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What controls the strength and brittleness of shale rocks?

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With respect to the productivity of gas shales, in petroleum science the mechanical behavior of shales is often classified into rock types of high and low 'brittleness', sometimes also referred to as 'fraccability'. The term brittleness is not well defined and different definitions exist, associated with elastic properties (Poisson's ratio, Young's modulus), with strength parameters (compressive and tensile strength), frictional properties (cohesion, friction coefficient), hardness (indentation), or with the strain or energy budget (ratio of reversible to the total strain or energy, respectively). Shales containing a high amount of clay and organic matter are usually considered as less brittle. Similarly, the strength of shales is usually assumed to be low if they contain a high fraction of weak phases.

We performed mechanical tests on a series of shales with different mineralogical compositions, varying porosity, and low to high maturity. Using cylindrical samples, we determined the uniaxial and triaxial compressive strength, static Young's modulus, the tensile strength, and Mode I fracture toughness.

The results show that in general the uniaxial compressive strength (UCS) linearly increases with increasing Young's modulus (E) and both parameters increase with decreasing porosity. However, the strength and elastic modulus is not uniquely correlated with the mineral content. For shales with a relatively low quartz and high carbonate content, UCS and E increase with increasing quartz content, whereas for shales with a relatively low amount for carbonates, but high quartz content, both parameters increase with decreasing fraction of the weak phases (clays, kerogen). In contrast, the average tensile strength of all shale-types appears to increase with increasing quartz fraction. The internal friction coefficient of all investigated shales decreases with increasing pressure and may approach rather high values (up to ≈ 1). Therefore, the mechanical strength and elasticity of shales is not simply related to the total clay and kerogen content, but depends mainly on porosity and overall composition, including mechanically strong (quartz, pyrite), intermediate (calcite) and weak (clay, organics) minerals.

The investigated shales show typical semibrittle behaviour with increasing ductility with increasing pressure and temperature and decreasing strain rate. Under similar conditions, the mechanical behavior is mainly controlled by porosity and – within the investigated range of pressure and temperature – less affected by mineral content. We conclude that the correlation between brittle strength and mineralogy is strongly formation depended, but high porosity generally promotes ductile creep at lower strength. Complete shale constitutive laws are required to allow extrapolation of the test results to the production timespan of unconventional reservoirs.