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Orthogonal fracture formation in the South Wales coalfield: implications from a field study and fluid overpressure of quartz veins

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Orthogonal fractures can easily make networks in geological formations and are of great importance for permeability and fluid transport in subsurface reservoirs. Despite many studies focusing on the formation of orthogonal fractures, no clear and generally accepted model has been established as yet although their formation is widely believed to occur during crustal uplift or exhumation. Here we provide new insights into their mechanism of formation based on the results of a fieldwork and analytical study of orthogonal fractures and quartz veins in alternating sand-shale layers in the South Wales coalfield, which is one of foreland basins developed in relation with north-south compression of the Variscan Orogeny.

More than 3,000 fractures were measured at various localities extending from southern end to northern end of the basin. Most of the fractures in the sandstone layers, are extension fractures (mode I cracks), and become arrested at contacts with shale layers. The fractures strike north-south and east-west. Some fractures are filled with shale, probably supplied from adjacent shale layers, suggesting the shale behaved as semi-ductile material at the time of fracture formation. A remarkable observation is that most of the fractures are perpendicular to bedding planes throughout the basin. This is despite the fact that the beds are strongly folded as a result of the Variscan Orogeny. The perpendicular attitude suggests that the fracture formation somewhat predates or coincides with that of folding. This implies that the orthogonal fractures in this area did not form during crustal uplift/exhumation but rather during basin growth at the time of regional north-south convergence and associated compression of the Variscan Orogeny.

By using aspect (length/thickness) ratios of quartz veins of the same geometry as the orthogonal fractures, fluid overpressure (driving pressure) at the time of fracture formation is estimated at around 33 MPa for fractures striking north-south and 18 MPa for those striking east-west. Although the thick Dinantian Carbonates immediately underlie the sandstones of the Coal Measure Group, carbonate minerals are absent in the veins, suggesting that the main driving stress for fracture formation may not have been buoyancy related to a deeper fluid source in the underlying carbonates but rather local stress concentrations, resulting in differential stresses, in the sandstones. These conditions imply that both north-south and east-west extensional stress fields were induced in the sandstones during the basin growth under the regional north-south compression.

The process responsible for the north-south extension within the sandstones is, at this stage, not entirely clear. One possibility is that cyclic stress and strain concentration in thrust zones could induce tensile stresses during stress relaxation of syn- and post-slip period of major thrusts. Viscous behaviour of the shale in the study area may have generated the north-south tensile stress fields in the sandstones that resulted in fracture formation.