Integrated geophysical characterization of the near-surface at Priddis, Alberta

J. Helen Isaac, Lei Zhi, Don C. Lawton, and L. R. Bentley
Geoscience Department, University of Calgary

Summary

We integrated shallow well data with seismic reflection and refraction surveys and electrical resistivity data acquired on the University of Calgary lands at Priddis, Alberta, in 2012. The purpose was to derive a model of the near-surface and to predict the lithology to be encountered in a new well drilled in the autumn of 2013 for the installation of a permanent downhole seismic recording and monitoring system.

There is a good match between the velocity model derived from the refraction survey, the interpretation of reflectors on the reflection data, the electrical resistivity inversion and the lithology in existing well A. A sandstone penetrated between 65 m and 90 m in well A was predicted to be encountered updip at depths between about 25 m and 50 m in well B, drilled in October, 2013. Well B turned out to have three sandstones within this interval, from 23-28 m, 31-37 m and 46-50 m. A major resistive unit, interpreted to be a sandstone, correlates to strong reflectors on the reflection seismic data and a relatively high velocity on the seismic refraction velocity model. We predicted that the top of this unit would be encountered at about 95 m depth in well B. Our predictions turned out to be accurate, as well B penetrated a sandstone from 91-102 m. A hard shale with sandstone ledges was penetrated at 124 m in well B and slowed the drilling of the well. It projects onto well A deeper than the total depth but correlates to a high amplitude reflection on the seismic data.

We created a near-surface model and had confidence in the accuracy of this model since we had integrated several geophysical data sources with existing well data.

Method

Seismic data

A seismic reflection survey was acquired in July, 2012, and a seismic refraction survey was acquired in September, 2012, both utilising a mini-vibroseis source and 3C geophones. We picked first breaks on the refraction data and calculated refraction statics using a generalized reciprocal method inversion algorithm (Palmer, 1981). The near-surface velocity-depth model (Figure 1a) obtained through this inversion is adequate for showing general trends although the absolute values are inexact.

We processed stacked and post-stack time migrated the reflection data. Reflectors that dip to the east can be seen clearly on this section (Figure 1b). This dip is consistent with the 30° dip indicated on geology maps and seen in outcrop along the hill to the west of the field area (GSC, 1941; Isaac and Lawton, 2010).

Well data

A shallow well (Well A) was drilled to 137 m in 2007 (Wong et al., 2007). The well penetrated clastic rocks of the Palaeocene Paskapoo Formation. A major sandstone was encountered between 65 and 89 m depth, with minor, thin sandstones in the section above. The sonic log shows an increase in seismic velocity at the top of the sandstone and a decrease at the base, where the synthetic seismogram indicates a strong negative seismic response. The individual minor sandstones are too thin to be resolved by our seismic data.

Electrical resistivity data

The electrical resistivity line was coincident with the refraction line although a little longer. The sequence used for acquiring data was a pre-defined dipole-dipole electrode array, which included approximately 40% reciprocal measurements. Two different unit electrode spacings, 5 m and 10 m, were used to improve data density and both vertical and horizontal resolution in the near surface and to achieve a maximum depth of investigation.

We processed the resistivity data using the RES2DINV program, which runs a smoothness-constrained Gauss-Newton least-squares inversion (Sasaki, 1992; Loke, 2000; GeoTomo, 2013). Forward modelling utilized the finite-element method to adjust the node positions to follow the topography. We chose parameters to minimize the error generated by the forward modelling algorithm and an L1 norm constraint was applied to both the data and the model to minimize the difference between the calculated and measured resistivities (Zhi, 2013).

The approximate reliable depth of investigation, based on model resolution, is about 60 m (base of plot in Figure 1c). The resistivity values range from 16 to 66 ohm.m and the entire pseudosection is relatively conductive. The tomogram shows that the depth to bedrock is about 5 m and that the upper bedrock is highly heterogeneous and dominated by sandstone and mudrocks. Three major anomalies (outlined by white ovals labelled A, B and C) are located at horizontal distances 280-360 m, 415-440 m, and 450-580 m. These are interpreted to be sandstones within the bedrock, as they tend to be very resistive (> 52 ohm.m, red-to-purple colour).

Integration of results

All the geophysical data plotted separately in Figures 1a, 1b and 1c are superimposed in Figure 1d with the well lithology and a synthetic seismogram in depth added. The seismic refraction line and electrical resistivity profile were projected 215 m along strike onto the seismic reflection line, and well A was projected 345 m.

The sandstone encountered between 60 and 95 m depth in well A is indicated by the shallowest yellow band in Figure 1d. It correlates to a small, shallow resistive unit at about 430 m distance on the electrical resistivity profile.

A bright reflector dipping to the east between surface locations 350 m and 100 m and between elevations of about 1120 m to 1060 m correlates with a strong resistive (red) unit observed between 500 m and 600 m on the electrical resistivity data (oval C). It also corresponds fairly well to a high velocity unit in the refraction survey (in orange). We interpret these to be geophysical responses to a sandstone.

The area of low resistivity in dark blue centred around 400 m correlates to an area of poor reflectivity on the reflection seismic data and low velocity (green) on the refraction velocity model and is interpreted to be the geophysical response to a shale.

From these integrated data we predicted that the major sandstone encountered in well A would be penetrated in well B from about 25 m to 50 m below the surface. We also predicted that a resistive sandstone would be encountered at around 95 m depth below the surface.

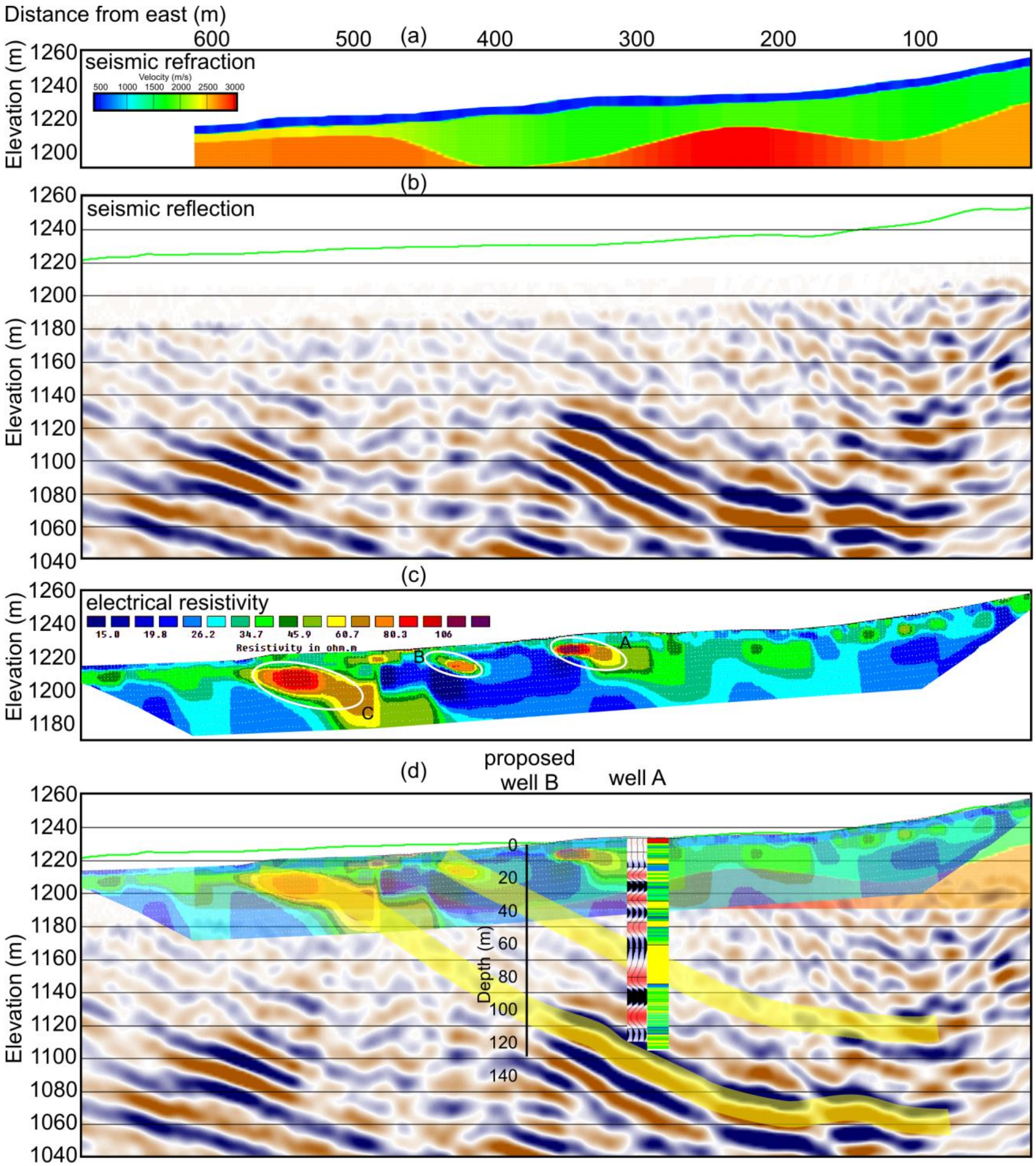

Figure 1. (a) Near-surface velocity model from seismic refraction data; (b) Seismic reflection data, post-stack time migrated converted to depth; (c) Electrical resistivity inversion; (d) All data plotted with synthetic seismogram and lithology for existing well A and location of the well drilled in October 2013. The yellow overlay represents sandstones encountered in well A and expected in well B.

Postlude

Well B encountered grey sandstones at depths between 23-28 m, 31-37 m and 46-50 m, which we correlate to the sandstone encountered between 65 and 90 m depth in well A. An 11-m thick sandstone was found at 91-102 m depth and correlates to the resistive sandstone that we predicted from seismic character and electrical resistivity to be encountered at 95 m depth.

The drillers encountered a very hard unit, described as a shale with sandstone ledges, at about 125 m depth, which slowed the drilling considerably. This we correlate to a high amplitude reflection on the seismic data which was below the total depth of shallow well A.

Summary

The integration of seismic reflection data, a seismic refraction velocity model, inverted electrical resistivity data, and information from a nearby well allowed us to build with confidence an image of the near subsurface (<200 m) at Priddis, Alberta. We used the integrated data to predict the lithology to be encountered in a new well drilled in October, 2013. We predicted that the sandstones penetrated by well A would be encountered in the interval 25-50 m depth in well B. Well B actually encountered grey sandstones at depths of 23-28 m, 31-37 m and 46-50 m. A highly resistive body which correlated to high amplitude reflectors on the seismic data was predicted to be a sandstone and that it would be encountered at about 95 m depth. The well indeed entered a sandstone at 91 m depth. It also drilled with difficulty through a very hard layer at about 124 m depth. This we correlate to a strong reflection on the seismic data.

We conclude from this study that the integration of seismic and electrical resistivity data can be used to develop a near-surface geological model. We used this model to predict the lithology to be encountered in a new well but it could also be valuable for use in statics estimations.

Acknowledgements

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