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The influence of bedding and pore space-anisotropy on strain localization, mechanical anisotropy and transport properties in porous sandstone

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Significant anisotropy in mechanical behaviour and failure strength may arise from planar rock fabrics such as bedding or preferred alignment of inequant voids in sedimentary rocks, cleavage in slates, and preferred orientation and/or arrangement of minerals and cracks in crystalline igneous and metamorphic rocks. Elastic anisotropy of a rock can be related to its fabric, a seismic manifestation of which is shear-wave splitting. Textural anisotropy can also result in pronounced anisotropy of tensile and compressive strength, which may be associated with different failure modes and deformation mechanisms, depending on how stress is applied relative to the anisotropy planes. On the borehole scale mechanical anisotropy and anisotropic rock strength can significantly influence the morphology and interpretation of wellbore breakout as well as the inference of in situ stress.

In this study, we focussed on sedimentary rocks and studied the microstructural attributes that govern anisotropic failure in Rothbach and Diemelstadt sandstones of nominal porosities 20 and 24%, respectively. Rothbach sandstone has a relatively heterogeneous structure with granulometric layering that alternates between zones with significant contrasts in porosity and grain size. Diemelstadt sandstone presents a relatively more homogeneous structure, significant P-Wave anisotropy and a mean pore space geometry inferred by magnetic susceptibility (AMS) approximating to an oblate spheroid. Conventional triaxial experiments were performed at constant strain rate and room temperature on saturated samples of both rocks cored at various orientations with respect to the sedimentary bedding. For Diemelstadt sandstone, the samples cored parallel to bedding were stronger than those cored perpendicular to bedding. The mechanical anisotropy was more pronounced and significantly different in Rothbach sandstone. The sample cored perpendicular to bedding were stronger than those cored parallel to bedding, while oblique samples (45°) showed an intermediate strength. The mechanical anisotropy of Diemelstadt sandstone is in agreement with a simple conceptual model of layered material. For Rothbach sandstone, our results are consistent with the preferential orientation of intergranular grain contacts subparallel to bedding according to the principle that an increase of the total contact surface alleviates stress on each individual contact and therefore provides more strength to the overall structure. In the shear-enhanced compaction domain, microstructural analysis as well as X-ray tomography revealed that compaction localization occurred preferentially in samples of both rocks cored perpendicular to bedding. In Diemelstadt the preferential development of sub-horizontal discrete compaction bands in the bedding plane resulted in significant permeability anisotropy which was quantified over a wide range of effective pressures.