Gypsum veins as hydrofractures in layered and faulted mudstones: implications for reservoir permeability *Poster*

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Mineral veins and reservoir permeability

Mineral veins form when water solutions passing through fluid-transporting fractures gradually seal the fractures as minerals precipitate. Many mineral veins are hydrofractures, that is, fractures generated at least partly by an internal fluid pressure. For most mineral veins, the fluid generating the hydrofracture is geothermal water. Other hydrofractures include fractures generated by magma (dykes, sills, inclined sheets), oil, gas and groundwater (many joints), as well as manmade hydraulic fractures in petroleum engineering. Hydrofractures are primarily extension fractures (Gudmundsson et al. 2002). The formation of hydrofractures is one of the two basic mechanisms for the generation and maintenance of permeability, particularly in fluid-filled heterogeneous reservoirs such as those commonly associated with petroleum, groundwater, volcanic and geothermal fields. The other, and better-known, mechanism for permeability development is the formation of shear fractures, that is, faults.

The permeability development in fractured reservoirs, such as those for groundwater, geothermal water and petroleum, depends on fluid overpressure and transport in hydrofractures (Aguilera 1995). It has been proposed that a high fluid pressure in a reservoir can create high temporary permeability through hydrofracturing (Aguilera 1995; Gudmundsson et al. 2002). This hydrofracturing may result in mineral vein networks. Such palaeohydrofractures give information about past fluid flow and flow networks. Studying mineral veins is thus important for understanding fluid and mineral transport in rocks and reservoirs.

Figure 1: Reverse fault in the profile at Watchet.There is a network of white gypsum veins on either side of the fault plane, which stops abruptly at a grey siltstone layer and is absent in the overlying mudstones. A gypsum vein follows the fault plane to a higher level than the vein network in the adjacent layers. View southeast; the person provides a scale.

Faults and gypsum veins in mudstones

Here we present field measurements of mineral veins in coastal sections near the village of Watchet on the Somerset Coast of Southwest England (Fig. 1). The cliffs provide excellent outcrops of subhorizontal to gently dipping red mudstone beds with horizons of nodu-

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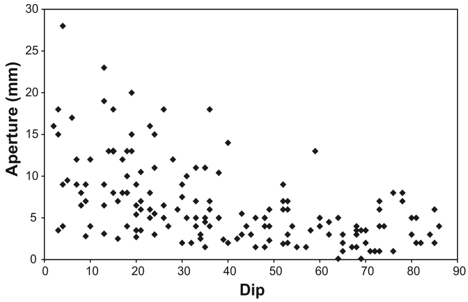

Figure 2: Aperture /dip relationship of 160 gypsum veins measured at Watchet. The thick veins are subhorizontal indicating that the minimum principal compressive stress was oriented vertically at the time of vein formation, a situation occurring during basin inversion.

lar gypsum and of siltstone of the Upper Triassic Mercia Mudstone Group.

In the upper part of the red mudstones there are laterally impersistent evaporite-rich horizons, mainly of white nodular gypsum. In part of the studied section west of Watchet Harbour, there are many thin beds of grey-green carbonatic siltstones, as well as nodular gypsum horizons. The beds are dissected by many faults and numerous gypsum veins. In some beds, there are dense anastomosing networks of fibrous gypsum (satin spar) veins which may have formed during transient hydraulic fracturing (Cosgrove 2001). The exact mechanism for the formation of gypsum veins, however, is still a matter of debate. Proposed mechanisms include mineral precipitation in open fractures, formation due to crystallisation pressure, and hydraulic overpressure (Shearman et al. 1972; Gustavson et al. 1994). Based on 160 measurements, the veins in a dense vein network do not show any preferred orientation. The thickest veins, however, are subhorizontal (Fig. 2), indicating a horizontal orientation of the maximum principal compressive stress during their formation. Thus, the vein networks were partly developed during horizontal basin compression, a stress state which may have existed during basin inversion associated with Alpine Tectonics in the late Cretaceous and early Tertiary. 97 crosscutting relationships, as well as mostly perpendicular vein fibres, indicate that the veins are primarily extension fractures; that is, they show hardly any evidence of shear displacement. In a 300 m-long profile dissected by (mostly) normal faults with small displacements, 24 faults (out of 28) have veins following them, indicating palaeofluid transport along the fault planes.

Formation of gypsum veins as hydrofractures

Mineral veins form through several related processes: fracturing, mineral dissolution, transport and precipitation. These processes may occur simultaneously and be repeated many times to form a single mineral vein. For a vein to form there must thus be a fluid, a material source, a fracture providing space, and suitable pressure-temperature conditions for material precipitation. We propose that for the gypsum veins at Watchet water was transported from deeper levels in the sedimentary basin along faults into the mudstones where it got access to nodular anhydrite. The water then dissolved the anhydrite and formed gypsum. The volume increase due to this reaction and the low permeability of the mudstones lead to build-up of high fluid pressure in the nodules that, eventually, created hydrofractures at the ends of their long axes. The resulting hydrofractures connected the gypsum nodules. Calcium-sulphate saturated fluids, transported along the faults, got access to evaporite-free mudstone layers where dense anastomosing vein networks developed. Most veins were arrested during their propagation by layers with contrasting mechanical properties (generating stress barriers). Some veins, however, propagated through the barriers along faults to shallower levels.

Permeability of heterogeneous reservoirs

Our results have important implications for fluid transport in reservoirs and the formation of hydrofractures. The gypsum veins at Watchet indicate hydrofracturing rather late in basin history during inversion and exhumation (Cosgrove 2001). The veins show that fluids from deeper levels in the sedimentary basin can be transported along faults into rather impermeable host rocks. When injected into the host rocks, the overpressured fluids induce new hydrofractures. Provided the host rock has a low permeability and is sealing the nodules, the fluid overpressure is then partly related to the volume change at the hydration of nodular anhydrite to gypsum. The hydrofractures propagate until they become arrested at layers with contrasting mechanical properties. Individual layers or 'compartments' in a fluid reservoir can be connected vertically through faults in which case the reservoir may develop a high temporary permeability. The gypsum veins following many fault planes indicate the faults transported water through the mudstones. This transport, presumably, occurred either during fault slip or through the formation of hydrofractures along the fault planes. Hydrofractures can transport fluids through low-permeability rocks. When the fluids are supersaturated with respect to certain minerals, or when there exists a local material source, mineral veins may form. At Watchet, nodular anhydrite acted as local material source. The present results suggest that high temporary permeabilities can develop in reservoirs not only during early burial but also during basin inversion — and that these permeabilities are primarily due to the formation of hydrofractures.

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