The effect of preexisting joints on normal fault evolution – Insights from field work and analogue modeling

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Huge hydrocarbon reservoirs worldwide are bound to brittle lithologies that are affected by interacting fracture networks. For a better prediction of reservoir qualities a basic investigation of such interactions is important. In this context, the present work aims for an understanding of the effect of preexisting joint sets on normal fault geometries. Methods used for this work include a field study, remote sensing and analogue modeling.

The Grabens Area of the Needles fault zone in the Canyonlands National Park, Utah/USA was chosen as field prototype. This arcuate array of young grabens (estimated to be younger than 100 ka) extends over several kilometers along the Colorado River in Permian brittle lithologies with distinct preexisting joint sets. The graben-bounding normal faults formed due to gravity-driven extension above Pennsylvanian evaporites. The well-preserved outcrops and the stratigraphic similarity to producing reservoirs make this region a perfect field analogue.

The work in this area included more than 70 ground penetrating radar (GPR) surveys along and across graben floors. Remote sensing of this area consisted of geographic information system (GIS)-based mapping of over 20,000 joints and 500 faults from high resolution orthoimagery as well as calculations of drainage pattern and dip directions from digital elevation models.

For the analogue modeling cohesive and very fine-grained hemihydrate powder was used as an analog for brittle lithologies. To create cohesionless open joints within the sensitive powder, sheets of paper were attached on strings inside the deformation box. The powder was then sieved in, embedding the sheets almost entirely. Finally the paper was carefully removed by using the strings, leaving thin open voids. In this work the angle between the strike of the joint-set and a defined basement-fault was incrementally changed between 0° and 25°. Analytic methods include high resolution time-lapse photography and particle imaging velocimetry (PIV) to analyze the spatial deformation patterns.

The GIS analysis revealed a correlation between joint and fault orientation. Sinkholes, mapped in airborne imagery and in the field, indicated steep-dipping dilational faulting close to the surface. This is consistent with the observation that graben walls coincide with original joint surfaces without slickenlines or toolmarks. Additional measurements of heave and throw at some outcrops allowed estimating fault dips at depth. The GPR surveys worked well for the upper 10 m of sediment and the interpreted profiles implied an ongoing horizontal extension as well as in some cases changing rates of displacement or sedimentation. The analogue models finally confirmed the findings that faults localize along the preexisting joints at the surface, requiring a change in fault geometry at depth. The models came up with very similar structures and features as observed in the field and airborne imagery. Hence, it could be shown that preexisting joint-sets do affect normal fault geometries distinctly.

References

Kettermann, M. (2011). The effect of preexisting joints on normal fault evolution – Insights from field work and analogue modeling. MSc thesis, RWTH-Aachen