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Wedge Modelling and Waveform Classification for sub-resolution thickness estimation in the Appalachian Basin

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Summary

The Marcellus Formation contains organic-rich shales sandwiched between various carbonate layers. These carbonate layers often vary in thickness. Using zero-phased seismic data, peaks and troughs represent interfaces of meaningful geologic sequences that can be associated with formation boundaries identified on well logs. However, the ability to distinguish between the top and base of the intervals with seismic data becomes challenging in regions with thin layers. Well data does not suffer from the same restrictions as seismic for vertical resolution, but it does have limitations when is comes to spatial information, particularly in structurally complex basins. Appropriately mapping of reservoir architecture is material for optimizing target selection and geosteering for the successful landing of wells. We evaluated different thickness mapping techniquesto assess lateral variation in bedding that varies from tunning thickness (1/4 wavelength) to thin beds (1/8 wavelength). We discuss the application of a classification scheme to the seismic data based on the waveforms generated in a wedge model. Doing so enabled us to capture the structural behaviour away from well locations and discriminate thin yet relevant geologic sequences in the seismic data.

Introduction

We combined two analysis methods of investigating seismic data and detail a workflow used to help infer bedding thickness variation of the Lower Oakta Creek interval—which thins and pushes toward the definition of a thin bed or 1/8 wavelength. The analysis methods we combined are wedge modelling and waveform classification.

Wedge modelling is a valuable tool for the interpreter to assess the impact of tunning, or interfering reflection energy, on seismic data. Widess (1973) documents the impact of seismic signature related to bedding thickness. As bedding thins, the wavelet begins to either constructively or destructively interfere increasing the difficulty of isolating amplitude related information, from the top and base of an interval (Brown, 2011). Relative positioning of the peaks and troughs will also deviate from the geologic boundary (Figure 1). Through wedge modelling the interpreter can inoculate themselves from misinterpreting seismic artefacts as geologic features.

Waveform classification is a method of analyzing waveforms in an interval of seismic data grouping them into distinct categories of a representative waveform shape, often referred as a neuron. Waveform classification is most commonly associated with the Self-Organizing Map, or Kohonen Map, machine learning technique. This technique extracts the representative waveform shapes and orders them by degree of variability. The neurons may also be fixed allowing the user to identify regions that best match idealized or expected waveforms.

Workflow

First, wedge modelling. This can begin with a synthetic wedge of elastic properties or with existing well data of a chosen interval that is thinned or thickened. The wedge model is convolved with a wavelet, analytical or extracted from the seismic data, and simulates a seismic response at the various bedding thicknesses created in the model. Second, waveform classification. Generally, an unsupervised approach is used which updates the waveform in the respective classes. However, in this implementation of waveform classification, we fixed the neurons of the initial classes to identify where the seismic data best matched the seismic response modelled at the various bed thicknesses from the wedge (Figure 2). Waveform Classification is known to be sensitive to the interval chosen. As such this was also tested to ensure a useful result was obtained.

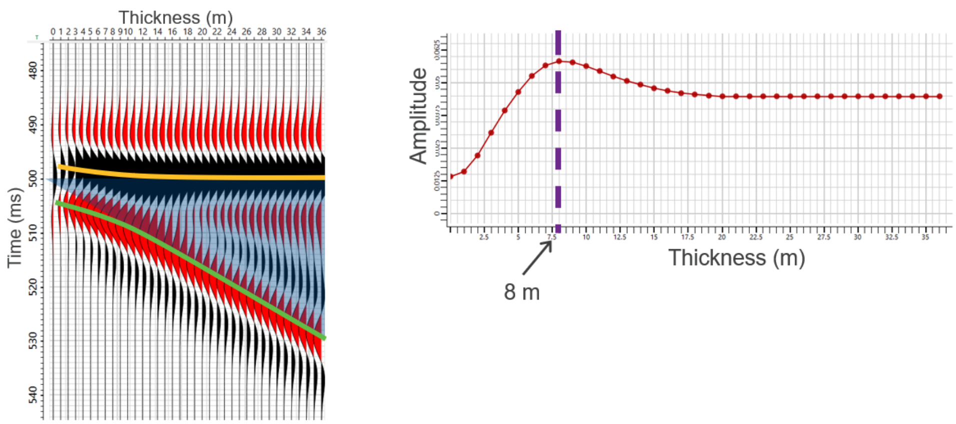

Figure 1. Example of wedge modelling. The left is a representative wedge model showing the limitation of imaging thin beds. The right is a tunning curve (Meckel and Nath, 1977), which can be used to identify the limit of separability of a given wavelet frequency used in modelling. The increase in amplitude is generated by the constructive interference of the peak of a wavelet from the top of the wedge is aligned with the side lobe of a trough of a wavelet from the base of the wedge.

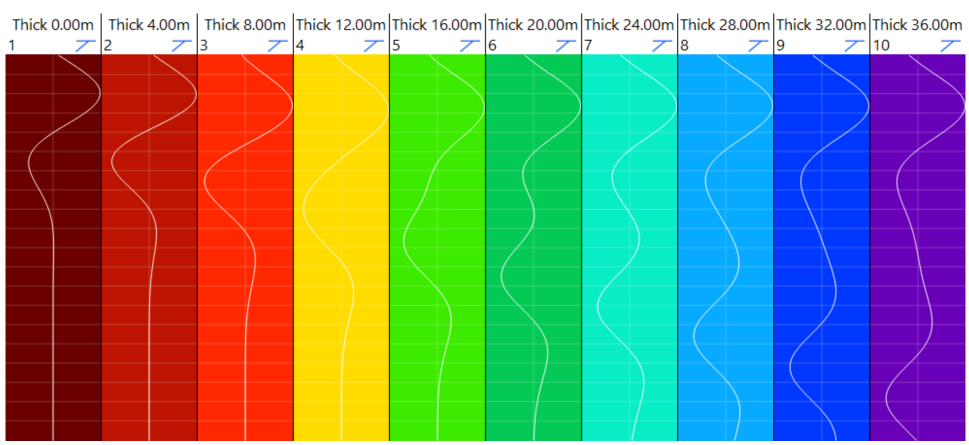

Figure 2. Waveform Classification of the wedge model into 10 facies. These waveforms are the neurons used to represent target interval thicknesses.

Observations

From waveform analysis on the seismic data, we can see that the Lower Oatka Creek interval is structurally and stratigraphically complex between wells. Conventional seismic interpretation allows the interpreter to quantitatively determine an isomap thickness until the tunning threshold, or 1/2 wavelength. If an isomap is created solely from well data, we get accurate thickness at the well locations but have increase uncertainty between the wells. Leveraging wedge model waveforms and classifying them as representative of specific interval thickness produces a relevant and useful map identifying thinner intervals than possible from conventional mapping techniques. Figure 3 is a schematic representing the advantages and limitation of the well based and seismic based approaches to creating isomaps.

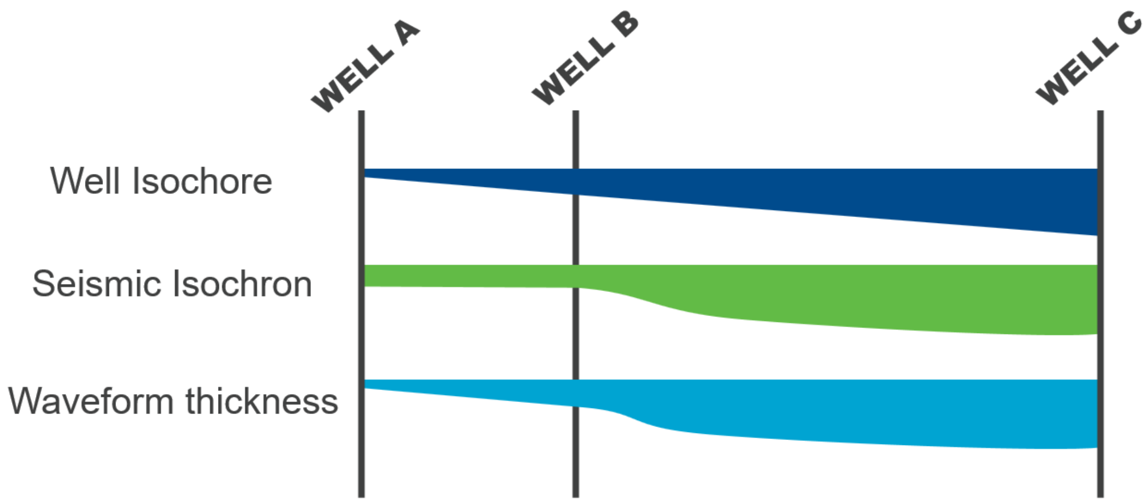

Figure 3. The top schematic highlights that an isomap from well data can achieve incredible vertcile precision at that cost of spatial resolutions. The middle schematic emphasizes the spatial accuracy that can be captured in seismic data but also the lack to resolve thin features. The bottom schematic represents the opportunity with waveform classification with a wedge model.

References

Brown, A., R., 2011, Interpretation of 3D Seismic Data, SEG Investigations in Geophysics, No. 9, p. 203-216.

Meckel, L. D., Jr., and A. K. Nath, 1977, Geologic considerations for stratigraphic modeling and interpretation, in C. E. Payton, ed., Seismic stratigraphy — applications to hydrocarbon exploration, AAPG Memoir 26, p. 417–438.

Widess, M. B., 1973, How thin is a thin bed?, Geophysics, Vol. 38, p. 1176–1180.