Summary

Information may be extracted from seismic data cubes using attributes that represent specific characteristics of the data contained in the cube. Examples of typical attributes are dominant frequency, RMS amplitude, and spatial variance. The description of complex geological features usually requires information from multiple attributes. One possibility for simultaneous attribute analysis is attribute triplets in continuous-color representation as red, green, blue (RGB) or hue saturation value (HSV). We describe a method to sharpen the continuous-color representation of multiple attributes with the goal of providing structural lineaments for geological interpretation. We represent three different attributes in RGB and extract the structural, which is contained in the boundaries of the colors in the RGB image.

The primary results are cubes containing structural lineaments on the one hand and the structure-sharpened RGB images on the other hand. The technique may also be applied to combinations of more than three attributes.

Methodology

The technique concerns a method to sharpen the continuous-color representation of multiple attributes with the goal of providing structural lineaments for geological interpretation. The seismic data required to apply this technique are configured in a cube. In the first step, multiple attributes are extracted from the seismic cube using either commercially available or specific software. Such attributes may comprise signal properties such as amplitude and frequency, structural properties such as curvature and gradient, or statistical properties such as variance. Each of these attributes is enhanced to optimize the further analysis.

Next, three attributes are selected and allocated to the red, green, and blue bands in a continuous-color RGB representation. The dynamic range of the data is extended to the third power of the resolution of each single attribute. This increase in dynamic range allows image processing to be applied to the data.

For structural interpretation of seismic data cubes, several attributes are extracted and usually compared in separate displays. This approach makes it difficult to extract structural information from multiple attributes simultaneously. Our goal was, therefore, to develop a method that requires information from multiple attributes and allows the extraction of structural lineaments from the simultaneous analysis of multiple attributes in continuous-color representation. We will describe the methodology and apply the technique to structural delineation within individual layers as well as to structure correlation between several layers. We chose an erosional structure from Australia to demonstrate the technique.
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band gradient provides edges, which represent structural lineaments contained in the data. In the final step, the structural lineaments are convolved with the previously generated RGB image, thus providing a structurally sharpened RGB image of this attribute combination. Usually, such an image represents the geological character of the area of investigation more realistically than the description by one single attribute alone. Figure 1 shows the generic workflow for structurally sharpened multiattribute analysis in continuous color RGB.

We will now illustrate each of these processing steps on time-slice seismic data from an erosional structure in Australia (Figure 2). We begin by band-pass filtering the seismic data. We generate nine bands of 10 Hz bandwidth each and select one high frequency (60 Hz), one middle frequency (30 Hz), and one low frequency (10 Hz) band each (Figures 2a, 2b, and 2c). The three frequency slices are considered the input attributes.

We allocate the 60-Hz slice to red, the 30-Hz band to green, and the 10-Hz band to blue in a continuous-color RGB image (Figure 2d). This image combines the characteristics of the three input attributes in one RGB image. Because we aim at extracting the structural information from the attributes, we convert the RGB image to HSV (Figure 2e) because the HSV image represents the information contained in the color in the hue band; whereas, the color-independent intensity information is represented in the saturation band. We extract the saturation band, run edge detection on the intensity data, and display the edge contours in grayscale (Figure 2g). These contours represent structural lineaments contained in this single time slice. We will later see that the elongated structure represents the subcrop boundary around an eroded anticlinal structure. In the final step, we convolve the edge (Figure 2g) with the RGB image (Figure 2d). The result is a structure-sharpened RGB image that reveals the spectral structure of the seismic data within the time slice (Figure 2h).

For validation, we extract the time slice and corresponding section from the seismic cube. We plot them on top of each other such that the bottom of the time slice fits the top of the section (Figure 3). The section shows an anticlinal structure, the top of which is eroded. On both flanks of the anticline, flat continuous layers dip away from the anticline.

Conventional data are displayed as amplitude in grayscale (Figure 3a) and are compared with the RGB image created from the 60-, 30-, and 10-Hz frequency bands. The RGB images more details in both the time slice and the section. For the last implementation, we choose the spatial variance attribute, which highlights areas of significant lateral change in the seismic cube and is well-suited to reveal sudden vertical changes. We extract the spatial variance attributes for frequency bands of 60, 30, and 10 Hz, which we used in the RGB analysis above, and generate the structure-sharpened variance RGB image. Figure 4 shows...
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selected steps in the workflow generating the structurally sharpened RGB image for the spatial variance.

Figure 4: Generation of structure-sharpened RGB for spatial variance attribute obtained from 60-, 30-, and 10-Hz frequency bands. 30-Hz variance time slice (a), 60-, 30-, and 10-Hz variance RGB (b), edge of HSV saturation band (c), and structurally sharpened spectral variance RGB (d).

Results and discussion

For validation, we extract three seismic horizons from the seismic cube (Figure 5): one above the erosional discontinuity horizon (blue), one on this horizon (green), and one below (red). We will drape the results from the structural attribute analysis onto these horizons.

Figure 5: Location of horizons in the data cube and main structural orientations of the anticline. The green arrows indicate the direction to north.

Figure 6: Result from structurally sharpened attribute RGB images draped on a set of three horizons around the erosion horizon and correlation with conventional seismic inline and crossline sections. Conventional RMS amplitude in grayscale coloring (a), structurally sharpened spectral amplitude RGB (b), and variance attribute RGB (c). The latter are computed for 60-, 30-, and 10-Hz frequency bands. The main axes of the anticline – NW-SE and SW-NE – are shown as arrows below the erosion horizon. On either flank of the anticlinal structure, we observe flat layers pinching out towards the top of the anticline. The green arrows indicate the direction to north.
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The results of structurally sharpened RGB attribute analysis are draped over the horizons around the erosion horizon of the anticline (Figure 6). We have partially cut away the horizons from front to back to reveal the structural changes from layer to layer. The horizon below the erosion extends across the entire cube, the erosion horizon itself is cut away by about 50%, and the remaining analysis surface is covered by the horizon above the erosion horizon.

Figure 6a shows the grayscale coding of the instantaneous amplitude; this is the usual way of coding and displaying seismic data. For orientation, four crossline sections were inserted at the lines where the horizons were cut. The amplitude display reveals only the outline of the anticline (yellow dashed line), but does not show details.

Figure 7: Comparison of structural characterization from instantaneous amplitude (a), and the merge of spectral RGB amplitude and variance (b).

The spectral RGB from 60, 30, and 10 Hz (Figure 6b) clearly reveals the subcrop around the anticline, which results from the pinch-out of the layers on the flanks of the anticline. It is highlighted by the strong black signature. Within the anticline, structures are revealed in the layers above and on the erosion horizon; whereas, the horizon below the erosion does not reveal any noticeable structures.

The spectral variance RGB showing the spatial distribution of variations in the 60-, 30-, and 10-Hz frequency bands maps mainly small-scale structures and lineaments (Figure 6c). These small structures are mainly observed on the erosion horizon and below, and may correlate with fluvial channels. Sets of lineaments sub-parallel to the main anticlinal axis are observed across the SE part of the anticline. They may represent local fault zones. The layer above the erosion horizon contains larger-scale structures that are identical to the structures mapped by the spectral RGB.

The use of spectral attributes – whether as amplitudes or as spatial variance attributes – appears beneficial for structural mapping of geological structures. The instantaneous amplitude, which consists of the spectral sum of the amplitudes of the individual frequencies, does not reveal subtle structures because of interference by the individual frequency bands. The merge of different spectral attributes in RGB provides the continuous-color coding of the spectral attribute values in a large dynamic range. Subtle frequency changes are mapped as color changes and can be used to distinguish small-scale structural and sedimentary features. Figure 7 demonstrates how much structural detail can be gained from using spectral attributes (Figure 7b) compared to the standard approach using the instantaneous amplitude (Figure 7a).

Conclusions

The extraction of spectral attributes from seismic data and representation in continuous colors reveals structures that cannot usually be mapped by conventional instantaneous amplitude processing. The extraction of structural lineaments from the HSV attribute cube further enhances the potential for structural delineation by seismic data.

Spectral RGB analysis of amplitude data generally reveals larger structures, the internal structure of which can be mapped using spectral-variance RGB analysis. The combination of these complementary data sets provides a detailed structural insight for all scales.

Acknowledgements

The author thanks Phil Bilsby and Kevin O’Sullivan for processing the seismic PSTM cube, Peter Wang for the discussion of the attributes, and WesternGeco for permission to publish the data.
EDITED REFERENCES
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REFERENCES