

**MINE GAS AND COAL DUST EXPLOSIONS AND METHANE OUTBURSTS - THEIR
CAUSES AND PREVENTION**

John De...k Flint

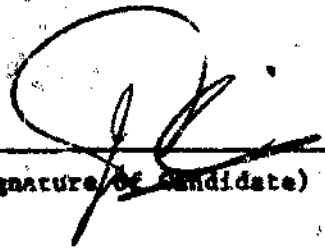
Volume I

**A Dissertation submitted to the Faculty of Engineering,
University of the Witwatersrand, Johannesburg, for the Degree of
Master of Science in Engineering**

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DECLARATION

I declare that this dissertation is my own, unaided work, It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.



(Signature of Candidate)

27 day of October 1990

ABSTRACT

Ignitions of methane and coal dust have caused considerable loss of life and damage to installations in South African collieries during the past century. The phenomenon of methane outbursts have also resulted in the creation of dangerous conditions underground.

The dissertation examines the causes of methane outbursts and the seven main ignition sources leading to methane and coal dust explosions. These ignition sources were derived from an examination of Mines Department inquiries extending back to 1891, the date of the first known ignition of mine gas. Selected incidents were chosen from the official inquiries for each ignition source and these are dealt with in detail. This includes an investigation into the many factors which developed prior to the individual explosions and the effects of the aftermath of such incidents.

Precautions to be adopted to prevent methane outbursts and minimise the risk of methane and coal dust explosions as a result of the seven ignition sources are detailed at the end of each chapter.

DEDICATION

To my wife, Shirley, and our children, John, Keith and Pamela.

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CHAPTER 1

1.1 INTRODUCTION

During the past century in South Africa, approximately 52 major incidents have occurred resulting from ignitions of methane and coal dust involving considerable loss of life and damage to installations. The methane and coal dust explosion which occurred in 1926 at the No. 2 pit of the Durban Navigation Collieries, for example, killed 125 persons and the re-establishment of production at the colliery took 4 months to achieve. It is the author's view and that of almost every Mining Engineer in the Republic that, following the example of the United Kingdom, the outcome of such serious incidents should be made known to the Mining Industry in an attempt to prevent such incidents occurring again. Unfortunately this is not the case in the Republic of South Africa and frequent requests to the Mines Inspectorate have met with little success. An analysis of several major incidents contained in the Mines Inspectorate offices in Dundee, as discussed in the dissertation, reveals some unique circumstances surrounding these disasters of which most Mining Engineers are unaware and hence unable to take future preventive action in mining operations.

The Northfield Colliery disaster in 1943 was preceded by a succession of events, if one studies the Inquiry evidence, which can only be described as a recipe for disaster.

As more and more relatively shallow coal reserves are depleted, so will the Mining Engineer of the future have to grapple with the problems of working the deeper and more gassy coal seams, particularly in the Transvaal. This problem will be aggravated by the fact that relatively high daily production tempos will be called for - daily production calls of 30 000 to 40 000 tons of coal will be the norm and to achieve these tonnages consistently and safely will require a high degree of technical knowledge and

competence, not the least being the awareness of the dangers of methane and coal dust and the methods in dealing with these occurrences.

The evidence given at Inquiries into the 155 incidents, including instantaneous methane outbursts, is available from the Government Mining Engineer's Department. From the incidents, it is possible to sub divide the causes of the ignitions and the format of the dissertation, into the following chapters.

2. Ignitions of Firedamp by frictional heat and sparking.
3. Ignitions of Firedamp by lightning and stray currents.
4. Ignitions of Firedamp by blasting operations and mine explosives.
5. Ignitions of Firedamp by spontaneous combustion including heatings in the goaf and mine fires.
6. Ignitions of Firedamp by electric sparking and faulty electrical equipment.
7. Ignitions by flames.
8. Instantaneous methane outbursts.
9. Conclusions.

In each of the abovementioned chapters, the author proposes to deal with the problem, building into each sub heading/chapter the examples available from the Mines Inspectorate Inquiries relating to the various incidents and then to arrive at proposals, after research work, in order to prevent further incidents from occurring in the future based on the premise that 'prevention is better than cure'.

It is not intended to incorporate a separate chapter on the conditions for a methane/coal dust explosion to occur. However, it is the author's intention to deal with this aspect in each of the abovementioned chapters.

1.2 NUMBER AND SEVERITY OF METHANE AND COAL DUST EXPLOSIONS

An examination of the available evidence derived from various source material reveals the following list of explosions which have occurred in South African collieries over the past 100 years:

Table 1.1

Date	Colliery	Nature of Explosion	Fatalities
Natal			
1891	Elandslaagte	Methane	1
1897	Elandslaagte	Methane	3
	Natal Navigation	Methane	Nil
1898	Natal Navigation	Methane	2
	Campbell	Methane	Nil
	St. George	Methane	Nil
1899	St. George	Methane	4
	South African	Methane	2
	South African	Methane	Nil
	Natal Navigation	Methane	Nil
1901	New Campbell	Methane	31
1902	Glencoe	Methane	Nil
	Glencoe	Methane	Nil
	Crown	Methane	Nil
1903	St. George	Methane	2
	Ramsay	Methane	Nil
	South African	Methane	2
1904	Ramsay	Methane	1
	Elandslaagte	Methane	Nil

Table 1.1 (Contd.)

Date	Colliery	Nature of Explosion	Fatalities
Natal			
1905	Crown	Methane	Nil
	Glencoe	Methane	1
	Glencoe	Methane	Nil
	Newcastle Steam	Methane	Nil
	Dundee Coal	Methane	1
	South African	Methane	Nil
	South African	Methane	1
1906	Elandslaagte	Methane	18
	Elandslaagte	Methane	1
1907	Ramsay	Methane	1
1908	Glencoe	Methane/Coal Dust	77
1908	Cambrian	Methane/Coal Dust	Nil
	Ramsay	Methane	1
1909	South African	Methane	1
1910	Cambrian	Methane	Nil
1911	Utrecht	Methane	Nil
1912	Natal Navigation	Methane	Nil
1914	S.A. Collieries	Methane	1
1915	Hlobane	Methane	1
	Hattingspruit	Methane	1
1918	Hlobane	Methane	Nil
	Northfield	Methane	Nil
1919	Durban Navigation		
	No. 2	Methane	1
	Northfield	Methane	Nil
1921	Northfield	Methane	1
	Hlobane	Methane	1
	Bannockburn	Methane	Nil
	Burnside	Methane	6
1922	Utrecht	Methane	Nil
	Burnside	Methane	20
	Natal Navigation	Methane	Nil
1923	Hlobane	Methane	12

Table 1.1 (Contd.)

Date	Colliery	Nature of Explosion	Fatalities
Natal			
1926	Burnside	Methane	1
	Durban Navigation		
	No. 2	Methane/Coal Dust	125
1928	New Tendege	Methane	1
	Tshoba	Methane	Nil
1930	Burnside	Methane	38
1937	Utrecht	Methane	Nil
1941	Utrecht	Methane	15
1943	Northfield	Methane/Coal Dust	78
1944	Tshoba	Methane	Nil
1944	Hlobane No. 1	Methane	57
1945	Tshoba	Methane	Nil
1948	Cambrian	Methane	Nil
1949	Utrecht	Methane	Nil
1951	Durban Navigation		
	No. 2	Methane	9
	Northfield	Methane	3
1952	Hlobane No. 2	Methane/Coal Dust	Nil
	Hlobane No. 2	Methane/Coal Dust	1
1953	Northfield	Methane	5
1954	Newcastle-Platberg	Methane	1
1955	Carnarvon Anthracite	Methane	1
1956	Cambrian	Methane	2
1960	Durban Navigation		
	No. 3	Methane	Nil
1961	Elandsberg Anthracite	Methane	Nil
	Natal Coal Exploration	Methane	Nil
1962	Ingagane	Methane	Nil
	Northfield	Methane	10
	Enyati	Methane	1

Table 1.1 (Contd.)

Date	Colliery	Nature of Explosion	Fatalities
Natal			
1965	Hicbane No. 1	Methane/Coal Dust	Nil
	Indumeni	Methane	Nil
	Durban Navigation	Methane	Nil
	Kilbarchan	Methane	Nil
	Newcastle Platberg	Methane	Nil
1966	Kilbarchan	Methane	Nil
	Indumeni	Methane	Nil
	Natal Coal Exploration	Methane	Nil
1967	Indumeni	Methane	Nil
	Indumeni	Methane	Nil
	Kilbarchan	Methane	Nil
	Indumeni	Methane	3
1968	Natal Coal Exploration	Methane	Nil
	Kilbarchan	Methane	Nil
	Indumeni	Methane	Nil
	Durban Navigation	Methane	Nil
	Enyati	Methane	3
	Utrecht	Methane	Nil
1969	Northfield	Methane	Nil
1970	Durban Navigation	Methane	Nil
1971	P.C.J. Contractors	Methane	28
1972	Newcastle Platberg	Methane	Nil
1974	Durban Navigation	Methane	Nil
1975	Durban Navigation	Methane	Nil
1976	Durban Navigation	Methane	2
1977	Durban Navigation	Methane	Nil
	Durban Navigation	Methane	Nil
1978	Newcastle Platberg	Methane	Nil
1979	Newcastle Platberg	Methane	Nil
	Balgray	Methane	1
	Durban Navigation	Methane	Nil
1980	Durban Navigation	Methane	Nil
	Balgray	Methane	Nil

Table 1.1 (Contd.)

Date	Colliery	Nature of Explosion	Fatalities
Natal			
1981	Balgray	Methane	Nil
	Durban Navigation	Methane	Nil
	Newcastle Platberg	Methane	10
	Balgray	Methane	Nil
	Newcastle Platberg	Methane	Nil
	Durban Navigation	Methane	Nil
	Balgray	Methane	Nil
1982	Durban Navigation	Methane	1
1984	Durban Navigation	Methane	Nil
	Durban Navigation	Methane	Nil
Transvaal and Orange Free State			
1935	Consolidated		
	Marsfield	Methane/Coal Dust	95
1936	South Rand		
	Exploration	Methane	Nil
1941	Consolidated		
	Collieries	Methane	Nil
1943	Consolidated		
	Marsfield	Methane	Nil
1944	Consolidated		
	Collieries	Methane	Nil
1945	Landau/Navigation	Methane	10
1947	Consolidated		
	Collieries	Methane	1
1951	Cornelia	Methane	11
1956	Schoongezicht	Methane	8
1957	Springfield	Methane	8
1960	Schoongezicht	Methane	Nil
1961	Coalbrook	Methane	7
1962	Springfield	Methane	1
1972	Umtu	Methane	Nil
1974	Albion	Methane	13

Table 1.1 (Contd.)

Date	Colliery	Nature of Explosion	Fatalities
Transvaal and Orange Free State			
1975	Usutu	Methane	Nil
1977	Usutu	Methane	1
1980	Ermelo Mines	Methane	Nil
1980	Coalbrook	Methane	Nil
1981	Ermelo Mines	Methane	Nil
	Ermelo Mines	Methane	2
	Springfield	Methane	2
1982	Bosjespruit	Methane	Nil
	Springfield	Methane	Nil
	Ermelo Mines	Methane	11
1983	Springfield	Methane	Nil
	Springfield	Methane	Nil
	Ermelo Mines	Methane	1
1984	Ermelo Mines	Methane	6
1985	Middelbult	Methane/Coal Dust	30
	Springfield	Methane	2
	Springfield	Methane	Nil
	Springfield	Methane	Nil
1990	Ermelo Mines	Methane	Nil

The incidents of methane outbursts in South African collieries are set out in Table 8.1 in Chapter 8.

While no fatalities have occurred as a result of these outbursts, it is evident, from the project study, that the vast quantities of methane and coal dust liberated, coupled with the destruction of the ventilation appliances, create an unfavourable environment in the working faces. The 155 incidents quoted in Table 1.1 resulting in 799 fatalities, justify an examination of the problem.

The project suffered from a limitation in that much emphasis was placed on Official Mines Department Inquiries and in many instances conflicting evidence and blatant untruths come to the

fore. An attempt has been made to highlight and eliminate such episodes.

With regard to methane ignitions and coal dust explosions, it has been established that 6 ignition sources have occurred and the central chapters are devoted to an examination of each of these sources, namely, spontaneous combustion, electric sparks, flames, lightning and stray currents, frictional heating and blasting.

CHAPTER 2 IGNITIONS OF METHANE BY FRICTIONAL HEAT AND SPARKING

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- 2.6.2 Ermelo Mines. 12th November 1982. Ignition of methane in old workings.
- 2.6.3 Bosjespruit Colliery. 9th March 1982. Ignition of methane at a continuous miner.
- 2.6.4 Durban Navigation Collieries. 21st September 1968. Ignition of methane while coal cutting.

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- 2.9 **CONCLUSION**
- 2.10 **REFERENCES**

2.1 INTRODUCTION

In 1981 a methane explosion at 07h00 on a Saturday morning at the goaf edge of a stooping section in a Transvaal colliery killed 2 men and injured a further eleven section workers. Officials, at a loss to explain the origin of the explosion, put forward a theory that the miner had allowed uncertificated Black workers to fire charges in the split or in a fender which blast had ignited the methane. Subsequent investigations revealed that in all probability the explosion was caused by frictional heat during a collapse of strata in the goaf. Such was the lack of knowledge at operational level in the industry at the time on the dangers of ignition of firedamp by frictional heat and sparking.

With the increased level of maximum extraction techniques practiced (pillar and rib pillar extraction and longwalling) and the greater use of continuous miners both in development and retreat systems of mining, the hazard of frictional heat and sparking will increase proportionately. Frictional heat arising from the steel of coal cutter picks and the picks of continuous mining machines striking quartzitic sandstone has been the cause of many methane ignitions.

The flame from a blown out shot or a fire is more visible and spectacular than frictional heat and sparking and is viewed as a more efficient ignition source (often erroneously) in an explosive methane/air mixture. It is necessary therefore to examine the ignition temperatures of methane/air mixtures as a point of departure when studying ignitions resulting from frictional heat which is generally not that visible.

Secondly, an examination is made of overseas laboratory experiments dealing with frictional heat and sparking between

various elements and substances. Very little, if any, research has been carried out in South Africa on this subject.

The knowledge gained from overseas research into frictional ignitions of methane is applied to conditions which have existed in South African collieries. Conclusions have been drawn as to the possibility of ignitions being caused by this ignition source.

The known cases which have been reported and investigated are given, several of the more important incidents are discussed in detail and finally precautionary measures to prevent such phenomenon from occurring in the future are dealt with in this Chapter.

2.2 STATISTICS

2.2.1 Overseas

Hartwell (1965) states that ignitions caused by frictional heating can be grouped into those resulting from cutting operations and a much smaller number resulting from other frictional means such as hand blows from picks, rocks falling on metal work, etc. Table 2.1 compares the number and percentage of ignitions in the United Kingdom from all frictional causes and those from cutting only in the successive six year periods of 1952 to 1957 and 1958 to 1963.

Table 2.1 Ignitions caused by frictional heating

Year	No. of Frictional Ignitions	Percentage of Total Ignitions	Ignitions during Cutting	Other Frictional Causes
1952	10	38.5	9	1
1953	14	32.6	12	2
1954	9	33.3	7	2
1955	11	36.7	9	2
1956	16	53.3	15	1
1957	8	23.5	8	-
	68	Mean annual % 35.8	60	8
1958	8	32.0	8	-
1959	5	17.2	5	-
1960	16	16.5	14	2
1961	8	38.1	7	1
1962	8	42.1	8	-
1963	9	47.4	8	1
	54	Mean annual % 39.7	50	4

Figure 1 shows the number and locations of ignitions of firedamp in British coal mines from January 1958 to December 1964.

Table 2.2 shows the cause and location of ignitions and Figure 2 the number of ignitions in coal mines.

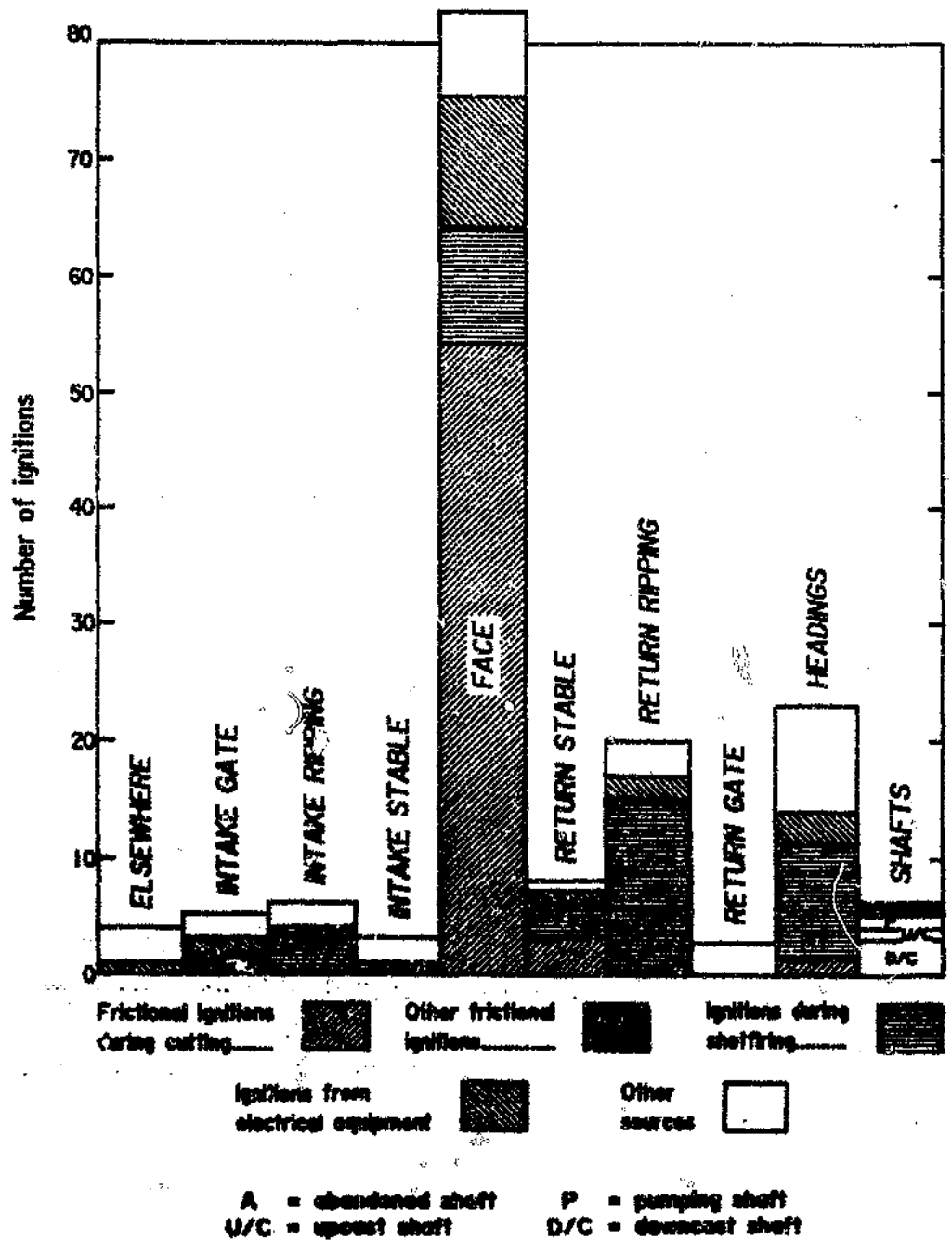


Figure 1

**NUMBER AND LOCATIONS OF IGNITIONS
OF FIREDAMP IN COAL MINES
1st JANUARY 1936 TO 1st DECEMBER 1964.**

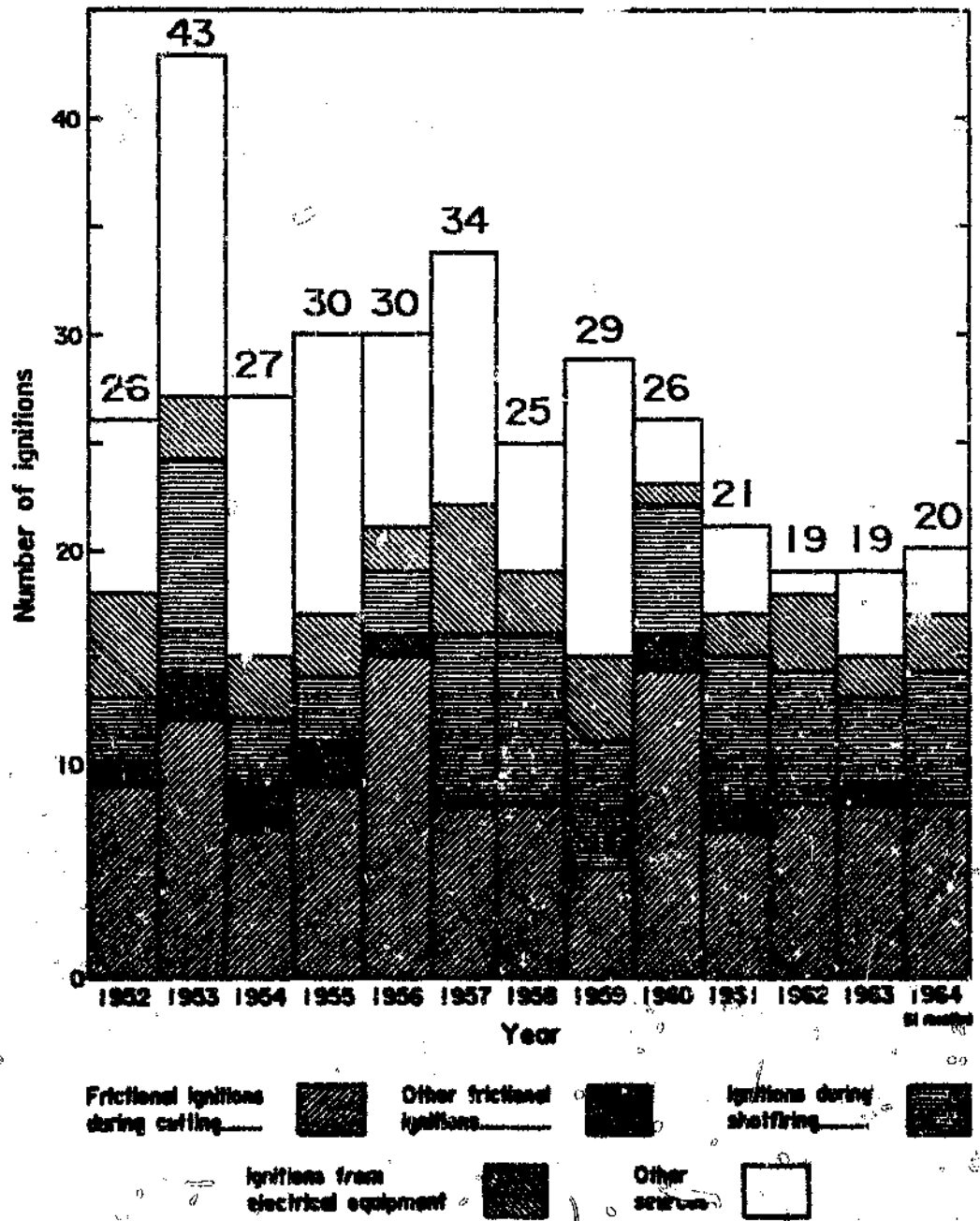


Figure 2

IGNITIONS IN COAL MINES

That the numbers are small must reflect low gas emissions, since in the majority of headings, unlike faces, rock is being deliberately cut. Although few in number, ignitions in drivages are potentially more dangerous because of the generally low airflows.

During the period 1980-1986 there were 40 ignitions in the Federal German Republic (Marthe, personal communication, 1987). Within this total, 17 were caused by shearers, 14 by boom-type roadheaders and 9 by full-face tunnelling machines - a much higher proportion in headings than in the UK. In relation to the number of machine types in use, these correspond to rates of 0,020, 0,015 and 0,196 ignitions per machine per year. Over the same period in the UK for roughly similar coal outputs, there were 75 ignitions, 66 with shearers and 4 with boom-type heading machines.

Table 2.4 Number of Ignitions by Machine Type

Machine	Period (April - March)					Total
	1965 to 1970	1970 to 1975	1975 to 1980	1980 to 1985	1985 to 1987	
Shearer						
Fixed	51	40	20	2	2	113
Ranging	4	5	19	26	13	67
In-web	-	-	14	16	9	39
Trepanner	16	17	7	1	-	41
Trepan-Shearer	3	3	-	-	-	6
Plough	1	-	-	1	-	2
Coal Cutter	4	3	-	1	-	8
Total	79	68	60	47	22	276

Frictional ignitions caused by the cutter picks on power loaders and heading machines continue to be a hazard. In 1981 they totalled 24 - equal to the highest recorded total (for 1977). Figure 6 shows that over the last fifteen years the average incidence has persistently remained at about 14 incidents per year on longwall faces despite a reduction in the number of power loaders at work.

Table 2.2 Cause and Location of Ignitions

	Location							No. of ignitions	% of total ignitions
	Faces	Stables and fast ends	Rippings	Gate Roads	Headings and narrow workings	Shafts	Elsewhere		
Frictional heating during cutting	54	3	-	-	1	-	-	58	37
Frictional heating: rock/metal	-	-	1	2	-	1	-	4	3
Shotfiring	10	4	19	-	10	-	-	43	27
Electricity	11	1	2	1	3	-	1	19	12
Static electricity	-	1	-	-	-	-	-	1	1
Lightning discharge	-	-	-	-	1	-	-	1	1
Naked lights	2	-	-	1	5	-	-	8	5
Smoking	1	-	4	2	3	-	-	10*	6
Faulty Flame lamps	1	1	-	-	-	-	-	2	1
Spontaneous combustion	2	-	-	-	-	-	3	5	3
Flame cutting	-	-	-	-	-	4	-	4	2
Unknown	1	1/2	-	1 1/2	-	1	-	4	2
No. of ignitions	82	10.5	26	7.5	23	6	4	159	-
% of total ignitions	52	7	16	4	14	3	3	-	100

Hartwell (1955) further states that in the twelve year period 37 percent of reported ignitions were attributed to frictional heating and of these nine tenths occurred during cutting (41 ignitions with conventional cutters and 9 with trepanners and shearers in the last half of the period). There was a 3 to 4 percent rise in the proportion of frictional ignitions in the later six year period and there has been a noticeable trend in the last three years towards a higher proportion of ignitions with trepanners and shearers; for instance, of the 8 ignitions during cutting already reported in 1964, two were with cutters, two in trepanner pre-cuts and four with shearers.

The importance of frictional heating as an igniting source may be judged from Figure 2 which shows the part played by all frictional ignitions in the last twelve years.

Fortunately the large majority of the more recent ignitions in cuts have involved relatively small accumulations of firedamp evolved from freshly exposed surfaces of the coal; the inflammations have usually been confined to continued burning of gas in the cut for periods of up to 30 or 40 minutes in a gassy seam before being extinguished. In one such incident in a 1.7 metre cut at the face of a development heading, flame was extinguished 1 1/2 hours after ignition occurred; in another the violence of the ensuing explosion was sufficient to disturb stone dust on a barrier 120 metres from the face; in others the development of fires has led to the sealing of districts.

Basington Colliery (1951: 81 killed) experienced a large scale explosion which was initiated in the cut and served to emphasise the serious hazard from ignitions of this nature.

These ignitions may be more frequent than the above data suggest for it would be idle not to think that ignition of small quantities of gas have occurred, particularly at the back of deep cuts, without being noticed. In general it would appear from such data as are available that ventilation velocities on the

face have little or no influence on air movements in the cut and the only certain preventive measure that can be applied at present is the positive ventilation of the cut.

On 24th February 1979 an underground coal mine explosion in the No. 26 Colliery, Glace Bay, Nova Scotia, killed 12 miners. In its final report on the disaster, issued in April 1980, Canadian Department of Labour investigators attributed the explosion to a frictional ignition.

The last mine explosion disaster in the United States in which frictional ignition was considered a likely cause occurred on 16th December 1963 at Carbon Fuel Company No. 2 Mine at Helper, Utah. Investigators of this explosion in which nine miners died found that it had originated at the face where an explosive mixture of methane, air and coal dust had been ignited either by frictional sparks from the bits of a continuous miner cutting into top rock or by arcs or sparks from electrical equipment.

Since 1970, when a miner was asphyxiated as the result of a frictional ignition, no mine fatalities in the United States have been attributed to this cause. However, frictional ignitions reported to MSHA have accounted for an average of more than three injuries a year to continuous miner operators and their helpers in the past 10 years. In some cases, according to an MSHA Technical Support Industrial Safety Branch report (1979), methane flames travelled 15 metres or more from the point of ignition at the face.

Despite a downward trend in the frequency of mine explosion disasters in recent decades, the frequency of reported methane ignitions in underground coal mines has been rising with the increasing use of heavy mining machines and explorations of gassier coal seams.

The accompanying table (Table 2.3) lists frequency of reported methane ignitions by source from 1971 through 1980. By totalling

the figures for consecutive five-year periods, it can be seen that there were a total of 180 reported frictional ignitions during the first half of the decade and 329 ignitions during the last half of the period.

Especially alarming to MSHA Industrial Safety Branch Personnel and to Bureau of Mines fire and explosion researchers was the increase from 47 ignitions in 1978 to 97 in 1979. Although frictional ignitions decreased to 72 in 1980, the decrease is not being viewed as a reversal of the long term upward trend and researchers note that the 1980 total is still higher than that of any previous year except 1979.

Most of the ignitions occurring each year involve the cutting bits of mining machines. According to an MSHA analysis of 223 frictional ignitions attributed to continuous miners from 1971-1976, about 64 percent were caused by bits striking roof rock and 22 percent were the result of bits striking inclusions within the coal seam. The remaining 14 percent were attributed to bits striking the mine bottom.

In a recent article, Welby G. Courtney (1981), supervisory research Chemist at the Pittsburgh Research Centre, outlined the various research approaches and broke them down into four broad areas; preventing formation of flammable mixtures, preventing ignition of flammable mixtures, ignition quenching and face inerting. If a machine operator is cutting into hard materials where there is a local flammable air/methane zone, a methane ignition and explosion can occur.

Table 2.3 This table shows the annual frequency of underground frictional ignitions reported in the United States for the past 10 years. During the past five years, such ignitions occurred nearly twice as often in underground coal mines as they did during the earlier five-year period

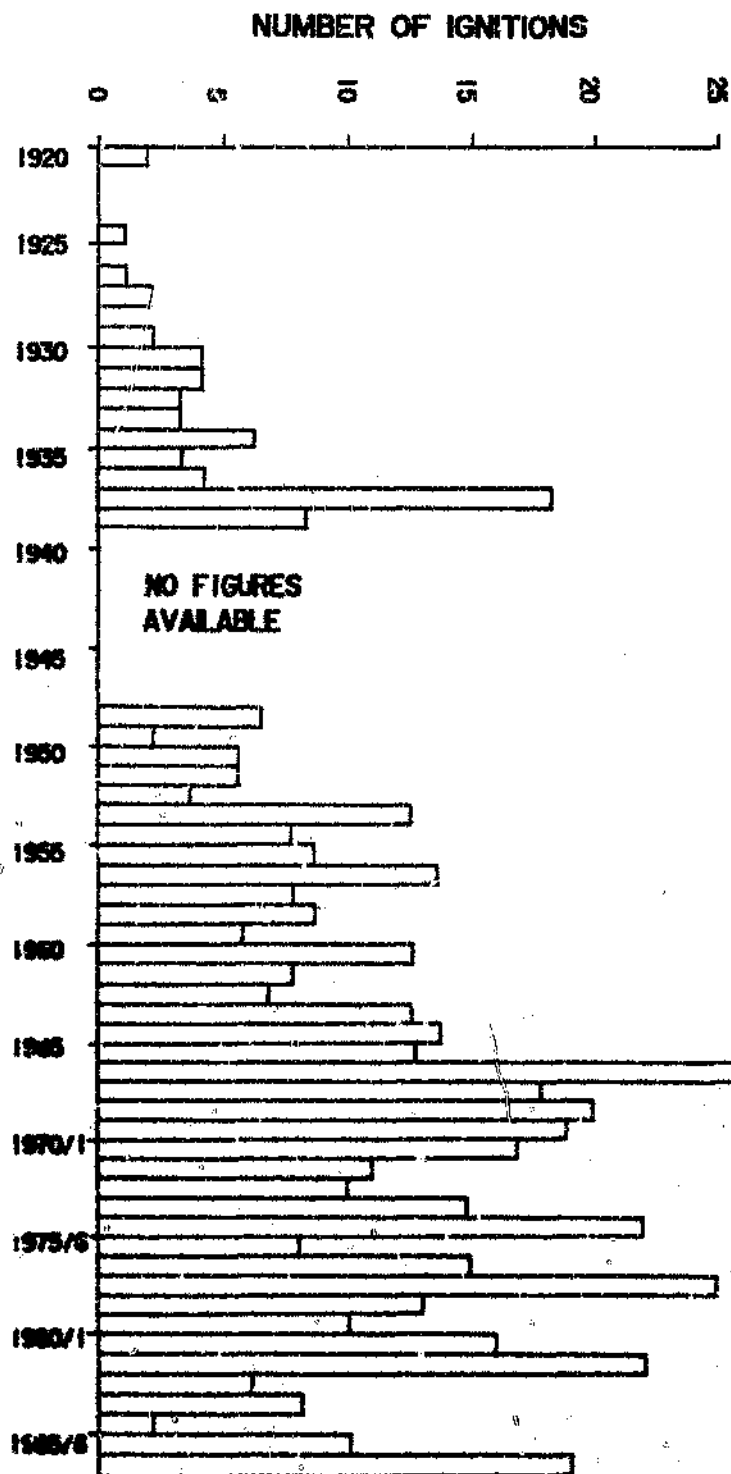
	1971	1972	1973	1974	1975	1976	1977	1978	1989	1980
Continuous										
Miner	30	20	22	44	50	57	37	36	74	55
Cutting										
Machine	3	1	0	1	1	1	0	0	0	1
Roofbolter	0	1	1	0	2	3	2	8	10	5
Roof Fall	1	2	0	0	1	2	0	0	0	1
Shearer	0	0	0	0	0	4	7	2	13	10
Hand Pick	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>1</u>	<u>0</u>	<u>0</u>
Total	34	24	23	45	54	67	46	47	97	72

The annual totals of firedamp ignitions in the United Kingdom (Browning 1988) caused by cutting tools, since reporting of these was made compulsory, is shown in Figure 3. The year 1965 covers a 15 month period when the change was made from calendar years to fiscal years (April to March). It was in 1965 that the first ignitions occurred with power loaders and it is the incidents since then that are relevant to current mining practice.

In the 22 year period to March 1987, there have been 302 ignitions reported, an average of just under 14 per year. Coalface machines have been responsible for 276 of these, with 25 occurring in headings and 1 involving roofbolting. Despite some 370 colliery closures, there has only been a slight downward trend in number of incidents (Figure 4). When the numbers are related to output (Figure 5), there are signs that the rate is increasing. One might have expected the increase to be greater

**INCIDENCE OF FRICTIONAL IGNITIONS
IN UK COALMINES**

Figure 3



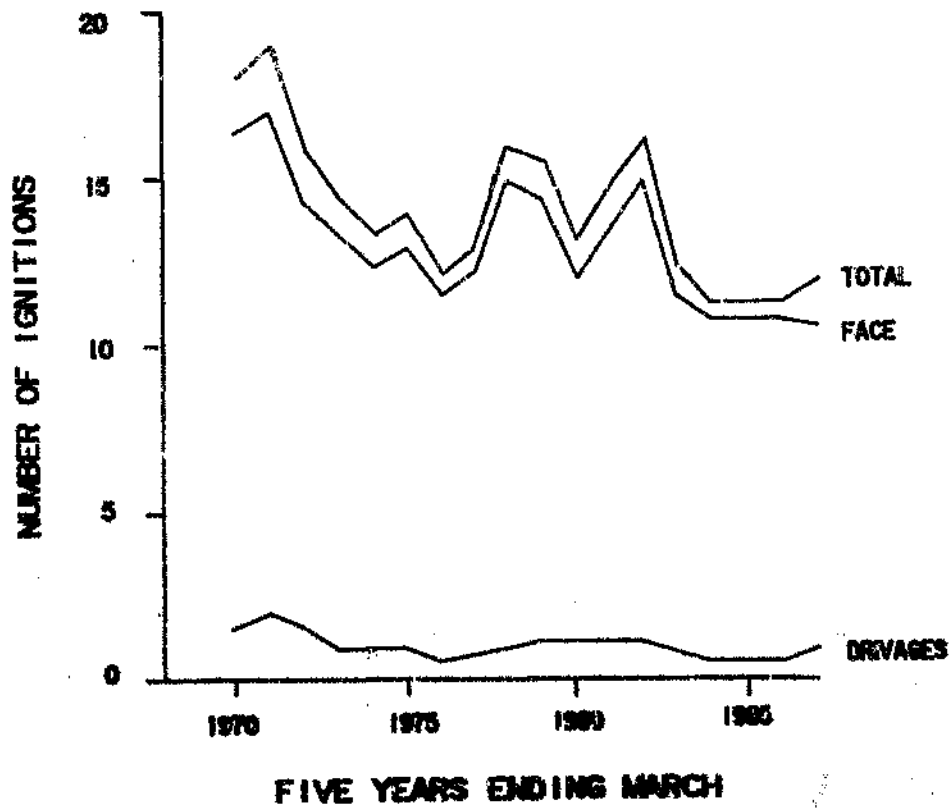
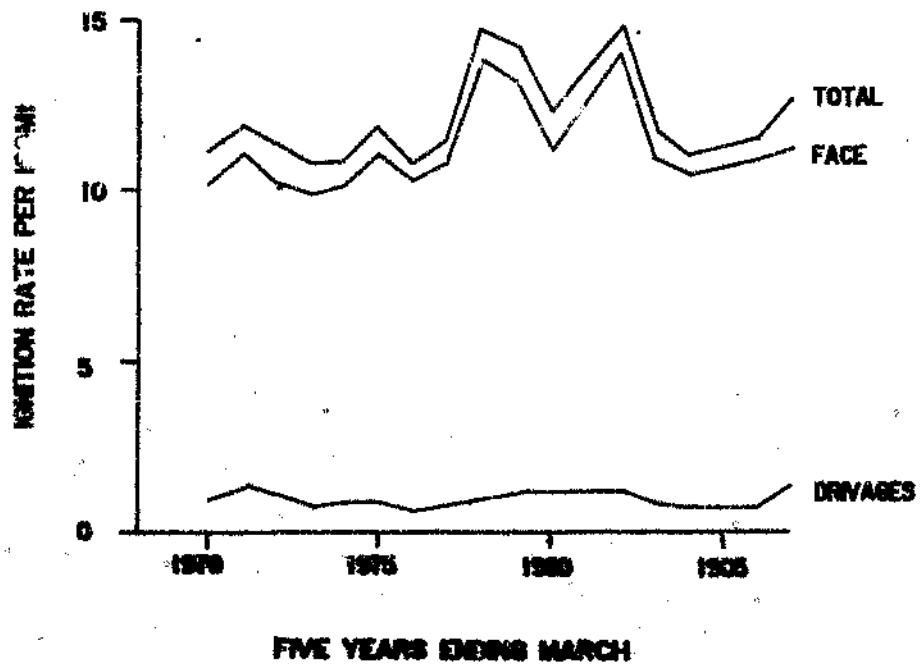


Figure 4
NUMBER OF FRICTIONAL IGNITIONS
AVERAGED OVER FIVE YEARS



FIVE YEARS ENDING MARCH

Figure 5
IGNITION RATE PER 100MI
AVERAGE OVER FIVE YEARS

with the introduction of multi-machine faces and larger, more powerful machines able to cut readily through harder strata.

One clear feature from the figures is that ignitions are more likely to occur in the thinner seams; although seams 1,2 m and under comprise only 25% of the working faces, they are responsible for some 65% of the ignitions. This is put into perspective by the figures for the past 5 years when there was 1 ignition for every 27 faces at 1,2 m seam height and less compared with 1 ignition for every 88 faces in the thicker seams. The higher rate in thin seams may in part be due to the machines used in these conditions.

Statistics relating to coalface machine types are shown in Table 2.4. The table reflects the changes in machine utilisation over the years, and in general, the numbers for the different machines is in proportion to the numbers in use. The exception is the in-web shearer which does appear to have a much higher incidence. An analysis of ignitions for the 10 year period 1973-1982 (Slater, unpublished data, 1982) showed that ignitions occurred with in-web shearers at a rate of 0,121 per machine per year. Other rates were 0,016 for trepanners, 0,014 for ranging drum shearers and 0,013 for fixed drum shearers. However, this does not necessarily convey the true picture, since some machines may only be used in conditions where there is no ignition risk. If the rates are estimated on the basis of use on known frictional ignition risk sites, the rates become 0,124 for in-web shearers, 0,133 for trepanners, 0,030 for ranging drum shearers and 0,027 for fixed drum shearers. These results clearly indicate that the in-web shearer and the trepanner have characteristics which make them more prone to ignitions, although it must be remembered that both machines are usually based in thin seams.

Of the 302 frictional ignitions since 1965, only 25 (8,2%) occurred in drivages, 11 of which involved continuous miners and dirthaders, 11 boom type roadheaders, and 3 other machines.

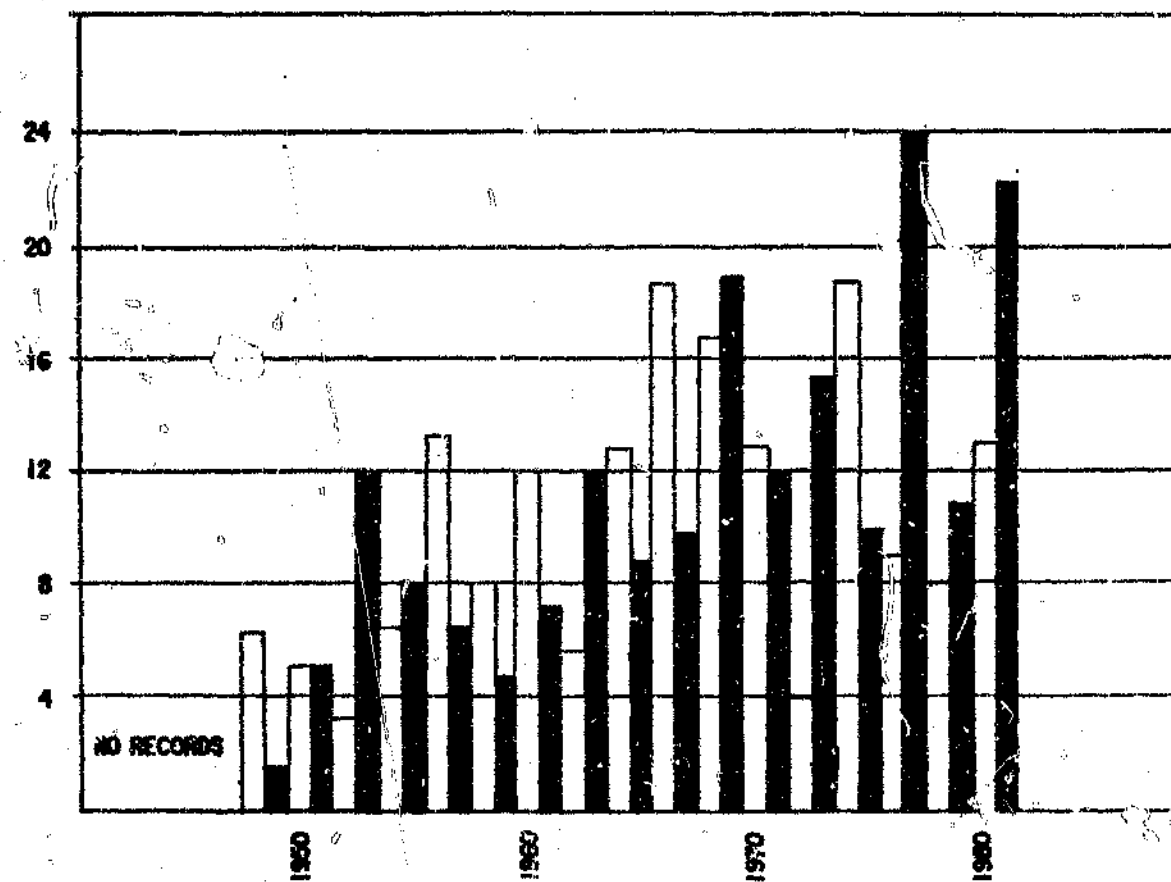


Figure 6

**NUMBER OF FRICTIONAL IGNITIONS
YEARLY ON LONGWALL FACES.**

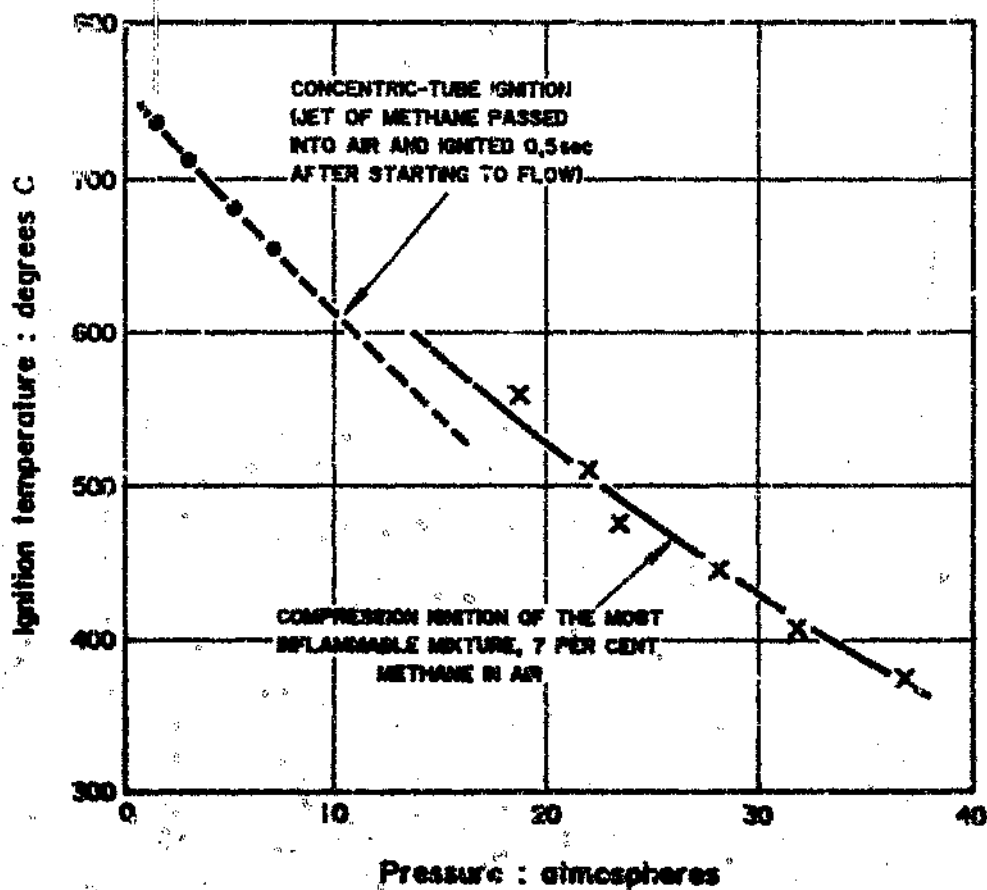


Figure 7

**EFFECT OF PRESSURE ON THE
IGNITION TEMPERATURE OF METHANE IN AIR**
After Dixon and Harwood, (1935)

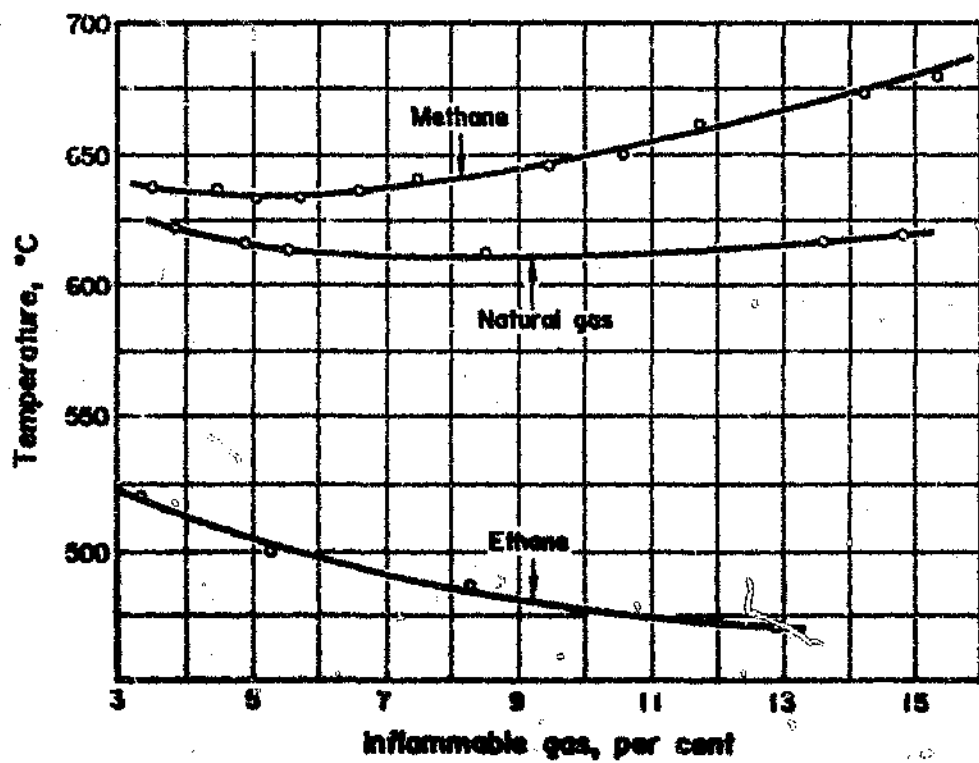


Figure 8

**RELATIVE IGNITION TEMPERATURES OF
METHANE, NATURAL GAS AND ETHANE IN AIR
AS OBSERVED IN A HEATED QUARTZ VESSEL
After Janos and Denks, (1926)**

temperature will cause its ignition. It is therefore necessary to consider not only the ignitibility of mixtures of methane and air, but what may be termed the "incendivity" of various sources of heat with respect to them.

The reasons for this sustained frequency of incidents are complex and varied and include the ever-increasing power applied to the cutting element and the continuing evolution of the shearer and in particular the in-web shearer.

2.2.2 South Africa

Viljoen (1988) in dealing with ignitions and explosions of methane, says that an evaluation of the information available for the period 1970 to 1986, reveals that the causes and origins can be classified as follows:

Causes

- Neglecting to test for methane
- Inadequate ventilation

Sources

- **Blasting operations**
Directly by flame or by inherent hot gases
- **Electricity**
Damaging or misuse of electrical equipment
- **Friction**
High speed impact of metal on metal or on rock
- **Lightning**
Via boreholes or strata
- **Other**
The use of prohibited articles on roof collapses in goaf areas
- **Unknown**

A summary of the aforementioned sources which contributed to explosions is given below (for the period 1970 to 1986).

Table 2.5

Source	Number of incidents	%	Number of fatalities	Number injured
Blasting	10	16	39	23
Electricity	6	9	68	16
Friction				
Coalcutters	13	20	-	-
Continuous miners	14	21	-	18
Shearers	1	2	-	-
Roofbolters	2	3	-	-
Lightning	6	9	-	-
Other				
Naked flame	2	3	30	10
Roof collapses	7	11	-	9
Unknown	4	6	27	3
Total	65	100	164	79

From Table 2.5 we may conclude that explosions and ignitions resulting from frictional heat and sparking accounted for 10 of the 65 incidents or 46%.

2.3 IGNITION TEMPERATURES OF METHANE (FIREDAMP)

Morris (1984) has done considerable research into early experiments conducted on ignition temperatures of methane.

2.3.1 Definition

If a mixture of firedamp and air is gradually raised in temperature throughout its extent by some external source of heat, the rate of combination between oxygen and methane gradually increases. It becomes readily measurable at temperatures of about 300°C . The reaction between oxygen and methane is accompanied by an evolution of heat, so that the products of combustion, and any unburnt mixture with which they mingle, are at a higher temperature than that supplied to them by the external source of heat; and as an increase in temperature increases the rate of reaction, there is a tendency for this rate of reaction to go on increasing rapidly until the whole of the methane, or the oxygen, in the mixture is consumed. If the initial temperature imparted to the mixture by the external source of heat is sufficiently high, the rate of reaction will become so rapid as to produce "flame". Thus the combination between oxygen and methane, instead of proceeding at a steadily increasing speed to a conclusion, will be completed comparatively suddenly by the passage of flame through the mixture. The value for the initial temperature imparted to the mixture that will just enable this phenomenon ultimately to occur is the ignition-temperature of the mixture.

2.3.2 Early Experiments

Coward and Wheeler (1925) stated that the earliest recorded observations on the ignition temperature of firedamp were made by Davy in 1816 who stated that "well burnt" charcoal, ignited to the strongest red heat, did not explode any mixture of air and of the firedamp; i.e. charcoal that burnt without flame was blown up to whiteness by an explosive mixture containing the firedamp, without producing its inflammation.

Coward (1954) continued that Mallard and Le Chatelier (1830) attempted to make a more precise determination of the minimum temperature of ignition of methane by heating methane-air in closed porcelain tubes. They obtained ignitions in the range of 600°C to 750°C , and in addition discovered the now well-known lag on ignition, which reached about 10 seconds at the ignition temperature and gradually fell to almost zero as the tube temperature was increased to 1000°C . This discovery served to explain Davy's difficulty in igniting firedamp with iron rods, for convection would rapidly replace any unit of the mixture in contact with a rod.

The fact that the range of temperature over which ignition occurs is lower when the methane is mixed with oxygen than when it is mixed with air shows that the ignition temperature is dependent upon the concentration of the reacting gases. Hence we would expect to find that different mixtures of methane and air should have different ignition temperatures. This has been found to be so by Taffanel and Le Floch (1913) who employed a variant of Mallard and Le Chatelier's method of experiment, using heated vessels of different sizes.

Table 2.6 Relative Ignition Temperatures of Mixtures of Methane and Air (Taffanel and Le Floch)

Methane in air Percent	Relative ignition temperatures	
	15 cubic centimetres Degrees Celsius	275 cubic centimetres Degrees Celsius
6.9 to 7.0	735	675
8.2 to 8.3	735	680
9.0 to 9.2	742	680
10.1 to 10.3	755	710
11.9 to 12.0	765	710

The important fact demonstrated by Taffanel and Le Floch is that the ignition temperatures over the whole range of mixtures were lower when the vessel employed in the experiments was larger. This is an effect of surface or "catalytic" action as affecting the values obtained for ignition temperatures by methods of experiments which involve contact of the mixture with a heated surface, and was first pointed out by Dixon and Coward (1909).

Dixon and Coward (1909) devised a new method of experiment whereby the inflammable gas and the air (or oxygen) could be heated separately, and then allowed to mingle. After successive trials, a temperature could be found such that when the hot inflammable gas and the hot air mixed with one another a flame appeared. For methane the figures given by Dixon and Coward are: with air, 650°C to 750°C ; with oxygen, 556°C to 700°C . Ordinary variations in barometric pressure were found to have no appreciable effect on the ignition temperatures.

2.3.3 Ignition Temperatures observed with Minimised Surface Effects

In order to reduce surface effects on the ignition temperatures of gases, H.B. Dixon in 1914 used two methods of experiment.

In the first method, the concentric-tube method, a jet of gas (e.g. pure methane) issued from a narrow tube into the centre of a wide vertical tube up which a stream of air was moving; the gas and air were thus preheated to the common temperature of the two tubes, and mixtures of all compositions between pure methane and pure air would be formed around the jet. With flowing gases and a slowly rising temperature, ignition of methane occurred within the range of about 540°C to 750°C , according to the various rates of flow in the tests (Dixon and Coward 1909). A small alteration was later made in the procedure; at a chosen temperature and with a steady stream of air, a supply of methane was suddenly started and the interval of time before it ignited was measured; the rate of flow of methane was increased in successive series of experiments until almost identical results were obtained with further increases; (Coward 1934):

Table 2.7

Time interval before ignition Seconds	Ignition Temperature $^{\circ}\text{C}$
0.5	722
0.6	718
1	701
2	684
3	674
5	663

In the second of Dixon's methods (Dixon and Harwood, 1935) consideration is given to a method of experiment suggested by Nernst which, as elaborated by Dixon (1914), probably records with considerable accuracy the true ignition temperatures of various mixtures - at high pressures. In this method the mixture of known composition, is compressed adiabatically and thereby rapidly heated throughout its extent. The degree of compression required to cause ignition of the mixture is determined by successive trials (with fresh charges of the mixture) and the

temperature corresponding with that compression can be calculated from the formula:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\gamma - 1}$$

in which T_1 and T_2 are the temperatures of the mixture before and after compression (expressed in degrees absolute); V_1 and V_2 the initial and final volumes; and γ is the ratio between the mean specific heats of the mixture of gases at constant volume and at constant pressure.

There are, unfortunately, no reliable determinations available of the ignition temperatures of mixtures of methane and air by this method. The figure given by Falk, (1907) who was the first to use the method, is 650°C for a mixture containing 10 percent of methane; but Dixon has shown that his experimental arrangements were defective and liable to give too high results. Probably between 600°C and 625°C is nearer the truth, and such a figure represents the ignition temperature at the pressure employed to produce it, namely, between 1 and 40 atmospheres.

A correlation between the concentric tube and the adiabatic compression results for the ignition temperature of methane in air is shown in Figure 7 (Dixon and Harwood 1935). The two curves relate to different ranges of pressure, for the concentric tube experiments were limited to a maximum of about 7 atmospheres pressure; whereas the adiabatic compression experiments (with mixtures at various initial temperatures and pressures) were limited to a minimum of about 19 atmospheres, attained as a result of the sudden compression. However, the results of the two series are nearly in line and suggest that the observations in both were largely independent of possible catalytic effects by solid surfaces in contact with the gases.

Coward and Greenwald (1927) stated that experiments were concluded by Jones and Dunkle along procedures similar to that

developed by Taffanel and Le Floch (1913) and Mason and Wheeler (1924).

A cylindrical quartz vessel of 108 cubic centimetres capacity was heated in an electric furnace to a predetermined temperature, evacuated, and the required gas mixture introduced. The lowest temperature to which vessel had to be heated to obtain ignition of the mixture was observed. Ignition occurred after a time interval (lag) of several seconds, during which the mixture self-heated as a result of its slow combustion.

Ignition temperatures observed in this way have no absolute value, for they vary with the size and shape of the vessel used and apparently with some other factor. For these reasons such observations have not been regarded as other than relative.

Figure 8 shows the results obtained for methane, ethane, and a natural gas of the approximate composition CH_4 , 88.7; C_2H_6 , 7.4; C_3H_8 , 1.4; C_4H_{10} , 1.0; and H_2 , 1.5 percent. The ignition temperature of the natural gas was lower than that of methane throughout the whole series of inflammable mixtures. The difference in these circumstances ranged from about 15°C to 55°C for mixtures of equal content of inflammable gas. It is clear that the higher hydrocarbons have a greater proportionate influence on the ignition temperature when the total inflammable gas is present in greater amounts.

Knowledge of the time lag in ignition is important in comparing the inflammability of gases, for in practical operations the dangerous gas mixture may be constantly flowing past the high temperature source of ignition and therefore may have a period of contact which is less than the lag.

This time lag of ignition will be discussed in more detail in Chapter 4 (Explosions caused by explosives).

2.3.4 Effects of Small Quantities of Foreign Substances

Coward (1965) stated that several substances, accelerators and inhibitors, have proved to have a considerable effect on the ignition temperature of methane. Dixon found that the presence of traces of nitrogen peroxide in the atmosphere of the concentric-tube apparatus reduced the ignition temperature of methane; the effect reached a maximum of 122°C in the presence of 0.7 percent of NO_2 . This discovery, which led to important results in the chemistry of chain reactions, suggested also the possibility of discovering a technically useful inhibitor and Dixon found that the presence of small fractions of one percent of iodine and several compounds containing iodine or bromine raised the ignition temperature of methane by 80°C and more.

Both carbon dioxide and nitrogen raise the ignition temperature of methane in air, in the concentric-tube apparatus, but only by a few degrees for each percentage of the added gas (Coward, 1934).

The presence of a little ammonium nitrate dust or finely divided solid explosive reduced the ignition temperature of a puff of methane and air blown into a heated tube, from 700°C down to 330°C in an extreme case. Other combustible substances had a much smaller effect so it is possible that the action of the explosive was largely due to nitrogen peroxide produced by thermal decomposition (S.M.R.B. Annual Reports for 1942, 1943 and 1944).

From this short summary of the attempts that have been made to determine the ignition temperatures of gaseous mixtures it will doubtless be realized that, despite its value as a measure of the absolute ignitibility of a given mixture, the ignition temperature does not tell a Mining Engineer all that he needs to know regarding the possibility of that mixture being ignited. The fact that a mixture has an ignition temperature of say 600°C does not necessarily mean that any source of heat at that

2.4 IGNITION SOURCES

2.4.1 General Account

Ramsay (1965) stated that the ignition of gas by mechanical action occurs in circumstances, common enough in a heavy industry, in which motion takes place against frictional resistance. Very little heat is taken to ignite gas and the absorption of energy by the process is of negligible importance to the motion of the bodies concerned. Hence although there is a vague connection in that the greater the powers involved the more favourable can be the chances of an ignition, the connection is very loose and certainly there is nothing like a quantifiable relationship.

The phenomenon divide immediately into two:

- (i) Frictional ignitions in which the energies are derived purely from mechanical sources, example rock on rock.
- (ii) Frictional ignitions in which the process is initiated by a mechanical source but brought to fruition by a chemical evolution of heat, example light alloy on rusty steel.

The nature of friction has been made much clearer by the research of Bowden (1958) and his colleagues. Briefly, solid bodies make contact through no more than a few points, their number and area being decided by the total load. If the load is increased the points yield, progressively bringing other surfaces into contact. The process continues until stability is again reached when the new load is equal to the product of a new surface area multiplied

by the stress at which contact surfaces are operating. When such surfaces are dragged across one another, the local dissipation is great, the contact points are soon brought to softening temperatures and the load spreads to an increased area with the temperature at which the load carrying surfaces are operating being the softening point of the more easily softened body.

Impact is somewhat different of course, but although impact may take place with neither surface loaded beyond the elastic limits, the more common situation is likely to be one in which plastic deformation occurs together with the associated evolution of heat.

It is important to note that the temperatures reached in frictional ignitions of the first kind (chemically inert) are normally much less than those reached in frictional ignition of the second kind, or by explosives or by electric arcs. The latter group involve temperatures ranging up to 2500°C or more whereas pure frictional ignition (chemically inert) is not likely to exceed 1200°C .

2.4.2 Ignition of Firedamp by Frictional Heat and Sparking

Frictional heat and the sparking often associated with it have been regarded as more or less proven causes of explosions in coal mines. The emphasis tended to be laid, for a while, on the incendiarity of the sparks; possibly because of their more obvious appeal to the eye of an observer. Later, the surface from which glowing particles had been torn seemed to be the more dangerous because a simple friction spark (that is, one that is unaided by burning) could not be hotter than the surface from which it had been eroded and would in fact be cooling from the moment of its creation; besides, the hot surface remains in relatively long contact with the neighbouring part of the firedamp-air mixture whereas the flying spark is constantly moving into fresh mixture. Still later, and quite recently,

attention has been directed mainly to the danger of those hot particles of matter which may maintain and even increase their temperature by burning, such as the sparks from aluminium and its alloys and even ferrous metals. The temperatures attainable in the burning of readily combustible metal particles have been variously estimated as some 2700°C to 3700°C (Rae, 1961), at which temperatures magnesium and aluminium are so quickly vaporised that they burn as flames rather than as glowing particles. At such temperatures the lag on ignition of methane must be very short so that it is not surprising that light-metal sparks are incensive.

2.4.3 Frictional Heat and Sparking in Coal Mines

Sparking is no more than an extreme form of frictional heating in which particles of the bodies concerned are torn off and ejected glowing visibly. Concern with sparking was first expressed in connection with the the Spedding Mill. Volta (1777) questioned the safety of Spedding's invention following experiments in which a hydrogen/air mixture was ignited. It is unlikely that he ignited methane/air in the same way but his views on the Mill appear to have been accepted. Be that as it may, from Volta's time onward, mechanical ignition has, time and again, been reported as the source of mine explosions.

Considerable laboratory experiments have been undertaken overseas regarding the ignition sources of methane in the sphere of frictional heat and sparking. In addition, reports of actual experiences in mines are invaluable as will be shown later in this chapter.

Coward and Ramsay (1965) reported that falls of roof, especially where a hard rock is involved, have given rise to frictional effects that have caused ignition of firedamp.

They continued that the report of the Prussian Firedamp Commission (1886) described a series of observations in German mines thus: "gradual bending in of the roof, accompanied by ominous crackling; and then suddenly, with a crash like thunder, the masses of rock fall in, and the place is lighted up for several seconds by flaring streams of sparks which together form a veritable 'sea of lurid fire'".

Ignitions of gas by hard rock falling onto iron or other hard rock have been reported (Gray, 1908; Redmayne et al, 1914; Rogers, 1950). More serious in their results was an explosion at Lewis Merthyr, South Wales, in 1956, ascribed to the impact of rock falling onto a steel arch (Jones, 1957).

Well authenticated reports of ignitions caused by impact between tools and various hard rocks were summarised by Burgess and Wheeler (1929).

Sparkings by the picks of coal cutters has been frequently reported (Roberts, 1952) and there was at that time a general impression amongst mining people that it was not dangerous. "But an analysis of all reported cases of ignitions of firedamp (in Britain) from 1937 to 1951 has shown that, excluding ignitions from naked lights, coal cutter picks are second only to explosives as an igniting medium; 91 ignitions were caused by coalcutter picks and 100 by explosives" (Roberts, 1952).

2.4.4 Experimental Work on Frictional Ignitions of Firedamp

Frictional sparks may be incandescent particles of rock or certain metals, or burning particles of matter produced as a result of frictional contact between rubbing surfaces.

Experiments were carried out at the Experimental Mine Barbara in Poland when high speed film was taken of sparking produced by

contact of a metal disc and cutter head against sandstone. These films showed that the source of ignition of a methane/air mixture was a concentration of incandescent sandstone particles attached to the rubbing surfaces (Logejko, 1977). Experiments at the same location showed that in the case of frictional contact of steel on steel, a dense stream of sparks is produced which is responsible for ignition of the gas mixture. When steel or sandstone is in frictional contact with pyrite, the pyrite undergoes burning and a stream of burning particles is produced.

Some sparks are passive in relation to oxygen, while others are active. Typical examples of passive sparks are those produced from contact with sandstone or sandy shale. Such particles do not enter into a chemical reaction with oxygen, since they are themselves oxides. Sparks produced by the abrasion of sandstone or sandy shale are limited by the plasticisation temperature, which is about $1\ 200^{\circ}\text{C}$. The ignition capacity of these particles depends on the temperature and size of the exposed rock surface and on the particle concentration on the zone of rubbing.

Active sparks are those which enter into reaction with oxygen; the reaction is exotherm so that the ~~additional~~ energy increases both temperature and ignition capacity. The temperature of such sparks depends mainly on the quantity of heat produced by their combustion in unit time. Some of these sparks possess a low level of chemical activity, such as steel or pyrite. Particles of steel burning in air or in an explosive atmosphere, may attain a temperature of the order of $1\ 700^{\circ}\text{C}$ while those of pyrite may reach a temperature in excess of $1\ 700^{\circ}\text{C}$. Sparks possessing a high level of chemical activity are typically light alloys of aluminium or magnesium, especially when in contact with rust. The heats of combustion of aluminium and magnesium are respectively $30,1\ \text{MJ/kg}$ and $27,8\ \text{MJ/kg}$, compared with $71\ \text{MJ/kg}$ for pyrite (Logejko, 1977).

Burning particles of light alloys of aluminium and magnesium have been shown to have attained temperatures of the order of $3\ 700^{\circ}\text{C}$ (Rae, 1961).

(a) Friction between rocks

Mayer (1886) ignited firedamp readily by the friction between a piece of compact sandstone and a revolving disk of the same rock, in the course of some 10 or 15 seconds; a piece of shale held against a sandstone disk became incandescent at the points of friction, and ignited illuminating gas but not firedamp.

Burgess and Wheeler (1928) readily ignited firedamp with various types of sandstone; the more quartzitic sandstones seemed to be the more dangerous. The heated area of contact at the edge of the stationary rock where it met the rotating wheel appeared to be the source of ignition, but it was found possible to ignite firedamp by the particles of fused rock that were sometimes thrown off from the heated area. An estimate of the minimum energy required to produce ignition in these experiments suggested that a piece of sandstone weighing about 50 kilograms and falling for a few metres onto the sharp edge of a similar rock could produce ignition in a mine. Nagy and Kawensk (1960) in an apparatus similar to that of Burgess and Wheeler, obtained ignition of natural gas (90 percent methane) with a peripheral speed of the sandstone wheel, rotating against sandstone rock, equivalent to a free fall of 0.67 metres. A shale rock held against a sandstone wheel also gave ignitions, but less easily. In all these experiments, however, the distance for which rock was rubbed on rock in order to obtain ignition was greater than the distance of fall required to gain the rubbing velocity.

Ramsay (1965) states that the temperature reached in frictional contact is limited to that at which the rock softens. Of the rocks met with in coal mining, only the quartzitic rocks produce ignitions. In experiments in which rock sliders are held in contact with rotating rock wheels, ignitions are not produced except with these rocks with powers in excess of about 0.746 KW or when the contact persists in excess of 0.746 KW, or when the contact persists for distances ranging from 20 cm up to 5 metres depending on the conditions of the experiment.

(b) Friction between Steel Tools and Rocks

Steel rubbing on sandstone in the way just described produces ignitions readily enough and with similar values of load and rubbing distances, although rather greater values of the latter tend to be required. Tungsten carbide on sandstone behaves similarly. Ignitions can be obtained also with other metals, for example, nickel (melting point $1\,420^{\circ}\text{C}$), nickel-copper alloys and copper (melting point $1\,080^{\circ}\text{C}$).

Ignitions are readily obtained by the impact of tools on quartzitic rocks; readily with steel tools but also with bronze picks and even with brass. It is likely that the ignitions with bronze and brass occur only after the tool has picked up rock fragments so that it is more a case of rock on rock.

Ignitions occur when iron pyrites is struck by a steel tool but the mechanism is not understood. It is suspected that the ignitions are brought about not by any combustion of the pyrites but by thin shavings of steel, cut from the tool by the pyrites, oxidizing so rapidly that they reach temperatures high enough to cause ignition. Bands of pyrites (iron disulphide) have been shown to be capable of producing ignition when cut into by a blunt tool; fine pyrites powder is produced which ignites at low temperatures and burns with a sulphur flame.

Generally speaking, the bright sparks encountered when grinding steel with other abrading materials, such as sandstone or carborundum are also thought to be burning flakes of steel.

Burgess and Wheeler (1929, 1930, 1931) made an extensive series of experiments on the ignition of firedamp by the friction between steel and rocks. In the first of these reports, experiments which ultimately led to the demonstration of ignitions of firedamp with a chain coalcutter cutting through hard rock were described: "Ignitions were obtained with a cutting speed between 18 mm and 450 mm per minute, with picks of

carbon steel and tungsten steel. The depth of cut was 75 mm to 125 mm and along most of its length only the three lower rows of picks cut into the rock, the centre ones grazing over it and the top three rows being free of it".

Another report described further experiments with coalcutter picks and hard sandstone rocks, which gave "a localised form of sparking, which is capable of igniting firedamp under conditions likely to arise under mining conditions".

(c) Mechanism of Ignition

Blickensderfer et al (1972) and Burgess and Wheeler (1929) found in the laboratory that it is very difficult to ignite mixtures of methane and air by the mechanism of sparking. Methane has a high ignition temperature (650°C), and sparks do not usually possess an adequate combination of life time, temperature, and surface area for ignition. Gases with a lower ignition temperature, such as hydrogen, are ignited fairly easily by sparks from machine tools.

As early as 1929, Burgess and Wheeler referred to a stationary spark at the contact between the pick and the rock, which can be equated to a hot spot. This hot spot is composed of a surface layer of either molten rock or metal, and is caused by frictional sliding. The layer normally consists of the material with the lowest melting point, and the maximum temperature does not normally exceed this value. It is suggested that the area and the temperature of the hot spot, together with the methane concentration, determine whether ignition can occur.

In rocks containing iron pyrite, the mechanism of ignition is thought to be the burning of finely ground pyrite, rather than a hot spot on the rock. Frictional sliding between the machine tool and the rock is responsible for the initial heating.

Blickensderfer (1975) noted that the maximum temperature of a hot spot is the melting point of either the tool material or the rock. The maximum width of the hot spot is the width of the tool. The length of the hot spot above a certain temperature varies with the speed of the tool and the cooling rate of the molten rock or metal.

It is implied in the literature that, as the temperature of the hot spot caused by frictional impact increases, the area needed to cause an ignition of methane decreases. However, the possible effect of the thermal conductivity of the rock and the thickness of the hot spot upon the area required for ignition have not been investigated. The maximum temperature of the area heated by frictional impact depends upon the melting point of the tool and the rock. The area of the hot spot depends upon the width of the tool and the speed of cutting.

(d) Rocks likely to cause Ignitions

An attempt is made to identify the ignition hazard associated with a particular rock. The mechanism of ignition when these rocks are impacted by machine picks is important in this respect and two general categories of rocks can be identified:

- (i) Those where a hot spot develops on the surface when impacted, and
- (ii) Those that are liable to self heat on impact owing to the presence of pyrite.

Burgess and Wheeler (1929) noted that rocks with a high quartz content are an ignition hazard when impacted. Rae et al (1964) concluded that only rocks with a high melting point, such as those containing appreciable quantities of quartz, are likely to cause ignitions by the mechanism involving a hot spot. Blickensderfer et al (1974) suggest that the quartz content and

particle size are important parameters affecting ignition potential.

Powell et al (1975) conclude that the following general characteristics of rocks are most likely to cause ignitions from a hot spot developing on the surface:

- (i) A quartz content greater than 30 percent,
- (ii) A particle size greater than 10 μ m and usually greater than 70 μ m, and
- (iii) the rock remaining 'strong' at temperatures of at least 1250°C.

Other factors were also thought to be important. In particular, the thermal conductivity of the rock was considered to have a substantial influence. Wynn (1952) noted that the quartz had a low thermal conductivity, and it was thought that this could be one of the reasons why rocks containing appreciable quantities of this mineral have a high ignition potential when impacted.

The rocks that are most likely to cause ignitions when impacted by machine picks as a result of the formation of a hot spot are those having both a relatively large quartz content and particle size. The strength of the rock at a temperature of 1250°C also appears to be important. Nodules of iron pyrite are an ignition risk owing to the self-heating of dust generated from an impact. It is not clear, however, whether iron pyrite disseminated within a rock increases the risk of an ignition of methane. Some authors consider that the thermal conductivity of a rock has a substantial influence upon the incendivity, although this has not been established through experimentation.

For practical mining purposes rocks can be considered in terms of their potential for frictional ignition of a methane/air mixture. The following classification has been used (NCB, 1977).

1. Average ignition potential:
Sandstone with 20 to 50% quartz
Pyrite-ironstone.
2. High ignition potential:
Sandstone with 50 to 70% quartz
Pyrite sandstone
Pyrite siltstone
Pyrite fireclay.
3. Very high ignition potential:
Pyrite quartz.

2.4.5 General Information available from Overseas on the
Ignition Potential of Sandstones



McVey, building on the knowledge gained from overseas research and strength tests conducted by himself at the Chamber of Mines Research Organisation, reports that there are two groups of information available from overseas coal mining countries regarding ignitions in the goaf. The first group includes the findings of investigations into methane ignitions in collieries. These indicate that there have been many events over the years that approximate to the event under discussion at Ermelo Mines Limited. For example, there are 11 ignitions due to falls of ground reported by the U.S. Bureau of Mines for the period 1959 to 1980. More detailed reports of similar events are described by Coward and Ramsay (1965) in which it appears that the falling of rock in the goaf is accompanied by frictional heating which results in ignitions of methane. From the foregoing the necessary criteria for the friction ignition to occur are the relative movement of rock, that the rock is hard and has a quartz content above a certain minimum critical value.

The second group of information results from laboratory experiments which have been conducted to quantify the ignition potential of a number of materials in various relative configurations. It is this second group of information which is most instructive in assessing the probable cause of ignition during roof falls and goafing. There are certain findings on methane ignitions which are generally accepted as being correct. Those that are relevant to this report are discussed here.

(a) Physical Conditions required to cause a Frictional Ignition

Of overriding significance is the finding that methane-air mixtures can be ignited by the friction/impact of rock on rock. This has been shown by Rae (1964) when he conducted two series of experiments where sandstone sliders were pressed against a rotating sandstone wheel. He was consistently able to cause ignitions of a surrounding atmosphere of methane/air when certain speed and contact pressure criteria were met. His findings were not unique as others had previously shown the same effect but in a less precise manner. Because of the quality of the data presented by Rae, it is used in this report to create an example showing the incendiarity of rock-on-rock sliding.

Rae showed clearly two effects, the first being the relative incendiarity of various materials rubbing on each other. These included limestone, sandstone, steel, tungsten carbide and various other metal alloys. In these experiments, the most incendiary materials in any rubbing configuration of speed contact and pressure were sandstone rubbing on sandstone. The second effect was that rubbing time to ignition was shown to decrease with increase of both speed of rubbing and contact pressure.

In the Ermelo Mines Limited case (McVey, 1986) only the sandstone rubbing on sandstone is dealt with and thus an inspection of Rae's results using this material is appropriate. At the maximum

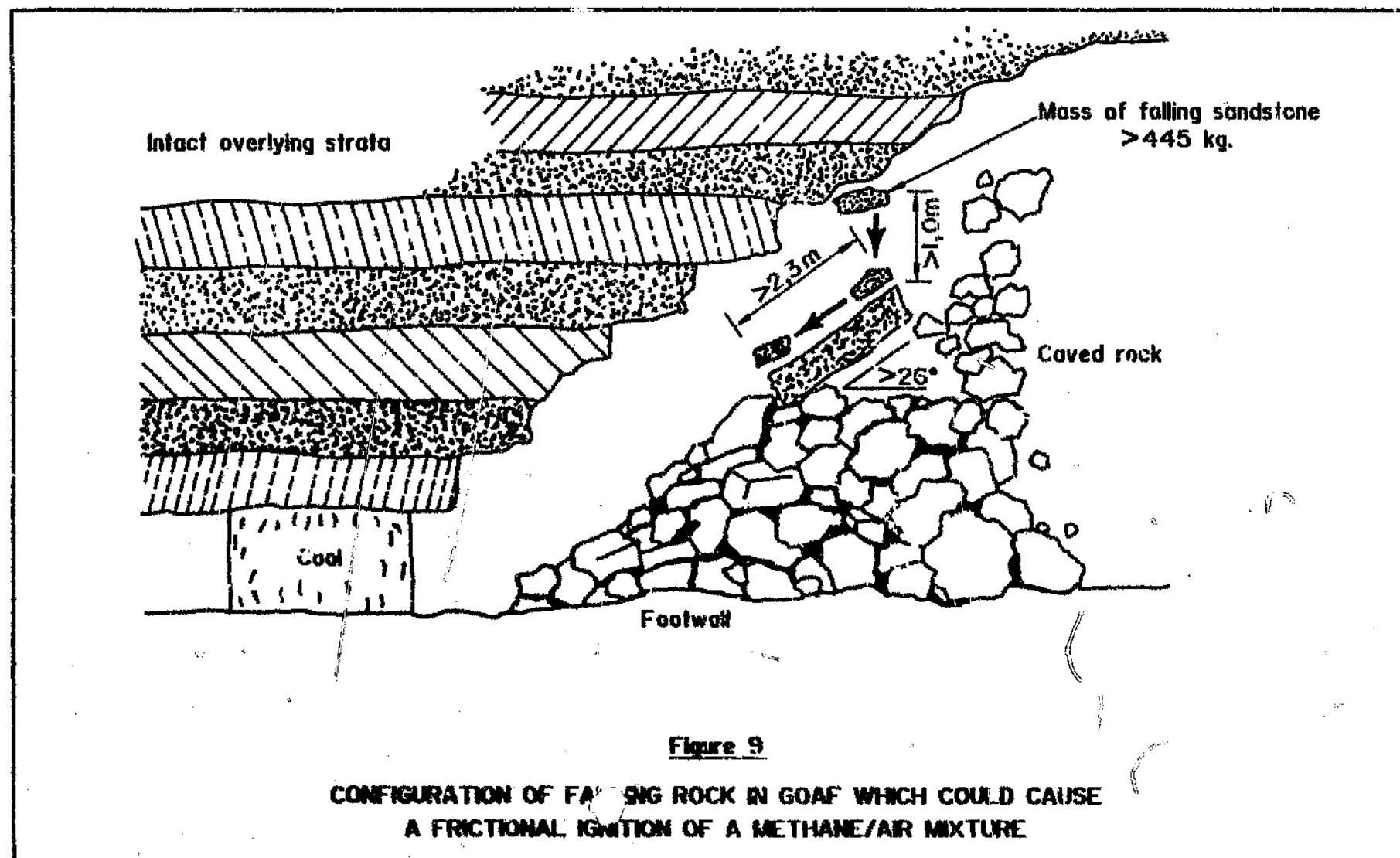
load that his rig was capable of applying, this being 400 kg to a 25 mm square slider, ignition occurred after an average of 0,5 seconds of sliding contact at a speed of 4,6 metres per second. This situation could occur if a piece of sandstone of similar composition were to break away from the goaf, slide for more than half a second at 5 metres per second or faster, and be large enough to apply a contact pressure of over 65 MPa. If the coefficient of friction of sandstone on sandstone is assumed to be 0,5 then the minimum slope angle that the piece of sandstone will maintain a constant speed or accelerate on is 26° . The mass of the rock necessary to apply a force of 400 kg normal to the plane of contact is thus

$$\frac{400 \text{ kg}}{\cos 26^{\circ}} = 445 \text{ kg}$$

The height that the piece of rock would have to fall vertically to attain an initial speed of 4,6 metres per second is 1,08 m and the total distance covered during sliding contact would be 2,3 m. (McVey, 1986). This is shown diagrammatically in Figure 9.

On assessing the applicability of the above to the typical goafing or caving situation, it is readily seen that the conditions described could occur underground. The many millions of tons of sandstone that are displaced by the extraction of coal every week dictate that the probability that the required minimum size of rock will fall and slide for the required minimum distance is high. Certainly, it is possible that the described frictional sliding conditions will be met some of the time underground (see Springfield Colliery example).

There are two further conditions which must be met before an ignition will occur. An explosive mixture of methane must exist at the area of sliding contact of the rocks, and the rocks in question must have similar incendivities to those used by Rae in his experiments. The fact that an ignition occurred at Ermelo Mines Limited adequately covers the first condition. The second



condition, which is basically the comparison of the Ermelo Mines Limited sandstone and the sandstone used by Rae and other researchers in similar tests is covered in the following section.

(b) The Influence of Rock Composition on Incendivity

The term sandstone covers a wide range of mineral configurations. A sandstone is a poly-mineral material, made up of grains of quartz cemented together into a solid mass by a matrix of another mineral which can be a feldspar, a carbonate, or one or more of several other minerals. The grain size distribution of the quartz is variable, as is the ratio of quartz grains to binder matrix material. Porosity is also variable. The strength of sandstone varies with the quartz grain size, the matrix mineral, the ratio of the two foregoing, and porosity.

The incendivity of sandstone also varies with differences of composition. To understand the effect of this variation in incendivity, a brief description of the mechanism of ignition by frictional heating is required. When two bodies rub on one another, energy is lost at the points of contact due to deformation of surface asperities. This is accompanied by an increase in temperature where this deformation takes place. The temperature reached by the two surfaces will not be higher than the melting point of that material with the lower melting point. At this temperature, the lower melting point material becomes molten, the coefficient of friction drops to a very low value and the ability to generate further frictional heat by rubbing is lost. This is the case for sandstone rubbing on sandstone; the melting point of the matrix mineral of sandstone determines the melting point of sandstone and in a strong coarse-grained sandstone this is about $1\ 250^{\circ}\text{C}$. Coincidentally, the minimum temperature of a hot surface momentarily exposed to a methane/air mixture required to cause ignition is $1\ 200^{\circ}\text{C}$. A further factor in this process is the time which the hot surface produced by friction will remain hot. At $1\ 250^{\circ}\text{C}$ the contact time

between the gas/air mixture and the hot surface to cause an ignition is in the region of 15 to 30 ms. The heat of crystallization of the molten mineral combined with the low thermal conductivity of sandstone create conditions where the hot spot remains hot for long enough to cause an ignition. The foregoing characteristics of high melting points, high mechanical strengths up to the melting point and low thermal conductivities are not present in coal-associated rocks other than sandstones. The only other coal-associated rock known to be incendiary is iron pyrite, which, if heated by friction, can burn in air in a powder form and thus cause ignition.

The factors in the composition of sandstone which affect incendiarity have been studied by Rae (1964) and by Powell and Billinge (1975). Rae studied various rock types in the laboratory, whilst Powell and Billinge studied the type of rock which was being cut by roadheading machines in Britain. The results of these independent studies occur in the following:

- (i) The incendiarity of a sandstone increases with increasing quartz grain size.
- (ii) The incendiarity of a sandstone increases with increasing quartz content.

Expanding on these statements it can be said that sandstone with a dominant particle size of greater than 100 microns and quartz content of more than 50 percent is incendiary. A siltstone of dominant particle size between 10 and 100 microns and a quartz content of more than 50 percent is incendiary but less so, whilst shales which have dominant particle size less than 10 microns are again less incendiary.

2.4.6 Comparison of Sandstone Sample from a Colliery with Sandstone used by other Researchers

The sample supplied by a colliery to the Chamber of Mines Research Organisation was analysed and the results are discussed here. The reason for analysing this sandstone sample was to ascertain whether it fulfills the conditions for incendiarity.

(a) Strength

Uniaxial compressive strengths were determined for five 76,2 mm x 25,4 mm cores. The strength of the rock was found to be 50,0 MPa $\pm$ 6,5 at 95 percent confidence limits. Full test results are shown in Table 8. This compares closely with the sandstone samples used by Rae (1964), which had a uniaxial compressive strength of between 43 and 64 MPa.

Table 8 Uniaxial compressive strength test results for samples of sandstones from two South African collieries

The following are the results of tests carried out at the Chamber of Mines Research Organisation's testing facility. All tests have been carried out in accordance with the standard procedure described by the International Rock Mechanics Society.

Material	Test	Uniaxial compressive strength (MPa)
Sandstone (A)	1	74
	2	72
	3	77
	4	77
	mean	<u>75</u>
Sandstone (B)	1	48
	2	56
	3	58
	4	55
	5	51
	mean	<u>54</u>

(b) Mineralogical Description

From a thin section, the composition of the sample was determined to be 73 percent quartz, these being the grains, held in a matrix of 12 percent feldspar, 5 percent mica and 10 percent accessory minerals.

The description of the sandstone used by Rae (1964) indicates that it consisted mainly of quartz and feldspar, with a small amount of mica.

(c) Grain Size

The mean grain size of the sample as determined from the thin section was 530 microns. From all the foregoing, the sample has been classed as a coarse-grained arkosic quartz arenite.

A sandstone with this dominant grain size fulfills the condition for incendivity laid down by Powell and Billinge (1975) who stated that a sandstone with a dominant grain size of greater than 100 microns will be incendive.

2.4.7 Friction between Steel Tools and Rocks - Laboratory Tests

Kelly and Forkner (1976) have conducted extensive research using an abrasive-impact incendivity apparatus to simulate abrasive impacts between steel and minerals that might be present during the pneumatic transport of coal. The experiments highlight several important aspects of frictional heat and sparking which could be used to draw conclusions in studying this phenomenon in South African Collieries.

(a) Abstract

Laboratory equipment, which simulates abrasive impacts between steel and minerals that might be present during pneumatic transport of coal, was used by the Bureau of Mines to characterize the potential explosion hazard of such collisions in an atmosphere of fine coal dust, air and methane. A variety of coal mine rock materials, including sandstone, limestone and pyrite-bearing limestone, were impacted with specimens of pipeline steel. Tests were conducted in atmospheres containing zero to 6.4 vol-pct methane mixed with zero to 300 mg/l of coal dust.

Coal dust in air alone was not ignited by abrasive impacts but additions of as little as 1 vol-pct methane to the coal dust and air mixture resulted in ignitions. Steel impacting against sandstone caused ignitions in mixtures of coal dust, air and methane and the probability for ignitions increased with an increase in methane. No ignitions occurred with impacts of steel on limestone or pyrite-bearing limestone, even when large showers of sparks were produced.

Ignitions in coal-air-methane mixtures were found to be caused by a hot friction-induced smear on the impacted rock at the impact site rather than by sparks. High speed photography was used to verify this observation.

(b) Introduction

Ignitable mixtures of methane and coal dust could exist in the pipeline or in auxiliary equipment during haulage operations. Such mixtures could be ignited by sparks or frictional heating generated during coal transfer by collisions of tramp materials against each other or with the pipeline walls. Hard tramp material such as pyrite-bearing limestone (commonly known as "sulfur balls"), limestone, shale, sandstone, iron and steel

could inadvertently enter the pipeline, where they would be likely to collide with the inner walls of the pipe.

Experiments by Hartmann, Nagy, McGibbeny and Christofel (1952) showed that a low percentage of natural gas in the atmosphere enhances the ignitability of coal dust by permissible explosives.

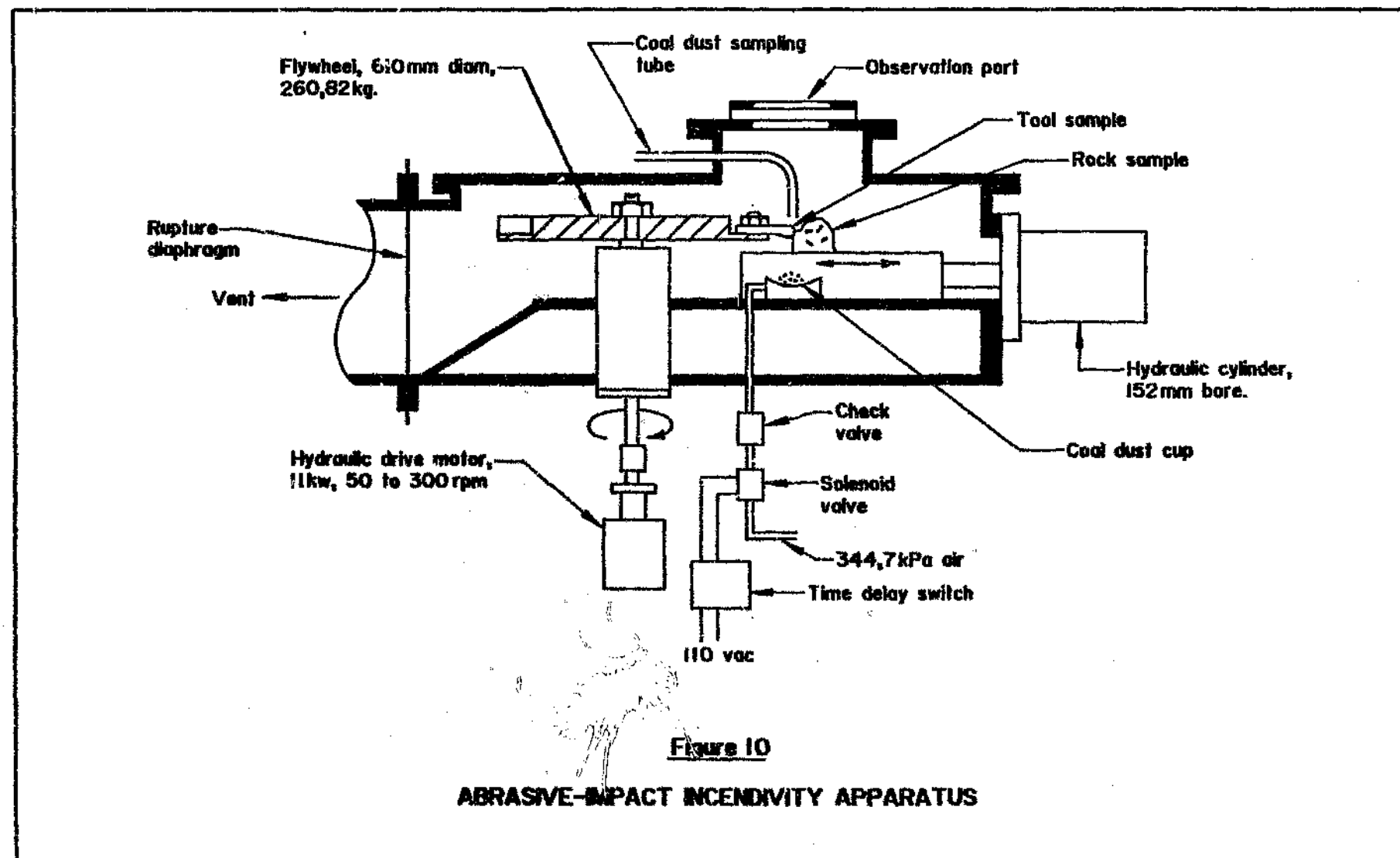
Nowhere in the literature have there been reports of ignition studies in coal-air-methane mixtures by abrasive-impact heating. Suzuki, Takaoka and Fujii (1965) report that coal dust dispersed in air can be ignited both by frictional sparks and by a hot surface under some heavy-contacting conditions between a high speed rotating steel wheel and a steel slider.

(c) Experimental Equipment and Procedure

Abrasive Impact Incendivity Test Equipment

Impacts between low carbon steel specimens, representing pipeline materials and mineral specimens were produced in an abrasive-impact incendivity apparatus, shown in Figure 10. The test apparatus consists of a massive rotating wheel that carries metal impact specimens; the metal specimens make low angle abrasive impacts against mineral specimens inside an explosion chamber. A rock vice holding the mineral block is advanced toward the rotating metal specimen by a flow regulated hydraulic cylinder whose advance rate can be varied from zero to 0.018 inch (0.046 cm) per revolution. A fan mixes the flammable gas and air prior to a test. Natural gas containing 92 vol-pct methane was used. Results of an analysis of the gas were as follows, in vol-pct: 2.5 C_2H_6 , 0.2 O_2 , 92.1 CH_4 , 1.7 N_2 , 0.1 C and 0.9 C_3H_8 ; CO_2 and H_2 were not detected.

Electronic tachometry is used to monitor and record impact energy and the revolutions per minute of the flywheel. The kinetic energy released in the collision of the steel and rock samples is



calculated from the change in angular velocity measured just before and after impact, with appropriate corrections for friction losses of the moving parts. Explosions in the chamber are vented to the outside of the building through a weak wall consisting of a polyethylene diaphragm 0.004 inch (0.010 cm) thick and 16 inches (40.6 cm) in diameter.

(d) Test Procedure

Multiple-Impact Mode

The majority of the abrasive-impact incendivity tests were conducted in a multiple-impact mode. The metal impact specimen mounted on the flywheel was rotated at a tangential velocity of 900 fpm (4.57 m/sec) while a rock specimen was advanced hydraulically into the impact zone. Repeated impacts were made until either an ignition was produced or the metal specimen cut about 5/16 inch (0.8 mm) into the rock, causing contact of the flywheel and rock.

The rock specimen advance was interrupted periodically as the impacts occurred to allow a maximum development of the frictional hot spot on the rock surface. The coal dust was dispersed into the pre-mixed air-methane atmosphere only when a sizeable hot spot had developed. The time delay between the instant of dispersion and ignition was measured with a stopwatch, and the coal dust cloud density at the instant of ignition was thereby deduced from the calibration curve in Figure 11 relating density to settling time. Initial coal dust cloud density for all tests was 300 mg/l, which resulted from a coal charge of 36.6 g in the dust cups. Time delays of 2 to 4 sec were noted between the instant of coal dust dispersion and ignition, resulting in dust cloud densities of 300 to 190 mg/l.

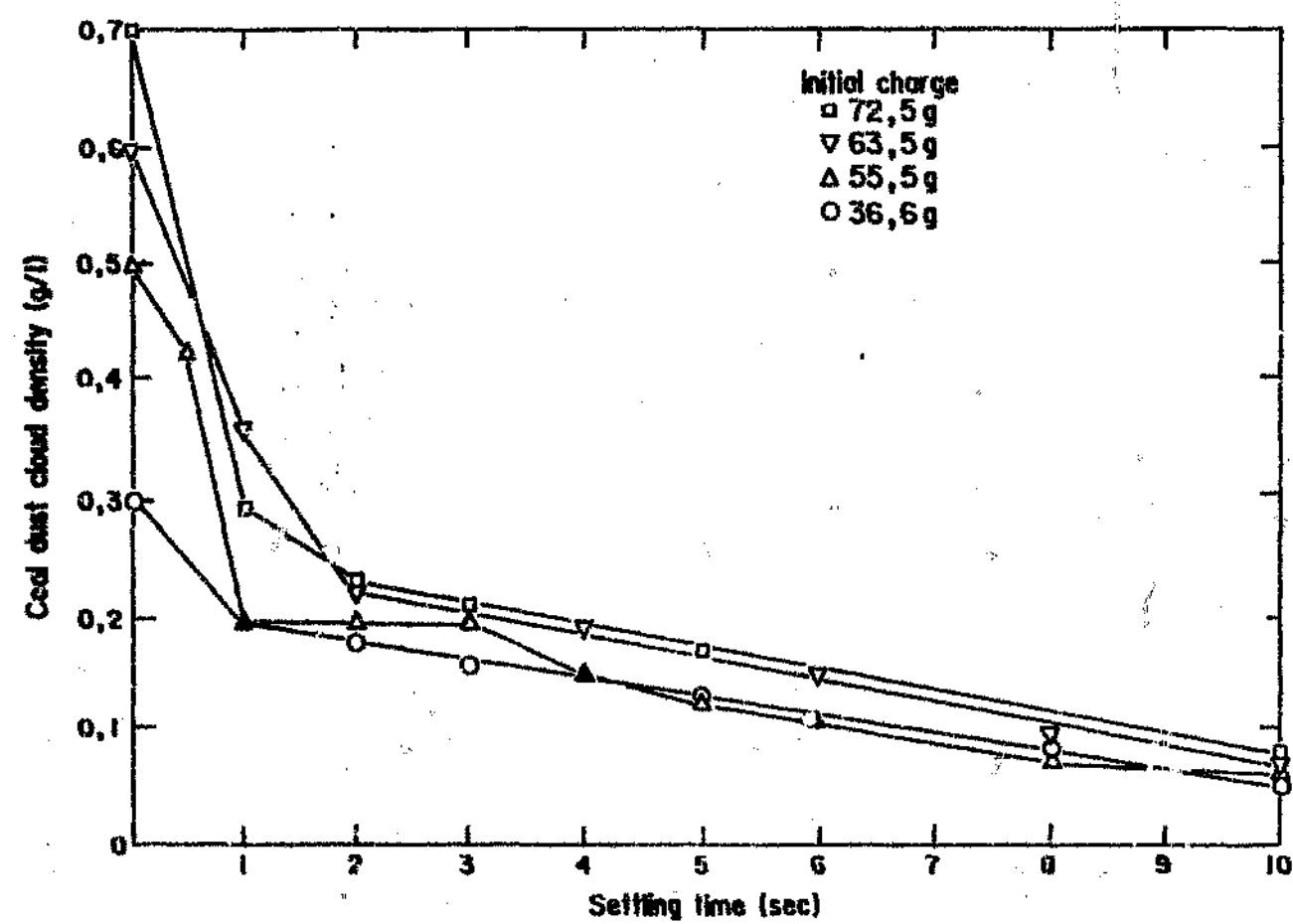


Figure II
RELATIONSHIP BETWEEN COAL DUST CLOUD DENSITY
AND SETTLING TIME

(e) Results and Discussions

Multiple-Impact Mode. Effect of Coal-Methane Composition

Frictional impact of low carbon steel (pipe line grade) at 900 fpm (4.57 metres per second) against quartzitic sandstone caused ignitions in mixtures containing 200 to 300 mg/l coal dust and methane contents of 5 vol-pct down to as low as 1 vol-pct. Coal dust clouds of up to 300 mg/l density were not ignited by the same frictional heating conditions. Methane-air mixtures containing 5.0 and 6.4 vol-pct methane were ignited 60% and 100% of the time respectively. Ignition data for the above tests are shown in Table 9. Visual observations of frictional impact ignitions of coal-air-methane mixtures indicate that a hot smear of metal on the sandstone is the ignition source. No ignitions were observed from sparks ejected from the impact site.

Table 9. Abrasive-impact ignitions of coal-air-methane mixtures using C-1020 steel against quartzitic sandstone at 900 fpm (4.57 m/sec)

Methane vol-pct	Coal dust cloud density range during test mg/l	Number of ignitions in 5 tests	Percentage of ignitions
0	300	0	0
0.5	300-0	0	0
1.0	1 300	1	20
2.0	1 300	1	20
3.0	2 300-190	2	40
4.0	3 300-190	3	60
5.0	300	3	60
5.0	0	3	60
6.4	0	5	100

¹ One ignition at 300 mg/l coal dust.

² Two ignitions at 190 mg/l coal dust.

³ One ignition at 300 mg/l coal dust and two ignitions at 190 mg/l coal dust.

No ignitions were produced in a mixture of 4 vol-pct methane with 300 mg/l coal dust from frictional impacts of low carbon steel on limestone. No hot smears were observed and only a fraction of the sparking that occurs in steel on sandstone impacts was noted.

The limestone is too soft and non-abrasive to produce a highly incendive condition such as that occurring on sandstone.

Impacts of low carbon steel on "sulfur balls" produced tremendous showers of sparks, but no ignitions of coal-air-methane or methane-air. No hot smears were observed to form on the impact surface, even though much sparking was evident. Like the limestone, "sulfur balls" are soft enough to be easily worn or fractured away, and very little metal was smeared on the impact surface. Mixtures in air included 2 vol-pct methane plus 300 mg/l coal dust, 4 vol-pct methane plus 300 mg/l coal dust, and 6.4 vol-pct methane. In each test, the coal dust was dispersed only after a copious shower of sparks was obtained.

Effect of Tangential Impact Velocity

A study was made to determine what effect tangential velocity of steel specimens impacting sandstone has on ignition probability in a coal-air-methane atmosphere. Specimens of low carbon steel were impacted against quartzitic sandstone at velocities of 450, 600, 750 and 900 fpm (2.29, 3.05, 3.81 and 4.57 m/sec respectively) with a steady rock feed rate of 0.006 inch (0.015 mm) per impact. An atmosphere of 4 vol-pct methane and 300 mg/l coal dust was used. Five duplicate tests at each velocity resulted in the following:

450 fpm (2.29 m/sec) - many dull red sparks ejected with a dull smear on the rock, no ignition.

600 fpm (3.05 m/sec) - same as foregoing.

900 fpm (4.57 m/sec) - a few red sparks and very bright flashing smears on rock with each impact, resulting in three ignitions in five tests.

Initial observations of these tests indicated that the ignitions occurred only when the bright hot spot or smear developed on the

rock at the impact site, and this condition developed very easily with a tangential specimen velocity of 900 fpm (4.57 m/sec).

Single Impact Mode

Single low angle impacts of quartzitic sandstone, quartz (agate), "sulfur ball" material, cobalt-bonded tungsten carbide, type A-36 steel, C-4130 steel, and aluminium were made against A-36 steel. Tangential velocities of 900 and 1100 fpm (4.57 and 5.59 m/sec respectively) were used in two types of explosive atmospheres. No ignitions resulted in atmospheres of either air and methane or flowing acetylene. The following specific results were noted:

1. Quartzitic sandstone on A-36 steel. The sandstone specimens fractured each time. No hot smears were seen, although an occasional tiny spark was ejected.
2. Quartz (agate). The agate chipped, but did not fracture as readily as the sandstone. Some small sparks and small hot smears on the steel were observed.
3. "Sulfur balls". No sparks or hot spots were observed. Severe fracturing of the specimens occurred.
4. Cobalt bonded tungsten carbide. Commercial coalcutter pick tips were impacted against A-36 steel with no resulting ignitions. No sparks or hot smears were observed.
5. A-36 steel and C-4130 steel. No hot smears were observed but some dull sparks were produced.
6. Aluminium. Impact specimens of aluminium were struck against both clean and rusty A-36 steel, and also against a steel plate with a heavy rust layer. A few very small sparks were observed, but no evidence of a thermite reaction was noted. Apparently the tangential velocity was too low to cause initiation of a thermite reaction.

Due to the negative ignition results in air-methane and air-acetylene from single impacts, the tests were not conducted in mixtures of coal dust, air and methane.

Failure to produce a sufficiently large frictional hot spot to ignite methane in air from impact of sandstone on steel appears to be a result of the fracturing of the sandstone. Apparently, the impact energy is absorbed in creating new surface in the rock specimen rather than in producing heat by friction.

Ignition Source

Visual observations of ignitions of air-methane and coal-air-methane mixtures from frictional impacts of steel on sandstone indicated that the ignition source was a hot smear on the rock rather than ejected sparks on a heated impact specimen. Verification of this observation was made with the aid of highspeed cinematography. An ignition of an explosive mixture consisting of 300 mg/l coal dust and 4 vol-pct methane was photographed at 2 000 frames per second. The ignition was caused by frictional impact of low carbon steel rotating against quartzitic sandstone at 900 fpm (4.57 m/sec). The ignition and flame front can be seen to originate at the hot smear at about 11 m/sec after impact, as shown in Figure 12.

Summary and conclusions

Since not enough energy to create an incendive condition could be concentrated by a single low angle impact, single impacts of sandstone, "sulfur balls", limestone, quartz, tungsten carbide, steel and aluminium on pipeline steel failed to ignite air-methane or air-acetylene mixes. Multiple impacts of low carbon steel on "sulfur balls" and limestone also failed to generate sufficient frictional heating to ignite air-methane or coal-air-methane mixtures.

The only incendive results were obtained with multiple frictional impacts of low carbon steel on quartzitic sandstone, which shows

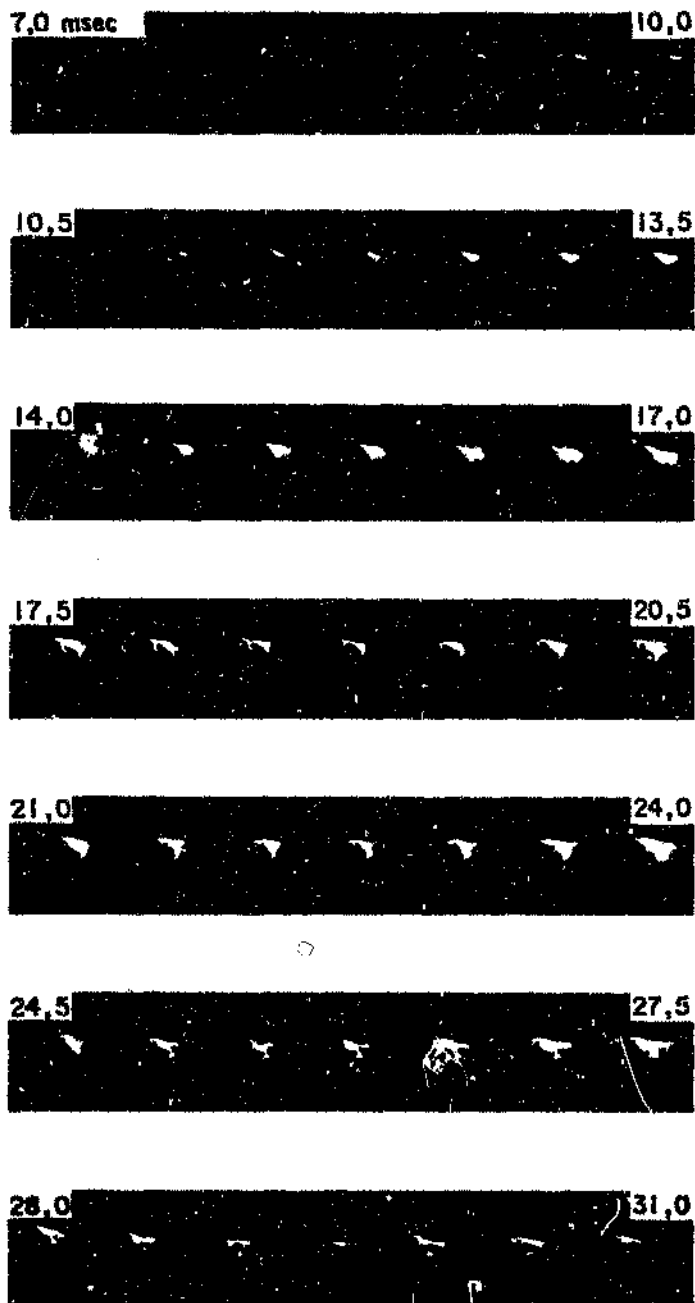


Figure 12

**HIGH SPEED FILM STRIP SHOWING IGNITION OF
COAL-AIR-METHANE ORIGINATING AT FRICTIONAL HOT SPOT.
Time is shown at top of each strip (in milliseconds)**

that a mixture of air and 6.4 vol-pct methane is more easily ignited than coal dust alone or coal-air-methane mixtures. All of the tests on air and 6.4 vol-pct methane resulted in ignitions, whereas no coal dust clouds up to 300 mg/l density were ignited. A mixture of 1 to 2 vol-pct methane in air with 300 mg/l coal dust ignited in one out of five tests, 3 vol-pct methane in coal dust ignited in two of the tests and 4 to 5 vol-pct methane in coal dust ignited in three of five tests. A mixture of 5 vol-pct methane in air (lower explosive limit) also ignited in three of five tests. These results indicate that the probability of coal dust ignition increases as methane is added.

The effect of tangential velocity of a steel specimen impacting a quartzitic sandstone target is a strong factor in determining whether or not a mixture of coal dust air and methane will ignite. Ignitions failed to result below the tangential velocity of 900 fpm (4.57 m/sec). The ignition source for multiple impacts of steel on quartzitic sandstone in coal-air-methane was shown in high speed cinematography to be a heated smear on the sandstone rather than sparks.

Based on the results of the multiple-impact tests with steel on quartzitic sandstone, an explosion hazard exists in coal dust where 1 vol-pct or more methane is present. However, results of single-impact tests indicate that ignition of such a mixture, or of air and methane, is very unlikely from the type of low angle, glancing impact that tramp rock or metal would make in a coal carrying pipeline.

Description of Rocks

1. Quartzitic sandstone. A medium to coarse grained, buff to red brown sandstone consisting almost entirely of angular to subrounded quartz grains, with some secondary overgrowth of quartz. Trace of montmorillonite. (Geographic source unknown).

2. Sulfur balls. A partially metallic brown to black carbonate-sulfide rock consisting essentially of siderite and calcite, and very fine grained pyrite, with some coaly material and limonite. The pyrite content varies through the rock from 0 to 100 pct, with a spot average of 60 to 70 pct. Some small veins of relatively coarse grained secondary pyrite penetrate all of the structures. Small nodules of lighter coloured calcite were randomly scattered throughout the rocks. Additionally, veins, clots, stringers and disseminations of carbonaceous (coaly) material occur randomly in the rock. From Humphrey No. 7 coal Mine (Consolidation Coal Co.), Monongalia County, W. Va.

3. Limestone. A very fine grained, gray, fossiliferous limestone. From Blaney-Bowser, Kittanning, Pa.

An important aspect is that if methane and coal dust are present in the air simultaneously, the lower limit of explosibility of each is lowered depending on their relative concentration in the mixture. As shown in Figure 13 for minus 200 mesh Pittsburgh coal dust, the dust concentration decreased from 60 grams per cubic metre at 0% methane to 0 grams per cubic metre at 5% methane in air (Kawenski et al. 1979).

2.4.8 The Cutting Tool

Kelly and Forkner's laboratory experiments with regard to abrasive impacts of hard minerals with pneumatic pipeline steel are supported by Morris (1984) who deals with the ignition potential of the cutting tool. Morris' findings are crucial to this aspect of frictional heat since, in many of the incidents quoted, the explosions have their ignition source in coalcutter and continuous miner picks impacting on quartzitic sandstone - either in the seam or as a roof in the roadways.

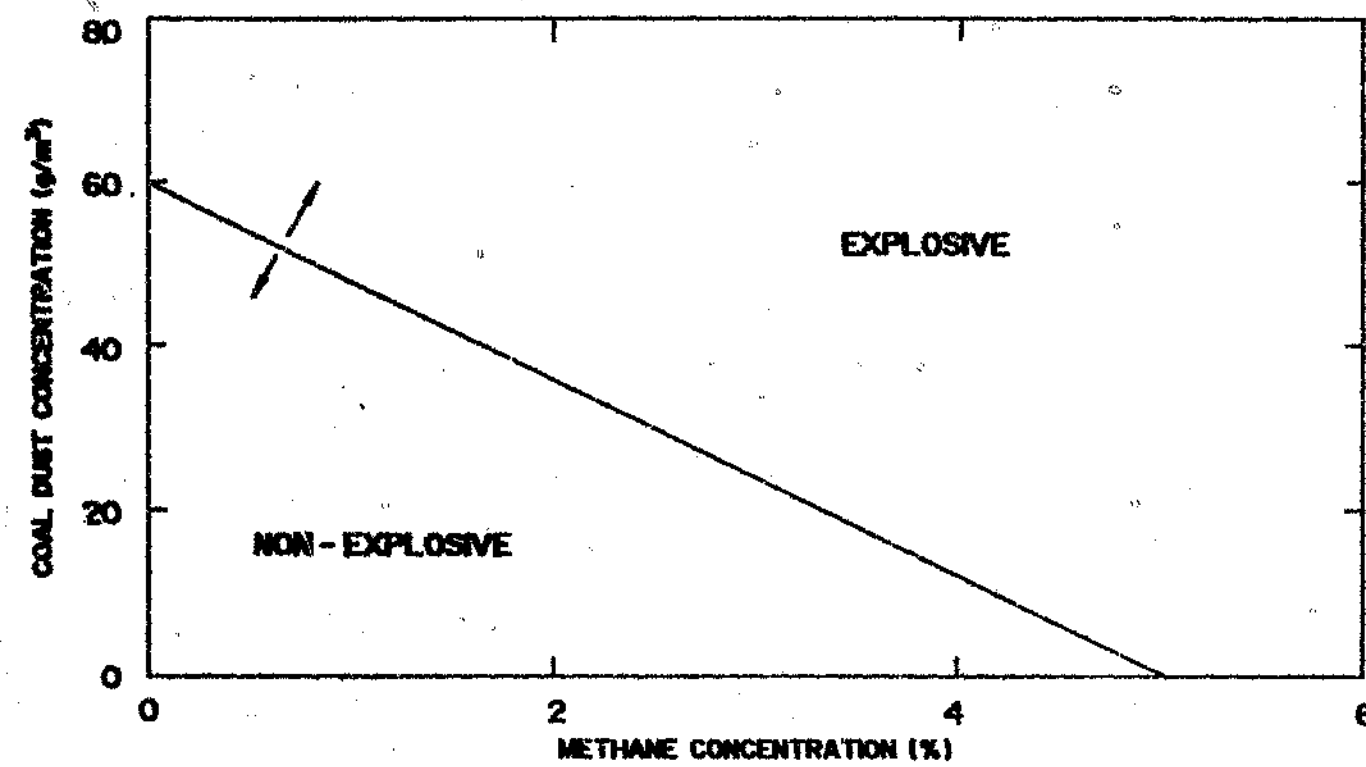


Figure 13
MINIMUM EXPLOSIVE CONCENTRATIONS OF COAL DUST
IN METHANE / AIR ATMOSPHERES

Several parameters regarding the ignition potential of the cutting tool have been investigated, these being pick material, wear, heating, geometry and rotation. Studies are continuing in some of these areas at the present time.

Laboratory studies on the ignition potential of cutter picks show a wide variation of potential, suggesting that testing conditions have a strong influence on the value of the results. With variables such as gas concentration, velocity, energy, bearing pressure and humidity, this is not surprising.

For practical applications there are two basic types of cutter picks. The plumb-bob shaped pick with a cylindrical shank is typical of the first type, while the flat cutter pick is typical of the second type. The former type is designed for point attack and is free to rotate in the pick holder. This ability to rotate is designed for prolonging pick life but is decidedly disadvantageous in relation to heat dissipation. The relatively loose fit of the pick in the box minimises the effective transfer of heat generated, through the body of the pick to the pick box. This condition forces the pick to operate at a much higher temperature and facilitates frictional ignition. Flat cutter picks are rigidly fastened in the pick box and as a consequence there is a more effective heat transfer to the pick holder, so that the pick operates at a lower temperature.

A flat cutter pick tested on Ruhr sandstone, which contained 74 percent quartz became red hot after cutting a few metres (Schriever and Marx, 1980). Temperatures up to 850°C have been recorded for uncooled point attack bits. Methane has been ignited by a metal bar coated with pyritic dust at a temperature as low as 644°C (Blickensderfer et al, 1974).

The physical strength of steel and hard carbide pick inserts decreases rapidly at temperatures above 500°C and the component life is substantially reduced. Reduction of temperature would

reduce the probability of a frictional ignition and simultaneously increase the bit life by a factor of up to 10.

(a) Material of Pick Tool

Early work suggested that the material of the cutting tool contributed little to the cause of ignitions of methane-air mixtures. More recent work states that the material of the pick tool does have an influence upon the probability of ignitions.

Burgess and Wheeler (1929) carried out experiments in which various steels were held with an edge in contact with a rotating wheel of quartzitic sandstone in an explosion chamber. Ignitions were obtained from all the steels, and there was no significant difference between them. In tests on machine picks made from both carbon and tungsten steels, there were no appreciable differences in the time taken to ignite methane between the two pick materials.

Allsop and Wheeler (1939) carried out experiments in which blunt picks made from carbon steel and tungsten steel impacted iron pyrite. There appeared to be no difference in the incendiarity of the two steels.

Rae (1964) noted that soft metals, such as copper and brass, that have a melting point lower than the ignition temperature of methane can cause ignitions as a result of a hot spot mechanism when impacted on quartz rocks. Particles of rock embedded in the metals were observed. The hot spots produced were molten rock, rather than molten metal, and were thought to have been due to the friction of rock on rock. No tests were carried out on the relative incendiarity of these soft metals, steels and tungsten carbide.

Blickensderfer et al (1972) tested several metals and metal alloys for ignition potential. They concluded that tungsten

carbide was considerably less incendive than commercial carbon steels of the types that are used for pick shanks.

It was therefore concluded that the steel shanks of cutting tools, rather than the tungsten carbide tip, were primarily responsible for face ignitions. Stainless steel was found to be less incendive than commercial carbon steels, but more prone to ignitions than tungsten carbide.

The mechanism of ignition in these tests, however, was stated to be that of sparking. It was noted that methane mix. with air was very difficult to ignite by sparking and a hydrogen-air mixture, which ignited easily, was used.

In further tests, Blickensderfer et al (1974) noted the applicability of the results obtained with the hydrogen-air mixture to ignitions caused by hot spots in methane-air mixtures. In addition, a hard metal alloy, TiB_2 -CuNi, was found to have a lower ignition potential than tungsten carbide. No reasons were given for the differences in ignition potential between the various metals or metal alloys.

Blickensderfer (1975), in a theoretical approach, developed an energy-balance equation for the mechanism of ignition by hot spots on rock. The formula implied that the melting point of the tool had an effect upon ignitions. The lower the melting point of the tool, the less energy would be required to form a metal smear on the rock. For a given energy input, therefore, the easier it would be to form this molten layer which is a major contributor to ignitions as discussed previously. Conversely, the lower the melting point of the metal, the lower would be the temperature of the hot spot. In the tests described above, none of the authors attempt to explain the differences in incendivity, or otherwise, between different pick materials by comparing their respective melting points.

On the basis of tests with pick-body steel and tungsten carbide, Roepke and Hanson (1983) suggested that the ignition potential depends upon the back clearance of the tool, rather than on the material. When the back clearance angle was positive, neither of the materials ignited a methane-air mixture. With a negative back clearance angle, ignitions readily occurred with both materials. The authors did not attempt to give an explanation for these effects.

It can be seen that there are contradictions in the literature surveyed. The very early work indicates that the pick material does not influence the likelihood of igniting methane-air mixtures. The later literature implies that tungsten carbide tips are considerably less incendiary than the body steel of a pick. It is also suggested that, if the material of a pick is changed, for example to a tip of the hard-metal alloy TiB_2 -CuNi and a body of stainless steel, a tool could be designed that would be less likely to produce ignitions. Very recent work implies that the effect of the back-clearance angle, rather than the material from which a machine tool is made, influences its incendiarity. The normal forces acting on picks increase dramatically as the back-clearance angle is reduced to less than about 5 degrees, which has an effect on the rate of heating at the rock-pick interface. However no authors have attempted to equate their experimental results with a mechanism of ignition. It is clear, therefore, that the effect of the material of a cutting tool upon the risk of ignitions has not been researched adequately. Reference should however be made to the work done by Kelly and Forkner which has been described in this chapter.

(b) Pick Wear

Many authors agree that worn picks are considerably more incendiary than sharp ones. Some aspects of the effects of wear on the ignition potential of machine picks have been investigated only very recently.

Powell et al (1975) and Blickensderfer (1975) conclude that ignitions will not occur while picks remain sharp. During ignition tests, Powell et al noted that the duration of cutting for a 50 percent probability of ignition was considerably more for sharp picks than for worn picks. These authors considered that extra time was needed for wear of the cutting tool to occur.

A marked increase in the ignition potential of picks was noted by Sheag et al (1983) when the wear flat extended to the steel shank. The reason for this was thought to be the greater incendiarity of commercial carbon steel relative to tungsten carbide.

Roepke and Hanson (1983) concluded that the mechanisms of ignitions caused by frictional impact appear to be largely controlled by the back-clearance angle of the pick. The back clearance can, of course, be influenced by the wear of the cutter tool.

The literature implies that worn picks are considerably more incendiary than sharp ones, particularly if the body steel comes into contact with the rock being impacted. Recent investigations suggest that the incendiarity of a coal-cutting tool may be greatly increased if wear occurs so that the back clearance angle becomes negative.

(c) Pick Heating

Experimentation has been carried out recently into the effect upon the potential to ignite methane from a pick that was heated before cutting. An earlier theoretical approach implied that there is an initial pick temperature effect. Larson et al (1983) preheated worn picks to a temperature of between 120°C and 150°C to simulate a machine tool that has been heated as a result of cutting coal and compared their ignition potential with that of

cool picks having the same degree of wear. No justification was given for the range of temperature to which the tools were pre-heated. It was found that, at pick speeds of 0,96 and 1,9 metres per second, the ignition potential for the hot picks was considerably more than for the cool ones.

In the energy-balance equation developed by Blickensderfer (1975), an initial cool-temperature effect is implied. It is implicit from the equation that the higher the initial temperature of the pick, the less energy is required to form the metal smear on the rock. For a given input of energy, therefore, the easier it will be to form this molten layer, which is a major contributor to ignitions of methane-air mixtures.

Comparing pre-heated worn picks with cool ones at a speed of 2,86 metres per second, Larson et al (1983) deduced that their incendiaries were essentially the same. The reason for this was thought to be cooling of the pick by air.

It is suggested in the literature that, as machine tools become hot, their potential to ignite methane-air mixtures increases. However, at pick speeds of more than approximately 2,83 metres per second, the indications are that there is little difference in incendiarity between hot and cool cutting tools. A possible explanation for the higher speed effect was thought to be that air cooling of the picks reduced their temperature between successive impacts.

(d) Pick Geometry

The work relating to pick geometry has tended to concentrate upon the tip area and diameter of the shank. This is because previous experimentation concluded that the tungsten carbide tip was less incendiary than the body steel and that wider picks increased the area of the hot spot.

Larson et al (1983) compared a commercial tool of plumb-bob shape with a bullet-shaped pick of smaller diameter. The angles of the carbide insert and body cone in both tools were essentially the same. It was found that, as the pick diameter increased, so did the ignition frequency. Hanson (1987) in comparing plumb-bob with pencil-type picks, reached similar conclusions. In addition, he noted that, if the diameter of the tungsten carbide tip and the immediate shank was smaller, the ignition potential was reduced.

Three types of conical picks were compared for ignition potential by Roepke and Hanson (1983). All these cutting tools had a tip angle of 90 degrees, but the size of the tungsten carbide tips in relation to the end of the shank was different in all cases. A widely used commercial pick, which was used as a reference, had the smallest tip which did not cover the end of the shank. The tip of the second pick covered the end of the shank. The third tool was a non-commercial type, which was termed the 'mushroom-tip pick', in which the tungsten carbide tip had a greater diameter than the end of the shank.

It was found that the reference pick was considerably more incendive than the other picks. The mushroom-tip pick had the next greatest ignition potential. The authors did not expect the latter result, because they thought that the larger tip, by protecting the steel shank, would prove to be less incendive. They therefore carried out additional tests on tungsten carbide and coalcutting steel to monitor the effect of back clearance angle, since this factor was thought to be responsible for the anomalous results.

Two radial-type picks were also tested, one with a cutting tip that was larger than normal. Both these tools had the same ignition potential as the least incendive conical pick tested.

For the conical picks, it was found that shanks of larger diameter increased the ignition potential of the tool. The

cutting tip of this type of pick also appears to be important. If the tungsten carbide covers the tip of the shank, this has an adverse influence on the incendivity of the machine tool. The geometry of the pick can influence the wear, which in turn may have an effect on the back-clearance angle. It is suggested by the literature that the back-clearance angle has a marked influence upon the ignition potential of machine tools. It appears from the few tests that have been carried out that radial picks have a relatively low incendivity.

(e) Pick Rotation

In testing conical-type picks for the effect of rotation within the pick block, Larson et al (1983) noted that no ignitions occurred when the tool rotated, but the incidence was high when the pick was locked. The authors stated that this type of tool will rotate when unbalanced side loading overcomes the resistance friction between the shank and the block, and they therefore recommended an angle of skew to induce rotation. The authors did not give any reasons why rotation should influence the ignition potential of a tool.

Hanson (1983) also carried out experimental studies in this area but concluded that conical picks that rotate can produce ignitions. However, the rotating cutting tools could be subjected to considerably more wear before becoming incendive. It is suggested, therefore, that pick rotation influences incendivity and that incendivity is related to wear.

It is clear that, if conical picks rotate within the block, the ignition potential of the tools will be reduced. This is probably due to geometrical considerations; by rotating, the picks tend to be subjected to unbiased wear.

(f) Cutting Parameters

Several aspects have been investigated that relate machine cutting parameters to the risk of ignition of methane-air mixtures. These are the speed of cutting, the rate of advance of the machine tool, the depth of cut, and the cutting forces.

(g) Speed of Cutting

The effect that the speed of the pick has upon the ignition potential of the tool has been investigated by several authors. The influence of this parameter on sharp, blunt, and pre-heated picks has also been investigated.

When considering sharp picks, Blickensderfer (1975) concluded that, by increasing the cutter-tool speed, a greater area of the hot spot, which is capable of igniting methane, is produced on the rock. An example is used to illustrate this point. The hot spot is considered to be a molten smear of carbon steel at an initial temperature of 1450°C . The smear will cool with time. At a pick speed of 1,5 metres per second, part of the smear would have cooled to below a temperature of 1200°C at a distance of about 0,7 cm behind the pick. If the speed were increased to 4,5 metres per second, however, the pick would have travelled a proportionately longer distance before the hot spot cooled to 1200°C or less, this length being approximately 1,6 cm. The length of the hot spot at or above a temperature that will ignite methane therefore increases as the speed of the pick is increased. The area of the hot spot, which has a marked effect upon ignitions, will also be greater, since the width is a constant.

Powell and Billinge (1975) and Larson et al (1983) concluded that the probability of igniting methane with sharp picks increases with speed. Larson et al noted that the ignition potential of worn picks was greater when the speed of cutting increased. The

difference in the ignition potential between the speed increments was not, however, as great with worn picks as it was with sharp picks.

Larson et al in tests on worn picks that had been pre-heated, found that the probability of ignition was reduced when the speed of cutting was increased which was the opposite effect to that found for cool picks. The authors thought that this was probably due to air-cooling of the machine tool.

It can be concluded that, when picks are not pre-heated, the effect of increasing the speed is to produce a greater length, and therefore area of hot spot on the rock. This in turn leads to an increased probability of ignition. For pre-heated machine tools, the opposite effect can be expected. The picks become less incandive as the speed is increased which may be due to air cooling.

(h) Rate of Advance

Blickensderfer et al (1975) noted that the advance rate of a pick into rock had little or no effect upon the ignition potential. Larson et al (1983) concluded that as the advance rate during a cutting sequence increased, the number of cuts to ignition decreased. When the advance per cut was plotted against the cut depth, however, it was found that the depth of cut at ignition was the same for all advance rates.

The implications are that the rate of advance of a machine tool into rock has no direct influence on the probability of ignition. It is suggested that the governing factor is the depth of the cut rather than the rate of advance.

(i) Depth of Cut

Several authors have paid attention to the depth of cut, but only Powell et al (1975) and Larson et al (1983) have carried out experiments to evaluate the effects of this parameter. They noted that, as the depth of cut increases, so do the forces and rate of heating of the rock and tool. Both these factors can increase the probability of ignition.

The literature suggests that the depth of cut has a great effect upon the ignition potential of machine cutting picks. The implications are that this parameter has an obvious and central role in ignitions. As indicated later, depth of cut is interrelated with cutting forces.

(j) Cutting Forces

Powell and Billinge (1975) concluded that there is no direct relationship between the probability of ignition and the cutting forces. It was found that ignitions were not associated with the sudden force of an impact. These authors appear to regard the depth of cut, rather than the cutting forces, as the controlling parameter in ignitions.

There is an obvious interrelationship between the depth of cut and the cutting forces. In order to cut deeper, larger forces are required both in the direction of cutting and normal to the pick. Although the literature emphasizes the depth of cut, from a mechanistic point of view, the cutting forces, particularly the normal force, appear to be more important. With increasing normal force, the friction between tool and rock increases. Authors consider that this friction causes the hot spot to form on hard rocks and is responsible for the self-heating of pyrite. It seems logical to assume, therefore, that the cutting forces, rather than the depth of cut as implied in the literature, is the major factor affecting ignitions. The effect on ignitions of a

reduction in the back-clearance angle of picks is also probably due to an increase in normal forces.

(k) The Effect of Water

Cooling of a point attack pick is more difficult than for a flat cutter pick owing to the loose fit of the former and the need to provide a water jet external to the body of the pick. A water pressure of about 15 MPa and a flow of 4 l/minute per pick can be necessary to ensure good extinguishing effects with a point attack pick. However, a channel can be provided in the body of a flat cutter pick to cool it and to direct the water flow onto any stream of incandescent particles. A flow pressure of only 600 to 800 MPa can achieve this with such a pick.

Powell et al (1975) and Powell and Billinge (1975) noted that water could be effective in reducing ignitions, but that the direction of application is important. Water can be used best when directed onto the freshly cut rock behind the pick, parallel to the instantaneous cutting direction. If supplied normal to the rock behind the pick, ignitions would be decreased but not as effectively. When water was directed in front of the pick, which is equivalent to pick flushing, no noticeable reduction in ignition potential was apparent. Sprays rather than jets were found to be the most effective form of applying the water.

Wilson (1984) described ignition tests carried out by the USBM on a modified coalcutting pick for use on longwall shearers that allowed water to flow through a channel in the tool. The water was directed to a point where the pick struck the rock or coal, that is, immediately behind the cutting tip. With the correct water pressure it was possible to suppress ignitions completely even in the most adverse circumstances.

It is evident that the application of water can reduce or even eliminate ignitions of methane-air mixtures. The most effective

way in which water can be used is in a spray directed onto the rock immediately behind the pick. The implication is, therefore, that the water must be directed onto the hot spot as it is formed which has the effect of either cooling the hot spot to below the ignition temperature of methane-air mixtures or of preventing the formation of the hot spot.

2.4.9 Friction between Metal and Metal

There have been a number of experiments conducted by various investigators to simulate some of the conditions that occur in coal mines under regimes of frictional ignition. A summary of the results noted by Desy et al (1975) and Kravchenko et al (1976) is given in Table 10. Frictional ignition can be considered in relation to the method of contact. This is divided into three groups, namely, single impact, rubbing and intermittent impact.

The energy involved in frictional ignition is more than two orders of magnitude greater than the minimum required to ignite a methane/air mixture.

The conditions under which methane/air mixtures can be ignited have been studied by a number of investigators.

For a small platinum sphere moving at a velocity of 4 m/s, a temperature of about 1 200°C was necessary to secure ignition at an 8 percent methane/air mixture (Silver, 1937).

An alumina surface of 400 mm² in area was placed in the wall of an explosion chamber and required heating to over 1 100°C in order to ignite a 7 percent methane/air mixture, and this temperature increased to 1 600°C when the area was reduced to 6.25 mm² (Rae et al, 1964).

Table 10 Frictional ignition of methane/air mixtures (Kravchenko et al, 1976)

Type of Contact	Experiment	Comments
Single impact	Steel on steel	Probability of ignition directly proportional to impact energy Maximum ignition at angle 50°
	Steel on Al alloys	
	Steel on Mg alloys	
Rubbing	Al and Mg alloys on rusty steel at relative velocities of 2-3 m/s	Incendivity of sparking increases up to a sliding velocity of 100 m/s
Intermittent	Combination of above	Surface of bodies in contact greatly heated impact and may occur over large area

(a) Friction involving Heavy Metals

Methane can be ignited by rubbing steel on steel but ignitions are not readily obtained and then only at high loads and with considerable lags in ignition. Recent experiments at S.M.R.E. showed that a 25 mm square mild steel bar pressed against a mild steel wheel with a peripheral speed of about 4,57⁰ metres/second gave ignitions at loads down to about 250 kgs and with times to ignition of about 100 seconds; by the time ignition occurred the bar was red hot and white hot flakes of steel were being torn from it. Experiments with severe impact between really hard steels have produced ignitions of methane-air with much less total energy dissipation; nonetheless steel on steel is one of the least incendive combinations met with in coal mining.

(b) Frictional Ignitions of the Second Class (those involving light metals)

It so happens that all the metals which combine exceptional lightness and strength have a high heat of oxidation and, in a

finely divided state, burn furiously. Furthermore, if the metal is in intimate contact with an oxide, for example, rust, combustion is readily initiated; this is the well-known thermite-type reaction. The smears of aluminium, for example, left on a rusted steel surface after an aluminium bar has rubbed against it can easily be provoked into giving off brilliantly incandescent sources that ignite gas instantly; all that is required is a light glancing blow from a hammer weighing a few grams.

By alloying them with other metals, their incendivity can be reduced but, unfortunately, not to an acceptable level until the resulting alloy is no longer light. So far no one has found an effective way of overcoming this disadvantage.

(c) Results of Research by Kelly and Forkner

Kelly and Forkner conducted laboratory tests with a single impact mode with cobalt bonded tungsten carbide, type A-36 steel, C4130 steel and aluminium against A-36 steel. Tangential velocities of 4.57 and 5.59 metres per second were used in two types of explosive atmospheres. No ignitions resulted in atmospheres of either air and methane or flowing acetylene. The following results are recorded:

Cobalt-bonded tungsten carbide. Commercial coalcutter pick tips were impacted against A-36 steel with no resulting ignitions. No sparks or hot smears were observed.

A-36 steel and C4130 steel. No hot smears were observed, but some dull sparks were produced.

Aluminium. Impact specimens of aluminium were struck against both clean and rusty A-36 steel, and also against a steel plate with a heavy rust layer. A few very small sparks were observed, but no evidence of a thermite reaction was noted. Apparently the

tangential velocity was too low to cause initiation of a thermite reaction.

(d) Experiments on Metal on Metal

Coward and Ramsay (1965) stated that ignition of firedamp by the frictional effects of metal rubbing on metal has been most difficult to obtain experimentally except when the abraded particles produce much extra heat by their own oxidation, as occurs with the sparks from a "lighter". The difficulty in general is probably mainly because the thermal conductivity of a metal is greater than that of a rock but in some cases oxidation of metal may make ignition more difficult by reducing the oxygen content of the contiguous atmosphere.

(e) Sparks from a Cigarette "Lighter" or Flanelamp Relighter

The Miners' Lamp Committee, in discussing the proposed use of a pyrophoric cerium-iron alloy in a relighter for flame lamps, wrote that they would "need to be assured by exhaustive experiments of the unreality of the danger that is presumed to be created by the presence within the lamp of unconsumed particles of cerium alloy before we could recommend the adoption of the 'pyrophor' igniter".

Quantitative information about the incendivity of particles from authorised relighter alloys has been given by Rae (1956). Such particles ignite spontaneously when heated in air to about 180-200°C, a temperature commonly reached by the gauzes of a flame safety lamp.

Particles of the pyrophor alloy which are much larger than those that are ignited by the action of a relighter may break away without being ignited, and may be large enough to inflame methane

when they are ignited by the gauze, yet small enough to pass through the gauze of a lamp. The methane-air mixture most easily ignitable by this means was close to the lower limit of inflammability of methane (5.3 percent).

(f) Friction of Steel on Steel

Burgess and Wheeler (1929) caused a 400 mm diameter steel locomotive wheel to revolve in contact with a steel girder. With a load of 1 ton and a wheel speed of 1120 r.p.m., with frequent sanding which produced brilliant sparks, an 8.1 percent methane-air mixture was not ignited during a trial lasting 20 minutes. When a shield was used to concentrate the sparks, several ignitions were obtained with the same wheel speed and half the load; one ignition occurring in 1 1/2 minutes, before the rail had become red hot and much before the rail was hot enough in itself to ignite firedamp. Supplementary tests with a different apparatus failed to give any ignition under various conditions, including the use of various steels that gave various types of sparks. Later experiments (Safety in Mines Research Board, Annual Reports, 1942, 1943), gave ignitions of firedamp-air with a high-carbon steel wheel revolving with a peripheral speed of 9.2 metres per second and cutting into mild steel; "this speed is much higher than any reached by coalcutter picks in ordinary use, but highspeed cinephotographs showed that a hand pick may reach this speed before striking. A wheel of a run-away tub may skid along the rail at a higher speed still".

Schultze-Rhonhof and Weichsel (1951) obtained ignition of firedamp by pressing spring steel against a steel disk revolving with a peripheral speed of about 60 m/sec (18 000 ft/min). Schultze-Rhonhof (1956) quoted experiments by Vereinigten Leichtmetallwerken, in which a piece of very hard steel falling onto a plate of hard steel gave ignitions when the impact energy was 40 kilogramme-metres, which is equal to 392 joules, and also quoted similar experiments at the Technische Hochschule in

struck a steel roof girder. The casing of the drill was an alloy containing about 94 percent of magnesium; and ignitions of firedamp were readily obtained by dropping a piece of the alloy onto a rusty steel plate, under a variety of conditions representative of pit usage. The second investigation (Titman, 1954) extended the work to the whole range of magnesium-aluminium alloys and showed that the danger of ignition decreased with a decreased proportion of magnesium but was not altogether eliminated if pure cast aluminium was used. Incidentally, the most easily ignited mixture of methane and air contained 6.4 percent of methane, an observation supporting the general experience that mixtures a little above the lower limit of inflammability are the most easily ignited by friction sparks. Titman and Wynn (1954) showed that the sparks produced by the impact of steel or zinc on rusty steel were much less incendive than the sparks from light alloys on rusty steel. They also quoted experiments by Bowden and Lewis (1958) on the minimum weights of ignited single particles required to ignite firedamp which indicated the following order of decreasing incendivity: magnesium and aluminium, titanium, zirconium, "pyrophor" (cerium alloy) cerium, thorium. Rae (1959) also found that the minimum weight for titanium was between those for magnesium and pyrophor found earlier (Rae, 1956). However, the order of incendivity given by these experiments is not a measure of the hazard of ignition by abrasive friction, "for the brittleness and the mechanical properties of the solids are of primary importance since this determines whether particles will be detached or not and influences their size" (Bowden and Lewis, 1958).

Experimental support was found by Rae (1959, 1960) for the hypothesis that, briefly, the friction between light alloy and rusty steel initiates a thermite-like reaction which sets fire to particles of the smeared metal that are projected into, burn in and inflame, the neighbouring gas.

Smears of light alloy on rusty steel can be produced by impact or friction insufficiently vigorous to produce ignition at the time

2.5 NUMBER AND DATES OF INCIDENTS

The recorded incidents of ignitions of methane by frictional heat and sparking in South Africa are set out below:

- (a) Consolidated Collieries Limited. May 1947. Two methane explosions in stooping section possibly from an incendiary spark. 1 killed, 1 injured.
- (b) Schoongezicht Colliery. 1956. Ignition of methane due to faulty fan (frictional ignition). 19 killed.
- (c) Durban Navigation Collieries Limited. September 1968. Ignition of methane in cut. No casualties.
- (d) Durban Navigation Collieries Limited. April 1975. Methane ignition due to friction between drill steel and sandstone. No casualties.
- (e) Usutu Koolwyne Bepark. October 1977. Ignition of methane while cutting with coalcutter. Nil casualties.
- (f) Usutu Koolwyne Bepark. February 1980. Explosion of methane in continuous miner section. 1 injured.
- (g) Ermelo Mines. November 1980. Methane exploded at a continuous miner. 1 injured.
- (h) Ermelo Mines. January 1981. Methane ignition in continuous miner section. 2 injured.
- (i) Ermelo Mines. April 1981. Methane ignition due to continuous miner picks causing spark. 2 injured.

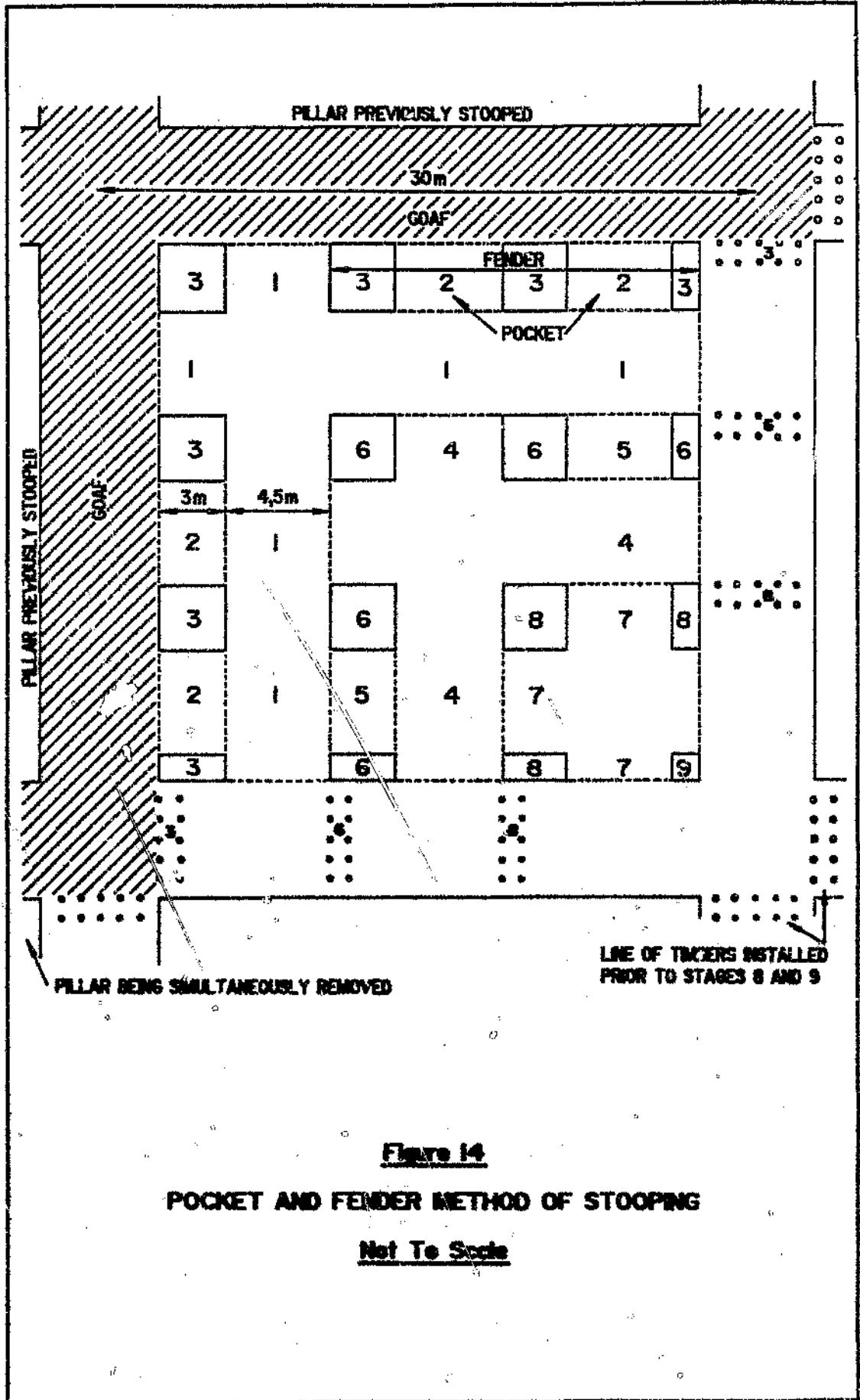


Figure 14

POCKET AND FENDER METHOD OF STOPPING

Not To Scale

Geology

Figure 16 depicts the geological formation in the vicinity of section B302. The immediate roof of the seam consists of a competent medium grained quartzitic sand-tone which tends to fracture in large blocks some blocks measuring 1 to 2 metres in thickness and 6 to 8 metres wide and 10 metres in length. The roof does not 'goaf' easily but 'hangs up' forming a cantilever type beam over the goaf line thereby placing high abutment loads on the fenders.

The Incident

The Section Manager reported as follows:

On 28 February 1981 it was reported that a methane explosion had occurred in Section B302, Vlei shaft, at about 07h20 on that day. I subsequently established that the seven Blacks were reportably injured in the accident. Eighteen other workers sustained superficial injuries.

On 2 and 3 March 1981, accompanied by the Inspector of Mines I visited the scene of the accident and noted details which have been embodied on a detailed 1:500 scale, Figure 17, and 1:5000 regional plan, Figure 18.

Section B302 is a 7 road section which is being stooped on the middle 5 roads using the pocket and fender method. The pillar centres are 25 m with a bord width of 5,5 m. The working face is on a 45° line retreating back to the main development.

Stuttgart giving ignitions with an impact energy of 200 kilogramme-metres. Recently Schulz and Dittmar (1963) have obtained ignitions of methane-air mixtures by impact of hard steel on a hard steel plate with impact energies as low as 25 kilogramme-metres. The type and speed of impact is a very important factor.

(g) Aluminium-painted Rusty Iron

Following a report received by S.M.R.B. from H.M. Factory Inspectorate, of violent flashes, more like minute explosions than sparks, observed when aluminium-painted rusty iron was lightly struck by a tool, Thomas (1941) showed that firedamp could readily be ignited by such means. The sparks were ascribed to a thermite-like reaction between oxide of iron and aluminium and were obtained from various aluminium paints provided the painted surface had at some time previously been heated to some 200°C to 300°C. Kingman and others (1952) extended the observations and Grice (1952) summarised the details as follows:

"The available experimental evidence from all sources endorses the opinion that aluminium and iron oxide in intimate contact, when raised in temperature by a sharp blow, may give sparks or flashes that will readily ignite certain inflammable gas or vapour-air mixtures."

Aluminium paint on rusty steel would seem to provide the condition for producing incensive sparks; but in practice most commercial paints contain a bonding medium which, when new, interposes a barrier between the two reacting substances and so lessens the hazard. The experiments of Thomas (1941) and of Kingman et al (1952) prove that, in many instances, pre-heating may cause a deterioration in the paint film which usually increases the potential hazard considerably. It may be urged that, if pre-heating has this effect, other factors, including normal ageing, which are known to cause visible deterioration in

paint films may also enhance the conditions for the production of incendive sparks. In any event the pre-heating temperatures are such that no steel structure painted with aluminium paint would be immune from the risk of being raised to such temperatures if introduced into a coal mine.

The main criticism that must be levelled at all the experimental work so far published is the lack of quantitative assessment of the hazard and the determination of the energy dissipated at the moment of contact. In this latter connection it must be pointed out that in all the experiments discussed the energy used was of a relatively low order.

The suggestion has been made that the experimental evidence does not indicate a great hazard attached to the use of aluminium. This is surely the wrong approach. It is known that under certain conditions, much more severe than those described in the papers mentioned but well within the range of frequent occurrence in a mine, friction between steel surfaces will produce incendive sparks. Typical of such occurrences are the full swing of a pick accidentally hitting a prop or girder, the collision of a loaded tub with an arch on a roadway, or the grinding impact of moving machinery. What has now been established is that the presence of aluminium paint greatly increases this risk, for apart from all other considerations, the energy dissipated in the impacts likely to occur in a mine would itself be sufficient to pre-heat the paint well above the temperatures used experimentally.

(a) Sparking from Light Metals and their Alloys

Much of the heavy work of coal mining would be eased by the use of light metals, for example, in props and bars and arches for roof supports. Research has been necessary to assess the incendivity of sparks due to friction and impact with such materials.

Firedamp was ignited when a piece of an alloy, part of a fan-blade of an electrical drill, was held against a hard steel wheel rotating at a high speed. The alloy was at first said to be "aluminium" (S.M.R.B. Annual Report, 1943), but later this description was corrected to "magnesium" (Margerson et al, 1953).

Aluminium friction plates of steel props were discovered in Holland to be capable of giving incendive sparks under certain conditions, when the props were either under load or being released from load (Schultze-Rhonhof and Weichsel, 1951). The danger, they concluded, would be reduced, if not eliminated, by using an aluminium-copper-magnesium alloy, with as little silicon content as possible, and by improving the design of the props; moreover, props made of the same alloy did not give sparks when rubbed against the steel clamp of the props. A subsequent paper by Schultze-Rhonhof (1956) discussed several ignitions underground and described experimental work on the subject; it concluded with the statement (translated): "Given the right choice and composition of the aluminium alloys and the correct designing of props and bars of this material, the inherent risks of firedamp ignition from aluminium sparking can be kept within such limits that the continued use of support components in aluminium, having regard to their other advantages, appears reasonable". Brenner and Eversheim (1958) collected the results of tests made in several German laboratories and concluded that, of the practically useful alloys, certain alloys of aluminium-magnesium-silicon and aluminium-zinc-magnesium presented the least danger, particularly if they contained traces of beryllium; but they concluded with a cautionary note about the applicability of laboratory tests to all the various conditions of a mine.

S.M.R.B. has made a series of detailed investigations, inaugurated by Wynn (1952), on the incendivity of "sparking" by light alloys. The first (Margerson et al, 1953) arose from an ignition of firedamp in a Cannock Chase colliery, observed when an electric drill (not powered at the time) fell, and probably

and such smears can give rise to incendive flashes if subsequently struck by a light glancing blow with a light object. For example, a hammer blow on the steel wedge of an aluminium linked bar roof support system can produce sparking; a light hammer moving at only about 3 metres per second can strike sparks from rusty steel smeared with aluminium and this can ignite methane. Also, ignitions can occur from the flash produced when aluminium foil wrappings of the type used for confectionery and generally known as "silver paper" resting on rusty steel are struck a light glancing blow (Stephenson, 1962). The author has witnessed these experiments at the S.M.R.E. at Buxton, and confirms the 'explosions' produced by striking foil a glancing blow with a steel hammer.

The function of the rust, which makes incendive sparking so easy on the impact of light alloys with steel, is generally accepted as the provision of oxygen for a thermite-like reaction. An incidental observation, for which no explanation was offered, was made by Weichsel (1955): he found that a small amount of moisture was necessary for the production of incendive sparks in a dropping-weight apparatus like that of Titman (1954).

So far, light metal alloys that are incapable of giving incendive sparks have proved to be unsuitable in their mechanical properties for use as materials for most mining equipment. A paper by Rae and Nield (1960) concluded that "the most desirable properties of these (experimental) alloys from an engineering point of view, hardness and ductility, are those properties which together give the greatest incendivity for a given aluminium content". Also "in general terms all aluminium-based alloys must be considered capable of giving incendive sparking". Only when the aluminium content has been reduced to one atom in three can the ignition hazard be regarded as reduced to a tolerable level, but such alloys no longer possess the advantage of lightness.

- (j) Balgray Colliery. May 1981. Ignition of methane while cutting - picks came into contact with dyke. Nil casualties.
- (k) Balgray Colliery. July 1981. Ignition of methane while cutting. Nil casualties.
- (l) Bosjespruit Colliery. March 1982. Explosion of methane in continuous miner section. 6 injured.
- (m) Springfield Colliery. May 1982. Ignition of methane while cutting face. continuous miner. 1 injured.
- (n) Ermelo Mines. November 1982. Methane explosion - possible cause frictional sparking. 11 killed.
- (o) Springfield Colliery. August 1983. Ignition of methane in continuous miner section. 1 injured.
- (p) Springfield Colliery. November 1983. Methane ignition while cutting a face. 2 injured.
- (q) Springfield Colliery. February 1985. Methane explosion in goaf due to frictional sparking. 2 killed, 11 injured.
- (r) Springfield Colliery. June 1985. Ignition of methane in goaf. Nil casualties.

2.6 DETAILS OF INCIDENTS/PHENOMENON

From all the known incidents recorded in South Africa, 4 incidents have been chosen to illustrate the phenomenon.

2.6.1 Springfield Colliery. February 1981. Ignition of Methane in Goaf

On the 28th February 1981 (a Saturday) at 07h20 two methane explosions occurred in section B302 killing two men and injuring a further 11. The section was a 7-road pillar extraction section employing the pocket and fender method of extraction and utilising conventional cyclic coal mining and loading equipment (loaders, shuttlecars and coalcutters with handheld electric drills). The goaf line was kept at 45° to the main axis of the section.

Pocket and Fender Method of Pillar Extraction Figure 14 refers.

In this method of extraction the goaf edge support consists of a thin pillar of coal equal in width to the height of the workings. This is referred to as the fender.

At each lift holes, the fender is then cut through in appropriate places into the goaf; these holings are referred to as pockets. The small pillars left in the fender are known as snooks.

Reference to Figure 15 will show the sequence in which pillars are removed.

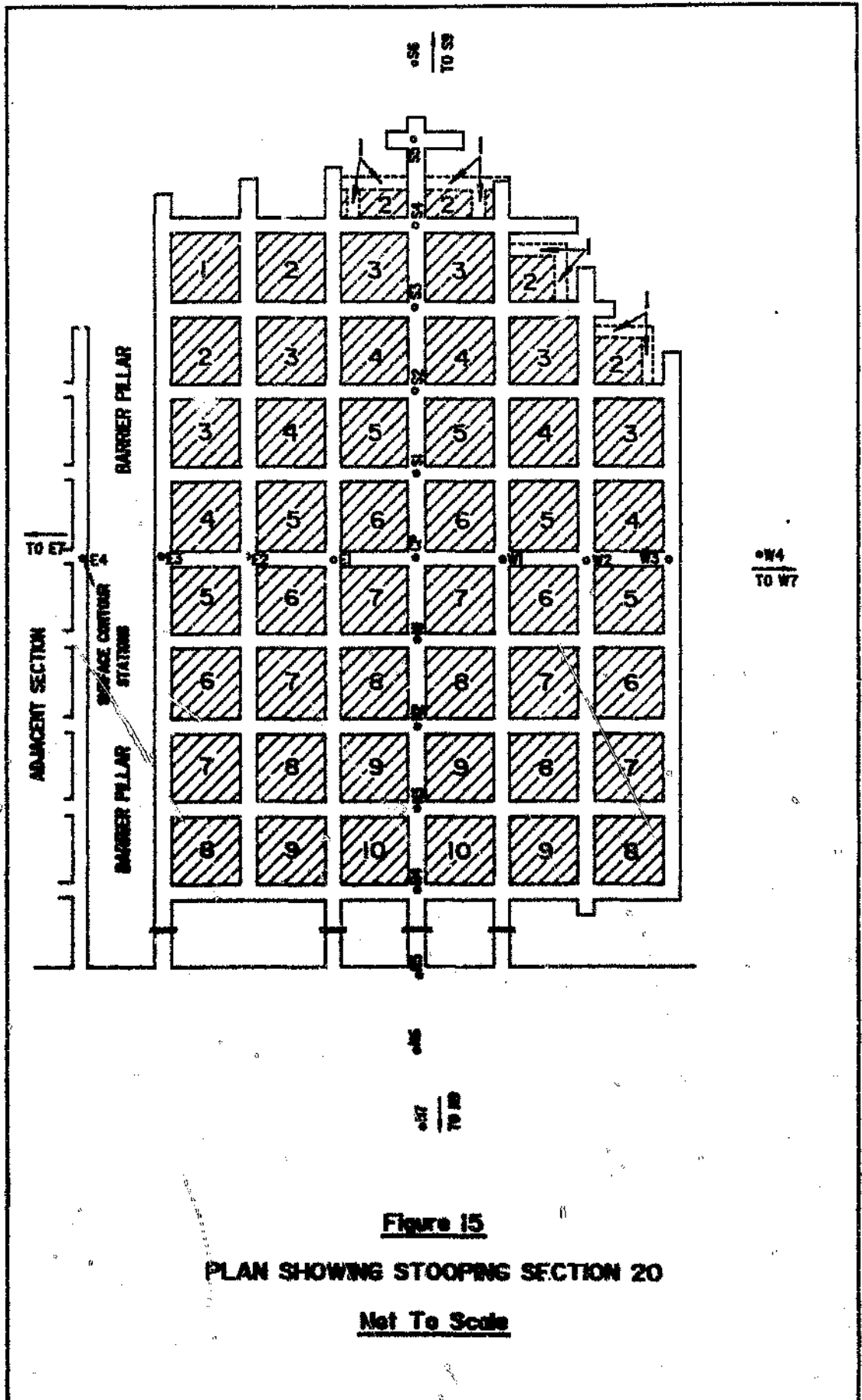


Figure 15

PLAN SHOWING STOPPING SECTION 20

Not To Scale

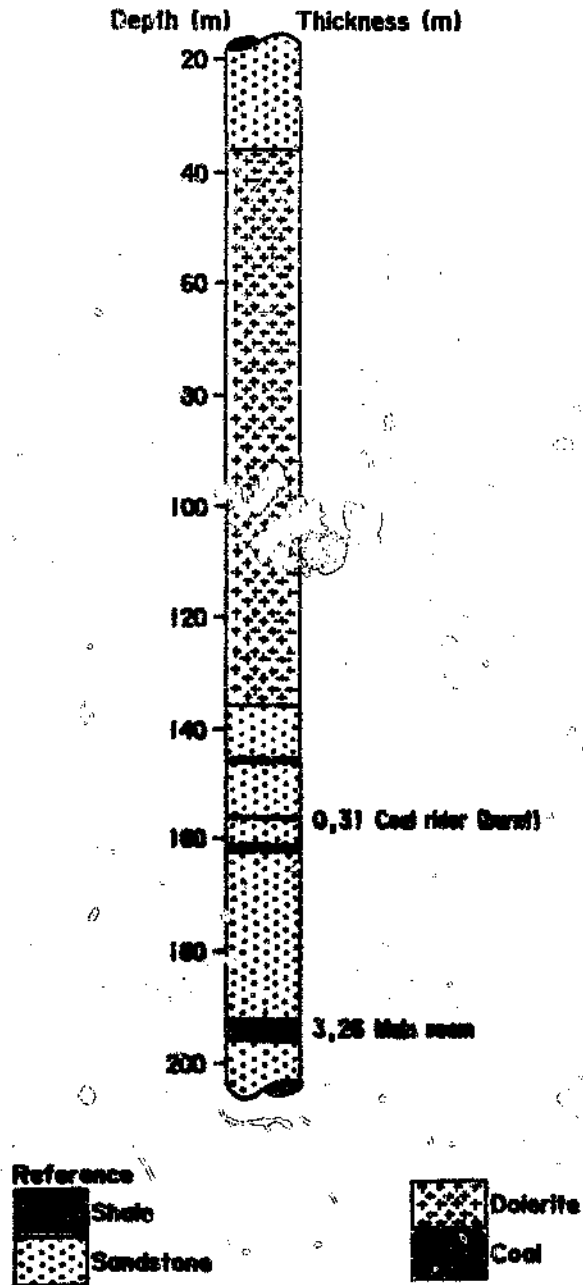


Figure 16

STRATIGRAPHIC SUCCESSION OF SPRINGFIELD COLLIERY COALFIELD

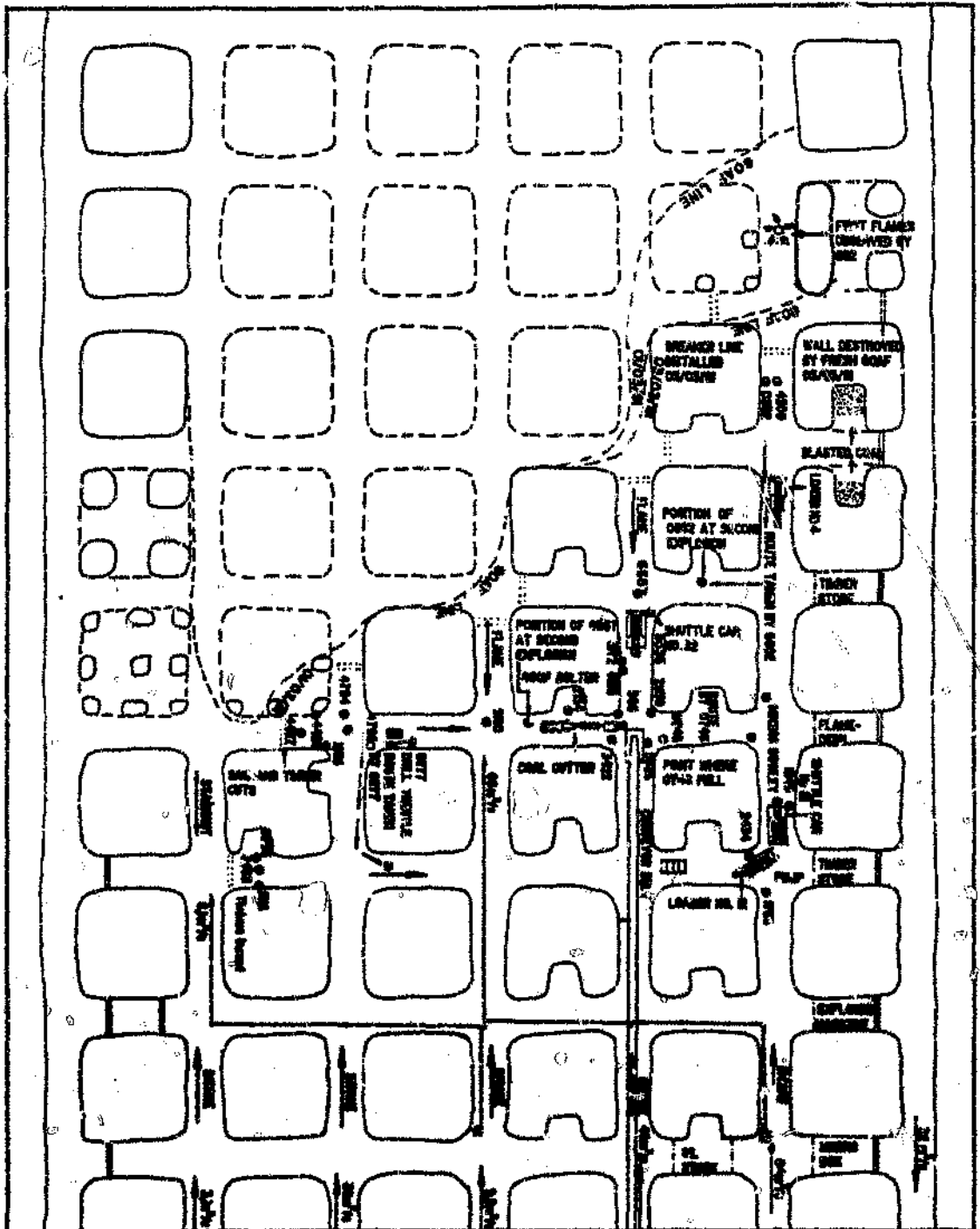


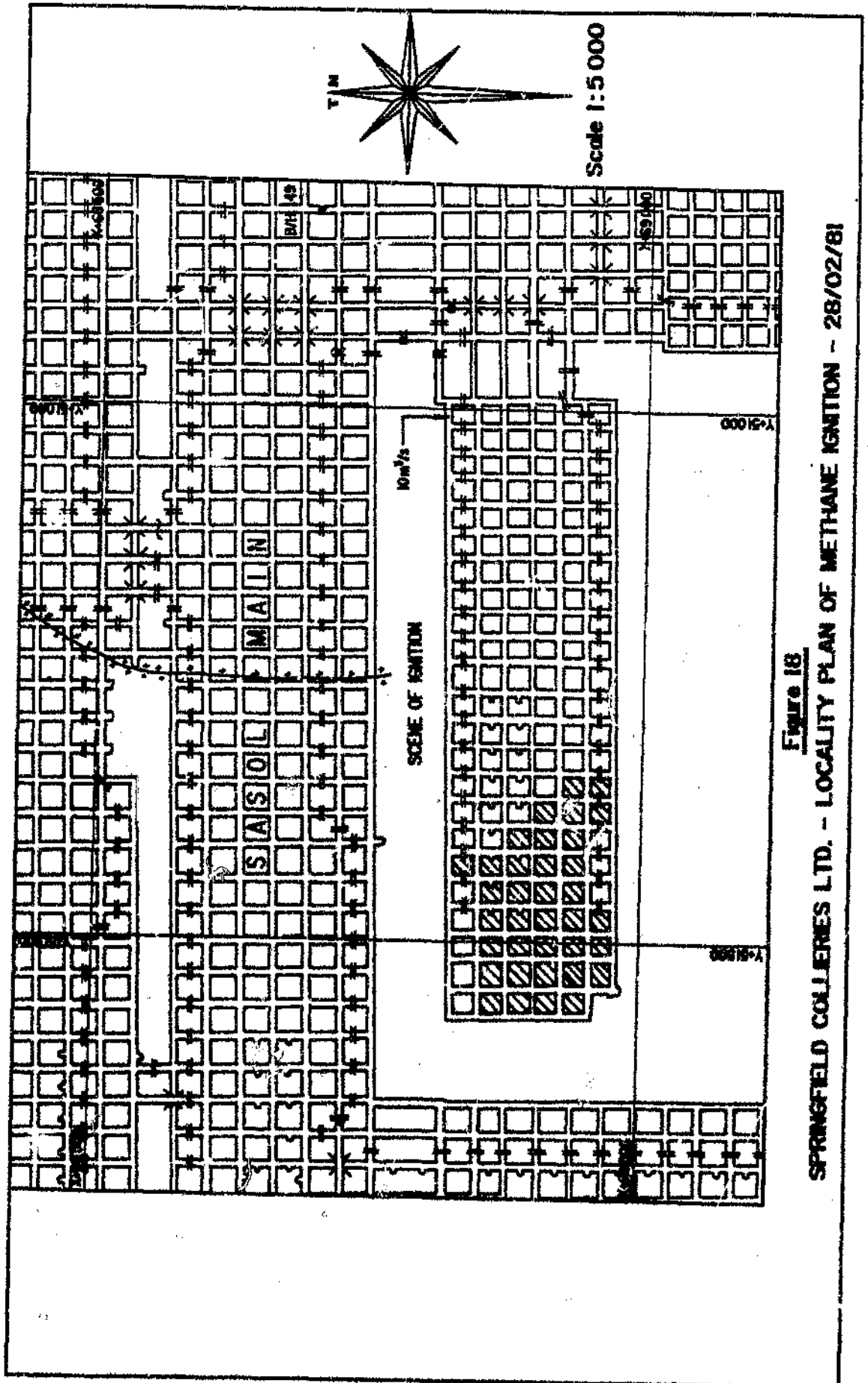
Figure 17

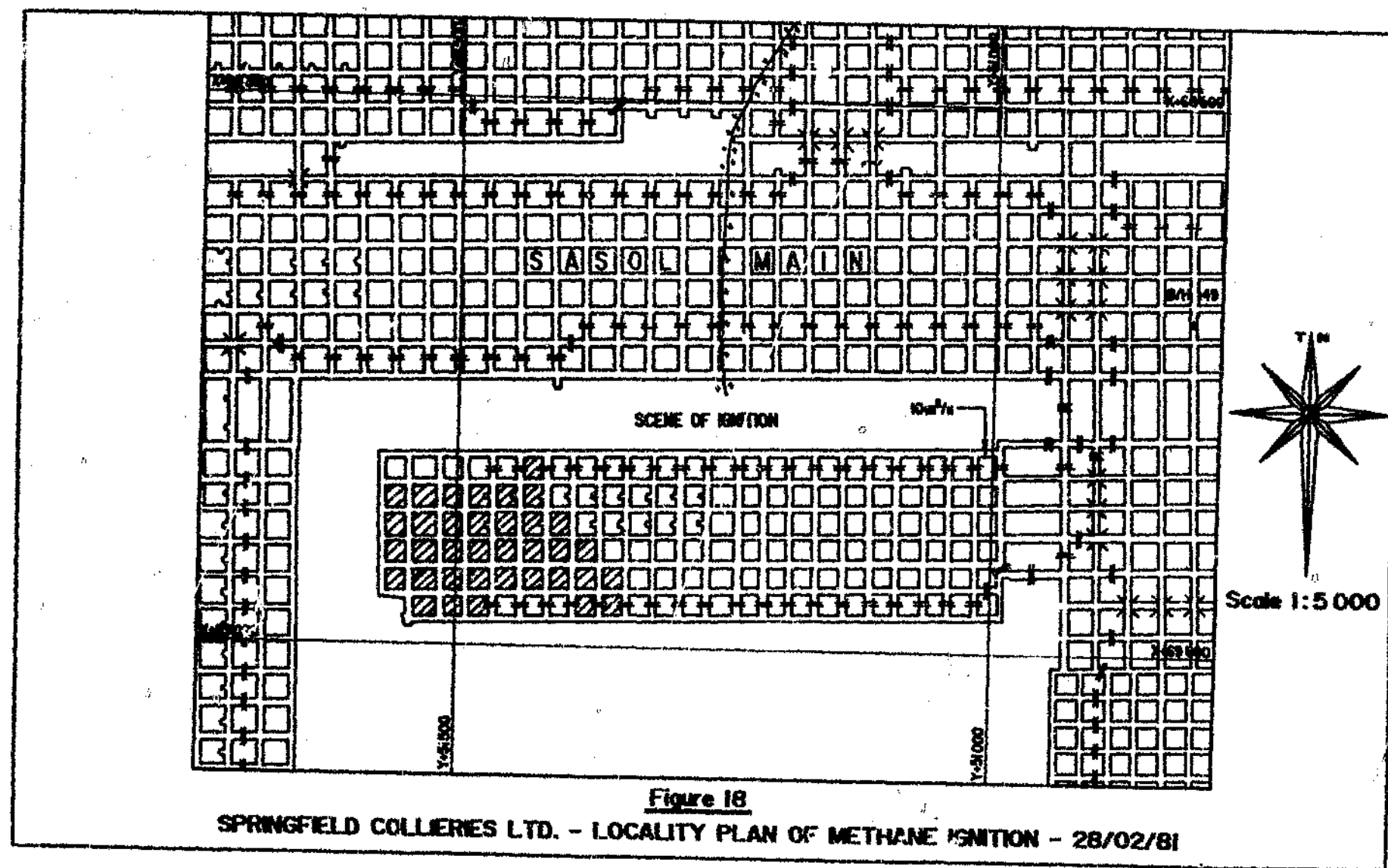
SPRINGFIELD COLLIERIES LTD.

PLAN SHOWING SCENE OF METHANE IGNITION

IN SECTION B302 VLEI SHAFT ON 28/02/81 AT 07:20.

Not to scale





The section is ventilated by the main body of air which is drawn through the intake roads numbered 2 to 6 and returned via No. 7 road. The air in No. 1 road is stagnant.

Auxiliary fans are installed for providing air along the face line and particularly for ventilating the development during the initial cutting through of pillars, but also for any other area where ventilation is required.

The average production in Section B302 amounts to 400 tons/shift which would require a volume of $10 \text{ m}^3/\text{sec}$ of air in order to comply with the requirements of the regulations.

The latest ventilation survey which was carried out in Section B302 on 17 February 1981 indicated that the face area was ventilated by means of two fans situated in No. 4 and 6 roads and the total intake volume was $20 \text{ m}^3/\text{sec}$.

A further, more detailed ventilation survey carried out after this accident on 2 March 1981 indicated that there were no auxiliary fans in Section B302 and that the respective volumes of air flowing through the individual roadways were zero in roadways 1 and 2 and gradually increasing to $13,5 \text{ m}^3/\text{sec}$ in roadway No. 6 with a total volume of $21,4 \text{ m}^3/\text{sec}$ returning through roadway No. 7 (arrows thus on plan 17).

I have no knowledge of the removal of the auxiliary fans in Section B302. I visited this section on 25 February 1981 and can recall seeing the fan in roadway No. 4, but did not notice whether the fan in roadway No. 6 was there or not. The flow of ventilation through the section, however, appeared to be in order.

From observations made at the scene of the accident it appeared that timbers and other combustible objects had been exposed to varying degrees of heat in the area parallel to the goaf line between roadways 2 and 5 and between splits C and E.

The heat appeared to be most intense at a point in the vicinity of roadway 2, split C, and diminished in a northerly direction. This was also substantiated by the severity of burns of the persons employed in this area.

A detailed inspection of the area, however, did not reveal the cause of the ignition.

To my knowledge no methane has ever been detected in this section.

It is quite possible for methane to be released when goafing takes place and for the methane to be present in the goaf area without its presence being detected by normal, routine methane tests.

After rescue operations had been completed and on arrival of the mine proto team, gas samples were taken at regular intervals at the regulator in the return airway. These samples indicated initial concentrations of 3% CH₄ and 500 PPM of CO respectively at 11h56. These concentrations gradually diminished until 15h45 when the air was clear (see Table 1).

Table 1 Gas Readings at Regulator. 28th February 1981.

Time	CH ₄ %	CO PPM
11h56	3%	500
12h32	2.5%	60
13h08	Nil	60
13h43	Nil	30
14h10	Nil	20
14h43	Nil	10-15
15h14	Nil	10
15h45	Nil	5

In order to prevent a similar occurrence Section B302 has been temporarily stopped and the volume of air to the section has been increased to $32 \text{ m}^3/\text{sec}$ in an effort to clear any methane which may still be present in the goaf area. All tests for methane since 3 March 1981 have, however, been negative. Endeavours are also being made in future planning to provide bleeder roads adjacent to stooping sections so that the return air will flow directly from the goaf area into the return airway in a direction away from the working area.

It would be possible to ventilate the face of Section B302 without the use of auxiliary fans, but then a line of brattices would have to be installed roughly parallel to the face in order to course the air towards roadway No. 1 and thus sweep the face.

I did not authorise the removal of either of the fans in Section B302.

I did not notice any brattices in Section B302 after this accident.

Without the use of auxiliary fans or brattices the ventilation would tend to be more concentrated towards the return airway at roadway No. 7 and the left hand roadways in the panel would be starved of air. This is, in fact, what happened as can be seen from the ventilation survey conducted on 3 March 1981, the readings of which are indicated by arrows thus .

During the investigation of the accident I questioned all the available witnesses, and as far as I could ascertain no electrical machinery was being used and no blasting had taken place at the time of the accident.

The explosives used in this section comprise 200 gm Ajax (200 mm x 29 mm) cartridges and electric detonators varying from instantaneous to No. 5 millisecond delays.

The Chief Engineer of the colliery inspected the section after the explosion to examine all electrical appliances with the objective of ascertaining whether the explosion had been initiated by an electrical flash. After the examination his evidence was that:

"After I had been informed of this accident I visited Section B302 for the purpose of determining whether there were any defects to the electrical equipment in the section and whether any of the equipment could have been the cause of a methane ignition. I conducted these inspections on 1 and 2 March 1981 and again on 3 March 1981 in the presence of the Inspector of Machinery.

My inspections covered all the electrical equipment and the cables feeding them including the flamedeen banks, 2 shuttlecars, 2 loaders, a coalcutter, a rockbolt machine, a pump and an electric drill.

I made a thorough search of the flameproof boxes of the equipment for signs of flashing, but all the equipment and cables were in order and no signs of flashing were evident.

The electric drill, the cable serving it and a faulty cable serving one of the shuttlecars were removed for a more detailed examination on surface but this too did not reveal any signs of flashing or any other defects which could have caused a methane ignition. The shuttlecar cable was not connected at the time of the accident."

Based on the Engineer's evidence it is possible to rule out an electric flash as the initiator of the explosion.

Central to the investigation at this stage was the ventilation of the section, the position of two auxiliary fans prior to the explosion on the 16th February 1981 and the air quantities in the section.

Two weeks prior to the accident, the mine Ventilation Officer reported that 20 m³/sec was intaking into the section with 19 m³/sec in the return airway. Two fans shown on the plan Figure 17 were delivering 5.1 m³/sec to roadway No. 2 and 4.5 m³/sec to roadway No. 4. Each fan delivered air through a flexible ducting and an air curtain (as shown on Figure 17) to prevent recirculation of air. No recirculation was taking place according to his tests. A methanometer was used to test for methane and the goaf line and return airway (No. 7 road) were found to be free of gas.

Another interesting aspect of the ventilation was that no brattice cloth had been erected in the intake roadways to course or divert the intake ventilation to the left hand side of the section (No. 1 road) and then along the goaf line to the return airway in No. 7 road. The responsible Official relied on the two auxiliary fans to ventilate the goaf line.

On the 16th February 1981 the Mine Overseer gave instructions for the fan in No. 6 road to be removed to another section "because there was an adequate volume of air flowing along that part of the section and it (the fan) was not serving any purpose". Several days later the fan in No. 4 road was also removed to another section without the Mine Overseer's approval; neither of these acts were recorded in the Shiftbosses' log book thereby endorsing these changes. Subsequent to the removal of the fans the Mine Overseer reported that:

"I checked the flow of ventilation in that part of the section after the fan had been removed and found it adequate. The miner confirmed that blasting fumes were being effectively cleared."

The mine's standard procedures dictated that all auxiliary fan installations in sections were to be sited by the Mine Overseer (following an explosion in 1962 caused by an incorrectly sited fan which was recirculating air over the fan motor). The Mine Overseer in evidence after the explosion stated that:

"It is standard procedure to move fans forward as the section advances and I did not personally select the site as there would only be one suitable site where the fan could possibly be moved to and that is the position where the fan would automatically be installed."

Both fans were installed in this section in January 1981. Apart from the fact that a fan was required in another section, the Shiftboss had established that the fan in No. 4 road was not necessary. He stated that:

"On 2 January 1981, while I was in Section 302, I noticed that the blasting fumes did not withdraw from the section on the left hand side. I then determined that the fan in No. 4 road was recirculating and after I stopped the fan, found that the blasting fumes were leaving. Because we still required a fan in another section, I decided to move the fan there. I did not obtain permission for this, but it was my intention to inform the Mine Captain the following day and to obtain his approval."

On the 27th January 1981 I did an early shift with the miner and we tested for methane along the face and the breaker line with a flame safety lamp. All the tests were negative. The flame safety lamp was not fitted with a test tube (probe).

I did not think about erecting brattices to prevent the fan from recirculating.

When I arrived at work on February 16 1981, the other Shiftboss mentioned to me that the fan in No. 6 road had been removed because a fan was required for section 30. He also mentioned that this had been done with the approval of the Mine Captain."

There were no other fans available underground to install in the other section."

It is not clear how:

- i. the removal of this fan in No. 4 road improved the ventilation in the section (the blasting fumes dissipated);
- ii. the Shiftboss could have taken such a decision, without thinking of the consequences of having the fan removed.

On the 28th February 1981 at 20h00 (13 hours after the explosion) it was discovered that one of the two main fans on surface had tripped out on overload at the main substation without giving a warning alarm.

The fan in question was equipped with an automatic alarm system which is operated from the same power source which feeds the fan motor with the result that when the current tripped out at the sub station there was no current to set off the alarm system. Since the accident, the alarm system has been improved by installing a back-up alarm system in the sub station, thus if the fan motor should trip out on overheating, for instance, the alarm system at the fan chamber will be activated and should the trip out occur at the sub station the alarm system there will be activated.

The evidence of the Proto Team Captain, who entered Section B302 two hours after the explosion was as follows:

"As we walked into the section in question, I took carbon monoxide samples in the air and found that the carbon monoxide gradually increased. I immediately suspected that there was insufficient air to ventilate the section as the air was dense, yet it was then already 09h30 while I was advised about the explosion at 07h30.

I then took a reading at the regulator in the return airway and determined that a volume of $10 \text{ m}^3/\text{sec}$ flowed through the section. I then increased the air regulator, following which another

reading indicated that the air increased to $16,6 \text{ m}^3/\text{sec}$. I took CH_4 and CO readings at regular intervals, the results of which are indicated on Table 1.

When I first entered the section there was virtually no movement of air. However, after I increased the size of the air regulator, there was noticeable air movement; but I took no air velocity measurements."

It follows from the gas percentages and ventilation volumes measured two weeks before the incident and after the incident that the one main fan could have tripped prior to the explosion, thereby reducing the quantity of air into this section from $20 \text{ m}^3/\text{sec}$ to $10 \text{ m}^3/\text{sec}$.

At 07h30 on the 28th February 1981 a chain of events had led to an explosive methane build up in and at the goaf edge.

Two fans were reinstalled in the section by the 3rd March 1981 and they are shown in position on Figure 17 (together with the air readings at that time).

The Ignition Source

The miner had drilled, topped and blasted the two back to back splits in road F between Nos. 6 and 7 roads and was preparing to blast the snooks between Nos. 5 and 6 roads and splits G and H.

He was standing in split D in No. 6 road. A heavy goaf occurred and after some 5 seconds flames were seen in the goaf area followed by an explosion. He maintains that prior to blasting he had examined the goaf edge and found it to be free of methane.

The Miner's Box Attendant who was delivering explosives to the face of No. 6 road states:

"I was an eye witness to the accident in which several workers were injured in a methane explosion in our section on 28 February 1981.

At the time of the accident I was delivering a box of explosives to the face in the tractor road (no. 6 road). I was about 10 m (indicated) from the breaker line when a heavy fall of roof occurred beyond the breaker line. I looked up in that direction and saw white smoke issuing from below a slab of shale measuring about 0,4 m thick and 4,0 m long (indicated) which had fallen. At first there was only a little bit of smoke but it then increased in volume and after a while I saw flames coming out from under the slab of rock. The flames suddenly grew much larger and reached towards the roof. I then turned around and ran away. As I reached the second split I looked around and noticed that the flames were burning fiercely near the hanging. I ran into the second split and as I rounded the corner a loud explosion took place behind me. I was thrown to the ground by the air blast and as I was getting up a second explosion occurred and immediately afterwards the whole area was enveloped in heavy coal dust and flames which appeared to come from all directions; I was knocked to the ground again after which I crawled towards the tip on all fours. The flames and dust withdrew almost immediately after the second explosion.

After I had initially noticed the smoke under the rock I pointed it out to my co-worker and when the flames started rising I ran away ahead of him. When I ran into the split he was still in the roadway and took the full force of the explosion from the direction of the fire.

I have no idea of what caused the fire under the slab of rock.

I was at the waiting place when the Miner examined the section at the beginning of the shift.

We were preparing to blast the pillars towards the left of the breaker line when the accident happened. No blasting was done at the time. We had blasted the faces further back (in Split E between roads 6 and 7 indicated) earlier during the shift."

This evidence is corroborated by three other witnesses who say that they saw smoke (white, black, grey and green in colour) issuing from between large sandstone slabs which were sliding on top of each other. The possibility that these four witnesses concocted a story to conceal illegal activities - possibly blasting operations - which they could have been busy with at the time of the accident cannot be ruled out. All four are adamant, however, that the explosion followed a heavy goaf which in turn led to frictional heat. A sample of the sandstone present in the roof of this area has the following characteristics as shown in Table 2:

Table 2 Analysis of Quartz Content of Roof Sandstone

Quartzite	82.2% by volume
	80.0 by mass

The evidence thus lies more heavily weighted towards frictional heat as the cause of the ignition. In further support of this hypothesis is the evidence of the Section Manager who stated that:

"I cannot recollect what the face outline was in the area between No. 1 and No. 2 roads. I can remember seeing that the roof had partially goafed in the area ahead of roadway No. 4 and that the roofbolts in that area had either sheared or the washers had been stripped off over the end of the bolts.

At the accident I found that the area between roadways No. 1 and 2 had goafed as indicated on Figure 17. The area had not goafed solid and there was an open space above the broken rock.

There is a very slight dip from North to South in the coal seam at the position where this accident happened."

The section, by all accounts, was well stonedusted.

In evidence, witnesses stated that the colour of the flames of the explosion in the goaf was yellow, blue and green. The Inspector of Mines rejected this evidence as being false (explosion flames cannot be green they maintained). In the coal dust explosion at the Hlobane No. 2 pit in April 1956 witnesses gave evidence that the flames were blue, yellow and green in colour. One can only conclude that Blacks interpret a certain colour which arises in the flame of an explosion as green.

2.6.2 Ermelo Mines Limited. November 1982. Ignition of Methane in Old Working

Ermelo Mines is situated 25 kms west of the town of Ermelo. The mine works the main seam (C Lower) which is 1,6 metres thick and lies at a depth of 120 metres below surface. Bord and pillar working is practiced with 6 metre wide bords and 18 metre pillar centres. A typical seam section is shown in Figure 19. The immediate roof layers consist of 0,6 metres of shale, and 0,75 metres of laminated micaceous sandstone. Roof support in the roadways consisted of 1,5 metre long roofbolts, 1,5 metres apart in either direction. A further seam exists 2 metres above the mined seam. Methane pressure from the upper seam has been known to exert pressure on the roof of workings in the main seam particularly on intersections. In order to reduce this pressure, boreholes on each intersection were drilled to the upper seam to drain off methane. Once the methane has drained off then the flow ceases. This policy was extensively practiced in Indumeni Colliery to drain the methane from the top seam. The mine is regarded as being extremely gassy and several ignitions have been recorded in continuous miner sections when picks strike the sandstone roof.

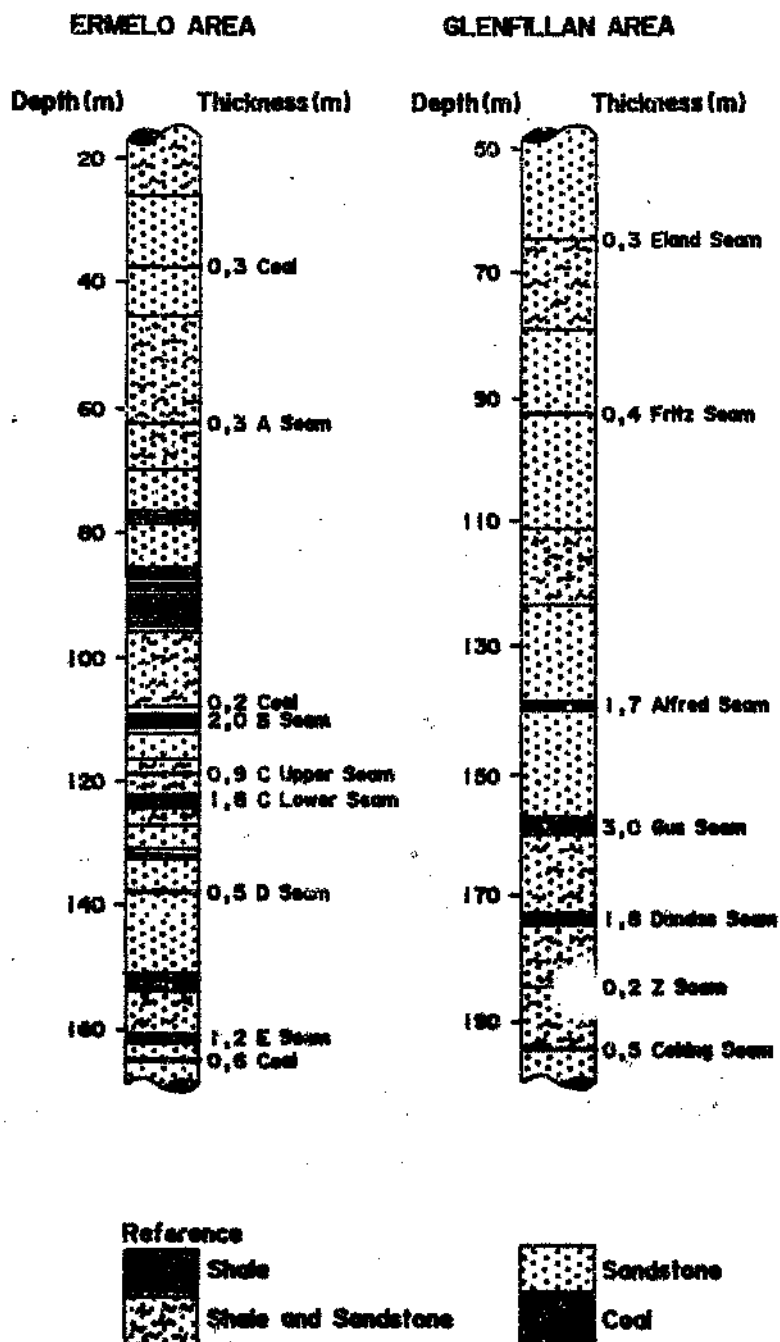


Figure 19

**STRATIGRAPHICAL SUCCESSION OF THE
EASTERN TRANSVAAL COALFIELD**

Explosion

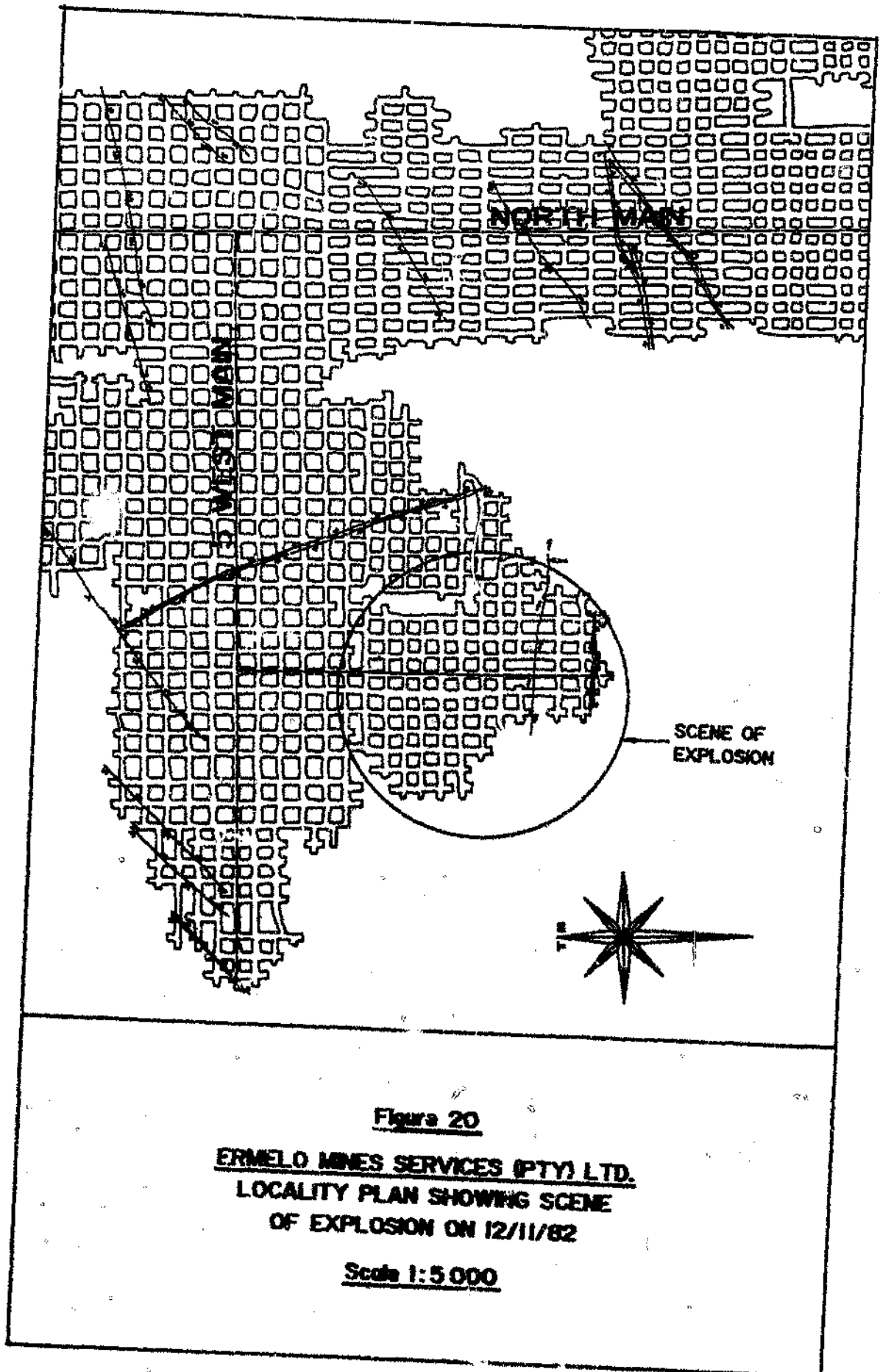
On the 12th November 1982 a methane explosion occurred in panel No. 6 at 10h30 killing 11 persons and injuring a further 10 persons. Of the 11 persons fatally injured 10 were overcome by asphyxiation and one died of a fractured skull as a result of being struck by a brick from one of the brick stoppings blown out during the explosion.

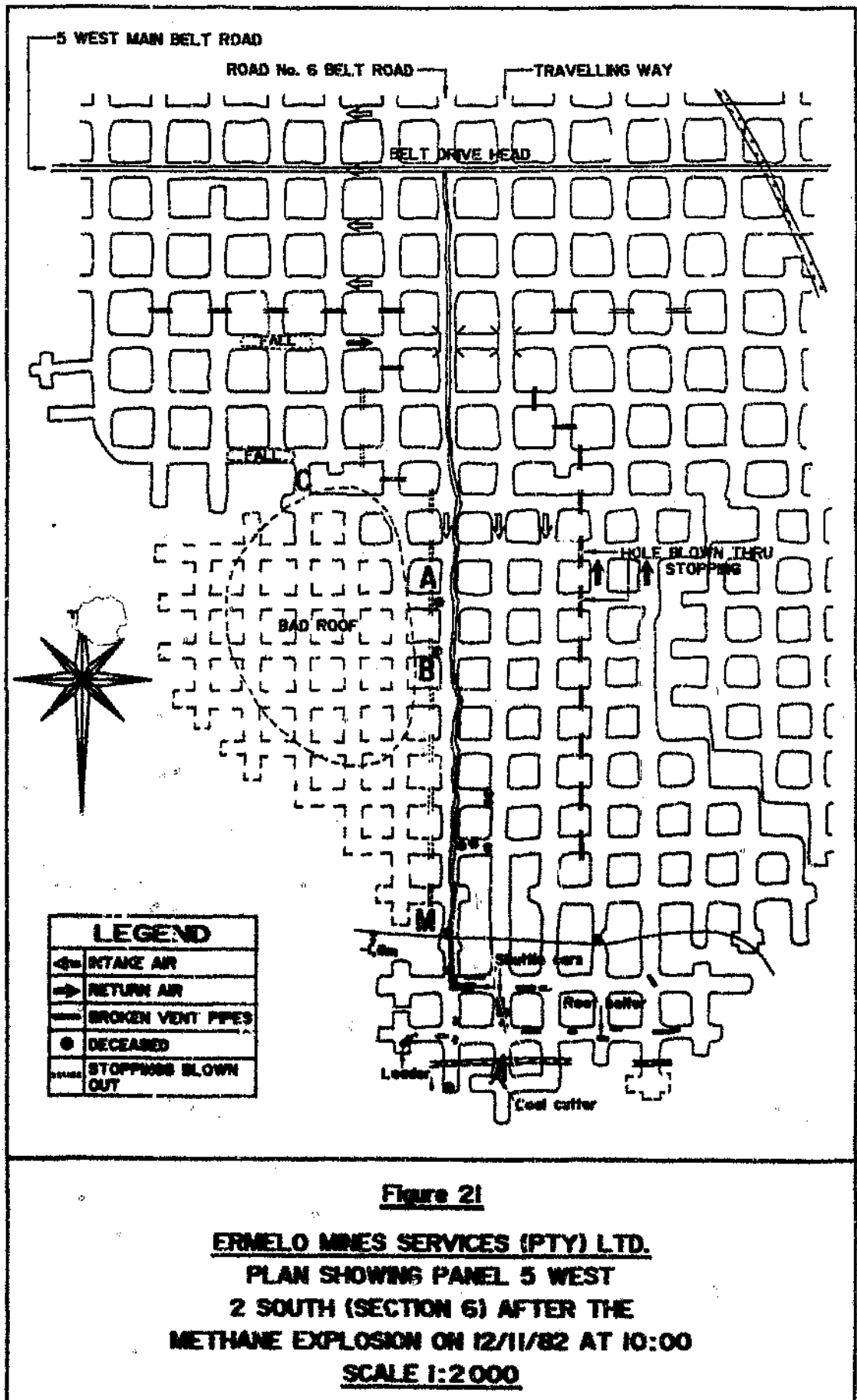
Figure 20 is a locality plan of the area where the explosion occurred and Figure 21 is a detailed plan of Section No. 6 showing the "bad roof" area, the ventilation stoppings, direction of air flow and position of coal winning machines. This plan also shows the stoppings blown out by the explosion, the debris from disintegrated stoppings and packs blown up in the explosion.

Mining Policy

The section commenced development in a southerly direction as a 10-road panel. However due to poor roof and floor conditions on the West side of the belt road (bad roof) it was reduced to a 6 road section. In order to protect the workings from the "bad roof" area, brick stoppings were erected between the 1st and 2nd right hand companions. However, the last split to the right (M) outbye of the fault was sealed off using a plastic brattice the day before the explosion. Roadway C was open to the return airway. Air was thus bleeding through the "bad ground" area. In addition a 60 mm diameter borehole into the "bad ground" area was downcasting.

On the day before the explosion (11th November 1982) the plastic brattice cloth in the last right split (M on the plan Figure 21) was replaced by a brickwall thus isolating the "bad ground" area from the working section. $12.4 \text{ m}^3/\text{sec}$ was measured in the three intakes on the 7th October 1989. The quantity of air leaking through the unplastered brick stoppings into the "bad ground" area was not measured but evidence was that there would be some





leakage through the 12 brick stoppings thereby preventing a build up of methane in this area. The last stopping at split M was erected on the Mine Overseer's instructions, the objective being to seal off this old worked out area from current workings. This was standard practice at the colliery (evidence given at the Inquiry by the Mine Manager). No sampling pipes were installed through stoppings into the "bad ground" area, neither were air samples taken from this area to determine the methane content of the air inside the sealed district.

From evidence, the explosion originated in the sealed off "bad roof" area shown on plan Figure 21.

- All the brick stoppings between the belt road and the "bad roof" area were destroyed and the debris blown in an easterly direction across the belt road. 10 kg pieces of brick stoppings were blown 50 metres east of the travelling road.
- The conveyor belt was seriously damaged.
- All electric cables were seriously damaged.
- The extent of the debris is shown on the plan of the section (Figure 21).
- Plastic warning signs showed indications of burning as shown on the plan Figure 21 at positions X, Y and Z.
- No signs of burning or an explosion were evident anywhere in the section south of the 1,5 metre downthrow fault.
- No signs of scorching of timbers in the brushed area of the haulage and travelling way was evident.
- Both air crossings were destroyed.

- The major force of the explosion blast occurred at position A-B on the plan Figure 21.

Unfortunately all eye witnesses to the explosion were killed and this made investigations difficult. Some witnesses who could have provided additional insight on the explosion had resigned or deserted. Carbon monoxide poisoning was the major cause of fatalities.

Environmental condition in the section after the explosion

The only air samples taken after the explosion (by the Proto Team Captain) are given in Table 3 below:

Table 3 Air Sample Measurements after Explosion

Time	Gas Concentrations
08h15	Methane - 5%
12h45	Carbon monoxide - 1000 p.p.m. Carbon dioxide - 0.02% Methane - 1.0%
14h00	Carbon monoxide - 300 p.p.m.
15h00	Carbon monoxide - 100 p.p.m.

These samples were taken two pillars back from the working faces (at the switch bank and fan in the travelling way).

The Cause of the Explosion

The epi-centre of the explosion originated in the sealed off "bad roof" area. A difference in pressure would have existed between the intake airway and the "bad roof" area across all the brick stoppings since the "bad roof" area was still connected to the

main return airway at point C on the plan Figure 21. Hence it would be unlikely for methane to enter the belt road from the sealed off areas. No real change in the barometric pressure occurred during the day of the explosion.

The first question therefore to be answered is how could an explosive mixture of methane have built up in such a relatively short time span in the sealed off area? The gas build up did not result from a sudden release of methane inside the sealed area because it is apparent that the whole area was not filled with methane. An examination of the section plan would indicate that before the last stopping was erected at point M in the section, what air entered the "bad roof" area would have followed a direct route to point C thus leaving large areas adjacent to this route unventilated. Further, since roof falls had occurred in this area, it follows that the roof where falls occurred would have been higher than the roof in roadways where falls had not occurred. Since methane is lighter than air (specific gravity 0.553) it is possible that, in the roadways west of road C, methane had collected in the roof cavities, caused by falls of ground, in large quantities before the ignition on the 12th November 1982.

During the 15 hour period following the sealing of roadway M it is possible that a tongue (tongues) of methane from the cavities had enveloped the normal roof and that somewhere a methane concentration had reached the explosive limits between 7.5% and 15%.

The Ignition Source

- No contraband was found on persons or in the affected area.
- Neither persons nor equipment were found in the sealed off area.

- All flame safety lamps and other lamps were found to be in order.
- No blasting operations had taken place at the time of the explosion. The Miner's blasting battery and cable were found in an unconnected state and hanging against the ribside.
- No thunderstorms, no veld fires nor other fires were recorded near the 60 mm diameter borehole which was downcasting into the sealed area.
- The accident scene underlies an Eskom overhead power line. As far as can be established no stray currents were experienced from this power line.
- A detailed examination was made of all electric cables and machinery in the belt road and section itself. Apart from a flameproof light which was found open at the time of the explosion near the waiting place all electrical apparatus was found to be in order. Had this light been the ignition source then the bodies found in the belt road would have reflected burns. None of the bodies evinced any burn marks. The only person who suffered burn marks to his face and hands was a Polish electrician under training. He was discovered near the waiting place with a side cutter in his hand. The side cutters showed no signs of a short circuit flash.
- No signs of spontaneous combustion was evident in the area.

The most likely cause of the ignition was frictional heat as a result of a fall of roof in the "bad roof" area. This could either have been quartzitic sandstone on sandstone or quartzitic sandstone on roofbolt steel since the epicentre of the explosion was in the sealed-off area.

2.6.3 Bosjesspruit Colliery. 9th March 1982. Ignition of Methane at a Continuous Miner

Introduction

With the advent of the greater use of continuous mining machines, especially in deeper and relatively more gassy seams, the incidence of methane ignitions as a result of frictional heating between steel picks and sandstone bands is increasing. The percentage deep mined coal won by continuous miners in 1988 was 32%.

The incident deals with 6 face workers who suffered burns to their faces and hands as a result of a methane explosion resulting from frictional heating between continuous miner picks and sandstone. The incident occurred in a cross cut from a roadway which had penetrated a dyke. The situation described is a recurring theme throughout this project dealing with methane and coal dust explosions; roadways which have penetrated dykes are likely to emit high quantities of methane and be poorly ventilated. Methane build-ups occur which, for some or other reason, remain undetected - and an ignition source, in this case frictional heating is all that is required to ignite the explosive mixture.

The Incident

The No. 4 seam lies at a depth of approximately 180 metres and the explosion scene is depicted on the plan Figure 22. The section, worked on the bord and pillar system, had intersected a 6 metre wide dyke which had burnt the coal on either side for approximately 15 metres. Both the main and the left hand companion had penetrated the dyke and the split off the main haulage was being advanced in a westerly direction to hole with the left hand companion. The face was 37 metres from the last through road which recorded a velocity of intake air of 1,1 metres per second, well above the legal standard of 0,25 metres per second. The seam height in the section was approximately 3 metres.

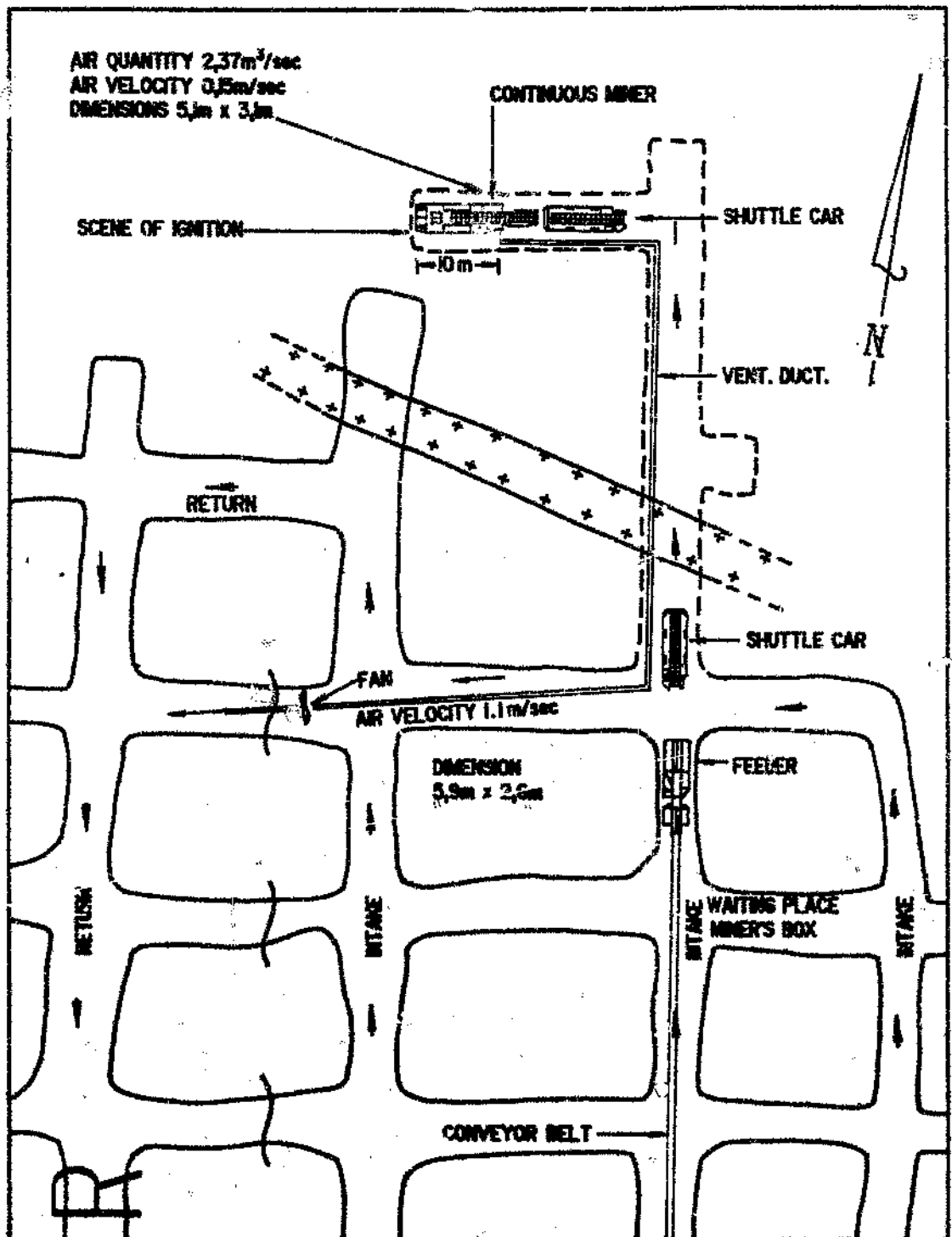


Figure 22

BOSJESSPRUIT COLLIERY

**PLAN SHOWING SCENE OF FIRE
 IN FT77 SECTION NORTH ON 09/03/82
 AT A DEPTH BELOW SURFACE OF $\pm 70\text{m}$**

Not to scale

The Antilation of the split off the main haulage inbye of the dyke was by means of an exhaust fan and ventilation tubing which extended into the face. From the measured velocity of air at the continuous miner it is calculated that the air quantity at the machine was $2.37 \text{ m}^3/\text{sec}$, very little, if any, of which was reaching the face. Figure 23 shows the face details and the shortcomings resulting from the sole use of an exhaust ventilating system, the ducting being 9 metres back from the face. It is unlikely under these circumstances that any methane emission from the burnt coal zone would be removed or be sufficiently diluted to prevent a methane explosion. At best the air in the face area, where the greatest risk of frictional heating exists, will be disturbed by the revolving cutter drum of the continuous miner and the operation of the dust extraction system on the machine.

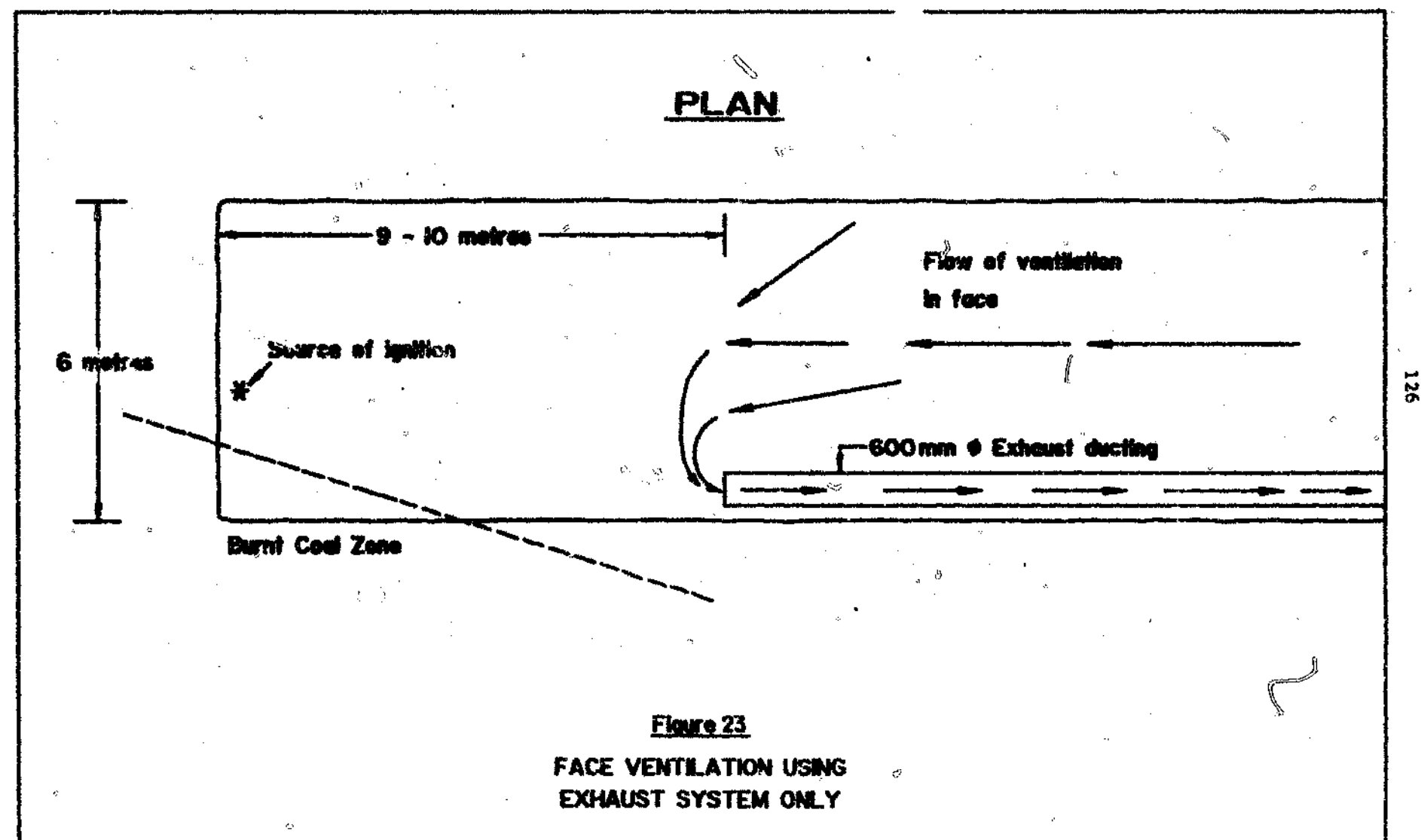
Conditions in the section are described by the Section Manager who stated that:

"Upon my arrival I found that the ventilation curtain, as indicated on Figure 22, was lying on the ground together with parts of the exhaust pipe. I tested for carbon monoxide and carbon dioxide as well as methane, but there was no indication of any of the aforementioned gas.

The test was carried out after the ventilation conditions had returned to normal.

I measured the volume of air and found that it was as shown on the plan Figure 22, namely $2.37 \text{ m}^3/\text{sec}$ in the area of the ignition, that is, over the continuous miner. The incoming fresh air velocity above the continuous miner was $0.15 \text{ m}^3/\text{sec}$. At the time of the accident the continuous miner had just commenced a new cut in the face.

I revisited the scene of the accident accompanied by the Inspector of Mines during his in-situ inspection of the scene.



Once again we tested for methane gas in the dyke area as indicated on Plan No. 22, as well as the position where the fire existed. The tests were all negative.

The available ventilation was sufficient for healthy working conditions and in accordance with legal and mining standard specifications.

After visiting the scene of the accident I concluded that the continuous miner must have cut through a methane pocket which caused the ignition. The ignition occurred in a dyke area where the existence of methane gas is likely.

My conclusion was that an ignition could have been caused by the picks of the continuous miner cutting into a piece of quartz. I noticed that quartz and sandstone were present in the area between the coal. This area has no history of the presence of methane, even when penetrating a dolerite dyke where methane gas is not prevalent.

If it is found that methane exists in any area, all electrical apparatus except fans are switched off and Personnel withdrawn from the area to a safely ventilated area.

The presence of methane gas was not reported to me prior to the accident.

Stonedusting in this area was closer to the face than the standard requirements, namely past the last through ventilation. The stonedust was in no way affected by the fire. There were sufficient flame safety lamps supplied to this section, all of which are in order.

No further questions."

The evidence of the Team Leader who was operating the continuous miner is as follows:

"I am a Team Leader.

On the day of the accident I was the Operator of the continuous miner busy cutting coal when a loud thud occurred. I tried to flee but I realised I had been burnt. I noticed that the flame had started at the cutting head which was moving backwards. Originally the flame started in the roof and spread everywhere. It felt to me as though the flame burned for a long while but in actual fact it was over in seconds. I never saw whether anybody extinguished the flame but it just stopped burning.

By Court:

The water sprays on the cutting head worked efficient. I actually saw sparks on the cutting head. Patches of stone were present in the coal. I had already cut approximately 10 metres before the ignition occurred. I saw several sparks for a while before the accident occurred.

I had a flame safety lamp with me on the continuous miner. Immediately prior to the accident there was no indication of methane. I tested for methane prior to the accident. The test was negative. I do not have a certificate but my Miner taught me to test for gas. I would have recognised it if there had been methane gas present.

The ventilation pipe was in order but I could not actually feel the air circulating.

I have been employed in East I shaft for four years and this is the first time such an accident has occurred.

We have been taught to watch for methane gas - we are afraid of it.

Whilst I was cutting nothing abnormal was observed regarding dust; it was absorbed as normal."

The evidence of the Section Engineer who examined both the continuous miner and the shuttlecar after the explosion, indicated that both machines were in order. He could find no fault with the flameproofing of the units. The cables were also in order.

A pertinent point in the evidence of the Mine Overseer, who visited the section 4 days before the explosion, was that he did not test for gas in the main haulage road which was already 15 metres through the dyke. He accepted the assurances of the Miner that "the tests were negative". In addition his evidence that "the exhaust fan ducting was up to date" went unchallenged in the Inquiry. What is meant by the term "up to date"?

- No standard procedures for ventilation and gas testing were called for or tabled, and no reference is made in the Inquiry documents to the use of electronic methanometers mounted on the continuous miner which would provide a warning of methane build ups at the cutting head. The operator was provided with a flame safety lamp for gas testing.

The Shiftboss in evidence stated that 'the Miner and I were at the miner's box when the operator (of the continuous miner) reported that he had intersected stone with the cutting drum. We went to the face to inspect it and noted that the roadway had intersected burnt coal on the left hand side of the face. We examined the face for methane using a flame safety lamp and found no gas. As I was leaving the section (I was 150 metres outbye of the waiting place) I heard an explosion and returned to the main drive where I encountered injured workers'. The author quotes the Shiftboss's evidence since it is important. Tests were made for methane, they proved negative and a methane explosion occurs albeit two hours after the inspection. It was the miner's first shift at this colliery. The explosion did not develop into a coal dust explosion since the section was adequately stonedusted.

No methane readings were recorded either before or after the incident which makes analysis of the accident difficult.

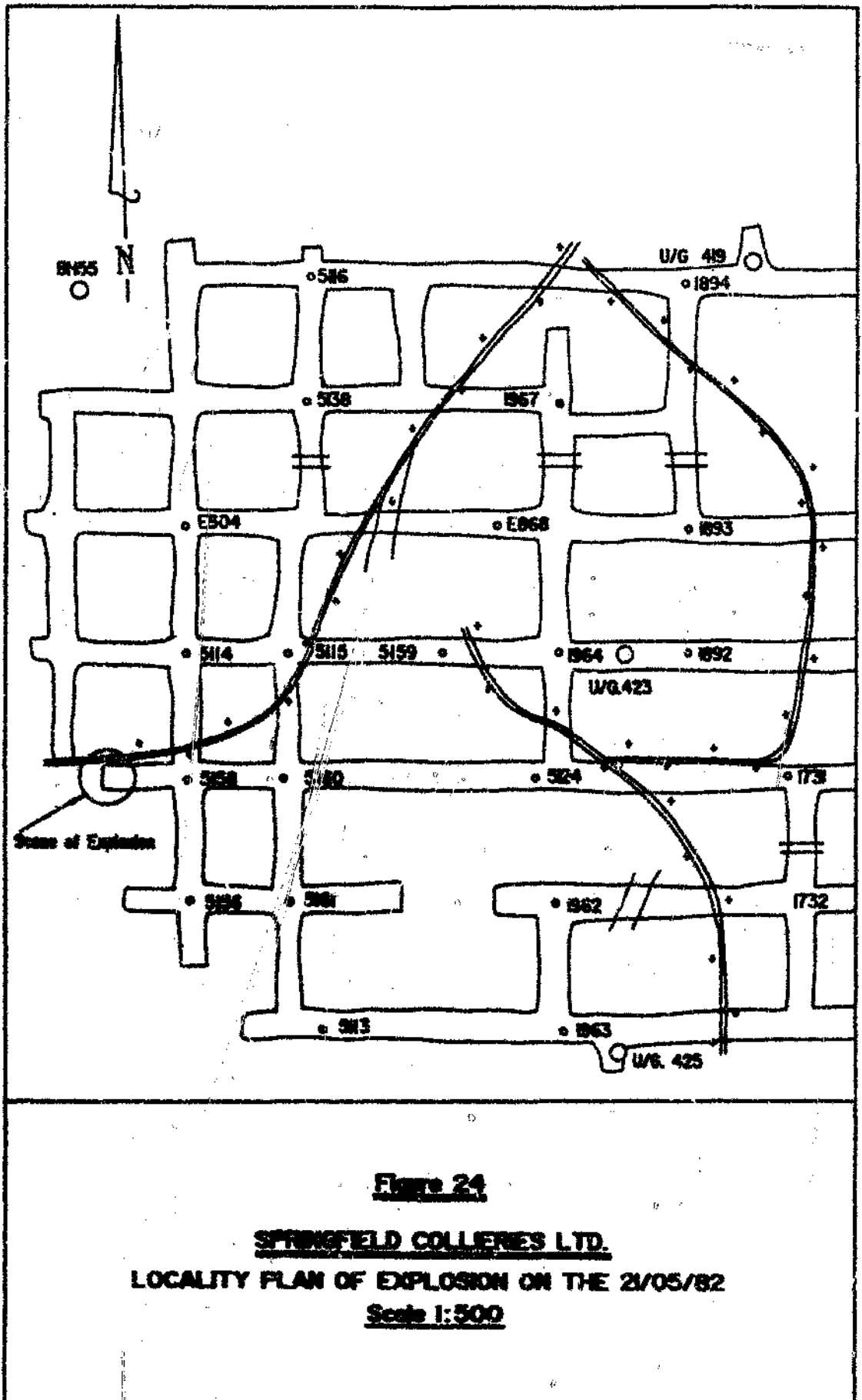
Two similar incidents to the one above occurred at Springfield Colliery in May 1982 and August 1983.

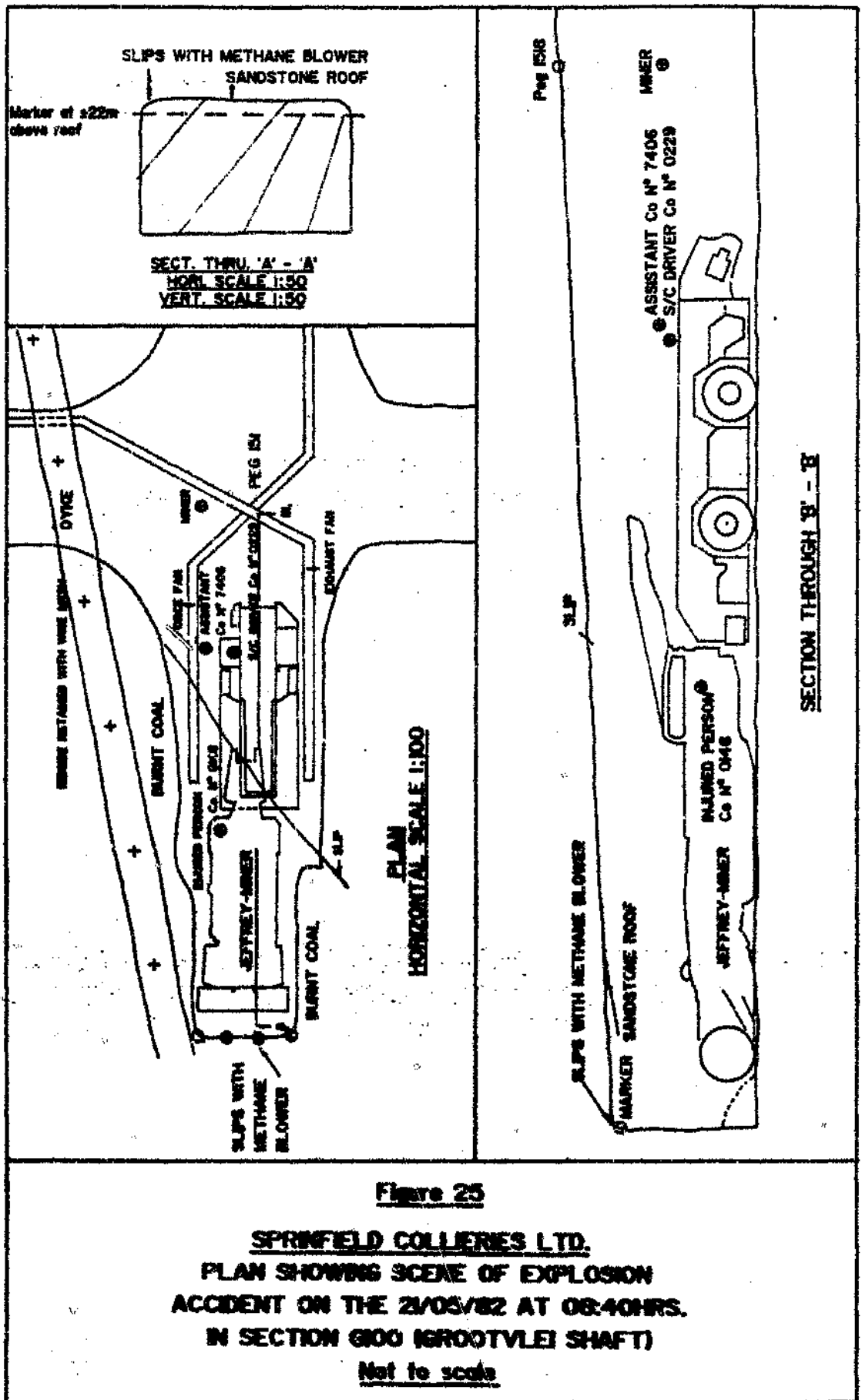
Figure 24 shows a locality plan of the first incident and Figure 25 details of the face when the ignition occurred. In this incident the Operator of the continuous miner was burnt when frictional heat from picks striking a sandstone roof ignited methane issuing from a blower adjacent to a dolerite dyke. Both the forcing and exhaust methods were used to ventilate this face, a method which the author endorses when faces are being worked in burnt coal.

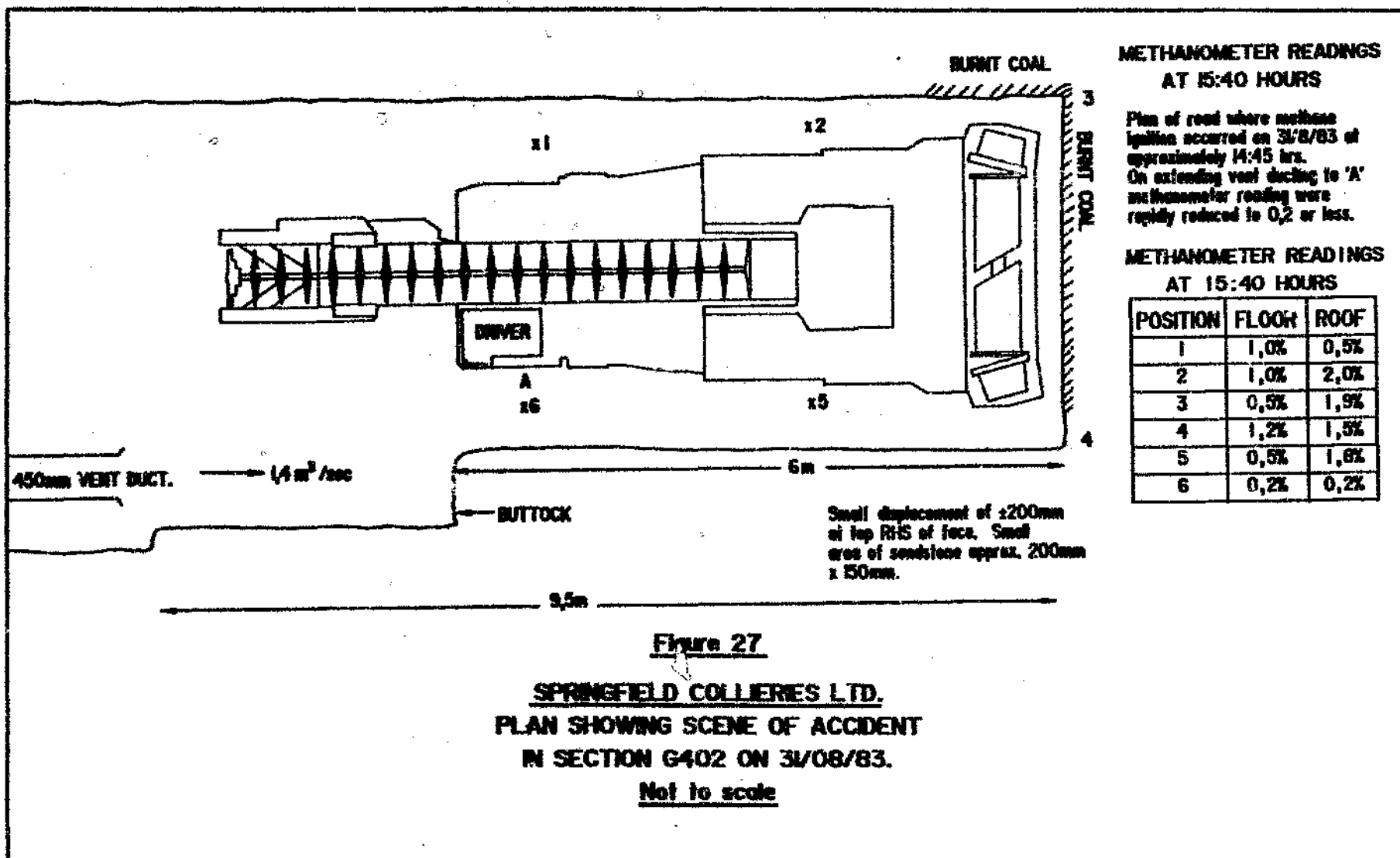
Figure 26 and Figure 27 shows a locality plan and face plan respectively of the second ignition. The continuous miner was advancing in burnt coal, when the picks struck a sandstone band, in the upper right hand face, igniting methane. The Operator was burnt. In this instance the face was ventilated by a force fan only and the 450 mm diameter ducting was 9.5 metres from the face. Table 4 shows the methane readings in the face 1 hour after the ignition when the ventilation ducting was extended to within 6 metres of the face.

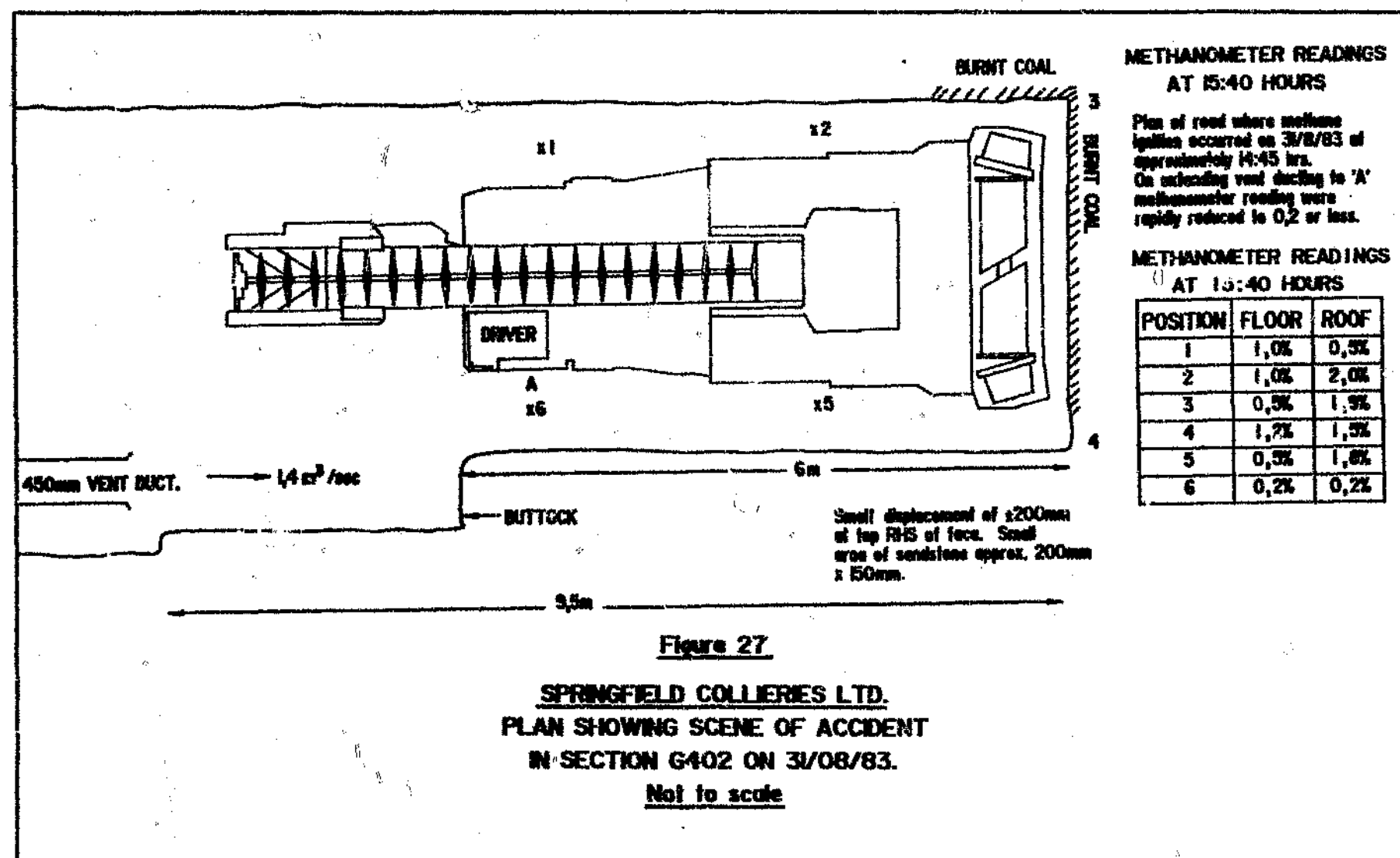
Table 4 Methane Readings after Ignition

Position in Face	Floor	Roof
1	1.0%	0.5%
2	1.0%	2.0%
3	0.5%	1.9%
4	1.2%	1.5%
5	0.5%	1.8%
6	0.2%	0.2%









In every instance the percentage methane was well below the ignition range.

It is common practice in Australia to use line brattice to ventilate headings being worked with continuous miners, a practice which has not found favour in South Africa.

2.6.4 The Durban Navigation Collieries. 21st September 1968. Ignition of Methane while Coal Cutting

A non-casualty accident occurred on the 21st September 1968 when firedamp was ignited in an undercut during coal cutting operations.

Figure 28 is a locality plan of the section showing the layout of the auxiliary ventilation fans, ducting and water pipes in the section. Figure 29 depicts a seam section showing the position of the undercut.

The Section Manager, in his evidence, stated that:

"At about 09h00 on the 21st September 1968, the Mine Overseer on duty reported to me that he had received a telephone call from Section 27 that an ignition of inflammable gas had occurred in the face of the belt road and that the gas was burning in two undercuts. The Miner reported to the Mine Overseer that he had contacted his Shiftboss and that they were attempting to extinguish the fire by using fire extinguishers, stonedust and water.

I immediately telephoned the Mine Manager who in turn alerted a proto team and notified the Mines Department.

On being notified of the fire, I proceeded to No. 6 shaft but en route, at about 09h15, the Mine Overseer contacted me by telephone and told me that the fire had been extinguished.

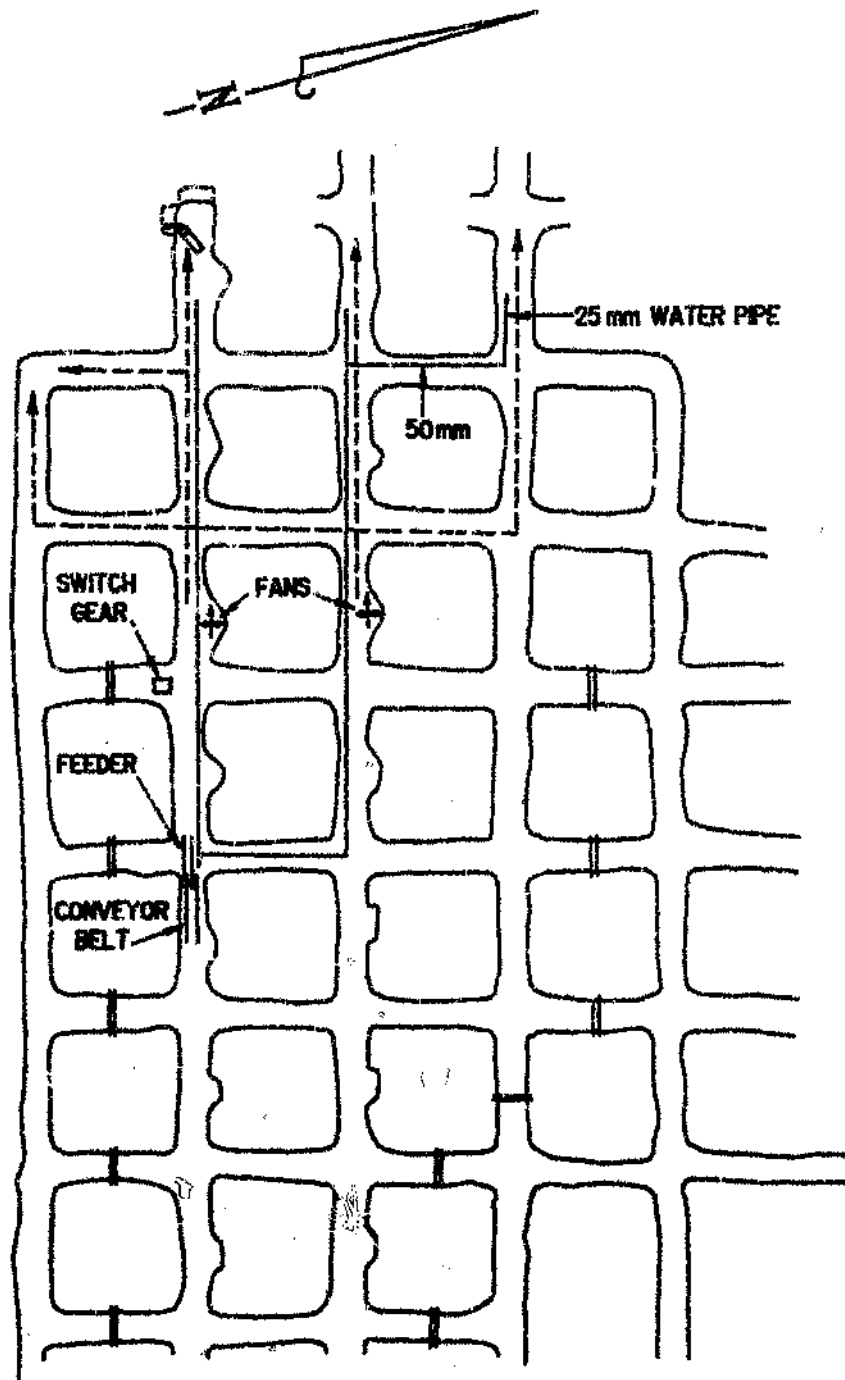


Figure 28

DURBAN NAVIGATION COLLIERIES LTD.
LOCALITY PLAN SHOWING SCENE OF FIRE
IN 27 SECTION ON 21/09/68

Scale 1:1200

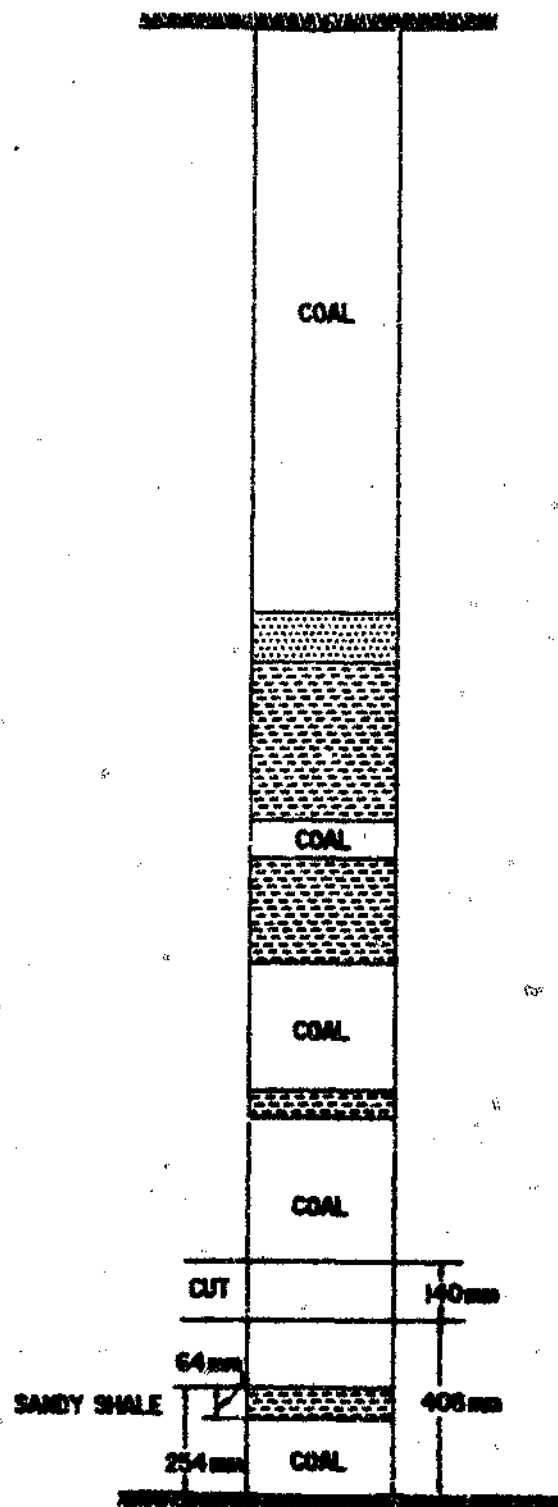


Figure 29

DURBAN NAVIGATION COLLIERIES LTD.
SECTION OF FACE AT SCENE OF FIRE ON 21/09/68
Not to scale

At about 10h15 I accompanied the Mine Manager, the Resident Engineer and the Inspector of Mines to Section 27 and upon arrival I found that the entrance to the belt road had been fenced off.

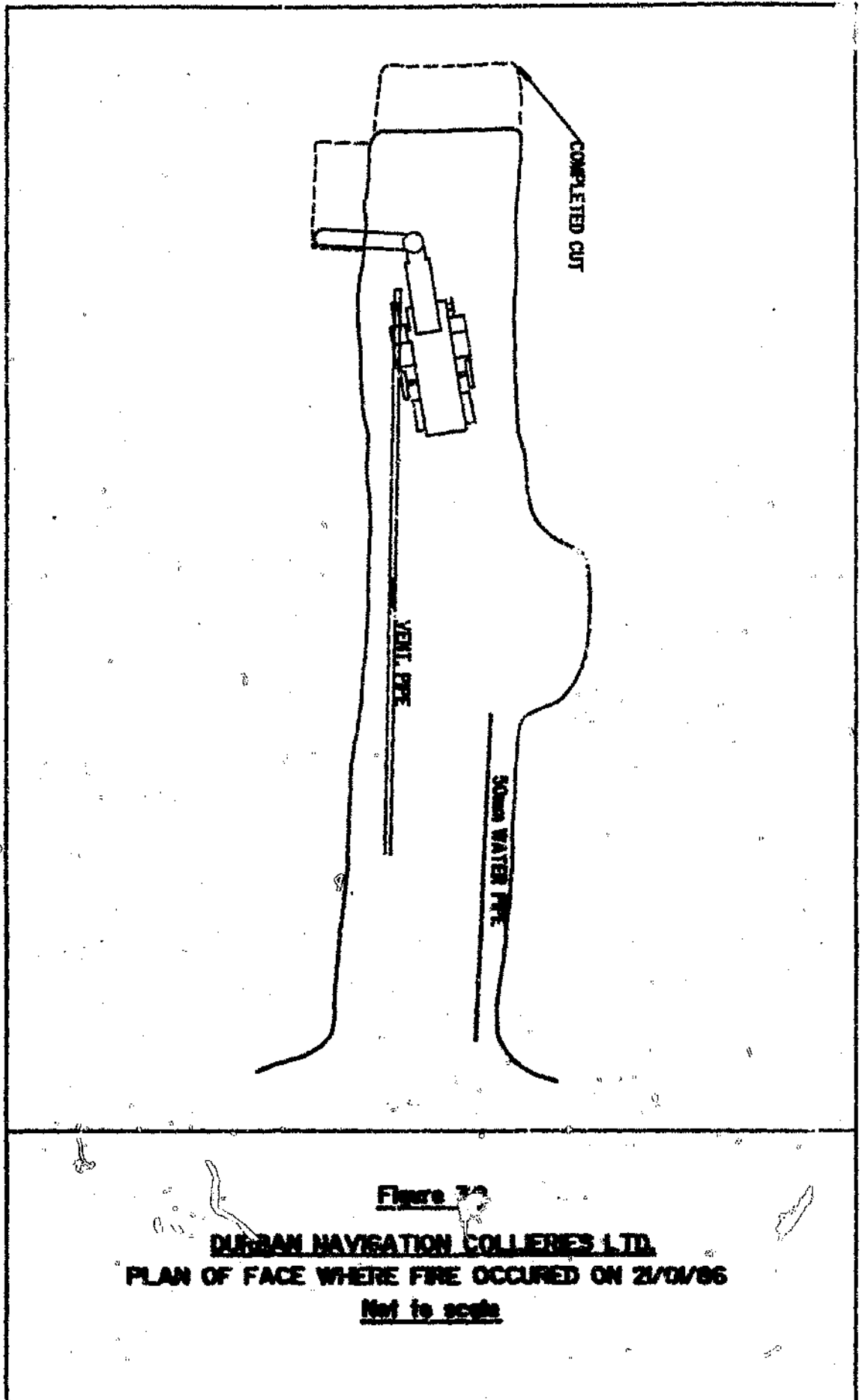
I inspected the scene and found a coalcutting machine near the face on the left hand side of the road. I saw that the machine had almost completed undercutting the face. I also saw that a cut had been completed on the advancing face of the heading. I had a plan of the section and a section of the coal face drawn up (Figure 30).

The belt road was ventilated by means of a force fan delivering $3,36 \text{ m}^3/\text{second}$ through a 550 mm duct which was within 5,4 metres from the face. The cross sectional dimensions of the roadway were 3,35 metres high by 4,6 metres wide - there was a strong flow of air over the face.

The water reticulation service was within 15 metres of the face of the heading and the pressure in the 50 mm pipe according to a pressure gauge was 1400 KPa. The water hose which was normally attached to the coal cutting machine was lying on the floor as it had been used to extinguish the fire. Normally the water hose is attached to the coal cutting machine and the water is sprayed onto the jib and the pick chain takes the water into the undercut. It was not possible to say if water had or had not been used during the undercutting of the face. All the coal was very wet.

By Court:

From my investigations into the ignition it appeared that whilst the coalcutter operator was undercutting the face as shown in Figure 30 there was the sound of an ignition of inflammable gas and flames appeared out of the undercut and spread to the adjacent undercut. These flames burnt to the height of about two metres. The coalcutter Driver switched off the power to the



machine and called the Miner who went to the face. The Miner attempted to extinguish the fire by means of water, stonedust and a fire extinguisher. He also sent for his Shiftboss and had a duty Mine Overseer notified by telephone. The Miner and Shiftboss managed to extinguish the flames by means of a fire extinguisher and also by throttling the ventilation thereby reducing the fanning effect of the air current. The Shiftboss suffered ill effects from the fumes liberated by the fire extinguisher.

I examined the coal face but did not find any coking of coal. During the inspection in loco I tested for inflammable gas with an Oldham methanometer and found 0.15% in the general body of the air with the force fan delivering its full quantity. I detected 1.2% in the undercut and by using a probe I detected 1.5% in the back of the undercut. I switched off the force fan and immediately layering of the methane took place; within five minutes there was a 450 mm layer containing +5% methane against the roof.

I restored the ventilation and after the gas had been cleared I had the coal cutting machine started and had the undercut completed. Water was applied in the normal way and during the cutting I tested continually for inflammable gas but I did not detect any coming out of the undercut which was 1.8 metres deep - normally a cut of 2.42 metres is taken.

I did not find any sockets or misfires on the face. The cut had been taken in clean coal - no stone or pyrites were visible. I did not find a blower of methane in the heading.

The only known geological disturbance in the vicinity of Section 27 is a 3.6 metre thick dyke running parallel to the right hand side of the section and is about 110 metres away from where the ignition took place. It is known that inflammable gas is occluded in the coal but gas has not been detected in the section for some considerable time.

I examined the picks of the coal cutting machine and found that two were missing and the tungsten carbide inserts of two were slightly chipped - the remainder were in excellent condition. After the undercut had been completed I felt the picks and found that they had not heated up to any considerable extent.

In my opinion the ignition was probably caused by a spark created during the cutting of the coal and igniting the methane liberated in the cut - normally about 3.0% methane is found in the undercuts in a gassy section such as Section 27. The possibility of dry cutting cannot be overlooked.

There were no casualties as a result of the ignition. There was a loss of some 400 tons (of production) due to the coal cutting machine having to remain idle until the inspection in loco was completed and the cost to the mine has not as yet been determined.

The coal cutter Operator had 6 years experience on the colliery. According to the Miner the safety lamp was burning before and after the ignition.

An investigation by the Fuel Research Institute is in hand to determine whether or not there is some substance in the coal that could have caused the ignition.

No further questions."

The coal cutter Operator in the section stated that:

"During the shift of the 21st September 1968 I undercut the face of the belt road with my machine. The cut was taken about 450 mm (indicated) above the floor elevation. Whilst I was cutting the coal my helper was spraying water on to the moving pick chain. The hose was actually clamped to the machine and the water was spraying on to the picks.

After I had completed this cut I moved the machine back a short distance, swung the jib over and started cutting the left hand ribside. Again the cut was taken in coal and about 450 mm above the floor elevation. My safety lamp was burning all the time and I did not detect any inflammable gas whilst I was cutting. I had almost completed the second cut when light green flames came out of the cut. These flames spread to the first cut and burnt about 1,8 metres up the face.

I immediately switched off the power at the machine and sent my assistant to switch off the power at the main switch.

I told him to call the Miner whilst I stood guard at the entrance to the roadway.

The Miner arrived soon after my helper left and told me to fetch a fire extinguisher at his box. I left the place and when I returned with the fire extinguisher the Miner was trying to extinguish the flames with water. I handed him the extinguisher and he played the contents on the flames. Soon afterwards our Shiftboss arrived and the flames were extinguished.

By Court:

I am absolutely certain that water was being played on the pick chain whilst I was cutting the face.

The pick chain did not stop from the time I started the second cut until the ignition occurred. I examined the pick chain before I started cutting. Two picks were missing but there was nothing wrong with the remainder. After the ignition I noticed that two picks were chipped.

The ventilation was very good and was on all the time I was cutting in the belt road. I tested for gas before I cut the first face and I tested again before I started on the second cut.

No further questions."

What is of technical interest is the fact that the tungsten insert on two of the picks had broken off, and that dry cutting could possibly have been taking place. Both these aspects are not uncommon practices where supervision is either lacking or weak or when the water supply to the section has been disrupted. The rapid build up of methane in the roadway when the auxiliary fan was stopped indicates that methane was being given off freely in the undercuts.

In a similar methane ignition incident at Springfield Colliery in November 1983, ventilation readings were taken immediately after the ignition in every face of the section. Figure 31 shows the locality of the section and the details of auxiliary fan positions, diameter of ducting, distance of ducting from faces, ventilation velocities and quantities. The ignition occurred in the second left hand companion back-over which was being advanced in burnt coal, and the face details are shown in Figure 32. The section was worked using trackless mechanised equipment (loaders and shuttlecars). The ventilation standards in the section were adequate as will be seen by referring to Figure 31.

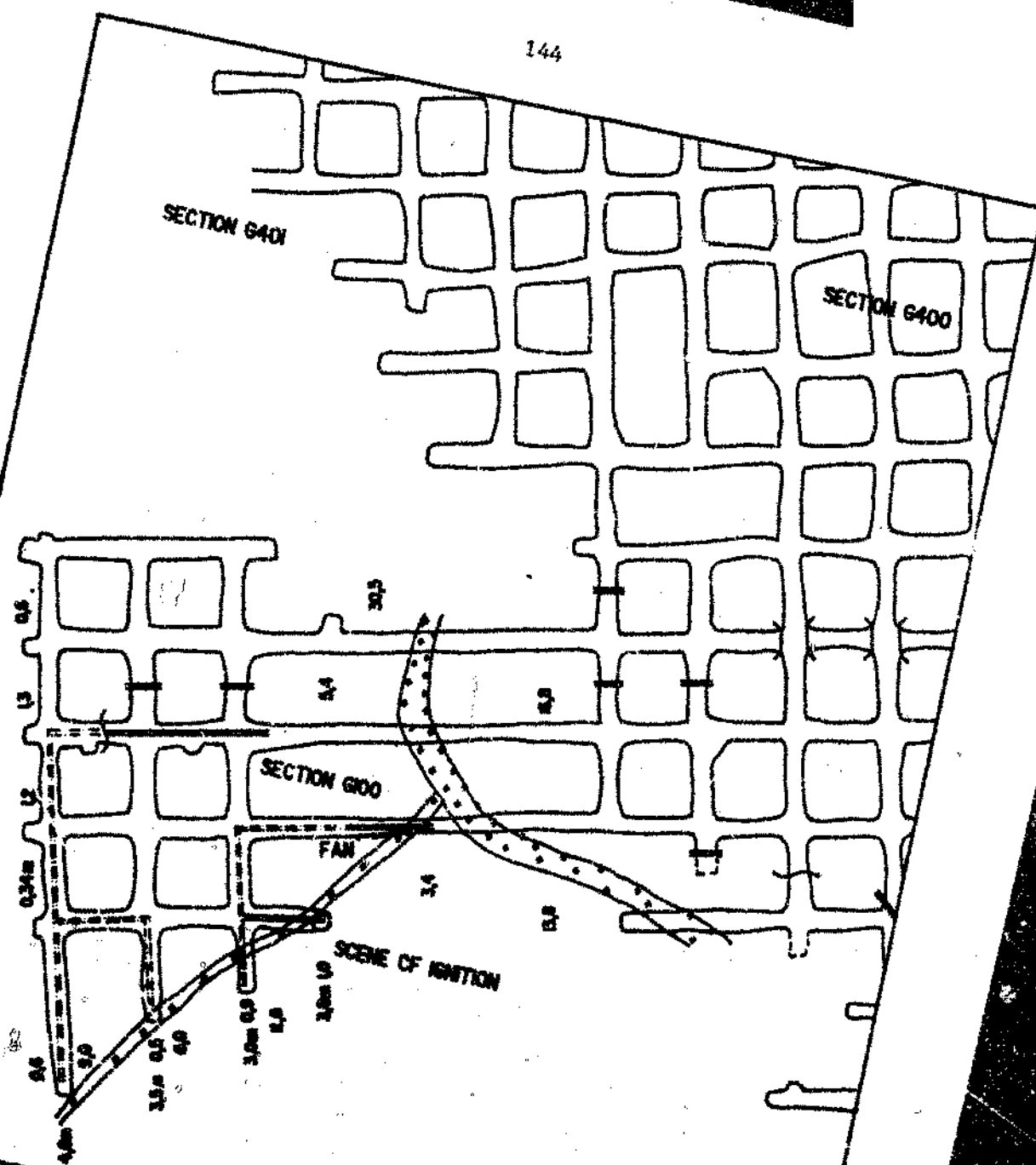


FIGURE 3
SPRINGFIELD COLLIERIES LTD.
LOCALITY PLAN OF IGNITION IN SECTION G100 ON 4/11/83
Not to Scale

SECTION 6400

SECTION GRID

FBI

SCENE OF IDENTIFICATION

ENCLOSURE
SEYMOUR COLLIERY LTD.
LOCALITY PLAN OF IGNITION IN SECTION 6100 ON 4/11/83
MAY 12 1983

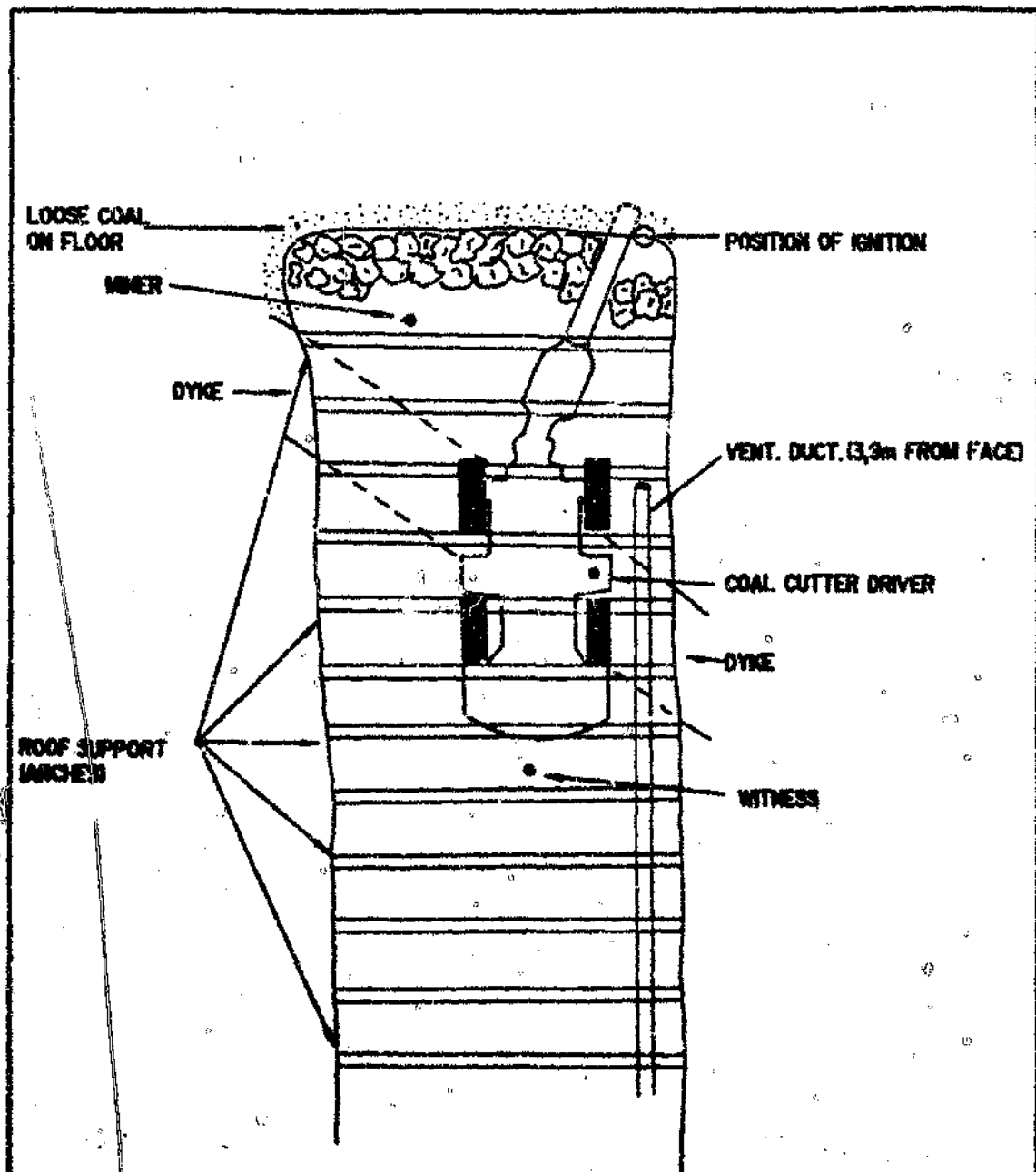


Figure 32

SPRINGFIELD COLLIERIES LTD.
PLAN SHOWING SCENE OF IGNITION
IN SECTION 6100 ON 4/1/83 AT 10:30

Not to scale

2.7 SUMMARY OF THE MAIN POINTS ARISING FROM THE INCIDENTS

- The 45° goaf line worked in a stooping section to control the caving makes efficient ventilation of such a section difficult especially when the intake air enters the section at the lower end of the goaf as shown in Figure 33. The ventilation at point A has the tendency to travel across the section to the return airway at point B (the shortest route) and not to point C where adequate ventilation is required to remove the fumes of blasting and also methane accumulations. Any deficiency in the brattices along the line A-C as shown in Figure 33 will short circuit air to point B, with the possibility of an ignition at point C due to a lack of ventilation.
- + Persons exposed to the flame of an explosion suffer severe body burns.
- The positioning of auxiliary fans in pillar extraction sections (see Chapter 5 Canadian Colliery) is important. Fans positioned in sections with no thought and removed from the section without the permission of senior Officials cause a dangerous build up of methane in and along the goaf line. An ignition source is all that is required to initiate an explosion.
- Insufficient ventilation supplied to the pillar extraction sections. 20 m³/sec would appear to be insufficient.
- Inadequate supervision over the siting of fans. No brattice cloth curtains were erected in the section (Springfield) to course the ventilation along the 45° goaf line.

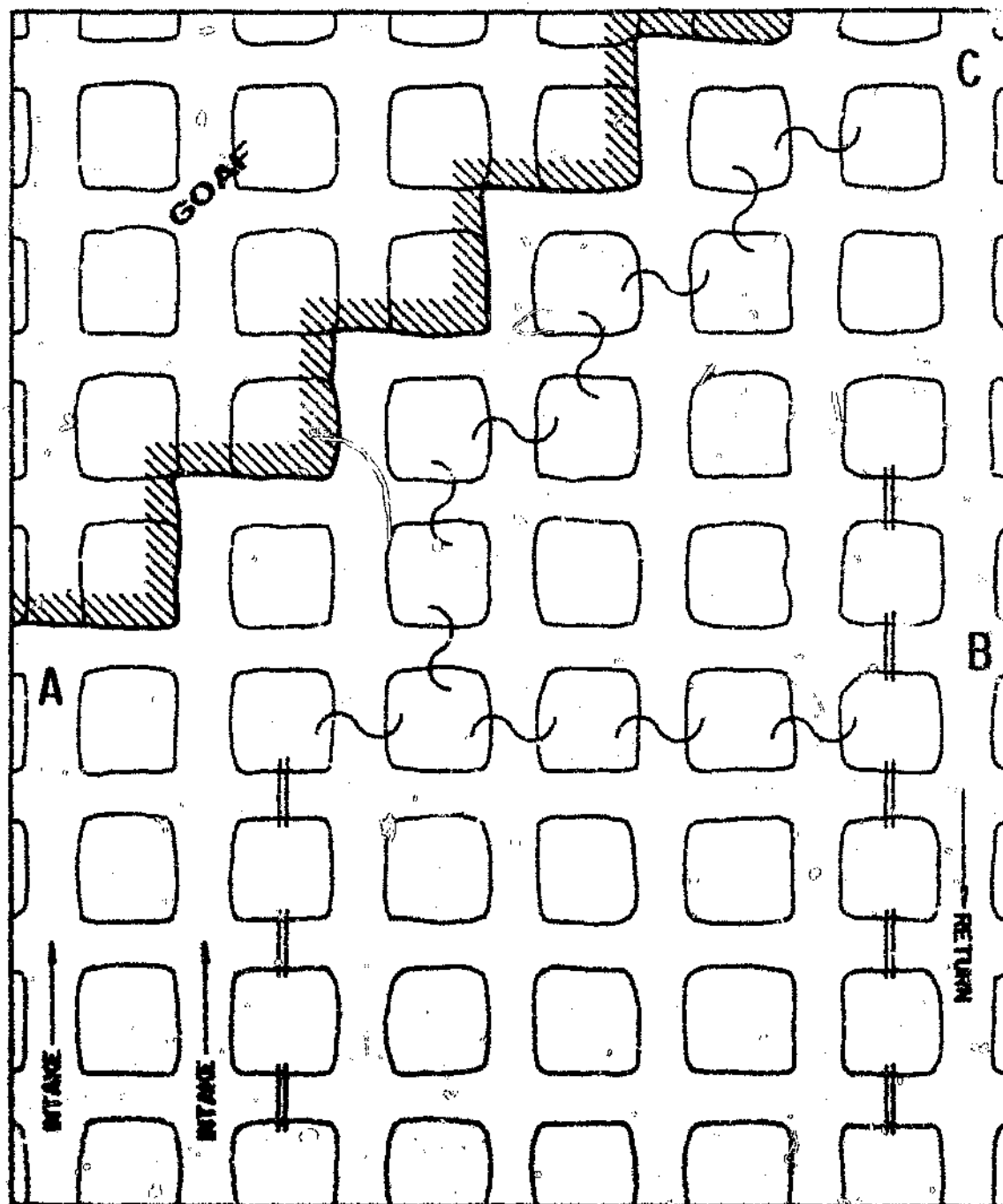
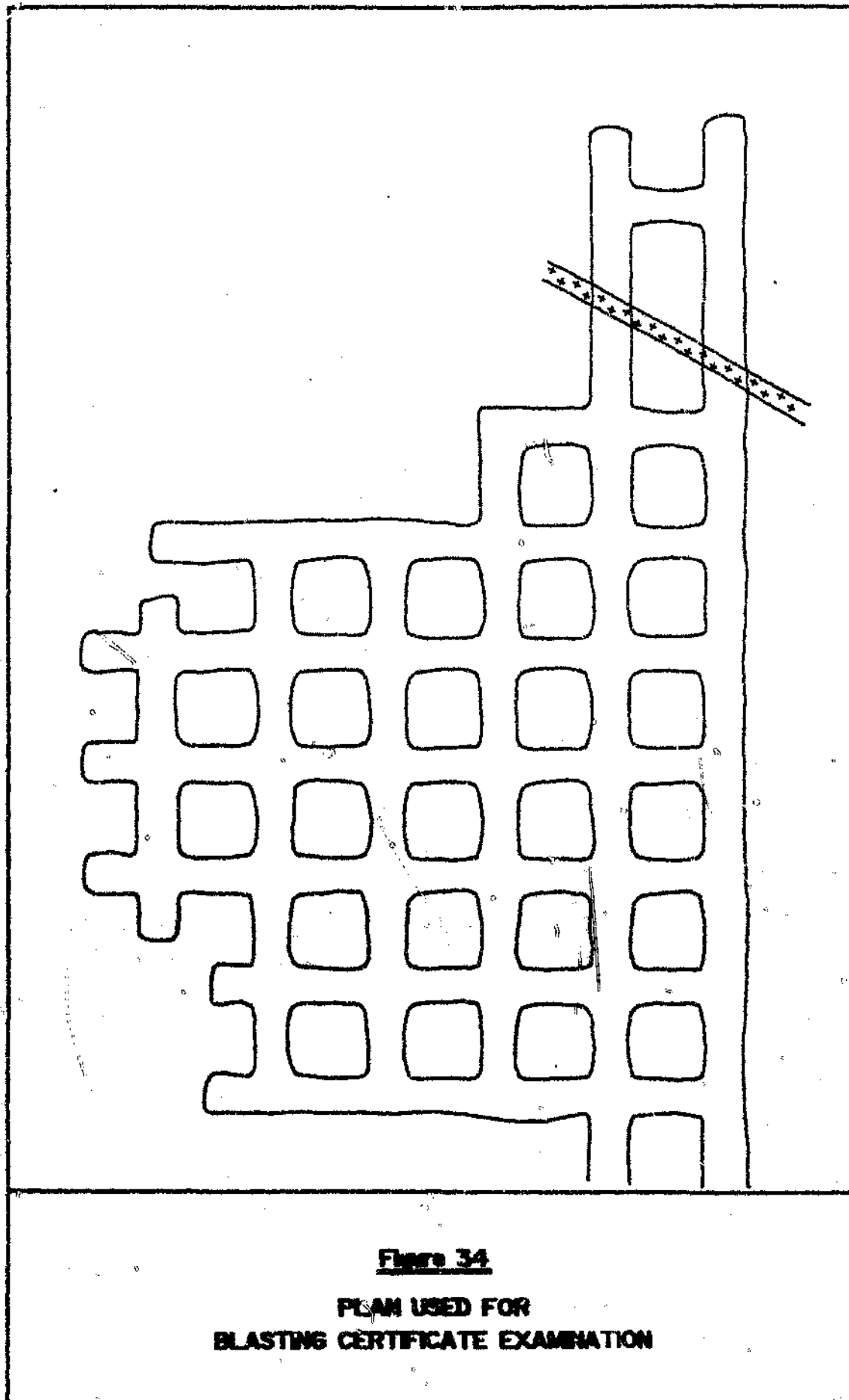


Figure 33

**PLAN OF GOAF LINE VENTILATION
IN PILLAR EXTRACTION**



- Officials and Miners (including machine Operators) always claim, after an explosion, that tests for methane gas had proved negative prior to the incident.
- Marked changes in the quantity and velocity of ventilation entering a section are not always discernible by those persons working in the section. The author has, on many instances entered sections to find little movement of air in the section - yet operations proceed at the normal tempo. An example of this is quoted below (from a recent safety overview at a gassy pit):

"A. Team No. 1 - Section G708/3

1. Clock on bank out of order.
2. Grass untidy in the entrance area.
3. Section transformer door closure inadequate. Doors can be opened sufficiently to allow hand access.
4. A new sign required to denote electricity not skull and crossbones.
5. Roads not mowed from G700s.
6. Production target: 25 200 tonnes
trending: 28 188 tonnes.
7. Brattices not sealing - open on sides causing leakage.
8. Air velocity 0.4 m/sec in No. 1 roadway - far below the mine standard of 1 metre per second.
9. Return velocity 1.6 m/sec - 20 m³/sec; this should have been 40 m³/sec as it was recorded two days ago.

10. The tip attendant did not stop entry to the tip area.

11. Reading at ventilation column discharge 9.9 m/sec.

Ventilation

1. Air volume only 20, 4 m³/sec. At least 30 m³/sec is required for 3 auxiliary fans.

2. Brattice stoppings not up to date.

3. Ventilation ducting within 5, 6 m of the face and generally in good condition.

4. Size of vent tubing not correct; should be 760 mm prior to the split instead of 600 mm.

5. 5 ends being ventilated off 1 fan, example

air flow, 1,2 m/s

1,1 m/s

2,1 m/s

1,0 m/s

1,4 m/s 0

7,8 m/s

6. One fan with joint box loose and not bolted. Stopped immediately for rectification. Fan was also loose on trolley.

7. No methane detected in the general body against the roof but 1,2% found in drill hole of split.

It transpired later that two large ventilation doors had been inadvertently left open."

It is of paramount importance to line management that any fault in the operation of main fans be detected immediately

and be rectified. If the main fans stop for any reason, senior management should be notified without delay.

- The quartz content of sandstones which overlay coal seams where secondary extraction is likely to take place should be ascertained. High quartz content in sandstones is a cause of frictional heat during goafing.

The goaf area of pillar extraction sections can become a reservoir of methane.

- Evidence of witnesses who were involved in methane/coal dust explosions can prove to be valuable and should not be dismissed with impunity. This is highlighted in the Springfield Colliery explosion where witnesses stated that the flame of the explosion was yellow, blue and green in colour. A similar description of an explosion is given by witnesses in the Hlobane coal dust explosion in 1952.

- Unworked coal seams which exist above the seam being worked have been known to contain methane under pressure and which can find its way into the seam below.

- Sealing off an area known to contain methane can result in a build up of methane gas to within explosive limits. Precautionary methods to prevent methane explosions are generally ignored when sealing off old areas. The possible ignition sources are also not always considered.

- The decision to seal off old areas is sometimes taken at a low supervisory level (Shiftboss or Mine Overseer).

- No provision is made to install sampling pipes into seals when sealing off abandoned areas.

- The force of an explosion destroys structures in such a way that it is possible to determine the epicentre of the blast

(see Chapter 4 - The Durban Navigation Colliery No. 2 explosion in October 1926).

- Explosions destroy aircrossings and ventilation appliances.
- Carbon monoxide poisoning (Ermelo Mines Limited) can be a major cause of death in methane explosions. This is substantiated by the results of the ventilation samples taken in a section after the explosion.
- Old areas which are sealed off are rarely examined before sealing takes place so as to determine the state of the gases in the area. Cavities in the roof are liable to contain dangerous accumulations of methane. Tongues of methane can extend from such cavities and layer against the roof in dangerous percentages.
- Flameproof electric lights within the 200 metre limit from the faces can be opened by electricians with the power still on.
- Roadways which penetrate geological disturbances such as dykes invariably encounter excessive methane emission in the form of blowers, and generally, ventilation of these ends is inadequate and poorly planned. Methane build up in these faces often goes undetected. Ignition sources are varied - in this case frictional heat.
- Ventilating headings (especially those advancing through dykes) by means of exhaust fan systems alone is inadequate to ensure the removal/dilution of methane in the face.
- Ventilation ducting should be as close to the face as is practical - ducting which terminates 9 metres from the face will not ensure that methane is adequately diluted.

- On-board ventilation, dust extraction and methane detection systems on continuous mining machines are often non-operational and insufficient attention is paid to the maintenance of these appliances.
- Sandstone measures in the Karoo system contain between 30% and 70% quartz.
- Mining personnel sometimes blandly accept that ventilation standards are adequate when in fact upon closer examination, they are not adequate.
- Pockets of methane under pressure are likely to occur and be encountered in areas of burnt coal and dykes (see Chapter 8 - Methane Outbursts).
- Quarzitic sandstone bands in the roof of the mineable horizon of the coal seam will cause incendive sparking and frictional heat when cut by coal cutters and continuous mining machines.
- Flame safety lamps supplied to machine operators are not a reliable means of detecting methane emissions during operations, since they are difficult to read during operations especially if they are set much higher than eye level.
- 'No methane gas was detected prior to the explosion', a recurring theme during this investigation. Four days before the accident, the Mine Overseer, in evidence, stated that he visited the section and the main drive, but did not test for methane. He accepted the assurances of the Miner that no methane was present.
- Lack of standard procedures in the section. For example, the Shiftboss stated that "the ventilation ducting, was

found to be up to date". Against what standards are these observations measured?

- The continuous miner was not equipped with an automatic methane detector.
- Inexperienced Miners are placed in charge of sections - in the case of the Bossjespruit explosion it was the Miner's first shift at the colliery.
- Lack of detailed methane and carbon monoxide readings after the explosion - this makes it difficult to analyse the conditions in the section after the explosion.
- The use of forcing and exhaust ventilation systems in headings worked by continuous mining machines would indicate that such faces are better ventilated; this system is however no guarantee that explosions will be prevented but the force of the explosion is diminished.
- The colour of the flames which were visible in the cut after the ignition were described as green which correlates with eyewitnesses in explosions in other collieries.
- Tungsten carbide tips were missing from two picks on a coal cutter chain when a methane ignition occurred.
- It is possible that as a result of weak supervision, water was not being used on the cutting chain during cutting operations.
- In gassy pits methane can build up rapidly in roadways when the ventilation current is disrupted.

2.8 PRECAUTIONARY MEASURES

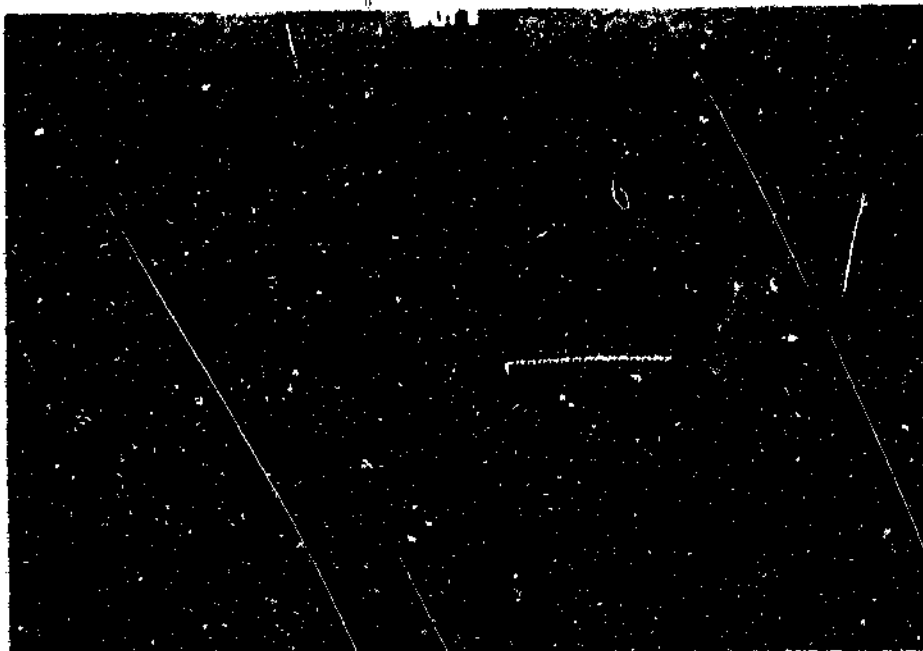
2.8.1 Goaf and Goaf Line Ventilation

The ventilation of the goaf line has been dealt with in Chapter 5. Roadway brattice curtains can only be maintained in good working order by sound supervision and training of mining Officials. With reference to Figure 33 it would be more advisable to make the right hand barrier road (B) the intake airway rather than the return and ensure that air firstly reached point C.

Photo No. 1 shows a typical auxiliary fan installation with a brattice curtain to prevent the recirculation of air over the fan motor. Fans recirculating methane laden air over faulty motors have caused methane explosions. Hence brattice curtains on the inbye side of fans should be standard mine ventilating practice.

The Shiftbosses log book should make provision for the logging of all auxiliary fan installations, which entries should be countersigned by the Mine Overseer who will thereby indicate his awareness of all fan installations.

The quantities of air recommended for ventilating stooping sections are given in Chapter 5, as is the position of brattice curtains in a typical section to ensure adequate ventilation to all faces.



2.8.2 Gas Testing

Unless senior Mining Engineers insist, and set an example, on the testing for methane in every face during underground inspections, junior Officials and Miners will not carry out these tests thoroughly. The author has, over many years, been highly critical of Officials who fail to test for methane in all working faces on a routine basis. Evidence at inquiries, time after time, following an explosion, is that tests showed no methane was present in the faces - yet the question must be asked as to how a methane explosion could have occurred if no methane was present? It is highly probable that in most cases no tests were conducted for methane prior to the explosion.

2.8.3 Ventilation Quantities to Sections

Ventilation quantities in sections may deteriorate substantially but not become discernible to those persons working in the section as proved previously in this Chapter. These reductions are generally due to:

- Stoppage of one or more of the main surface fans.
- Falls of roof in intake and return airways.
- Officials sealing off returns inadvertently. The author has experienced this aspect on several occasions. In one instance (at Springfield Colliery in 1955) a night shift Shiftboss actually bricked off a main return airway having misunderstood instructions to erect a seal in another area. This incident typifies the serious lack of knowledge and training of mine Officials particularly with regard to ventilation.

Figure 34 is a plan of a section. For almost 25 years this plan has been used to test prospective Miner's knowledge of

ventilation in the Blasting Certificate examinations. Miners learn to ventilate the plan "parrot fashion".

It is these miners who are eventually promoted to Shiftboss level (and who brick off main return airways by mistake).

- Major ventilation doors between intakes and returns are often left open thus causing serious shortcircuiting of air. Interlocking devices should be installed to ensure that both doors cannot be simultaneously opened.
- Water plugs developing in wet upcast shafts and thereby causing temporary restrictions.

In gassy pits velocity recording instruments should be installed in each ventilating district and connected to the central control to give audible and visual displays of any changes in air velocity to the sections.

In addition all main fan installations on surface should have a back-up alarm system in the fan sub station so as to record and give a warning that the main fan has tripped especially if the motor has tripped out due to overheating. The circuitry for this system is shown in Figure 3. The alarm system cannot be solely operated from the power supply which feeds the fan motors since when the power supply trips to the motors there is no supply to feed the alarm system.

The procedures to be followed in the event of a power trip are set out below:

Power Failure

Main Fan Failure

- a. The person who discovers that the main fans have stopped must notify the most senior Official at the shaft (Assistant Manager, Mine Overseer, Engineer, etc.)

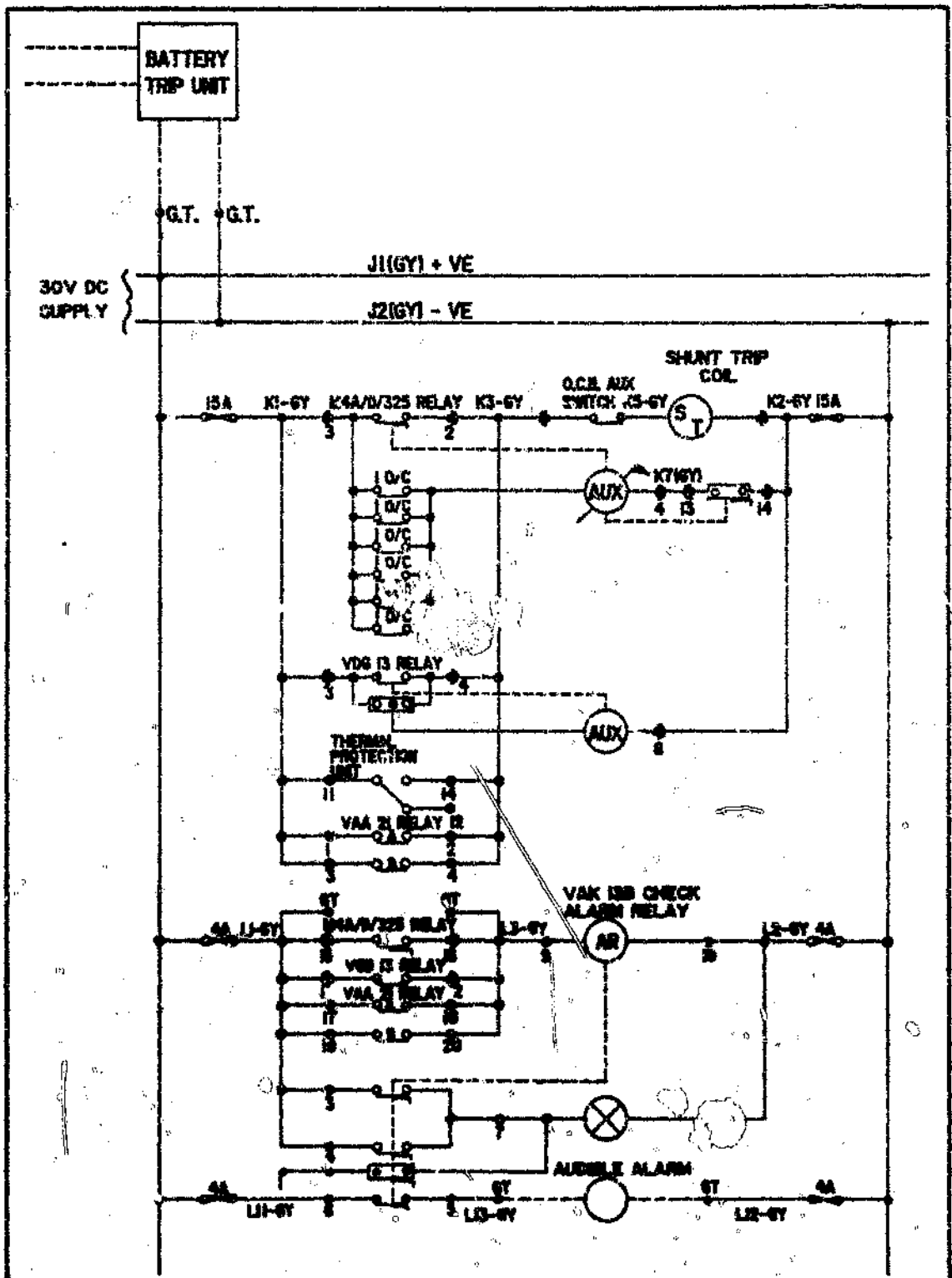


Figure 35

SPRINGFIELD COLLIERIES LIMITED

VLEI FANS No. 1 AND No. 2.

AUDIBLE ALARM - 30V DC SYSTEM IN FAN HOUSES

- b. This Official must find out what the reason for the stoppage is and when it can be restarted.
- c. In case the fans cannot be restarted immediately, the Official must notify all underground sections.
- d. The underground power in the area served by a main fan installation will be automatically tripped if two or more fans stand for longer than 45 minutes.

Total Power Failure

- a. The person in charge (Miner, Artisan, Team Leader, etc.) must immediately withdraw all the people under his supervision to the waiting place in production sections, or to a safe area where there is normally through ventilation.
- b. Notify the nearest Official, who must find out what the problem is and notify the Assistant Manager/Mine Overseer or Engineer.

In all the above circumstances the senior Official on the shaft (Assistant Manager or Mine Overseer) together with the Engineer (Section Engineer or G.E.S.) must decide how serious the situation is and to what extent people have to be withdrawn from underground. We must also notify the Mine Manager and Chief Engineer.

The following action must be taken, dependant on the instruction from the Manager/senior Official.

The Miner shall:

- a. Ensure that all persons including Engineering and other Personnel are withdrawn to the waiting place.

- b. Ensure that the power is immediately switched off in his section/s.
- c. After power has been restored, re-examine his section/s and test for inflammable gas at the following positions:
 - Inside all advancing headings (dead ends) at the faces.
 - Electrical equipment such as sub stations.
 - Flamedeen Bank
 - Auxiliary fans

Only after all the above places have been found to be free of inflammable gas may the auxiliary fans in the sections be started.

In the event of methane being found at any place in the section, the accumulated methane must be diluted by directing ventilation from the intake entrance to the affected area. The purpose is to have no more than 1.0% of methane in the last through road or in the return airway.

- d. Make out a Fireman's report and forward it to the Shift Overseer as soon as possible.

After power has been restored to the main surface fans following a stoppage of more than an hour

- a. The main surface fans shall be restarted by the Surface Electrician.
- b. Underground power to be switched on after all checks for inflammable gas has been carried out and the affected areas have been declared free of flammable gas.

- c. All Miners will carry out examinations as per initial examination at the beginning of each shift.
- d. Fireman's report to be made out by Miner and forwarded to the Shift Overseer.

Power restored after fan failure during weekends

- a. A Miner who is a holder of a Gas Testing Certificate and an Electrician shall proceed underground and restore the power to all the sections and in all the areas including substations, flamedeena, auxiliary fans and workshops.
- b. On completion of the inspection, the Miner shall fill in a Fireman's report and forward it to the Official on duty.

2.8.4 Quartz Content of Sandstone

While there is little that can be done regarding the high quartz content of sandstone layers above stooping and longwall sections, it is of advantage to Mining Engineers to be aware of the quartz content, if only to encourage them to take all possible precautions to prevent a build up of methane in and around the goaf. This applies also to sandstone bands in development ends.

2.8.3 The Goaf Area

Bleeder roads and methane drainage through boreholes to surface should be the standard procedure in maximum extraction methods of working (see Chapter 5).

2.8.6 Unworked Seams above the Mined Seam

There are many examples of large quantities of methane being emitted from unworked coal seams lying above the existing

workings (Glencoe Colliery, Durban Navigation Colliery, Cambrian Colliery, Springfield Colliery, Indumeni Colliery to quote but a few).

Methane drainage by boreholes from the lower seam to the upper seams (see Chapter 8) and by boreholes to surface (Chapter 5) have proved effective in safely removing this threat, although the former method is always fraught with the danger of methane layering in the lower workings.

2.8.7 Sealing off of Old Areas

The sealing off of old worked out areas is not in itself a difficult task and in fact takes place in all collieries at regular intervals and generally without incident.

Apart from major roof collapses or subsidences which may destroy stoppings due to the air blast, the two most dangerous conditions which arise when sealing off are the build up of explosive methane/air mixtures and an ignition source, in this instance, frictional heatings arising from the collapse of quartzitic sandstone roof.

It is often, in the case of frictional heat resulting from falls of roof, difficult to prevent such an incident and the Mining Engineer has thus to deal with the prevention of an explosive build up of methane and air in the panel.

Sealing off fires by means of sealing walls is the method most generally used to bring fires under control on South African coal mines. The reasons for this may perhaps be found in the following:

- a. It is a relatively safe method of controlling a fire.

- b. It is relatively cheap compared to other methods.
- c. It can usually be done quite quickly, especially if the panels are laid out correctly.
- d. Coal Miners are in the normal course of activities well prepared to do underground building; material and trained manpower are therefore always readily available to construct sealing walls.
- e. It offers a relatively permanent solution to the problem, particularly where panels are no longer needed for production purposes.

However, there are a few serious problems that may occur when a fire area is sealed off and these should be kept in mind, namely:

Leakage

Almost no sealing wall can be regarded as absolutely airtight, mainly because of the fact that the strata surrounding the seal is not airtight because of natural fracture planes in the coal and also because of cracks that are induced by the mining process.

Leakage becomes a real problem in multi-entrance panels that are subjected to high pressure differentials across the sealing walls.

Leakage stemming from such pressure differentials may cause a fire to remain reasonably active for a very long period because of the continuous adding of oxygen to the fire (in old sealed off panels such leakage conditions may even be the cause of new fires within the area sealed off - the biggest fire in a South African coal mine in recent years started in exactly this manner within a sealed off area).

Various techniques such as shotcreting and grouting may be used to reduce leakage. In certain circumstances, pressure equalisation chambers may also be used to reduce leakage but, in the opinion of the author, this technique has thus far not been applied in South Africa because of the practical problems that it entails (example, a sophisticated pressure regulating system has to be used, additional walls have to be built, continuous supervision is required, and so on.)

Explosions

The danger of gas explosions within a fire area or a sealed area is the most general danger usually related to the use of panels to seal off fires, particularly when open flames or glowing coal is present. This danger stems from a combination of two factors, namely:

- a. The accumulation of flammable gases such as methane, hydrogen and carbon monoxide within the panel.
- b. The diminished or interrupted supply of air that may dilute flammable gases or carry these away and thus help keep the concentration of the mixture below explosive levels.

The presence of flammable gases may be attributed to the following sources:

- a. Natural release of methane in particular (but also hydrogen, as well as other hydrocarbons) from the surrounding strata, which may be accelerated by the heat of the fire.
- b. The reaction of steam with red hot coal within the fire area, with the consequent release of hydrogen and carbon monoxide (the so called "water gas" reaction).
- c. The oxidation or burning of coal, which leads to the release of carbon monoxide.

The sampling procedures and the interpretation of gas sample results from sealed off areas are a very real problem encountered after sealing off.

When the gas mixture within the fire area becomes explosive, it is advisable to withdraw all workers from the underground working sites if explosion resistant seals are not used. The fact that the gas mixture is within explosion limits does not mean that it is necessarily going to explode, but it does mean that it is potentially explosive and that in the right set of circumstances it will indeed explode.

After seals have been completed, every effort should be made to minimise leakage. This may be done by means of vermiculite plaster, shotcreting, grouting and pressure equalisation chambers.

When explosive-resistant walls are not used, it is possible for the walls, in the right set of circumstances, to be destroyed by an explosion within the area, and for such an explosion to be further propagated as a coal dust explosion with dangerous consequences. In order to prevent the propagation of such an explosion, it is essential to take effective precautions against such an event. The precautions may be in the form of the spreading of stone dust in the area of the seals (it is proposed that a radius of at least 25 m around the seals be sprinkled with stone dust) or it may be in the form of stone dust barriers erected in strategic positions. It is also advisable to use stonedust filling between the double walls of the seal.

The sealing walls should immediately be equipped with the necessary fittings which may include the following:

- (i) gas sampling pipe(s);
- (ii) water sprinkler pipes to prevent the fire from jumping the seals (if required);
- (iii) A drainage pipe, with a valve to drain away water from behind the walls (if required);
- (iv) a pipe to maintain ventilation and establish the final seal.

The position of the sealing walls must be determined on the basis of the following considerations:

- (i) minimum risk to workers involved in construction of the seal (example bad roof, and so on);
- (ii) ease of transporting materials;
- (iii) condition of surrounding strata in terms of fragmentation, presence of seams faults, magmatic passages, and so on;
- (iv) the possibility of ventilating walls without using mechanical devices with a view to later inspection and sampling;
- (v) minimum number of walls that have to be built - every additional wall increases costs, time and leakage.

If possible, concrete walls should be reinforced (example, by means of wire mesh) particularly where explosion-resistant walls are built. In addition, the side walls should be hitched and old drilling steel should be drilled in radially and tied to the reinforcement in order to obtain a better bond at the concrete/coal interface.

If the intention is to make the sealing walls explosion resistant, the walls should be of such construction that the maximum pressure that can be expected within the sealed-off area during an explosion can be resisted. The following formula may be used for calculation purposes:

$$P_o.A_m = 2 (w + h) . l . f \quad (5-35)$$

Where:

P_o = maximum explosion pressure (MPa)
 A_m = surface area of sealing wall (m^3)
 w = width of sealing wall (m)
 h = height of sealing wall (m)
 l = thickness of sealing wall (m)
 f = shear strength of concrete or coal, whichever is the lowest (MPa)

The thickness of the concrete wall that is required can therefore easily be deduced by means of equation (5-35):

$$l = (p_o.A_m) / 2 (w + h) f \quad (5-36)$$

Civil engineers usually make use of a design shear strength of concrete which is a function of the specified uni-axial crushing strength (core strength) of the concrete; example, for concrete with a core strength of 25 MPa a design shear strength of 0,78 MPa is used, while concrete with a core strength of 15 MPa has a design shear strength in the order of 0,5 MPa. Coal on the other hand has a shear strength of approximately 5 MPa and if a design strength with a safety factor of 10 is used to allow for different seams, fragmentation during blasting, and so on, the design strength is in the order of 0,5 MPa.

In the Ermelo explosion of November 1982 several deficiencies are found with regard to the sealing of the "bad ground" area.

- The stoppings were not plastered to prevent air leaking into the sealed areas.
- No sampling pipes were installed in the stoppings and hence no samples of the air mixture behind the seals were taken to

provide Officials with a guide as to the state of the atmosphere in the a.

- The decision to seal the area was taken at junior Official level; in fact, the area was not entirely sealed since one roadway into the return was left open and no reason was given as to why this was done.

Areas are sealed off from the current workings for several reasons:

- a. The coal seam has been worked out and the area is no longer required for ventilation or travelling purposes.
- b. If still used as a ventilation district there is danger of spontaneous hearings, fires and roof falls occurring.
- c. It is not required for ventilation intakes or returns.
- d. It is necessary to ensure that the oxygen content of the air in the area is reduced to a level which will not support combustion.
- e. To reduce the areas underground requiring supervision to the minimum, thereby effectively increasing supervision elsewhere. It isolates the mine into manageable compartments.

In the case of the Ermelo Mines explosion the reason for sealing off the area would have been to isolate the "bad ground" area from the working sections and possibly to use the ventilation circulating into the "bad ground" area in the working faces on the left hand side which were in good ground conditions.

Standard procedures for sealing off old workings will assist in minimising the risk.

Stopping a working place permanently

- a. The Environmental Officer or other appointed person must be informed when mining operations cease in a panel, heading or area permanently. Adequate ventilation conditions must be maintained during reclamation activities until the walls sealing the working have been completed.
- b. Until the walls are installed, tests for methane and airflow must be made on a weekly basis by the Shift Overseer and be recorded in his log book.
- c. Prior to final sealing all boreholes and shafts shall have cables removed and, in the case of boreholes, the casings removed and they should be plugged or otherwise sealed.

Prospect boreholes to be sealed after completion. Where possible the casing must be removed. If this is not possible, the top 1 m should be removed and concreted over.

- d. Under normal circumstances, the stoppings should consist of brick walls or the equivalent, situated 1 m back from the inbye corner of the pillars forming the panel entry.
- e. A heavy gauge non-metallic sample pipe, of not more than 6 mm diameter, should be built into the upper portion of the stopping to enable the atmosphere within the panel to be sampled. The pipe must extend to beyond the first split in the panels and should be suspended against the roof.
- f. Where panels or sections have had a history of emissions of methane and where, in the opinion of the Manager, a dangerous condition may develop, the panel shall be sealed off by means of explosion-proof stoppings.

An explosion-proof stopping shall consist of two brick walls or the equivalent situated a distance apart equal to half

the perimeter of the roadway, well anchored into the roof, floor and sides. The space between them shall be tightly packed with sand, rubble or fly ash. (Under no circumstances should carbonaceous material be used).

The position and dimensions of all explosion-proof stoppings shall be recorded on the plan of the underground workings.

- g. The Manager, or his duly authorised representative, shall test the atmosphere behind the stoppings and against the roof at the stopping for methane, at quarterly intervals, and log the results on a methane record card kept at the entrance (wall) to the area, and also logging the results in a book provided for the purpose, example, Methane Register - permanent stopped workings. The record card is kept in a steel or plastic folder.

Once conditions have stabilised in the sealed area, the Manager may decide to dispense with sampling of area.

The Environmental Official must test for methane at quarterly intervals, countersign the methane record card and log the results.

Temporary Stopped Workings

The ventilation arrangements and air volumes required in temporary stopped areas during the non-productive period must be detailed in a layout prepared by the Environmental Officer or other appointed person.

Permanent stoppings/brattices must be built up to the second last through road - no temporary brattices should be used.

All entrances must be barricaded off and "NO ENTRY" signs must be displayed on the barricades.

Such temporary stopped workings must be checked on a weekly basis by the Shift Overseer for methane and in the Shift Overseer's log book.

The Environmental Officer or other appointed person must visit the temporary stopped area at monthly intervals and submit a report on the ventilation conditions.

Where old or abandoned workings are adjacent to a section which is being worked and the area is known to be giving off methane freely, it is advisable to withdraw workers from the operating section until all seals are properly established and air samples taken from the sealed area reveal that an explosive mixture does not exist behind the seals.

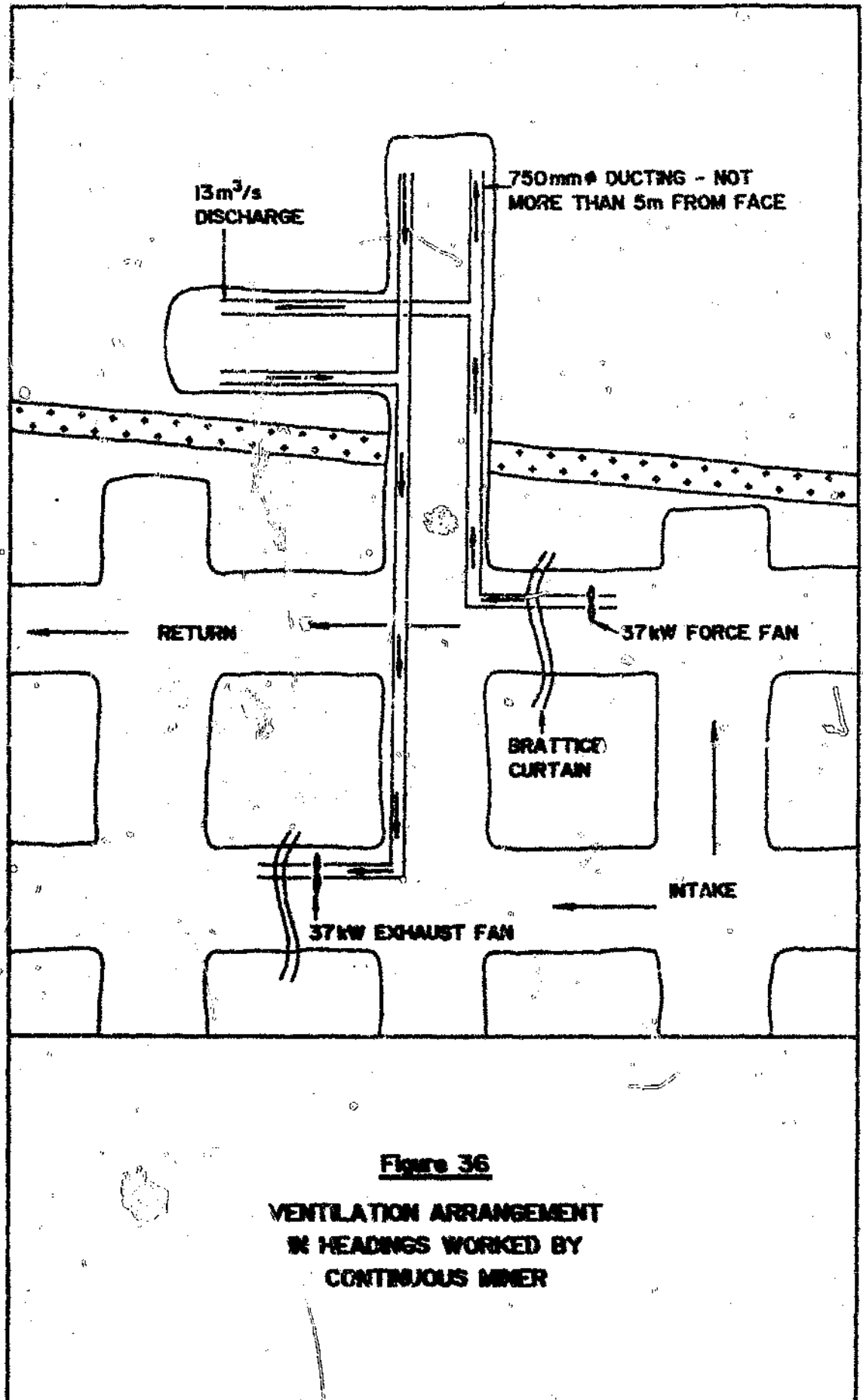
2.8.8 Self Rescuers

The correct use of self rescue apparatus will save lives in the event of an explosion since many deaths after an explosion are caused by carbon monoxide poisoning.

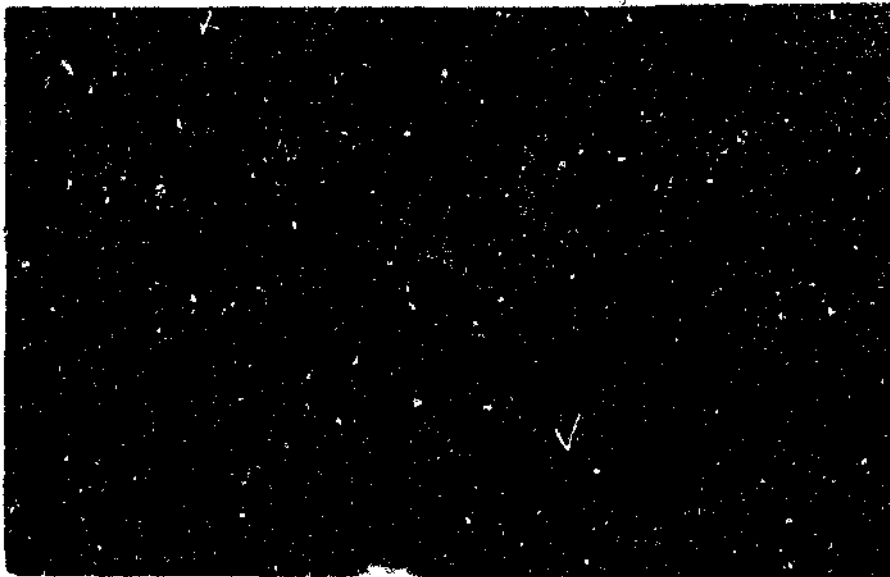
2.8.9 Ventilation of headings which have penetrated geological disturbances

Figures 36, 37, 38 and 39 depict the ventilation methods suggested for headings being advanced by continuous miners in both high and low seam conditions. The basic aim is to deliver the maximum quantity of ventilation into the roadway so as to dilute any methane which may be present in the face. 37 KW fans delivering $10-13 \text{ m}^3/\text{second}$ through 750 mm diameter ducting should be used. Ducting should be extended to within 5 metres of the face.

Evidence given at inquiries indicates that mine Officials do not take seriously the standards of ventilation, quantity of air and







"Boast not thyself of tomorrow: for thou knowest not what a day may bring forth".

Anxious relatives and friends gather at the pithead at Senghenydd, October 14, 1913. A disastrous coal dust explosion (the second at this colliery in a decade) claimed the lives of 439 men.

The ignition source was claimed to be either an electric or frictional spark.

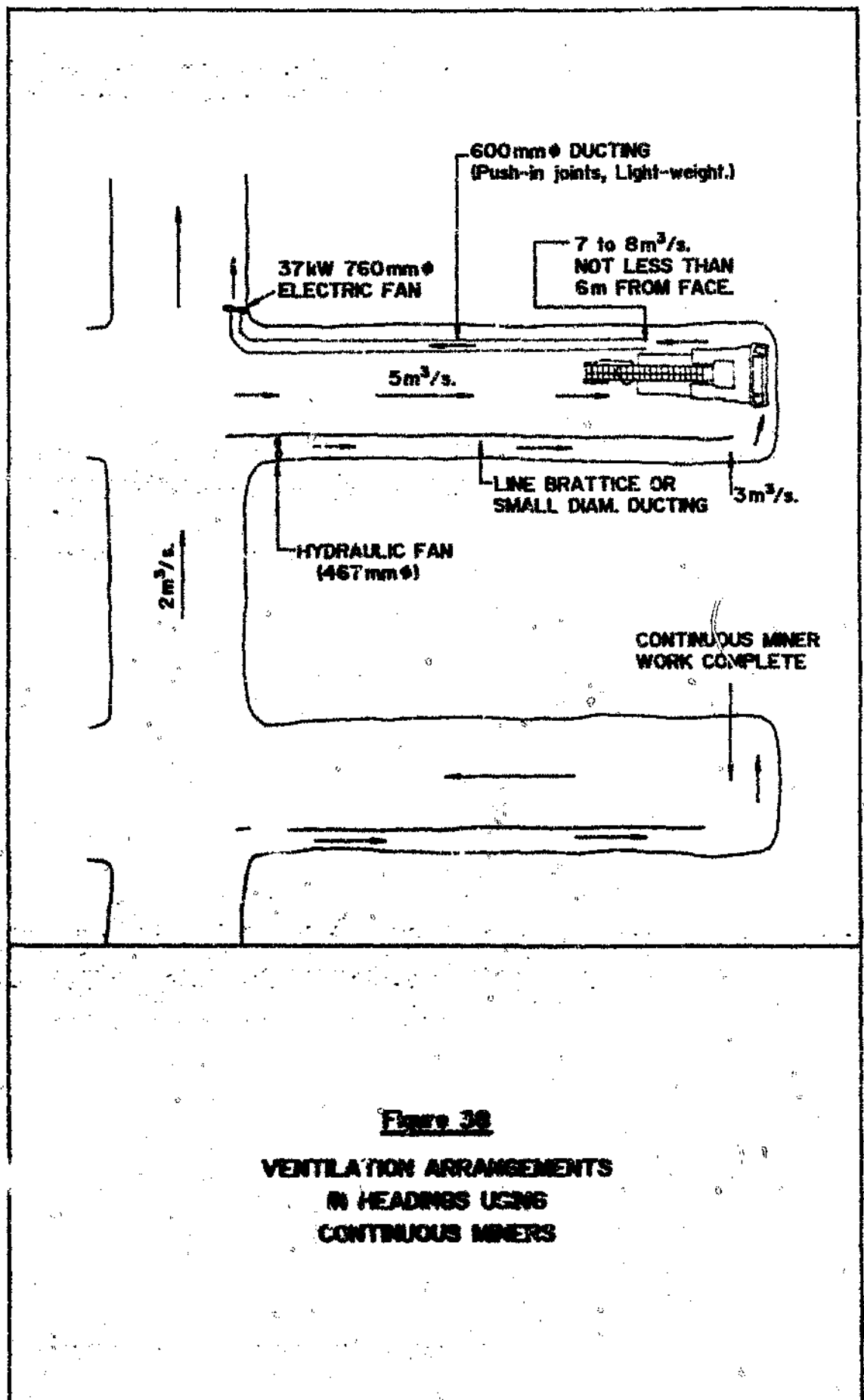


Figure 38

**VENTILATION ARRANGEMENTS
IN HEADINGS USING
CONTINUOUS MINERS**

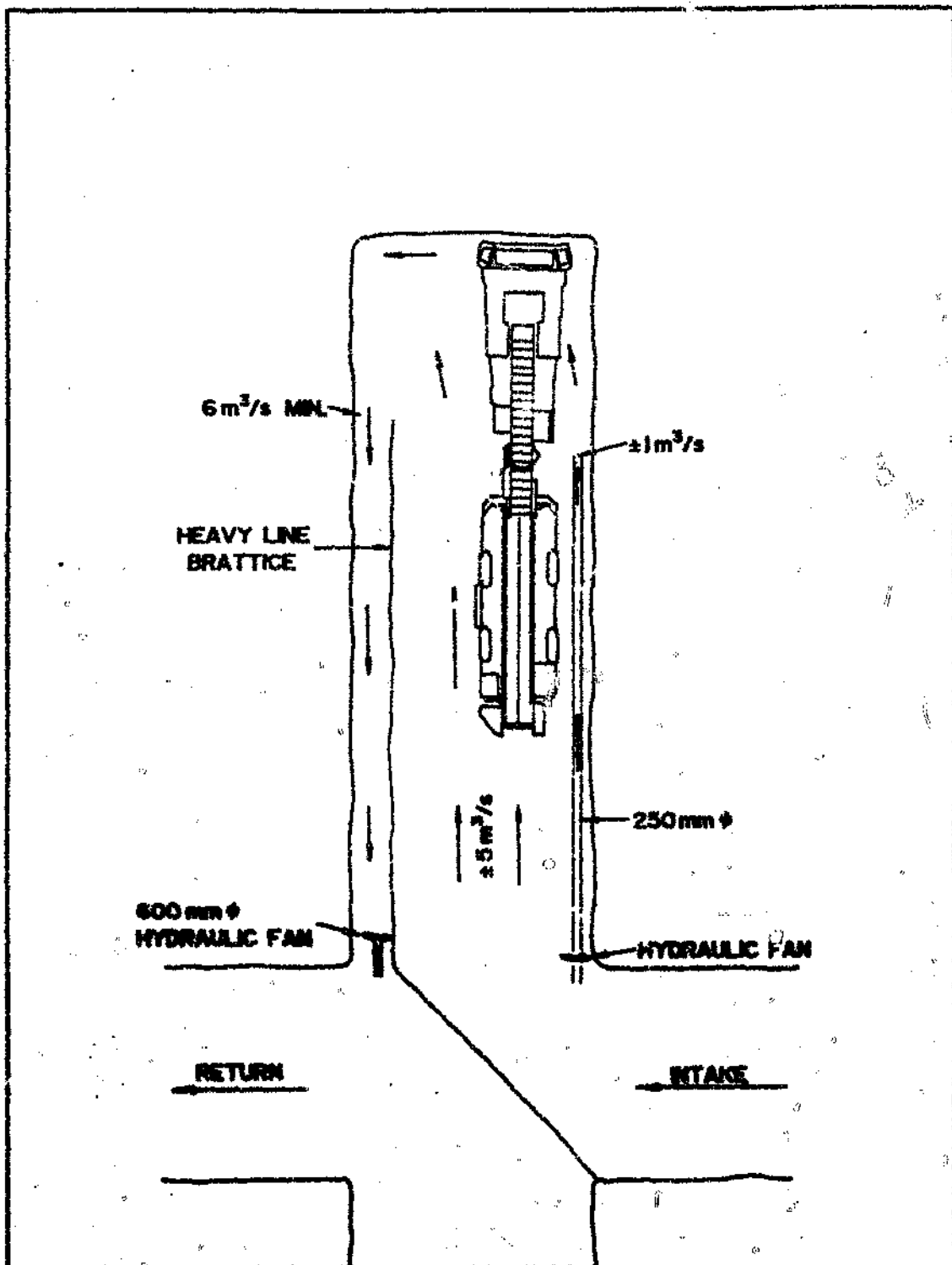


Figure 39

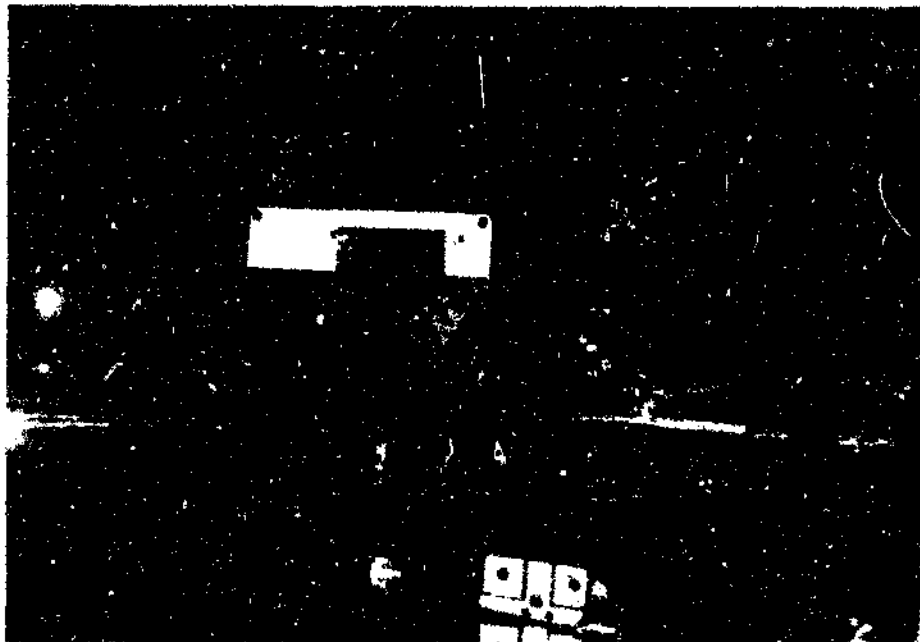
**VENTILATION ARRANGEMENT
IN HEADINGS WORKED BY
CONTINUOUS MINER**

methods of dust suppression used on continuous miners and coalcutters. In fact there would appear to be a lack of standard procedures on collieries since these are never called for nor produced as evidence in the case of ignitions.

If mine procedures are to be used to hold Officials responsible for adequate face and section ventilation, then these Officials should be equipped with instruments to measure and calculate air velocities and quantities. Honzech type velometers should be standard issues to Miners and Shiftbosses for determining quantities of air in ducting into each face.

2.8.10 Continuous Miners

All continuous miners should be equipped with continuous recording methanometers, the heads of which are mounted in the cutting head not more than 1.5 metres from the cutting drum. The methanometer is mounted in the Operator's cab as shown in the photograph below.



The digital read out is clearly observable by the Operator at all times. Flame safety lamps are difficult to read and are not recommended for use on mobile machines. Table 5 below shows the normal settings on the automatic firedamp detector at which the machine will cut out, together with details which indicate the state of the Automatic Firedamp Recorder.

Table 5 Machine Mounted Methanometer MKIII

Indications

00	or Numeric = % CH ₄ present
F	AC supply fault
F ₁	Display internal fault
F ₂	Power supply to head fault
F ₃	Incorrect output from head
F ₄	Battery completely discharged
L	Low battery
O	Over 3% CH ₄ present
P	Pilot tripped (above pre-set value)
A	Alarm (between pre-set alarm and pilot)

Push recall button:

P	Pre-set pilot level
A	Pre-set alarm level
1-9	Memory recall max CH ₄ levels

Range: 0-3% v/v CH₄

Detector head to be calibrated approximately every 350 working hours.

2.8.11 Standard Procedures

Every mine should have a series of standard procedures which

should be updated every six months. More importantly the Training Department should have copies which should be used to train all employees at the mine.

2.8.12 Mining Experience

Mine Management who place new employees in positions of responsibility before ensuring that they are adequately trained to the tasks to be performed do themselves, the colliery, and the employees a grave injustice - particularly when their work entails dealing with gassy conditions which may be present in conjunction with an ignition source.

This premise is supported by the evidence of the Bosjespruit Colliery ignition in which it was the Miner's first day at the colliery. No evidence exists showing that this new employee had undergone a period of training.

2.8.13 Report on the state of the environment after an explosion

Following the frictional ignition in the goaf at Springfield Colliery (1981) detailed gas samples and air quantities were recorded. The Mining Engineer is thus able to analyse these results and arrive at conclusions as to the adequacy of the ventilation versus mine or industry standards and note the state of the atmosphere in the section. For instance, the air quantities measured in the return airway were considerably lower than the standards. Additional air was circulated into the section by opening a regulator. Subsequently, it was established that one of the main surface fans had tripped out.

The importance of sampling and testing for the following conditions is highlighted:

- Intake, face and return air quantities.
- Velocities of air in fan ducting and then quantities in the ducting (high velocities will ensure the air sweeps the face clear of dangerous percentages of methane).
- Distance of ducting from the faces.
- Position of auxiliary fans.
- State of atmosphere with respect to percentage oxygen, methane, carbon dioxide and carbon monoxide in all parts of the section.
- Details on ventilation appliances.
- Condition of picks on coalcutters, continuous miners and sheavers.
- State of all automatic firedamp recorders on mobile production machines.

When the ventilation is disrupted in a gassy section methane will build up rapidly.

2.8.14 Cutting Tools

The presence of quartzitic sandstone in the roof and floor or in lenses in the coal seam itself calls for a high degree of supervision, not only in respect of ventilation and dust suppression, but especially the conditions of cutting picks. Where picks exist with the tungsten carbide either worn or broken off these should be replaced immediately with new picks thereby lessening the possibility of frictional heating as an ignition source.

Recent data obtained with a single chisel bit cutting into sandstone is shown in the accompanying graph (Figure 40). The drum speed was 47 revolutions per minute with a corresponding bit speed of 3.33 metres per minute. The depth of cut was adjusted to 5 millimeters.

The graph shows the number of strikes, averaged over a number of trials, that were required to produce ignition as a function of bit wear. It can be seen that the number of strikes decreases sharply where bit wear corresponds closely with the first exposure of the steel shank to the cutting action. This suggests that modification in bit design to prevent early exposure of the shank material would moderate the tendency for cutting bit action to cause ignitions. This possibility is being explored using the two bit designs for reducing shank exposure by enlarging cutting tips of chisel bits and plumb-bob bits which are shown in the accompanying drawing (Figure 41). In the drawing, chisel bit (a.) and plumb-bob bit (c.) are standard designs. Chisel bit (b.) and plumb-bob (d.) are the newer designs.

The main feature of both of the designs pictured for each bit type is a modification in tip geometry to prevent early exposure of the shank during the cutting cycle. The plumb-bob design has recently been evaluated in laboratory studies using the modified bits mounted on the Joy shearer drum. Both the conventional plumb-bob bit and a modified "mushroom" plumb-bob design were mounted on the drum at diametrically opposed points and tested against a sandstone block.

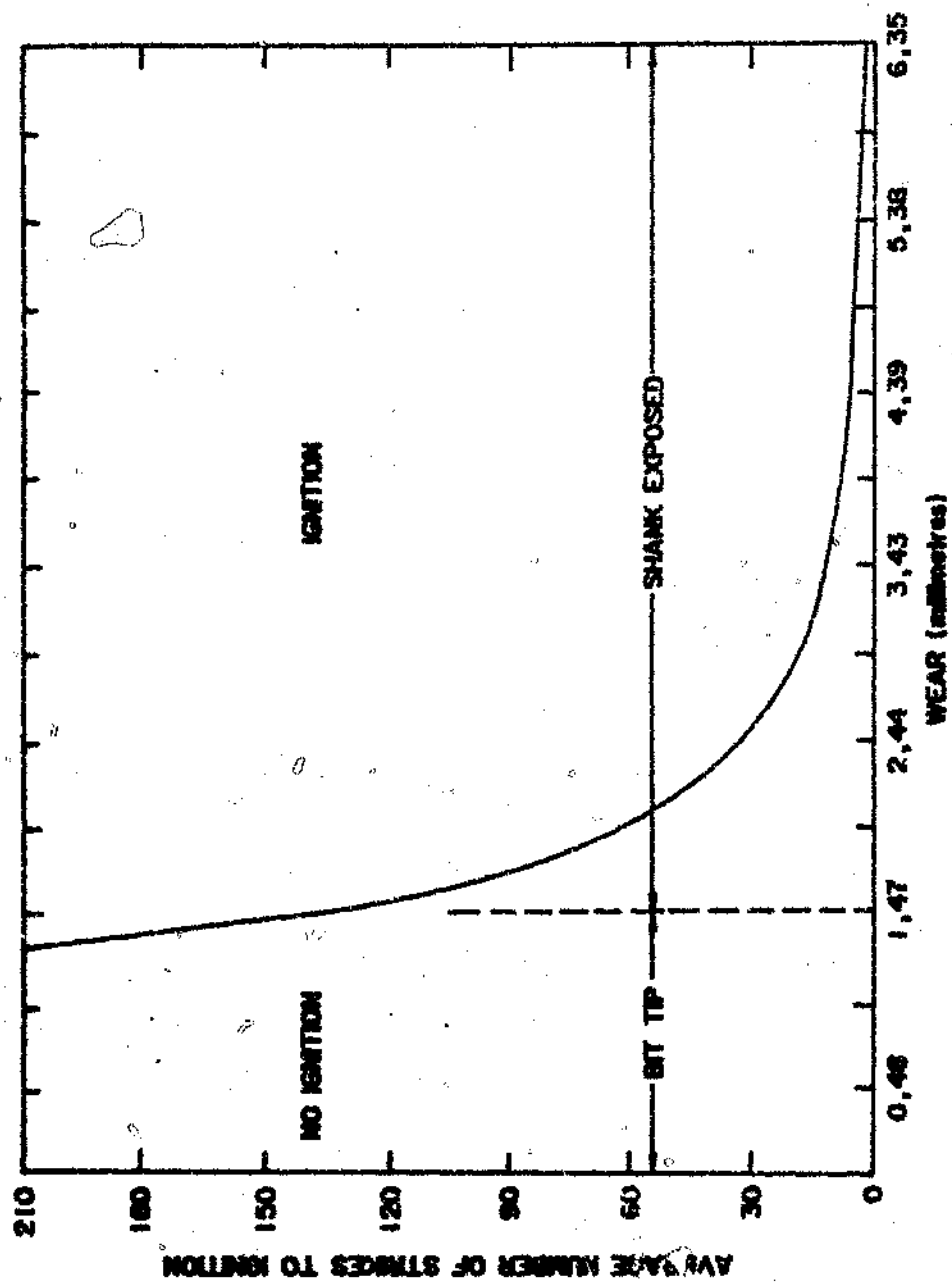
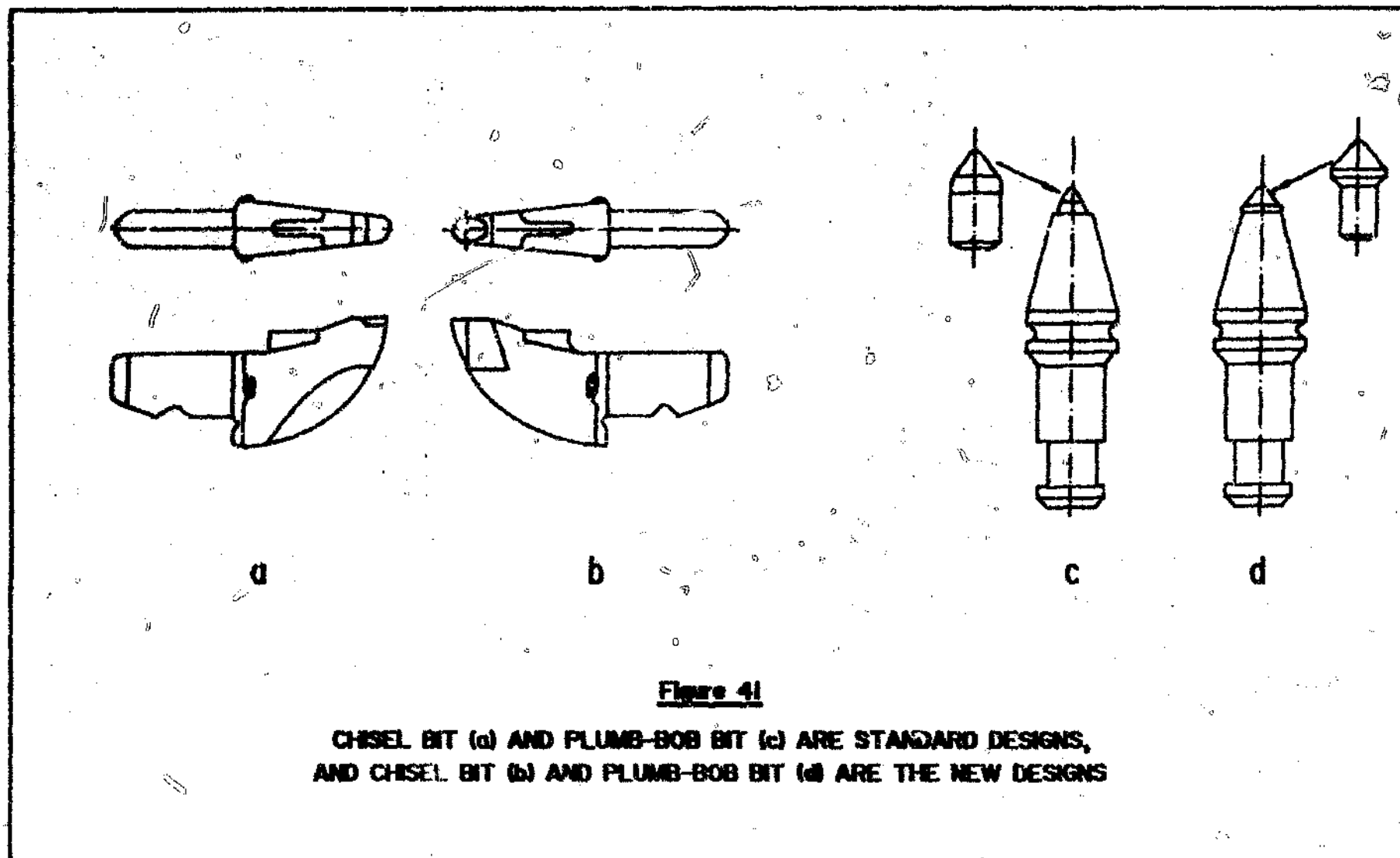


Figure 40

**EFFECT OF CUTTING BIT WEAR IN INCREASING
THE POTENTIAL OCCURRENCE OF FRICTIONAL
IGNITIONS OF METHANE-AIR MIXTURES**



2.9 CONCLUSIONS

Frictional heat and sparking has been the cause of serious methane ignitions and explosions on South African collieries. It is difficult to eliminate this ignition source in the goaf in pillar extraction and longwall workings. However, the practice of bleeding ventilation over the goaf and using boreholes drilled from surface into the goaf to drain off methane will assist in ensuring that dangerous methane/air mixtures do not develop in these areas. There is a need to be aware of the quartz content of the overlying strata where second mining methods are practiced, since this aspect has a direct bearing on the degree of frictional heat developed when the goaf caves.

Ventilation plays a major role in preventing the formation of explosive methane/air mixtures. In pillar extraction ventilating air should be directed along the goaf line using auxiliary fans and ventilation brattice curtains. The use of both exhaust/forcing fans in the development ends mined by continuous mining machines is recommended. Fan ducting should terminate no further than 5 metres from the face in order to ensure that the ventilating current sweeps across the face. The use of automatic firedamp detectors and velometers to monitor environmental standards on site is important.

Supervision and training is often neglected but means of improving this aspect of the operations by the introduction of formal courses are well documented. Unless supervisors set an example and test for methane regularly, explosions will continue to occur.

Cutting picks which are tipped with tungsten carbide, which revolve during cutting and which are water-cooled with the water spraying behind the pick to cool the hot smear will reduce the possibility of ignitions.

More planning and thought needs to be given to the sealing off of old worked-out areas.

2.10 REFERENCES

1. Oakes, A., Flint, J.D. and Kinghorn, J.; Report on a visit to investigate the application of continuous mining machines in shortwall and pillar extraction. Internal Report Anglo American Corporation. 1975.
2. Morris, Dr. R.; Methane ignitions - A Worldwide Phenomenon. Volumes I and II. A treatise submitted to the Department of Mining Engineering, University of Nottingham, for the degree of Doctor of Science. 1984.
3. Strauss, S.J.; Verbal Communications. 1989.
4. Fauconnier, Dr. C.J.; Die Behaar van Ondergrondse Vure in Suid Afrikaanse Steenkoolmyne. Voorgele ter vervulling van die vereistes vir die graad Doctor in Ingenieurswese in die Fakulteit Ingenieurswese, Universiteit van Pretoria. Pretoria. 1981.
5. Inspector of Mines, Natal. 748/68. Durban Navigation Collieries Limited. 21st September 1968.
6. Inspector of Mines, Heidelberg. IMHA 233/82. Bosjesspruit Colliery. 9th March 1982.
7. Inspector of Mines, Heidelberg. IMHA 308/81. Springfield Colliery. 20th March 1981.
8. Inspector of Mines, Ermelo. Ermelo Mines Services (Pty) Limited. 12th November 1982.

9. Browning, Eric J.; Frictional Ignitions. Fourth International Mine Ventilation Congress. Brisbane. Queensland. 1988.
10. Watson, R.W.; Prevention and Suppression of Gas Explosions in Mines. Explosions and Fires in Coal Mines Symposium. Aust. I.M.M. 1981.
11. Stafford, Samuel. Coal Mine Ignitions of Methane by Friction show a Five-Year Rise. Australian Institute of Mining and Metallurgy. Ignitions, Explosions and Fires in Coal Mine Symposium.
12. Browning, E.J.; Frictional Ignitions. Fourth International Mine Ventilation Congress. Aust. I.M.M. Melbourne. 1988.
13. Anderson, F.G., Evans, R.L. and Felinso, R.G.; A Study of Dust Control Methods for Continuous Mining of Coal. Bureau of Mines, Information Circular No. 8205. United States Department of the Interior. 1963.
14. Kelley, John E. and Forkner Bob L.; Ignitions of Coal Dust, Air and Methane from Abrasive Impacts of Hard Minerals with Pneumatic Pipeline Steel. United States Department of the Interior. Report of Investigations 8201. 1976.
15. McVey, S.A.; Report on Ignition Potential of Sandstone Sample from Ermelo Mine Services (Pty) Limited. Internal Report No. IR390/86. Project No. CM3C10. Chamber of Mines of South Africa Research Organisation. 1986.
16. McVey, S.A.; Report on possible causes of Ignition of Methane in the Goaf in South African Collieries. Internal Report No. IR 89/86. Project No. CM3C10. Chamber of Mines Research Organisation. 1986.

17. Ramsay H.T., Wass, C.A.A. and Hartwell, F.J.; A Summary Account of the Manner and Frequency of Ignition of Firedamp in British Coal Mines. The Mining Engineer No. 60. September, 1965.
18. Smart, A.G.; Photographs of Auxiliary Fan Curtains and Automatic Firedamp Recorders. Arno Colliery. 1989.
19. Viljoen, P.L.J.; Case Histories and Preventive Measures with Relevance to Methane Ignitions/Explosions. Symposium on Methane Detection and Explosion Prevention. Mine Ventilation Society of South Africa. 1988.
20. Inspector of Mines, Heidelberg. H.D.16. N/C 72/77. Ermelo Mine Services (Pty) Limited. September 1977.
21. Inspector of Mines, Heidelberg. 437/82. Springfield Colliery. May 1982.
22. Inspector of Mines, Heidelberg. 723/83. Springfield Colliery. August 1982.
23. Inspector of Mines, Heidelberg. 1136/45. Consolidated Collieries Limited. October 1945.
24. Inspector of Mines, Dundee. 218/75. Durban Navigation Colliery. April 1975.
25. Inspector of Mines, Dundee. 232/52. Hlobane Colliery, No. 2 Pit. March 1952.
26. Inspector of Mines, Dundee. 288/79. Balgray Colliery. April 1979.
27. Inspector of Mines, Dundee. 836/65. Durban Navigation Colliery. September 1965.

28. Inspector of Mines, Dundee. 245/52. Hlobane Colliery, No. 2 Pit. March 1952.
29. Inspector of Mines, Dundee. 262/81. Balgray Colliery. May 1981.
30. Inspector of Mines, Dundee. 382/81. Balgray Colliery. July 1981.
31. Inspector of Mines, Heidelberg. 53/85. Springfield Colliery. June 1985.
32. Inspector of Mines, Heidelberg. 41/81. Ermelo Mines (Pty) Limited. April 1981.
33. Inspector of Mines, Heidelberg. 49/80. Ermelo Mines (Pty) Limited. November 1980.
34. Inspector of Mines, Heidelberg. 11/80. Usutu Collieries. February 1980.
35. Coward, H.F. and Wheeler, R.V. (1925); The Ignition of Firedamp. Safety in Mines Research Board, Paper No. 32.
36. Coward, H.F. and Ramsey, H.T. (1965); Ignitions of Firedamp by Means other than Electricity and Explosions: A Review. Safety in Mines Research Establishment. Report No. 231, October.
37. Bowden, F.P. and Lewis, R.D. (1958); Ignition of Firedamp by Stationary Metal Particles and Frictional Sparks. Engineering. August 22, 1958. pp 241-242.
38. Hartman, I., Nagy, J., McGibbeny, E.B., and Christofel, F.P.; Ignition of Coal Dust by Permissible Explosives. Bureau of Mines. R.I. 4873, 1952, pp 21-22.

CHAPTER 3**IGNITIONS OF FIREDAMP BY LIGHTNING AND STRAY CURRENTS****3.1 INTRODUCTION****3.2 THE PHENOMENON OF LIGHTNING-RELATED INCIDENTS****3.2.1 Historical Background****3.2.2 Regional Ground Flash Density****3.2.3 Lightning as an Initiator of Methane Explosions****3.2.4 The Penetration of Lightning Disturbances into an Underground Mine****3.2.5 Hazards Associated with Abandoned Workings****3.2.6 The Effect of a Drop in Barometric Pressure****3.2.7 Earthing Properties of Roofbolts and Mine Floors****3.3 THE PHENOMENON OF IGNITIONS DUE TO STRAY CURRENTS OTHER THAN THOSE DUE TO LIGHTNING****3.3.1 Stray Currents****3.3.2 Risk of Ignitions as a result of Stray Currents****3.4 NUMBER AND DATES OF INCIDENTS****3.5 DETAILS OF INCIDENTS/PHENOMENON****3.5.1 Coalbrook Collieries Limited****3.5.2 Ermelo Mines Services (Pty) Limited****3.5.3 Usutu Collieries Limited****3.6 SUMMARY OF PRACTICES REVIEWED****3.7 PRECAUTIONS TO BE ADOPTED****3.8 CONCLUSION****3.9 REFERENCES**

3.1 INTRODUCTION

Lightning-related incidents in shallow coal mines have led to several methane explosions and to loss of life. Lightning can give rise to high potentials between points near to one another underground in shallow collieries. Over the years both premature ignition of explosives in charged faces and ignitions of methane air mixtures have occurred due to lightning in mines.

The mechanisms which link lightning disturbances (and a drop in barometric pressure) and stray currents to methane explosions are examined with particular reference to underground conditions prevailing at the time of the lightning surges.

The known incidents are listed and several case studies have been analysed.

The chapter concludes with a discussion of the measures which should be taken to prevent the ignition of methane by lightning surges.

3.2 THE PHENOMENON OF LIGHTNING-RELATED INCIDENTS

3.2.1 Historical Background

In recent years, the South African Coal Mining Industry has experienced a considerable number of underground incidents or disturbances, which were frequently related to the passage of lightning storms on the surface. These incidents included electrical shocks or visible sparking from underground equipment, premature detonation of explosives and methane explosions. These incidents were particularly prevalent in shallow collieries and were of considerable concern to the various mining groups concerned. A number of wide-ranging investigations were initiated by certain of these companies and these culminated in 1978 in the formation of a co-operative sub-committee of the Explosions Hazards Advisory Committee of the South African Coal Mining Research Controlling Council - with a view to carrying out an in-depth study of the problem and to formulating appropriate safety measures.

In the ensuing years, this Sub-committee initiated a number of actions, including:

1. The implementation of comprehensive procedures for reporting and investigating specific incidents.
2. A laboratory study of the susceptibility of electric detonators to ignition by lightning-type surges.

3. A series of underground measurements in collieries with a view to investigating the nature and magnitude of lightning surges in such situations - including detonator circuits.

Arising out of these studies, several measures have been implemented as a means of improving safety. These include the preparation of a "Code of Practice for the Avoidance of Hazards Underground due to Lightning" which has been issued from the office of the Government Mining Engineer to all collieries, as well as the development of a more effective lightning warning unit. The latter has proved to be very effective in several collieries and has prevented injuries to miners.

The earliest known methane ignition as a result of lightning initiation was at the Schoongezicht Colliery on the 2nd December 1960.

During tunnelling operations in the Swiss Alps, Berger (1977) demonstrated that lightning strikes on the surface could cause currents to penetrate to sufficient depths to initiate the firing of detonators. The incidents mentioned below illustrate that a similar situation could prevail in the shallow coal mines of the Eastern Transvaal.

3.2.2 Regional Ground Flash Density

Plate 1 depicts the coalfields of South Africa whilst Plate 2 shows the lightning density map for South Africa derived by the Lightning and Stray Current Sub-Committee of the Explosion Hazards Advisory Committee of South Africa.

This extensive research yielded invaluable data based on the number of lightning flashes per square kilometre per annum. This highlighted the vulnerable areas such as:

Piet Retief	13
Carolina and Utrecht	10
Ermelo	9
Bethal, Middelburg and Witbank	8

The lightning density map allowed for a lightning warning system to be implemented at those mines which became an area of concern.

An examination of the recorded incidents reveals that most of the collieries are situated in the high density areas of lightning strikes and lie at shallow depths.

The practice of ventilating old workings with just sufficient ventilation to "keep the panel fresh" can lead to the build-up of explosive quantities of methane in the panel. Sparks as a result of stray currents arising from lightning strikes could cause a methane explosion.

3.2.3 Lightning as an Initiator of Methane Explosions

Methane explosions are believed to be initiated underground when lightning causes electric sparks with sufficient energy in proximity to pockets of methane, to ignite methane/air mixtures of the appropriate proportion.

Lightning-related sparking underground is thought to arise in a variety of ways. For example, transient voltage surges on a metal structure underground can create sparks where small discontinuities occur in the metal structure, such as along a conveyor system or between a strainer wire and roofbolt. Sparks could also occur at the extremities of such structures. In other instances, the high potential gradients developed during the dissipation of lightning currents in the rock strata could cause sufficiently energetic sparks to ignite critical methane mixtures in gas pockets.

A lightning discharge is a discharge of electricity through a gas at atmospheric pressure and can take three forms:

- a. A discharge between a part of the atmosphere having a volume charge of electricity, generally a cloud, and the ground.
- b. A discharge between two parts of the atmosphere, each part having a definite volume charge of electricity, but of opposite signs.
- c. A discharge from a part of the atmosphere having a volume charge into a part of the atmosphere in which no initial volume charge is present.

In the first case, the ground forms an electrode but in the two latter cases, the discharge does not pass between electrodes.

The theory of lightning is expressed as follows:

Figure 1 is a diagrammatical representation of the field of force about a region of the atmosphere, A, containing a volume charge of electricity, say the cloud of a thunderstorm. For simplicity the volume is represented as a sphere placed some distance above the ground, the latter being perfectly level and smooth.

The region of greatest electrical intensity is obviously at B, the lowest point of the cloud. There the air will "break-down" first and ionisation occurs. As soon as this happens the lines of force move towards the conducting region and in consequence the field there increases, especially at the upper and lower parts of the conducting region. This is shown diagrammatically in Figure 1b.

The increase of force causes further ionisation and the conducting region extends along the lines of force, both upwards into the cloud and downwards towards the earth, as shown in Figure 1c. (Larmor and Larmor 1914).

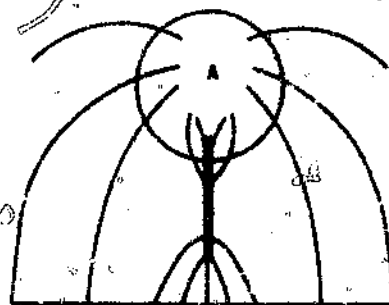
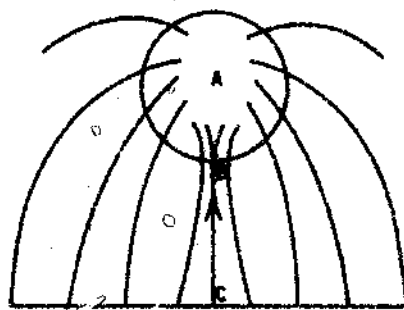
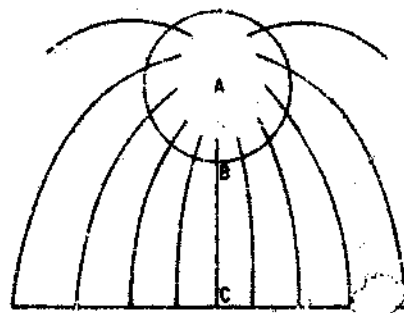


Figure 1

AFTER LAMOUR AND LAMOUR (1914)

Methane explosions are believed to be initiated when lightning causes electric sparks with sufficient energy in proximity to pockets of methane/air mixtures with the appropriate proportions i.e. 5 - 15% CH₄. The minimum ignition energy for methane is thought to be about 0.25 MJ, having a 540°C ignition temperature (Lightning and Stray Currents Sub-Committee Report, 1986).

The high potential gradients developed during the dissipation of lightning currents in the rock strata could lead to sparking. This problem will naturally be worse if, during the lightning storm, power to the mine is interrupted (as was the situation in the first case study discussed) and the ventilation fans stop allowing for an accumulation of methane. It is also more likely to occur in abandoned workings where the ventilation is often poor.

3.2.4 The Penetration of Lightning Disturbances into an Underground Mine

Figure 2 illustrates several important features of a typical colliery mining situation and depicts several possible lightning disturbance mechanisms.

In the event of a lightning strike on the surface close to a working area, lightning currents could penetrate into this area through direct conduction in the intervening soil and rock media. Any large conductive structures underground (such as conveyor units or power cables), as well as the mine excavations, cause local distortion of a current distribution in the underground strata. This leads to steep potential gradients in close proximity to such underground (semi-earthed) structures. Investigations into a number of lightning-related incidents have highlighted the possibility that this mechanism could have been involved.

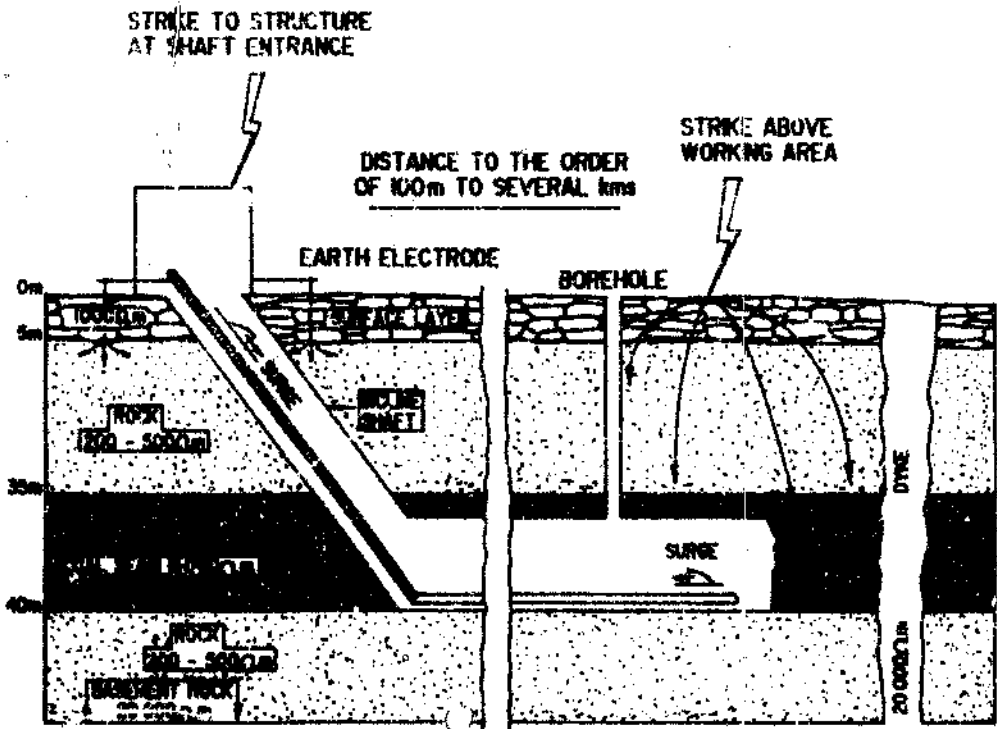


Figure 2

**A COLLIERY SIMPLIFIED SITUATION - DEPICTING
HOW LIGHTNING SURGES MAY ENTER COLLIERIES**

The circumstances of a number of such incidents have also indicated the possibility that local perturbations of the terrain - such as boreholes, dykes and geological faults - could either increase the penetration depth of lightning current or locally modify their distribution. A further variation of this mechanism could include the temporary redistribution of an electrical charge immediately after a nearby lightning strike, during the subsequent collapse and redevelopment of the thundercloud and lightning electric fields. This again leads to surge currents on underground conductive structures.

A second mechanism whereby lightning surges could enter a mine is through direct strikes to the structures at a shaft entrance or at ventilation shafts.

This sudden rise in potential would propagate as a travelling wave (voltage surge) down into the mine via shaft structures such as power cable armouring, water pipes and conveyor systems.

A third possible mechanism of a lightning disturbance could entail direct electromagnetic induction into detonator/exploder circuits. Very high electromagnetic fields are associated with the discharge of the lightning channel.

In the event of direct strikes in close proximity to susceptible circuits, the surrounding soil medium would be "illuminated" by such fields. These fields could lead to the possibility of surge current induction into the detonator/exploder circuits.

The study of rock strata, of South African coal mines, from the surface to the coal seam and below (exploration borehole logs) has revealed a typical pattern of horizontal layered sandstone and shale with minor coal seams above the No. 2 seam, which is the most frequently worked. The resistivity pattern is accordingly complex.

Geophysical reports of Arnot Colliery and Bank Colliery, recorded by the Lightning and Stray Current Sub-Committee, records various resistivity and a few permittivity values for coal and the other strata encountered in the Eastern Transvaal coalfields. The very high resistivities given for coal (particularly when dry and measured perpendicular to the bedding planes) are remarkable when compared with the values for the overlying and underlying strata.

Consideration of these figures makes clear the possibility that under some circumstances the coal seam (whether partially removed by mining or not) may have large lightning-sourced potential impressed across it from roof to floor, acting like the dielectric in a capacitor.

These geophysical reports record the following:

i) Arnot Colliery

Surface sandstones 1000 to 10 000 Ohm-m; main sandstone shale sequence 00-400 ohm-m to depths of "several tens of metres".

ii) Bank Colliery

Ecce sequence 400-1000 ohm-m. Dry soil layer (10 000 ohm-m) on surface. Clay-less than 50 ohm-m. Intercalations of shales, siltstones and fine grained sandstones with appreciable silt content: 400 ohm-m. 700-900-1200 ohm-m: coarse grained well-sorted sandstone; 200-2400 ohm-m: grit or coarse sandstone.

No. 2 seam coal: 15 000 to 30 000 ohm-m. Mine floor resistivity 400-600 ohm-m dry, 100 ohm-m wet. Basement rocks are of comparable resistivity to that of coal.

The geological layout of a typical coal mine in the Witbank area is shown in Figure 3.

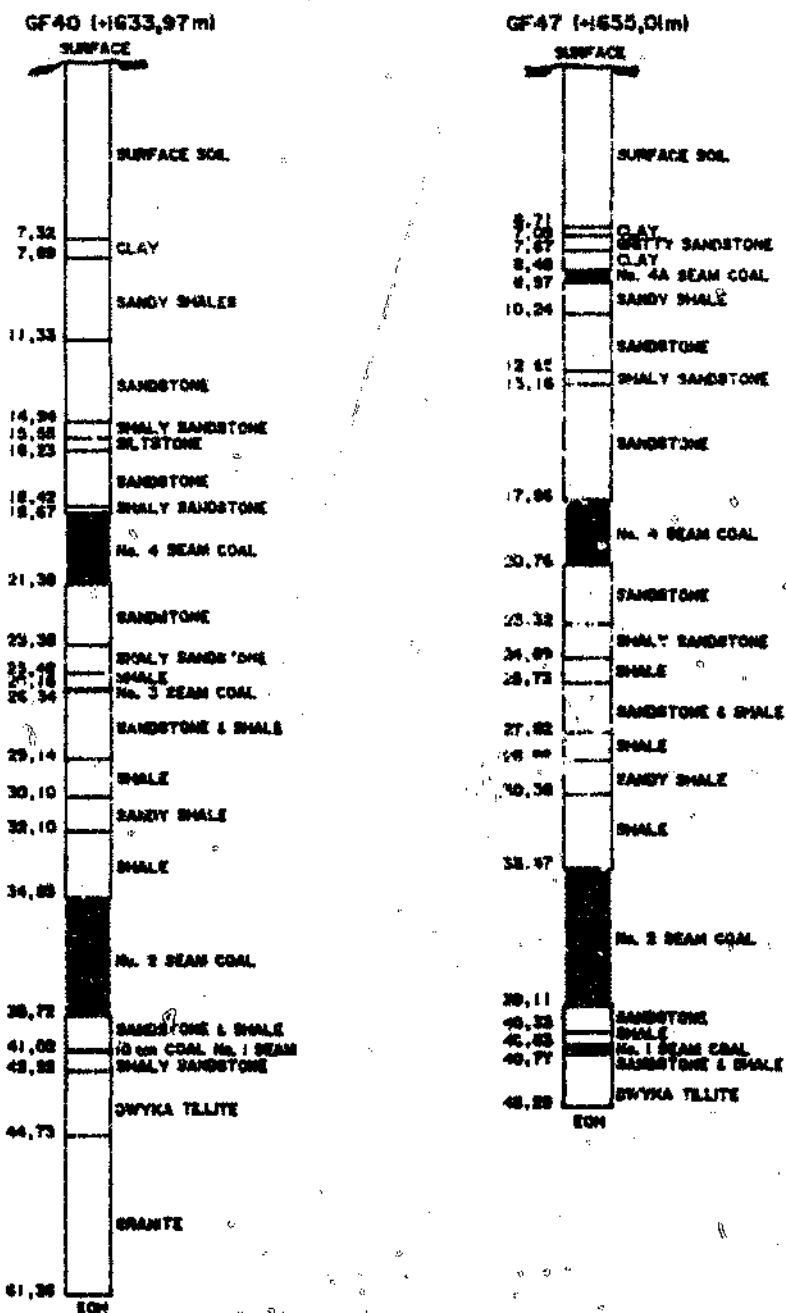


Figure 3

TYPICAL GEOLOGICAL PATTERN OF
A COAL MINE NEAR WITBANK,
AFTER NAUDE (1984)

Not to scale

The penetration depth of lightning current is proportional to the resistivity of the rock (Berger, 1977), that is, the higher the resistivity the greater the depth of penetration. If one examines Figure 3, a soil-sandstone-shale-coal-sandstone-shale coal pattern is observed. The resistivities of the ground layers are considerably lower than that of the coal seams; 0.300 to 1.0 k m in relation to 15 to 1000 km of the coal (Caldenhuyts et al, 1985). This explains the penetration depth of lightning above the coal; in other words, the criterion of a shallow coal mine. Certain "aiding factors" such as dykes, which have a high resistivity of approximately 50 k m and boreholes may influence the depth of penetration.

Direct lightning strikes to earth in the vicinity of shallow underground collieries have over the last fifteen years been the cause of a number of premature ignitions of charged shoeholes and also of methane explosions; in most cases the incidents have not been of major severity but have nevertheless occasioned serious concern.

The result of such lightning strikes is that high voltages may appear transiently at places within the workings of a colliery and cause the firing of detonators or sparks which may ignite methane-air mixtures when these are present.

The detailed mechanisms involved in creating these two generic effects in underground mines are little by little coming to light as a result of study and research.

For the present the theories remain in general that high potentials and resulting sparks or other current flow effects result from:

- a. direct flow of lightning current through the rock formations surrounding a working coal face (and in the face itself) due to a strike close by; and/or

- b. the transfer of a high potential by metalwork in the mine from a more or less remote point (for example, an above ground conveyor gantry) to the working face, following a direct lightning strike to the above ground steelwork.

A voltage of about 50 kV has been measured between a coal face and earthed metalwork in a colliery due to lightning.

On various occasions men have received electric shocks from roofbolts or machines during lightning storms.

Detonators (sometimes a number of detonators connected in series) have been fired simultaneously by lightning currents.

The notes which follow have been compiled with the Witbank (Transvaal) coalfield area specifically in mind.

Measured earth resistivities on surface vary very widely depending on soil types and depth of soil, the nature of the underlying rock strata and moisture content. Resistivity of surface layers tends to be higher in the Highveld winter period than in the wetter summers.

Therefore to establish low resistance earthing electrodes (for lightning or power system earthing purposes) on surface, it is desirable to get them deep enough in the ground to avoid drying out during the dry season. The depth below surface of the ground strata which are of importance from a resistivity point of view in determining the electrode's resistance to the mass of earth is then largely dependent on the vertical and horizontal dimensions of the electrode system concerned. This is likely to be of the order of metres or tens of metres for electrode systems designed to have reasonable earth resistances for average local conditions so that even for electrical system and lightning protection earthing systems on surface, the resistivity of the earth to a depth of 10-50 metres may be of importance.

Representative resistivities are of the following orders:

Surface soils	100 to 1000 ohm-m
Clay (occasional)	Under 50 ohm-m
Coarse grained sandstones	700 to 100 ohm-m
Fine grained sandstones	400 to 1200 ohm-m
Shales and mudstones	200 to 400 ohm-m
Bituminous coal	In situ: 5000 to 100 000 ohm-m
Igneous basal rocks	10^5 to 10^6 ohm-m
Dolerite (dykes)	50 000 ohm-m

As can be seen, the resistivity of dry coal tends to be relatively high.

The net effect may be that a coal seam may act a little like the dielectric in a capacitor, and may have a major effect on the pattern of lightning current flow from surface to depth. If its resistivity is high relative to that of the formations above it, this could result in high potential arising across it at the time of nearby lightning strikes.

One coal sample from Arnot Colliery tested in a laboratory gave the following figures:

Parallel with bedding Normal to bedding

As received	120 000 ohm-m	10^8 + ohm-m
After 40 min in tap water	60 000 ohm-m	app 10^7 ohm-m
After 16 hours in tap water	6 000 ohm-m	app 10^6 ohm-m

It is clear that moisture content is of crucial importance and that the nature of any dissolved substances in the absorbed moisture is also likely to be crucial in determining effective resistivity of coal in situ. In particular it should be noted that the layered nature of coal deposits means that horizontal and vertical resistivity measured values are extraordinarily different in samples tested in the laboratory. In practice it is

not known to what extent vertical fractures in a coal seam may reduce or nullify the effect of the horizontal layering.

It should be noted that lightning currents have strong high-frequency components and that resistivity of soil is frequency dependent, reducing with increase in frequency. Permittivity effects may also be of importance in relation to lightning currents.

3.2.5 Hazards Associated with Abandoned Workings

The study of accident reports indicates that lightning related methane explosions had occurred on several occasions in abandoned workings. Once sealed off, such mining areas often develop non-critical methane-air mixtures, although this may take a considerable period of time. In order to minimise the hazards of methane explosions, therefore, a number of precautionary principles should be applied.

3.2.6 The Effect of a Drop in Barometric Pressure

In 1948, Charles Holster in the U.S.A., and Jean Bessemoulin in France, pointed out the striking analogy between the variations in pressure temperature and firedamp explosions. Out of 41 cases of explosions studied, Holster observed that, with one single exception, they were all preceded by a sudden drop in atmospheric pressure.

The opinion of Bessemoulin was that the same phenomenon was at the origin of the disasters of Courrieres in April 1948 and of Centralia, U.S.A. in March 1947, which occurred during the passing of a cold storm front.

The hypothesis was expressed that this drop in atmospheric pressure on the earth's surface, caused an expansion of gases

underground, especially of the firedamp deposits in old workings. After that, the electric field of the atmosphere, modified by stormy weather, could easily create the spark initiating an explosion. On December 27 1974 at approximately 05h30, a firedamp explosion occurred at a depth of 710 m in the Six-Sillons seam at Lievin, killing 42 miners. At the same time the barometer readings in the meteorological stations at Lille, Abbeville and Saint Quentin had recorded a sudden drop in atmospheric pressure in the Lens coalfield. (Refer to Figure 4). Lievin is marked in a triangle, the three points of which are the towns of Lille, Abbeville and Saint Quentin.

Meteorological measurements taken by means of a balloon probe were detecting sufficient humidity to produce an unstable cloud mass above the Lens coalfield.

Fauconnier (1981) quotes the changes in pressure over seals in old workings as a result of changes in barometric pressure.

Table 3.1 Example of the change in pressure over walls with change
in barometric pressure (Data: Springfield Colliery)

Time	Barometric Pressure (kPa)			Pressure Difference over walls (Pa)
	Surface	Underground	In Panel	
06h00	85,079	85,488	85,428	- 60
06h20	85,132	85,533	85,453	- 80
06h40	85,159	85,573	85,463	-110
07h00	85,078	85,526	85,466	- 60
07h20	85,131	85,540	85,480	- 60
07h40	85,144	85,560	85,480	- 80
08h00	85,172	85,586	85,491	- 95
08h20	85,187	85,605	85,485	-120
08h40	85,219	85,640	85,525	-115
09h00	85,239	85,660	85,535	-125
09h20	85,242	85,686	85,576	-110
09h40	85,235	85,653	85,568	- 85

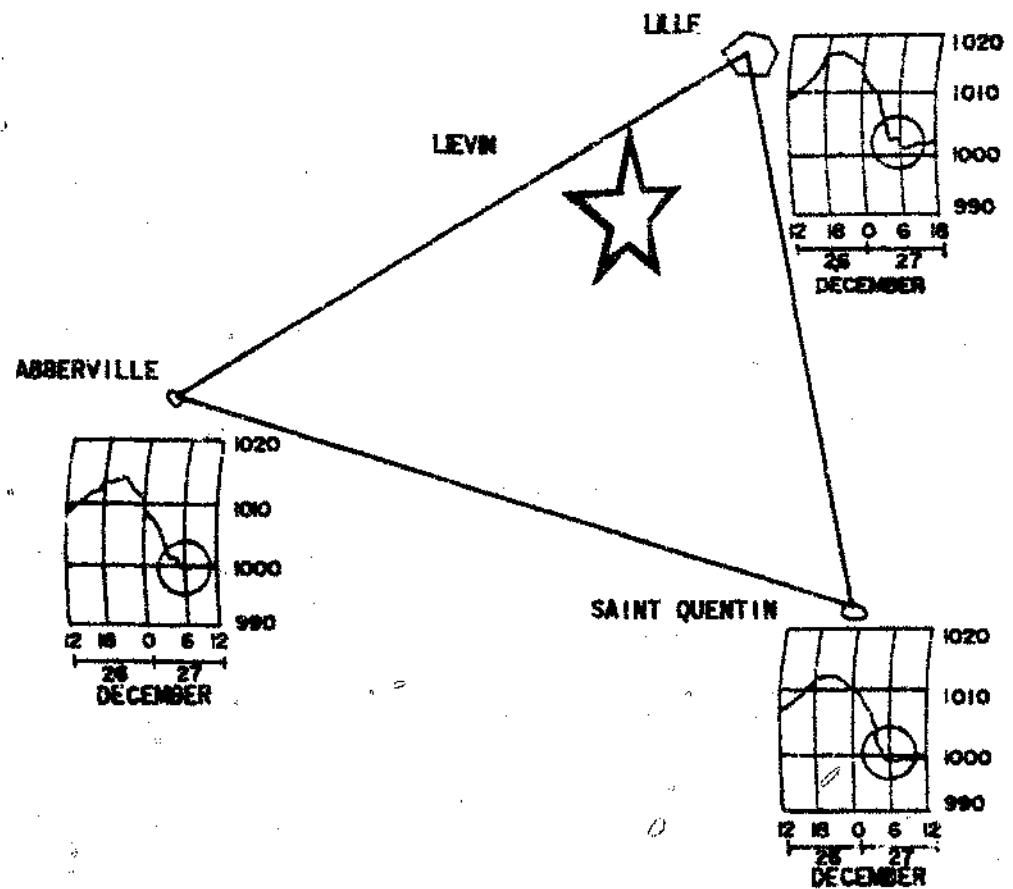


Figure 4

AFTER SEROUSSI, (1976)

Time	Barometric Pressure (kPa)			Pressure Difference over walls (Pa)
	Surface	Underground	In Panel	
10h00	85,226	85,537	85,567	- 70
10h20	85,211	85,620	85,570	- 50
10h40	85,198	85,609	85,574	- 35
11h00	85,164	85,578	85,588	+ 10
11h20	85,132	85,556	85,586	+ 30
11h40	85,106	85,546	85,626	+ 80
12h00	85,080	85,502	85,622	+120
12h20	85,051	85,446	85,596	+150
12h40	85,010	85,422	85,582	+160
13h00	84,972	85,382	85,562	+180
13h20	84,944	85,344	85,544	+200
13h40	84,916	85,313	85,533	+220
14h00	84,895	85,280	85,500	+220
14h20	84,864	85,246	85,486	+240
14h40	84,863	85,232	85,452	+220
15h00	84,839	85,260	85,450	+190
15h20	84,839	85,220	85,400	+200
15h40	84,851	85,233	85,383	+150
16h00	84,892	85,286	85,366	+ 30
16h20	84,923	85,328	85,388	+ 60
16h40	84,920	85,328	85,383	+ 55
17h00	84,926	85,333	85,368	+ 35
17h20	84,596	85,346	85,346	0
17h40	84,998	85,392	85,352	- 40
18h00	85,038	85,432	85,352	- 80

The importance of these figures is that methane which has accumulated behind the seals in the old workings could find its way into workings outside the seals during periods of low pressure (by leaking through the seals). Sparks resulting from lightning may ignite this methane causing an explosion.

3.2.7 Earthing Properties of Roofbolts and Mine Floors

The roofbolts which are in use in Eastern Transvaal Collieries are of various types and lengths. The notes which follow refer to common or typical practice but do not cover all cases.

Expansion Shell Type Roofbolt

This type of roofbolt is fixed after insertion into the hole drilled into the roof by tightening a nut on its threaded lower end. This has the effect of causing the conical wedge steel assembly at its upper end to expand and grip the sides of the hole tightly, enabling the plate which is clamped against the roof by the tightening of the nut to provide a substantial supporting force.

Resin-Grouted Roofbolts

In recent years the use of resin-grouted roofbolts has become very common. In this case the hole (22 to 28 mm diameter) which has been drilled for the roofbolt (which is typically 1.5 m long by 16 mm diameter) has one or more two-compartment resin capsules pushed up into it. The roofbolt is then pushed home and when rotated breaks these capsules, and mixes the two resin ingredients which then set quite rapidly, after which the nut can be tightened providing the required support to the roof.

The electrical resistance to earth of roofbolts of both types have been measured underground at various times in various mines and laboratory resistivity tests on resins have been performed at the Amcoal Research and Development Department at Vandyksdrift.

Typical resistance figures for expansion shell type roofbolts recorded have ranged from 10 000 ohms to 40 000 ohms per roofbolt.

Resin grouted roofbolts have given an extremely wide range of earthing resistance figures which are clearly dependent on a number of factors including the resistivity of the material in which the roofbolt is fixed, whether the bolt is grouted over its whole length or merely near the top end (point anchor) and the characteristics of the resin employed. The lowest in situ figures encountered have been of the order of 300 ohms to 500 ohms, while figures in the range 1 000 ohms to 5 000 ohms are common and some have been higher, probably when bolts have been set in coal.

Again the existence of a poorly ventilated area is evident, together with a conductive ventilation pipe in the shaft collar seal.

Sparking potential from the lightning strike caused one or more sparks between unbonded conductors thereby inducing a methane explosion in the partly ventilated shaft. Engineers on the mine were not aware of the earthing code for headgears and did not know the details of the earthing on surface.

3.5.2 Ermelo Mines Services (Pty) Limited

Introduction

One pump attendant died and a second worker sustained ruptured eardrums when a methane explosion occurred in an incline shaft.

The explosion was initiated by stray currents from an electrical storm on surface. The survivor saw the flames against the roof a few seconds before the explosion occurred.

An accumulation of methane in the shaft resulted from the fact that the power supply to the fan tripped out several hours prior to the accident.

The two workers, considering the possibility of flooding of the shaft due to the heavy rains, took a calculated risk by entering the unventilated shaft. They obviously did not know that there was a possibility of a gas build-up and thought that the compressed air supplied to the pumps would suffice.

This is a typical case of loss of life due to inadequate training.

The coal seams at this colliery are notoriously gassy.

3.3 THE PHENOMENON OF IGNITIONS DUE TO STRAY CURRENTS OTHER THAN THOSE DUE TO LIGHTNING

3.3.1 Stray Currents

Fortunately, the risks posed by other forms of stray current which originate from causes outside the mine have not, so far as is known, yet been the cause of any explosion in a South African colliery.

Such currents may however pose risks, particularly in relation to methane ignition in mines; as electric rail traction activities by The South African Transport Services (SATS) expand (both D.C. and single-phase A.C.) and locomotive power per train (and hence traction supply currents) increase and the Electricity Supply Commission (ESKOM) transmission lines proliferate (leading to an increase in the chances of dangerous stray A.C. induced currents occurring) stray current problems underground may be expected to increase also.

Large amounts of return D.C. traction current leak away from the rails and find their way back to trackside supply substations through the ground. It is such currents which may be troublesome in underground collieries; in collieries in Britain and the U.S.A. and in a tunnel in South Africa, there have been accidents in which detonators in charged holes have been fired by D.C. stray currents. Some of these accidents are shown in Table 3.2.

Table 3.2

(i)	1958	Broughton Tunnel Natal	Blasting Accident	DC Traction Current (SAR) suspected
(ii)	1978	South African Coal Estates	High DC Rail potential	DC traction return current

(i) Possible Sources

- Railway traction circuits:

a. D.C. current through the ground (and also possible induction due to short-circuit current transients).

b. Single phase A.C. (Induction from overhead traction wires and conduction through ground).

- Electromagnetic induction by unbalanced component of alternating current in overhead power lines (normal and fault current).

- A.C. earth fault current (by conduction, from overhead power lines).

- Radio signals.

- Inductive effects within the mine power distribution system (such as longitudinal potentials induced in earth conductors of asymmetrical trailing cables).

(ii) Dangers posed by such sources

Possible risks arising from Stray Currents

- Premature ignition of explosives

- Ignition of methane
- Electric shock to human beings
- Corrosion of buried structures and structures in contact with the ground
- Interference with proper operation of electrical equipment.

Jackson (1987) states there is a network of electrified railways in the Eastern part of the Transvaal. Lines in the Witbank area are supplied at 3 000 V d.c. by an overhead feed with track return to the traction substations, which are spaced ten to fifteen kilometres apart. Despite the provision of insulation between rails and the concrete sleepers and the installation of heavy return current conductors in parallel with the return rail, appreciable voltages above earth arise on rails and a substantial proportion of the current drawn by locomotives returns to the traction supply substations via leakage to the general body of earth and via other unintended paths.

The result is that appreciable D.C. potentials can be measured between the body of earth and local metalwork almost anywhere in the area, including points underground in collieries. The highest local potentials occur close to railway lines carrying long, multi-locomotive trains.

Rail potentials may exceed 50 volts during normal operation (such as passage of a train hauled by five 6E1 locomotives). Measurements made at about 80 m depth in a colliery haulage directly below the railway have given peak roofbolt potentials to earthed metal of about 8V at the time of passage of trains, though average levels in the same colliery were a fraction of a volt.

It does not appear that potentials of this order are likely to provide much risk of direct incendive sparking. However, a fatal shot-firing accident, in very unusual circumstances, did take place in the Westoe Colliery (U.K.) due to stray d.c. traction currents which entered the mine via metallic paths. (Given low

resistance current paths, quite substantial stray currents can flow in favourable circumstances).

A different possible risk situation may exist when traction supply short-circuits take place. In this case, for a very short period, track voltage may theoretically be elevated to something like one quarter to one half of the supply voltage. During this brief instant, therefore, very high leakage currents to earth may occur, with possibly serious results. The rapid rate of rise of such fault current implies the possibility of induction effects also occurring.

There is no record in South Africa of any explosion in a colliery being initiated by traction current. It is however a current source posing certain risks.

Power Lines

Overhead power lines carrying alternating current are normally constructed with three phase conductors as closely spaced as possible and carry moderate levels of three-phase current which is theoretically exactly balanced. Little or no induced voltage on parallel conductors therefore occurs in most cases.

However, in practice there is often a small degree of imbalance (e.g. 1% to 2% or more). Further, at very high voltages (220 kV and higher and quite often at lower voltages) the conductors are horizontally disposed so that for a parallel conductor (e.g. a fence, telephone line or cable sheath) close to, but to one side of the line, induction by the nearest conductor is not exactly cancelled by that from the others, so that the resulting asymmetry results, on its own, in substantial parallel induction occurring.

The higher the voltage the wider the phase spacing and consequently the greater the probability of induction trouble arising.

The unbalanced portion of the line current has a theoretical return depth through the earth dependent on the equivalent resistivity of the current path. This depth is of the order of hundreds of metres (or even kilometres) for local ground conductivities.

3.3.2 Risk of Ignitions as a result of Stray Currents

Further, as in the case of the lightning hazards discussed earlier, it is necessary to review and conceivably to do certain test work concerning the energy levels required in sparks between various materials to ignite methane for the direct and alternating voltage sources being considered, and likewise to review the voltage, current and energy levels likely to be able to set off detonators of various types as a result of stray currents.

Overall, the present known situation is that in the future stray railway traction currents may reach levels which could conceivably pose methane ignition risks in underground collieries. Further theoretical and practical study seems necessary to define the risks in numerical terms, in particular in relation to methane ignition.

3.4 NUMBER AND DATES OF INCIDENTS

The graph depicts the incidents in relation to the months of the year.

It is of interest to note that no incidents occurred during the winter months.

Table 3.3

Date	Location	Fatalities	Description
2nd December 1960	Schoongezicht Colliery	Nil	Methane explosion in old workings.
10th April 1967	Indumeni Coal Mines	Nil	Methane explosion as a result of lightning or faulty electric light fitting
28th August 1972	Usutu Coal Mines Limited	6 injured	Methane explosion in standby section
3rd January 1974	Albion Colliery	13 killed 23 injured	Methane explosion in old panel
15th December 1976	Usutu Coal Mines Limited	Nil	Methane explosion in old workings
29th October 1977	Usutu Coal Mines Limited	Nil	Methane ignition (between shifts) in producing section
12th February 1980	Coalbrook Collieries	Nil	Methane explosion in sealed vertical shaft

Table 3.3 (Contd.)

Date	Location	Fatalities	Description
6th November 1983	Ermelo Mines	1 killed	Methane explosion in sinking shaft
25th October 1984	Ermelo Mines	6 killed	Methane explosion caused by lightning

3.5 DETAILS OF INCIDENTS/PHENOMENON

3.5.1 Coalbrook Collieries Limited

Introduction

At approximately 19h00 on the 12th February 1980 an explosion occurred at the No. 2 vertical shaft at the above colliery. The methane explosion destroyed the concrete seal at the top of the shaft, damaged the steel headgear and broke windows in neighbouring buildings. A severe thunderstorm occurred in the vicinity of the shaft at the time of the explosion.

The mine was extremely gassy and in 1961, a methane explosion caused severe damage to an incline shaft killing 7 persons who were engaged in the cutting of steel girders which were obstructing the removal of a feeder in the shaft.

The Incident

This area of the mine in the vicinity of the shaft had been worked out and had recently been sealed. The shaft is vertical and has a depth of about 200 m. The shaft seal was reportedly completed on 9 February 1980, and comprised a concrete plug approximately 1 m thick. This had been cast upon steel shuttering laid previously across the shaft collar. A 100 mm diameter steel vent pipe had been cast through this plug and, during the period between 9 and 12 February, fresh air was being drawn into the shaft through this pipe - via an exhaust fan located at another shaft several kilometres away. This fan was reportedly exhausting at a flow rate of about 50 m³/sec.

The explosion occurred during a thunderstorm in the area and, at the time, lightning was reportedly observed striking the steel headgear above the shaft. The shaft seal was totally destroyed in the explosion and the steel headgear was also extensively damaged.

The steel platform and related structural elements at the top of the headgear were carefully inspected and all potential strike points examined for evidence of recent flash root termination. No such evidence could be found.

A heavy gauge stranded aluminium earth cable was connected between this air terminal unit and a buried earth electrode at the base of the structure. The intervening connection clamps were opened and inspected for evidence of the recent passage of discharge current but again, no such evidence was found. In addition, in examining this earth cable in the course of its passage up the steelwork of the headgear, no indications were found of any recent flashmarks - as normally would have been present had high impulsive currents passed through the structure.

In the absence of any positive evidence, it is concluded that lightning did not strike the headgear - alternatively, had such a

flash taken place, the discharge current must have been exceptionally weak.

Observer evidence

The following points were noted from the evidence:

- a. All observers confirmed a thunderstorm in progress and heard a thunderclap - followed almost immediately by the explosion. (Excluding allowance for methane ignition and propagation times for the explosion, this probably puts a lightning flash termination within a radius of about 300 m).
- b. At least one observer apparently heard the leader approach - which is consistent with being within a few hundred metres of a discharge.
- c. No observer positively saw a flash strike the top of the headgear. In fact all observers were reportedly dazzled by the brightness of either a flash in the vicinity, or its reflections, or the explosion itself. One observer had the impression of a flash to the base of the headgear - near the vertical portal structure.

A Boilermaker's Helper gave evidence that he heard the crack of lightning. The sky lit up and a dust cloud rose out of the shaft followed by a dull blue flame which arose with the flying concrete. Before he heard the lightning bolt, he saw the flash of lightning. It moved from South towards North and appeared to strike the ground between the two legs of the headgear on the West side.

Immediately after the explosion pieces of concrete began to fall. He was certain that the flash of lightning did not strike the top of the headgear but that it struck the ground.

It is considered that the above evidence is consistent with a lightning flash in the immediate vicinity of the shaft, just prior to the explosion. The absence of discharge evidence on the structure of the headgear, however, argues against such a flash having been to the structure itself.

The possibility of an oblique flash terminating at the base of this structure is considered extremely improbable, since a structure of this height and shape would normally be expected to exhibit an attractive effect within a radius of about 40 - 100 m.

It is concluded therefore that a ground flash terminated somewhere in the immediate shaft vicinity - probably on one of the nearby buildings, or associated structures, rather than to the headgear directly.

It is thought that this flash was sufficiently close, either to induce sparking potential in the steel ventilation pipe (which was reportedly not directly bonded to the shaft structural steel work and thus was "floating"), or to cause the flow of ground currents in the steel railway lines which led to the shaft tip and again were not directly bonded and thus could have given rise to local spark discharges.

It should be emphasised that extremely low energy spark discharges are capable of igniting critical methane/air mixtures (of the order of 1 MJ or less). In the potential presence of such mixtures therefore, all conductive elements in the vicinity should be galvanically bonded, in order to obviate any transient differences in potential or spark discharges.

Conclusion

This explosion occurred as a result of the lack of galvanically bonding between conductive material in the vicinity of a shaft and a connection to a well-earthed common electrode at the shaft top.

Stratigraphy

Figure 5 depicts a typical stratigraphic section of the coal measures at Ermelo Mines.

Sinking operations had been completed prior to the accident in this 420 m long incline shaft of which the bottom was approximately 125 m below surface. The shaft has an inclination of 17° to the horizontal.

Shotcreting and equipping of the shaft commenced several days prior to the accident.

The Incident

The incident occurred at the recently developed Tweefontein inclined shaft.

Figure 6 shows a locality plan of the workings in relation to the Tweefontein shaft.

According to witnesses who were near the mine, there was a thunderstorm in the vicinity of the shaft at the time of the accident.

No evidence of a direct lightning strike could be found, burn marks as a result of a high electric current or of noticeable amounts of remaining magnetism in steel objects could not be traced. This, however, does not mean that no bolt of lightning occurred. Currents of a few kiloamperes could have flowed in the shaft's pipes, as well as currents of hundreds of amperes in the steel mesh installed in the roof, without it being evident in the investigation.

When a lightning bolt strikes near the mouth of a shaft, it is possible that a portion of the lightning current will flow in the

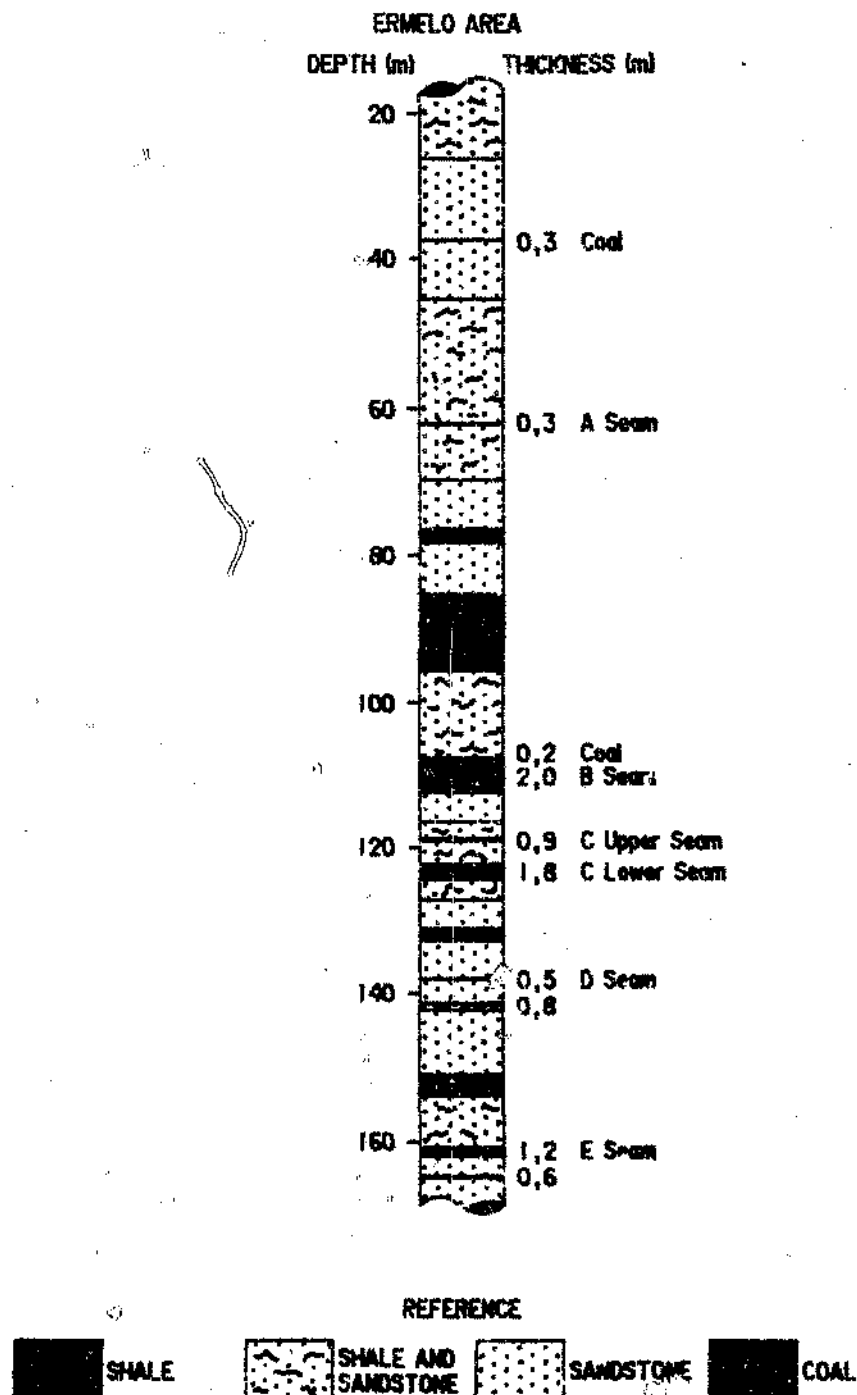
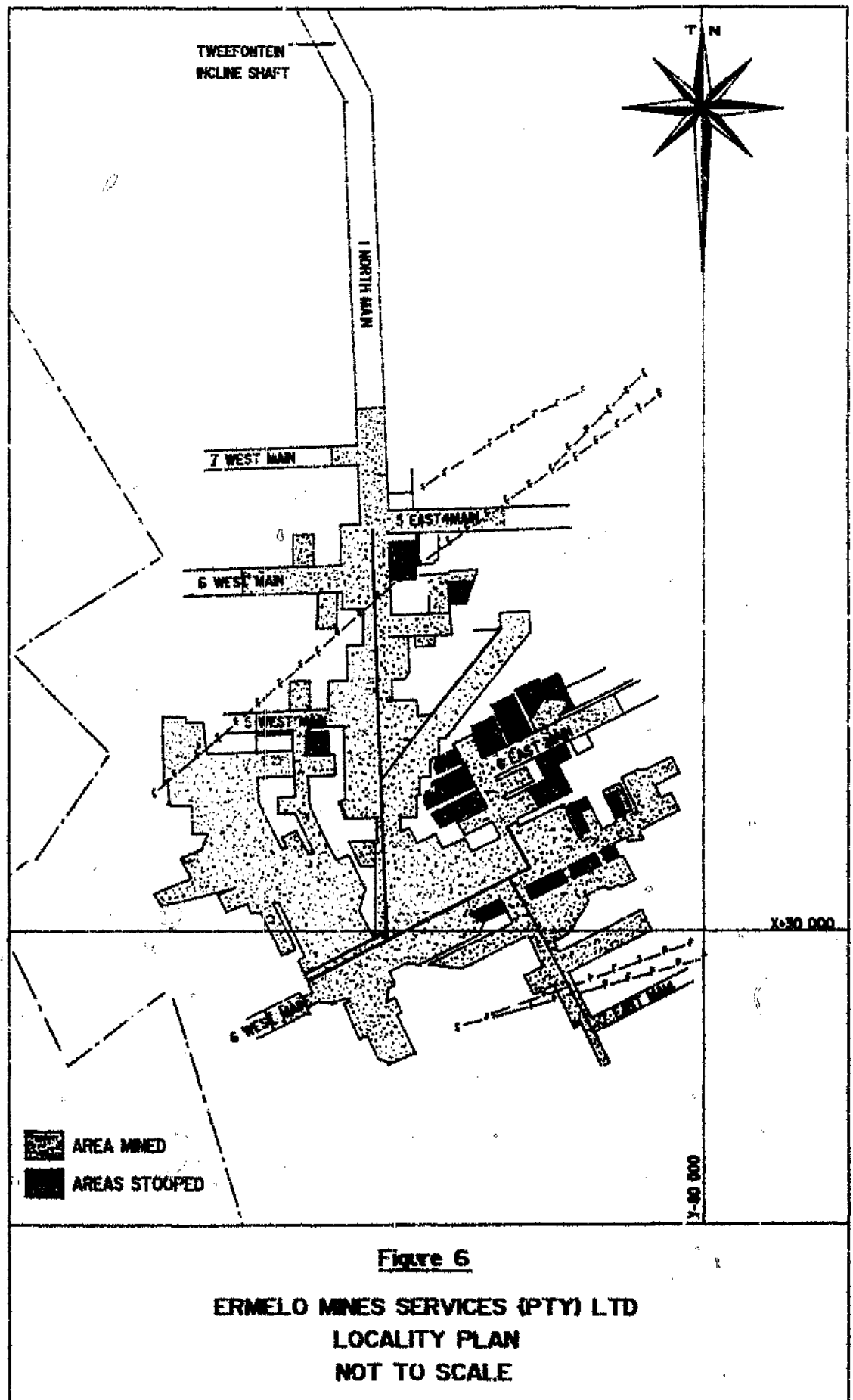


Figure 5

GEOLOGICAL STRATIGRAPHY OF ERMELO MINES



pipes, rail lines, electric cables and concrete reinforcement of the shaft.

The pipes, rail lines and electric cables are electrically continuous and should not cause any sparks, except at the points where they end. However, the steel mesh reinforcement placed in the roof may easily cause sparks where various pieces of mesh are joined. Laboratory tests have shown that reasonably large sparks develop at such a joint if about 100 ampere of lightning impulse current should flow through it.

Figure 7 shows a typical cross section through the incline shaft looking North East.

The Mine Manager's evidence is quoted below:

"At the time of the accident which occurred at approximately 16h50 on 6 November 1983, the sinking of the shaft had been completed and the shaft was in the process of being equipped.

One person had died and one injured in the accident.

The deceased and the injured were Pump Attendants. They were both employed by the shaft sinking contractors.

The Mine Manager visited the scene of the accident at Tweefontein shaft and arrived there at 19h45. The shaft contained more than 5% of flammable gas and an inspection of the scene was not possible.

The shaft was tested for gas at 16h30 on 8 November 1983, and less than 2 percent was measured after a 150 millimetre diameter hole had been drilled from surface to the bottom of the shaft. The proto team started installing a ventilation column and I went into the shaft to inspect the scene of the accident in the presence of the Inspector of Mines and others. It was clear to me at the time that a methane explosion had occurred.

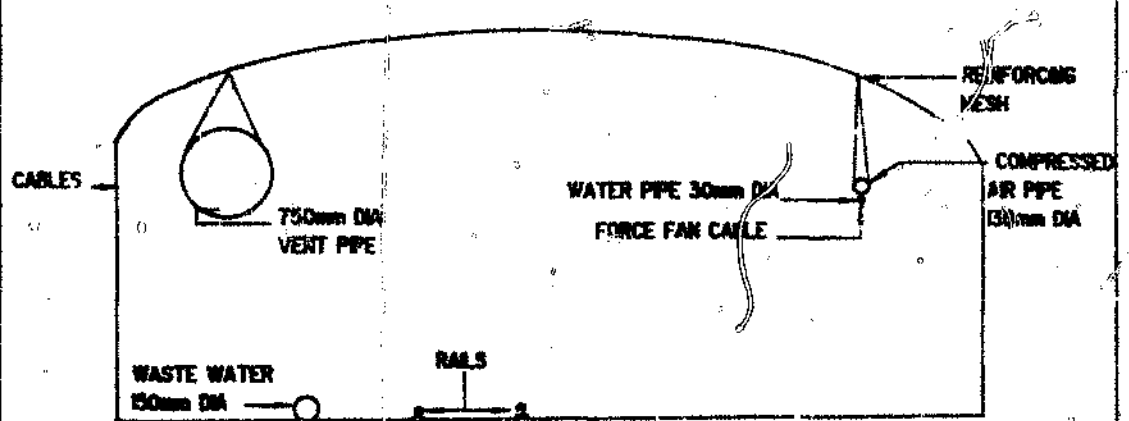


Figure 7

ERMELLO MINES SERVICES (PTY) LTD

**A TYPICAL CROSS SECTION THROUGH
A SHAFT LOOKING N/E**

The scene and the shaft were surveyed and a plan was drawn up depicting the scene before and after the explosion. I submit this plan as Figure 8. I submit the locality plan of the shaft in relation to the rest of the mine workings as Figure 7.

At the top of the shaft there were a number of badly damaged galvanised ducting pipes. The fans had been moved from their original position by the force of the explosion. The one fan moved about a metre and the second was moved for approximately 45 metres.

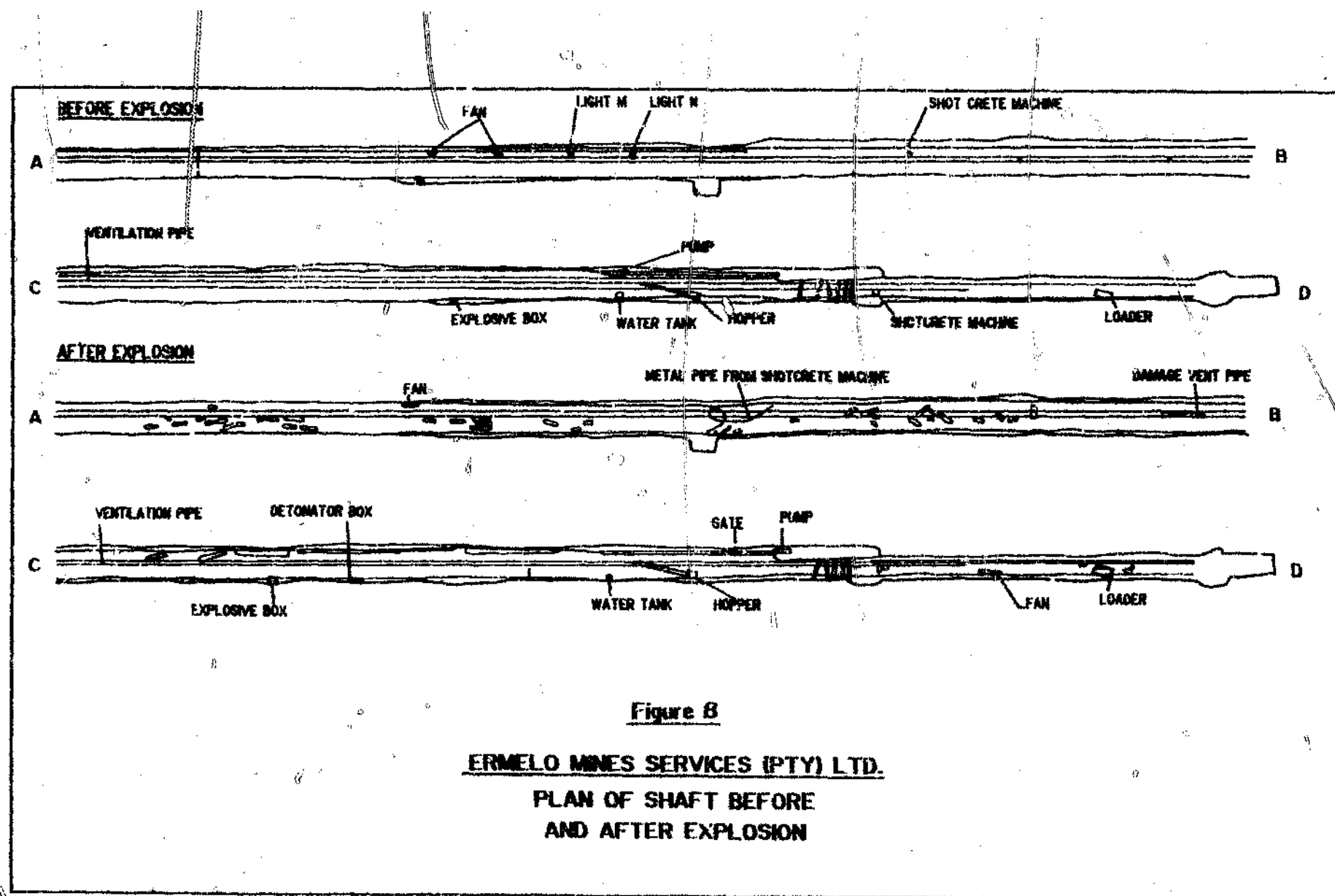
There were clear indications that heating took place on the cables. The indications were that the seat of the explosion was 200 to 230 metres below the portal of the shaft. In the vicinity of the pump station, a tin was found, wrapped around a drillstem handrail upright in a manner indicating that the explosion had taken place above this point.

Plastic seals had been used on the ventilation column and signs of burning were observed right down to below the C seam intersection position. Methane was issuing from both the B and C seam intersections. Approximately 380 metres from the portal of the shaft, flattening of the ventilation pipes was observed and below this very little damage to the pipes had taken place.

The deceased was found near the pump station which is approximately 350 metres from the shaft portal as indicated on Figure 8.

In this area there were also badly burnt pieces of plastic, hoses and cables. A number of damaged hard hats were found in the shaft in the positions as indicated on the plan. The bottom of the shaft was full of water.

Approximately 300 metres from the portal, pieces of the wooden frame of the detonator box were found scattered from 300 to 320 metres from the portal as well as explosives cartridges.



The wire mesh, approximately 220 metres from the portal, was ripped away from the roof and a piece was lying on the floor approximately 200 metres from the portal. This had fallen as a result of the explosion.

The surface boreholes to the shaft were examined and it was found that they were all sealed by means of concrete.

The Mine Ventilation Officer had carried out a ventilation survey in the shaft on 3 November 1983 and the report of his survey is submitted as Table 3.4.

Table 3.4. Development Ventilation Report

Tweefontein		Date	3.11.83	Ref No. T83/1	
Diameter of Column in mm		Area of end in m ²		Volume in m ³ /s	Distance from face in m
Time Leakage Force Exh.				Force Exh.	Force Exh. Blast in m
09h40 15%		570 760	15,6	2,2 3,6	13,5 39,5 15,0 5,0

Two flameproof exhaust fans in series exhausted 9,9 cubic metres of air per second and a force fan forcing 2,6 m³/sec was used to clear the toe of the shaft (see Figure 8a).

The ventilation set up as it was prior to the accident was satisfactory as there was no blasting being done in the shaft. Methane had been encountered in the shaft before.

During my inspection, no signs of contraband were found in the shaft. The two cap lamps used by the now-deceased and the other injured person were examined and found to be flameproof.

The barometer readings recorded on the mine during the week show fairly high readings up to Saturday 5 November 1983 and a drop

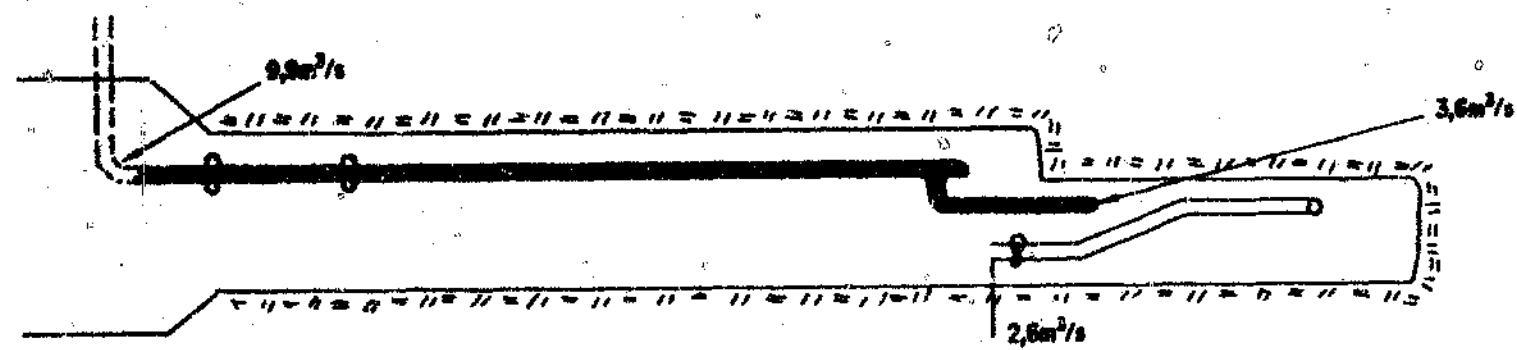


Figure 8a

ERMELO MINES SERVICES (PTY) LTD
PLAN OF VENTILATION AT FANS
IN SHAFT BOTTOM

was recorded thereafter and the pressure remained constantly low right through the day.

During my inspection in loco, the only two obvious places where methane was being made was at the intersections of the two coal seams. Because of the presence of flammable gas in the shaft and because of the destroyed ventilation column, the body of the now-deceased could only be recovered on Tuesday 8 November 1983 after ventilation had been restored at 20h00.

The explosive boxes found in the shaft were found to be deformed and it was thought that detonation of explosives could have occurred inside the boxes. Experiments conducted on surface in the presence of the Chief Inspector of Mines, indicated that this was not so, because similar boxes had holes blasted through when 5 detonators were set off in a box, 25 detonators caused the box to disintegrate and one stick of explosives, that is 200 grammes of Ajax, completely demolished the box."

The security at the top of the shaft and the status of the power supply to the shaft on the day of the accident are described by the shaft Guard.

"All persons going underground are checked by me to see that they do not take contraband into the workings. I also check the cap lamps. When the shift knocked off at 14h00 I also left. I was not replaced by another guard as there was no further shift after the day shift as it was a Sunday.

The Pump Attendant had not yet arrived. We had left at 14h00 because it was raining heavily. The day shift was busy casting concrete at the portal and because of the rain the work could not proceed. We all knocked off at 14h00 instead of 15h00 as we were supposed to.

When I knocked off, I closed the gate and secured it with a chain. I could not lock the gate as the man I had relieved had

not left the lock. I closed the gate before I left.

When I left there were no persons underground. I am certain because I know the persons on duty on that day and I knew where they were working. The Pump Attendants on my shift were on surface because the electricity was off when we arrived at the beginning of the shift. The Engineer arrived and restored the power. The power was off on three occasions but I cannot remember the times. The engineer was around and restored the power.

The electricity was off when we left.

The pump shift remained behind when we left. They remained to wait for the other shift to relieve them."

Evidence indicates that the power supply to the shaft tripped out at 13h17 and that although reports had been made of the power failure, it had not been restored at the time of the explosion.

A Fitter Helper gave evidence as follows:

"My work as a Fitter Helper entailed my having to go underground at the shaft. At the time of the explosion, I was on surface in the vicinity of the shaft. Before the explosion there was lightning and rain. I was looking at the shaft at the time of the explosion. I do not know if there was a lightning flash at the time of the explosion. I saw the equipment and debris being blown out of the shaft.

The power at the shaft was off. I cannot remember how long it had been off before the explosion."

The one Pump Attendant who survived the explosion has provided a description of what happened prior to the explosion.

"I can remember the accident which occurred on 6 November 1983 at the Tweefontein shaft.

I was working as a Pump Attendant. There were two of us working at the time.

There was no one present at the gate when we went down. The gate was closed but was not locked. I was aware that the power was off and that the fans were not working. We went underground because another worker came out of the shaft. We are taught that we may not go underground when the fans are standing. We went down to pump the water at the bottom of the shaft to prevent it being flooded.

There was a diesel plant on surface which the Fitter was to start up.

My intention was to go down, switch on the pumps and come out again. We realised that the fans were not working, but that the compressor would supply some fresh air at the pumps.

When we went down, we switched on the first pump which is a big pump. The now-deceased stayed at this pump and I went down to the bottom of the shaft to start up the other pumps. I switched on the one pump and as I was switching on the small submersible pump, I felt a blast of air from up the shaft. I ran away and stood next to the sidewall. After the concussion subsided, I looked up the shaft and saw flames against the roof. I then heard a loud explosion. The flames disappeared and I then saw smoke in the air. The air blast threw me to the ground. The explosion followed less than five seconds after I saw the flames.

I smoke but did not have any matches or cigarettes with me. They were in a jacket on surface. I was taught that I should never take matches or cigarettes with me underground.

The now-deceased did smoke but I have no idea whether he had cigarettes and matches with him. I did not see him smoke underground. I do not know what set off the explosion. I cannot identify any of the hard hats shown to me in this court."

An important aspect of the evidence was that the shaft sinking contractors admitted that their Pump Attendants were not taught to take flame safety lamps into the shaft to test for gas. Furthermore, no documented proof existed that Contractor workers reviewed any safety or training instructions; for example, that workers are not to proceed into workings when the fans were on stop.

A drop in barometric pressure was recorded during the day prior to the accident and this low pressure was maintained until after the explosion. This fact, in itself, would have envisaged the release of methane from the shaft bottom which had intersected the coal seams.

Discussion of evidence

The Lamproom Attendant's statement that he had heard no thunder nor saw any lightning prior to the accident and that it did not rain until after 15h00, is refuted by all the other witnesses who were in the vicinity of the shaft on the day of the accident.

The two Attendants entered an unventilated shaft and proceeded beyond a contraband checkpoint where there was no guard as required by Regulation 15.11.1.

The shaft was completely without electricity at the time of the accident. The explosion could therefore not have been caused by defective electrical equipment.

The only other sources of electricity in the shaft were an approved compressed-air operated dynamo-light and the two cap

lamps worn by the two workers. Examination of these units proved that they were all in a flameproof condition after the accident.

The only alternatives are that the spark which caused the explosion came from contraband, of which no signs were found either on the now-deceased or in the shaft, or was caused by stray currents from lightning.

The latter possibility was investigated by the Electrical Transience and Lightning Division of the Electrical Power Department, National Electrical Engineering Research Institute of the CSIR. Although no positive evidence of a direct lightning strike was detected, the report concludes that the possibility of a flow of electricity from such an occurrence causing a spark, cannot be ruled out.

Circumstantial evidence showed beyond any doubt, that the atmosphere was heavily charged with electricity during that period before the accident occurred and, by process of elimination, this appears to have been the only source of a spark which could have caused the explosion.

The role played by explosives

The warped explosives boxes mentioned, indicated the possibility that explosives therein may have detonated.

This theory was tested on surface. The total destruction caused by 25 detonators or one stick of explosives proved this theory to be a fallacy. Even 5 detonators, exploded inside a similar box, caused undeniable damage, the equivalent of which was not noticeable in the two boxes found underground.

An examination of the shaft (Figure 8) reveals that the following steel equipment had been installed during sinking:

- Rails
- 150 mm diameter waste water pipe.
- 150 mm compressed air pipe, 50 mm clean water pipe and the force fan cable all suspended from the roof on the east side of the shaft.
- 760 mm diameter galvanised ventilation pipe and cables suspended from the roof on the west side of the shaft.
- The roof of the shaft had been supported with reinforced mesh.

Since no sign of arcing was found near the seat of the explosion, it is only possible to postulate the cause of the ignition based on current knowledge of lightning problems in shallow mines.

Firstly, the interruption of power led to an accumulation of methane in the shaft bottom area above the two coal seam levels.

Secondly, the depth from surface was approximately 120 metres.

Thirdly, Zeh (1987) states that the location of conductive structures underground play a prominent role in the probability of an ignition occurring.

Fourthly, the shaft was wet which could influence the amount of energy which could couple into an earthing bond (Zeh, 1987).

The most likely cause of the explosion was a lightning strike, at the shaft entrance, to the rails or water pipes. The voltage surges travelling down the shaft conductive structures (rails, water pipes, ventilation ducting or cables) could create sparks where discontinuities occur. This would likely be at joints or the shaft bottom extremities of such structures particularly rails. Jackson (1987) states that a voltage of 50 kV has been

measured between the coal face and earthed metal work during lightning storms.

Conclusion

Several electrical trips, the third of long duration, resulted in a fan stoppage in the new incline shaft which had been developed to the coal measures. Methane was being given off freely from the two coal seams and, as a result, methane built up in the 420 metre long shaft.

Two Pump Attendants entered the unguarded shaft to pump out water while about to start the second of two pumps a methane explosion occurred at a distance of 250 metres from the shaft portal.

There was a severe lightning storm on surface at the time.

An examination of the scene of the explosion pointed to stray currents from lightning as the only initiator of the explosion.

3.5.3 Usufu Collieries Limited

Introduction

A violent methane explosion occurred in a section where work had ceased some 6 months prior to the explosion.

The mine workings are relatively shallow and the seam is regarded as gassy. The details of the incident are discussed with particular reference to the equipment and electrical cabling which had not been removed from the panel and the reduction in ventilating air which circulated through the worked out area.

Stratigraphy

Figure 9 shows the depth of the coal measures and the type of overburden encountered in the area of the mine. Of note is the absence of dolerite sills overlaying the coal seam, which sills have been shown to have a high resistivity.

The Incident

Figure 10 shows the underground workings at the colliery, the shaft bottom area, together with the upcast shaft, the Main North haulage (012-016), the main return airways (011-03) and the panel 0.2.0 where the explosion originated.

The seat of the explosion was traced to Panel 0.2.0 which had been stopped 9 months prior to the explosion on the 28th August 1972. From evidence the conveyor belt had become too long and rather than install a tandem drive, the section was moved,

The section conveyor had not been removed from Panel 0.2.0, neither had the lightning cable and bell wires. The situation of all electrical gear in the affected section is shown in the line drawing, Figure 11, which has been reconstructed from evidence at the Official Inquiry.

All pipes to the section had been removed.

The situation on surface at 16h55 is described in evidence by a Shift Overseer.

"At that stage there was terrible thunder and lightning. I looked in the direction of the fan and the next moment I saw a bolt of lightning strike the fan. After four or five seconds I heard a tremendous shock and tremor. I looked in the direction of the shaft opening and saw dust pouring out of it. I immediately suspected that it had been a methane gas explosion. It was 4.55 pm when I noticed the smoke coming from the shaft."

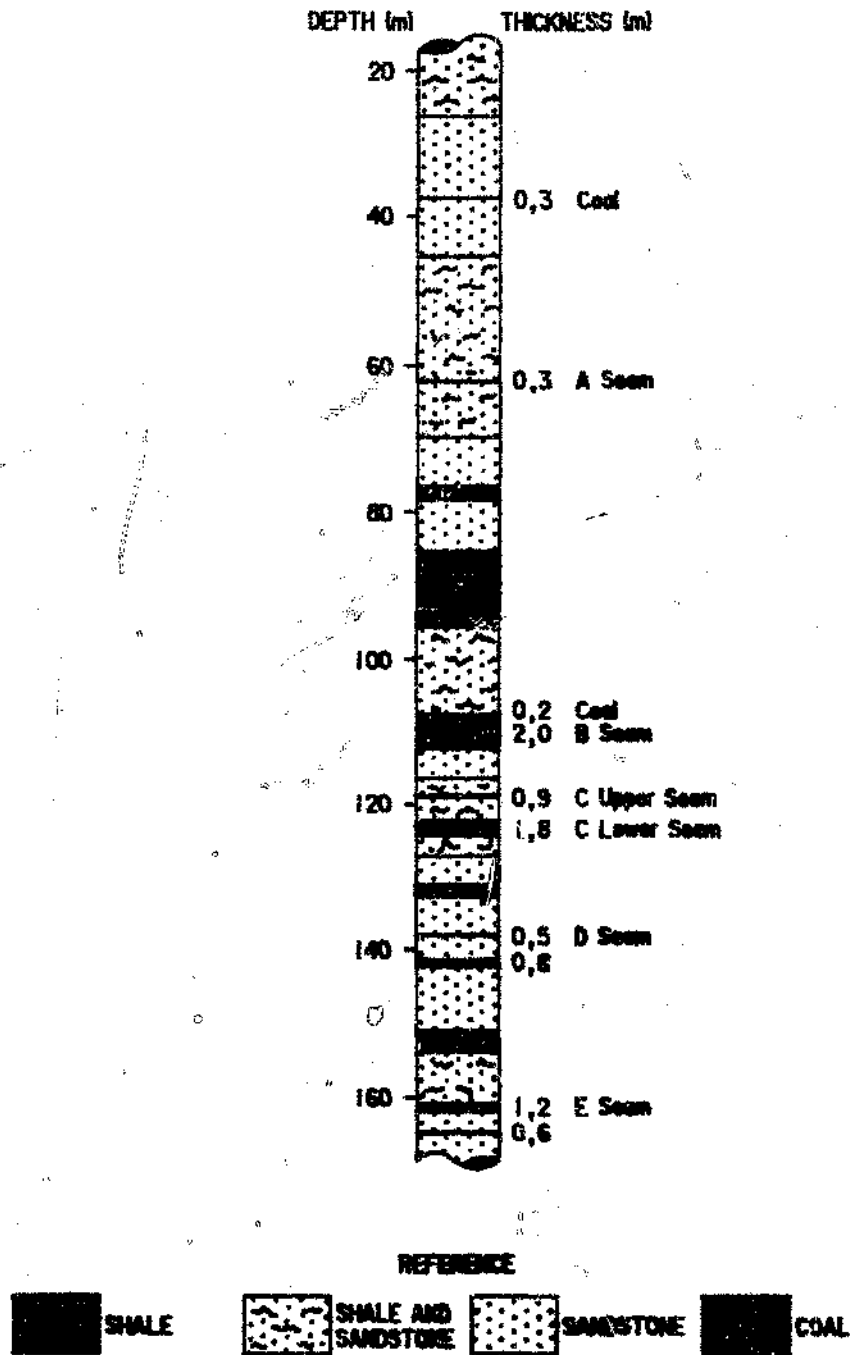


Figure 9

GEOLOGICAL STRATIGRAPHY OF USUTU COLLIERY

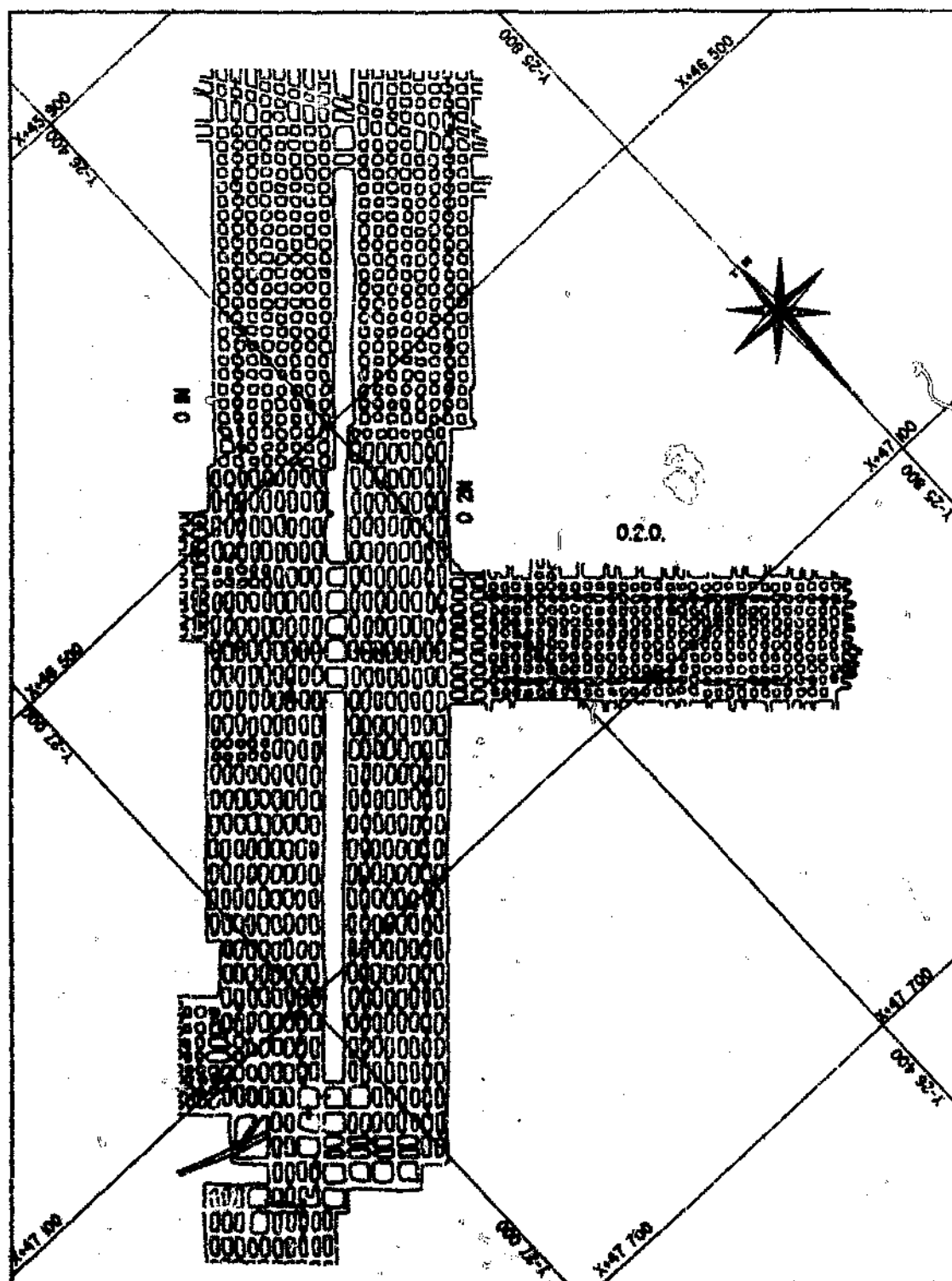


Figure 10

USUTU COLLIERY

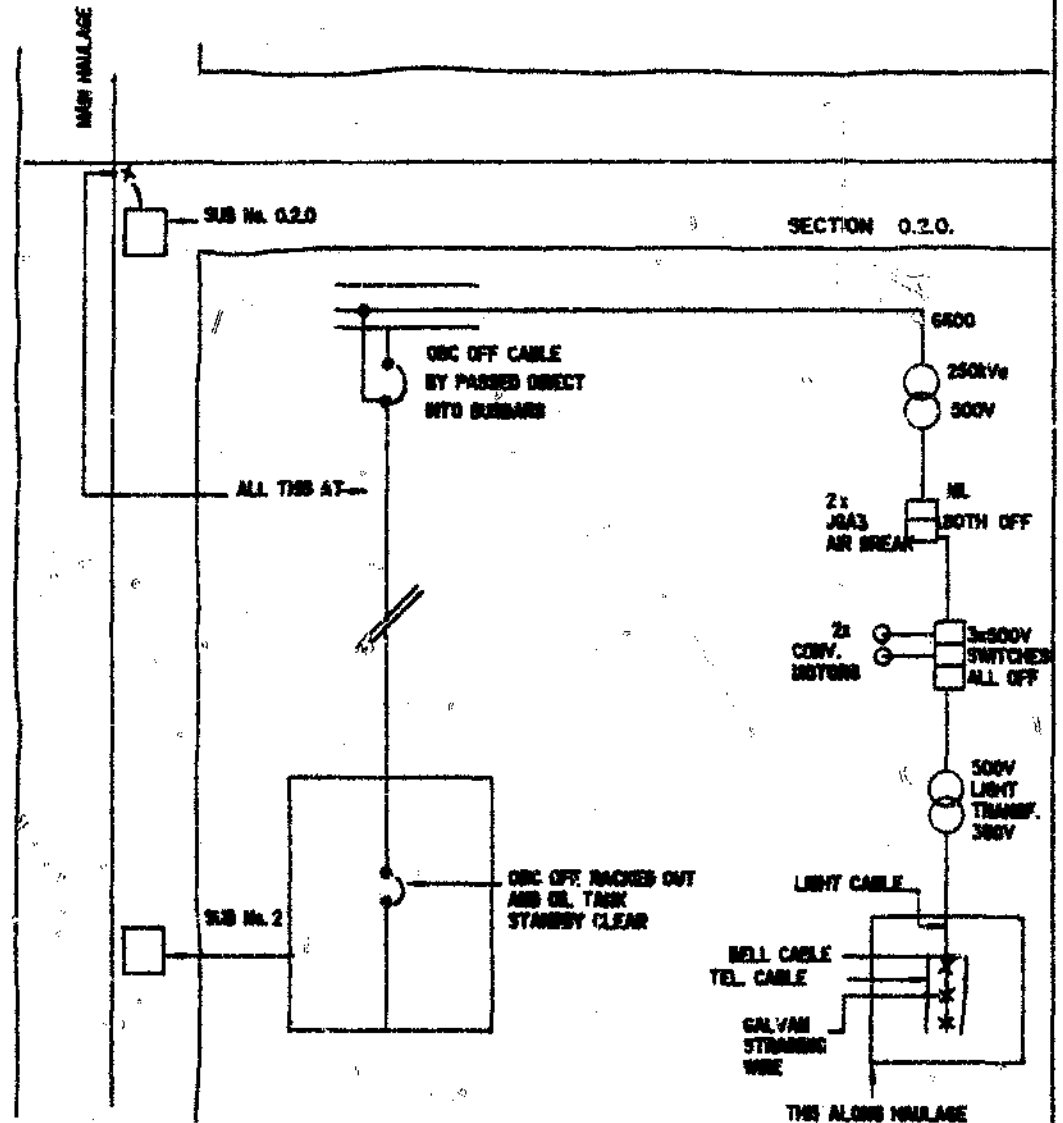
MAIN PLAN OF UNDERGROUND WORKINGS

AND PANEL 0.2.0.

Not to Scale

SPARK COULD HAVE BEEN VIA

- (1) STRAINING WIRES IF SUPPORTED ON WOOD PEGS
- (2) CONVEYOR STRUCTURE - DOWN INCLINE SHAFT IF NOT EARTHED
- (3) STATIC ELECTRICITY IF CONVEYOR STRUCTURE WAS NOT EARTHED
- (4) TELEPHONE CABLES
- (5) BELL CABLES
- (6) ALONG ARMOURING OF POWER CABLE IF NOT PROPERLY EARTHED

Figure IIUSUTU COLLIERY

PLAN OF CABLES ETC. INTO PANEL 0.2.0.

The main fan covers had been blown off and there was considerable damage underground. Stoppings at Q, x and y and air crossings at x and y had been blown out. Regulators for Panel 0.2.0 had also been damaged and the panel was laden with carbon monoxide. The conveyor structure in the panel was badly damaged also."

In April 1972, ventilation to the Panel 0.2.0 totalled $7.6 \text{ m}^3/\text{second}$ and tests for methane in the area by Shift Overseers on normal fire patrols were negative.

However, in August 1972, the Mine Surveyor reported to the acting Mine Overseer that $47 \text{ m}^3/\text{second}$ of air was somehow leaking through Panel 0.2.0. The acting Mine Overseer in evidence stated:

"I asked the Shift Overseer to carry out a survey and he reported to me that $34 \text{ m}^3/\text{second}$ was passing through section 0.2.0. I then told him to reduce the quantity to plus minus $18 \text{ m}^3/\text{second}$. He reported back to me that he had changed it to $17 \text{ m}^3/\text{second}$. I did not deem it necessary to check his readings.

I did not wish to reduce the ventilation drastically since I did not know what the effect would be. I knew that, in the past, there was $7 \text{ m}^3/\text{second}$ in the section. I did not have any misgivings in this regard.

I cannot think of any reason why more air was suddenly passing through this section. To my knowledge no change had been made since I had taken over from the other Mine Overseer."

The Shift Overseer took air readings which totalled $34 \text{ m}^3/\text{second}$ leaking into Panel 0.2.0. He then states in evidence that "these figures were reported to the Mine Supervisor. He then instructed me to ensure that about $18 \text{ m}^3/\text{second}$ went in. The following day I constructed walls there. The intersection at Y was completely walled in and at X an opening of 1.1 metres x 0.7 metres was left. I then took measurements again at this spot. The reading

(with anemometer) now was 2,29 metres/second which I then calculated to be $17 \text{ m}^3/\text{second}$ but which I now calculate to be $1,76 \text{ m}^3/\text{second}$. I did not take any further readings and I also did not see whether the regulators at P and Q were open."

There was an earthing mat in the surface substation at the East mine to which all earthing systems were connected. This substation had a lightning conductor on the first power mast to the substation - the fan had no lightning conductor.

Conclusion

For some unacceptable reason the air leakage into a spare panel had increased from $7,55 \text{ m}^3/\text{second}$ to between $34 - 47 \text{ m}^3/\text{second}$. The Acting Mine Overseer gave a Shift Overseer instructions to reduce the quantity to $19 \text{ m}^3/\text{second}$ which he duly did by closing regulators into the section. However, his calculations were incorrect and were not checked or followed up by the Acting Mine Overseer. The Shift Overseer calculated that he had reduced the quantity to $17 \text{ m}^3/\text{second}$ whereas the actual quantity was only $1,7 \text{ m}^3/\text{second}$. Methane, bleeding from fissures, accumulated in the spare panel and was not detected. Two weeks later a severe lightning storm on surface resulted in lightning striking the fan or its vicinity. It is concluded that the voltage surge caused a spark in the spare panel igniting the explosive mixture.

3.6 SUMMARY OF PRACTICES REVIEWED

1. Areas had been partially sealed off and just sufficient air was allowed into the area to create an explosive mixture as a result of methane bleeding into the partially sealed panel through fissures and faults.
2. In the case of 1 above, conductors such as steel pipes, boreholes cased or not cased but wet or full of water, cables and conveyor structures have been left in the area. These provide ideal conductors.
3. Steel headgears and buildings in the vicinity of shafts are ideal lightning conductors.
4. Adequate earthing mats were not provided on surface and high voltage surges are conducted into methane filled areas through conductors rather than to earth. Mining Engineers are not aware of the need to provide adequate earth mats adjacent to surface structures such as steel headgears. In this regard it is often the problem that major safety issues are not conveyed to all employees on the mine, who are therefore unaware of inherent dangers.
5. Methane accumulations in shafts and sections which range from 5% to 29% (within the inflammable and explosive ranges) occur as a result of power failures causing a stoppage to main or secondary ventilating fans.
6. Senior Mine Management are not fully aware that lightning related problems underground in certain areas are very real ones. Not much research had been done on the relative resistivities of overburden and coal seam measures.

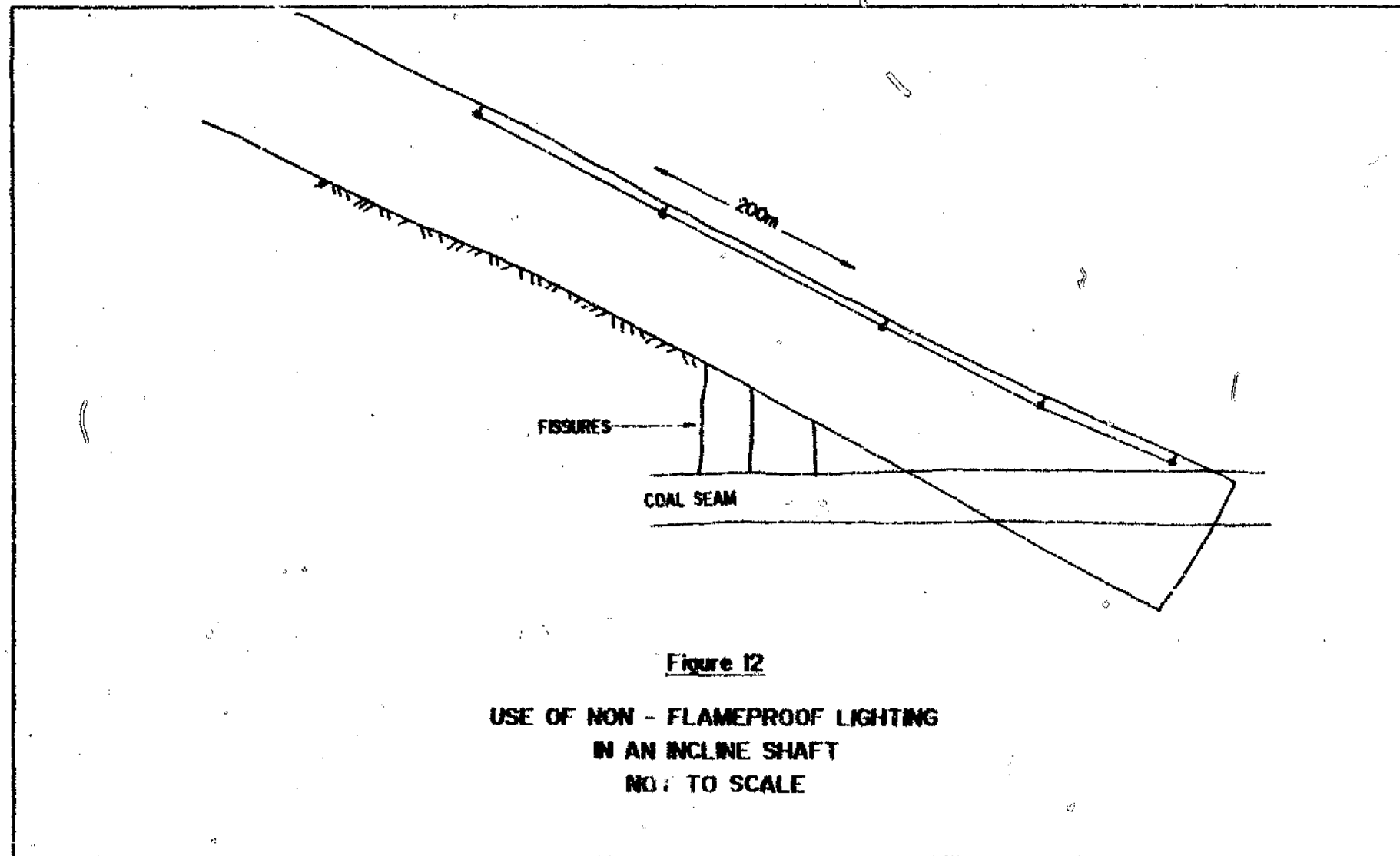
7. Access to shafts are not adequately fenced off or guarded thereby allowing unauthorised persons to enter when dangerous conditions exist; for example, a power trip stopping the main ventilating fans.
8. Senior Officials entered an incline shaft after a methane explosion using a compressed air hosepipe to provide oxygen for breathing without the support of Proto Teams - a foolhardy act.
9. Senior Mine Management are not aware of illegal work being performed on Sundays.
10. Senior Mine Management will always be faced with the perennial problem of conflicting evidence. In the Ermelo Mines (1983) explosion, the following evidence supports this statement.

"The Lamproom Attendant's statement that he had heard no thunder nor saw any lightning prior to the accident and that it did not rain until after 15h00, is refuted by all the other witnesses who were in the vicinity of the shaft on the day of the accident."

11. Inadequate training of mine workers will result in accidents as supported by the statement:

"The two workers, considering the possibility of flooding of the shaft due to the heavy rains, took a calculated risk by entering the unventilated shaft. They obviously did not know that there was a possibility of gas build-up and thought that the compressed air supplied to the pumps would suffice."

12. The use of non-flameproof lights in a sinking shaft where methane is being given off freely, could lead to a methane explosion. The methane being diluted has to flow back up the shaft over non-flameproof lights as shown in Figure 12.



13. In the Albion Colliery explosion, three prospecting boreholes from surface to an abandoned panel (the seat of the explosion) were not shown on the mine plans and hence not sealed on surface. One of these boreholes was cased with a steel pipe. See Figure 13.

It is a common occurrence underground that boreholes are inadvertently holed by workings. These boreholes are not shown on mine plans and they invariably contain water.

14. A lack of lightning arrestors at the top of shafts is a common feature in this investigation. Lightning will thus have a tendency to strike the most prominent feature which is not likely to be earth bonded.
15. Figures 14, 15 and 16 have been developed from evidence taken at the Schoongezicht Colliery explosion on the 2nd December 1960. The mine was extremely gassy and the explosion in the old workings was caused by a lightning strike to the top of the borehole followed by a surge in voltage down the borehole which led finally to a spark in the old workings which were filled by an explosive mixture of methane/air.

Details of this Schoongezicht Colliery explosion on the 2nd December 1960 are given below:

Figure 14 depicts the scene before the explosion. Section 4 was worked up until July 1960 and reports indicated that methane was being given off freely. The power cable from surface was used to supply power to Section 4 and the two core cable was connected to a telephone in Section 4.

During the third quarter of 1960, Section 4 was stopped and the cables were disconnected. Figure 15 shows the position

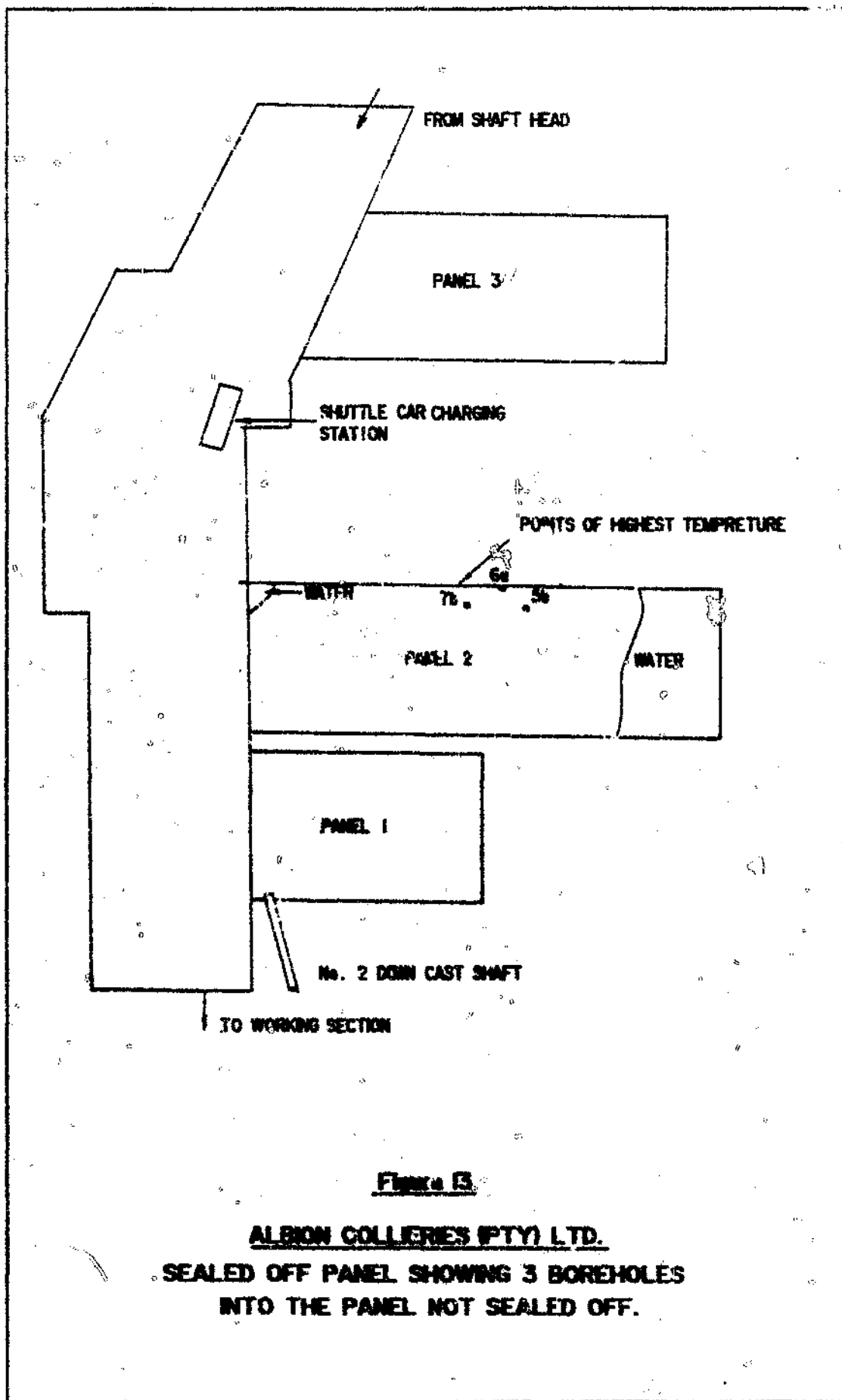


Figure 13

ALBION COLLIERIES (PTY) LTD.

**SEALED OFF PANEL SHOWING 3 BOREHOLES
INTO THE PANEL NOT SEALED OFF.**

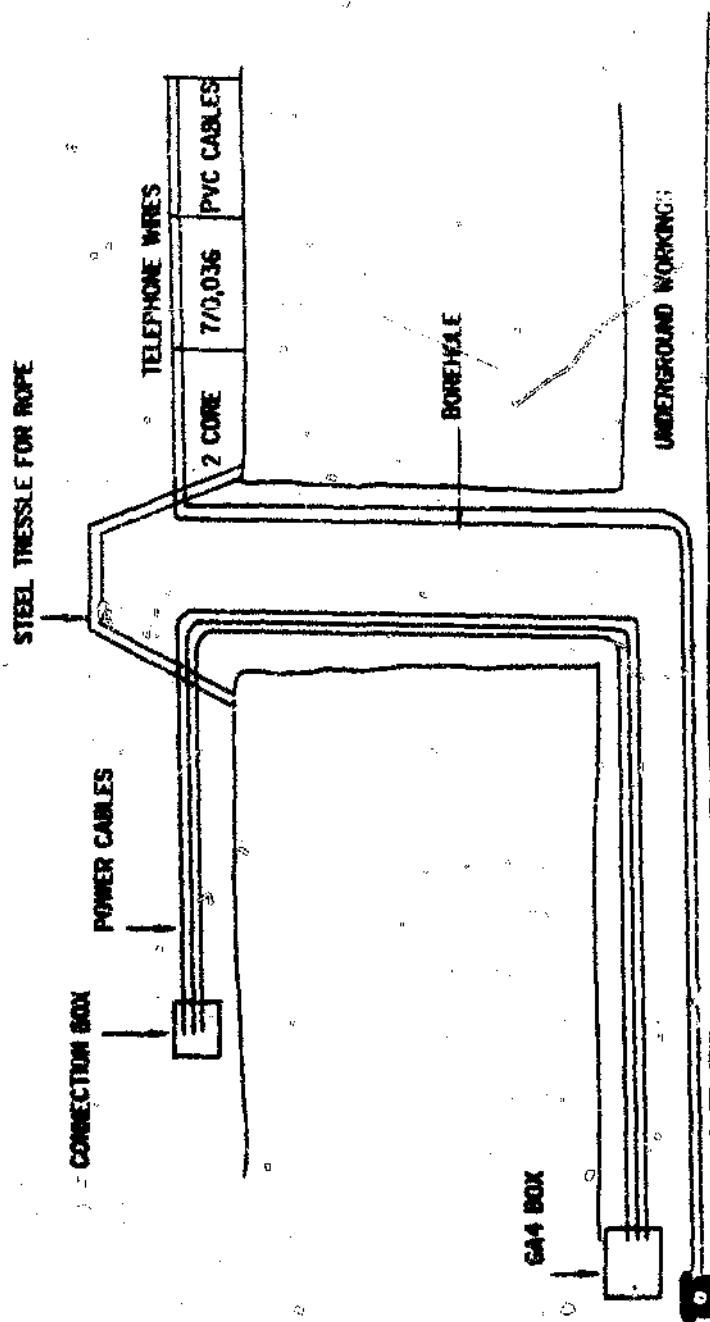


Figure 14

**SCHOONGEZICHT COLLIERY
DETAIL PLAN OF CABLE SYSTEM
IN BOREHOLE BEFORE EXPLOSION.**

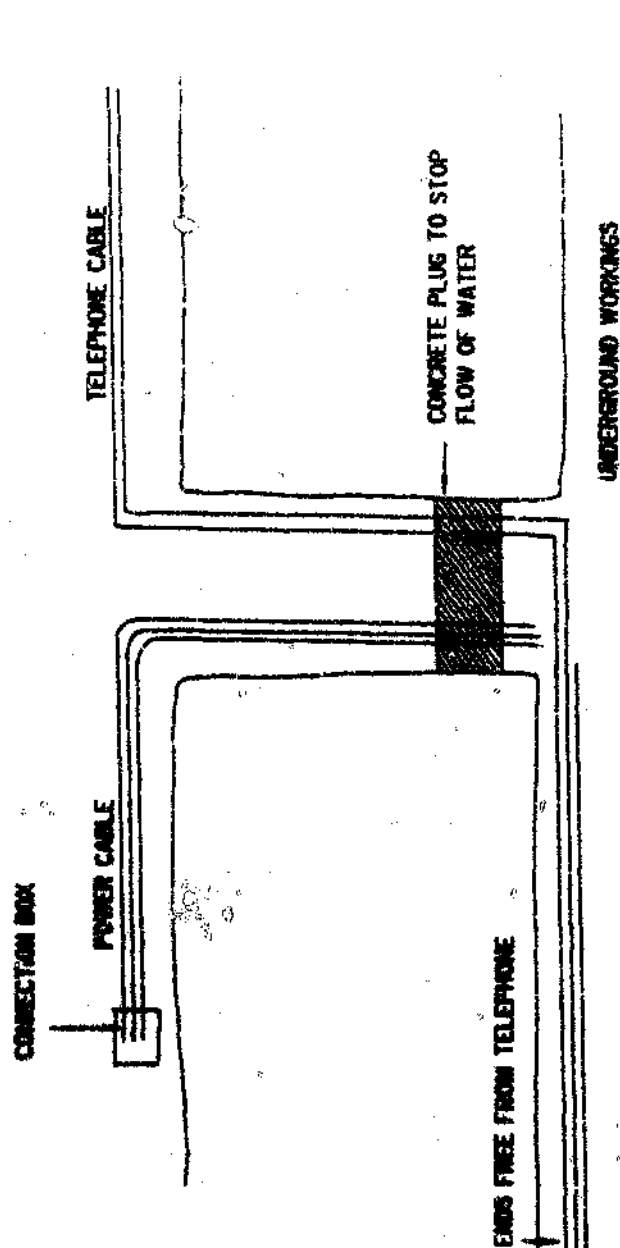
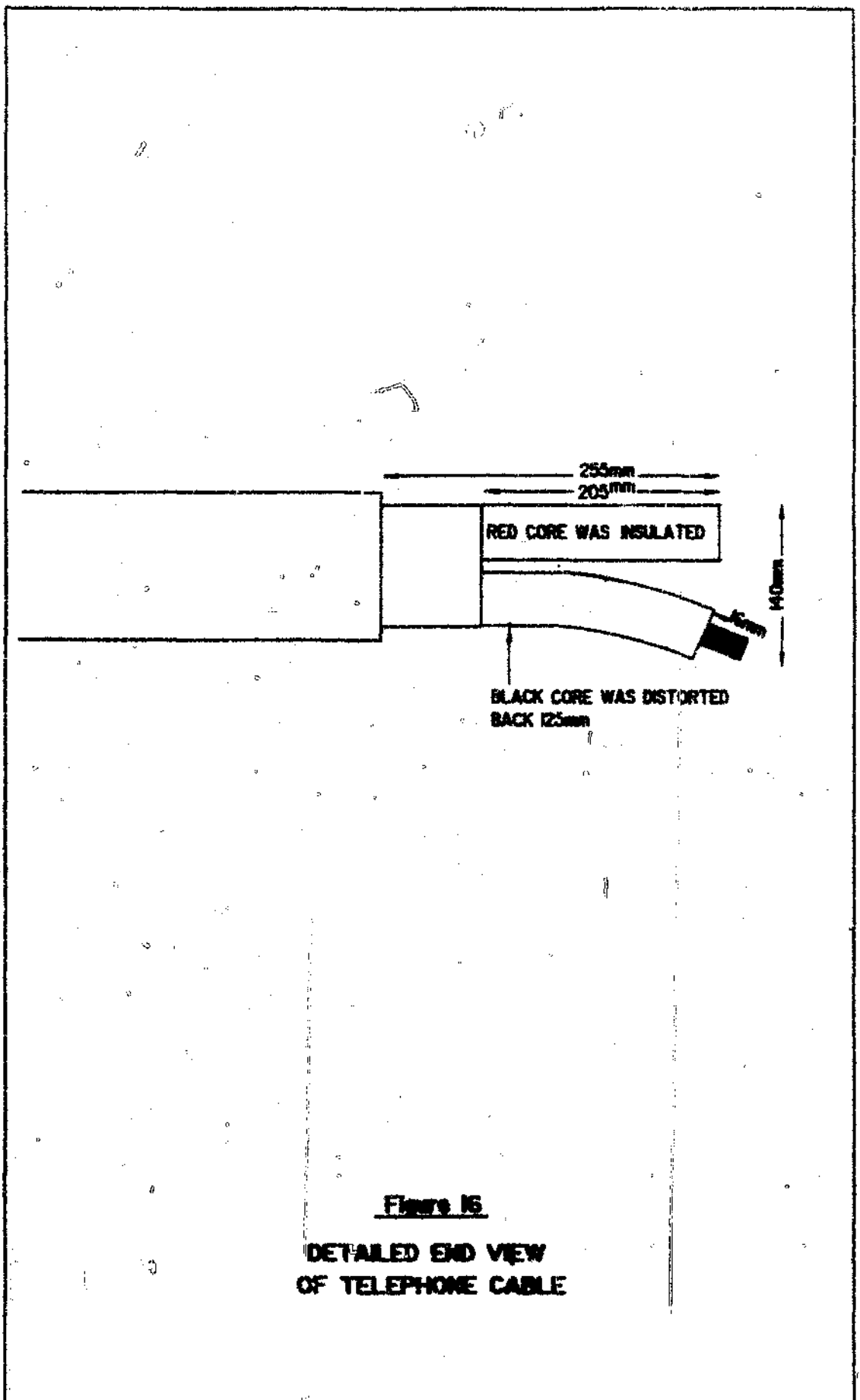


Figure 15

**SCHOONGEZICHT COLLIERY
DETAIL PLAN OF CABLE SYSTEM
IN BOREHOLE AFTER EXPLOSION.**



at the time of the explosion (14h50 on the 2nd December 1960). The borehole was closed with a concrete plug as shown in Figure 15.

The Electrician's evidence is quoted below:

"I disconnected the cable from the telephone. Then I cut the open ends off with side cutters, at the end of the cable. I then taped both ends up with insulation tape.

Then I removed the telephone. The end of the telephone cable I just left against the wall.

The manager indicated that the power had gone off, as reflected by his electric clock, at 14h50.

We then came out of the mine and proceeded to the site of the borehole on surface. At this borehole I observed that there was no transformer and the low tension cable was lying on surface on the ground with a connection box on its end. There was a pair of telephone lines mounted under the power line on the poles, attached to a two core PVC cable at the last pole, which cable went down the borehole.

By court: As far as I am concerned I think all the normal precautions were taken with regard to protection. I could not say if an inclined current could travel down the telephone cable and ignite an accumulation of firedamp below it. I did not see the set up underground at the borehole. I certainly think all the necessary precautions were taken underground regarding the disconnection of the telephone cable."

An inspection of the section after the explosion revealed that some disturbance and heat was found at the end of the telephone cable. Figure 16 shows the detail of the end of this cable in the section.

The Electrician's evidence is as follows:

"We found the end of the telephone cable lying as shown in Figure 16 on the ground not in the water. The outer PVC covering was cut off, about 250 mm back from the ends.

The inner common PVC cover was cut off about 200 mm back from the ends and the two ends were lying about 150 mm apart.

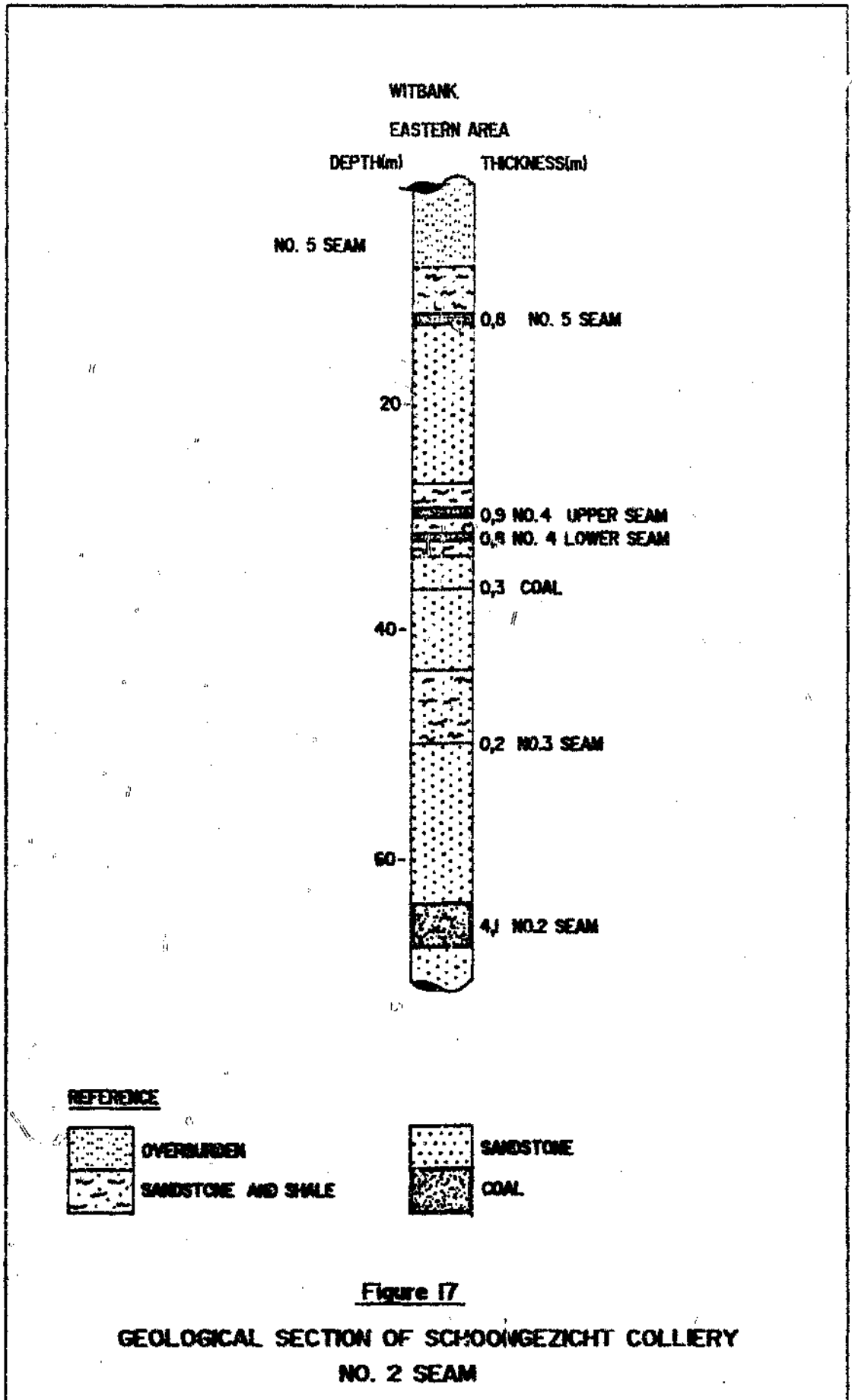
The red PVC wire was still insulated at its end, the back wire showed a distortion of its insulation about 120 mm back from its end. The wire was uninsulated for about 175 mm.

This, in my opinion, was due to some form of distortion due to the explosion or during the explosion.

The end showed signs of having been insulated before the explosion; there was still a small piece of insulation sticking to the PVC covering and one could distinctly locate the former position of the insulation tape before the explosion due to the fact that the PVC, uncovered by the insulation tape, showed clear signs of being heated up and distorted. That which had been covered was not distorted.

A careful investigation for the ignition sources pointed only to a discharge of atmospheric electricity during a lightning storm from conductors passing through B.H. 225 to surface."

Several questions in this evidence remain unanswered. Was the borehole cased? If so, to what depth? Were the cables armoured? At the date of this incident, the Mining Industry tended to use paper insulated lead covered wire armoured cable. Was the armouring earthed at either end of the cable? The depth of the No. 2 coal seam from surface was 65 metres as shown in Figure 17.



The serious situation which may arise in collieries, is highlighted by the contents of a letter sent by the Area Inspector of Mines to the Manager in October 1956 following a methane explosion which killed 12 persons. The concern of Mining Engineers regarding the quantity of section ventilation and the environmental state in abandoned workings is highlighted.

"Last week after the explosion in the South Development ends, I instructed you to reduce the number of producing sections to 5 sections in view of the unsatisfactory ventilation conditions in your mine.

On 10th October 1956, I also instructed you that only approved flameproof equipment should be used in your producing sections.

I require that:

1. The number of producing sections in your mine shall not exceed the quotient of your total downcast air supply in m^3/second divided by $19 \text{ m}^3/\text{second}$.
2. You shall have delivered to me personally within 48 hours of the receipt of this notice, a certificate to the effect that the electricity supplied to all the abandoned sections and other abandoned areas of your mine have been disconnected at the nearest practicable point to the shaft bottom. This certificate shall be signed by yourself and the responsible Engineers.
3. Within 96 hours of receiving this notice, you shall have delivered to me personally a certificate from a recognised ventilation expert indicating whether the ventilation arrangements in your coal mine are such that:

- a. The best use is being made of the available downcast air.
- b. Adequate protection is being afforded the areas of the mine in use against invasion of firedamp from abandoned or temporarily abandoned areas with or without the main fans in operation.
- c. In the event of the answer to (b) above being in the negative all labour, except such labour as may be required to rectify matters, shall be withdrawn from the workings of your mine until such time as the necessary precautions have been completed.
- d. Entry to abandoned areas is to be prevented by the construction of permanent stoppings at all points where such entry can be gained. You are required to furnish me with weekly reports on the progress of this work, the weeks starting from today, until the work has been completed.

Please sign, date and return the copy of this letter to me."

Signed - Chief Area Inspector of Mines.

In many instances it is necessary for Mining Engineers to realise that only "tough and uncompromising attitudes" as shown above will gain the required safety objectives.

- 16. Lack of bleeder roads in pillar extraction sections can result in a build-up of methane in the goaf. When the goaf is connected to surface via a borehole, it is possible to have a spark develop in the goaf as a result of a lightning strike at the top of the boreholes.

Lightning is known to have caused a methane explosion in the goaf area of a stooping section at Ermelo Mines Services (Pty) Limited.

Six workers out of a total of 24 employed on pillar extraction, died as a result of carbon monoxide poisoning when two methane explosions occurred in the goaf, at an estimated 200 m from where they were working and at a depth of 120 m. Nobody suffered any burns nor did any of the eye witnesses see any flames at the time of the explosions.

The exact cause of the explosion could not be determined as the suspected explosion area was inaccessible.

This area, however, contained an open 220 mm diameter borehole downcasting 0,22 m³/sec of fresh air into the goaf.

At the time of the accident severe lightning occurred in the vicinity of the borehole. It is concluded that the lightning current penetrated the body of the earth above the goaf, probably via the wet borehole which acted as a conductor, when lightning struck the ground in the area. This resulted in the occurrence of sparks underground which ignited the critical methane/air mixture in the vicinity of the borehole.

Had this borehole been filled and/or sealed, this accident might not have occurred.

Figure 18 shows the locality plan of the stooping section together with the borehole which was cased with a steel pipe for 2 metres only at the surface. Management were unaware of the existence of this borehole.

17. Not all boreholes are recorded on mine plans. Hence the section working plans do not display boreholes and mine Officials are not aware therefore of these possible

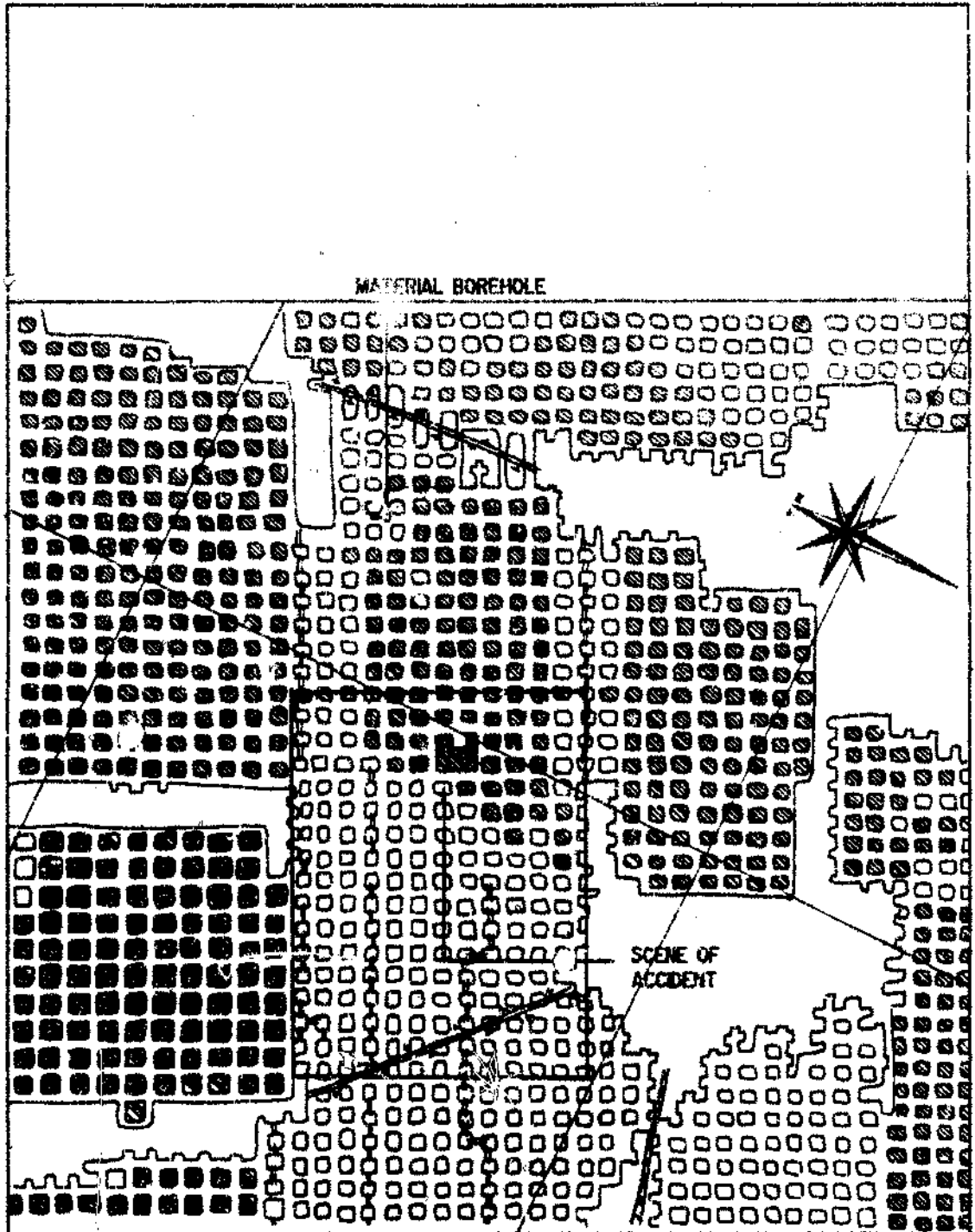


Figure 18

ERMELO MINES SERVICES (PTY) LTD
LOCALITY PLAN OF BOREHOLE
INTO STOOPING SECTION
SCALE 1 : 5000

conductors. In many instances the top of these holes are cased with steel pipes which are themselves excellent conductors.

18. When main ventilating fans are stopped for extended periods (longer than 2 hours) dangerous methane accumulations may occur. Notwithstanding that underground power supply may be isolated, an electric storm on surface may cause a methane explosion. (IMN/DC 374/67 Indumeni Coal Mines Limited).
19. In sections where work has ceased, the ventilating quantities are often substantially reduced (from 30 m³/second to 7 m³/second) while material and equipment is being reclaimed. Ventilation changes are also frequently made by breaking down stoppings in neighbouring sealed sections and temporarily replacing the seal with a brattice curtain. If this curtain is disturbed, ventilation will short circuit the section where reclamation is in progress thus allowing a dangerous build up of methane. A lightning storm on surface could result in a strike to surface and a resultant voltage surge into the gas-filled area with sparking as an initiator of a methane explosion.
20. In the case of the explosion at Uxutu Collieries East Mine on the 28th August 1972, ventilation changes were carried out by a Shift Overseer who closed the regulators reducing the air flow to the section considerably. His superiors failed to check his ventilation calculations which proved to be erroneous and did not follow up by visiting the area after the changes had been made.

3.7 PRECAUTIONS TO BE ADOPTED

The preceding sections have provided details of several documented and researched incidents. Based on these, the following conclusions and observations can be listed.

1. The dangers which arise from only partially sealing off worked-out sections in shallow mines are great.

Where sections are giving off methane freely the section should either:

be totally sealed off using, at least, 225 mm brick stoppings which are well hitched into the roof, floor and sides and then plastered with a cement mixture on the outside of the stopping;

- or remain adequately ventilated so that dangerous methane accumulations do not build up in the section. In this case an examination of the section at two weekly intervals should be undertaken by an official of Shift Overseer status. The results of the examination should be recorded in the Shift Overseer's logbook.

This second alternative is not always open to Mining Engineers particularly where ventilation is required in producing sections. Furthermore, the erection of expensive explosion proof stoppings to seal off old panels is generally not practicable both economically and from a time constraint point of view.

In a situation such as that at No. 3 shaft, Coalbrook, the relative merits of sustaining low capacity ventilation in the shaft after sealing (i.e. through a vent pipe) should be critically examined. In this situation, a non-conductive vent pipe would be advisable.

2. It would be advisable that all prominent surface structures, such as the shaft headgear, be removed prior to shaft sealing. Where extensive surface conductive elements are also in the immediate vicinity (such as railway lines), these should be removed.

All conductive material in close proximity to the shaft should be galvanically bonded i.e. shaft collar, structural steelwork in a shaft plug, any pipework passing down the shaft. All such elements should be well earthed to a common electrode - preferably the existing main earth electrode at the shaft head.

3. Where practical, shaft sealing operations should be scheduled out of the lightning season, in order to allow the safe attainment of non-critical methane/air mixtures.
4. Whenever practicable, sealing-off operations in old sections should be scheduled to take place out of the lightning season to reduce the possibility of a build-up of critical methane/air mixtures whilst there is a significant lightning hazard.

When sections of workings are to be sealed off, it is important that all elements of metalwork and metal equipment be removed from the workings. This applies particularly to items such as conveyor structures, power and telephone cables, pipes, rails and wires, including those attached to roofbolts. Furthermore, no pipe or cable entering the area via a borehole or otherwise should be left in position and it is desirable that borehole casings in holes from the surface be withdrawn where possible.

The purpose of these measures is to minimise the risks of incendiary sparks occurring in a critical methane/air mixture. Such sparks may emanate from metal objects of appreciable size when these are subjected to high potential gradients during a lightning storm overhead or to high

levels of electromagnetic induction due to nearby lightning strikes.

In addition, large surface structures, such as headgears, should be removed from permanently sealed-off shafts.

A cased borehole will provide an excellent conductive path into a mine.

5. Jackson (1987) deals with the need for earthing on surface and states that "it is desirable for the current from a direct lightning strike to a mine headgear or other structure to be absorbed and dissipated by its earthing arrangements so completely that there is virtually no rise in potential of the connected metalwork extending down the shaft. This may be a counsel of perfection, but the provision of a well-designed earthing system should allow direct strokes to be safely withstood without consequent danger underground. With the relatively high soil resistivities encountered in the highveld area (hundred to thousands of ohm-metres) the solution most usually found practical consists of a loop (or ring) counterpoise conductor buried round the perimeter of the structure being protected and connected to it at various points, including corners and major vertical steelwork members. The addition of radial counterpoises and/or vertical driven rods will further reduce the earthing impedance, and the use of rods will possibly enable moister soil layers to be brought into contact with the earthing system, improving the earth resistance.

Shaft headgears, fan housings, and more minor installations such as borehole access points to underground mines (containing pipes or for materials) all require suitable earth electrode systems to minimise the chances of high voltages being introduced into a mine.

It may be noted that the carrying out of surface soil resistivity measurements (necessary to a precursor in designing an earthing system) is something of an art. A series of measurements is desirable to give equivalent resistivities to various depths (e.g. 1m, 2m, 4m, 10m, 20m, 40m, 80m). Precautions must be taken by using sufficiently long test spikes, and if necessary wetting them with salt water, to ensure that the measurements are not being affected by high test spike resistance."

6. Mining Engineers should hold 6 monthly reviews of all surface and underground earthing standards to ensure that responsible officials are fully aware of the requirements.
7. The worked-out panel (No. 2) in which the explosion occurred at the Albion Colliery (3.1.1974) was described by the Mine Manager as dirty, dry and dusty. No stone dust had been applied to this panel (I.M. Wit A. 220/74). It is necessary to ensure that all worked-out panels are swept clean and stonedusted to prevent the initiation of a coal dust explosion following on from a lightning induced methane ignition. As a Shift Overseer at Springfield Collieries in the 1950's, the Author recalls that when rails were removed from the old areas of a section prior to a double track extension, all coal ballast and loose coal was systematically loaded into mine tubs before the rails were lifted. This sound practice is still applicable; old workings should be swept and cleared of all loose coal.
8. After sealing off a panel, an independent inspection (for example by an Environmental Officer) should be made to ensure that all brick seals are in place. At Albion Colliery (1974) a brick stopping in the third entrance to the affected panel had not been built and ventilating air was leaving this panel through this entry. The result was the build-up of an explosive methane/air mixture.

The erection of such seals should be notified to the Mine Surveyor in writing so that they are recorded on the mine plans.

9. Employees should report, and Mining Engineers should investigate, incidences of electrical shocks being experienced underground.

Lightning has also frequently been the cause of electric shocks experienced by men working underground, particularly when metalwork which is bonded to the mine's electrical earth systems is touched. For example, when a shuttlecar is touched by a person standing on the floor, or when a roofbolt is touched by someone standing on a loader or other machine. Although shocks of this nature have not been the cause of any known injury as yet, they do have a negative effect on morale. In mines where such shocks are experienced during thunderstorms, it should be regarded as an indication that there is a substantial local risk of premature detonation of explosives in charged holes, and possibly also of the ignition of critical methane accumulations, due to lightning.

10. The Code of Practice for the avoidance of hazards underground in Collieries, due to lightning, deals with the Earthing of Metalwork in Mines as follows:

Earthing of Metalwork in Mines

General

The primary means of minimizing the effects of stray potentials and currents is to ensure that all extensive metalwork (e.g. conveyor structures, rails, piping and cable sheaths, etc.) is well earthed and bonded together so that all exposed metalwork is kept as close as possible to the electrical potential of the earth at all times. (Bonding is the connecting together of separate metal items to prevent

the occurrence of potential differences between such items. The risk of sparking between them, or of an electric shock being received by a person touching one, or both such items, is thereby eliminated).

Power Supply Equipment

The earthing and bonding normally required in terms of Mines and Works Regulation 21.6 for electric power supplies underground in a colliery is aimed at ensuring a secure, low-resistance metallic circuit from every point on the high and low voltage power distribution network in the mine back to the earthing electrode of the incoming power supply substation on the surface. Cables are screened and protected by earthed sheaths, screens and/or armouring to prevent the exposure of live conductors in the event of damage to a cable; and to provide a good return path for fault current to supply-transformer neutrals when insulation breakdowns occur, thus ensuring that earth fault protection operates correctly and cuts off the power. Earth fault currents are often intentionally limited in magnitude to minimise the rise of the potential of earthed metal during the very short periods for which earth fault currents flow. For safety reasons, electrical equipment underground is enclosed in earthed metal housings of flameproof construction where necessary.

Bonding of Metalwork

Although all the abovementioned precautions are usually taken, certain additional measures which are important to ordinary electrical safety and also play a part in protection against lightning and other stray current effects, are often neglected. These include the bonding together of adjacent metalwork - such as conveyor drive motor frames and conveyor steelwork - sometimes insulated from one another due to the use of non-conductive shaft coupling.

elements and the separate mounting of motors on concrete pedestals. The head of each conveyor structure must also be electrically bonded to the steel structure of the conveyor onto which it discharges.

Note - Bolting of steel structure elements provides a sufficiently continuous bond for this purpose. In the absence of such bolted connections, a suitable electrical bond should be installed.

Cross-bonding of Electrical and Other Metalwork

In principle, all continuous metallic service elements, such as cable sheaths and armouring, pipes, conveyor structures and rails which follow common parallel routes should be cross/bonded at regular intervals not exceeding 500 metres. Ordinarily, such cross-bonding will be done at high tension cable joint locations and transformer installation points, and should also include low voltage signalling and lighting cable armouring where these are present.

Bonding Conductors

It is recommended that bonding conductors should be of stranded copper or galvanised steel wire of 70 mm² cross-section or larger, to ensure that they are strong enough mechanically to ensure reliability in service. Where cross-bonding problems are experienced e.g. where signal cable armouring forms part of the connection, it is recommended that suitable earthing cable clamps and lugs are used in a bolted connection.

Connection of Metalwork to Underground Earthing Electrodes

Transient potential differences can develop between, for example, a conveyor structure or mobile electrically powered machines and the roof, face and floor of the workings.

presenting the risk of electric shocks to people during thunderstorms and also of discharges across charged faces to nearby "earthed" metal objects such as coal drills, which may result in the premature detonation of explosives. Such risks arise particularly in the case of extensive workings where the electrical substation earth on the surface may be two to five kilometres away from a face area.

The general aim is to minimise these transient differences in potential, and this may be achieved by providing a local electrical connection between the body of earth in the working area and the nearby continuous metallic service elements.

Some success may be achieved in this regard by connecting the face end of conveyor structures to nearby roofbolts, which should be connected together in groups of at least three. This should be repeated at intervals of not more than 200 m as the working face advances. Despite the high individual electrical resistances of the roofbolts to earth, conditions can be improved substantially by this means.

The roofbolts must be of a type that has a good earth connection with the surrounding strata.

Unless the flameproof switchgear at the face is already a cross-bonding position, this equipment should, in addition, be bonded directly to the conveyor.

Earthing Precautions against Lightning

A primary protective measure against lightning is to ensure that all metal conductors entering an underground mine are well earthed at the surface. This requires attention at the collar for vertical shafts and to the points where inclined shafts and adits reach ground level. In addition, connections with underground workings such as the armouring

and/or sheaths of power and telephone cables and pipes passing through boreholes, as well as the steel casings of the boreholes themselves, should be well earthed at the surface; and underground they must be bonded to any nearby metalwork close to their points of entry to the workings.

For an effective design of an earthing system it would be advisable to conduct a soil resistivity survey in the vicinity of the mine workings. If the probability of direct strikes is high, then experts on protection should be consulted since earth geographic region and mine installation may have its own particular constraints.

As a general principle at the collar or portal of a shaft, it is recommended that a copper ring conductor be buried round the shaft opening at a minimum depth of 0.5 m. and that it be connected at several points to the shaft steelwork and headframe, inclined conveyor structure or fan housing, whichever may be the case. Where a shaft conveyor delivers direct onto a stockpile, it may be useful to have the ring conductor encircling the latter. In order to obtain a satisfactorily low earthing impedance, it may be necessary to improve the earthing electrode system by adding radial buried conductors and/or vertical driven rods.

Figures 19, 20 and 21 illustrate typical earthing electrode arrangements and electrode resistances achievable under various soil resistivity conditions.

At the entrance to the shaft or adit, all pipes, rails, cables, conveyor structures and handrails, as well as all other continuous metalwork in the shaft, should be bonded together and to earth.

Where applicable, the relevant provisions of SABS 03 (The Protection of Structures against Lightning) as well as the recommendations contained in the section of the Chamber of

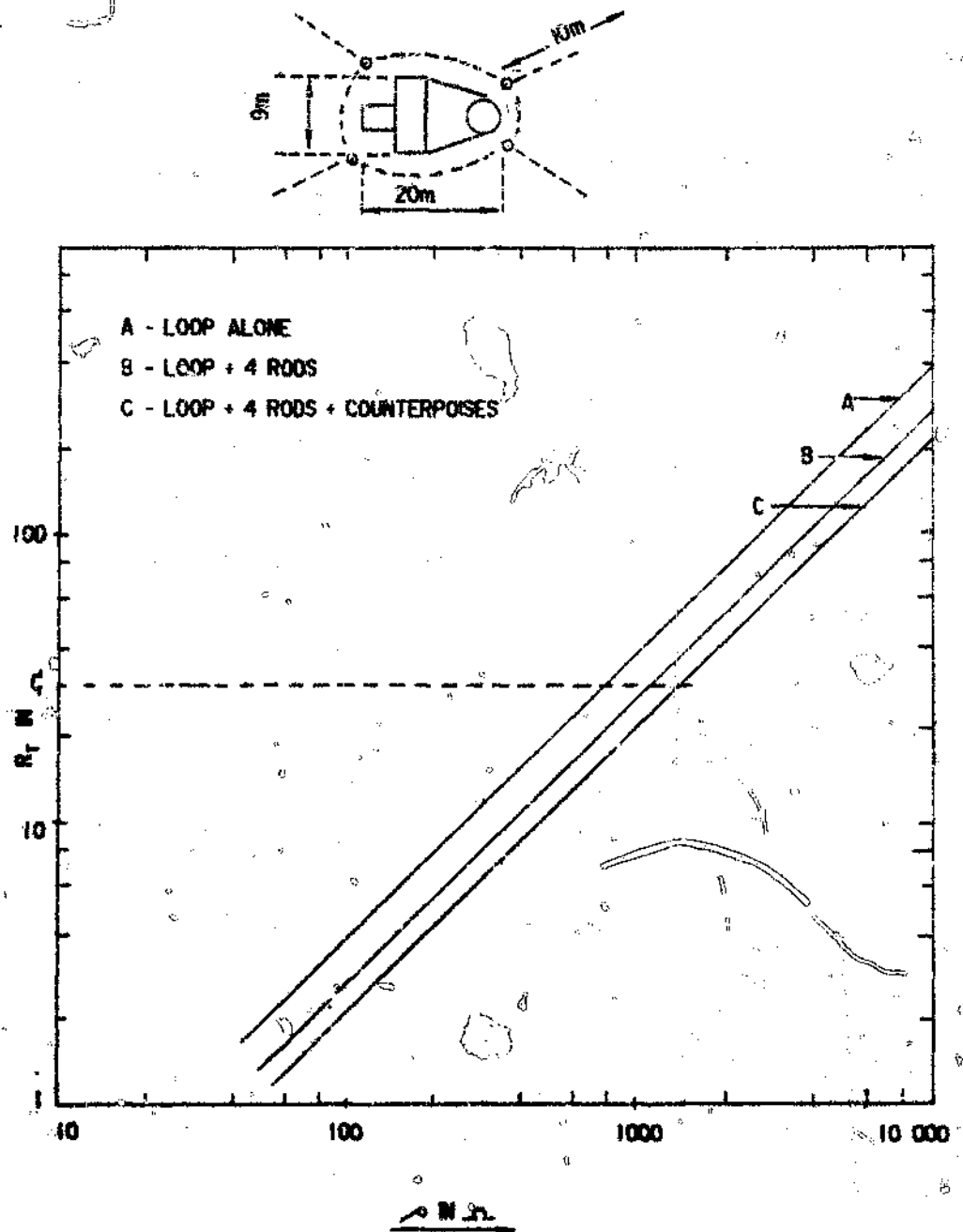


Figure 19

**VARIATIONS IN ELECTRODE RESISTANCE:-
EXAMPLE OF RESULTS FOR FAN-HOUSING**

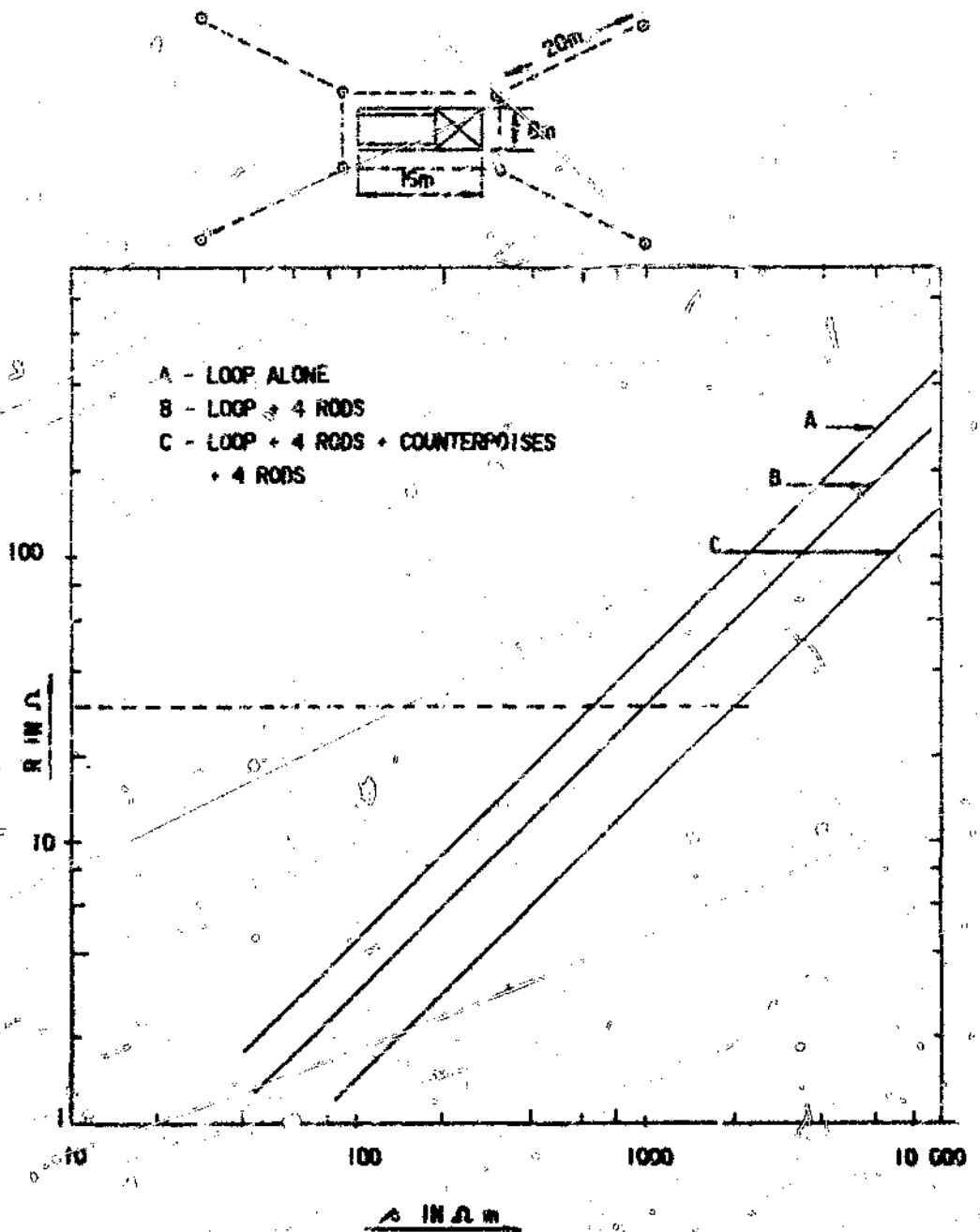


Figure 20

VARIATIONS IN ELECTRODE RESISTANCE
EXAMPLE OF RESULTS FOR HEADGEAR

17. I.M.N. N/C 878/67. Indumeni Coal Mines Limited. Methane Explosion in sinking shaft. 1967.
18. I.M.H.A. 1631/72. Usutu Collieries Limited. Methane Explosion. 1972.
19. I.M.H.A. N.C 82/77. Usutu Collieries Limited. Methane Explosion. 1977.
20. I.M.E.A. 258/83. Ermelo Mines Services. Methane Explosion in sinking shaft. 1983.
21. I.M.E.A. 187/84. Ermelo Mines Services. Methane explosion in goaf of stoping section. 1984.
22. Fauconnier, C.J.. Die Beheer van Ondergrondse Vure in Suid-Afrikaanse Steenkoolmynne. Voorgele ter vervulling van die vereistes vir die graad Doktor in Ingenieurswese in die Fakulteit Ingenieurswese Universiteit van Pretoria. Pretoria. 1981.
23. Larmor, J. and Larmor, J.S.B., Lightning. Proceedings of the Royal Society of London, Series A, Volume 90 p 31.2 1914.
24. Berger, K., Protection of underground blasting operations. Lightning. Volume 2.; Edited by R.H. Golde, Chapter 20, Academic Press, London. 1977.

**MINE GAS AND COAL DUST EXPLOSIONS AND METHANE OUTBURSTS - THEIR
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John Derek Flint

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4.6.2 Northfield Colliery

- (a) Introduction
- (b) Stratigraphy
- (c) Ventilation and Stonedusting
- (d) The Incident
- (e) Conclusion

4.7 SUMMARY OF THE PRACTICES REVIEWED**4.8 PRECAUTIONS TO BE ADOPTED****4.9 CONCLUSION****4.10 REFERENCES**

