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Estimation of effective Young's moduli of sedimentary rocks in fault zones

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For predictions of local stress fields, fracture propagation and the associated permeability development in rocks and fluid reservoirs (such as of petroleum, gas, geothermal, and ground water), numerical models are widely used. Most numerical programs in solid mechanics are based on the linear elasticity theory because many rocks behave as linear elastic up to 1-3 % strain at low temperature and pressure. For homogeneous, isotropic rocks two elastic constants must be determined; most commonly used are Young's modulus and Poisson's ratio. Young's modulus is a measure of the stiffness of a linear elastic material, defined as the ratio of stress to strain in Hooke's law. Poisson's ratio is a measure of the absolute ratio of strain in perpendicular directions. The range of Poisson's ratios for bedrocks is, as compared with Young's modulus, narrow. In numerical models we therefore focus on the effects of changes in Young's modulus in mechanically layered rocks on fracture emplacement (propagation, arrest and offset).

In situ (site) elastic properties are normally different from those measured in the laboratory. It has to be taken into account that Young's modulus increases with increasing confining pressure, but decreases with increasing temperature, porosity, or water content. In particular, however, in situ static Young's moduli tend to be as much as 1.5 to 5 times lower than those measured of the same rock types in the laboratory. This is mainly because fractures reduce the stiffnesses of in situ-rock masses whereas the rock samples measured in the laboratory are essentially free of fractures. There is an inverse correlation of the number of discontinuities (mechanical breaks or fractures of low or zero tensile strengths in the rock) and its "effective" Young's modulus (the Young's modulus resulting from fracturing) that can be used to estimate the effective Young's modulus of the rock mass, a procedure referred to as up-scaling.

In this connection fault zones are of particular importance. Fault zones commonly consist of two major mechanical units, namely a fault core and a damage zone. The fault core, primarily composed of breccia or gouge, is formed through repeated slip on the fault plane. Its Young's modulus is typically rather low; the rocks even may deform in a plastic manner. The fault damage zone, occurring on both sides of the fault core, consists of rocks with many fractures of various sizes that are typically subparallel to the main fault plane. In the fault damage zone, the fracture frequency commonly increases towards the fault core, which means that the effective Young's modulus of the rock mass decreases proportionally. To understand the infrastructure of fault zones in fluid reservoirs, field studies in outcrop analogues of rocks of comparable stratigraphy, lithology and facies may help.

Here we present first results of field studies and analytical models on fault zones in the North German Basin. The focus is on outcrop analogues in the Egge-Fault-System and the Leinetal-Graben; in both areas fault zones are similar to fault zones in the subsurface further north. We studied in detail 51 normal, reverse and strike slip faults that occur in various sedimentary rocks, covering the entire stratigraphy from Upper Carboniferous to Cretaceous. We divide each fault zone into many parts of equal thicknesses for which we estimate effective Young's moduli using well known analytical models. The results show various widths of damage zones and a considerable range of fracture frequencies therein. From these follow different distributions of Young's moduli for the diverse lithologies, stratigraphies, fault types and fault orientations. We finally use these Young's moduli as basis for numerical models on fracture propagation and connectivity within the represented fault zones.