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Extension fractures and fault zone structure in layered carbonate rocks

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Layering is a common feature of many rock masses. In particular, many sedimentary rocks are layered because of depositional changes (stratification), and diagenetic processes. Mechanical layering, where the mechanical properties, particularly the Young's moduli (stiffness), vary between layers, may coincide with changes in grain size, mineral content or facies. The mechanical layering of the rock is important because it commonly results in abrupt changes in local stress fields that may lead to fracture arrest. However, if all the beds in a rock mass have essentially the same Young's modulus and their contacts are welded together (sealed or healed) the beds may function mechanically as a single layer.

Here we explore how mechanical layers relate to sedimentary layers in carbonate rocks. This we do by investigating the effects of sedimentary layering (and/or bedding) of the host rock on the emplacement and geometries of extension fractures such as joints and mineral veins as well as on the internal structure of fault zones. Detailed field studies were carried out at two localities: (1) the Jurassic Blue Lias at the coast of the Bristol Channel Basin, UK, and (2) the Triassic Muschelkalk in northern Germany. In both study areas, calcite veins occur almost exclusively in the cores and damage zones of faults, whereas jointing is pervasive.

The field observations show that most joints, and many mineral veins, become arrested, primarily at layer contacts. Fractures that are restricted to single layers are referred to as stratabound, whereas for non-stratabound fractures, layering does not affect fracture growth. Different types of fractures react in various ways to host-rock layering. Fractures formed at great depths are generally less likely to become stratabound, but different fractures also seem to "feel" the rock layers and contacts dissimilarly. For example, mineral veins are much more often non-stratabound than joints. In our study areas there is also a clear inverse correlation between layer thicknesses and joint frequencies, particularly for layering on a decimeter-scale. The calcite veins, however, are not related to layer thickness. As for the internal structure of fault zones, there commonly occurs a clear damage zone with increased fracture frequency, whose width correlates with the displacement at the main fault plane. Fault zone structural indices (width of damage zone divided by the total width of the fault zone) are in the range of 0.6 to 0.99. This means that the fault damage zones are generally thick compared to the total fault zone width. There are, however, considerable differences of structural indices for different fault zone orientations in the northern German Muschelkalk.

The results have important implications for the permeability of fluid reservoirs, such as for petroleum, gas, geothermal or ground water. Correlations with layer thicknesses may be used for joint frequencies in the subsurface. Predictions on how many reservoir fractures are likely to be stratabound may help to predict if there are interconnected fracture systems so that the reservoir reaches the percolation threshold needed for significant permeability. High fault zone structural indices indicate a clear increase of permeability related to the fault zones.