Reservoir Characterization of Plover Lake Heavy-Oil Field*

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Abstract

Enhanced production of heavy oil from the Cretaceous and Mississippian sands of Eastern Alberta and Western Saskatchewan presents many challenges – requiring a more complete description of lithology, porosity, permeability, and changes in reservoir fluid composition and physical properties. Our reservoir projects near Plover Lake, Saskatchewan seek to produce reservoir models that are consistent with all available data including well logs, cores, produced fluids, and seismic data. Thus far, we have effectively used dipole sonic data and multicomponent 3-D data to effectively delineate sand layers. Core measurements suggest that interbedded shale layers will impact vertical permeability and consequently oil production. In order to effectively map production and reservoir changes, we propose to use time-lapse (4-D) seismic surveys to update our reservoir models. These seismic measurements are coupled to laboratory measurements of V_P/V_S from core samples and detailed oil-column profiling of fluid properties. Experience with 4-D seismic data at nearby Bodo Field, near Provost, Alberta, has shown that seismic monitoring can effectively map the reservoir changes due to cold production. Hence, we advocate a reservoir characterization strategy that involves the use of logs, cores, and a base 3-D seismic survey to describe geology with repeated multicomponent 3-D surveys being used to map reservoir changes. Our study shows reservoir studies on models and real data from the Plover Lake area, along with planned future research.

Introduction

This paper examines a combined geological and geophysical reservoir analysis for a heavy oil field near Plover Lake, Saskatchewan, where Nexen Inc. has applied both hot and cold production methods. Oil sands of the Devonian-Mississippian Bakken Formation are found in NE-SW trending shelf-sand tidal ridges that can be up to 30 m thick, 5 km wide, and 50 km long. Overlying Upper Bakken shales are preferentially preserved between sand ridges. The Bakken Formation is disconformably overlain by Lodgepole Formation carbonates (Mississippian) and/or clastics of the Lower Cretaceous Mannville Group. Since sandstones and carbonates have a lower V_P/V_S ratio than shale (due to higher relative S-wave velocities), V_P/V_S maps from multicomponent seismic data help to identify thickening sand and carbonate layers within the target zone.

This analysis of an initial 3D-3C survey is described in a recent paper by Lines et al. (2005). In the future, we plan to examine changes within the reservoir due to cold production by the use of time-lapse seismology.

For this study, the 3D-3C seismic data was acquired by Veritas DGC using the VectorSeis® digital multicomponent recording system over an 8 square kilometer surface area. Multicomponent interpretation is made possible by a few dipole sonic logs, as well as many sonic and density logs.

The estimated V_P/V_S maps in this study are largely based on travel time methods. However, a recent paper by Dumitrescu and Lines (2006) uses AVO analysis and simultaneous inversion to provide high-resolution images of the heavy oil formations. Finally, we examine cores from this area to provide a fine scale description of rock property variations in the field.

Methodology and Preliminary Results

The travel time method for creating V_P/V_S maps from multicomponent data that is both robust and straight-forward. Flat events on vertical stacks are predominantly PP reflections, but on radial stacks are mostly due to PS conversions. Hence, interval travel times from a radial component stack contain information about S-wave velocities, and together with the corresponding travel times from the vertical component stack provide us with the necessary information to calculate V_P/V_S, the ratio of P-wave to S-wave velocities.

Figure 1 shows travel time picks for the vertical and radial components on seismic lines in the Plover Lake Field. The exploration targets are sand ridges within the Bakken Formation at a depth of about 800 m. For our travel time picking, we initially used the Sparky Coal of the Mannville Group (~780 m) as a reference horizon above the Bakken and the Torquay Formation (Devonian carbonate at ~830 m) below the Bakken. Unfortunately, the Torquay is difficult to interpret on the seismic data, and it turns out that better travel time picks can be obtained from a slightly deeper reflection (“base event” at ~1000 ms, PP time).The process of picking travel times was guided by the use of dipole sonic logs. These logs allowed us to compute PP and PS synthetic seismograms to aid interpretation of the Sparky and Torquay horizons throughout the vertical and radial 3D volumes.

The resulting V_P/V_S maps produced a very interesting and encouraging result for lithology discrimination. On the northern half of the map shown in Figure 2, 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 which defines the erosional edge of both the Bakken sand ridge and overlying Lodgepole Formation. Low V_P/V_S values in the middle of the map correspond to thicker Bakken and Lodgepole, while higher V_P/V_S on the southeastern side of the map correspond to a zone where the Bakken Sand and Lodgepole Formation have both been eroded. In summary, when this V_P/V_S map is compared to previous interpretations based on well data and conventional (vertical component) data, the correlation of the map to other sources of lithology information is excellent. It should be mentioned that two other V_P/V_S maps based on different horizon picks are very similar to Figure 2 - suggesting that travel time mapping of V_P/V_S is very robust and reliable. Another encouraging note is that this V_P/V_S map is very similar to those obtained by Dumitrescu and Lines (2006) using AVO analysis.

The complete reservoir characterization involves going beyond analysis of logs and seismic data. An examination of core from the Plover Lake Field is being completed in order to better understand the reservoir rock properties. Heterogeneities in the reservoir can be more completely understood by examining core such as that shown in Figure 3.

The complete reservoir characterization involves going beyond analysis of logs and seismic data. An examination of core from the Plover Lake Field is being completed in order to more completely understand the reservoir rock properties and the permeability barriers due to shale layers. The inhomogeneities in the reservoir can be more completely understood by examining core such as that shown in Figure 3.

By examining these core samples, we realize the possibility of permeability barriers and the need for more sophisticated reservoir models and the need for enhanced seismic resolution. Additionally, we need to more completely understand the reservoir changes by using time-lapse seismology and rock physics measurements to link time-varying seismic properties to reservoir conditions. Further experiments are being planned.

Conclusions and Future Work

The computation of V_P/V_S maps from a 3-D multicomponent seismic survey has been very interesting and useful in delineating lithology changes. However, it would be interesting to also characterize reservoir changes due to cold production. Such reservoir changes have been modeled numerically but require further verification through physical modeling. Due to subtle nature of production effects, it is our opinion that cold production reservoir effects could best be detected by repeated time-lapse multicomponent surveys. The differencing of time-lapse surveys should eliminate lithology effects and emphasize effects due only to cold production. For this reason, a time-lapse multicomponent survey is being proposed to answer the reservoir monitoring questions for the Plover Lake Field. The time-lapse seismic results and the well information can be used to update the reservoir models.

Additionally, we need to more completely understand the reservoir changes by using time-lapse seismology and rock physics measurements to link time-varying seismic properties to reservoir conditions. P- and S-wave measurements on core samples will be subject first to various effective confining pressures and later the inclusion of candidate pore fluids. One major objective is to assess the dependence of the P- and S-wave velocities on the heavy oil viscosity and composition. Physical properties and compositional data from core and produced fluid analyses may help characterize and model reservoir changes.

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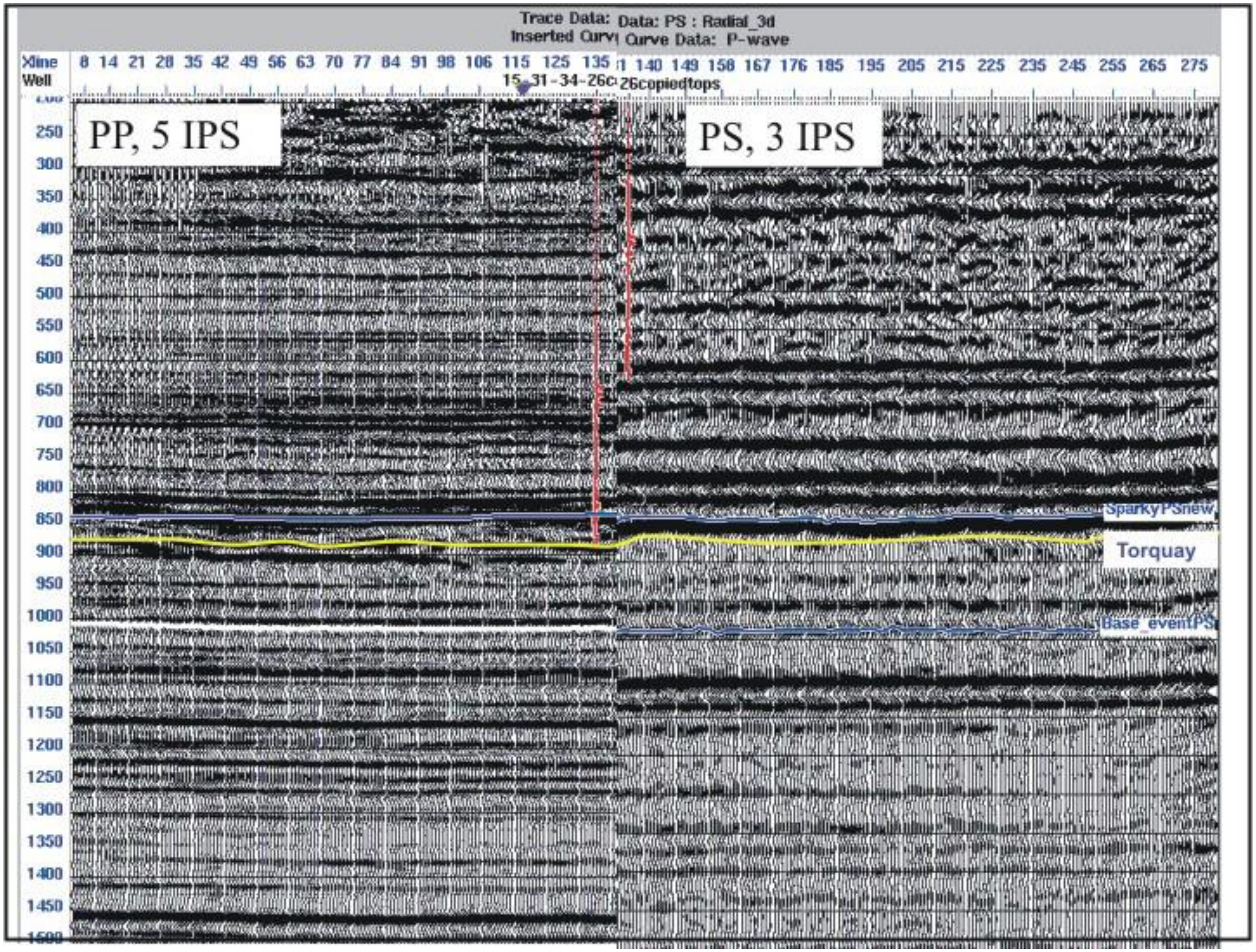

Figure 1. Comparison of PP (left) and PS inlines (right) at a time scale corresponding to a V_P/V_S ratio of 2.33 (IPS = inches per second). The PP section times are between 200 and 1500 ms, and the PS section times are between 600 ms and 2770 ms.

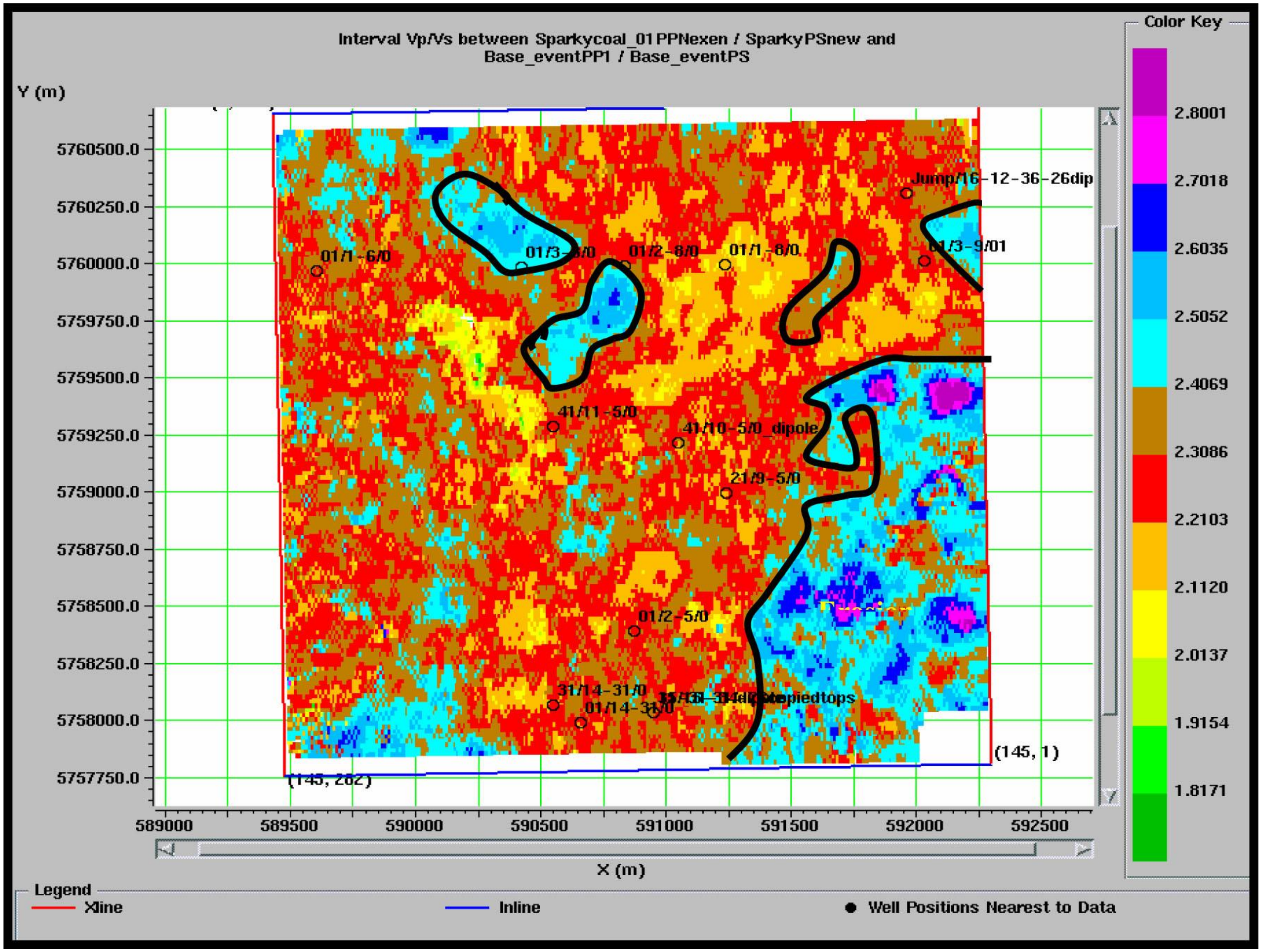

Figure 2. V_P/V_S map for a 2.75 km by 2.75 km area of the Plover Lake Field. Low V_P/V_S values in the middle of the map correspond to thicker Bakken and Lodgepole, while higher V_P/V_S on the southeastern side of the map correspond to a zone where the Bakken Sand and Lodgepole Formation have both been eroded – suggesting that V_P/V_S is a good lithology discriminator.

Figure 3. Boxes of core taken from the Bakken Formation at Plover Lake Field.