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Stress heterogeneity in fractured crystalline rock masses at the EGS sites of Soultz and Basel

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The state of stress in the subsurface is often assumed to maintain a constant orientation, and have a magnitude that increases approximately linearly with depth. We present evidence of significant variations in the orientation of the maximum horizontal principal stress over scales ranging from metres to hundreds of metres within the granitic reservoirs of the Soultz-sous-Forêts and Basel Enhanced Geothermal System (EGS) project sites. Stress orientation is inferred from borehole breakouts and drilling induced tension fractures (DITFs) identified in ultrasonic borehole image logs. One or other of these robust stress-orientation indicators occur extensively, and in places, more-or-less continuously, along the granite section of wells at both sites, providing a detailed profile of stress orientation. At both sites it is found that stress orientation is constantly changing. At Soultz, the variations follow a power law scaling with an index close to -2.0, indicating self-affine behaviour where variations appear progressively "rougher" at shorter scales. Abrupt reversals in the trend of stress-orientation change coincide with the location of natural fractures, suggesting that the variations reflect stress perturbations associated with the natural fractures. The perturbation in stress orientation near a fault intersected in the Soultz reservoir at 4.7 km depth extends over several hundred metres along the borehole and produces a deviation of the local stress orientation from the mean direction of up to 90° degrees. A change in the style of wellbore failure from compressional (breakout) to tensional (DITF) also occurs near the fault crossing, indicating that stress magnitudes are also affected. In the Basel EGS borehole, breakout width as well as orientation varies along the borehole, providing evidence that the stress magnitudes also vary in that reservoir. The practical consequences of these observations for reservoir development is that the linear relations usually assumed and obtained by averaging stress indicators over long distance may not be representative of the local stress conditions on the structures in the rock mass that are the target of the reservoir stimulation efforts. The results also render it doubtful that the natural stress conditions acting at the focus of earthquakes induced on structures within the reservoir as a response to fluid injection can be determined with confidence from borehole stress measurements.