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Anisotropic and heterogeneous mechanical properties of a stratified shale/limestone sequence at Nash Point, South Wales: A case study for hydraulic fracture propagation through a layered medium

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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 rocks with different mechanical and elastic properties remains poorly constrained. Yet this is a key issue controlling the propagation of both natural and anthropogenic hydraulic fractures in layered sequences. Here we report measurements of the contrasting mechanical and elastic properties of the Lower Lias at Nash Point, South Wales, which comprises an interbedded sequence of shale and limestone layers, and how those properties may influence fracture propagation.

Elastic properties of both materials have been characterised via ultrasonic wave velocity measurements as a function of azimuth on samples cored both normal and parallel to bedding. The shale is highly anisotropic, with P-wave velocities varying from 2231 to 3890 m s-1, giving an anisotropy of ∼55%. By contrast, the limestone is essentially isotropic, with a mean P-wave velocity of 5828 m s-1 and an anisotropy of ∼2%. The dynamic Young's modulus of the shale, calculated from P- and S-wave velocity data, is also anisotropic with a value of 36 GPa parallel to bedding and 12 GPa normal to bedding. The modulus of the limestone is again isotropic with a value of 80 GPa. It follows that for a vertical fracture propagating (i.e. normal to bedding) the modulus contrast is 6.6. This is important because the contrast in elastic properties is a key factor in controlling whether fractures arrest, deflect, or propagate across interfaces between layers in a sequence. There are three principal mechanisms by which a fracture may deflect across or along an interface, namely: Cook-Gordon debonding, stress barrier, and elastic mismatch. Preliminary numerical modelling results (using a Finite Element Modelling software) of induced fractures at Nash Point suggest that all three are important. The results demonstrate a rotation of the maximum principal compressive stress across an interface but also a confinement of tensile stress within the host layer.

Mechanical properties have been characterised by indirect measurement of the tensile strength using the Brazil-Disk technique. Measurements were made in the three principal orientations relative to bedding, Arrester, Divider, and Short-Transverse, and also at 15° intervals between these planes. Values for the shale again showed a high degree of anisotropy; with similar values in the Arrester and Divider orientations, but with much lower values in the Short-Transverse (bedding parallel) orientation. The tensile strength of the limestone is considerably higher than that of the shale and exhibits no significant anisotropy. Current work is underway to characterise the fracture propagation properties by measuring the fracture toughness and fracture ductility of both rocks using a combination of the Semi-Circular Bend and Short-Rod techniques.