A Sand Channel Interpretation Using 3D Multi-component Seismic Data: Ross Lake, Saskatchewan

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SUMMARY

A 3C-3D seismic survey was acquired over Husky Energy Inc.'s Ross Lake oilfield, Saskatchewan in 2002. In June, 2003, a walkaway VSP was conducted in well 11-25 of this field. We developed an interpretation of the target sand body using both PP and PS seismic data. On the PP time thickness map, the target sand of the Dimmock Creek member of the Cantuar formation of Mannville Group of Lower Cretaceous, clearly stands out as a thick anomaly. This may be a result of differential compaction as well as velocity effects due to the high porosity, high permeability sandstone containing 13° API heavy oil. The far-offset VSP helped to identify the events on PS seismic section and provided a key bridge to correlate PP and PS seismic data. From P-source and S-source zero-offset VSP, the interval Vp/Vs in well 11-25 is calculated. This in turn allowed us to estimate an S-velocity log by dividing the P-velocity log by derived Vp/Vs curve. A resultant PS synthetic seismogram increased the confidence of PS seismic event identification gave a guide to pick PS horizons which correspond to same geological formation as PP horizons. Combining PP and PS time thickness maps, a Vp/Vs map between the horizons surrounding the reservoir suggests a shale-cut or shaly part within the target sand body. This interpretation is supported by the existing horizontal well. Other anomalies from the Vp/Vs map also suggest further drilling targets.

INTRODUCTION

The Ross Lake oilfield, operated by Husky Energy Inc, is located in south-western Saskatchewan, Canada. The reservoir is interpreted as a Cretaceous-age channel sand in the Dimmock Creek member of the Cantuar formation of Mannville Group with high porosity (>30%) and high permeability (3 Darcies). The produced oil is heavy, about 13° API. There are 4 vertical wells in the area of interest, and one horizontal well is also drilled within the channel sand body. The sand is over 30 m thick in the 11-25 well and there is about 12-13 m of oil pay. There is no gas cap.

A 3D multi-component VectorSeis® seismic survey was shot by Veritas DGC in this area using 0.5 kg dynamite in May, 2002. In June 2003, a multi-offset VSP survey was conducted by Schlumberger Canada and the CREWES project in well 11-25. The zero-offset VSP used two types of source: 8 - 180 Hz sweep vertical-vibe and 5 - 100 Hz sweep horizontal-mini-vibe. All the offset VSPs used only the P-wave source.

INTERPRETATION

Veritas DGC of Calgary processed this 3C-3D seismic data and delivered the post-stack Kirchhoff migrated datasets of vertical, radial and transverse component, which covers about 7.5 km2 with N-S Inline range 1-132 and E-W Crossline 1-91 in 25 m × 25 m CDP bin. The PP data show an average signal bandwidth of about 8-100 Hz at 800-1300 ms window. The PS-radial data, in the window of 1000-2000 ms, has narrower frequency bandwidth of about 10-60 Hz. The PS-transverse data in same window as PS-radial shows a narrower bandwidth of 10-40 Hz. Only PS-radial data is interpreted here. By default, PS refers to the processed PS-radial component in the following text.

Rock properties

To get a localized genaral sense of Vp/Vs value, a crossplot of Vp and Vs is generated (Fig. 1) by using 4 regional wells which have shear sonic logs, unfortunately, none of them is within this 3C-3D seismic survey area. The color bar, the gamma-ray value, indicates the lithology roughly. The green dots with Vp ~ 3500 m/s indicates the reservoir sands. The red line is a regression of all the points (excluding two grey color zones) with value of Vp = 1.416*Vs + 1070. Three constant Vp/Vs lines (1.5, 2.0 and 3.0, respectively, black) are overlain too. The Vp/Vs value ranges from 1.8 ~ 3 for shallow layers above the reservoir.

Logs and synthetics

The PP synthetic seismogram is created using the conventional sonic and density logs. Because no shear-sonic log is available in well 11-25, we used the P- and S-source zero-offset VSP to derive the Vp/Vs curve. The first break time of all the 130 downhole geophones (7.5 m interval) for PP and SS downgoing wavefields (1-way travel time) are picked to get the interval Vp/Vs. The S-velocity log is estimated by dividing the P-velocity log by VSP-derived Vp/Vs. A 10/15-40/50 Hz Ormsby wavelet is used to generate the PS synthetic seismogram. Fig. 2 shows the zoomed part of the un-stretched, un-squeezed PP (left panel) and PS (right panel) synthetic which is squeezed to correlate with the PP synthetic seismogram.

PP data interpretation

The PP synthetic seismogram from well 11-25 (EW Crossline 11 and NS Inline 41) and zero-offset PP corridor stack are used to develop the correlation between geological formations and seismic events. The PP seismic data shows very good correlation with the synthetic and zero-offset VSP.

The time thickness map between Rush-Lake and IHACM (abbreviation for Index Horizon Above Cantuar Marker) shows a clear north-east to south-west bar shape anomaly with large time thickness (Fig. 3). The horizontal well was drilled along this anomaly, which is the heavy-oil-saturated loose sand.

PS data interpretation

To display the PS data in PP time, we apply a constant Vp/Vs=2.35, or a squeezing factor of (1+2.35)/2 = 1.675 for the PS data. We also need an additional 125 ms bulk shift up for the squeezed PS data to correlate with PP data. This relation is confirmed by inserting the 700 m offset VSP's PS map into the PS seismic section at the location of well 11-25 (Fig. 4).

Fig. 5 displays the smoothed PS horizon Rush-Lake and IHACM pickings in blue color. The three red horizons are PP horizons converted into PS time by Tps = (Tpp + 125) × 1.675. At the right half of this crossline, the PS and PP horizons are nearly at the same time. At the left half, the set of PS horizons is parallel with the PP set of horizons but with a regular trend. This phenomenon is consistent through all the east-west crosslines, and may indicate that the refraction or long-wavelength statics for PP and PS are different.

The PS time thickness map between the IHACM and Rush-Lake is then created (Fig. 6).

Vp/Vs map and lithology interpretation

Finally, using

$$Vp/Vs = \frac{2 * \Delta Tps}{\Delta Tpp} - 1 \quad ,$$

the map of apparent average Vp/Vs between the IHACM and Rush-Lake is achieved (Fig. 7). The main features are:

1. The north-south trend with low Vp/Vs value (1.7 ~ 2.0) at the left half and upper right corner. These may be good, tight sands, in which the P-wave travels rapidly or channel sands without hydrocarbons. Possibly, they may be other incised features not belonging to the Dimmock Creek Member.

2. Four purple blocks with high Vp/Vs value (> 2.4) are interpreted to be shale or shaly.

3. The sand reservoir stands out clearly on Vp/Vs map. The reservoir with the PP time anomaly has an upper part with Vp/Vs about 2.1 and lower part with Vp/Vs about 2.15 ~ 2.25. However, there is a horizontal stripe with Vp/Vs about 2.3 ~ 2.4, which prior to having the horizontal well results, we interpreted as a shale cut or shaly-sand.

In summary, for this high porosity, high permeability, loose sand play saturated with heavy oil, the hydrocarbon accumulation is correlated with: a) a middle range Vp/Vs value about 2.15 ~ 2.25; and b) large PP time thickness.

Horizontal well result

Based on the conventional P-wave interpretation, Husky drilled a horizontal well 5-25 on the PP time thickness anomaly in July 2002. The 600 m long horizontal part stayed in the Dimmock Creek Member, and cross about 19 CDP bins on the seismic map. Fig 8 is the zoomed Vp/Vs map with the trajectory of the horizontal part of well 5-25, also use refined color range to show the details of variation. To find the relationship between the measured (while drilling) Gamma Ray log and seismic derived Vp/Vs value, a local nomalization is applied to both GR and Vp/Vs. Fig 9 displays the nomalized variation of GR and Vp/Vs, with the x-axis as the horizontal part of well 2-25 trajectry starting from the location of drill bit cutting into Dimmock Creek fomation (CDP bin #1, north-east end)) to the bottom of the hole (CDP bin #19, south-west end). The Vp/Vs map has predicted a shaly interval that was indeed encountered in the well. These two curves show a promising correlation.

CONCLUSIONS

On the PP time thickness map, the target sand body clearly stands out as a thick anomaly.

As expected, the VSP data is a great help to interpreting PP and PS seismic. The zero-offset PP corridor stack has an excellent correlation with PP seismic at the well location. The far-offset PS VSP-CDP map dramatically helps to identify the events on PS seismic section and is a key bridge to correlate PP and PS seismic data.

P-source and S-source zero-offset VSPs provide the interval Vp/Vs curve in the well 11-25 which, in turn, helps estimating S-velocity log. The PS synthetic seismogram increases the confidence of PS seismic event identification and provides the essential guide to pick PS horizons.

Combining the PP and PS horizon time thickness maps provides a Vp/Vs map between horizon IHACM and Rush-Lake to give more detailed lithological information. It suggests there is a shale-cut or shaly part within the target sand body. This interpretation is supported by the existing horizontal well. Other anomalies from the Vp/Vs map also suggest further drilling targets.

ACKNOWLEDGEMENT

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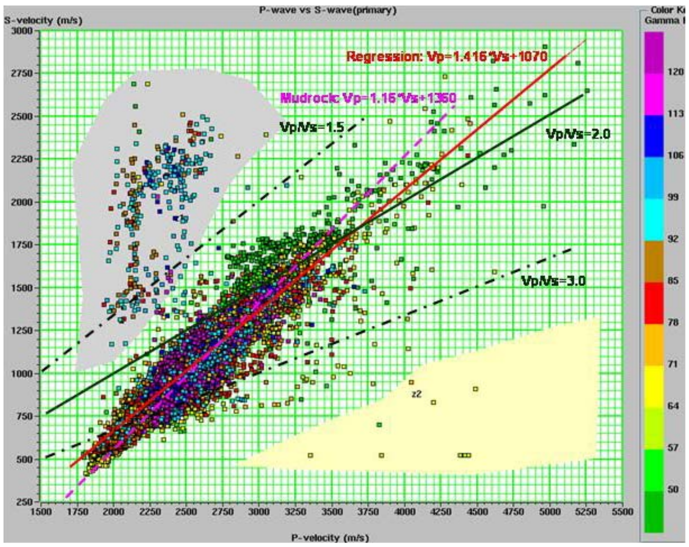

Fig. 1. Crossplot of Vp and Vs from regional well logs.

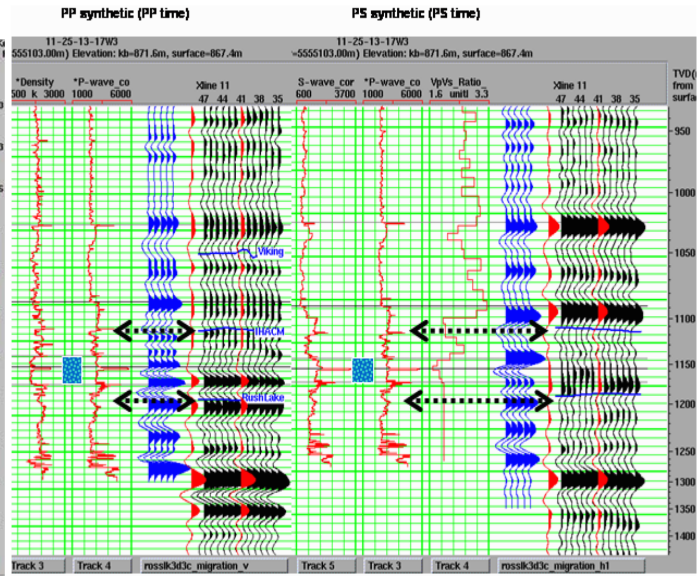

Fig. 2. Logs, PP and PS synthetics at well 11-25

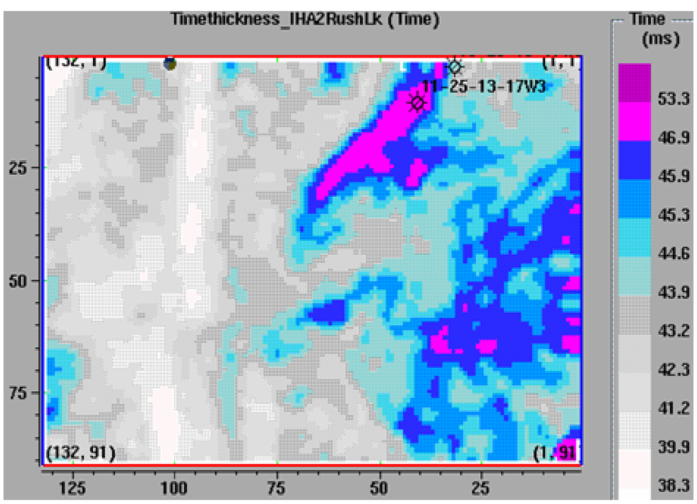

Fig. 3. PP time thickness map from the 3C-3D seismic survey.

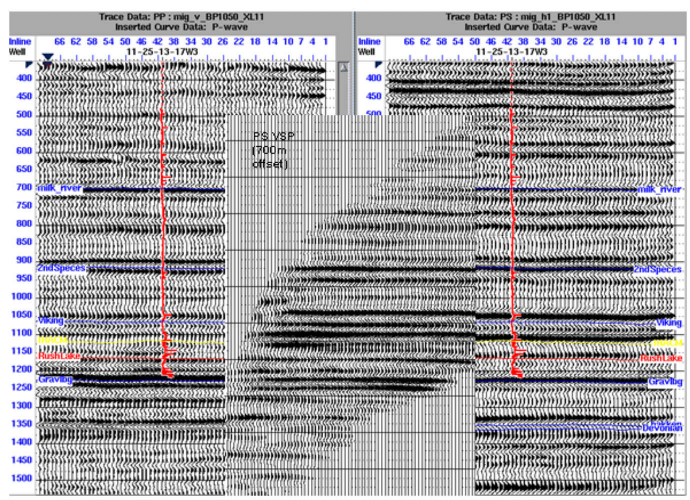

Fig. 4. PP and PS seismic correlation.

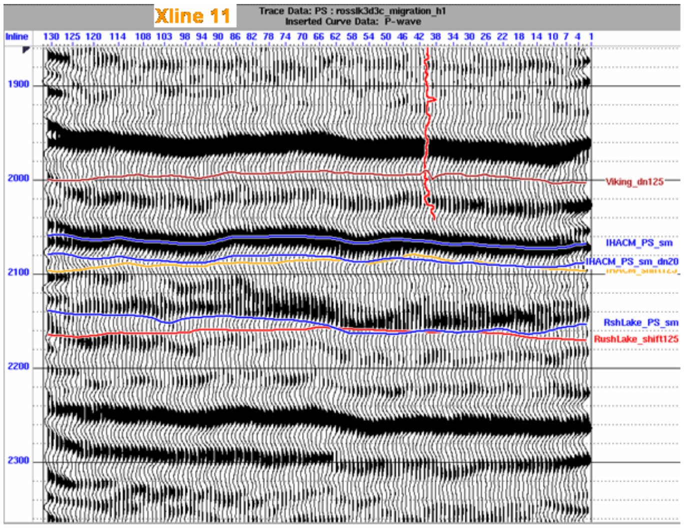

Fig. 5. Horizon picking on PS seismic data.

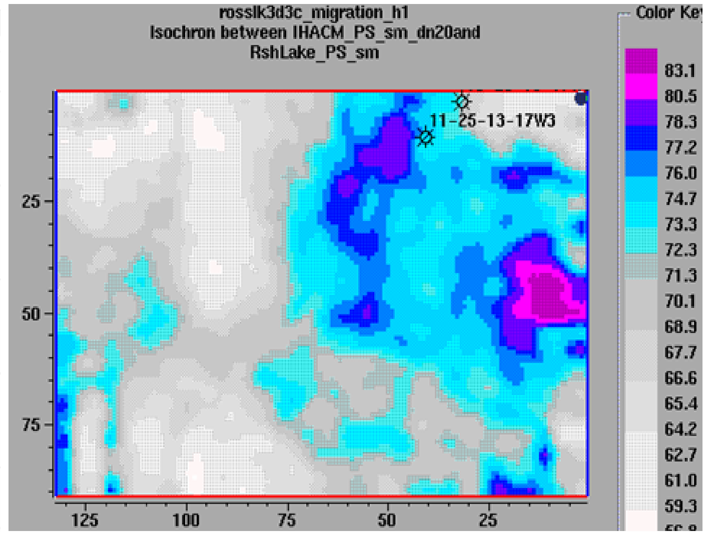

Fig. 6. PS time thickness map for the IHACM and Rush-Lake horizons.

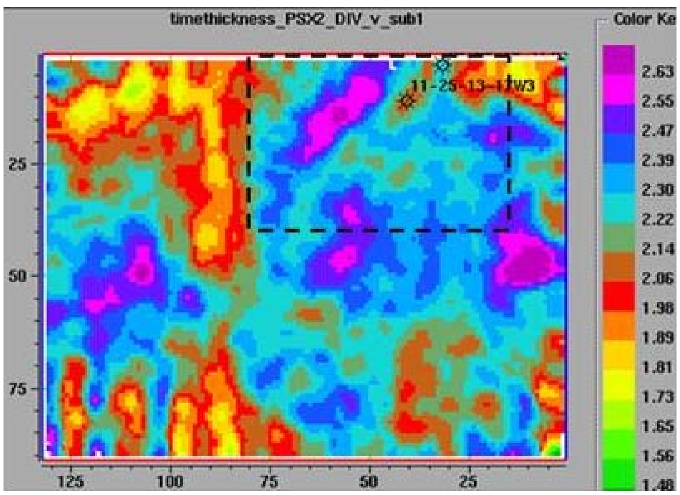

Fig. 7. Vp/Vs map between the IHACM and Rush-Lake horizon.

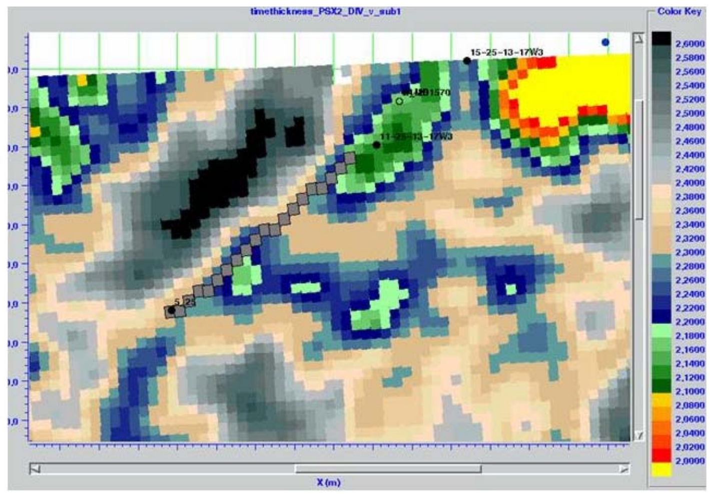

Fig. 8. Expanded Vp/Vs map, highlighted with the horizontal well trajectory.

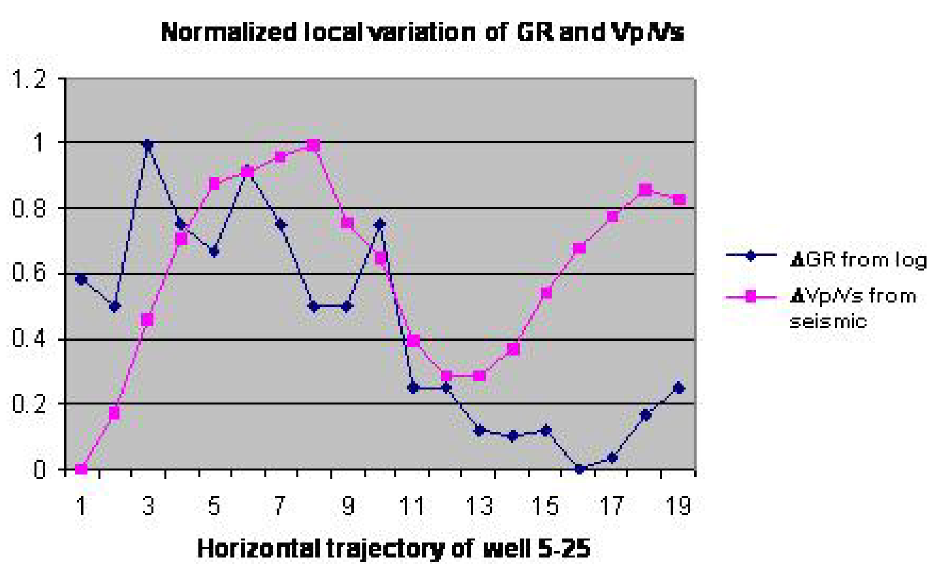

Fig. 9. Plot of the normalized variation of MWD GR and seismic Vp/Vs along the horizontal part trajectory of well 2-25.