Enhanced Fault Imaging from Seismic and Geological Model

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Summary

Imaging faults is a complex process, which requires a combination of various approaches. Methods based on the gradient vector field, obtained from the seismic 3D cross correlation, is sensitive to any local variation. Deriving the vector field to local dip, curvature or oriented filters such as variance, is used extensively to enhance structural discontinuities. By analyzing the maximum of variance, a new attribute depicts the probability of fault occurrence. Although it shows a skeleton of the fault network, it remains difficult to use it for automatic extraction.

Another method consists in using derivatives of a relative geological time model, obtained during a comprehensive interpretation process. In such case, the fault image is directly related to the vertical throw and provides a high level of detection even where the seismic variance is limited due to a low signal to noise ratio. To increase the precision of the detection, surface attributes for each relative age are computed in the flattened space and then converted to the seismic domain.

With such technique, the calculation of the extrema values of the deepest descent gradient shows the fault break points at a sub seismic accuracy and is related to the vertical throw. It becomes a complementary attribute to the variance and the fault probability. Applied to the Exmouth data set, located on the North West Australian margin, these various types of attribute were used to interpret complex faulted deposits in the reservoir level.

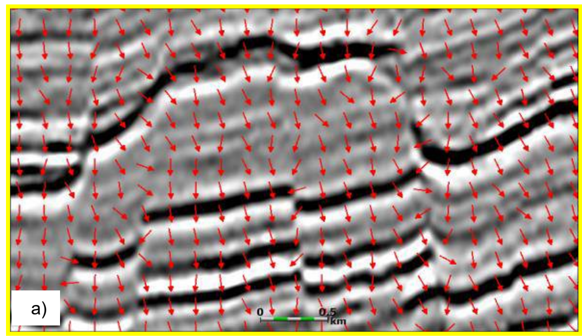
Introduction

Seismic attributes have been used extensively to image faults for the past decade. Even though algorithms, imaging technologies and hardware are improved year after year, detecting faults from the seismic remains a complex task. In this paper, two complementary approaches are presented: one based on the local vector field directly computed from the seismic data and the other one related to a relative geological time (RGT) model, computed during the seismic interpretation process.

Gradient Vector Field

The gradient vector field reflects the orientations of events in the seismic volume and represents a very important source of information to have a preliminary view of the main geological trends. It is computed using the normalized cross-correlation to 3D matrix and allows to have automatically a local vector for each sample in the entire seismic volume (Fig 1.a). The gradient vector field constitutes a major input to determine the local dip and azimuth and, to some extent, can be used to highlight stratigraphy as well as structural discontinuities.

For each vector, the local dip and azimuth are estimated and used for various attributes calculation (Fig 1.b). Although this information is sensitive to faults, it only shows local variations and cannot be related to the displacement of the fault plane. Several applications derived from the gradient vector field have been proposed for fault enhancement, such as dip-steered coherence (Marfurt et al, 1999), structure-oriented filter (Luo et al, 2002; Wang, 2008, 2012) and also curvatures, which are widely used for structural discontinuities detection (Roberts 2001, Marfurt, 2006).



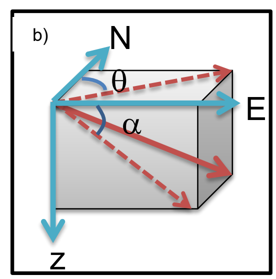


Figure 1: *Calculation of the local vector based seismic 3D cross correlation. For each seismic sample, a vector provides the local dip and azimuth, which will be used to compute structural attributes.*

In this work, the local vector field has been applied to a seismic data set coming from the Exmouth Sub-basin, which is part of the North Carnarvon Basin, along the West Australian margin and characterized by a complex fault system in the reservoir level.

A local dip attribute was computed from the Principal Component Analysis of the principal Eigen vector of the covariance matrix. Despite this attribute shows main fault lineaments (Fig 2.b), the image is too heterogeneous to clearly detect fault planes. Even though this level of detection can be optimized by using a range of curvature attributes (Fig 2.c), it remains complex to extract structural discontinuities. Therefore, dip-steered coherence analysis (Marfurt et al, 1998), such as variance, provides a significantly better image of the structural discontinuities but still depends on the seismic signal heterogeneities in the vicinity of the fault, inducing approximations in the local dip calculation (Fig 2.d).

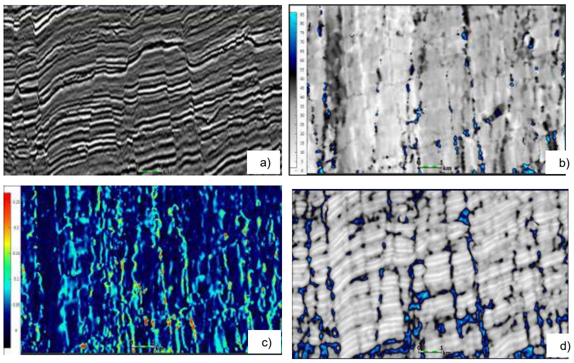


Figure 2: *Various attributes based on the local vector field. (a) Seismic; (b) Local dip from the PCA of the covariance matrix, (c) Maximum curvature and (d) Variance.*

Fault detection can be done on each time slice of the volume by computing the extrema values of the variance in the direction spatially perpendicular to the gradient vector. This attribute gives a first image of the fault network skeleton, where each value is related to the probability of a fault location (Fig 3). However, this information has to be treated carefully in three dimensions, as the maximum probability does not strictly match with the actual fault plane, due to lateral seismic heterogeneities. This is the reason why such an attribute cannot be used to extract automatically the fault planes but has to be used as a guideline to constrain the manual fault interpretation.

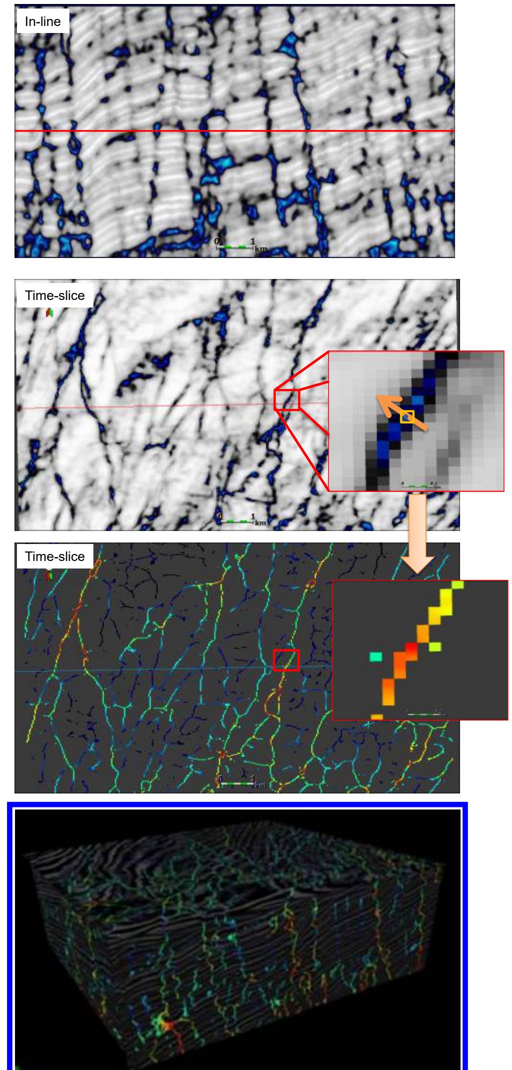


Figure 3: *Fault probability attribute. (a) Variance is taken as input attribute. (b) A vector is computed on each sample (c) the maximum of variance on each time slice according to the vector orientation to image, (d) the fault probability attribute shows potential fault lineaments but is still related to seismic lateral variations.*

Geological Model Derivative

Another complementary technique consists in taking into account a Relative Geological Time (RGT) model as an input for fault attributes. This model is obtained from a novel approach in seismic interpretation, which aims to propagate and sort horizons chrono-stratigraphically (Pauget et al, 2009). Thanks to the RGT model, this comprehensive approach is a new input for fault imaging complementary to seismic attributes. By applying spatial derivatives, structural discontinuities can be clearly highlighted. Indeed, as vertical derivatives are sensitive to stratigraphic discontinuities, spatial derivatives of the relative ages show clearly the occurrence of faults even in zones characterized by a poor seismic signal to noise ratio (Fig 4.c).

Besides, whereas seismic attributes only show local variations, the RGT model derivative is directly related to the vertical throw of the fault. Although such results are promising, it is required to check first the quality of the RGT model, which may need some manual refinement by the interpreter, prior the attribute computation.

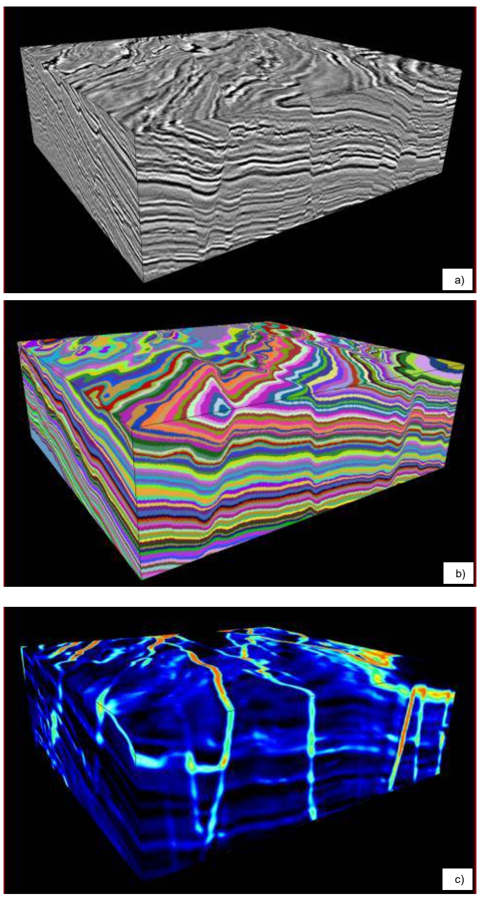


Figure 4*: Fault attributes derived from the RGT model. (a) Seismic (b) RGT model (c) Spatial gradient of the model*.

Surface Attributes Conversion

For each horizons coming from the RGT model, there is a range of attributes such as dip, azimuth, curvature, which allows to detect subtle faults and fractures, sometimes at a sub-seismic accuracy. Like for the fault probability, the deepest descent gradient computes the maximum dip variations, detects the fault break points on each surface and is related to the vertical throw.

To convert these attributes into volumes, a method was adapted to compute surface attributes in the flattened domain where the vertical scale represents relative geological ages. It then becomes possible to apply any surface attribute, such as the dip or the deepest descent gradient, and generate them in the seismic domain by unflattening (Figure 5). This technique provides a high resolution fault image relying to geology and not to seismic signal variations.

Conclusions

The use of the local vector field for attributes computation is a good method to have a first image of the faults based on structured oriented filters, such as local dip, curvature, or fault probability. However, by using the RGT model as a new input, it offers a new dimension, where the fault image is related to the vertical throw. This technique has been adapted to compute any surface attribute on a flattened space and convert them in the seismic space by unflattening. The surface attributes are more precise and improve the fault detection capacity.
Applied to the Exmouth data set, located on the North West Australian margin, this method allowed to constrain the structural interpretation and understand complex faulted deposits in the reservoir level.

Acknowledgements

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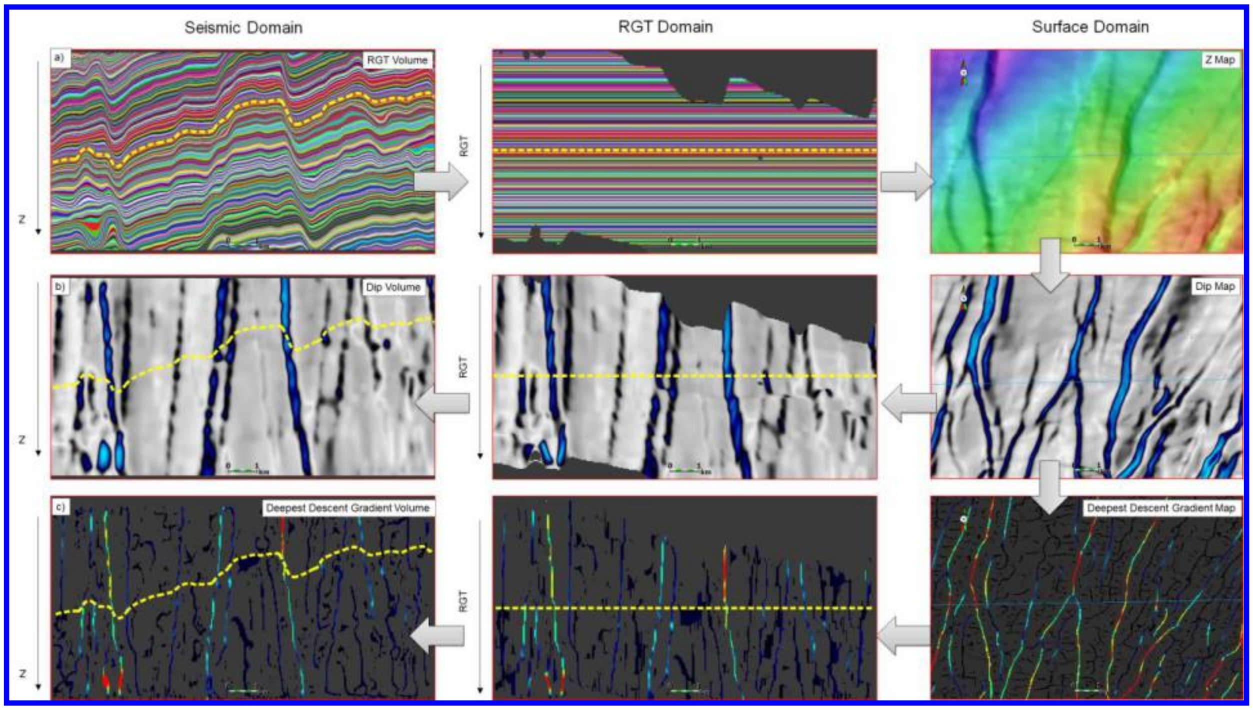

Figure 5: *Surface attribute conversion to volumes. (a) the RGT volume is flattened, the intersection of each horizon is computed on both domains. (b) Dip variation for each surface is reported in the flattened space and then converted in the seismic domain. (c) The deepest descent gradient, which represents the maximum of dip, shows fault break points. Converted to the seismic domain, it reveals at a better resolution the fault planes.*

EDITED REFERENCES

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