

Best-practices in 2D sequential restoration – Part 1: Section preparation

Move™ provides a comprehensive set of tools to evaluate and analyse an interpretation in 2D. An interpretation can be checked for line-length, area balance, or other space problems and the structural validity of horizon and fault shape can be tested. The most powerful method in evaluating an interpretation or extracting commercially valuable information regarding structural evolution is sequential restoration. A sequential restoration (e.g. Figure 1) is a process by which deformed beds are returned to their original, pre-deformation shapes by applying algorithms to simulate the reversal of geological processes. Applying these algorithms sequentially allows the intermediate stages between the fully deformed and fully restored stages to be examined, providing a technique to answer commercially important questions relating to the geological evolution of an area, as well as to test the validity of an interpretation.

Every restoration is unique, and the workflow applied will depend on the structural setting, deformation style, mechanical stratigraphy and ultimately, the aim of the restoration. A sequential restoration may be required for several reasons, including strain calculation for fracture modelling or well stability, assessment of structural evolution (e.g. timing of trap formation), petroleum systems modelling, and palaeo-fault seal analysis.

This monthly feature is the first in a 2-part series that will outline the main assumptions made prior to carrying out sequential restoration. From these articles, user will be provided with advice on best-practice workflows and techniques to be employed. The primary focus of Part I is cross-section preparation, whereas Part II will cover how to use the restoration algorithms.

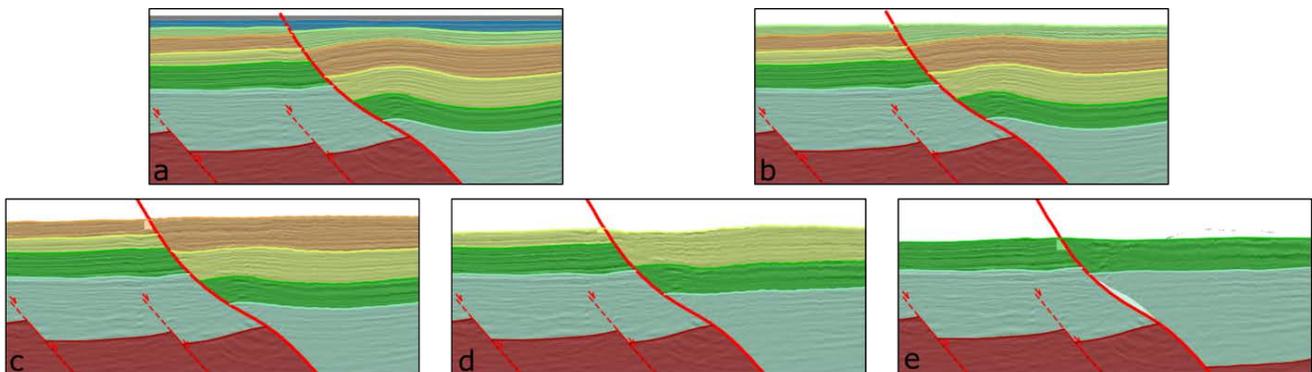


Figure 1. Example of a sequential restoration where physical compaction and normal fault offset are restored for a 2D interpreted seismic section from the northern Red Sea. Note the variation in structural geometry - particularly the development of the hanging wall anticline. Data provided courtesy of BP Gupco.

1. Putting cross-section interpretation in its geological context

Throughout any restoration process, it is important to keep in mind the wider geological and tectonic setting and to apply methods and algorithms in the restoration process that are appropriate to the local mechanical stratigraphy and tectonics. Different interpretations of the same data, made without any regional geological or tectonic knowledge, have been shown to vary dramatically with one study showing interpretations of the same cross-section ranging from extensional tectonics to thrust tectonics to salt tectonics (Bond et al. 2007). There will never be a situation in which all the data to constrain the precise nature of the subsurface is available, but by accounting for what is available (e.g. surface outcrop, drill core, palaeontological data, previous studies etc.) we can be more confident in the interpretations that form the inputs used in restoration.

2. Line length/area conservation and the assumption of plane strain

The lengths and areas of the pre-tectonic (restored) horizons should be consistent with the present-day (deformed) interpretation (Chamberlain, 1910; Dahlstrom, 1969). Anomalous horizon lengths and areas should be investigated as possible inconsistencies in the interpretation, which may need to be revised. Interpretations are often carried out on cross-sections that are not straight. Conservation of area can only be tested by assuming that the transport direction of deformation is the same as the orientation of the cross-section on which the restoration is being carried out; this is the assumption of plane strain. It is necessary therefore, to generate a straight cross-section and to project the data (seismic reflection data, horizon and fault interpretations, etc.) to the straightened cross-section. Move can be used to calculate the deformation transport direction, or direction of most structural change should be determined, by analysing the orientations of available dip data in a model, which can be done in the Vertex Attributes Analyser. The suggested section plane (calculated from the dip data) can be toggled on from the Display options on the right-hand side of the window (Figure 2). This will indicate the direction of most structural change, based on the collected data, and can be used to determine the section orientation. A section can then be created at this angle using the tools in Create Section, and data projected using Project to Section.

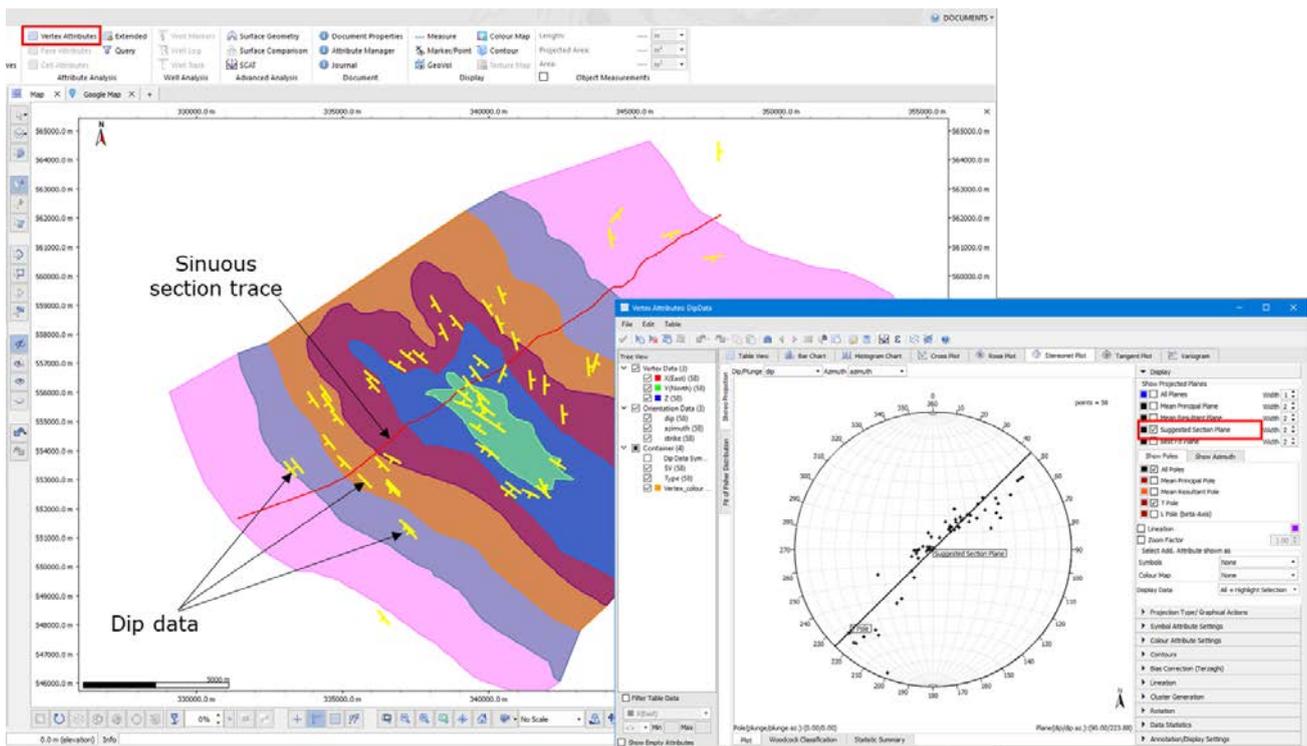


Figure 2. A sinuous section trace and dip data across an anticline structure. Selecting the dip data and opening the Vertex Attributes Analyser allows a stereographic projection of the dip data to be plotted (inset) and the most appropriate section orientation displayed. Model courtesy of Midland Valley.

3. Depth conversion

Prior to carrying out any validation or structural analysis, any time data must be converted to depth. The shapes of horizons and structures presented in the time domain will usually not represent their true forms, often having unrepresentative thickness in the z-axis. Furthermore, the relative positions of different parts of a model will vary between the time and depth versions of the data as a result of variable velocities through the model, resulting in inaccurate fault offsets and spurious structures such as pull-up anticlines. Therefore, structures kinematically modelled using time data as an input will not be geometrically valid (Figure 3).

Depth conversion of a cross-section in Move can be performed in four ways: using a fixed time-to-depth conversion, using an equation which varies the time-to-depth relationship with depth in the section, using interval velocities and depth coefficients for each interpreted horizon, or using a database of time-depth relationships e.g. checkshot data from a well. More information on the methods and theory for depth conversion can be found in the help pages or the Knowledge Base.

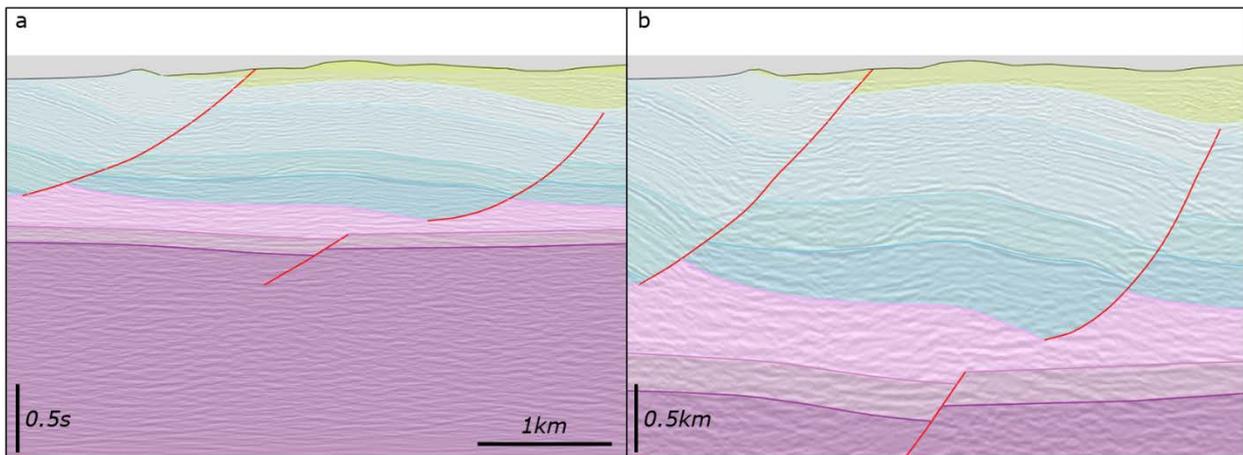


Figure 3. Part of an interpreted seismic section from the Weymouth Anticline in time (a) and in depth (b). Both sections are viewed with no vertical exaggeration. Note the difference in shape of the faults and horizons. Kinematic modelling of time structures will not be valid. Data are available from the U.K. Onshore Geophysical Library (www.ukogl.org.uk).

4. Validating interpretations

The results of a sequential restoration can only be considered valid if the starting interpretation is geologically consistent and geometrically coherent. Move contains a range of tools to help validate an interpretation prior to carrying out a sequential restoration. More information on these techniques can be found in the **Section Analysis Monthly Feature** and the **Structural Validation and Balancing Monthly Feature**.

5. Tidy interpretations

A tidy interpretation is one with tight connections between faults, horizons and section limits. The 2D kinematic modelling algorithms in Move work best with tidied interpretations. Auto-tracking software will introduce inconsistencies by, for example, interpreting horizons through faults or creating gaps or short lines resulting in an interpretation that is not an accurate representation of the subsurface horizons and faults. These inconsistencies will render any kinematic restoration method invalid and should be addressed prior to beginning a sequential restoration. A quick way to test for problems of this nature is to use the **Tidy** tool. The Tidy tool will identify overlapping lines, locations where horizons and faults are not snapped, and the presence of anomalous short lines that may not be immediately apparent. The tidy tool allows the user to automatically correct minor inconsistencies, such as snapping horizons to faults (Figure 4).

6. Resampling

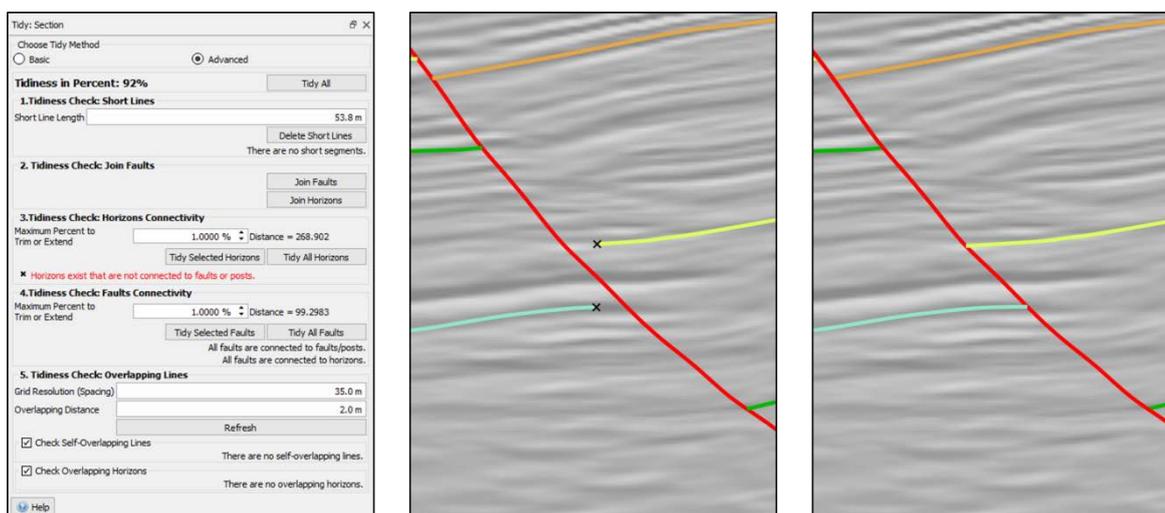


Figure 4. The tidy tool. Horizons that are not snapped to faults of section posts are identified with black crosses and can be automatically corrected using the 'Tidy All Horizons' button. Data provided courtesy of BP Gupco.

Artefacts from auto-tracked interpretations, if not addressed, can impact the results of kinematic restoration undertaken on the interpretation. Minor interpretational mispicks can be neutralised by resampling the nodes on the line interpretations. The resampling tool allows the user to specify a preferred node spacing or to apply a smoothing algorithm to replace the nodes that make up a line. The resulting uniform line node spacing will maximise the effectiveness of algorithm-driven transformations during restoration. It is recommended that line interpretations be resampled prior to beginning a sequential restoration to ensure an appropriate sampling. For more details on the resampling methods available and how they work, please see **the Resample Tool Move Feature**.

7. Polygon Creation

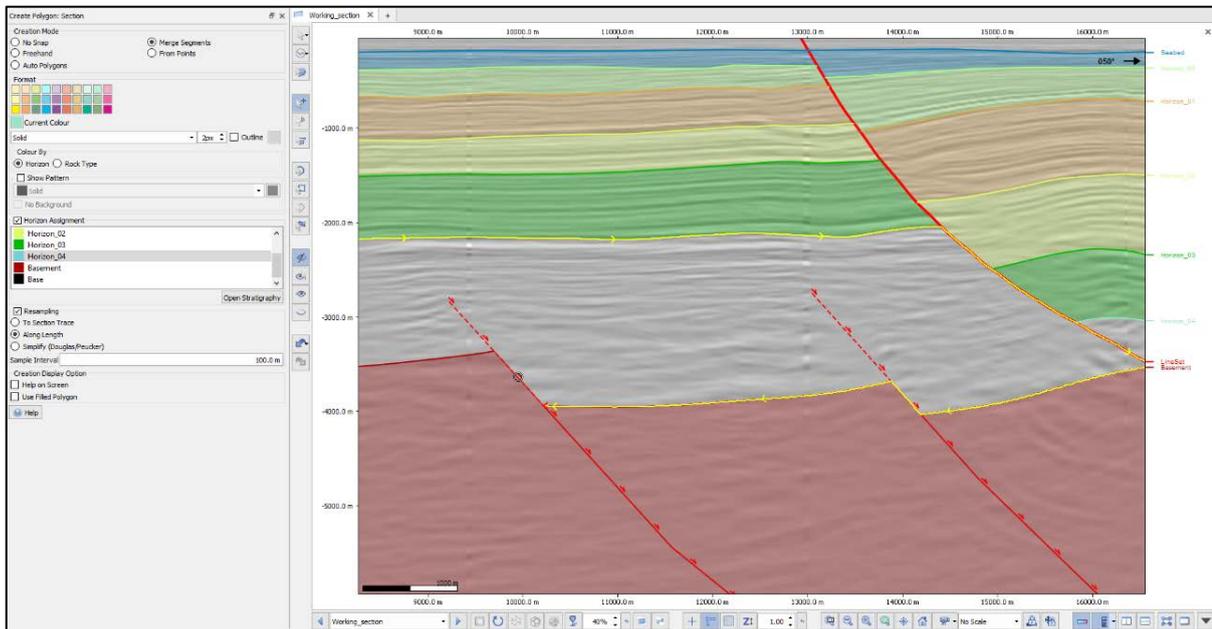


Figure 6. Using the Polygon tool to create polygons with the Merge Segments functionality. The cursor will become a circle when hovering over a valid line to use as a polygon boundary. Data provided courtesy of BP Gupco.

Polygons in Move are filled areas with specific horizon properties bound by faults, horizon tops or section limits. The creation of polygons is a useful means of visualizing and analysing the cross-sectional area representing a particular horizon. Move uses polygons to create calculation grids which are used to calculate the movement of seismic or other images on a cross-section when performing depth conversion or kinematic operations. There are five methods of polygon creation in Move, accessed via the **Polygon** tool in the **Model Building** tab. The Polygon tool is linked to the **Tidy** tool, therefore on opening the Polygon tool, the Tidiness of the cross-section interpretation will be displayed as a percentage. If the cross-section is 100% tidy, choosing **Auto Polygons** and clicking **Apply** will create the polygons automatically. To change the transparency of polygons in a section - for example to display the seismic image behind them - use the keyboard shortcut **Ctrl+Alt+k** to select all polygons and change the value of Transparency on the Display toolbar at the bottom of the Section View window.

8. Summary

Using the foundations of best-practice outlined above should result in the cross-section interpretation being ready to provide valid results during the sequential restoration process. In summary, the cross-section should be straight and in the depth domain; the interpretation needs to be geologically and geometrically valid, tidy and uniformly sampled; polygons representing the cross-sectional area of each unit should be created to aid with the transformation of seismic images and for visualization and analysis purposes.

Part II of this monthly feature will look at the functionality of tools used in 2D sequential restorations, outline some best-practices to follow and highlight potential pitfalls.

9. References

Bond, C. E., Gibbs, A. D., Shipton, Z. K., & Jones, S. (2007). What do you think this is? "Conceptual uncertainty" in geoscience interpretation. *GSA today*, 17(11), 4.

Chamberlin, R.T., 1910. The Appalachian folds of central Pennsylvania. *The Journal of Geology*, 18(3), pp.228-251.

Dahlstrom, C.D.A., 1969. Balanced cross sections. *Canadian Journal of Earth Sciences*, 6(4), pp.743-757.

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