VP/VS Characterization of a Heavy-Oil Reservoir

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Summary

Seismic monitoring of heavy oil cold production is becoming an increasingly important reservoir characterization method, in which we need to take full advantage of elastic wave imaging. In the following case history from Plover Lake, Saskatchewan, Canada, we examine the computation of VP/VS maps as deduced from traveltime measurements on the vertical and radial components of multicomponent records. This type of VP/VS mapping is robust and represents an excellent method of distinguishing lithologies.

Introduction

There are vast reserves of heavy oil in the Western Canadian sedimentary basin (estimated by many to be on the order of 1 trillion barrels). Tools for monitoring hot production, as outlined by Watson et al. (2002), are well-known. Cold production of heavy oil, as described by Lines et al. (2003) is becoming increasingly popular, due to advances in progressive cavity pump technology and the low energy requirements for this type of enhanced oil recovery (EOR). Many seismic monitoring methods can be used in both hot and cold production - including the mapping of VP/VS variations.

This paper examines the use of VP/VS mapping for a heavy oil field near Plover Lake, Saskatchewan, where Nexen has applied both hot and cold production methods. We use Nexen's 3-D multicomponent seismic survey, acquired by VeritasDGC and processed by Sensor Geophysical. For the vertical and radial components, processing flows were similar but not identical. For the vertical component, the flow included steps such as statics corrections, surface consistent deconvolution, velocity analysis, NMO, AGC, CMP stacking, f-xy deconvolution and and poststack time migration. The radial component processing flow was similar, but used CCP stacking, rather than CMP stacking. Also, a phase rotation was applied after migration for event identification.

After processing was completed, VP/VS mapping was done by researchers at the University of Calgary. The VP/VS interpretation technique uses traveltime isochron mapping of multicomponent data as means of distinguishing lithologies.

Theory and Methods

There is a methodology for creating VP/VS maps from multicomponent data that is both robust and straight-forward. For flat reflectors, the method involves picking reflections for the same reflecting horizons on the vertical and radial components of a multicomponent survey. For flat events, the vertical component reflections are predominantly PP and the radial reflections are predominantly PS conversions. The traveltimes, denoted as t_{PP} and t_{PS} respectively, provide us with the necessary information to derive the ratio of P-wave velocity to S-wave velocities, denoted as VP/VS. In this paper, we show that this ratio will be very useful for both discriminating lithology and possibly for detecting reservoir changes.

The use of VP/VS ratios for characterizing both steam fronts and sand deposition was lucidly described by Watson et al. (2002). By the use of rock physics and multicomponent seismology, Watson demonstrated that "short wavelength" decreases in VP/VS ratios were caused by steam injection (temperature increase) in the oil sands, whereas the "long wavelength" decreases in VP/VS were caused by thickening sand layers.

In this paper, we demonstrate VP/VS applications for Plover Lake heavy oil field – a field which has undergone both hot and cold oil production. We compute the VP/VS ratios from a multicomponent survey, intending to examine lithology variation and reservoir changes due to production.

The methodology is outlined in Figure 1. It basically involves measuring traveltimes for two reflections on the vertical component section to find PP interval traveltimes and then picking the corresponding horizons on the radial section to find the PS interval traveltimes for the same depth interval.

The derivation of the VP/VS ratio is as follows. Consider the thickness for the layer between the two reflections as depicted in Figure 1. This thickness is given by:

$$d = \frac{V_P t_{PP}}{2} = \frac{V_S t_{SS}}{2} \quad . \tag{1}$$

The converted wave traveltime can be expressed in terms of the 2-way P-wave and S-wave traveltimes by the following.

$$t_{PS} = \frac{t_{PP}}{2} + \frac{t_{SS}}{2} \qquad (2)$$

Upon substituting for t_{SS}, we obtain the following expression for the VP/VS ratio.

$$\frac{V_P}{V_S} = \frac{2t_{PS} - t_{PP}}{t_{PP}} . \qquad (3)$$

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Data Examples from Plover Lake Fields

This process of picking traveltimes on the two sections is guided by the use of dipole sonic logs. These logs allow us to compute synthetic seismograms for the vertical components. We used these synthetic seismograms to pick the Sparky and the Torquay reflections. These two events bracketed the heavy oil reservoir sands in the Bakken formation. Unfortunately, the Torquay pick is a difficult one, and it turns out that a better time pick is obtained for an event (termed the "base event") that is slightly deeper and just below the depth of the dipole sonic log. To perform the correlation of the events on the PP and PS, sections we plotted the two sections at a scale of 5 inches per second for the PP section and 3 inches per second for the PS section after tying the Sparky event. By equation (3), we see that this traveltime ratio corresponded to a VP/VS ratio for the Bakken sand interval of 2.333, which is a value very close to that given by the dipole sonic log. After initiating this pick based on the dipole sonic, the picks are carried throughout for the vertical and radial components of the 3-D 3-C seismic survey. Equation (3) is used to produce a map of VP/VS for the entire survey.

Results

The resulting VP/VS map of Figure 3 produced a very interesting and encouraging map for lithology discrimination. On the northern half of the map, we have marked enclosed features with dark lines to indicate an eroded Lodgepole formation. In the same figure, we have also marked a boundary along the southeastern side of the map to define the erosional edge of both the Bakken sand ridge and overlying Lodgepole formation. In summary, low VP/VS values in the middle of the map correspond to the thicker Bakken and Lodgepole, while the higher VP/VS zone on the southeastern side of the map corresponds to the zone where the Bakken sand and the Lodgepole formation have been eroded. This VP/VS map is compared to previous interpretations based on well data and conventional (vertical component) data. The correlation of the map with other sources of lithology information is excellent. At present, we are also looking at the "short wavelength" variations in VP/VS to examine correlations with reservoir changes caused by cold production. Finally, it should also be mentioned that two other VP/VS maps based on other reflector picks are very similar to Figure 3 - suggesting that the traveltime mapping of VP/VS is very robust and reliable.

Conclusions

The mapping of VP/VS variations in heavy oil reservoir provides a very robust lithology discriminator. This method has been tested for both hot and cold production situations. Additionally it appears that VP/VS mapping is also an indicator of reservoir changes.

References

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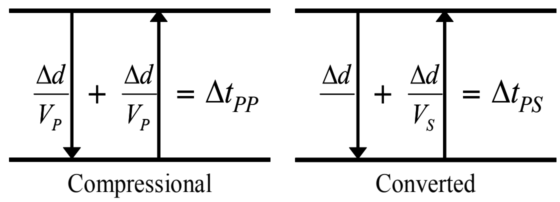

Figure 1: Traveltime measurements on the vertical and radial components.

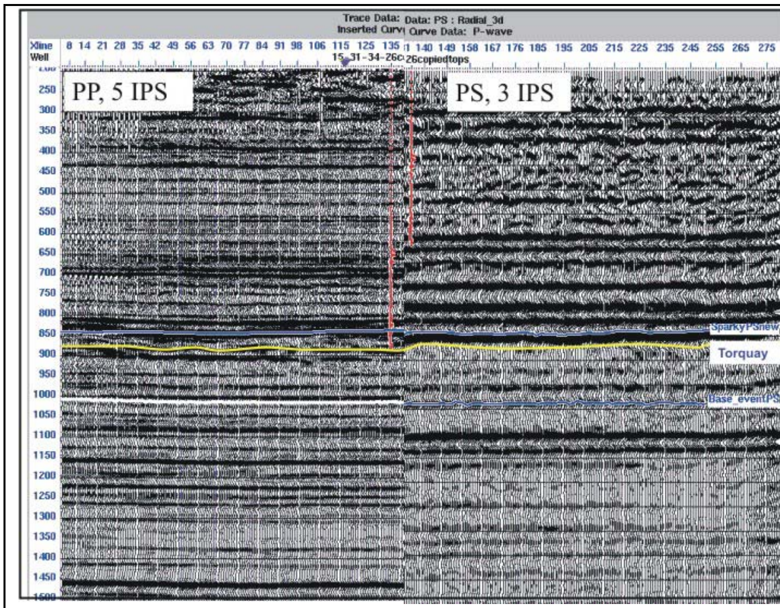

Figure2: This figure displays the PP section and the PS section at a time scale corresponding to a VP/VS ratio of 2.333.

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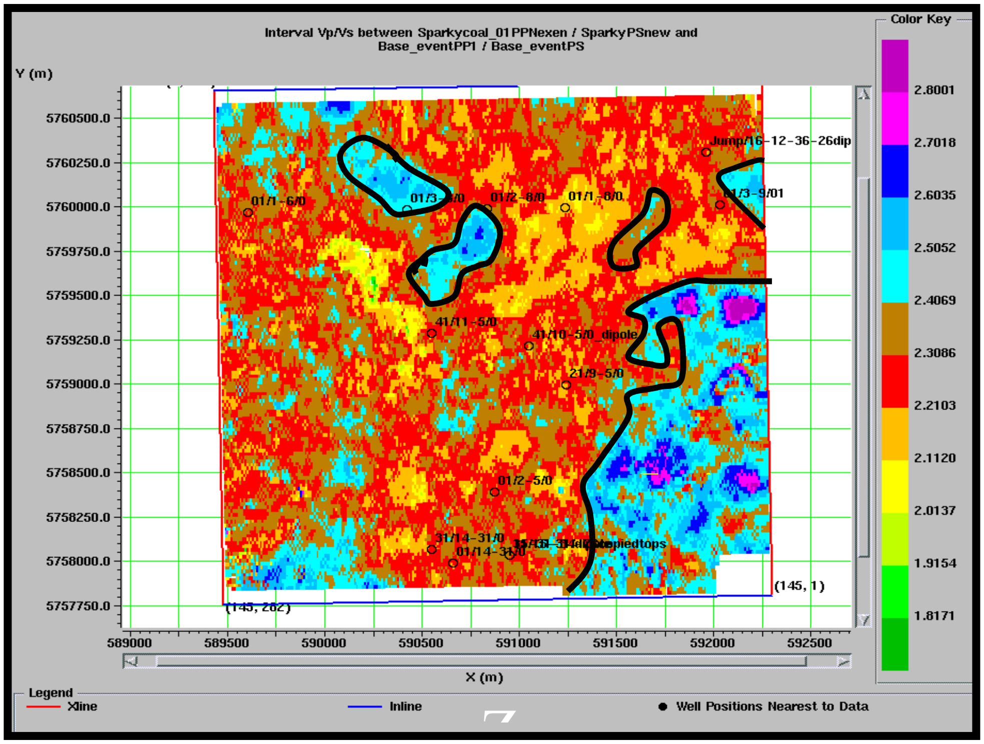

Figure 3 The VP/VS map for the Plover Lake field. The boundary between the Bakken formation and eroded zone are denoted by the dark lines – suggesting that VP/VS is a good lithology discriminator.