced subsurface pore pressure changes: ARMA 18-0949; 9 pp.

Holt, R.M., Bauer, A., Bakk, A., 2018, Stress path dependent velocities in shales:Impact on 4D seismic interpretation. Geophysics (in press).

*Skempton, A.W., 1954, The pore-pressure coefficients A and B: Geotechnique **4**, 143-147.*