

Uncertainty Modelling in Fault Analysis

The sealing capacity of a fault can be estimated by constraining the interaction between fault throw and the surrounding stratigraphy. Throw is calculated as the vertical offset of cut-off lines defined by the intersection of horizon surfaces with a fault. Stratigraphy can be derived from interpretation and conversion of petrophysical log data. In both cases, errors in interpretation will affect the accuracy of subsequent fault seal prediction. In Move2018, the **Uncertainty Modelling** tool within the **Fault Analysis** module can be used to constrain the probability of a particular outcome by stochastically modelling throw and stratigraphy scenarios (Figure 1). Uncertainty Modelling will be used in this feature to evaluate the likely sealing potential of an isolated normal fault, located offshore of Nova Scotia.

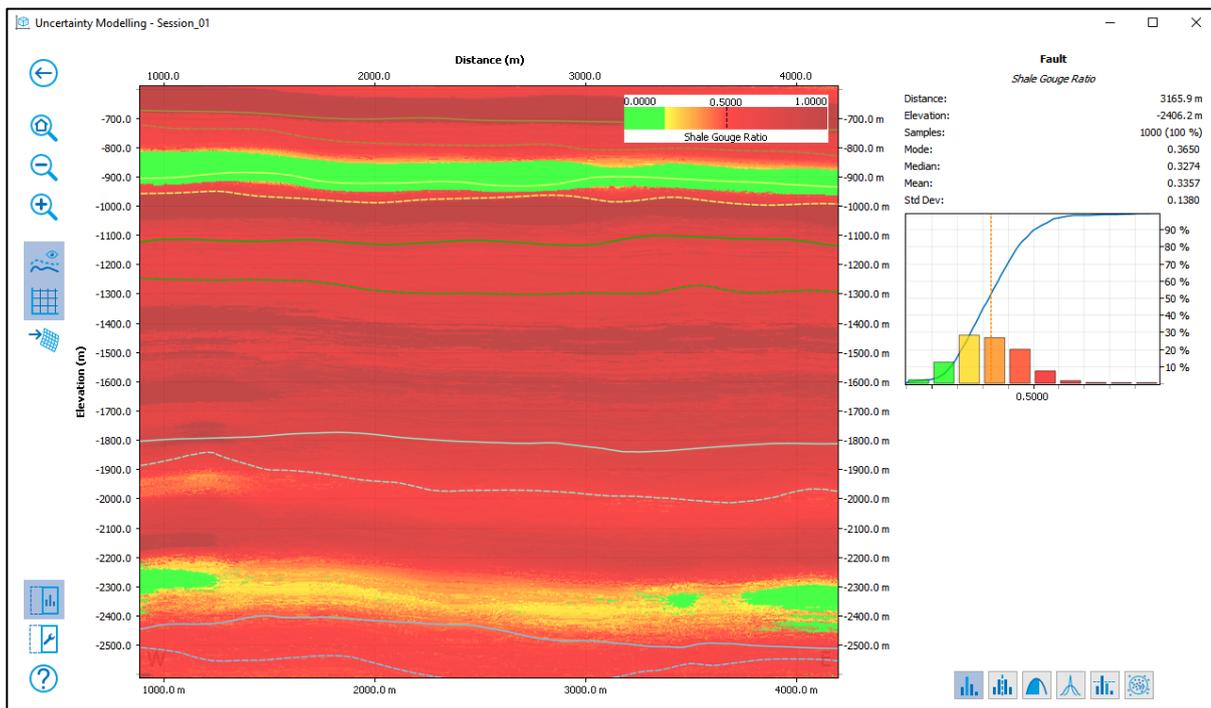


Figure 1: Mode Shale Gouge Ratio results for a normal fault interpreted offshore Nova Scotia, Canada.

Uncertainty Modelling theory

Errors in data interpretation and depth conversion can result in inaccuracies in fault seal prediction. Uncertainty Modelling stochastically simulates deviations in the vertical position of cut-off lines (Figure 2a) and the magnitudes of V_{shale} values (Figure 2b). Cut-off uncertainty is input into **Uncertainty Modelling** as one standard deviation; this value can be varied down the fault, thereby incorporating the effects of uncertainties associated with depth conversion and diminishing data resolution with depth. The uncertainty in V_{shale} values is also defined by specifying one standard deviation. For each model iteration, new cut-off elevations and V_{shale} values will be selected, with the combined results having a Gaussian distribution. The results of the stochastic modelling provide probability outcomes for lithological juxtaposition or fault seal proxies, including shale gouge ratio and shale smear factor.

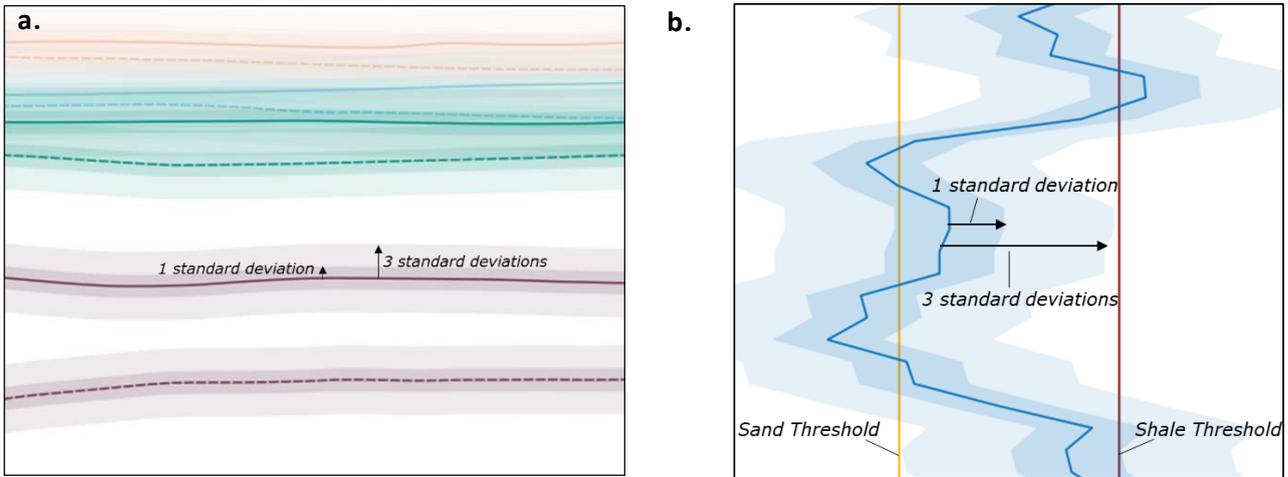


Figure 2. One and three standard deviations of a) cut-off line elevation and b) Vshale value.

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 Scotian Basin developed during Triassic rifting of the North American and African plates (Wade *et al.*, 1995). The studied fault zone is interpreted from the Penobscot seismic cube and comprises two southerly-dipping normal faults (Campbell *et al.*, 2015). The interpreted faults accommodate up to 200 m normal offset on Jurassic to Cenozoic horizons, and display elliptical throw distributions, typical of isolated normal faults (Figure 3). The near-fault stratigraphy is defined by a Vshale log on well L30, situated in the hanging wall of Fault 1 (Figure 3b). Oil shows were found in a four-way closure in the Missisauga Formation within the hanging wall of Fault 1. In the following workflow, the sealing risk for a second trap, located in the footwall of Fault 1, is evaluated (Figure 3 and 4).

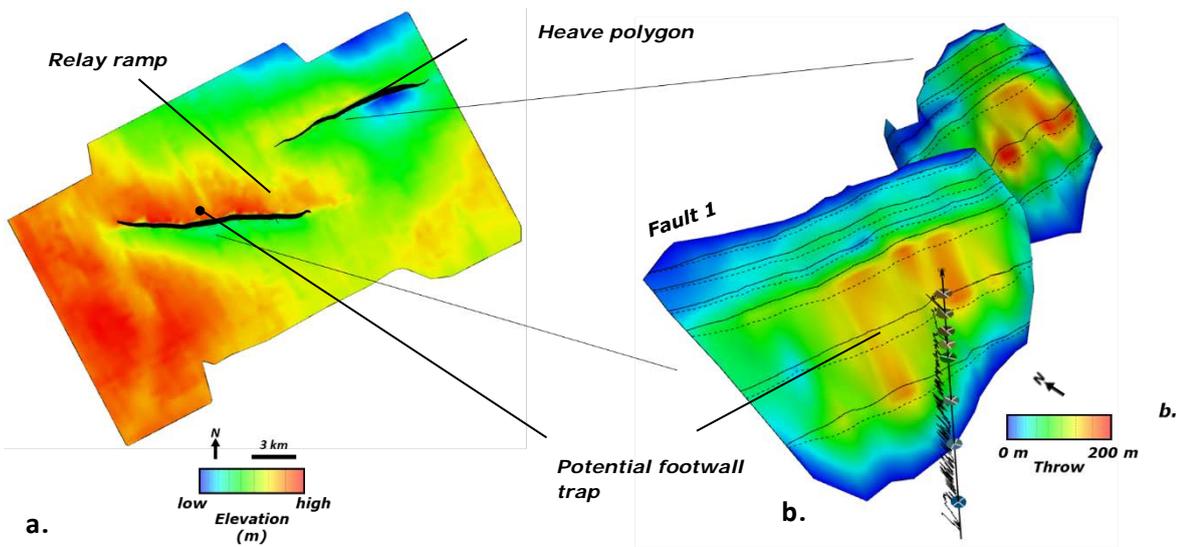


Figure 3. a) Map showing Missisauga Formation horizon colour mapped for elevation and fault heave polygons. b) Distribution of present-day throw on fault surfaces and location of potential footwall trap within the Missisauga Formation.

Creating cut-off lines and assigning wells

Prior to implementing uncertainty analysis, hanging wall and footwall cut-off lines are created using the Fault Analysis tool (Figure 3b).

1. Open the **Fault Analysis** module from the Modules tab.
2. Collect faults, horizons and wells into the toolbox.
3. On the **Horizons** sheet, click **Create Cut-Off Lines**.
4. Click on the **Wells** sheets and assign a Vshale or gamma log, or logs, to faults.

Calculating Juxtaposition and Shale Gouge Ratio from interpreted data

Across-fault lithological juxtaposition (Figure 4a) and Shale Gouge Ratio (SGR) (Figure 4b) distributions can be calculated from interpreted cut-off lines and the conversion of gamma logs to Vshale.

1. In Fault Analysis, click on the **Seal Analysis** sheet.
2. Under **Lithological Juxtaposition**, click **Create Lithological Juxtaposition**.
3. Under **Seal Proxies**, choose **Shale Gouge Ratio** and click **Create Seal Proxy**.

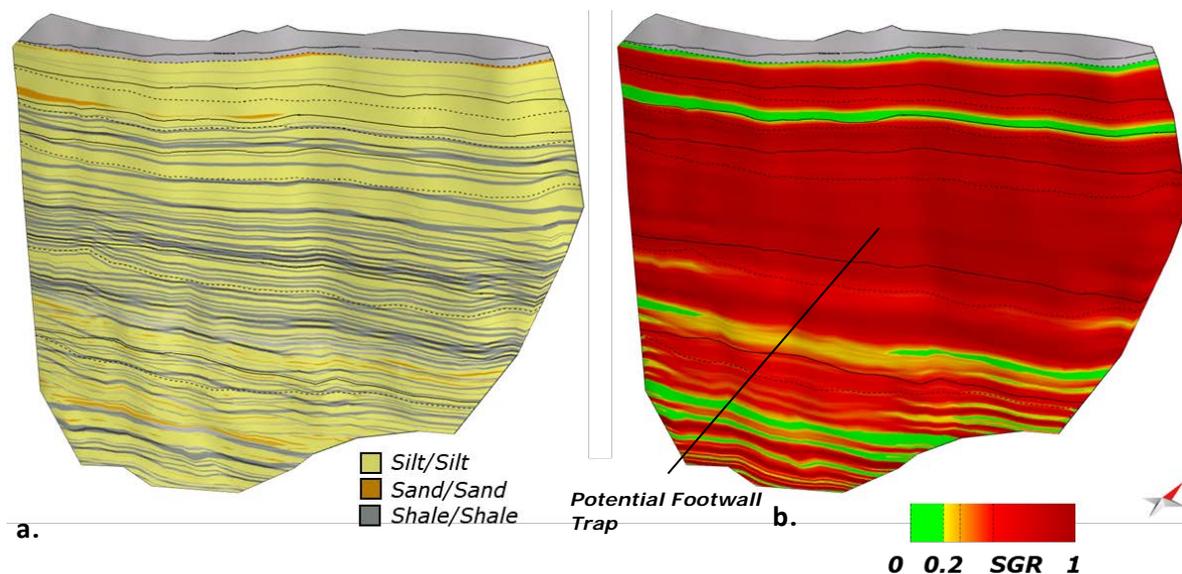


Figure 4. Fault 1 colour mapped for a) Lithological juxtaposition and b) Shale Gouge Ratio derived interpreted cut-off lines and converted gamma log.

Results

Fault seal analysis suggests that there is no sand/sand juxtapositions in the trapped reservoir interval. Moreover, the SGR is calculated to be > 0.2 , a value below which, a fault is expected to leak (Childs *et al.*, 1997). In the following sections the confidence of these results will be investigated.

Setting up and running a Lithological Juxtaposition Uncertainty Model

The **Uncertainty Modelling** tool is found at the bottom of the **Seal Analysis** sheet along with **Fault History** and **Fault Triangle** plots. The tool requires a series of user-defined inputs.

1. On the Seal Analysis sheet, click on **Uncertainty Modelling**.
2. Choose **Fault 1**.
3. Under **Property**, select **Lithological Juxtaposition**.
4. Define **Cut-Off Deviation** as **25 m** to **50 m**.
5. Define **Vshale Deviation** as **0.2**.
6. Under **Visualization**, set the **Raster Size** to **1920x1080**.

Juxtaposition uncertainty will only be calculated for the centre of the fault. A calculation area can be defined visually by holding **Ctrl** and drawing a box in the **Preview** window. Figure 5 shows the toolbox set up for uncertainty modelling.

7. Click the **Play** button in the bottom right-hand corner of the window to run the simulation.

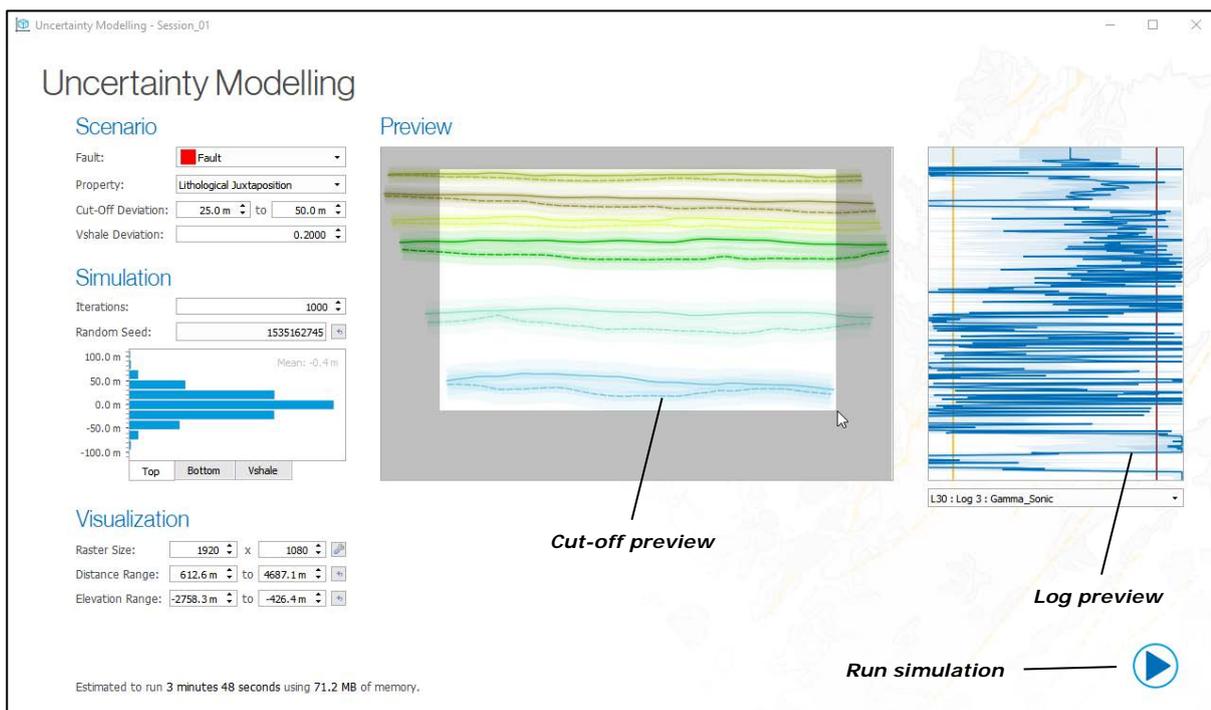


Figure 5. Uncertainty Modelling set up for Lithological Juxtaposition analysis.

Results

Following completion of the simulation, the mode juxtaposition results will be displayed. This shows the most likely outcome at each point on the fault surface. **Clicking** on any point on the fault will plot the percentage frequency for each juxtaposition outcome to the left of the main window. Alternatively, to interrogate the juxtaposition outcome of an area, a polygon can be drawn by holding **shift** and **loop** selecting the required data (Figure 6).

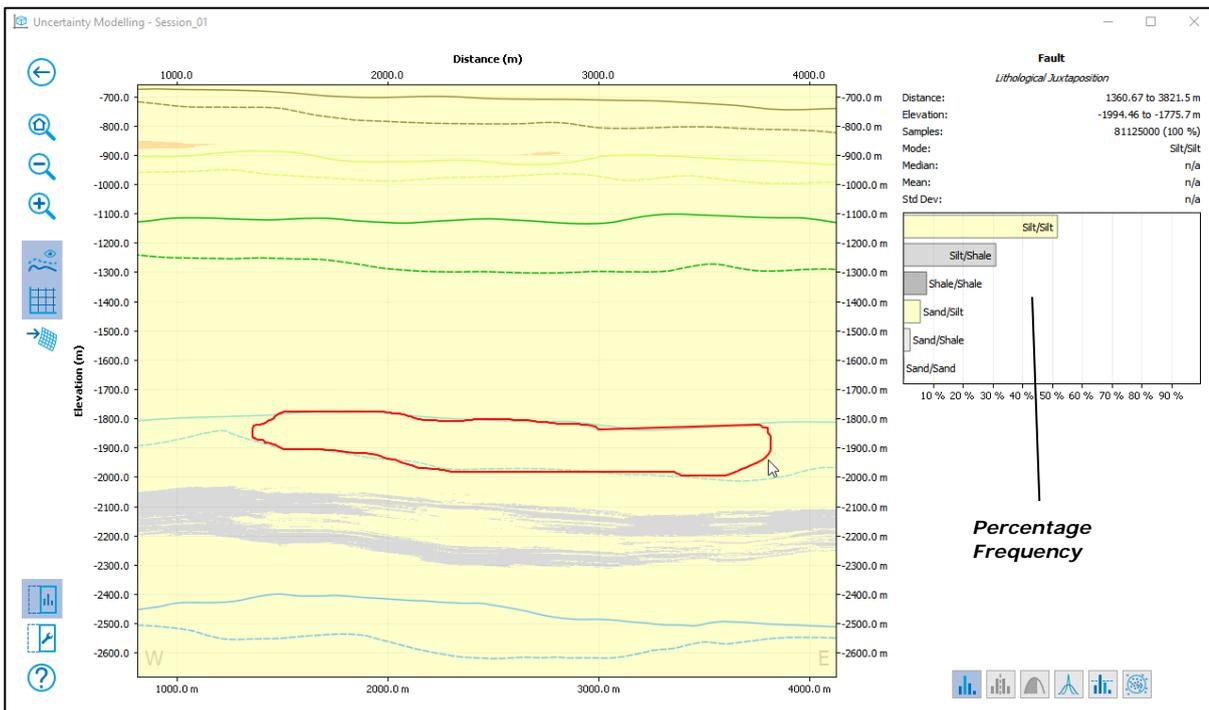


Figure 6. Mode outcome for Lithological Juxtaposition for Fault 1. The results show that a Silt/Silt juxtaposition is most likely.

The Uncertainty Model indicates that a Silt/Silt juxtaposition is the most likely outcome within the user-defined polygon. This suggests that a Sand/Sand juxtaposition in the Missisauga Formation is unlikely (<1%), reducing the risk of across-fault leakage within the potential trap.

Fault seal is supported by visualizing the Outcome Probability, which shows likelihood of an outcome normalised between 0.0 and 1.0. Analysis of the Outcome Probability results indicates that there is < 1% chance of a Sand/Sand juxtaposition in the selected area. This contrasts to the top and bottom of the fault, where probability of a Sand/Sand juxtaposition increases (Figure 7).

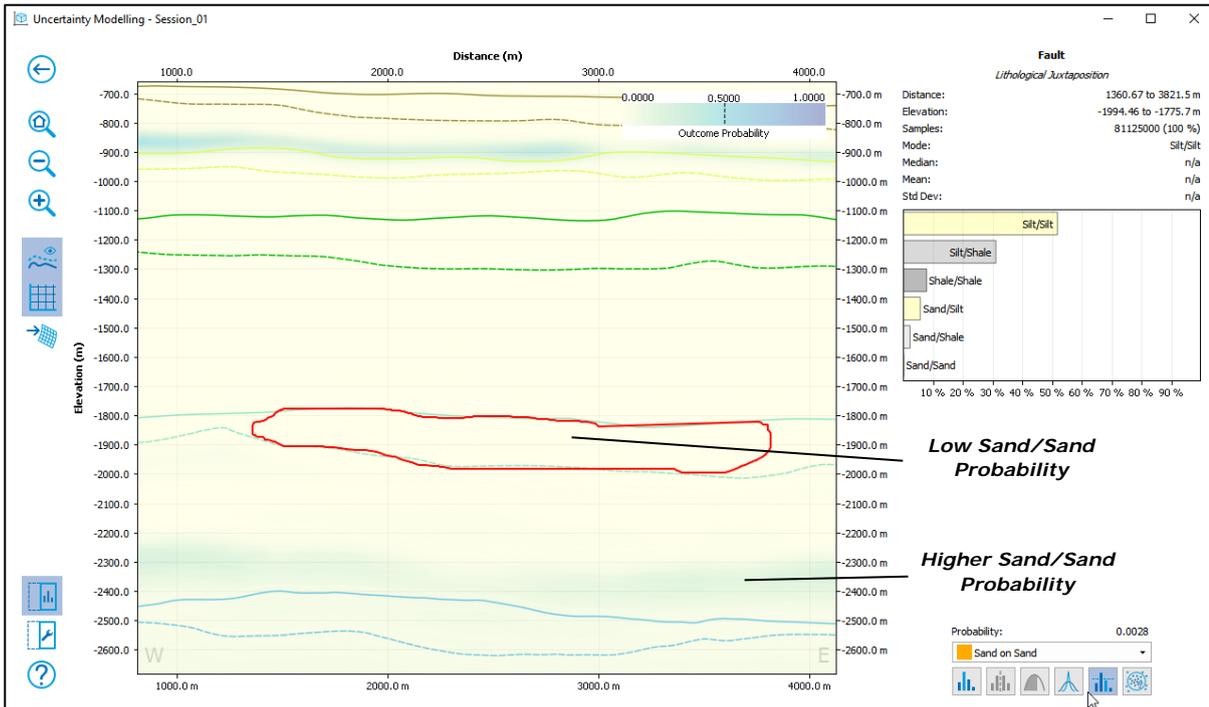


Figure 7. Outcome Probability for Sand/Sand juxtaposition for Fault 1. The results show that the probability of a Sand/Sand juxtaposition is less than 1%.

Setting up and running a Shale Gouge Ratio Uncertainty model

The **Uncertainty Modelling** can be re-run to calculate **Shale Gouge Ratio (SGR)**.

1. Click back at the top-left of the window to return **Uncertainty Modelling** control panel.
2. Choose **Fault 1**.
3. Under **Property**, chose **Shale Gouge Ratio**.
4. Define **Cut-Off Deviation** as **25 m to 50 m**.
5. Define **Vshale Deviation** as **0.2**.
6. Under **Visualization** set the **Raster Size** to **1920x1080**.
7. **Right-click** on the preview window to reset the calculation area.

Results

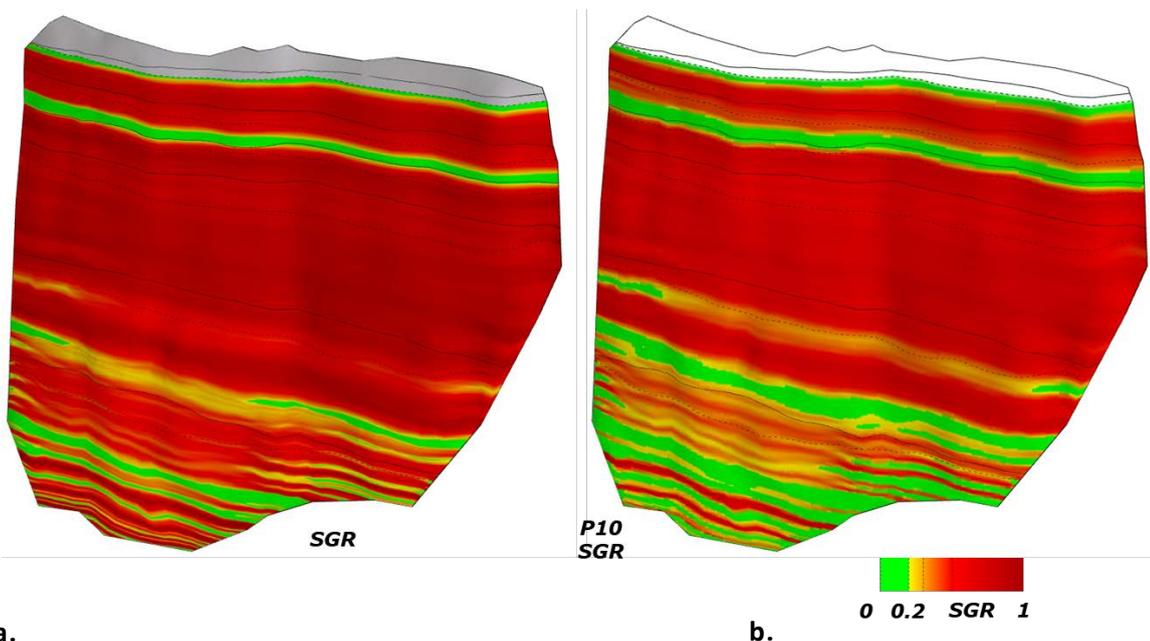
Whilst across-fault juxtaposition comprises discrete outcomes, SGR ranges continuously from 0.0 to 1.0. Consequently, percentile outcomes can be visualized, allowing worst-case fault seal scenarios to be interrogated. The **P10** scenario for Fault 1 is visualized in Figure 8, this indicates that there is 90% confidence that Missisauga Formation will be sealed in the footwall of the fault.



Figure 8. P10 SGR result for Fault 1 showing SGR of > 0.2 in the trap area.

Exporting results to fault surface

Uncertainty modelling results can be exported to the 3D fault surface by selecting **Transfer Data to Fault** on the left of the Uncertainty Modelling window. This allows visual comparison of uncertainty outcomes with previously calculated colour maps (Figure 9). Moreover, the probability results are saved as vertex attributes on the fault.



a.

b.

Figure 9. Fault 1 showing a) SGR calculated from interpreted model and b) the P10 Uncertainty Modelling results transferred to the 3D fault surface.

Summary

Uncertainty Modelling allows evaluation of the risk of fault seal by modelling lithological juxtaposition or seal proxy scenarios. In this feature, this workflow demonstrated that a normal fault located offshore Canada, has < 1% chance of containing a Sand/Sand juxtaposition and 90% chance of accomodating a SGR of > 0.2 at a key trapping interval. The results support the initial fault seal analysis and indicates that there is a low risk of across-fault leakage from the footwall reservoir horizons.

References

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

Campbell, T.J., Richards, F.B., Silva, R.L., Wach, G., Eliuk, L., 2015. Interpretation of the Penobscot 3d seismic volume using constrained sparse spike inversion, sable sub-basin, offshore nova scotia. *Marine and Petroleum Geology* 68, 73–93.

Childs, C., Walsh, J.J. and Watterson, J., 1997. Complexity in fault zone structure and implications for fault seal prediction. *Norwegian Petroleum Society Special Publications*, 7, 61-72.

Wade, J.A., Williams, G.L., MacLean, B.C., 1995. Mesozoic and Cenozoic stratigraphy, eastern Scotian Shelf: new interpretations. *Canadian Journal of Earth Sciences* 32, 1462–1473.

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