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Evolution of stress and strain during 3D folding: application to orthogonal fracture systems in folded turbidites, SW Portugal

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We present field data and numerical modeling results which show the evolution of stress and strain patterns during 3D folding resulting in an orthogonal fracture system. The field area is located near Almograve, SW Portugal. The area is part of the Mira Formation which itself is part of the South Portuguese Zone (SPZ). The structural development of the SPZ is characterized by southwest vergent folding and thrust displacement. The metamorphism in the SPZ increases from diagenetic conditions in the southwest to greenschist-facies conditions to the northeast. The Mira Formation is composed of turbiditic layers of Carboniferous age with low sandstone to shale ratio. The data was gathered at three outcrops which show structures similar to chocolate tablet structures in the folded sandstone layers. Chocolate tablet structures are generated under simultaneous extension in two directions and show two fracture systems of the same age which are perpendicular to each other. However, the Mira Formation is located in a convergent area. Also, the outcrops near Almograve show two fracture systems of different age. The fractures orthogonal to the fold axis and the bedding are crosscut by fractures parallel to the fold axis and orthogonal to the bedding.

Our hypothesis for the evolution of the observed fracture systems is as follows; the older fractures which are now orthogonal to the fold axis and to the bedding plane were generated during compression while the layers were still approximately horizontal. They are parallel to σ_1(i.e. mode 1 fractures). The second and younger fracture family was generated in a phase where there is local extension in the fold limbs. These fractures are orthogonal to the far-field σ_1, parallel to the fold axis and perpendicular to the bedding. The shortening direction is constant during the entire folding process.

We test our hypothesis with numerical modeling. We use 2D and 3D finite element codes with a mixed formulation for incompressible flow and a viscous rheology. The stress and strain tensor components are calculated at each numerical nodal point. The stress and strain fields are visualized through ellipses and ellipsoids which are calculated using the eigenvalues of the respective tensors. The shortest main axis represents the direction of the smallest stress σ_3 and the longest main axis represents the direction of the largest stress σ_1. To generate two orthogonal fracture systems in the fold limbs we expect a relatively rapid change of the stress field in the fold limbs during folding. With a relatively slow change of the stress field we would expect to see more than two fracture systems with a wide range of fracture orientation which we did not observe in the field. The preliminary 2D results show, as expected, a sudden flip of the main axes of the stress ellipse which corresponds to a change from limb-parallel compression to extension. For the 3D model we expect similar results and we will investigate the impact of different deformation boundary conditions on the evolution of the 3D stress and strain fields.