Geophysical Research Abstracts
Vol. 12, EGU2010-13434, 2010
EGU General Assembly 2010

Facies composition and scaling relationships of extensional faults in carbonates

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Fault seal evaluations in carbonates are challenged by limited input data. Our analysis of 100 extensional faults in shallow-buried layered carbonate rocks aims to improve forecasting of fault core characteristics in these rocks. We have analyzed the spatial distribution of fault core elements described using a Fault Facies classification scheme; a method specifically developed for 3D fault description and quantification, with application in reservoir modelling. In modelling, the fault envelope is populated with fault facies originating from the host rock, the properties of which (e.g. dimensions, geometry, internal structure, petrophysical properties, and spatial distribution of structural elements) are defined by outcrop data.

Empirical data sets were collected from outcrops of extensional faults in fine grained, micro-porosity carbonates from western Sinai (Egypt), Central Spitsbergen (Arctic Norway), and Central Oman (Adam Foothills) which all have experienced maximum burial of 2-3 kilometres and exhibit displacements ranging from 4 centimetres to 400 meters. Key observations include fault core thickness, intrinsic composition and geometry.

The studied fault cores display several distinct fault facies and facies associations. Based on geometry, fault cores can be categorised as distributed or localized. Each can be further sub-divided according to the presence of shale smear, carbonate fault rocks and cement/secondary calcite layers. Fault core thickness in carbonate rocks may be controlled by several mechanisms:
(1) Mechanical breakdown: Irregularities such as breached relays and asperities are broken down by progressive faulting and fracturing to eventually form a thicker fault rock layer.
(2) Layer shearing: Accumulations of shale smear along the fault core.
(3) Diagenesis; pressure solution, karstification and precipitation of secondary calcite in the core.

Observed fault core thicknesses scatter over three orders of magnitude, with a D/T range of 1:1 to 1:1000. In general the complete dataset shows a positive correlation between thickness (T) of fault cores and the displacement (D) on faults. For increasing displacement relationships, the D/T relationship is not constant. The D/T relationship is generally higher for small faults than for larger faults, which implies that comparisons between small and large fault with respect to this parameter should be handled with care.

Fault envelope composition, as reflected by the relative proportions of different fault facies in the core, varies with displacement. In small scale faults (0-1 m displacement), secondary calcite layers and fault gouge dominate, whereas shale dominated fault rocks (shale smear) and carbonate dominated fault rocks (breccias) constitute minor components. Shale dominated fault rocks are restricted to shale-rich protoliths, and fault breccias to break-down of lenses formed near fault jogs. In medium scale faults (1-10m), fault rocks form the dominating facies, whereas the amount of secondary calcite layers decreases due to transformation into breccias. Further, in shale rich carbonates the fault cores consist of composite facies associations. In major faults (10-300 m displacement) fault rock layers and lenses dominate the fault cores. A common observation in large scale faults is a distinct layering of different fault rocks, shale smearing of major shale layers and massive secondary calcite layers along slip surfaces.

Fault core heterogeneity in carbonates is ascribed to the distribution of fault facies, such as fault rocks,

secondary calcite layers and shale smear. In a broader sense, facies distribution and thickness are controlled by displacement, protolith and tectonic environment. The heterogeneous properties and the varied distribution observed in this study may be valuable in forecasting fault seal characteristics of carbonate reservoirs.