Geophysical Research Abstracts
Vol. 17, EGU2015-7128, 2015
EGU General Assembly 2015

Fracture properties from tight reservoir outcrop analogues with application to geothermal exploration

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In geothermal reservoirs, similar to other tight reservoirs, fluid flow may be intensely affected by fracture systems, in particular those associated with fault zones. When active (slipping) the fault core, that is, the inner part of a fault zone, which commonly consists of breccia or gouge, can suddenly develop high permeability. Fault cores of inactive fault zones, however, may have low permeabilities and even act as flow barriers. In the outer part of a fault zone, the damage zone, permeability depends mainly on the fracture properties, that is, the geometry (orientation, aperture, density, connectivity, etc.) of the fault-associated fracture system. Mineral vein networks in damage zones of deeply eroded fault zones in palaeogeothermal fields demonstrate their permeability. In geothermal exploration, particularly for hydrothermal reservoirs, the orientation of fault zones in relation to the current stress field as well as their internal structure, in particular the properties of the associated fracture system, must be known as accurately as possible for wellpath planning and reservoir engineering.
Here we present results of detailed field studies and numerical models of fault zones and associated fracture systems in palaeogeo¬thermal fields and host rocks for geothermal reservoirs from various stratigraphies, lithologies and tectonic settings: (1) 74 fault zones in three coastal sections of Upper Triassic and Lower Jurassic age (mudstones and limestone-marl alternations) in the Bristol Channel Basin, UK. (2) 58 fault zones in 22 outcrops from Upper Carboniferous to Upper Cretaceous in the Northwest German Basin (siliciclastic, carbonate and volcanic rocks); and (3) 16 fault zones in 9 outcrops in Lower Permian to Middle Triassic (mainly sandstone and limestone) in the Upper Rhine Graben shoulders. Whereas (1) represent palaeogeothermal fields with mineral veins, (2) and (3) are outcrop analogues of reservoir horizons from geothermal exploration.
In the study areas of palaeo¬geothermal fields in the Bristol Channel (1), all mineral veins, most of which are extension fractures, are of calcite. They are clearly associated with the faults and indicate that geothermal water was transported along the then-active faults into the host rocks with evidence of injection as hydrofractures. Layers with contrasting mechanical properties (in particular, stiffnesses), however, acted as stress barriers and lead to fracture arrest. Along some faults, veins propagated through the barriers along faults to shallower levels. In the Northwest German Basin (2) there are pronounced differences between normal-fault zones in carbonate and clastic rocks. Only in carbonate rocks clear damage zones occur, characterized by increased fracture frequencies and high amounts of fractures with large apertures. On the Upper Rhine Graben shoulders (3) damage zones in Triassic Muschelkalk limestones are well developed; fault cores are narrow and comprise breccia, clay smear, host rock lenses and mineralization. A large fault zone in Triassic Bunter sandstone shows a clearly developed fault core with fault gouge, slip zones, deformation bands and host rock lenses, a transition zone with mostly disturbed layering and highest fracture frequency, and a damage zone. The latter damage zone is compared to the damage zone of a large Bunter sandstone fault zone currently explored for geothermal energy production. The numerical models focus on stress field development, fracture propagation and associated permeability changes.
These studies contribute to the understanding of the hydromechanical behaviour of fault zones and related fluid transport in fractured reservoirs complementing predictions based on geophysical measurements. Eventually we aim at classifying and quantifying fracture system properties in fault zones to improve exploration and exploitation of geothermal reservoirs.

Acknowledgements
The authors appreciate the support of 'Niedersächsisches Ministerium für Wissen¬schaft und Kultur' and 'Baker Hughes' within the gebo research project (http://www.gebo-nds.de), the Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMU; FKZ: 0325302, AuGE) and the Deutsche Forschungsgemeinschaft. GeoEnergy GmbH, Karlsruhe, is thanked for explorational data.