A Proposed Workflow for Converted-Wave Event Registration – The Step Between Processing and Interpretation

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Abstract

We present a workflow template for identifying converted-wave reflection energy that involves interpretive processing and forward modeling. We then identify equivalent reflectors on the PP and PS sections (registration). The data were recorded using VectorSeis® multicomponent digital accelerometers. These sensors provide a cost-effective means to acquiring multicomponent data without impacting the quality of the conventional p-wave data. Therefore we will also present the results of a direct (one-to-one) comparison of the digital VectorSeis® data to coil-geophone arrays and single coil geophones.

Geological Setting

The Williston Basin is a large, roughly circular depression on the North American Craton covering several hundred thousand square km across parts of the American states of North Dakota, South Dakota, and Montana, and the Canadian provinces of Manitoba and Saskatchewan. The Williston Basin began to subside during the Ordovician Period around 500 million years ago and it underwent periods of subsidence throughout the rest of the Phanerozoic.

During the latest Early Carboniferous, the Williston Basin was subjected to broad epeirogenic uplift accompanied by deep subarieal erosion. This along with a final phase of epeirogenic uplift accompanied by a major drop in sea level, produced the unconformity that separates Lower Permian from Mississippian strata throughout the basin.

These eustatic and structural events generated a series of angular unconformity traps (Figure 1). The seismic was shot to detect and delineate one such trap in the Alida formation of the Mississippian.
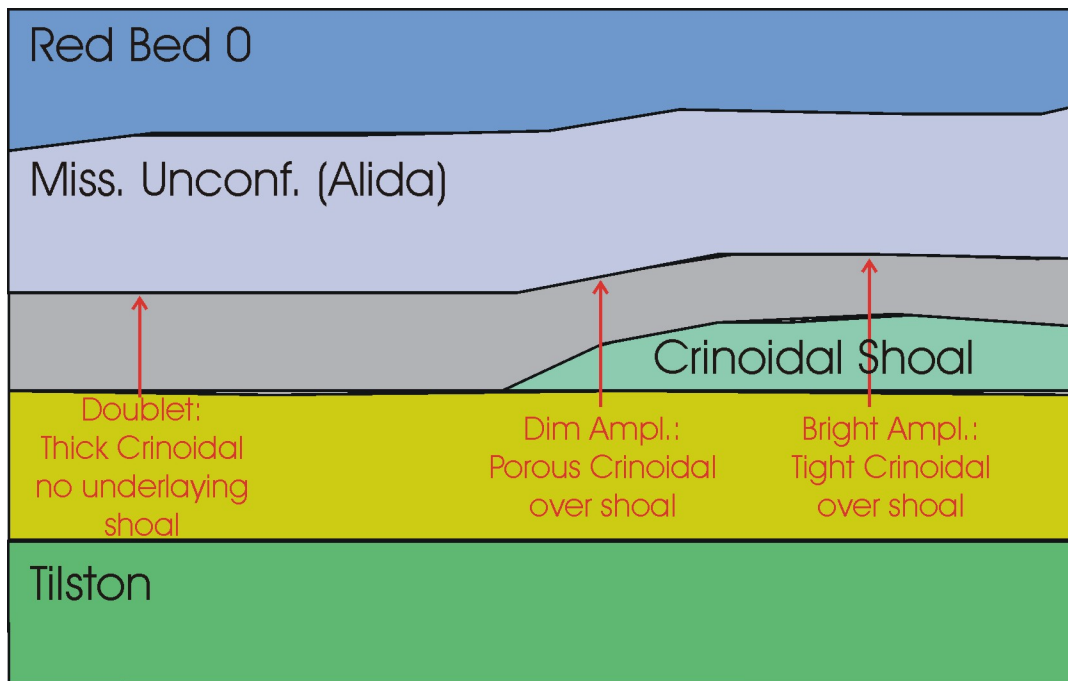

Figure 1: The above cartoon illustrates the thinning of the Mississippian Alida as it ramps up onto the crinoidal shoal. The typical seismic response is annotated at the arrows.

Acquisition

In July 2001, Veritas acquired a series of side-by-side 2D seismic test lines in order to evaluate the performance of the VectorSeis® digital sensor compared to 6 string coil-geophone arrays and single coil geophones. The data were recorded in the Arcola area of SE Saskatchewan, Canada. In all cases the receiver interval was 20m and the shot interval was 80m and 1Kg of Pentolite at 18m. All the data were recorded using the I/O RSR recording system.

Input/Output's, digital sensor, VectorSeis®, has two principal components, a micro-machined silicon accelerometer with a small inertial mass, suspended by miniature springs and a custom designed, mixed-signal ASIC control chip. Force re-balanced feedback operation provides a 24 bit digital output directly from the sensor unit obviating the need for A/D converters in the recording system. The acceleration-proportional output shows a flat transfer- and phase-response from very low frequencies up to 500Hz. Implementation of the digital sensor is in an

orthogonal 3-component arrangement forming the core of the VectorSeis® recording system. Data is acquired on a VRSR platform, 6 x 3C stations per box.

The operational advantages of recording multicomponent data with these new purpose built multicomponent sensors is substantial; they require fewer connections and cable, the overall weight of the equipment is reduced and the sensors do not have to be levelled in the field, since this can be corrected for in processing. The ability of the sensor to work at none-vertical orientations increases the acquisition rate and improves coupling since the sensor is not adjusted for leveling purposes. The VRSR recording system utilizes a transcription process that separates the different components into individual files thus reducing processing time and uncertainty in trace identification. The final result is more accurate and affordable multicomponent acquisition compared to conventional coil geophones.

Data Comparisons
Side-by-side comparisons show that a single (point receiver) VectorSeis® sensor provides equally interpretable data to 6 string geophone array data and single sensor (point receiver) geophones. Figure 2 shows the side by side comparison with identical processing flows. Further to the data being of comparable quality is the fact that the VectorSeis® sensors have proven to be as robust and easy to use as conventional geophone arrays. However, with VectorSeis®, we are recording the full elastic wavefield at no additional cost.
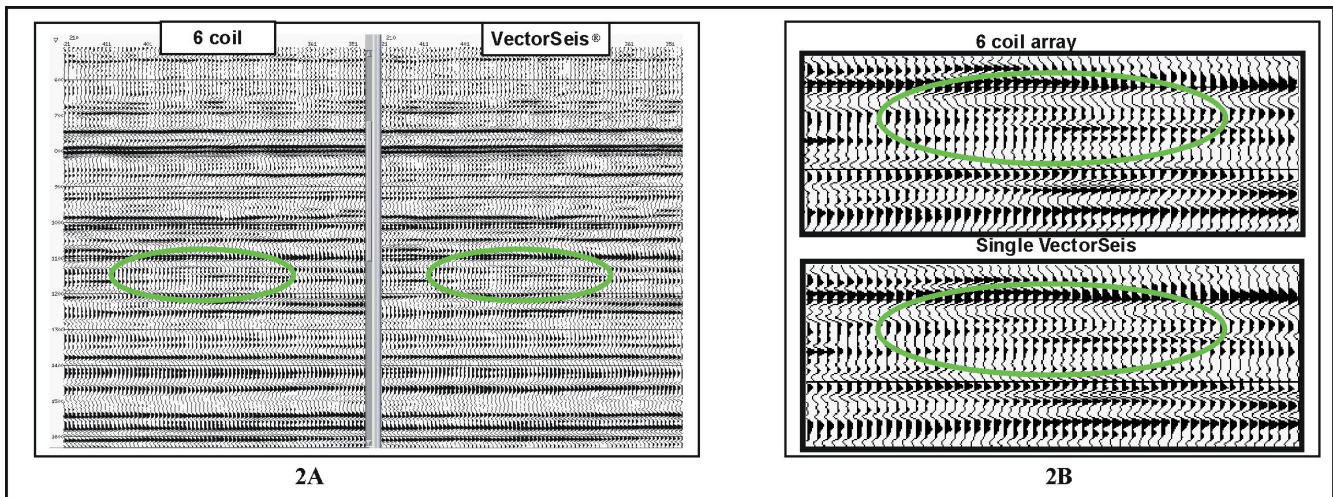

Figure 2: Figure 2a shows the p-wave 6 string array data on the left and the p-wave single VectorSeis® data on the right, while figure 2b is a blow up of the zone of interest illustrating the similarity in response characteristics between the two sensors.

Converted-Wave Interpretation Workflow
Since VectorSeis® is a multicomponent sensor, we were also able to process the converted-wave data recorded during the Arcola test. The converted-wave data were processed through a standard c-wave processing flow and subsequent interpretation revealed a significant amplitude anomaly on the PS section. One of the major obstacles limiting the use of converted-wave data is the availability of appropriate interpretation software. In order to explain the converted-wave anomaly, we had to devise an interpretation scheme that allowed us to confidently identify equivalent horizons on the p-wave and converted-wave sections.

We have identified four independent processes which help the interpreter to establish equivalent horizons between the PP and PS data. The first clue is provided in the converted-wave velocity analysis. Figure 3 shows the semblance style analysis used to pick Vp/Vs, given the compressional velocities. The Vp/Vs values from semblance analysis are usually good enough for crude correlations. At this point the correlation can be fine-tuned using structural and stratigraphic anomalies, such as faults and structural anomalies. The most important tool for correlation between the PP and PS data is borehole shear measurements (either dipole sonics or converted-wave VSP's), preferably recorded to the very near surface. This requirement is due to the rapidly changing Vp/Vs ratio with depth in the shallowest portions of the earth's crust. Figure 4 shows the PP synthetic tied to the PP seismic in depth with the PS synthetic tied to the PS seismic in depth and the well logs that were used to create each of the synthetics. The final check for correlation purposes is one of common sense. That is, do the sections support a consistent geological interpretation and have each of the steps been in support of each other. Figure 5 shows the correlated PP and PS sections displayed in PP time.

Conclusions
We have compared data acquired with single VectorSeis® digital sensors versus data acquired with 6 string coil-geophone arrays. The comparisons suggest that there is no loss of data quality going to single VectorSeis® sensors in this area. We have also introduced a 4 step process for correlating PP to PS seismic. Finally we have compared the PP section to the PS section and identified the play with slightly more detail on the PS section.
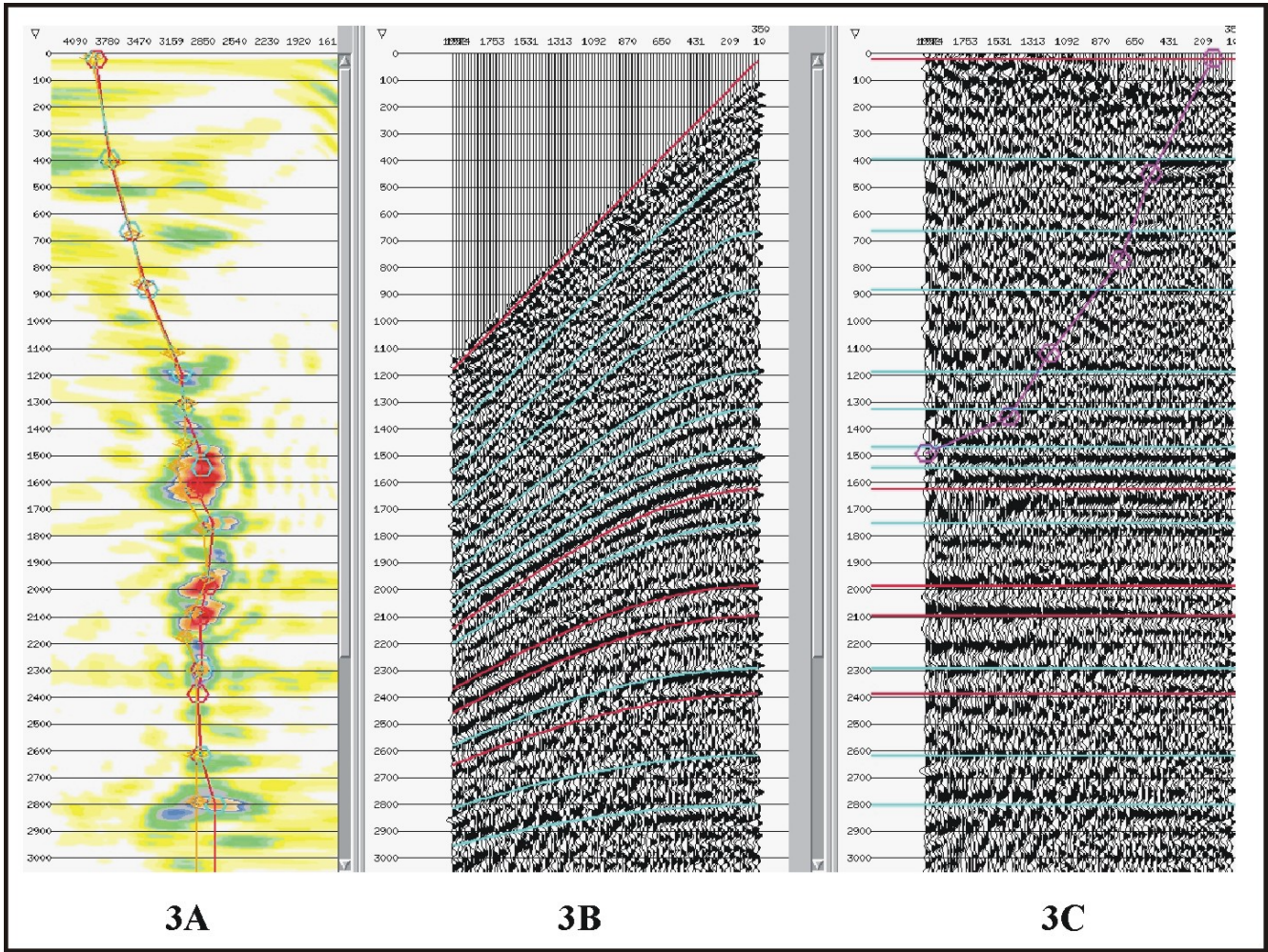
Figure 3: Figure 3a is the semblance plot for Vp/Vs analysis. The Vp/Vs values range from 1.5 on the right to 4.2 on the left. Note that the Vp/Vs is fairly constant (~2.85) from about 1.45 seconds to 3.0 seconds. Figure 3b shows the super-gather (coff) uncorrected with the converted-wave NMO curves. Figure 3c shows the c-wave NMO corrected gathers with the mute. Note the high quality reflection energy and the flat gathers indicating correct velocities.
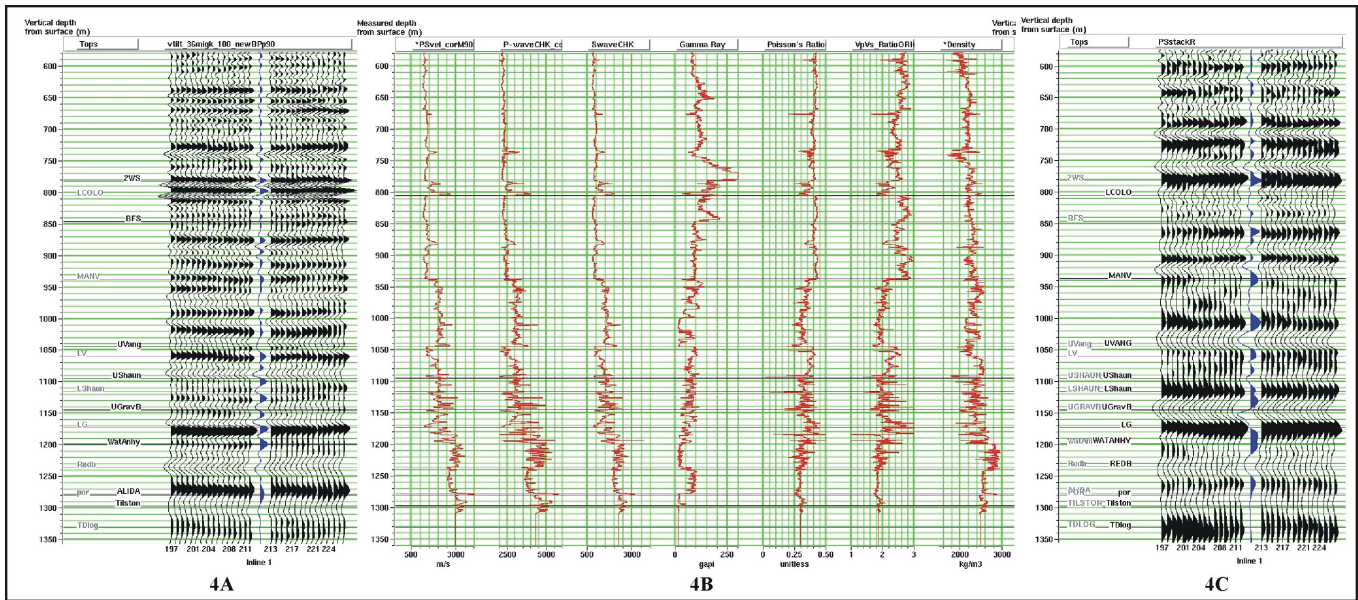

Figure 4: Figure 4a shows the PP seismic with the PP synthetic in the middle. Figure 4b shows the log curves used for the synthetics. Figure 4c show the PS seismic with the PS synthetic in the middle. All plots are displayed in depth.
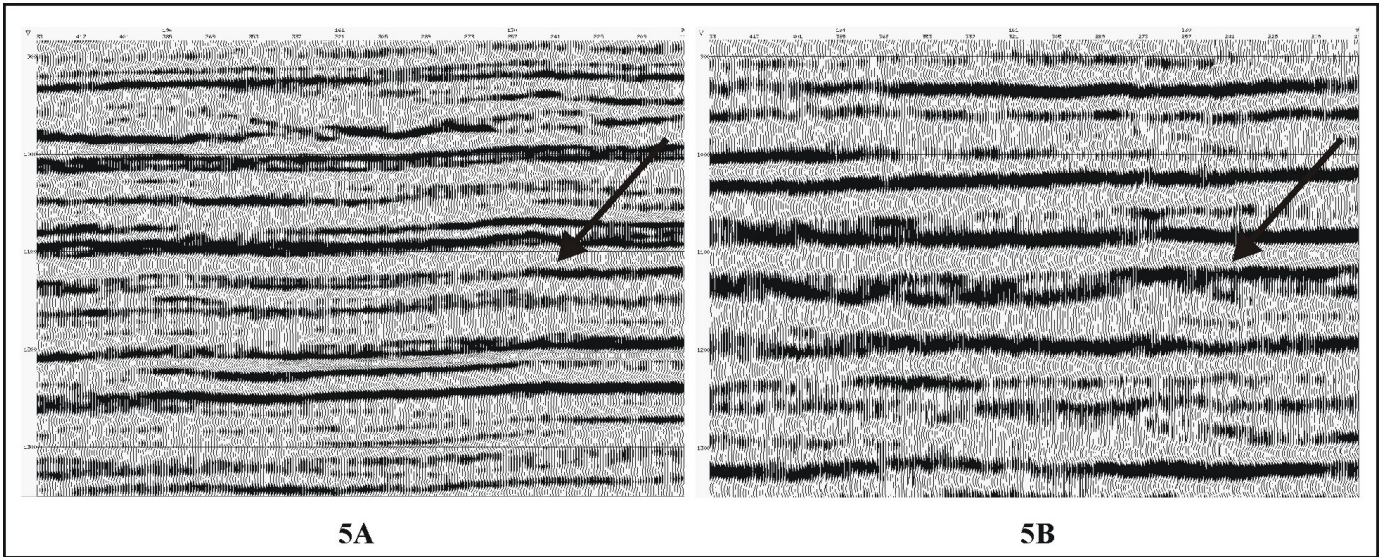
Figure 5: Figure 5a shows the PP seismic with the zone of interest identified by the arrow. Figure 5b shows the PS seismic in P-wave time, again with the arrow indicating the zone of interest. Note the clear delineation of the shoal, flank and off-shoal signature on the PS section.