

Seismic applications in coalbed methane exploration and development

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ABSTRACT

Introduction

Exploration seismic techniques may be applied to the development of coalbed methane reservoirs, a potentially important new energy source in Alberta. A review of existing and newly developed technologies demonstrates that seismic methods are an invaluable tool in CBM prospecting and development.

Previous seismic work related to coal has examined the reflectivity and resolvability of thin coal beds in the subsurface. Coal typically shows strong contrasts in seismic velocity and density with respect to bounding strata. Gochioco (1991) noted that although coal seams are extremely thin relative to seismic wavelength, their large acoustic impedance contrast with surrounding rocks results in distinct reflections, and the limit of resolution of coal beds may be closer to $\lambda/8$ rather than $\lambda/4$. Lawton and Lyatsky (1991) examined coal reflectivity based on density contrast, demonstrating that density logs alone may be used to model the seismic response of coal beds, although both velocity and density logs are used in this study.

Dewatering and gas injection, the necessary steps in enhanced coalbed methane recovery (ECBM), affect the bulk density and seismic velocity within a geological formation. These changes in density and velocity in turn alter the amplitude and travel times of seismic reflections (Gunter et al., 1999). A site in Alberta has been selected to test ECBM production using CO₂ injection into the Ardley coal zone. The late Cretaceous Ardley coal zone has CBM reserves estimated at 25 TCF and gas contents ranging from 2.0 to 5.5 cc/g throughout the province (Beaton, 2003).

Successful geological sequestration of CO₂ has been implemented in an aquifer of the Sleipner field in the North Sea. Time-lapse seismic monitoring has been effectively used at Sleipner and has demonstrated a heterogeneous CO₂ saturation pattern within the aquifer (Eiken and Brevik, 2000). Injection of carbon dioxide into the strata has altered the acoustic impedance of the strata, resulting in increased reflectivity within the formation, amplitude variations, and a velocity push-down effect (i.e. increased travel time) for all reflections beneath the top of the aquifer. It is believed similar effects will be noted at the Alberta site but on a different scale, based on different thicknesses and properties of sequestering

formations at both sites.

Numerical Modelling

Numerical modelling tested the viability of time-lapse seismic imaging at the Alberta field test site. Digital dipole shear-sonic, compressional sonic, and density well logs through the Ardley coal zone were used to generate synthetic seismograms before and after dewatering. Density and velocity values within the coal zone were altered to simulate the effects of CBM production, after which new synthetic sections were created. Velocities were reduced by 20% and densities by 15% based on physical parameter testing of Ardley coal samples (Richardson and Lawton, 2002). The expected change in the seismic response of the coal zone is illustrated by examining the difference between the seismograms (Figure 1).

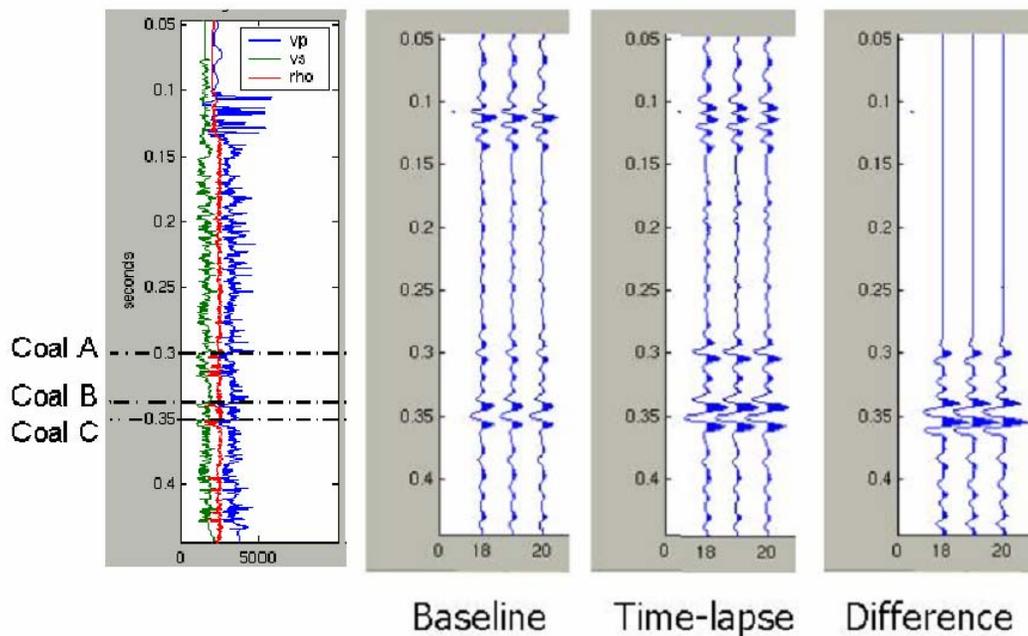


Fig. 1: Well logs from 6-22-50-11W5 illustrate three clear coal markers within the Ardley zone. The P-P response of these coal seams is shown by convolution with a 50 Hz Ricker wavelet, showing a clear coal response in the baseline survey. After time-lapse each coal seam shows an increase in reflectivity, and all events underlying the uppermost coal response have been delayed in time.

Shear wave velocities are not affected by formation fluid, although compressional waves are indeed sensitive to fluid variations. As such, the traveltime for a converted wave will be slightly altered, as the downward motion of the wave (the p-wave) will have its velocity reduced through the coals, whereas the upgoing motion will travel at the same velocity as the original converted-wave. Events underlying the upper coal are expected to arrive at later times, but the magnitude of this change is less than the magnitude of the equivalent P-P change, as traveltime is only affected in one direction. The modelled converted-wave

response (Fig. 2) shows that amplitudes are greatly increased after the coal is dewatered, and all underlying events are delayed in time.

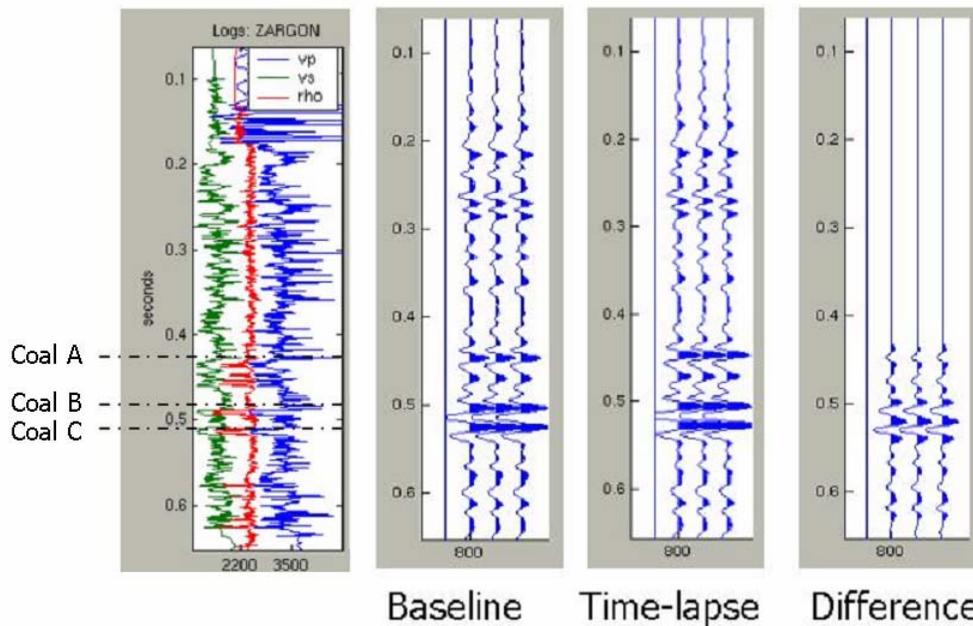


Fig. 2: The modeled P-S response of the 6-22 well. The first coal event shows the reflectivity change resulting from the changes in reservoir properties. The second and third coal events show changes not only in reflectivity, but in travel time as well. Reflections beneath the coal seams exhibit no changes in reflectivity, but variation from baseline results from the travelttime change.

Numerical modelling has shown that the dewatering of coal can be effectively imaged using time-lapse seismic surveys. Tracking dewatered zones within coal seams may allow for optimal positioning of gas injection and production development wells. Numerical modelling demonstrates “proof of concept”, and provides parameters to be considered in survey design prior to a field CBM trial.

Field Data

In order to optimally design a 3C-3D survey to test time-lapse imaging of ECBM, multicomponent vertical seismic profiles were obtained of a CBM test well drilled in the Ardley coal zone using three different sources. Surface seismic was recorded on single-component geophones during the shooting of the VSPs. At this test site near Red Deer, the top of the Ardley coal zone is at approximately 290 m depth KB. The geometry of the survey is illustrated in Figure 3.

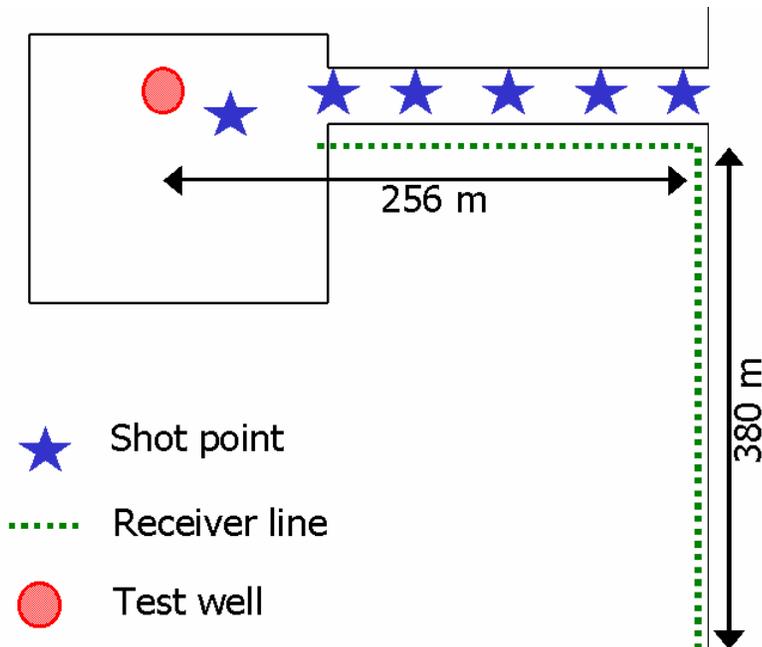


Fig. 3: Geometry of the seismic acquired at the test field site. A walkaway multicomponent vertical seismic profile was recorded in addition to a zero-offset multicomponent VSP and single-component surface seismic. Image is not to scale.

The first source tested for the zero-offset survey was a P-wave Vibroseis truck, using a sweep of 8-150 Hz with a 1 ms sampling rate (referred to as “big-P”). A smaller “mini” P-wave truck-mounted Vibroseis unit was also tested, using an 8-250 Hz sweep, as well as a “mini” shear-wave truck-mounted Vibroseis, sweeping 8-150 Hz (referred to as “mini-P” and “mini-S”, respectively). Both the mini-P and mini-S sources recorded using a 1 ms sampling rate. Multicomponent receivers were spaced at 5 m intervals from TD to surface within the wellbore.

Frequency spectrum analysis of the big-P VSP data indicates that bandwidth of 15-150 Hz is usable (*Table 1*). Applying Gochioco’s $\lambda/8$ resolution calculation (1991), and assuming a 3000 m/s average velocity, the limit of resolution for coal seams using the big-P source is approximately 2.5 m. Upper and lower contacts for the 9 m thick Ardley coal zone are clearly resolved on the big-P VSP data with strong amplitude events.

Data Source	Usable Bandwidth at depth of coal	$\lambda/4$ resolution	$\lambda/8$ resolution
Big-P	15-150 Hz	5 m	2.5 m
Mini-P	15-220 Hz	3.4 m	1.7 m
Mini-S	15-80 Hz	4.7 m	2.4 m

Table 1: Usable frequencies in VSP data and corresponding limits of resolution for different sources. Mini-P vibroseis data produced the highest recorded frequencies and thus, the highest resolution at the level of the coal zone.

Higher usable frequencies recorded on the mini-P data set (Table 1) allow a calculated limit of resolution of approximately 1.7 m. Examining the VSP data, however, clearly shows a reflection within the coal zone (Figure 4). This reflection may represent a shale parting or a tight calcite streak within the coal, although log data shows the largest contrasting strata package within the coal zone measures only 0.5 m. This suggests that strong velocity/density contrasts within a coal zone may result in an even smaller limit of resolution, potentially allowing detailed mapping of individual seams within a coal zone, or locating undesirable tight streaks prior to CBM development.

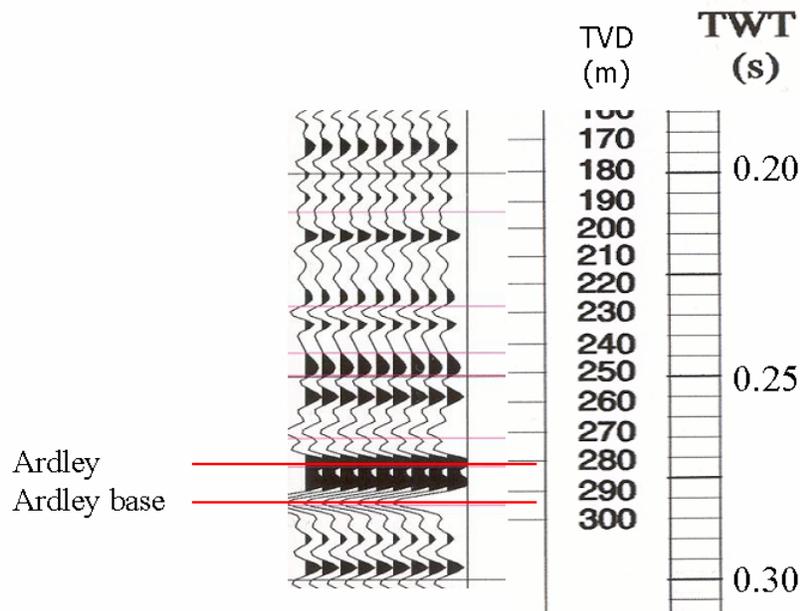


Fig. 4: Corridor stack of vertical component of mini-P zero offset VSP from the field test site. The top and base of the Ardley coal both produce strong amplitude reflections. A secondary event within the coal zone is also visible. Polarity is reverse that of the 1-D models above.

Upper and lower coal contacts produce strong amplitude reflections recorded on the horizontal component of the mini-S VSP data. Zero-offset mini-S data has slightly higher limit of resolution than big-P data (Table 1), and has a usable bandwidth of 15-80 Hz. Estimating a shear velocity of 1500 m/s, the calculated

limit of resolution is approximately 2.4 m. This value is strikingly high for shear-wave data, but it must be remembered this coal is in the shallow section, and little attenuation has occurred relative to deeper data sets normally examined. Deffenbaugh et al. (2000) noted similar high resolutions in the shallow section in an examination of the resolution of converted waves.

Surface seismic data at the test site also recorded a high amplitude reflection from the coal zone. Stacked data from the test site is very low fold, but the coal reflection is clearly visible on a filtered shot record (Fig. 5). Amplitude variations with offset are noted in the coal response. A full-fold 3D survey will improve data quality substantially.

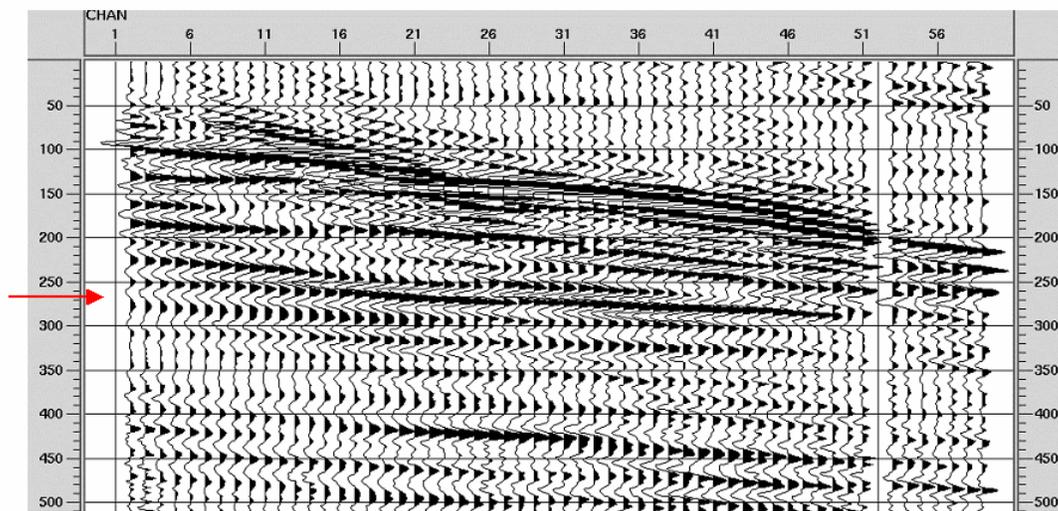


Fig. 5: Filtered shot record of surface data collected at the test site – channel spacing is 10 m (corner at channel 22), vertical scale is in ms. A red arrow highlights the coal response. Amplitude variations with offset are noted in this reflection.

A full seismic monitoring program of ECBM production will also include full well-log suites such that physical properties of coal seams may be determined, allowing the construction of detailed models. Synthetic seismograms may also be constructed from these well-log suites and tied to seismic surveys. VSP surveys will provide detailed seismic studies of the area surrounding the borehole, and crosswell seismic surveys will allow greater examination of the coal seam in particular.

Recommendations and Future Work

Source tests illustrate that a “mini” P-wave truck-mounted Vibroseis unit is an appropriate source for imaging coal seams at a depth of approximately 300 m, yielding much higher resolution data than a conventional Vibroseis truck. Ardley

coal zone contacts at the test location may be effectively imaged using any of the three sources tested, and surfaces within the coal may be detected using the high-frequency mini-P source. It is recommended that a mini-P source be used for any ECBM time-lapse data being recorded at this site.

Data recorded at the test site allow for the creation of detailed numerical and physical models, allowing ideal design parameters for a full-scale 3C3D ECBM time-lapse survey design to be determined. Attribute analysis of coal events from the zero-offset VSP surveys, walkaway VSP surveys, and surface seismic is anticipated to provide useful information regarding the physical properties of the coal and thus, its suitability for CBM development.

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