Curvature-Fracture Relations in Clay Experiments

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Layer curvature is often used as a proxy for fracture intensity (FI) in subsurface seismic analyses (e.g. Chopra and Marfurt 2010). This usage is based on beam bending calculations in which tensile strain, and the resulting FI, is proportional to the beam curvature. We experimentally tested this hypothesis by deforming clay models that are 3-5 cm thick and subjected to basement compression (thrusting) or extension (normal faulting). The FI (total fracture length/area) and the clay surface curvature were determined in 10-20 intervals during each experiment. Clear correlation is observed between the FI and the corresponding measured magnitude of the local clay curvature under both compressional settings (r2=0.95) and extensional setting (r2=0.61). These experimental results support the use of layer curvature as an indicator for FI in subsurface analysis. The detection of common rock fractures typically falls below seismic resolution, yet fractures are often critical to porosity and permeability in hydrocarbon reservoirs. Multiple studies link fractures to structural curvature following the assumption that extension fractures are generated on the extending side of flexed and folded. For example, curvature calculations from 3D seismic data were correlated with fractures presence in borehole image logs by Hunt et al. (2010), Nissen et al (2009), and Ericsson et al. (1998). Potential fracture zones seen by lineaments in the subsurface were identified using the curvature attribute in 3D seismic surveys by Chopra and Marfurt (2010, 2008, 2007), Nahari et al. (2009), and Hart (2006). Beam theory (Manaker, 2007) indicates that the tensile strain, ε, at the convex part of a beam with thickness, h, that is flexed with radius of curvature, Rc, is linearly proportional to the curvature magnitude, k,:

$$\varepsilon, = h/2R\ c = kh/2$$

We hypothesized that clay model experiments will exhibit similar relationships. We report here the result of clay model experiments in which we used homogenous clay cakes (1.22 g/cm^3, or 76.2 lb/ft^3) with approximate dimensions of 7.87 in (20 cm) long, 5.91 in (15 cm) wide, and 1.97 in (5 cm) thick. A laser scanner positioned above the clay cakes captured 3D-surface images at vertical and horizontal resolution of 75 DPI (~0.015 in, or 0.0381 cm point density) every two minutes. A typical experiment lasted approximately 30 min. The experimental apparatus consists of a horizontal table with one moveable side-wall, one stationary side-wall and a deforming base. We ran four experiments. In the extensional experiment, the clay cake was placed on top of two rigid, thin metal plates that were moved away from each other. In the compressional experiments, the clay cake was placed on two metal wedges with inclinations 45°, 30°, and 15° that moved toward each other to simulate reverse basement faulting. The curvature of the clay surface was calculated from the laser scans using commercial software and the fractures were mapped on digital photographs of the clay surface. Curvature over the area of deformation was calculated in each stage by placing three polygons at fixed locations and averaging the curvature within each polygon. FI was calculated for these polygons by dividing total fracture length in each polygon by the polygon area.

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