Advanced Multiattribute Imaging and Geobody Delineation of Jurassic and Triassic Stratigraphic Targets

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Abstract

We present the results of multiattribute imaging and geobody delineation applied to stratigraphic targets such as Jurassic channels and Triassic beaches and spits, imaged in data from the Norwegian sector of the North Sea. Interpretation based on the examination of seismic amplitude alone is challenging due to the complexity and subtleness of these features.

To improve the definition of these Mesozoic targets, we have applied a multiattribute approach, combining frequency decomposition, seismic attribute analysis techniques, advanced visualization, and a new method of multiattribute geobody delineation. Attributes have been selected that are sensitive to the edge and magnitude response of sedimentary structures, while the use of narrow band spectral magnitude volumes allows small scale frequency variations to be analyzed. These different sources are corendered using advanced color and opacity blending, providing multiattribute composite image volumes for subsequent interpretation and as input to further geobody delineation. The use of such advanced visualization has resulted in a collection of 3D volumes that successfully distinguish the internal and overbank geometry of chan-

nels as well as the structure and extent of Triassic sandbars.

A new geobody delineation system has been designed to track visible structures in color blended images. The method is semi-automatic, allowing the interpreter to interactively guide the delineation process. Application of this technique has allowed the user to isolate and extract individual Jurassic channels, the seismic response of which varies considerably, as independent 3D geobodies.

We believe that the use of such advanced multiattribute visualization and delineation techniques is applicable to similar provinces globally.

Introduction

Multiattribute approaches to seismic attribute analysis focus using a number of individual seismic attributes that are sensitive to different geological features or elements of single feature to create a more complete description. Usually we require input attributes to be independent (Barnes, 2000) although multiattribute techniques are particularly successful when input attributes are chosen to show complimentary or related information; for instance, attributes may be selected which are sensitive to different scales of fracturing and faulting, or to highlighting channel edges versus channel infill. Methods for combining multiattribute information can be numerical (through geostatistical analysis, neural networks, and cluster-based classification, or through visual (color and opacity blending). The use of color blending in seismic attribute analysis is a well established technique (Laughlin, *et al.*, 2002) but until recently the use of such RGB images has been limited to qualitative assessment. It is our aim to extract quantifiable and geologically meaningful results from multiattribute images, particularly color blends and opacity blends.

We have created and combined a set of seismic attributes that greatly aid the delineation and understanding of sedimentary features and potential reservoirs. The workflow is straightforward to apply and comprises data conditioning, attribute generation and combination stages as described below and outlined in Figure 1.

Methodology

Noise cancellation

The signal-to-noise ratio of the data is improved through application of a combination of structurally oriented and adaptive-noise-cancellation filters (Hoecker and Fehmers, 2002). The noise cancellation algorithms are designed to preserve information by aligning the filter with reflectors. Adaptive noise cancellation also preserves reflector edges, such as faults/fractures and stratigraphic terminations, and subtle amplitude variation across the reflectors. Enhancing the image quality by removing noise is important, in order to generate attributes of the highest possible resolution and which have the best chance of capturing subtle stratigraphic details. Figure 2 shows a segment of a vertical section of the seismic data through features of interest, before and after noise cancellation, highlighting the improvement in reflector continuity.

Attribute generation

As part of the structural and stratigraphic attribute analysis workflows, a structurally oriented (SO) semblance edge attribute and envelope attribute were generated. Structurally oriented semblance is a multi-trace attribute chosen to highlight the edges of channels and very thin spit features and can also be used to show faulting (Marfurt *et al.*, 1998). Envelope is a single-trace attribute and a measure of reflection strength, and was used to highlight the high amplitude stratigraphic features present in the data set. Figures 3 to 5 show the noise-cancelled seismic amplitude, envelope, and structurally oriented semblance attribute volumes illustrating the different ways in which the attributes highlight the channel features. Conventional 3D geobodies are created from a single volume (such as the envelope volume) by thresholding and performing a connected components analysis, in which high envelope values are included as geobodies and low values are ignored. Geobodies are ranked by body size, and very small bodies are omitted from the analysis.

Using this workflow, we found that segmentation of the Jurassic channel and Triassic spit systems could not be effectively performed simultaneously due to differing characteristics. We therefore parameterized the geobody extraction for each depositional system independently and at the end combined the two body sets into a single volume. This is a multistep and time consuming process but is the only way to segment two channel systems using a single attribute. The final body volume was populated with envelope values to show the magnitude variation within the extracted features.

Figure 6 shows the geobody volume centered at a Triassic beach and spit.

Opacity blending

Opacity blending is a visualization technique in which multiple attributes can be colocated and viewed simultaneously by adjusting their relative transparency levels. Opacity blending is most effective when attributes showing different types of features are used, with complimentary color maps. Figure 7 shows a blend of structurally oriented semblance marking edges using a gray-scale color map, in which the envelope highlighting high magnitude targets are plotted using a rainbow color map. Note how this opacity blend successfully highlights the Triassic landforms and the Jurassic channels. By covisualizing two attributes a greater level of information is seen within the volume.

Frequency decomposition and RGB blending

Frequency decomposition is used to generate three band-limited magnitude response volumes with discrete central frequencies (Fig. 8). In this example, the conditioned reflectivity data are decomposed to produce volumes showing the magnitude response at 19 Hz, 26 Hz, and 39 Hz. These individual volumes are normalized and ascribed to each of the red, green, and blue channels of an RGB display (Fig. 9). The resulting composite RGB image shows variation in hue and intensity that correlates with the change in magnitude response at the different frequencies. Visualization in this manner allows variations in lithology, bed thickness, and pore-fill to be seen with high visual contrast. Figure 10 shows individual channels as bright regions of distinct color, enabling improved interpretation of channel migration and braiding.

Multiattribute Delineation

We have developed a geobody delineation system using a probabilistic deformable model, driven by a statistical representation of a geological region of interest. A deformable model is an adaptable (active) contour (Kass *et al*. 1988) that changes its shape to represent the underlying data. Deformable models can be generally categorised as explicit or implicit models. Our implementation utilizes the advantages from both model representations. The application of active contouring delineation to seismic attribute analysis has previously been highlighted as an emergent method for auto-tracking channels and other stratigraphic features (Chopra and Marfurt, 2008).

Explicit active contours define a deformable model as an explicit geometric model. Active contours work by fitting a model to object boundaries under the control of two forces: *external forces* that pull the model toward image features such as edges; and *internal forces* that act as smoothing constraints or object model constraints (Fig. 11).

In 3D, this representation often takes the form of a triangulated mesh with each vertex (Fig. 12) doubling as a control point during deformation of the model. This representation has the advantage that the model's boundary is well-defined, meaning that processing is reasonably simplistic and boundary properties such as curvature are easily calculated and influenced. The geometry is also defined in a minimalistic manner which makes this a resource-friendly representation thereby minimizing processing times.

The main disadvantage of this simplistic representation is that it allows the model's faces to overlap during deformation, resulting in model self-intersection. Preventing or appropriately resolving cases of self-intersection is a non-trivial task and requires significant additional processing, making natural changes to the model's topology such as merging and splitting very difficult to handle, especially in real-time.

Implicit level sets (Osher and Sethian, 1988) do not directly define the model's surface/boundary. Instead, the model is represented as a changing collection of points that satisfy a certain function when sampled over a Cartesian grid. The Cartesian grid is generallyy defined to coincide with the corresponding data set's voxels, such that this technique has similarities with voxel-based region growing techniques. The model's boundary may be generated on demand by using an appropriate polygonization technique but, during deformation, boundary properties such as curvature are often based on local estimations.

This model's greatest advantage is its natural handling of topological changes: since the model's surface is implicit, its boundary is free to merge and split during any deformation step with no additional processing costs. The main disadvantage of level sets is the large amounts of memory required to hold the data structure during deformation and the processing which tends to be time-consuming.

The presented geobody delineation system makes use of the well-defined geometry and boundary properties of the explicit models to best calculate and integrate the data-driven forces acting on the surface. The model’s surface evolves iteratively based on these forces until it reaches an equilibrium state or is halted by the interpreter. The model has an implicit internal structure that allows topological changes to the model. This internal representation also allows the coarseness of the model to be modified by the interpreter.

Model forces

During each step of the evolution, the model's contour is altered under the influence of a force f, with data-driven external and shape-constrained internal components. Forces are calculated at each of the model's vertices. The external force pushes the model toward voxels having similar characteristics while the internal force pulls the model back towards one having acceptable curvature. The total forces applied to the model are

$$f = \sum_{i=1}^{\tau} \alpha f_i^{ext} + \beta f_i^{int}, \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where τ is the total number of vertices, f_i^{ext} is the external force, f_i^{int} is the internal force, and α and β represent user-defined weights that balance the relative force contribution.

The external force is evaluated at each surface vertex and is determined by calculating the likelihood that a voxel is in the immediate vicinity of the vertex belongs to the model. The external force at each vertex is taken to be the number of voxels that meet a probabilistic acceptance criterion that can be modified by the interpreter. The internal force is used to regulate the model's shape. This force can regulate localized or global changes. The interpreter can alter the level of influence between the external and internal forces by modifying α and β.

Topological changes

The implicit internal framework allows topological changes for the extraction of complex geological boundaries. The model dynamically adapts its topology to fit the data, allowing a geobody to split into multiple items or to merge into one as appropriate. The dynamic nature of the model allows geological features separated by discontinuities to be initialized in multiple locations. This internal framework also supports 'coarse-to-fine' deformation, allowing a quick approximation of the geological boundary. Once the interpreter is satisfied with the initial estimation, a more detailed (fine-tuning) deformation can be performed obtaining a more accurate fit to the data.

Multidimensional data

Traditional active contours locate image boundaries by seeking regions having a high gradient from one-dimensional data. Boundary segmentation from complex multidimensional data such as RGB color blends requires a more sophisticated approach. Our geobody delineation system has an underlying probability model (independent feature model), which assumes the presence (or absence) of *N*-dimensional features. Commonly with RGB color blends, three features represent a single model, one for each frequency channel, although each frequency channel could represent multiple models.

The model assumes that each feature independently contributes to the probability that voxels belong to a given geobody. As a result the probability model can be initialized (trained) very efficiently using a supervised learning technique that only requires a small amount of training data.

The interpreter has full control over the initialization and statistical representation (features) of the probability model as well as over the adjustment of the probabilistic acceptance criterion during deformation.

Application of deformable model to stratigraphic features

The RGB color blends provide details of the channel system geometry and internal character that are startlingly clear to the interpreter and which greatly aided interpretation. The expression of these systems within RGB blends, although very clear to the eye, is the result of variations in seismic response that are complex and subtle, making complete and isolated extraction of these elements as 3D geobodies impossible using standard geobody delineation techniques. The geobodies shown in Figure 13 have been extracted with a new geobody delineation system that is designed to track visible structures in RGB blended images, and is semi-automatic allowing the interpreter to interactively guide the delineation process. Application of this technique has allowed effective isolation and extraction of the two different channel segments previously shown as one in Figure 6 as independent units.

Conclusions

A workflow based on new and existing 3D seismic attribute analysis techniques has been used to identify potential reservoirs and sedimentary systems in Jurassic and Triassic stratigraphy from a seismic reflectivity data set from the Norwegian sector. The workflow is straightforward to apply and has shown details of the imaged sedimentary systems with extraordinary clarity. In particular, combining structural and stratigraphic attributes using opacity blending highlights details within the interior structure and along the edges of channels, beaches, and spits. Volumetric frequency decomposition and RGB color blending enhances subtle, but potentially important, variations in stratigraphy. A new multiattribute delineation technique is crucial in allowing the channels and spits, which are characterized by complex variations in seismic response, to be delineated as separate3D bodies.

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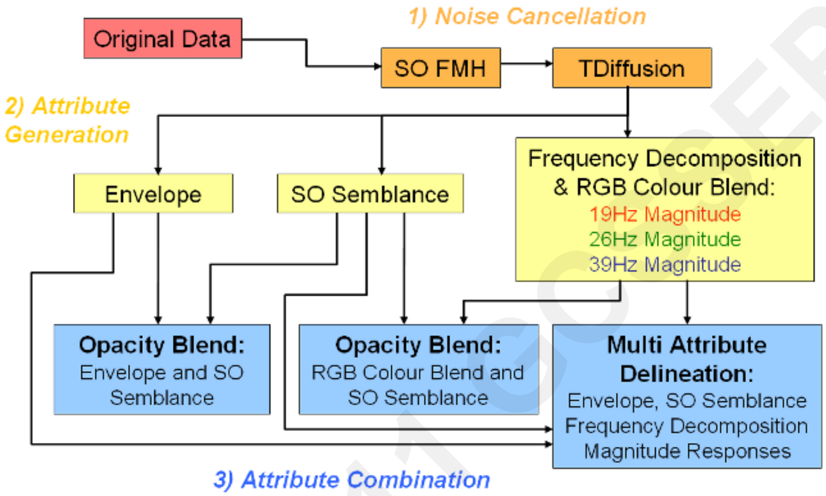


Figure 1. Workflow outlining the processes used to create multiattribute delineation of stratigraphic features within the dataset. Noise cancellation involves application of a Structurally-Oriented-Finite-Median-Hybrid (SO FMH) filter followed by a Tensor-Diffusion (TDiff) filter, which together act to attenuate coherent and random noise, thus improving reflector continuity while preserving edges. Seismic attributes sensitive to stratigraphic variations are envelope, structurally-oriented (SO) semblance, and frequency decomposition magnitude responses. As the final step, attributes are combined using opacity and color blending techniques which is subsequently used as input to the multiattribute delineation.

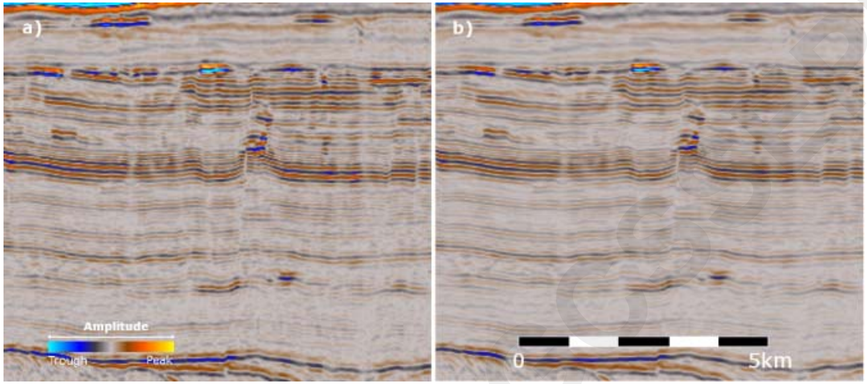
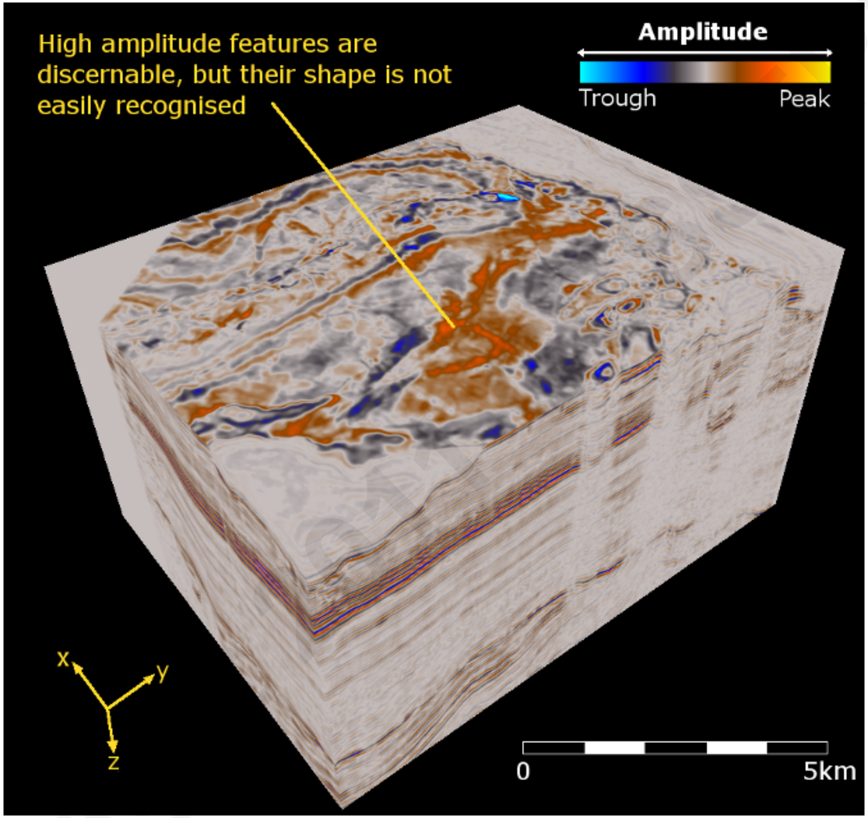


Figure 2. Result of noise cancellation of the seismic dataset shown in vertical section. (A) The original seismic data has a significant amount of random noise which is noticeable as scatter along the reflectors. (B) Noise-cancelled data has greater continuity along reflectors while maintaining real amplitude variations and edges.



High amplitude features are discernable, but their shape is not easily recognised

Figure 3. Time slice view of the noise-cancelled data showing amplitude variations associated with Jurassic channels. Although these features are discernable their detailed structure is not easily identified.

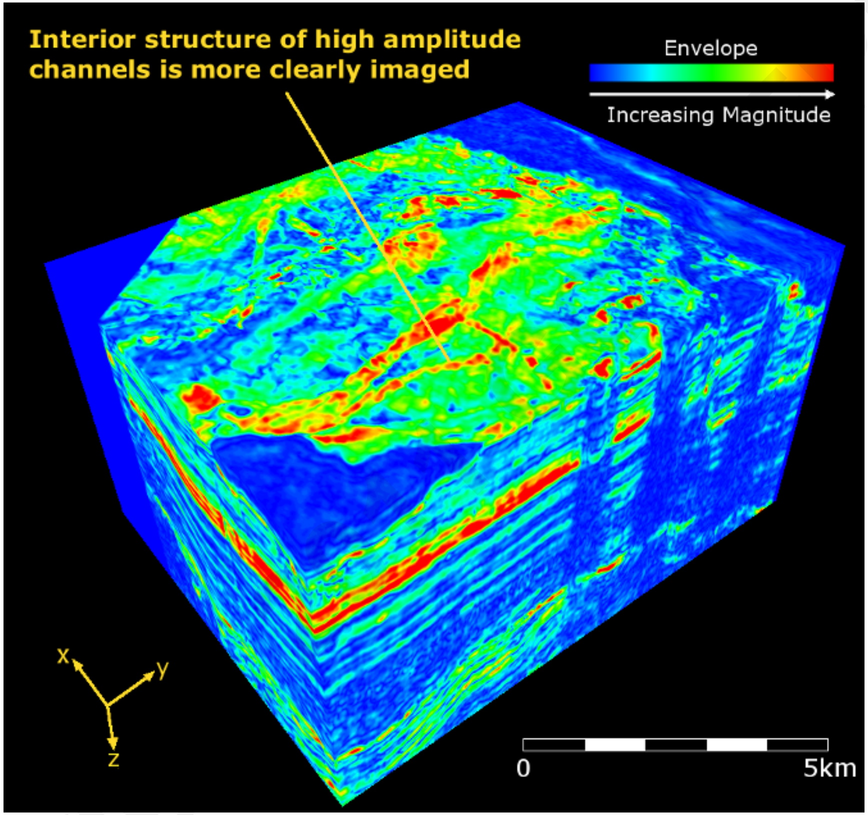


Figure 4. The envelope attribute is a measure of the reflection strength (the square root of the sum of the squares of the original data and its Hilbert transform) and allows the Jurassic channels to be followed with greater continuity. The envelope attribute alone cannot distinguish between neighboring and overlapping channels.

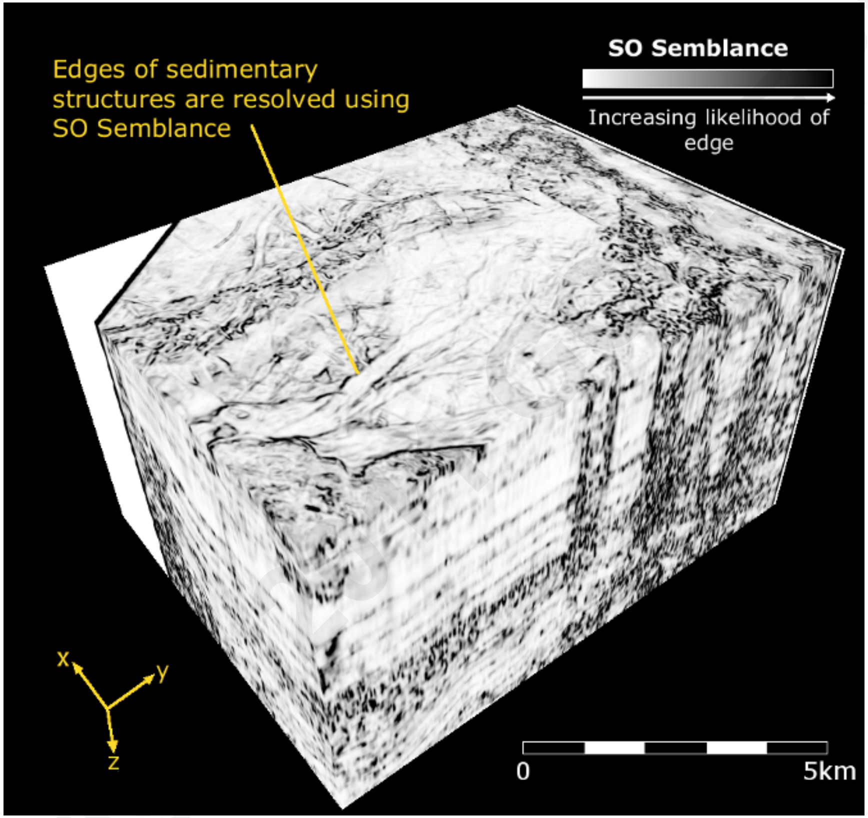


Figure 5. Structurally oriented (SO) semblance is an edge attribute that has been used here to define channel edges, thus highlighting the interplay between individual channel braids. As well as channel edges, SO semblance is also sensitive to faults and low-amplitude chaotic regions and therefore cannot be used as a unique channel identification volume; instead it is used in combination with other attributes to improve confidence on the extent of our stratigraphic features.

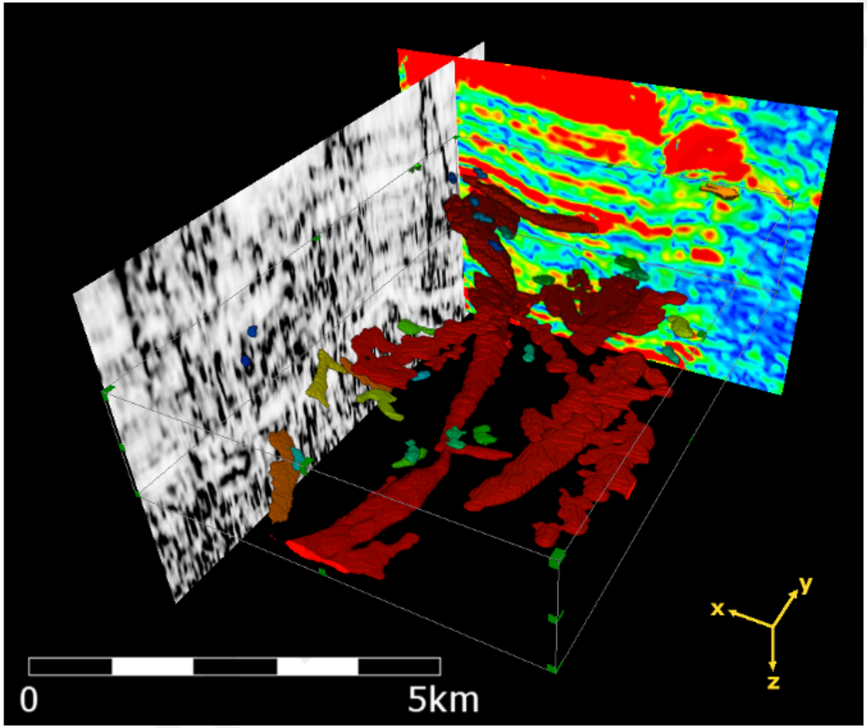


Figure 6. Triassic beach and spit system geobodies generated through thresholding of the envelope attribute. Geobody size is represented by color; small geobodies are shown as blue and large bodies are red. Although this method is successful in extracting bodies which are expressed as high amplitudes, it is evident that neighboring bodies can merge together and several smaller bodies occur that are not of geological significance.

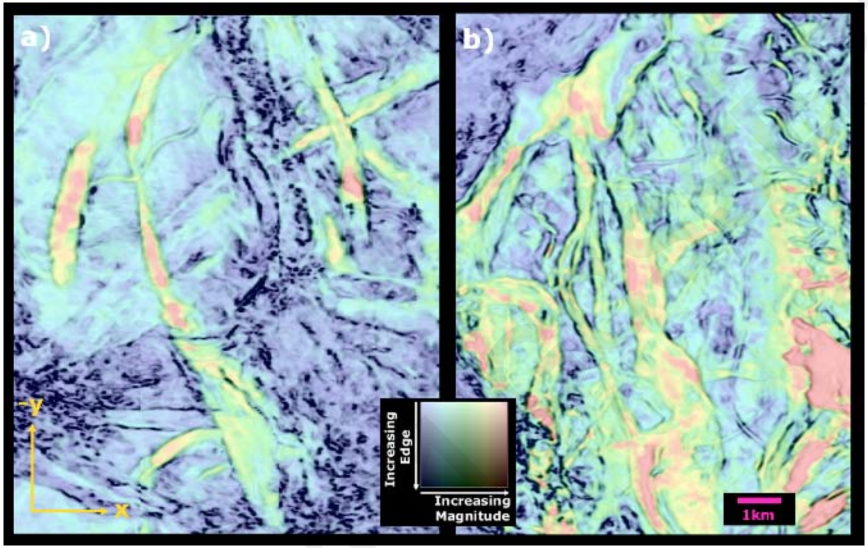


Figure 7. SO semblance and envelope opacity blend for (A) Triassic spit system and (B) Jurassic channels. By combining these two complimentary seismic attributes, a greater level of constraint is attained as to the extent and infill of the stratigraphic features of interest.

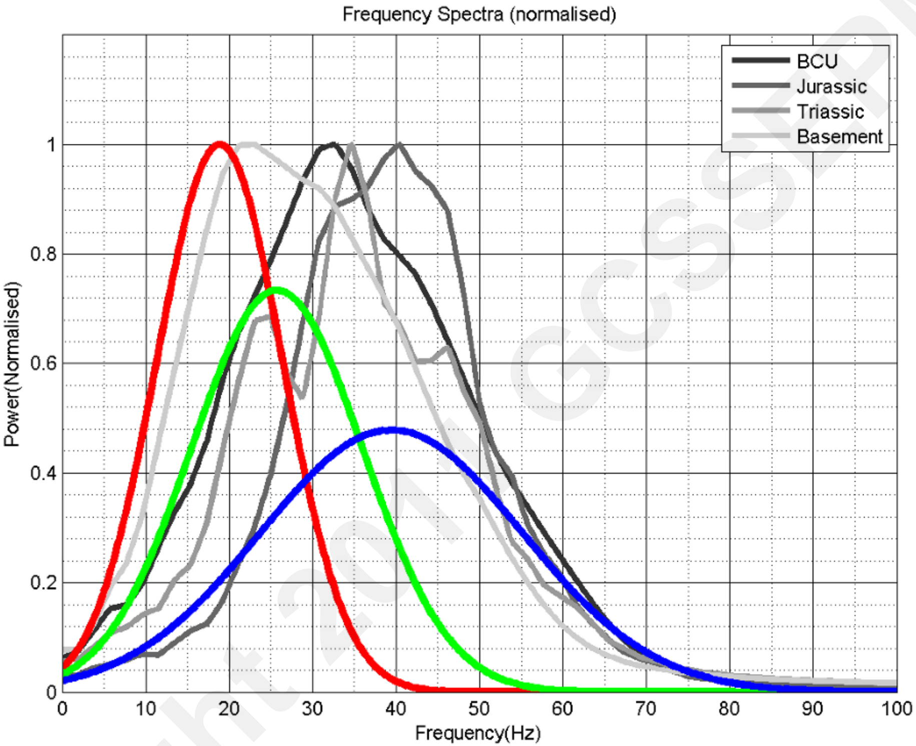


Figure 8. **Representative frequency spectra extracted along the BCU, Triassic, Jurassic, and basement horizons in shades of gray. These spectra can be represented by band-limited components centered about 19 Hz (red), 26 Hz (green), and 39 Hz (blue) and are generated through frequency decomposition and used in subsequent RGB blending images. Although each band is centered at a different frequency, their spectra overlap. When combined these bands represent variations across the entire frequency range. When a red, green, and blue color map is applied to each of the frequency decomposition magnitude responses, the variation in frequency is expressed as a change in hue and the variation in magnitude is expressed as change in intensity.**

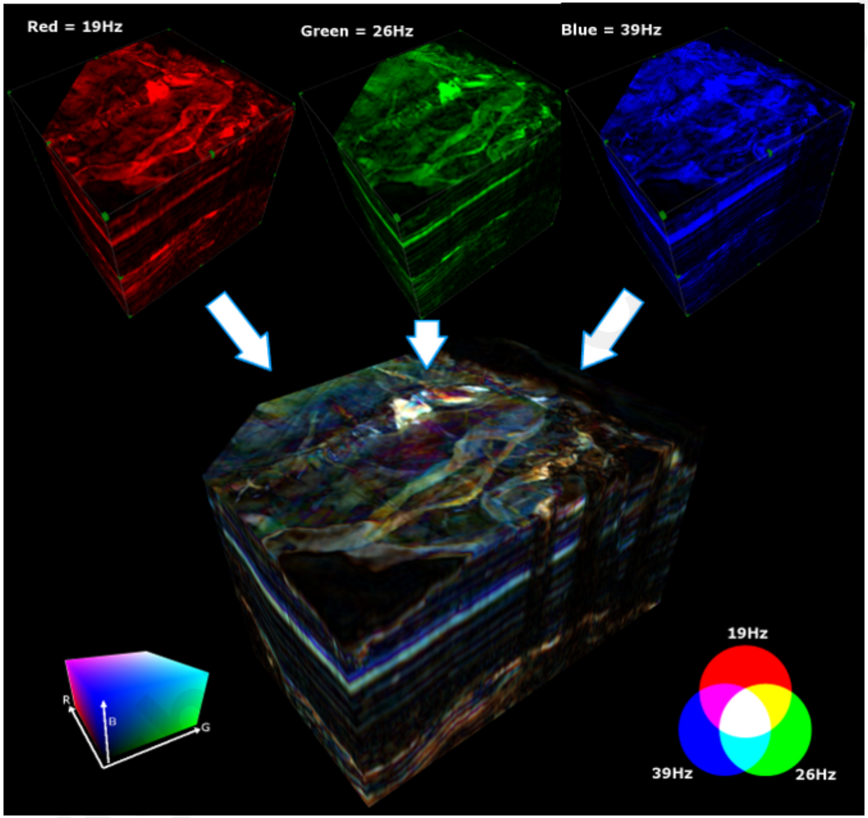


Figure 9. RGB color blend composed of 19 Hz (red), 26 Hz (green), and 39 Hz (blue) band limited magnitude responses. Also shown are the associated 3D RGB color space (lower left) and conceptual RGB color table (lower right). The RGB blend shows variations in the Jurassic channels as changes in hue and intensity in more detail and clarity than when they are imaged with individual attributes.

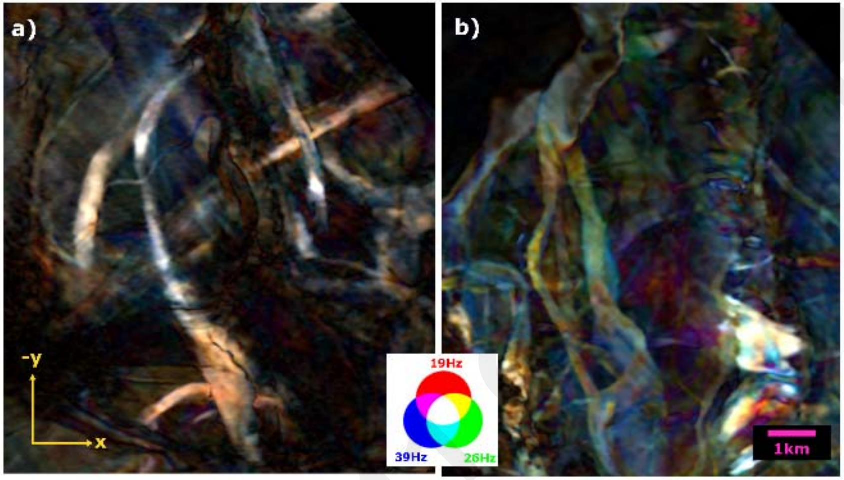


Figure 10. Frequency decomposition RGB blend showing the (A) Triassic spit system and (B) Jurassic channels. In the Triassic section, transgression of beaches is evident from the change in frequency response expressed as a change in color in the RGB blend. In the Jurassic, similar color differences show individual channel elements that would otherwise be difficult to distinguish.

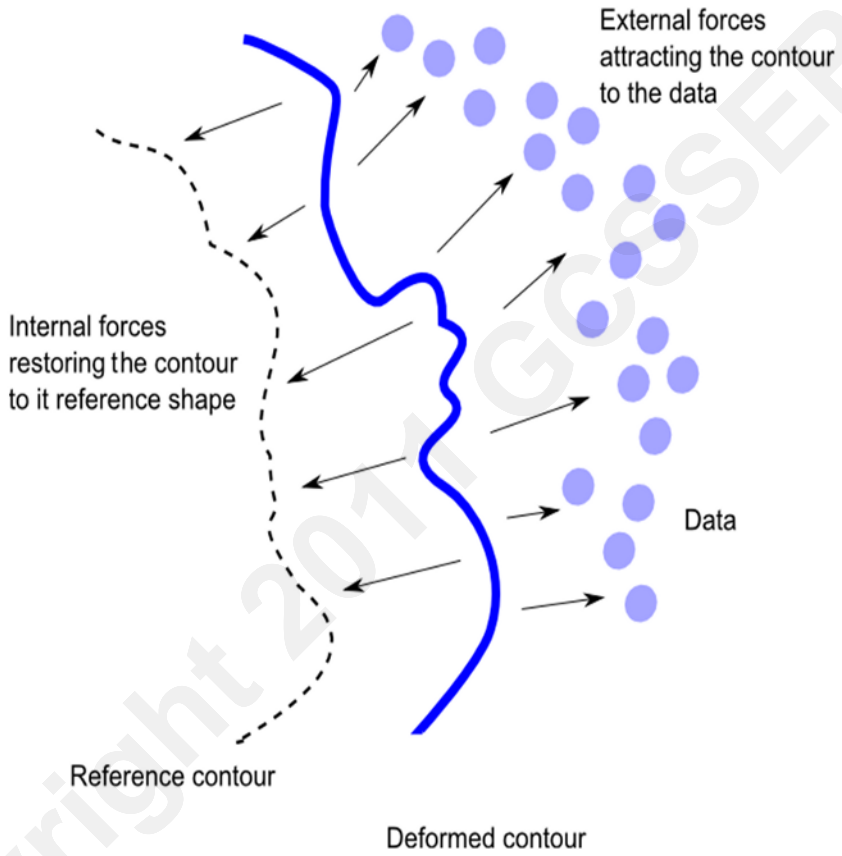


Figure 11. The explicit active contour model balances internal forces which act to restore the geobody to its reference shape and external forces which fit the geobody to the data.

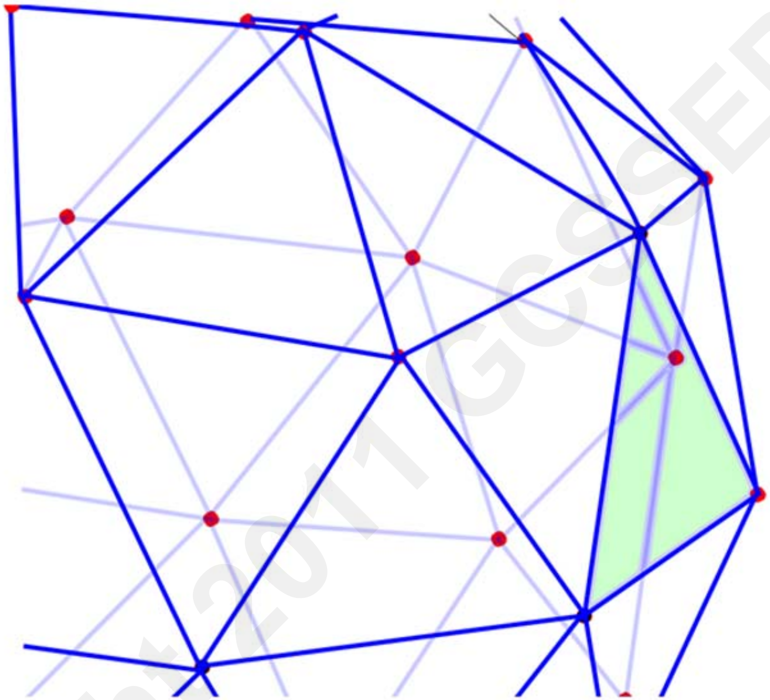


Figure 12. The active contour geobody exists as a triangulated mesh. The coarseness of this surface can be adjusted to suit the complexity of the geobody.

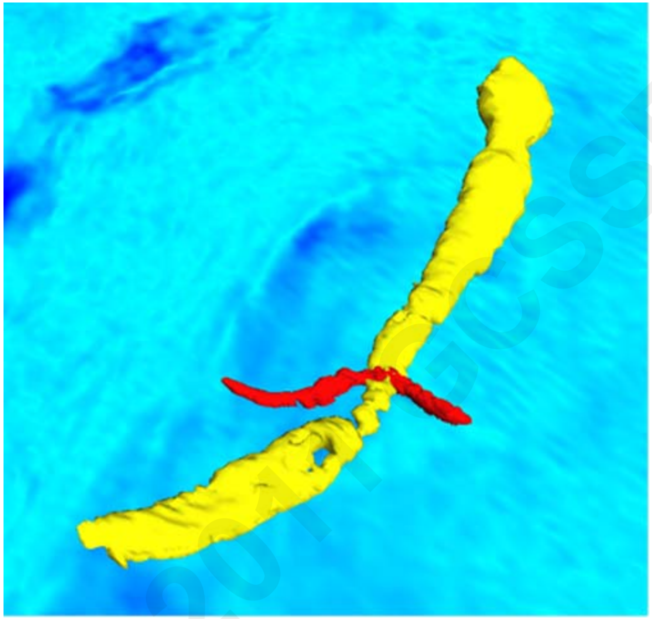


Figure 13. Multiattribute delineation of the 3D Jurassic channels using active contouring. Due to their differing seismic characteristics, this technique is able to isolate neighboring and overlapping features which can then be extracted as independent geobodies. Such an extraction would be quite difficult using conventional thresholding with single attributes.