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Predicting Fluid Paths By Integrating Production and Drilling Data: Seeing the Invisible

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Abstract

Natural fractures and faults in the subsurface play an important role in fluid flow and accumulation. Therefore, identifying and mapping the distribution of fractures and faults systems is critical to understanding the fluid dynamics within a reservoir.

Although fractures and small-throw faults are not easily identifiable using conventional 3-D seismic techniques, their orientation and intensity can often be inferred using seismic attributes such as coherence and seismic curvature.

This case study will demonstrate how seismic curvature was used to map small scale fractures in a Saudi Arabian oil field which has been affected by premature water breakthrough. Premature water breakthrough is an increasing concern to all the geoscientists and engineers involved in developing the field. Curvature illuminates subtle fracturing that was difficult to detect with conventional seismic amplitudes. Using curvature allows geoscientists to map, for the first time, small-scale fractures believed responsible for bringing water prematurely to the top of the reservoir. The integration of image logs, zones of lost fluid circulation, production test and well test data has increased our interpretation confidence and helped optimize the placement of future horizontal wells.

INTRODUCTION

The seismic expression of structural and stratigraphic discontinuities such as faults and channels may include lateral variation in waveform, dip, and amplitude. Estimates of seismic coherence (e.g. Bahorich and Farmer, 1995; Marfurt et al., 1998, Gerstzenkorn and Marfurt, 1999; Marfurt and Kirlin, 2000) provide a quantitative measure of the changes in waveform across a discontinuity. Estimates of apparent dip (e.g. Dalley et al., 1989; Barnes, 2000; Marfurt et al., 1998: Marfurt and Kirlin, 2000; Marfurt, 2003) provide a measure of change in reflector dip magnitude and azimuth across a discontinuity. Additionally, estimates of amplitude or coherent energy-weighted amplitude gradients (e.g. Luo et al., 1996, 2003; Marfurt and Kirlin, 2000; Marfurt, 2006) provide a measure of change in reflector amplitude across a discontinuity. Such discontinuity measures can highlight the boundaries between fault blocks, stratigraphic units, diagenetic alteration, and hydrocarbon accumulation.

One of the major goals of exploration seismology is the delineation of fractures. Fractures are found in nearly every reservoir, rock type, and depth; they may also be found in source rocks, reservoir rocks and cap rocks. Petroleum explorationists pay a great deal of attention to locating these fractures in order to predict reservoir performance. Fractures can either advance or hinder our efforts in producing a reservoir. They may be confined to the reservoir or connect to deeper, water-bearing formations. Locating these fractures and identifying their orientations can help the explorationists benefit from their presence or avoid their problems.

Using seismic coherence to detect fractures has been investigated since the first emergence of the coherence cube as a new attribute of seismic data. Skirius et al. (1999) used seismic coherence in carbonates in North America and the Arabian Gulf to detect faults and fractures. Luo et al. (2002) showed some examples from a Saudi Arabian carbonate field where amplitude gradients helped in delineating fractures. While coherence and amplitude gradients can often detect lineaments, reflector curvature is more directly linked to fracture distribution (Lisle, 1994; Roberts, 2001, Bergbauer et al., 2003). Hart et al. (2002) and Melville et al. (2004) have used horizon-based attributes (including various curvature attributes) to identify structural features that may be associated with fracture-swarm sweet spots. Hart and Sagan (2005) have used curvature to delineate stratigraphic features of interest. Stewart and Wynn (2000) pointed out that it may be necessary to examine curvature at various scales to account for different wavelengths, which was later initiated by Stewart and Wynn (2003) and Bergbauer et al. (2003) on interpreted horizons. While his paper also dealt with curvature computed from interpreted horizons, Roberts (2001) anticipated that volumetric estimation of reflector curvature should be possible.

I have applied these curvature attributes on a 3D data from Saudi Arabian field. We find that the most positive and negative curvatures are the most valuable in the conventional mapping of lineament -including faults, and fractures. Volumetric curvature attributes show previously unimaged continuations of faults compared to the well-established coherence geometric attribute.

EVALUATION OF ALTERNATIVE DERIVATIVE CALCULATIONS

Luo et al. (1996) showed that lateral changes in reflector amplitude can be enhanced by a simple derivative, or Sobel filter, which can be approximated by convolving the seismic data with the vector [-1,0, +1]. Clearly, if this simple approximation to the first-derivative is valuable, we might assume that we can obtain superior results by replacing our 3 sample, 2nd order accurate [-1,0, +1] operator with a longer-length, higher-order accurate approximation of the first-derivative. Alternatively, we may obtain better derivative-based edge detection by exploiting recent advances made in the 2-D image processing literature (Torreao and Amaral, 2002) and applying them to 3-D seismic data. A third alternative is to modify the fractional order horizontal derivatives developed and applied to 2-D potential field data by Cooper and Cowan (2003), and modify them to estimate 3-D reflector curvature. Such fractional order horizontal derivatives should allow us to analyze our data over a range of wavelengths and thereby delineate different scale features from the same time slice of 3-D seismic data.

In this paper, our primary focus is on estimating curvature, rather than edge detection. Fortunately, even when viewed on time slices, vector dip is relatively slowly varying when compared to seismic amplitude. In fact, the lateral variability of vector dip is closer to that seen in photographic images and potential field data rather than that seen on seismic amplitude time slices.

MEASURE OF CURVATURE

Seismic reflectors are rarely planar, but are usually folded or even broken. Many regions of the earth's subsurface can best be described as chaotic. Most published work in mapping reflector shape has been restricted to represent interpreted horizons by their curvature (Lisle, 1994; Stewart and Wynn, 2000; Roberts, 2001; Sigismondi and Soldo, 2003). This work in turn has been based on a great deal of literature in mapping surface topography or terrain (e.g. Mitsova and Hofierka, 1993; Wood, 1996). In this paper, we wish to develop an algorithm that estimates reflector shape on a complete cube of seismic data without the need for prior interpretation.

APPLICATION

To illustrate the value of our method, we calculate curvature attributes for a data set from Saudi Arabian field Figure 1a. We begin by comparing the edge detection using coherence volume in Figure 1b and negative curvature in 1c. We note that the fault seen in the curvature time slice Figure 1c does not at all show up on the coherence time slice Figure 1b.

CONCLUSIONS

We have developed a means by which powerful seismic attributes that could previously be applied only to interpreted horizons can now be applied to the entire uninterpreted volume of seismic data. These curvature attributes, are independent of, and complementary to, the popular measures of seismic coherence.

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REFERENCES

Al-Dossary, S. and K. J. Marfurt, 2006, 3D volumetric multispectral estimates of reflector curvature and rotation: Geophysics, 71, 41–51.

Bahorich, M.S., and S. L. Farmer, 1995, 3-D seismic discontinuity for faults and stratigraphic features: The coherence cube: The Leading Edge, 16,1053-1058.

Barnes, A. E., 1996, Theory of two-dimensional complex seismic trace analysis: Geophysics, 61, 264-272.

Barnes, A. E., 2000, Weighted average seismic attributes: Geophysics, 65, 275-285.

Bergbauer, S., T. Mukerji, and P. Hennings, 2003, Improving curvature analyses of deformed horizons using scale-dependent filtering techniques: AAPG Bulletin, 87, 1255-1272.

Cooper, G. R., and D. R. Cowan, 2003, Sunshading geophysical data using fractional order horizontal gradients: The Leading Edge, 22, 204-205

Dalley, R M., E. E. A. Gevers, G. M. Stampli, D. J. Davies, C. N. Gastaldi, P. R. Ruijetnberg, and G. J. D. Vermeer, 1989, Dip and azimuth displays for 3-D seismic interpretation: First Break, 7, 86-95.

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

Luo, Y., S. al-Dossary, M. Marhoon and M. Alfaraj, 2003, Generalized Hilbert transform and its application in Geophysics: The Leading Edge, 22, 198-202.

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., and R. L. Kirlin, 2000, 3-D broadband estimates of reflector dip and amplitude: Geophysics, 65, 304-320.

Marfurt, K. J., 2006, Robust estimates of 3-D reflector dip: Resubmitted after minor revision to Geophysics.

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

Stewart, S. A., and T. J. Wynn, 2000, Mapping spatial variation in rock properties in relationship to scale-dependent structure using spectral curvature. Geology, 28, 691-694.

Figure 1a: Input time slice

Figure 1b: Output coherence time slice


Figure 1c: Output curvature time slice