Reconnaissance of geological prospectivity and reservoir characterization using multiple seismic attributes on 3-D surveys: an example from hydrothermal dolomite, Devonian Slave Point Formation, northeast British Columbia, Canada

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Abstract

Recent advances in visualization technology and seismic attribute analysis are beginning to revolutionize the landscape of 3-D seismic interpretation. This presentation focuses on the interpretive use of post-stack seismic attributes for seismic reservoir characterization. Multiple seismic attributes facilitate structural interpretation & recognition of seismic stratigraphy, but as importantly, they may offer clues to lithology typing and estimation of fluid content from seismic data. Potential benefits include reduction of stratigraphic & structural drilling risks, seismic reservoir characterization in exploration settings, and value increase of new & vintage 3D seismic data.

Immediate improvements in drilling risk reduction can be obtained by using multiple seismic attributes. This enhancement occurs because each seismic attribute computation resembles a filter that decomposes reflection data into its constituents, and, as a consequence, use of multiple seismic attributes restores much of the discriminating information retained in the originally recorded wavefield (Barnes, 2001; Taner, 2001). Thus, each seismic attribute, for instance, amplitude, inadvertently contains only a subset of the total information recorded, since a single seismic attribute represents only one numerical property of a propagating seismic wavefield.

In this presentation, we advocate the use of geometric attributes in conjunction with relative acoustic impedance and frequency-derived seismic attributes. In the past, use of geometric attributes was mostly limited to edge detection, where edges in the seismic data commonly represent faults or stratigraphic terminations (seismic facies changes). In this series of regional case studies in Canada (including the Devonian Slave Point Formation), we use post-stack seismic attributes to

- Determine the azimuths of conjugate fracture trends in the subsurface
- Identify “leaky” vs. sealing fault segments & possible migration/charge/escape pathways.
- Identify “sweet spots” in the subsurface

Blind testing helped confirm validity of interpretational approach in identifying gas zone prospectivity and has resulted in ranking of future prospect locations. 3-D seismic examples are from northeast British Columbia, Canada (Bubbles Survey) and were provided by Olympic Seismic. Results from this case study should find application in seismic exploration for fractured and hydrothermally altered carbonates worldwide.

Introduction

Recent advances in visualization software technology and seismic attribute analysis are beginning to revolutionize the landscape of 3-D seismic interpretation. Interpretive use of multiple post-stack seismic attributes facilitates seismic reservoir characterization by improving structural subsurface analysis. Additionally, joint attribute analysis enhances recognition of seismic facies and associated seismic stratigraphy. But as importantly seismic attribute analysis may offer clues to lithology typing and estimation of layer porosity and fluid content.

Potential benefits of seismic attribute analysis include

- mitigation of stratigraphic & structural drilling risk,
- reservoir characterization during exploration and exploitation,
- better identification and definition of "sweetspots,"

The northeast of Canada's vast British Columbia Province (366,255 mi2 [948,600 km2]) is host to several large gas fields (>300 Bcf) that produce from reservoirs developed in hydrothermally dolomitized reefal carbonate platforms of the Givetian (Upper Devonian) Slave Point formation (Figures 1-3). Chemical phase change from limestone to reservoir dolostones has been linked to several phases of descent and rise of Mg^{2+}-yielding brines in the Western Canadian Sedimentary Basin during Late Devonian through Carboniferous time (Morrow, Stasniuk, and Zhao, 2001). The Bubbles 3-D seismic survey is located in sector 94-G, British Columbia, Canada. The seismic bin size is 35m. x 35 m. The processed record length is 3.0 seconds at a sample rate of 2 ms. Seismic attribute selection for Slave Point 3-D seismic surveys is largely influenced by distinct geological characteristics of hydrothermal dolomite reservoirs, fracturing (faults & joints), lithology, porosity, and structural elevation.

2. Interpretive Use of Geometric Attributes in Geological Prospecting:

In this presentation we apply multiple geometric seismic attributes in order to identify and to map orientation and density of fractures in the subsurface. Additionally, we will use side-by-side combinations between a frequency attenuation attribute called "energy absorption" and a geometric attribute in order to determine sealing properties of faults and to identify possible hydrocarbon migration pathways. Lastly, we use a geologically calibrated combination of post-stack seismic attributes to substitute as prospect risking parameters instead of performing conventional risk analysis (i.e., source, migration, trap, reservoir, seal).

2a. Fracture Detection

Scrolling through the dip azimuth probe we observe linear features in time slice view (Figure 4). Contrasting these features to amplitude data, we observe that (a) amplitude data are void of these azimuthal trends, and (b) that no significant structural offset occurs across these features in vertical seismic sections. We interpret the linear features criss-crossing the time slice as open fracture trends. An interpreter needs to convert the obtained azimuth trends by adding the amount of rotation the inline has undergone from North. This step becomes necessary because the dip azimuth attribute is measured as an angular deviation from the inline trend (inline varies in y). The obtuse angle (the larger angle between the two fracture trends) is approximately 120° identifying these features as a conjugate fracture set.

2b. Sealing Properties of Faults: Detection of "leaky" vs. sealing faults

The Energy Absorption Analysis program extracts frequency information from a cascading series of small time gates along the seismic trace, then, it employs a simple series of steps to compare the spectra in successive time windows to detect anomalous high-frequency energy loss as a function of two-way traveltime. The algorithm generates anomalous absorption values only when energy decay exceeds background levels. Simultaneous use of the multi-trace geometric attribute, semblance, (alternatively, any other coherency-class attribute may be substituted) and the energy absorption attribute in adjacent time slices allows comparison of identical areas on time slices and their respective attribute expressions (Figure 5). In doing so, interpreters may be able to discern high or low energy absorption along edges (faults) in the seismic data. The respective patterns are interpreted as non-sealing faults (high energy absorption = open fractures in fault zone causing attenuation) and sealing portions of fault segments (low energy absorption = cemented & tight fault gouge lithologies).

2c. Identification of reservoir "sweet spots"

This seismic attributes exploration strategy in carbonates seeks to combine geological and geophysical observations in order to predict suitable reservoir development in hydrothermal dolomite. The following rationale is employed:

(a) for dolomitization caused by convective flow to occur, conduits must exist. Fractures (faults & joints) constitute ideal pathways for hydrocarbon migration and subsequent reservoir charge. Thus, semblance, a multi-trace geometric seismic attribute, is used to differentiate similar from dissimilar seismic samples (dissimilar or incoherent seismic data are caused by stratigraphic or structural edges).

(b) degree of dolomitization of limestone bioherms evokes certain changes in seismic signal expressions that can be classified and catalogued applying self-organizing neural network technology to the seismic data. The resultant 3-D attribute volume allows distinction between limestone (tight, no reservoir) and dolostone (potential reservoir rock) in many cases (Figure 6).

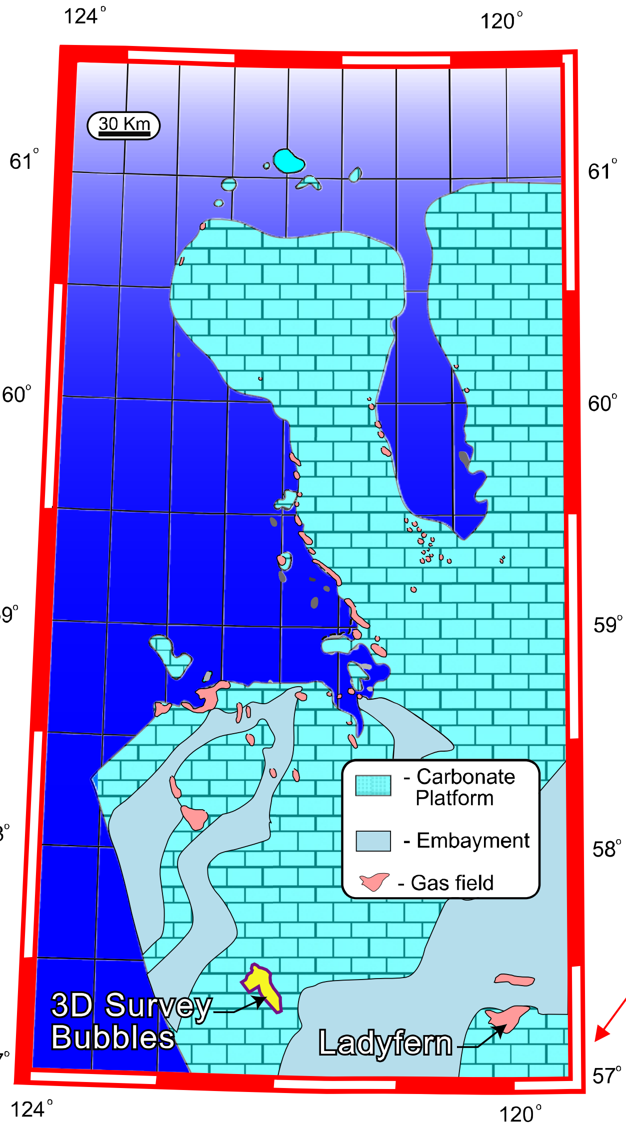
(c) dolomite reservoirs are characterized by high compressional velocity. Dolomite rock velocity is slowed mostly because of porosity development rather than being reduced by substitution of lighter hydrocarbon-bearing fluids mixtures in the pore space. Relative acoustic impedance is band-limited, but it serves as a measure of property changes within the same layer.

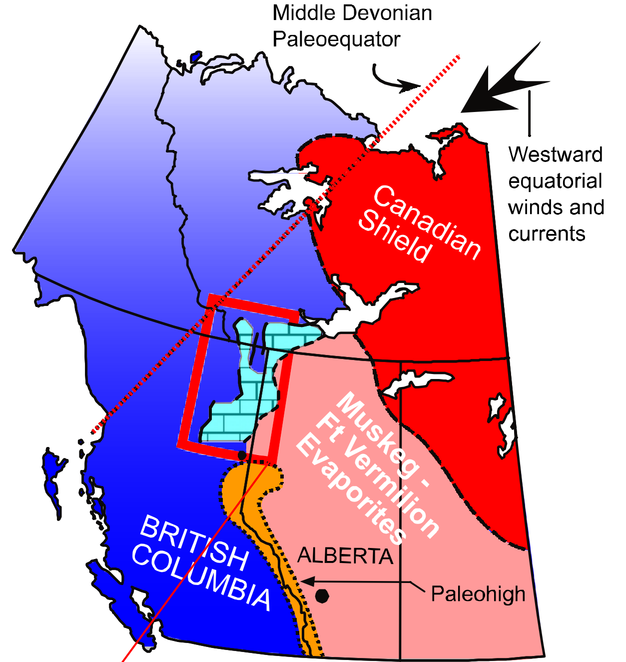
(d) integration of wireline, mudlogging, core and production data may permit designation of regional GWC, and as a consequence, exclusion of suitable reservoir rock from prospectivity.

3. Conclusion

Using selected geological & geophysical knowledge of formation data, seismic attributes can be employed to specifically illuminate discrete reservoir properties. Selective application of multiple seismic attributes mitigates drilling risk leading to

- better prospect economics through early successes,
- reduced finding cost, and
- value increase of new & vintage 3-D data.





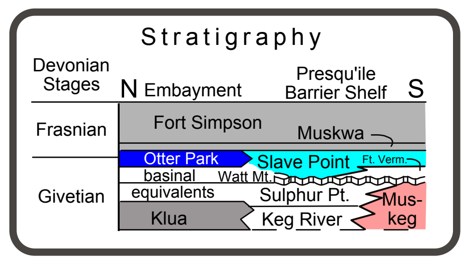


Fig.1 (bottom right) Devonian (part) Stratigraphy. Fig. 2. (upper right) Index Map of study area. Figure 3 (left) Devonian Slave Point paleogeography. Figures 1 & 2 adapted and modified from Morrow, Stasniuk & Zhao, 2001. Figure 3 adapted and modified from Morrow, Stasniuk & Zhao, 2001; Madi, 2003.

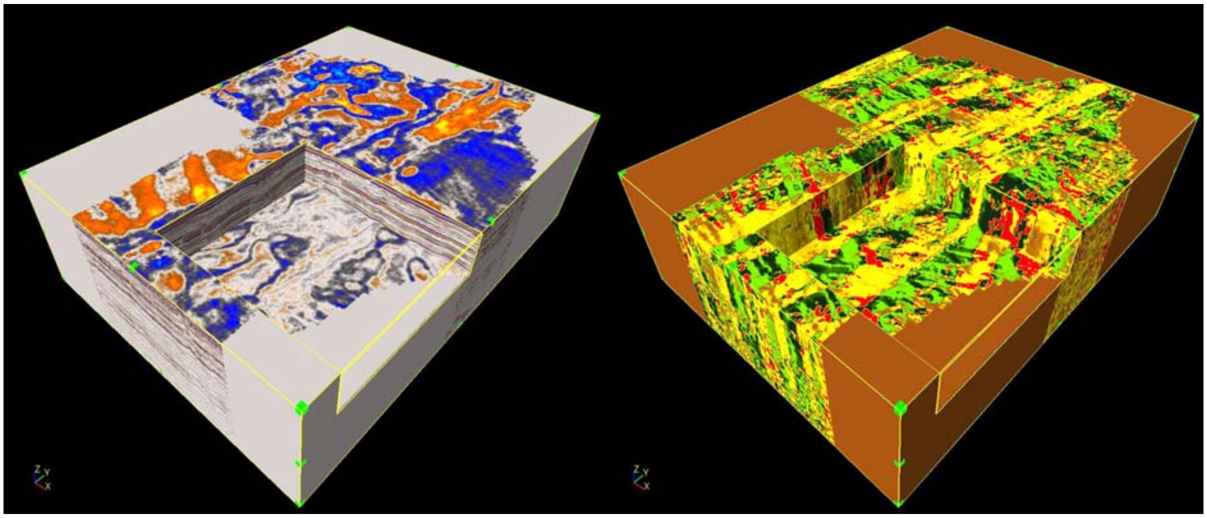


Fig 4. Amplitude (left) vs. Dip Azimuth (right) - Note counterclockwise rotation of fracture trends in dip azimuth volume (top to bottom slices)

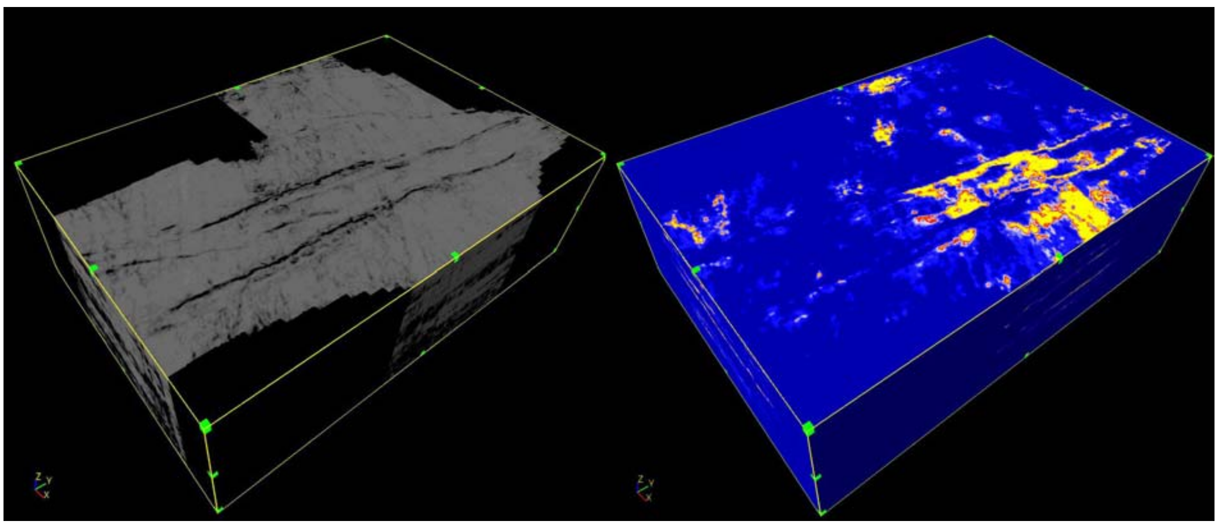


Fig 5. Similarity (left) vs. Energy Absorption (right) - Note absorptive character of faults (permeable, non-sealing) on the right to non-absorptive (tight, sealing) on the left. In Similarity, the faults appear in black and in EAA, the absorptive portions of faults are in yellow

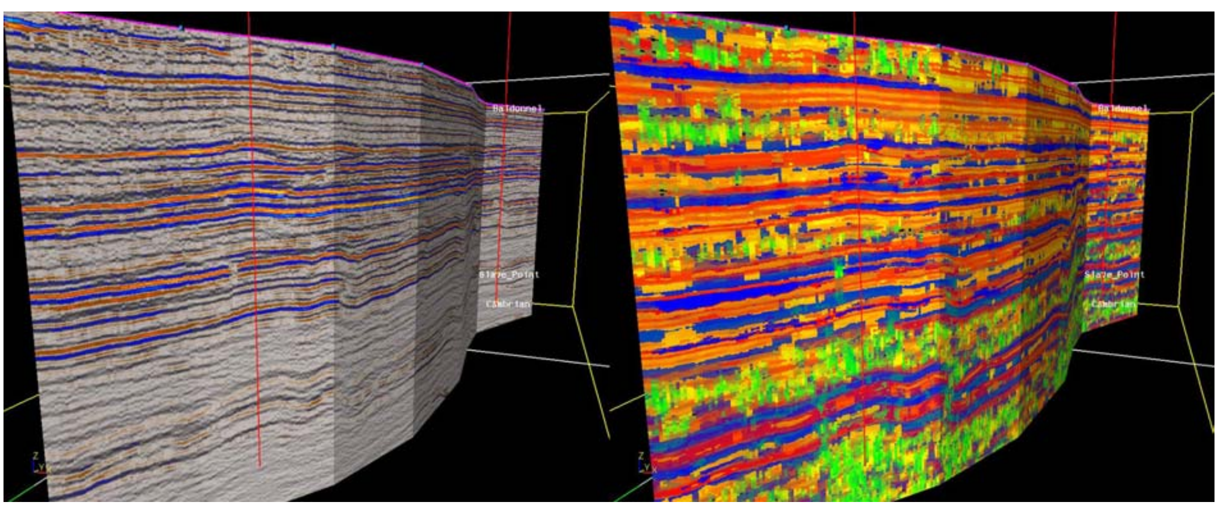


Fig 6. Amplitude (left) vs. Seismic Facies Indicator (KSOM) (right) - Seismic Facies Indicator depicts acoustic changes in Slave Point Formation from well in rear (non-productive) toward well up front.

References

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