Impact of ductile deformation in modifying the subsurface stress states in reservoir and fault zones.

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Abstract:

Rocks encountered at engineering depths typically behave as a linear-elastic medium and fail by brittle fracturing at short time scales. However, at longer time-scales, they can also exhibit time-dependent ductile deformational behavior due to its porous structure and/or the presence of some ductile phases. Such ductile behavior can alter stress in the earth over time under boundary conditions of the subsurface, because ductile deformation relaxes differential stress but the vertical stress typically remains constant over time. Such alteration in stress can occur as local effects if rocks exhibit ductile behavior at varying degrees depending on the rock type and environmental condition. Stress heterogeneity caused by such effects must be characterized in many geomechanical problems such as hydraulic fracturing and earthquake fault mechanics.

Laboratory testing of shale gas reservoir rocks reveal that time-dependent creep deformation in these rocks is strongly dependent on composition, namely the volumetric content of clays and organic material. The time-dependent creep behavior can also be described as a power-law function of time[1]. Extrapolation of these results to geological time scales based on linear viscoelastic theory predicts that such variation in creep behavior due to rock composition can create stress heterogeneities at the formation scale, consistent with observations from some shale gas reservoirs[2].

In another set of experiments, the time-dependent creep properties of fractured granites were investigated. Granite rocks were heated in the oven prior to testing to promote cracking, in order to obtain analogue samples of fault damage zone rocks. The fractured granites, despite the absence of any ductile mineral phases, exhibit some time-dependent creep behavior due to the slight amount of shear-enhanced compaction that is facilitated by small amounts of slip along randomly oriented micro-fractures[3,4]. These results suggest that stress states can be locally altered along active fault zones by the ductile behavior of fault damage zone rocks, due to the enhanced fracture density. We analyzed borehole image logs from the Taiwan Chelungpu-fault Drilling Project to characterize the stress variation along a wellbore that penetrates a seismically active fault. Results show that the stress state is more isotropic around the fault zone confirming expectations from laboratory results.

[1] Sone and Zoback, 2014, *Int. J. Rock Mech. & Mining Sci.*, 69, 120-132.
[2] Sone and Zoback, 2014, *J. Petroleum Sci. & Eng.*, 124, 416-431.
[3] Sone and Condon, 2017, *51st US Rock Mechanics / Geomechanics Symposium*, 17-433.
[4] Condon and Sone, 2018, *52nd US Rock Mechanics / Geomechanics Symposium*, 18-977.