Porosity channeling and fracturing in fluid over-pressure zones

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It is important to understand the effects of fluid over-pressure in rocks because gradients in over-pressure can lead to failure of rocks and expulsion of fluids. Examples are hydro-fracturing in engineering as well as fluid generation during hydrocarbon maturation, metamorphic reactions or over-pressure below seals in sedimentary basins. In order to have an understanding of the complexity of effective stress fields, fracture, failure and fluid drainage the process was studied with a dynamic hydro-mechanical numerical model. The evolution of fluid pressure build up, fracturing and the dynamic interaction between solid and fluid is modeled. Three scenarios are studied: fluid pressure build up in a sedimentary basin, in a confined zone and in a horizontal layer that is offset by a fault. Results indicate that the geometry of the fluid-overpressure zone has a first order control on the patterns including porosity evolution and fracturing. If the over-pressure develops below a seal in a sedimentary basin, the effective differential and mean stress approach zero and the horizontal and vertical effective stresses flip in orientation leading to horizontal hydro-factures or breccia zones. If the over-pressure zone is confined vertically as well, the standard effective stress model develops with the effective mean stress decreasing while the differential stress remains mainly constant. This leads to semi-vertically aligned extensional and conjugate shear failure at much lower over-pressures than in the sedimentary basin. A perfectly aligned horizontal layer that increases in fluid pressure internally leads to a horizontal hydro-fracture within the layer. A faulted layer develops complex multi-directional failure with the fault itself being a location of early fracturing followed by brecciation of the layer itself. All simulations undergo a phase transition in porosity evolution with an initially random porosity reducing its symmetry and forming a static porosity wave with an internal dilation zone and the development of dynamic porosity channels within this zone that drain the over-pressure. Our results show that patterns of fractures, hence fluid release, that form due to high fluid overpressures can only be successfully predicted if the geometry of the geological system is known, including the fluid overpressure source and the position of seals and faults that offset source layers and seals.