Fault Damage Scaling: Insights from field data in carbonate rocks and analogue modelling

Sylvain Mayolle\textsuperscript{1}, Roger Soliva\textsuperscript{1}, Stephane Dominguez\textsuperscript{1}, Yannick Caniven\textsuperscript{1,3}, Christopher Wibberley\textsuperscript{2}, and Gregory Ballas\textsuperscript{1}

\begin{itemize}
\item \textsuperscript{1}Geosciences Montpellier, University of Montpellier, Montpellier, France
\item \textsuperscript{2}TOTAL EP, CSTJF, Av. Larribau 64018 Pau, France
\item \textsuperscript{3}RICE University, Houston, Texas
\end{itemize}

Fault damage zones present a renewal of interest to better understand stress perturbations around faults, earthquake's ground motions and fluid flow in the upper crust. Although numerous studies provide significant amounts of data from a broad variety of rocks, the processes controlling fault damage development are not clearly understood and scaling properties in carbonate rocks remain poorly studied. D-T (displacement - DZ thickness) data compilations show strong scattering and are acquired using different methods and at different places along the faults (including tip, wall, link, or inner and outer damages), therefore rendering difficult a proper definition of the scaling relationship.

First, we analyse fault/fracture systems at the outcrop and map scale and define displacement - thickness (D-T) scaling of fault damage zones using scanlines, in carbonate rocks in France and Spain. We determine fault displacement and damage zone thickness perpendicular to fault planes and far from fault tips for 12 selected faults in four study sites. The data show a logarithmic decrease of fracture frequency from the fault cores. This decrease is characterized by local frequency peaks corresponding to variably-linked secondary fault segments and abandoned tips within the fault damage zone. D-T data comprised between 0 and 100 m of net fault displacement show a nearly linear scaling with very little scattering. Including two additional data for D > 100 m, the best fit corresponds better to a power law. The linear scaling is explained by well-known processes of fault growth such as stress perturbations around faults and fault segment linkage. The non-linear trend shown by the largest faults suggests that at this scale the faults become restricted at their lower tips by the base of the brittle crust.

Secondly, we analyse fault damage growth using analogue modelling of normal faults in a sand box. The model is composed by a 5 cm thick layer of dry sand deposited above a 2 cm thick ductile “kinetic sand” (sand and silicone) layer. The experiment is analysed in cross-section using image correlation allowing to calculate the velocity field and strain tensor over the fault zones including
their damage pattern. Fault damage thickness obtained using the strain field appears to grow linearly with respect to shear displacement when the fault is contained into the dry sand layer. When the fault lower tip reaches the kinetic sand, fault damage begins to growth non-linearly with shear displacement, revealing that the brittle layer thickness is the main parameter governing the non-linear scaling.