Seismic methods in coalbed methane development, Red Deer, Alberta, Canada

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Summary

Vertical seismic profiles of a coalbed methane test well near Red Deer, Alberta provide useful data regarding the physical properties of the coal and its suitability for development. Analysis of three different test sources indicates that a mini P-wave truck-mounted Vibroseis is an effective source for this test site, allowing high resolution data leading to the identification of intra-coal events. 

Vp/Vs analysis of the strata indicates Vp/Vs of greater than 3.0 in the shallowest section (<100 m depth) decreasing to 2.5 at a depth of 300 m.

Introduction

A site in Alberta, near Red Deer, has been selected to test enhanced coalbed methane (ECBM) production using CO₂ injection into the Ardley coal zone. The late Cretaceous Ardley coal zone has CBM reserves estimated at 52 TCF and gas contents ranging from 2.0 to 5.5 cc/g throughout the province of Alberta (Beaton, 2003). At the test site, the Ardley coal is at a depth of 290 m. Dewatering and gas injection, the necessary steps in 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 (Richardson and Lawton, 2002). Seismic monitoring of the ECBM pilot project includes vertical seismic profiles of each test well, cross-well surveys, and repeated 3C-3D surveys over the site.

The first test well was drilled in December, 2002, with accompanying vertical seismic profiles shot in January, 2003. Attribute analysis of this VSP data provides useful information regarding the physical properties of the coal and thus, its suitability for CBM development.

Methods

In order to optimally design the 3C-3D survey used for time-lapse imaging of the pilot, 3-component vertical seismic profiles were obtained in the test well using three different sources. Zero-offset VSPs were shot using compressional and shear sources, and two compressional sources were used for walkaway surveys. Surface seismic data was also obtained using single-component geophones during the recording of the VSPs. The top of the Ardley coal zone at the site is at approximately 290 m KB. The geometry of the survey is illustrated in Figure 1.

The first source tested for the zero-offset survey was a 44,000 lb. P-wave Vibroseis truck (“big-P”), using a sweep of 8-150 Hz. 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. Three-component receivers were spaced at 5 m intervals from TD (300 m) to surface within the wellbore, and all recording was undertaken at a 1 ms sampling rate. Surface receivers were planted at 10 m intervals.

Results

Frequency spectrum analysis of the big-P VSP data indicates a usable bandwidth of 15-150 Hz. Upper and lower contacts for the 9 m thick Ardley coal zone are clearly resolved on the big-P VSP data with high amplitude reflections from the coal zone (Figure 2).
Higher bandwidths of 15-220 Hz were recorded on the mini-P data set. Examining the VSP data clearly shows an event within the coal zone (Figure 3). This reflection may represent a shale parting or a tight calcite streak within the coal, although log data shows the largest impedance contrasts bound a layer within the coal zone that is only 0.5 m thick. The high bandwidth recorded suggests that strong impedance contrasts within a coal zone may allow detailed mapping of individual seams within a coal zone, or locating undesirable tight streaks prior to CBM development.

Deffenbaugh et al. (2000) noted similar high resolutions in the shallow section in an examination of the resolution of converted waves.

A comparison of corridor stacks from each source is illustrated in figure 5.
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Figure 4: Corridor stack of horizontal component of mini-S zero offset VSP, correlated with a synthetic seismogram (middle) and the corridor stack for the big-P data. The top and base of the Arldley coal both produce strong reflections on the S-wave data, although the upper contact is imaged as a point of inflection rather than as a peak maximum, as in the compressional VSP data. Two-way times have been converted to p-wave time for ease of comparison of the data sets.

Figure 5: Comparison of corridor stacks for the big-P, mini-P, and mini-S sources. A slight phase rotation is noted in the shear data compared to the compressional data. All plots are in p-wave time for ease of comparison.

The use of different sources allows a detailed examination of the Vp/Vs character of the shallow strata (Figure 6). Examination of the first arrival times for each source demonstrates high average Vp/Vs (greater than 3.0) in the shallowest strata down to 100 m depth, decreasing to average Vp/Vs of 2.5 at 300 m.

Figure 6: Depth vs. average Vp/Vs for Red Deer test well indicates high Vp/Vs values in the shallow section above 100 m depth, and gradually decreasing ratios from 100 m to 300 m.

Surface seismic data at the test site 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 (Figure 7). A full-fold 3D survey is expected to successfully map lateral facies and thickness changes of the coal zone across the survey area. Repeated surveys over the course of enhanced coalbed methane production will likely image changes in the coal response resulting from dewatering and gas injection (Richardson et al., 2002). These changes in response should be indicative of the accompanying physical changes in reservoir properties.

Seismic data collected during this first phase of the pilot project allows for detailed numerical and physical modeling of the test site, thus allowing optimal design of time-lapse surveys to be completed in later phases.

Figure 7: Filtered shot record of surface data collected at the test site – channel spacing is 10 m with a corner at channel 22, marked by green arrow, vertical scale is in ms. A red arrow highlights the coal response.
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A full seismic monitoring program of ECBM production will include full well-log suites such that detailed physical properties of coal seams may be determined throughout the survey area. Repeated 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 in this area, 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 Red Deer site 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 3C-3D 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 provides useful information regarding the physical properties of the coal and thus, its suitability for CBM development.

Analysis of the horizontal components of the compressional walkaway VSPs will allow an examination of the converted-wave response of the strata. This data may provide insight into shear-wave anisotropy and thus orientation of fractures, using methods described by Thomsen et al (1995).

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References


