Fault History analysis in Move

The new **Fault History** plot in Move™ provides a method to conduct a quick-look analysis of the evolution of faults through time. By restoring the vertical displacement of a fault (throw) and physical compaction, the evolution of the throw distributions, across-fault juxtapositions and sealing proxies can be rapidly analysed ahead of a complete 3D restoration. This Move feature demonstrates how to set up the parameters and display settings in the Fault History window and how to easily quantify key aspects of the structural history and sealing evolution of a fault.

Fault History diagrams are generated by projecting the fault surface onto a vertical plane parallel to the average fault strike (Rippon 1985, Barnett *et al*. 1987, Walsh and Watterson, 1990). The Fault History plot shown in Figure 1 displays the vertical offset between the projected hanging wall and footwall cut-off lines (solid lines and dashed lines, respectively, highlighted by blue labels). Present-day juxtaposition and seal distributions are colour mapped onto the plot. To the right of the main plot, the **Shale Gouge Ratio** curve for a specific vertical section is also shown.
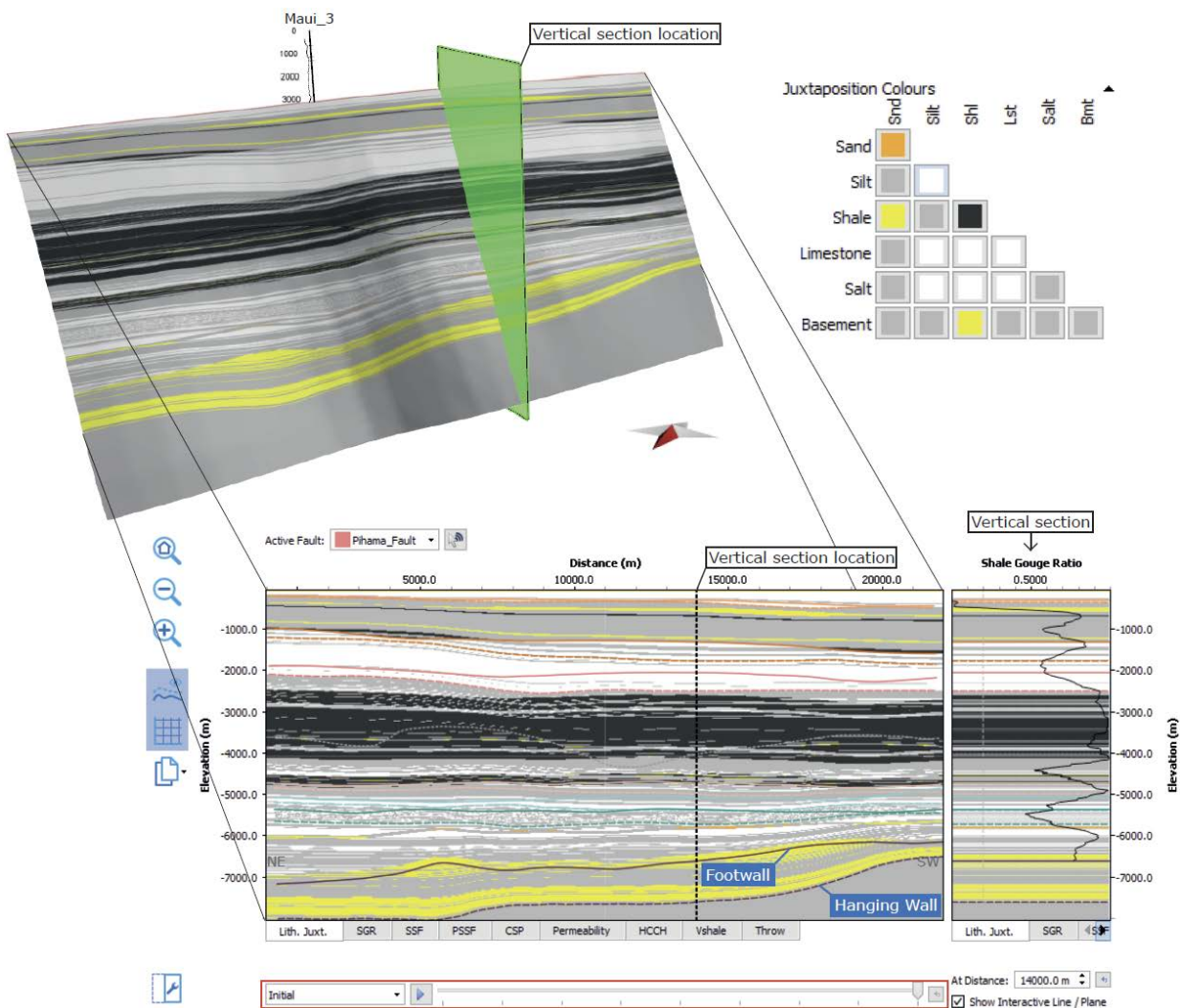

Figure 1: Projection of a fault surface in Move onto the Fault History diagram. Lithology is constrained by the gamma log data of the well Maui_3. Juxtaposition Colours can be defined by the user within the Fault History diagram. A green interactive plane in the 3D View and vertical dashed line in the fault plot indicate the location of the vertical section, which shows the Shale Gouge Ratio curve. The red rectangle at the base of the plot highlights the horizon list and restoration slider.

Using the **horizon list** or the **restoration slider** highlighted in red at the bottom of the main plot in Figure 1, throw distributions, across-fault juxtapositions and sealing proxies can be calculated for different time-steps during the evolution of a fault.

Figure 2 illustrates the throw restoration method used in the **Fault History** plot in Move. The rectangles in the top of the figure (a, b) display simplified Fault History plots including the footwall and hanging wall cut-off lines of two horizons. The sketches in the lower portion of the figure (c, d) correspond to an oblique 3D view of the faults and horizons, which were projected onto the top plots. From the present-day time-step (Fig. 2a, c), throw is restored by vertically joining the uppermost hanging wall cut-off (Horizon 1 hanging wall in Fig. 2) to a static footwall cut-off (Horizon 1 footwall in Fig. 2). Underlying hanging wall cut-offs (Horizon 2 hanging wall in Fig. 2) move vertically relative to the restoration of the uppermost cut-off. Red arrows in Figure 2 represent the amount of throw restored. The results of the vertical displacement restoration are shown in Figure 2b and 2d.
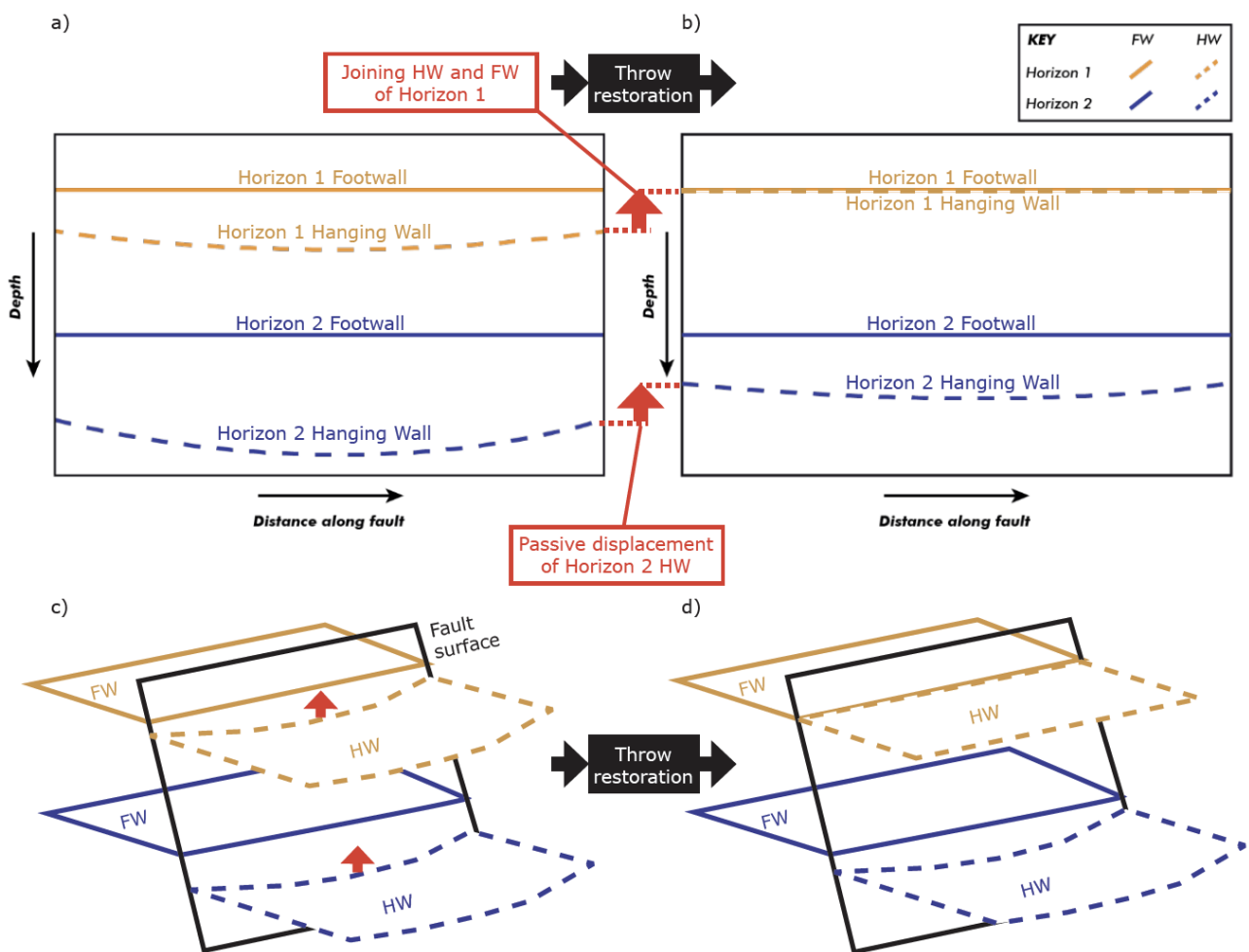

Figure 2. Throw restoration in Fault History. Top portion (a, b) represent the projection of the fault surface shown in the bottom 3D models (c, d). a, c) Initial displacement distribution. b, d) Displacement of Horizon 1 hanging wall restored. The Horizon 1 hanging wall cut-off (orange dashed line) is restored to a static Horizon 1 footwall cut-off (orange solid line). Horizon 2 hanging wall cut-off (blue dashed line) is passively displaced with respect to Horizon 1 hanging wall. Red arrows represent the amount of throw restored.

Removal of the effects of physical compaction can be optionally performed by using the exponential curve defined in Sclater and Christie (1980).

$$f = f_0 \, (e^{-cy})$$

This feature allows an immediate graphic analysis of the fault properties at each stage of the structural evolution, providing a valuable calibration of the fault behaviour through time, ahead of a complete 3D restoration.

Using Fault History to analyse palaeo-sealing capacity and fault evolution

An example from the Taranaki Basin, located offshore New Zealand, will be used to illustrate the application of the Fault History diagram. The Taranaki Basin initially formed during Late Cretaceous – Paleocene NW-SE extension, related to the opening of the Tasman Sea. Inversion occurred during the Oligocene - Miocene, resulting in reverse reactivation of pre-existing normal faults. Since the Miocene, both Cretaceous normal faults and Oligo-Miocene faults have been further reactivated in a normal sense (Giba *et al.*, 2012; Reilly *et al.*, 2015).

The **Fault History** plot will be used to assess the sealing conditions of the Pihama Fault, which developed on the SE margin of the Taranaki Basin. The palaeo-sealing analysis will be conducted at the time of reservoir charging (5.5 Ma). The stratigraphy on either side of the fault is constrained by two gamma logs from wells located in the footwall and the hanging wall. The workflow includes the following steps:

1. Ensure the **Stratigraphy** has been correctly defined, by clicking on Stratigraphy on the **Data & Analysis** tab (Fig. 3).
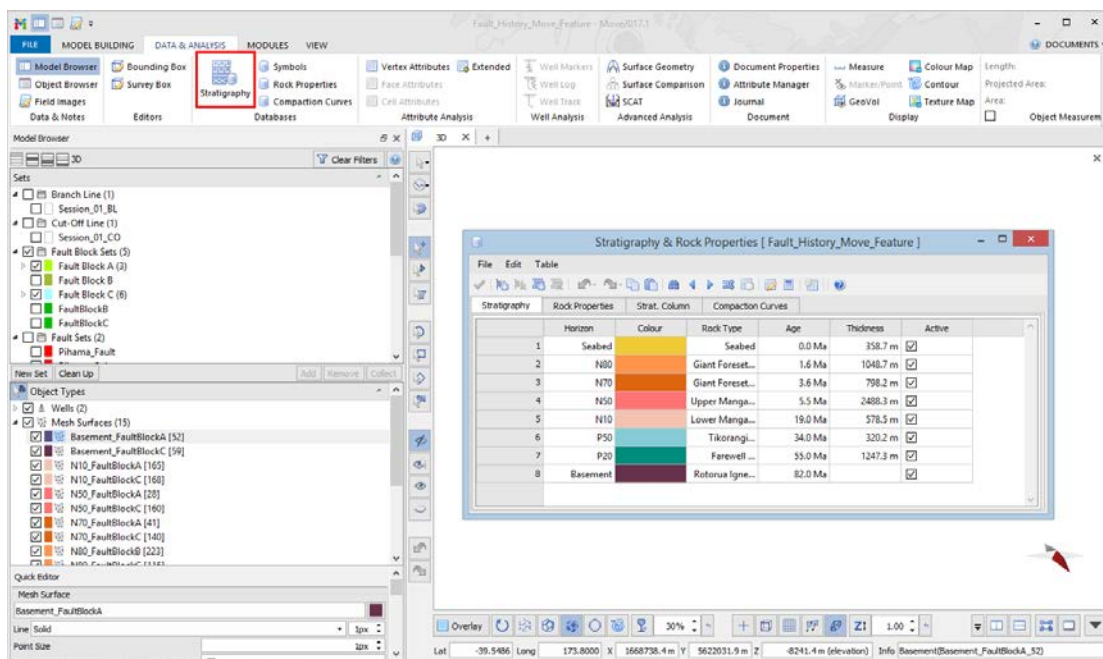

Figure 3. Stratigraphy & Rock Properties window in Move, accessible from the Data & Analysis tab.

2. Select all surfaces and wells in the model and click on **Fault Analysis**, located on the **Modules** tab (Fig. 4).
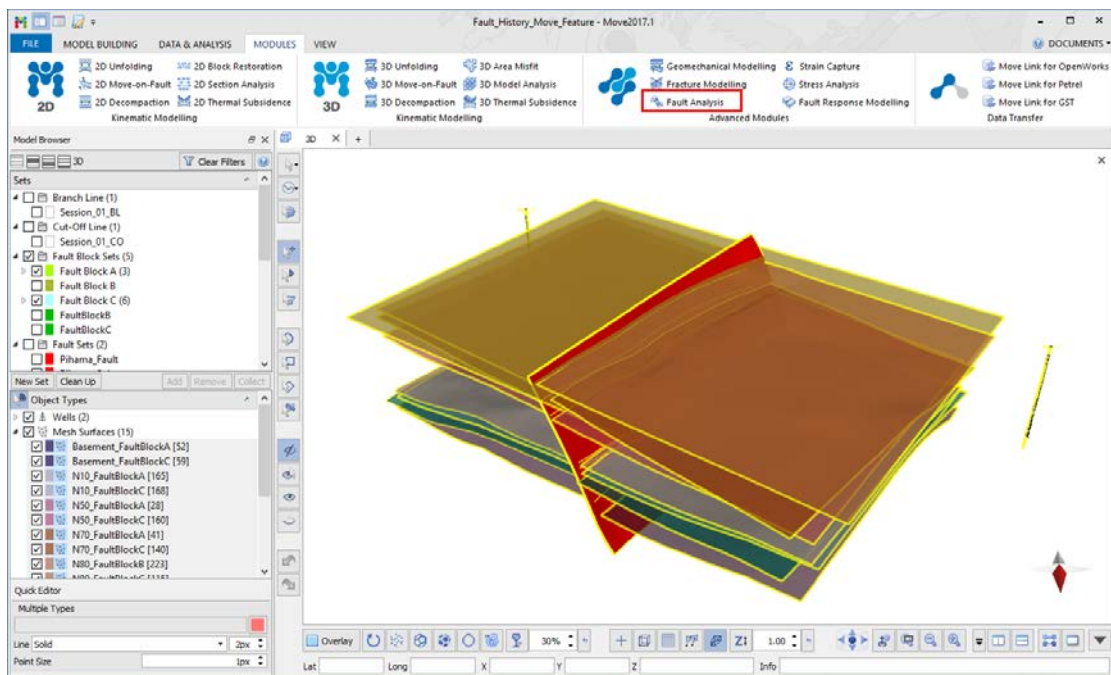

Figure 4. All horizon surfaces, fault surfaces and wells in the 3D model are selected (highlighted yellow). Red rectangle on the Modules tab highlights the Fault Analysis button.

3. Use the **Horizons** sheet to create **Cut-off lines** and define the **Top Horizon** (Fig. 5). To activate the Define Top Horizon option, do not collect the top horizon into the toolbox or highlight the top horizon in the list (in the toolbox) and click Remove.
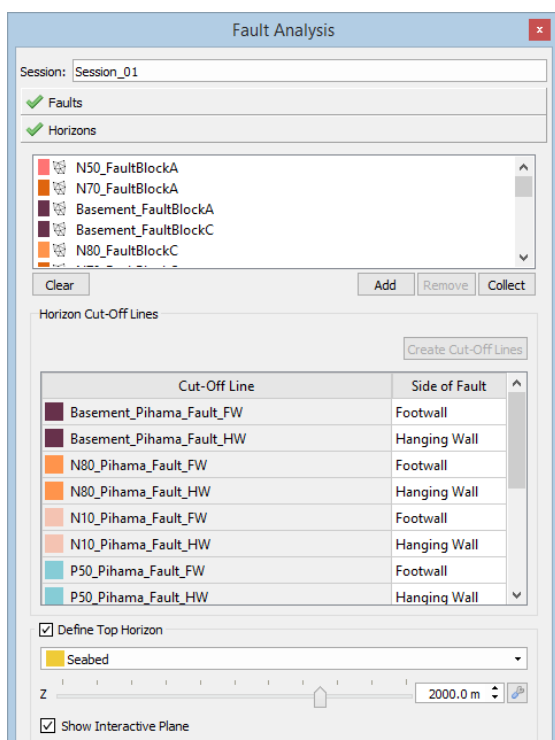

Figure 5. Cut-off lines created and Top Horizon defined on the Horizons sheet.

4. On the **Wells** sheet, make sure that wells are correctly assigned to the **Footwall** and the **Hanging Wall** (Fig. 6). Set up parameters for each gamma log to convert it to **Vshale** using a Vshale correction curve.
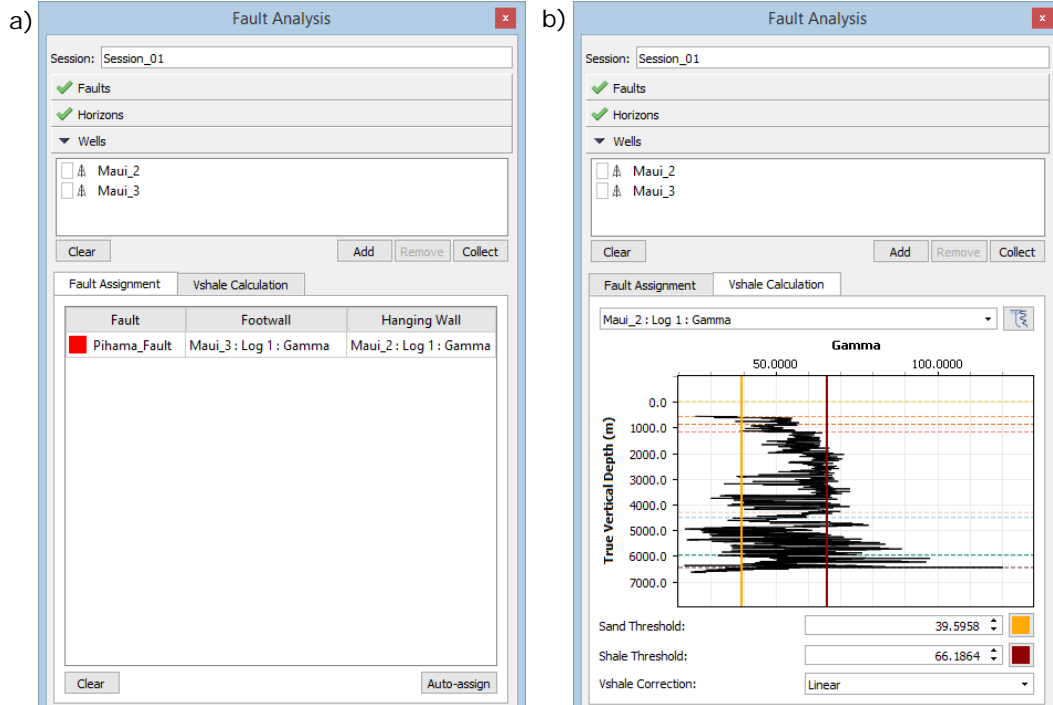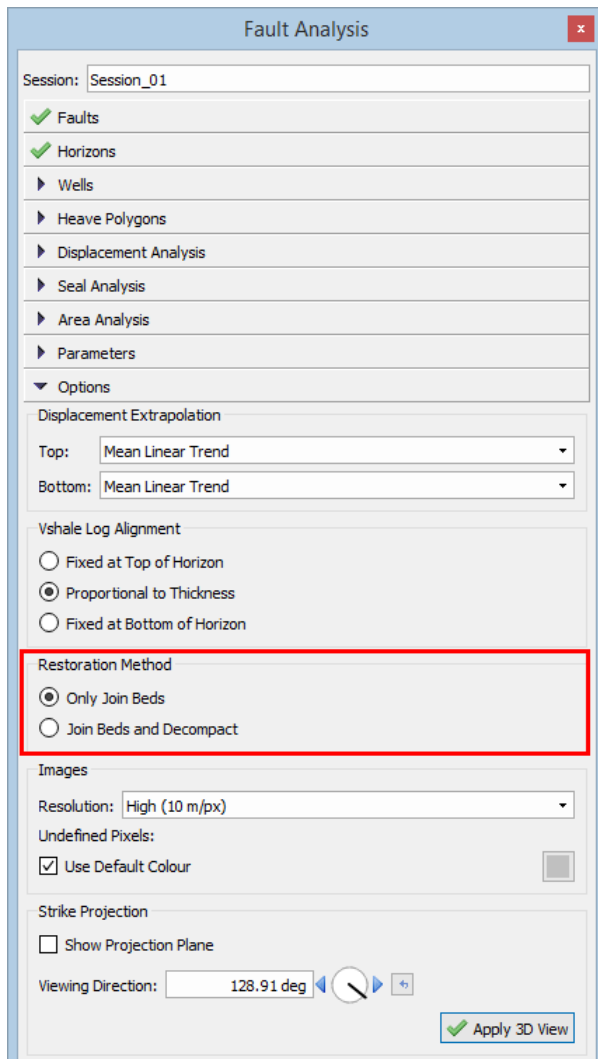

Figure 6. Fault assignment (a) and Vshale Calculation (b) on the Wells sheet.

5. Select the **Restoration Method** on the **Options** sheet (Fig. 7).

Figure 7. Restoration Methods on the Options sheet.

6. Click on **Fault History** at the bottom of the **Seal Analysis** sheet (Fig. 8) to open the Fault History diagram window.
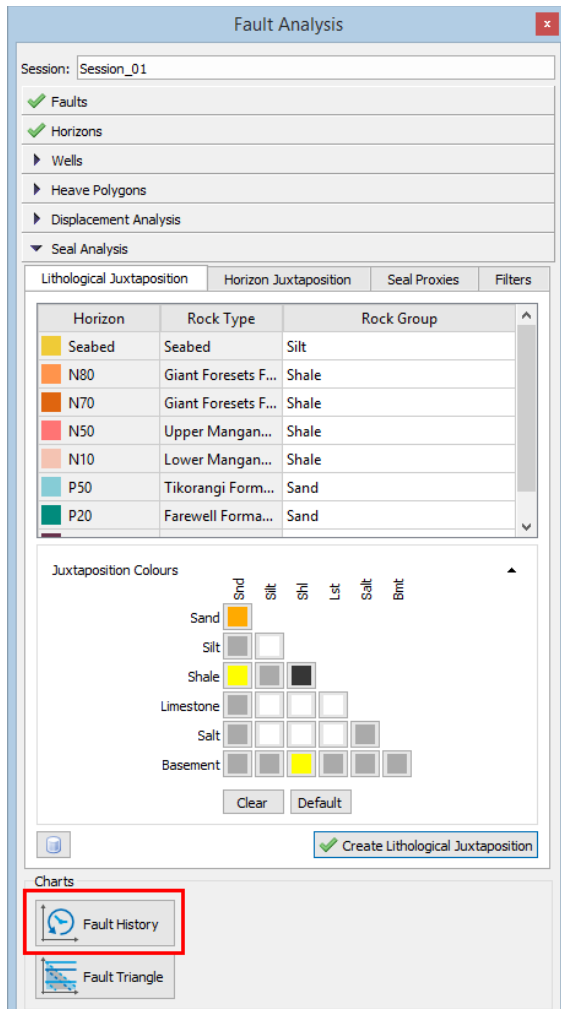

Figure 8. Fault History button (highlighted by red rectangle) on the Seal Analysis sheet.

Analysing palaeo-sealing capacity

Reservoir charging in the Taranaki Basin is estimated to have occurred during the Miocene (Thrasher 1990) which, in the Pihama Fault area coincides with the deposition of the Upper Manganui Formation (5.5 Ma). To display the results of the fault throw distribution analysis at 5.5 Ma, use the **horizon list** or the **restoration slider** at the bottom of the Fault History window (Fig. 9). A number of properties can be visualized in the background of both the main fault plot and the cross-section plot. In Figure 9, **Shale Gouge Ratio** is displayed in the strike-projected fault and **Permeability** is shown on the cross-section plot at a lateral distance of 11.8 km from the north-east edge of the fault plane.
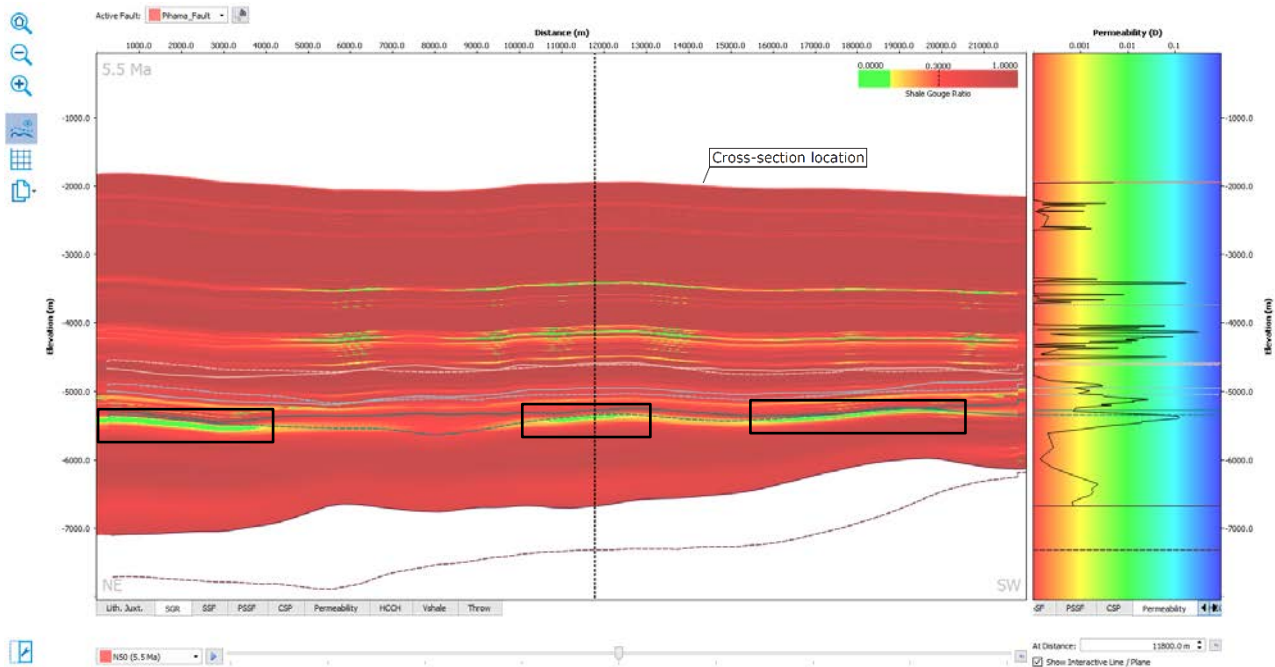

Figure 9. Fault History diagram for the Pihama Fault at 5.5 Ma. Shale Gouge Ratio is displayed in the strike-projected fault plot (left). Black rectangles highlight the three main areas where Shale Gouge Ratio values are < 0.2, and consequently across-fault flow is likely to occur. Permeability is shown in the vertical section plot at distance 11.8 km from the NE edge of the fault. If Show Interactive Line / Plane is toggled on, a vertical dashed line in the fault plot indicates the location of the vertical section.

It can be seen from the **Fault History** diagram that although the Pihama Fault was predominately sealing 5.5 Ma ago, across-fault flow was potentially active in at least three areas on the fault surface. Those areas are displayed in green, where the calculated **Shale Gouge Ratio** values are < 0.2. The left-hand and right-hand areas are ~4000 m long and ~100 m in thickness, and a smaller area close to the centre of the plot is ~2000 m long and ~100 m in thickness.

A **Juxtaposition Filter** can be used to identify Silt on Silt juxtapositions on the fault plane. This is activated by opening the **Display Settings** and clicking on the **Toolbox** button on the bottom left of the Fault History window. Figure 10 shows an example of the application of the juxtaposition filter to identify silt on silt contacts in the Farewell Formation. Other **Display Settings** can be configured, such as **Chart Visibility**, **Background Transparency**, **History Animation** and **Juxtaposition Colours**.
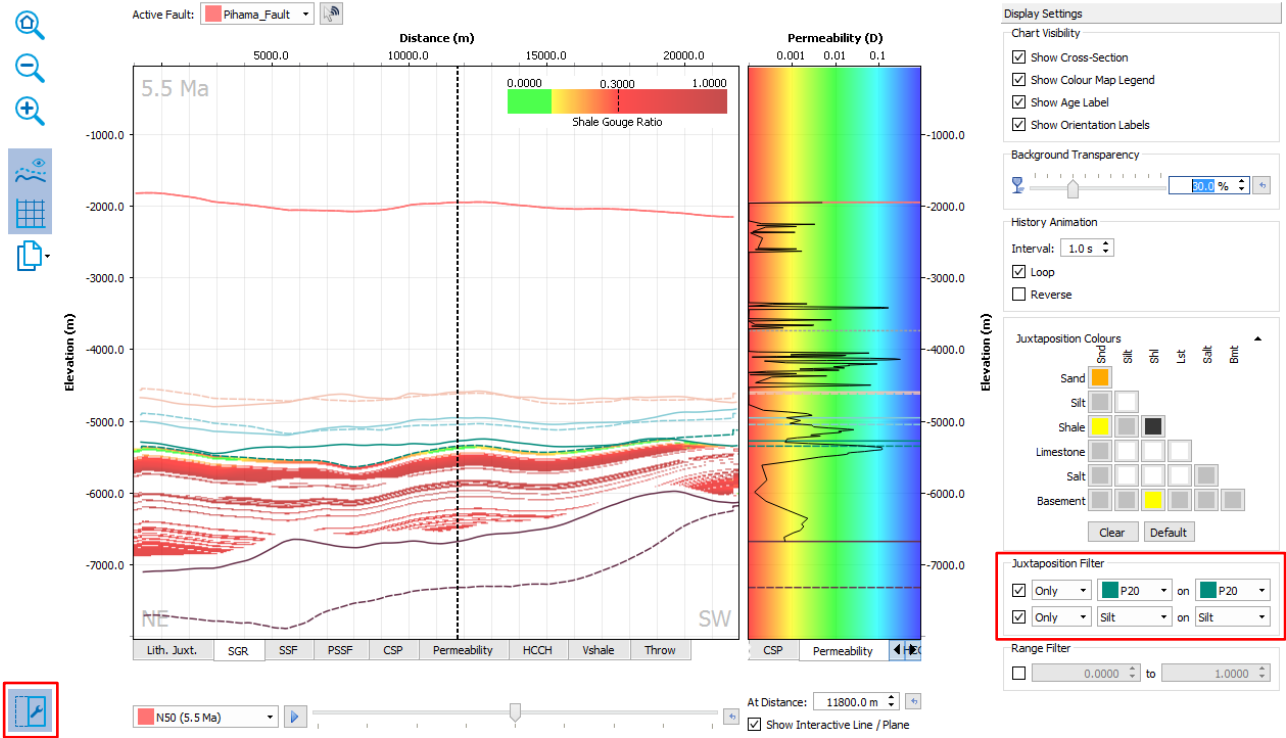
Figure 10. Use the Toolbox button (bottom left, highlighted in red) to open the Display Settings toolbox (right). A Juxtaposition Filter (bottom right, highlighted in red) can be used to focus on specific horizons and/or lithological juxtapositions. Farewell Formation is labelled as P20 in the Juxtaposition Filter options.

Analysing fault evolution

The **Fault History** diagram can also be used to help reveal the kinematic evolution of a fault through time.

In order to examine fault throw, set the **Background Transparency** to 100% using the **Display Settings** toolbox. This will hide the lithological juxtapositions or seal proxies. Then use the **Restoration Slider** at the bottom of the Fault History window to display the initiation of the Pihama Fault development (55.0 Ma) and drag the slider progressively towards the right to observe each step of the fault development up to the present-day. Alternatively, click on the **Play** button next to the slider to show an animation (Fig. 11, highlighted in green). Use the **Zoom In** and **Zoom Out** buttons to focus on specific parts of the fault. This setup allows the Move user to follow the progressive changes in the relationship between footwall and hanging wall cut-off lines for all of the horizons in the model.

As an example, Figure 11 shows the geometry of footwall and hanging wall cut-off lines on the Pihama Fault at 55 Ma (Fig. 11a) and 34 Ma (Fig. 11b) stages. Comparison of these restoration steps reveals that during this time, the fault throw increased in the north-eastern part of the fault, as recorded by the distance between the Farewell Formation hanging wall (dashed) and footwall (solid) cut-off lines. This is highlighted by the red rectangle in Figure 11b. In contrast, an increase in vertical displacement during this period was absent in to the south-west (see blue rectangle in Fig. 11b).

If you require any more information about **Fault History** or **Fault Analysis**, then please contact us by email: enquiries@mve.com or call: +44 (0)141 332 2681.
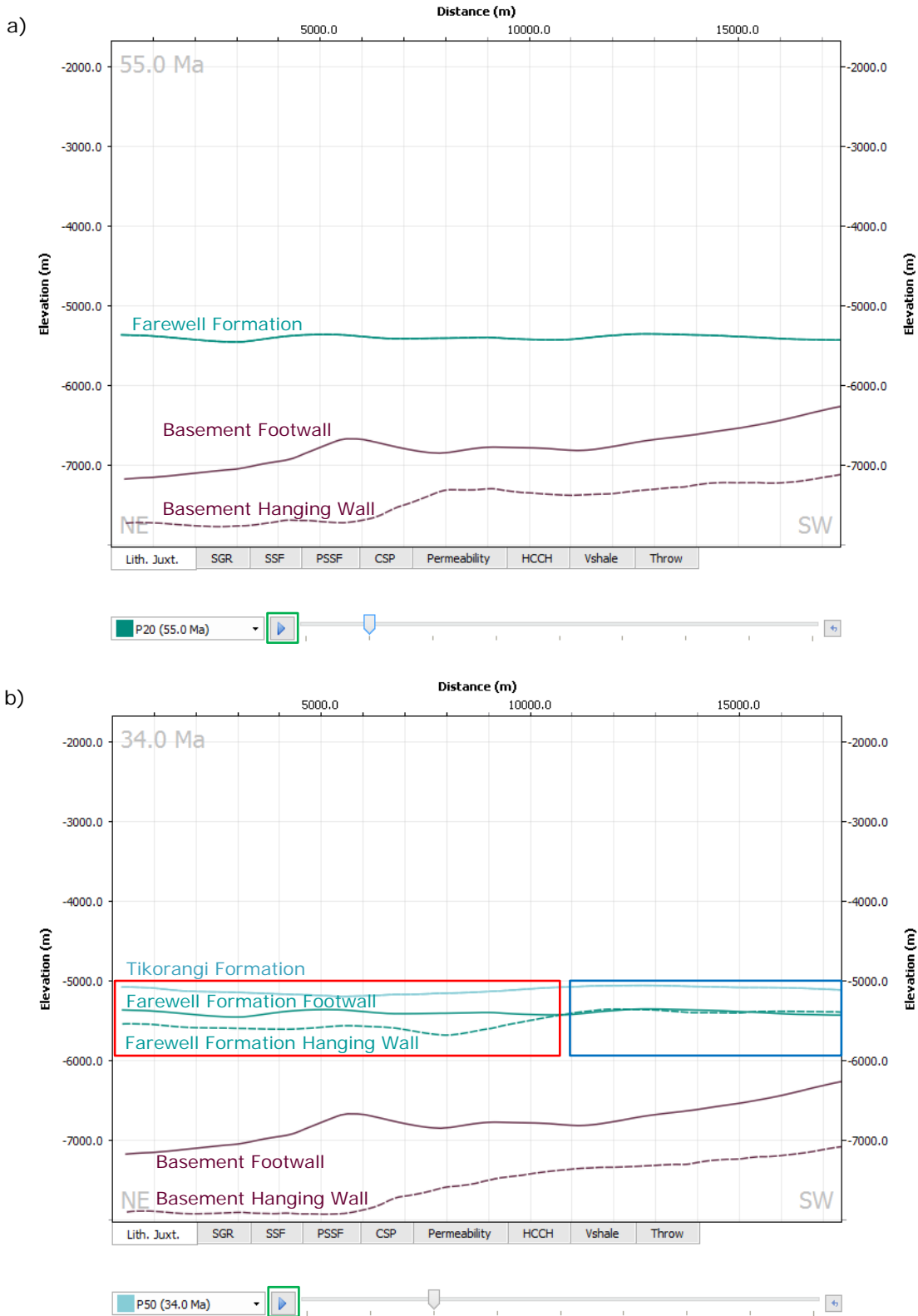
Figure 11. Evolution of hanging wall and footwall cut-off lines distributions on the Pihama Fault between 55 Ma and 34 Ma. Comparing both stages helps to reveal that throw increased during this age interval in its north-eastern part, as recorded by the distance between Farewell Formation hanging wall and footwall cut-off lines (highlighted by red rectangle). At the same age interval, increase of throw was absent at the south-western part of the Pihama Fault (highlighted by blue rectangle). Clicking the Play button (highlighted in green) allows to see an animation.

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