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Brittle-ductile mechanics of sedimentary basins: advances in 4D kinematic and dynamic deformation models for structural interpretation

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Geological faults range from a sharp displacement discontinuity to a more or less thick zone of shear bands. The average orientation of faults in sedimentary basins indicates that the bulk friction coefficient of the composite material, i.e. the stratigraphic sequences, has similar value to the fiction of granular sand. This property is one of the justifications to use analogue sand box experiments to simulate structural evolution on a small scale. In numerical computations, the process of faulting can be modelled using an elasto-plastic constitutive law with a pressure sensitive limit state and a nonassociated flow rule. It is the property of a material to soften that leads to a localisation of the deformation along shear bands. Sand box simulations and numerical computations of fault orientations have shown their strong dependence on boundary conditions: structural discontinuities nucleate and develop at points of small perturbations or defects. However composite brittle-ductile stratigraphic sequences also have the ability to accommodate loading by folding with homogeneous or heterogeneous deformation patterns, this time reflecting the internal distribution of the rocks mechanical properties. Numerical modelling of faulting and folding is still a challenge for mid to long term research and development projects. Still the numerical modelling of basin evolution requires a good idea of the timing of faulting and folding for it to be tied to a scenario of sedimentation, erosion and regional tectonic stress evolution. Practical solutions for structural restoration and basin modelling, were found in the 80's through the 90's by using simple geometric and kinematic models. 2D palinspastic restorations were performed either in map-view or in depth converted cross sections. In the 80's, rigid-body jigsaw motions were the first computerised restoration algorithms used to perform restorations of faulted blocks. These were soon followed by the addition of

internal deformation to faulted blocks. The vertical or inclined shear algorithms were used in extensional basins and the flexural slip in contraction areas. Many other kinematic models have progressively enriched the library of balanced cross section algorithms with Tri-shear and mixed modes as one of the latest releases. The passage from kinematics to mechanical approaches appeared for the first time in the mid 90's, essentially formulated to solve the restoration of folded and faulted stratigraphic surfaces: the so-called ironing of developable surfaces. Since 2000, rapid solvers for elasticity problems were developed to undertake volume based 4D restorations, while the family of kinematic models were still routinely applied to solve restoration of stratigraphic horizons (2D) or strata (in 2.5D and not true 3D). Current developments are being focused on a volumetric restoration using a variety of techniques including the finite elements, the boundary elements or the mass-spring finite difference algorithm. The practical benefits of these techniques will be discussed using examples of faulted strata restorations. Forward modelling of the restored states permits the prediction or validation of compaction and fracturing through time.