AUSTRALIAN EXPERIENCE IN LONG-HOLE IN-SEAM DRILLING TECHNOLOGY FOR SEAM GAS DRAINAGE

by

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ABSTRACT

The use of long-hole in-seam drilling techniques for seam gas drainage ahead of mining was introduced to the Australian coal industry by ACIRL in mid-1981. ACIRL's research program has involved the development and demonstration of drilling and borehole survey technology in addition to evaluating the gas drainage potential of long-hole in-seam boreholes.

This paper presents the results of the long-hole drilling carried out to date in the Illawarra District of the New South Wales coal fields. Drilling experience in relation to both vertical and horizontal directional control of the drill string, drill performance and borehole survey techniques are discussed. In addition, results of gas drainage effected by the long boreholes are presented. Future potential and requirements for further development of this technology are reviewed.

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INTRODUCTION

Australian Coal Industry Research Laboratories Ltd. (ACIRL) with the assistance of grants from NERDDC and ACA, is currently undertaking a research program with the objective to develop and demonstrate the technology for drilling horizontal holes in excess of 600 metres in coal seams to effect the drainage of gas from the seams in advance of mining. Once the techniques are fully developed long-hole drilling will provide a useful tool to the Australian coal mining industry not only for gas drainage but also for general in-seam exploration. Face emissions of methane and the occurrence of outbursts in development headings can be successfully reduced and possibly eliminated when pre-drainage of the seam gas is correctly carried out.

DRILLING EQUIPMENT

Using conventional equipment, horizontal drilling of coal seams is limited to depths of approximately 120 m. This hole length is restricted due to the uncontrollable deflection of the drill string into the floor or roof strata. Therefore to overcome this problem three basic requirements must be met.

(i) A drill rig which has strict control over the drilling parameters of rotation speed, thrust, feed rate and flushing water pressure.

(ii) A drill rig which provides enough thrust to push and pull drill rods to the depth required.

(iii) An instrument that will accurately survey the vertical and horizontal direction of the hole as it is being drilled.

ACIRL has leased an ACKER 'Big John' coal degasification drill on a three year tenure as part of the methane drainage research project. This machine has a capacity to drill over 600 m long in-seam holes. Plates 1 shows the drill operating underground during commissioning trials at West Cliff Colliery. Prior to the commissioning of the drill rig at West Cliff Colliery a number of changes had to be made to the machine in order to comply with the N.S.W. Coal Mine Regulations. The major work carried out was the fitting of approved flame proof electric components, the replacing of belt driven apparatus with chain drives and the installation of approved methane monitoring systems.

Details of the drill components and associated equipment were given by Richard & Allan (1981). These are summarised below.

DRILL FEATURES

The drill is mounted on a mobile 4 wheel drive chassis with a hydraulic motor drive connected to an independent power pack. The hydraulic power pack is trailer mounted and powered by a 415V, 38 kW flame proof electric motor. The power pack and drill can be up to 90 m apart to enable the motor to be in intake air while drilling in gassy environments.

The rotation unit of the drill has a hydraulic four speed transmission and automatic chuck. This enables a rotation speed range of 0-600 r.p.m. and a torque range of 800-3000 N.m. The drill feed frame has a total 3.3 m travel with a maximum thrust of 45 kN at feed rates of up to 19.8 m/min. The feed frame can be angled hydraulically to allow drilling of inclined boreholes 15° either side of horizontal.

The drill can operate through a stuffing box at the front of the feed frame which is connected to the borehole standpipe to allow separation of gas, re-circulation water and cuttings. A separate 10 kW electric powered bean pump is used for flushing water and also to transport the survey tool up the drill string.

Figure 1 shows a typical set-up configuration for the drill and equipment.

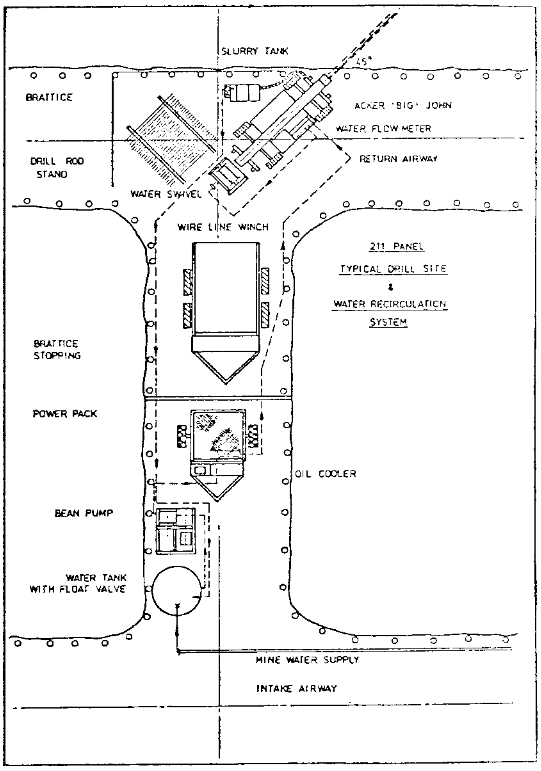

Fig. 1 - Typical set-up for Acker Drill

DRILLING CONSUMABLES

Drill rods

These are BQ size, flush jointed wire line rods. These rods were chosen for the dual purpose of firstly allowing the passage of borehole survey instruments and secondly the rods are flexible enough to enable hole deviation. 60 m of stainless steel rods were provided in addition to the 600 m of cold-drawn steel rods. The stainless steel rods are used adjacent to the resting position of the survey instrument behind the bit to provide a non-magnetic surround for the tool.

Drill bits

A number of tungsten carbide bits have been tried to date. The most successful bits were:

83 mm diameter 4 wing drag bit,
83 mm assembly drag bit,
80 mm pilot with reamer bits.

All these bits were capable of extremely high penetration rates (up to 10 m/min) under ideal conditions. Unfortunately where holes deflect into the roof or floor strata the tungsten carbide bits wear easily and may require replacement to complete the hole to the desired depth.

Stabilisers

Both standard steel and stainless steel 83 mm diameter stabilisers have been used for drilling. Without the use of stabilisers the hole tends to wander in the horizontal direction. The correct combination of stabilisers for a given drill string is critical for control of the bit direction in the horizontal plane. This is also a function of the nature of the particular coal being drilled but is one of the major areas of research required in long-hole drilling technology. A typical configuration for a horizontal hole, as used at West Cliff, was: Bit, 0.5 m stabiliser, 3 m rod, 1.5 m stabiliser, 3 m rod, 1.5 m stabiliser, then the remainder of drill string.

The problem with excessive use of stabilisers is that they significantly added to the weight of the head of the drill string forcing it down, and by making the string more rigid to control horizontal deflection they also result in less flexibility to control and correct vertical deviation.

Check valves

A stainless steel one way check valve is placed on the stainless steel stabiliser 4.5 m behind the bit. The purpose of this is to
(i) Stop the survey instrument at this point in non-magnetic surrounds.
(ii) Allow water to only flow up the drill string to enable the survey instrument to be pumped up the hole.

BOREHOLE SURVEYING

Borehole surveying is carried out using an Eastman Single Shot Borehole Survey Tool. Surveys are taken approximately every 10 m to 20 m of drilling progress in order that a correct borehole trajectory can be maintained.

The tool is inserted into the drill string with a trailing wire attached, then pumped up to the end of the hole by high pressure water. After a pre-set time has elapsed the camera within the instrument is triggered and the image of the compass points indicating vertical inclination and horizontal azimuth is exposed onto a film disc. An hydraulic winch controlled by the drill operator retrieves the instrument and the disc is developed by the drillers to check the borehole direction.

On determining the status of the hole the driller can adjust the drilling parameters of thrust, rotation and stabiliser placement to keep the hole travelling on the desired course within the coal seam.

DRILL COMMISSIONING - WEST CLIFF COLLIERY

DRILLING PROGRAM

The program consisted of drilling several long holes ranging in length from 200 metres to a target length of 600 metres to degas areas thought to be prone to outbursts. The major objective of the program was to commission the drill, and gain experience in operating it and the use of the survey technique. Figure 2 shows the holes drilled at West Cliff Colliery during the commissioning trials of the Acker Drill.

The initial three holes in 211 Panel were used to train West Cliff drillers on the drill. The subsequent six holes were drilled into the block which will form the tailgate panel and barrier pillar for the proposed No. 2 longwall. These were drilled from 312 Panel and 470 Panel respectively.

Holes from 312 were drilled at an inclination of 2° rise and direction was approximately parallel with major cleating, the drill course was toward the advancing 471 Panel.

Holes from 470 Panel were headed across the major cleating at a dip of approximately 1.5° towards an area approximately two pillars in advance of the return airway face, with the objective of penetrating a known mylonite area and possible outburst zone.

The initial procedure was firstly to drill a 150 mm diameter hole to a depth of 9.0 metres. A 100 m diameter copper standpipe was then centrally grouted in this hole and the grout allowed to cure overnight. A 80 mm bit was then used to penetrate the plug in the standpipe and the hole was drilled through this to its final length.

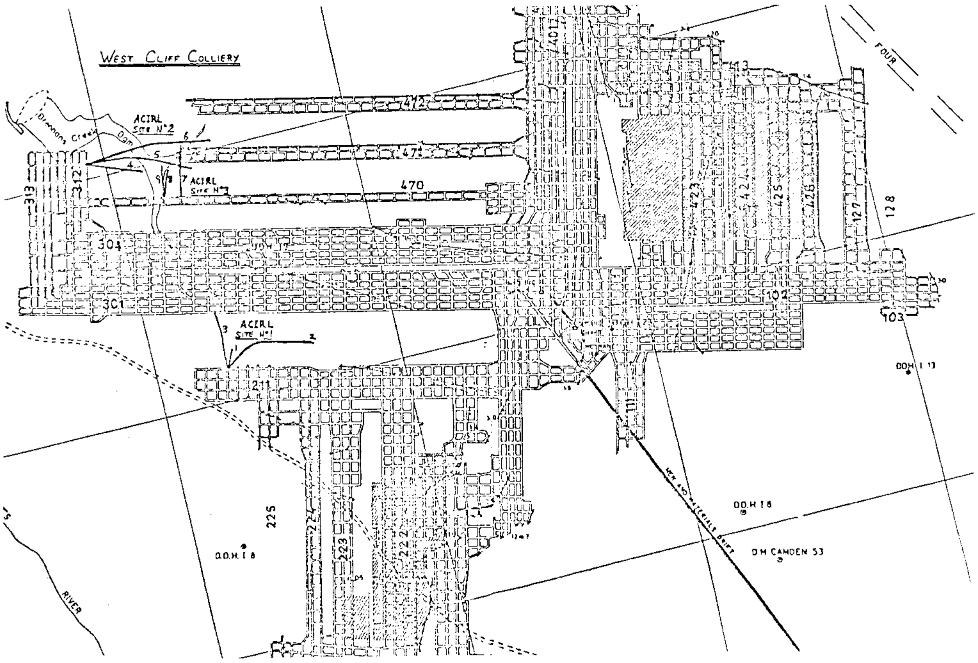

Figure 2 - Colliery Workings & Borehole Locations

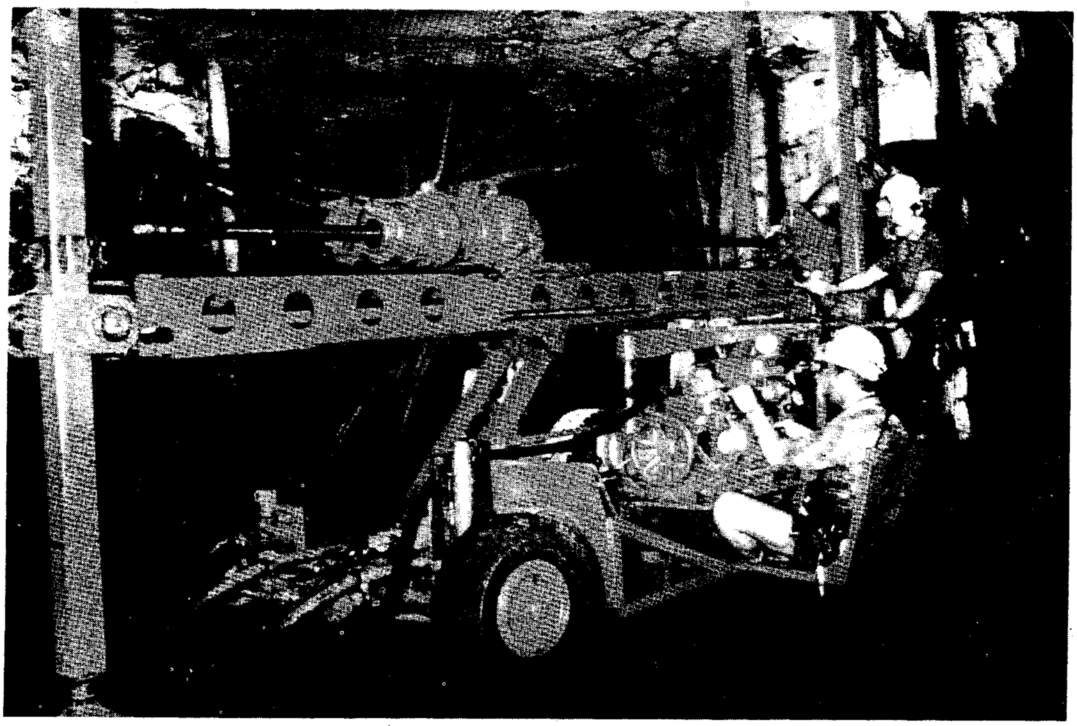

Plate 1 - ACIRL Acker Drill at West Cliff Colliery

DRILLING PARAMETERS

To maintain a horizontal trajectory or to follow the dip of a coal seam is difficult because of the natural tendency of the drill string to arc downward as a result of gravity. Changes in hardness of the seam, e.g. mylonite zones, hard inclusions etc. cause the bit to deflect unpredictably.

The parameters followed at West Cliff are principally the same as used by the U.S.B.M. Due to lack of any quantity of reliable published data on power, thrust, rotational speed, hole depth, bit configuration and the effects of these factors on hole deviation and trajectory, methods were developed by ACIRL during the course of the program to suit the conditions found in the Bulli Seam at West Cliff Colliery.

The main parameters affecting the trajectory of the drill string are thrust, bit rotation speed and feed rate. Examples of the effect of thrust and bit rotation speed on the drill string trajectory are tabulated below. It should be noted that effects will vary from one drilling site to another dependent on seam dip, cleat, coal strength, mylonised zones, and most importantly hole depth. The basic principle, however, is that increasing thrust and decreasing rotation speed causes the bit to climb, and vice-versa.

Table 1
Effect of Thrust and Bit Rotation on Hole Trajectory

Rotation Speed (rpm)	Thrust (kg)	Trajectory Behaviour
400-550	1100-1650	drops downward
180-330	1700-2650	maintains course angle
90-180	2700-4000	climbs upward

STABILISATION OF THE DRILL STRING

Conditions experienced at West Cliff necessitated the drilling of several holes with only a bit and drill string without stabilisers. This revealed that trajectory could be controlled through thrust and rotational speed control although horizontal deviation was found to be unpredictable.

No stabilisation - effect on vertical deviation - Drilling with this assembly at speeds up to 550 r.p.m., with slow feed rate and low thrust, caused the bit to wear the bottom of the hole thus inducing the bit to arc downwards. Increasing the thrust and feed rates tended to cause the drill string to ride up the hole wall on the left side thus pushing the bit upwards and outwards to the right (this occurs with clockwise rotation; anticlockwise rotation would still cause the bit to rise but tend to push the bit left). Holes with the greatest amount of hole deviation had no stabilisers.

600 mm stabiliser directly behind the bit - The addition of a 600 mm long stabiliser directly behind the bit caused the trajectory to arc towards the roof. The stabiliser was 2 mm less in diameter than the bit, and the weight of the drill string lying on the bottom of the hole tended to tilt the stabiliser and bit upwards, hence the bit followed a trajectory into the roof.

1500 m stabiliser 3 m behind the bit - By moving the stabiliser 1 rod length back along the drill string (3.0 m) this configuration allowed the weight of the bit and flexibility of the rod to tilt the bit downwards and consequently the trajectory arced down also. If the stabiliser was moved another rod length back (6.0 m from the bit) the trajectory was steeper.

600 mm stabiliser behind the bit plus 1500 mm stabiliser 3.0 m behind the first stabiliser - A combination of 600 mm long stabiliser directly behind the bit and a 1500 mm stabiliser 3.0 m behind the first was tried in the belief that this would maintain a horizontal path. This theory proved wrong; the tendency for the trajectory to arc downward continued although several combinations of thrust and rotation speeds were used. Separating the stabiliser by another 3.0 m allowed the flexibility at the rod joint and the drill string bowed upward, hence the trajectory tended upward.

30 m of heavy drill string behind the bit - U.S.B.M. has used a drill string combination of a heavy NW drill rod in place of the BQ rod behind the pit. This rod weighs 451 kg and the equivalent length of BQ rod weighs 176 kg in comparison. The NW rod stiffens the drill string and adds weight to the bottom side of the bit. The U.S.B.M. state that this assembly can be made to drill horizontally as well as upward or downward, but as yet ACIRL has not tried this method.

EFFECT ON HORIZONTAL DEVIATION

With clockwise rotation of the drill string and applied thrust pushing the bit, the natural tendency is for the drill string to arc to the right. Even with stabilisers on the drill string this occurs, although not as much as when drilling without stabilisers.

Future development of horizontal direction control includes evaluating different stabiliser designs, and eventually the use of down-hole motors used in conjunction with hole orientation equipment. ACIRL recognises the need for accurate directional drilling to effectively drain gas from potential coal production blocks through the use of parallel horizontal long holes.

Table 2

Hole No.	Panel	Drilled Length (m)	Ŧ Time Taken to Drill	* Change In Height over Length (m)	Horizontal Deviation
1	211	72	1 hour	- 2.0	0°
2	211	352	4 days	+ 11.6	44°
3	211	225	8 days	- 3.8	19°
4	312	194	4 days	+ 4.3	1°
5	312	442	5 days	+ 13.0	8°
6	312	471	11 days	+ 15.9	19°
7	470	195	6 days	+ 5.0	9°
8	470	103	10 days	- 5.6	8°
9	470	165	12 days	- 1.6	5°

Ŧ All drilling was essentially one single shift per day.

* These vertical borehole changes refer to deliberate deviation of the hole to follow the seam contours.

The times provided in this table are actual drilling times. In addition to these times allowances must be made for 2 x 7 hour shifts spent setting up the drill at each site and installation of the standpipe for each borehole. Transporting the rig from one station to another consumes two more 7 hour shifts.

Effect on horizontal deviation

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A summary of results obtained from the holes drilled is as follows:-

Hole No. 1 - This was a demonstration hole used to familiarise the drilling crew with setting up and the standpipe installation procedure. Unfortunately this hole dipped severely into the floor and could not be salvaged. The 72 m was drilled in 1 hour without stabilisers or surveying.

Hole No. 2 - The roof and floor strata were not intersected at any time during the drilling of this hole. Of all the holes drilled this one had the greatest horizontal deviation (44°) mainly attributed to the drill bit penetrating a potential outburst zone (indicated by violent gas and water emission from the hole) while drilling with high speed and thrust, thus causing the bit to veer right and follow the mylonised zone of weak coal. This hole was drilled using a South African "Widdia" pilot bit and reamer and without stabilisers on the drill string.

Hole No. 3 - The purpose of this hole was to check both the drilling and surveying accuracy by intersecting a heading across a barrier pillar. This hole hit the roof strata twice. On both occasions the bit and stabilisers were lost up the hole, however it was possible to deviate around these and continue the hole. Interestingly the last 60 m of this hole was drilled with no bit. The hole was 11 m (19°) off line on intersecting the target panel (confirmed by both survey and visual location of the hole in 301 Panel).

Hole No. 4 - The hole was stopped after drilling 196 m due to the risk of losing a bit in the coal of a future longwall panel, i.e. a potential source of frictional sparking at the face. Floor strata was intersected and drilled for 30 m until the hole could be deflected back into the coal seam. Slow penetration rates occurred when mylonite zones were being drilled with a stabilised drill string. Both the stabilisers and bit choked up with the powdered coal, stopping the passage of flushing water. To overcome this problem a bit had to be run up and down the hole every 2 m to clear the hole.

An additional problem was that the nature of the mylonised material did not allow for consistent drilling speeds and thrust to be adopted, with the result that vertical control of the hole was difficult to maintain.

Hole No. 5 - This hole was stopped at 442 m once again due to the hole deflecting into a future longwall panel. No stabilisers were used in the drill string as mylonised material was frequently encountered. This resulted in a substantial improvement in penetration rates but at the expense of horizontal direction control. For example the hole was deepened from 200 m to 380 m in one shift, with an on-site drilling time of 7 hours. Unfortunately, the horizontal deviation of the hole was excessive with a change in direction of 18° over the hole length.

Hole No. 6 - This hole was the longest hole drilled at West Cliff Colliery with a final length attained of 471 metres.

The drilling parameters were fixed at 360 r.p.m. rotational speed and 1500 kg thrust at the start of the hole. These parameters were expected to produce a +2° rise in the hole. No stabilisers were used with the 82.6 m, 4 wing drag bit.

After 45 m mylonite zones were intersected, with the result that the hole started to develop a negative dip. The rotation speed was slowed down to 180 r.p.m. and thrust increased to 2700 kg however this did not appear to assist in changing the course of the hole. Each time a mylonite zone was intersected the drill lost speed and would have eventually stalled if the drill operators had not pulled the bit away from the end of the hole. In fact it can be concluded that when drilling through mylonite the operator has virtually no control over his machine.

At 147 metres the hole hit the floor of the seam. The angle of entry would have been approximately 4°, which is a combination of the hole dip -2° and the seam dip of +2°. This was achieved by increasing the thrust to 3000 kg. The speed of rotation was gradually increased to 500 r.p.m. for it was considered that the lower speeds would produce chippings that would be too large to flush effectively. The hole re-entered the seam at 213 m after a maximum hole climb of +6.5° was achieved.

At 213 m the drilling parameters were changed to 300 r.p.m. with a range of thrust from 2400 kg to 2900 kg, until after a distance of 387 m the bit dropped back into the floor, entering the floor at approximately -2.5°. To lift the bit out of the floor rotation was reduced to 280 r.p.m. the thrust was increased in steps from 2900 kg to 4200 kg. At 447 m the bit re-entered the coal seam, the hole angle being +8°. The bit speed was increased to 320 r.p.m. and thrust decreased to 3000 kg in order to reduce the vertical deflection of the hole. This manouvre did not work and the bit hit the roof at 471 m at a hole angle of +8°. The sandstone roof was found virtually impossible to drill especially at the high speeds and low thrust required to provide a downdip on the hole.

Attempts were made to slot the hole downwards by running the drill bit back and forwards along the hole between 420 m and 470 m. Unfortunately this was not successful on this occasion.

The hole was abandoned at a total distance drilled of 471 m. The rise of the hole from collar to the end was a total of 15.9 m with a horizontal deviation through 19°, which resulted in the hole being 86 m off target.

Hole Nos. 7, 8 and 9 - This series of holes was drilled in a northerly direction from 470 Panel in order to drain 471 Panel in advance of mining. The development of 471 Panel had been stopped by the colliery management as a result of excessive face emissions and the likelihood of outbursts occurring.

Hole 7 reached a depth of 195 m, which located the hole across the full width of 471 Panel.

Holes 8 and 9 were drilled to depths of 150 m and 105 m. Hole 8 was stopped when excessive and uncontrollable dip of the drill string occurred. The rapid rate of descent from +3° to -4.5° within a length of 30 m was attributed to the use of a fixed three wing drag bit. This was the first and only time this bit was used.

Hole 9 could not be completed to its planned depth owing to the fact that the rig was required to be transported to the surface for maintenance before being transported to a new site at Tahmoor Colliery.

PROCESSING OF THE DRILLING RESULTS

The drillers must keep a thorough log of all the information pertaining to the drilling operations. This information is coded onto computer sheets or telexed through to ACIRL's computer facilities for up to date processing so that an accurate and up to date record of the hole location is maintained.

Table 3 lists the processed results of the borehole survey of Hole 6. These calculations, although relatively simple, are time consuming and therefore ideal for processing by computer. Basically the program calculates the average dip and direction between each survey station. These values are then used together with the length between each station to calculate the co-ordinate of each of the stations. Compensation is made for magnetic variation and the effect of dip on planar geometry. The result is a plot of the holes trajectory on a grid co-ordinate plan. The scale of the plan can be adjusted to any value so that the mine surveyors merely trace the plot onto the colliery's plan.

Vertical deviation is calculated by simply accumulating the average dips between each station. By dividing the vertical deviation by the length between each station the very useful value of vertical deflection rate is obtained. This value can be used for analysing the effect of changing the drilling parameters.

Apart from the geometry of the borehole the computer stores the drilling parameters of rotational speed, thrust and flushing water pressure. Therefore a data base is obtained from which a variety of information can be graphed. Figure 3 is a typical comparative

Table 3

COMPUTER PRINTOUT RESULTS - BOREHOLE SURVEYING   HOLE: NO. 6 312 PANEL

Initial Drill Set Up: +2.0° Dip, 76.6° Grid   Isogonel Correction: 11.6°

STATIONS	FIELD DATA				CALCULATED DATA						
	Average Dip (o)	Dip (o)	Direction (o)	Distance Drilled (m)	Average Direction (°)	Cumulative Intersection Length (m)	Average Cumulative Projected Length (m)	x-coord for Horizontal (m)	y-coord for Horizontal (m)	Cumulative Height Coordinate (m)	Vertical Deflection Rate (m/m)
0 to 1	2.0	2.0	65	15.62	76.6	15.5	15.4	15.1	3.6	0.54	0.03
1 to 2	1.5	2.0	65	45.62	77.1	45.5	45.2	44.3	10.3	1.33	0.02
2 to 3	0.5	1.0	66	69.62	77.6	69.5	69.0	67.8	15.4	1.53	0.00
3 to 4	-1.25	0.0	66	93.62	77.6	93.5	92.8	91.2	20.6	1.01	-0.02
4 to 5	-2.25	-2.50	66	117.62	77.1	117.5	116.6	114.6	25.9	0.07	-0.03
5 to 6	-2.25	-2.0	65	135.62	76.1	135.5	134.4	132.1	30.2	-0.63	-0.03
6 to 7	-0.5	-2.5	64	153.62	74.6	153.5	152.1	149.4	35.0	-0.79	-0.00
7 to 8	2.75	+1.5	62	165.62	73.1	165.5	164.0	160.9	38.5	-0.21	0.04
8 to 9	5.25	+4.0	61	183.62	72.6	183.4	181.6	178.0	43.9	1.43	0.09
9 to 10	4.75	+6.5	61	213.62	77.1	213.3	211.3	207.1	50.5	3.91	0.08
10 to 11	3.5	+3.0	70	243.62	87.1	243.2	241.3	237.0	52.1	5.74	0.06
11 to 12	4.0	+4.0	81	273.62	94.6	273.2	271.1	266.9	49.7	7.84	0.07
12 to 13	3.5	+4.0	85	303.62	98.6	303.1	300.8	296.5	45.2	9.67	0.06
13 to 14	1.25	+3.0	89	387.62	99.1	387.1	383.9	379.4	31.9	11.50	0.02
14 to 15	1.75	-0.5	86	405.62	97.6	405.1	401.7	397.2	29.5	12.05	0.03
15 to 16	5.5	+4.0	86	423.62	97.1	423.0	419.5	415.0	27.3	13.78	0.09
16 to 17	7.5	+7.0	85	447.62	96.1	446.8	443.2	438.7	24.8	16.91	0.13
17 to 18	7.5	+8.0	84	491.0	94.1	470.6	467.0	462.4	23.1	20.04	0.13
		+8.0	84		95.6						

plot which is used to determine the effect of drilling parameters on the borehole trajectory. It shows plots of bit rotation speed, thrust, vertical deviation and horizontal deviation against borehole length in the horizontal plane.

LONG-HOLE GAS FLOW RESULTS

Seam gas flow as measured from each borehole with a 50 mm "Barco" venturi and magnehelic gauges installed in line between the standpipe and the main gas range in the panel.

Some problems arose from the use of this equipment for monitoring causing length time delays in its maintenance, mainly

a) The reduction from the standpipe diameter (100 m) to the Venturi diameter (50 mm) caused some build up of coal particles at the reducer hence restricting gas flow.

b) In-hole build up of water would cause surging of gas while the hole was on vacuum. This necessitated disconnecting the hole from the venturi and allowing the gas and water to be cleared into the return airway. In some cases water would flow from the hole for periods in excess of 10 minutes.

The vacuum also caused water vapour to enter the magnehelic gauges and actually fill the body of the gauge thus making the readings suspect and in some instances render the gauges inoperative. To overcome some of the problems associated

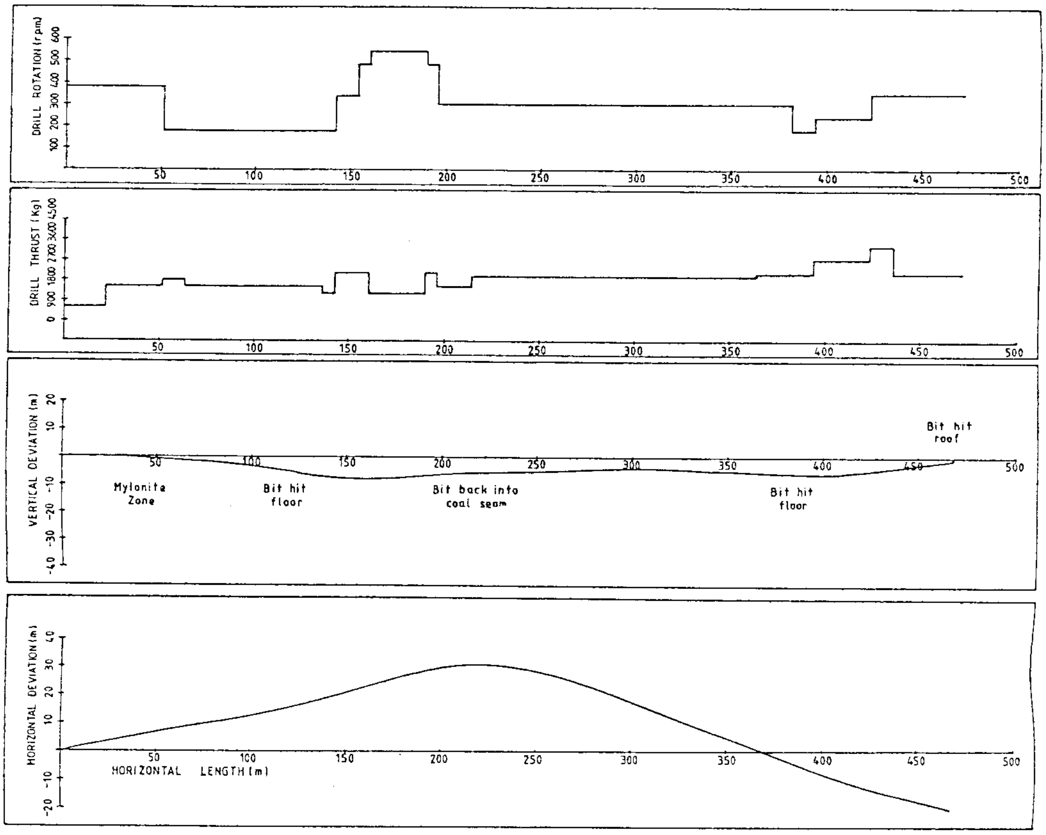

Figure 3. - Typical Borehole Result Plots

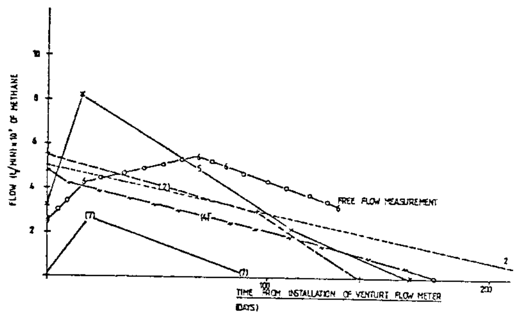

Figure 4. - Borehole Gas Flow v. Time

with magnehelic gauges it is suggested that a pair of vacuum gauges be used on each venturi rather than having a direct measurement of pressure differences.

c) Foreign matter often clogged the pores on the venturi.

d) Owing to the above factors, incremental flow measurements during the progress of drilling the holes, although attempted, were a failure.

e) Also due to the above factors the initial gas flow from the boreholes could not be accurately obtained.

Figure 4 shows the flow of methane against time for each of the drainage holes monitored. Unfortunately only a small number of measurements were taken due to firstly the maintenance required on the instruments and secondly the drilling sites were located in remote sections of the mine workings which were rarely travelled.

The main factors that come from these plots are

(i) The drainage life of the holes drilled into virgin coal (Holes 2, 4, 5) was approximately 160 days. The only variation to this was Hole 6 which was still draining 2,900 L/min of methane from the seam after 134 days without a significant drop in flow rate. This measurement was taken when there was no vacuum being applied.

(ii) In general the drainage holes showed considerable gas flows. A maximum flow of 8,100 L/min recorded was from Hole 5, while Hole 6 indicated flows in excess of 4000 L/min over a period of 94 days. All the holes drilled into virgin coal were giving flows in excess of 2000 L/min after 100 days of installing the instruments. When these values are compared with the gas flows recorded in the 304 Panel drainage block (Allan et al (1981)) then the advantages of long-hole gas drainage can be appreciated. In 304 Panel no hole (av. length 100 m) obtained a flow in excess of 1400 L/min while the typical individual hole flow rates were 400 to 500 L/min.

(iii) From Figure 4 it can also be seen that a number of holes showed an increase in flow after the venturi flow metres were installed. This was due to drilling water being graduallyforced out of the coal until eventually only gas was flowing in the hole. In particular, Holes 4 and 5 showed no gas flow for a number of days after completion. However as the water was cleared from the hole by the seam gas pressure the flow increased dramatically. It is suggested that in the future at the completion of drilling a drainage hole that compressed air be used to flush out the residual drilling and seam water.

CONCLUSIONS

Although at the time of writing this paper the maximum hole depth drilled was 471 metres, the authors consider that drilling holes in excess of 600 metres is feasible in the near future.

The major task to be overcome is control of horizontal deviation of the hole. With this accomplished horizontal long-hole drilling will become a useful tool in the Australian coal mining industry.

Information which ACIRL has gained from these initial long-hole drilling trials can be summarised as follows:

1. Vertical bit direction can be controlled through the correct use of thrust, bit rotation speed, feed rate and

stabilisation. Experience at West Cliff showed that for maximum climb rotation speed was 180 r.p.m. at 1500 kg thrust. For maximum downward deflection rotation speed was 520 r.p.m. at 500 kg thrust with a feed rate of 0.5 m/min. These values assume a hole depth of zero metres. Compensation for the depth of the hole must be made. From Hole 2 drilled in 211 Panel it was found that for each metre drilled the applied thrust should be increased by 5.3 kg in order to overcome the friction and weight of the drill string. This particular hole was drilled at an average angle of +2°.

2. Lateral control in coal drilling is directly related to speed and drill string stabilisation. When speeds greater than 300 r.p.m. were used, excessive deviation from the planned path occurred. It was also indicated than when drilling was undertaken without stabilisers horizontal deviation was extreme.Unfortunately when stabilisers were used while drilling through mylonised zones of coal, very poor penetration rates were achieved. This was caused by the choking up of the stabiliser waterways with cuttings. This resulted in an inadequate supply of flushing water to the bit.
3. Except for three wing solid blade bits, bit design did not appear to have a significant influence on hole deviation. Therefore bit selection should be based on cost, penetration and wear rates. All the bits used at West Cliff Colliery were imported from overseas.
4. The borehole surveying was found to be reliable except for the occasional poor film exposure. It is good practice to have a spare set of film and processing liquid.
5. The judgment and skill of the drillers is of significant importance to the success of the program. How the driller uses the tools and stabiliser combinations can be the deciding factor in the consistency with which horizontal long holes are drilled.
6. Penetration rates were generally impressive. A maximum hourly rate of 70 metres was achieved while the best daily rate was 180 metres achieved during one shift.
7. Methods of maintaining horizontal and vertical control whilst drilling in mylonised areas need to be developed. The drillers had no control over the bit when mylonite zones were penetrated. Generally the bit dived to floor.
8. The use of stabilisers requires more study. Type of stabiliser and positioning on the drill string are critical factors which as yet have not been clarified enough during the initial trials.
9. When the drill bit entered the floor it was important that the re-entering into the coal seam be carefully planned. One one occasion, the re-entry angle was too steep (+8°). This resulted in the bit hitting the roof after only 23 metres. The drill thrust must be reduced well before re-entry into the seam is anticipated. Ideally the bit should re-enter the seam at approximately $+\frac{1}{2}^{\circ}$ above the seam dip.
10. Stainless steel rods and stabilisers were utilised in the drill string so as to provide a non-magnetic environment for the borehole survey instrument. Stainless steel is considerably weaker than normal drill steel and considerably more costly. This material was positioned immediately behind the drill bit where the highest stress on joints occurs. As a result numerous joint failures occurred

with the female ends "belling" and male ends fracturing.

To overcome this problem ACIRL has developed rods and stabilisers better suited to the fatigue environment of the rods immediately behind the drill bit. These rods consist of high tensile steel joints which have been force fitted and welded onto the stainless steel rods. The stabilisers are 80 mm diameter with three wings running 0.5 m along the rod on each side of the joint.

11. The location of mylonite zones was easily determined from the drilling. Each time a zone was intersected the drill began to stall. Another indication was the return flushing water foaming in the settling tanks.

FUTURE DEVELOPMENTS

There is still need for considerable research and development effort in the technology of horizontal long-hole drilling. ACIRL's current gas drainage research program aims to concentrate on this aspect, particularly the methods of improved horizontal control, deliberate borehole steering with down-hole motors, and borehole surveying. In addition, the ACIRL program will evaluate the relative efficiencies of long-hole gas drainage as against current (100 m borehole length) practice.

A copy of the objectives of the ACIRL drilling program at Tahmoor Colliery are listed in the Appendix. Also included is a plot of the first hole drilled at Tahmoor (Figure 5). Using the type of stabilisers described in conclusion (10) above, excellent horizontal control was achieved with a maximum of only 3° deviation over the hole length of 320 m.

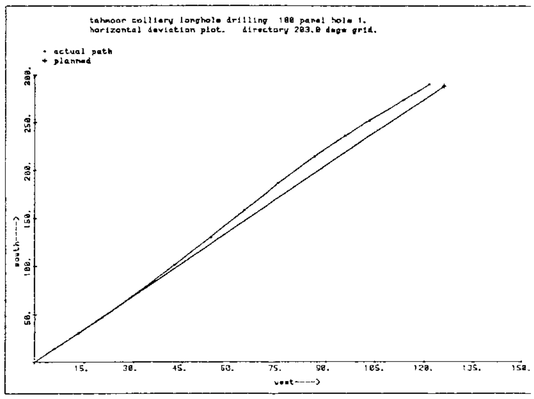

Fig. 5 - Tahmoor Hole 1 - Horizontal Deviation

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APPENDIX

OBJECTIVES OF ACIRL LONG-HOLE DRILLING RESEARCH - TAHMOOR COLLIERY

1. Determine effectiveness of flank long-hole drilling for gas drainage ahead of development panel front (at least 3 holes from each of 2 sites, one each side of panel. N.B. Holes should not intersect panel heading line). Collect data from face/panel emissions to check effectiveness of drainage.
2. Use drilling program in (1) above to determine location of major dyke ahead of panel.
3. At completion of closest flank holes to panel sides conduct incremental (5 m intervals) gas flow pressure tests from

back of hole to determine gas flow profile on either side of panel. Use this data to detect gas flow anomalies (possible mylonite-outburst zones) - correlate with drilling information. Possible third hole to determine if zones of gas flow anomalies are linear.

4. Determine coring capability of Acker drill at maximum hole lengths (and use core for seam gas content determinations).
5. Determine maximum drilling length capable, plus effect of directional (horizontal) drilling control.
6. Determine effect of hole diameter on gas drainage flows.

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DISCUSSION

B. HAM (M.I.M. Holdings): One of the reasons that long holes are being investigated is for the prevention of outbursts. By drilling into a zone that is liable to outbursting, the drilling crews become exposed to a certain amount of risk. What safety precautions are used to protect the drilling crews?

B. HEBBLEWHITE (A.C.I.R.L.): With one of the holes at West Cliff, in fact a number of the holes, there were some small bursts in the hole, evidenced just by gas and water blowing out of the hole. Basically non-return valves are used in the rods to prevent burst energy of gas. Outside the rods a system can be connected straight up so that actually the gas is not vented but it is carried away from the drillsite through the flexible tube to prevent rapid gas accumulation. It can be vented into the returns a safe distance away or connected direct to a gas pipeline. With the rigidity of the set-up, the type of burst that you will get in a borehole really presents no great risk in terms of energy or gas release so long as preparations for it have been made.

R. WILLIAMS (Collinsville Coal): With regard to the directional problems experienced at West Cliff in drilling through the mylonite, the stabiliser in use at the time was of a type that clogged easily in mylonite. If a different stabiliser had been used such as the type used at Tahmoor, would there have been better control in the horizontal plane?

B. HEBBLEWHITE: Yes. The stabilisers used at West Cliff were the standard ones which were a full cylindrical set up. The later one used at Tahmoor was one of A.C.I.R.L.'s own designs. Certainly it would clear more easily but Mr. Richmond might like to add to this.

A. RICHMOND (A.C.I.R.L.): The stabiliser in use at Tahmoor is a three wing stabiliser - just three wings jutting out and joints were reinforced to give that rigidity. Stainless steel is a terrible material for joints, the edges round with increasing thrust on them and it was found that after drilling a 400 m hole it is good luck if there is a satisfactory stainless steel rod after that length.

R. WILLIAMS: Returning to the comment by Mr. Ham regarding the danger of gas blow back, it might be possible even with a check valve and gas-water separator, that if there was a large enough gas flow back it could come back along the outside of the rods and blow through the water outlet into the working area. Is that a possibility?

B. HEBBLEWHITE: Drilling is done through the stand pipe all the time, through a 9 m fully grouted stand pipe. It is uncertain what pressure it would take to shift that lot. Probably it is quite possible eventually that with a high enough pressure the whole stand pipe grouted system could be blown out. But this is probably talking of a higher pressure than that experienced in most outburst areas. Unless that were to happen, the check valves and seals in the water reticulation system in the hole and at the drill would prevent the problem described.

E. TOMLINSON (West Cliff): Regarding blow out danger. In drilling the holes at West Cliff the 9 m of stand pipe was grouted in the hole as has already been pointed out. The stand pipe was then attached to a large 100 mm valve which was in turn attached, through an adaptor, to the machine itself, so any likelihood of an outburst along the annulus between rods and hole was not creating much danger at all, unless there was sufficient pressure generated to dislodge the machine.

J. ALLEN (A.C.I.R.L.): The only time that a burst did give a significant problem was associated with the water passageways as was suggested. It could have been a major problem if the check valve was not in a satisfactory condition. The gas pressure would overcome the check valve itself and come down the rod. This did occur in a slight fashion, it did come down the check valve and out at the water swivel end of the rod. In those occurrences it could be quite dangerous if it occurred during a rod joining operation or water swivel fitting (putting it on the drill rod); that is when the damage might occur. Apart from that, if the unit is in a sealed condition and the outburst does come down the waterways it is going out the side of the machine through the 100 mm Victaulic water outlet and would not endanger the men operating the machine because it would be going towards a slurry pit. It must be ensured that the check valves are in top condition at all times. That is most important. The check valves must be dependable to hold the gas pressure.