VSP Analysis at the Ross Lake Heavy Oilfield, Saskatchewan

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In June 2003, the CREWES Project, Husky Energy Inc., and Schlumberger Canada conducted a multi-offset VSP survey at Ross Lake oilfield, Saskatchewan. This paper describes processing two of the data sets with vibrator source offsets of 53m and 400m. The processing results have a frequency bandwidth from 10Hz to 90Hz. The corridor stack (from 53m offset) ties the offset section (from 400m) nicely as well as the synthetic seismogram generated from wireline log data. Q values for both P wave and shear wave were also estimated through spectral ratio method. We extracted Qp values from 28 to 51 over the interval of 450m to 1000m and Qs values from 6 to 22 over the interval of 200 to 800m. Observed velocity dispersion across the spectrum from sonic to seismic frequencies is consistent with the previous Q values.

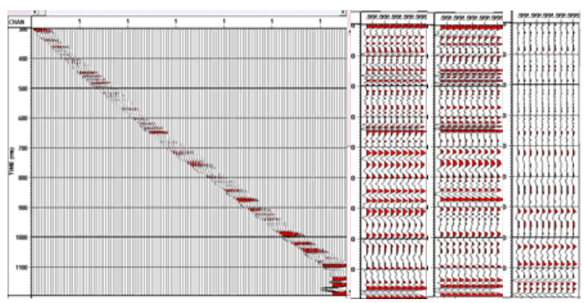
Introduction

The Ross Lake heavy oilfield (of Husky Energy Inc.) is located in southwestern Saskatchewan (Figure 1). The producing reservoir is a Cretaceous channel sand in the Dimmock Creek member of the Cantuar formation of the Mannville Group. In June 2003, the CREWES Project, Husky Energy Inc., and Schlumberger Canada conducted a multi-offset VSP survey in well 11-25-13-17W3. The zero-offset VSP survey used both vertical and horizontal vibrators as sources, but the vertical vibrator only was used for offset VSP surveys. All the surveys were conducted with a downhole five-level, three-component receiver from 197.5 meters to 1165meters every 7.5 meters. Two VSP surveys, offset 53m and 400m are described here.

Data Processing

For the zero-offset VSP data, traveltime inversion for velocity was conducted based on first break picking. The resultant velocities are used for NMO correction and sonic log calibration. A mean scale gain function was calculated in a 200ms window around the first arrival time and then applied to entire traces to balance the amplitude between each traces. Exponential gain was also used for amplitude recovery. The upgoing and downgoing waves were separated by 13-trace median filter. To attenuate multiples and enhance the resolution of VSP data, a deterministic waveshaping deconvolution operator was designed from downgoing waves and applied to upgoing waves. Before stack, a 50ms corridor mute was applied to the data to remove multiples and other noises. By comparing the stack with and without corridor mute, we see that the corridor stack has higher resolution (Figure 2). Subtracting corridor stack from non-corridor stack, multiples can be estimated (Figure 2).

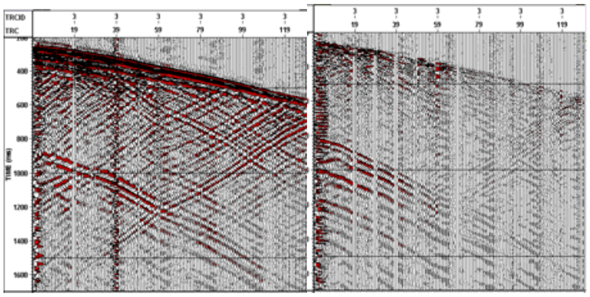
Figure1. Location of Ross Lake oilfield, Saskatchewan (from Xu and Stewart, 2003)



(a) (b) (c) (d)

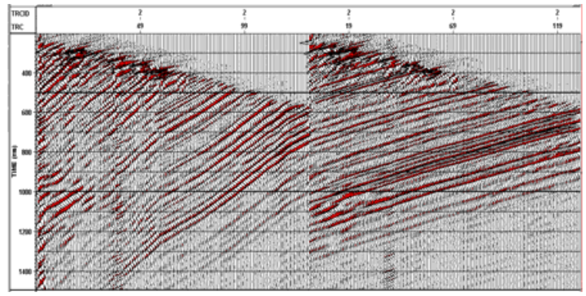
Figure 2. Corridor mute (a) and the stack trace (duplicated for 10 times) with (b) and without corridor mute (c). (d) is the result subtracting corridor stack from full stack.

For offset VSP data, hodogram analysis was implemented at each depth level for horizontal geophones to determine the polarization of the various wave modes. After data rotation, most of the P and SV energy was redistributed to Hmax (the horizontal channel in the source-receiver plane). Both the downgoing and upgoing waves become clearer. There is little P energy on Hmin (the horizontal channel orthogonal to the source-receiver plane), but SH wave exists on Hmin (Figure 3). It is thought to be generated by imperfect verticality of the source or heterogeneity of near surface structure. To unravel the upgoing P waves and upgoing SV waves, the upgoing wavefield should be first separated from both channel Z and Hmax. By time-variant rotating the two datasets the upgoing P and upgoing SV wave will be separated each other shown as Figure 4. The rest processing flow resembles that of the zero-offset case. Finally, the VSP-CDP mapping was introduced to map the time-depth domain P data into offset-time domain similar to surface seismic images.



(a) (b)

Figure 3. Hmax (a) and Hmin (b) from X Y channel rotation (offset=400m).



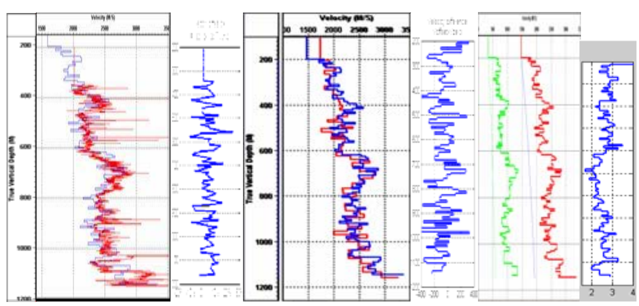
(a) (b)

Figure 4. Upgoing PS (a) and PP (b) wave from upgoing waves of Z & Hmax after time-variant rotation (offset=400m).

Results

<u>Velocity inversion from VSP data</u>

The sonic log and velocity estimated from the zero-offset VSP are similar but with the sonic values somewhat higher (Figure 5a). The average difference between sonic log and zero-offset derived velocity is 3.7%. The velocity from offset (400m) VSP is slightly lower (2%) than that from zero-offset (Figure 5b). Considering the frequency difference (Figure 6e) of offset VSP data and zero-offset VSP data, the difference may be caused by velocity dispersion (the difference can produce about 2% velocity dispersion with Q value 45). The shear velocity ranges from 500m/s to 1360m/s (Figure 5e, green line). Average Vp/Vs is 2.8 above 600m, 2.2 for 600m-900m, and 2.6 from 900m to the bottom of the well (Figure 5f).



(a) (b) (c) (d) (e) (f)

Figure 5. The velocity from zero-offset VSP (a, blue line), offset VSP inversion (c, red line, overlapped by velocity from zero-offset VSP, blue line) and velocity from the sonic log (a, red line). (b), (d) is the difference of the velocities from zero-offset VSP and sonic log & the velocities from offset VSP individually.

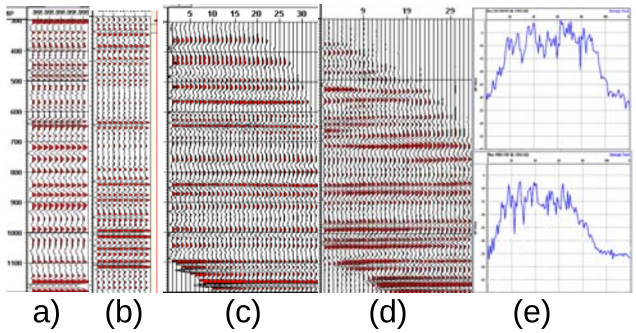


Figure 6. Corridor stacks of P wave from the horizontal vibrator (a) and shear wave from vertical vibrator (b) zero-offset, VSP-CDP mapping result of PP wave (c) and PS wave (d, processed by Schlumberger) of offset VSP, and (e) amplitude spectrum of P wave corridor stack (upper) and VSP-CDP mapping result (lower).

VSP processing result

The correlation between P-wave and S-wave processing results is reasonable, but with some intriguing differences (all the data in Figure 6 are plotted in PP time). The corridor stack result of zero-offset VSP provides a largely multiple-free trace with frequency bandwidth from 10Hz to 95Hz. Compared with the corridor stack trace, residual multiples on VSP-CDP mapping result can be determined by event discrepancies. The average signal-to-noise ratio of PP wave VSP-CDP mapping result is about 15. Its frequency bandwidth is 10Hz to 85Hz. The synthetic seismogram generated from well log data ties the VSP processing results very well. A good correlation is also found for the VSP results and an intersecting surface seismic section (Figure 7). The surface seismic section is extracted from a 3-D volume as described by Xu and Stewart (2003).

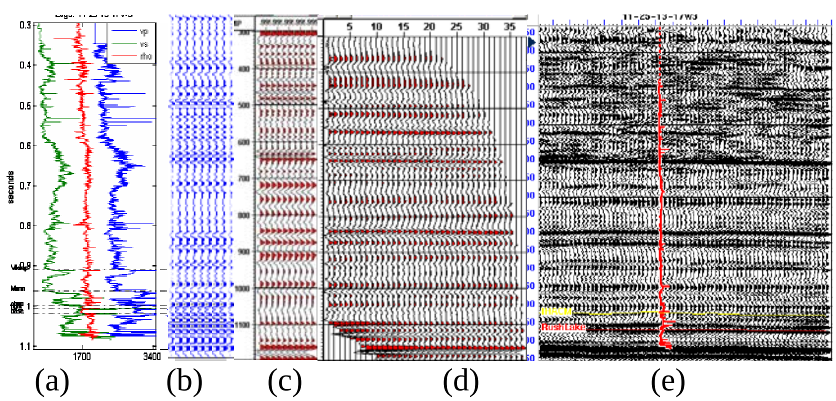


Figure 7. Velocities from the sonic log (a), synthetic seismogram (b, repeat 10 times), corridor stack of vertical vibrator zero offset (c), PP wave VSP-CDP mapping result of offset VSP (d), and (e) surface seismic data with the sonic log spliced into it at the well location (from Xu and Stewart, 2003).

Attenuation Analysis

Both vertical vibrator and horizontal vibrator were used for Ross Lake zero-offset VSP survey. For Q estimation, downgoing P waves and shear waves were extracted from vertical vibrator records and horizontal vibrator records separately. From the spectral ratio method, the attenuation-depth structures were determined and the estimated P wave and shear wave Q values are shown in Table 1. The shear waves appear to have more attenuation than the P waves. The overall trend is an attenuation decrease with depth for both P wave and shear wave. When comparing the estimated Q value with the result of Xu and Stewart (2005), the Q value of P wave over depth 400m-1000m are similar although Xu and Stewart (2005) used surface sweep signal as reference.

While the average Qp estimated over an interval of 200m to 1200m is 67 and Qs is 23 by Haase and Stewart (2004), it appears a little higher than the values estimated in this paper.

Table 1. Estimated Q values for P wave and shear wave. The values estimated in this paper are given as (a), (b) represent Xu and Stewart's values (2005), (c) are the average Q values of Haase and Stewart (2004).

	Depth	***Qp***			***Qs***	
		(a)	(b)	(c)	(a)	*(c)*
Above RIBSTNG	200-450m		--		22	
RIBSTNG –MILKRV	450-600m	28	30		6	
MILKRV -1WSPK	600-800m	51	55	67	17	23
1WSPK-VIK	800-1000m	46	40			
VIK- MASFLDSH	1000-1165m		--			

Conclusion

Zero-offset and offset VSP data from the Ross Lake heavy oilfield, Saskatchewan are discussed in this paper. The processed results have a high signal-to-noise ratio, with an overall value of about 15. The frequency bandwidth of PP wave VSP-CDP mapping is 10Hz to 90Hz. The results of the zero-offset VSP processing and offset VSP processing result correlate nicely and also tie the synthetic seismogram and surface seismic image convincingly. The velocity difference (2%) determined from the zero-offset and offset VSP data could be explained by velocity dispersion. The Q values for P wave and shear wave are also estimated from zero-offset VSP survey. The results indicate higher attenuations for the shear waves than the P waves.

Acknowledgement

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