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Understanding creep in sandstone reservoirs – theoretical deformation mechanism maps for pressure solution in granular materials

Suzanne Hangx and Christopher Spiers

High Pressure and Temperature Laboratory, Faculty of Geosciences, Utrecht University, P.O. Box 80021, 3508 TA Utrecht, the Netherlands

Subsurface exploitation of the Earth's natural resources removes the natural system from its chemical and physical equilibrium. As such, groundwater extraction and hydrocarbon production from subsurface reservoirs frequently causes surface subsidence and induces (micro)seismicity. These effects are not only a problem in onshore (e.g. Groningen, the Netherlands) and offshore hydrocarbon fields (e.g. Ekofisk, Norway), but also in urban areas with extensive groundwater pumping (e.g. Venice, Italy).

It is known that fluid extraction inevitably leads to (poro)elastic compaction of reservoirs, hence subsidence and occasional fault reactivation, and causes significant technical, economic and ecological impact. However, such effects often exceed what is expected from purely elastic reservoir behaviour and may continue long after exploitation has ceased. This is most likely due to time-dependent compaction, or 'creep deformation', of such reservoirs, driven by the reduction in pore fluid pressure compared with the rock overburden. Given the societal and ecological impact of surface subsidence, as well as the current interest in developing geothermal energy and unconventional gas resources in densely populated areas, there is much need for obtaining better quantitative understanding of creep in sediments to improve the predictability of the impact of geo-energy and groundwater production.

The key problem in developing a reliable, quantitative description of the creep behaviour of sediments, such as sands and sandstones, is that the operative deformation mechanisms are poorly known and poorly quantified. While grain-scale brittle fracturing plus intergranular sliding play an important role in the early stages of compaction, these time-independent, brittle-frictional processes give way to compaction creep on longer time-scales. Thermally-activated mass transfer processes, like pressure solution, can cause creep via dissolution of material at stressed grain contacts, grain-boundary diffusion and precipitation on pore walls.

As a first step to better describe creep in sands and sandstones, we have derived a simple model for intergranular pressure solution (IPS) within an ordered pack of spherical grains, employing existing IPS rate models, such as those derived by Renard et al. (1999) and Spiers et al. (2004). This universal model is able to predict the conditions under which each of the respective pressure solution serial processes, i.e. diffusion, precipitation or dissolution, is dominant. In essence, this creates generic deformation mechanism maps for any granular material. We have used our model to predict the amount and rate of compaction for sandstone reservoirs, and compared our predictions to known subsidence rates for reservoirs around the world. This gives a first order-comparison to verify whether or not IPS is an important mechanism in controlling reservoir compaction.