PREMING INVESTIGATIONS FOR THE PREDICTION
OF HAZARDS AHEAD OF FACES

By

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ABSTRACT

The most appropriate technology needs to be applied to preming geological investigations to achieve reliable data for predictions of geological conditions ahead of mining. The paper describes the application of various investigatory techniques in BHP's Illawarra Collieries which are used to provide reliable assessments of structure, the nature of the coal and surrounding strata, and the fluids contained in the strata. The techniques used include surface seismic, in-seam seismic, borehole drilling, electromagnetic and aeromagnetic surveys, hydrogeological investigations and in-mine mapping. The results of various case studies are presented as examples of the application of techniques.

INTRODUCTION

In today's sensitive economic climate with the demands for high productivity coal faces, the intersection of unexpected geological hazards at the coal face can prove disastrous. In the past, geological investigations could often best be done using a continuous miner. Today's high tonnage rapidly advancing coal faces demand reliable predictions of coal seam geology immediately ahead of the faces and in the overall areas to be mined. Accurate geological knowledge is imperative to efficient mining. Investigations have to maximise the information achieved at minimal cost. The most appropriate technology has to be applied to site specific problems. The investigations need to provide accurate information on the three dimensional structure of the coal, the nature of the coal and its quality, the nature of the strata surrounding the coal and the influences exerted on these materials by their contained fluids and the prevailing stress.

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To achieve the above aims the Illawarra coal geology section of the BHP Steel International Group, Collieries Division is applying its efforts in the Southern Coalfield (Figure 1) of N.S.W. to define the geological and geotechnical environments for mining under two time scales

1. the short term i.e. up to 3 years, and
2. the long term i.e. 5 to 10 year period.

Figure 1 BHP Illawarra Collieries - Location

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Premining investigations have been advanced to various stages throughout BHP's Illawarra coal mining leases and coal exploration authorisations. Regional assessment (i.e., exploration Stage 1 - Standards Association of Australia 1982) has been conducted throughout the whole area. Commercial evaluation (exploration Stage 2) has been conducted in all areas immediate to the mine workings but is continuing in the more remote areas. These investigations are used to upgrade data to suitable levels of confidence for investment decisions to be taken (Johnson et al., 1986). The exploration Stage 3, mine planning, is being conducted on a routine basis in areas critical to mine planning and exploration Stage 4, bulk sampling and/or trial mining, is considered as the stage of immediate premining investigations from the underground workings.

Until the early 1980's the principle exploration tools for coal were the drilling rig and the continuous miner. Boreholes were drilled on one kilometre or greater spacings to intersect the coal seams. Coal seam structure between boreholes was interpolated. Because of the nature of mining, more detailed information on structures was obtained from probing with the continuous miner. Some geophysical techniques such as oil field type surface seismic were applied but were found to be too coarse for reliable prediction of structures which could affect coal mining. The late 1970's and the 1980's have seen a technological revolution in the field of coal seam exploration. To satisfy the demands of coal geologists, geophysical techniques have been borrowed often from the oil industry and enhanced to provide better resolution as required for coal.

**EXPLORATION TECHNIQUES**

Techniques are now applied as appropriate including:

1. high resolution seismic techniques from the surface to locate major faults,
2. in-seam seismic techniques from underground to locate smaller scale structures,
3. geophysical techniques such as EM and aeromagnetics for the location of cindered coal, dykes, intrusions and strength data and tested for gas content. Geophysical logs are used for further indications of lithology, gas contents, water-bearing strata and rock strengths. Hydrogeological data are obtained from boreholes for determining contained fluid pressures and permeabilities of coal seams and surrounding strata to assist with the design of gas drainage projects and to provide information on the potential for outbursts.

In-seam drilling is used with success to locate and define structures in advance of longwall operations. Ross et al. (1987) described the success of drilling for geological investigations in BHP's McQuarie Collieries. In the Illawarra, the in-seam drilling technique is used mainly for seam gas drainage and for occasional checking of structural predictions based on in-seam seismic. The future potential in the Illawarra for longhole drilling is high.

The various techniques for exploration are well described by Johnson et al. (1986).

**REGIONAL EXPLORATION**

Regional investigations for exploration Stage 2, commercial evaluation, are conducted to provide suitable levels of confidence for investment decisions. Sufficient field data are required for the formulation and contrast of alternative mine development and coal production plans, the analysis of risk factors, market surveys, etc. The objectives as defined in Johnson et al. (1984) are:

1. to accurately delimit prospective mining blocks,
2. to determine actual ranges of local variations in coal seam characteristics and coal quality,
3. to assess the in-ground tonnages of coal in each marketable grade,
4. to indicate as reliably as possible the presence of unfavourable geological structures or other hazards to mining and
5. to provide engineering data on the coal measure rocks, overburden, groundwater and gas, their variations and distributions to levels of precision suitable for initial mine planning, designing and economic evaluations.

The main tools used in the Illawarra area at this stage of exploration are borehole drilling, aeromagnetic surveys and surface seismic.

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Borehole drilling is conducted on a broad spacing to determine the coal quality, quantity and broad depth and structure of the coal and the nature of the surrounding materials and contained fluids. Borehole spacings at this stage are ideally one kilometre but in many cases are approximately two kilometres. Borehole drilling is neither practical nor cost effective as a means of detailing structure at depths mined in the Southern Coalfield.

In early 1987 an aeromagnetic and radiometric survey was flown over the Southern Coalfield in conjunction with other Illawarra companies. Magnetic data were gridded and contoured by computer and further processed to produce false colour images which allow enhancement and better clarification of anomalies. Preliminary results show that many dykes and subsurface intrusions are clearly delineated by the technique.

In the early 1970’s some broadly spaced lines of surface seismic were shot throughout the area to provide a general indication of major structures. The lines were shot using typical oil field seismic parameters, i.e. single fold, large charges and large groups of geophones. The data were of low frequency and hence low resolution (Figure 2). In 1986 the Mini Sosie technique was applied to an area to determine whether this technique could be used for cost effective structural mapping. The Mini Sosie technique is suitable mainly for broad scale structural mapping in an area at this level because of its lower cost than dynamite surveys. However the latter produce better resolution of smaller structures.

**PREMINING INVESTIGATIONS**

The major objectives of premining investigations (exploration stages 3 and 4) are to better define the geological and geotechnical environments to be mined, the properties of the coal seam and the surrounding strata and the delineation of any specific hazards. From this work, short term mine plans can be prepared, allowances can be made for the intersection of hazards and strata control parameters and gas drainage parameters can be defined. The work is basically conducted in two stages, one from the surface and one from underground.

**SURFACE INVESTIGATIONS**

Surface investigations in the Illawarra area for immediate premining include the use of high resolution seismic, seismic tomography, borehole-to-face and borehole-to-borehole in-seam seismic for the definition of structural hazards, BM for the location of cindered coal and borehole studies for definition of coal quantity and quality surrounding strata types and strengths, support requirements and the nature of included fluids.

**High Resolution Seismic**

In 1986 and 1987 high resolution seismic surveys were conducted in the Appin and Tower Colliery areas to define the structure in areas of immediate mining interest. The 1987 work conducted at Appin Colliery involved the shooting of some 15 line km of high resolution seismic along lines spaced at 200 m apart. They were oriented in two directions perpendicular to faulting indicated in a previous high resolution seismic survey located ahead of the Colliery’s longwall mining panels. The shooting was conducted using 10 ounce charges in 12 m deep shotholes, 40 m apart with geophones located each 10 m along the line. Offset shooting was conducted with recording geophones located along the line of shooting and along the next line 200 m away to provide effectively two lines of data for each line of shooting.
Figure 3 shows a typical section with the presence of faulting obvious. Figure 4 shows the locations and magnitudes of faulting interpreted from the seismic survey.

Seismic Tomography

Shots are fired in the borehole and/or on the surface to geophones located in the bore and on the surface. More than one borehole can be used to increase coverage. The technique produces tomograms showing seismic velocity distribution in the rock mass which in turn can be related to rock characteristics. The net effect is to increase the influence of the bore from the diameter of its core to up to 500 m in radius.

Electromagnetic Survey

The EM technique was used in 1986 and 1987 in the Nebo Colliery area to detect cindered coal in the Kongawillie seam at depths of around 400 m (Boyle and Poole, 1987). The work was conducted with EM depth probes along traverses over a suspected igneous intrusion boundary. The boundary of the cinder was located at a sufficient accuracy for mine planning. Previously the cinder boundary had been defined as being between two boreholes located 1 km apart. The use of the EM technique has allowed an increase in coal reserves. The technique does have some limitations in that the absence of conductors in the profile can be interpreted as either no intrusion or complete intrusion with no cinderling. The technique relies on the detection of a lower resistance layer, e.g. cinder in the strata.

Borehole Studies

The company operates its own Warman 1500 top drive drill rig for all major drilling requirements. Investigation boreholes are usually hammer drilled as open holes to approximately 10 m to 15 m above the Bulli seam and then bored to below the Kongawillie seam. More extensive roof coring is generally not conducted because of the swelling nature of green shales in the Wombarra Shale section which has to be cased as part of the open hole. When the overburden core is recovered fresh samples are selected for the measurement of strain relaxation as part of a trial for stress interpretation measurements. The core is bored and sealed in a humid environment to minimise moisture loss. The core is photographed to provide a permanent visual unbiased record. It is then lithologically and geotechnically logged to provide data for strata control planning. Figure 5 shows a typical geotechnical log.

Coal cores are sealed immediately upon retrieval into gas desorption cylinders and the total desorbable gas content is measured. Gas content testing is critical to mining design to cope with methane drainage, ventilation and potential outbursts.
Figure 5 Geotechnical log

The borehole is geophysically logged with either the Company's own logging equipment or by contractors. Typical logs run include density, natural gamma, dual spaced neutron-neutron, sonic and caliper. These data are used for lithological interpretations, the determination of strength indices and the location of potential aquifers.

Hydrogeological studies were conducted during 1987 in selected boreholes to obtain data on the nature of fluids contained within the coal seams, their pressures and the permeability of the coal seams and strata. The work was conducted to obtain valuable information on virgin gas and water conditions to assist with methane drainage and potential hydrofrac design. This work indicated that the permeability of the coal in the Tower Colliery area is 0.1 milli Darcy and the permeability of the overlying roof strata is 0.01 milli Darcy. The measured fluid pressures in the coal can be higher than hydrostatic by approximately 50 m which is certainly the case in the Wanganui seam, but in the Bulli seam, the effects of colliery workings can be noted. To further confirm this work and to provide information on the effects of approaching mine workings on contained fluids, pressure transducers are set into the coal seams prior to grouting of the borehole. Figure 6 shows pressure decay curves from the pressure transducers set in the Bulli seam in two bores located 1 km and 600 m respectively from Tower Colliery workings and the pressure decay curve of the Wanganui seam in the bore located 600 m from the Bulli seam workings. The Bulli seam pressure at a distance from the workings reached equilibrium at a pressure equivalent to 50 m excess head, but pressure slowly reduced with time. The pressure in the Bulli seam 600 m from the workings reached equilibrium at a water head equivalent to 80 m less than hydrostatic. The pressure in the Wanganui seam was equivalent to 20 m head greater than hydrostatic. The pressure in the Bulli seam was low due to drainage effects associated with the nearby colliery workings, but the Wanganui seam was effectively isolated from the colliery workings. These observations confirm the very low strata permeability measured in downhole studies.

The pressure transducer set into the Bulli seam is incorporated in a standard in-seam seismic geophone. This geophone is
Figure 6 Seam fluid pressures set into the bore to allow later borehole-to-borehole and face-to-borehole in-seam seismic studies to be conducted.

Strata Gas Studies

Drilling in the Appin/Tower area over the years has indicated the presence of natural gas from the strata of the Bulgo Sandstone of the Triassic Narrabeen Group and lower units. Flows have generally been very small and have only been noticed due to the smell of the hydrocarbons. Maddocks (1985, internal BHP report) indicated the presence of a natural gas field centred on the Douglas Park syncline in the Appin/Tower area. The effect of this strata gas on longwall mining has led to long production delays due to gas flows into the workings accompanying strata relaxation above the longwalls following extraction. The strata gas was allowed entry to the mine through...
workings because of the increased permeability of the destressed strata. Numerous "gas outs" were experienced (Battino, 1987). In 1985/86 a MNERDC sponsored project showed that large volumes of strata gas could be released via boreholes drilled into the Bulga Sandstone terminating approximately 120 m above the Bulga seam and that the amount of gas transferred to the mine workings from the strata could be greatly reduced (Battino, 1987). Figure 7 illustrates typical gas production which commences after the longwall has progressed approximately 70 m past the borehole. Research is currently being conducted to determine the optimum spacing for boreholes over longwalls to maximise the gas drained from the strata and to minimise gas passed into the mine workings.

Computer Processing

In recent years the introduction of the MEX computer data base has allowed rapid processing of geological data collected from this phase of exploration with more cost effective preparation of appropriate plans and sections.

The geological models produced will be used for mine planning evaluations.

UNDERGROUND INVESTIGATIONS

Detailed underground investigations are conducted on a regular basis to provide the mine operators with the information they require to design safe roadway and extraction conditions while maintaining maximum coal tonnage, minimum contamination and optimum coal quality. The success of this work depends on the close interaction between the geologist, the strata control engineer and the mine operators.

Detailed coal quality and quantity studies are mainly centred around measurements of seam thickness, definition of potential contamination and routine sampling of coal for quality analyses. These data are then provided to the operators as predictions of seam thickness variations, incremental tonnages along their extraction blocks, contamination content and frequency (e.g. due to stone rolls, roof breakage or floor cutting). The information is also used for the prediction of washplant yields and overall production tonnages of marketable coal.

Structural investigations are based on borehole data, progressive revision of surface seismic data and the conduct of in-seam seismic surveys. The geologist must be familiar with the structure of the coal and the strata in the area to be mined. This knowledge comes from routine mapping of joints, faults, dykes, cleats etc. in the coal to allow predictions of structural changes to be made on a day to day basis. In-seam seismic surveys are now routine in RHP's longwall mines and are shot as new gate roads are completed to allow the prediction of structures for the next two longwall blocks.

Figure 9 shows the results of one survey conducted at Cordeaux Colliery in which a 0.7 m fault previously intersected in the workings was predicted to increase in magnitude to the south to approximately 3 m over the proposed longwall block. Other features were also noticed, one of which was interpreted to be a stone roll and others which were interpreted to be small structures possibly of nuisance value. Figure 9 also shows the structure as determined from mining. This survey provided invaluable information which permitted optimal planning prior to intersection of the structures.

![In-seam seismic predictions versus fact](image)

The presence of water in roof strata can prove detrimental to mining. At Appin Colliery in 1987 a roof fall occurred in the longwall maingate when the longwall was stopped opposite a cutthrough for a weekend period. Accompanying this roof fall was the inflow of copious amounts of water. A review of geophysical logs indicated the presence of water-bearing strata approximately 20 m above the coal. Figure 9 shows the gamma and neutron logs from which the interpretation was made. The presence of water is indicated by a low neutron count for a sandstone of corresponding low gamma count. Sandstones free of water or gas normally show low gamma counts and high neutron counts. Available geophysical logs are closely scrutinised in the area of proposed longwall mining to give forewarning of other potential water inflows.

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The geotechnical logs of bore cores and the geophysical logs provide the information required to design strata control parameters for development roadways and longwall extraction panels. The most valuable data are the lithological nature of the roof strata, the presence of fracturing in the way of joints or bedding planes, the strengths of the materials and the prevailing stress regime. These interactions are well documented by Gale (1965) and others. The design of longwall supports is highly dependent on the thickness of the seam to be mined and the nature of the immediate roof materials. Figure 10 compares the natural gamma and lithological logs for two different boreholes with markedly different roof types. The interpreted immediate roof thickness for each is shown. It is the immediate roof which mainly governs the longwall support capacity required. It is obvious from the example in Figure 10 that the lithology in the right hand bore would require a far greater support capacity than the lithology of the roof material in the left hand bore.

**CONCLUSIONS**

Reliable geological predictions are required for economic and efficient mining. The application of appropriate investigative techniques as described above can supply...
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reliable data for interpretation and prediction of hazards and conditions ahead of mining. In many situations existing techniques require modification for local peculiarities and in other situations new techniques are required to solve local problems. Continuing introspection of geological and geophysical techniques and approaches to problems provides the tools to assist the mining industry to achieve economical mining in the 20th Century.

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REFERENCES


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