REVISED FINAL REPORT TO
T.D.M. MOURA

By

A. J. Hargraves

January, 1987

INTRODUCTION

This Report embraces and supersedes all previous reports.

On 5/8/86 Dr. Hargraves was requested to investigate the source of gas which led to the explosion at Moura No. 4 Colliery on 16/7/86. He proceeded to Moura on 5/8/86 and was briefed by Mr. M. Caffery in Moura that afternoon. The briefing covered aspects of the explosion and following recovery, and activities since to determine the cause. The work was to be carried out in collaboration with the Department of Mines Officers as well as Company Officers, the whole ensemble of investigations to be regarded as a Company - Mines Department joint effort.

It was learned that a comprehensive suite of over one hundred dust samples had already been collected by Mr. C. Ellis of the N.S.W. Department of Industrial Relations, for analysis at the Department of Mines Laboratory at Redbank, Queensland.

Samples collected on advice from Ellis based on Appin experience

The explosion had occurred on dayshift, a working shift, during pillar extraction in the Main Dip area. Pillar extraction comprised splitting of pillars in C Upper seam, repeatedly pocketing the splits, leaving some irregular stooks, and taking bottoms or some bottoms by grading down into the floor, through stone and into or through C Lower seam. The explosion is presumed to have occurred by ignition of gas. Presumably also some coal dust exploded before the explosion was suppressed by stonedust and water, or before it died out because of an adequacy of stone dust mixed with roadway dust. Appendix 1 is a chronology of some of the events in the extraction in sixteen days prior to the explosion. Appendix 2 is a chronology of some of the events in the seven days following.

The most prolific sources of gas in an expanding goaf of a retreating extraction are the adjoining seams if close enough to be relieved and tapped by the extent of the goaf. In the case of Moura No. 4, these are Seams A, B, and D. Perhaps also C Lower adjoining the worked C Upper and Middle Seams could be involved if the grading down during the retreating extraction to form the goaf did not breach the 0.5m of stone separating the C Upper from C Lower, if such stone was generally relatively impermeable, and if, in the course of

extraction, progressive floor heave did not achieve progressive breaking of such stone with progressive tapping of gas from C Lower. Added to these gas sources, there had been a history of some gas blowers at Moura No. 4, associated with a zone of parallel shears, and the forming goaf embraced such a shear zone on the projection of a zone in 3 South with such an experience of a blower.

The explosion of 16/7/86 occurred at a time when the goaf was being enlarged - the means of tapping adjoining seams - and the presumed sudden appearance of gas in quantity is also considered to be related to the influence of geological anomalies - particularly the shear zone - in influencing the mechanics of caving.

To pursue further background detail of the explosion as possible data for back-analysis of the source of gas, and any other associated matter, the first inspection of the mine was made on 6/8/86 in company with representatives of the Department of Mines. The party included a Government photographer making his second visit to the mine. This inspection included the geometry of the workings as far as the outbye goaf perimeter, such geological structures as could be observed in the roadways and by inspection of the visible goaf, and the explosion itself, as data contributing to the establishment of the point of ignition, substantiated by any indication of the source of ignition. At this, and any further inspections, aspects of possible importance were documented including notations on mine plans.

As a result of all of the above an understanding of the detail of the brief to investigate the source of gas had developed. To best visualise the situation, a draft "E-W" section was prepared from inbye the goaf to outbye the reverse fault.

These are the main bases upon which the following report of investigation depends, the investigation of the source of gas leading to the explosion at Moura No. 4 Colliery on 16/7/86, with some seemingly pertinent peripheral issues.

LOGISTICAL DETAILS

5/8/86 - 8/8/86	Visit to Moura
8/8/86 -	A "Position Statement" was provided (Appendix 3)

12/8/86 - 14/8/86	With Inspector D. Wilson in N.S.W.
	13/8/86 Dept. Industrial Relations, Wollongong
	Southern Mines Rescue Station, Wollongong
	The University of Wollongong
	14/8/86 Dept. Industrial Relations, Londonderry
	Dept. Industrial Relations, Lidcombe
19/8/86 - 22/8/86	Visit to Moura
1/9/86	A Report for August 1986 was prepared
3/9/86	Visit to Division of Mineral Physics and Mineralogy, C.S.I.R.O., North Ryde
17/9/86	A requested "Interim Report" was provided for the visit of Dr. A. Roberts from U.K.
1/10/86	A Report for September 1986 was prepared
19/10/86 - 23/10/86	Visit to Moura
23/10/86	An informal draft "Seam gas from exploration bores" was provided (part of Appendix 4)
29/10/86	Visit to Division of Mineral Physics and Mineralogy, C.S.I.R.O., North Ryde
5/8/86 - 11/86	Generally in Wollongong, with frequent correspondence, courier and telephone contact with Moura.

GAS DATA

THE GOAF AS A PERMEABLE STORAGE

General U.K. experience with caving of longwall roofs is of flexing and closure of mostly argillaceous roof strata with limited expansion of caved material. Australian experience with caving of goafed areas has been more of fracturing and expansion of more arenaceous roof strata into blocks and voids. These general differences are manifested in the differences experienced in surface subsidence over extracted areas - in the U.K. with vertical subsidence over the centres of large goaves not much less than the thickness of extraction and in Australia with vertical subsidence usually less than half thickness of extraction.

The flexing and cracking of largely argillaceous interseam strata on the one hand provide improved facilities for permeation of gas from adjoining seams into the extracted area. On the other hand the disintegration with abilities for orientation of detached blocks of

arenaceous strata in the roof provides ready permeability between adjoining overlying seams and the extracted area many orders greater than in the virgin state and provides a goaf void volume significantly greater than occurring in flexing strata.

These diverse factors about U.K. and Australian caving mechanisms haveled to the adoption of the notion of blocky caving of Moura C Seam goaf. However, as acknowledged previously, (Nguyen, Enever and Mallett, 1983), "geological discontinuities will play a critical role in caving performance" as well.

DETERMINING SOURCE OF GAS IN THE EXPLOSION

Geological Structural Examination

Figures 1 to 4 depict what is understood of the structural setting of the Main Dip Goaf. A 1:150 scale blocky model of longwall extraction of C Seam (Wold and Hargraves, 1984) employed about 40 layers of blocky stone between C Upper Seam roof and A Seam floor, a distance of perhaps 55m. This is of the same order of the number of petrological subdivisions stated in drilling logs, as summarised in Table 1. The maximum number is in Bore 10042, with

TABLE 1

Interburden Details

Hole	Weathered Rock	Surface to A roof m	Surface to B roof m	Number of Interburden Components B to C	C to D	D to E
10088	7.2	111.5	122.0	11	21	19
10111	?	97.6	?	22 (A-C)	5	5
10040	?	81.8	100.3	9	7	
10041	?	138.6	?	15 (A-C)	6	5
10042	?	115.5	?	42 (A-C)	8	3
Average all holes				19.8	9.4	6.4

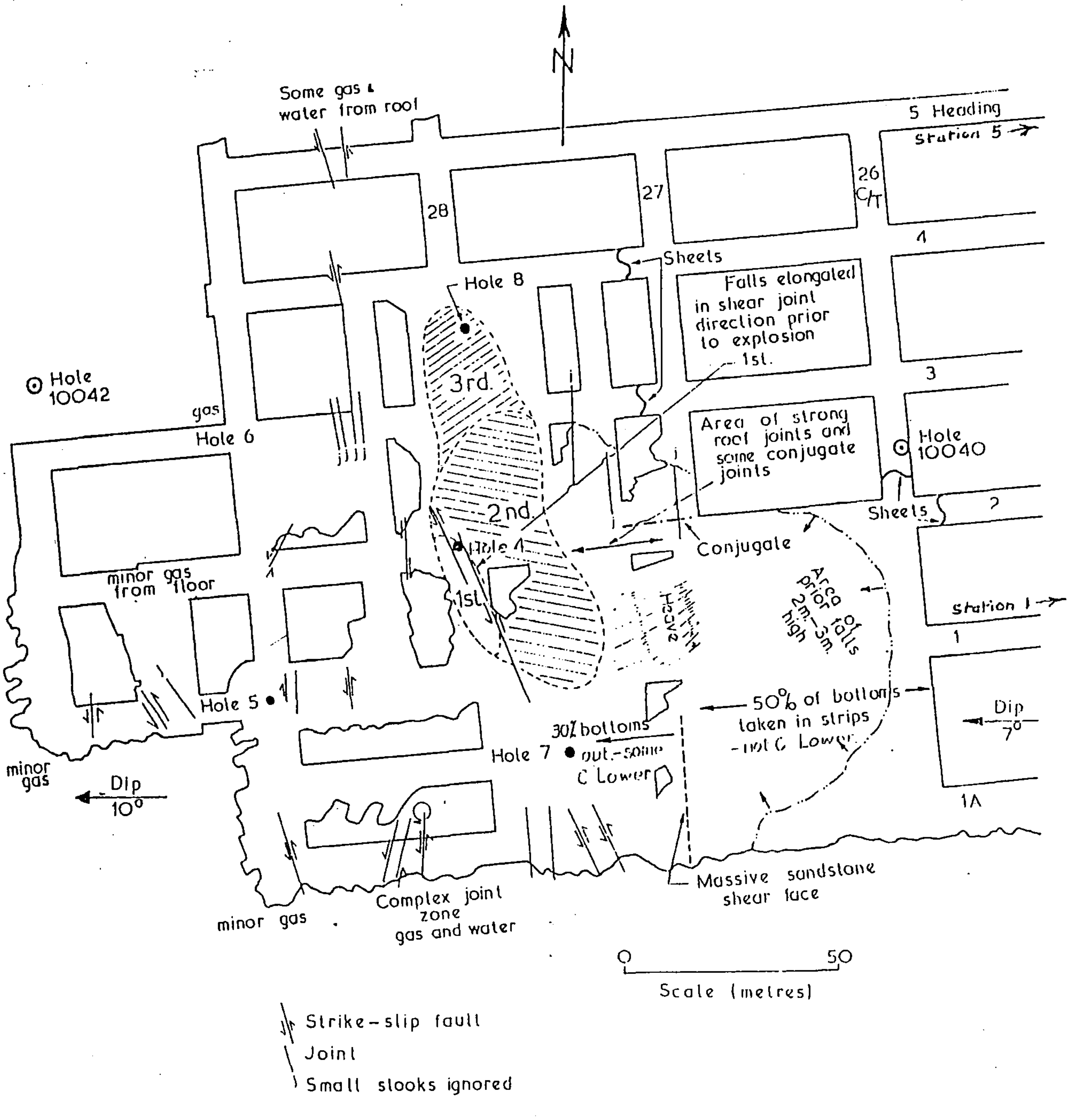


Fig.1. Main Dip Goaf 16-7-86

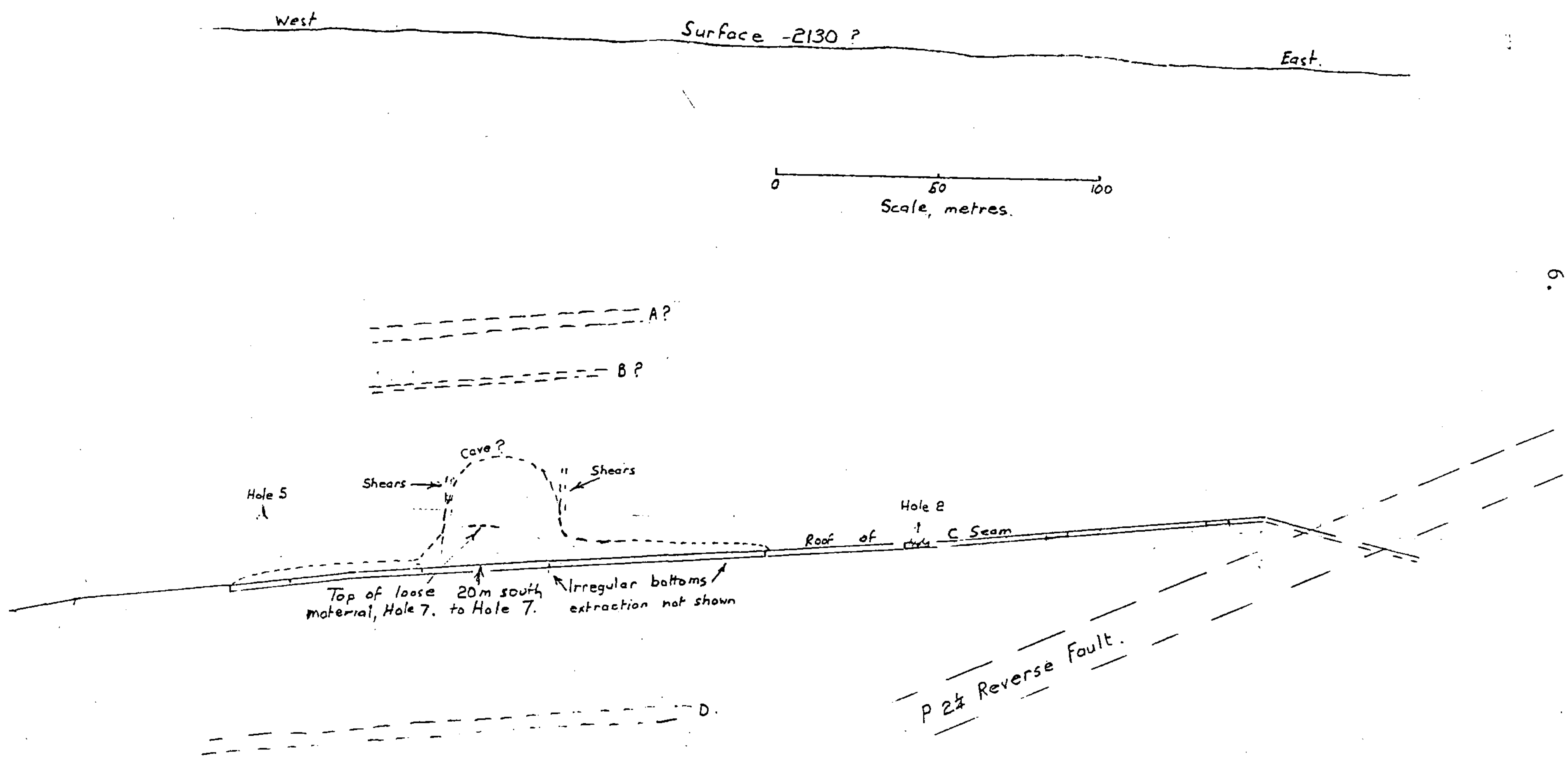


Fig. 2. Section along No. 1 Heading

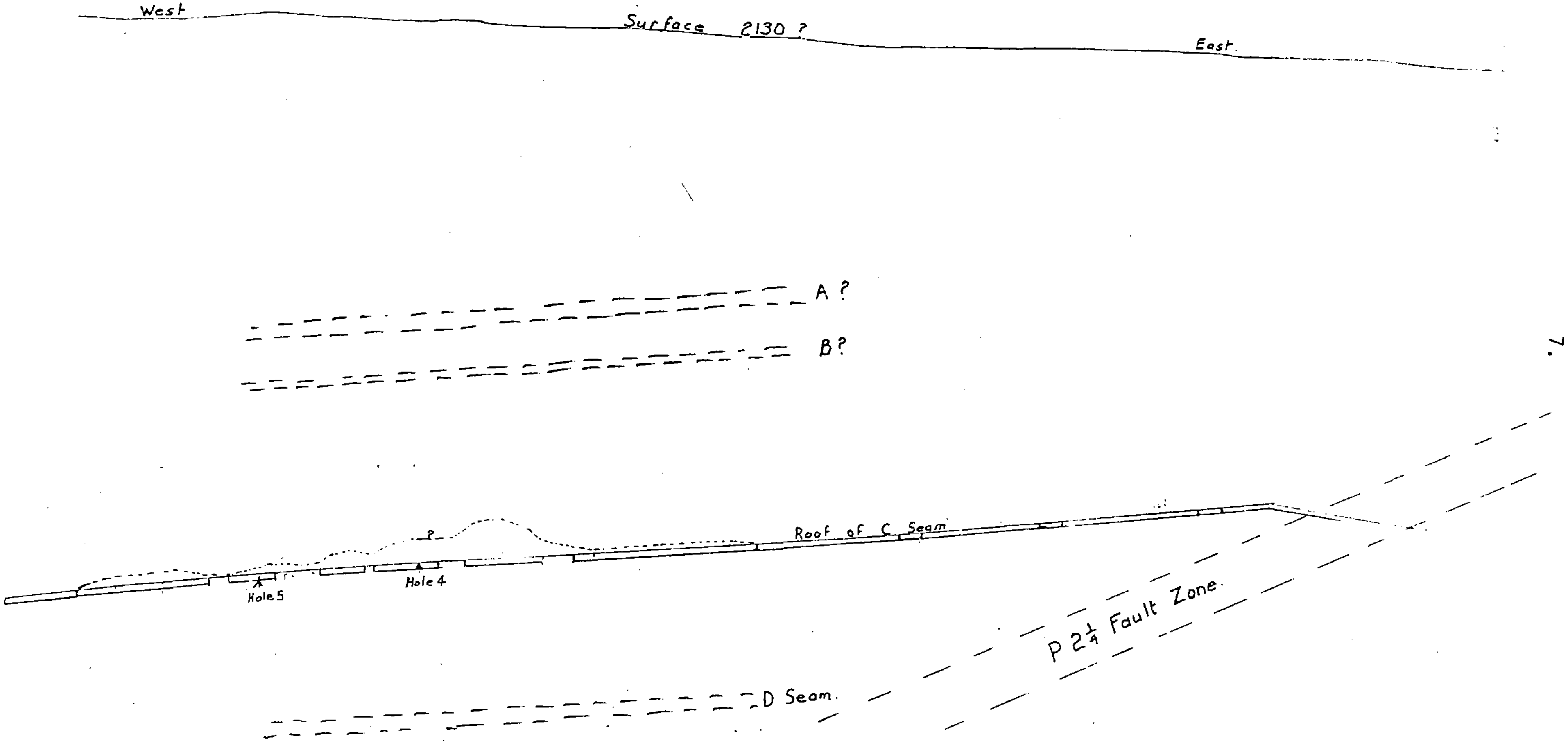


Fig. 3. Section along No. 2 Heading

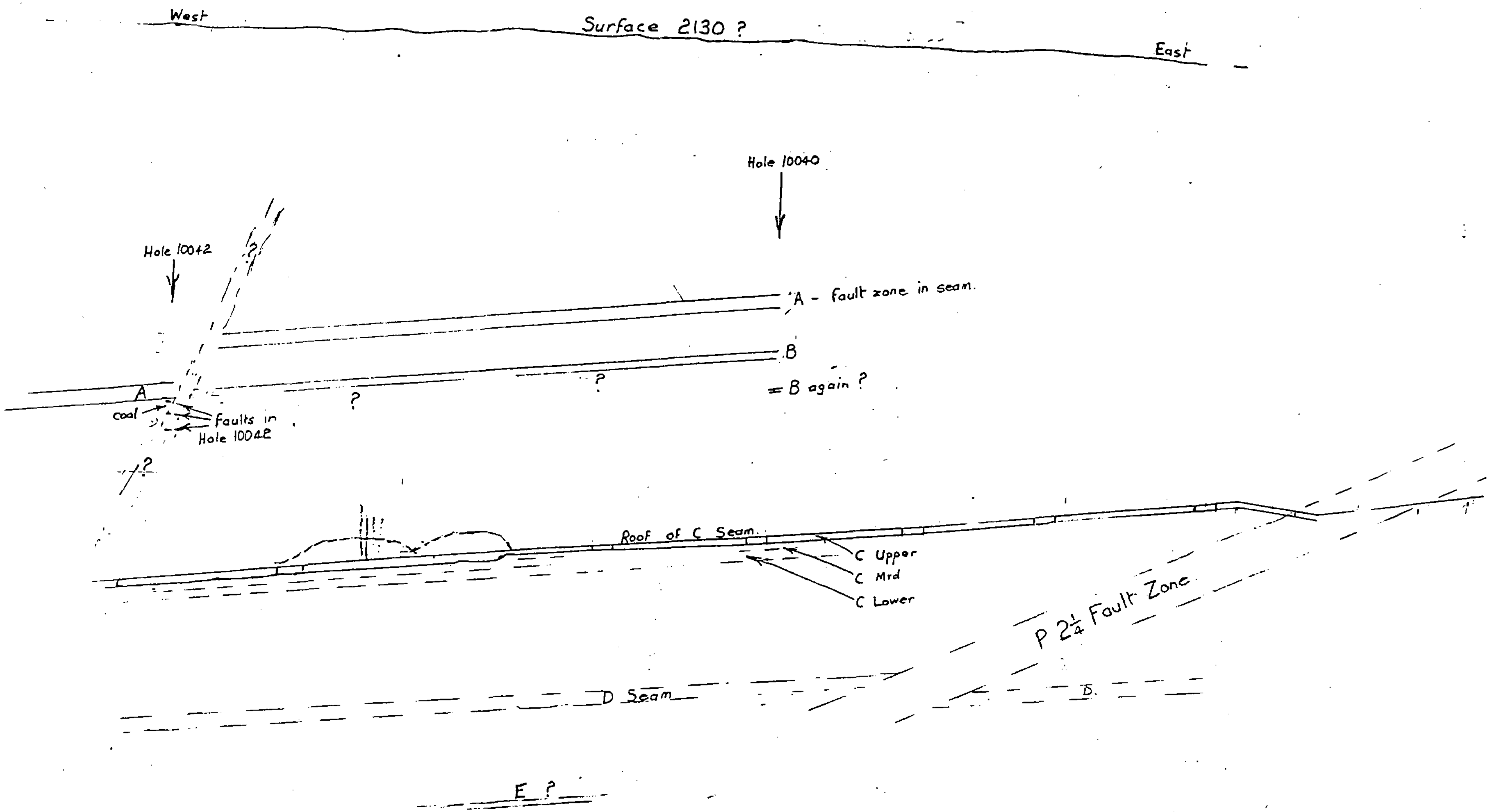


Fig. 4. Section along No. 3 Heading

petrological subdivisions approaching 40 (although with some faulting) and the average of the five bores considered, nearly 20. These, and the figures for other interseam distances attest to the blocky nature of the general interseam sandstone strata, and to their generally blocky behaviour to be expected. The modelling which was continually monitored by precise photogrammetric measurements indicated a piping rather than broad arching type of caving. A bulking factor of 1.03 was deduced, and such a factor would provide multiple, highly permeable fluid escape paths.

Using this idealised model as a basis of understanding the performance of the Main Dip goaf leading up to the events of 16/7/86, consideration should be given to these further points.

1. The Main Dip area was being extracted pillar by pillar, leaving stooks in the goaf.(Fig. 1). Any smaller stooks would crush and roof blocks would drop out around the larger stooks, and some tilting and sliding of balanced blocks could occur. The initial sag at the A Seam horizon could be delayed under the influence of larger stooks below.
2. The grading down and recovery of bottom coal would have a twofold influence on behaviour of caving material - stooks left behind would be more slender and more likely to crush out and the extra space below normal floor level would tend to promote more upward extension of the cave.
3. The only planes of weakness modelled were bedding planes and joints in interseam strata to provide a "blocky" model. But (a) the strong set of "shear" planes traversing the extraction area at about 165^{o}(Fig. 5) and the conjugate planes were not modelled and (b) apart from the observed P2¼ fault outbye apparently dipping under the extraction area (Figs. 2, 3 and 4), the logs of exploration holes 10040 and 10042 (which straddle the goaf area) indicate faulting in the vicinity of A and B Seams at least in the area of the Main Dip goaf, and (c) Hole 10088, about 500m to the south indicates further faulting or anomalies showing A and B Seam virtually together.

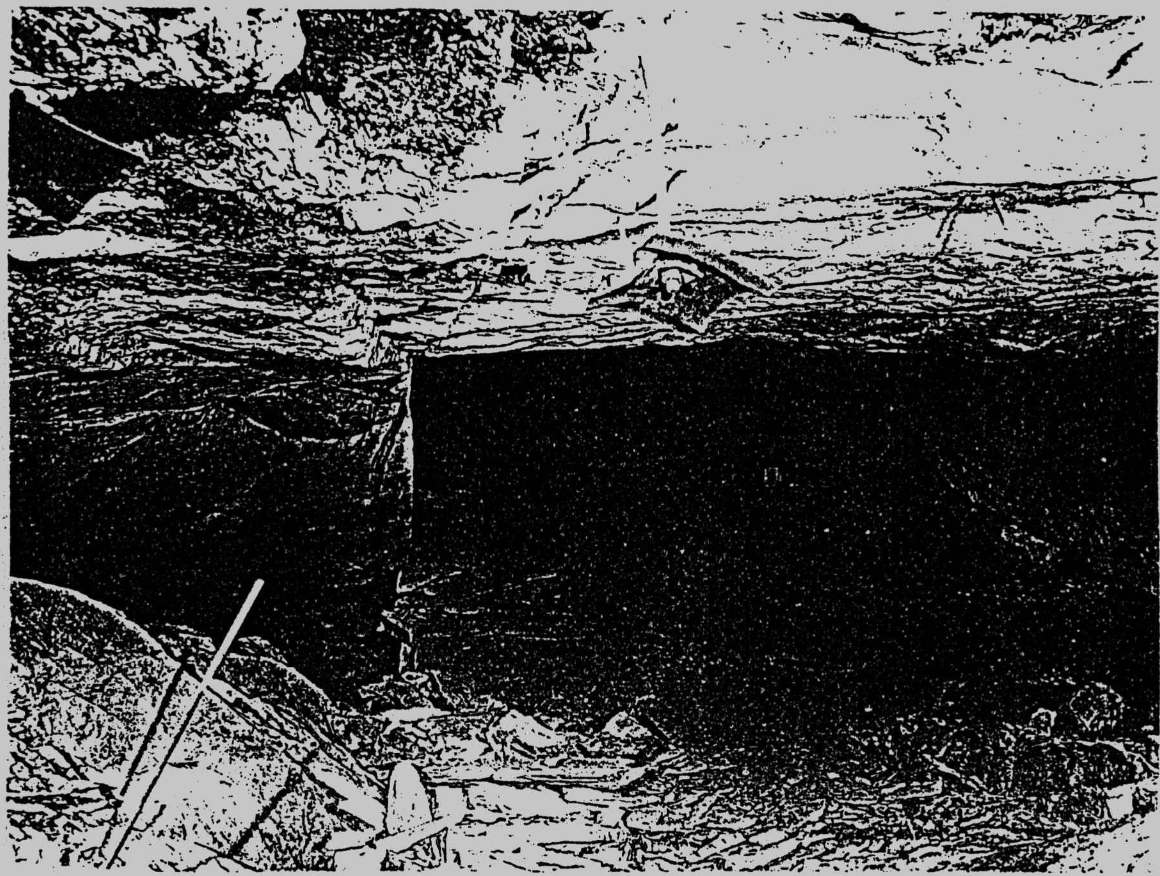


Fig. 5. Shear plane traversing the Main Dip Goaf

Faulting and other persistent planes of weakness have a strong influence on caving and subsidence, inducing movements to occupy such planes if not too divergent from the geometry dependent on the mechanics of caving on the one hand, and to provide stages in the caving process on the other hand.

If the blocky longwall model is valid, one might expect when the span of goaf in C Seam extraction approaches 80m, that the first settlement would extend upward towards the vicinity of A and B Seams (Fig. 6). The above points not modelled should tend to induce caving higher or to induce caving earlier with narrower spans, which seem to be the case. Thus any favourable steeply dipping planes of weakness could extend the cave further upward, and any flat-lying planes of weakness above could provide a target horizon for a particular stage of caving. Any such first exposure of an Upper Seam would relax it, increasing its permeability. A very low resistance path would be provided for the releasing gases down into the C Seam goaf. Any coal of A and B Seams actually caved as

80m after total extraction?

What would be the position as per goaf formed at 16/7/87

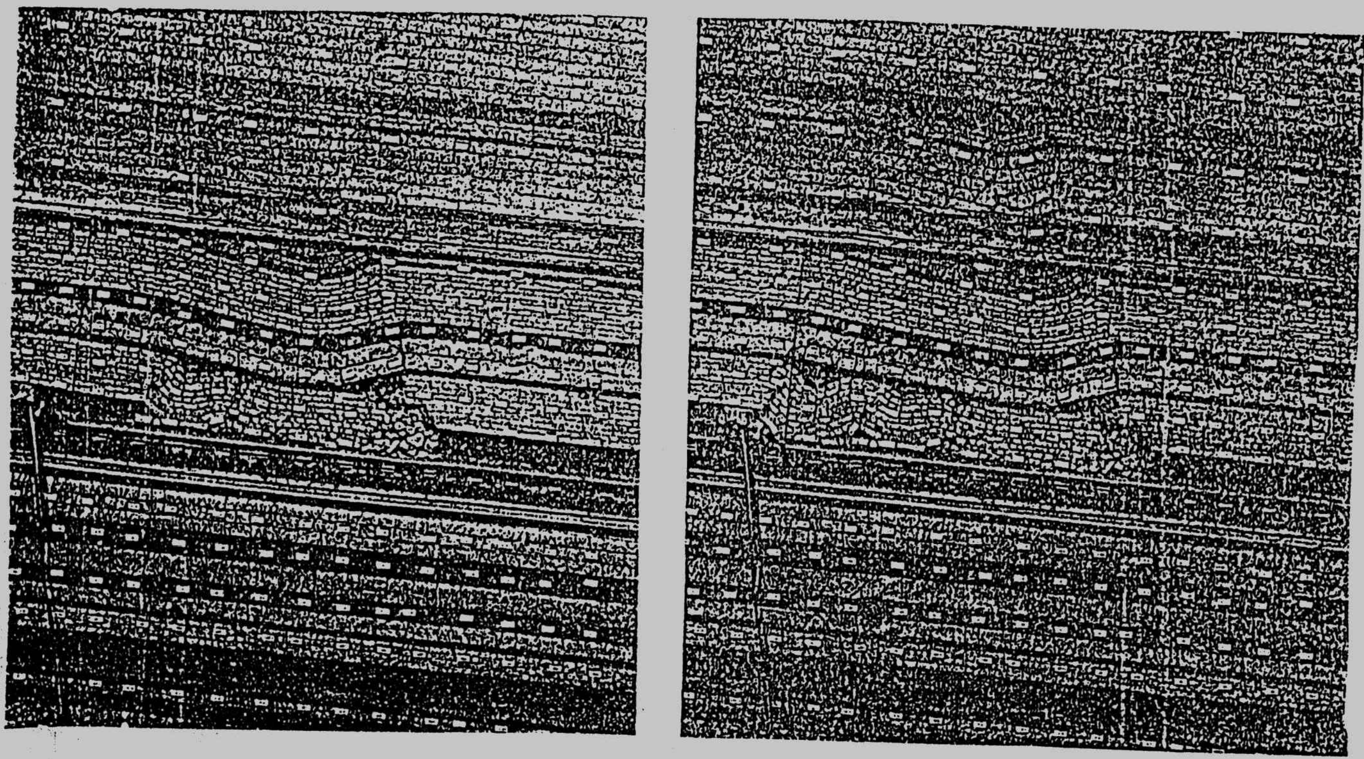
well would tend to break up according to weaknesses across bedding planes and cleats, thereby releasing gases even more quickly in such granular form. A sudden exposure of A or B Seam, if gassy, might even result in disintegration of exposed coal.

Wold and Hargraves (1984) did not identify movements in the floor strata down to D Seam (Fig. 6) but acknowledged that stress relaxations in floor with equivalent increases of permeability would occur. It was postulated that for an extraction span of 150m or more the tensile zone could reach D Seam. (Fig. 7 is of a physical model of a W. German coal mining situation, showing relief of floor as well as of roof following extraction.) What relevance to #4.

On the basis of this work the extent of real caving in the goaf (Figs. 1, 2, 3, and 4) being much less than the 150m span figure stated by Wold and Hargraves (1984), the roof strata as a sudden source of gas in the Main Dip Goaf appears a much stronger possibility than the floor, particularly if the understood position of the P2¼ fault well below the floor of the Goaf (Figs. 2, 3 and 4) is valid.

Whilst any real influence of the P2¼ fault on the mechanisms leading to gas release and explosion on 16/7/86 might be discounted because it would lie too far underfoot of the explosion area (Figs. 2, 3 and 4), more recent reports are indications of a clockwise swinging strike to the south and reversal of dip of the P2¼ fault just to the south and west of the goaf area. Accordingly perhaps the P2¼ fault should not be completely discounted from possibility of influence and perhaps this means a slight possibility of the gas which exploded deriving from the floor.

The volume of the goaf is equivalent to the coal removed less surface subsidence volume and is occupied by an equivalent volume of air, but now mostly in the voids of the caved material. Any significant ventilation is restricted to the outbye perimeter and to the pumping action in the remainder resulting from barometric fluctuations with a continuous drift outbye towards the returns of any gas issuing from the inbye perimeter. Thus, at the time of installing the four sheets to improve goaf edge ventilation before resuming mining on the morning of 16/7/86 (Fig. 1), and ignoring any slight surface subsidence, there was a



(a) Mining C Seam before third fall, total span 80m

(b) Mining C Seam after third fall, total span 81m.

Fig. 6 . Model of extraction of C Seam showing sudden first exposure of A and B Seams.

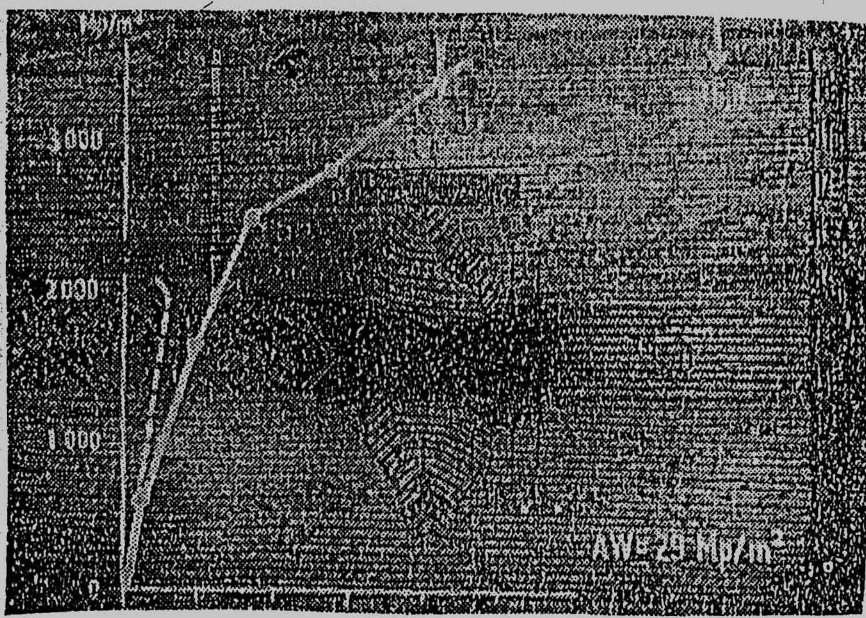


Fig. 7. Extraction model showing significant floor heave as well as roof collapse - modified from Everling (1974).

volume of about 67,000m^3 of air "trapped" in fallen material and a volume of about 22,000m^3 in the outbye goaf perimeter.

If the blocky model is a valid representation of the Main Dip extraction area, it seems unlikely that a particular fall creating a windblast would be associated with a concurrent fall from a horizon near an adjoining seam releasing sufficient gas to create an explosive atmosphere in the goaf, unless fortuitously, because of the differences in elevation for two such events to be related.

Analogy between 4 South Sub and Main Dip Goaf

4/S Sub is subject to similar gas sources to Main Dip Goaf. It has been the subject of several anomalous gas situations, including the development of significant water gauge of overpressure behind the seals, significant response to leakage past the seals at times of low barometer and probable increase in leakage of the whole 4/S sealed unit as a result of suspected damage to those seals in the explosion. (Whilst the fan was not working, up to 6% CH_4 has been found at the seals with the barometer falling, and up to 3.5% CH_4 with rising barometer). (A continual study over several days of barometric pressure, manometric pressure across seals and of gas leakage through seals would allow reasonable estimation of gas make within the goaf).

The gross area of 4/S Sub (Fig. 8) is 60,000m^2 and the major and minor dimensions are approximately 250m x 200m. The limits of surface subsidence over this area, about 300 x 250m, are shown in Fig. 7 as well as the point of maximum subsidence of 1.5m. Ignoring the expansion of intervening strata due to partial and total destressing, the nett volume of the goaf is equivalent to the extracted volume less surface subsidence volume, in the case of 4/S Sub:

Nett volume =

Extracted Volume say 160,000m^3 - Subsidence Volume 20,000m^3 = 140,000m^3

In attempting to use the same basis for a valid volume of Main Dip Goaf, in the absence of any subsidence data on Main Dip Goaf, an extrapolation of subsidence over 4/S Sub will be used as a basis, assuming the same depths of cover.

The dimensions of the real Main Dip Goaf are approximately 120m x 75m. As a first approximation, assuming the maximum subsidence is proportional

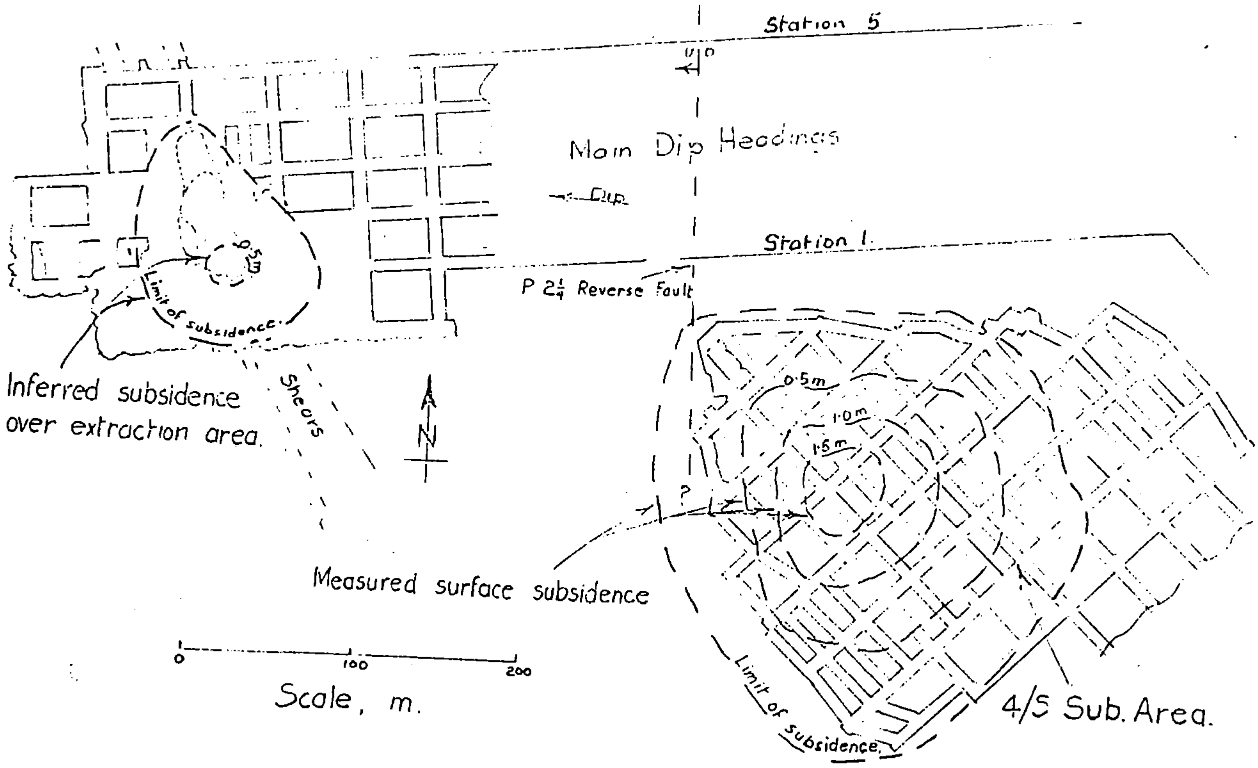


Fig. 8. Plan of 4/S Sub.

to the minor span of goaf and using the subsidence pattern of 4/S Sub it would be:

Maximum Surface Subsidence = $\frac{75}{200}$ x 1.5m = 0.56, with limits of subsidence on the surface about 145m x 90m. A figure for the volume of subsidence could be 3000m^3 (Fig. 5). But caving in blocky strata is not regular, but occurs incrementally and suddenly, and subsidence is not an instantaneous mechanism, but progresses with time during active extraction, and subsidence movements cease some time after extraction finishes. Thus it could be assumed that at time of explosion, 16/7/86, following on active extraction, only portion of the final subsidence for that extraction had taken place, say 2000m^3 and that by the present time, most ground movements over Main Dip Goaf have ceased with total volumetric subsidence of 3000m^3. Thus the figure of extracted volume of Main Dip Goaf stated above, 90,000m^3, should be reduced by only 2000m^3 to provide Goaf free volume on 16/7/86 (88000m^3) and reduced by a further 1000m^3 to provide Goaf free volume today (87000m^3).

Inferred Events

It seems obvious that prior to the real explosion, an event occurred sufficient to require withdrawal from the extraction split. It was a reasonably orderly withdrawal; the equipment was backed out. It seems, from the position of coal on the belt that the event occurred before any more coal was cut, perhaps before the empty shuttlecar reached the continuous miner. It seems possible that either a stook in the goaf collapsed, with progressive working in the goaf following, or a large slab near the goaf perimeter slipped down, with further noise of stress readjustments continuing, to make it prudent to withdraw the equipment from the vicinity of the goaf edge. If the point of ignition was in the vicinity of cutthrough 26 with shuttlecars and Landrover, perhaps a windblast should be assumed to destroy the recently installed sheets and to allow gas from the goaf to reach that cutthrough which otherwise would have been in intake air. As the explosion occurred at the time when the barometer was falling (Fig. 9), possibility of normal bleeding out of the goaf due solely to barometric change is an important consideration. Perhaps this bleed-out tended to layer.

Presumably the event did not include significant gas in the general body of air or enough to switch off the continuous miner. As both shuttlecars were empty, probably whilst the last full car was discharging the empty car proceeded down towards the continuous miner but the miner did not commence to fill it before the event occurred to cause the withdrawal of both. Presumably in this time the last-filled car had emptied and was in the shunt somewhat in the position where the inbye car was found.

Although seam gas pre-drainage holes around the perimeter were known to have been still bleeding gas at time of extraction, the chance of such holes revitalising to create a problem is not considered a possibility. Some holes had collapsed where intersected by mylonite and could have blocked to burst out later, but the volumes involved would be small when compared with the goaf volume. The average maximum flow per hole was about 360m^3/day, but now the total flow from, say, the 15 holes would be about 1500m^3/day, say, 1m^3/min. Such continuous discharge, supplementing normal continuous ribside emissions from the perimeter of the Main Dip Goaf had created insignificant proportions of CH_4 in the returns of the Goaf in the days preceding the

16/7/86 explosion as shown at return monitoring points (Table 2) as shown in Figs. 1 and 8. Notwithstanding this apparent insignificance, it is a matter of fact that there is an average nett issue of CH_4 from the Goaf from the C Seam of several m^3 of CH_4/minute. If the sheets were blown out, it would leave a volume of over 90,000m^3 of air virtually stagnant around and within the goaf. To bring this volume from zero CH4 up towards 100% CH_4 would take something like 20 days based on the C Seam holes and ribside emissions only.

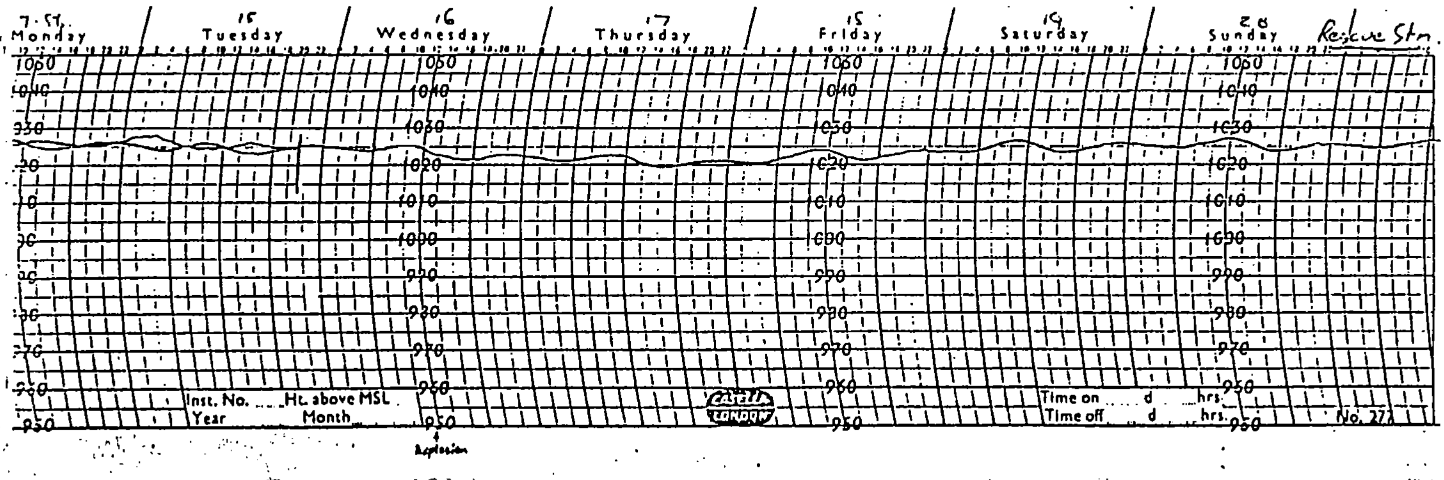


Fig. 9 . Barograph record of 16/7/86, Rescue Station, Moura.

TABLE 2

Maxima from CH_4 Monitoring in Ventilation

Date 1986	Air Analyses % CH_4 Main Return Station 4	Dip, South Side Station 1	4/S Sub Station 6
July 7 Monday	0.42	0.06	0.57
8	0.54	0.33	0.78
9	0.48	0.27	0.96
11	0.69	0.36	0.66
12	0.63	0.25	?
13	0.42	0.21	?
14	0.39	0.15	0.48
15	0.42	0.24	0.54
16(10.30 a.m.)	0.48	0.30	0.66

Analysis of Seam Gas Data

Data available around 16/7/86. Information on the days before the explosion are given in Appendix 1 and on the days following are given in Appendix 2. Some supplementary information mainly from J. Brady is included for completeness.

1. On 16/7/86 from 10 a.m. to 2 p.m. the barometer dropped 2.5 millibars (Fig. 9) A drop of 0.6 millibars/hour is equivalent to the issue of $0.9m^3$/ min of goaf atmosphere of total volume $90,000m^3$. (A study of 8 random weeks of barometric records shows the greatest drop to be 8 millibars in 6 hours, an average drop of 1.3 millibar/hour).
2. On 16/7/86 at 2.15 p.m. just inside the Fan Portal, just outbye No. 1 Cutthrough an average of 3 methanometer readings gave 2.71% CH_4. At that time $8m^3$/sec of air was intaking Acky's Portal plus a very slight intake into the Main Intakes adjoining the place where the return sample was taken, say $2m^3$/sec total
3. On 17/7/86 at 2.30 a.m. in the same place there was 2.5% CH_4 and the airflow had increased to a maximum of $14m^3$/sec, again mostly intaking at Acky's Portal.
4. When the fan was re-started at 4.55 a.m. on 18/7/86 on diesel motor, just ticking over, the pressure was 7.6mm water gauge. Quantity flowing in Acky's Intakes at 5.30 a.m. was $12.4m^3$/sec. Quantities in the (Armco) intakes at 6.15 a.m. were $27.7m^3$/sec (Man and Supply road) and $69.9m^3$/sec (Conveyor road).
5. On 18/7/86 at 9.23 a.m. air with 1.45% CH_4 was coming out of 3/S. The return had $20.28m^3$/sec at 1.45% CH_4.
6. Apart from a short time when airflow was further reduced to try to conserve N_2 - from 6 p.m. 21/7/86 to 4 a.m. 22/7/86 NIL water gauge - the fan continued on the same setting (with approximately 7.6mm watergauge) throughout the recovery.
7. On the afternoon of 21/7/86 the airflow in South Return at No. 20 Cutthrough was $14m^3$/sec with 0.9% CH_4. Taking into consideration the addition from Acky's return, the maximum would have been, say $20m^3$/sec, total.

These limited ventilation details are summarised in Table 3.

<u>Ventilation and Gas</u> There were six monitoring stations around the mine,

Station 1	In the Dip South Return, inbye 4/S Junction - it is the major return from the Main Dip Goaf
Station 2	In 3/SE
Station 3	In 3/SW
Station 4	In Main Return inbye the fan
Station 5	In Dip North Return, just inbye 2/N
Station 6	Near 4/SE

TABLE 3

Available data on CH_4 in atmosphere after explosion

Date	Time	%CH_4	Airflow m^3/sec	CH_4 m^3/sec	Location
16/7/86	11.10?	E X P L O S I O N			
16/7/86	14.15	2.71	10	0.27	Main Return
17/7/86	14.30	2.5	14	0.35	Main Return
18/7/86	04.55	-	110		Main Return
18/7/86	09.23	1.45	20.28	0.29	3/South
21/7/86	16.00?	0.9	14	0.13	South Return

Each point was an air sampling station and an air velocity measurement station. Station 6 was virtually the same air current as Station 1,(Fig.8) only augmented by some air leakage from intake, any gas emissions from ribsides passed, and bleed through 4/S, etc. seals passed on its way. Volume at Station 1 should be slightly less (say 1m^3/sec) than volume at Station 6. Station 4 is the main return just inbye the fan. The particular interests are of Stations 1, 5 and 6. (Another interest would have been of Station 4 in the post-explosion period, if airflows had been known.) Table 4 is a single and typical set of measurements taken at Stations 1 to 5 on 24/6/86 when the main fan watergauge was 48.25mm and the barometer was 1024 millibars

TABLE 4

Ventilation Survey, 24/6/86

Station	Location	Methane %	Air quantity m^3/sec
1	Dip South Return, inbye 4/S	0.3	34.1
2	3/SE	0.3	22.6
3	3/SW	0.8	30.6
4	Main Dip - inbye fan	0.4	118.4
5	Dip North Return, below 2/N	0.2	28.0
6	Near 4/SE	0.4(?)	35.0 (?)

For a more complete specification of the gassiness of the mine, including the effect of barometric changes on output of goaves and any effect of barometric changes on emissions from the virgin seam, continual monitoring for at least one 24 hour period with its diurnal variation would be required. A different step towards such specification, using only maxima, lay in the Record Book notations, as shown in Table 2 .

Taking the average of the maxima of Dip, South Side (Station 1), 0.265% CH_4 (which compares with the spot value, Table 3) and airflow a total maximum gas output figure for Main Dip Goaf becomes

$$\frac{0.265}{100} \times 34.1 = 0.09 m^3/sec.$$

Main Dip Goaf October 1986 In an attempt to assess the gas make of the now quiet Main Dip Goaf a short programme of monitoring airflow and gas content around the seals was undertaken. (Shortly after sealing, sometimes there was negative pressure, sometimes positive pressure behind the seals; now, apparently it is always positive). Concurrent barometric readings on the outbye side of the N seal and manometer pressures across the seal were used to assist in interpreting the results, which are shown in Figure 9. Regarding the watergauge of pressure across the seals, it might be expected that at times of equal pressure drop from the inbye side to the outbye side of the seals there would be an equal leakage of goaf atmosphere into the air circuit outbye the seals. Presuming a still atmosphere and a steady state of atmospheric composition behind the seals, therefore, at times of equal watergauge an equivalent equal amount of CH_4 would take part in such leakage. But, although the pattern of watergauge pressure has the same general peaks and depressions as the make of leakage CH_4, any precision ends there. Also, it is recognisable that barometric fluctuations are the cause of peaks and depressions of the watergauge plot. To establish any better relationships between barometer, watergauge and leakage of methane from behind seals would require a more precise and longer monitoring of these three variables, with continual analyses of the atmospheres behind the seals (seen as the major places of leakage) after temporarily sealing off all borehole conduits to the surface. Necessarily, then, the goaf would need to be considered as an intact atmospheric entity, only supplied by seam gas emitting into it from virgin coal and only losing goaf atmosphere through the five seals, with no losses elsewhere such as through the shear zone to other outlets or through 4/S Sub Goaf through any interconnection of the two Goaves.

If the 30 hours of monitoring (Fig.10) (unfortunately subjected in the middle to a change of ventilation circuit) can be regarded as representative along with a representative pattern of barometric fluctuation, and an assumed steady atmospheric composition behind the

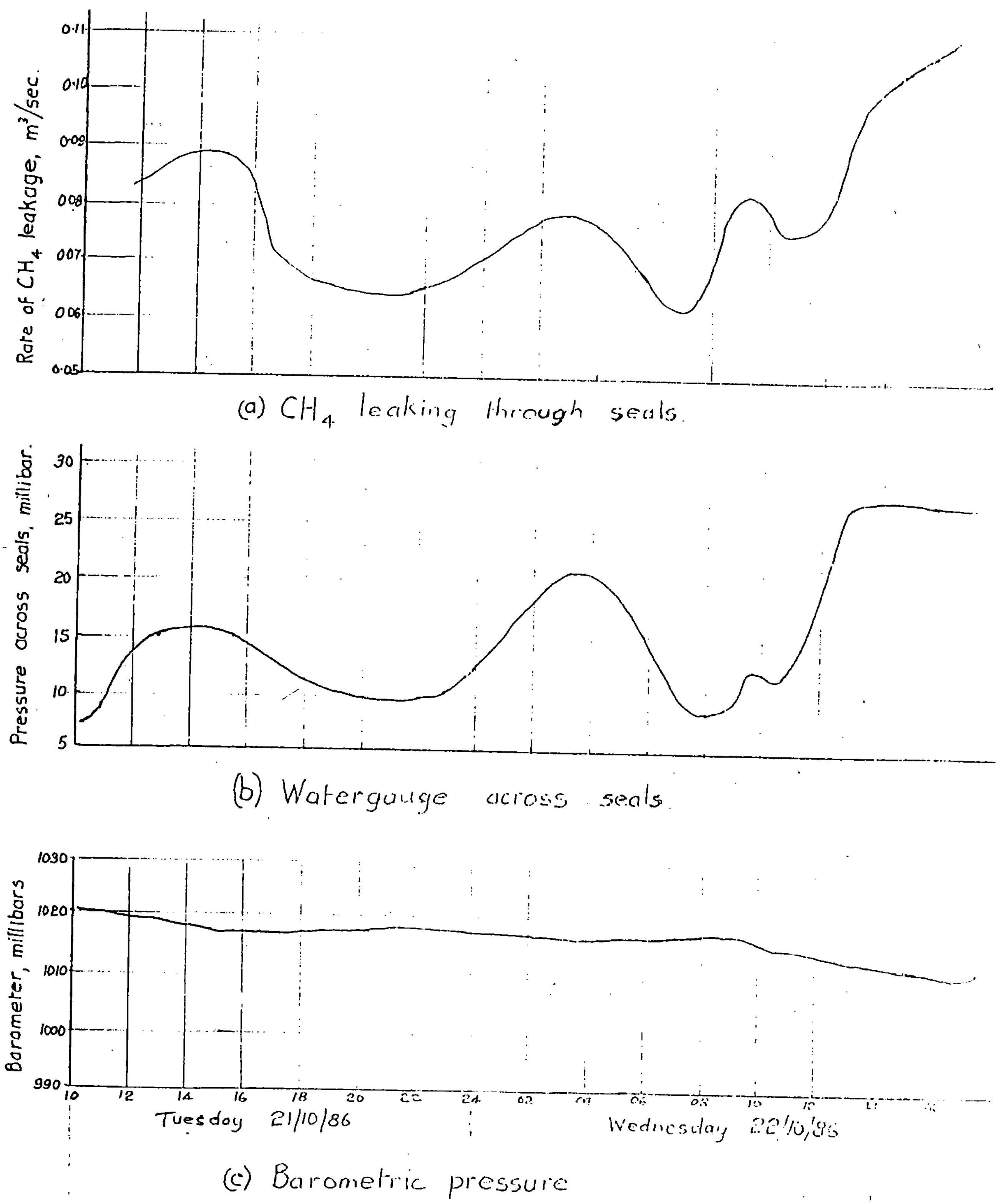


Fig. 10. Variables in leakage through seals, Main Dip Goaf

seals, always at overpressure relative to the ventilation current on the outbye side of them, then the pattern of CH_4 leakage can be assumed to be the CH_4 make into the sealed area. That average figure appears to be about $0.075m^3$/sec, say $6500m^3$/day (4.6 tonne/day), an interesting figure. This $0.075m^3$/s average figure compares well with the maximum figure of $0.09m^3$/sec (calculated above) for emissions from Main Dip Goaf, and the figures of about 0.12 m^3/sec after the first sealing of the Goaf on 23rd August and about $0.07m^3$/sec after the second sealing on 22nd September, figures provided by Mr. M. Caffery.

Gas monitoring around 16/7/86 Fig. 11 gives the trace of CH_4 monitoring at Station 5 , North Return of the Main Dip Goaf, and Station 1 , the South Return on the 16th July 1986. The trace ceases at about 10.30 a.m., all subsequent sample being in the sampling tubing damaged in the explosion. Neither these traces Fig. 11, nor the record of maxima in the previous 15 days (Table 4) show any anomalously high results, let alone any approach of CH_4 concentration towards the lower explosive limit, about 5%. Experience after a high CH_4 peak is always of an extended tail before normal concentrations are reverted to. Hence although analysis from each sample point was in turn, in rotation and therefore continual rather than continuous, no peak could completely escape the record as it would be signified by its tail which would spread over at least several subsequent 10 minute-spaced analysis plots. Hence the monitoring immediately prior to the explosion as evidence of source of gas in the explosion is unavailable. Likewise after the explosion, the sampling tube damaged inbye is unreliable as to point of source of sampled atmosphere, although the record provides evidence of products of combustion and of unburned CH_4, and of fresh, newly emitted CH_4 as the time passed following the explosion. The mobility of the explosion and of explosive products after the destruction of ventilation structures and sampling for analysis installations prevented any specific usefulness of such post-explosion analyses for back analysis of the explosion and identification of the source of the explosion gas.

In retrospect, it would appear that isotopic analysis of gaseous products of the explosion could assist in identifiying the extents to which CH_4 and coal dust played in the overall explosion area.

The time when the last sample for analysis left the sample points was very close to the time when the barometer began its fall towards the middle of the day (Fig. 9) with which it could have brought out of the goaf gases enriched in CH_4. Undoubtedly with the falling barometer the

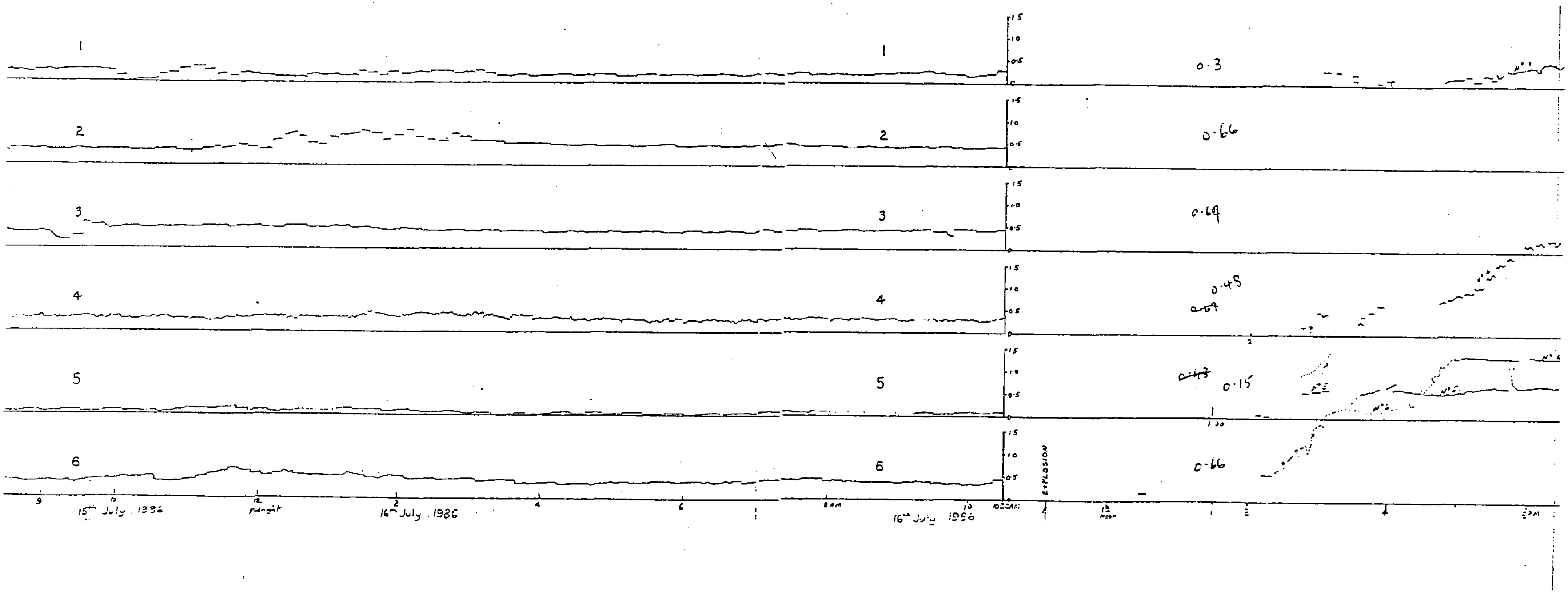


Fig. 11. Traces of CH_4 monitoring on 16/7/86

Goaf returns would have been enriched in CH_4 in the same way that they still are. (Fig.11), but without the resistance to escape now presented by the seals, amounting to up to 27mm of watergauge, and without the present escape of goaf gases through boreholes to the surface, the flowing out of Goaf atmospheres in response to barometric drop would have been more dramatic. Air quantities in the North and South side returns of the Main Dip Goaf were varied somewhat according to the location of extraction, and totalled about 62 m^3/sec. It is likely, but not necessarily so that any release of gas would be associated with the then area of extraction. In the case of any surge of atmosphere from the goaf as a result of a sudden barometric drop, this would probably be released towards the rise side of the goaf (S. side) as the atmosphere would have been enriched in CH_4, and been lighter, with added tendency towards the higher volume of the two returns.

On 16/7/86 there was a fairly steady drop of barometric pressure of 3.5 millibars in the 5 hours from about 11 a.m. to about 4 p.m. (Fig. 9). This represents an average proportionate droprate of $\frac{3.5}{5} \div 1025 = 0.0007$/hr causing an equivalent expansion in goaf gas of 0.0007/hr. Thus, the goaf of 88,000m^3 emitted part of its atmosphere at the rate of $0.0007 \times 88{,}000 = 61.6m^3$/hr equivalent to 0.017$m^3$/second. Two counter possibilities exist for CH_4 entering goaves, mixing due to turbulence created by the barometric breathing and solids and voids in the cave, and segregations due to gravity before mixing. (Different gases mix readily but practically do not unmix due to density differences). If the component gases in the stagnant goaf had layered, which seems more likely, that issue could have been virtually pure CH_4, the composition of gas in all seams (Table 5) (Appendix 4). Adding to this the Goaf perimeter and pre-drainage hole output mentioned above of at least one and probably several m^3/minute, say 2m^3/min, the total gas release would be of the order of 0.05m3/sec, not taking into account the increase of hole and ribside emission with reduction of pressure and any irregularities in the (assumed) steady barometric fall from 11 a.m. to 4 p.m. Such quantity of CH_4 could only become explosive in air if issuing into an (unlikely) airstream of no more than 1m^3/min. Thus, although it does not appear that the normal make of gas in the goaf, plus a barometric exhalation of CH_4 rich gas already in the goaf could have provided an

TABLE 5

Typical Seam Gas Analysis

Seam	Gas Analysis (air + N_2 free) CH_4%	CO_2%	Sample Source
X	High	Low	Inconsistent upper seam close to water table in many holes
A	99	1	
B	97.2	2.8	Hole 10086. Core of B Seam at 90m depth
C	99.4	0.6	C Upper, C Mid and C Lower Average of Short Underground holes. Aug. 1986
D	99.2	0.8	Short underground hole in D seam (Moura No. 2) Aug. 1986
E	>99	<1	
X,A,B?	99.7	0.3	Hole 10083. C Seam under water, open hole sample

atmosphere to explode, it certainly could have provided an atmosphere favourable to the explosion and propagation of explosion basically fuelled by other agencies.

Considering the issue of goaf gas relatively pure CH_4 at the rate of $0.05m^3/sec$, two physical agencies would affect its points of release. One would be the ventilation airstream skimming the goaf and, dependent on its velocity, tending to mix the gas by turbulence, and the other the tendency of the gas to creep out at the lip of the goaf at highest R.L., perhaps to layer at the top of the ventilation airstream as the layer tended to follow the most favourable upward path, even perhaps against the airflow - i.e. up the intake. This is shown in Fig. 12 with most likely point of gas issue at R.L. 1976. For the gas to have layered in the intake, in the first instance it would have needed to move from R.L. 1976 there downwards as a layer 100m with a fall of 6m, into No. 3 Heading before moving up dip. With a layering index of 2.76 this is unlikely. Any layering was much much more likely to have followed the ventilation return moving up into 1A Heading.

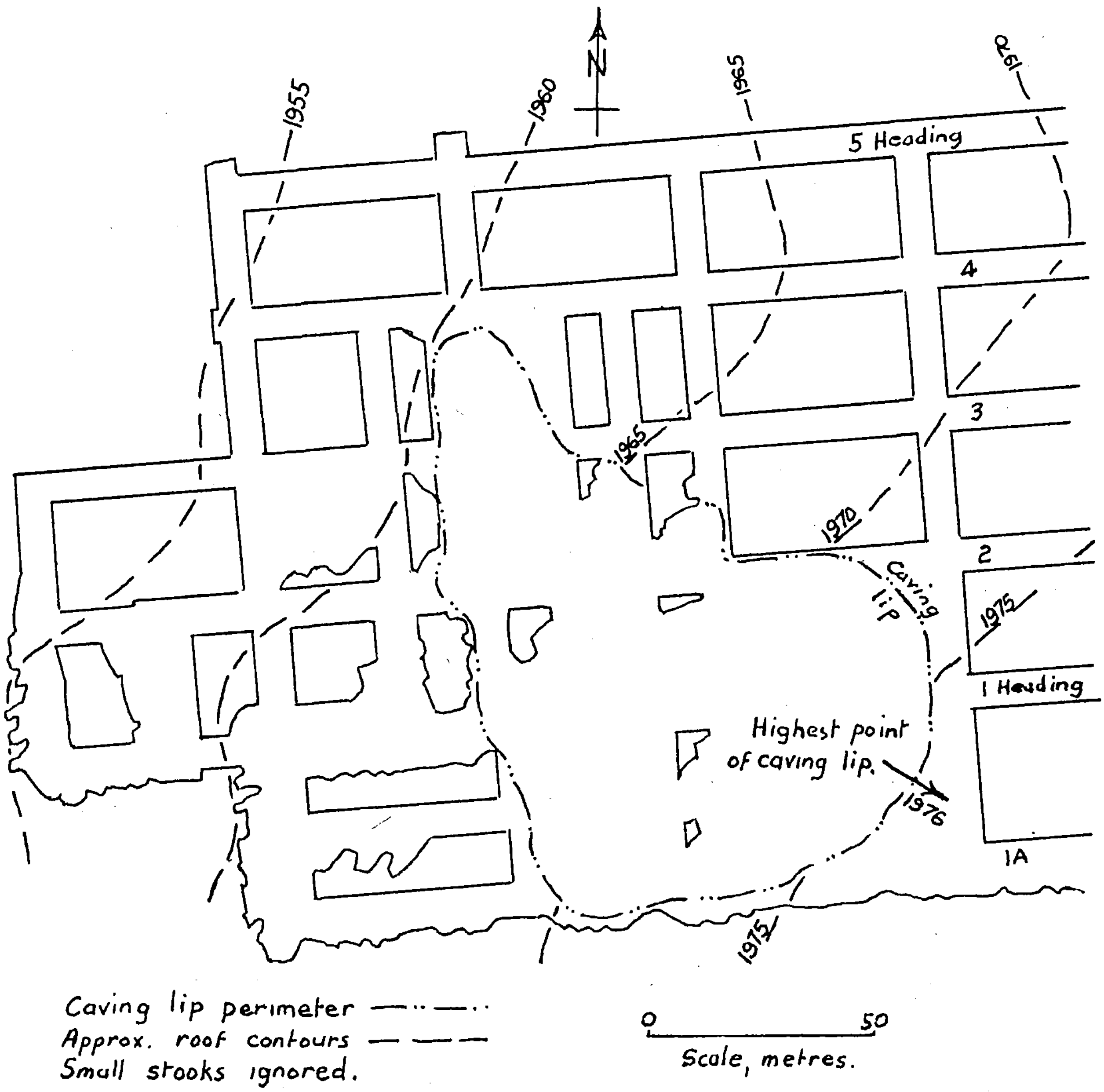


Fig. 12. Main Dip Goaf approximate caving lip 16/7/86

Airflows on 16/7/86 As stated above, air quantities in the North and South Returns of the Main Dip Goaf were varied according to the location of extraction. Just prior to commencing mining on 16/7/86 four sheets (Fig. 1) had been installed to direct the air down Heading 3, into Cutthrough 27 and closely around the extraction workplace. The total air passing would have been about 62m^3/sec, then divided arbitrarily between the North and South Returns. A survey made 3 weeks prior to the explosion between 23 and 24 Cutthrough showed 28.0m^3/sec in the North and 34.1 m^3 in the South Return. (Table 4). At least three quarters of this figure should have reached Cutthrough 27 where the mining was taking place.

The gases ignited Table 3 and derived Fig. 13 indicate gas emissions in the hours and days following the explosion to be not significantly different from the days preceding the explosion. None of these rough data give any indication of an extended tailing off of CH_4 emission such as would suggest a preceding (but missed) peak in CH_4 emission.

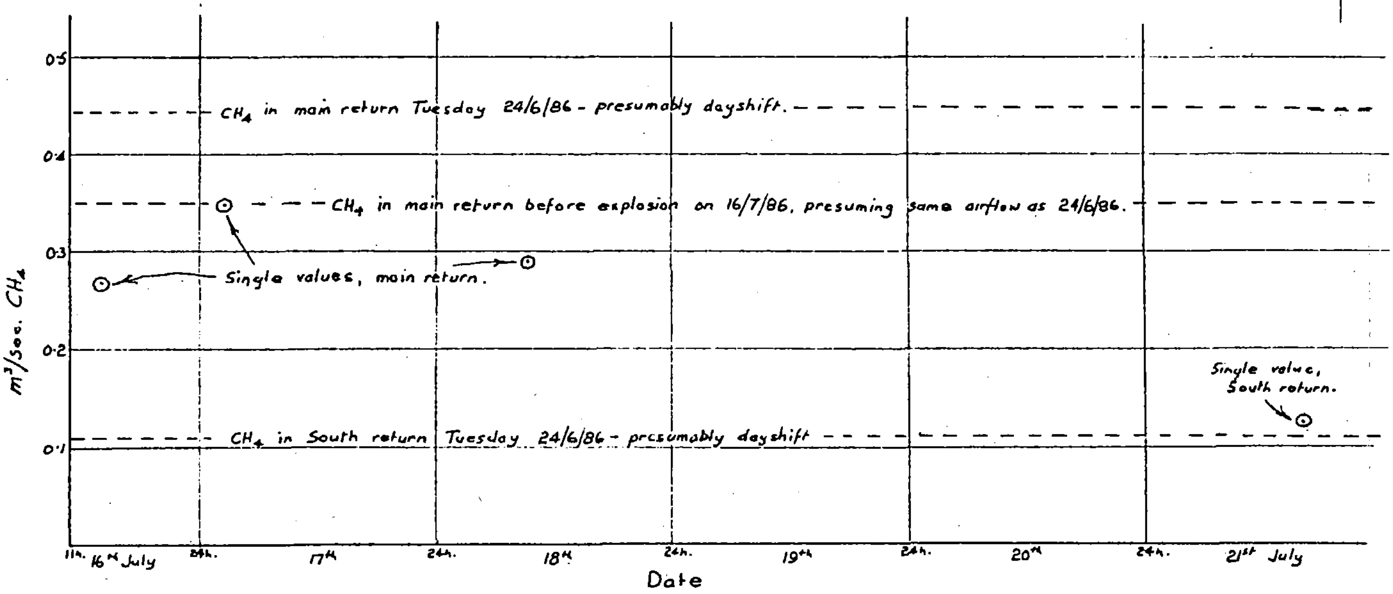


Fig. 13. Correlation of normal CH_4 experience with CH_4 after explosion.

Involvement of Gases from the Various Seams

There are differences in composition of seams A, B, C and D (Table 6) all considered as possible sources of gas during extraction, as stated above, but with less emphasis placed on D. These differences are studied related to possible differences in sorptive capacity, in the absence of sorption isotherms for seams other than C.

Various figures have been given for the depth of the water table, including one measurement of 21m. On the assumption that the water table is at the depth of 30m, that the gas pressure at the water table is atmospheric and that gas pressure is hydrostatic below the watertable, for C Seam, the sorptive capacities at various depths below surface are obtained from the sorption isotherm (Bartosiewicz and Hargraves, 1985) with a subsidiary depth scale equivalent to the gas pressure scale (Fig. 14). (The unmeasured but undoubted influence

of stress in reduction of sorptive capacity has been ignored in this case). Thus, it can be seen that at the mean depth of the Main Dip Goaf, 170m, the sorptive capacity for dry CH_4 of C Seam dry coal is 14.8 m^3/tonne. Reducing this to 78 % for moist CH_4 the sorptive capacity becomes 11.5m^3/tonne.

Has Dr Hargraves measured or assessed after measurements.

TABLE 6

Comparative Analyses of Moura Seams

Seam	Thickness m	V.M.% afd.	Ash %	Analysis origin
A	4.8	32.0	4.9	Holes 10040, 1, 2
B	1.5	33.4	31.0	Hole over 4/S Sub
C	5.94	29.5	14.0	Hole 10088
(Total)		29.1	11.4	Bartosiewicz & Hargraves (1984)
	6.81	29.6	12.8	Hole 10042
D	4.54	30.6	14.7	Hole 10088
	4.79	29.0	9.1	Hole 10042
	4.52	29.5	12.3	Hole 10040
E	1.78	28.9	18.8	Hole 10088

For a comparative depth: sorption curve for seams A, B, D and E, without any actual laboratory result, the best approximation would be obtained by making allowances for differences in analysis from C Seam, on the basis that sorption capacity increases with reduction in volatile matter in proximate analysis, and vice versa. For such an exercise, available proximate analyses are summarised in Table 6.

As differences in coal composition between Seams C, D and E are not great, and as approximations are all that are possible, it should be sufficient for this exercise to assume similar sorptive capacities for Seams A, B, C, D and E. Fig. 15 then is an extension of Fig. 14 and gives moist CH_4 sorptive capacities for seams A, B, C, D and E, m^3.tonne, in any strata vertical section, all related to the depth below surface of C Seam. The particular figures for each seam with C Seam at the horizon of the Main Dip Goaf, 170m below surface, based on the assumptions:

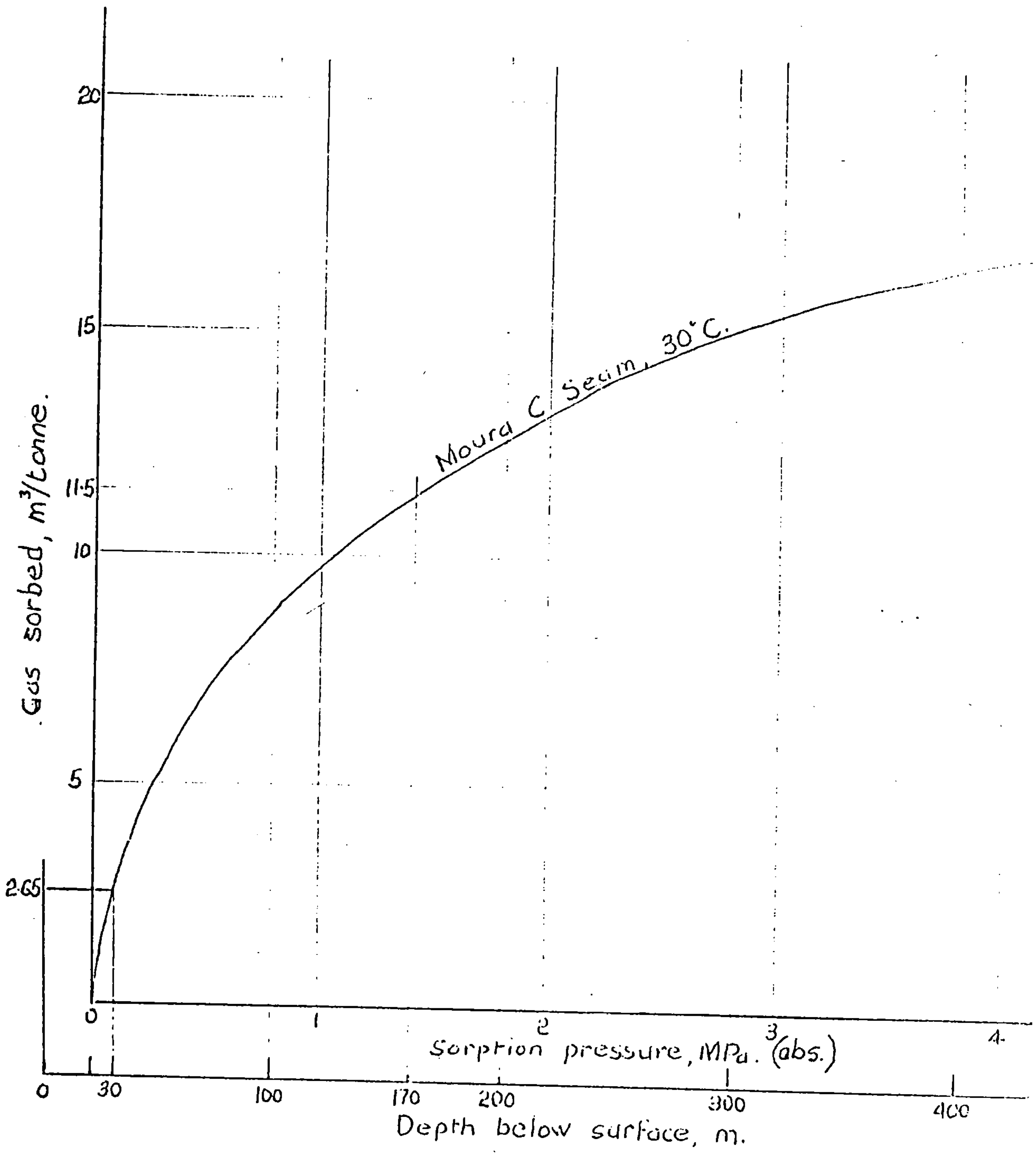


Fig. 14. Relationship of sorptive capacity of coal to depth below surface

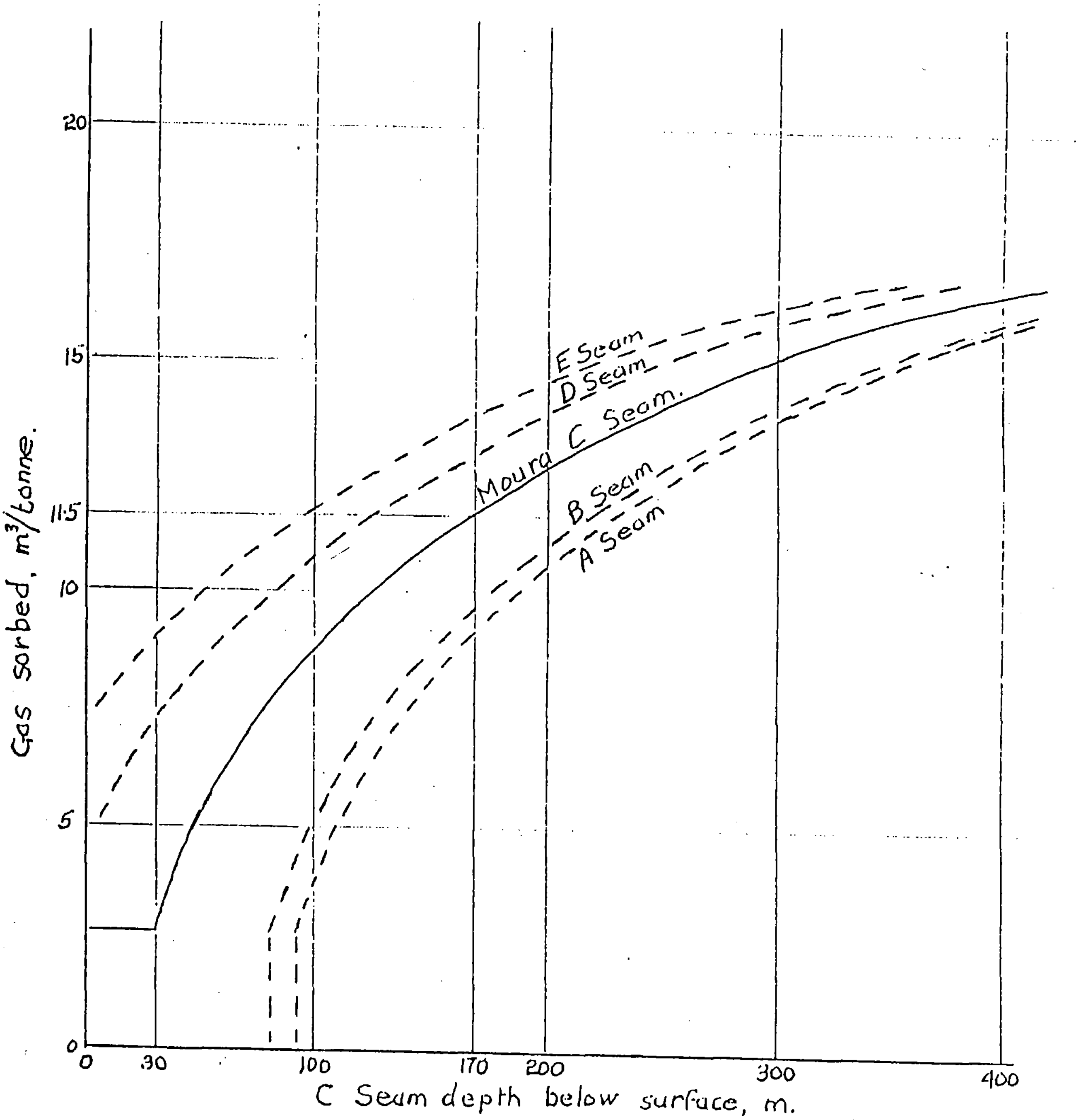


Fig. 15 Comparative gas contents of seams A to E Moura in vertical section relative to depth below surface of C Seam

Thickness A Seam	4.8m
Centre A Seam to Centre B Seam	11.2m
Thickness B Seam	2.9m
Centre B Seam to Centre C Seam	50.9m
Thickness C Seam to centre D Seam	7.0m
Centre C Seam to centre D Seam	44.8m
Thickness D Seam	4.6m
Centre D Seam to centre E Seam	30.1m and
Thickness E Seam	1.7m

are shown in Table 7

TABLE 7

A comparison of gas contents of various seams, Main Dip Goaf area

Seam	CH_4 Sorbed m^3/tonne	Depth, m
A	9.0	108
B	9.6	119
C	11.5	170
D	12.8	215
E	13.7	245

With a pillar extraction activity within a virgin coal perimeter, and with pillars of long time formation, as was the case of Main Dip Goaf, the pillars themselves would be virtually winded of gas. Indications are that with the pillars in the top of C seam, and with subsequent grading down to lower horizons in C seam, the development process and partial bottom winning would have commenced the progressive degassing of the whole of C seam, so that the assumption could be made that the whole of C seam pillar coal within the virgin perimeter was virtually winded of gas and was making no significant contribution to CH_4 make in the ventilation return. The occurrence of some heaves within the goaf would tend to confirm this situation. The only significant source of CH_4 addition to the goaf atmosphere, therefore, would be any CH_4 issuing from the virgin coal of the perimeter (including that known to be issuing from some abandoned in-seam drainage holes) and any CH_4 permeating up from relieved seams in the floor/or down from relieved or caved seams in the roof. Regarding such relief and perhaps caving of such adjoining seams, the mechanism is that with a continually mined, continually expanding goaf, any areas of relief and caving of adjoining seams are also continually expanding but with perimeters related to the expanding virgin perimeter of the working seam, but always less. The two situations of relief and caving have different characters,

1. from an area of <u>relief</u> in an adjoining seam to the openings of the working seam is a permeation path with permeability reduced from the virgin situation, but a finite permeability such that the pressure loss in such permeation only allows a partial pressure drop at the adjoining seam, and

2. from an area of <u>caving</u> in an adjoining seam to the openings in the working seam is a virtually free passage with negligible permeability such that the caved and broken coal will be at a pressure of mine atmosphere.

The perimeter of relieved coal is therefore at a pressure somewhere between its virgin pressure and mine atmosphere pressure, depending on the back pressure of the permeation path, and the perimeter of caved coal is therefore at mine atmospheric pressure, and such perimeters, like the perimeter of virgin coal of the working seam, allow permeation of gas laterally to continue indefinitely. With working extractions and expanding perimeters in the working seam, such perimeters expand in relieved and/or caved adjoining seams. With a static perimeter in C Seam around active pillar extraction as was the case at Main Dip Goaf only the relieved and/or caving perimeters in adjoining seams would expand. With a static perimeter in C Seam around stopped pillar extraction as is now the case at Main Dip Goaf, the expansion of relieved and/or caving perimeters in the adjoining seams has stopped and a steady state of gas emission from perimeters of adjoining seams exists similar to the steady state emissions from C Seam perimeter. These situations are depicted in Figs. 6, 16 and 17. Fig. 7 is of a physical model of a W. German coal mining situation, showing relief of floor as well as of roof following extraction - undoubted but not considered important for gas in this case.

<u>INCENDIVITY</u>

For back analysis of data to arrive at the source of gas on 16/7/86, knowledge of the point of ignition would be very useful. The elimination or discounting of other possibilities heighten the possibilities of frictional ignition within the goaf. As frictional sparking between steel roofbolt washers and roof sandstone can be

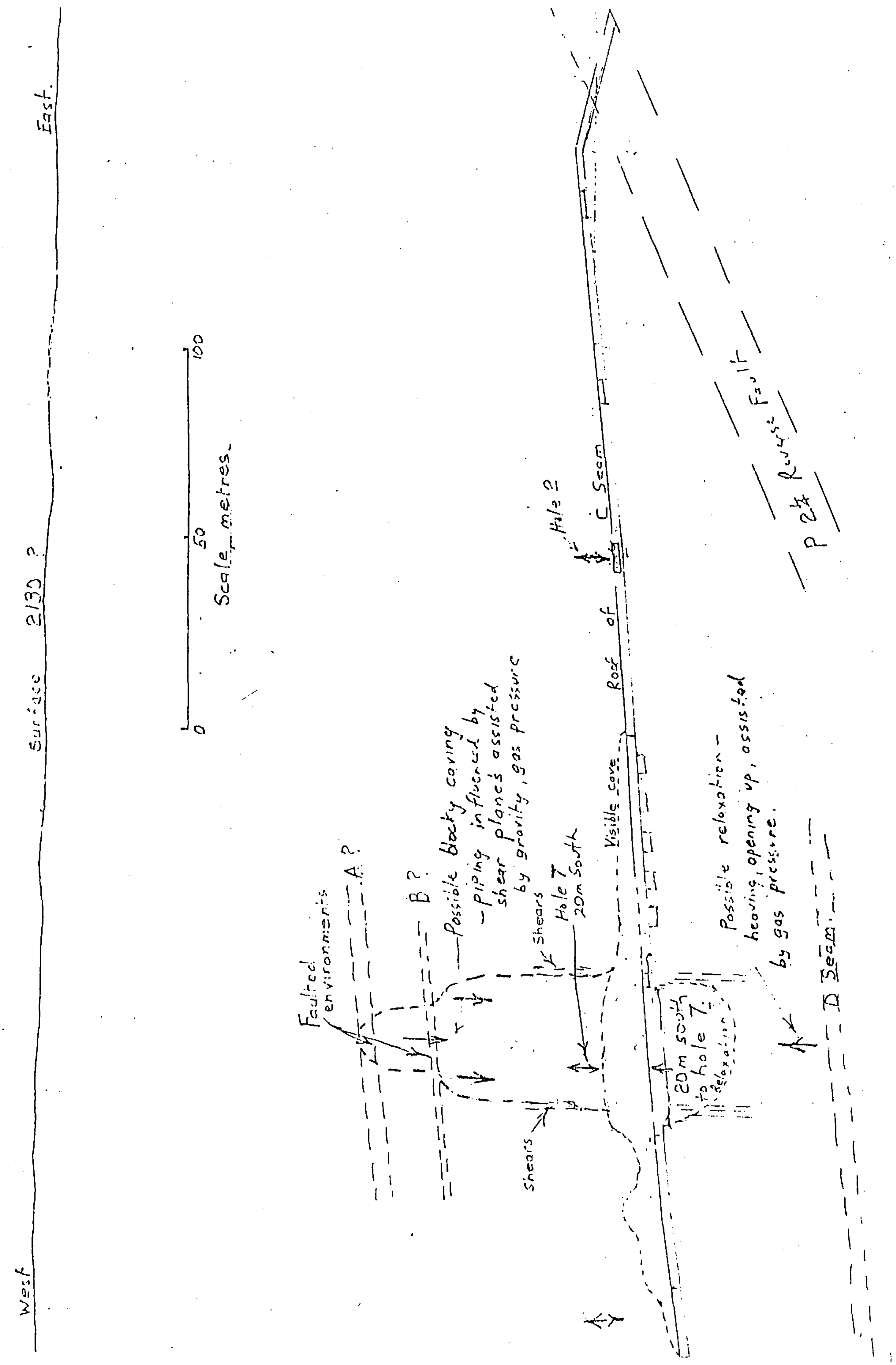


Fig. 16. Interpreted section along No. 1 Heading

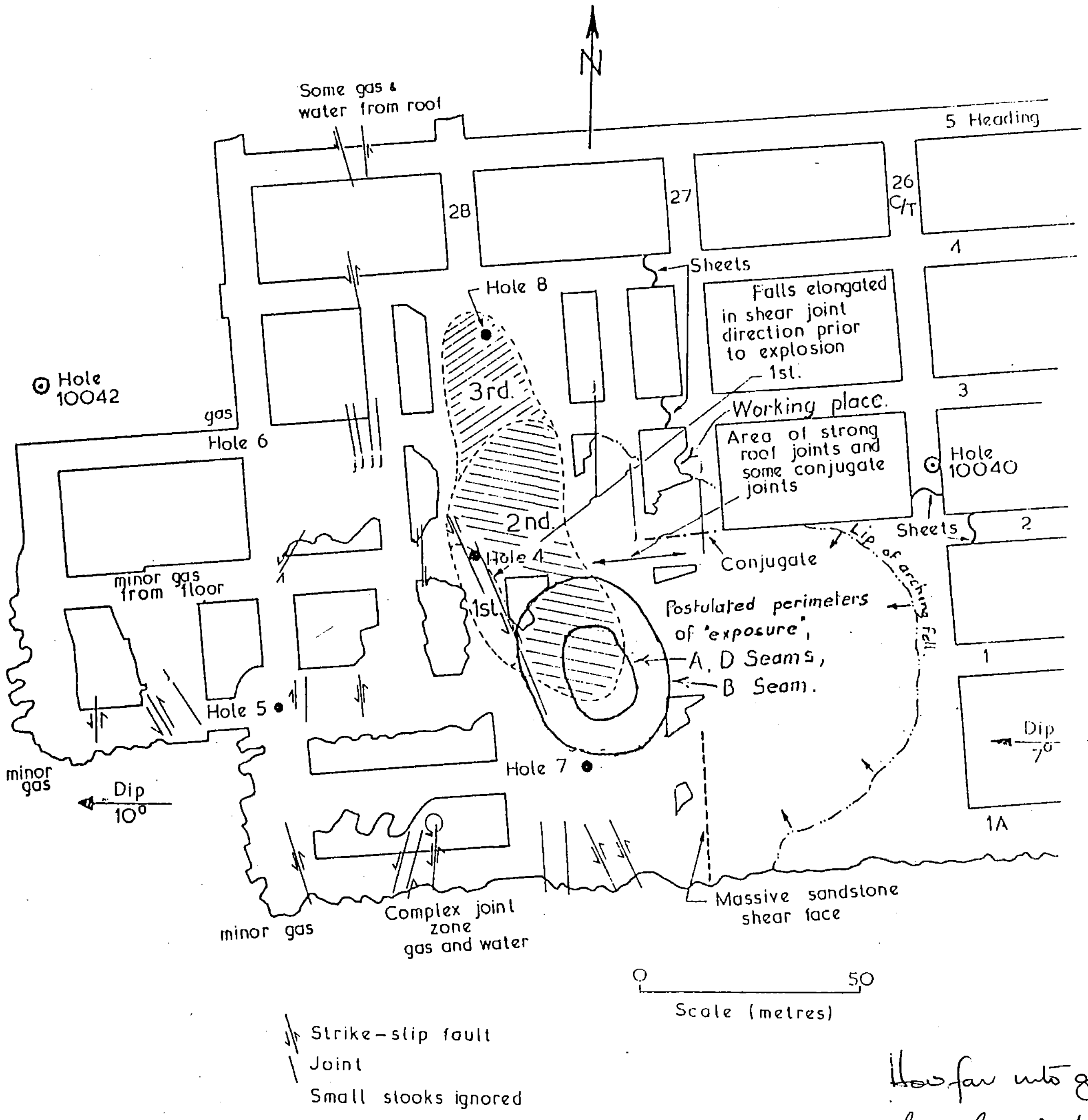


Fig. 17. Possible Main Dip Goaf Movements 16/7/86

How far into goaf along line of hol heading and JB. explore.

Opinion re possibl "perimeter of exposure"

demonstrated, this test has been extended to incendivity. Whilst the interest of this Report lies in the outcome of such testing, it appears from their description that the incendivity tests applied involve considerable windage, tending to lessen incendivity because of its cooling effect. But it must be conceded that in most conceivable situations of frictional sparking due to falling roof sandstone striking a spark by friction on another object, the nature of the situation would appear to create significant air movement in any case. (In fact some overseas experiments (SMRE 1957, SMRE 1958) show that stone free-falling from a high CH_4 atmosphere into normal air below takes (sucks) with the stone some of the rich CH_4 into the vicinity of collision posibilities with sparking and with the possibility of ignition.) However, in seeking to represent the worst condition in practice it is felt that incendivity testing should be done under the stillest explosive atmosphere conditions achievable.

A circumstance where falling or subsiding sandstone could glance or graze steel is illustrated in Fig. 18, a roofbolt "butterfly" projecting out beyond a caving lip. Fig. 19 shows the fallen sandstone slab with the graze mark of the butterfly.

Fig. 18. Roofbolt "butterfly" projecting beyond caving lip

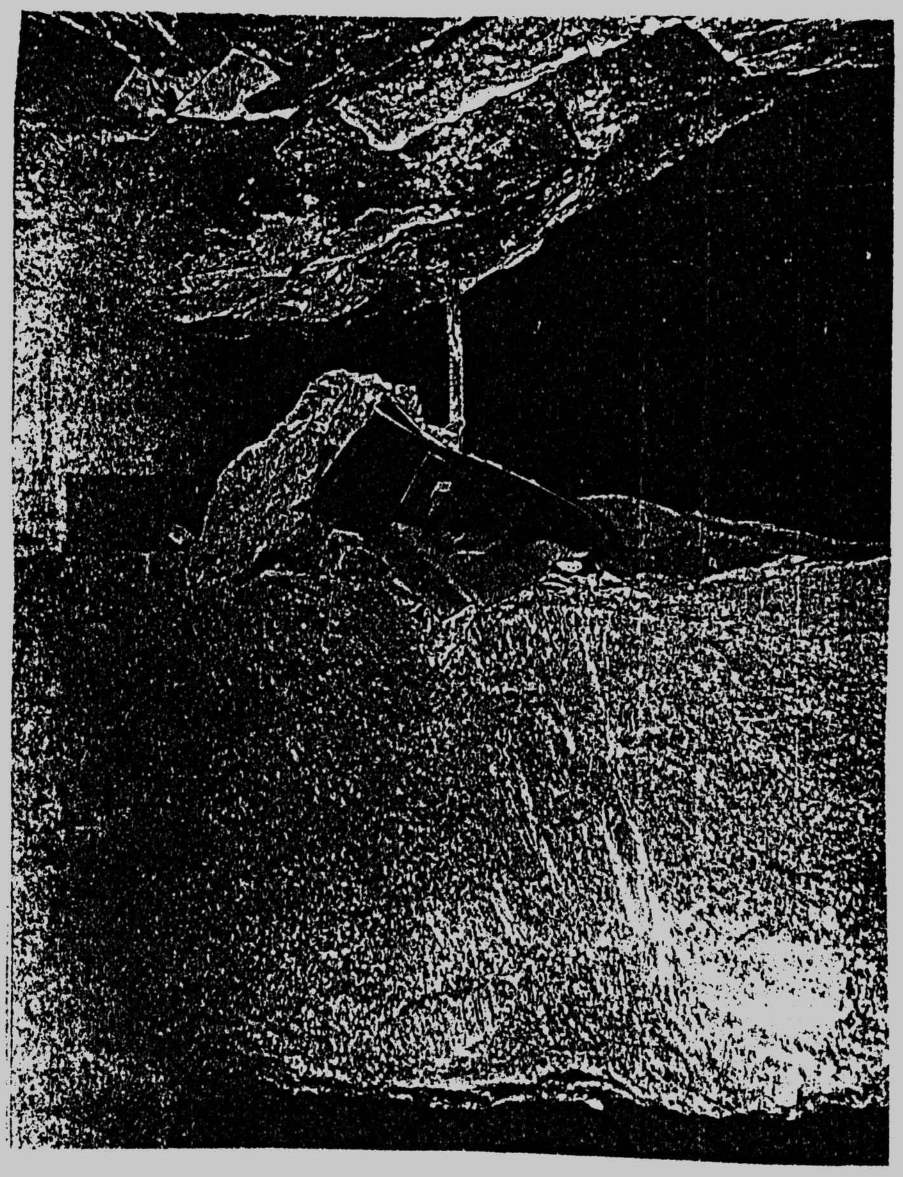


Fig. 19. Graze of "butterfly" on fallen sandstone slab.

REVIEW OF PREVIOUS GAS OUTBURSTS AND BLOWERS

Outbursts and blowers in 3/S

There were minor outburst experiences during continuous mining in 3/S District. These occurred on a somewhat mylonitic small fault and the amount of coal displaced was small. More noteworthy for this investigation were the blowers which occurred also in 3/S, on intersection of particular shears in the shear zone (somewhat on the projection of the shear zone from the Main Dip). The most important of these blew violently into the heading, creating a fog and discharged gas and milky (gas laden) water for a period of time, and days after was still emitting some gas and had left an open narrow cavity up into the roof as eroded and left by the issuing fluids.

Gas experience in 4/S Sub

There are no details of gas experience in the development or extraction of 4/S Sub. Development terminated to the west close to the alignment of the projections of P2$^1/_4$ fault and of the Shear Zones of 3/S and Main Dip. After extraction and sealing up of 4/S Sub it is known that on at least one occasion there was a pressure build-up behind the seals (referred to above), supposed due to an abnormal release of gas somewhere in the area. This is one of the bases for regarding 4/S Sub as a possible analagous case with Main Dip Goaf, with a (presumed) sudden release of abnormal gas. Also, during the explosion and/or subsequent period, apparently there was abnormal gas activity through the seals of 4/S Sub (Appendix 1). (More geometric details are needed of the extraction and the unexplained occasional development of internal pressure in 4/S Sub as well as of the surface subsidence to contribute better to the understanding of goaf conditions at Moura No. 4 generally.)

Main Dip during development

There are several gas notations on the plans of the Main Dip area to suggest some gas experiences during the development which were noteworthy. Some are shown in Fig. 1 and most are associated with faults, shears, joints etc. as components of the shear zone trending in the direction of the westerly limit of 4/S Sub and the Shear Zone in 3/S. Further, pre-drainage drilling was used in conjunction with the development of the Main Dip and some peripheral holes remained, still bleeding gas during subsequent extraction. Evidence of this continued such as the hole into the southern ribside of 1A Heading at 26 cutthrough still gently blowing gas on 6/8/86, and probably the gas bubbling in the water accumulated in No. 5 Heading at about 27 Cutthrough on the same date and subsequently.

Main Dip Area (after completion and) during extraction

There are no details of any gas experience during the pillar extraction and it should be assumed that there were no untoward gas occurrences. Appendix 2 records some observations during the

extraction from 30/6/86 to 15/7/86 including details of floor, seam and roof opening up but no gas releases were reported in association. Fig. 6 includes such observations and other geological, gas, etc. data prior to the explosion. In regard to the events of 16/7/86 leading up to the explosion, the Interim Report of 17/9/86 presumes an immediately prior event giving rise to a 'reasonably orderly withdrawal" of equipment and men. It seems unlikely that, if this prior event involved noticeable gas issue, the continuous miner would have been slowly (necessarily) trammed back to where it was found after the explosion. It seems most likely that a second event was the one which introduced the gas mixture to the ignition point.

Another possibility is that there was a series of connected events commencing with withdrawal of equipment from the extraction place because the goaf was working, the gentle exhaling of rich CH_4 from the goaf as a result of falling barometric presure and continuing gas make, the tendency of such rich CH_4 to layer from the goaf perimeter with the relatively low velocities there to be ineffective in preventing such layers and with the roof rising steadily outbye to encourage the retention of layers and their movement outbye perhaps in intake as well as return, and the possibility, with continuing working of the goaf, of falling sandstone bringing with it CH_4 rich gas towards the sites of potential frictional sparkings. (SMRE 1957, SMRE 1958).

FUTURE TREATMENT OF MAIN DIP AND 4/S SUB GOAF AREAS

As referred to in progress reports a pressure equalisation plan is proposed for both the Main Dip and 4/S Sub sealed areas. Both goaf areas have borehole connections to surface and it is proposed that both of these be equipped with an exhaust chimney grouted into the upper portions of the holes at the surface, with appropriate pipe

fittings to allow bleed-down of gas make from the goaves through a flame trap and non-return valve (Fig. 18) and thus avoid over-pressure behind seals. The expected output figure of $0.075m^3$/sec stated above would be an average, output fluctuating inversely with barometric pressure fluctuations. At times of barometric rise, with the surface non-return valve closed a slight under pressure may occur inbye the seals; under pressure reduced by continuing gas make inbye the seals as well as by any in- leakage of air. Adequate sampling offtake points, shut-off valve, protective fencing and protective lighting arrestors would complete the surface installation which should require minimal attention. The non-return valves would be set just above horizontal to minimise the pressure differential required for their operation and to ensure positive closure when not exhausting. (Depending on their design, it could be necessary to have the "horizontal" connection at a few degrees to the horizontal as shown in Fig. 20). The overcoming of pressure differential of the flame trap and non-return valve would be assisted by the motive column of the high CH_4 - lighter than air - goaf gas. (Hole 7 has a 4" BSP thread at the surface end of casing presently installed throughout the hole). (An appropriate flame trap for a first installation could be the 120mm dia., 80mm high Mine Rover inlet flame installed in a "5 inch' pipe).

Such sealed goaves with surface borehole connection could be considered as disposal areas for any future underground seam gas drainage, areas always operating at slightly above atmospheric pressure to obviate any in-leakage of air - perhaps with modified seal stoppings for greater integrity of seal and with permanent manometers for ready monitoring.

MINING, MINING GEOMETRY AND GAS EXPERIENCE

Instantaneous Outbursts

The possibility of an instantaneous outburst of the C seam has been raised. Instantaneous outbursts are not phenomena of pillar extraction, especially of relatively small pillars formed for a number of years. (The pillars of about 45m minimum dimension at Metropolitan Colliery in somewhat higher rank coal at over twice the depth of Moura

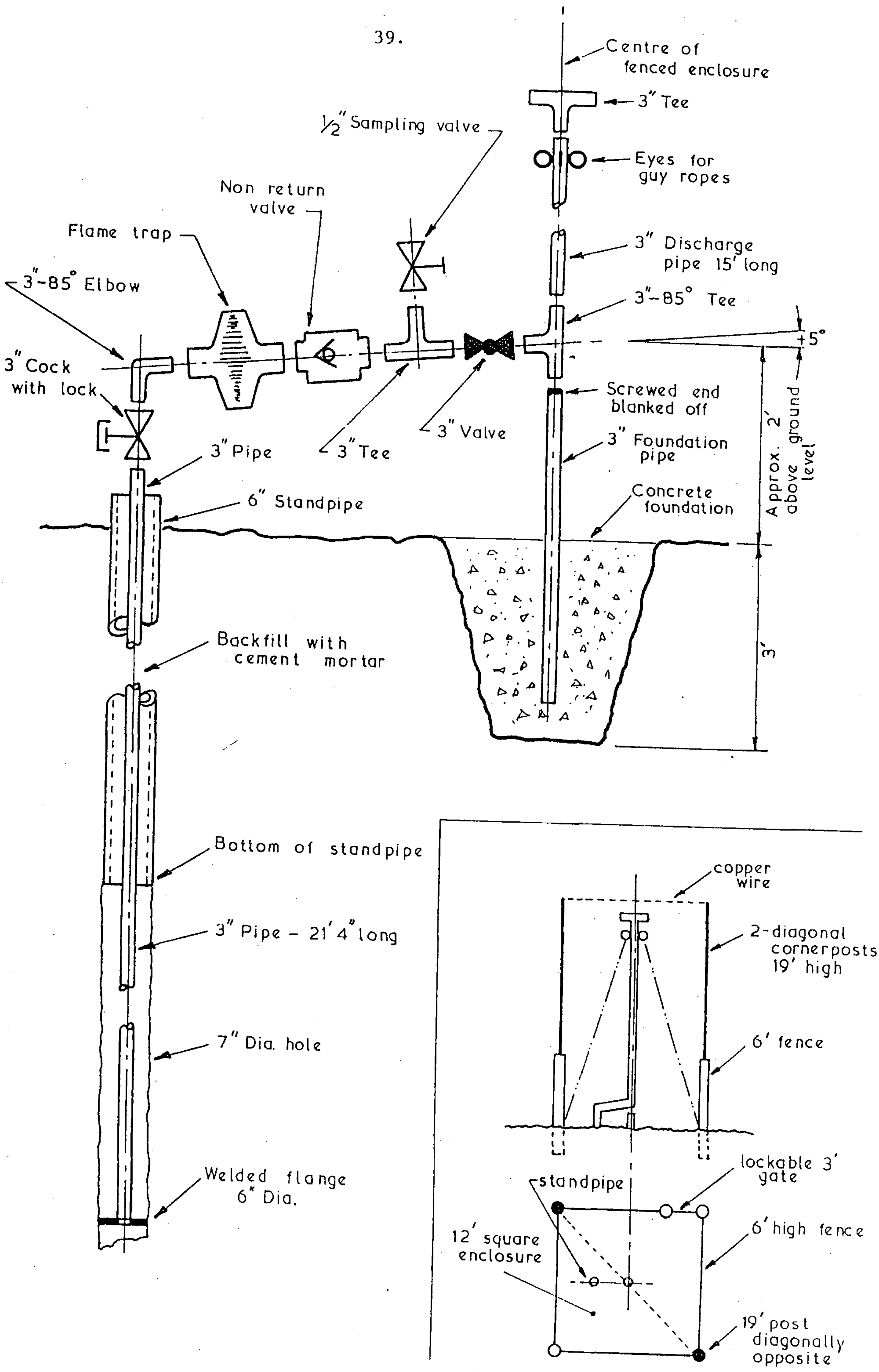


Fig. 20. Schematic of surface drainage drillhole installation

No. 4 were found to be virtually winded of gas six months after formation). If any likelihood existed of an instantaneous outburst in a pillar under extraction, it must be in the splitting of a large fresh pillar with some significant geological disturbance encountered.

The two closest known analogies to the possibility of virgin B and/or A seams to outburst when undermined by caving from below are

1. at Thorez Colliery in Poland in 1985, during development of a lower seam in the vicinity of faulting, progressive loading out of fallen roof following an instantaneous outburst in the working seam undermined an upper seam which experienced a violent instantaneous outburst of 500 tonnes, overwhelming the development and causing fatalities, and

2. at Great Mountain Colliery in S. Wales, during cross-measure rising some 20 years ago. A virtual cross-measure rise to explore an upper seam (Big Vein) had stopped short of the coal by perhaps 0.4m. The exposing shots created a vast outburst and much stone fell as well. The area was virtually overshelmed and the work was not proceeded with.

The possibility of an instantaneous outburst having occurred from B and/or A seams with a similar mechanism to these examplesis affected by several factors:

1. The shallower depth - say 120m of B and/or A Seams than C the working Seam makes outbursting less likely because of (a) lower gas content per tonne of coal (Table 7), and (b) lower general stress environment.

2. The lower rank of Seams B and/or A (Table 6) makes the seam less prone to outbursting.

3. At depth of 170m, C Seam only experienced a real instantaneous outburst on a fault, and that was a small occurrence, but

4. Intersection of a seam cross-measure, analagous to sudden caving of strata below to expose the seam (presumed) is a more prone situation.

Overall it seems unlikely that an instantaneous outburst of B and/or A seam did occur. A study of soot samples deposited in goaf - if with significant proportions of partly devolatilised coal dust, would heighten the possibility.

The Mechanics of extraction and caving of the Main Dip area.

Fig. 2 is a generalised EW section along No. 1 Heading, traversing probably the widest portion of the goaf with minimum stooks left behind. Fig. 16. shows the caving of the goaf extended further than depicted in the Interim Report, somewhat on the lines of the Wold and Hargraves (1984) model, (Fig. 6), but narrow in the EW plane due to the contribution of the shear zones on the E and W. The cave (Fig. 17) is shown extending to the floor of A seam, with perhaps, some automatic guidance from the bounding shears, and maybe any conjugate shears. The piping nature of the caving towards the upper seams, as seen in model in Fig. 6 is further constrained by the shears. The fault zones seen in drillholes below A and B Seam horizons may well be a flatlying fault in the plane of one seam of such geometry as to promote rapid caving upward. The piping upward of the goaf cave would have been assisted in the blocky material if shear planes or their conjugate planes spaced apart at C Seam horizon became closer as they continued upward. Likewise, with the cave approaching A and B Seams, their gas pressure would assist gravity in displacing underlying stone.

Conversely, although not seen in the floor, there is little doubt that this persistent shear system penetrates the floor also. If such shear planes or their conjugate planes converged as they continued downwards, there is little doubt that, in an area where heaving is occurring, the squeezing upward of the trapezium shaped discrete blocks would take place also. If some fracturing were to take place as a means of freeing such trapezium-shaped blocks for movement, then a sudden floor heave accompanied by a bump and liberation of gas issuing from the lower seams would be quite a possible sequence of events.

Fig. 17 shows the possibilities of both of these events which could provide seam gas to form a flammable mixture in a portion of the goaf free volume. Regarding the more likely, such would depend on more detailed mapping of the shears and other planes of weakness. In general, the liberation of the upper seam gas would be assisted by gravity forces and could be sudden, like the blast of a shotgun and of the lower seam gas hindered by gravity and could be likened to the inflation of a rock bubble, perhaps to crack. The lower D Seam is marginally closer to C seam than is the B/A Seam in the roof. Seam E in the floor is further away than both (and could be discounted as contributing to a first flush of gas). The gas pressures and sorbed gas are greater of seams in the floor than of seams in the roof.

There may be some tendency for light seam gas, such as essentially CH_4 to remain in high places, such as in high goaves, as layered seam gas with a transition zone at the gas - air interface, and inevitably of mixtures above the lower explosive limit existing in such transition. Any falls or movement in the cave would stir up air-gas movement and promote mixing. In the case of floor emissions, the need for the light seam gas (density 0.54 relative to air) to rise up through the air in the goaf makes for turbulence and mixing rather than for layering. Finally, if caved, the relaxation pressure around involved coal would be virtually atmospheric allowing all sorbed gas to desorb down to atmospheric pressure and allowing exposed ribs to emit gas just as from the working seam. Relaxed seams, whether in roof or floor would have only partial relaxation of seam gas pressure and would desorb gas down to this pressure. The perimeters of caved coal and of relaxed coal would be the extent to which gas in the seam would establish its own gas pressure gradients respectively to atmospheric pressure and to some higher pressure according to the gas permeability of the relaxed strata.

The fortuitous sub-parallelism of the extraction "line" of Main Dip Goaf and the shear zone appears to have allowed such shear zone to have had maximum influence on the shape of the cave and the manner of caving, a situation probably best to avoid in future. Further the pattern of stooks, some small, some large, some to crush, some to collapse, undoubtedly disturbed the progress of caving.

C Upper and Lower Seams

The possibility of a floor burst releasing retained gas from C Lower Seam was considered, perhaps even an instantaneous outburst of C Lower involving pulverulent coal. There have been such examples of floor bursts, with copious gas verging on instantaneous outbursts usually under faulted conditions at Collinsville (bottom coal) and Leichhardt (reverse faulted seam), (and at Chinakuri in India the classical example apparently without faulting) all during development. The classical example of floor bursts of gas during extraction is from the Silkstone Seam in Yorkshire, U.K. where massive floor rocks breaking intermittently give rise to correspondingly intermittent floods of gas into the workings. A similar but possibly less important occurrence has been the intermittent high issues of floor gas (Balgownie Seam and lower) in longwall extraction of the Bulli Seam at Appin Colliery - now largely regulated by post drainage in the floor. In the U.S.A. at Olga Colliery in the Pocahontas Seam violent pillar bursts occurred during pillar extraction. The gas occurring with such phenomena was not from the pillars of the working seam but from other seams closely adjoining, suddenly relieved by the bump, which allowed their gas to traverse intervening strata to the extraction area.

To test this possibility at Moura No. 4 a short drilling programme tested gas emissions and pressures from virgin C Upper Seam rib and from C Lower, directly under the virgin C Upper hole and from C Lower from holes in the pillared area bordering Main Dip Goaf. Whereas the rib holes in both C Upper and Lower blew copious gas, as was to be expected, and immediately commenced to develop pressure until leak- age occurred due to the shallowness of the seal in both cases, the C Lower holes in the goaf environment had negligible if any

gas issue, so that a pure gas sample was impossible, and developed no gas pressure over periods of hours. Accordingly the presumption of insignificant gas in C Lower Seam at time of extraction became a conclusion.

Other seams

The nature of extraction of C Seam at Moura was anticipated as a blocky rather than flexing situation, and events seem to have substantiated the blocky modelling done previously. Such modelling indicated a high blocky cave, almost a "piping" upward from a comparatively narrow goaf to expose and sag A (and B) seam. The model indicated no similar floor movements, perhaps influenced by the different treatment of top and base in the model. The model did not incorporate any geological structural anomalies. This model differs from the classical more flexible understanding of goaf caving (influenced undoubedly by more argillaceous superincumbent rocks) of caving extending upwards from 5 to 10 times extraction height, with diminishing relaxation above that. The factor in this instance would be at least 15 times.

Time sequence to attain these collapses.

In practice, the goaf was traversed by a shear zone, striking rather parallel to the present elongate goaf dimension. Also, not far outbye the goaf a very flat lying reverse fault (P2 1/4) had been encountered and this appears to underlie the goaf, but according to exploration drilling, is not encountered above D seam in one intersection, nor above D and E seams in another. However changing strike and dip reversal reported not far to the south would complicate its projection into the goaf area. One exploration hole particularly indicated complex faulting in the vicinity of A and B seams in the goaf area, (Fig. 16) and this faulting could be flat lying.

A likely explanation of the mechanics of caving of Main Dip Goaf appears to be of a high blocky cave guided at least by the confines of the shear zone and aided by a structural weakness near the horizons of A and B seams encouraging their subsidence into the cave and with their exposure, sudden release of their intersticial gas, perhaps even verging on an instantaneous outburst, with disintegration and fast release of the gas sorbed in the detached coal and commencement of continuing degassing from the exposed seam perimeters. (All emergency holes encountered noteworthy gas from A and B Seams.) Now, all fast degassing is over and the contribution of gas from A and B seams to the goaf is small, according to their short exposed perimeters (Fig. 17) and the (lower) virgin gas pressure according to their shallow depths. Wold and Hargraves (1984) anticipated that flushes of gas would recur during production in longwalling as a result of recurring intermittent advances of caving to A and B seams.

Considered less likely, however not completely discounted, is the possibility of the gas deriving from floor movements below the goaf assisted by flanking shear planes and perhaps by other unidentified geological structures underfoot. Such would have the effect of opening up permeation paths to the underlying D seam with appropriate permeation back-pressure and establishment of a perimeter of relaxation in D Seam (no greater size, say, than the perimeter of exposure of A and B Seams, Fig, 17) for continuing gas emission against such back- pressure to the atmospheric pressure in the workings. Now, all fast degassing would be over and the contribution of gas from D Seam to the goaf would be small, according to such short relaxed perimeter and its (higher) virgin gas pressure according to its greater depth.

Total gas considerations

When a virgin rib is exposed, gas emissions from the ribside usually are initially at a maximum, then fall away asymptotically towards some constant figure unless more rib is exposed. Exposed and detached virgin coal, on the other hand commences with a high rate of emission, tailing off to virtually zero in some finite time as the detached coal reaches equilibrium with the pressure of the surrounding atmosphere. Variations in atmospheric pressure affect emissions from both virgin and detached coal, but have their important influence on gases already emitted and the atmospheres containing them.

Thus the gas emitted into an expanding goaf of a retreating extraction comprises (a) gas from the virgin ribs of the working seam emitting probably at its lowest (asymptotic) rate, plus (b) gas from progressively exposed and detached coal, emitting at a rate from each

lump decreasing with time to virtually zero within finite time, plus (c) gas from progressively exposed adjoining seam perimeters each newly exposed unit of perimeter, emitting initially at a high rate, then decreasing asymptotically with time towards a constant value, plus (d) gas from seams partially relieved within a perimeter of relief and permeating against backpressure into the goaf, thus yielding a finite amount of gas at a reducing rate with time in a finite time yet with perimeter increasing with progress of extraction plus (e) gas from beyond the perimeter of relief emitting initially at a high rate against the permeation backpressure, then decreasing asymptotically with time towards a constant value according to the backpressure but modified whilst extraction continues according to new perimeter relieved. These components are shown in Fig. 21. No comparative scales are attempted either for time or for flow rates or taking account of seam thickness in all graphs. For any one extraction geometry (a) always occurs, (b) and (c) may occur and/or (d) and (e) may occur and the total gas in the return(s) of the goaf is the sum of (a) plus whichever other components apply. For any particular extraction geometry, the value of (a) at any time would depend upon time since exposing the perimeter and whether perimeter gas make rate had yet reached the asymptote value, the value of (b), during mining (progressive detachment) would be related to production rate, the value of (c) would depend on the span of caving at the adjoining seam at that time, the value of (d) during mining (progressive relief) would be related to production rate and the value of (e) would depend upon the span of relief of the adjoining seam at that time. Both (d) and (e) would also depend upon the permeability of the inter-seam strata.

Is time period secs, minutes, hours or days? What is likely relationship between max flow rate and rates which ~~are calculated~~ can be ~~eg~~ assessed after an event.

In the case of Main Dip Goaf it is concluded that the strongest possibility is (a) plus (b) and (c), both (b) and (c) referring to both the overlying Seams A and B. The possibility of (a) plus (d) and (e) or even (a) plus (b) and (c) plus (d) and (e) where (d) and (e) refer to underlying Seam D is accepted but not promoted at this stage. In either case the time of gas release leading to explosion, 16/7/86, is identified as the moment of first caving to A seam in the probable case and the moment of first relief of D seam in the possible case.

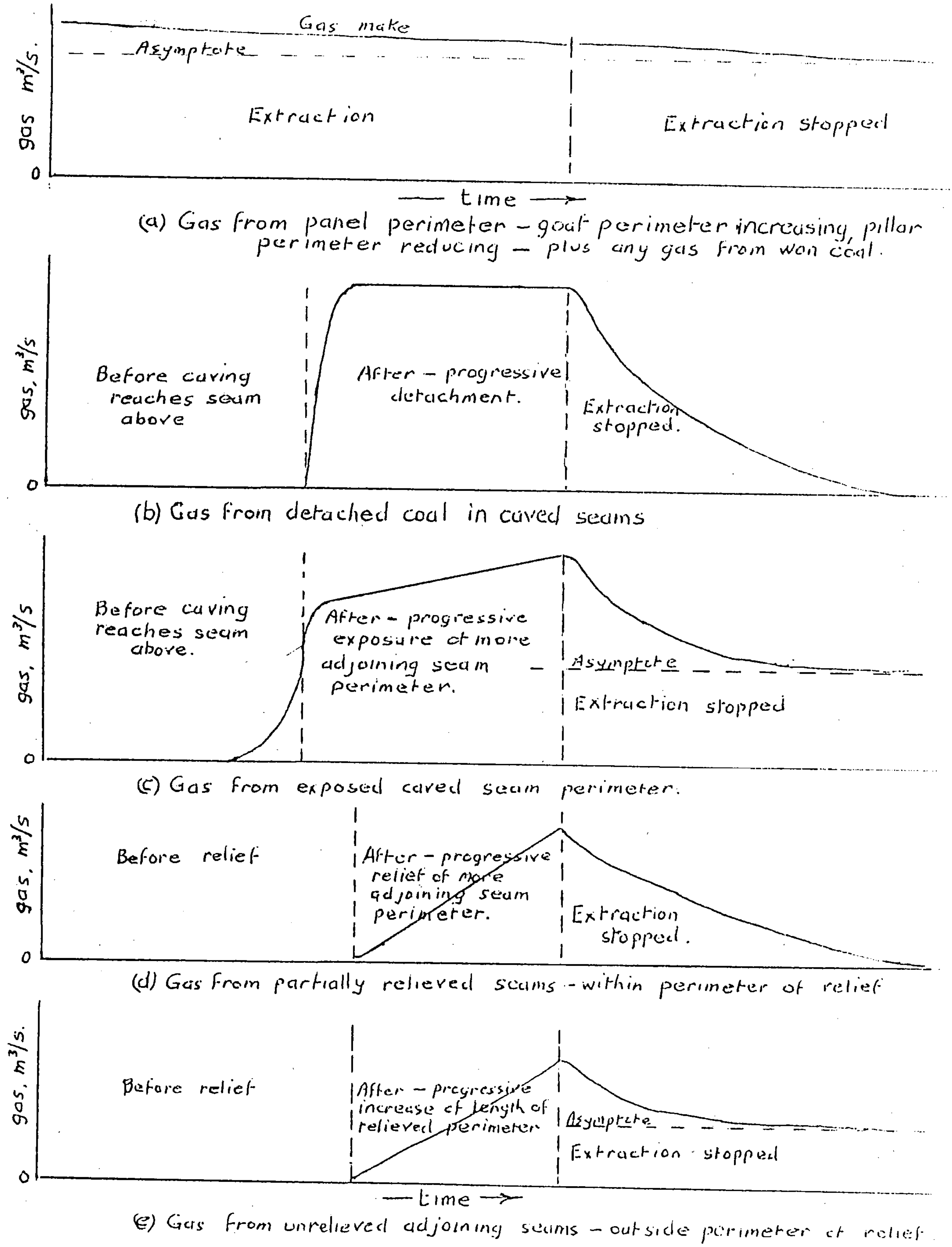


Fig. 21. Components of gas issue into a goaf of a working seam within a deck of seams.

Identifying the Moura No. 4 gas situation

Whilst it appears most likely that the problems of 16/7/86 were related to a sudden, if not violent emissive caving of A seam, perhaps associated with the collapse of a small slender stook to precipitate the cave, it is only the most probable of several possibilities. The nature of gas emissions under the situation of adjoining seams is depicted in Figure 19. Were the seam gases of different composition - normally meaning $\frac{CH_4}{CH_4 + CO_2}$ ratio - then it might be possible to identify the normal sources of goaf gases, but the chemical composition of C, D and E seams is virtually the same, more than 99% CH_4, with every indication that seams A and B have similarly pure CH_4. Preliminary isotopic analyses of seam and goaf gases, however, indicate differences, differences between isotopic composition ^{13}C in CH_4 of C Seam, D Seam and A, B and X Seams as well as Main Dip Goaf gas as sampled through Borehole 7 about 4 weeks after the explosion. (In retrospect, early isotopic analysis of afterdamp may have been able to distinguish seam CH_4 from distilled from coal during the explosion and perhaps even CO_2 derived from combustion of seam gas CH_4 and of coal dust.) According to Fig. 21. the contribution to goaf gas from caving adjoining seams reduces significantly when caving ceases and, as a very rough approximation, and not allowing for the lower virgin pressure of A Seam relative to of C Seam, using the comparative exposed perimeters of A Seam and C Seam, in the goaf (Fig. 15) the contribution of A (and B and X) Seam gas in the presently inactive extraction of Main Dip would be a very small percentage of the whole make of gas into Main Dip Goaf. It would only be at times of normal to high extraction when the volume of A Seam gas depicted in examples (b) and (c) of Fig. 21 would be of comparable order of magnitude with the volume of gas concurrently issuing from C Seam, depicted in example (a) of Fig. 21. Tentatively, as isotopic analyses of ^{13}C in CH_4 of X, A and/or B Seam gas indicate heavier C than in C Seam, and as ^{13}C for goaf gas was something in between, a basis is suggested for establishing the seam origins of mixed seam gases. But analytical trends so far can only be regarded as tentative pending confirmation from further samples and analyses.

MINIMISING GAS EXPERIENCE

In any generalised pattern of development and extraction it is inevitable that gas will be released from the working seam from the coal won and from exposed working perimeters and following extraction of the working seam that gas will be released from any adjoining seams according to the areas caved or relieved and to the resultant perimeters for drainage eventually towards the working area. The rate of release of these gases will reflect production rates, and for planned high production rates it may be necessary to employ seam gas drainage to minimise the gas entering ventilation to achieve compliance with safety and statutory requirements, and for other reasons including economies in ventilation and possible utilisation. Generally, regularity of geometry and regularity of production will produce regularity of gas issue, but already the extraction process at Moura No. 4 has been identified with some intermittency of caving (Appendix 1), (Wold and Hargraves, 1984) and of gas issue.

Knowledge of previous drainage
How effective
If not why not
How improve.

There already has been some experimentation in seam gas pre-drainage and tentative patterns are in existence and some work has been done towards routine pre-drainage ahead of development. (With partial seam gas drainage comes shrinkage and reduction of stress with possible support benefit - at the expense of possible increase in dust.) The gas experiences in 4/S Sub and Main Dip extractions make desirable some programme of post-drainage - the collection of gas liberated from coal detached from and exposed of adjoining seams in the caving process and the interception of gas before release from seams relaxed and made more permeable by extraction of the working seam. As Moura No. 4 knows from its approach to pre-drainage, it is a new field and there are no standard procedures and it is developing its own patterns found to be effective. Likewise post-drainage, although a long-standing and effective field in advancing extractions overseas, is largely a new field in retreating extractions in Australia and elsewhere and is being developed and used very effectively in several Australian extractions, particularly retreating longwalls at considerable depths of cover. Post-drainage is recommended for extractions in Moura No. 4, even at such shallow cover as less than 200m., because of the obviously high gas sorptive capacity of the coal and the demonstrated

tapping of adjoining seams by extractions. The peak issues of gas are a particular problem related probably to the intermittency of caving. The remaining uncertainty of the origin of peak issues of goaf gas should be resolved to give better direction to post-drainage, and post-drainage experiments should follow, leading to a standardised approach. Whilst the two sealed goaves are now quiet, further strata readjustments could give rise to further sudden gas issues, but, as stated above, such should diminish in importance after the first. Further, more extensive goaves of greater volume should be able to withstand sudden gas issues with less disturbance. Such factors notwithstanding, the direct liberation of surplus goaf gases through boreholes to surface is commended for consideration.

CONCLUSIONS

With various contributory data incomplete at this stage, any conclusions relating to the (presumed) sudden appearance of gas to contribute to the explosion of 16/7/86 can only be tentative, but can be improved. However, there are reasonably strong indications of interpretation of events. Strong gas issue was not a feature of the extraction of Main Dip Goaf up to 15/7/86. Strong gas issue was a possibility at the time of the explosion, but is unlikely to have been the event which gave rise to the "orderly withdrawal" of the continuous miner. What this preceding event was is still largely surmise. Perhaps caving produced a windblast shortly before the explosion. In the afterdamp and in the period of days for its dispersal, CH_4 was a significant component to strongly suggest its contribution to the explosion rather than pure coal dust, indeed the almost invariable historic situation worldwide. But back-analysis of the meagre CH_4 records following the explosion (Fig. 13) suggests only normal CH_4 emission. Now, a period of months having elapsed since the explosion, CH_4 derived from the Main Dip Goaf is barely significant, as might be expected from such a virgin rib perimeter of a not extensive goaf.

There is no possibility that an instantaneous outburst from C Seam occurred during extraction. There is a remote possibility that high and rapid caving of B and/or A Seam gave rise to an instantaneous outburst - but if so, then it occurred subsequent to the event which gave reason for withdrawal outbye of the continuous miner.

Insignificant gas was left in the C Lower Seam in the extraction area, certainly insufficient to give rise to a blower from C Lower. Floor blowers as a result of relief of stress on D Seam are considered unlikely also. More likely if sudden, was a copious but short-lived emission from B and/or A Seams when subsidence and caving over the goaf reached their vicinity. The shear zone traversing the goaf area played a significant part in early high caving over the goaf.

The gas sources in the extraction are seen to be

1. mined pillar coal and floor coal - small,
2. the perimeter of exposed virgin C seam,
3. detached coal in caved seams above,
4. the perimeter of caved overlying seams,
5. the coal within the perimeter of stress relief of seams in the floor,
6. the virgin coal outside the perimeter of stress relief of seams in the floor, and
7. any gas emitting from surrounding non-coal strata.

Most of these components emit in higher quantities during active mining extraction.

The similarity of chemical composition of the gases from the several seams does not allow ready identification of components of the total CH_4 found in goaf atmosphere. There is a possibility that differing isotopic composition of the gases from the various seams can assist in identifying proportionate origins of goaf CH_4.

Regarding the source of ignition most of the above is derived from a paucity of fact, without much positive data to reconstruct the explosion and make positive conclusions. It is understood that the source of ignition is still not known and that frictional ignition is not ruled out. If ignition occurred in the goaf, the evidence is obscured in the caving of 16/7/86 and in the elapsed time since.

Regarding the reduction of uncontrollable gas issues it is suggested in hindsight above that there could be better control of goaf with a breakline at an angle as great as possible with the shear zone, rather than sub-parallel as recent experience has been. Likewise, if extraction involves the leaving of stooks in the goaf then these should be as small as possible to ensure their progressive crushing out not far from the extraction line, rather than stronger and still sustaining high load when nearer the centre of the goaf. Notwith- standing this, it would be better to employ an extraction method which leaves no stooks, such as retreating longwall.

The implication of Wold and Hargraves (1984) that caving could always be accompanied by intermittent flushes of gas from the roof is accepted as being implied whatever the orientation of the breakline or the direction of retreat. But the first break is seen as the most significant, introducing gas from a second source, and any measures taken to minimise this peak might be considered.

Further, it is desirable to minimise, if not to eliminate stretches of goaf perimeter where caving material can free-fall. The chances of achieving this may be enhanced by inducing first breaks as early as possible in the formation of a goaf.

The drilling of conventional post-drainage holes in the roof before the first break occurs would seem to be a counter to the occurrence of a severe gas burst with the first break. There is no experience of extensive goaf formation at Moura No. 4 and so the magnitude of gas flushes with second and subsequent intermittent breaks can only be surmised. Given that the first break sets up a gas pressure gradient in the overlying seams, a gas pressure gradient flattening with time (but steepening with extraction in the direction of extraction yet never regaining its virgin pressure value) it could be assumed that the magnitude of any second and subsequent flushes of gas would be less than at the initial break. Hence post-drainage up-holes should be considered for drilling before and in the expected vicinity of the first break, holes to intersect the A and B seams. For such first holes at least, exhausting may not be essential, unless as part of a continuing programme of post drainage to tap free gas accumulations high in the goaf.

Whereas the seeming normality of the period immediately before the explosion during the visit by the Undermanager to the Main Dip Goaf area suggests sudden unexpected events to condition the area for explosion, (and regarding gas this is interpreted as an unexpected sudden gas emission) this is by no means proven. With lack of supporting evidence for such sudden emission further attention is drawn to normal progressive emissions to cover the availability of a flammable gas for explosion, even layering of rich CH_4 gas displaced from a CH_4 filled goaf - above the seam roof line - and perhaps tending to layer in the favourably upward sloping outbye environment.

The connection of sealed goaves to the surface, with appropriate controls, through vertical drillholes appears to offer advantages in self draining and avoidance of overpressure and leakages into mine workings. The expected exhaust from Main Dip Goaf and expected larger exhausts from the larger areas of 4/S Sub and other 4/S extractions, although fluctuating, would not be insignificant and should warrant consideration of utilisation to offset installation costs. Such self-draining goaves would seem to offer benefits as a depository for other seam gas drainage experiments and trials, if not as a routine principle in standardised gas drainage activities. Further, should re-entry be needed, the virtual equalisation of pressures across the seals would make re-entry less complicated.

APPENDIX 1

Inspections and Observations of DIP 3 Extraction Area (M. Caffery)

Monday 30th June, 1986

Inspected with Holt and Baczynski (Dames and Moore) along goaf edge from No. 4 Heading to No. 1 Heading. Roof had previously fallen off shear (mylonite) zone in No. 28 cross-cut between No. 1 and No. 3 Headings. Some local fall of 600mm flaky roof in punch between No. 1 and No. 2 Heading. Extensive crushing of outbye rib line of No. 27 cross-cut from No. 1 to No. 3 Heading. Tension cracks were observed in the same area along the centre of the cross-cut. There was also evidence of floor heave here also. Generally bed slips in the area No. 26 to No. 27 cross-cut had taken weight and opened. These bed slips and tension cracks have been located and identified. The maximum span of unsupported roof at this stage was 45 metres (apart from some minor stooks) in the centre of the goaf area. The line of small pillars inbye No. 27 cross-cut appear to be within the abutment zone and therefore under less stress than the outbye rib line of this same No. 27 cross-cut. Generally the extracted area was quiet with very little nipping of timber, although roof and floor movements had busted out a number of props.

Mining was taking place in No. 1A Heading punching ribs and grading bottoms.

827 tonnes.

Tuesday 1st July, 1986

No underground inspection and no reported changes in goaf or general conditions.

Mining continued in No. 1A Heading punching rib.

Wednesday 2nd July, 1986

Inspection of extraction area with Poppit, Cumner and Mason. Tension cracks in No. 27 cross-cut from No. 2 to No. 4 Headings have extended. Floor movements in same area with roof to floor 2 metres separation. Observed tension crack in roof running outbye of No. 27 cross-cut in No. 2 Heading. No change in the goaf area.

Mining No. 1A Heading grading bottoms.

1180 tonnes.

Thursday 3rd July, 1986

No inspection and no reported change in goaf or general conditions.

Mining No. 1A Heading, punching rib and taking bottoms.

Friday 4th July, 1986

Area inspected with no noticeable change observed.

Appendix 1 (Contd.)

Monday 7th July, 1986

Inspection with Poppit (Brady also on site). No change noticed in goaf area.

Mining was being carried out in small pillar between No. 1 and 1A Heading, (1), commencing at the beginning of dayshift. Indicator props taking weight soon after being stood.

617 tonnes.

Afternoon shift commenced split (2).

377 tonnes.

Crush zone in rib line outbye No. 27 cross-cut now extended 3 - 4 metres into pillar with approximately 1 - 1½ metres of coal spalled off rib.

Tuesday 8th July, 1986

No inspection and no reported change in goaf and conditions.

Dayshift completed split (2) and commenced lifting fender (3).

706 tonnes.

Afternoon shift completed lifting fender (3) and started next split (4).

444 tonnes.

Wednesday 9th July, 1986

Inspection with Poppit,no observed changes in tension cracks etc. Dayshift completed split (4) and commenced fender (5).

672 tonnes.

Afternoon - repairs to hydraulics on miner, completed fender and commenced split. (6)

253 tonnes.

Thursday 10th July, 1986

Inspection of area and located and marked tension cracks in No.27 cross-cut and also inbye No. 27 cross-cut on No. 3 Heading. Rib coal spalled off outbye side of No. 27 cross-cut, approximately 1 - 1.5m depth. First fall in goaf at approximately 9.00 a.m. between No. 1 and No. 3 Headings. Fallen from approximately 3 - 4 metres up. 0.5m thick beds come down with some coarser grain massive sandstone breaking from further up. Floor heave in No. 27 cross-cut from No. 1 to No. 2 Heading. Dayshift complete split (6) and commenced fender (7).

717 tonnes.

(Appendix 1. Contd.)

Afternoon completed fenders (7) and (8) and flit over weekend.

603 tonnes.

Friday 11th July, 1986.

Inspection of extraction area. Further fall in goaf from No. 3 Heading to No. 4 Heading prior to this inspection. Observed where the roof had broken off along joint line in roof 20 - 30 metres long. Roof appears to have broken from 4 - 5 metres up.

Dayshift punched the small pillar (9), No. 1 to No. 2 Heading after brushing floor in No. 27 cross-cut.

740 tonnes.

Afternoon set up for next split (10) and completed same (narrow fender)

564 tonnes.

Monday 14th July, 1986

No inspection of extraction area and no report of further falls. Dayshift commenced fender (11) and completed and then commenced next split (12).

648 tonnes. (310 tonnes - fender - 340 tonnes - split).

Afternoon continued split (12) and lifted fender (13).

702 tonnes.

Tuesday 15th July, 1986

Inspected section, no further fall in goaf observed. Noticeable weight along goaf edge inbye No. 3 Heading. Observed tension cracks in No. 4 Heading running outbye to Crib Table No. 26 cross-cut. Heaving in goaf area No. 1A to No. 2 Heading. Dayshift commenced split (14).

APPENDIX 2

Chronology of Events After Explosion 16/7/86 (J. Brady)
(edited 21/10/86)

1. After the explosion Joe Duncan and George Ziebell got in to Dip 2 Bootend before being driven back.

2. At 9.20 p.m. on 16th July the GFG tube samples on the upcast at the surface showed 2200 ppm CO and 600 ppm H_2 - with 2.8% CH_4 with the natural ventilation pertaining. No. 1 hole into the Dip section was completed at 4.00 a.m on 17th - hole exhausted gas - 1.2% CH_4 880 ppm CO.

Inspections showed that at 12 cutthrough - air crossings were damaged.

Still on 17th rescuers got to 21 cutthrough on the return side.

On 17th by 5.00 p.m. the fan was ready to start, temporary repairs had been done by the night of 17th it was known that the continuous miner had been pulled back.

On the 17th at 11.45 p.m. 10 bodies were located.

By 5.00 a.m. on the morning of 18th the fan was running under diesel power, allowing variable speed. Depression was 0.3 inch w.g.

At 2.30 p.m. J. Brady and K. Allison went underground. There was a strong smell and smoke on Sth. side return therefore No. 2 hole was drilled.

On the morning of Saturday 21st No. 2 hole was being drilled.

No. 3 hole was starting - for the purpose of perhaps N_2, perhaps H_2O introduction.

Hole 2 was finished at 3.15 p.m. and was sampled - 90 ppm CO, 600 ppm H_2 and 1.1% CH_4.

At 4.00 p.m. it was deduced that there must be an active fire and the exploration party was cancelled.

It was decided to use N_2 from 8.00 a.m. on 22nd and to reassess the situation. 82 tonnes of N_2 were on site. No. 3 hole was still drilling. Holes 4, 5 and 6 had been finished therefore holes 1, 2, 4, 5 and 6 had holed into workings. No. 3 was completed subsequently and was in rib.

Hole 4 went into a cavity at the top of a fall - the original test gave 5% CH_4.

On Sunday 20th they put liquid N_2 down, because the evaporator had not arrived. 30 tonne were used - it froze the holes.

At 11.30 a.m. a team went underground for exploration of the face area. Near No. 9 hole they got high CO (the tube lowered down the hole for sampling had stopped some distance up the hole); they found much smoke and deduced that there was a fire. Confidence in sample results was destroyed.

On Tuesday 22nd it was hard to keep the N_2 level in the goaf. With the fan off there was too much natural airflow.

On the same day they found a fire in 24 cutthrough. They installed brattice seals across the 5 headings between 21 and 22 cutthrough.

At 6.00 a.m. on 22nd all N_2 had been discharged into the mine. The O_2 was 17% and CH_4 was 2%.

By Wednesday 23rd it was concluded that the N_2 was holding things stable -

At 01.30, the O_2 was 14% and the CH_4 4.4%.

At 08.20 Hole 10 over the hot zone (24 cutthrough) was finished - N_2 was injected .

At 12.30, O_2 was 12% 11.7%, 13.7% and then 8.1% at which stage it was considered safe to have a go.

By 5.00 p.m. all the bodies were out.

On Thursday 24th the O_2 behind the brattice was less than 12%.

The rescue team felt that the heating was controlled; it was planned to put fly ash down to smother it. The swillys were full of water.

Friday 25th was spent trying to stabilise the heating by covering it with fly ash. On Monday 28th evening Clive Ellis and Grahame Hardie came to Moura.

Clive identified areas for sampling from 14.30 to 17.00 hrs and spent Tuesday 29th dust sampling into the return area.

Wednesday 30th and after were spend in measurements, photographs, etc.

All flameproof enclosures were found to be intact.

A subsequent meeting listed matters for consideration: frictional sparking, electrical sparking, frictional heating, incendive spark from diesel, flame safety lamp, caplamp, methanometer, electrical fittings, battery watches, any alloys, any contraband, static electricity.

There was no major fall in the downdip goaf prior to the explosion.

The continuous miner and cable were de-energised for a long way back-bye.

A shuttlecar cable in the area of its anchor was damaged - Car 30.

Car 30's brakes were on, lights were on and everything else was in the off position.

Car 31's brakes were on, lights were on, everything else was in the off position. The driver's position against rib was unrealistic, but there were no tyre dragmarks.

The Landrover was in 1st gear, the handbrake was on, the bonnet had been blown off, and the whole car had been moved. The tank had fuel, there was water in the scrubber, and one head tank was dry and one was full of water.

The cover of the plastic seat was burned - the foam inside was not. One body was under the cablereel of the inbye shuttlecar and he had no injuries consistent with being run over. His blood level of CO was 4.8%, his cause of death was asphyxiation, maybe he was suffocated therefore because he could not ventilate his lungs. There was no report of any evidence of fire in the mine. The caplamps, cables, methanometer, transformer(which appears OK),the conveyor idlers, the alternator on the Landrover, the conveyor idlers,hotspots on the minerover are all under investigation, some at Redbank Laboratories The last shuttlecar load had been on the belt 3 mins and the one before that for 10 mins. Both shuttlecars were empty.

Regarding the potential of a spark from the diesel - all flame proof equipment appears OK.

The exhaust manifold is to be checked.

The flame safety lamp, which was recovered on site, appeared to be OK. As a confirmation all other flame safety lamps were checked and found to be OK.

The watches found were probably OK.

Regarding alloys, an aluminium Entenox cylinder was found underground.

No contraband was found. The possibility of static electricity from the belt conveyor and from other belts, and hoses is under investigation.

The dogwatch inspection of the goaf edge with a methanometer had yielded nil CH_4. Nil means from nothing to 0.1%.

The Under Manager reported no major gas accumulations in the goaf. There are Barograph and monitoring system records.

There seems no way that 4/S sub panel was the source of gas in Main Dip Goaf.

There are details of prior gassing out of 4/S sub.

There may be some correlation of breakline and shears and gas in extraction. There was report of gas from the shear zone when intersected in development.

The CH_4 in the panel is so little now - what has changed?

Are all surface holes intaking?

The instantaneous outbursts in No. 4 mine only had small cones. Some pre-drainage had been done from the top of the seam.

Is it possible that the bottom coal had blown? Is it possible that there were gas blowers in the shear zone?

In February 1978 there were 3 entries and 2 returns at 1 and 12 to 11 in 14. with steeps to 1 in 8?

C seam is 7m thick and the top section 2.8m is mined.

The major fault P2¼ was encountered and major concentrations of CH_4 occurred on the fault. (The "Taj Mahal" in 4 Heading was on P2¼ fault).

Thereafter methane drainage was started (1983) and stood for 12 months whilst work was carried out elsewhere. It was not stopped for drainage. The drainage is documented elsewhere.

In April 1986 the development downdip was stopped and partial extraction commenced. Abutment pressure outbye was manifested as ribcrush, tension cracks, and about early July, commencement of heave.

Some brushing was done in the floor but for quality reasons floor brushing was minimised and they went for total extraction - top coal only.

There were also stooks and hangup of roof. Therefore the top coal only decision, was made for from 27 cutthrough outbye. Comprehensive inspections of the goaf were made by many people. There was no flammable gas nor anything above normal was found in the goaf.

There were 2 monitoring posts in the S return outbye: No. 6 between 13 and 14 cutthroughs; No. 9 outbye 3 cutthrough.

With commencement of extraction CO rose from 0 to 3 ppm.

Also water was pumped into the waste from day 1.

From 7th - 15th, took out two pillars, then the CM was moved to start lifting off fender. The place was stonedusted and 4 brattice stoppings (as shown on plan) were installed. That was afternoon shift on 15th. There was no gas at all around the goaf either in the general body or layering.

On 16/7/86 it was decided to narrow the fender by taking a strip off the outbye side 2m - 2½m thick with appropriate timbering and roof bolting.

The Undermanager was in the pit 8.15 - 10.15 a.m.

The road was watered, extra props were set. In the pit the mine surveyor marked on the plan everything which had been extracted to then. He reported everything as quiet (S. side). The transport driver visited 3 times during shift.

Two belt patrolmen walked inbye on the belts and to the face and went out. All conveyor rollers were OK.

The supply man left the supply trolley behind in the shuttlecar shunt. (this was tipped over in the explosion).

The supply driver reported that conditions were OK up until 10.55 when he left.

After the explosion there was a full car of coal on the belt from 13 cutthrough outbye. 13 cutthrough is 3 minutes outbye, therefore everything was normal until at least 3 minutes before.

There were 8 other people in the mine at the time.

Some felt a strong pressure wave with ears popping, then a rumble. One man in 4/S heard a loud bang. In 3 South only a rumble. The 2 men in the severest windblast were at the bottom of No. 1 belt.

The lightweight 17 year old was blown against the rib and his ears popped - he heard no noise.

People on the surface reported thick clouds of dust.
The supply man returning with another trolley to the mine saw it. No-one on the surface heard anything - only saw a dark grey/black cloud - one reported smoke.
(Therefore there was only one single report of a bang - went deaf - ear pain).
No windblast was felt in 3/S - only pressure. Some say twice, a few seconds apart. One said it was at 11.07.
Mechanical watches of the victims were frozen - broken - at 11.04 and 11.06.
The communciations centre said the main fan went out. 2 engineers saw that the baffles had blown to 20 - 30m away from the fan. The assumption was of a large goaf fall. 2 Men (Undermanager Joe Duncan of No. 2 and Transport operator George Ziebel of No. 4) went into the mine in a vehicle and found 2 men running up the beltroad to the surface. The Deputy in 3/S (at Acky's Portal) made contact by phone with 5 men inbye and told them to make their way out to Acky's (southern) Portal. He met them some distance inbye. The Deputy subsequently went into 3/S twice to get self rescuers. The young man in 3/S walked back into the dust and made his way out - to 23 cutthrough and up belt road and out. Ziebel and Duncan went down the travelling road to No. 2 cutthrough - found dust - backed the vehicle out, - met the young man on his way out, may way to Dip and to the boot end and noticed debris etc. They sent to the surface and asked for a flame safety lamp. There was no methane in the air. They got the F.S.L. brought in from the surface because they were concerned with O_2 deficiency. They could hear water running through the pipes. (perhaps this was about 11.50) Then they heard air escaping through compressed air pipes.
They continued in to the 4/S underpass - visibility was nil. Much more debris was evident - it was too difficult to walk along. They were equipped with goggles and dust masks. They reported a cordite sort of smell to the rescue team which met them on their way out.

The rescue team found debris on the travelling road and got to 22 cutthrough - just outbye the"Taj Mahal" area. They walked to the beltroad and saw the dev station. They retreated and met the 2nd rescue team at the transfer point of the 2 belts and the telephone.
They were told to withdraw both teams because of high concentrations of CO.

Perhaps this was about 12.30 p.m. They arrived at surface at perhaps 13.15. After 12.30 no dust was to be seen on the surface. In excess of 5000 ppm CO was detected at the fan (Drager tube).

G.F.G. tubes were filled in return and sent to Rockhampton and to A.C.I.R.L. (The results were received at about 18.30 - 9600 ppm CO? 2.2% CH_4 5000 ppm H_2 - all tentative results).

Air was intaking at Acky's portal, 11 - 12000 c.f.m.

Later in the night barely any intake in the belt and man and supply roads. Therefore the only real intake was Acky's portals.

The air coming out of the return drift was warm - perhaps a haze, but no dust. The main travelling road was clear down to 8 cutthrough. Late at night there was very high CH_4 outbye 4/S cutthrough. Gas could be heard coming out of 4/S Sub seals 1½ pillars away. (Elsewhere, everything was quiet).

Explosive mixtures at No. 4 monitoring point: - as the barometer reading dropped the air went into the explosive range (afternoon)?

Holes were bored from the surface and outbye for monitoring reasons. On Sunday some went into S return to try to reconcile the surface hole sample with the roadway samples. The smoke was thick. Water was in the hole. Air was downcasting the hole.

The ventilation reading in the S return - natural ventilation flow - was maybe 0.8% CH_4 plus some CO.

N_2 plus H_2O was going into goaf - A Total of 35 tonne of liquid N_2. (It was noticeably cold at 21 cutthrough) but otherwise generally hot.

N_2 was being lost as fast as it was being put in - it appeared impossible to reduce O_2 below 12%. It was known that there was a heating and that some coal was ashed out and props burning.

Because N_2 was being lost too fast requiring more than 14 tonnes/hour of N_2 it became necessary to seal. Stoppings were put in and were very successful.

The O_2 started dropping very well and CH_4 was going up.

On Wednesday 23rd therefore a hole was bored over the heating. The last 4m. was drilled with compressed N_2 to exclude air and it holed through at 08.20.

They continued to put in N_2 through the drillrods.

They had CH_4 6% and O_2 down continually to under 12% (Previous holes drifted 3m to NW and this was compensated for in laying this hole out.

Rescue work was held up, then for 5 hours a N_2 high injection rate was

maintained on site, 33 men took part in the body recovering teams. The bodies were out by 17.00. Condensation is increasing.

How to reconcile minimal CH_4 from inbye (Centre of gravity of stopping blocks?).

Water in transformer road 22 - 23 cutthrough - water scoured floor to 20 cutthrough.

The "Taj Mahal" structures were 1 - 4 pillarlengths outbye, including a 1½ tonne sandstone picec 60m outbye. Mortar is 4:1, 5:1, sand:cement.

Stoppings are 7m x 2½m x 2.8m.

APPENDIX 3

POSITION STATEMENT AS AT 8/8/86 - MOURA No. 4 COLLIERY

1. The primary object was to investigate the abnormal gas contributing to the explosion

   (a) Source
   (b) Composition
   (c) Mechanics of release

In regard to (a) it is virtually certain that the source was outside of the C upper seam, the major seam being mined and the mid-C seam, the seam being broached intermittently by grading down. There is some possibility that the source could be C lower seam, separated from C upper and Mid - C by a stone band of 0.5m thickness. The strongest possibility is that the source was in overlying B seam or underlying D seam and presently the former is favoured. These possibilities are being explored particularly by examination of further detail of the caving and relaxation associated with the goaf. This involves somewhat intuitive back analysis of the caving process based on clearly sequential events and back analysis of other available data, some available, and some requested.

In regard to (b) it is virtually certain that the chemical composition of the gas is almost pure methane, following on from previous work in Nos. 2 and 4 Collieries and from tentative understanding of seam gas compositions from exploration boring. These assumptions and presumptions are being confirmed by specific sampling undertaken and to follow and chemical analysis to follow. In regard to shades of difference between seam gases of seams B, C, and D it is felt that differences leading to source of Moura No. 4 goaf gas could lie in differences of isotopic composition noted previously* in work on decks of seams by the C.S.I.R.O. (then) Division of Fossil Fuels. Chemical and Isotopic investigation has recently been completed from partitioning mixed seam gases from lump coal and from boreholes in another colliery, and is the subject of a paper just prepared for publication by Gould (C.S.I.R.O.) Hargraves and Smith (C.S.I.R.O.). Arrangements have been made for the C.S.I.R.O. to analyse isotopically the seam gas samples mentioned above (for chemical analysis) as well as Main Dip goaf return air, enriched by reduced flowrate.

In regard to (c) the possibilities, as above, lie in C Lower, B and D seams. The decision of highest probability will depend largely on strata control data, and information has been gathered and is being gathered to contribute to the overall consideration including geomechanical possibilities and probabilities. The strongest possibility considered at present is increased vertical caving and/or relaxation distance influenced by pronounced planes of weakness such as the SSE trending "shears", possibly the same as experienced in

3/South, No. 4 Mine, and shown in some cases to be great fluid conduits, and perhaps influenced by flat lying reverse fault planes underfoot, etc. This, combined with the tendency of massive widely jointed roof and floor strata, perhaps with planes of weakness somewhat parallel to the average breakline, to break intermittently instead of regularly and progressively, to release larger volumes of gas from adjoining seams at more widely spaced times, may have some bearing on the (obvious) higher concentration of methane needed to provide explosion conditions.

2.

In part as contributory to the understanding of 1a and 1b above, some additional activities were committed to cooperative work in investigation of explosion propagation to follow back to a point of ignition. In the course of this it has been inevitable that possible sources of ignition have come under discussion.

Future Work

Immediate future work follows from the sequence set out under 1a, b and c above and from any further directions indicated in the course of these studies. Particularly, future work will involve requested information regarding:-

- Barograph 16/7/86
- Details of gas in main return before and after including statutory analyses
- Details of gas airflow before and after
- Spontaneous combustion history
- Logs of emergency holes
- Details of coal analyses all seams
- Stratigraphic sections
- Details of gas from exploration drilling - all seams
- Details of any floor heaves
- Isopach of parting between C top and mid and C lower
- Dip of reverse fault
- Isopach of total height extracted, together with stook dimensions
- Same shear as in 3/S - persistent lengthwise and presumably vertically ?
- No. 2 U/G vertical shaft log - have
- Flow from drill holes still blowing when extraction left area?

Dr. A. J. Hargraves

APPENDIX 4

SEAM GAS AND GOAF GAS

(a) The following tentative notes were given to P. Ledger and others on 21/10/86

SEAM GAS FROM EXPLORATION BORES

BORE No.	SEAM LETTER	AV. DEPTH m	AS ANALYSED, %				AIR FREE %		
			CO_2	O_2+Ar	N_2	CH_4	CO_2	CH_4	N_2+Ar
10084	X	59	3.31	12.60	83.95	0.14	7.38	0.31	92.31
							95.92	4.08	
	A	?	-	Blew out	-	caved in	- washed out		-
					No	sample			
10086	A	88	0.37	20.27	79.11	0.25	8.78	6.46	84.76
							58.0	42.0	
	B	91	0.58	13.7	66.2	19.5	1.46	50.72	47.56
							2.8	97.2	

General Notes The conditions of gas sampling were not ideal. The large amount of air in the samples, especially hole 10086 Seam A made the air free analysis quite suspect, being derived from such a small component. The inference drawn was that the amount of gas in the sample was small, in keeping with the shallow depth. The other two samples had less air dilution and the deduced seam gas analysis was therefore more reliable. Apart from these chemical analyses, it is hoped to perform isotopic analyses on the CH_4 from all three samples, but the smallness of the samples of air free seam gas and therefore pure CH_4 may preclude such analysis in the case of X seam Hole 10084 and A Seam, Hole 10086.

Hole 10086 A Seam, at depth of 88m has seam gas composition 9% CO_2, 6% CH_4 and 85% N_2. The accuracy of this deduced composition may be impaired by the large amount of air and small amount of seam gas in the sample. Again, this could reflect the small amount of gas in the coal due to the comparatively shallow depth.

This is a typical shallow level seam gas containing the normal, deeper origin essentially CH_4 plus little CO_2 seam gas largely camouflaged by the

products of oxidation of coal by air entrained in meteoric water including the residual inert N_2 + Ar. In the moist environment, oxidation CO_2 (which should equal in volume about 0.27 the volume of residual N_2 + Ar) (say 23.1% CO_2 instead of 9% CO_2 as shown), is partly dissolved and transported away by the water and is not fully represented in the sample.

If the normal, deeper seam gas has a significant proportion of N_2, as some deeper seam gases do, then the oxidation component of this seam gas would be less and the loss of oxidation CO_2 dissolved and transported away would be less too. The validity of this possibility would be partly verifiable from an analysis of a A Seam gas downdip, as close as possible, but clearly well below the water table.

B Seam, at depth of 91m, has seam gas composition of 1% CO_2, 51% CH_4 and 48% N_2. As with A Seam, the apparent seam gas composition has a large amount of N_2, suggesting oxidation by air in meteroic water, but less N_2 and even less CO_2 in the gas, and the CO_2 as a ratio to the N_2 content suggesting an even higher proportion of CO_2 dissolved and transported away. The ratio of CO_2 to CH_4 is more in keeping with the deeper seam gases sampled at Moura. As with A Seam, analysis of B Seam seam gas from further downdip, yet not remote from this hole could give some idea of the composition of the deeper seam gas contributing to this comparatively shallow seam gas - on the assumption that most gas movement upward is in the plane of the seam.

Hole 10084 X Seam, at depth of 59m has seam gas composition of over 7% CO_2, less than half of one percent of CH_4 and over 92% N_2. The original sample has comparable O_2 with that from B Seam in hole 10086, suggesting that the N_2 to CO_2 ratio in shallow seam gas - in a light blackdamp from oxidation - is very dependent on the facilities for dissolution of the CO_2 from oxidation which vary from environment to environment.

Concluding Where faults exist, no doubt there is facility for upward migration of seam gases from lower to upper seams - not taken into account in the above considerations presuming preferred movements upward within seams. However, previous chemical analyses of seam gases in several lower seam intersections in the one hole give very similar results, suggesting interconnection. However again, isotopic analyses of several seam intersections in boreholes in the South Sydney Basin have given quite different results which suggest minimal interconnection (Smith et. al. 1985). This isotopic technique is being used to determine the degree of interconnection between the seams at Moura.

Also not taken into account in the above considerations is any propensity of Moura coals to spontaneous oxidation when exposed to air, and the inevitable entrainment of air in the combined seam cuttings plus issuing gas sample bag. But the analysis of gas from A Seam from Hole 10086 was largely air and perhaps the oxygen component would have been significantly reduced in the prolonged time between sealing the sample and the analysis, if oxidation in the sample bag was an important factor.

In summary all chemical analyses are typical of shallow level seam gas - gas from above the existing or recent water table.

These analyses and these derived remarks throw some doubt on the preferred explanations in the Report to 30/9/86, which were based upon an advised order of depth of water table, 30m below surface, and the resultant presumption of virtually undiluted deep level seam gas below that, with development of seam gas pressure on a hydrostatic basis below that assumed 30m below surface water table. Neither hole 10084 nor 10086 is in the immediate vicinity of the Main Dip Goaf, and it would assist in verification of seam gas composition in the Main Dip Goaf area to have analyses of gases deriving from A and B seams in that area. Should light blackdamps be confirmed this would immediately redirect attention to the floor and deeper level seam gas as the major gas supply for the explosion in C Seam workings on 16/7/86. But the seam gas pressure of light blackdamps is unlikely to be such as to project cores, etc. out of corebarrels, as experienced at comparatively shallow intersection depths at Moura. <u>Are any goaf area holes still available for exclusive sampling of gases from A and B seams?</u>

To use isotopic composition for identification of origins of goaf gas components, it is necessary for the gases from separate seams to differ isotopically. With respect to CH_4 this appears to be the case at Moura. The $\delta^{13}C$ values of gases from D and C Seams are $-69 \pm 1‰$ and $-60 \pm 2‰$ respectively and of gas from the open borehole intersecting the overlying X, A, B and possibly C Seams, $-49 \pm 1\%$. This trend for increasing $\delta^{13}C$ content of CH_4 with decreasing depth of burial is the reverse of that previously observed in the South Sydney Basin. The $\delta^{13}C$ value of $-62‰$ measured for gas released from cuttings from B Seam enclosed with water in a plastic bag is considered to be unreliable. The $\delta^{13}C$ value of the associated CO_2 ($-32‰$) indicates bacterial oxidation of CH_4. Thus a goaf gas in C Seam working comprising mainly gas from

(b) The following notes derive from subsequent isotopic analyses and discussions with the Division of Mineral Physics and Mineralogy, C.S.I.R.O.

Date	Sample	Seam	Av.depth m	Air and N_2 Free		Isotopic	
				CH_4 %	CO_2 %	CH_4 $\delta 13_{C‰}$	CO_2 $\delta 13_{C‰}$
11/8/86	B/H4 C Seam Goaf	C+?	170	86	14	-45	-9
11/8/86	C Upper	C	170	99.5	0.5	-62	-4
14/8/86	B/H 7	C+?	147	95	5		
22/8/86	C Lower 2 Heading	C	170	99	1		
22/8/86	C Lower 5 Heading	C	170	99	1	-59	4
	C Upper 5 Heading	C	170	99	1	-61	4
15/9/86	D 5N/W	D	180?	99	1	-69	-15
19/9/86	D Dip	D	190?	99	1	-70	-14
14/10/86	Hole 10086 Cuttings	B	?	97	3	-62	-39
14/10/86	Hole 10086 Cuttings	A	?	40	60		
14/10/86	Hole 10084 Cuttings	X	59	4	96		-16
18/10/86	Open hole 10083	C?,B, A, X	to 231	99.7	0.3	-49	-22

caved overhead seams should be heavier (δ ^{13}C value more positive) than C Seam gas alone. From the Table of isotopic analyses it is clear that composition of the goaf gas collected sometime after the caving ($\delta^{13}C$ -45%) closely approximates that of the mixed gas recovered from the overlying X, A and B Seams ($\delta^{13}C$ -49%). Therefore invasion of the goaf with gas from this overlying source appears to be a possible explanation of the situation.

Conversely, some time after extraction stops and caving has finished the only contribution from upper seams is gas issuing from the caved virgin perimeter - likely less than the greater virgin perimeter in the C (working seam) - and from coal less gassy than the coal of the deeper C (working) seam - hence whilst standing goaf gas should be marginally heavier than the C Seam, it should not be clearly heavier as with active extraction and caving.

The above is on the presumption that the only other seam gas released by extracting in C Seam is gas from caved seams above. Were seams in the floor significantly relieved by the goaf, then lighter gases from lower seams would enter the goaf and tend to make goaf gases lighter. (An analagous case is the extraction of the Bulli Seam, for example at Appin Colliery. The Bulli Seam is the top seam of the Illawarra measures and extraction of the Bulli Seam only taps gases from seams in the floor - thus since seam gases from the Bulli (No. 1), the Balgownie (No. 2) and the Wongawilli (No. 3) Seams are often substantially different isotopically, (Smith et. al. 1985) then the Balgownie and Wongawilli Seams, being relieved and contributing significant gas during Bulli Seam extraction, would produce goaf gas isotopically different from Bulli Seam gas alone.)

The above considerations do not take account of the gas in intervening strata - mostly sandstone. A general statement about the gassiness of sandstone is that sandstone has sorptive capacity of the order of one tenth that of coal. In general, one would expect the CH_4 in associated sandstones and shales in which the organic material is finely dispersed (Rigby and Smith 1982) to be more like that associated with petroleum, with a greater $\delta^{13}C$ content than in CH_4 from coal seams. In the Moura example, with seam thicknesses of the order of one tenth the thickness of intervening sandstone strata, the volume of gas in intervening sandstone strata could be comparable with that of the seam caved above the caved sandstone. But differences in permeability, and more particularly differences in bedding and joint spacing and strength of coal and coal measure strata, as affecting friability and comparative average caved "particle" size are important in affecting the relative rates of issue of gas from the two caved materials, at least in the early stages of caving.

Because the isotopic composition of CO_2 may be influenced in many ways e.g. invasion by externally produced CO_2, chemical oxidation of coal, bacterial oxidation of CH_4, exchange with, or precipitation as, carbonates etc., no attempt has been made to characterise the goaf gases by this means.

(c) Perhaps these unique matters warrant further examination and investigation, not so much as to explain aspects of a past occurrence as to provide a back analysis basis extended where pertinent to provide a more valid guide to forecasting gas experiences in "total" extraction in the future.