Using Fault Response Modelling and Stress Analysis to evaluate fractures for well planning

This month's feature illustrates the use of the **Fault Response Modelling** and **Stress Analysis** modules in **MOVE** to evaluate near fault fracture distributions. The results of the analysis can be used to inform decision making processes such as planning positions and orientations of wells.

To illustrate the workflow a case study example from a strike-slip pull apart basin, similar to the Vienna basin in Austria, will be used (Figure 1). In the basin a prospect has been identified in a down thrown fault block. Flow tests from a well that intercepts the fault block suggest that the majority of flow is along fractures.

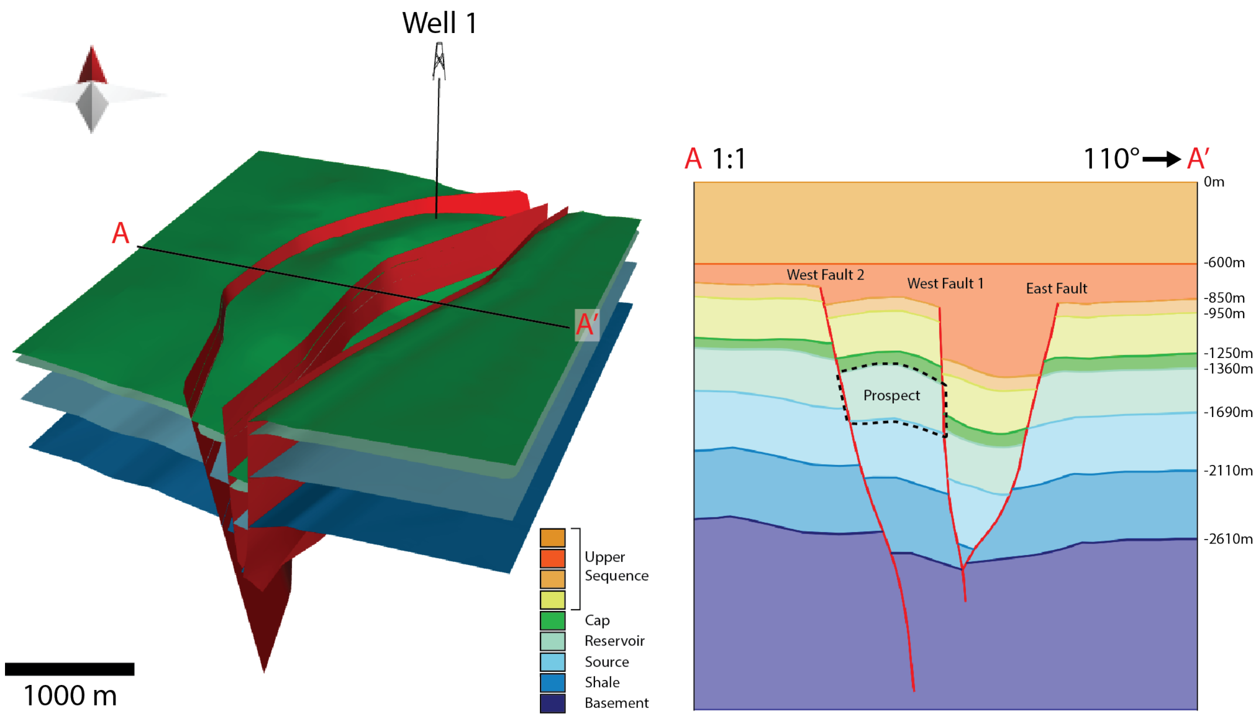

Figure 1: Left) 3D model of the study area, the upper sequence is not displayed; the top horizon shown is the cap rock. Right) Cross section through the study area running A-A', with the Prospect highlighted.

The objective of the analysis is to better understand fracture distributions to inform the planning of a production well. The planned well should intersect as many open fractures as possible, maximizing the benefit of secondary (fracture) permeability during production.

In order to achieve this a **Fault Response Modelling** simulation of fault movement was run in MOVE (October 2017 MOVE Monthly Feature). From the results of the **Fault Response Modelling** simulation, fracture distributions were predicted. The response of the predicted fractures to the current stress regime was then assessed using the **Stress Analysis** module to determine which fractures are likely to be critically stressed and enhancing fluid flow.

Fault Response simulation – Predicting fracture distributions around faults

Fault Response Modelling implements elastic dislocation theory to model movement along faults. This is achieved by displacing each of the triangles that make up a fault mesh surface along a slip vector (Comninou and Dundurs, 1975; Jeyakumaran et al. 1992). The slip vector can be defined for individual faults or calculated from a regional stress field.

In this case a regional stress field was used to calculate the slip vector. This stress field was determined by running multiple **Fault Response Modelling** simulations and varying the orientation and magnitude of the three principal stresses (Figure 2).

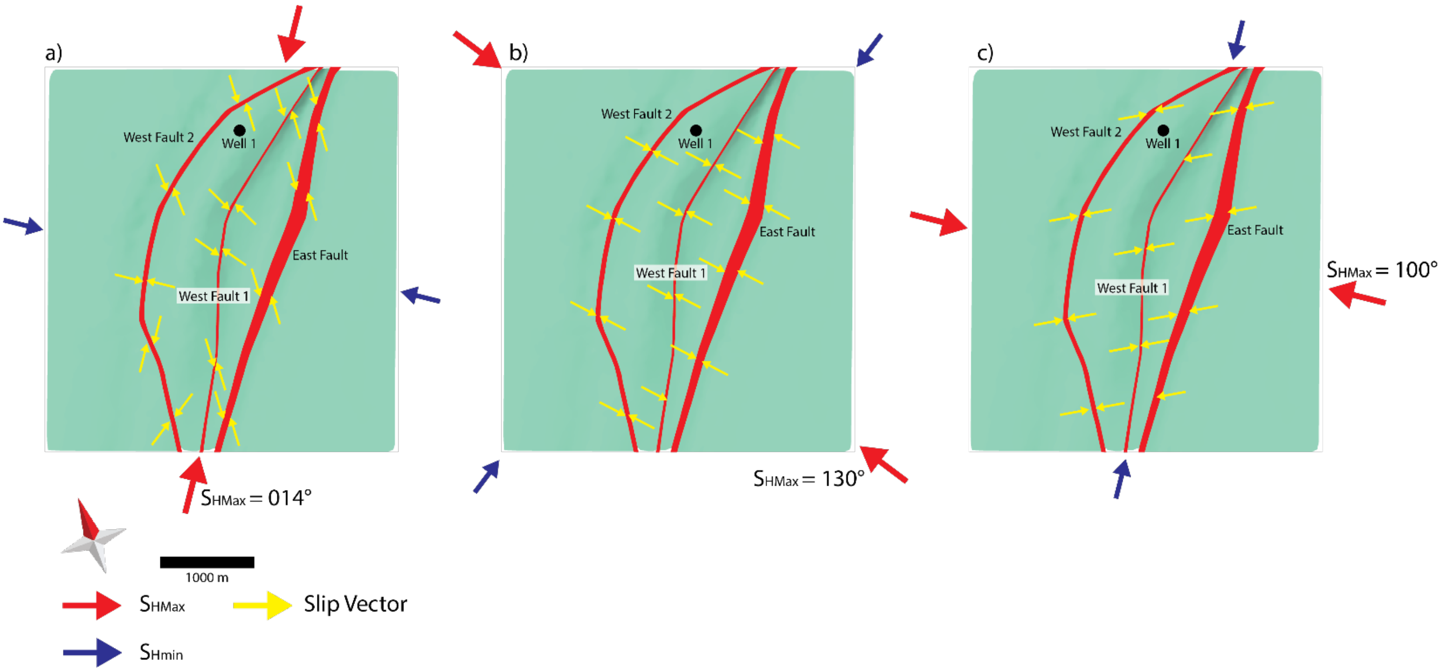

Figure 2: The Reservoir Surface shown with strike-slip stress regimes tested during this analysis, where; a) S_{Hmax} = 014° and S_{Hmin} = 104°; b) S_{Hmax} = 130° and S_{Hmin} = 040°; c) S_{Hmax} = 100° and S_{Hmin} = 010°; the calculated slip vectors are shown for each stress regime for each of the three faults.

The Z elevation displacement of the reservoir surface during the **Fault Response Modelling** simulation can be compared to observed elevation data, providing a validity check. If predicted Z elevation displacement matches the observed vertical displacement trends (Figure 3), the input stress regime is considered valid, increasing confidence in the **Fault Response Modelling** simulation.

Here it was determined that a strike-slip regime with S_{Hmax} = 014° and S_{Hmin} = 104° matched the observed elevation closest (Figure 3a).

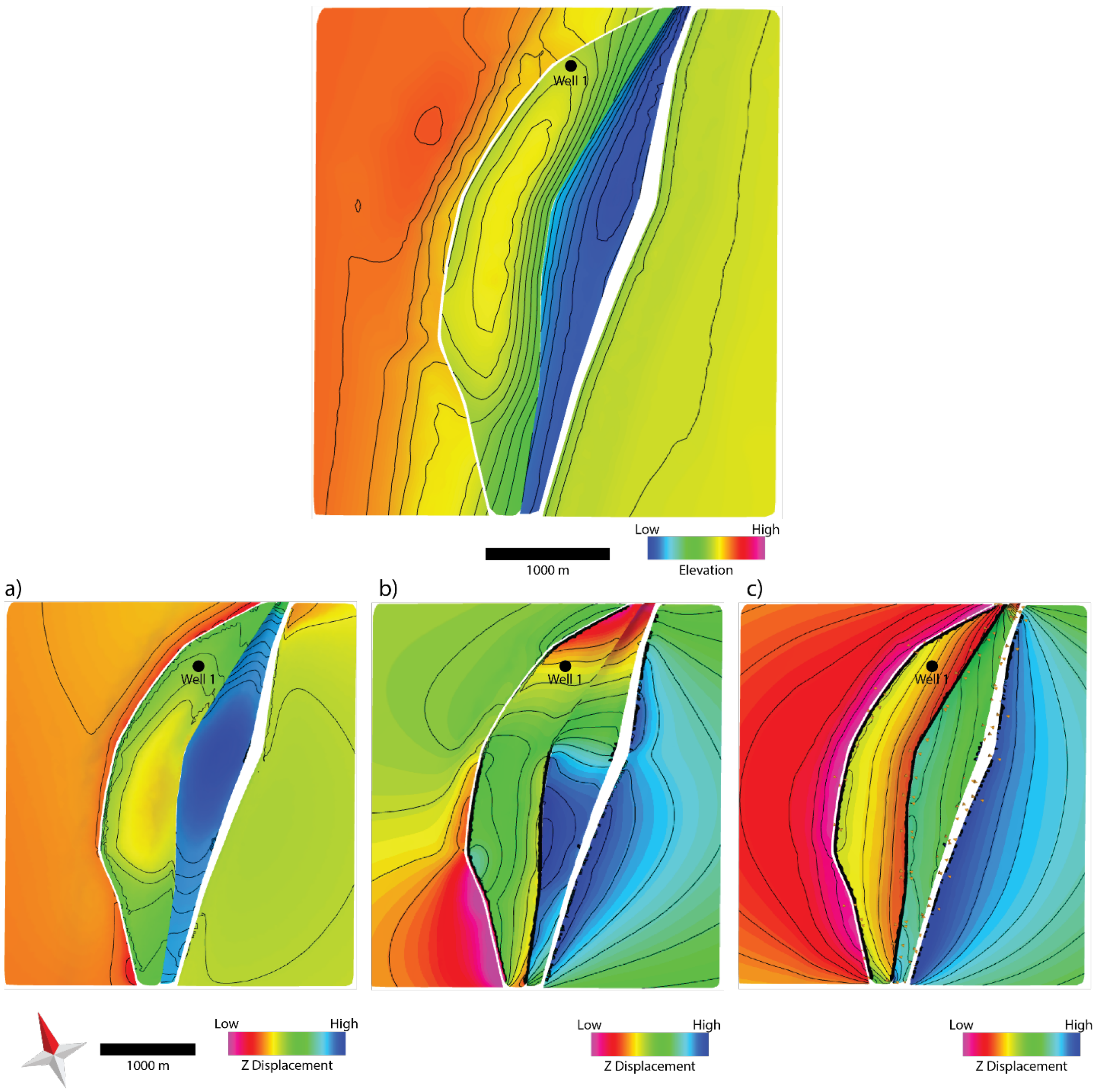

Figure 3: Top) The Reservoir horizon colour mapped for elevation.

Bottom) The Reservoir horizon colour mapped for Z displacement following a Fault Response Simulation using a strike-slip stress regime with a) S_{Hmax} = 014° and S_{Hmin} = 104°; b) S_{Hmax} = 130° and S_{Hmin} = 40°; c) S_{Hmax} = 100° and S_{Hmin} = 10°.

With the **Fault Response Modelling** approach validated, the strain calculated from the simulation for the reservoir surface can be used to predict fracture orientations and intensities (described in August and September 2017 MOVE Monthly Features). The orientation of one of the predicted shear planes closely matched the observed fracture orientation data recorded in Well 1 (well location in Figure 4). This gives confidence in populating the rest of the model with fractures formed by this mode of failure.

The magnitude of the axis of maximum stretching (ε_1) can be used to predict the relative intensity of fractures within the reservoir (Figure 4b). These values can then be scaled using the fracture data recorded from Well 1.

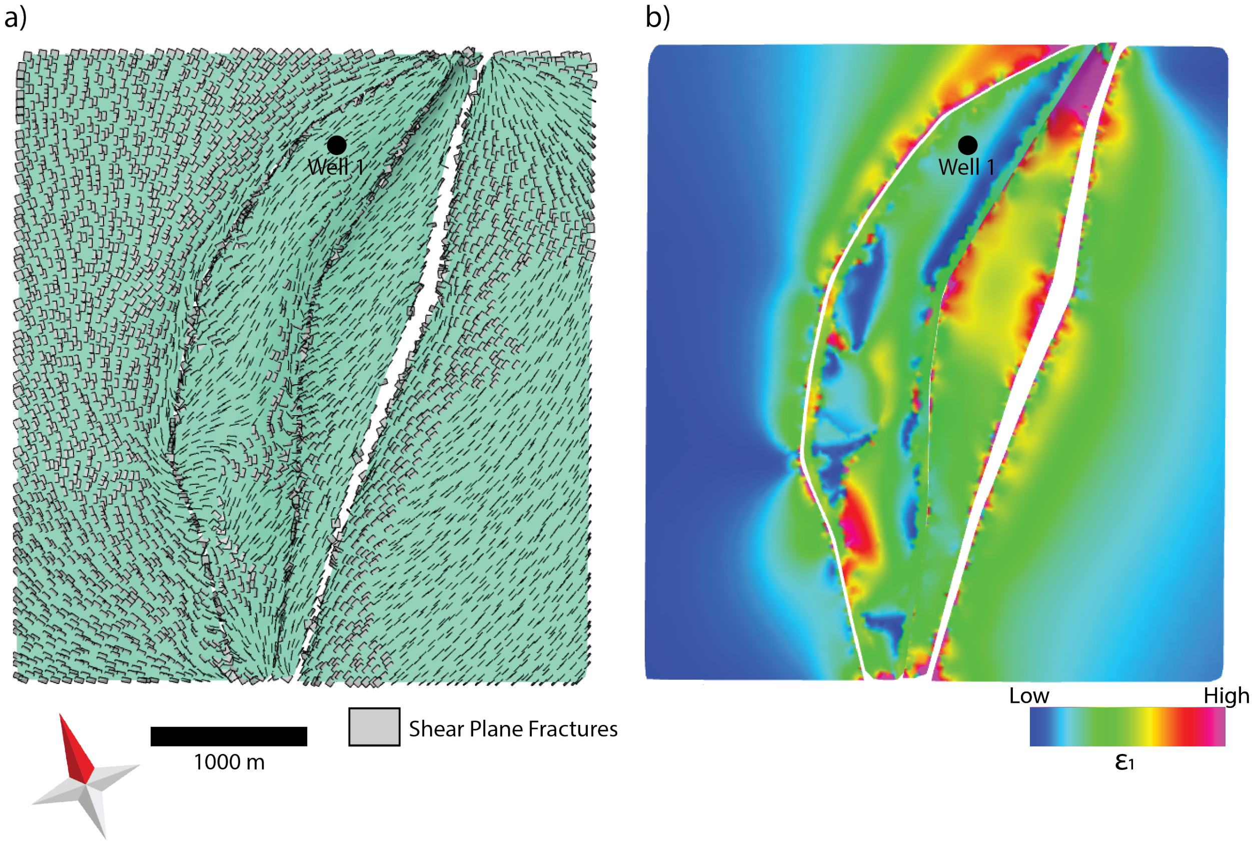

Figure 4: a) The Reservoir horizon overlain with the predicted shear plane fractures that have been validated against fractures observed in Well 1; b) The Reservoir horizon colour mapped for the magnitude of the axis of maximum stretching, ε_1; high values indicate a larger number of fractures.

Stress Analysis – Assessing the response of fractures to the present day stress field

Following the generation of fractures, the **Stress Analysis** module was used to calculate the Slip & Dilation tendency of the predicted fractures under the present day regional stress regime.

Slip Tendency is the likelihood for a plane of weakness to fail in shear mode; Dilation Tendency is the likelihood of a plane to fail in tensile mode. High values of Slip & Dilation tendency may be a proxy for fractures openness (aperture) and, if so, can be used as an input parameter for calculating fracture aperture and the fracture contribution to secondary porosity and permeability in the reservoir (Ferrill et al. 1999, Marks et al. 2018).

The results from the **Stress Analysis** indicate that areas in the South-West of the prospect fault block have large numbers of fractures (high ε_1 values (Figure 5a)) and these are more likely to be open and enhancing fluid flow (high Slip & Dilation tendency (Figure 5b)). These results would need to be validated using additional well data to further reduce uncertainty.

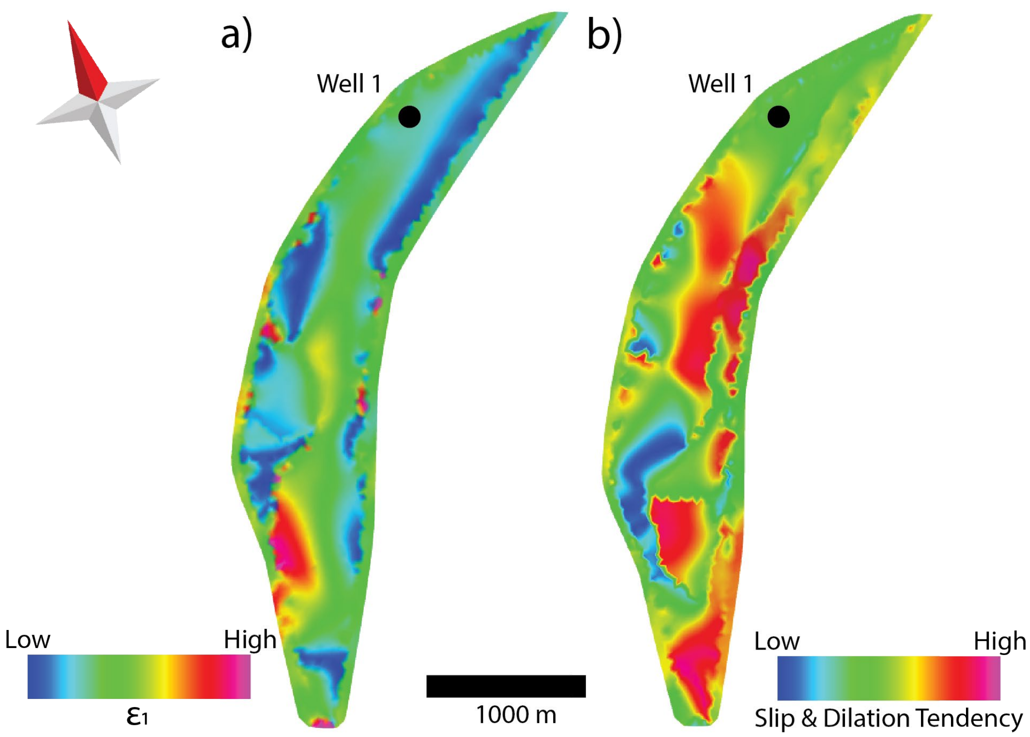

Figure 5: a) The Reservoir horizon in the Prospect fault block colour mapped for a) the magnitude of ε_1 - high values indicate a larger number of fractures; b) Slip & Dilation tendency - high values indicate fractures that are more likely to be open and enhancing fluid flow .

Well Planning – Identifying areas of high permeability and fracture intensity

For well planning, an area needed to be identified with a high fracture intensity (high strain (ε_1)) and with these fractures enhancing permeability (high Slip & Dilation tendency). The product of strain (ε_1) and Slip & Dilation Tendency was calculated for the reservoir horizon to create a proxy for a high number of open fractures. Based on the proxy results, an area in the South-West of the Prospect fault block was identified as a good location for drilling (Figure 6a).

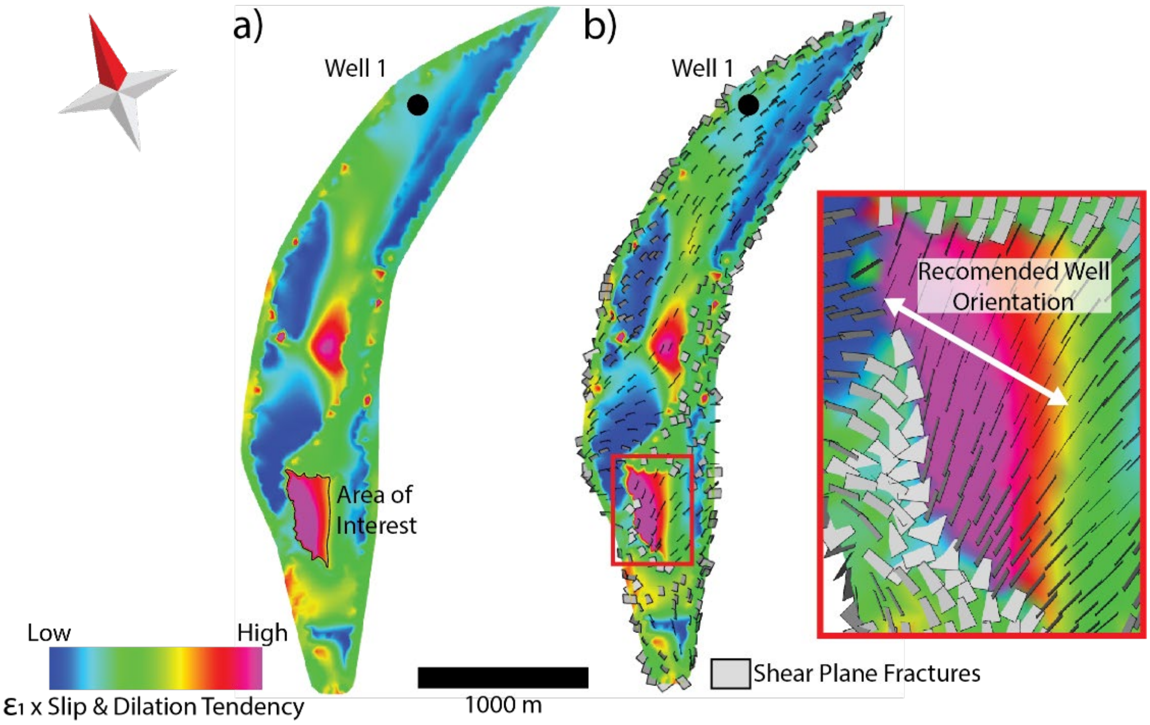

Figure 6: The reservoir horizon in the prospect fault block colour mapped for a) the product of ε_1 and Slip & Dilation Tendency - the area of interest for drilling is highlighted; b) the product of ε_1 and Slip & Dilation Tendency overlain by the predicted fracture set – the inset shows the area of interest with the

As stated above, the recommended well orientation needed to intersect as many open fractures as possible. To achieve this it must be planned to run perpendicular to the trend of fractures at its location. In the area of interest the fractures trend 210°–230° and therefore the recommended well orientation is along a bearing between 115° and 125° (Figure 6b).

move™ feature

Conclusions

Using a workflow such as the one described here allows for the strain associated with fault movements to be modelled using elastic dislocation theory with the **Fault Response Modelling** module. The calculated strain can then be used to predict fracture orientations with intensities derived from the strain magnitude, which can be scaled to observed fracture intensity information from wells.

Using the **Stress Analysis** module in MOVE, the stress state of these fractures can be quantitatively assessed, and the impact on fluid flow hypothesized. This information, when validated against known well data, can be used to guide well planning.

The next step following this analysis would be to model the impact that these predicted fractures have on production rates using a reservoir simulator such as REVEAL.

If you require any more information about MOVE or any part of the Petroleum Experts software suite, then please contact us by email: edinburgh@petex.com or call: +44 (0) 131 474 7030.

References

Comninou, M. and Dundurs, J., 1975. The angular dislocation in a half space. *Journal of Elasticity*. **5(3–4)**, 203–216.

Jeyakumaran, M., Rudnicki, J. and Keer, L., 1992. Modeling slip zones with triangular dislocation elements. *Bulletin of the Seismological Society of America*. **82(5)**, 2153–2169.

Ferrill, D. A., Winterle, J., Wittmeyer, G., Sims, D., Colton, S., Armstrong, A. and Morris, A. P. 1999. Stressed rock strains groundwater at Yucca Mountain, Nevada. *GSA Today,* **9(5)**, 1–8.

Marks, F., Valcarcel, M., Macaulay, E., Ramos, D., Garcia, A., Buitrago, A. and Mesa, J., 2018. Modelling Deformation and Stress to Assess Reservoir Potential in Fractured Carbonates: Cesar Rancheria Basin, Colombia. In: *Abstracts of 80th EAGE Conference and Exhibition 2018, Copenhagen, 11–14 June 2018*.

Move Monthly Feature: Fracture Modelling Part 1. August 2017. http://www.petex.com/media/2698/2017-aug_fracture-modelling-part-1.pdf

Move Monthly Feature: Fracture Modelling Part 2. September 2017. http://www.petex.com/media/2702/2017-sept_fracture-modelling-part-2.pdf

Move Monthly Feature: Fault Response Modelling Applications. October 2017. http://www.petex.com/media/2704/2017-oct_frm.pdf