Attribute-Assisted Automatic Fault Extraction - A Case Study in a Tectonically Complex Area Offshore East Coast of Canada*

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Search and Discovery Article #41925 (2016)**
Posted October 31, 2016

*Adapted from oral presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

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Abstract

The geological history of sedimentary basins in the Grand Banks is complex due to the influence of several cycles of Mesozoic rifting related to the opening of the North Atlantic. Subsurface evaluations of the recent Harpoon and Bay du Nord discoveries show the reservoir intervals are extensively faulted. While some aspects of the basin development are still debated, the implications for exploration and field development are clear: complex fault networks can significantly affect regional hydrocarbon migration pathways and result in local reservoir compartmentalization. To determine whether the faults are generally sealing or open to hydrocarbon flow, a thorough understanding of the structural fabric is needed. Exploration and reservoir development in highly faulted areas presents a significant challenge for the structural interpreter. Much detailed mapping is usually needed before the tectonic fabric of a complex area is fully understood. Nonetheless, in most cases, a comprehensive fault interpretation is impossible due to time constraints, data quality and, in most cases the very large number of faults. Attribute-assisted fault extraction can identify a complete fault network within a very short timeframe. In this case study, we will walk through the workflow that was applied to a 3D post stack data set from the east coast of Canada. The workflow consists of: data conditioning to clean the data to minimize false positives; selecting appropriate attributes to image the full extent of the faults (this is dependent of the fault type, data quality and seismic response); optimizing the combination of attributes by enhancing the fault responses; and extracting the faults. As part of the workflow, limited frequency bandpass volumes are also used. Using reflectivity data with limited frequency content enables faults to be investigated at different scales. The results can be used at exploration scale to gain a thorough understanding of the tectonic history of an area, and at reservoir scale to assist the manual picking of fault sticks for the geocellular model. In conclusion: implementing a data-driven fault extraction workflow into the normal seismic interpretation routine can generate significant time savings for the seismic interpreter and cost-savings for a subsurface project. The extractions enable a more rapid and robust identification of faults. They can also highlight the structures, which have implications for hydrocarbon migration and reservoir production.

Attribute-assisted automatic fault extraction

A case study in a tectonically complex area offshore East coast of Canada

H. M. Garcia, J. Dexter, R. Martin

Outline

- Location
- Challenges
- Data
- Attributes
- Fault Extraction
- Integration
- Conclusions

Location

- Data from the Bay du Nord area
- 300 miles NE of St. John's
- Water depth 3600 feet

Presenter's notes: Bay du Nord was discovered 2013. It is located on the east coast of Canada, in the northern Flemish Pass, 300 miles NE of St John's, in water depths of 3,600 feet.

Challenges

- Detail mapping
- Structural complexity
- Very large number of faults
- Times constrains
- Data quality

Presenter's notes: In highly faulted areas, as is the Bay du Nord the structural interpreter is faced with many challenges. In order to understand the tectonic fabric of a complex area much-detailed mapping is necessary. Mapping of reservoir horizons and fault planes can significantly affect hydrocarbon volume estimation. In terms of **Structural complexity,** The Flemish Pass has experienced 3 main rifting events associated with the North Atlantic, and each phase has a different structural orientation. This has resulted in a complex network of fault blocks and segments at Jurassic level. The faults must be imaged before reservoir connectivity and segmentation can be assessed. **Another challenge is the Very large number of faults.** Over 200 faults here interpreted within the field development area to provide a detailed understanding of structural development of the reservoir. **Time constraints**: Time-saving workflows are essential so that subsurface interpretations can be provided as input to business decisions in a timely manner e.g. to meet license application deadlines, corporate and budget deadlines, project deadlines. Under laying all this is data quality.

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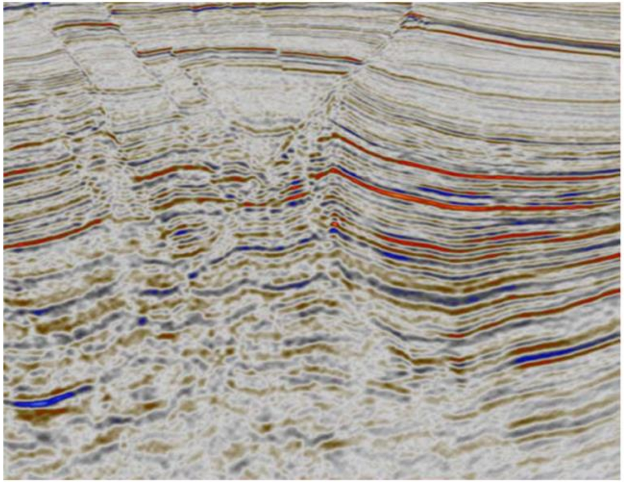
Data

- PSDM Original volume

  Specially processed volume to highlight the faults.

Noise attenuation:

- Clean the data
- Preserve the faults



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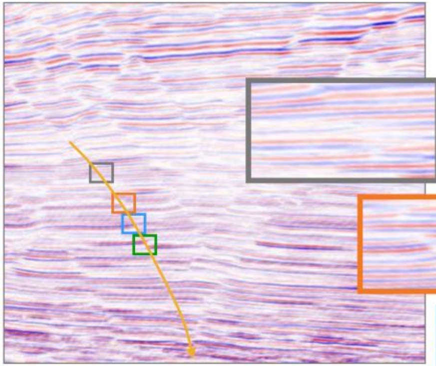
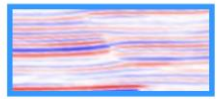
Presenter's notes: This data set had a special processing workflow applied to improve the fault imaging. The first step of the fault extraction workflow was to conditioning the data. For that a noise attenuation workflow was applied. This consisted in the application of structurally oriented filters in order to remove the noise without smearing across the fault. The benefit is that in a cleaner data set the attributes calculation will produce less false positives.

Attributes

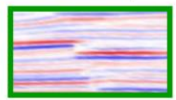


The reflectors are continuous with no amplitude variation across the fault plane

Reflectors are continuous and present an abrupt amplitude variation across the fault plane



Reflectors are continuous with a slight inflection and amplitude variation across the fault plane



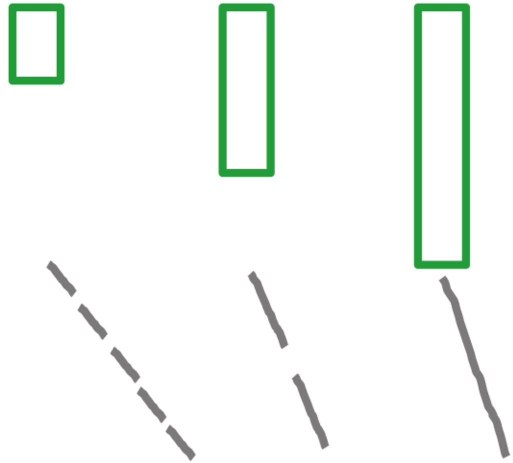
The reflectors are discontinuous with amplitude variation across the fault plane

Presenter's notes: There are several things to consider when choosing what attributes to use to image the fault. There is a fundamental difference between the way humans look at the data and machines. Humans are very good at identifying patterns; we have no difficulty in mapping this fault with its full extension. Machines on the other hand when analysis the data will see that on this section of the fault there is a clear break in the reflectors and a lateral change in amplitude. On the next section of the same fault, the reflectors are continuous, with an inflection and amplitude change. The next one the reflectors are continuous with a big amplitude change. In addition, on the last one, the reflectors are continuous and there is no amplitude change. Therefore, for the machine it is impossible to see this as a single, continuous fault. This type of limitation must be taken into account when designing the fault detection workflow.

Attributes

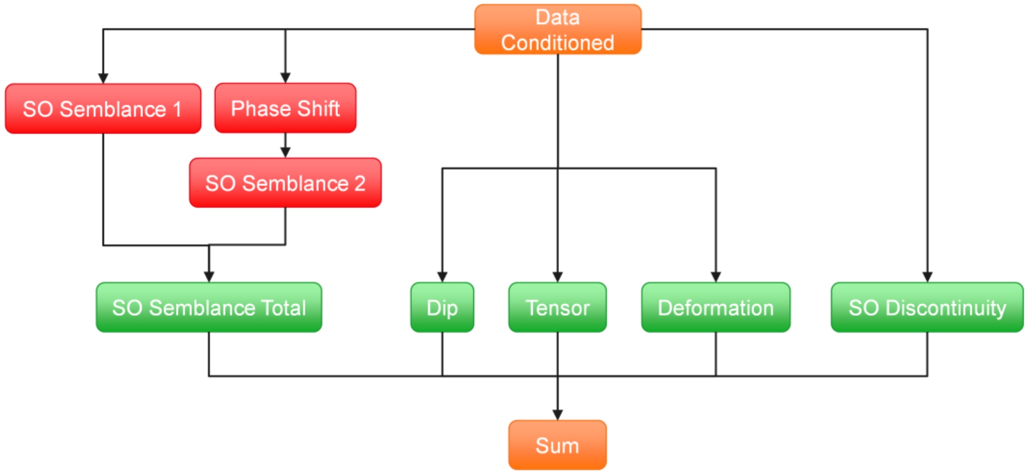
Fault Imaging footprint dimension:

Attribute Response:



Presenter's notes: One other aspect, now when optimizing the attribute filter size is the filter vertical size. A balance must be achieved between the attributes response continuity and the verticalization of that response. If a small filter size is used, the attribute response is less continuous but the true angle of the fault is imaged. In order to increase the attributes response continuity we must increase the filter's vertical size. This is attained at the expense of the angular position; the fault will be more vertical.

Attributes



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Presenter's notes: This was the workflow created to image the faults. We used five attributes: SO Semblance, Dip, Tensor, Deformation and SO Discontinuity. Since, as we have seen, faults (and most of the times the same fault) have different seismic characters each attribute will "look" at the data in a different way allowing us to image the full fault network. We will now look at the individual attributes.

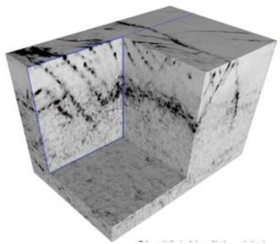
Attributes

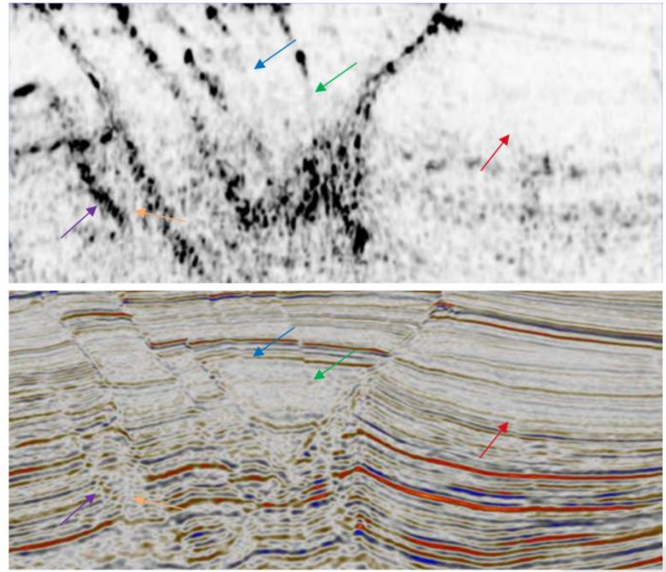
Tensor

(amplitude)

This attribute is based on a local gradient structure tensor.

Identifies faults as lateral changes in amplitude, provides good continuity along regional faults.





Presenter's notes: Tensor is based on the local gradient structure tensor and is best at imaging faults that have a lateral change in amplitude. It is also very resistant to chaotic areas. The limitation is off course its lack of response in low amplitude areas.

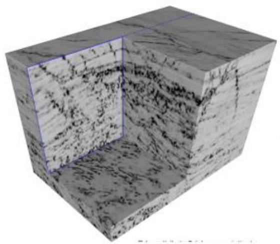
Attributes

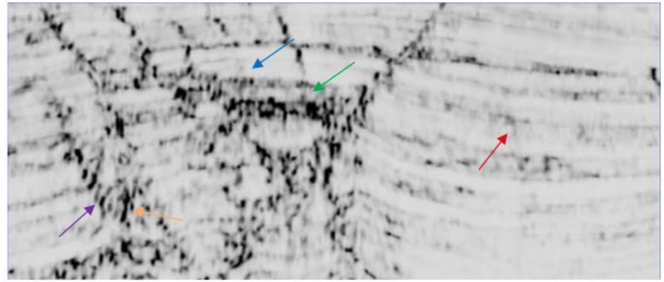
SO Semblance

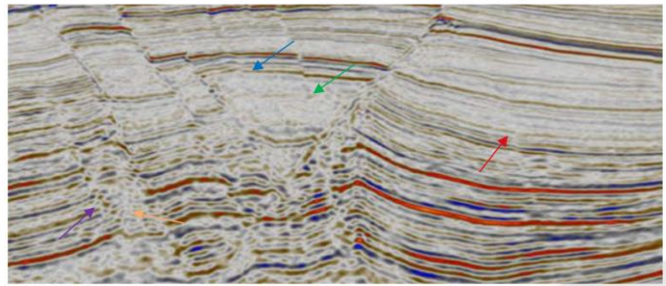
(phase)

This attribute is based on a measure of the Structurally Oriented Semblance.

Identifies faults phase breaks. Similar to coherency







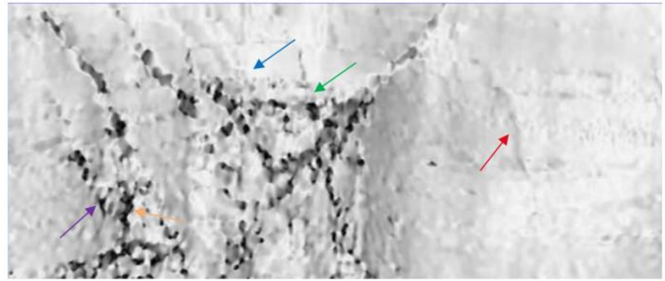
Presenter's notes: Structurally Orientated Semblance will identify fault that have breaks on the reflectors, that is, phase changes. It is independent of amplitude and therefore highlights low amplitude chaotic areas. SO Semblance was calculated twice, once on the zero phase data and again on a 90^{o} phase rotated data. The two results were then added. This was done to minimize the horizontal striping in the attribute response.

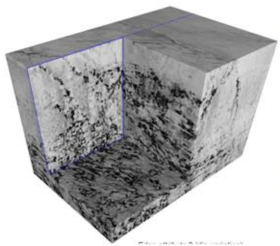
Attributes

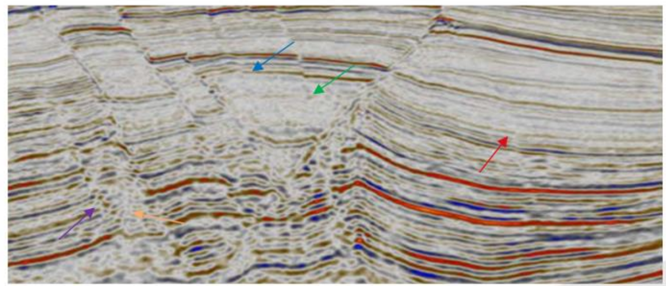
Dip

(inclination)

This attribute was used due to the special processing that was applied to the data. This processing made the fault planes appear as reflectors making dip the ideal attribute to identify them.







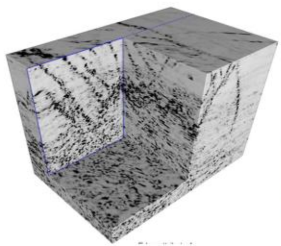
Presenter's notes: A special processing was applied to the data, as a result some of the faults are reflectors. To image this fault the dip attribute was used. Because the fault planes have a much higher dip was the surrounding reflector the dip attribute is ideal to image them.

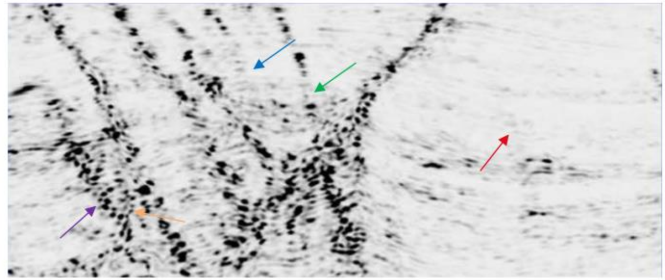
Attributes

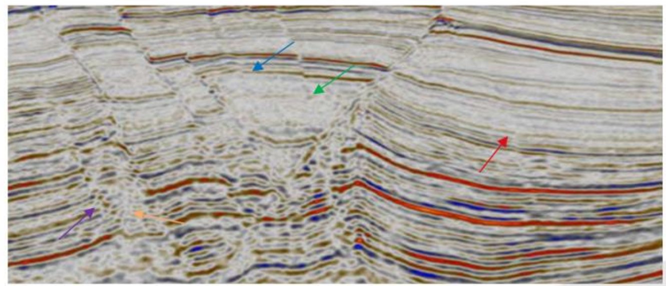
SO Discontinuity

(statistical)

SO Discontinuity makes statistical variability measurements within a specific footprint. It does this by calculating the structurally oriented variance of the Noise Cancelled volume and the Standard Deviation within the footprint, and combines them.







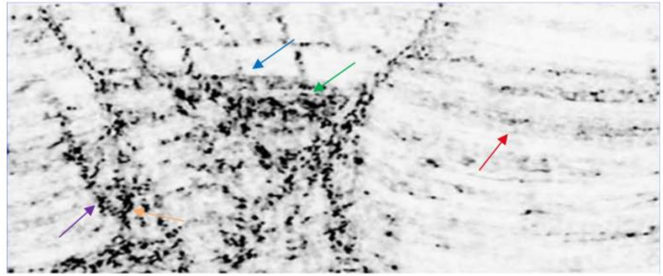
Presenter's notes: SO Discontinuity is a statistical attribute. It calculates the variance and standard deviation and combines them. This attribute sits midway between the Tensor and SO Semblance, picking up both phase breaks and amplitude changes.

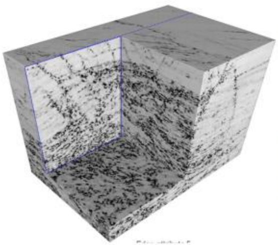
Attributes

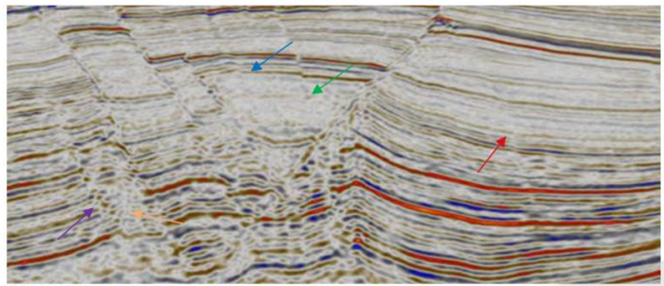
Deformation

(vector)

The Deformation module analyses the distribution of the 3D orientation vectors relating to the Dip and Azimuth values within a 3D neighborhood surrounding the current point







Presenter's notes: The Deformation performs a vector analysis. This attribute is very good at imaging faults with a varying orientation from the surrounding.

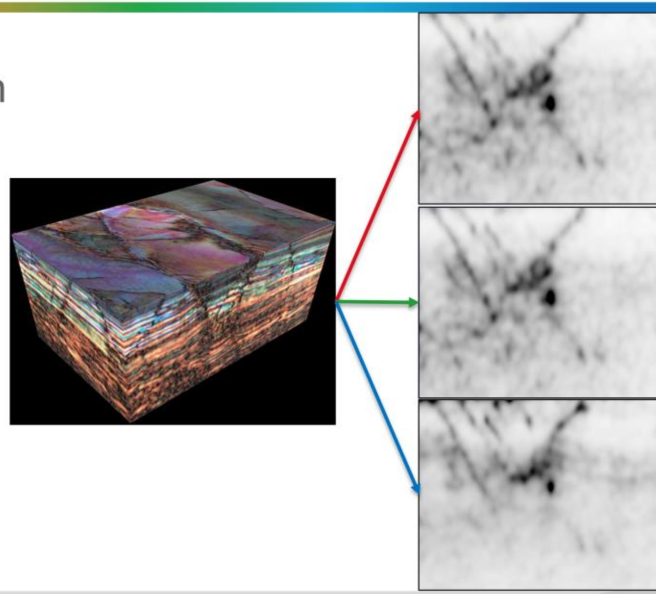
Attributes

Frequency decomposition

(frequency)

Frequency decomposition and color blending can also be use in fault detection.

- Weak response from the three volumes at the same time
- Areas of rapid change in the magnitude volumes
- Faults at different scales

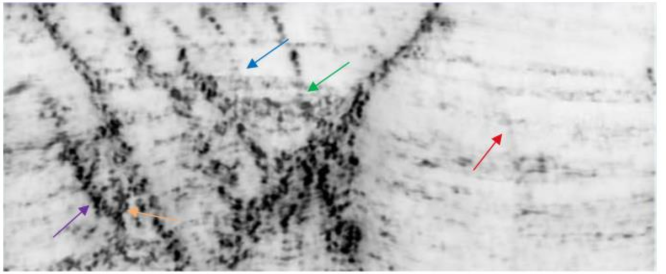


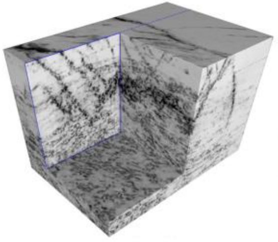
Presenter’s notes: Frequency decomposition color blend volumes are mainly used for stratigraphic analysis but they can also be used for imaging faults. On a color blend, from frequency decomposition, the faults will be images as dark lineation. This corresponds to areas where the frequency response from the three volumes is weak, at the same time. On the individual magnitude volumes, this corresponds to areas of rapid lateral change of the attribute. This characteristic can be used to identify and isolate this faults responses.

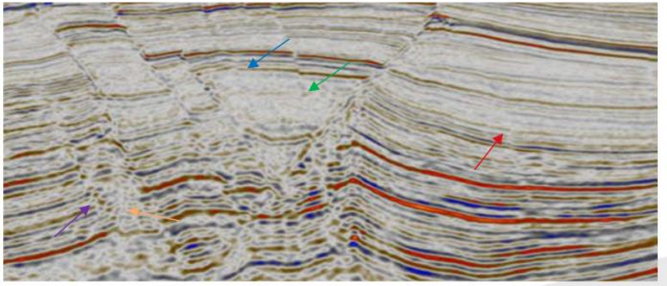
Attributes

Sum

All the individual volumes were combined.







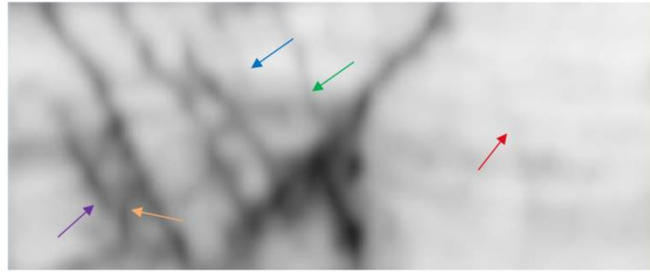
Presenter's notes: The individual attribute volumes were properly scaled and added in one single volume. This new volume has all the benefits from the individual attributes and the areas noise and/or false positives are attenuated.

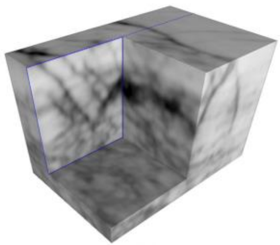
Fault Enhance

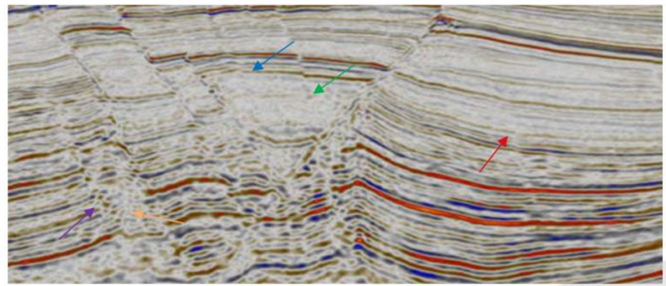
Fault Enhancement

Last step before the detection

Increase vertical continuity of the faults and difference from the background value.







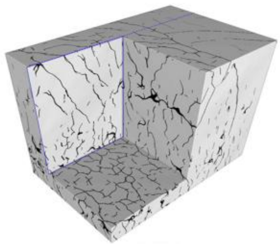
Presenter's notes: The fault enhance is the last step before the actual detection. In this stage, the vertical continuity of the faults and the difference from the fault and the background value is increased. This is achieved by applying a Gaussian smoothing filter to the data.

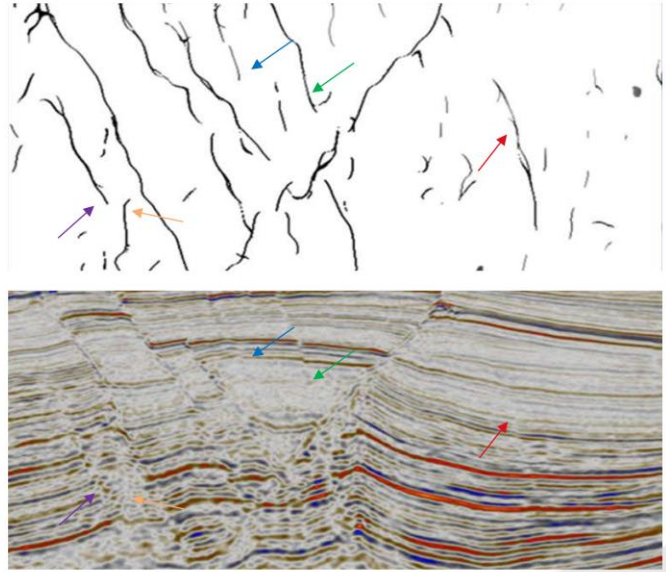
Fault Detect

Fault Detect

Ridge operator

Fault as single voxel lineation



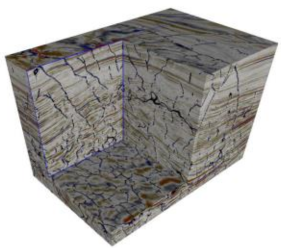


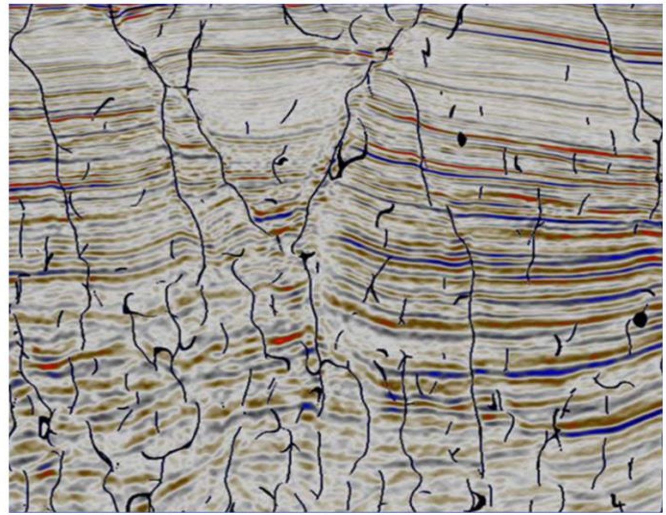
Presenter's notes: During the detection stage, a ridge operator is applied to the data. The operator looks for peak values of the attribute within the filter size and extracts them as single voxel lineation. The attribute value must also be above a certain local threshold value, set by the user, in order to be marked as a fault.

Integration

Fault In

Detected fault network is embedded in the reflectivity data.





Presenter's notes: The optimal deliverable to the structural interpreter is this volume, were the detected fault network is embedded in the reflectivity data. The interpreter will have more confidence in the interpretation and the all process will be faster since the obvious faults are already marked and he can concentrate his efforts in the more difficult areas.

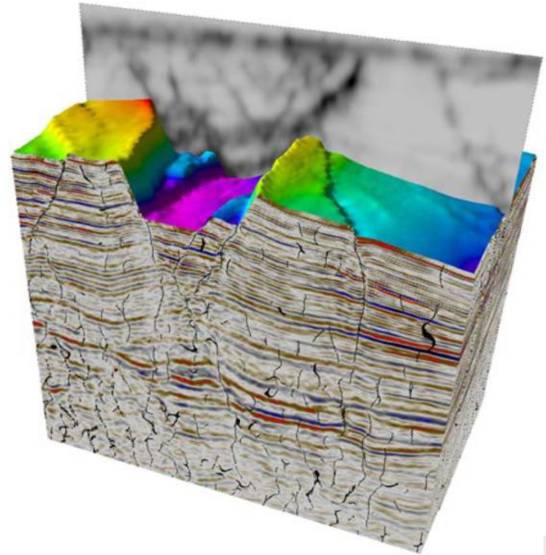
Discussion

- Combination of volumes
- Investigation on the number of attributes used
- Cross plot, CMY

Presenter's notes: Due to the nature of this work, this was part of a three day consultancy engagement further optimization of the workflow is necessary, specially the number of attribute volumes to use in the final combination. This will have repercussion in the processing time. This optimization can be achieved by cross plotting the different attributes to see if we are repeating information. In a more visual approach, CMY blends can be used. We take advantage of fact that on the color blend we can see the relationship of the three attributes and how they relate to each other.

Conclusions

- Significantly reduce the interpretation time
- Increase the interpretation confidence
- Interpreter can focus is efforts on more complex areas
- Better understanding of the fault network and implication on production
- Generate detailed reservoir models
- Overall cost-savings for a subsurface project



Presenter's notes: Implementing a data-driven fault extraction workflow into the normal seismic interpretation routine can be very advantageous:

- **Significantly reduces the interpretation time:** enables timely geoscience input to business decisions.
- **Increase the interpretation confidence:** makes structural interpretations more robust and improves the quality of the geoscience input to a business decision.
- **Interpreters can focus their efforts on more complex areas** or on details important in the geocellular model (fault truncations and intersections, segment definitions etc)
- **Better understanding of the fault network:** is important for understanding the structural history of an area, field segmentation and implications for production.
- **Generate detailed reservoir models:** these are a key part of the evaluation of any hydrocarbon discovery where a field development decision might be made.
- **Overall cost-savings for a subsurface project:** more geoscience work can be achieved within shorter timeframes.

Q&A

Thank you

Question?