2006

Advances in Surface Seismic Acquisition, Processing and Interpretation

A. Rodegheiro
Illawarra Coal, BHP Billiton

L. Fredericks
Illawarra Coal, BHP Billiton

Publication Details
This conference paper was originally published as Rodeghiero A and Fredericks, L, Advances in Surface Seismic Acquisition, Processing and Interpretation, in Aziz, N (ed), Coal 2006: Coal Operators’ Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2006, 132-150.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au
ADVANCES IN SURFACE SEISMIC ACQUISITION,
PROCESSING AND INTERPRETATION

Allen Rodeghiero\(^1\) and Luke Fredericks\(^1\)

**ABSTRACT:** Seismic Reflection surveys and borehole drilling have been the two primary exploration tools used in Illawarra Coal’s operations in the Southern Coalfield. For the past 10 years the exploration department has been using their in house acquisition system developed by BHP. However, this system was limited to 180 channels and two dimensional surveys and a more advanced system was required with a much larger channel capacity for modern three dimensional seismic surveys. In July 2004 Illawarra Coal acquired a more advanced seismic acquisition system from Vibtech in the UK, which enabled high resolution three dimensional surveys to be conducted.

Acquisition, processing and interpretation techniques have also been improved through the use of three component inseam geophones, depth conversion of data, shear wave acquisition for the near surface interval, statistical analysis and integration with other data including boreholes, downhole geophysical logs, seismic, airborne magnetics, surface and inseam mapping, surface to inseam drilling and inseam drilling.

Processing and interpretation techniques have been refined to suit the local geology within the Illawarra region. Some of the methods used to improve the value of the interpreted data include:

- Depth Conversion
- Full waveform sonic and VSP to improve velocity analysis
- Acquisition, processing and interpretation of three component geophones at coal seam level to define structural lineaments, stress domains and possible dykes and
- Modelling of strata gas reservoirs from seismic and downhole geophysical data

**INTRODUCTION**

Seismic reflection surveys have evolved to become an integral part of resource exploration. This technique has evolved to allow access to sensitive land areas and also rugged terrain and minimising land disturbance. Since the early 1980’s seismic surveys are an integral component of exploration programs to ensure that future mining areas are free of detectable structure and hence contributing to the effectiveness of mine planning.

Illawarra Coal has recognized the value of high resolution seismic surveys, resulting in the purchase of a new acquisition system in 2004 known as the Vibtech Infinite Telemetry System with an 840 channel capacity to advance our seismic acquisition into the 3D realm.

Illawarra Coal’s mining lease areas can be subdivided into two main geographical regions. The Northern area consists of relatively undulating countryside. The region is moderately populated and consists of a number of townships, rural farmland and considerable infrastructure such as main highways, high voltage transmission lines, gas lines, water reservoirs and canals. The Bulli seam is mined in this region by Appin, Douglas and West Cliff Collieries. Within the southern area, Dendrobium Colliery mines the Wongawilli seam and is located within Sydney Catchment Authority land which consists of deeply incised gorges and rugged bush. Figure 1 shows the location of Illawarra Coal’s operations.

\(^1\) BHP Billiton, Illawarra Coal
REGIONAL GEOLOGY

BHP Billiton Illawarra Coal operates in the Southern Coalfield, which is the southern portion of the Permo-Triassic Sydney Basin, as shown in Figure 2, and contains the Illawarra Coal Measures of Late Permian Age. Sandstones, shales and mudstones of the Narrabeen Group, which in turn are overlain by the Hawkesbury Sandstone, a massive quartzose sandstone unit that varies in thickness due to erosion, overlie the Illawarra Coal Measures. The Wianamatta Group lies stratigraphically above the Hawkesbury Sandstone and is the uppermost unit in the northern part of the Southern Coalfield.

Within the Illawarra Coal Measures the Bulli Coal is the uppermost coal member and is the only economic seam that is currently mined at Appin, Douglas and West Cliff Collieries. The Wongawilli Coal, some 30-40 metres below the Bulli Coal, is mined at Dendrobium colliery.
Seismic Reflection surveys have been conducted in the Illawarra Coal region since the early 1970’s. Throughout the years the technology and techniques have improved increasing the confidence of information obtained. The improvement of the data quality has resulted in seismic exploration methods becoming an integral part of resource calculations.

BHP Collieries developed its own in-house seismic acquisition system in the early 90’s which had a 180 channel
capacity. This limited the surveys to two dimensional lines and small low-fold 3D. Although providing high
resolution the system was inhibited by slow acquisition time, reduced flexibility in surface access for acquisition
and limited off-set capability. The new equipment commissioned in June 2004 is the Vibtech Infinite Telemetry
System with an 840 channel capacity. This has allowed the department to undertake an extensive 3D campaign
with high resolution data to accurately image relatively small faults at coal seam level. On good quality 2D data,
faults are only detectable when their vertical displacement is greater than seam thickness. With good quality 3D
data, image processing allows small displacements to be imaged on the coal seam reflection surface. Resolution
of faults down to half seam thickness displacement is possible with this method. The new system utilises
telemetry to transmit the data from the digitisers to the recording station. This allows rapid data return and
acquisition in difficult terrain.

2D surveys are conducted in areas where access is limited or low impact access is required due to environmental
constraints. Historically dynamite has been used as the primary energy source and is preferred. However, the
majority of exploration areas are located in environmentally sensitive, residential and/or rural areas and the use of
alternate source energy is currently being investigated. The use of low impact seismic sources such as Vibroseis,
Mini-Vibroseis and Mini-Sose mechanically input seismic energy into the ground via heavy equipment,
eliminating the need for drilling and explosives.

Early seismic surveys utilised Oil field technology with low often single fold 2D data acquired over large regions.
Broadly spaced shot and receiver locations provide low resolution data quality, in excess of 40m at coal seam
level. Data recorded from these early surveys were only able to identify large scale structures and coal seam
continuity. There is a specific example where a fault with a 60m throw was not detected.

During the 1980’s as technology improved substantial experimentation were conducted to improve the seismic
method. Various source configurations were trialled including directional shot and multiple shots. Directional
shots were used to direct the source energy toward the coal seam, in theory to achieve a stronger reflection signal
and better resolution of the coal seam. Multiple shots in the same hole were tested to enable a more accurate
analysis of the slower velocity weathered zone in the near surface. However, these techniques were not adopted
due to poor results and limited resolution.

Source and receiver configurations were tested extensively to determine the optimum parameters for reflection
techniques on coal seam targets in the Southern Coalfields. This led to higher resolution closely spaced receiver
and nominal source spacing used in modern survey techniques.

Good results from the various trials and experiments throughout the 80’s and early 90’s encouraged BHP
Collieries to develop their own seismic acquisition system. In 1993 the Surface Seismic Portable Transient
Recorder (SSPTR) system was developed. This system consisted of a 180 channel capacity and a 24 bit system
capable of recording at a 0.25 millisecond sample rate. Resolution was significantly improved resulting in a
useful tool for defining any fault structures that would impact on underground coal mining operations. Vertical
displacement down to 5 m could now be imaged.

The primary technique before 2004 was high resolution 2D surveys, which defined the boundaries of the current
mine plans. Parameters were nominally 5 to 20 m line spacing for shot and geophone locations with 450 g of high
explosive placed at the base of 14 m drill holes, which places it below the weathering zone. These shot holes are
then stemmed to the surface with gravel in order to focus the explosive shockwave below the slow velocity layer
and prevent venting of material. Initiation of the shots is via a coded UHF signal from an Encoder at the Central
Control Unit known as the ‘Macha or Boom Box’ in which, a time break is set to synchronise the detonation of
the shot with the recording system. The signal is received by a Decoder wired to the detonator at the shotpoint
which detonates the source via an electrical signal.

Trials have been conducted using Vibroseis, Mini-Sose and Mini-vibe as a replacement source energy to be used
in areas where drilling of shot holes and the use of dynamite are not desirable. These areas include roads, higher
density residential and environmentally sensitive areas. In late 2005 Mini-Vibe trials were conducted over a 2D
line that had already been acquired using the traditional dynamite source with the same acquisition parameters for
a direct comparison of data quality. Figure 3 displays an image of the mini vibrator during acquisition.

The results of this trial were encouraging with reasonable data quality and reflector continuity, making it a viable
option in sensitive areas. The dynamite source energy, however, has a much broader dynamic range and provides
better data quality and hence higher resolution. Further trails are to be conducted later this year using a Hemi-60,
30 tonne vibrator to verify if better data quality can be obtained with a higher energy vibroseis source.
An expression of interest by BHP Billiton Illawarra Coal for a new seismic system in 2003, resulted in Vibtech Infinite Telemetry System being selected and was commissioned in June 2004. The commissioning determined that the Vibtech system complied with BHP Billiton and Australian standards along with the operational requirements of Illawarra Coal.

The Infinite Telemetry system is a hybrid of cellular and cable communication. The cellular nature of the Remote Acquisition Units (RAU) (Figure 4) free the design and deployment restrictions previously experience in many full cable systems. Each RAU has four channels with Illawarra Coal purchasing an 840-channel system. Central Access Nodes (CAN) (Figure 5) receive the cellular data from the RAU’s and send it via optic fibre cables to the Central Computer Unit (CCU) for recording. This provides a rapid data transfer by reducing the data traffic, particularly when operating all 840 channels.

The equipment has been designed with a comprehensive status, alarm and fault detection system, which provides the operator and maintenance personnel the facility to monitor the operation of the equipment and to quickly identify any faults. RAU’s and CAN’s have built in LED systems that give instant diagnostics of fault and operational modes. The operator at the CCU has a comprehensive remote display of the majority of the diagnostics, which are easily viewed, updated and on many occasions can be remotely remedied.

One of the advantages of using Vibtech was the ability to provide hardware and software upgrades to suit Illawarra Coal requirements. This is usually difficult with larger oil based supplier equipment. During the time of purchase the system was the lightest per channel on the market, which has benefits for BHP Billiton Health Safety Environment and Community (HSEC) standards and permits the use of a small field crew for acquisition. Lithium-ion batteries power all the field equipment which dramatically reduces equipment weight compared to traditional lead-acid batteries. Future refinements and technology advancements will enhance the equipment and improve the acquisition process.
Fig. 4 - Remote Acquisition Unit, RAU

Fig. 5 - Central Access Node, CAN
The main advantage of the new system is the capability to conduct 3D surveys. The 840 channels allows a lateral surface cover of approximately 1km$^2$ in a static layout and provides enough redundancy to roll the equipment along while shooting for unlimited size surveys.

The IT system has a high dynamic range with the ability to record down to 0.25 millisecond sample rates. Data transfer from the RAUs to CANs is wireless via a 2.4 GHz ISM band allowing rapid data transfer. Geophones are 48 Hz and are grouped into sets of 4 which are digitised by a single RAU. All RAU’s receive a GPS timing signals via a VHF radio, this ensures an accurate and unique time break for each shot.

The fibre optic, despite allowing rapid data transfer, has also become one of the major issues during acquisition. The fibre is military specification, with a tough Kevlar and plastic coating which is deployed between CANs. Animals such as kangaroos, rodents and livestock often chew through the casing cutting the fibre connection and lead to substantial costs for repairs. Future development of a 5.8 GHz radio Cell-Link between CANs will eliminate the need for the fibre. Figure 6 displays an advanced digitising unit that includes GPS timing on all RAUs. This RAU is currently in development and expected to be available in 2007. In some locations, such as dense bush and undulating terrain, the VHF signal is interrupted and it is not possible to acquire the correct timing. The GPS on each RAU would eliminate this problem. As GPS technology advances the RAU’s could also self survey, which will reduce site survey costs.

Fig. 6 - Future RAUs with inbuilt GPS units for timing and survey

2-D AND 3-D SEISMIC METHODS

Survey Design

Survey parameters used by Illawarra Coal have been refined through significant testing to optimise the quality of the data received. Two and three dimensional surveys are both widely used. Despite the push to conduct 3-D surveys with their superior resolution at coal seam level and total area coverage, 2-D lines must still be used to acquire data in less accessible and environmentally sensitive areas.
2-D Seismic Surveys

The 2-D method used by Illawarra Coal involves a line of receivers, geophones, usually greater than 2 km to provide and adequate data spread. The inline distance between receivers is 5 m-20 m, shot points are placed at every 2\textsuperscript{nd} or 3\textsuperscript{rd} receiver. Fold is calculated over the length of the 2-D survey and denotes the number of common reflection points or common mid points (CMP) that occur at each geographical location along the line. The higher the fold the better the resolution obtained from the data. In a typical 2-D survey design a nominal fold of 30 is required to obtain the desired resolution. As discussed earlier the quality of seismic reflection data varies from site to site and field parameters must be modified to achieve a similar quality result. Table 1 below outlines the different field parameters used in mine areas with different geological conditions.

Table 1 - Variations in field layout parameters

<table>
<thead>
<tr>
<th>Mine Area</th>
<th>Shot Spacing</th>
<th>Receiver Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appin Area 3</td>
<td>5m</td>
<td>10m</td>
</tr>
<tr>
<td>Dendrobium Area 2 &amp; 3</td>
<td>7.5m</td>
<td>15m</td>
</tr>
<tr>
<td>Douglas Area 7 &amp; 8</td>
<td>10 m</td>
<td>20m</td>
</tr>
</tbody>
</table>

Reasons for the change in data quality include;

- Changes in surface lithology – Sandstone / Shale
- Residual soil depths and weathering zone
- Nature of topography
- Residential, environmental and infrastructure obstacles.

To achieve higher fold along a 2-D line with a major obstacle, for example a highly incised gorge, additional shots are included in the design on either side. This increases the nominal CMP coverage beneath the structure resulting in better resolution and continuity of coal seam reflectors. Shot spacings are reduced at the start and end of 2-D lines to boost the fold and increase resolution on the geographical survey limits. Figure 7 displays a survey configuration of a 2-D survey acquired over an 80 m gorge and the resulting 2-D seismic section.

![Fig. 7 - Increased number of shots either side of the gorge to boost fold](image-url)
3D Seismic Surveys

To date there have been a total of twelve 3-D surveys acquired in the Illawarra Coal mine lease areas. Two of which were conducted prior to the commissioning of the Vibtech equipment using contract equipment. There is considerable variation in design depending on the depth and nature of the targets. Prior to the purchase of the new equipment, orthogonal geometry was used for acquisition and although full coverage was obtained there were a number of discrepancies noted in the data.

Orthogonal geometry requires the shot lines to be positioned perpendicular to the receiver lines. Figure 8 displays the acquisition footprint resulting from orthogonal survey design from the Cataract 3-D survey acquired in 1998. This occurs when offset and azimuth ranges cause a deterioration in fold in linear zones. Parallel geometry such as this is commonly used for marine surveys and requires small distances between shot and receiver lines for adequate cross-line sampling to avoid this issue.

![Fig. 8 - Acquisition footprint observed in the Cataract 1998 3D survey](image)

Orthogonal geometry requires the shot lines to be positioned perpendicular to the receiver lines. Figure 8 displays the acquisition footprint resulting from orthogonal survey design from the Cataract 3-D survey acquired in 1998. This occurs when offset and azimuth ranges cause a deterioration in fold in linear zones. Parallel geometry such as this is commonly used for marine surveys and requires small distances between shot and receiver lines for adequate cross-line sampling to avoid this issue.

To minimise the impact of this phenomena an alternate survey design known as slant geometry was implemented. Slant geometry is simply a method of positioning the shot and receiver lines at a discrete angle from one-another to more evenly distribute CMP locations for a smoother result. Slant geometry tends to have better distribution of offset and azimuths for low fold data (Vermeer, 2002). This results in increased data quality and reduced survey costs. This technique has been adopted for 3-D survey design with an offset of $45^\circ$ found to have the best result in fold coverage and data resolution.

Calculating fold, azimuths and offsets is essential for a successful survey. High fold is necessary for suppressing the recording noise, including ground roll created by the source and background noise such as wind, roads or overhead powerlines. In a 3-D survey fold is calculated by the number of CMP traces that fall inside a 10 x 10 metre bin in the survey geometry. For optimum results surveys in the Illawarra Region are designed to achieve 20 to 30 fold using a 600 m offset limit. This has been found adequate to minimise the signal to noise ratio.

MESA Field software is used for the design process. It is a user friendly PC based software in which surveys can be designed and shot synthetically to provide optimum field parameters and fold coverage. Figure 9 is an image of the MESA software display showing an aerial photo of the survey area with nominal shot and receiver positions overlain by an image of the resulting fold distribution. This is a powerful tool for quickly and easily designing a 3-D survey with optimum field parameters for the best overall result.

Once the design is finalised, the software has the ability to produce survey scripts created from the design that can be loaded directly into the acquisition system to enable an immediate start to the survey.
Acquisition and Logistical Challenges

The lightweight nature of the equipment has allowed a smaller crew for acquisition, with an average of one observer, one shot firer and five other field personnel. This results in constant work for the group, who are involved with the flagging, pegging of shot and receiver locations, drilling, acquisition and rehabilitation of the site.

Safety is the primary focus of many field operations. The seismic crew has had extensive training covering all aspects they will encounter in the field. There is an initial BHP Billiton induction covering all 15 HSEC standards and 10 fatal risk protocols. Individuals are then trained and tested on the entire seismic standard operating procedures as well as undertaking a 4WD training course. The crew is also involved in Leading Zero harm, BHP Billiton safety initiative, which highlights any safety risks in the field.

Logistical issues such as land access, highways and underground services can be taken into consideration in the design stage, where modifications are made to the design to negotiate a difficult area. Alternate sources such as Vibroseis, Mini-vibe and Mini-Sose have also been used as an alternate source to dynamite to minimise the environmental impact. Technology advances such as Magneseis detonators were developed as an alternative to electric detonators for shooting in close vicinity to powerlines.

The following are examples of 3-D designs that required substantial planning in difficult areas:

High voltage transmission lines and high pressure gas lines passed through a West Cliff 3-D survey area as shown in Figure 10. An exclusion zone around the gas line of 100 m was required for shot locations and only low impact vehicles, John Deer Gators, were permitted to drive over the gas line easement. Shots holes were not drilled under the power lines due to the safety reasons and where holes were required close to power lines, Magneseis detonators were used.
Magneseis detonators were adopted by Illawarra Coal in the 1990’s as safety concerns were identified that electrical detonators may be initiated by electrical currents produced by the ambient electromagnetic field associated with high voltage power lines. Magneseis detonators, as the name suggests, use a magnetic coil that produce a specific electromagnetic field to initiate the shot.

![Diagram of 3-D survey Westcliff_5_2](image)

**Fig. 10 - Logistical issues of 3-D survey Westcliff_5_2, high tension power lines and gas line**

A Douglas 3-D survey shot in January 2005 faced a number of logistical issues including: the Hume Highway, a large gorge and the gas line. The telemetry nature of the equipment enabled receivers to be placed on both sides of the Hume Highway, (Figure 11) which allowed data to be collected from under the highway. In the centre of the survey there was a large gorge where shots and receivers could not be positioned. To overcome the issue, additional shots and receivers were positioned around the gorge to boost fold under it.

**SEISMIC PROCESSING AND INTERPRETATION**

Seismic data consists of digital samples of seismic energy recorded at each channel or geophone at discrete intervals in time series. For example in a typical 3-D seismic survey, digital data must be recorded simultaneously at 840 channel locations at a sample rate of 0.5 milliseconds. The record length for these shallow reflection seismic techniques is usually one second which equates to 1.7 million samples recorded at any one shotpoint. In a typical 3-D survey acquired by Illawarra Coal there would be anywhere up to 2000 shots recorded for the entire survey. Seismic data processing is required to sort this data into a useable format and includes the application of mathematical algorithms to boost signal and remove unwanted noise. This is required to produce two and three dimensional images of the subsurface geological structure. Reliable and accurate processing techniques are required to convert raw seismic shot records into interpretable seismic sections. Figure 12 displays the seismic energy recorded from a single shotpoint in a 3D survey.
Fig. 11 - Logistical issues of 3-D survey Douglas_8_1, Deep Gorge, Hume Highway and gas line

Fig. 12 - Typical shot record from a 3D seismic survey

This raw data record displays the seismic data recorded and the inherent noise associated with ground roll energy, noisy channels and loss of signal with depth.
Processing Flow

The processing flow applied to the seismic data is dependant on the nature of the geological subsurface at any one site and may vary greatly from location to location or changes in geological environment. As discussed in a previous section the geological environments in the Illawarra Coal exploration region are essentially subdivided into two main regions with significant differences in topography and geological overburden.

Although differences exist in velocity analysis, deconvolution and residual static calculations of various datasets the processing flow or set of processing operations remains the same for all seismic data acquired to ensure interpretation reliability across the exploration areas.

The data processing is contracted to Velseis Processing in Brisbane who apply a standard processing flow to all datasets and produce four final versions of each with different processing parameters applied. The data can then be viewed with different processing applied for improved structure interpretation. The different products supplied by Velseis include:

- Filtered and Migrated with Spectral Whitening,
- Filtered and Migrated,
- Unfiltered Final, and
- Unfiltered and Migrated Stacks.

The nominal processing sequence is as follows:

1. Reformat Promax internal format
2. Edit Bad & Reverse Polarity Traces
3. Apply geometry
4. Apply Refraction Statics
5. Correct for Spherical Divergence
6. Surface consistent Spiking Deconvolution
7. Spectral Whitening
8. 1st Pass Velocity Analysis
9. 1st Pass Residual Statics
10. 2nd Pass Velocity Analysis
11. 2nd Pass Residual Statics
12. Common Midpoint Point Trim Statics
13. Pre-stack Automatic Gain Control
15. 2D Steep Dip Explicit FD Time Migration, Smoothed Stacking Velocities
16. Post stack frequency enhancement
17. Bandpass Filter

The refined processing procedures provide two dimensional sections of the subsurface geology and the coal seam reflectors are then digitised to provide a structural surface of the coal seam. Figure 13 displays a fully processed seismic section with the Bulli seam and faults interpreted.

Interpretation and Results

The interpretation process involves viewing all seismic sections in the survey and interpreting or picking the reflected energy from the Bulli coal seam. All data can then be depth converted using another processing technique, where seam depths from borehole data and mine levels are tied in with the seismic picks to convert the seismic data from time domain into true vertical depth.

Initial interpretation of the data involves picking the Bulli seam reflector, mapping any faults and/or disturbed zones. Figure 14 is a three dimensional topographic image of the top of the Bulli seam created from digitised picks of the interpreted Bulli seam reflector from a recent 3-D survey. The picks are extracted from SEGY files as x,y,z coordinates in which there are approximately 10,000 points for every 1km$^2$ of survey data. The SEGY file data is viewed on SeisWin, software which was created by Dr Binzhong Zhou of CSIRO (Figure 13 and 15). These figures display fault structures that can be clearly identified on the sections.
Fig. 13 - 2D seismic section showing Bulli seam and interpreted faults

Fig. 14 - Bulli seam surface from a recent 3-D Seismic survey
The SeisWin Depth conversion involves picking the Bulli seam reflector and saving the picks into the seismic lines file. The picks from all the lines in an area are then tied to one another so that the Bulli reflector time on one line correlate to that on another. This creates a Bulli time surface which is in turn is converted into a depth horizon by applying a velocity correction to the time surface. Currently there are 250 2-D lines and 12 3-D surveys that have been depth converted creating good control for seam structures.

One of the main challenges facing Illawarra Coal is to predict areas where longwall mining will be hindered by small structures of seam thickness displacement. This is difficult from 2-D surveys as the resolution and line spacing of the technique often is not adequate to reliably pick the zones. Much more success has been gained from 3-D surveys where disturbed reflectors can be mapped through a zone (Figure 16).
Methane gas trapped in sandstones above the Bulli seam (known as strata gas) can be recognised on borehole geophysical logs. Recent work has been done to map the distribution of gas by identifying it in borehole and seismic data. The presence of gas in overlying strata can be recognised on 2-D and 3-D seismic sections due to the attenuation of seismic energy with depth. Gas attenuates the seismic signal and results in the loss of reflected energy below the gassy zone. See Figure 17.

Seismic attribute mapping a technique used by the petroleum industry is currently being investigated as possible tool for mapping the lateral distribution of strata gas.

Igneous intrusions are usually mapped by their magnetic susceptibility through aeromagnetic surveys. Some of the intrusions in the Southern Coalfield, such as the Nepheline syenite have low magnetic responses similar to the sedimentary host rocks and cannot be identified using this technique. In these areas seismic has been utilised to identify jacking between the coal seams due to sill intrusions. When deposited, igneous material intrudes weak bedding zones and coal seams destroying the coal quality and lifting up overlying sequences. Figure 18 displays a seismic section which has confirmed the presence of a known sill by the changes evident in strata thickness and loss of seismic signal below.
VERTICAL SEISMIC PROFILE (VSP)

Vertical Seismic Profiling, VSP, is the process of recording seismic energy in geophones placed down a borehole. Illawarra Coal has been installing tri-axial three-component geophones, two horizontal and one vertical, at the Bulli seam in all of their coal quality holes for the past 20 years, in some instances a geophone string with 60 channels down the length of the borehole to the Bulli seam. The new seismic digitisers are easily attached to the borehole geophones and are incorporated into 2-D and 3-D surveys providing an additional data-set.

The VSP is where the compression P-waves and shear S-waves are analysed to determine geological conditions such as stress fields and vertical structures. P-waves travel faster along the primary horizontal stress direction and slow when the pass through vertical fractures (Figure 19). When the S-wave passes through a fracture it splits into two separate components, SV-wave (vertical) and SH-wave (horizontal), the ratio between the two give an indication of the location and orientation of the vertical structures (Figure 20).
The principal stress direction is very important for effective mine planning as the orientation of the longwall must be parallel to the stress direction to minimise strata control problems. The stress direction is determined by analysing the arrival times of primary (compressional) seismic energy from each shotpoint on a survey. When the velocities are plotted in plan view a linear trend of high velocities becomes apparent and the principle stress direction determined. Figure 21 displays the principal stress direction determined by breakout analysis from the borehole acoustic scanner which is coincident with the maximum velocity and interpreted direction of maximum horizontal stress from the VSP analysis.
CONCLUSIONS

Advances in seismic acquisition systems, survey techniques, data processing and data analysis have been utilised by Illawarra Coal to significantly increase confidence in geological models of coal resources.

Integration of this broad range of datasets can provide a very detailed and accurate model of the coal resources to ensure a secure future in mine production and operations.

REFERENCES