Is consideration of fold growth important for prediction of subsurface fracture networks?

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The ability to predict subsurface joint orientation from the shape of a fold greatly facilitates hydrocarbon exploration and production. Predictions of joint orientation are commonly based on bed strike and curvature of the final fold shape. One problem that may arise from this type of prediction is that joints generally form in the earliest stages of folding when the fold shape was significantly different than observed today. The purpose of this study is to use plate bending theory to model joint orientations at plunging fold terminations, to determine the amount of joint rotation associated with fold growth, and to examine the degree of joint mis-interpretation that would result from predictions based on final fold shape.

Axially symmetric fold shapes were generated using a hyperbolic tangent equation. Because folds grow in a variety of different ways, three different end member types of fold growth were examined in this study: constant fold width, where the fold grows along axis (lateral propagation); constant fold length, where the fold widens perpendicular to the fold axis; and constant aspect ratio growth, where the fold grows equally in length and width with each growth increment. Growth of the fold can be simulated by deforming an early fold shape to a different final fold shape using a 3D flexural slip algorithm.

One method for simulating passive rotation and translation of early joints associated with fold growth is first to calculate joint orientations from an early fold shape, and then to deform those joints to the final fold shape using the 3D flexural slip algorithm. The amount of error that one would encounter by predicting joint orientations based solely on the final fold shape, which is preserved, can calculated by determining the angle between the early rotated joints and joint orientations based on the final fold shape. Joints predicted by early and final fold shape differ by up to 90° in each type of fold growth. In general, the limbs of the fold have the most significant difference in early and final orientation, commonly 50-90°, because early joints that end up along the fold limbs formed in significantly different structural positions on the early fold. Mis-interpreting joint orientations by as much as 50-90° would have significant implications for both subsurface fluid flow and for field interpretation of joints.

Because field geologists commonly examine the orientation of a given joint with respect to bed strike, it is logical to examine the amount of mis-interpretation described above in terms of the difference in joint rake. Rake is defined as the angle between bed strike and the orientation of a lineation (in this case, the trace of a joint) in the plane of bedding. Calculating the change in rake between early rotated joints and joints predicted using final fold shape reveals significant differences of up to 50° on fold limbs. This observation is particularly important when considering the implications of using fractures as paleo-stress indicators.

Distinguishing opening mode fractures (joints) from shear fractures is commonly a difficult task in the field, but is crucial to determining the paleo-stress field because joints record tension perpendicular to the plane of failure, and shear fractures record tension oblique to the plane of failure. Perhaps the most commonly cited model for fracturing associated with folding suggests that shear fractures commonly develop on fold limbs in orientations oblique to bed strike[1]. Application of this model to natural folds has commonly led to the assumption that oblique fractures on the limbs of folds are shear fractures without documenting that these fractures formed as shear fractures. All of the fold growth simulations we have examined have oblique joints on the final, preserved fold limb. These results call into question the interpretation of oblique fractures on natural fold limbs as shear fractures.

This study provides important guidelines for the degree to which joints may deviate from predictions based on structural position that can be expected in natural folds and highlights key areas where such deviation may be identified in the field. Current and future work will address how the methodology used to deform bed surfaces may affect joint rotation. A specific goal is to evaluate the sensitivity of joint rotations to the assumption of uniform, “in plane” transport in the 3D flexural slip algorithm.