

Characterizing the Near Surface with VSP and Well Logs

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Summary

Well logs and vertical seismic profiling (VSP) data were acquired in the Rothney well (05-13-022-03W5) over a depth of 137 m near Priddis, Alberta, to test their feasibility in characterizing the shallow subsurface. According to qualitative and quantitative analysis of well logs, five porous zones were identified and their porosities range from 0.34 to 0.58. The processed VSP corridor stack resolved these porous zones and the VSP stack correlated reasonably with the 1-D synthetic seismogram and other well logs. The P-wave velocities of clean sandstone ranged from 2500 m/s to 3100 m/s and shales from 1900 m/s to 2100 m/s. The quality of various well logs and VSP data provide considerable promise for the technique's use in aquifer detection and interpretation of seismic data.

Introduction

Shallow VSP and well logs were acquired near Priddis, Alberta. The goal of conducting these surveys is to develop techniques to characterize and image near surface. This information has application to seismic statics, ground water exploration, and geotechnical projects. The survey area is located within Paskapoo formation which is the largest single source of groundwater in the Canadian Praries: Over 100,000 wells out of 600,000 wells in Canadian Praries are located in Paskapoo formation (Grasby, 2006). Although many shallow surface seismic reflection technique has been used to map water saturated zones (Steeple and Miller, 1998; Cardimona *et. al.*, 1998), the surface seismic reflection method has inherent resolution limitations because the seismic wavelet propagates substantial distances through the weathered layer, resulting in rapid attenuation of the desired higher frequencies (Gochioco, 1997). The objectives of our study were to test whether the shallow borehole concepts can be used to overcome this limitation and to use these techniques to characterize the groundwater resources of the Paskapoo formation as well as to better characterize the rock units that make up the aquifer system.

Data Acquisition

In the summer of 2007, a 137m test well was drilled in Priddis for the CREWES project's research purposes and the University of Calgary's undergraduate geophysics field school. A suite of well log measurements including spontaneous-potential, gamma-ray, resistivity, caliper, temperature, density and neutron porosity logs were acquired by Roke Oil enterprise limited in the open hole (Figure 1) before the 15.6 cm diameter well was cased with PVC. The full-wave form sonic log, which is acquired after the well was cased, is shown in Figure 1 as well. At the time when the open-hole logs were taken, the static water level was 30 m. A set of 1.5 m offset VSP data was also acquired by using a sledge hammer as a seismic source and a 3C downhole sonde (Figure 1d) spaced at 0.5 m. The depth coverage of the VSP survey is 4 m to 63 m.

Well Log Analysis

According to driller's lithologic description, the test well penetrates mainly sand and shale layers. As shown in Figure 1, the depths of the stratigraphic interfaces and lithologies drawn from both the driller's description and the well logs match reasonably well. We have identified five porous zones (zones I to V). Out of these five zones, three were saturated with water at depths of ~30m (zone I), ~50m (zone III) and ~120 m (zone V) as indicated by the driller.

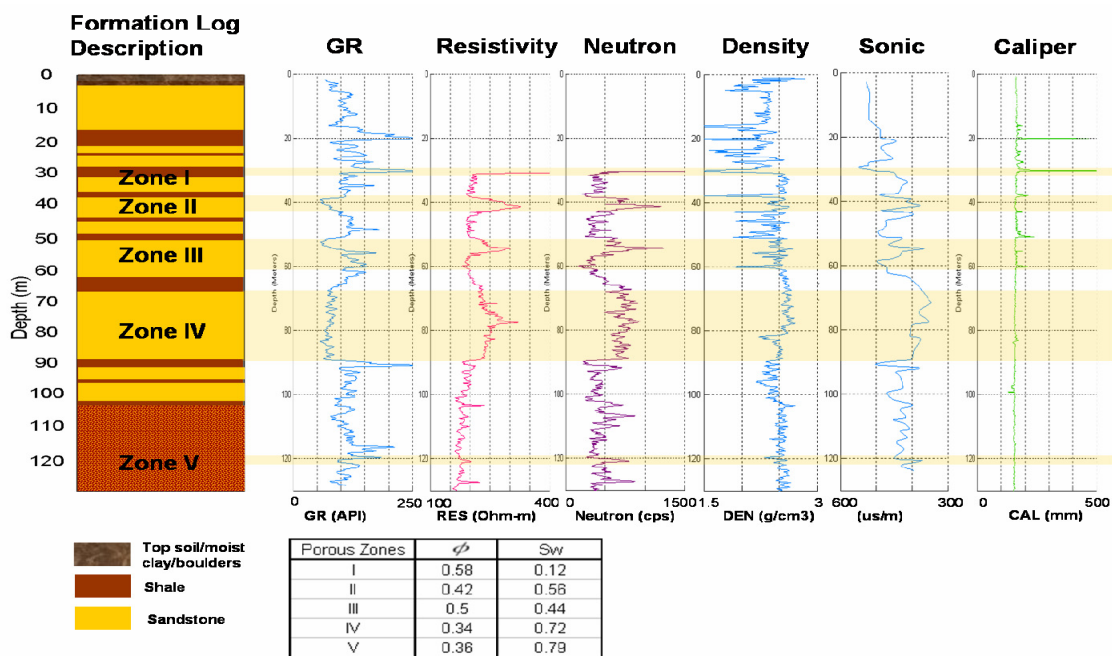


Figure 1: Formation log description recorded insitu while drilling (far left) and well logs acquired from Priddis test well. A table of porosities and saturations estimated from the well logs is shown for five porous zones.

Using the conventional quantitative well-log analysis methods (Asquith and Krygowski, 2004), which take account of information from gamma ray, sonic, borehole temperature and resistivity logs, estimates of porosity and saturation were calculated for all porous zones (see Figure1). The porosities in the five zones range from 0.34 to 0.58 with the highest porosities observed in the top three zones (I, II and III). The water saturations ranged from 0.12 and 0.79. As indicated by the caliper log at a depth of ~30 m (i.e. zone I), the half width of the interpreted fracture (50 cm) invalidates the resistivity measurement and thus the saturation estimate. As indicated by the caliper

and density logs, significant fracturing is likely occurring to depths of 60 m. The saturation estimates for fracture-free zones (zones IV and V) seem physically reasonable.

VSP Data Analysis: VSP Corridor Stack and Sonic Log Calibration

The VSP data from 1.5 m offset with a hammer source (Figure 2a) was processed to observe whether the porous zones are resolved in the final corridor stack. The standard processing flow of zero-offset VSP, which typically involves picking first arrival time, separation of up and down-going wavefields, deconvolution of up-going primary wavefields and corridor stacking, was used (Hinds and Kuzmiski, 2006) (Figure 2b).

Furthermore, using the observed first arrival time from the 1.5m near offset VSP data, the P-wave sonic log was calibrated. As shown in Figure 2c, the sonic traveltime becomes longer than VSP traveltime with increasing depth. Although sonic times are often expected to be shorter than the VSP traveltime at greater depths due to their higher source frequency (Stewart *et al.*, 1984), there are many cases where the sonic traveltimes are larger than VSP times at shallow depths (Goetz *et al.*, 1979). In this case, the delayed sonic traveltimes may be due to fractures occurring at depths less than 60 m whereas in 1.5 m-offset VSP survey, the traveltime delays due to fractures become less significant. The respective P-wave velocities of clean sandstone and shale zones ranged from 2500 m/s-3100 m/s and 1900 m/s-2100 m/s respectively after calibrating P-wave sonic log using VSP data.

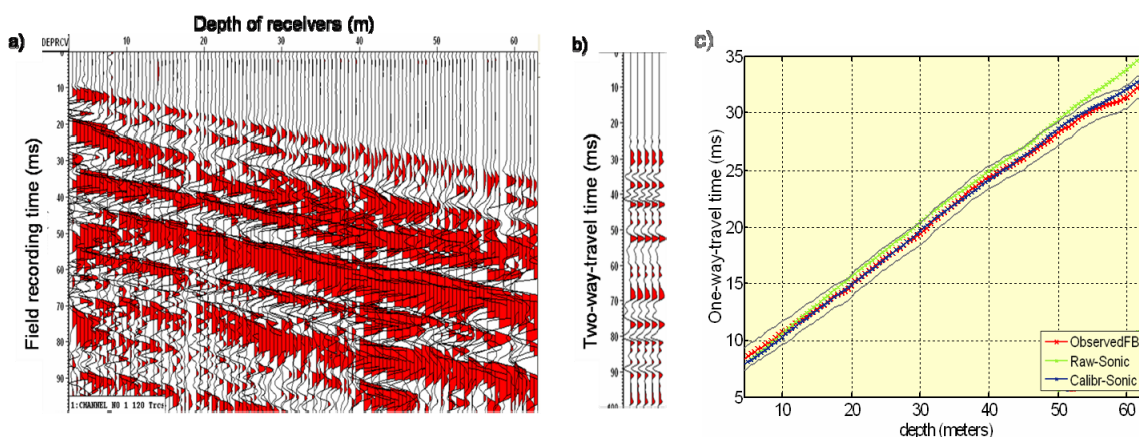


Figure 2: a) Raw shot gather of 1.5m offset (pseudo-zero offset) VSP acquired from Priddis test well (measured in field recording time), b) final corridor stack repeated 5 times (measured in two-way-traveltime), c) observed VSP traveltime (red), computed traveltime using un-calibrated P-wave sonic velocity (light green) and calibrated sonic traveltime (blue) in the field recording time.

Synthetic Modelling

A synthetic seismogram was generated for VSP interpretation. Based on the frequency bandwidth of the deconvolved up-going wavefield of the field data, a zero-phase wavelet was designed. From the sonic and density log, impedance and reflectivity was estimated (Figure 3a). The reflectivity function and the designed wavelet were then convolved to generate 1-D synthetic seismogram in two-way-traveltime (Figure 3b). To register the synthetic seismogram in depth, an overburden velocity was estimated from the VSP data using the top receiver-and-offset configuration and its recorded first arrival time. An overburden velocity of 520 m/s was assigned for depths less than 3.9 m (*i.e.* depth prior to sonic measurements). Since the sonic and density logs were sampled at different rates and because the density function is quite variable due to significant fracturing, 1-D

synthetic seismogram was also generated using the sonic log and the density value was estimated using Gardner's equation (Gardner, 1974).

Correlation of Synthetic, Corridor-Stack and Well Logs

In the synthetic seismogram, the three porous zones (zone I, II, and III) at depths of 30 m, 40 m, and 55 m (Figure 3) are resolved with a negative trough which indicates significant decrease in velocity and/or density within the zone. These zones are also resolved in the processed VSP corridor stack and their general wave characteristic reasonably well with the 1-D synthetic seismograms.

There is a slight discrepancy in position of the porous zone at a depth of 40 m (or 49 ms in two-way-traveltime) between the corridor stack and the 1-D synthetic seismograms. The small discrepancy in travel-times in the synthetic seismogram and a VSP corridor stack can be anticipated because of differences in geometry, source frequencies, trace signal-to-noise ratios and instrument timing errors (Gochioco, 1998). Also, the remnants of primary down-going waves and tube waves that are not effectively removed from the VSP might be interfering with the up-going primary field.

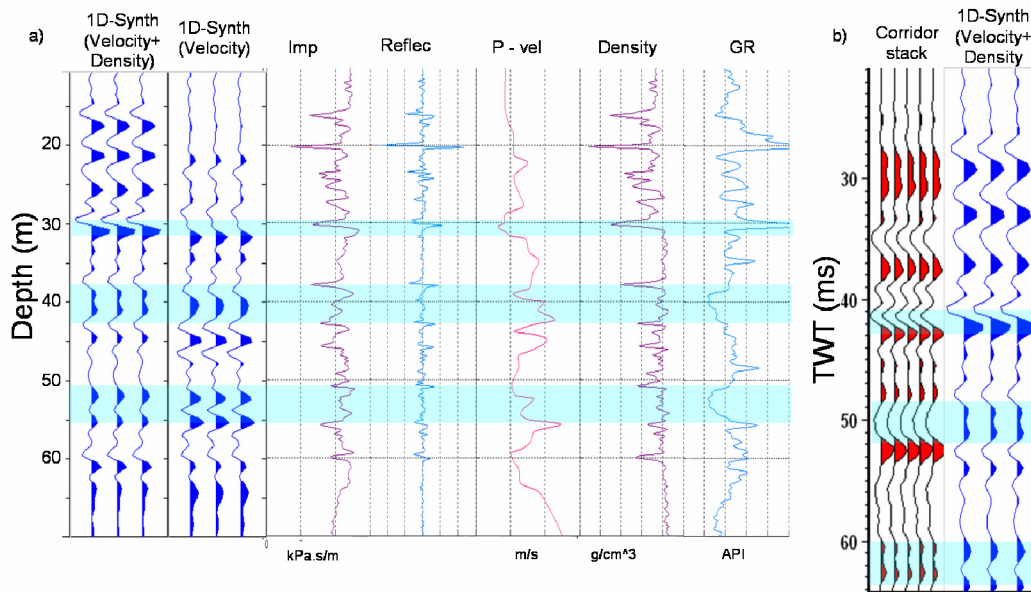


Figure 3: a) VSP corridor stack (left) and 1-D synthetic seismograms indexed in their two-way-traveltime, b) Correlation of 1-D synthetic seismogram with the well logs in their depths.

Conclusions

Well logs and VSP surveys were conducted in the Rothney well (05-13-022-03W5) in Priddis, Alberta to test their feasibility in characterizing subsurface features. According to qualitative and quantitative analysis of well logs, five porous zones were identified and their porosities range from 0.34 to 0.58. The respective P-wave velocities of clean sandstone and shale zones ranged from 2500 m/s-3100 m/s and 1900 m/s-2100 m/s respectively after calibrating the P-wave sonic log using the VSP data. The porous zones are characterized in both the shallow VSP corridor stack and well logs. The quality of various well logs and VSP provide considerable promise for their use in near-surface characterization.

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