move™ feature

Application of Fault Response Modelling

The Fault Response Modelling module in Move™ provides a geomechanical method for modelling fault-related deformation. The module calculates stress, strain and displacement fields around faults within an elastic half-space. The magnitude of fault slip can be calculated from boundary conditions, including a remotely applied stress regime. The resultant strain values can be used to constrain the orientation and intensities of fractures associated with faulting. In this monthly feature, Fault Response Modelling is used to investigate the orientation of fractures around a normal fault relay zone, located offshore Nova Scotia, Canada, to identify locations for fracture-driven subsurface fluid flow (Figure 1).

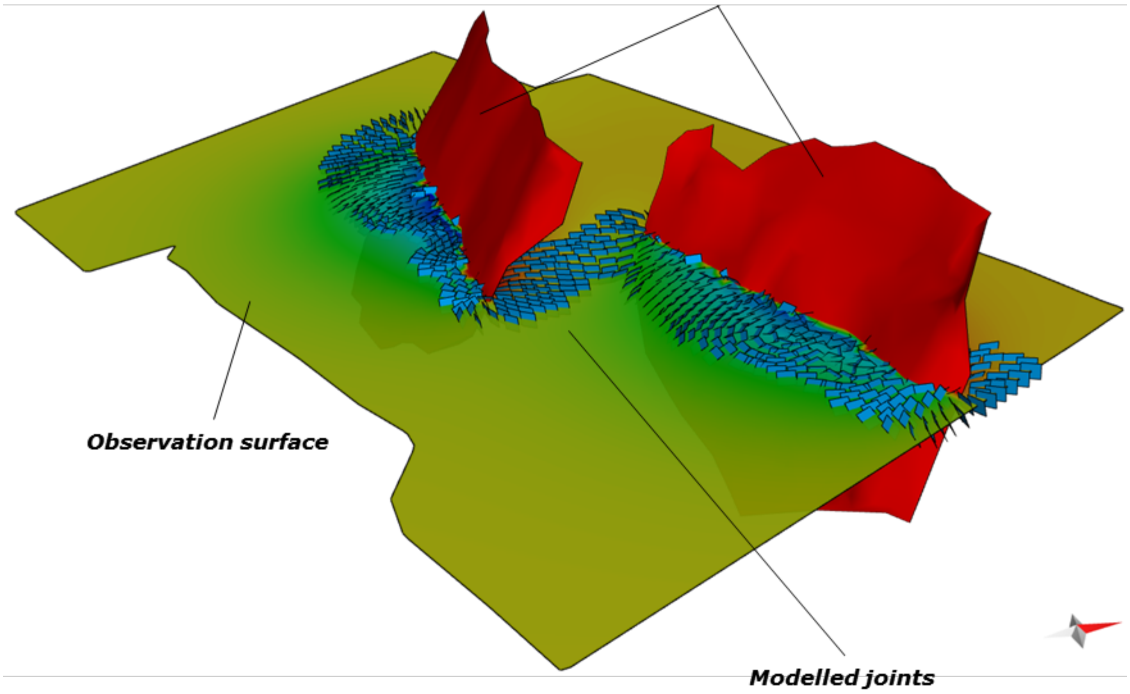

Figure 1. Fractures around a fault zone modelled using Fault Response Modelling. Structures interpreted from the Penobscot seismic cube, offshore Canada.

Fault Response Modelling theory

Fault Response Modelling is based on the theory of triangular elastic dislocations beneath a horizontal "free" surface. Above the free surface, material provides no resistance to fault-related displacements, which forms the boundary of an elastic half-space allowing variation in lithostatic and pore pressure to be accommodated. Each dislocation element corresponds to a slip vector on the triangular faces of a meshed fault surface (Figure 2). Dislocations on the fault surface displace points that comprise the surrounding observation surface (Figure 2), with the amount of displacement depending on magnitude of fault slip and the elastic properties of the intervening rock mass. In practise, this works by summing the effects of all dislocations, and calculating the total displacement of footwall and hanging wall of the fault (Comninou and Dundurs, 1975). The interaction of multiple fault surfaces can also be simulated by calculating the slip that would occur on dislocations within the elastic body under a user-defined regional stress field (Jeyakumaran et al., 1992).

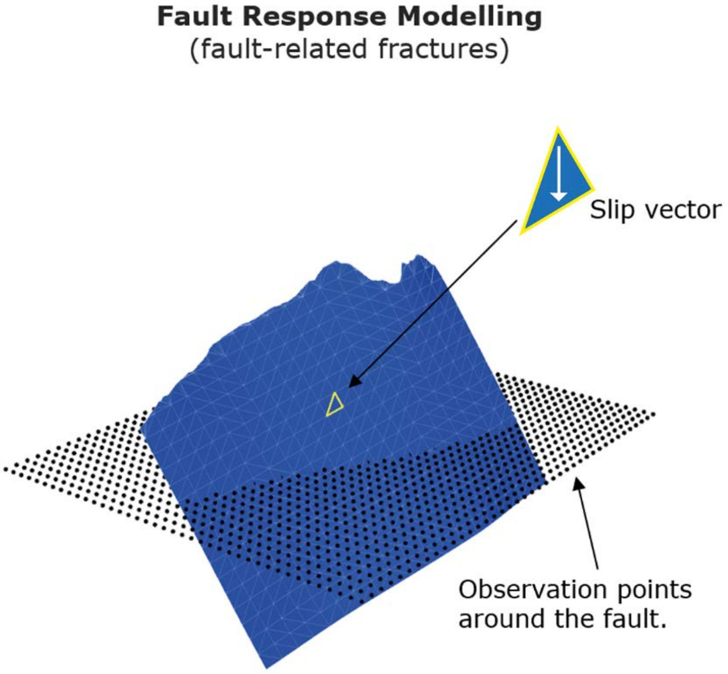

Figure 2. Illustration of a fault mesh (blue) showing the local slip vector resolved on a triangular mesh face. The implementation of triangular dislocation elements allows complex fault shapes to be modelled.

Normal fault relay zone

The study area is situated within the Scotian Basin, ca. 200 km to the south-east of Nova Scotia, Canada. The studied fault zone is interpreted from the Penobscot seismic cube and comprises two southerly dipping normal faults (Campbell et al., 2015). The Scotian Basin developed during Triassic rifting of the North American and African plates (Wade et al., 1995). The interpreted faults accommodate up to 200 m normal offset of Jurassic to Cenozoic horizons and display an elliptical throw distribution typical of isolated normal faults (Figure 3). In map view, the displaced horizons adhere to a relay zone geometry, where the transfer of displacement is accommodated by rotation of the intervening rock and development of a relay ramp. Fractures associated with the formation of relay zones have been identified potential locuses for subsurface fluid flow (Fossen and Rotevatn, 2016). In the following workflow, Fault Response Modelling will be used to test possible fracture orientations and the likelihood of failure.

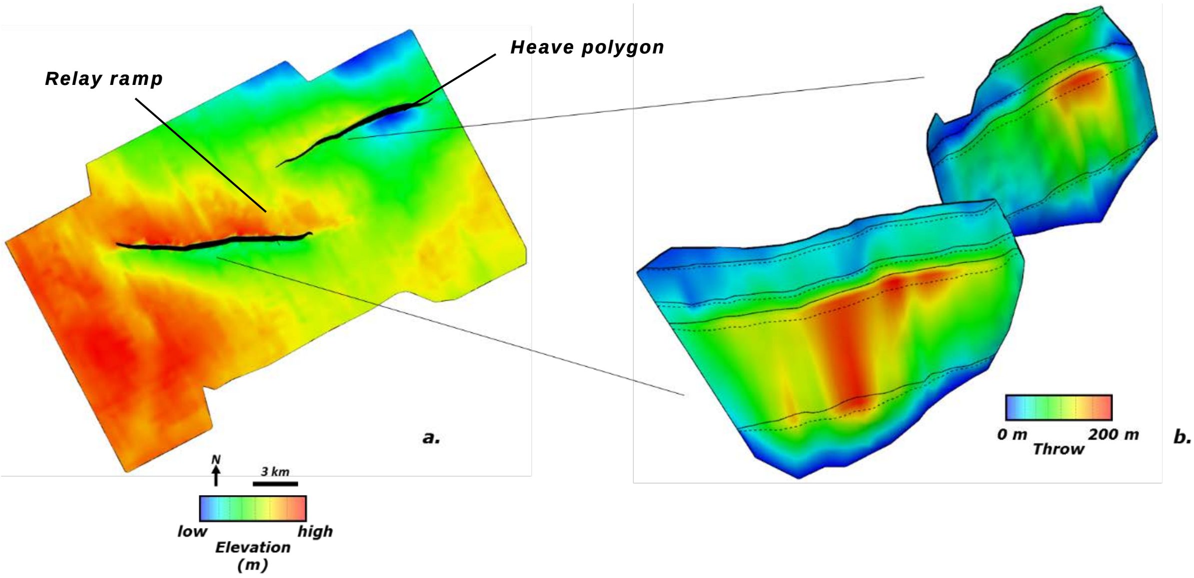

Figure 3. a) Map showing Early Cretaceous horizon and fault heave polygons. b) Distribution of present-day throw on the fault surfaces.

Defining fault slip

The magnitude and direction of slip accomodated by the fault zone is estimated by defining a normal stress regime, where the Cenozoic minimum horizontal stress (S_{hmin}) is orientated NW-SE (Yassir and Bell, 1994). The relationship between interacting faults is simulated using slip zone modelling (Jeyakumaran et al. 1992).

1. Open the **Fault Response Modelling** module.
2. Collect faults and observation grid into the toolbox.
3. In the **Input: Master Faults/Fracture Sets** sheet, make sure that both faults are selected and define displacement as **Remote Loading**.
4. Turn off **Use Opening-Closing Component** and turn on **Slip Zone Modelling.**
5. Navigate to the **Regional Stress** tab.
6. Rotate the regional stress field to a normal fault system, where σ1 is vertical and σ3 is orientated NW-SE (Figure 4). This can be done manually or using **Stress State Settings**.

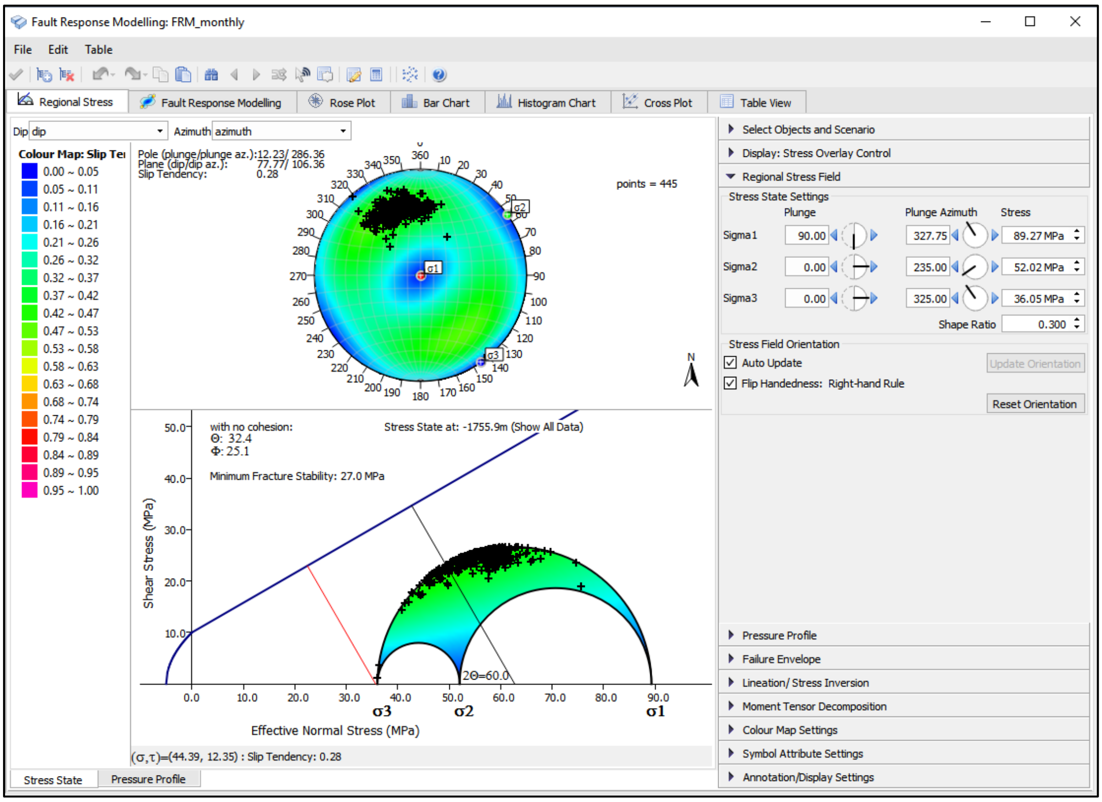

Figure 4. The Regional Stress sheet in the Fault Response Modelling interface

7. Return to the **Input: Master Faults/Fracture Sets** sheet and click **Update Slip Distriubution.**

Once updated, the results of Slip Zone Modelling are automatically colour mapped on the fault mesh surfaces. The modelled slip patterns are comparable to the throw distributions calculated across the fault zone. Slip vectors can be viewed and adjusted under the **Analyse Results: Vector Fields** sheet (Figure 5).

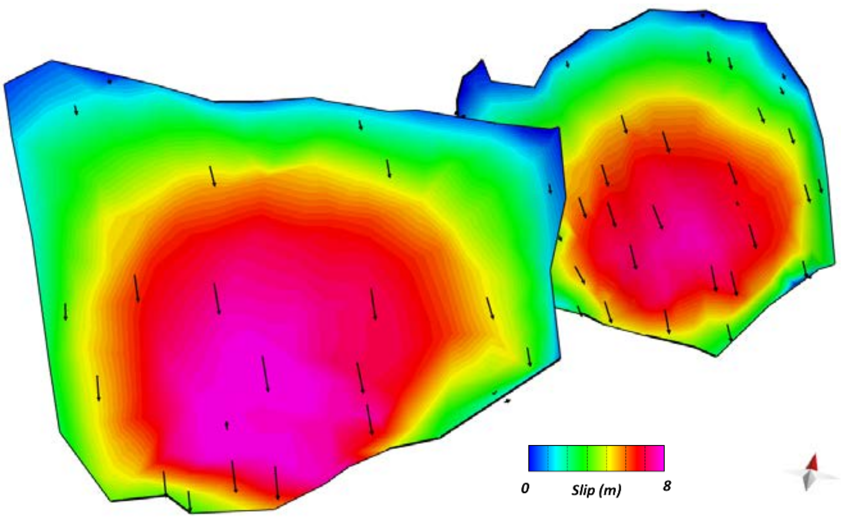

Figure 5. Modelled slip on the fault zone. Slip vectors shown as black arrows (length x5).

Running Fault Response simulation and visualizing results

After calculating fault slip, deformation around the fault is modelled by clicking on **Run Fault Response Simulation**. This process calculates displacement, an infinitesimal strain tensor and a stress tensor at each vertex of the observation surface. Using these data, the observation surface can be colour mapped for total displacement, strain and stress magnitudes.

1. Navigate to the **Analyse Results: Displacement, Strain and Stress Colour Mapping** sheet.
2. Click on **Total Displacement** (Figure 6a).

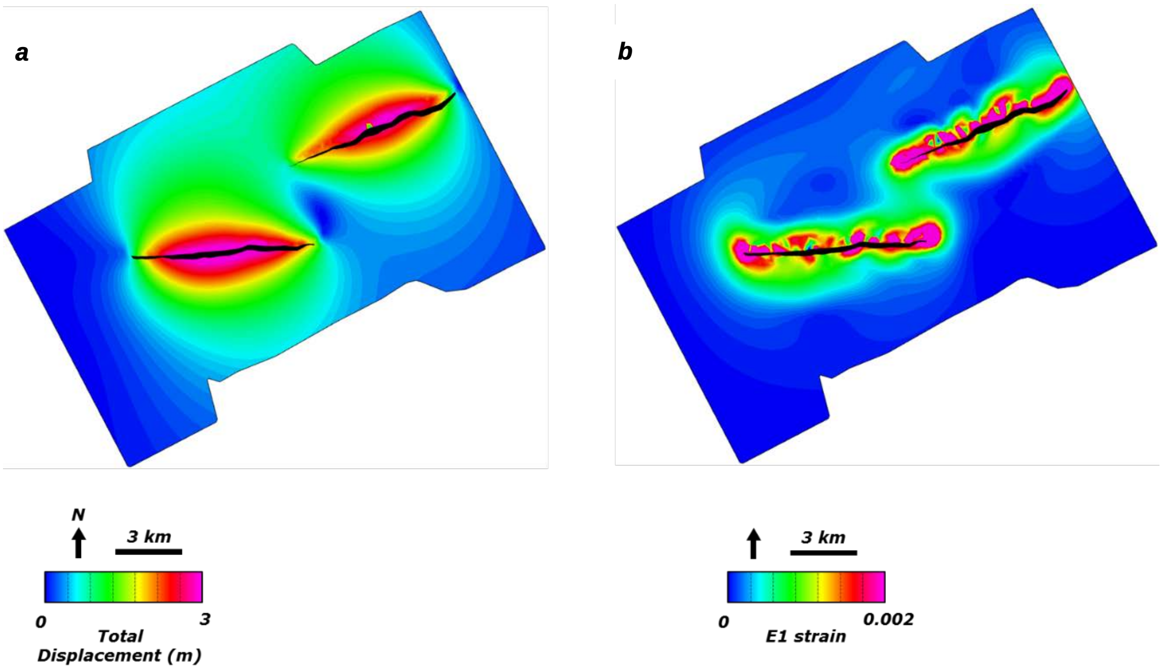

Figure 6. Results of the Fault Response Simulation, colour mapped for: a) displacement; and b) strain (E1) around the fault zone.

The Total Displacement results illustrate the transfer of slip between the faults. An offset **Displacement Surface** can be created under the options tab.

3. Navigate to the strain tab and click on **E1** (Figure 6b).

The E1 colour map indicates that there is higher strain within the relay ramp than the surrounding wall rocks (Figure 6b).

Modelling fracture orientation and distribution

The modelled principal strain directions define the orientation of joints and shear planes at each point on the observation surface. The fractures can be visualized and then filtered based on the likelihood that the rock will fail given the geomechanical properties of the model. Fracture filtering can be implemented using two methods: **Fracture Stability** or **Brittle Failure**.

Fracture Stability evaluates the magnitude of pore pressure change required to bring a fracture into failure. Where the calculated pore pressure is negative, the fracture is assumed to have failed.

Brittle Failure evaluates failure based on the change in the stress field associated with fault slip. Moreover, this method allows the nature of fracturing (i.e. shear or tensile) to be evaluated (Bourne and Willemse, 2001).

1. Navigate to **Fractures and Colomb Stress Change**.
2. Turn on **Show Fracture Planes: New Surface.**
3. Reduce the **Sampling** value to **1**.
4. Choose **Joints** under the **Strain Based** tab in the **Orientation of Planes: New Surface**.

The visualized joints illustrate the rotation in principal strain axes around the fault zone (Fig. 7a).

5. Tun on **Filter on Fracture Stability**

Fractures that are calculated to have failed (i.e. require a negative pore pressure to reach failure) are now visualized.

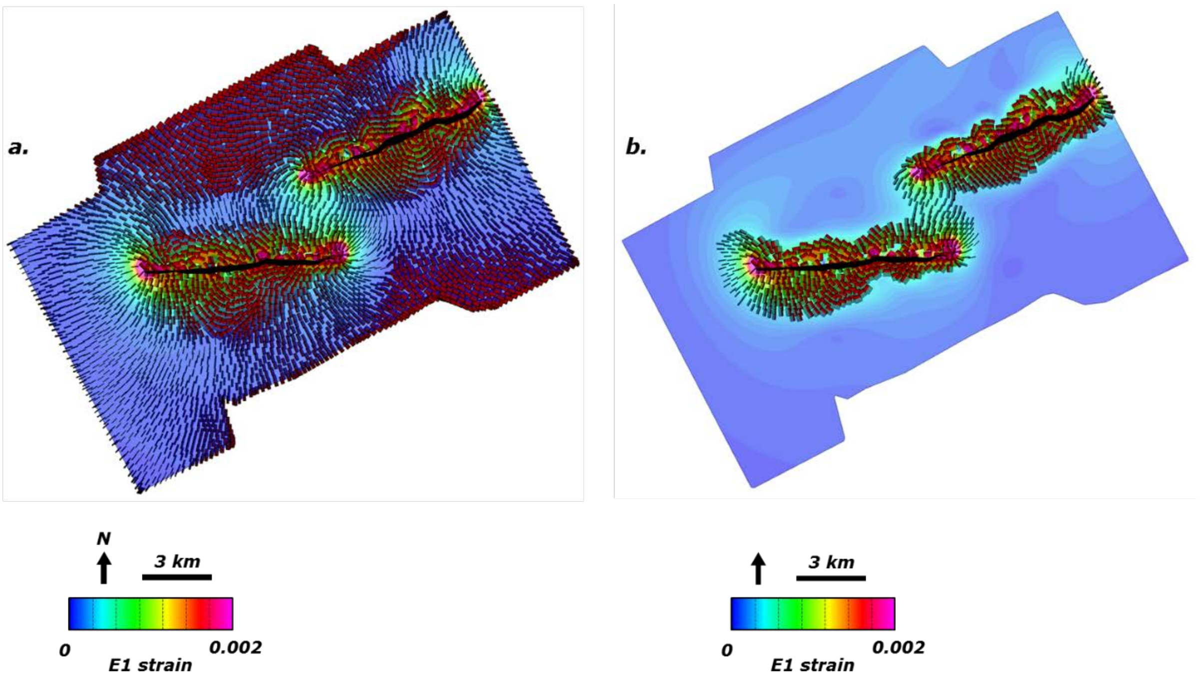

Figure 7. Visualized fractures around the fault zone. a) All fractures. b) Fractures filtered based on Fracture Stability.

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Results

Application of Fault Response Modelling indicates that fracturing will occur within areas of high strain around the normal fault zone. This is limited to the immediate hanging wall and footwall of the individual normal faults, and the adjoining relay zone. Consistent with previously published work, the joints formed within the relay zone are orientated at a high angle to fault strike (Kattenhorn et al., 2000). The reactivation of the joints under the present-day stress field can be evaluated using Move's **Stress Analysis** module. This method allows investigation of the impact of fault related fracturing on subsurface fluid flow. The results of this workflow can be used to aid well planning and reservoir modelling.

References

The authors acknowledge the use of seismic data from the Nova Scotia Department of Energy.

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If you require any more information about **Fault Response Modelling** or other **Fracture Modelling** workflows in **Move**, then please contact us by email: enquiries@mve.com or call: +44 (0)141 332 2681.