Government of **Western Australia**
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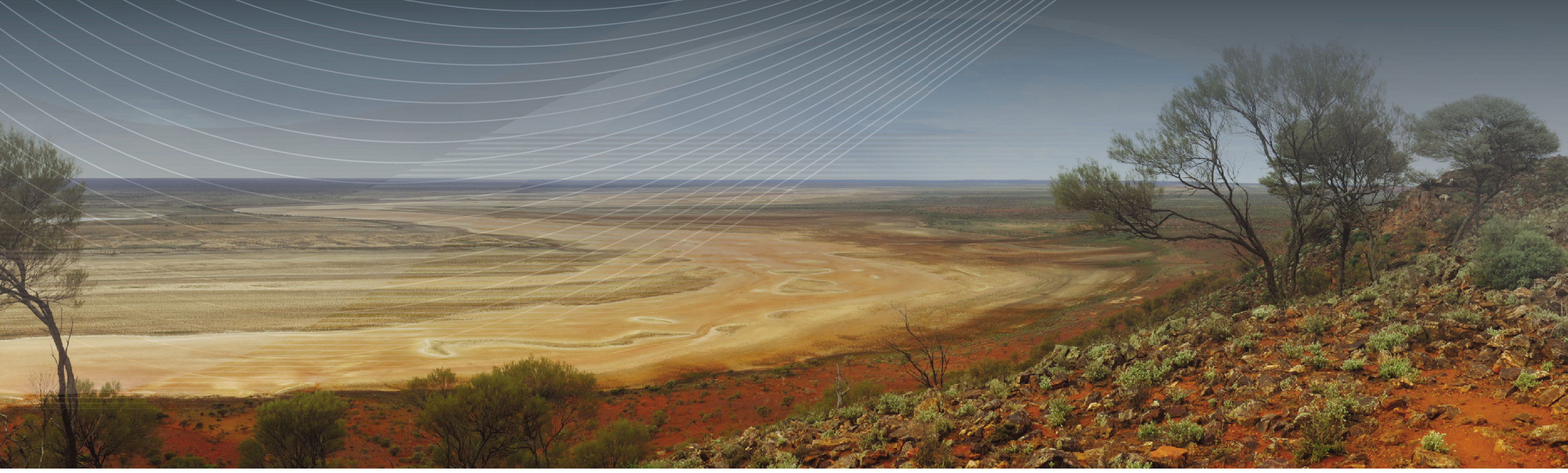
RECORD 2016/3

INTEGRATED EXPLORATION PLATFORM v2.5: AN INNOVATIVE VISUAL ANALYTICS PLUG-IN TO ESRI ArcGIS

by
JC Wong, E-J Holden, P Kovesi, K Gessner, and RE Murdie



Geological Survey of Western Australia

EXPLORATION INCENTIVE SCHEME

Centre for EXPLORATION TARGETING

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Geological Survey of Western Australia

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Cover image: Elongate salt lake on the Yilgarn Craton — part of the Moore–Monger paleovalley — here viewed from the top of Wownaminya Hill, 20 km southeast of Yalgoo, Murchison Goldfields. Photograph taken by I Zibra for the Geological Survey of Western Australia.

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Integrated Exploration Platform v2.5: An innovative visual analytics plug-in to ESRI ArcGIS

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Abstract

The quality of interpretation of geoscientific data impacts decisions that have significant financial implications for the minerals industry. Nevertheless, these interpretations are highly biased, thus variable among and within individual interpreters, leading to difficulty in the outcomes being reproduced. The Integrated Exploration Platform (IEP) aims to provide innovative data visualisation and analysis methods to maximise geological knowledge gain for users of Geological Survey of Western Australia (GSWA) data. Currently, the IEP will only work with datasets located in Western Australia. Harnessing the power of automated image analysis and interactive visualisation, this platform features data visualisation methods for simultaneous viewing of multiple datasets through blending tools, streamlined annotation tools for interpretations, and feature-evidence based interpretation assistance tools.

KEYWORDS: automatic image analysis, geological interpretation, geophysical data, GIS, visual analytics

Introduction

Geological data interpretation is a complex pattern recognition task. Using a wide range of quantitative and qualitative observations of varying resolution, interpreters are challenged to understand complex subsurface geology that was formed in the distant past. In essence, the interpretation task involves the identification of patterns of interest within a single dataset, making complex synthesis of patterns from multiple datasets, and making associations of patterns with existing experience or tacit knowledge to understand the geology. Interpretation outcomes are highly uncertain as there is significant variation in individual interpreter's geological knowledge or biases, data interpretation methods, and natural ability to see patterns in data and to make associations with memory. An additional challenge is that our pattern recognition ability is heavily influenced by what we are looking for, resulting in the high likelihood that we will miss features that are not expected or sought within data. This is commonly known as in-attentional blindness.

The Geological Survey of Western Australia (GSWA) has been collecting (and has made publically available) large volumes of different types of geoscientific data to promote and support exploration activities in Western Australia. Collaborative research between GSWA, through the Exploration Incentive Scheme, and the Centre for Exploration Targeting (CET) within The University of Western Australia (UWA) focuses on developing a GIS platform, namely the Integrated Exploration Platform (IEP). This function facilitates mineral explorers' effective utilisation of GSWA data by supporting their geological knowledge extraction through innovative data analytics methods. Currently, 2D datasets must be located in Western Australia — 2D datasets that extend outside the Western Australian boundaries will not be loaded (although non-geolocated 3D datasets may be loaded). This research is also supported by Australian Research Council (ARC) Linkage Grant (LP140100267).

Objectives

The IEP aims to support improved confidence in geological interpretation of a variety of exploration data (within Western Australia). It consists of three specific components. The first is visualisation methods that: 1) reveal useful geological information with clarity for a single dataset through image enhancement, and 2) assist integrated interpretation of multiple datasets by combining datasets in a single image to understand complementary or conflicting features between different datasets. The second is annotation methods to support geological interpretation of data in our visualisation framework. The last is feature-evidence interpretation support methods which combine automated feature detection and interactive visualisation to allow interpreters to check data evidence quantitatively and visually on interpreted structures.

The IEP introduces various multidata visualisation tools which are new to the existing GIS environment. Within a conventional GIS environment, multidata visualisation is achieved using a composite or ternary colour image. Up to three different single-channel datasets can be viewed at once but, generally, they are selected and viewed one at a time in a mutually exclusive manner. However, geological interpretation often requires identification of features of interest that appear within different datasets; for example, deep structures appear as discontinuities within magnetic and gravity data. The IEP allows interactive visualisation where transition between different images can be manipulated graphically to maximise the interpreter's ability to see complimentary or conflicting features in different 2D datasets for the same geographic location. Additionally, the IEP also introduces the visualisation tools to include non-map view 2D data, such as 2.5D cross-section data, as well as 3D volumetric data. This widens the capacity of the IEP to integrate more types of datasets in the process of making interpretations.

Furthermore, the IEP provides the novel functionality of giving computer-assisted feedback on structural interpretation of potential-field data to improve the quality of interpretation outcomes. This computer-assisted feedback is provided in the form of feature evidence which is generated using automated lineament detection algorithms. Given interpreted structures, feature evidence can provide a quantitative measure to indicate whether the mapped structures appear as discontinuities within data. Alternatively, strengths of local feature evidence can be displayed interactively over the source data to validate the context of existing interpretation lines. This type of feedback augments the user's ability to make adjustments, corrections, or verification decisions that are supported by data evidence.

The public release of the IEP (v2.5) is focused on garnering industry feedback to further develop more robust, user-friendly, and effective iterations of the IEP.

Technical background

Implementation

The IEP (Fig. 1) has been implemented as an extension to ESRI ArcGIS, a widely used GIS environment, to support the existing workflow of GSWA data users. The IEP includes multidata (2D, 2.5D cross-sectional, and 3D volumetric data) visualisation, interpretation annotation tools, and multidata evidence feedback as part of the confidence feedback system for computer-assisted and user-driven interpretation assistive tools.

The IEP has been implemented as a plug-in for ArcMap through the ArcGIS Add-in framework. The Add-in framework provides a simple foundation to build plug-ins and extensions for many of the ArcGIS family of applications. The Add-in framework utilises the ArcObjects environment (which is also used to implement many of the components of the ArcGIS platform itself), and is coupled with C# .NET for front-end interface implementation. Another benefit of using the Add-in framework is that it allows for simple and easy distribution of the IEP through a single *.esriAddIn file that can be emailed or downloaded, without need for additional licensing arrangements. Installing an Add-in type plug-in only requires opening the *.esriAddIn file on a computer system with ArcGIS already installed.

The display of 2D and 3D data in the IEP is achieved through utilising OpenGL (Open Graphics Library), the industry standard for high performance graphics. 2D blends are achieved through rendering raster data into a texture, which is then applied to a vector-rendered 2D rectangle representing the extent of the dataset. Through manipulating the alpha component of the texture colour, dataset textures can be rendered with a controlled degree of transparency. This allows for datasets to be 'stacked' on top of each other, with each layer blending with the layer underneath via control of the alpha component. 3D datasets are rendered in 3D vector graphics in OpenGL, implemented with modes for rendering voxels as points, cubes, or wireframe cubes. Further details regarding the camera implementation, colourisation of data textures, and partially overlapping datasets are found in Appendix 1.

Data visualisation tools

The philosophy behind the IEP visualisation methods is to exploit 'interactivity' and 'motion' for data interrogation. The visualisation methods include a suite of image blending tools that allow the user to generate an interactive display and vary the contribution from different datasets. There is also a data enhancement method called dynamic range compression (DRC; Kovesi, 2012) that is effective in analysing high frequency features in high dynamic range data such as geophysical magnetics data. These state-of-art data blending and enhancement tools can be used to interpret a variety of spatial datasets separately or combined. For a single dataset, different levels of information, such as varying scales of features, can be visualised interactively, and with multiple datasets, the blending tools provide a variety of ways to combine salient features in different datasets in a meaningful way.

Dynamic range compression

Some of the blending tools in IEP utilise the results from the DRC algorithm (Kovesi, 2012). This algorithm is especially useful for the display of data containing a high dynamic range such as magnetic data, and provides an alternative to the current industry standard of histogram equalisation. It is unique as a compression algorithm in that it preserves the phase of the data, which is recognised as the dominant component for perceivable information in an image. Specifically, this algorithm combines high-pass filtering and tone mapping techniques to effectively reduce the range of data values in order to be displayed. This is particularly necessary for geophysical data such as magnetics, which generally have a large range of values. The tone mapping technique is necessary to map data values to a limited number of tones or shades for displaying on computer monitors. This results in DRC outputs that preserve feature appearances and their overall sense of contrast. Furthermore, DRC allows the display of data at specific frequency cut-offs through the high-

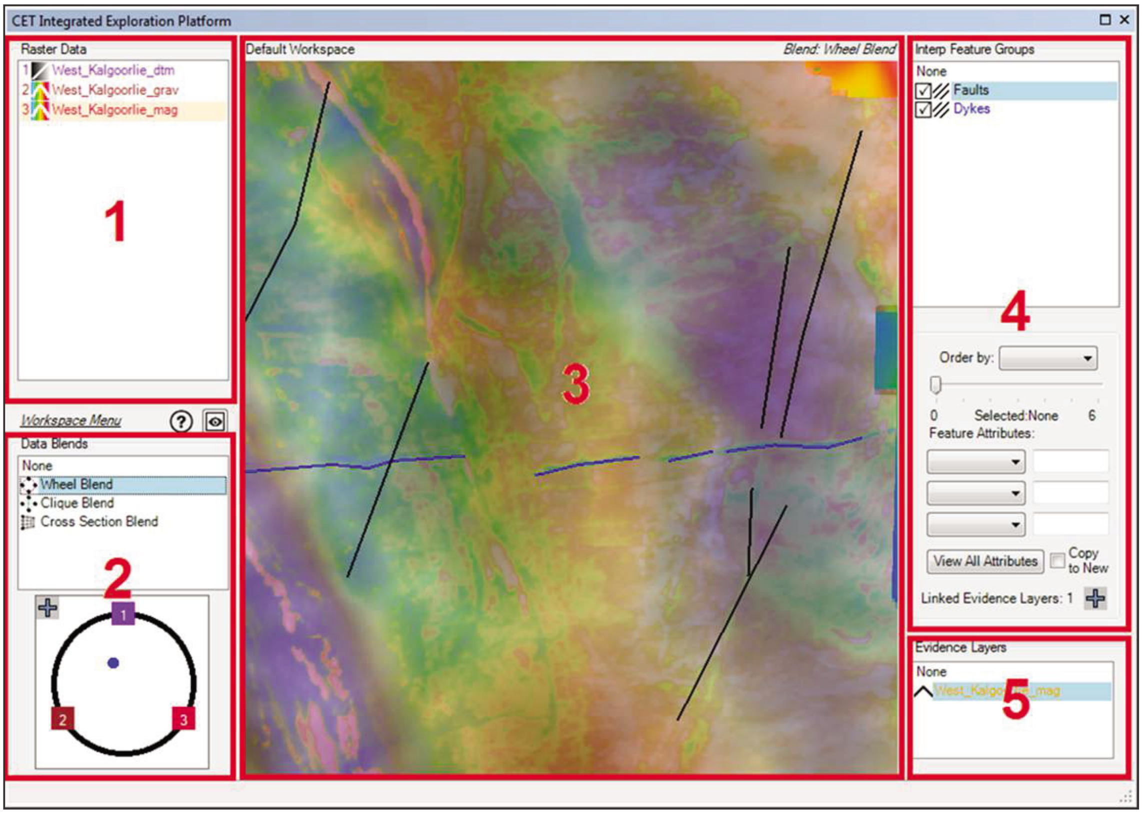


Figure 1. **The IEP v2.5 running as a plug-in through ArcMap. The main panels of the IEP interface are: 1 – dataset manager; 2 – blend manager; 3 – main display area; 4 – interpretation group manager; 5 – evidence layer manager**

pass filter, which is important for interrogating features at different scales during interpretation. Figure 2 shows an example of histogram equalisation compared with DRC results of aeromagnetic data.

2D blending techniques

Image blending, or cross-dissolving across images, is achieved through the linear combination of an arbitrary number of images:

$$I_b = w_1 I_1 + w_2 I_2 + \cdots + w_n I_n$$

where $\Sigma w_i = 1$. The weights, w_n, control the influence of each of the images, I_n, combined in the display. The IEP blenders utilise an interactive blend 'cursor' to control these weights and subsequent blend output.

Five blending tools, specific for plan-view 2D datasets, are provided: the barycentric triangle blender (Fig. 3), the clique blender (Fig. 4), the image wheel blender (Fig. 5), the parameter linear blender (Fig. 6), and the parameter bilinear blender (Fig. 7). Each of these can be useful for specific types of datasets. Details of these blenders can be found in Kovesi et al. (2014), and are briefly described here.

The barycentric triangle blender

This blender is useful for multiband data when a maximum of three bands are displayed. For example, radiometric data can be effectively visualised by assigning each data band of thorium, uranium, and potassium to each of the three blending nodes. As the blend cursor is moved around the triangle, a resulting blend is generated by the distance weight to each blending node (Fig. 3). These weights are calculated using barycentric coordinates (Coxeter, 1989) which provide an intuitive interpolation scheme across a triangle. Figure 8 illustrates the barycentric coordinates of a number of locations within a triangle. The coordinate values correspond to the hypothetical weights that should be placed at each vertex of the triangle in order for the triangle to balance at that point.

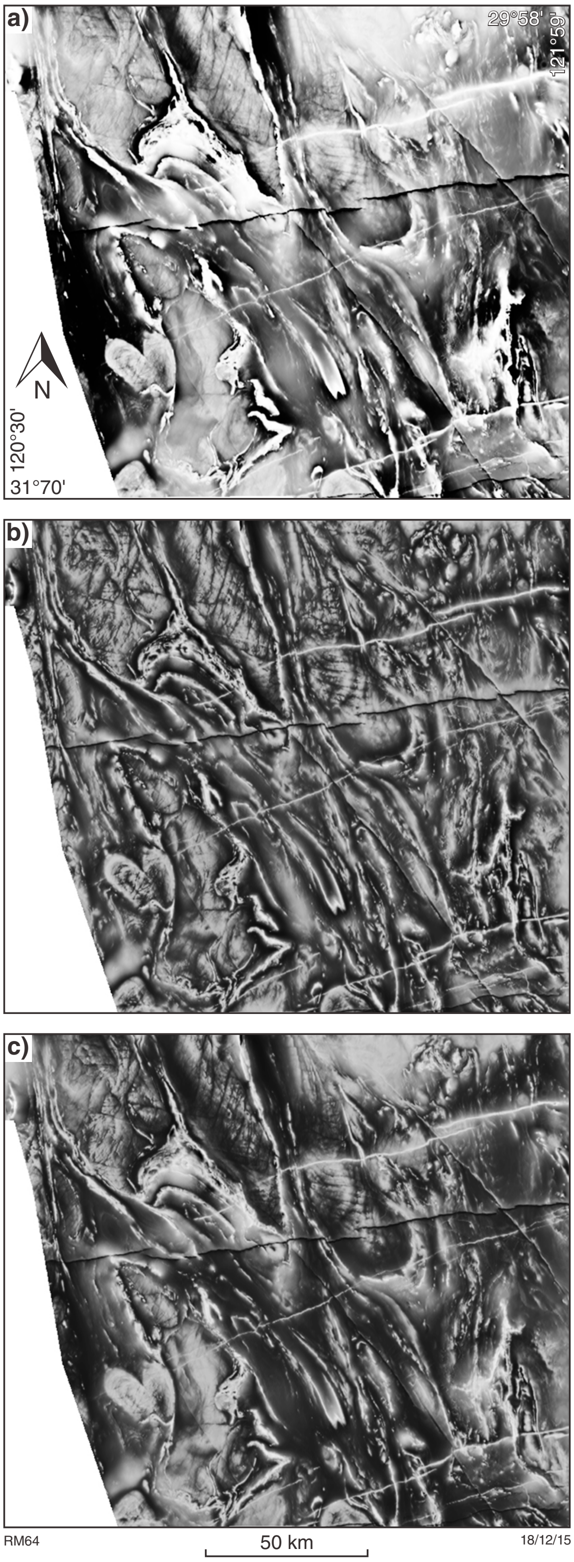


Figure 2. Comparison of the histogram equalisation and the dynamic range compression (DRC) methods on TMI data of the Yilgarn (courtesy of Fugro Airborne Surveys Pty Ltd.): a) the result of histogram equalisation, causing features in areas of extreme values to be 'washed out'; b) the DRC result with a filter size of 6.25 km; c) the DRC result with a filter size of 50 km. The DRC results show much better contrast of features with the additional benefit of user-controlled filter sizes, providing the facility to emphasise smaller features

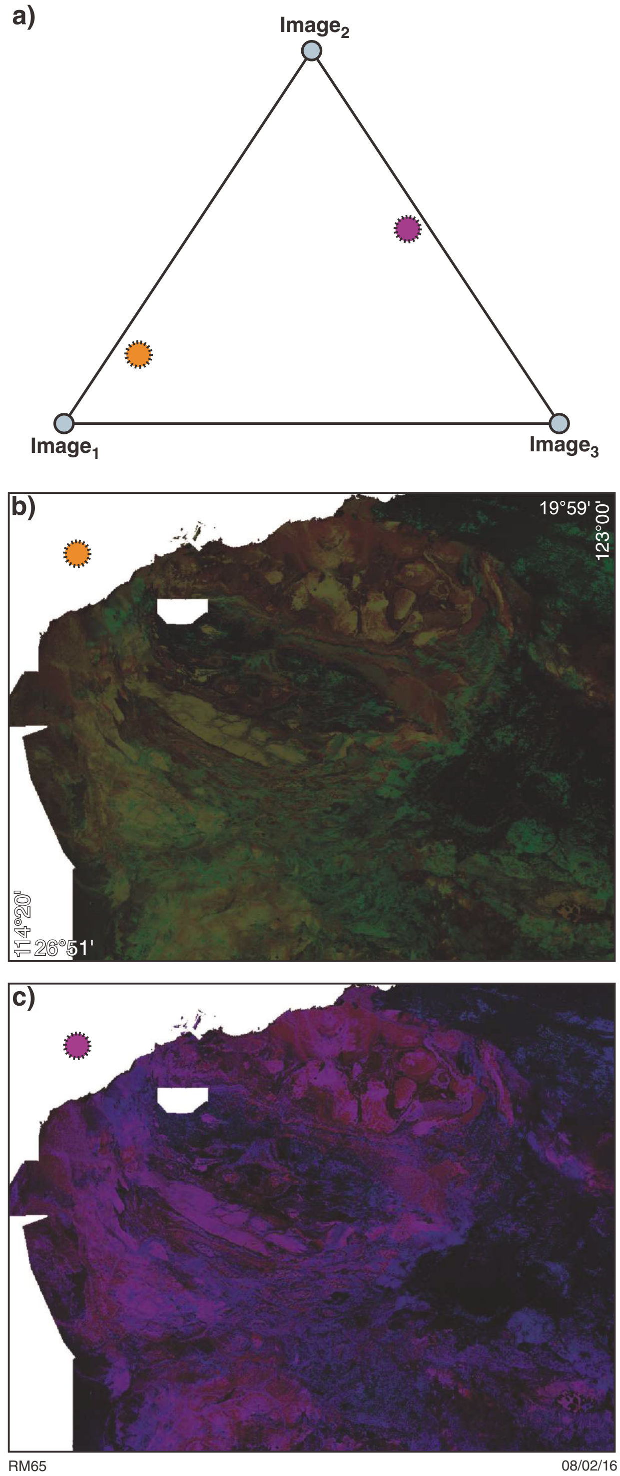


Figure 3. The barycentric triangle blender: a) the triangular blending control interface. Two blending combinations corresponding to the two colour coded positions (orange and purple dots) in the blending tool. Particularly useful for radiometric data, the two blending positions interactively show the contributions from each of the three images (in this case U, Th and K data assigned to primary colours); b) blend corresponding to the orange dot in (a) mainly comprised of Image1 (green channel Th); c) blend corresponding to the purple dot in (a) with a mix primarily of Image2 (red channel K) and Image3 (blue channel U), and a smaller contribution from Image1

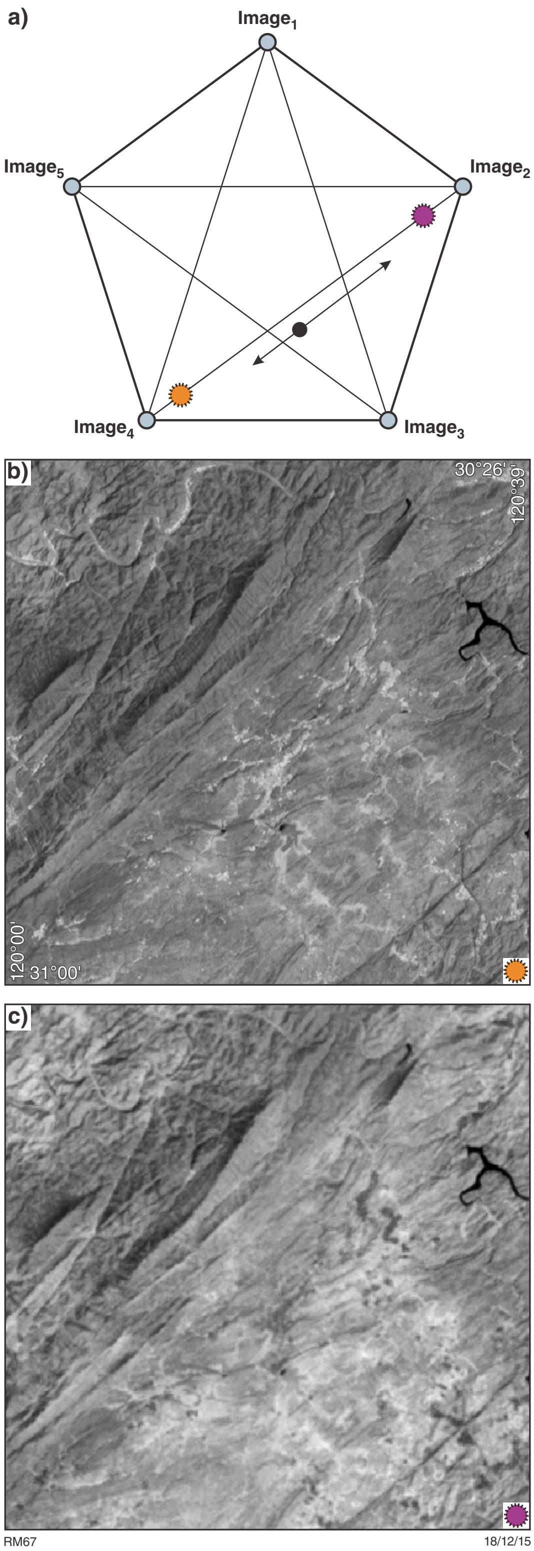


Figure 4. **The clique blender, for efficient blending between any two pairs of datasets: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool. This is particularly useful for multichannel data such as ASTER data. Each of the nodes represents one channel of data, and moving the cursor along any of the lines result in a simple blend between the two connected nodes; b), c) blends represented by the orange and purple dots, respectively, illustrate the effect of moving along the line between Image4 and Image2**

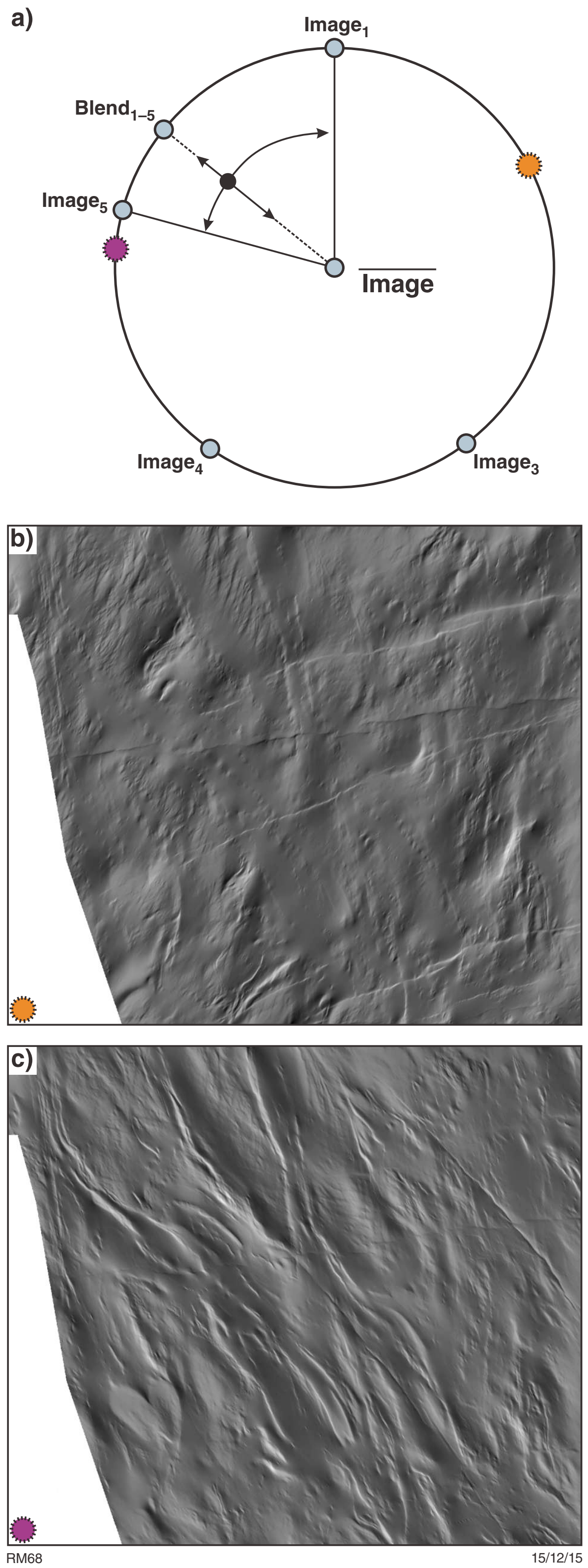


Figure 5. **The image wheel blender, used to visualise the orientation of structures: a) two blending combinations corresponding to the colour coded positions (orange and purple dots) shown in the blending tool. The five (or more) nodes represent geophysical data filtered with certain orientations; b) blend represented by the orange dot shows the data filtered with a relatively horizontal orientation; c) blend represented by the purple dot shows the data filtered at a more vertical orientation**

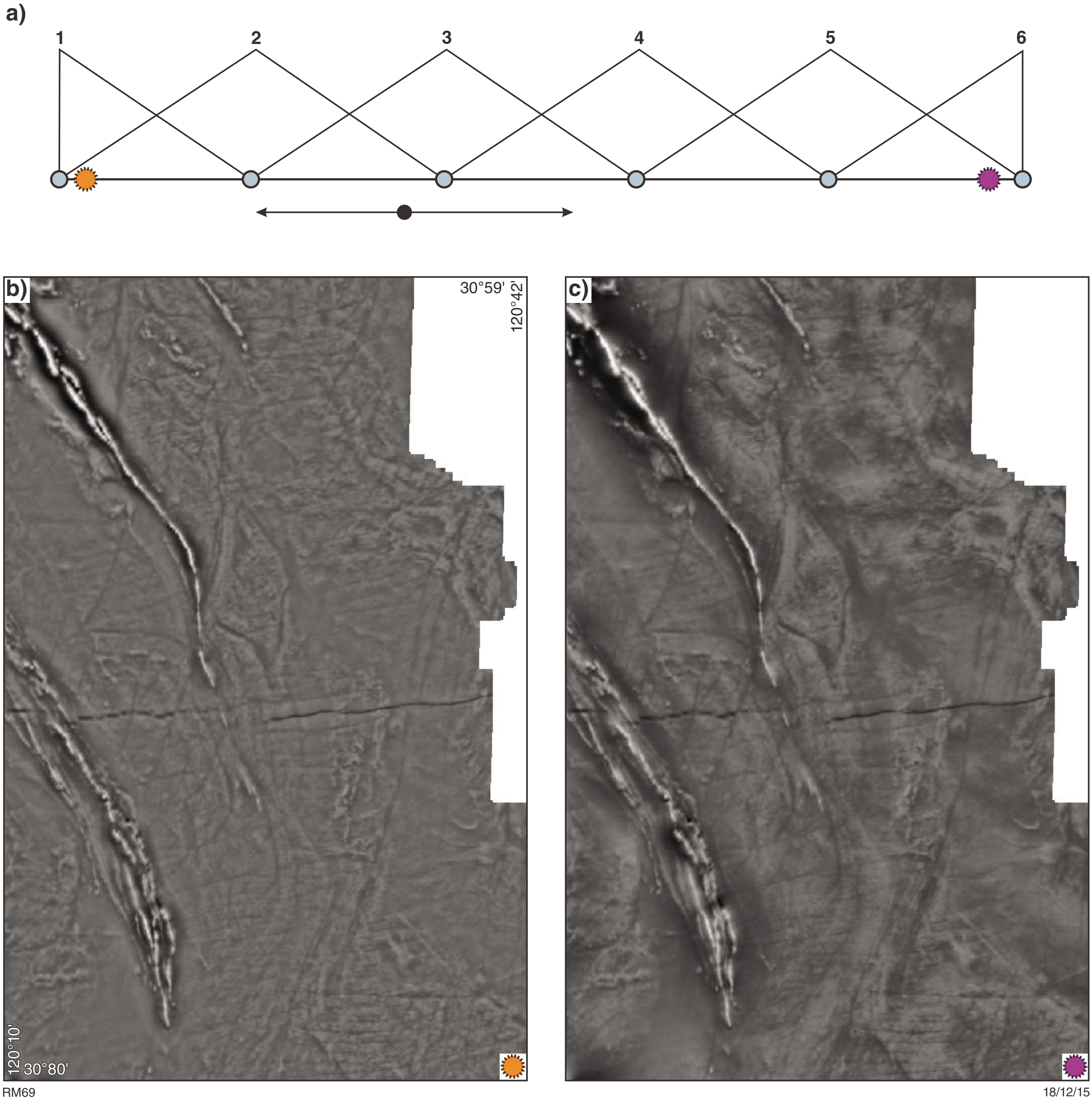


Figure 6. **The linear blender, for blending between results of varying filter parameter values: a) two different blending results are shown with the orange and purple dot symbols in the blender tool; b) blend represented by the orange dot shows magnetic data filtered at a short wavelength (higher frequency and finer features); c) blend represented by the purple dot shows an image that incorporates longer wavelength filter results of the data**

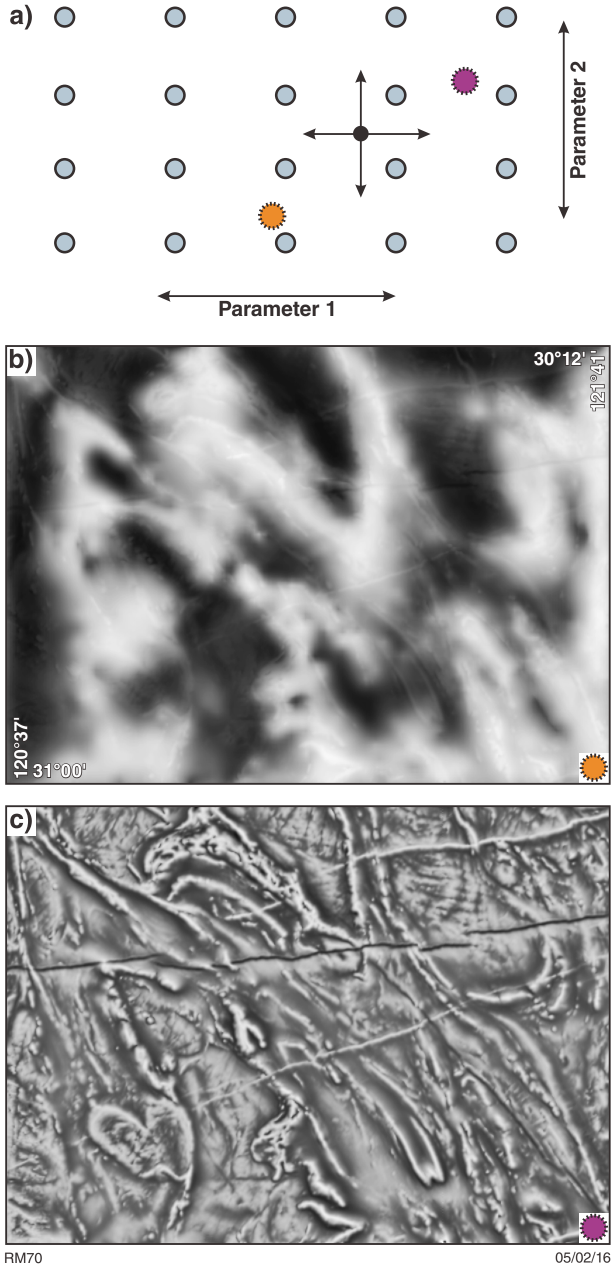


Figure 7. **The bilinear blender, for blending between results of two datasets (gravity on the left, and magnetic on the right), filtered over a range of parameter values: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool; b) blend represented by the orange dot shows DRC filter results at long wavelengths (deeper structures) blended with a strong contribution of gravity data; c) blend represented by the purple dot shows a blend of DRC filter results with short wavelengths and primary contribution of magnetic data**

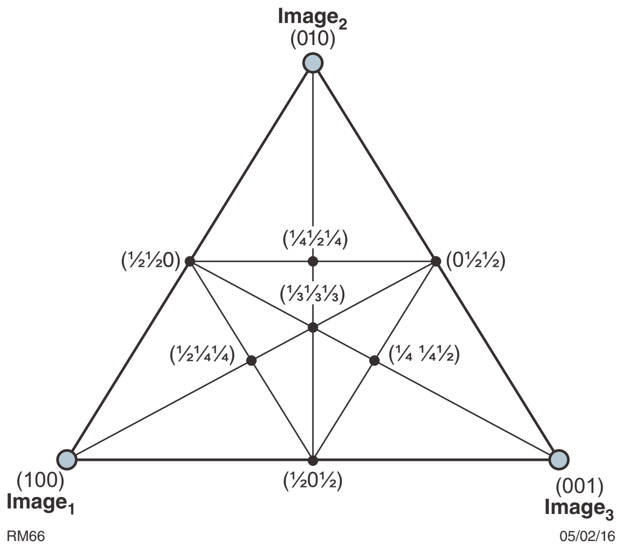


Figure 8. **Barycentric coordinates of some key locations within a triangle**

The clique blender

This blender is also a novel inclusion that is useful for comparison between arbitrary pairs of image data by moving the blend cursor along a selected line between the pair (Fig. 4). This blender may be particularly useful for data with multiple data bands, such as ASTER. Each of the desired bands for visualisation can be assigned to new blend nodes through dragging-and-dropping datasets onto the '+' node at the top left of the tool. Although there are no set limits on how many datasets are allowed, in practice we recommend at most eight datasets. Beyond this, the clique blending control tool becomes excessively unwieldy and complex to use.

The image wheel blender

This blender uses the distance to the centre and polar angle of the blend cursor to calculate the blending weight for each of the blending nodes around the edge of the circle. The average of all datasets is represented with the blend cursor at the centre of the circle (Fig. 5). Any number of datasets can be added to the blend tool by dragging-and-dropping datasets onto the '+' node at the top left of the tool. However, it is not recommended to exceed five datasets, due to the difficultly in visually comprehending the associations between individual datasets and the blend result. This blender may be particularly useful for visualising datasets with an intrinsic orientation component, such as orientation-angle-filtered magnetic data that identifies structures of particular orientation.

The parameter linear blender

This blender provides a rapid interactive view of data that have been filtered in some way over a range of different parameter values. Presented as a horizontal line, moving the blend cursor along the line will result in a blended image with results from different parameter values (Fig. 6). The left-most position represents the smallest value of the parameter, whereas the right-most position represents the largest. This blender is particularly useful for identifying variations of features from the output of the DRC algorithm.

The parameter bilinear blender

This blender extends the concept of a linear blender to two axes and allows for blending between two datasets that have been filtered over the same range of parameter values. The horizontal axis is used to blend between the two datasets, whereas the vertical axis is used for blending between filter outputs across parameter values. A typical use case is combining the DRC filter results of the same wavelength range over gravity and magnetic data (Fig. 7). In this case, the horizontal axis blends between gravity and magnetic filter results, and the vertical axis blends between variations in wavelength parameter values.

3D blending techniques

Additional blending tools cater for cross-section data and 3D volumetric data. By design, the following blenders move away from pure blend-weighting manipulation, but still exploit the use of 'interactivity' for data interrogation appropriate for the addition of the third dimension. These blenders utilise interactive manipulation to control various visualisation behaviours. In most cases, interactive sliders are used to set a parameter between 0 and 1, which is used to determine the extent of the behaviour specific to the blender.

The cross-section data blender

This blender allows for 2.5D cross-section data to be visualised along with plan-view data (Fig. 9). 2D plan-view datasets are added to the centre circle and blended in the same way as the image wheel blender. However, cross-section datasets are loaded into the bottom row and are manipulated through the two vertical sliders: the left slider controls the vertical offset rendering position, and the right slider controls the vertical exaggeration of the cross-section data. The blender is currently limited to four cross-section datasets, and five plan-view datasets, otherwise it would become too crowded and unwieldy.

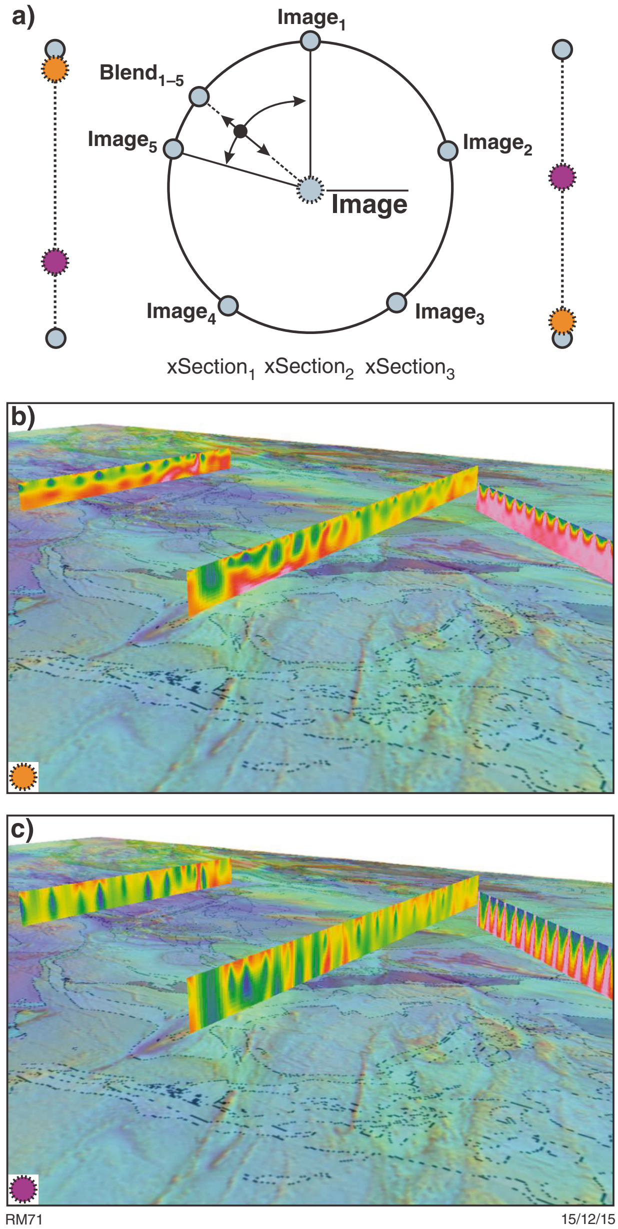


Figure 9. The cross-section data blender, for visualising cross-section data with blended plan-view data: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool; b) result of blends represented by the two orange dots corresponding to the vertical offset and exaggeration used; c) result of blends represented by the two purple dots corresponding to the reduced vertical offset and larger exaggeration used

The single 3D data blender

This blender is designed to allow for intuitive interrogation of a single 3D volumetric dataset. The blender provides nine different *Blending modes* for visualisation, as well as options to choose the *Data field* currently displayed (in cases where the 3D volumetric data contains multiple fields of data), and the *Voxel display mode* used to render the voxels (*Point*, *Cube*, or *Wireframe*). The nine visualisation modes and how they are interactively controlled are described by the following:

- Thresholded by Value (Fig. 10) – voxels are only shown if they have a value above the threshold limit determined by the interactive slider. This mode is useful for visualising the spread of values and the spatial correlations of data values.
- Thresholded by Value Range (Fig. 11) – the voxels are offset above the volume if they have a value within the threshold range, determined by the left and right limits of the interactive sliding box. The voxels outside of the range are rendered in greyscale below the offset voxels. This mode is useful for visually exploring clustering of values.
- Thresholded by Axis (Fig. 12) – voxels are only shown if their location is above or below, depending on the selection of a positive or negative axis respectively, the threshold for the position of the voxel. This threshold is determined by the interactive slider. This mode is useful for quick overall comprehension of the volume, visualised in a cutaway type manner.

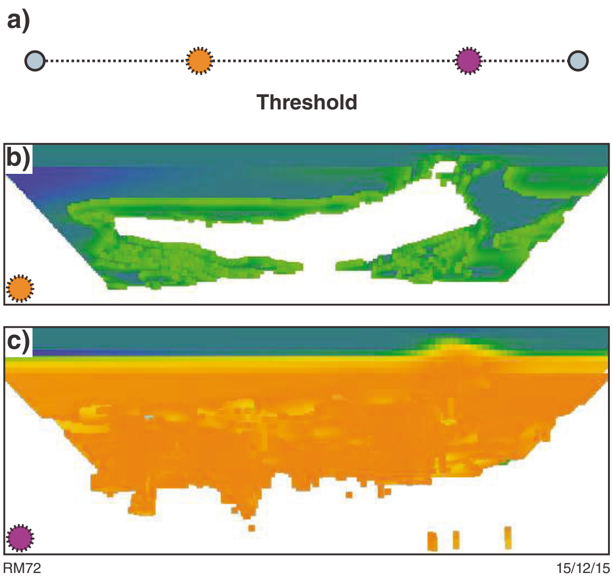


Figure 10. The single 3D data blender, threshold by value mode, for visualising the spread of data values within a 3D volume of data: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool; b) result of blend represented by the orange dot corresponding to the threshold limit on data values for voxels to be shown; c) result of blend represented by the purple dot corresponding to the higher threshold limit on data values for voxels to be shown

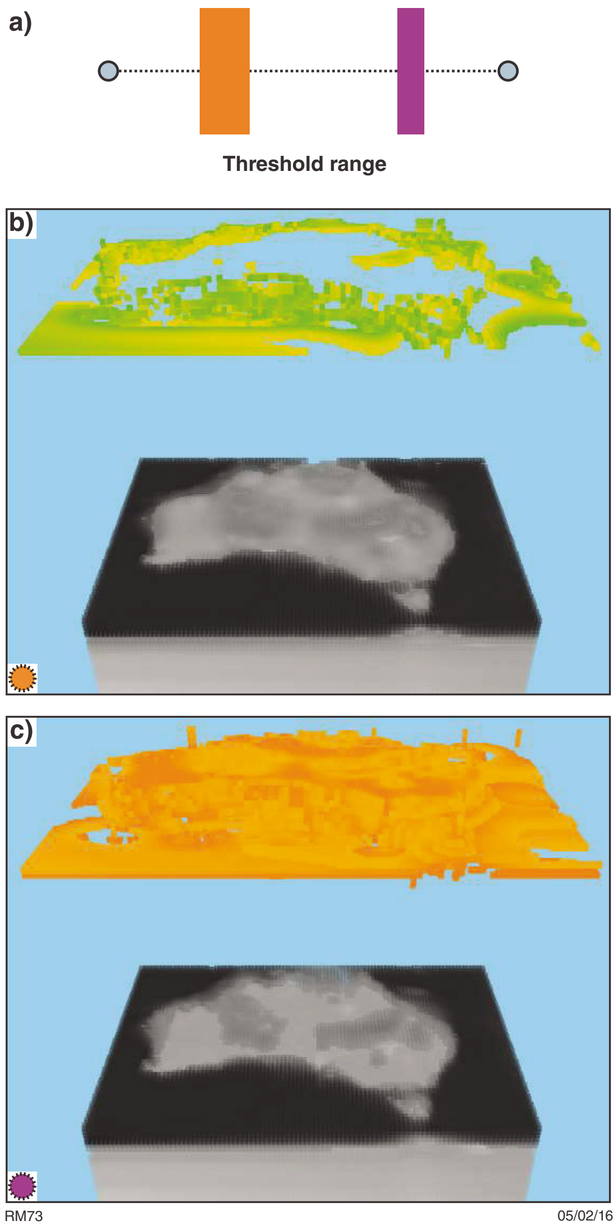


Figure 11. The single 3D data blender, threshold by value range mode, for visualising the clustering of data values within a 3D volume of data: a) two different blending combinations are shown with the orange and purple box symbols in the blender tool, indicating the range of values shown; b) result of blend represented by the orange threshold range with the voxels with valid data values shown; c) result of blend represented by the purple threshold range with the voxels with valid data values shown

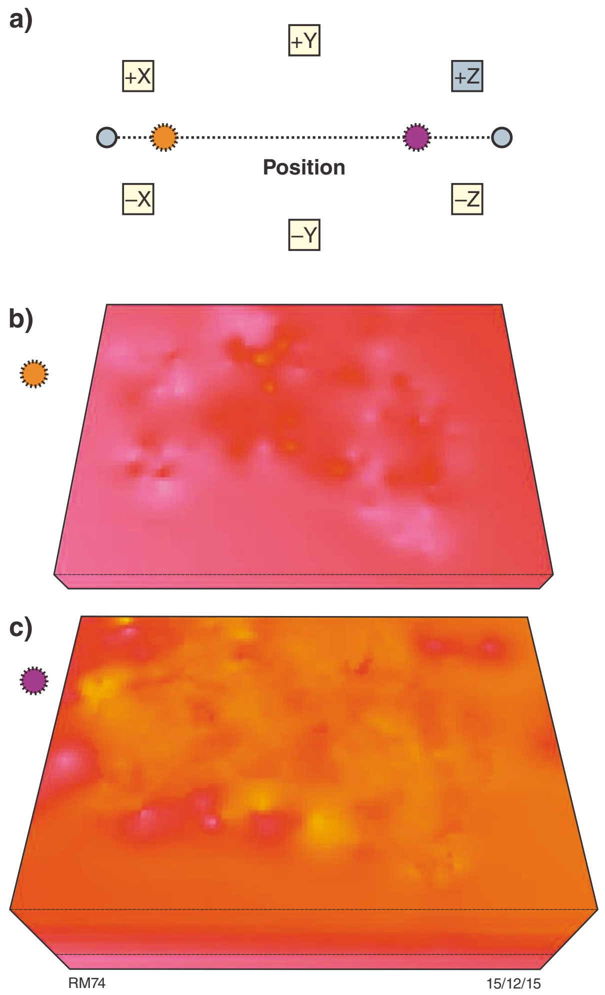


Figure 12. **The single 3D data blender, threshold by axis mode, for visualising planes of data within the 3D volume: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the position to threshold data along the Z axis in the positive direction; b) result of blend represented by the orange dot corresponding to the threshold limit of voxel position; c) result of blend represented by the purple dot corresponding to the higher threshold limit of voxel position**

- Slice Book (Fig. 13) – three slices of data, along the chosen axis direction, indicate visualisation planes fixed in the frame of reference, and the 3D dataset is moved through the slices, controlled by the position interactive slider. Fixing the visualisation planes allows for a fixed point of reference to observe how the data change along the chosen axis. The distance between slices is controlled by the separation interactive slider. This mode is useful to show the data variations at a fixed point of reference (the three slices), which is an effective way to visualise how data change as the data are stepped through.

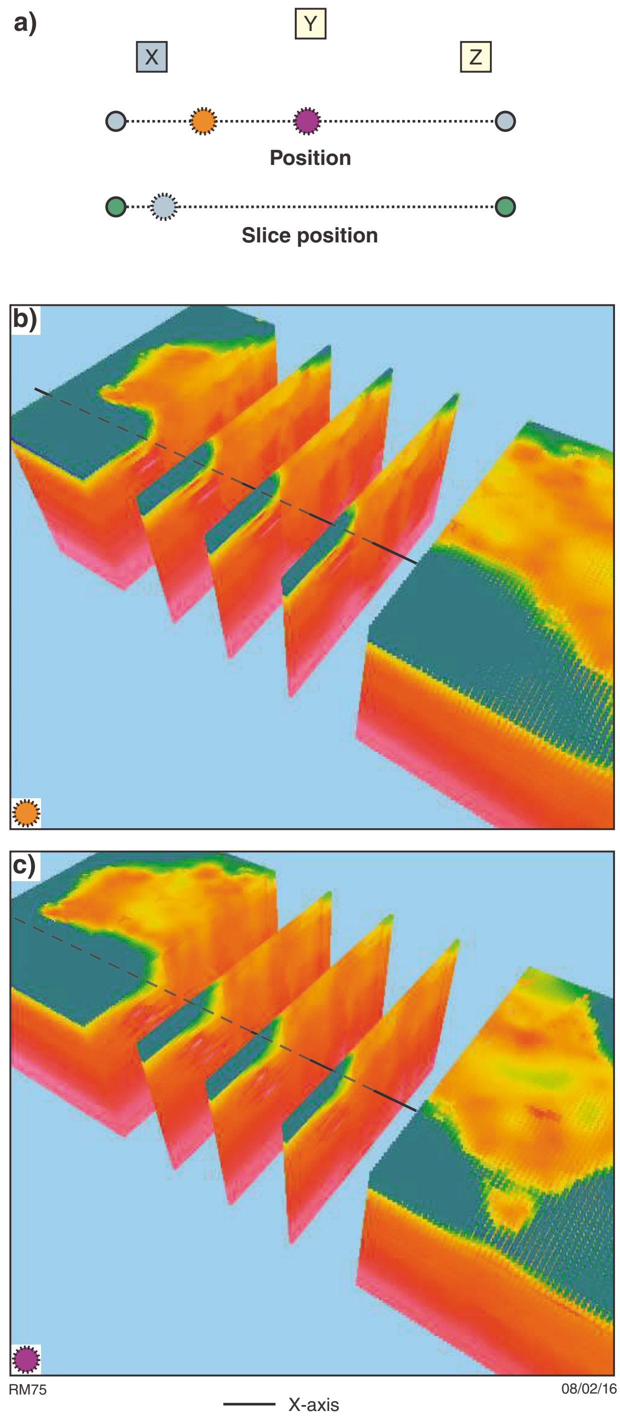


Figure 13. **The single 3D data blender, slice book mode, for visualising the change within 3D data at a three fixed points of reference: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the position of data in the X direction. Note that the slice separation distance is fixed for both examples; b) result of blend represented by the orange dot that determines the position of the data shown on the three slices; c) result of blend represented by the purple dot that determines the position of the data shown on the three slices**

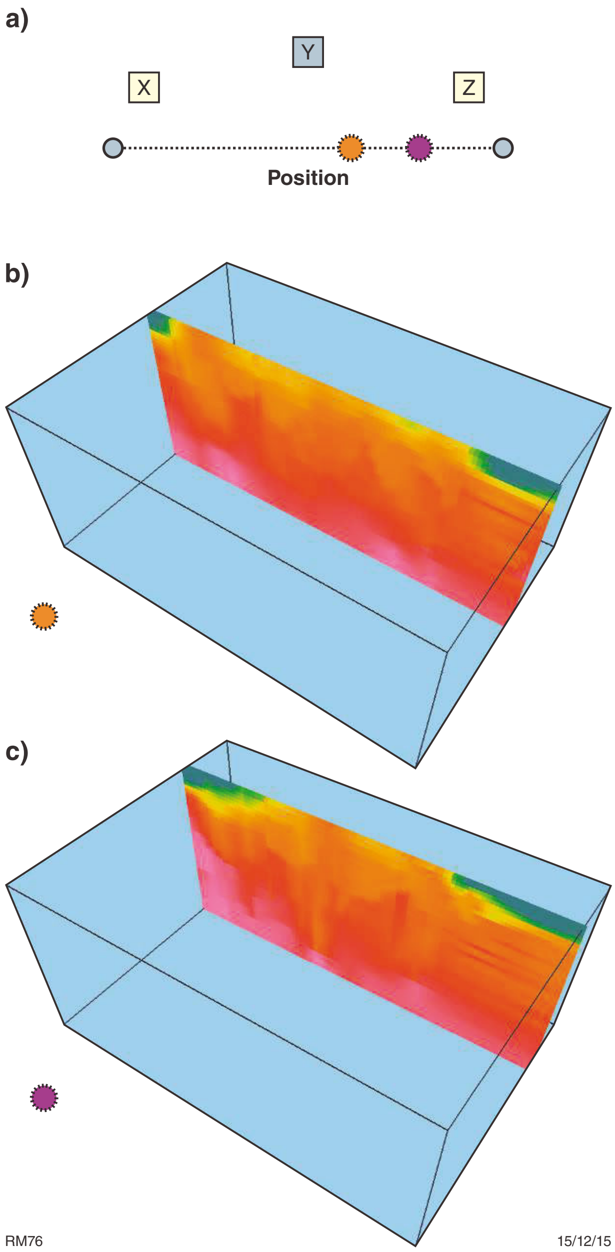


Figure 14. The single 3D data blender, single slice internal mode, for visualising a single slice of data shown within the outline of the 3D volume: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the selection of the Y-plane slice of data; b) result of bend represented by the orange dot that determines the position of the data slice shown; c) result of blend represented by the purple dot that determines the position of the data slice shown

- Single Slice Internal (Fig. 14) – a single slice of data is shown within the outline of the volume. The slice shown is selected by the interactive slider (in the chosen axis direction). This mode is useful for an isolated and unobstructed view of data.
- Single Slice Offset (Figure 15) – a single slice of data is shown offset above the volume (rendered in greyscale). The slice shown is interactively selected by the slider, along the chosen axis direction. This mode is useful for an unobstructed view of data while maintaining some context with the rest of the data.
- Double Slide Offset (Fig. 16) – two perpendicular slices are shown offset above the volume (rendered in greyscale). The slices shown are chosen by the blend cursor position in the blend box, which determines the position of the X and Y intersection of the slices. This mode is useful as an interactive, cutaway visualisation, providing context between two planes of data.
- Column Data Mode (Fig. 17) – displays a 3D 'column' of data, aligned along the chosen axis direction, located interactively by the blend cursor in the blend box. The additional horizontal slider determines the width of the column. This mode is useful for viewing data along an axis in a 3D manner, with the curvature of the column providing 3D context of the surrounding data.
- Sphere Data Mode (Fig. 18) – displays a sphere of data at the location specified by the blend cursor position in the blend box. The blend cursor determines the location of the centre of the sphere in the X–Y plane. The location of the sphere in the Z direction (the height of the sphere in the frame) is controlled by the vertical interactive slider. Lastly, the radius of the sphere is controlled by the horizontal interactive slider. This mode is useful for viewing data within a volume in a 3D manner, with the curvature of the sphere providing good 3D context of the data.

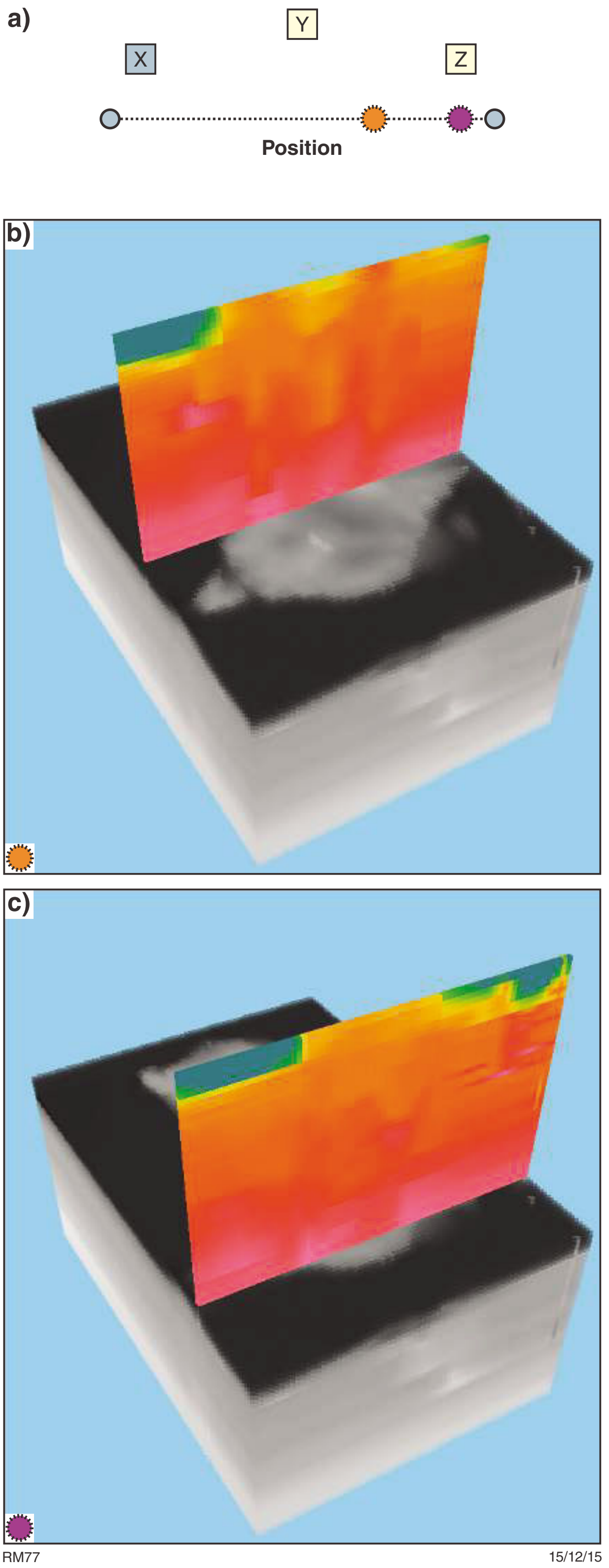


Figure 15. The single 3D data blender, single slice offset mode, for visualising a single slice of data shown offset above the 3D volume: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the selection of the X-plane slice of data; b) result of blend represented by the orange dot that determines the position of the data slice shown; c) result of blend represented by the purple dot that determines the position of the data slice shown

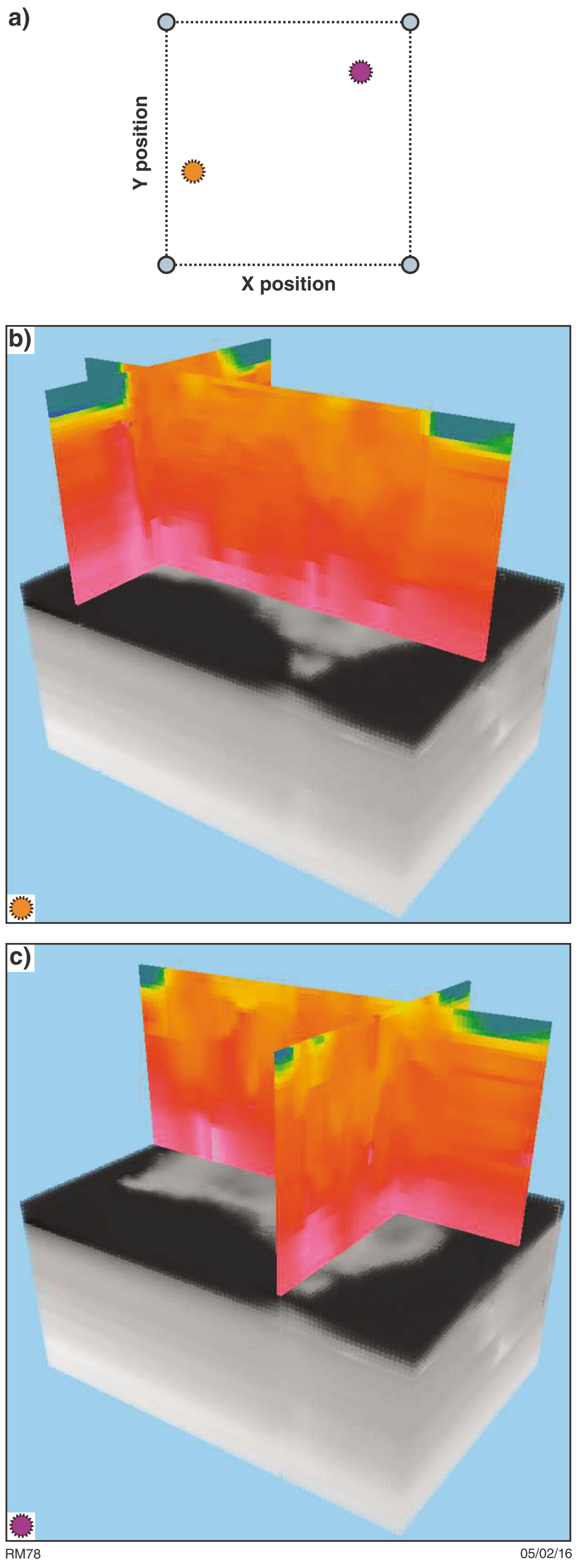


Figure 16. The single 3D data blender, double slice offset mode, for a cutaway-like visualisation of two perpendicular slices of data, which are shown offset above the 3D volume: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the intersection of the two data slice; b) result of blend represented by the orange dot that determines the positions of the two data slices shown; c) result of blend represented by the purple dot that determines the positions of the two data slices shown

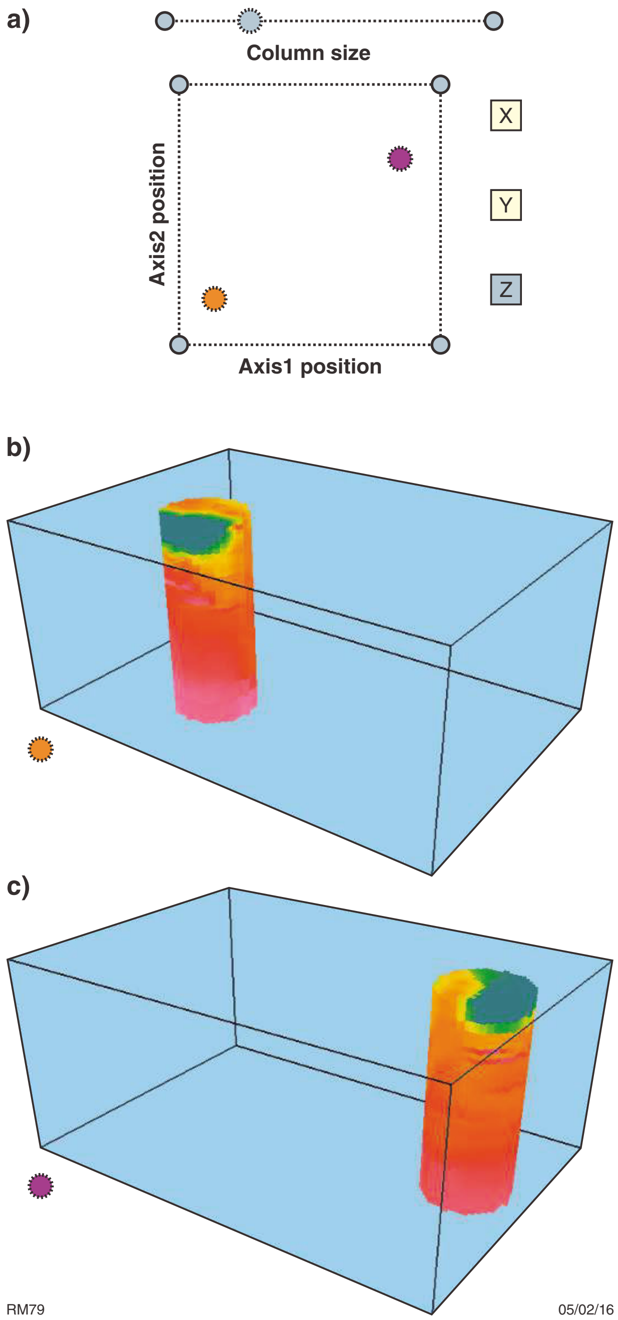


Figure 17. The single 3D data blender, column data mode, for visualising a 3D column of data within the outline of the 3D volume: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the location of the Z-aligned column of data. Note that the column size is fixed for both examples; b) result of blend represented by the orange dot that determines the position of the data column shown; c) result of blend represented by the purple dot that determines the position of the data column shown

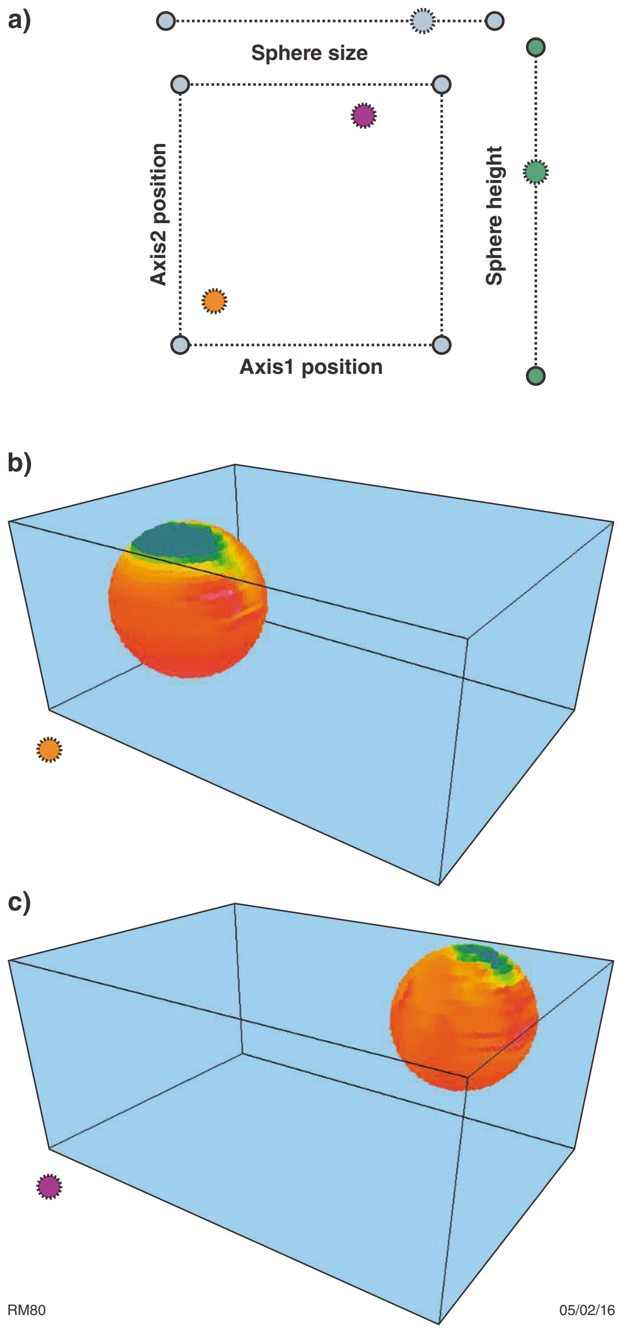


Figure 18. The single 3D data blender, sphere data mode, for visualising a 3D sphere of data within the outline of the 3D volume: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the location of the sphere of data. Note that the sphere size and height are fixed for both examples; b) result of blend represented by the orange dot that determines the position of the data sphere shown; c) result of blend represented by the purple dot that determines the position of the data sphere shown

The dual 3D data blender

This blender is designed to allow for visual comparison between two 3D volumetric datasets, such as multiple results from parameter variations in the 3D inversion process. Currently, the input 3D volumetric datasets are presumed to have the same dimensions and same number of data fields. Similarly to the single 3D data blender, this blender provides options for different *Blending modes*, the *Data field* shown, and the *Voxel display mode* used to render the voxels (*Point*, *Cube*, or *Wireframe*). The dual blender has three visualisation modes and the effects of the interactive controls are described by the following:

- Thresholded Range Similarity (Fig. 19) – the range of voxel values compared between the two 3D datasets is restricted to those that lie within the threshold range of data values. The range of values is determined by the left and right limits of the interactive sliding box. Furthermore, the voxels are coloured according to differences between data values using a rainbow colour map, whereby cooler colours indicate small discrepancies (strong similarity), and hotter colours indicate large discrepancies (weak similarity). These voxels can be further thresholded by the lower interactive slider that determines the limit of acceptable difference (i.e. degree of similarity) to display similar voxels. Note that a slider value at the highest acceptance of similarity will include all voxels within the range, since the difference limit of the lower slider is set to the maximum difference of values within the specified range. Thus, as the threshold range of values is adjusted, the maximum difference is recalculated and used as the limit of the lower slider. This mode is useful for comparing 3D regions within similar 3D models, such as those from a 3D inversion process.

- Single Slice Similarity (Fig. 20) – the voxels compared between two 3D datasets are restricted to the slice specified by the upper interactive slider, along a chosen axis direction. Similarly to the Thresholded Range Similarity mode, the voxels are coloured according to the differences between data values with a rainbow colour map. These voxels can be further thresholded by the lower interactive slider that determines the limit of acceptable difference (i.e. degree of similarity) to display similar voxels within the data slice. In this mode, the lower interactive slider is relative to the maximum difference across all data values within the two datasets (as opposed to being restricted to within the range compared). Thus, voxels of the deeper colour indicate the voxels with stronger difference between the models, and ‘missing’ voxels indicate unacceptable level of similarity (i.e. values are too different to be considered similar). This mode is useful for comparing slices of data within similar 3D models, such as those from a 3D inversion process.

- Single Slice Blend (Fig. 21) – two slices of data are displayed in a blended manner, one slice from each 3D dataset at the same equivalent location. The data slices shown are selected by the interactive slider, along the chosen axis direction. Note that one data slice is shown offset to be ‘in front’ of the other slice in order for the blending to work correctly. The blend weighting of the ‘front’ data slice is determined by the lower interactive slider. Since the blended slice is only shown in front of the other data slice, there may be viewing angles where the blend is not visible; for example, from behind the non-blended data slice as it obscures the view of the blended front slice. This mode is useful for comparing slices of data in a blended manner for two different 3D volumes.

a)
b)
c)

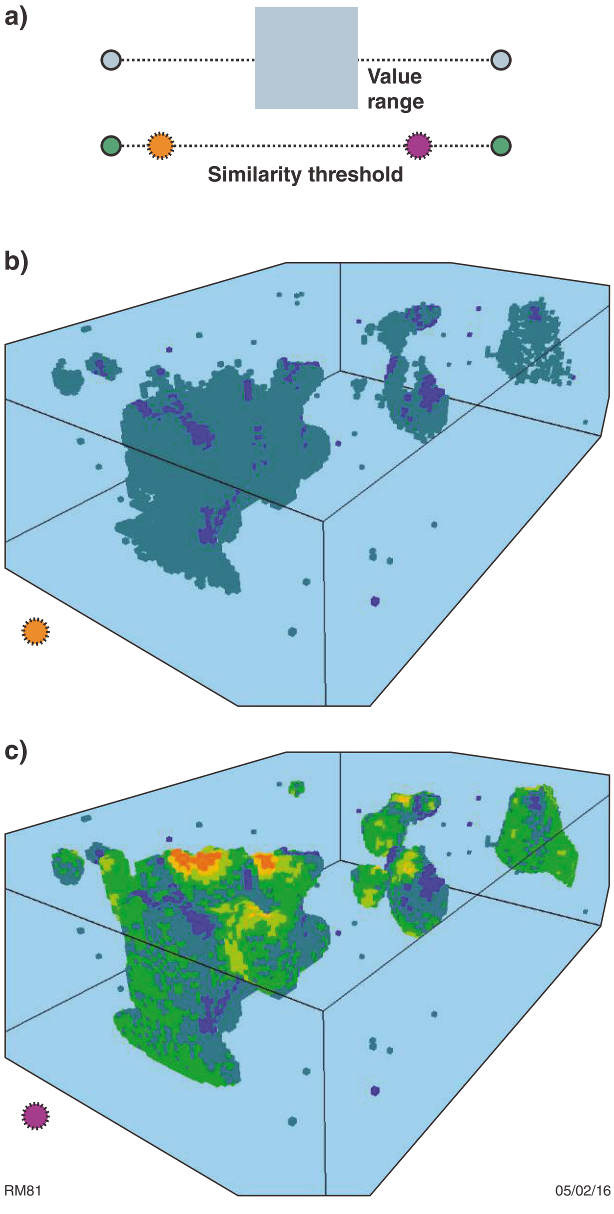


Figure 19. The dual 3D data blender, thresholded range similarity mode, for comparing voxels with similar data values, within a specified threshold range across two 3D volumetric datasets: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the limit of acceptable similar data values. Note that the threshold value range is fixed for both examples and cooler colours indicate strong similarity; b) result of blend represented by the orange dot that determines a harsh similarity limit; c) result of blend represented by the purple dot that determines a more relaxed similarity limit, with hotter colours indicating strong discrepancy of values

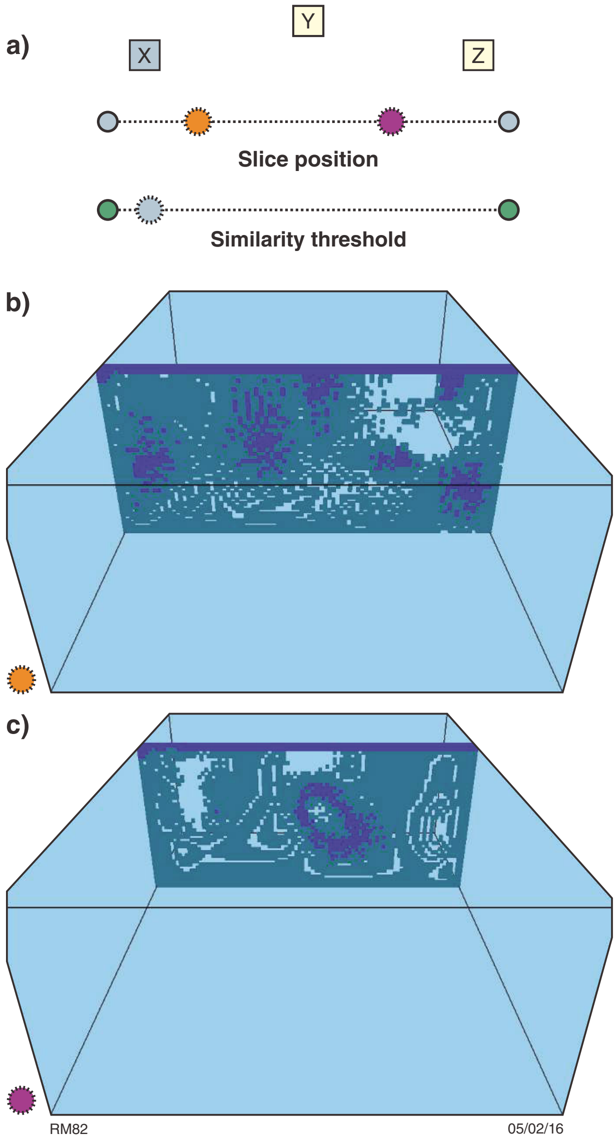


Figure 20. **The dual 3D data blender, single slice similarity mode, for comparing voxels with similar data values, within a slice of data across two 3D volumetric datasets: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the position of the X-plane slice of data to compare. Note that the similarity threshold is fixed for both examples, meaning missing voxels have values above acceptable similarity.; b) result of blend represented by the orange dot that determines the position of the data slice shown; c) result of blend represented by the purple dot that determines the position of the data slice shown. Deeper colours indicate stronger similarity**

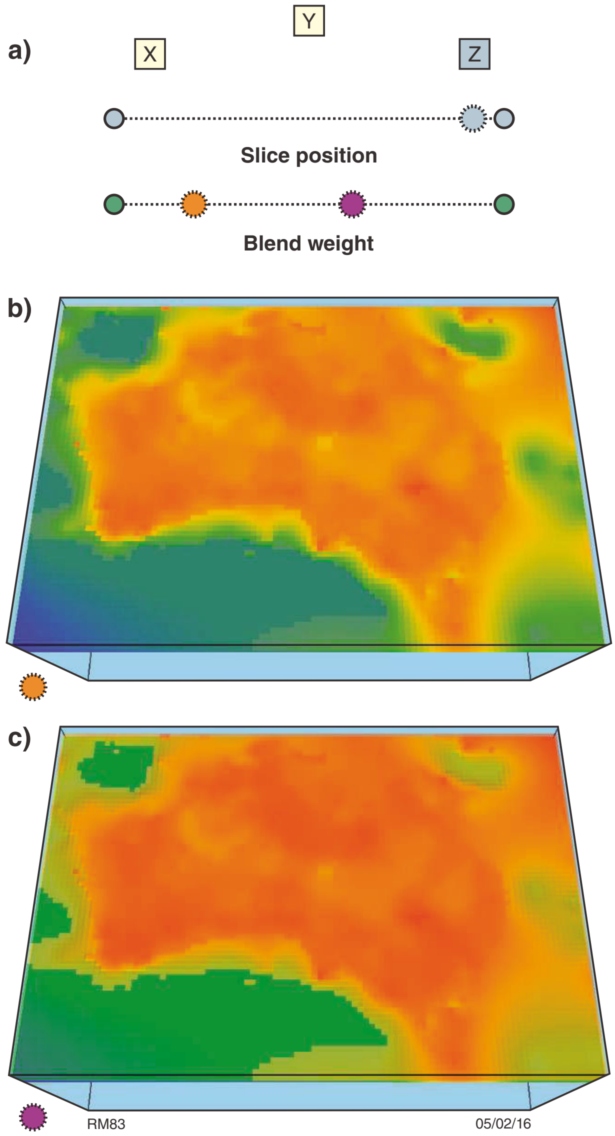


Figure 21. **The dual 3D data blender, single slice blend mode, for blending two slices of data at the same position across two 3D volumetric datasets: a) two different blending combinations are shown with the orange and purple dot symbols in the blender tool, specifying the blending weight for the Z-plane slice of data. Note that the slice position is fixed for both examples and the change of the blend weight only affects the data slice on top; b) result of blend represented by the orange dot that determines a blend with strong contribution from the first dataset slice; c) result of blend represented by the purple dot that determines a blend with a slightly stronger contribution from the second dataset slice**

Interpretation annotation tools

A novel schema has been implemented in the IEP to provide an effective interface for interpretation annotation. This approach focuses on ease of use and intuitive handling for creating and editing features, along with effective interfaces for comparison and management of custom attributes (Fig. 22). Some annotation features include:

- right mouse button drag selection that automatically transitions the system into edit mode
- only allowing selection of features belonging to the currently selected feature group
- setting custom group level attributes with optional default values as a template for features
- simple interface to traverse features attribute values
- a novel slider paradigm used to select features based on a sortable criteria (such as order of creation, annotated age, orientation, etc.).

Selecting and editing interpretation features

One of the novel features of the IEP interpretation annotation system is that the traditional editing mode is switched on and off by context. Instead of explicitly entering an 'edit mode', the IEP determines that an interpretation feature can be edited when it is selected. If an interpretation group is selected, and no feature is selected, then the IEP is automatically in feature creation mode. This aims to streamline the process of interpretation annotation, removing the need to micromanage the editing and creation modes.

The selection of interpretation features has been designed to be restricted to a currently selected interpretation group. In other words, features from the other groups are 'protected' from unintentional edits. Furthermore, the IEP introduces a mouse-drag selection schema, removing the need to click within an ambiguous distance of features to select them. To provide further ease of use where features are closely located, drag selection will select the feature that is contained 'the most' (calculated with a heuristic of the number of points enclosed, and the number of line segments intersecting the edges of the selection box) within the drag-select box. This removes the need for drag selection accurate to within a pixel to select the desired feature, especially for overlapping features. Once a feature has been selected, an additional mouse drag will select control points within the features, allowing for further finesse in editing.

Custom attributes for interpretation features

Custom attributes are added at the interpretation group level, meaning all features created as part of the group will inherit these attributes. Custom attributes can be one of three data types: strings, integers or floating point numbers. Custom attributes can also be optionally given a default value that is applied to all existing and created features belonging to the group. Note that when adding, removing or adjusting attribute properties on an existing interpretation group, the IEP will synchronise attribute updates to all existing interpretation features within the group.

Another feature in the IEP is the ability to quickly sort features by value of a custom attribute. This sorting is, by default, the feature creation order, but can be applied to any custom attribute. For example, it may be useful to sort by a feature attribute such as age, dip, strike, etc. A slider bar is used to quickly navigate through the sorted features, which also selects (and highlights) the features in real-time, providing a way to visualise the sorted ordering of features in a spatial manner.

Lastly, the IEP provides a dialog window specifically for displaying all attribute values of an interpretation feature, or for comparing all values of an attribute across all existing interpretation features, in a single list. Features can be traversed in a similar manner to the sorting slider bar, which provides a quick way to compare attribute values across features. Furthermore, comparison across all features is quickly accessed through a drop-down list of attribute fields. Such functions may be useful for quickly identifying empty or outlier attribute values. Feature attribute values can also be adjusted through this dialog window.

Interpretation assistive tools

The IEP utilises an interpreter-driven and computer-assisted approach in providing tools to assist with the process of interpretation. In particular, the IEP provides data evidence feedback on user-generated interpretation lines (Holden et al., 2016). This is achieved through automated lineament detection techniques, phase symmetry (Kovesi, 1997) for ridges and valley feature detection, and phase congruency (Kovesi, 1999) for edge detection. These techniques are applied to geophysical grids (most commonly magnetic data) and detect features by analysing the phase of the geophysical signal. Figure 23 illustrates how the phase symmetry of a signal can identify ridge and valley features, and how phase congruency can identify edges in a signal.

Using these techniques, feature evidence layers can be generated in the IEP from a number of user-selected source datasets. Each generated feature evidence layer can be linked and applied to an interpretation layer in two specific ways to assist interpretation. Firstly, the feature evidence layer can provide a quantitative measure of confidence on interpreted lines based on automated feature analysis results. This measure may be useful as an uncertainty indicator for interpreted structures used in 3D inversion modelling processes. Secondly, the feature evidence layer can be visualised as feature strength in context of interpreted lines to facilitate data-supported interpretation.

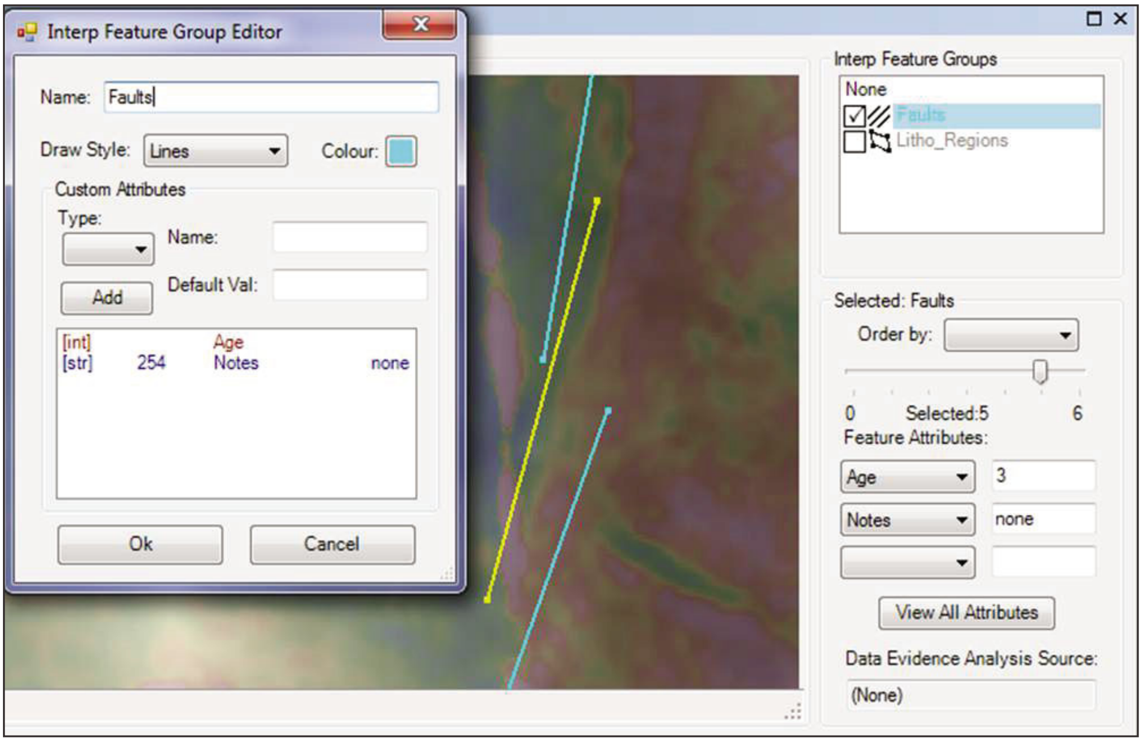


Figure 22. Some of the interfaces associated with interpretation annotation in the IEP. The schema implemented is an attempt to favour ease of use for effective annotation interpretation.

Quantitative measures of feature evidence

Quantitative measures of feature strength (from phase symmetry or phase congruency responses) are calculated from the feature evidence layer and are presented to the user through a status message in the lower left corner of the display area. These measures are updated as the user-controlled mouse cursor is hovered near an interpretation line.

The measures represent the feature evidence of structural interpretation lines and are quantified by aggregating the feature response strength (values between 0 and 1) along the interpretation line for each of the three feature types; i.e. ridges (positive phase symmetry responses), valleys (negative phase symmetry responses), and edges (positive phase congruency responses). These aggregated values are then normalised by the length of the interpretation line, to produce a measure between 0 and 1.

Given that real geophysical data will inevitably be influenced by noise, response values approaching 1 from phase symmetry or congruency are highly unlikely, since it is implausible that real data will exhibit pixel-perfect phase symmetry or congruency. Empirically, unaltered values of 0.1 are already considerable feature responses. Thus, the quantitative measures presented to the user have been transformed by a cube-root function, boosting areas with responses that are considered to have strong feature evidence. For example, the aforementioned unaltered value of 0.1 will be boosted to 0.4642. This transform has the effect of offsetting human bias so that evidence measures that are more representative of the feature evidence strength can be effectively communicated. Examples of the effect of the transform on selected features are shown in Table 1. Note also that the visualisation of feature evidence uses the unaltered values.

These quantitative feature evidence measures can also be forwarded to 3D inversion modelling processes using interpretation structures. These measures provide a mechanism to indicate the level of uncertainty with each interpretation line, which can then feed into quantifying the understanding of uncertainty, or the geodiversity, of the inversion model (Lindsay et al., 2013).

Visualising feature evidence

Feature evidence layers can also be visualised in an interactive way to support the structural interpretation of geophysical data. However, it is not a trivial task to present feature evidence in a way that does not obscure the original data the interpreter is viewing, but rather enhances the original data with feature evidence. We present a novel visualisation method, the *Data overlaying* method, which combines the original data with the feature evidence (unaltered values) into a single coloured representation that honours both contributing components.

Table 1. Comparison of quantitative feature evidence values

Interpreted structure	*Unaltered values: ridges / valleys / edges*	*Transformed values: ridges / valleys / edges*
Dyke – FID 285	0.0197 / 0.0203 / 0.0399	0.2701 / 0.2727 / 0.3417
Shear – FID 444	0.0316 / 0.0302 / 0.0489	0.3161 / 0.3114 / 0.3657
Fault – FID 620	0.1010 / 0.0719 / 0.2454	0.4657 / 0.4158 / 0.6260

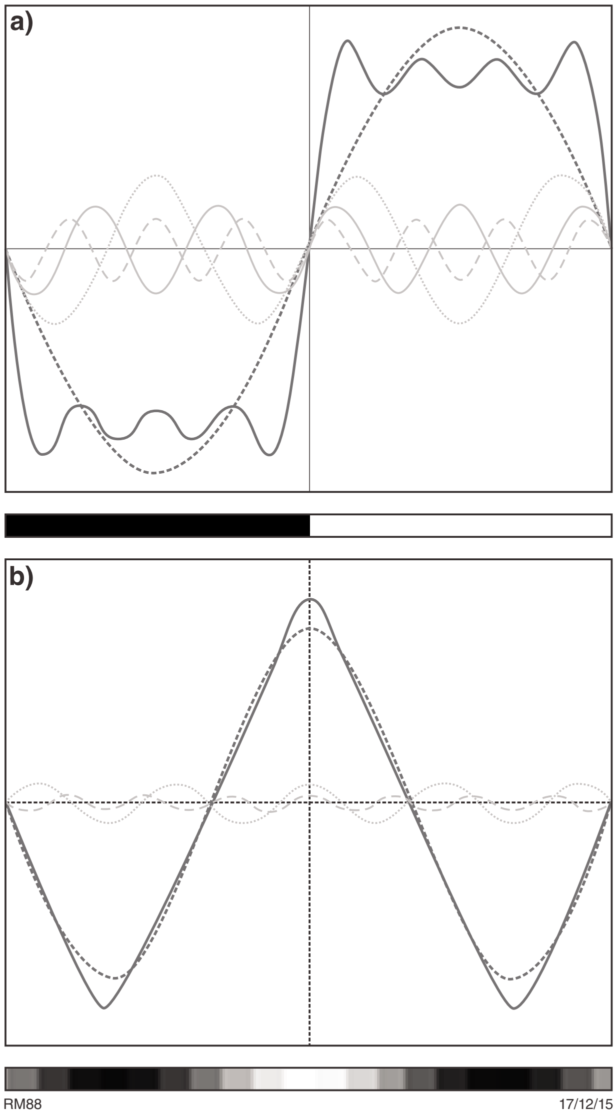


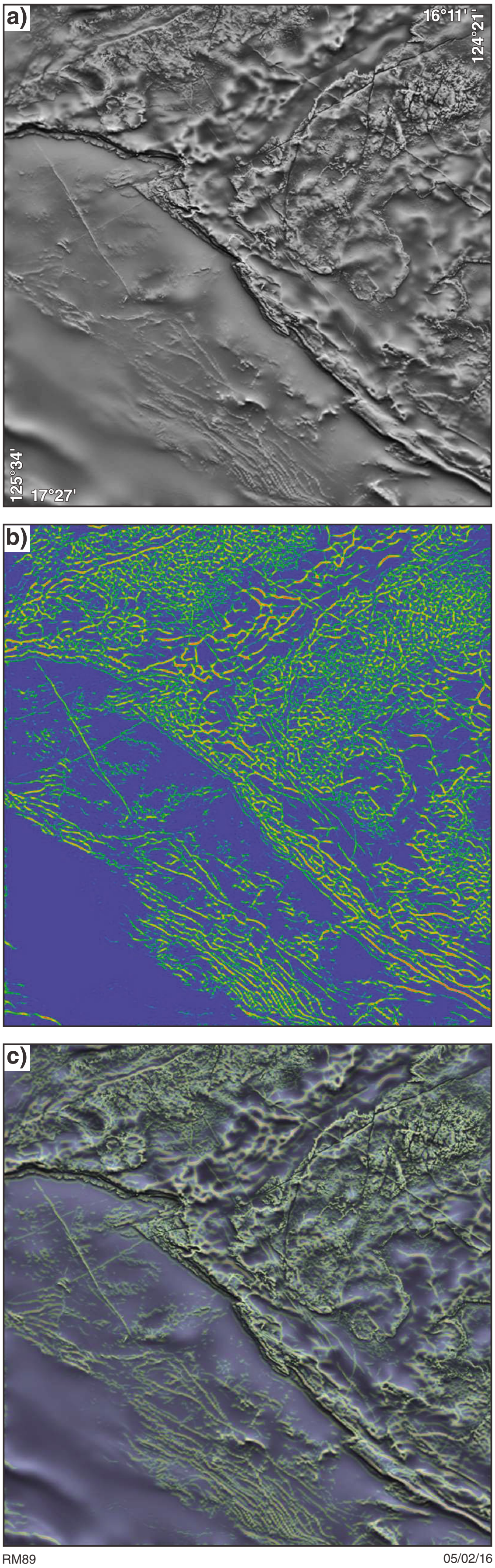
Figure 23. Illustration of how the Fourier components of a geophysical signal can be used to identify ridges, valleys, and edges. The top row shows two example 1D profiles of grid data: a) a step edge from low to high intensity; b) valley–ridge–valley features. Corresponding plots of these profiles are shown in solid lines. The waveforms of these profiles can be decomposed into their Fourier components (plotted as dashed lines). Note that points of positive and negative symmetry of phases of components indicate ridge and valley features respectively, and points of congruency in phase of the components indicate edge features (adapted from Kovesi, 1999).

This method is used in two visualisation modes: the field-of-view mode called *Spolight* mode, and vector-based mode called *On lines* mode. These two visualisation modes are discussed in more detail in the following sections. Additionally, a third visualisation mode, the *Full map* mode, provides the means for unaltered visualisation of the feature evidence (though obscuring the original data).

The data overlaying method

This method utilises the principles of chromaticity and luminance to combine information from both the originally viewed data and feature evidence layer. More specifically, the hue component is derived from the feature evidence data and the luminance component is derived from the viewed data. This means that the colour of a pixel is determined by the feature evidence (coloured with an isoluminant rainbow colour map to avoid false anomalies due to differing colours): cool colours represent low feature evidence (unaltered values of 0 show dark blue), and hot colours represent strong feature evidence (unaltered values of 1 show bright pink). Complementary to this, the intensity of the colour is determined by the viewed geophysical data, with darker colours representing low geophysical signal strength, and brighter colours representing high geophysical signal strength. For this reason, the viewed geophysical data should be displayed with a greyscale colour map (to provide correct luminance contributions). An example of this data overlaying method combining information from both geophysical data and feature evidence is shown in Figure 24. Further visualisation control is provided through interactively modifying parameters to control the strength of luminance and the polarity of the luminance signal. Both of these controls help account for different geophysical data characteristics, allowing for user control over the emphasis of the data on luminance. Furthermore, strong feature evidence may occur in low data intensity (thus causing low luminance and darkened colours). In this case, an option to invert the luminance polarity is provided, so that the user can quickly switch between normal or inverted luminance (Fig. 25) in order to reveal strong feature evidence in low luminance areas.

Figure 24. (right) The novel data overlaying visualisation method for combining the original evidence source data with the resulting data evidence layer: a) dynamic range compression filter result of magnetic data used as the source for the data evidence analysis; b) resulting data evidence layer for ridges (positive phase symmetry); c) resulting data overlay visualisation method that combines the information from the source data via the luminance component, and the data evidence layer via the hue component.



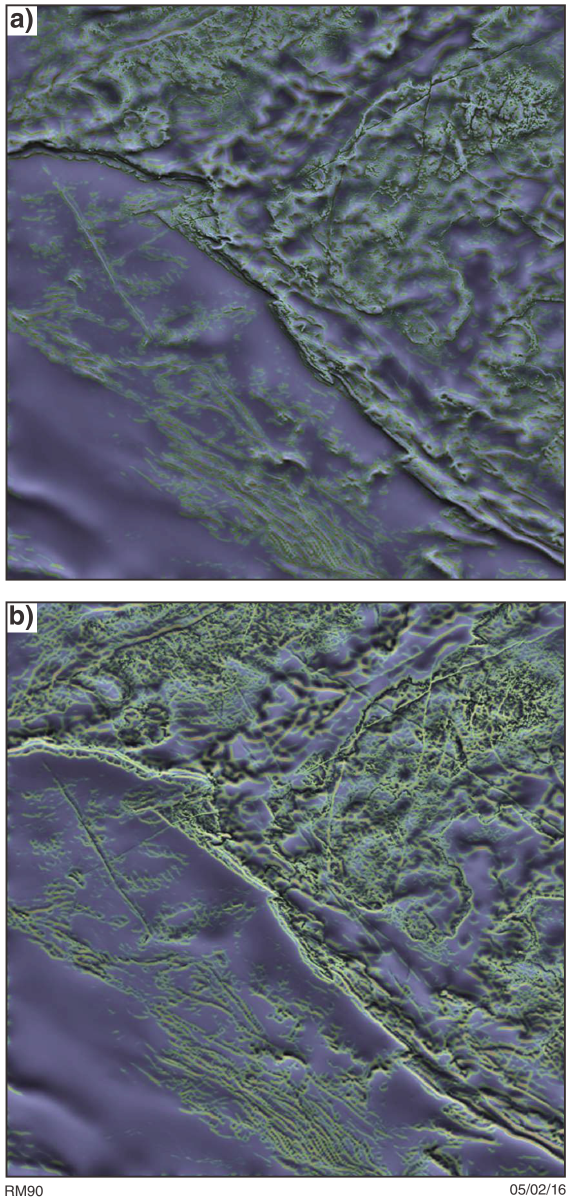


Figure 25. (above) The inversion of luminance component of the source data in the data overlaying visualisation method: a) data evidence layer for valley features combined with positive luminance polarity of the source data. Since many of the valley features are located in areas of low intensity in the source data, the resulting colours are subdued; b) inverting the luminance polarity effectively reveals valley feature evidence that is now combined with strong luminance.

The spotlight visualisation mode

This mode provides an interactive exploring tool that uses the data overlaying method only within a radius (spotlight) from the mouse cursor, creating a circular field of view (FoV; Fig. 26). This FoV of combined geophysical data and feature evidence visualisation is updated in real-time as the user moves the cursor, resulting in an intuitive tool to quickly compare regions with and without data evidence. In particular, this mode is effective in verifying the extent of interpretation lines over a feature by revealing if the feature evidence suggests extending or shortening the feature line. This mode is also effective in highlighting areas with strong feature evidence in areas of geophysical data with subtle contrast. The radius of the FoV and the strength of the luminance contribution from the viewed data can be adjusted interactively.

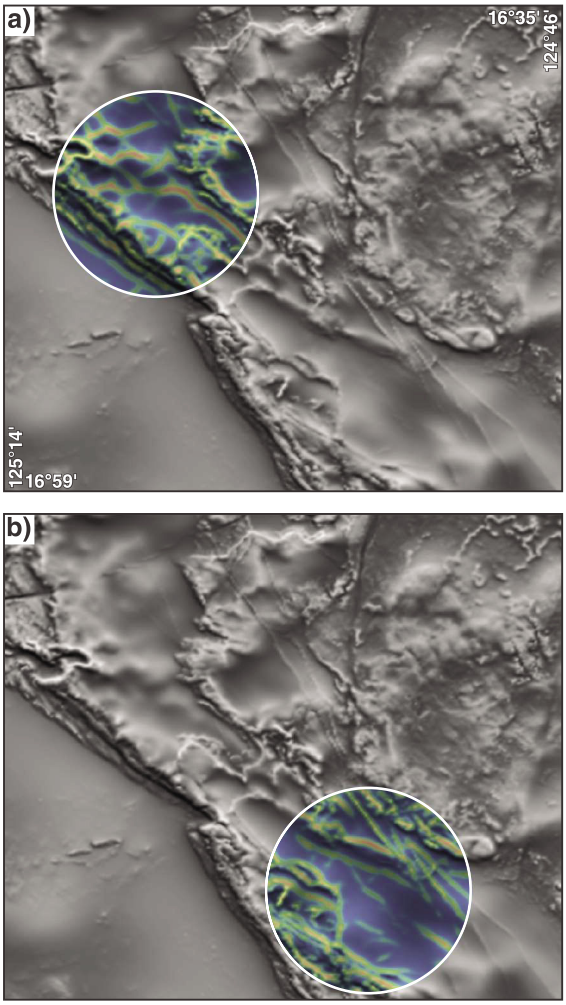


Figure 26. **Two examples of the *Spotlight* visualisation method for data evidence. Comparisons can be made of the corresponding areas between a) and b) where the spotlight area highlights data evidence, and suggestions of features that would otherwise be much more difficult to perceive.**

The on lines visualisation mode

This mode provides a powerful visualisation tool that gives an effective overview of feature evidence simultaneously across all interpretation lines. In this mode, the data overlaying method is applied to a rectangular 'window' along each interpretation line (Fig. 27). The on lines visualisation tool can provide quick assessment 'at a glance' of regions of lines that are strongly or weakly supported by feature evidence. As with the FoV mode, the strength of luminance contribution from the viewed data and the width of the rectangular windows can be adjusted interactively.

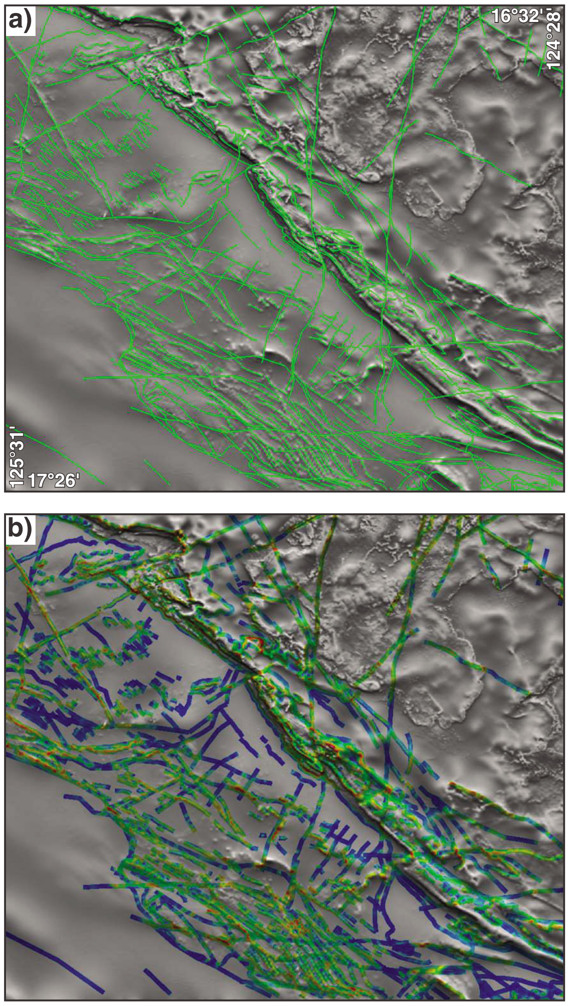


Figure 27. **An example of the *On lines* visualisation method for data evidence: a) annotation of the structural interpretation of the area. For illustration purposes, no distinctions are made between different types of structures; b) the edges data evidence layer shown *On lines*, along each of the interpretation lines, providing an effective overview of areas well supported by the data evidence.**

Getting started

System requirements

The Integrated Exploration Platform (IEP) v2.5 has been tested to run on systems with:

- Windows 7 (32 bit or 64 bit)
- 1GHz processor or faster
- 1GB of hard disk space or more
- 2GB of RAM or more
- DirectX 9 and OpenGL 2.0 compatible graphics card
- ArcGIS version 10.2 or later.

Installation

The IEP runs as a plug-in to ArcMap, and is implemented based on the ArcGIS Add-in framework. Installing the plug-in only requires a single installation file, CET_IEP.esriAddIn. To install the IEP, double click on the installation file on a Windows system installed with ArcGIS version 10.2 or later. The ArcGIS Add-in system will open a dialog confirming permission to install the plug-in. Click on the *Install Add-in* button to finish the installation.

To launch the IEP interface, open ArcMap. Then find the *Launch CET IEP Interface* command by clicking on the following menu items:

Customise → Customise Mode … → Commands (Tab) → CET Tools

Once located, drag the *Launch CET IEP Interface* command button to the ArcMap tool bar. Clicking on this command button will launch the IEP interface.

Interface overview

Figure 1 (see p. 3) shows the IEP interface, which consists of five main panels:

1. The dataset manager

   This area is used to manage the datasets that are added to the IEP interface. Datasets are added by dragging from the Catalog panel (within ArcMap), from the ArcMap table of contents, from ArcCatalog, or from Windows Explorer onto this list area. Datasets can be removed by a right click on the dataset file name and selecting *Remove data* from the context menu. Selecting a dataset from the list will display that dataset in the main display area.

2. The blend manager

   This area is used to manage the blends that are created. Blends can be created through the context menu accessed by a right click on the blend list panel. Blends can also be removed by selecting the blend, right clicking, and choosing *Remove blend* from the context menu. Blend nodes (the squares in each blend tool) are populated with datasets from the dataset list by dragging-and-dropping the datasets onto the node. The blend cursor (blue dot) controls the blend weighting in each blend tool. Blends can be exported as GeoTiffs via the *Export blend* option.

3. The main display area

   This is the main area used to display datasets, blends, and interpretation annotations. The view can be scrolled as well as zoomed in and out.

4. The interpretation group manager

   This area is used to manage feature groups created or loaded for interpretation annotation. Groups can be created, edited, deleted or saved via the right-click context menu. Existing interpretations (shapefiles) can also be loaded by dragging-and-dropping them into this list area from the Catalog panel (within ArcMap), from ArcCatalog, or directly from Windows Explorer. Features associated with the selected interpretation group are also managed in this area. Features can be selected through the slider, and its corresponding attribute values can be edited via the text boxes.

5. The evidence layer manager

   This area is used to manage the evidence layers generated within the IEP, through dragging datasets from the dataset list and dropping them onto the evidence layer list. Evidence layer attributes, such as selected evidence type and display modes, are accessed through the right-click context menu of the evidence layer list.

Using the IEP

Managing the list of datasets

In order to display or blend any dataset, it must first be loaded into the dataset list. This is done by simply dragging-and-dropping a dataset from ArcMap (a layer in the table of contents or from the Catalog panel), ArcCatalog, or Windows Explorer onto the data list panel. Added datasets are removed from the list by selecting it and using the *Remove data* option in the right-click context menu.

Rasterisation options are available for 2D plan-view, grid-type datasets (e.g. *.ers or *.grd if Geosoft plug-in is installed), 2.5D cross-section datasets (such as magnetotelluric data), and 3D volumetric datasets. Rasterisation parameters are accessed via the right-click context menu and contain options for the *Data stretch* (with options for *Linear normalisation* or *Histogram equalisation*) and the *Colour options* to be applied to display the dataset. In the case of 2D plan-view datasets, the rasterisation parameters are defaulted to histogram equalisation and a *Greyscale* colour map. For 2.5D cross-section and 3D volumetric datasets, the rasterisation parameters are defaulted to linear normalisation and a rainbow colour map.

Datasets that are already in a raster image format (e.g. *.ecw, *.tif, or *.jp2) are loaded as is, without applying transformation to the data or applying a colour stretch. Thus, the data stretch and colour options are automatically disabled for a loaded raster image.

An additional option is available for 2D plan-view datasets (grids and images), namely to *Run DRC*, which provides access to the phase-preserving dynamic range compression filter (see **Data visualisation tools** in **Technical background**). Selecting this option will bring up a window (Fig. 28) to specify the parameters used to run the filter over a range of cell sizes. The filter results are processed and accumulated into the original item in the dataset list, and can be accessed through the *Display DRC param* menu in the right-click context menu. The data stretch and colour options can also be applied the DRC filter results, but it is strongly recommended to only use linear normalisation for the data stretch, as the filter is designed for the purpose of displaying grid data without the need for histogram equalisation.

Finally, an option is provided to clear cached results of rasterisation and DRC filter results. By default, the previous results of rasterisation (and results from DRC filter passes) of datasets are cached, and are loaded in subsequent dataset loads to dramatically increase loading efficiency. However, for more flexible management of the rasterisation and filtering results, the option to clear this cache will erase previous results, thus forcing re-rasterisation and re-filtering.

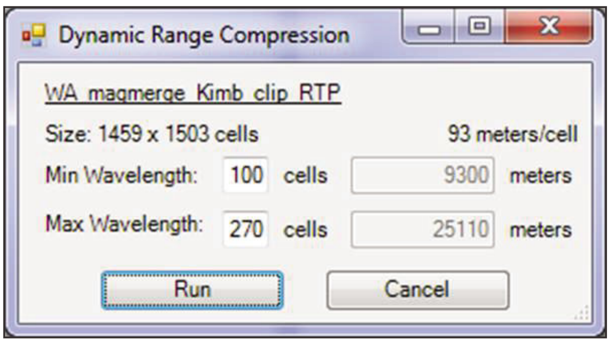


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Figure 28. The dynamic range compression (DRC) filter dialog window for setting the minimum and maximum wavelength of the filter range to be executed. Additional information of the grid dataset is provided for reference, such as the size of the dataset, the cell size, and the equivalent wavelength size in metres.

Supported datasets and limitations

For the IEP, the most reliably supported file formats for 2D plan-view datasets are: *.ers, *.ecw,*.jp2, *.tif, and *.grd (provided Geosoft plug-in is installed). Functionally, IEP leverages the ArcGIS Engine to load datasets, so other file formats may possibly be loaded, but normal behaviour is not guaranteed. 3D datasets, including 2.5D cross-section datasets, are currently only supported in specific ASCII file formats (see Appendix 2 for details).

Note that valid coordinate systems (recognisable by ArcGIS) are assumed, and are used to calculate the extent of the dataset. Using the ArcGIS Engine, the loaded coordinate systems of 2D datasets are temporarily converted into latitude and longitude coordinates (WGS84) to check and ensure datasets are within Western Australia. 2D datasets that extend outside the Western Australian boundaries will not be loaded. Furthermore, care should be taken to ensure datasets intended for blending are located in the same vicinity.

Managing the list of blends

The IEP image blending tools allow interactive and simultaneous display of different datasets. The basic concept of image blending is to generate a cross-dissolving effect across two images. However, the IEP blending tools extend this concept to facilitate the blending of multiple images, and 3D datasets, for simultaneous interpretation and integration.

Once a suitable number of datasets has been added to the platform, it is then possible to blend them. This is done by creating a blend through the right-click context menu of the blend list. This opens a *Blend Tool Creator* dialog (Fig. 29) to choose one of the eight currently available blend types. Once created, the new blend (the name can be customised with the *Blend Name* input) is added to the blend list and can be activated by mouse-click selecting it. Blends can also be removed by the same right-click context menu.

Exporting 2D blends

The result of a 2D blend can be exported to a GeoTIFF image, via the context menu by right clicking on the blend data list. Simply highlight the blend tool item to be exported and select the *Export blend* option. This will ask for a filename and location to save the GeoTIFF. Note that the export process will attempt to use the same georeference scheme as in the blend nodes. Exported GeoTIFF blend results can then be loaded in ArcMap. Currently, exporting the result of 3D blenders is not supported.

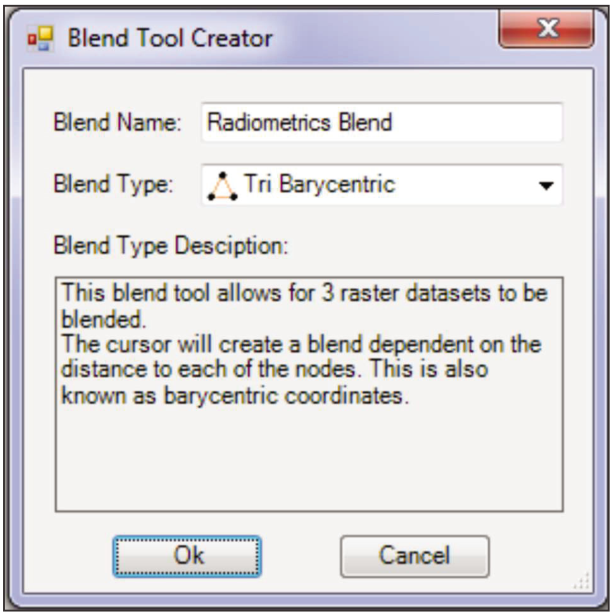

Figure 29. The blend tool dialog window to create new blends in the IEP interface.

Managing interpretation annotation

Interpretations are annotated in the IEP interface by creating interpretation feature groups and creating features for each group. There are a number of functions to provide a simple but flexible interface to represent and annotate interpretation. These include basic functions to create, select, edit, save, and load interpretation features. Further details are discussed in the following sections.

Interpretation feature groups

The IEP annotation tools support structural and lithological interpretations. These interpretations are managed as user-created interpretation *Feature groups*, which provide an intuitive grouping for interpretation *Features* created. Interpretation features are defined as a type of *Points*, *Lines*, or *Polygons*, and also can include user-created *attributes* which provide flexibility in annotating the meta-information associated (such as age, dip, strike, etc.) with the feature.

Interpretation feature groups are created, edited, and removed by the right-click context menu on the interpretation annotation group list. Choosing to create or edit a feature group will open the *Interp Feature Group Editor* dialog (Fig. 30). The user is given the options to set the *Name* (which should not contain spaces or non-alphanumeric characters and must be unique among existing groups), *Draw style* (a choice between points, lines, and polygons) and *colour*, and *custom attributes*.

Custom attributes for feature groups will be applied to every feature within that group. Editing attributes of a group with existing features will synchronise the attributes of the features with those of the group. Custom attributes can be one of three types (string, integers, or floating point) and can also be given an optional default value. If no default value is given, the value for that attribute remains null (blank) for the group and features in the group.

Note that the visibility of the feature group can be toggled via the checkbox associated with the feature group item in the feature group list.

Interpretation features

Interpretation features are created through mouse interactions while a feature group is both selected in the feature group list, and the visible flag is on. Generally, mouse clicks will add points to a feature, and right-click mouse drags are used to select existing features. Furthermore, a mouse drag on a selected feature will select the control points of the feature within the drag-select area. More intricate behaviour can be achieved through the commands listed in Appendix 3.

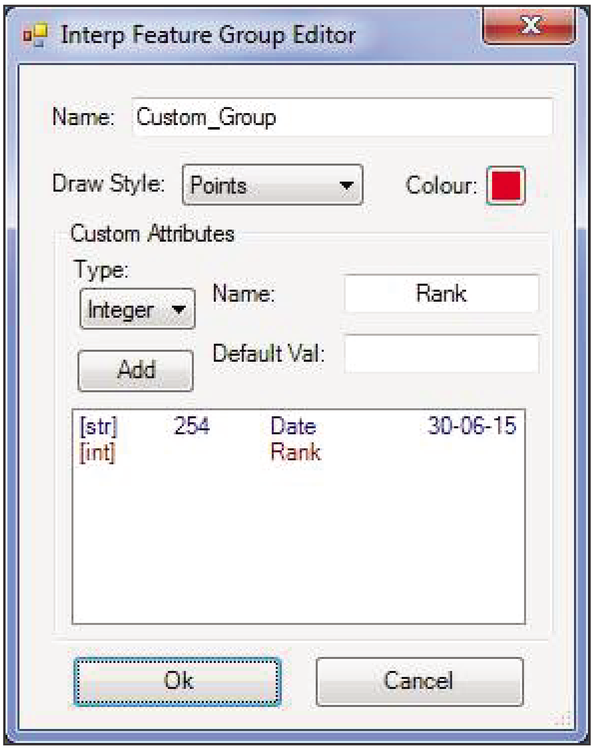

Figure 30. The interpretation feature group editor dialog. Feature groups (name, draw type, draw colour, and custom attributes) are created and edited via this dialog.

As features are created, the slider in the interpretation feature manager panel (Fig. 31) will be updated. This slider can also be used to select features. Any of the custom attributes including the feature creation order can be bound to the slider. Once an attribute is bound to the slider, the slider then represents the sorted order of features, and moving the slider will select features corresponding to the sorted order.

If a feature is selected via a right-click mouse drag select, the feature manager panel can then be used to update the values of the attributes (set via the feature group editor for the whole group). There are three fields to select and edit up to three attributes at a time. Selecting existing features will update the values to those associated with the newly selected feature. When you edit the value of an attribute in the value text field, the attribute is automatically updated.

For a more comprehensive editing of attributes, the *View all attributes* button can be used to open the *Interp Feature Attrib Editor* dialog (Fig. 32). Each of the existing features can be selected with the slider (similar to the one on the main interface) at the top of this dialog. Alternatively, all attribute values of the features can be compared by selecting an attribute field from the drop-down box. If a single feature is selected, all of its attribute values are shown in the main list (Fig. 32a). Similarly, if an attribute field is selected, all of the values across the features are shown in the main list (Fig. 32b). Any of the attribute values can be edited by selecting the attribute item and changing the value via the *Update value* text field.

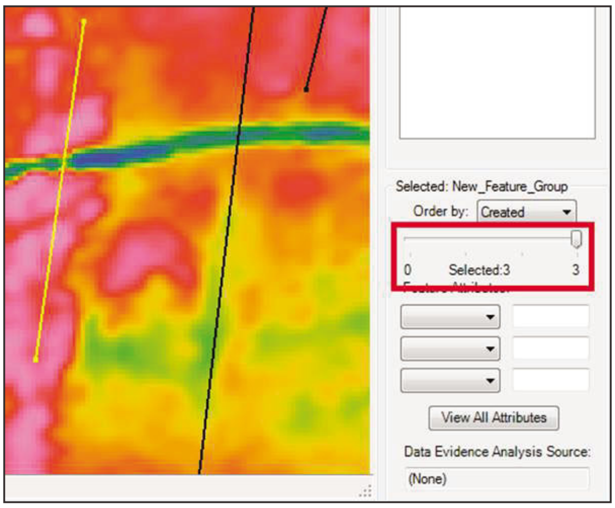

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Figure 31. **Interpretation feature slider control. Adding or removing features will update the slider (shown in the red box). The slider is useful for quick selection of features, ordered by a feature attribute. This example shows the slider selecting the last feature created (highlighted in yellow).**

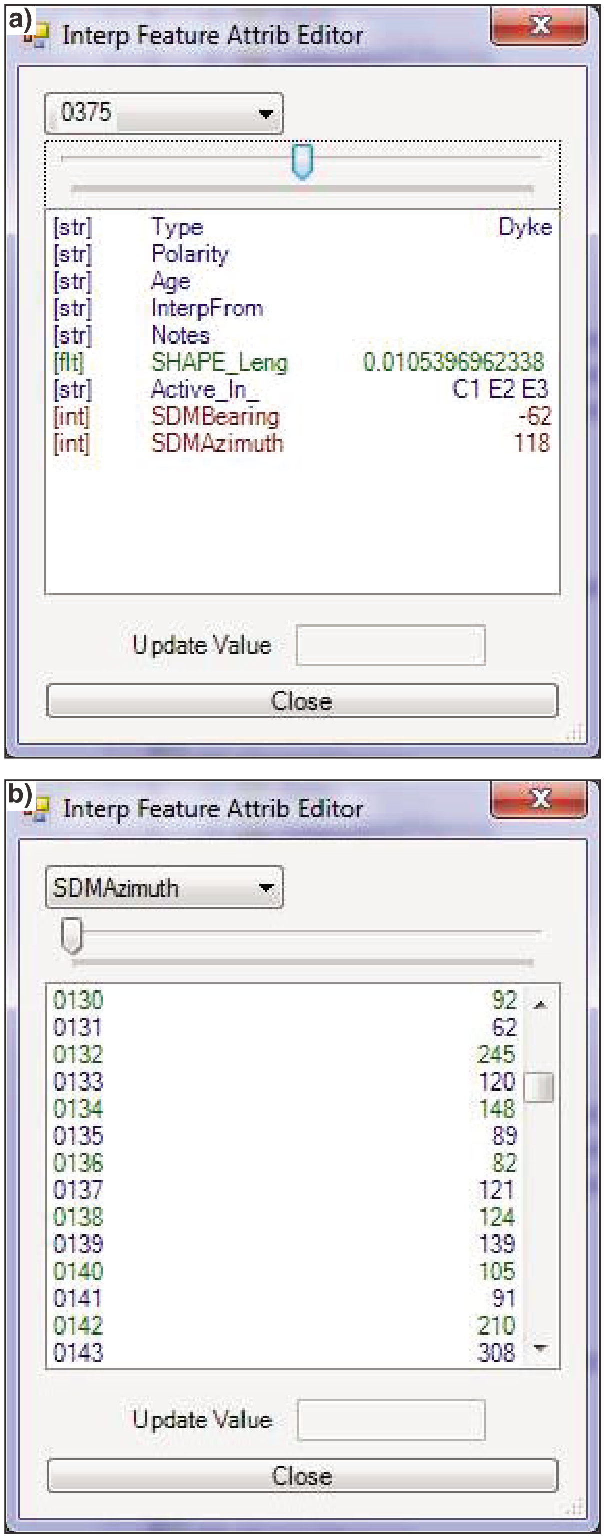

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Figure 32. **The interpretation feature attribute editor dialog: a) attribute values are shown for the feature selected by the slider; b) alternatively, attribute values across all features are shown for the attribute field selected by the drop-down list. In both cases, attribute values can be edited via this dialog.**

Saving and loading interpretations

Functions for saving and loading interpretations are accessed through the context menu by right clicking on the interpretation list. These functions can save or load a single interpretation group, save all interpretation groups into a directory, or load multiple interpretation groups from a directory. Note that all interpretation groups are stored and loaded as shapefiles. Furthermore, interpretation shapefiles can be dragged-and-dropped directly on the feature group list from the Catalog panel in ArcMap, from ArcCatalog, or from Windows Explorer.

Managing evidence layers

Feature evidence layers are calculated from a raster dataset (usually geophysical grids) as the source for feature evidence. This is done by simply selecting and dragging a raster dataset from the dataset list and dropping it onto the *Evidence layers* list. This initiates the feature evidence analysis process that, upon completion, will activate more options via a right-click context menu on the generated evidence layer, i.e. options for *Evidence type*, *Display mode*, and *Colour options*. Furthermore, evidence layers exist independently to interpretation feature groups, and so an additional step of explicitly linking an evidence layer to a feature group is necessary to apply the feature evidence to interpretation features.

Linking evidence layers to feature groups

Once an evidence layer has been generated, it can be linked to an existing feature group by dragging the evidence layer and dropping it onto the '+' node in the *Interp feature group* management area. The evidence layer can be unlinked by right clicking on the '+' node, and selecting the *Remove* option from the context menu.

Linking an evidence layer activates the quantitative evidence measures as the mouse hovers near interpretation features of the linked feature group. The quantitative evidence measures are displayed in the bottom left of the IEP interface in the status bar area. Linking evidence layers to a feature group also unlocks the *On lines* display mode (more details discussed in the following section), which displays the feature evidence along each interpretation feature.

The IEP also allows for the linking of multiple evidence layers to one feature group. However, only one layer is activated at a time, but the active layer can be cycled through by left clicking on the '+' node. Future versions of the IEP will further develop the functionality for integrated analysis of multiple evidence layers on a feature group.

Evidence display options

In the right-click context menu of a selected evidence layer, there are three options for *Evidence type*, which determines which of the three feature evidence maps (*Ridges*, *Valleys*, or *Edges*) are activated as the data evidence layer. Ridges and valleys are calculated from phase symmetry (Kovesi, 1997) and edges are calculated from phase congruency (Kovesi, 1999). Thus for ridges, features that exhibit a ridge-like signal will result in a strong positive phase symmetry response, whereas valleys will indicate features that exhibit a valley-like signal, i.e. negative phase symmetry. Finally, edges displays the strength of features that match an edge-like signal (where the phase components of the signal are congruent).

The *Display mode* option (a selection of a possible four) determines how the feature evidence layer is visualised. The first option is *None* to allow for the visualisation of the layer to be switched off. The second option, *On lines* (Fig. 33a), will combine the feature evidence with the currently viewed data (which should be shown with a greyscale colour map for the intended blending of information) in rectangle windows along each interpretation line. Note that evidence layers must be linked to a feature group before the on lines option becomes available. The third option, *Spotlight* (Fig. 33b), will combine the feature evidence with the currently viewed data in a circle area (field of view) centred at the mouse cursor, and provides intuitive viewing through the spotlight-like area to explore feature evidence. The final option, *Full* (Fig. 33c), simply displays the feature evidence in full opacity in front of the viewed data. Note that new interpretation features can be created and existing features edited while any of these visualisation modes are activated.

In both the on lines and spotlight modes, the strength of luminance contribution from the source data can be adjusted via hotkeys – or + to decrease or increase the contribution, respectively. The width or radius of the feature evidence and viewed data rectangles or circle areas can also be adjusted in both modes by hotkeys { or } to decrease or increase the width or radius. Lastly, the polarity of the luminance contribution can be inverted by hotkeys **9** or **0**, with **9** switching to normal polarity and **0** to inverted polarity. This inversion of polarity is particularly useful for highlighting areas with strong feature evidence strength occurring in low intensity areas of the viewed data.

The *Colour options* are identical to the options for the colour map used by grid and 3D datasets. However, the list of options of colour maps that the feature evidence layer can be colourised with is only available with visualisation in full mode. This is due to the data overlay visualisation using chromaticity and luminance (see **Data overlaying method** in **Interpretation assistive tools**), which requires an isoluminant rainbow colour map. Other colour maps may introduce unintended visual anomalies in the feature evidence visualisation. Thus, the colour options are disabled in the cases other than the full display mode option.

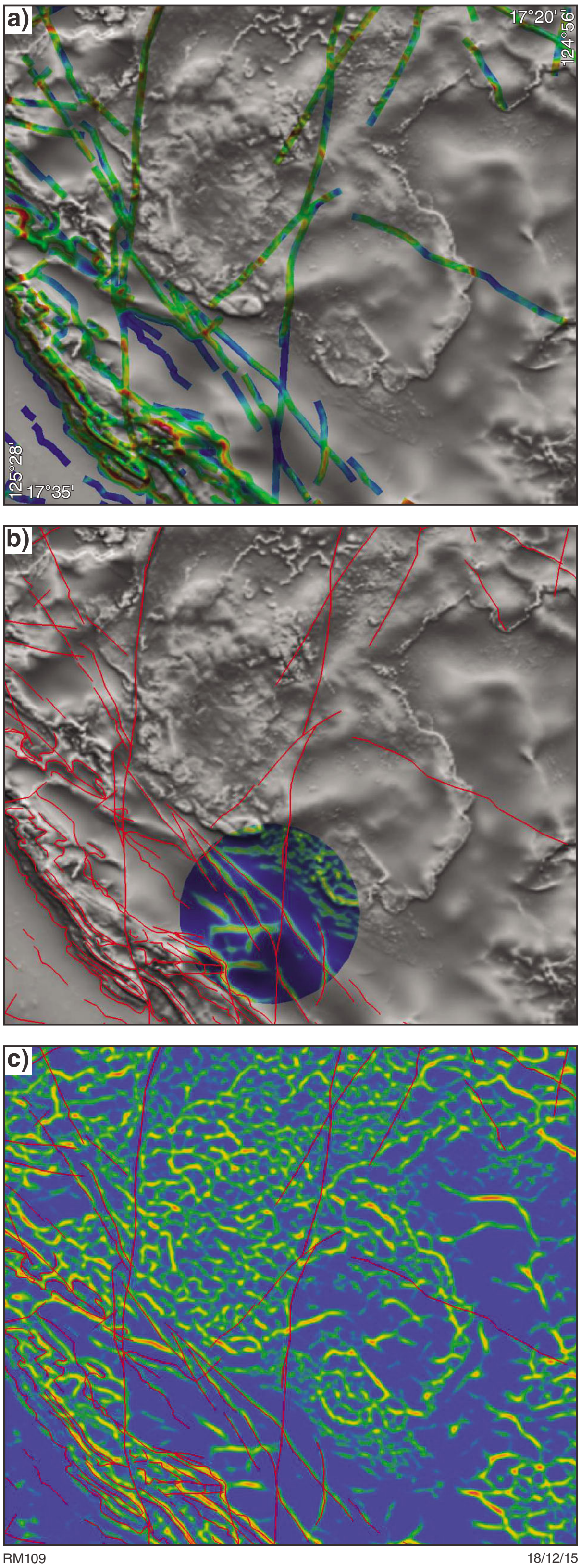

Figure 33. **Three modes of visualisation for the data evidence layer: a) data overlaying method is used in rectangular windows along each interpretation line; b) data overlaying method is used in a circular, spotlight region around the mouse cursor, which is rendered and updated in real time; c) data evidence layer is displayed in full opacity, obscuring the source data.**

Example workflow

This chapter gives an example workflow as a tutorial of using all the components of IEP.

Step 1: Loading datasets

Notes

- Datasets must be geolocated within Western Australia to be loaded
- Currently supported file formats:
    - **Image** (*.ecw, *.tif, *.jpg)
    - **Grids** (*.grd, *.ers, *.gxf)
    - **MT datasets** (ASCII file with extension of *.2MT or *.rho)
    - **3D voxsets** (ASCII file with extension of *.dat or *.3ds)

  Note: MT and 3D ASCII files are not recognised by ArcGIS, so can only be drag-and-dropped from Windows Explorer
- **Image** datasets dropped onto the list are loaded as is, and data and colour stretch options are disabled; however, images can also be treated as grids
- **Grid** datasets dropped onto the list are loaded with a default *Histogram equalised* and Greyscale colour map for the data and colour stretch options respectively
- **MT** and **3D** datasets dropped on the list are loaded with a default *Linear normalisation* and *Rainbow* colour map for the data and colour stretch options respectively.

1.1 Open ArcMap and launch the IEP interface.

1.2 Select a geophysical grid (preferably an *.ers file) from the Catalog panel in ArcMap (or optionally from Windows Explorer) and drag it onto the dataset list. It may take a few moments for the default rasterisation to complete.

1.3 It may be necessary to click on the *Camera refocus* button (which looks like an eye located next to the '?' button) to refocus the camera to the selected data item, especially if multiple items with different spatial references are loaded.

1.4 Modify the camera view of the dataset by left-click and dragging in the main display area to pan/scroll the view. The camera can also be zoomed in or out via the mouse scroll wheel.

1.5 Change the *Data stretch* to be *Linear normalised* and choose a different colour map in *Colour options*. Experiment and choose the most meaningful options for both data stretch and colour options.

1.6 Select the option to *Rename data* and change the name of the dataset represented in the list.

1.7 Note that subsequent loading of the same dataset will be much faster as IEP will load the previous rasterised result of the dataset, provided it has not been modified. The option to *Clear data cache* and *Clear all cached data* will clear the previous rasterised results and force re-rasterising of datasets on the next load.

Step 2: Creating a 2D blend

Note

- Currently five plan-view blend tools available:
  i. **Barycentric triangle** (good for radiometric data)
  ii. **Clique** (good for multichannel data like ASTER)
  iii. **Image Wheel** (good for revealing correlations)
  iv. **Param Linear** (good for a single filtered dataset)
  v. **Param Bilinear** (good for two dataset filtered over the same range)

2.1 Load at least three more datasets (which are in the same georeferenced location with similar size and spatial extent). These datasets may be grids (*.ers or *.grd) or raster images (*.ecw or *.tif). Note that the data stretch and colour options are disabled when loading a raster image.

2.2 Right-click on the blend list and choose the *Start new blend…* option from the context menu. A new dialog will be opened.

2.3 Name the new blend to something unique and select the *Clique* blend tool type. Note the brief description box that updates for each selected tool type. Click on the Ok button.

2.4 Make sure the new created blend is selected in the blend list. The blend tool area should now contain the clique blend tool.

2.5 Drag a dataset from the dataset list onto the '+' blend node. This will add the dataset to the blend tool as a new blend node.

2.6 Drag the other three loaded datasets from the dataset list to the same '+' blend node. The final configuration for four datasets in the blend tool is shown in Figure 34.

2.7 Hold mouse left-click down and drag along any of the black blend lines (the blue blend cursor dot will follow) to create a blend between the two connected pairs of blend node datasets.

2.8 Remove a dataset from the blend through the right-click context menu on the blend node you wish to remove.

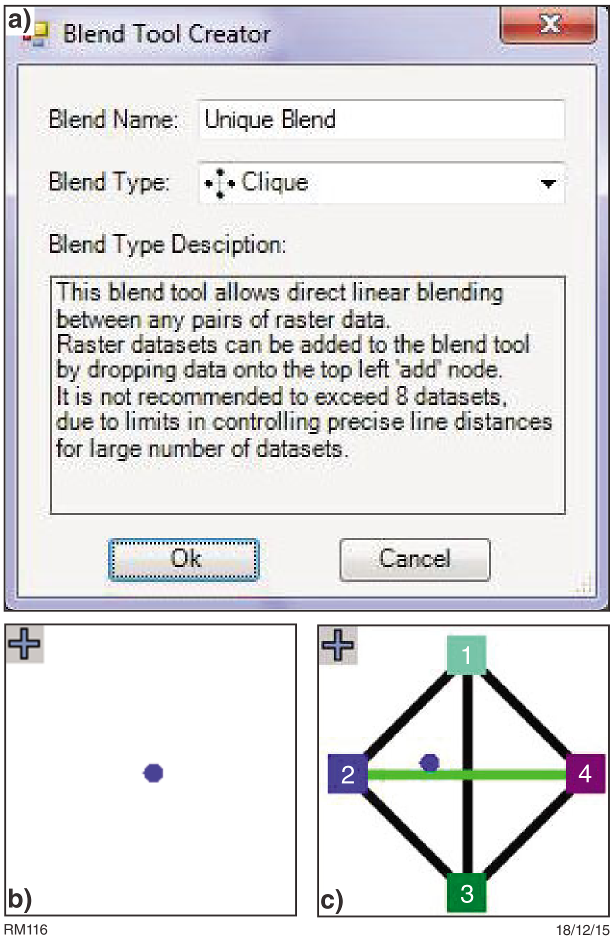

Figure 34. The clique blend tool populated with four datasets. The bright green line represents the pair currently blended.

Step 3: Creating a parameterised blend

3.1 Find two geophysical grids georeferenced to the same location in the Catalog panel in ArcMap, and load them into the IEP.

3.2 Select the first grid dataset in the list, and access the right-click context menu to select the *Run DRC…* option. This will bring up the *Dynamic range compression* dialog (see Fig. 28). Decide on a suitable range (in cells or metres) of feature size as DRC parameters. Input them as *Min wavelength* and *Max wavelength* parameters for the desired feature size in cells, and the equivalent size in meters will be updated on the dialog. Click on the *Run* button. Note this may take a few minutes.

3.3 Select the second grid in the list and repeat Step 3.2. For the best blend results, choose the same values for parameter range.

3.4 Create a *Param bilinear* blend tool similarly to the process in Steps 2.2 – 2.4.

3.5 Drag one of the first DRC items from the *Raster data* list to the left blend node, and then the other DRC item to the right blend node in the new blend tool.

3.6 Click and hold the left mouse button down and drag within the box region of the blend tool. This will result in a blend between the filtered results of the two DRC results of the datasets. Dragging the blend cursor horizontally will blend between the two datasets filtered with the same parameter. Dragging the blend cursor vertically will blend between results of changing parameter values.

3.7 Note that individual DRC results can also be displayed by selecting the DRC item in the raster data list and accessing the right-click context menu, then selecting the desired DRC parameter to be displayed under the *Display DRC param* menu. Only one DRC filter result can be shown at one time from displaying the DRC item in the raster data list.

Step 4: Exporting blends to ArcMap

Notes

- Only 2D blends can be exported and loaded into ArcMap.
- There is an unresolved issue of file locking — once a blend is loaded into ArcMap, the IEP can no longer access the file for subsequent saves to the same location. A workaround is to unload it from ArcMap prior to re-saving.

4.1 Select a 2D blend in the blend list to export, and choose the *Export blend* (*GeoTiff*)… from the right-click context menu (on the selected blend).

4.2 In the *Save As* dialog, choose a file location to save the blend as a geotiff.

4.3 Locate the geotiff in the *Catalog* panel in ArcMap or Windows Explorer, and drag-and-drop it into the table of contents in ArcMap.

Step 5: Creating a 3D blend

Notes

- Currently three 3D blend tools available:
    i. **Cross Section** (good for cross-section data visualisation combined with plan-view datasets)
    ii. **Single 3D Voxset** (good for visualising 3D volumetric data)
    iii. **Dual 3D Voxset** (good for comparing two 3D volumetric datasets)

5.1 To load a cross-section or volumetric dataset, the dataset needs to be in a specific ASCII text file format (see Appendix 2). 3D datasets will also have to be dragged from a Window Explorers window, since ArcGIS does not recognise these file formats. Once a suitable 3D dataset has been prepared, drag-and-drop it onto the raster data list in IEP to load it.

5.2 The options for data stretch and colour options still apply to 3D datasets. Experiment with the different options.

5.3 Create a *Cross Section Data* or *Single 3D Volume* blend tool (depending on whether a cross-section dataset or 3D volume was loaded) similarly to the process in Steps 2.2 – 2.4.

5.4 Drag the loaded 3D datasets into the new blend tool by dropping them onto the '+' node.

5.5 Experiment with visualising the 3D dataset by interacting with the blend controls.

For the cross-section data blend tool, plan-view datasets referenced to the same location as the cross-section data can also added to the blend. The left vertical slider controls the vertical offset of the cross-section data, and the right vertical slider controls the vertical exaggeration of the cross-section data. The circle controls the blend of all the plan-view datasets similar to the image wheel blender.

For the *Single 3D Volume* blend tool, a variety of options are available for choosing the *Data field* to display, the *Voxel display mode* and the *Blending mode*. In particular, the selection of a blend mode will alter the appearance of the blend tool to match the characteristics of the blend. See **Single 3D data blender** in **3D blending techniques** for more details on each visualisation mode and their use.

Step 6: Creating feature groups

Notes

- Properties and attributes of the feature groups can be edited at any time, and changes are synchronised to the existing features when the *Ok* button is clicked.
- Adding, selecting, and editing on features can only be done on the currently selected and active group in the *Interp group list*.

6.1 Select a 2D blend or a single dataset that reveals some structural or lithological information (such as magnetic data or blended gravity and magnetic data). Note that interpretation annotation on 3D datasets or 3D blends is currently not supported.

6.2 Right-click on the interpretation group list and select the *Start new group*… option from the context menu. This will open a new dialog (see Fig. 30).

6.3 Choose a unique group *Name*, select the *Draw type* to be *Lines* and choose a *Draw colour*. Also add two custom attributes: an integer attribute named *Age* with no default value and a string attribute named *Notes* with a default value of 'none' and field length of 254. Click the *Add* button to add each attribute and then click the *Ok* button when finished.

6.4 Create another feature group by repeating Steps 6.2 – 6.3, but choose the *Polygons* type instead with a different name and colour. Leave the custom attributes list empty.

Step 7: Creating features

7.1 Select the first *Lines* group in the group list, making sure the group's check box is shown as editable (a pen). Then left click somewhere on the main view displaying your chosen blend or dataset. This will start a new feature and will draw a temporary line from the clicked position to the mouse cursor position. Keep adding points to the feature through left clicks. Double click, right click, or use the Esc key to finish creating the feature.

7.2 Create a few more *Lines* features.

7.3 Select the second *Polygons* group in the group list. Repeat creation of several features as in Step 7.1.

7.4 Reselect the lines group. Then experiment with selecting lines features via the parameter slider in the interpretation feature manager panel (by selecting to sort by *Creation Order*, *Age*, or *Notes*). Also try selecting a feature by right-click and drag-selecting over features. Note that only features of the highlighted feature group can be selected.

7.5 Move a whole selected feature by holding the Shift key and then left dragging the feature to a new position. Individual feature points can also shifted the same way if a feature's points are selected prior to moving.

7.6 Select some features points in a selected feature. Press *Delete* or *Backspace* to remove them from the feature. Whole features can be deleted the same way if no feature points are selected. Note that new points can be inserted into the selected feature by right clicking to add the point at the clicked position. New points are inserted between the closest two existing feature points.

Step 8: Editing feature attributes

8.1 Select a feature in the lines group. Then select the age attribute in the first attribute field in the interpretation feature manager panel. Also select the notes attribute in the second attribute field. The value of the notes attribute should be updated to be 'none'.

8.2 Modify the notes and age values for the selected feature.

8.3 Select another feature in the lines group and modify the attributes to some different values.

8.4 Click on the *View all attributes* button in the interpretation feature manager panel. This will open a new dialog (see Fig. 32a).

8.5 Select one of the modified features by using the slider. Move the slider to other features to compare the attribute values. The attribute values can also be compared across all of the features by choosing the attribute field from the drop-down box in the top left (Fig. 32b). Note that attribute values can also be updated via this dialog with the *Update value* field.

Step 9: Saving and loading the interpretation

Note

- There is an unresolved issue of file locking – once an interpretation shapefile is loaded into ArcMap, the IEP can no longer access the file for subsequent saves to the same location. A workaround is to unload it from ArcMap prior to re-saving.

9.1 Save the interpretation group to a specified location. Right-click on the interpretation group list and choose the *Save groups…* option from the context menu. In the *Browse for folder* dialog, choose a directory location to save all the interpretation groups. All the interpretation groups are saved as shapefiles (*.shp).

9.2 Locate the saved interpretation directory in the Catalog panel in ArcMap. The *Lines* and *Polygons* feature groups should be listed as shapefiles. These can then be directly dragged-and-dropped into ArcMap.

Step 10: Feature evidence feedback

Notes

- Feature evidence analysis works best on plan-view geophysical datasets.
- Feature evidence layers are required to be linked to an interpretation group item to display with *On lines* modes.

10.1 Select a dataset in the *Raster data* list to be the source for the feature evidence analysis. High resolution geophysical data, such as magnetic data, produce the most meaningful results. Drag this selected dataset and drop it onto the *Evidence layers* list in the bottom right of the interface. The analysis will proceed, and may take a few minutes.

10.2 The *Ridges* feature evidence map is selected by default and should now be shown in *Full* mode. In the right-click context menu of the evidence layers list, select *Edges* under the *Evidence type* menu. Now the edges feature evidence map should be shown in full mode. Note that ridges, valleys, and edges can be quickly accessed by pressing the **1**, **2**, or **3** numbered keys respectively.

10.3 Select a different colour map used for displaying the evidence map under the colour options menu. Note that changes in the colour map can only be applied when the evidence layer is shown in *Full* mode.

10.4 Drag the evidence item and drop onto the '+' node in the feature group attribute area (ensure the group is not set to be invisible and selected in the interpretation group list). This will link the evidence item to the feature group item. Note that multiple layers can be linked in this way, although only one layer is active at a time, and the linked layers can be cycled through by clicking on the '+' node.

10.5 Change the *Display* mode for the evidence item to *On lines* mode. The evidence layer is now windowed around each interpretation line. Adjust the luminance strength by pressing the – and + keys. Also adjust the width of the windowing around the lines by pressing the { and } keys.

10.6 While in on lines mode, left click on the main display area to start creating a new interpretation feature. Note that the on lines windowing effect continues to be active as the line is drawn, and may provide data evidence assistance in determining the position and extent of the line. Finish creating the new feature.

10.7 Navigate to the *Display* mode menu under the right-click context menu of the Data Evidence Analysis Source box and select the *Spotlight* mode. Once in this mode, a circular field-of-view area will be centred about the mouse cursor. Move this spotlight around the dataset, noting the feature evidence. Similarly to the on lines mode, the luminance strength is adjusted by the – and + keys, and the radius of the circle is adjusted by the { and } keys. Note that the Caps Lock key can also be used to quickly toggle the spotlight mode on and off.

10.8 Switch the *Display* mode back to *Full* mode. Hover the mouse cursor over an interpretation line and note the quantitative values for feature evidence in the status message bar under the main display area. Move the mouse cursor along several interpretation lines to observe the changes in feature evidence values.

Step 11: Saving the workspace

11.1 Left click or right click on the *Workspace menu*, and select the *Save workspace…* option. This will open a *Save As* dialog. Choose a filename and click on *Save* to save the current workspace into the default documents directory. The workspace will then be saved, and will also appear under the *Open previous workspace* menu. Note that quick saving and loading can be accessed through the *Save default workspace* and *Load default workspace* menu options.

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Appendix 1

Additional technical implementation details

The camera mode

The camera is modified according to whether 2D or 3D data is displayed. While viewing 2D plan-view data, an orthogonal projection type camera is used to ensure correct scaling of datasets to the displayed view, and to remove potential distortion from a perspective mode. For 3D data, a perspective projection must be used for the camera to maintain a correct sense of 3D. However, a perspective camera can cause instances of 'z-fighting' (example shown in Fig. 35), a condition that occurs at certain viewing directions along multiple flat planes at certain distances from the camera. This occurs when the z component, or 'depth' of the 3D objects cannot be resolved correctly. In the IEP, this presents as texture planes flickering or merging with planes underneath it, as they are computationally collapsed to occupy the same virtual space. Changing the camera view, such as increasing the zoom, or viewing angle, can correct this visual problem.

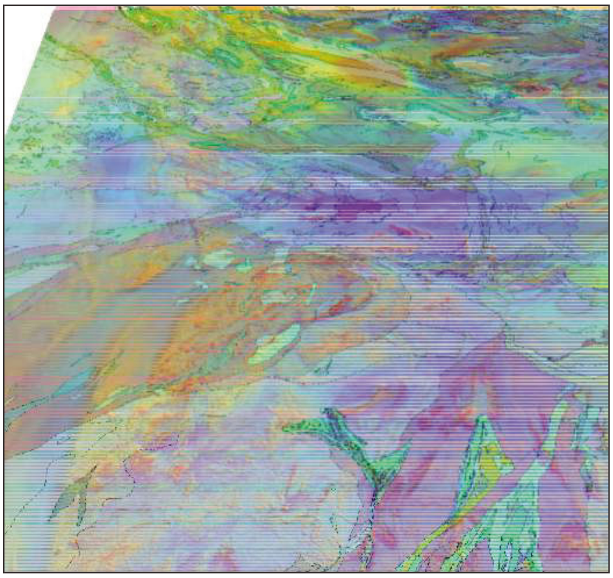

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Figure 35. An example of the z-fighting artefact. This can occur when viewing multiple stacked planes (which is how blending of datasets is achieved) with a 3D viewpoint, and the visual representation of the z component (i.e. depth of the planes) is confused between the closely stacked planes. This occurs as the planes are computationally rounded to overlapping positions at certain points on the plane, resulting in a mixed rendering of planes above and below in the stack. This situation can be resolved by adjusting the viewpoint.

Dynamic colour map swapping

Colour map swapping is a novel feature in the IEP for colouring grid data in a way that allows for the currently activated colour map to be changed on the fly (that is, instantaneously, without re-rasterising or modifying the grid data). This feature is implemented with an OpenGL palette shader. Colour maps in the IEP are represented as 256 x 1 RGB textures (such as the rainbow colour map in Fig. 36a), where the i-th pixel is the *i*-th colour of the given colour map. Grid data are then rendered as a greyscale texture (Fig. 36b) and coupled with a fragment shader that interprets the luminance value at each point on the grid as an offset into the currently activated colour map (final result shown in Fig. 36c). Hence the specified colour map is applied at render time, and changing the activated colour map simply requires changing the colour map texture passed to the palette shader.

Partially overlapping plan-view datasets

Datasets that are partially overlapping can cause additional problems, as areas of datasets that are non-overlapping result in the alpha component causing that area to be blended with the background colour not specific to any dataset (Fig. 37a). To rectify this situation, an *inclusion map* (Fig. 37b) is calculated whenever a dataset is added to a blend. This map specifies which datasets are overlapping (and by extension, areas where there are no other overlapping datasets) in order to calculate the correct alpha component to ensure proper blending contributions from each dataset. Since the inclusion map encodes the number of overlapping datasets, this information is used to adjust the relative weighting for each dataset for each overlapping region. An example of the final result of correctly adjusted blend weightings is shown in Figure 37c.

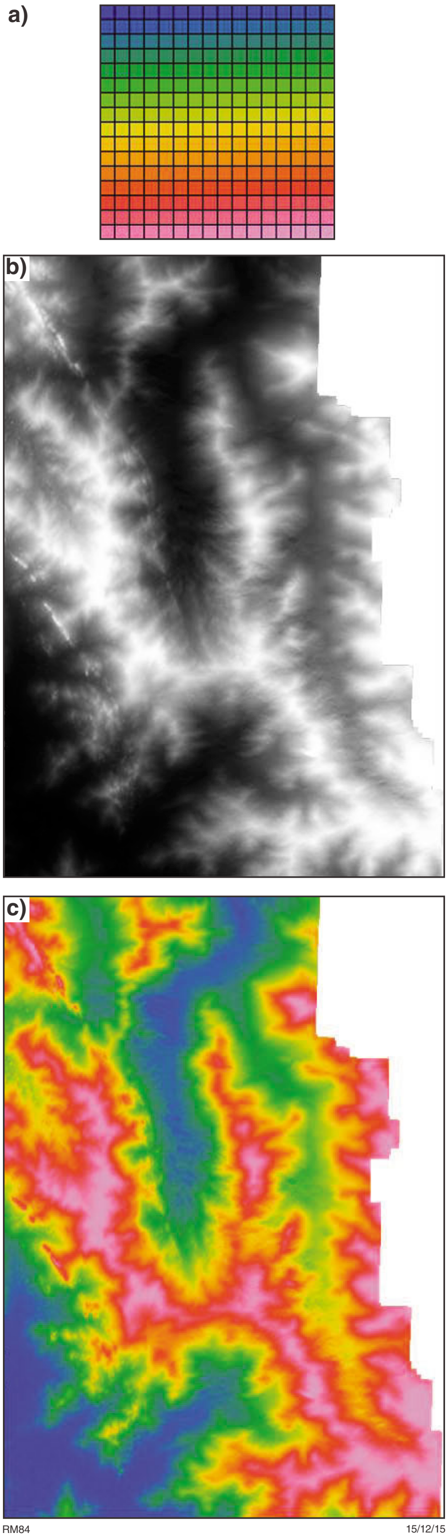

Figure 36. **The process of dynamic colour map swapping, using an OpenGL palette shader: a) the colour map is represented as a palette of 256 colours, covering the range of possible data values. This is stored internally as a 256 x 1 RGB texture, but is shown here wrapped to a 16 x 16 grid for convenience; b) the grid dataset is initially stored as a greyscale, so that the data values determine the corresponding position in the colour map, and thus the colour; c) the final composition through using the grid data values to choose the corresponding colour from the colour map.**

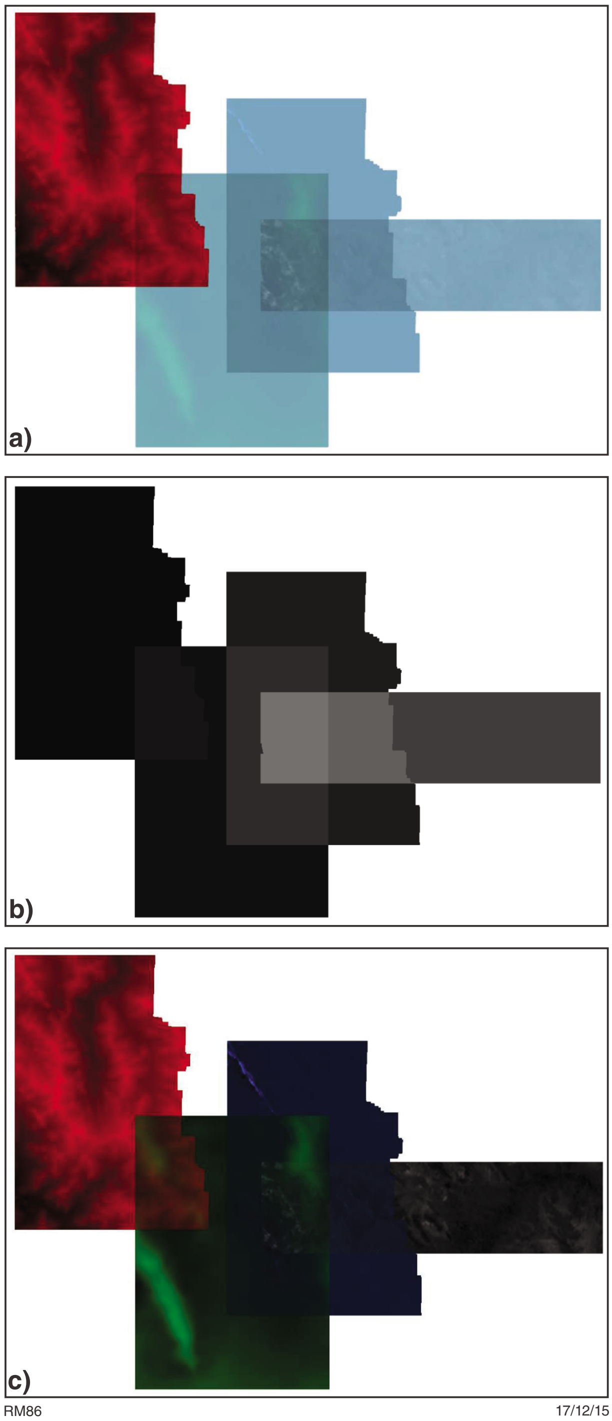

Figure 37. **The process of using inclusion mapping to determine correct blending weights: a) an example of not using inclusion maps, resulting in a constant blend weight across a layer. These layers are erroneously blended with the background colour; b) the inclusion map is generated by a bitwise aggregation of the layer's ID. This map allows for the graphics card to distinguish the areas where, and how many, datasets overlap; c) the final corrected blend weighting through utilising the inclusion map.**

Appendix 2

File formats for 2.5D cross-section and 3D datasets

The datasets for the cross-section and 3D volume data blenders in IEP v2.5 require specific ASCII file formats. Although they technically assume text ASCII files, the file name extension must be renamed to correctly identify the type of dataset. Note that 3D datasets are not yet correctly georeferenced, and do not load into any specific spatial reference. When blending, these datasets assume the spatial reference of the other datasets already loaded into the blender.

Cross-section data: file extension *.2mt

Format:

X Y Z Data

For example:

719285.100	7220359.000	-8278.859	5.702e+000
719480.900	7220164.000	-8278.859	5.494e+000
719676.500	7219968.000	-8278.859	5.196e+000
719911.400	7219733.000	-8278.859	4.701e+000

3D volumetric data: file extension *.dat

Format:

X Y Z Data1 Data2 Data3 …

For example:

564000.000000	6965000.000000	-0.000000	1.000000	0.010655
564750.000000	6965000.000000	-0.000000	1.000000	0.010993
565500.000000	6965000.000000	-0.000000	1.000000	0.010726
566250.000000	6965000.000000	-0.000000	1.000000	0.011233

3D volumetric data: file extension *.3ds

Format:

HEADER: ? lines then ? line at each depth interval

…

COLUMN	NAMES	…	
Data1	Data2	…	

For example:

HEADER: 14 lines then one line at each depth interval

MODEL:	AC	% AuSREM Crust
Origin:	RSES ANU	
Date:	2012 September	
Latitude (# points, interval):	71 0.50	% Latitudes: degrees, positive North
Longitude (# points, interval):	101 0.50	% Longitudes: degrees, positive East
Depth (# points, interval):	45 1.00	% Depth: km, positive down
%%		
Number of Value Fields:	4	width 10
P wavespeed:	Vp [km/s]	3 dec places
SV wavespeed:	Vsv [km/s]	3 dec places
Density:	rho (ρ) [Mg/m^3]	3 dec places
Mask		% 1.0 for constrained data, 0.0 rest
%%		

Depth	latitude	longitude	Vp	Vsv	rho	Mask
1.0	-10.0	110.0	1.478	0.000	1.025	1.0
1.0	-10.0	110.5	1.504	0.000	1.025	1.0

Appendix 3

Command list

The following is a list of the possible commands (also accessible via the '?' button) in the main display area for the IEP.

Camera controls (with mouse focus on the main display area)

- **Left click + drag** – Scrolls the view of the data
- **Mouse wheel** – Updates the view by zooming in / out
- **Left / right arrows** – Scrolls the view of the data horizontally
- **Up / down arrows** – Scrolls the view of the data vertically
- ***Eye* icon (next to '?' icon)** – Refocuses the camera on the last selected data item.

Interpretation feature controls (clicks and drags on the main display area)

- **Left click** – If a feature group is selected, this will start a new feature or continue a feature currently being drawn.
- **Right click** – If a feature is being created, this will add a final point and finish the feature. If a feature is being edited, this will insert a point between the two closest existing points of the feature.
- **Right click + drag** – Selects either: features of the selected group, or points of a selected feature.
- **Shift + left click + drag** – Moves selected features or feature points.
- **Shift + right click + drag** – Provided no feature is selected, will select either: multiple features of the selected group, or multiple points of selected features.
- **Esc** – Deselects a feature or feature points, or completes a feature currently being created.
- **Backspace / delete** – Removes a selected feature or feature points.

Data evidence visualisation controls

- **~ / |** – Toggles the data evidence visualisation mix on/off
- **- / +** – Decreases / increases the opacity of the data evidence layer
- **{ / }** – Decreases / increases the radius in *Spotlight* mode, or the width in *On lines* mode
- **9 / 0** – Normal / inverted intensity binding to colour map
- **1 / 2 / 3** – Switches to *Ridges* / *Valleys* / *Edges* data evidence layer
- **Tab** – Toggles the *Spotlight* mode on / off.

Appendix 4

Known issues

The following list notes the known issues that have identified but not yet rectified in this version of the IEP (v2.5).

- Locking conflicts with exported blends. Workaround is to remove file from ArcMap before export. Files may also need a right-click ‘refresh’ on the Catalog list to fully release the file or database. Then re-add the exported file back into ArcMap
- No undo functionality
- Large datasets (>800MB) may not load correctly due to limitations of converting to graphics card textures
- 3D datasets are not yet correctly loaded with a spatial reference
- Metadata not stored on exports of blends or interpretations
- Lack of north arrow and labelling in 3D views
- Blending datasets from different spatial references may result in inaccurate dataset extents, especially blending with a mix of geodetic and projected Cartesian systems
- Removing datasets that are used in blends will not remove the blend counterpart
- After maximising the IEP window, minimising can cause resize errors on some interface components. A workaround is to drag the corner to manually resize the interface
- The camera view is not updated to focus on an interpretation feature group as it does with blends and datasets.

Appendix 5

Bug report form

This form is for reporting bugs or issues that are found.

Please copy and paste headings into an email, fill in details, and send to Jason Wong (jason.wong@uwa.edu.au).

Date of report:

IEP version: (Check through *Customise* → *Add-In Manager,* and select *CET_IEP item)*

Description of bug or issue:

Steps to replicate:

Screen captures (if possible):

RECORD 2016/3

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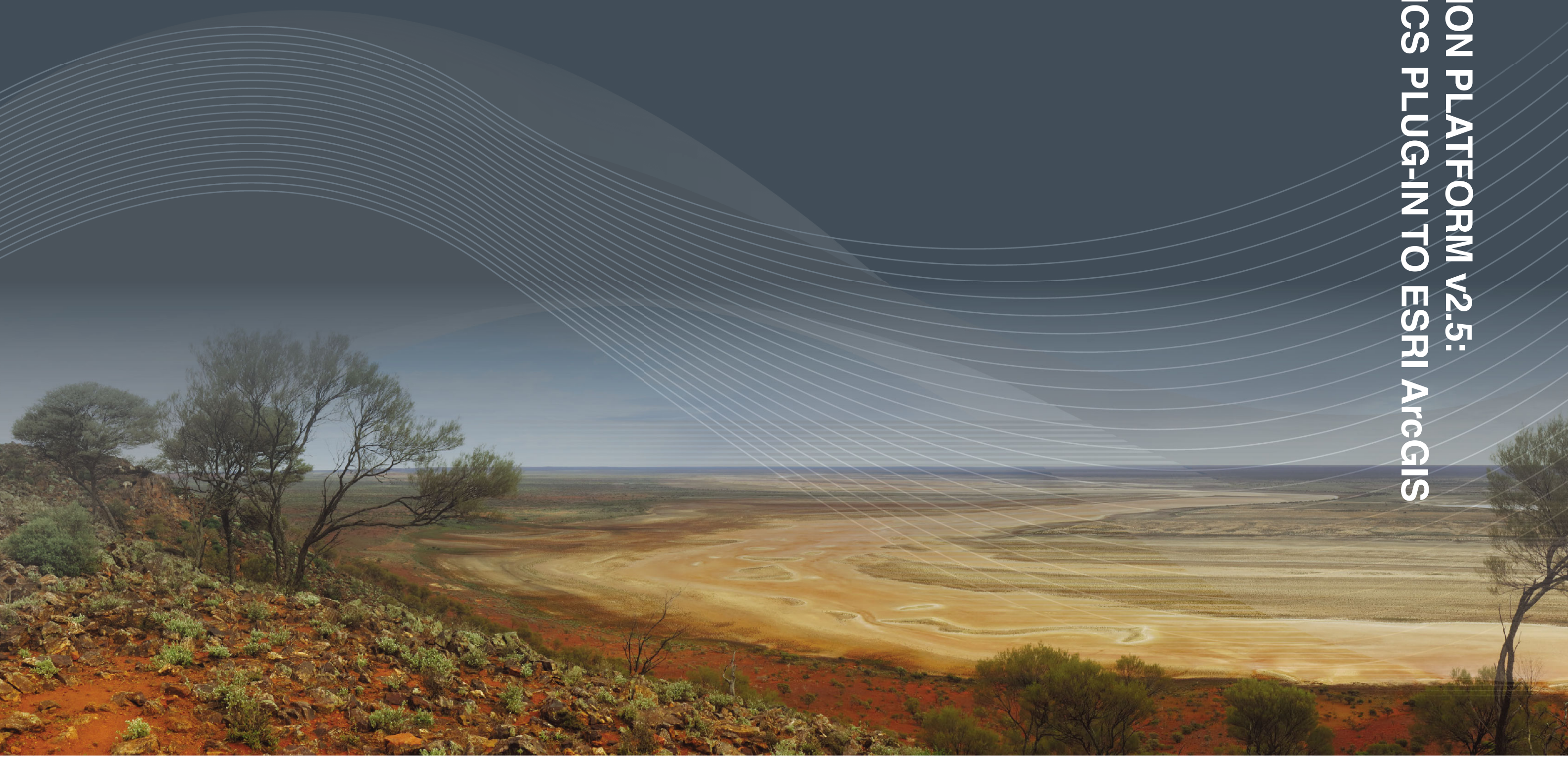
INTEGRATED EXPLORATION PLATFORM v2.5:
AN INNOVATIVE VISUAL ANALYTICS PLUG-IN TO ESRI ArcGIS



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