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Fluid transport in faults and associated hydrofracture injection into host rocks

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Faults may have strong effects on the permeability of their host rocks. Fault zones normally consist of two major hydrogeological units: a fault core and a fault damage zone. The core consists primarily of breccia and other cataclastic rocks; in the damage zone fractures of various sizes occur. Active faults commonly have great effects on the transport of crustal fluids. For groundwater, for example, the effects of fault slip during earthquakes include changes in the yield of springs, water table, and stream flow. Similar effects occur in hydrothermal systems. During fault slip (in an earthquake) all the pores and small fractures that meet with the slip plane become interconnected so that the fault may suddenly develop a very high hydraulic conductivity. The current stress field also controls fluid transport in fault zones. One reason for this is that fractures are sensitive to changes in the stress field and deform much more easily than circular pores. In a fault zone, most fractures in the damage zone are commonly subparallel to the main fault plane, in which case the effect of the current stress field can be strong. In a stress field where the maximum principal compressive stress is perpendicular to the strike of the fractures, many fractures will close and fluid transport is inhibited. In a stress field where the maximum principal compressive is parallel with the fracture strike, however, fractures tend to be open and fluid transport is enhanced.

The best evidence of former fluid transport pathways, particularly in deeply eroded, inactive fault zones, are networks of mineral veins. We present field examples of faults and mineral veins in layered sedimentary rocks from the Bristol Channel Basin, UK. The different lithologies studied include: (1) mudstones (Upper Triassic) with numerous faults and gypsum veins at Watchet, Somerset Coast (Southwest England); and (2) limestone and shale layers (Lower Jurassic) dissected by faults with calcite veins near Kilve, Somerset Coast, and at Nash Point, Glamorgan Coast (South Wales).

In all the study areas, the mineral veins are clearly related to the faults, indicating that geothermal water was transported along the then-active faults into the host rocks. At Watchet, local fluid overpressure was built up as a result of the volume change during the transformation of nodular anhydrite to gypsum so that networks of gypsum veins developed. The veins are extension fractures and show no preferred strike or dip except that the thickest veins are subhorizontal, indicating vein formation during basin inversion. At Kilve, calcite veins occur almost exclusively in the cores and damage zones of (mostly normal) faults, and there is evidence that the veins were injected as hydrofractures (fractures generated by internal fluid overpressure) from the fault planes into the limestone layers. Similarly, at Nash Point, calcite veins are clearly related to strike-slip faults. Some veins were clearly injected into the limestone layers of the fault damage zones directly from the fault planes.

Analytical models based on the length/thickness ratios of calcite veins yield fluid overpressures at vein formation of around 18 MPa, indicating fluid sources at a few hundred metres below the present outcrops within the sedimentary basin. Many inactive faults may have low permeabilities and even act as seals, particularly if they develop clay smear along their planes. Fault planes in sedimentary basins, however, tend to be weak in extension. Overpressured fluids that flow into such planes would be likely to follow the fault planes to higher stratigraphic levels as hydrofractures. These hydrofractures may then be injected into the host rocks in the damage zone of the fault zone and build interconnected fracture networks. Thus, faults and hydrofractures contribute significantly to the permeability of fluid reservoirs, such as those for petroleum, geothermal water or ground water.

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