

A06 Fractured Reservoir Permeability Structure Constrained by Geomechanical and DFN Models

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Fractured reservoir models are used for several different purposes, from prospect generation and well planning, reservoir simulation and depletion planning, to risk assessment and reserve calculations. They can be constructed from a number of different data sources and in a number of different ways. Discrete fracture network (DFN) models constructed from seismic data, facies models, borehole image data and dynamic data provide the most robust estimates of fracture permeability for use in single- or dual-media reservoir simulation. However, the results of geomechanical modeling are generally not directly integrated into DFN models.

Our approach is to use horizons and faults from a geocellular model within a geomechanical modeling package to help constrain fracturing within a DFN at each grid node. Combined with subsurface data and multivariate statistics, these data are used to generate a permeability tensor at each grid node.

We use a boundary element / elastic dislocation approach to forward model strains related to faulting. Elastic dislocation (ED) theory is widely used by seismologists to predict surface deformation following earthquakes. Elastic dislocation theory offers computational advantages of high resolution and speed for numerical methods of modeling fault displacements. Use of this theory has been extended to analyze the effects of geological displacements attributable to interacting sets of faults. Displacements and strains can be computed anywhere in the volume and for any fault geometry, for intersecting faults and for complex faulting histories.

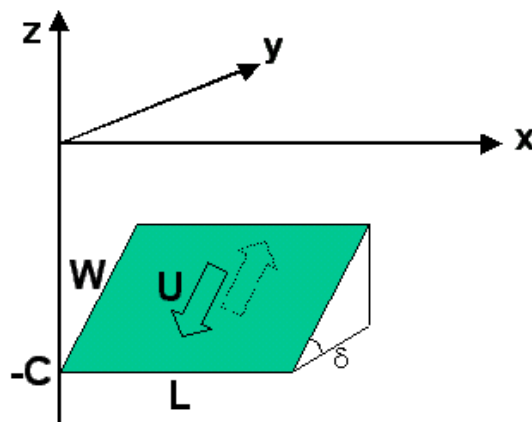


Figure 1: Single rectangular fault panel with uniform slip within an absolute reference frame. A fault is discretized using a series of these panels embedded within an elastic medium.

Mapped faults in the subsurface are approximated by an array of rectangular fault ‘panels’ (Figure 1), each of uniform slip, embedded in an elastic medium. Using horizon-based displacement boundary conditions on the modeled faults along with the regional strains and the equations of Okada (1992), the resulting displacement and strain tensor can be computed at any observation point in the medium (Figure 2). The stress tensor is computed from the strain tensor so that the orientation and magnitudes of the principal stresses, and the mode and most-likely orientations of failure (fracture) through the reservoir are determined using appropriate material properties.

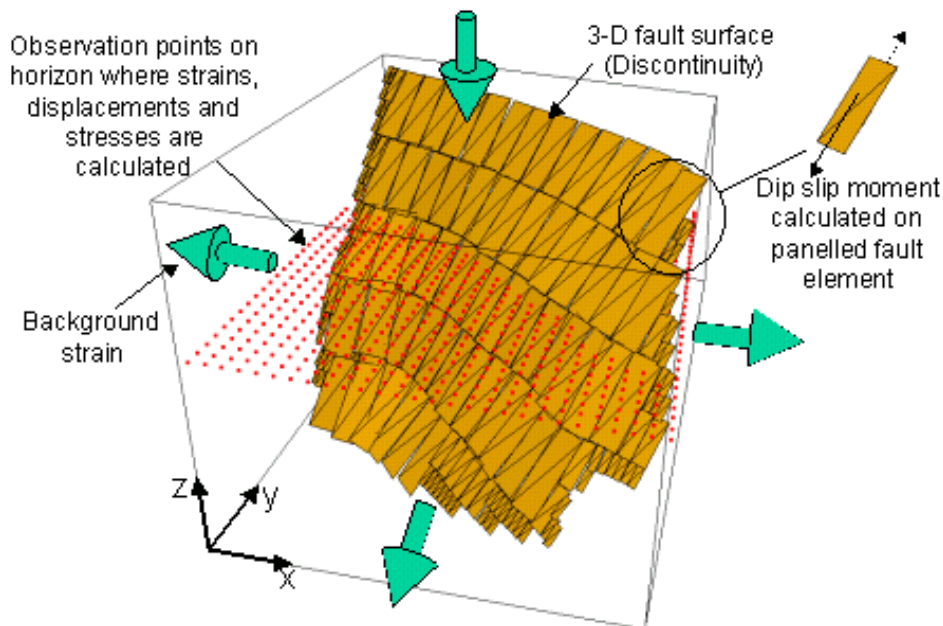


Figure 2: Fault represented as an array of panels, intersecting a horizon on which displacements, strains, and stresses are calculated.

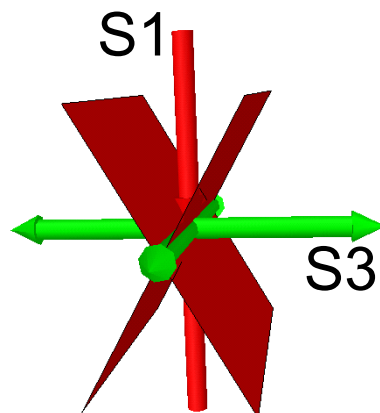


Figure 3: Principal strain axes (green arrows are extensional, red are compressional) and conjugate shear planes (red planes) calculated at a single point on a horizon.

The relative intensity of fracturing in different areas is indicated by measures of stress and/or strain at each grid node. Each grid node has an array of data associated with it, including strain, stress, failure mode, failure plane orientation(s), etc., which are visually represented as in Figures 3 & 4.

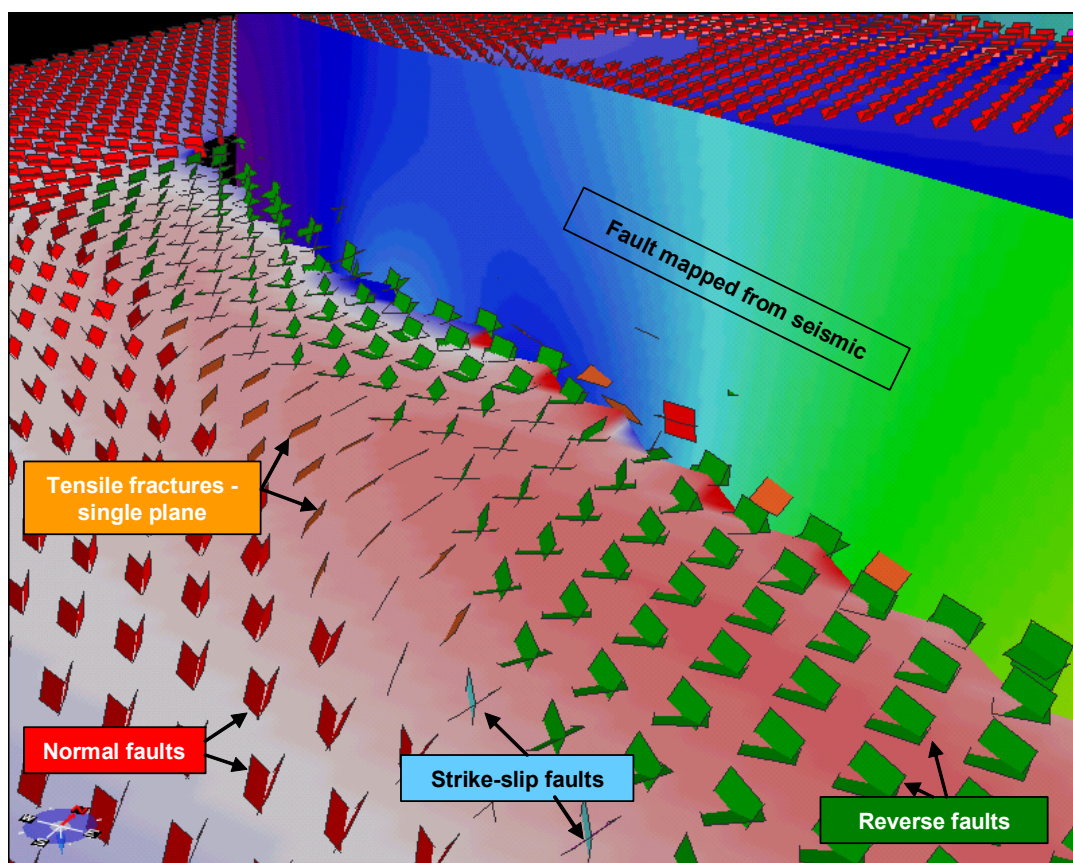


Figure 4: Perspective view of calculated failure modes and orientation planes at reservoir model grid nodes around a fault mapped from seismic. Fault displacement on the large fault is shaded such that lighter colors are larger values. The horizon is shaded by volumetric strain such that reds are +ve and blues are -ve. Note how the fracture orientations vary around the fault. The node spacing is 50 m x 50 m and pre-determined by the 3D geological grid of the facies model *or* the scaled-up grid of the simulation model.

After the geomechanical modeling is completed, we import the results into the DFN package. First, predictions of fracturing in terms of 1. failure mode, 2. failure orientation, and 3. strain magnitude from the elastic dislocation model are tested and calibrated against “ground truth” data, including the observed fracture density and orientation data from borehole image logs. The data are then incorporated into our linear discriminant analysis method, which includes observed fractures, seismic attributes, facies distributions, etc. An indicator variable is then produced that can be used to govern fracture density.

A DFN is constructed by combining information on fracture density/facies associations, 3D facies distributions, and the calibrated elastic dislocation modeling results. Strains are used to condition fracture densities, failure modes are used to condition densities and sets, and failure orientations are used to supplement fracture data from wells. Figure 5 shows the difference in predicted fracture density when the geomechanical results are and are not included.

Fracture permeability is calibrated to dynamic data by simulating fluid flow in the DFN itself and comparing the results to field dynamic data. The final model provides fracture permeability, porosity, and equivalent matrix block dimensions for each model cell, which vary as a function 1. facies distribution, 2. observed well data, 3. predicted strains, 4. predicted failure mode, and 5. predicted failure orientations.

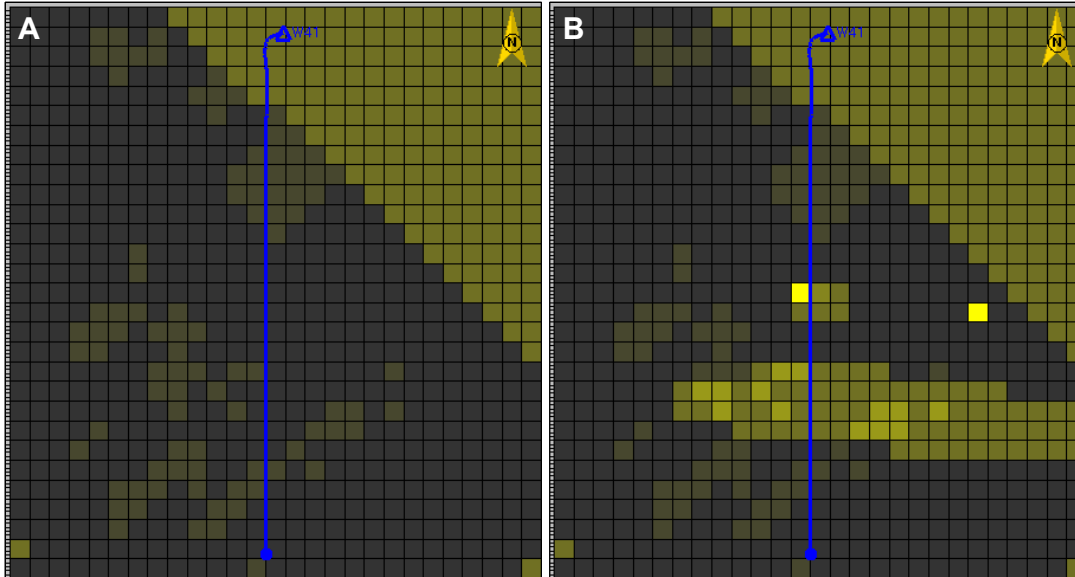


Figure 5: (A) Fracture density predicted using only observed fracture/facies relationships within wells (map view, horizontal well is in blue, fracture density is shaded from low to high using dark to light colors, respectively). (B) Fracture density predicted using same information as (A) but including the geomechanical modeling results – the fault that the well crosses is apparent. The cell size is 50 m x 50 m.

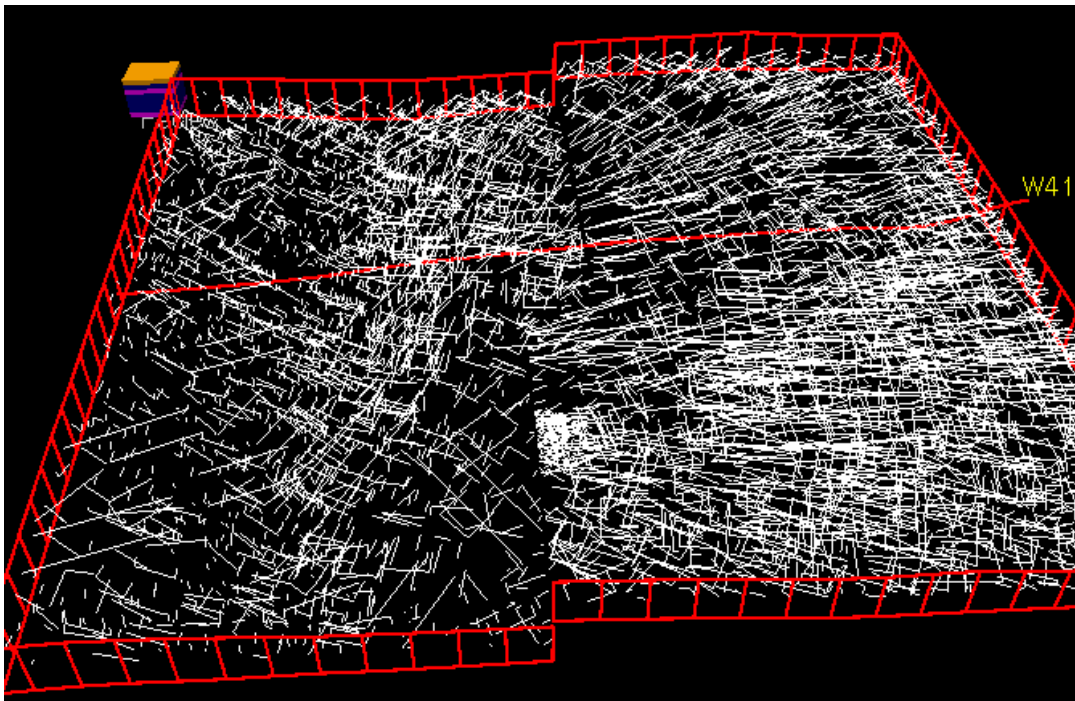


Figure 6: 3D perspective view of the same area as the maps in Figure 5, showing the faulted corner-point grid from the geological model, the well trajectory, and fractures predicted by facies associations and the geomechanical modeling results. Note how the fractures vary both in orientation and density as a function of the fault, but also have a facies-related density variation in the northeast corner of the model (view is to the West).