Seismic attributes for fault/fracture characterization

Satinder Chopra and Kurt J. Marfurt[+]*
**Arcis Corporation, Calgary; [+]University of Houston, Houston*

Summary

Seismic attributes have proliferated in the last three decades at a rapid rate and have helped in making accurate predictions in hydrocarbon exploration and development. Attributes sensitive to amplitude such as impedance inversion and AVO are widely used for lithological and petrophysical prediction of reservoir properties. Other attributes, such as coherence and curvature are particularly useful in mapping the structure and shape of geological features of interest. While attributes are sensitive to lateral changes in geology, they are also sensitive to lateral changes in noise. For this reason the input data needs to be properly conditioned. Volumetric attributes, which use a vertical window of data in their analysis, are in general more robust than horizon-based algorithms and make a significant difference to the quality of the results.

Introduction

Among the various geophysical techniques available for characterizing faults and fractures, 3D seismic attributes are particualrly useful for identifying faults, large fractures, and zones amenable to fractures that fall below seismic resolution. A very useful feature of 3D seismic is the fine sampling of data over the region of interest, giving a more accurate representation of the areal extent of the features. Also, while seismic amplitude changes associated with the features of interest may not be readily noticeable on vertical sections, horizontal sections (time or horizon slices) may yield distinctive patterns that the human interpreter is able to recognize and associate with well-established geologic models… Through such models, seismic attributes allow an interpreter to reconstruct a paleo depositional environment and/or deformation history. In this paper we discuss the application of poststack attributes for detection of faults and fractures. Dip-magnitude, dip-azimuth and coherence attributes have been used for the detection of faults and fractures for the past 10-15 years. We will demonstrate the how volumetric curvature, which measures lateral changes in dip and azimuth provide additional insight.

Discontinuity attributes

Seismic attributes that highlight discontinuities in the seismic data are useful for fault and fracture characterization.

Dip-magnitude and dip-azimuth

Rijks and Jaufred (1991) showed that horizon-based dip-magnitude and dip-azimuth are useful in delineating subtle faults whose displacements measure only a fraction of a seismic wavelet. A skilled interpreter recognizes alignments of such subtle offsets in map view as being either faults or artifacts.

Coherence

Bahorich and Farmer (1995) introduced the coherence attribute which computes coherence coefficients from seismic amplitudes on adjacent traces using a crosscorrelation technique. Subsequent algorithms based on semblance and eigenstructure led to more accurate coherence computation than initially demonstarted.

The coherence images clearly reveal buried deltas, river channels, reefs and dewatering features. The remarkable detail with which stratigraphic features show up on coherence displays, with no interpretation bias and some previously unidentifiable even with close scrutiny, appeal to interpreters.

Example

In Figures 1a and b, we show a comparison time slices at $t = 1240$ ms through the seismic amplitude and coherence volumes. The coherence volume was generated using a modified eigen decomposition algorttm, which employs a robust dip steering option for removal of the structural component (dip) from the coherence computation. Notice the clarity with which the fault patterns stand out, which would be difficult to decipher from the seismic alone. A chair display in Figure 1c shows the correlation of the fault patterns with their seismic signatures.

Curvature

Lisle (1994) demonstrated the correlation of a curvature measure (Gaussian) with open fractures measured on outcrops. Though the exact relationship between the open fractures, paleostructure and present-day stress is not yet clearly understood, different (Roberts, 2001; Hart et al., 2002; Sigismondi and Soldo, 2003; Massafero et al., 2003) have demonstrated the use of seismic measures of reflector curvature to map subtle features and predict fractures. A significant advancement in this direction has been the multispectral volumetrjc computation of curvature (Al-Dossary and Marfurt, 2006). By first estimating the volumetric reflector dip and azimuth that represents the best single dip for each sample in the volume , followed by computation of curvature from adjacent measures of dip and azimuth, a full 3D volume of curvature values is produced. There are many curvature measures that can be computed, but the most-positive and most-negative curvature measures are perhaps the most useful in that they tend to correlate most directly with conventional interpretation work flows. An attractive feature of curvature computation is the ability to be able to perform multi-spectral analysis of curvature which depicts different features at different scales of analysis (Chopra and Marfurt, 2007).

Example

Figure 2 shows a comparison of time slices at t = 2104 ms through the seismic amplitude, coherence, and most-positive curvature volumes, for a 3D seismic volume from the North Sea. Notice that while the coherence display is featureless in the areas of high coherence (white) areas, the most-positive curvature shows significant structural deformation in the clay marker. Any interpretation carried out on the curvature attribute needs to be correlated with the seismic, to make sure that the attribute makes geologic sense. In Figure 3 we show a chair display for seismic (vertical) and a time slice from the most positive curvature volume. Any feature seen in red color (high value of curvature) correlates with reflections that show localized anticlinal structure.

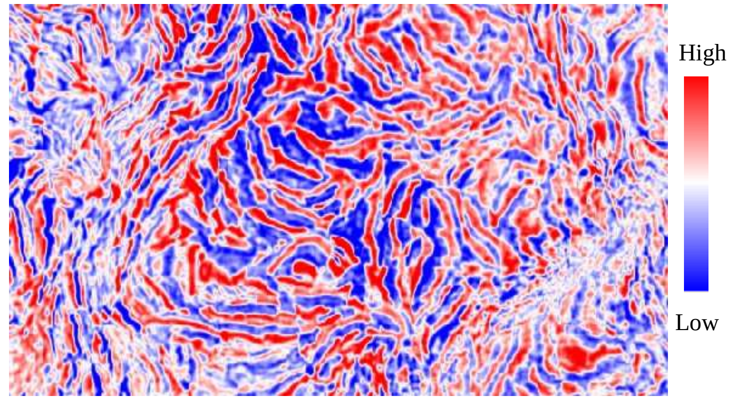
Conclusions

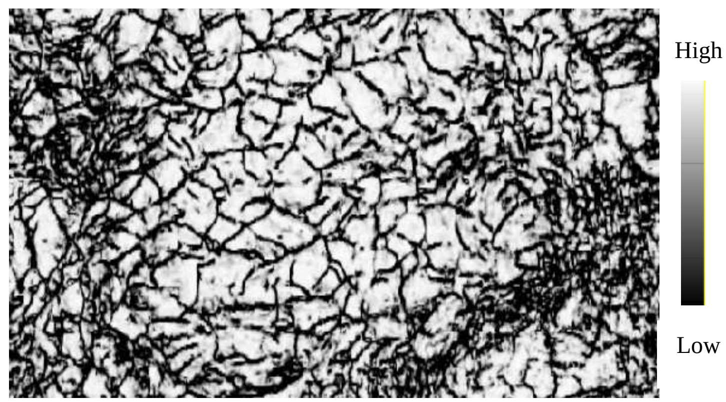
Seismic attributes are very useful for characterization of faults and fractures in 3D seismic data volumes. Coherence measure lateral changes in waveform. Sobel filters measure lateral changes in amplitude. Curvature measures lateral changes in dip and azimuth. In general, which attribute best illuminates a given geologic feature depends as much on the underlying geologic textures and lithologies as on the seismic data quality. However, we find that most-positive and most-negative curvature attributes offer provide better illumination of faults and fractures than other attributes.

Acknowledgements

We thank Oilexco, Calgary for the giving us permission to show the data examples included in this abstract. We also thank Arcis Corporation for the permission to publish and present this work.

(a)





(c)

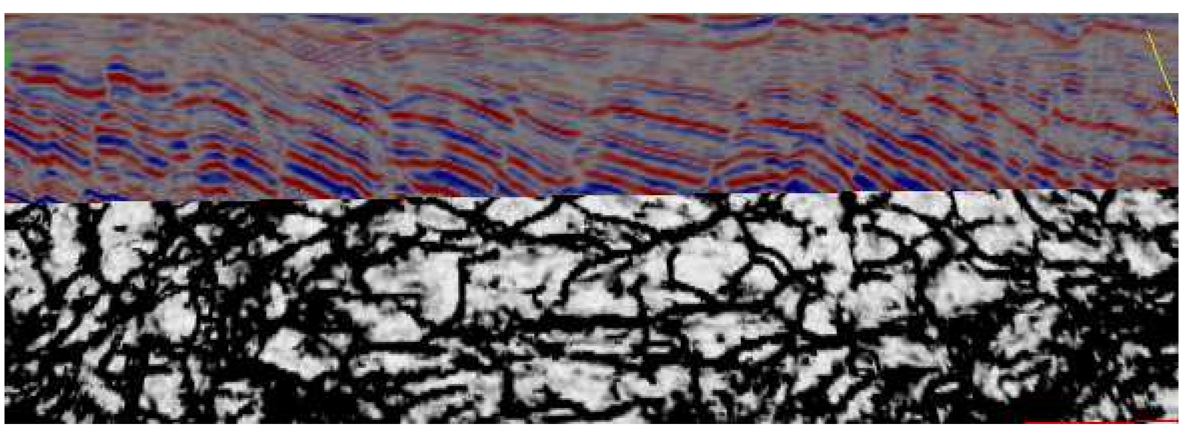


Figure 1: Time slice at t = 1240 ms through (a) seismic amplitude and (b) eigenstructure coherence volumes for a survey from the North Sea. Notice the accurate imaging of the fault pattern seen on coherence slice in (b), which is almost impossible to detect on the seismic. (c) A chair display of the fault patterns on the coherence and a vertical seismic section that helps correlate the fault breaks with their seismic signatures. *(Data courtesy of Oilexco, Calgary)*

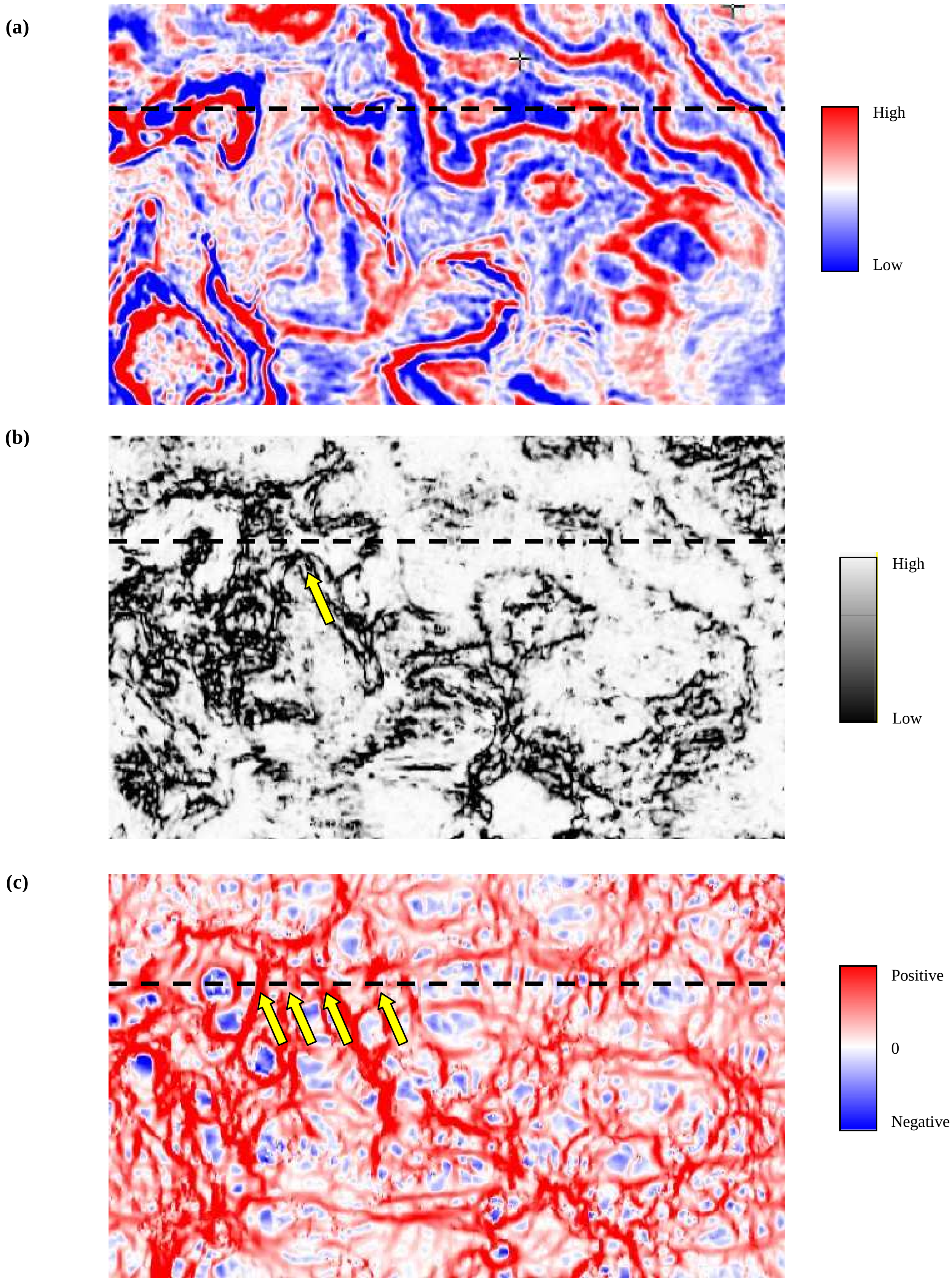


Figure 2: Time slics at t = 2104 ms through (a) seismic amplitude (b) coherence, and (c) most-positive curvature volumes. Notice that while the coherence display is featureless in the high coherence (white) areas, the most-positive curvature shows more detail in those areas. Yellow arrows indicate anticlinal features on the clay marker *(Data courtesy of Oilexco, Calgary).*

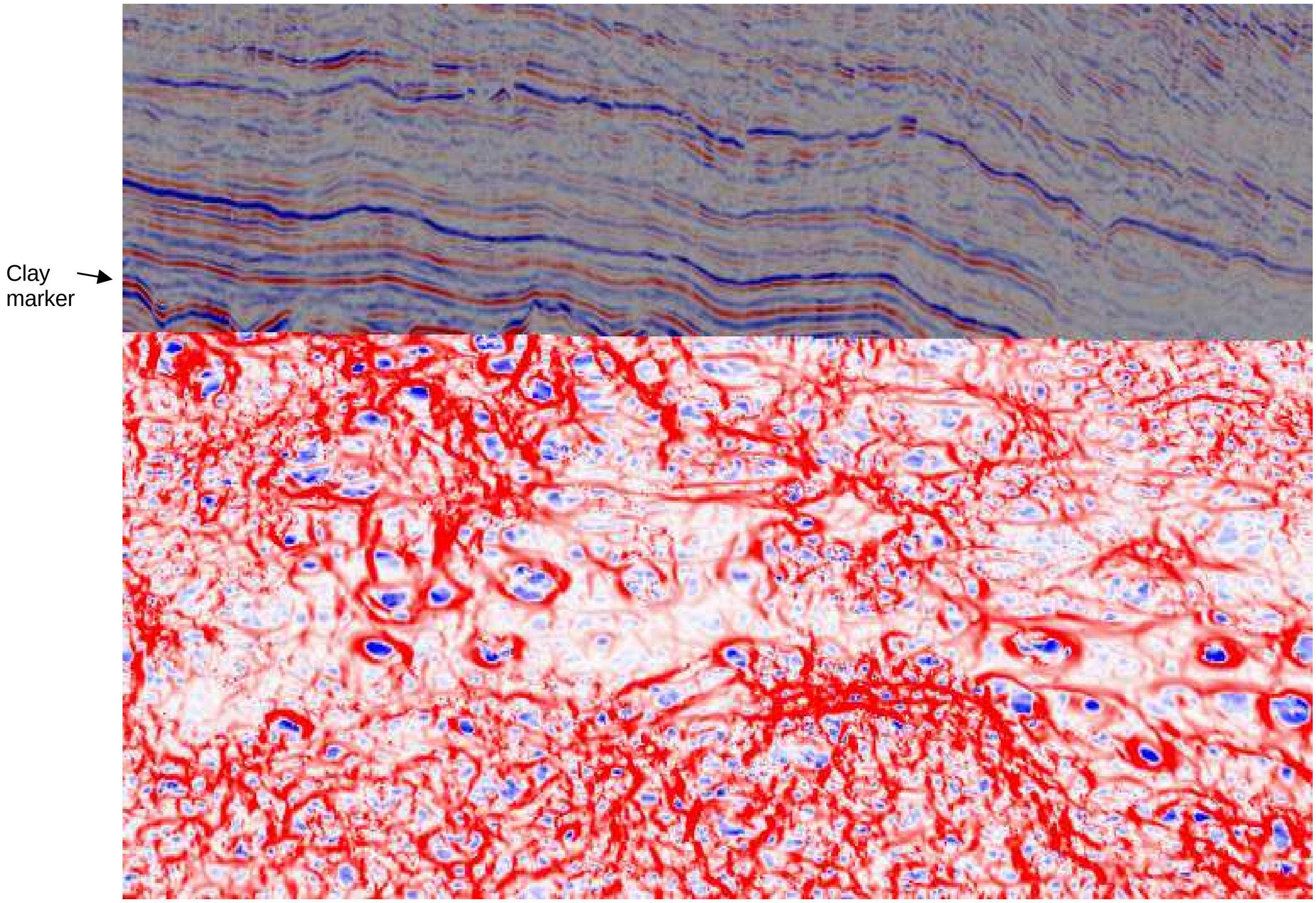


Figure 3: Chair display showing a segment of a seismic section (vertical) correlated with the time slice at 2104 ms from the most-positive curvature volume shown in Figure 2c. Notice how the features shown in red correlate nicely with the vertical structural features on the clay marker exhibiting positive curvature. *(Data courtesy of Oilexco, Calgary).*

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2007 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Al-Dossary, S., and K. J. Marfurt, 2006, 3D volumetric multispectral estimates of reflector curvature and rotation: Geophysics, 71, no. 5, P41–P51.

Bahorich, M. S., and S. L. Farmer, 1995, 3-D seismic discontinuity for faults and stratigraphic features: The coherence cube: The Leading Edge, 14, 1053–1058.

Chopra, S., 2002, Coherence cube and beyond: First Break, 20, 27–33.

Chopra, S., and K. J. Marfurt, 2007, Multispectral volumetric curvature adding value to 3D seismic data interpretation: Presented at the CSPG/CSEG Convention.

Gersztenkorn, A., and K. J. Marfurt, 1999, Eigenstructure-based coherence computations as an aid to 3-D structural and stratigraphic mapping: Geophysics, 64, 1468–1479.

Hart, B. S., R. Pearson, and G. C. Rawling, 2002, 3-D seismic horizon-based approaches to fracture-swarm sweet spot definition in tight-gas reservoirs: The Leading Edge, 21, 28–35.

Lisle, R. J., 1994, Detection of zones of abnormal strains in structures using Gaussian curvature analysis: AAPG Bulletin, 78, 1811–1819.

Marfurt, K. J., R. L. Kirlin, S. L. Farmer, and M. S. Bahorich, 1998, 3-D seismic attributes using a semblance-based coherency algorithm: Geophysics, 63, 1150–1165.

Marfurt, K. J., V. Sudhaker, A. Gersztenkorn, K. D. Crawford, and S. E. Nissen, 1999, Coherency calculations in the presence of structural dip: Geophysics, 64, 104–111.

Masaferro, J. L., M. Bulnes, J. Poblet, and M. Casson, 2003, Kinematic evolution and fracture prediction of the Valle Morado structure inferred from 3-D seismic data, Salta Province, northwest Argentina: Bulletin, 87, 1083–1104.

Rijks, E. J. H., and J. C. E. M. Jauffred, 1991, Attribute extraction: An important application in any detailed 3-D interpretation study: The Leading Edge, 10, 11–19.

Roberts, A., 2001, Curvature attributes and their application to 3-D interpreted horizons: First Break, 19, 85–99.

Sigismondi, M., and J. C. Soldo, 2003, Curvature attributes and seismic interpretation: Case studies from Argentina basins: The Leading Edge, 22, 1122–1126.