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Architecture of small-scale fault zones in the context of the Leinetalgraben Fault System

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Understanding fault zone properties in different geological settings is important to better assess the development and propagation of faults. In addition this allows better evaluation and permeability estimates of potential fault-related geothermal reservoirs. The Leinetalgraben fault system provides an outcrop analogue for many fault zones in the subsurface of the North German Basin. The Leinetalgraben is a N-S-trending graben structure, initiated in the Jurassic, in the south of Lower Saxony and as such part of the North German Basin. The fault system was reactivated and inverted during Alpine compression in the Tertiary. This complex geological situation was further affected by halotectonics. Therefore we can find different types of fault zones, that is normal, reverse, strike-slip an oblique-slip faults, surrounding the major Leinetalgraben boundary faults.

Here we present first results of structural geological field studies on the geometry and architecture of fault zones in the Leinetalgraben Fault System in outcrop-scale. We measured the orientations and displacements of 17 m-scale fault zones in limestone (Muschelkalk) outcrops, the thicknesses of their fault cores and damage zones, as well as the fracture densities and geometric parameters of the fracture systems therein. We also analysed the effects of rock heterogeneities, particularly stiffness variations between layers (mechanical layering) on the propagation of natural fractures and fault zones. The analysed fault zones predominantly show similar orientations as the major fault zones they surround. Other faults are conjugate or perpendicular to the major fault zones. The direction of predominant joint strike corresponds to the orientation of the fault zones in the majority of cases. The mechanical layering of the limestone and marlstone stratification obviously has great effects on fracture propagation. Already thin layers (mm- to cm-scale) of low stiffness – here marl – seem to suffice to change the local stress field so that it stops many joints. Well developed fracture networks are therefore in most cases limited to single layers.

From the data we finally determined the structural indices of the fault zones, that is, the ratios of damage zone and fault zone widths. By their nature structural indices can obtain values from 0 to 1; the values having implications for fault zone permeability. An ideal value of 0 would mean that a fault damage zone is absent. Such fault zones generally have low permeabilities as long as the faults are not active (slipping). A structural index of 1, however, would imply that there is practically no fault core and the fault zone permeability is entirely controlled by the fractures within the damage zone. Our measurements show that the damage zones of normal faults in the Muschelkalk limestone are relatively thick so that their structural indices are relatively high. In contrast to normal faults, reverse and strike-slip faults have smaller indices because of well developed brecciated fault cores. In addition we found that small-scale fault zones with parallel orientations to the major Leinetalgraben fault zones are more likely to have well developed damage zones than those with conjugate or perpendicular orientation. Our field data lead to the hypothesis that fault systems in the North German Basin may generally be surrounded by small-scale fault zones which have high permeabilities if orientated parallel to the major fault and lower permeabilities if conjugate or perpendicularly orientated. However, further studies of fault systems in different geological settings are needed to support or reject this hypothesis. Such studies help to improve the general understanding of fault zones and fault systems and thereby minimise the risk in matters of the exploitation of fault-related geothermal reservoirs.