The Seismic AVO of Wet and Dry CBM Reservoirs*

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Abstract

The seismic reflection characteristics of an Ardley Coal CBM reservoir are studied. The study reservoir has a high water saturation. Synthetic modeling is used to investigate the AVO response of the existing "wet" coals and that of hypothetical "dry" coals. Both the PP-reflection and the converted wave PS-reflection are investigated. The model results show that with sufficient bandwidth in the recorded signal, the AVO response of wet and dry coals is sufficiently distinct to discriminate between the different states of water saturation. In part to determine what bandwidth could be achieved in the field, the University of Calgary conducted a 1C-2D seismic survey at the study area in the summer of 2006. An ENVI mini-vibe source was used to generate a 10-200 Hz sweep. The signal to noise ratio diminished significantly above 100 Hz in the recorded data. However, although the signal bandwidth is limited and the targets are closely spaced thin beds, the coals are resolved as two distinct events in the migrated seismic section.

Introduction

This article investigates whether seismic AVO analysis can resolve the difference between wet and dry coals. Petrophysical log data from a well near Alder Flats, Alberta in the Pembina Field are used to model the AVO response of a prospective CBM reservoir. The coals belong to the Ardley Coals which possess high inherent water saturation. The AVO response of the wet coals and that of hypothetical dry coals are modeled in order to determine if the response is sufficiently distinct to discriminate the two saturation conditions in seismic data.

Petrophysical Logs

The well logs from a well in the study area show three coal seams here identified as Ardley 1, 2, and 3. Ardley 1 is at a depth of 414 metres and is approximately 9 m thick. Ardley 2 is at a depth of 404 m and is 4 metres thick. Ardley 3 is at a depth of 356 m and is 9 m thick. All are considered thin beds for seismic analysis. Additionally, Ardley 2 and 3 are closely spaced which will make them challenging to resolve as separate events in seismic.

Properties of Wet and Dry Coals

Wet and dry coals are expected to have different elastic properties. Research by Richardson and Lawton (2002) showed that Ardley Coals exhibit an approximate 26.9% reduction in P-wave speed and approximately 18% reduction in density when coals that are initially water saturated are completely dewatered in a laboratory setting. However, complete desiccation of coals is unlikely to occur in a reservoir environment. Additionally, when coals have lower water saturation, the cleat network will likely be filled with methane. As a result, the *in situ* rock properties are not expected to exactly mimic those observed in the laboratory environment. For the purpose of investigating the seismic response of wet and dry coals, a 10% reduction in both the P-wave speed and density is assumed, while the S-wave speed is assumed to be unaffected by the coal's water saturation. Thus the expected difference in coal properties for wet and dry coals is a difference in Poisson's ratio.

Zoeppritz Reflection Coefficients

The Zoeppritz Explorer (CREWES) was used to investigate the PP and PS reflection coefficients as a function of incidence angle. Figure 1a illustrates Rpp and Rps for the top of the Ardley 2 seam assuming average P-wave, S-wave, and density values from the well logs (i.e. wet coals). The Ardley 2 seam is overlain by a sandstone package. Figure 1b illustrates Rpp and Rps for the top of the Ardley 2 seam if the coals are dry (10% reduction in P-speed and density with no change in Sspeed). The greatest differences between wet and dry coals are evident in the normal incidence Rpp and the gradient of Rps.

Synthetic Offset Gathers

Figure 2 and Figure 3 illustrate the synthetic PP and PS offset gathers for two cases: wet and dry Ardley 1 and 2 coals. Modeling assumed a 90 Hz Ricker wavelet. As expected, the most distinguishing differences between the wet and dry case are the PP normal incidence amplitude and the PS gradient. Therefore, assuming no change in the overlying or underlying rock, AVO analysis should be able to discriminate between coals with higher and lower water saturation. Wavelets with bandwidth less than a 60 Hz Ricker wavelet are not able to resolve the Ardley Coal 1 and 2 seams as separate events.

June 2006 Field Survey

Two 1C-2D seismic lines were acquired by University of Calgary in June of 2006 at the study location near Alder Flats, Alberta. One line was oriented approximately north to south and the second was oriented east to west. The north-south line is closest to the study well. An ENVI mini-vibe source was used to generate a 10-200 Hz sweep. The nominal source interval was a 10 m interval for the north-south (N-S) line and a 30 m interval for the east-west (E-W) line. The signal-to-noise ratio diminished significantly above 100 Hz in the recorded data.

The migrated N-S section is shown in Figure 4. Spectral whitening was applied over 12-100 Hz and then band passed over the same frequency range. The processing flow omitted offsets less than 60 m because the aliased direct source noise dominated the near offsets. Figure 4 also illustrates the tie between a 90 Hz Ricker wavelet and the migrated N-S section. The Ardley Coal 1 and 2 seams are resolved in the section as separate seismic events.

Conclusions

Because wet and dry coals will exhibit different Poisson's ratios, AVO analysis may identify areas of higher or lower water saturation. Assuming no change in the surrounding rock, the normal incidence PP reflectivity of dry coals and the gradient of the PS reflectivity are higher for wet coals than for dry coals. However, because coals usually occur as closely spaced thin beds, it is critical to acquire sufficient bandwidth in the seismic signal to resolve coal seams as distinct seismic events.

Acknowledgments

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References Cited

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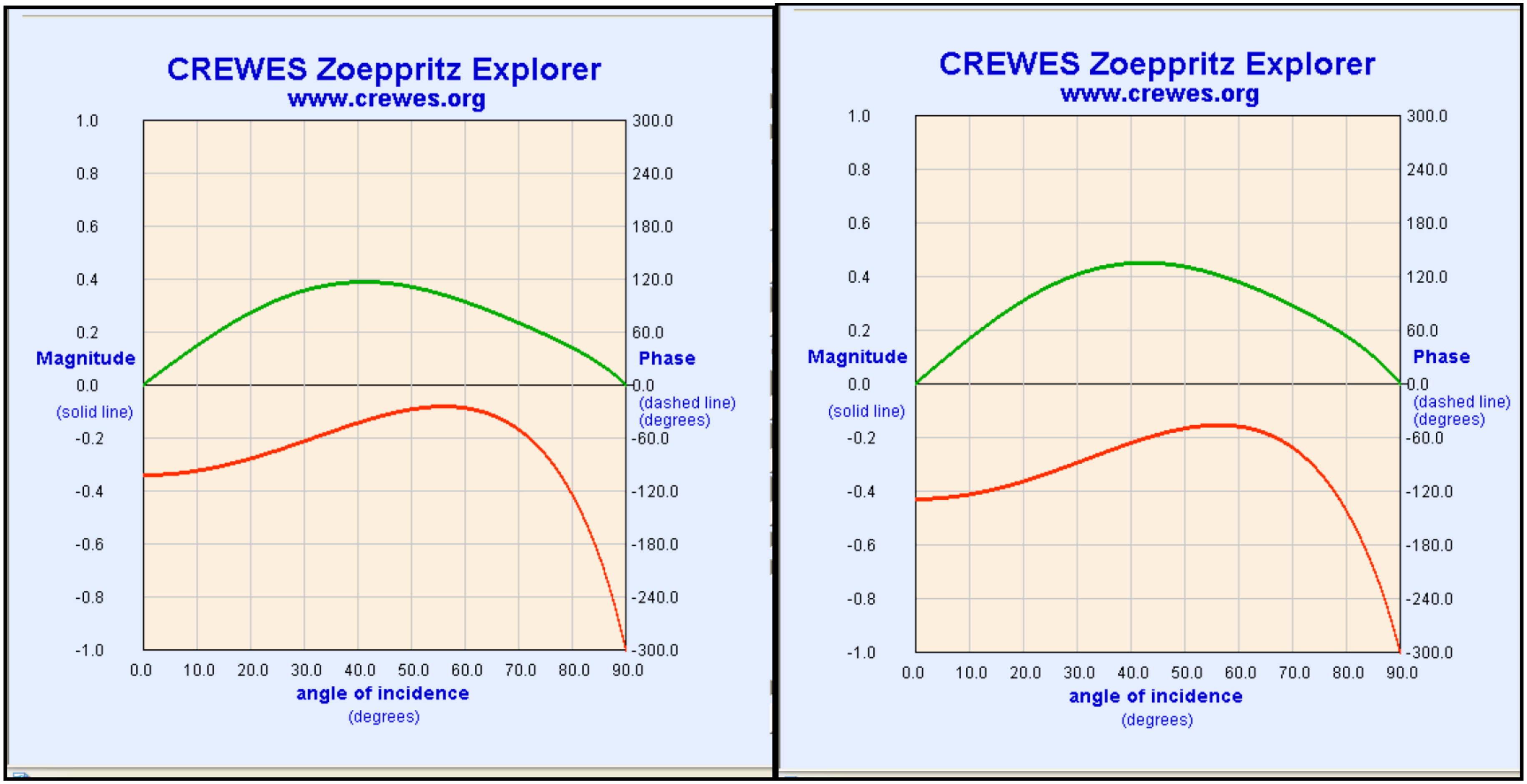
Richardson, Sarah E., and Don C. Lawton, 2002, Time-lapse seismic imaging of enhanced coalbed methane production: a numerical modeling study: CREWES Research Report 14.



(a) Wet coals (b) Dry coals

Figure 1. Reflection coefficients with angle of incidence for PP (red) and PS (green) waves at the top of the Ardley 2 well.

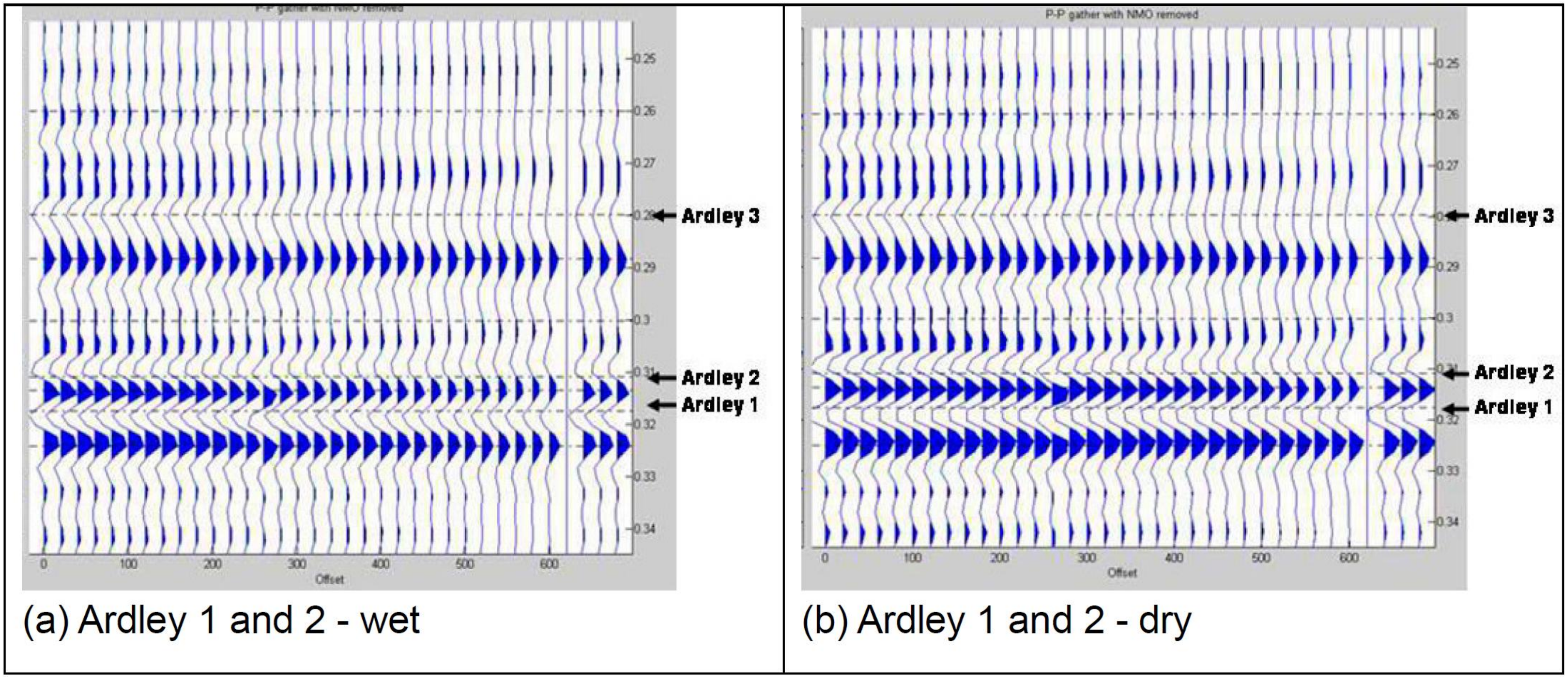


Figure 2. Synthetic offset gathers for PP reflections using a 90 Hz Ricker.

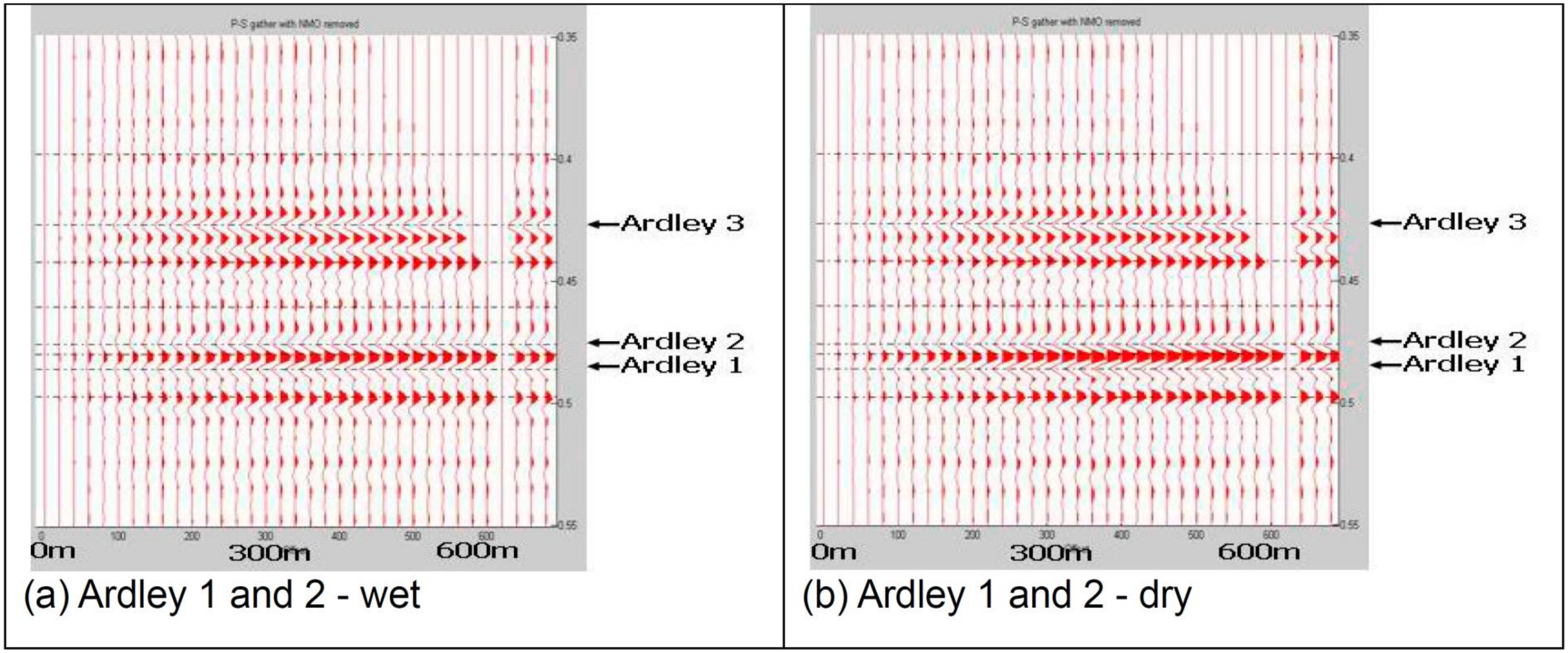


Figure 3. Synthetic offset gathers for PS reflections using a 90 Hz Ricker.

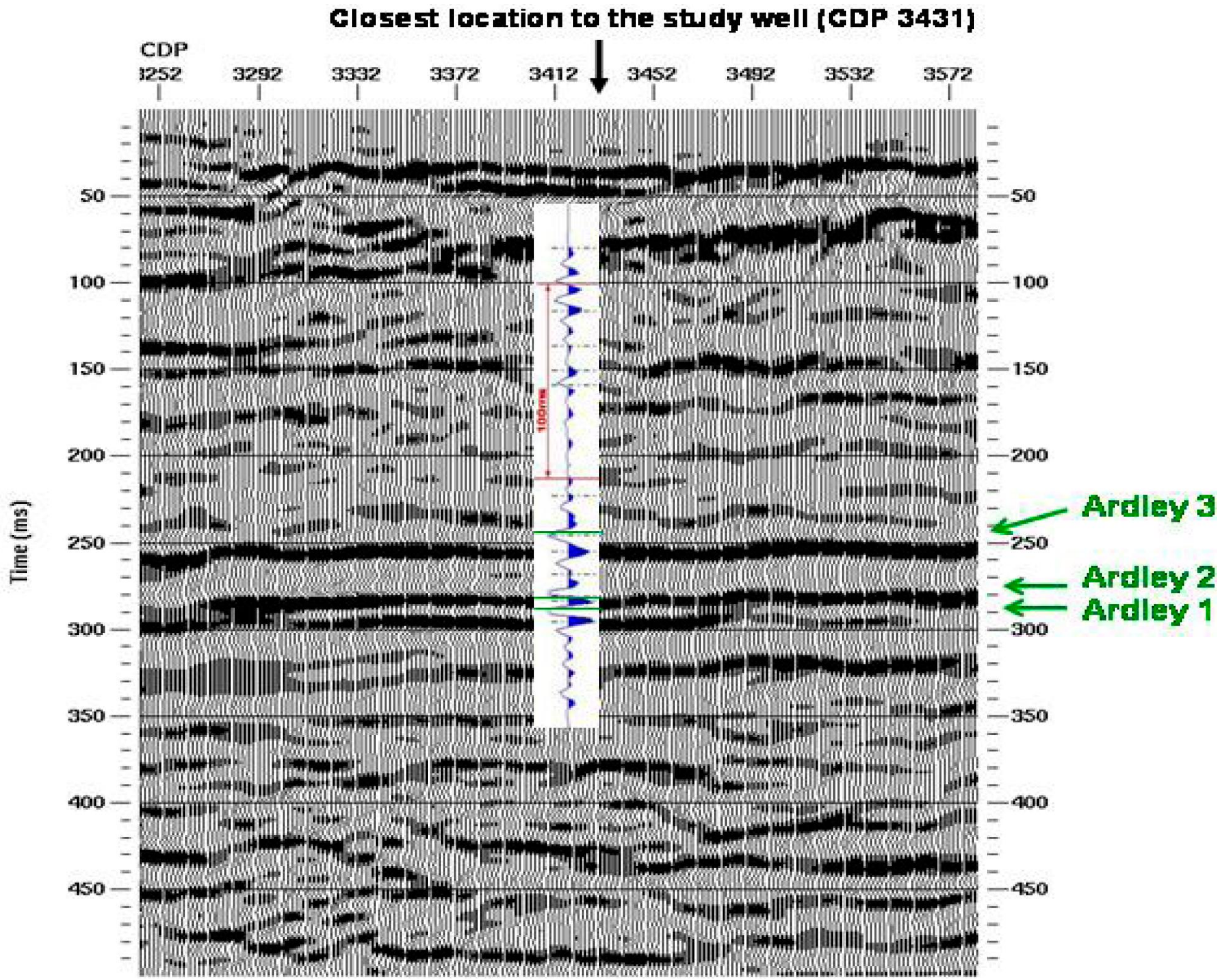


Figure 4. Migrated north-south seismic section with 90 Hz Ricker synthetic tie.