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3D seismic surveying for coal mine applications at Appin Colliery, NSW

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ABSTRACT

Modern underground coal mining requires detailed knowledge of geological faults and other geological features. A fault of throw greater than a seam thickness of about 3 m can cause enormous delays to mine production. BHP Coal has been using 2D seismic surveying for some time to map structures with throws down to about 5 or 6 m but in an effort to obtain better resolution (mainly through seismic coverage), 3D seismic surveys are now being undertaken.

For this application, the strength of 3D seismic surveying lies in the ability to establish the continuity of subtle features from one bin section to the next. Maps of the interpreted horizons allow very small features to be seen. Attribute analysis adds further structural and lithological information to the interpretation.

The present indications are that 3D seismic surveying is set to become a key tool in coal mine exploration.

Keywords: 3D seismic, attribute analysis, interpretation, coal mine.

INTRODUCTION

BHP Collieries operates five underground coal mines in the Illawarra region of the Sydney Basin that employ longwall mining techniques at depths typically greater than 400 m. Longwall mining is highly efficient but with mines producing coal worth some $0.5 million per day, every effort has to be made to maintain production. In this regard, one of the greatest uncertainties in the Illawarra region is the potential for a mine to encounter an unexpected geological fault.

Faults with throws of tens of metres occur in this region with fault throws varying significantly along strike. Furthermore, a fault with a throw of even seam thickness (3 m) will significantly disrupt mining. If that 3 m fault, however, becomes a monocline, then it can be mined. Very precise structural mapping techniques are required. Surface boreholes are unlikely to resolve such small structures and are expensive to drill in comparison to surface seismic surveying. However surface boreholes do provide an opportunity for structural mapping by down-hole seismic techniques.

BHP recognises the difficulty in locating faults through the drilling of vertical boreholes and has been developing seismic exploration techniques for use at their mines for over twenty years (Riley et al., 1997). In 1993, a telemetry seismic system was built for their specialist applications. This system uses 24 bit digitising at the geophone and currently has 208 channels. It is extremely robust and portable and well suited for use in the rugged bushland that is found over much of the ground surface.

Over 400 line km of high fold 2D seismic data has been shot using this system with explosives as the source. The results are generally of very good quality but there are always difficulties identifying faults with small throws. Where data quality is poorer, seismic data with refined parameters can be re-collected quickly and cost effectively using the in-house service.

In an attempt to improve seismic resolution, BHP shot a 3D seismic survey using their equipment at Appin Colliery in 1997. Earlier experimental 3D seismic surveys for coal exploration (Hatherly, 1991) showed that faults with throws of 4 m could be resolved. It was hoped that this survey, the first production 3D survey shot for coal mining in Australia, could provide similar resolution.

3D SEISMIC DATA ACQUISITION AND PROCESSING

Figure 1 shows the location of the survey and the mine plans. The survey area is about 1.5 km^2. Figure 2 shows the detail of the shot and receiver lines. The shot and receiver spacings were 20 m and 10 m respectively. The survey was shot with 4 receiver lines active and there were 36 (single) geophones in each receiver line. This design, allowed four fold data to be recorded into bins 10 m by 5 m. By increasing the bin size to 10 m by 10 m, the fold increased to 8. Eight fold 2D data previously shot in this area had given quite satisfactory results.

In detail, unequal shot line spacings were used because geophone rolls other than 12 at a time were not practical. Surface constraints (dams, houses etc) also dictated that not all shot and receiver lines could be straight. An advantage of 3D seismic surveying is that such inconveniences can be better accommodated than with 2D surveys. In most of this survey, continuous subsurface coverage was achieved.

Processing was undertaken by Velseis Processing using the Promax 3D package. As with most land seismic data, the most critical processing step was the determination of the statics corrections. This was particularly the case with these data because of cycle skipping in many of the first breaks.

Cycle skipping (shingling) is usually associated with thin layers in the near surface with alternate high and low seismic velocities. The high speed layers are of insufficient thickness to fully support a refracted wave and the waves emanating from them die out over distance. The first event then becomes a refraction from a deeper layer. In the case of the Appin 3D survey, we suspect that the cycle skipping was

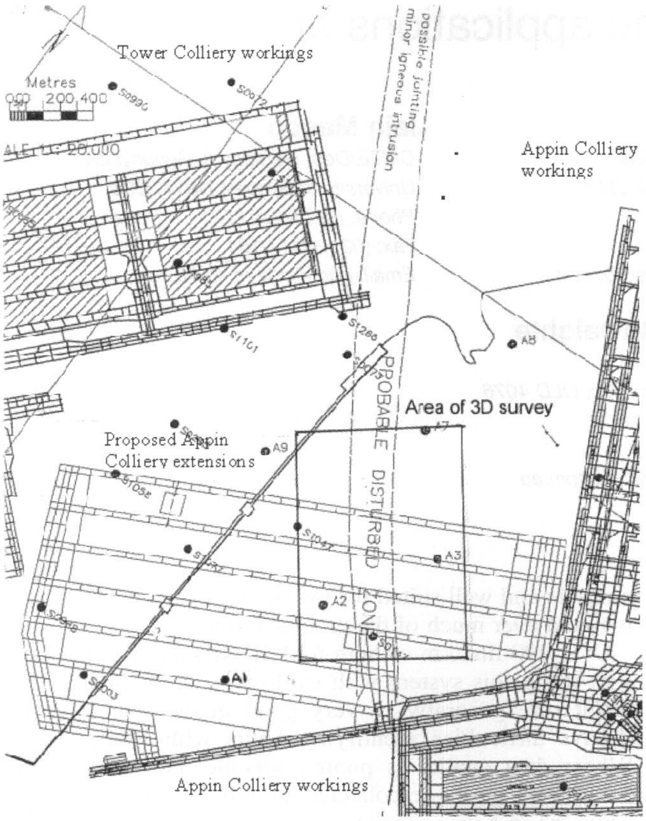

Figure 1. Map showing mine plans, the area of 3D seismic survey and the locations of exploration boreholes (the numbered dots).

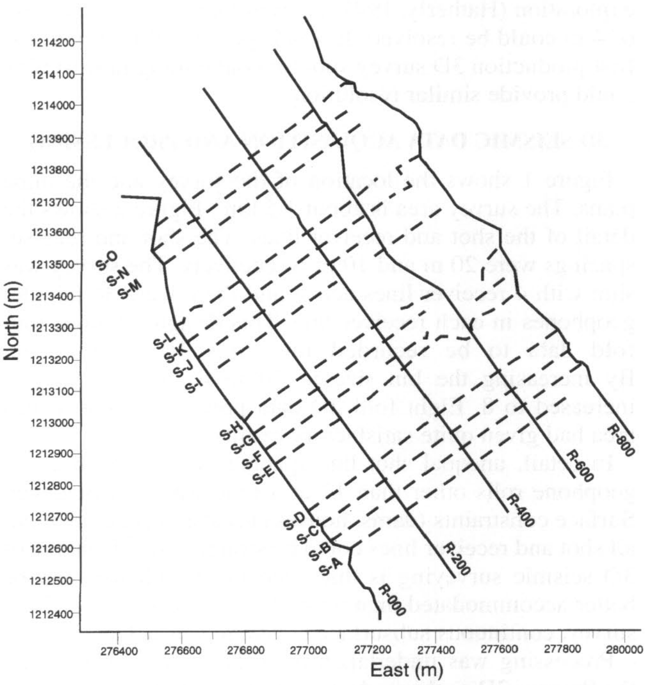

Figure 2. The full 3D survey layout. Five receiver lines (solid lines numbered R-000 to R-800) run from the Southeast to the Northwest and the shot lines (dashed lines S-A to S-O) run from the Southwest to the Northeast.

due to a perched water table created by heavy rain prior to the survey. To accommodate the cycle skipping, only those first breaks which were from the same refraction event were used for the refraction statics.

Otherwise, the data and the remainder of the processing sequence were typical for high resolution seismic reflection surveying for coal. Dominant frequencies were slightly greater than 100 Hz and velocities were in the range 3,500 m/s to 4,000 m/s. Gapped deconvolution and zero phase wave shaping deconvolution were both applied. 3D surface consistent residual statics were applied and there was a final application of FX-Y deconvolution to all traces in the 3D stack volume. Given the absence of steep dips and large structures, migration was not used.

INTERPRETATION

To interpret the 3D data set, the interactive program *SeisWin* was used. This is a general purpose signal processing and display program that runs on a PC under the MS Windows environment. It is designed for the analysis of various types of seismic and radar data sets. To allow interpretation of the 3D data, modifications were made to provide:

- easily manipulation of large volume data sets,
- auto-tracking utilities for reflection interpretation, and
- attribute analysis capabilities.

For the auto-tracking, interpolation between time samples (1 millisecond) was needed to obtain a smooth interpreted horizon. Seismic trace attribute analysis is rarely used in coal mining but we were interested in exploring its application in the interpretation of the subtle geological features. Capabilities were added to determine and display the instantaneous frequency, phase and amplitude (Taner et al., 1979) for vertical sections and for the interpreted horizon.

Figure 3 shows a typical in-line section running from southeast to northwest. The target Bulli coal seam reflector is at a time of around 0.3 seconds. It is continuous across the section and has a slight dip of about 3° to the northwest. Similar results were obtained for the other sections in the 3D volume and the overall interpretation is that there are no significant structures present.

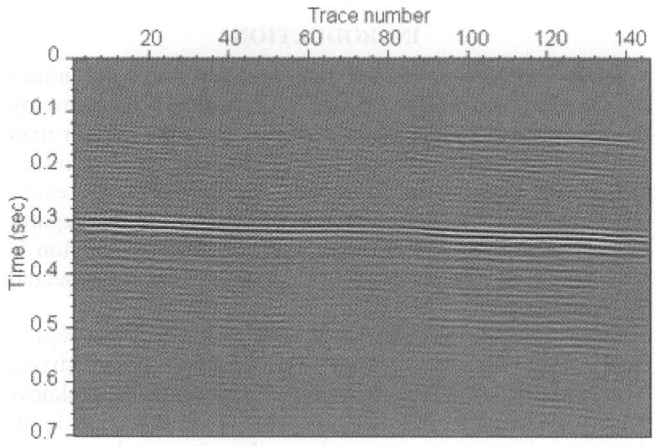

Figure 3. A typical seismic section (inline 42) from the 3D seismic volume.

The two-way reflection times are presented as a contour image in Figure 4. It is evident that there are two dipping regions A and C are separated by a flat zone B. The contours are at an interval of just 1 millisecond two-way time and are smoothly varying. This suggests that the vertical resolution in these data is very high. A simple test of this involved increasing the reflection times for the first 45 inline sections by one time sample. The result is shown in Figure 5 in a 3D perspective view. There is an obvious linear structure along inline 45.

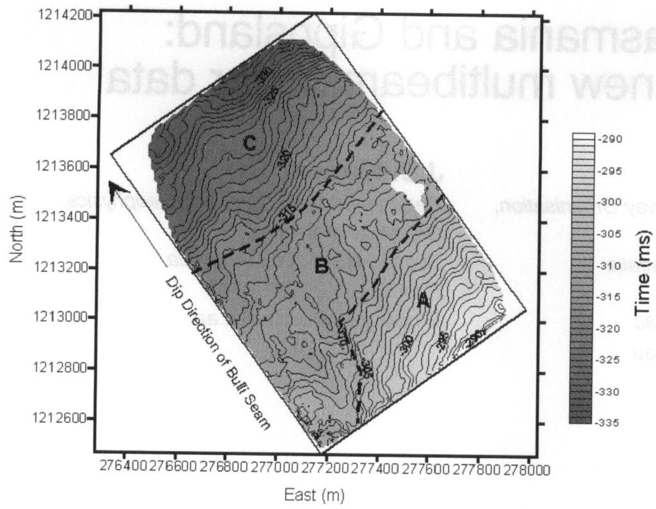

Figure 4. Two-way reflection time contours for the Bulli seam.

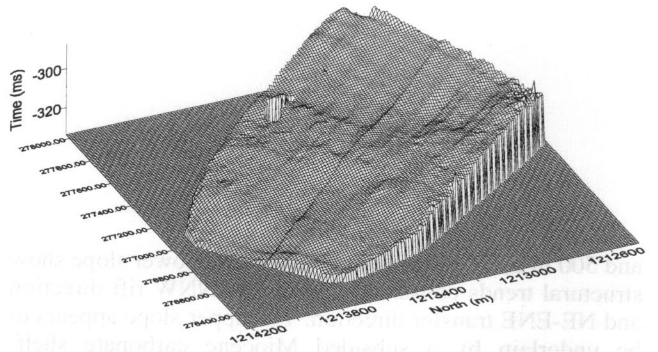

Figure 5. 3D perspective view of two-way reflection times viewed from the northwest with the times to the first 45 inlines increased by one millisecond.

While wavefront smearing would prevent a true fault from having such an abrupt expression, the accuracy of the computer time picking and the proximity of the lines on the 3D grid clearly allows the mapping of a very precise time surface. Subtle variations in the surface can thus be identified. It could well be that the vertical resolution of structures in these 3D data is better than 2 m.

This example also illustrates that in this context, vertical resolution is well below a half period criteria which is 5 milliseconds in this case. Fault mapping is quite different to resolving thin beds (Widess, 1973) and is mostly concerned with resolving lateral variations in reflector level. On a 2D section, a displacement in a reflector can be confidently picked by eye if it is of more than half the period of the reflection wavelet. However, accurate computer picking of an exact phase on the reflector wavelet allows very accurate tracking of the reflection time. It is when the reflection times from one bin line to the next can be compared, that subtle but consistent features become apparent. Hence for this type of application, 3D seismic surveying is an extremely powerful tool.

Maps of the instantaneous phase, instantaneous frequency and instantaneous amplitude for the Bulli seam reflection were also prepared. The instantaneous phase map showed values in the range 2.8 radians to 3.1 radians and indicated that no significant variations in wavelet interference, ie reflector separation, were present. Constant overburden conditions were suggested by the instantaneous frequencies, which were mainly from 0.3 to 0.4 radians/ms.

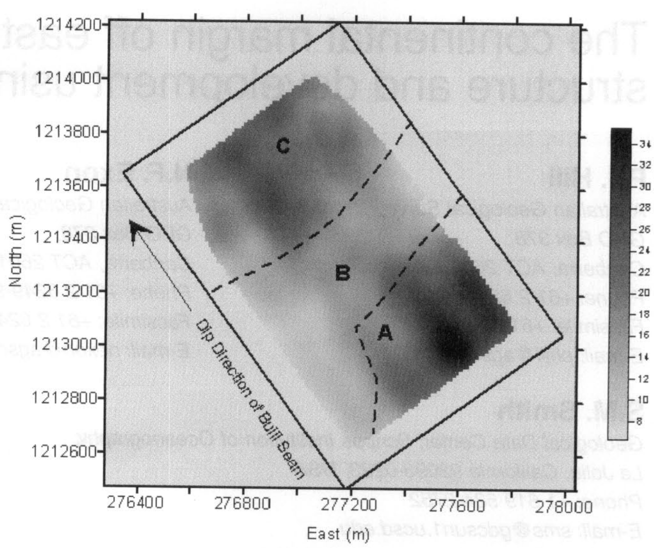

Figure 6. Instantaneous amplitude distribution for the Bulli seam reflections. Areas A and C have relatively higher reflection amplitudes and coincide with the regions of relatively steeper dip in Figure 4.

The initial map of the instantaneous amplitudes of the Bulli coal seam reflections showed patterns that mirrored the survey grid. When smoothed as in Figure 6, the reflection strength varied between nominal values of 6 to 36 and formed a pattern similar to the dip pattern in Figure 4. Zones A and C have relative high amplitudes while zone B has relative small amplitudes. We have no explanation for this correlation but it could be stress related and possibly due to lithological changes in rock properties influencing the structure. An explanation may become available once the area is mined.

CONCLUDING REMARKS

On the basis of the results of this survey, further 3D seismic surveys for detailed geological evaluations prior to longwall mining at Appin were recommended. In late 1997 a second 3D survey which covered 2.5 km^2 to the immediate southwest of this region was successfully shot. A third survey covering the northern part of the area is scheduled in mid 1998. In the Bowen Basin in Queensland, BHP shot a 3D seismic survey over the proposed Goonyella underground mine in March 1998. Nearby, the Burton Mine has also just undertaken a 3D seismic survey.

It is too early to report on the experiences of these surveys but clearly there is enormous interest in the potential use for 3D seismic surveying for detailed coal seam exploration. Specific coal seismic interpretation procedures will need to be developed. SeisWin is an excellent interpretation platform and a current research grant from the Australian Coal Association Research Program to CMTE will facilitate its on-going development.

ACKNOWLEDGMENTS

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