Delineation of a sand reservoir at Manitou Lake Saskatchewan: Interpretation of 3D-3C seismic data

Roxana M. Varga and Robert R. Stewart

ABSTRACT

Exploration targets of this survey undertaken in the Manitou Lake heavy oilfield include the Colony and Sparky sand channels, both members of the Cretaceous Mannville Group. These intervals are currently producing oil and gas in the area. Our goal is to investigate the usefulness of 3C-3D seismic in discriminating sand versus shale and find gas-charged porosity. Detailed registration of multicomponent seismic data aims to reduce the uncertainty of interpretation and improve well targeting. Seismic attributes, AVO, LMR and elastic impedance methods can complement the information for drilled wells and possibly identify new drilling locations.

We know from previous work that increasing sand yields greater porosity. Greater porosity can lower the P-wave velocity. So, a good reservoir should have a lower Vp value. The presence of hydrocarbons also lowers the Vp. The S-wave velocity is often seen to increase from shale to sand. Hence, Vp/Vs is lowered in hydrocarbon bearing sandstones. The interpretation of P-wave seismic reflection data can lead to ambiguous conclusions in certain exploration situations. Differentiation of prospective channel sands and non-productive shales could be problematic due to the similarity in P wave impedance of these two lithologies. We expect the PS data to be a direct measurement of the channel system, knowing the fact that should respond largely to the lithology and less to the fluid content.

ACQUISITION

The Manitou Lake 3C-3D survey was acquired for Calroc Energy Inc. by Kinetex Inc. near Manitou Lake, Saskatchevan, in February 2005. It covers an area of approximately 10 km^2, with twenty one south-north receiver lines and eighteen west-east source lines, with 200 m line spacing and 50 m station spacing (Lu et al., 2006). Figure 1 is shows the location. The seismic data includes a suite of logs from three different wells in this area. Acquisition parameters are shown in Table 1 from Kinetex Inc.

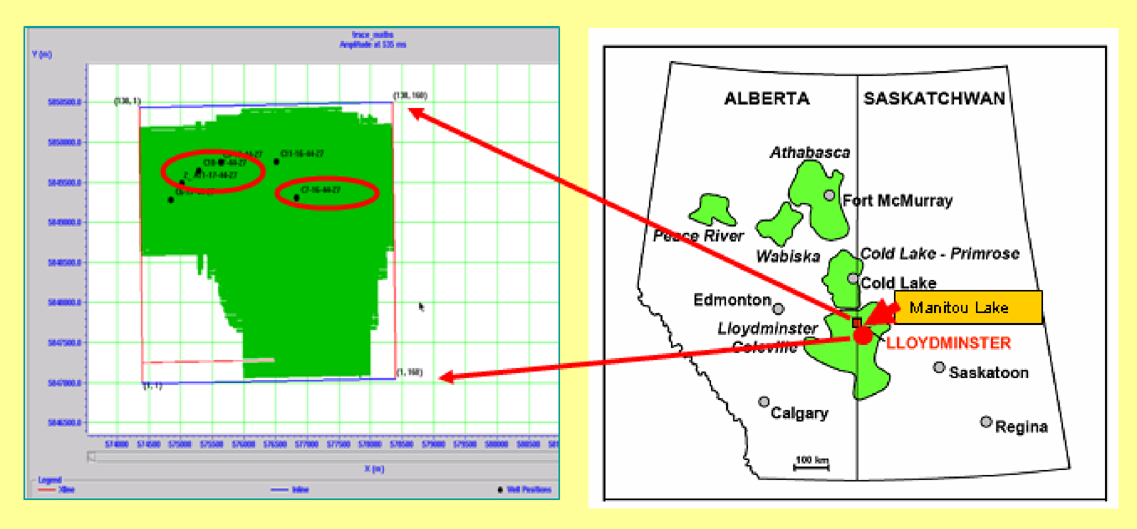


FIG. 1. Location of Manitou Lake: Map of major heavy-oil deposits of Alberta and Saskatchewan (after Watson, 2004) right, and 3D-3C Manitou survey in Hampson Russell software with the used well locations (red circles), left.

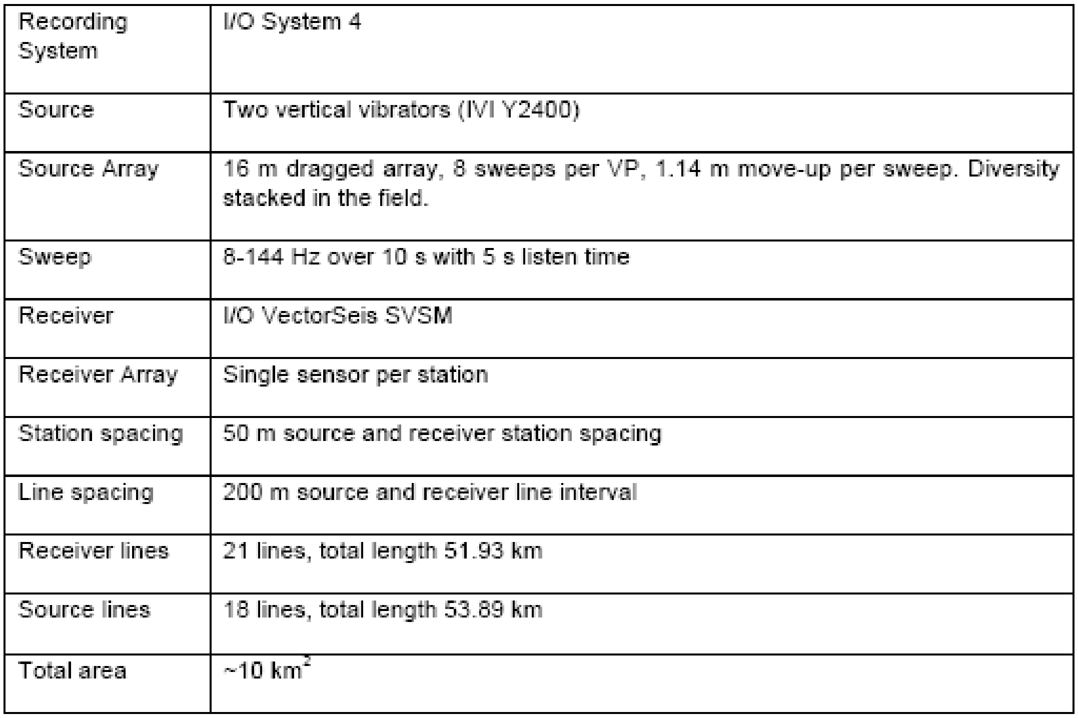
PROCESSING

The vertical (PP) and the radial (PS) component data has been processed to a final migrated volume by Hanxing Lu and Kevin Hall. The processing flow for Manitou Lake migrated sections consists of deconvolution, time variant spectral whitening and FD migration after CDP stack.

For the CDP gathers in the AVO analysis, the processing flow was done in the following order: SEGY input, 3D geometry assignment, true amplitude recovery, elevation statics and refraction statics, Surface consistent deconvolution, front end muting, velocity analysis, residual surface consistent statics, normal moveout and trim statics.

For this survey most of the coherent energy is in the 18-75 Hz range. (Lu et al., 2006)

Table 1. Acquisition Parameters (Kinetex Inc.).



Recording System	I/O System 4
Source	Two vertical vibrators (IVI Y2400)
Source Array	16 m dragged array, 8 sweeps per VP, 1.14 m move-up per sweep. Diversity stacked in the field.
Sweep	8-144 Hz over 10 s with 5 s listen time
Receiver	I/O VectorSeis SVSM
Receiver Array	Single sensor per station
Station spacing	50 m source and receiver station spacing
Line spacing	200 m source and receiver line interval
Receiver lines	21 lines, total length 51.93 km
Source lines	18 lines, total length 53.89 km
Total area	~10 km^2

Near offsets (0-400m) have been excluded in order to reduce the effects of source noise, because the PS data was much noisier than the vertical. PP shot and receiver statics have been calculated using GLI3D. Due to large lateral variations in the near surface shear-velocity field, it was difficult to calculate PS receiver statics. Non-surface-consistent receiver statics have been performed for the PS data.

GEOLOGY AND STRATIGRAPHY

According to the stratigraphic column for west-central Saskatchewan, Figure 2, the Colony sand member of the Pense Formation, and the Sparky member of the Cantuar Formation, are both part of the Cretaceous Mannville Group. Most of the sediments in the area were deposited during the Cretaceous, and the top of the Mannville marks a clear separation between the predominant sands in Mannville and the overlying marine shales of the Colorado and Belly River Groups.

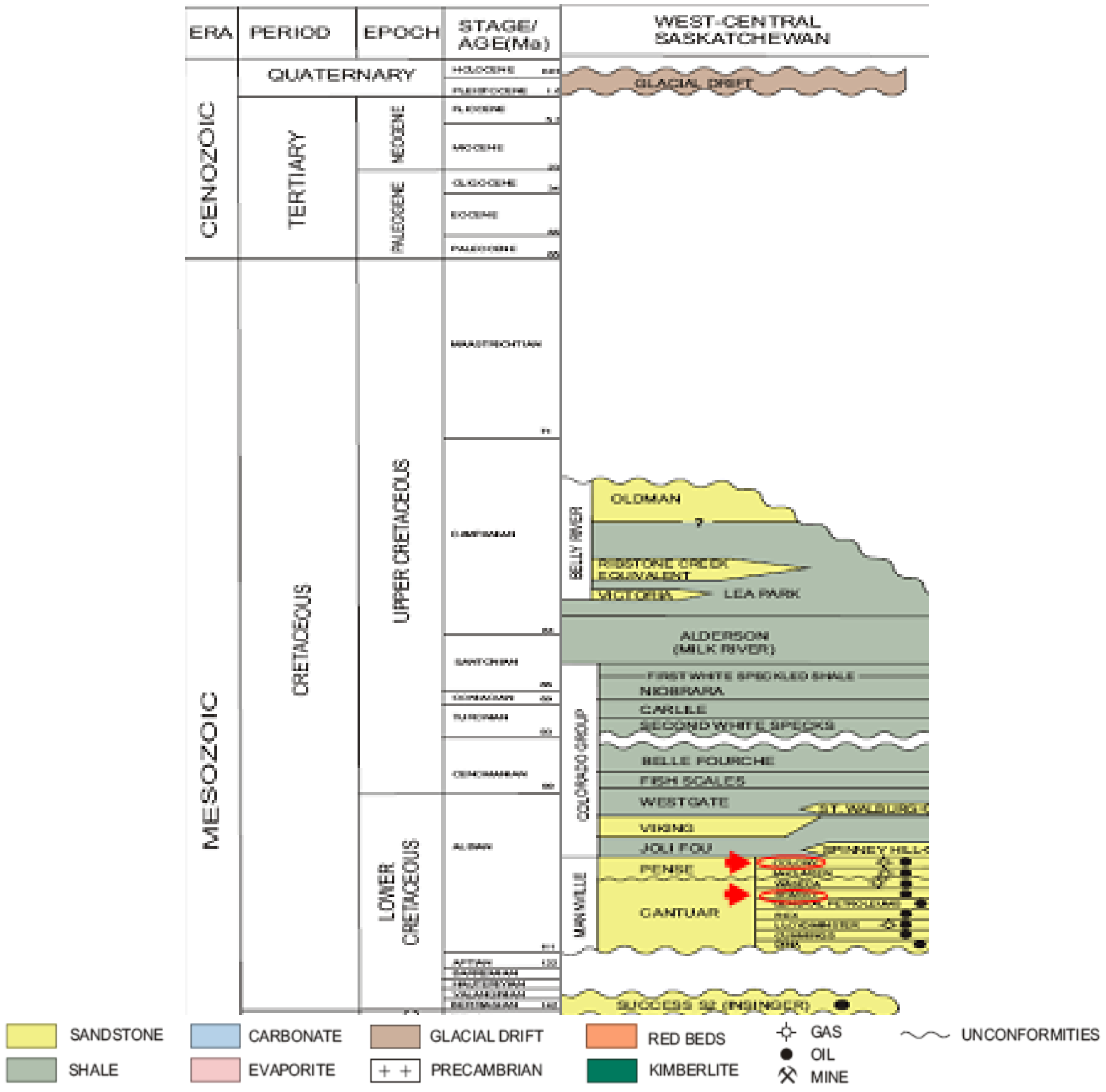


FIG. 2. Stratigraphic column for west central Saskatchewan (From Saskatchewan Industry and Resources, 2006).

In the area, the Mannville Group lies unconformably on Paleozoic strata, and its sedimentary pattern consists of an interplay of marine, estuarine and fluviatile agents acting in a setting controlled by paleo-topographic relief and eustatic and tectonic changes in relative sea-levels (Christopher, 1997). The Sparky member is informally grouped into the middle Mannville, which is dominated by sheet sandstone development, with narrow, channel sandstones and shales also present (Putnam, 1982). These units have been interpreted as a delta-front facies with associated tidal-flat, tidal-channel, and beach environments (Vigrass, 1977). The sheet sandstones in Sparky are commonly 6-9 m thick, and can be traced laterally for several tens of kilometers; however, they are commonly broken by thick ribbon-shaped deposits or sandstone pinchouts (Putnam, 1982).

The Colony sand member is unconformably overlain by the Joli Fou marine shale, representing the basal unit of the Colorado Group, which is dominated by marine shales encasing generally thin but extensive sandstones, such as the Viking, Dunvengan and Cardium formations, as important petroleum reservoirs in other areas (Leckie et al., 1994).

The exploration targets of this survey include the Colony sand and Sparky, both members of the Mannville Group, which are currently producing oil in the area. Figure 3 shows the P-wave amplitude map for the top of the Colony sand. The red circles indicate the three wells available for this study. These wells include spontaneous potential (SP), gamma-ray (GR), density (RHOZ), and resistivity logs. Wells A11-17 and C07-16 have both a P-wave sonic. Shear-wave sonic is available for well A11-17.

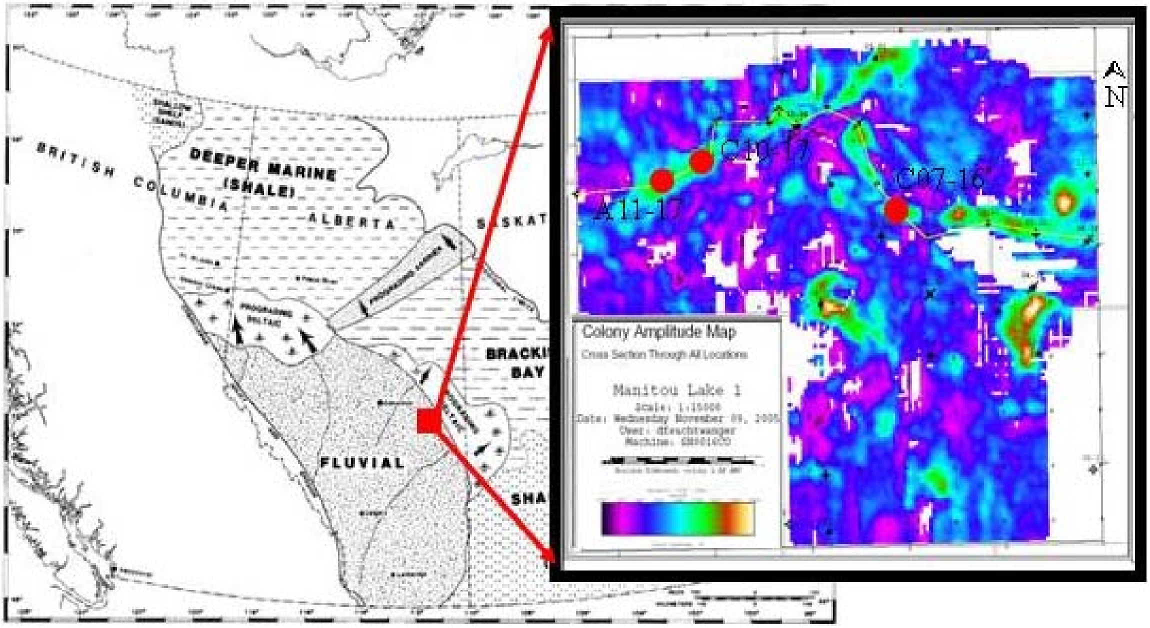


FIG. 3. Left: Paleogeographic reconstruction of the Upper Mannville deposition. The red square shows location of the area of study (modified from Leckie and Smith, 1992) Right: Amplitude map for the Colony sand. Red circles indicate the wells used in this project.

Deposition in the Western Canada Sedimentary Basin (WCSB) can be divided into two successions, based on two different tectonic settings affecting sedimentation. The Paleozoic to Jurassic platformal succession, dominated by carbonate rocks, was deposited on the stable craton adjacent to the ancient margin of North America. The overlying mid-Jurassic to Paleocene foreland basin succession, dominated by clastic rocks, formed during active margin orogenic evolution of the Canadian Cordillera, with the emplacement of imbricate thrust slices progressively from east to west (Mossop and Shetsen, 1994).

GEOLOGIC MODEL OF THE RESERVOIR

Figure 4 shows a schematic depositional model for the Colony sands, including the three distinct facies units. They include (A) channel facies, (B) crevasse splay facies and (C) interchannel wetlands facies.

The Colony sand member is the uppermost unit of the nine member informal subdivision of the Manville Group and consists of shales, siltstones, coals and sandstones. Deposition of this member occurred in an extensive complex of anastomosing channels sandstones, encased within siltstones, shales, coals and thin sheet sandstones (Putnam and Oliver, 1980); this is capped by the marine shales of the Joli Fou formation.

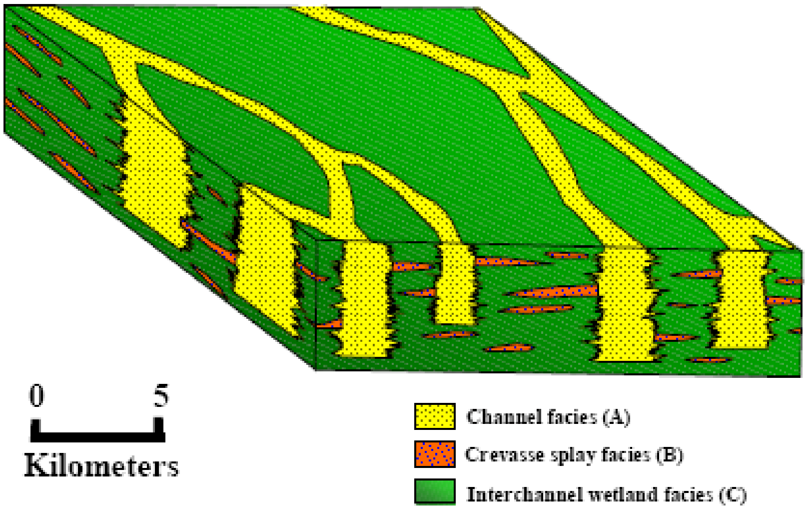


FIG. 4. Depositional model for the Colony sand member after Putnam and Oliver (1980) from Royle, (2002).

LITHOLOGY DIFFERENTIATION

At the A11-17 well location where a shear-wave sonic was available, three major types of lithology were selected in Figure 5: sands (yellow), shales (brown) and sand/shales (olive). Low values in gamma ray log indicates permeable sand interval with high porosities. Magenta arrow indicates the Colony formation and the red arrow the Sparky formation.

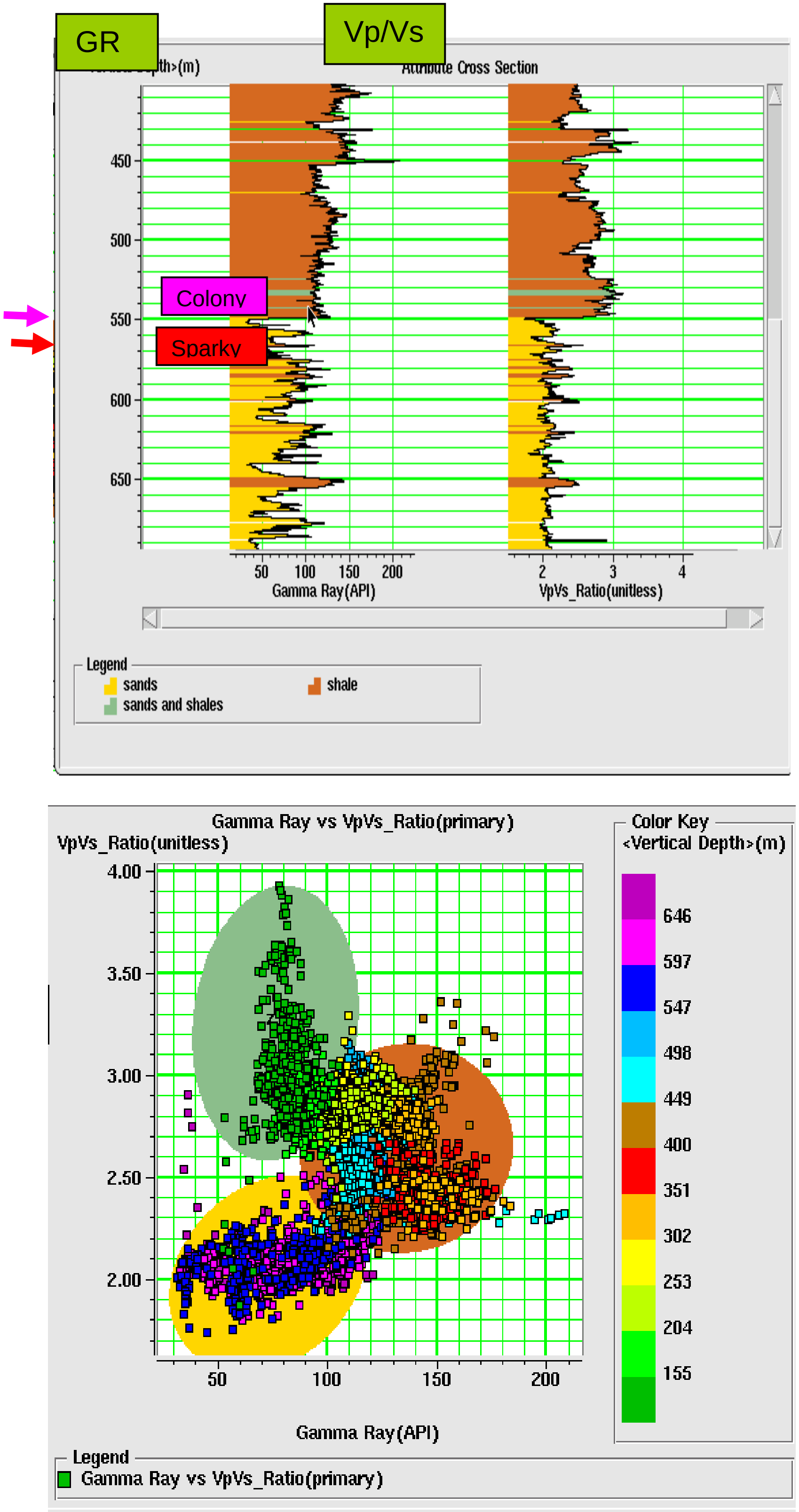
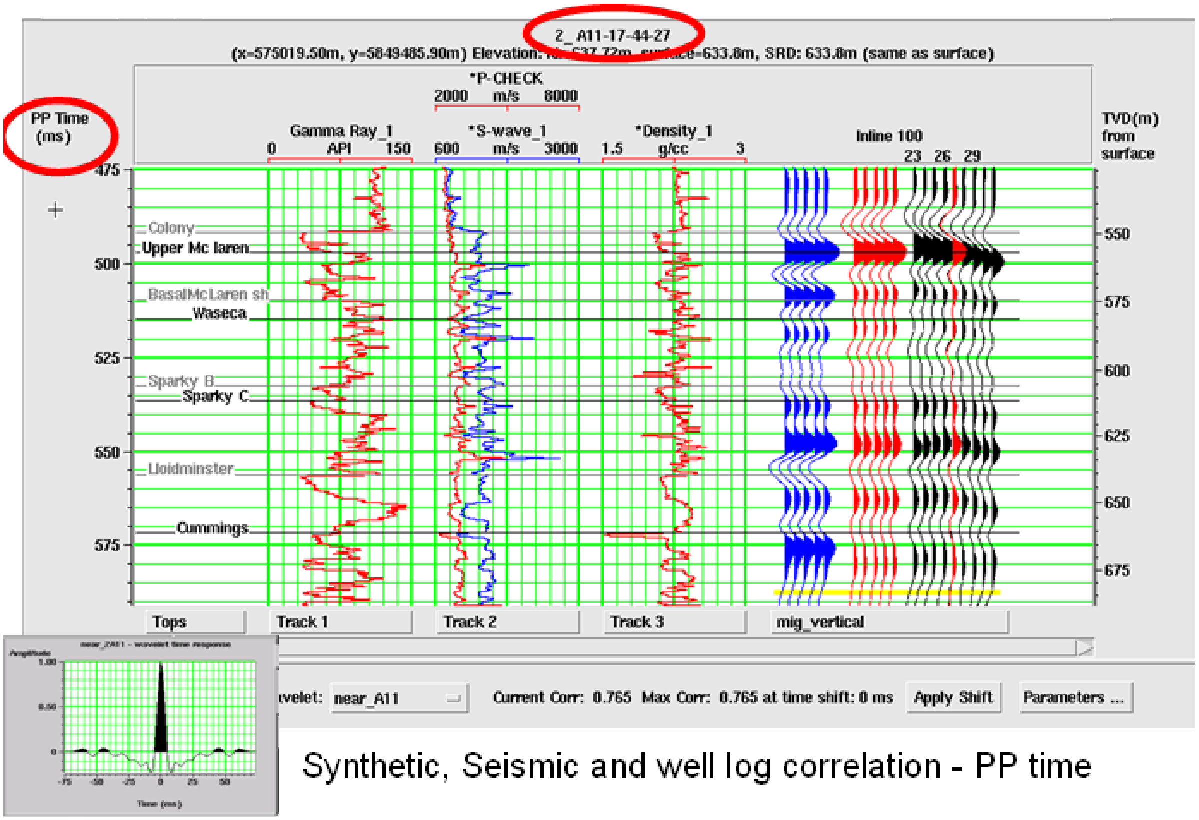


FIG. 5. Vp/Vs versus gamma ray for the well A11-17; up Cross-section showing the GR and Vp/Vs ratio at the Colony and Sparky formations.

PP INTERPRETATION

After the PP seismic data was processed, three sets of logs were chosen for correlations with seismic: A11-17, C10-17 and C07-16 (see Figure 6). The interpretation of the PP migrated volume was undertaken by correlating well logs to the seismic data and picking horizons based upon well control. During this time PS processing of the converted-wave seismic data was continued; velocities and statics were carried from the PP processing to PS processing.

Then PP-AVO analysis was performed on the processed PP-seismic data, using Hampson-Russell's AVO software. The PP-AVO attributes were inverted to derive rock properties information, such as reservoir rigidity and incompressibility (LMR).



Wavelet: near_A11

Current Corr: 0.765 Max Corr: 0.765 at time shift: 0 ms

Synthetic, Seismic and well log correlation - PP time

FIG. 6. Well log correlation with seismic section in PP time at well location A11-17. The wavelet (down) we used was extracted from the PP seismic data.

Figure 6 shows the well log correlation with seismic at the A11-17 location. From left to right, we can see the gamma-ray curve, sonic logs (P wave sonic in red and shear sonic in blue) and Density. We can note that the Colony sand channel was picked on a trough and shows a sharp decrease on the GR and density, an increase on the shear sonic and almost no change in the P wave sonic.

Sparky B is picked on a trough and Sparky C on a zero crossing, showing similar characteristics as the Colony sand channel.

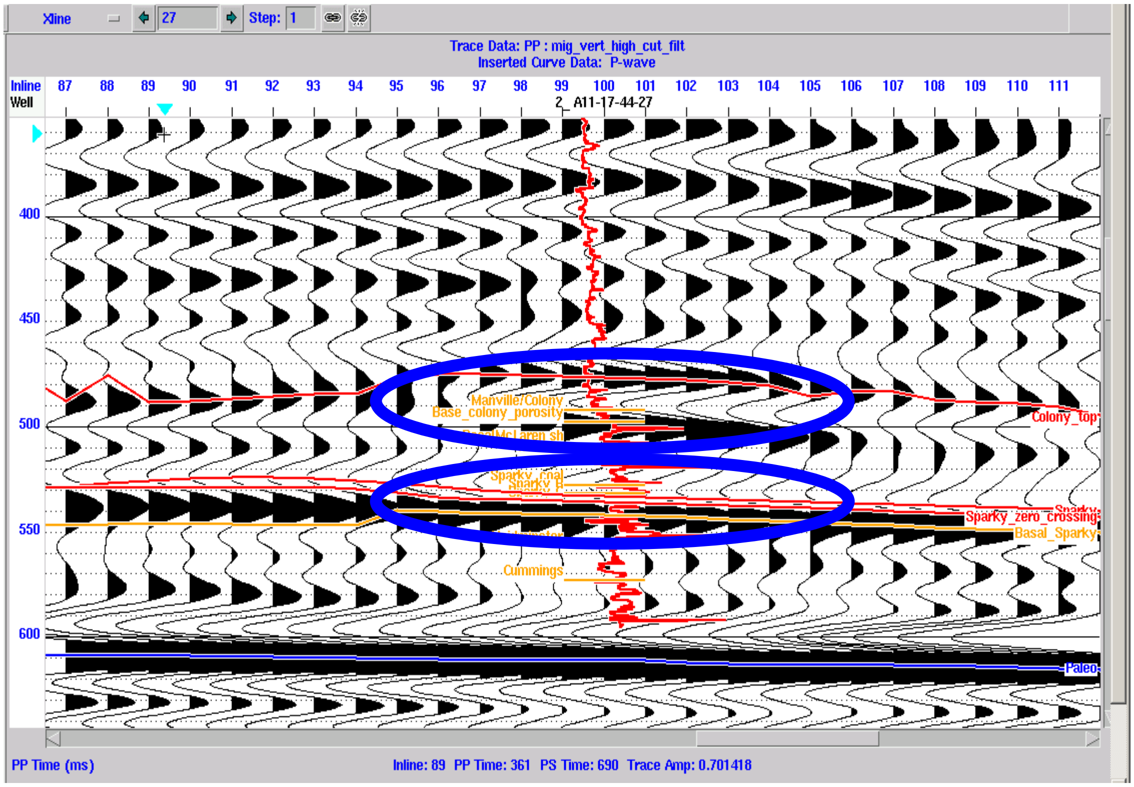


FIG. 7. PP section showing the picked Colony and Sparky horizons at the A11-17 well locations. In blue circle we can see the Colony and Sparky channels.

Figure 7 shows the Colony and Sparky horizons (red) and channels at the well A11-17 location (blue). Amplitude maps were generated at the Colony and Sparky, figures 8 and 9.

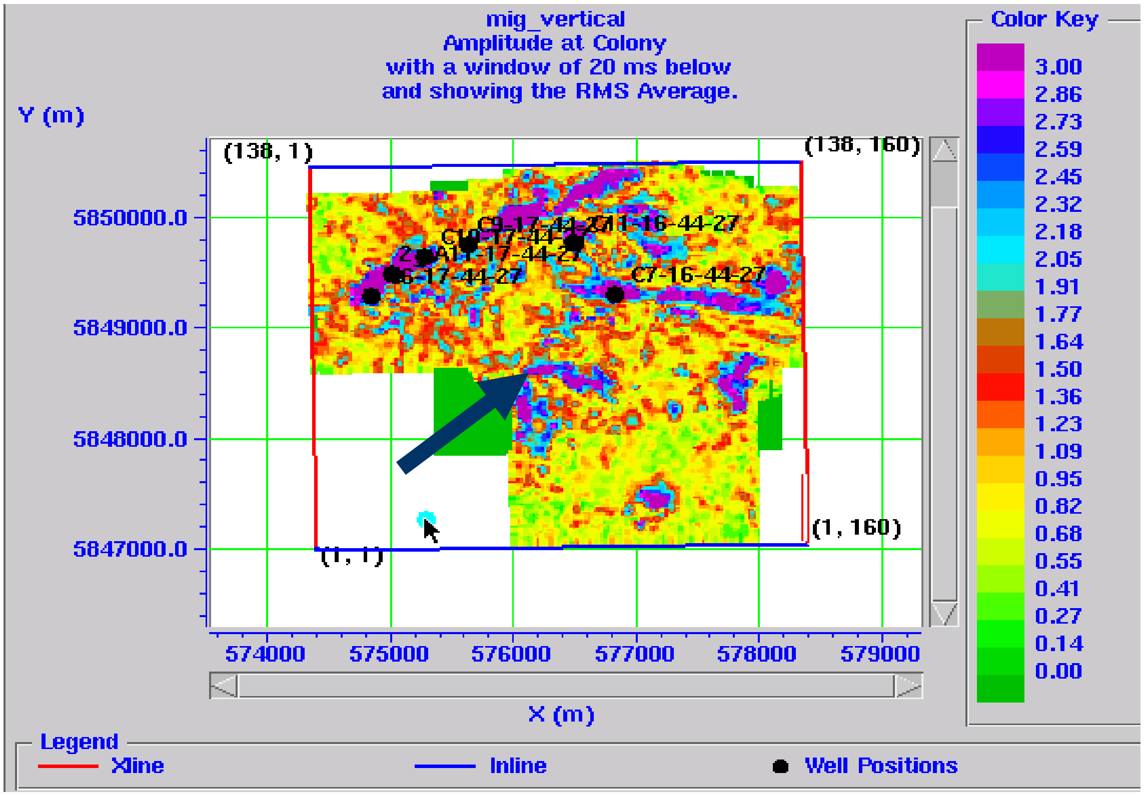


FIG. 8. Amplitude map showing PP RMS amplitudes at Colony, with a 20 ms window below the horizon.

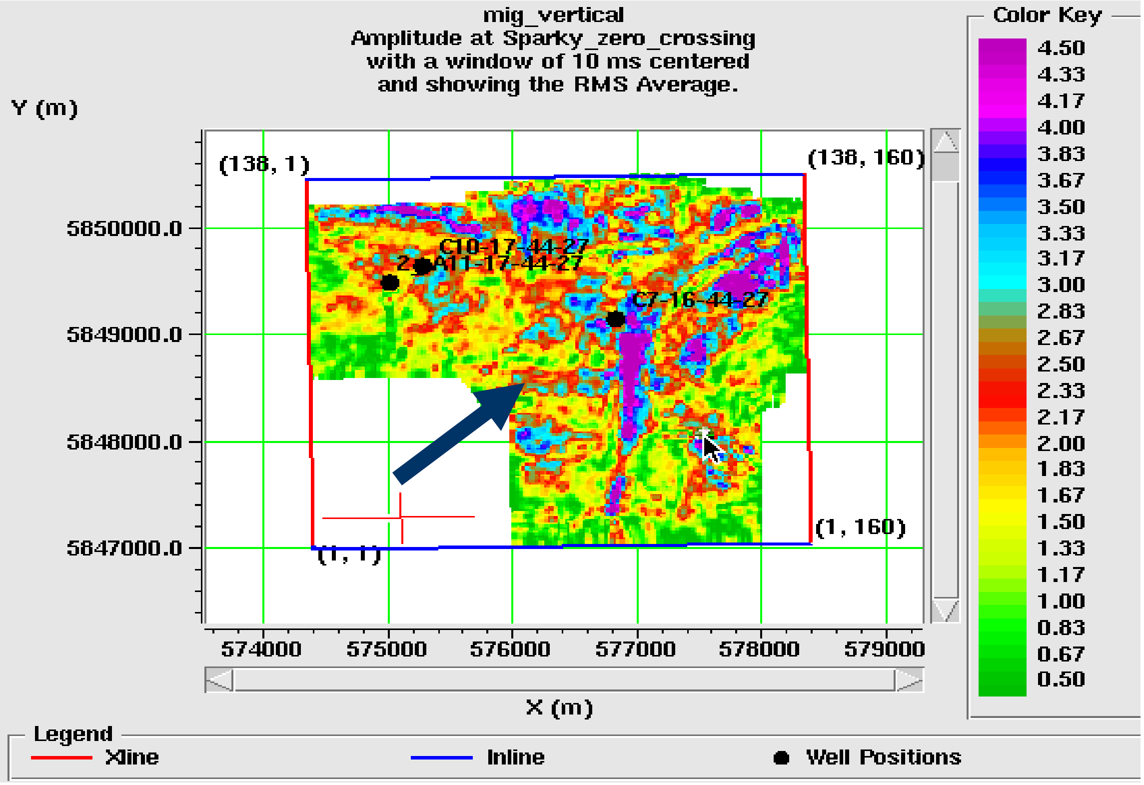


FIG. 9. Amplitude map showing PP RMS amplitudes at Sparky, with a centered 10 ms window. Blue arrow shows an unsuccessful drilling location, based previously only on PP amplitude maps.

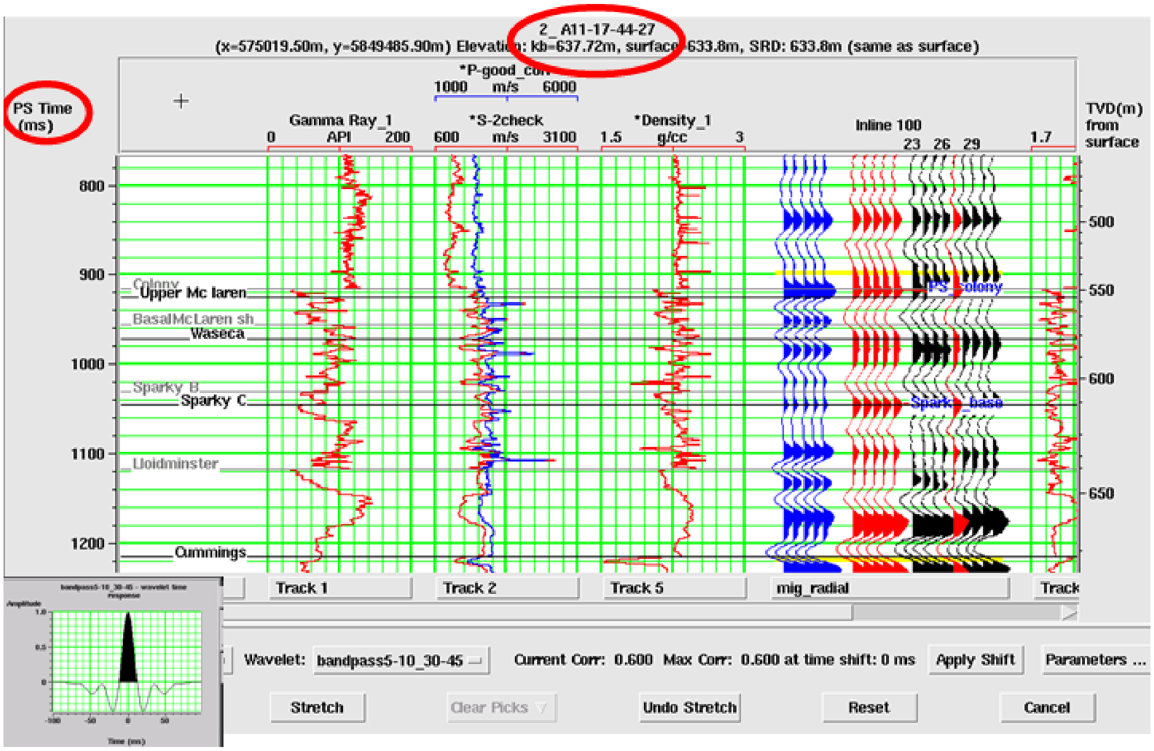
PP AND PS INTERPRETATION

Conventional PP seismic data acquired at Manitou Lake had limited value in detecting some targets. Coupled PP and PS seismic analysis can increase confidence in interpretation, give rock property estimates, and provide additional information for imaging the subsurface.

When compressional P waves reach an interface at non-normal incidence are partitioned into transmitted and reflected P and shear (S) waves. Significant energy is converted to S waves which, in the absence of azimuthal anisotropy will be recorded primarily on the radial (inline horizontal) component of the receiver. Due to the difference in travel path, wavelength and reflectivity, PS seismic sections can show significant changes in amplitude or character of events which are not apparent on conventional PP sections. Horizons can be better imaged on one or the other of the sections because of different multiple paths and wavelet interference effects such as tunning.

The next step was to create the PS synthetic seismograms. In the logs without a dipole sonic, shear logs were created using the Castagna's equation. The PS synthetic seismogram was correlated with the PS seismic volume in PS time. Registration was done in PP time, trying to shrink the PS section to match the PP section, as in Figure 11. We consider PS data to be a direct measurement of the channel system, given that PS data should respond largely to lithology.

There are some challenges when processing the mode converted data: some issues include separation of P wave arrivals and the large magnitude of shear-wave statics. Registration can be challenging. As seen in Figure 11, on the PS time correlated section, the Colony sand is picked as a pick and Sparky B and C is picked as a trough.



Wavelet: bandpass5-10_30-45

Current Corr: 0.600 Max Corr: 0.600 at time shift: 0 ms

FIG. 10. Synthetic, Seismic and well log correlation in PS time at well location A11-17. The wavelet (down) we used was extracted from the PS seismic data.

The data was loaded in both, Hampson Russell and Transform software, where registration was again performed. Figure 12 is showing the unregistered PP-PS display, Figure 13 is showing the registration using the amplitude envelope and Figure 14 shows the gamma adjustment. Amplitude envelope can isolate the amplitude information and discards the phase information. The energy packages are shown as in Figure 13; from left to right we can see in order the work space stretch, then the QC with gamma function applied and third, the QC plot for sparse Gamma grid. Colors show the co-rending of different adjustments.

Residual Gamma adjustment can be performed (figure 14) to take account of phase problems. In our case, it was not necessary to perform a phase adjustment. The objective for registration preparation is to enhance the geology-driven features that will guide the registration process, as boosting the frequency content in both PP and PS data. This can help amplify the event character, even as reflection continuity is reduced.

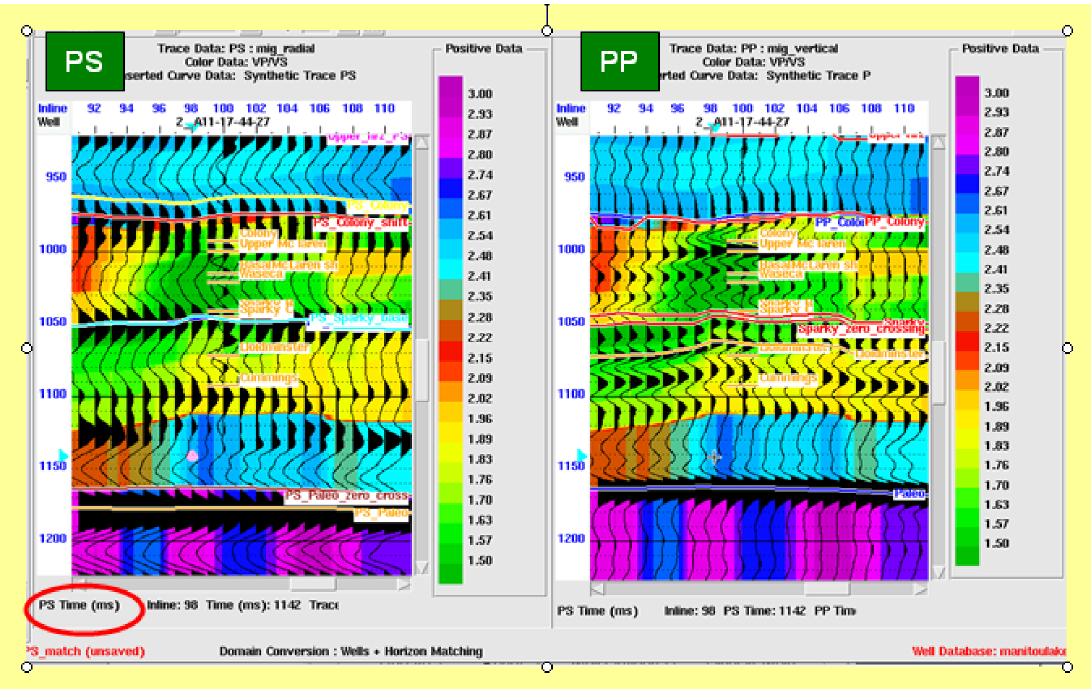


FIG. 11. Well A11-17. Registration and horizon match in Hampson Russell software.

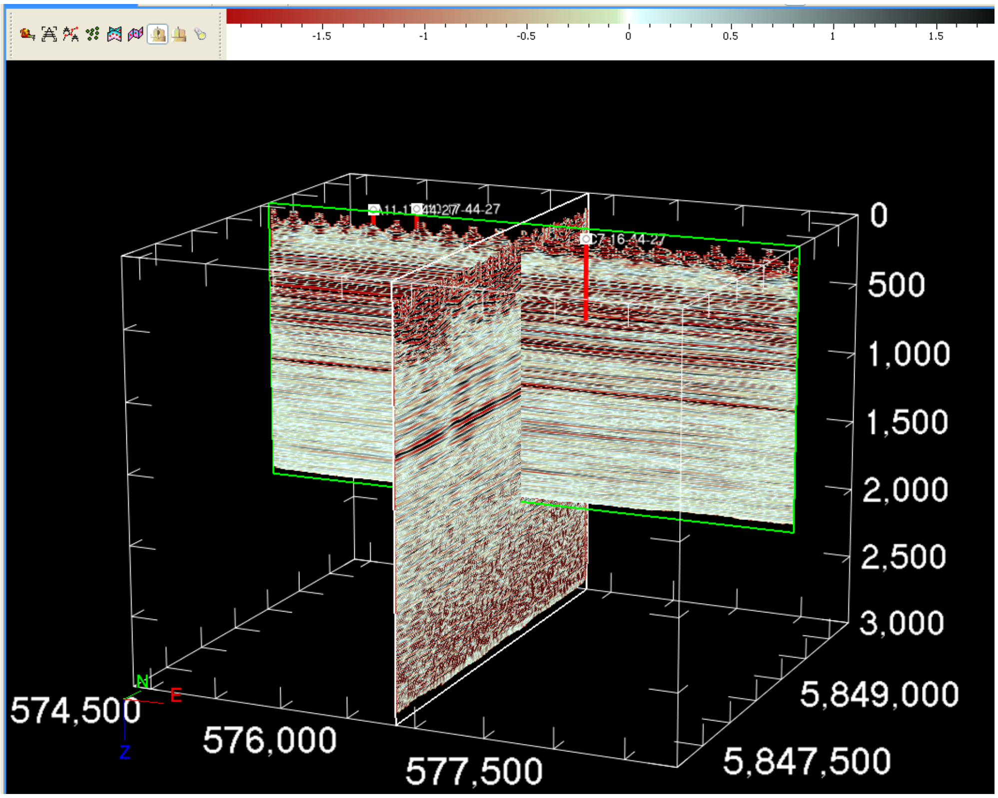


FIG. 12. Unregistered PP-PS display.

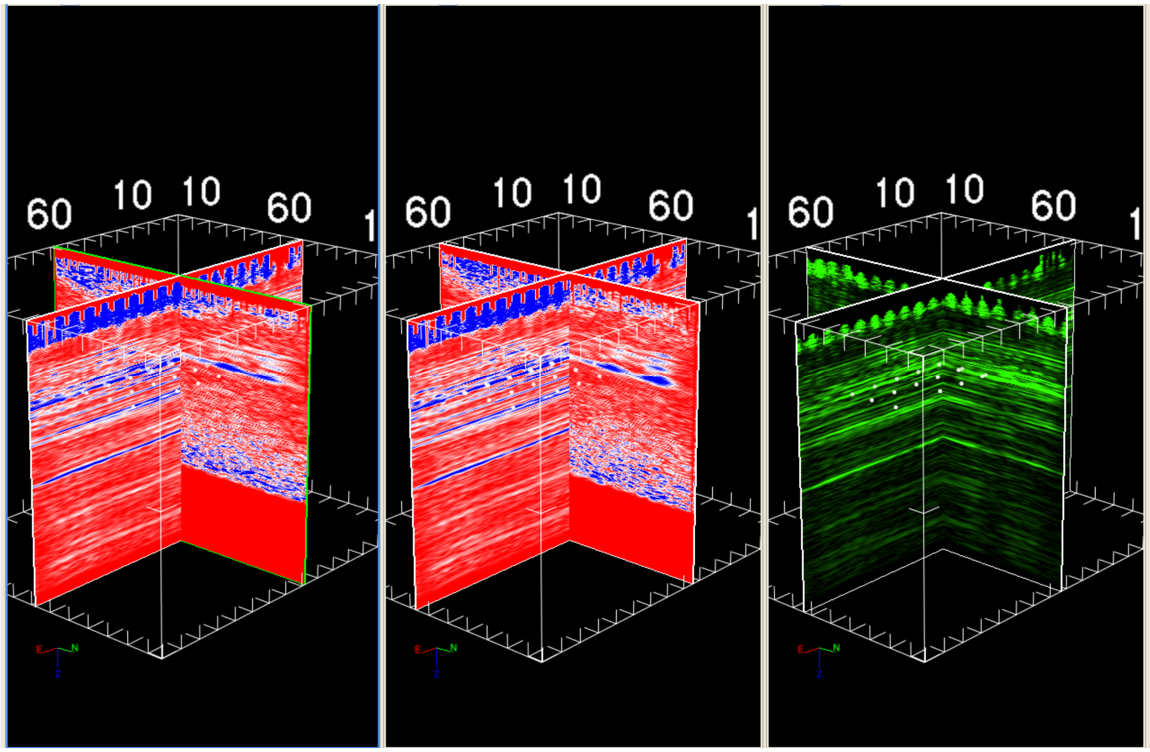


FIG. 13. Registration using amplitude envelope.

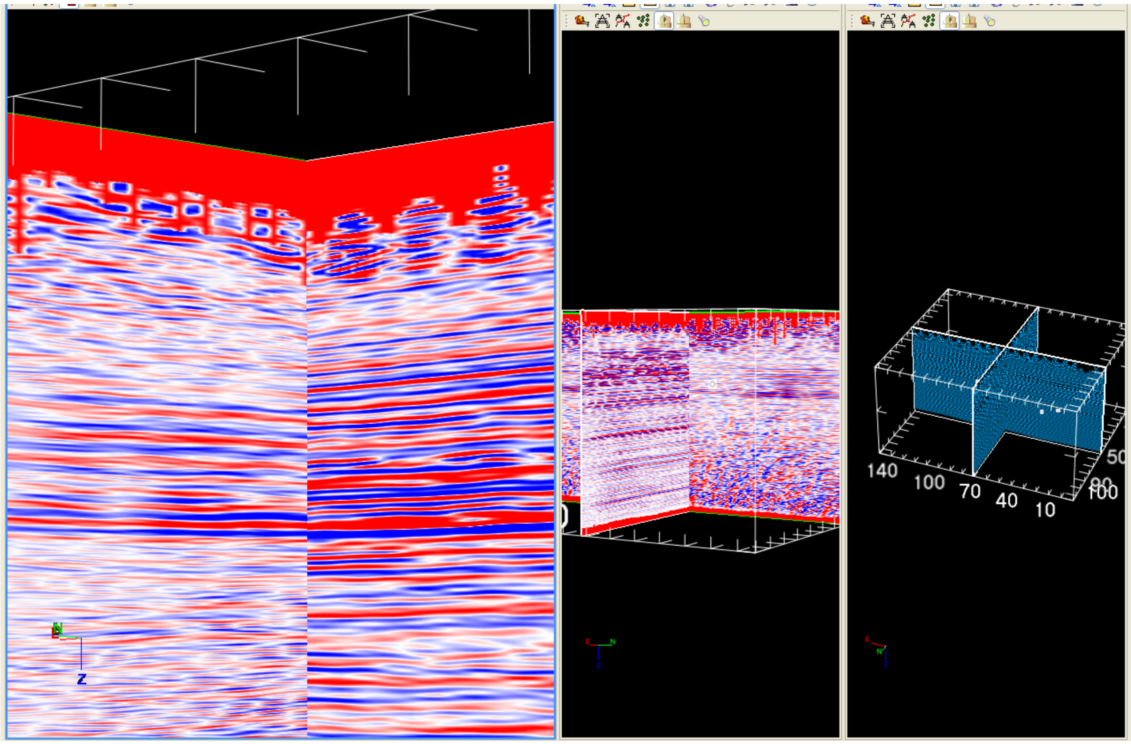


FIG. 14. Gamma adjustement (residual).

Upon completion of the PS processing, well log correlations were performed in PS-time to the PS-migrated stack to pick similar geologic events as those picked on the PP-migrated stack. This is a critical phase in the process as this can reveal the AVO expression of key events; for example, a peak on the PP-section does not necessarily correspond to a peak on the converted wave section. These horizons were used to register the post-stack PS data to PP-time. The horizons were used along with the PP-velocity model in the PP-AVO to perform a PS-AVO extraction. Attributes resulted from this analysis include P-Impedance Reflectivity (Zp), S-Impedance Reflectivity (Zs) and Density Reflectivity. First, the seismic data is trained at well locations to derive log properties (Hampson et al. 2001). Then, the training results are validated before being applied to the full seismic volume.

In Figure 15, a PS amplitude map (Hampson Russell) can help us to better understand the unsuccessful drilling location. On left, we can see the PP amplitude maps compared with the PS amplitude map at the Colony (up) and Sparky (down) sands. The black arrow shows an unsuccessful drilling location, based previously only on PP amplitude maps.

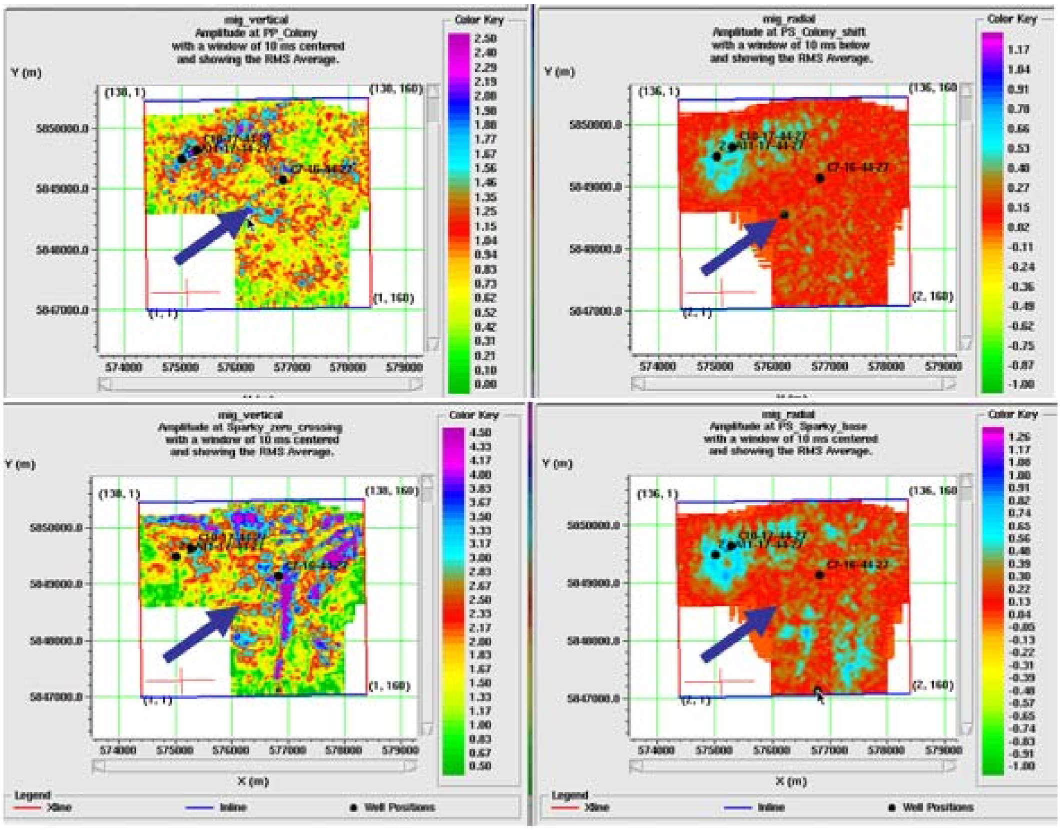
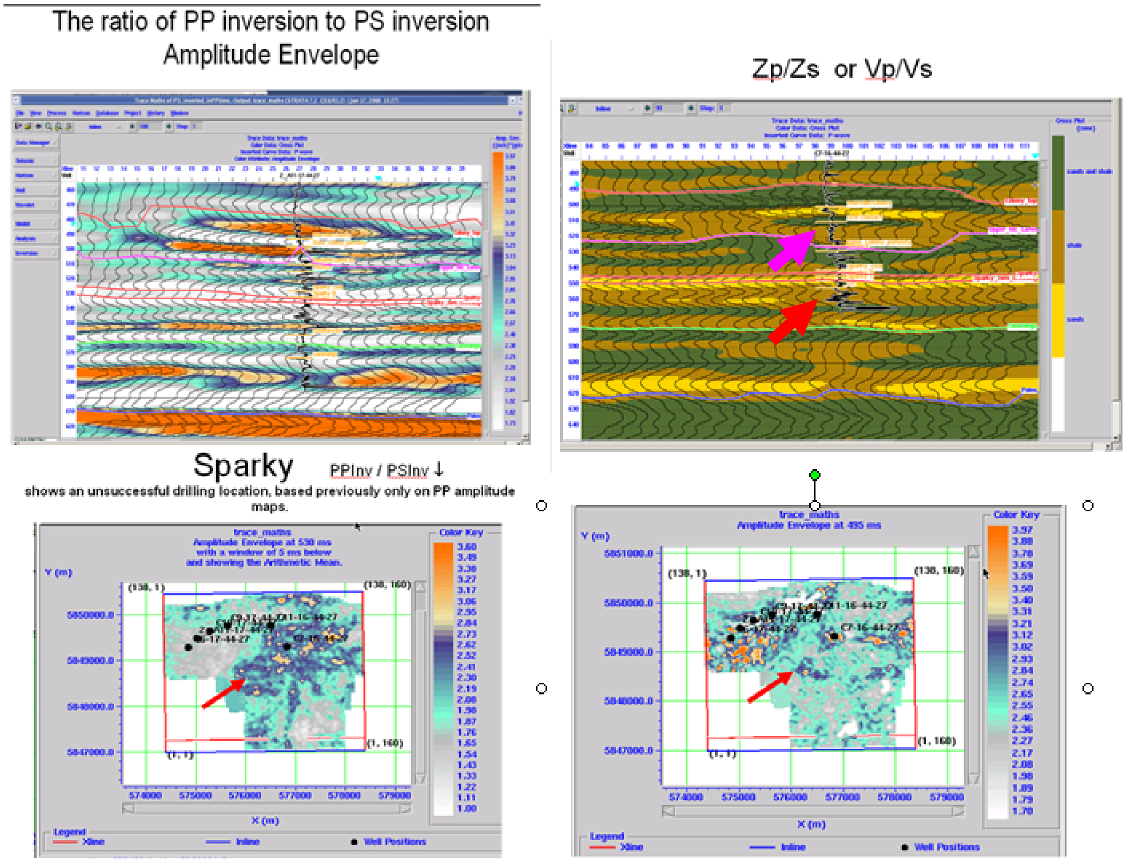


FIG. 15. PP amplitude (left) and PS amplitude maps (right) for the Colony (up) and Sparky (down) channels.

After registration, pre-stack and post-stack inversions were performed. A PS model in PP time was created for inversion. Model based inversion was chosen for the post-stack because of its better high frequency result. The ratio of the prestack joint PP inversion to the PS inversion is shown in Figure 16. On right, we can note the lithology differentiation for the ratio of the pre-stack inverted data. The yellow color represents the sands and corresponds to the Colony (pink arrow) and Sparky (red arrow) horizons, showing the sand channels. Brown color shows the shales, olive shows the mixed sands and shales. On left we can see the amplitude envelope for Zp/Zs. Down, the Sparky and Colony ratios time slices shows a low value in white. The missed location (red arrows) shows a higher value of Zp/Zs value.



shows an unsuccessful drilling location, based previously only on PP amplitude maps.

FIG. 16. Up: Zp/Zs amplitude envelope (left) and Zp/Zs lithology differentiation. Down: Sparky (left) and Colony (right) ratios time slices.

Figure 17 shows the co-rendered PP and PS amplitude envelope attributes at Sparky and Colony picked horizons, showing the dominant energy pockets in the data. Zero phase decon was used to increase the high frequency content of the data. The red arrows show the same missed drilled location.

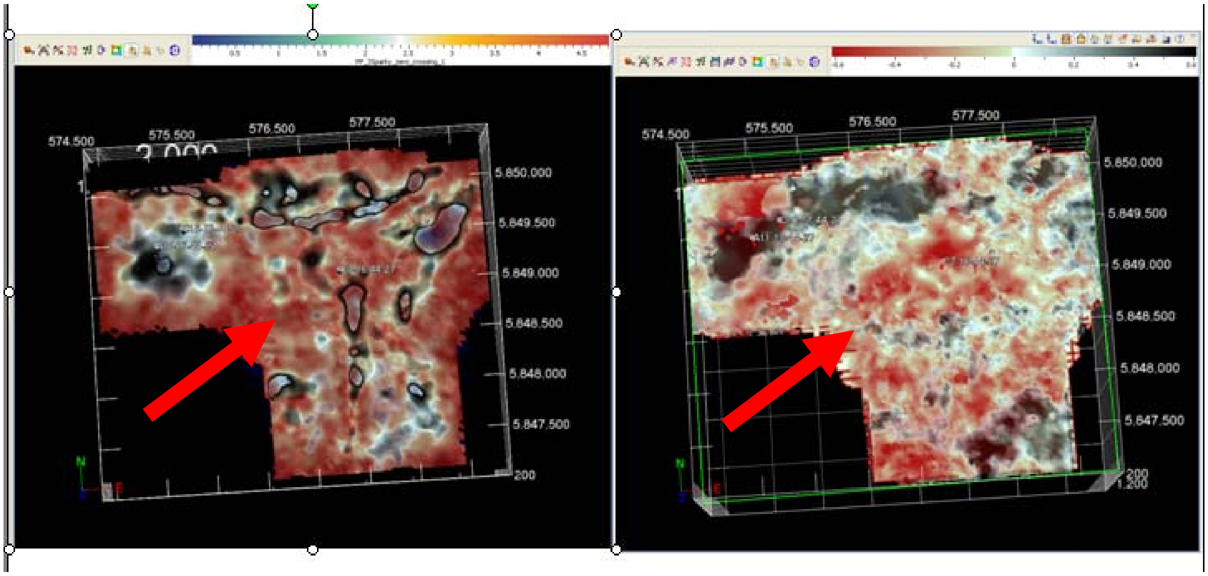


FIG. 17. Left: the Colony and right: Sparky horizons in Transform software. Amplitude envelope is co-rendered for both PP and PS data.

CONCLUSIONS

PS data is helpful in the planning and risking of new drilling locations. Differences in PP and PS amplitude maps can assist with drilling positioning, due to the direct response of PS data largely to lithology. Oil and gas saturated sand channels should give relatively low Vp/Vs values, a P impedance decrease and an S impedance increase. The channels can be filled with sands and/or shales, with similar P-wave impedances. From the dipole sonic log, we find that S-wave impedance is higher in the sands than in shales. The ratio of the prestack joint PP inversion to the PS inversion (Vp/Vs from amplitudes) in PP time is useful in delineating the reservoir. Vp/Vs values computed from time thickness ratios can help in estimating the rock type as well as delineating reservoirs. Since PP and PS reflectivities are different, attributes computed from PP and PS volumes show different geologic features.

ACKNOWLEDGEMENTS

We thank the sponsors of the CREWES Project at the University of Calgary for supporting this work. We also appreciate the donation of the seismic data to us by Calroc Energy Ltd., in particular to Brian Szatkowsky and David Feuchtwanger formely of Aguila Explorations Consultants Ltd.

REFERENCES

Anderson, P. F., 2007, Multicomponent case study – Continued Multicomponent Experience in Eastern Alberta, SEG/San Antonio 2007 Annual Meeting, Expanded Abstracts, p. 1878-1882.

Anderson, P.F, L. Chabot, and D. Gray, 2005, A proposed workflow for reservoir characterization using multicomponent seismic data: 75th Annual International Meeting, SEG, Expanded Abstracts, 991-99.

Anderson, P.F.,and R. Larson,2006, Multicomponent case study –One company's experience in Eastern Alberta: Recorder, **31**,5-10.

Hampson, D.P., B.H. Russel, and B. Bankhead, 2005, Simultaneous inversion of pre-stack seismic data: 75th Annual International Meeting, SEG, Expanded Abstracts, 1663-1637.

Putnam, P.E. and T. A. Oliver, 1980, Stratigraphic traps in channel sandstones in the Upper Mannville (Albian) and east-central Alberta. Bulletin of Canadian Petroleum Geology, **28**, 489-508.

Roth, M.,2006, Practical interpretation of multi-component seismic data: Recorder, **31**,23-26.

Sheriff, R.E., and L.P. Geldart, 1995, Exploration seismology: Cambridge University Press.

Smith, G.G. 1989. Coal resources of Canada: Geological Survey of Canada, Paper 89-4, 146

Stewart, R. R., Xu, C., and Soubotcheva, N., 2007, Exploring for sand reservoirs using multicomponent seismic analysis: J. Seis. Explor., **15**,2,1-25.

Vigrass, L.W., 1977, Trapping of oil at intra-Mannville (Lower Cretaceous) disconformity in Lloydminster area, Alberta and Saskatchewan: American Association Petroleum Geologists Bulletin, **61**, 1010-1028.