E02

Fault Facies and Analysis of Fault Heterogeneity Through Rock Lenses

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SUMMARY

We analyze fault envelope heterogeneity with implications for fault seal predictions, emphasizing fault core lenses as conduits for flow. The approach goes through 3D modeling of faults, applying the fault facies concept as a tool in statistical pattern recognition and database compilation. Various facies, such as fault lens, can be examined through shape, position, intrinsic deformation, and formation mechanisms. The outcome is statistical validated generic models for fault architecture that can be utilized in fault envelope design and subsequent flow considerations.

Faults represent three-dimensional zones characterized by significant petrophysical and structural heterogeneity. Reservoir modeling and flow simulation of these three-dimensional features can be handled using the recently developed fault facies methodology, which is specifically adapted for reservoir modeling purposes; faults are considered a three-dimensional fault envelope in which host rock structures and petrophysical properties are altered by tectonic deformation. This new approach to fault description expands on conventional reservoir modeling tools which include faults in a highly simplified manner using a combination of offsets along grid splits and calculated transmissibility multipliers (TM) to capture fault impact on fluid flow across faults. TMs are derived from integration of all effects due to fault components and geometry into a function of shale gouge, clay smear and juxtaposition, thereby obscuring the presence and effects of commonly observed 3D fault envelope heterogeneity. In contrast, the fault facies modeling populates explicit fault envelope grids with discrete fault facies originating from the host rock and organized spatially according to strain distribution and displacement gradients. This approach reproduces realistic fault zone structures and properties in reservoir models.

Fault facies definitions are based in field data on fault elements (Fig. 1) (dimensions, geometry, internal structure, petrophysical properties, and spatial distribution), facilitating pattern recognition and statistical analysis for generic modeling purposes. Further, fault facies can be organized hierarchically and scale-independent as architectural elements, facies associations, and individual facies.

Analyses of cores of extensional faults in sandstone and carbonate reservoirs establish common fault facies associations of discrete structures, membranes, and lenses. Measured core widths show a close correlation to fault displacement, which generally can be linked to the distribution of fault facies along the fault. The fault cores are bound by principal slip-zones (slip surface and marginal fault rock layers) that tend to be continuous and parallel to the fault core at the scale of the exposure. Membranes are continuous to semi-continuous, long and thin layers of fault rocks. Within the fault core, slip-zones and membranes make up the margin of lenses, which consist of host rock or inactivated fault rock.

Fault lenses represent a major uncertainty in fault seal prediction as they may form highly permeable conduits within otherwise flow-retarding fault core lithologies. We investigate the lenses in extensional faults, addressing; 1) the position of the lenses relative to, or within, the fault core, 2) the geometry and shape of lenses, 3) the influence of lithology, and 4) the mechanism active in the generation and development of the fault lens. The dataset on lenses are compiled from faults in analogue plaster-of-Paris experiments and from five areas of nearly unconsolidated sandstone (Bornholm, Denmark), moderately consolidated sandstone (Sinai, Egypt), well consolidated micritic limestone (Corinth, Greece), limestone interbedded with shales (Kilve, West England), and gneiss (Frøya, Central Norway).

Most observed lenses are four-sided (Riedel classification of marginal structures), and show open to dense networks of internal structures, many of which have an extensional shear (R) orientation. The shape of the lenses can be analysed by normalizing length (measured in the dip-direction) and width (measured in the strike-direction) to maximum thickness (c:a and b:a-ratios). The average c:a-ratio for lenses included in the datasets is in the range of 9:1 to 12,5:1, but varies. Several parameters affect the lens shape: Lithology affects the minimum/maximum sizes of the lenses; and (ii) the break-down of lenses from primary (1st order) to secondary (2nd and higher orders) fault lenses commonly causes a change in c:a-ratios.

Analysis of lenses generated in experimental faults in plaster-of-Paris experiments, show that the fault zone generally develops through several stages. (1) The first stage produces a through-going fault plane which, in some cases, is characterized by irregularities mainly from tip-line coalescence and segment linkage. (2) During continued fault movement, larger fault plane irregularities are smoothed by asperity bifurcation, which includes fault-related cut-off of irregularities. The lenses of the first two stages most commonly form in isolation. (3) The next step is characterized by the initiation of new asperity bifurcation lenses and by lenses created by splaying or coalescence of secondary faults with the master fault.

Commonly, complete duplexes are formed. (4) In the next stage, internal shearing of the individual lenses becomes prominent; lenses split into complex duplexes. (5) By further displacement, the fault localizes in a slip-zone and most lenses are transformed into fault rock membranes. From stage 1 to stage 4 a bulk widening of the fault zone occurs, mainly due to the development of lenses and stacking of lenses into duplexes. Locally, temporary thinning takes place, mainly by breakdown of lenses into fault rock membranes. At the final stage (5), there is bulk thinning of the fault zone along its full length.

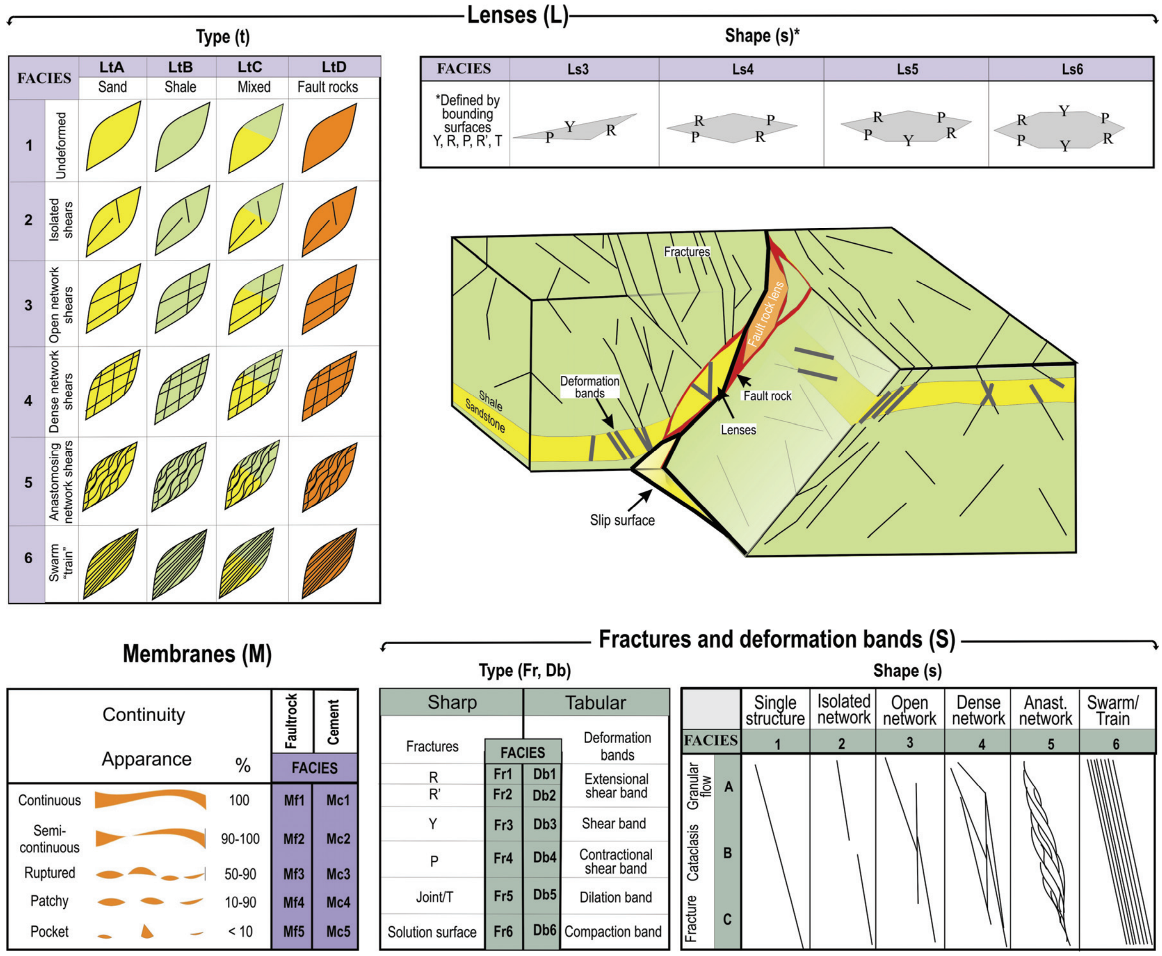

Figure 1 *Conceptual figure showing the main structural elements of extensional faults and examples of a fault facies classification scheme used to describe structural elements in the fault envelope. The schemes address structural elements in clastic units, describing structural element appearance, type and shape. Lens shape facies are depicted in Riedel fracture or shear zone orientations.*