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The influence of mechanical properties on fracture propagation across layered sequences

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While considerable effort has been expended on the study of fracture propagation in rocks in recent years, our understanding of how fractures propagate through layered sedimentary sequences with different mechanical properties remains poor. Yet, the mechanical layering is a key parameter controlling the propagation of fractures across such sequences. Here, we report measurements of the contrasting properties of rock strata within the Lower Lias at Nash Point, South Wales, which comprise a sequence of interbedded shales and limestones, and how those properties influence fracture propagation. Although the focus of the research is on improving the understanding of fracture propagation in unconventional oil and gas reservoirs, it is also applicable to understanding the development of fractures in Enhanced Geothermal Systems (EGS).

The static Young's modulus (Es) of both rock types was measured both parallel and normal to bedding. The shale is highly anisotropic, with Es varying from 2.4 GPa, in the bedding-normal orientation, to 7.9 GPa, in the bedding-parallel orientation, yielding an anisotropy of ∼107%. By contrast, the limestone has a very low anisotropy of ∼8%, with Es values varying from 28.5 GPa, in the bedding-normal orientation, to 26.3 GPa in the bedding-parallel orientation. Hence, a vertical fracture propagating across this sequence is subject to a modulus variation by a factor of about 12.

The tensile strength (σt) and mode-I fracture toughness (KIc) of both rocks were also measured, using the Brazil-disk technique and the Semi-Circular Bend methodologies, respectively. Measurements were made in the three principal orientations relative to bedding, Arrester, Divider, and Short-Transverse, and also at 15° intervals between these planes. Again, values for the shale show a high degree of anisotropy; with similar values in the Arrester and Divider orientations, but much lower values in the Short-Transverse orientation. By contrast, the σt and KIc values for the limestone are considerably higher than those for the shale but exhibit no significant anisotropy.

These observations are important because the contrast in mechanical properties is a key factor in controlling whether fractures arrest, deflect, or propagate across interfaces between layers in a sequence. Preliminary numerical modelling of induced fracturing in the Nash Point sequence (using a finite element modelling software) demonstrates both a rotation of the maximum principal compressive stress across interfaces, encouraging fracture arrest, and also the concentration of tensile stress within the more competent (high Es and high strength) limestone layers.