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Hydraulic fracturing and the creation of hydraulic breccias

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Vein systems that indicate paleofracture geometries can be found in variable settings including typical layer perpendicular and layer parallel veins. Some natural examples show layer parallel and perpendicular veins that appear to form synchronously. A more drastic example of fluid overpressures is the development of hydraulic breccias where the fractures also do not show a specific orientation. We argue that these structure develop due to local fluid overpressures leading to pressure gradients. Depending on the boundary conditions, for example seals in the system and localisation or non-localisation of fluid overpressure the developing effective stress fields can be quite complicated and the fluid pressure is not isotropic, but pressure gradients produce anisotropic stresses. We illustrate the complexity of the developing effective stress and fracture patterns with a hybrid numerical model linking pressure gradients to solid deformation. In the model fluid pressure rise below a seal leads to a decrease of the mean and differential stress of the solid. In a closed system where fluid pressure rise below a seal is not local, the main principle stresses flip with the effective horizontal stress becoming zero and the effective vertical stress tensile leading to horizontal hydrofractures. Such a system leads to the development of a hydraulic breccia if initially local high fluid pressure pulses produce vertical fractures. We argue that an fluid pressure gradients have to be taken into account to understand effective stresses in the Earth's crust.