Brooks Revisited

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ABSTRACT

The first CO_2 injection well was drilled in 2015 at the Containment and Monitoring Institute's Field Research Station near Brooks, Alberta. We used well logs from the new well to compare our pre-drill depth estimates of formation tops with those encountered in the well. Our estimate of the depth of the target Basal Belly River Formation, which we had derived from the seismic data interpretation tied to existing wells, was about 3.5 m high. We had also predicted a thin sand near the top of the Medicine Hat Formation and this prediction was 3 m high. Our predictions of the shale content in the Belly River Formation above the target injection zone are supported by gamma ray log and lithology data from the new well.

We created synthetic seismograms from the dipole logs acquired in the new well and tied them to the seismic data. The PP and PS data show good character matches between the seismic data and the synthetic seismograms. Although the seismic data did not require re-interpreting, we used the formation tops from the new well to revise the depth structure maps. We also updated the post-stack joint PP-PS inversion to 550 m depth by using the dipole logs from the new well.

INTRODUCTION

The Containment and Monitoring Institute (CaMI), established by Carbon Management Canada, has a Field Research Station (FRS#1) near Brooks, Alberta, where technologies for the measurement, monitoring and containment of subsurface fluids, including carbon dioxide, will be developed, refined and calibrated. A well was drilled in 2015 to a depth of 550 m and CO_2 injection will start very soon. The plans are to inject small amounts (up to 1000 tonnes per year) of CO_2 into the Upper Cretaceous Basal Belly River Formation, which is a water-wet sandstone capped by the shales, silts and silty sands of the Belly River Formation..

In previous CREWES Research Reports we discussed the geology of the study area and the processing and interpretation of 3D3C seismic data acquired there (Isaac and Lawton, 2014a; 2014b; 2015a). We correlated well logs over the study area to predict the geology to be encountered in the new injection well. To predict the sealing capacity of the Belly River Formation, we correlated the local wells to the nearest well with a lithology log, which is 15 km to the west, and to a producing well further west (Isaac and Lawton, 2014a). In this paper we discuss the geology encountered in the new well and the validity of our predictions.

We had generated synthetic seismograms to identify reflectors on the 3D3C seismic data acquired over the study area Alberta (Isaac and Lawton, 2015b; 2015c; 2016a; 2016b). We used P-wave sonic and density logs from a well on the periphery of the survey to create a PP synthetic seismogram, which we projected onto the PP seismic data in order to identify reflections. An interesting AVO effect at the top of the Milk River Formation compelled us to make an offset synthetic seismogram to properly tie that reflection. For this we needed an S-wave sonic, which we derived from the P-wave sonic using Castagna's equation. We also used the P-wave and derived S-wave sonic logs to make a PS synthetic seismogram to tie to the PS seismic data. Subsequently we obtained access to logs from the new injection well, which was drilled in 2015 in the centre of the survey, and in this paper we discuss the synthetic seismograms created from those logs, and their ties to the seismic data.

GEOLOGY

The new CO_2 injection well, 10-22-017-16W4M, was drilled at the CMC Field Station near Brooks, Alberta (Figure 1), to a depth of 550 m in 2015, and a comprehensive suite of logs was run in it. In the 2014 CREWES Research Report we discussed the geology of the study area and made prognostications for this new well (Isaac and Lawton, 2014a).

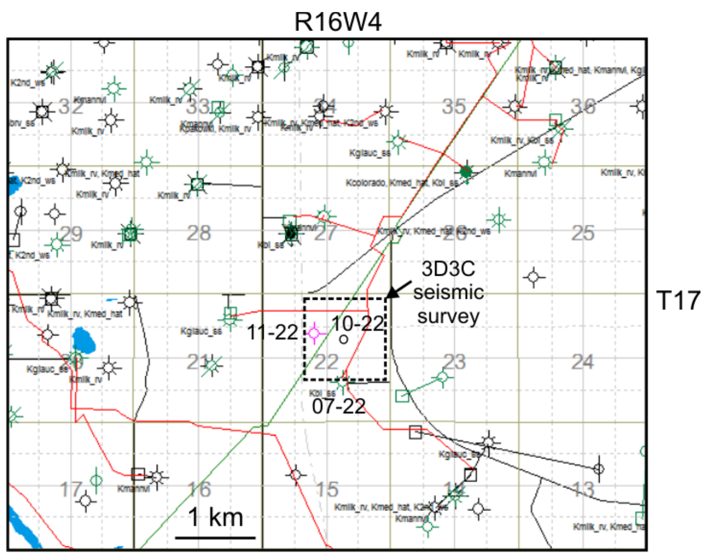

FIG. 1. The study area at Brooks, Alberta.

We predicted the depth of the top of the Basal Belly River sandstone to be +492 m, a thin sand near the top of the Medicine Hat Formation to be +284 above sea level (ASL), and the Basal Belly River to be 5-7 m thick. The sand tops came in at +489.5 m and +281 m ASL, respectively, and the Basal Belly River sandstone is 6.5 m thick. Based upon the maps of gridded well tops and the traveltimes from the 3D seismic data interpretation, we had expected the top of the Basal Belly River sand to be at a depth comparable to that in 07-22-017-16W4M, which is 492.6 m ASL (Isaac and Lawton, 2014b, Fig. 8). The sand depth turned out to be between the depths recorded in wells 11-22-017-16W4M and 7-22-017-16W4M.

Figure 2 shows the gamma ray, P-wave sonic, S-wave sonic and density logs from this well, and the interpreted lithology (courtesy Schlumberger). Surface casing was set to 226 m KB, and the gamma ray log is uncalibrated above this depth while the other logs do not start until below this depth. As would be expected, the primary target, the top of the Basal Belly River sandstone, shows a decrease in gamma ray and increase in sonic velocities. Overlying the target sand is a sequence of silts, shales, sands and coals.

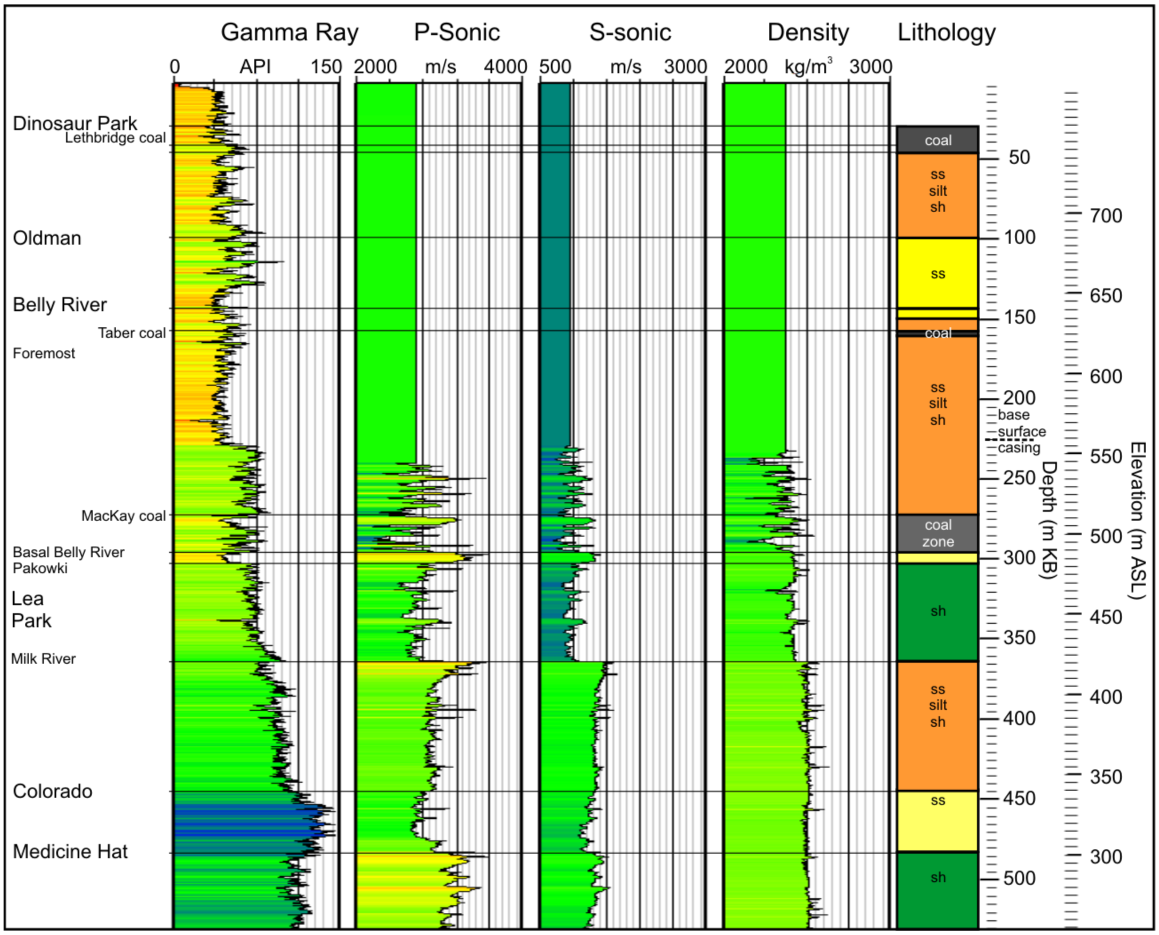

FIG. 2. The gamma ray, P-wave sonic, S-wave sonic and density logs from the new injection well 10-22-017-16W4M, with the lithology (courtesy Schlumberger).

Figure 3 is an expanded view of the lower Belly River correlated to the two other wells in Section 22. The top of the Basal Belly River sand is about 4 m higher than in the nearby 11-22-017-16W4M. The background is coloured green and yellow to indicate shale-prone or sand-prone zones, based upon the gamma ray log values. The Basal Belly River is a shoreface sand whose sand content varies (Dawson et al., 1994). Based on the gamma ray log, the sand quality in 10-22-017-16W4M appears to be better than that of 11-22-017-16W4M and 07-22-017-16W4M.

We previously studied the sealing capacity of the Belly River Formation by first calibrating the gamma ray log for well 11-22-017-16W4M to that of 16-25-017-18W4M, which is the nearest well with a lithology log. We then extended this correlation to include wells from a producing pool, Eyremore, in T19R18W4M, to compare the shale content of the Belly River Formation where it must be a seal to the shale content in Section 22-017-16W4M (Isaac and Lawton, 2014a). We update that figure by replacing the logs of 11-22-017-16W4M with those of 10-22-017-16W4M (Figure 4). We had estimated that the Belly River section above the target injection formation would be composed of about 40% silty sand and 60% silt/shale in the new well. We also predicted several shale units that are at least 10 m thick. The gamma ray log and lithology (courtesy Schlumberger) of the new well support these predictions.

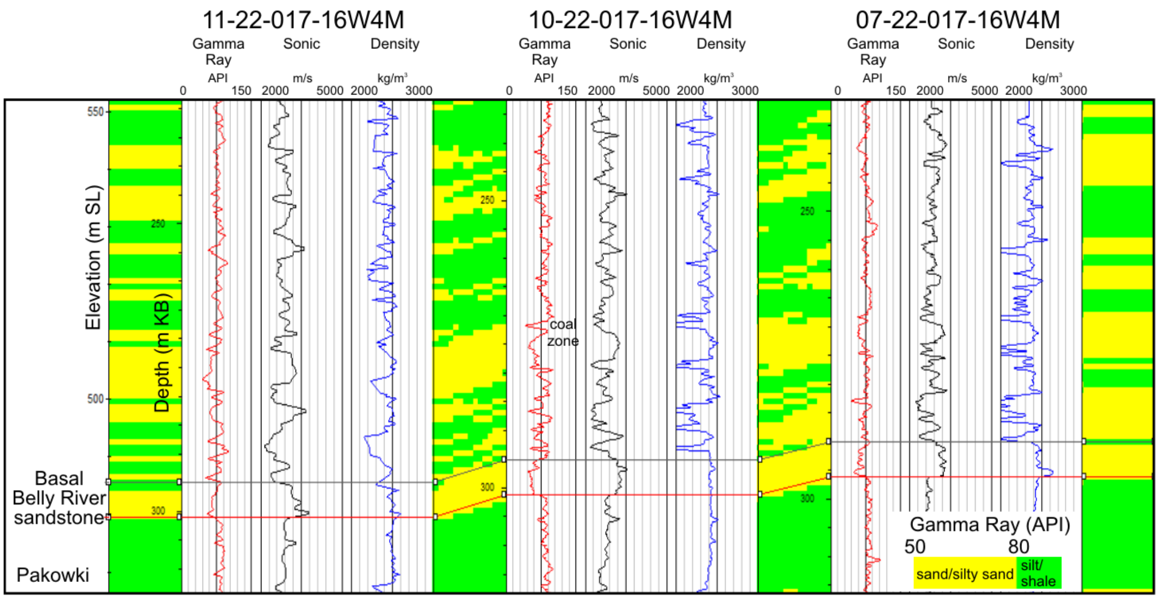

FIG. 3. Correlation of the target Basal Belly River across the three wells in Section 22.

Synthetic seismograms

The logs run in the new injection well included both P-wave and S-wave sonic logs, which we used to create synthetic seismograms. We created a multi-offset synthetic seismogram (Figure 5). The reflection coefficients are calculated using Aki and Richards' 2-term approximation (Aki and Richards, 1980) to the Zoeppritz equations (Zoeppritz, 1919) and the synthetic seismogram was generated using a wavelet extracted over a 200-800 ms window from traces around the well location. The target Basal Belly River unit is very thin (6.5 m), and is close to the tuning thickness for the wavelength of approximately 45 m. The character match is good and we are able to confirm the tops of the Basal Belly River, Milk River and Medicine Hat formations on the seismic data.

In Figure 6 we show the tie for the PS synthetic seismogram with the PS seismic data. The wavelet was extracted over a 0-1000 ms window from traces across the survey. The character match is very good and we are able to identify reflections to a PS time of 0.8 s.

To identify reflections deeper than 0.4 s on the PP data and 0.8 s on the PS data we used logs from a deeper well in the study area, well 7-22-017-16W4M. This well has no S-wave sonic log, so we had to derive one. To derive a more accurate S-wave sonic log than the one we derived last year (Isaac and Lawton, 2015b, 2015c) using Castagna's equation (Castagna et al., 1985), we crossplotted well C's measured Vp against Vs and obtained a linear regression formula for the Upper Cretaceous clastic rocks:

$$Vs=0.9*Vp-1290 \qquad \text{Equation (1)}$$

Using this formula, we derived a new S-wave sonic log from the P-wave sonic log, and created a multi-offset synthetic seismogram to tie to the PP seismic data (Figure 7).

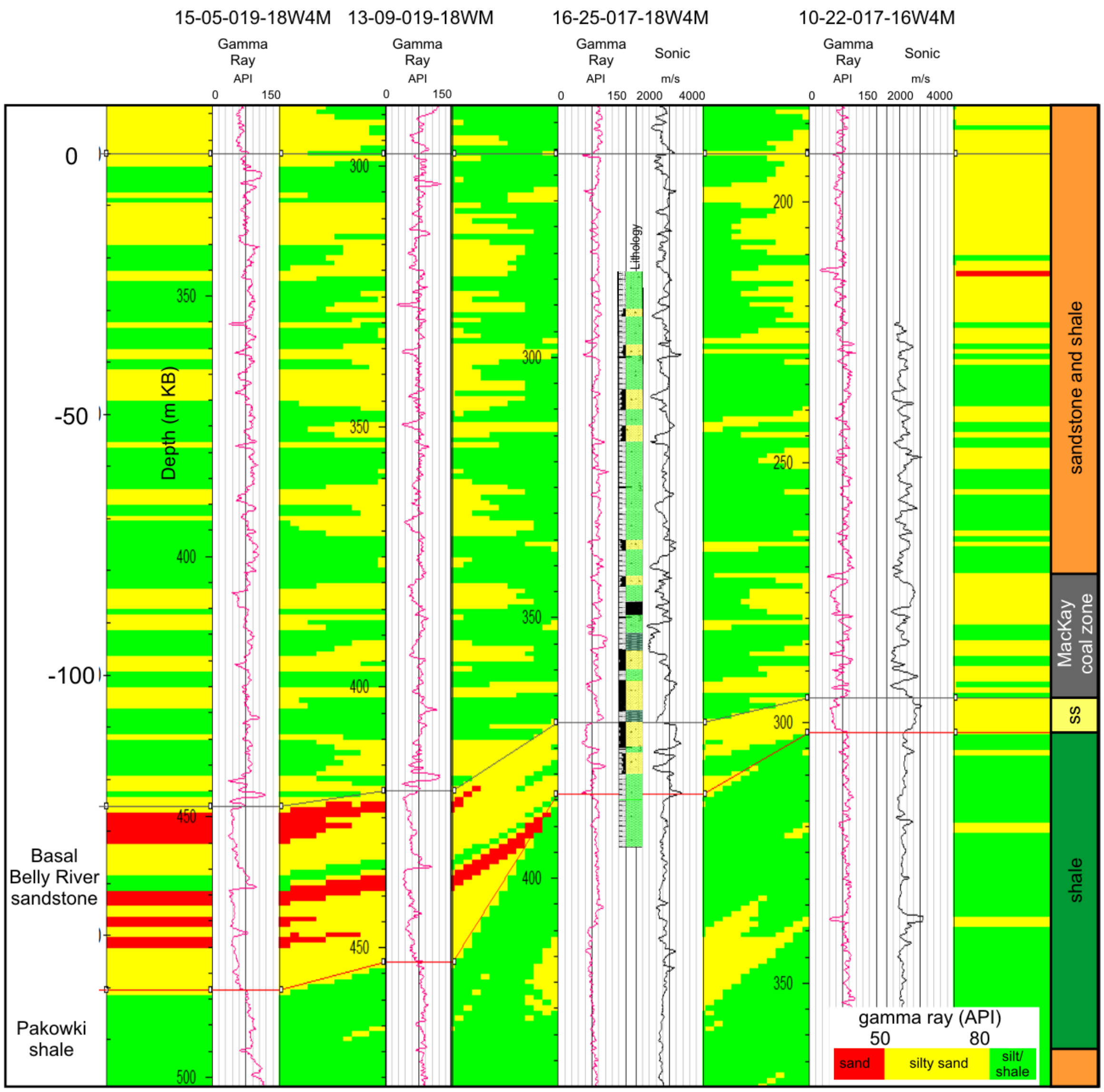

FIG. 4. Correlation of gamma ray logs from well 10-22-017-16W4M with well 16-25-017-18W4M, which has a lithology log, and wells 15-05-019-18W4M and13-09-019-18W4M, which are producing from a thick Basal Belly River sandstone. The logs are flattened on an event in the Belly River Formation.

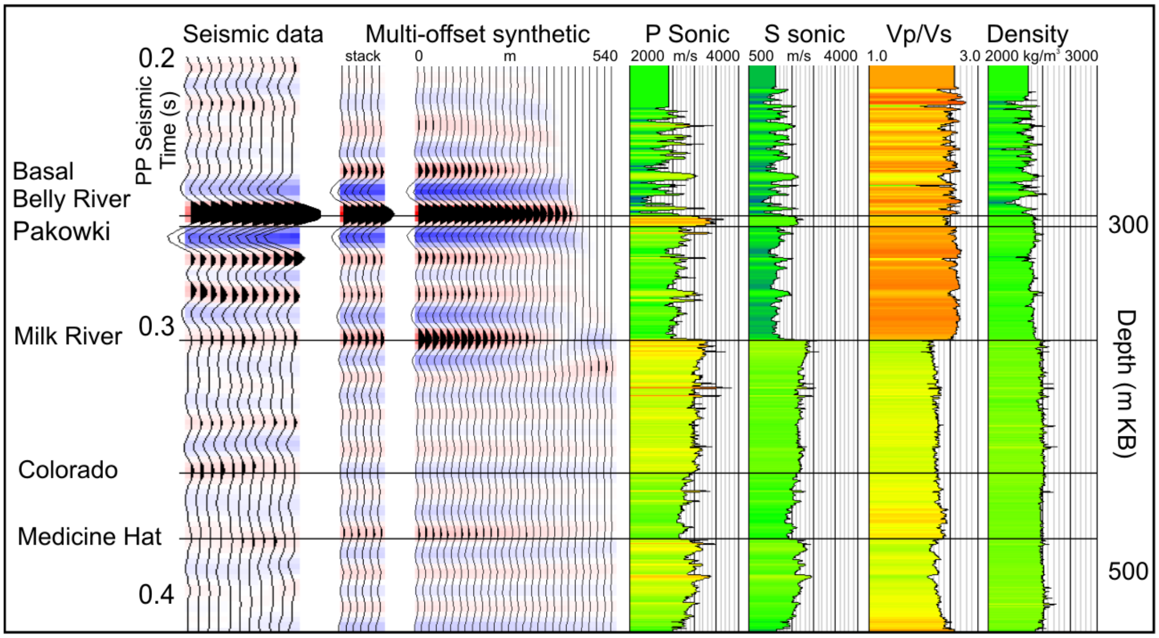

FIG. 5. Multi-offset PP synthetic seismogram for well 10-22-017-16W4M correlated to the PP seismic data.

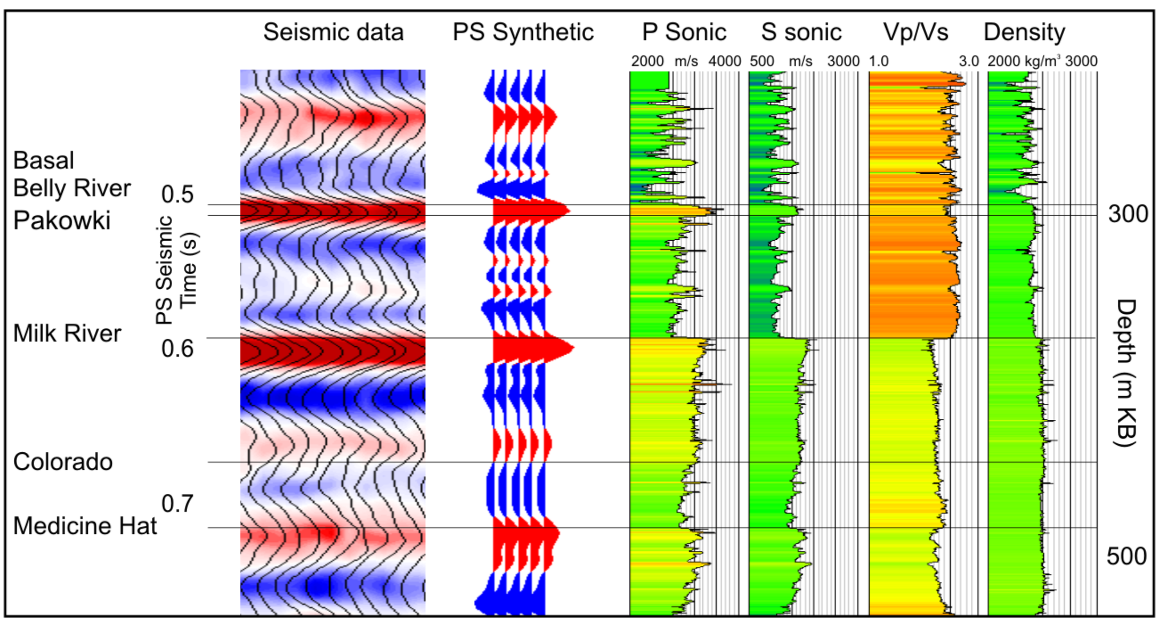

FIG. 6. PS synthetic seismogram for well 10-22-017-16W4M correlated to the PS seismic data.

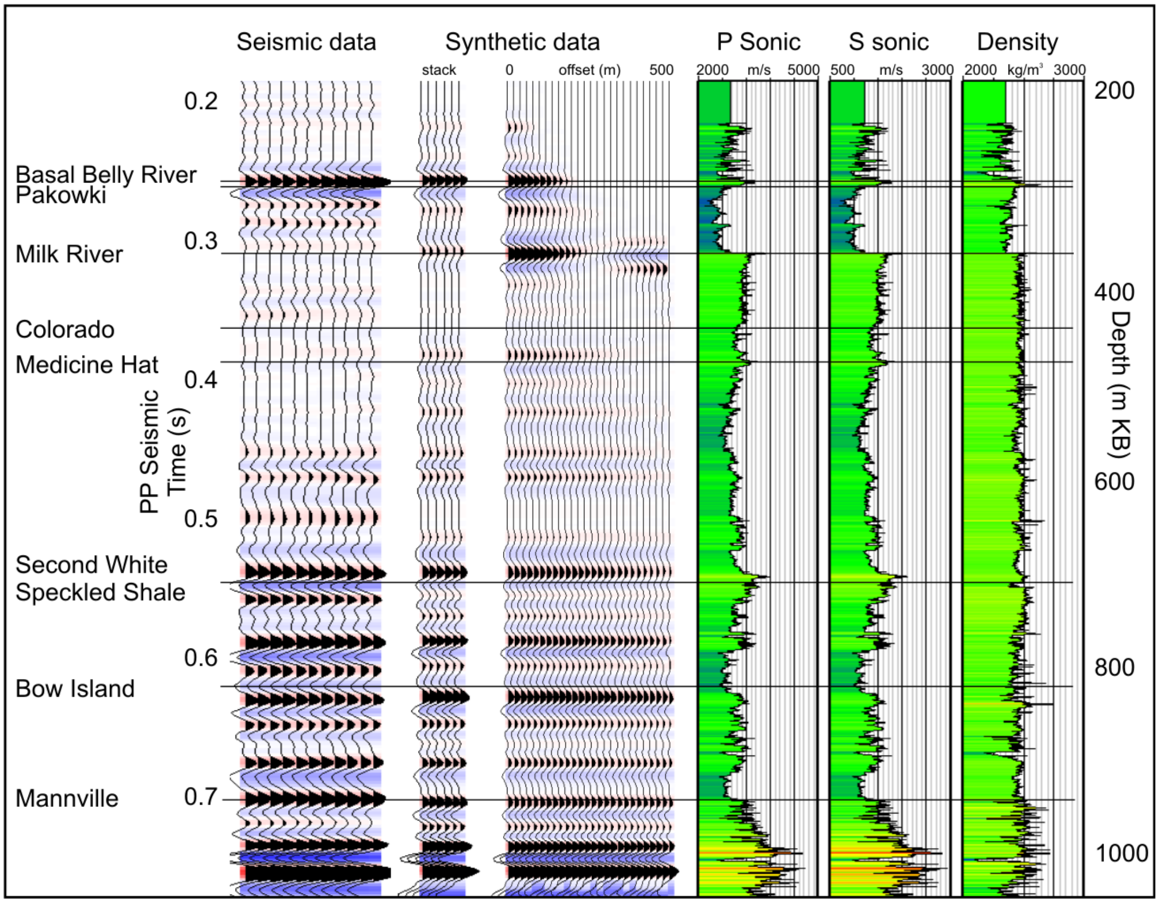

FIG. 7. Multi-offset PP synthetic seismogram for well 7-22-017-16W4M correlated to the PP seismic data to identify reflectors deeper than 550 m.

The synthetic seismogram was generated using the extracted wavelet, and the logs were stretched slightly over the Medicine Hat–Mannville interval to match the character of the seismic data. The Milk River response is the only one which has interesting AVO effects. We also tied the deeper formation tops to the PS seismic data (Figure 8).

After identified reflections on the PP and PS data sets, we had interpreted significant horizons. Our primary horizon of interest is the Basal Belly River, which is the target formation for CO_2 injection. The interpretations were not changed but the depth maps were updated using information from the new well. The updated smoothed depth maps of the Basal Belly River primary target and Medicine Hat secondary target are shown in Figures 9 and 10, respectively.

We also ran a new post-stack joint PP-PS inversion using only the dipole logs from the new injection well. Figure 11 shows the inverted Vp/Vs for line 101, plotted on the PP seismic data. We intend to compare this estimate of Vp/Vs with that obtained in the future after CO_2 injection.

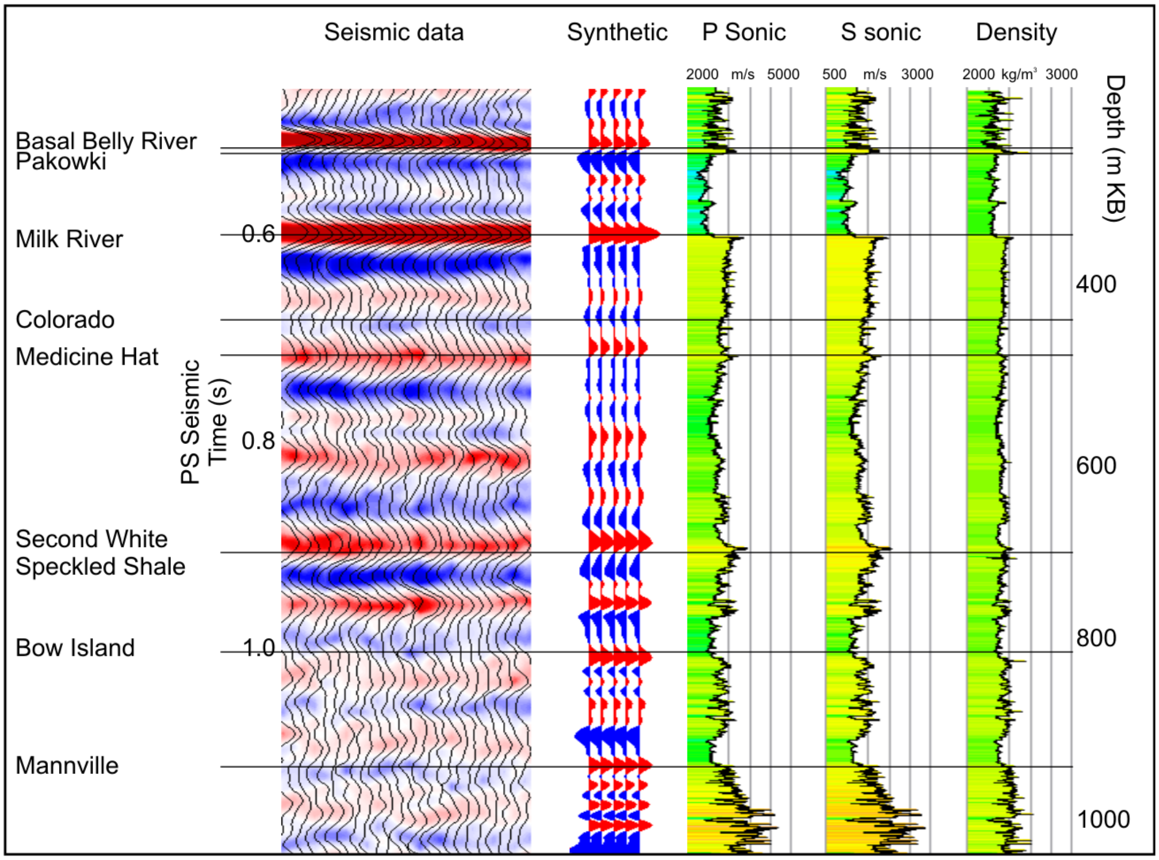

FIG. 8. PS synthetic seismogram for well 7-22-017-16W4M correlated to the PS seismic data to identify reflectors deeper than 550 m.

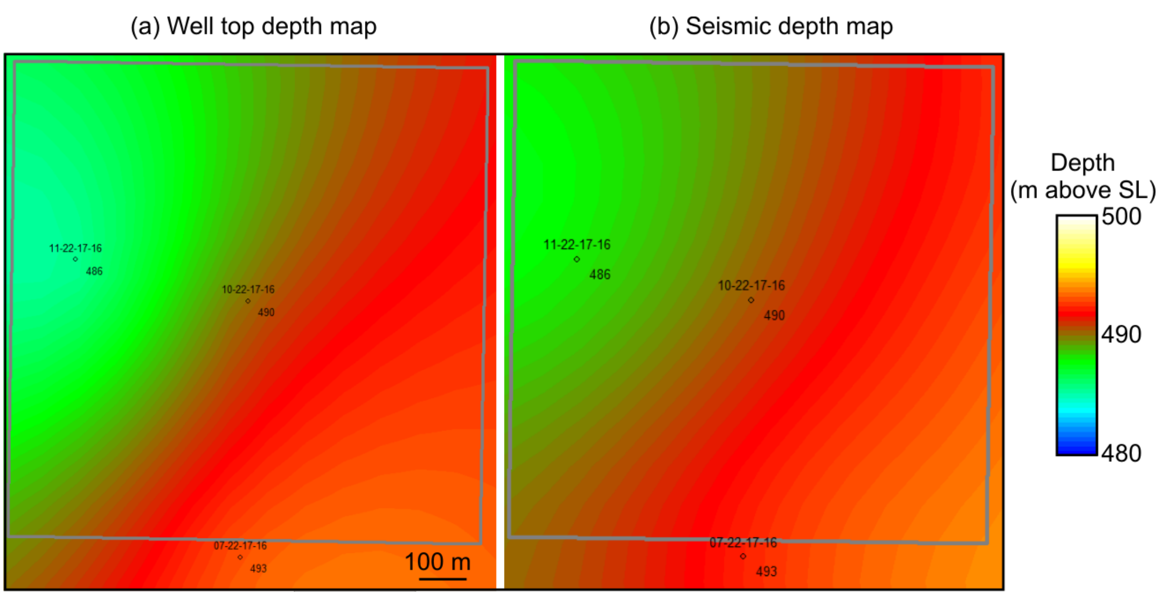

FIG. 9. Updated smoothed top Basal Belly River subsea depth map.

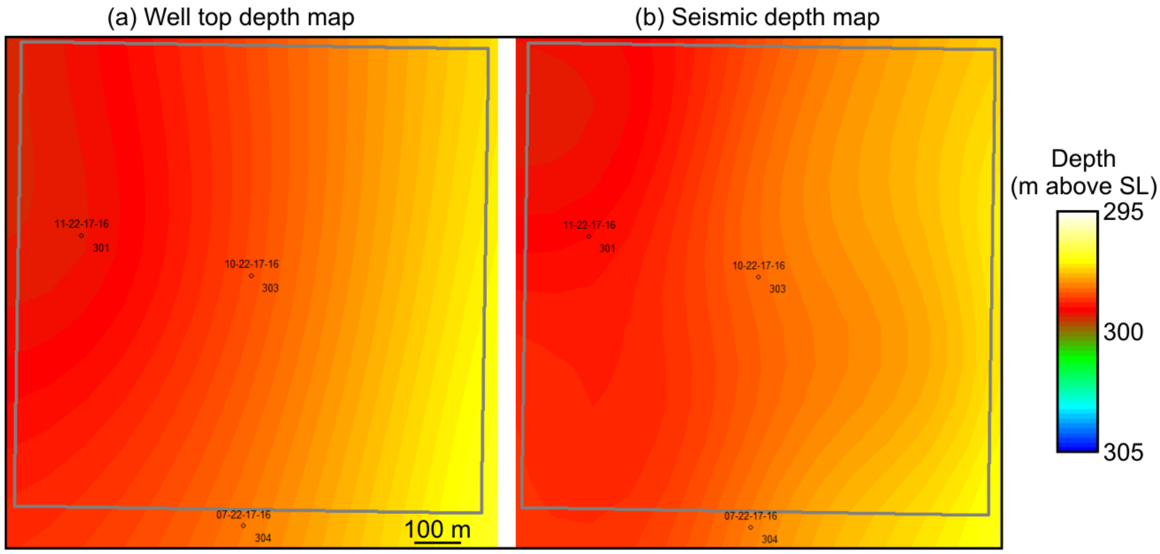

FIG. 10. Updated smoothed top Medicine Hat Formation subsea depth map.

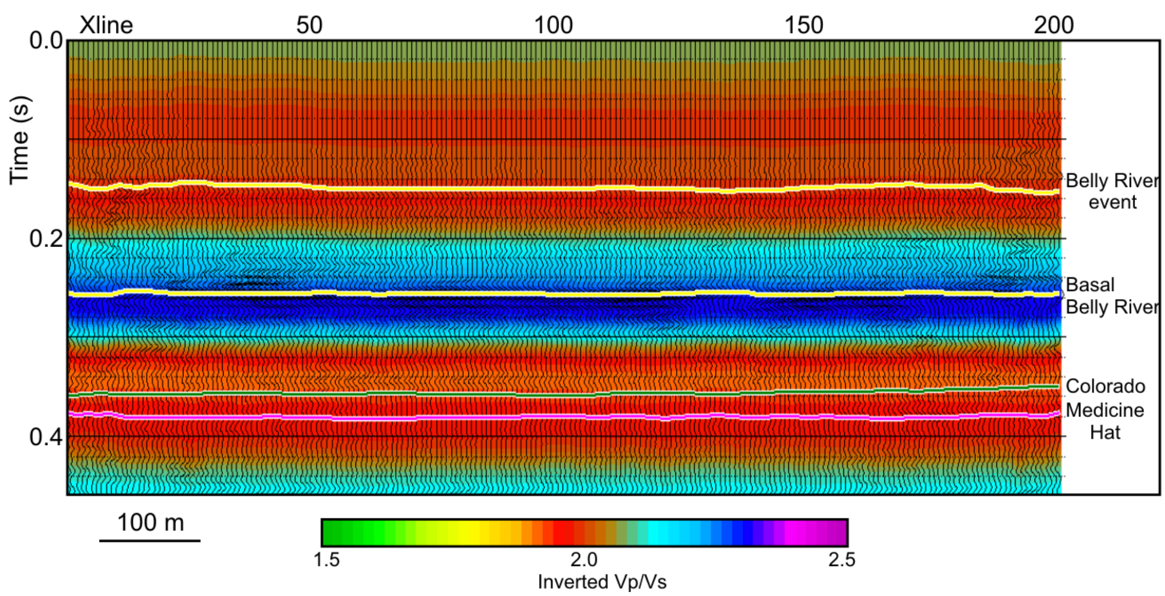

FIG. 11. Inverted Vp/Vs for inline 101 plotted on the PP data.

CONCLUSIONS

Our pre-drill estimate of the depth of the target Basal Belly River Formation, which we had derived from the 3D seismic data interpretation, was about 3.5 m high. Our estimate of the top of the thin sand near the top of the Medicine Hat Formation was 3 m high. The gamma ray log and lithology of the new well support our predictions of the shale content in the Belly River Formation above the target injection zone.

We created synthetic seismograms from the dipole logs acquired in the new well and tied the seismic data. The PS data show a very good character match between the seismic data and the synthetic seismogram. Although the seismic data did not require re-interpreting, we used the formation tops from the new well to revise the depth structure maps.

We also updated the post-stack joint PP-PS inversion using only the dipole logs of well 10-22-017-16W4M. This inversion is valid to just below the top of the Medicine Hat Formation.

ACKNOWLEDGEMENTS

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