# Using structural validation and balancing tools to aid interpretation

Creating a balanced interpretation is the first step in reducing the uncertainty in your geological model. Balancing is based on the principle that deformation neither creates nor destroys rock volume; this principle was initially applied by Chamberlin (1910, 1919) to determine the depth to the detachment underlying concentric folds (Fig. 1). In 2D, it is essential to balance sections parallel to the main transport direction, as one of the main assumptions is that there is little or no out-of-plane tectonic movement.

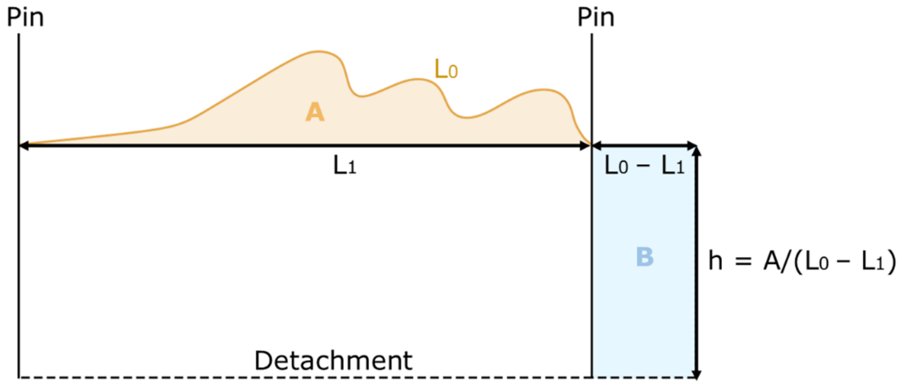


***Figure 1.*** *Schematic sketch showing depth to detachment calculation, based on the balancing principles, area A = area B. $L_0$: original bed length; $L_1$: width of deformed area; A: excess area; h: depth to detachment. After Chamberlin 1910.*

In this Move feature, the benefits of forward modelling to create a balanced interpretation are being highlighted. Forward modelling, as the term suggests, simulates deformation moving forwards through time. This interactive method can be particularly useful where data quality is poor, particularly at depth, to help guide the geometry and location of structures to produce a balanced interpretation. It also provides a rapid method for testing different structural concepts and in turn can reveal new information about the deformation history.

## 2D Forward modelling techniques in Move

*Software required*

In Move, the constrained model building tools can be used to create a balanced interpretation from the outset, or can be used test the validity of an existing interpretation. In the case study presented here, a workflow combining the **Fault Geometry** and **Horizons from Fault** tools will be demonstrated. This workflow uses the geometry of a fault to predict the geometry of hanging wall horizons where data quality is poor.

move core

For more advanced forward modelling, the **2D Kinematic Modelling** tools can be used to model the combined effects of structural deformation, subsidence and erosion. This workflow is often used to model deformation associated with slip on multiple structures and/or test different deformation scenarios to produce a valid structural model.

2D Kinematic modelling

Both forward modelling workflows require the use of kinematic algorithms to accurately model the movement of particles through geological time.

## Kinematic algorithms

The kinematic algorithms offered by the **Construct Horizons from Fault** and **2D Move on Fault** (Table 1) tools model the movement of particles associated with slip on a fault. The algorithms can be tested to determine which best reproduces the observed horizon geometries, with the results updated in real-time. Selecting the appropriate algorithm is key to accurately reproducing deformation through time.

***Table 1.*** *Overview of kinematic algorithms for forward modelling deformation in Move*

| Algorithm | Overview | Application |
|---|---|---|
| *Simple Shear* | Models diffuse deformation throughout the hanging wall by discrete slip between beds. The shear angle can be defined. This algorithm does not preserve line length. | Modelling internal hanging wall deformation associated with faulting in extensional settings: listric fault anticline rollovers, growth faults. |
| *Fault Parallel Flow* | Particles move in parallel flow pathways to the fault plane (Egan et al. 1997). An Angular Shear can be defined. | Modelling haningwall deformation which occurs discretely between beds e.g. compressional settings. |
| *Fault Bend Fold* | Displacement is modelled on a flat-ramp-flat structure using Suppe's (1983) Kink-band method. Hanging wall deformation results in an angular geometry, reflecting shape of fault. | Modelling Fault Bend Folds in a compressional setting. |
| *Fault Propagation Fold* | Models folding ahead of a propagating fault using Suppe & Medweff's (1990) Kink-band method. Results in deformation in the footwall as well as the hanging wall, which ceases once the fault has penetrated through the fold. | Modelling folding associated with structures in a compressional setting. |
| *Trishear* | Models deformed beds by simulating a triangular shear zone ahead of a propagating fault tip (Erslev, 1991). Results in thinning in hanging wall and thickening in footwall. The angle of the trishear zone can be defined along with the proportion of the trishear zone in the hanging wall / footwall. The amount the fault propagates relative to slip is also defined. Outside of the trishear zone, particles are modelled either with Fault Parallel Flow or Simple Shear. | Modelling deformation associated with structures at depth; folding associated with structures in compressional settings and drag associated with normal faulting. |
| *Detachment Fold* | Displacement on a horizontal detachment is translated vertically using Suppe and Medwedeff's (1990) Kink-band method. The angle of the backlimb and forelimb of the fold can be defined to determine the direction of fold vergence. | Modelling folding associated with decollements in a compressional setting. |
| *Elliptical Fault Flow*<br>*New for the 2017.2 release and will feature in May's newsletter.* | Using well established relationships based on field data, the magnitude of displacement is varied along the fault surface and decreases away from the fault. This allows deformation related to fault displacement gradients to be modelled and restored. | Modelling fault-related deformation in the hanging wall and footwalls of any fault system with non-uniform fault displacement profile and gradient. |

# Case study: Determining the geometry of beds at depth in an extensional setting

In this example from the Gulf of Mexico (Fig. 2), the seismic resolution at depth is poor. A normal fault has been interpreted in the shallow succession, with nine horizons interpreted in the footwall and eight horizons in the hanging wall. The geometry of the deepest horizon, the top of the Jurassic reservoir unit (dark purple), is uncertain in the hanging wall. The constrained model building tools in Move will be used to create a realistic fault at depth, which will then be used to determine the geometry of the reservoir unit in the hanging wall.

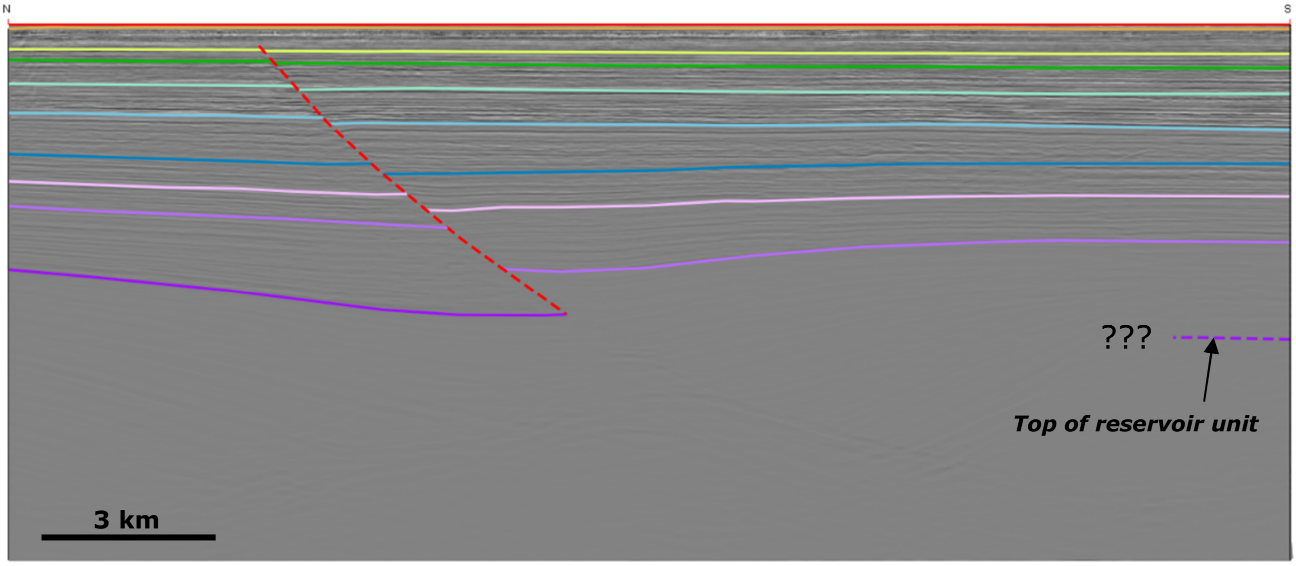


***Figure 2.*** *Seismic interpretation form the Gulf of Mexico – fault and horizon geometry at depth unknown. No vertical exaggeration.*

## A. Creating a realistic fault geometry

The **Fault Geometry** tool is used to construct a geometrically valid fault using the lowest observable hanging wall horizon geometry. The full theory behind this is provided in *'April 2016 Constrained Fault Construction'* Monthly Feature.

1. On the **Model Building** tab in **Move**, click **Fault Geometry** (Fig. 3).

2. Select a **Method**: The **Constant Heave Method** is used in this scenario as it approximates a simple shear deformation mechanism (White *et al*. 1986).

3. Define a **Regional level**; this is the elevation where it is assumed that no deformation has occurred. In this case, the elevation of the footwall horizon is used to define the regional (Fig. 4).

4. Collect the light purple hanging wall horizon into the **Hanging Wall** box and collect the observed fault stick into the **Fault** box (Fig. 3 & 4).

5. Define the **Shear Angle** for the **Constant Heave Method**; this is the orientation the particles move as slip occurs on the fault. Different shear angles can be

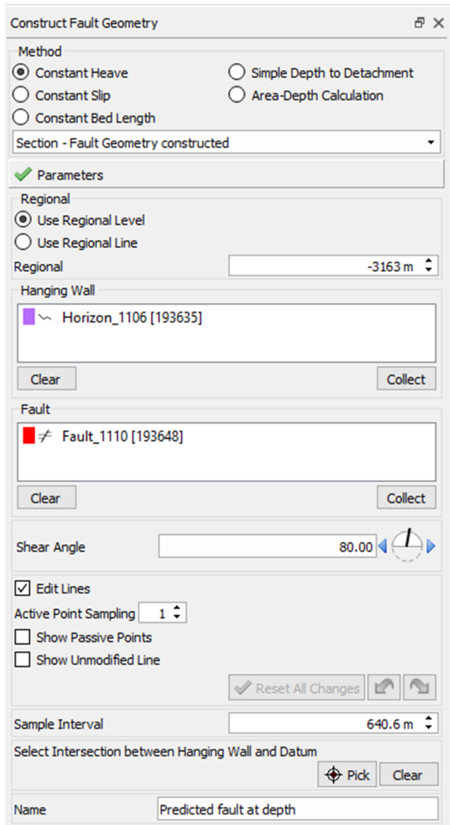


***Figure 3.*** *Fault Geometry toolbox.*

tested to provide alternative geometries; 80° is used for this scenario as it provides the best-fit with observed data.

6. On the Options tab, **Construction lines** can be toggled on or off.

7. Click on **Create Fault** to generate the predicted fault as an object (Fig. 4).

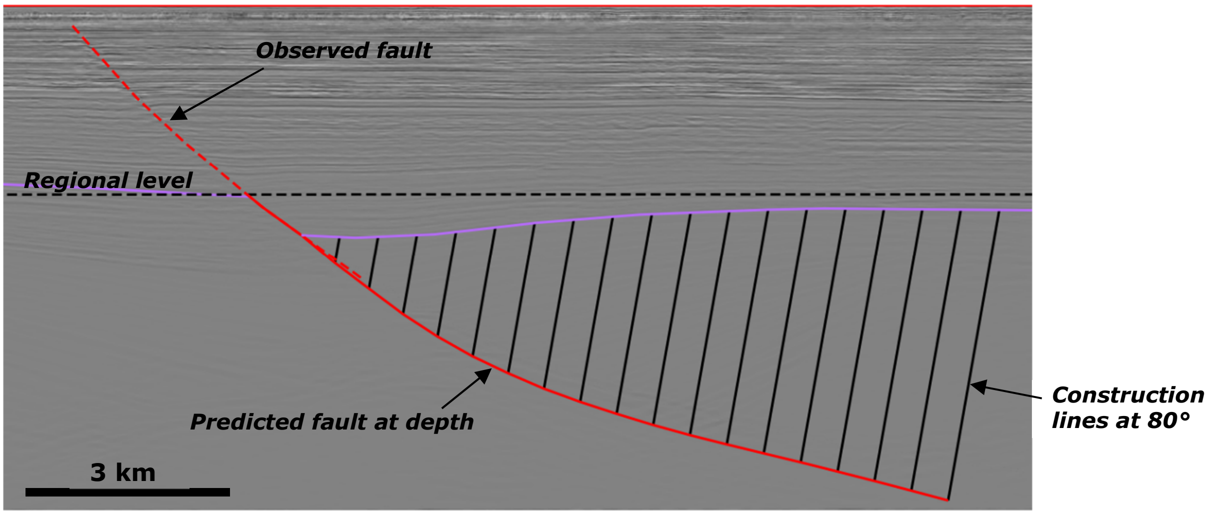


***Figure 4.*** *Fault at depth constructed using the Fault Geometry tool.*

## B. Creating a valid hanging wall interpretation

The geometry of the new fault (Fig. 4) can now be used to create a geometrically valid hanging wall interpretation using the **Construct Horizons from Fault** tool. The **Simple Shear** algorithm is most appropriate for an extensional setting and will be used to create a geological valid interpretation.

1. On the **Model Building** tab, click on **Horizons from Fault** and **Collect** the fault into the **Fault** box.

2. Select a **Method** - in this case **Simple Shear**.

3. Click on **Edit Fault** and change the **Active Point Sampling**, this will regulate the spacing of temporary nodes along the fault plane (highlighted with green dots in Fig. 5), which can be adjusted to further edit the geometry of the fault. Any modifications made to the fault geometry will automatically be reflected in the predicted horizon geometries.

4. Adjust the base of the horizons by dragging the **Basement level** vertically (white arrow in Fig. 5). Then adjust the lateral extent of the beds by dragging the **Construction lines** laterally (black arrows in Fig. 5).

5. On the **Movement** sheet, define the number and thickness of beds, and either a **Constant Heave** or **Variable Heave**. These can also be adjusted interactively: the thickness is adjusted by dragging the footwall horizon vertically; the fault heave can be adjusted by dragging the hanging wall horizon laterally (yellow arrows in Fig. 5).

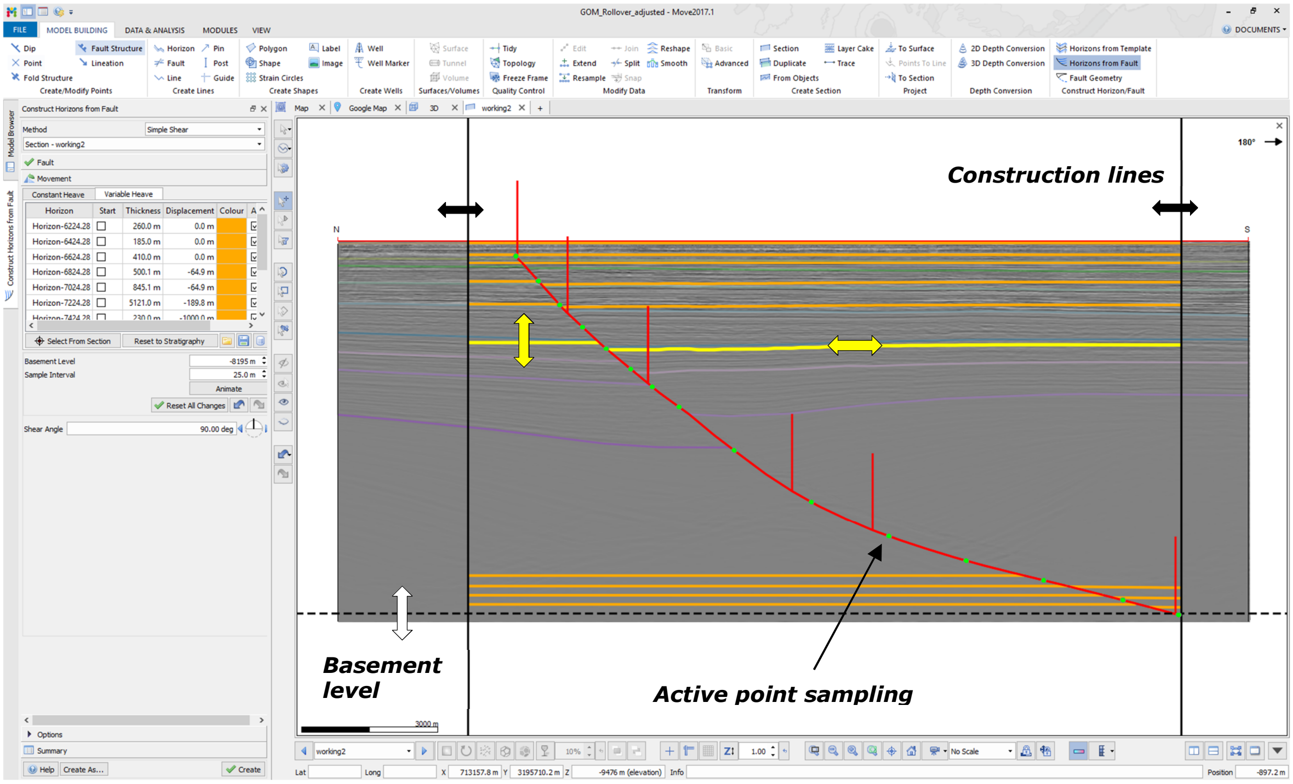


***Figure 5.*** *Move interface in Section View showing a seismic section with fault interpreted: horizon interpretation being created in Horizons from Fault tool.*

6. Using the options on the **Movement** sheet, adjust the shear angle manually. Alternatively, adjust the shear angle interactively by manipulating the shear vectors on the fault (Fig. 6): here it is adjusted to 80°, which is consistent with the shear angle used to create the original fault using the **Fault Geometry** tool.

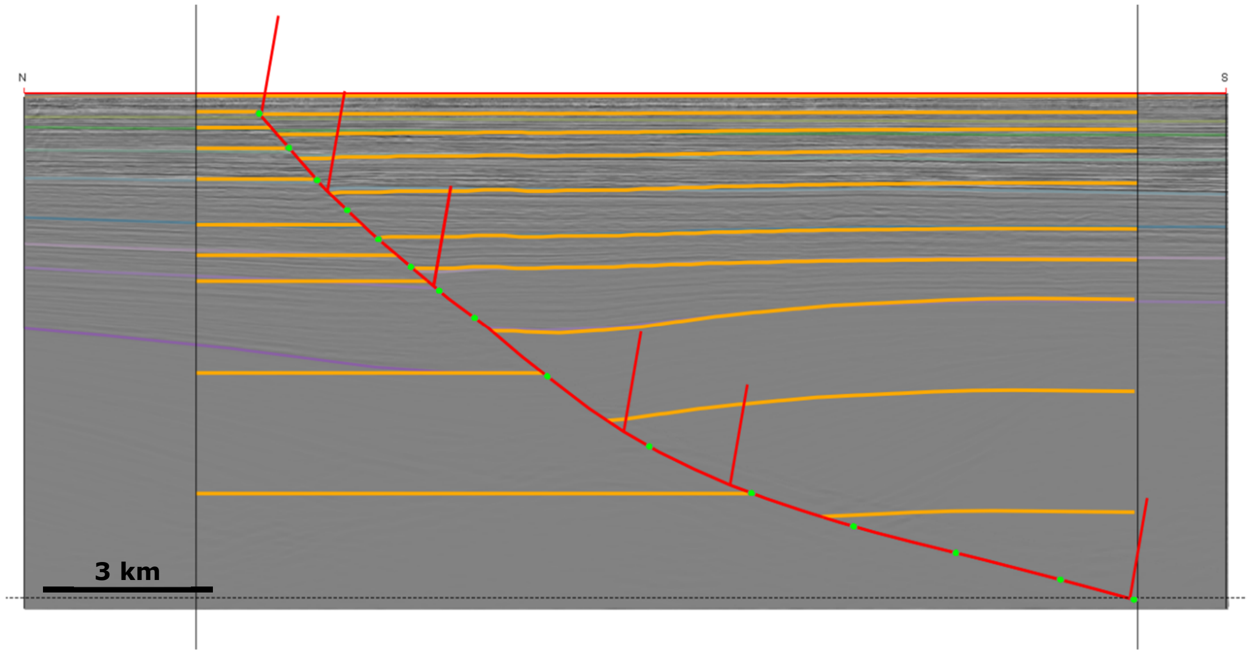


***Figure 6.*** *Seismic section in Move with horizon interpretation predicted and validated using Construct Horizons from Fault.*

The result of the constrained model building workflow predicts a hanging wall anticline geometry for the Jurassic reservoir unit (Fig. 7). This provides insight into the structural geometries, which may have economic implications such as hydrocarbon trapping potential.

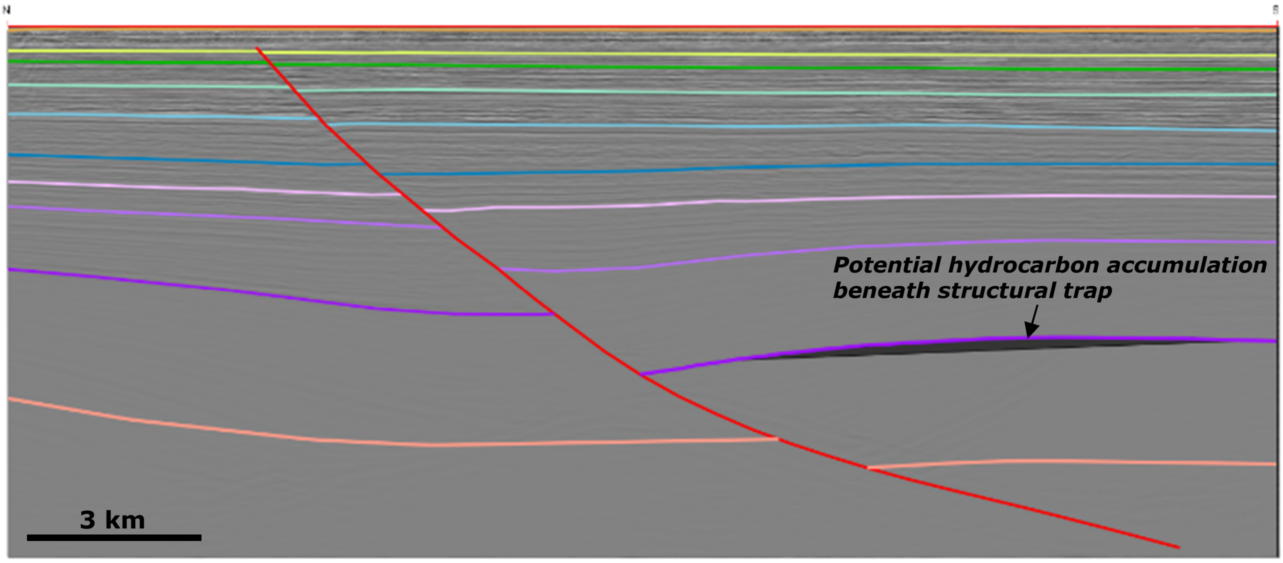


***Figure 7.*** *Revised seismic interpretation based on results of the constrained model building workflow. The reservoir unit is predicted to have an anticline geometry in the hanging wall.*

Data from: Triezenberg, P. J., Hart, P. E., and Childs, J. R., 2016, National Archive of Marine Seismic Surveys (NAMSS): A USGS data website of marine seismic reflection data within the U.S. Exclusive Economic Zone (EEZ): U.S. Geological Survey Data Release, doi: 10.5066/F7930R7P.

## References


Chamberlin, R. T., 1910, The Appalachian folds of Central Pennsylvania: *Journal of Geology Chicago*, **18**, p.228-251.

Chamberlin, R. T., 1919, The building of the Colorado Rockies: *Journal of Geology Chicago*, **27**, p. 225-251.

Egan, S. S., Buddin, T. S., Kane, S. J., and Williams, G. D., 1997, Three-dimensional modelling and visualization in structural geology: New techniques for the restoration and balancing of volumes, In: Proceedings of the 1996 Geoscience Information Group Conference on Geological Visualisation: Electronic Geology, V. **1**, Paper 7, p.67-82.

Erslev, E. A., 1991. Trishear fault-propagation folding: *Geology*, **19**, p.617-620.

Suppe, J., Medwedeff, D.A., 1990, Geometry and kinematics of fault-propagation folding: *Eclogae Geologicae Helvetiae* **83**, p.409–454.

Suppe, J., 1983a, Geometry and kinematics of fault-bend folding: *American Journal of Science*, **283**, 7, p.684-721.

White, N. J., Jackson J. A., and McKenzie, D. P., 1986, The relationship between the geometry of normal faults and that of the sedimentary layers in their hanging wall. *Journal of Structural Geology*, **8**, p.897-910.


If you require any more information about the workflow described in this monthly feature, then please contact us by email: enquiries@mve.com or call: +44 (0)141 332 2681.