Geophysical Research Abstracts
Vol. 19, EGU2017-9213-1, 2017
EGU General Assembly 2017

Kinematics and dynamics of salt movement driven by sub-salt normal faulting and supra-salt sediment accumulation – combined analogue experiments and analytical calculations

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In extensional sedimentary basins, the movement of ductile salt is mainly controlled by the vertical displacement of the salt layer, differential loading due to syn-kinematic deposition, and tectonic shearing at the top and the base of the salt layer. During basement normal faulting, salt either tends to flow downward to the basin centre driven by its own weight or it is squeezed upward due to differential loading. In analogue experiments and analytical models, we address the interplay between normal faulting of the sub-salt basement, compaction and density inversion of the supra-salt cover and the kinematic response of the ductile salt layer. The analogue experiments consist of a ductile substratum (silicone putty) beneath a denser cover layer (sand mixture). Both layers are displaced by normal faults mimicked through a downward moving block within the rigid base of the experimental apparatus and the resulting flow patterns in the ductile layer are monitored and analysed. In the computational models using an analytical approximative solution of the Navier-Stokes equation, the steady-state flow velocity in an idealized natural salt layer is calculated in order to evaluate how flow patterns observed in the analogue experiments can be translated to nature. The analytical calculations provide estimations of the prevailing direction and velocity of salt flow above a sub-salt normal fault.

The results of both modelling approaches show that under most geological conditions salt moves downwards to the hanging wall side as long as vertical offset and compaction of the cover layer are small. As soon as an effective average density of the cover is exceeded, the direction of the flow velocity reverses and the viscous material is squeezed towards the elevated footwall side. The analytical models reveal that upward flow occurs even if the average density of the overburden does not exceed the density of salt. By testing various scenarios with different layer thicknesses, displacement rate or lithological parameters of the cover, our models suggest that the reversal of material flow usually requires vertical displacements between 700 and 2000 m. The transition from downward to upward flow occurs at smaller fault displacements, if the initial overburden thickness and the overburden density are high and if sedimentation rate keeps pace with the displacement rate of the sub-salt normal fault.