

# Z-99 Using 3D Multi-component Seismic Data, Logs and VSP to Interpret a Sand-Shale Oil Reservoir

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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. An interpretation using both PP and PS seismic data is made. On the PP time thickness map, the target sand body, in 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  $V_p/V_s$  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  $V_p/V_s$  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  $V_p/V_s$  map between the horizons surrounding the reservoir suggests a shale-cut within the target sand body and 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.

A 3D multi-component VectorSeis® seismic survey was shot in this area using 0.5 kg dynamite in May, 2002. In June 2003, a multi-offset VSP survey was conducted in the 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 the 7.5 km<sup>2</sup> 3C-3D seismic data and delivered post-stack Kirchhoff migrated datasets of vertical, radial and transverse component. The PP data show an average signal band 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 PS-radial in the following text.

### Rock properties

A crossplot of  $V_p$  and  $V_s$  is generated (Fig. 1) by using 4 regional wells which have shear sonic logs, but none of them is in this 3C-3D seismic survey. The color bar, based on the gamma-ray value, indicates the lithology roughly. The red dots with  $V_p \sim 3500$  m/s indicates the reservoir sands. The red line is a regression of all the points excluding two grey color zones, given  $V_p = 1.50 \cdot V_s + 964$ . Three constant  $V_p/V_s$  lines (1.5, 2.0 and 3.0, respectively, black) are overlain too. The  $V_p/V_s$  value ranges from 1.8 ~ 3 for shallow layers above the reservoir.

### Logs and synthetics

No shear-sonic log is available in well 11-25, so we used the  $V_p/V_s$  values from the P- and S-source zero-offset VSP. The first break time of all the 130 downhole geophones (7.5 m interval) for PP and SS downgoing wavefields are picked to get the interval  $V_p/V_s$ . The S-velocity log is estimated by dividing the P-velocity log by VSP-derived  $V_p/V_s$ . 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 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 (a notable horizon) 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

On top of using a constant  $V_p/V_s=2.35$ , or a squeezing factor of  $(1+2.35)/2 = 1.675$  for PS, we needed 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 (Fig. 4).

Fig. 5 displays the picked PS horizon Rush-Lake and IHACM in blue color, smoothed by  $5 \times 5$  points. The three red horizons are PP horizons converted into PS time by  $T_{ps} = (T_{pp} + 125) \times 1.675$ . 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).

### $V_p/V_s$ map and lithology interpretation

Finally, using  $V_p/V_s = \frac{2 \cdot \Delta T_{ps}}{\Delta T_{pp}} - 1$ , the map of apparent average  $V_p/V_s$  between the

IHACM and Rush-Lake is achieved (Fig. 7). The main features are:

1. The north-south trend with low  $V_p/V_s$  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.
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2. Four purple blocks with high Vp/Vs value ( $> 2.4$ ) are interpreted to be shale.
3. The anomaly with longest travel time on PP time thickness map has the upper part with Vp/Vs about 2.1 and lower part with Vp/Vs about 2.1 ~ 2.2. In between, there is a horizontal stripe with Vp/Vs about 2.3 ~ 2.4, and interpreted as a shale cut.

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 2.1 ~ 2.2 (brown color on Vp/Vs map); and b) large PP time thickness (pink color on PP time thickness map).

## 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 within the target sand body. Other anomalies from the Vp/Vs map also suggest further drilling targets.

## ACKNOWLEDGEMENT

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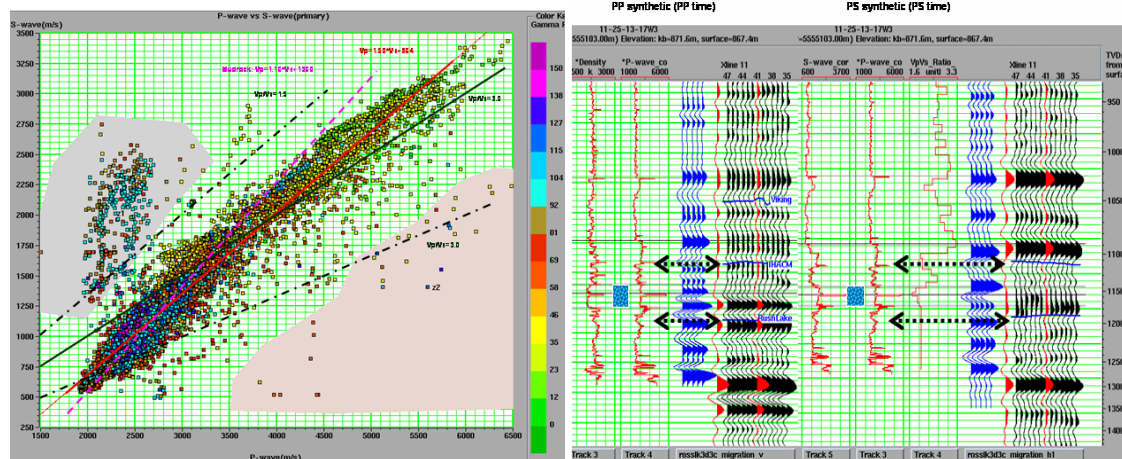


Fig. 1. Crossplot of Vp and Vs from logs.

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

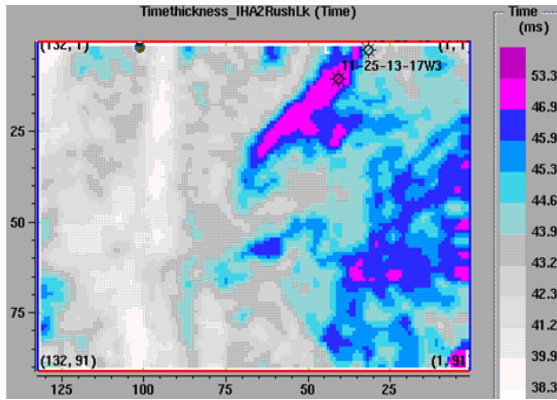


Fig. 3. PP time thickness map

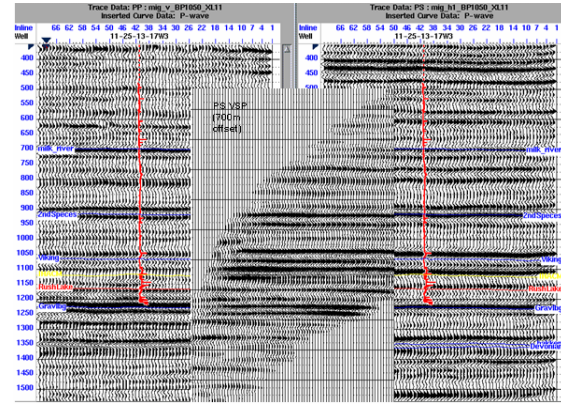


Fig. 4. PP and PS seismic correlation

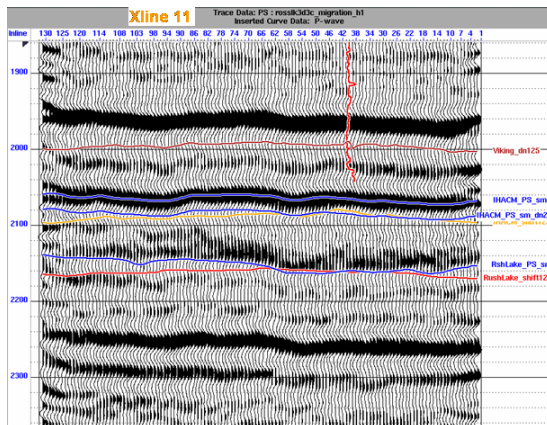


Fig. 5. Horizon picking on PS seismic data

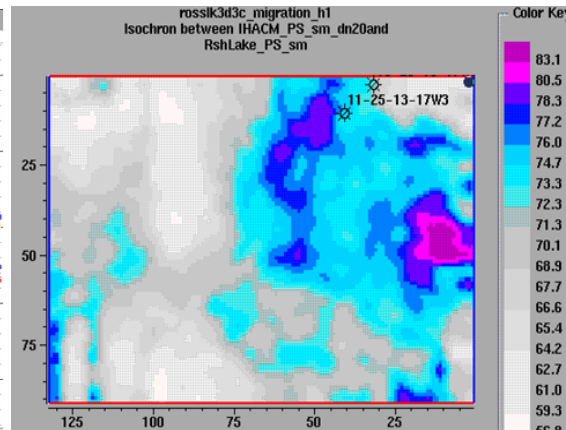


Fig. 6. PS time thickness map

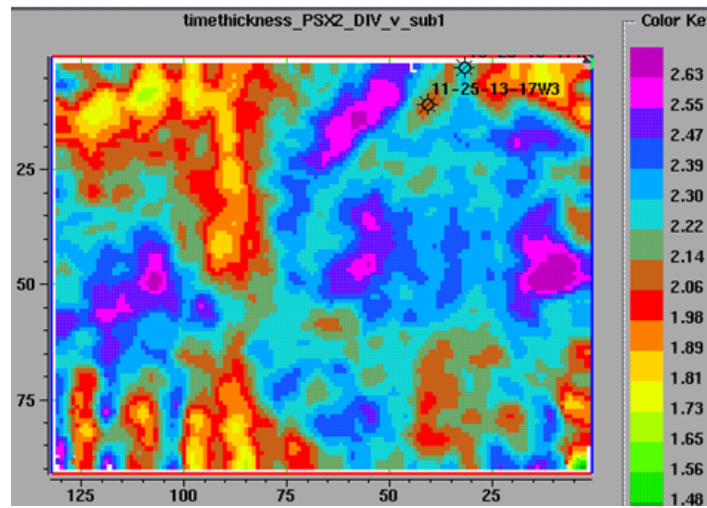


Fig. 7. Vp/Vs map between horizon IHACM and Rush-Lake.