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Geomechanics Predicts the Characteristics of Overpressured Basins

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SUMMARY

Sharp pressure transition zones, and alterations of stresses within overpressure compartments, are features that are predictable and expected consequences arising from the geomechanical behaviours of typical mud-rich successions. A qualitative analysis based on poro-plastic material responses explains how seals form, how they fail, and how the stress state evolves within compartments. The analysis predicts that rocks within overpressure compartments may be very weak due to dilational deformations. These conditions pose major challenges to drilling and production operations.

Overpressured basins often exhibit a range of common characteristics, with some of the important ones being a pronounced pressure transition zone, and significant increases in horizontal stress within the overpressured compartment (Fig. 1). These factors lead to difficult drilling conditions during exploration and appraisal, and to later geomechanical well problems during production of reservoirs. Is there something unusual about certain basins that causes these unhelpful situations to occur? The argument posed here is that these characteristics are, in fact, what one would normally expect to happen during rapid basin development of thick muddy rock successions.

The geomechanical behaviours of all basin rocks can be well-described by recognising that the varied components of the basin sequence represent poro-visco-plastic (PVP) materials. A simple, non-quantitative analysis, as outlined below, which based on PVP principles, predicts the major basin characteristics noted above for cases typical of many rapidly-subsiding basins. Therefore, the answer to the question is that, no, such basins and their unhelpful characteristics are not unusual.

For the purposes of this paper, PVP is simplified to PP (which effectively ignores rate effects), and the simple form is adopted such that directionality is also ignored (in practice, this means that plastic yielding is depicted in a P-Q parameter space; see Fig. 2). Also for simplicity, the conceptual model of the basin is simplified to a 1D column in which the vertical stress (calculated as $\rho.g.z$) is assumed to be the maximum principal compressive stress.

During rapid burial of a thick, muddy sequence, the pore waters need to be expelled in order to allow the sediments to undergo mechanical compaction (and the story here will leave out any consideration of temperature-related diagenesis, the so-called chemical compaction, although it can be readily incorporated). Of course, the muddy sediments have permeabilities that are lower than those of typical reservoir rocks, so the flow of pore water is slower across them (or to put it another way, more energy is dissipated when a given quantity of fluid flows along a given distance through muddy materials). Because the muddy sequence is heterogeneous along a vertical transect, some layer in it has a permeability that is too low to permit sufficient de-watering at some stage in the basin subsidence. Below that layer, overpressure is generated and the sediments there stop compacting (or slow their rate of compaction if we acknowledge the reality of PVP). The sediments above the particular layer continue to compact, since de-watering is not inhibited as much. However, as they compact, their permeabilities decline, and they increase the effectiveness of the proto-seal due to the additional loss of fluid potential energy in crossing them.

In geomechanical terms, the scenario just described can be re-said as: During the normal de-watering phase, each layer is losing porosity, so the stress state in each layer is lying on the "cap" of the yield surface for the material comprising that layer. When some layer starts to prevent de-watering, the stress states in the layers below that point depart from their yield surface (or in PVP, they shift to a lower-rate yield surface), with a cessation of compaction, but layers above the proto-seal have states that continue to lie on their yield surfaces, and hence continue compacting (Fig. 3). If rapid loading continues, a compartment of hard overpressure can develop, with rocks inside the compartment possessing anomalously high porosities.

As overpressure builds at depth, the fluid pressure in the seal interval rises. When this pressure increases to very high levels, the stress state in some rock layer (which had ceased yielding) now causes yielding in a dilational mode (Fig. 4), which we can infer will lead to permeability increases in that deforming material, and hence serve as a valving mechanism.

Within the overpressured compartment, the changes in effective stress state can lead to some layers reaching a similar dilational yield condition. However, because these layers are contained *within* the compartment, there is no dissipation of the fluid pressure after they yield. Indeed, the sealed situation causes such materials to evolve to low effective differential stress and low effective mean stress (Fig. 5). This means that the vertical and horizontal stresses become almost equal, which explains the increase in σ_h in overpressured compartments.

Thus, a simple geomechanical analysis, based on application of the PVP model, predicts the main characteristics of many overpressured basins. Reservoir rock layers within the overpressured compartment ought to have a geomechanical evolution similar to the one suggested for the muddy rocks – namely low differential stress. If that reservoir is depleted by production of its contained hydrocarbons, the horizontal stress will decrease significantly, and it may then be impossible to drill subsequent wells into or through that interval. This circumstance is simply the product of natural and induced geomechanical responses.

Fig. 1

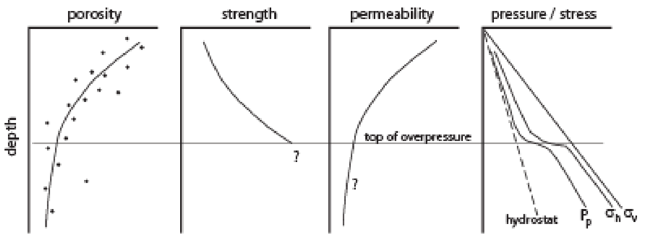

Fig. 2

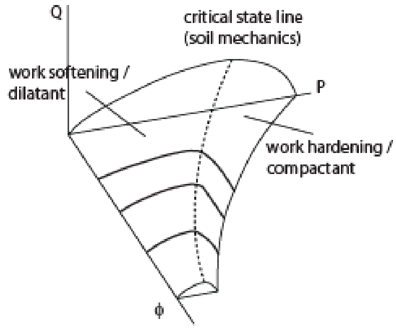

Fig. 3

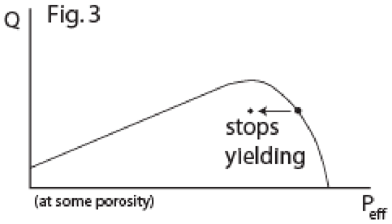

Fig. 4

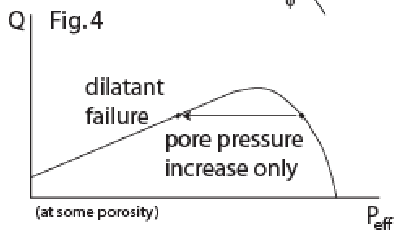

Fig. 5