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The effects of heterogeneity and anisotropy on hydraulic fracture propagation

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While considerable effort has been expended on the study of fracture propagation through individual rock types in recent years, our understanding of how fractures propagate through layered, sedimentary rock sequences with differing mechanical properties remains poor. Yet, this mechanical heterogeneity is a key parameter controlling the propagation of fractures across such sequences. Here we present numerical results, obtained using the Finite Element Method (FEM), that characterise fluid-driven, vertical fractures in multi-layer rock sequences comprising alternating layers with contrasting mechanical properties. The focus is on the effects on the crack-driving stress-field of variations in layer stiffness, layer thickness, and proximity of fracture tip to layer interface.

Using mechanical data gathered from an interbedded shale and limestone sequence at Nash Point, South Wales, we explore what mechanisms may cause fractures to propagate, deflect or arrest in such layered sequences. The contrast in mechanical properties of the shale and limestone at Nash Point is considerable. The limestone is essentially isotropic with a Young modulus of around 27 GPa while the shale is highly anisotropic with a Young's modulus varying by a factor of four from 2 to 8 GPa. The interbedded sequence at Nash Point can be used as a proxy for understanding fracture propagation in layered, unconventional hydrocarbon reservoirs in general, such as the Vaca Muerta formation of Argentina, which contains organic-rich shale layers interbedded with limestone, sandstone and ash layers, all of which have contrasting mechanical properties.

When the layer hosting a fracture tip is more stiff (e.g. limestone) than the adjacent layer (e.g. shale), then fracture arrest will normally occur at the interface with the more compliant layer (shale). However, the fracture can also become deflected at the interface due to rotation of the local principal stresses. By contrast, when the layer hosting the fracture tip is the more compliant one (shale), the fracture may also arrest at the interface, but commonly arrests within the host layer well below the interface. Fracture deflection may also occur before the fracture reaches the interface if the layer hosting the fracture is highly anisotropic, as is the case with many shales. Taken together, our results demonstrate that both heterogeneity and anisotropy within a reservoir sequence of mechanically contrasting layers must be understood before any reliable forecast of fracture propagation morphology can be made.