SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Final Project Report

Title: DETERMINE THE NEED TO RESEARCH THE TIME-
RELATED STABILITY DECAY OF BORD AND PILLAR
SYSTEMS

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Research
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CONTENTS

1 INTRODUCTION.

This report summarizes the findings of the work conducted to determine the need to research the time dependent decay of coal mine bord and pillar workings. It is intended for use by the relevant SIMRAC committees as background information to assist in decisions regarding research work that could be conducted to investigate the time related decay of bord and pillar workings. As the workings consist of pillars of varying shapes and sizes the study concentrated mainly on the aspects of pillar decay.

In presenting this report only the findings have been included as the reports from each of the contributors are included as appendices. These reports have not been changed in any way and are presented and submitted by the respective authors. It is therefore important to note that the background information to this report will be contained in these documents and not repeated in this summary report.

2 METHODOLOGY

To enable the most comprehensive input into the study, use was made of a working group consisting of the project leader and three other authorities in the field of coal mine strata control. This group consisted of Dr. J Oberholzer (Project Leader), Dr. B. Madden, Dr. J.N. van der Merwe, Mr. G.S. Esterhuizen and Mr. P.J.J. van Vuuren.

Inputs to the study were made in the following ways:

* Contribution in terms of the procedure used
* Participation in the working group
* Participation in the questionnaires
* Individual contribution following studies conducted
* Contribution in terms of knowledge gaps and research needs

3 DISCUSSION OF FINDINGS FROM STUDIES

3.1 **Esterhuizen, G.S. and van Vuuren, P.J.J**. Determination of the Effect of the Age of Coal Pillars on Accidents and Conditions of the Pillars. (Full report presented as Appendix 1).

In carrying out the task a pilot study was conducted to ascertain the effect of the age of pillars on the accident rate in underground pillar extraction sections. This study also included an investigation of the conditions of pillars in these sections.

Accident statistics over a ten year period were studied and visits were made to mines which were extracting pillars at the time of the investigation. It was found that the amount of information relating to accidents that could have been caused by a decay of pillars was insufficient, and poor correlation was obtained between the age of pillars and the accidents.

The poor correlation notwithstanding, the following conclusions were reached:

1. There is an increasing trend in the fall of ground accident rate as the age of pillars being extracted increases.

2. Pillar conditions at the stooping line deteriorate more rapidly as the age of the pillars being extracted increases.

3. Mine personnel do not perceive the age of workings as contributing to the hazards involved with pillar extraction.

4. The initial factor of safety of pillars being extracted has a dominant effect on the condition of the pillars at the stooping line.

5. Most of the fall of ground accidents occur at the stooping line , where deterioration is also the most severe.

6. The sensitivity of pillar condition to the initial factor of safety and to age results in increased hazards when old pillars with low factors of safety are extracted.

7. It was finally concluded that further research work would have to concentrate on enabling the extraction of older pillars with a low safety factor.

3.2   **B. Madden**. Coal Pillar Deterioration. (Full report presented as Appendix 2)

In this study three cases, where the decay of pillars had been comprehensively studied, were used as the basis for formulating conclusions regarding the need to further research this subject.

Through analysis of the cases it became evident that there are factors, other than those that are presently known, that have an influence on deterioration in the condition of pillars.

The following consequences of a decrease in pillar stability were identified:

1. Pillar deterioration occurring in main developments has the potential to jeopardize the safe entry and exit of workers inbye of any failure caused by this instability. Even though pillars in entries are designed to a higher safety factor than in normal panels the time related decay in strength will still pose a hazard.

2. The extraction of previously formed pillar will become increasingly more hazardous. It is foreseen that as significant reserves are contained in pillars, their extraction could become a viable proposition requiring that the state of the pillars be quantified.

3.3 **J.N. van der Merwe.** The Need to Research Time Related Corrosion of Coal Pillars in South Africa. (Full report presented as Appendix 3)

In this study use was made of literature as well as personal experience and work conducted in this field. From the literature three main conclusions derived:

1. Pillar systems which are stable initially may fail over time.

2. There have been attempts to predict pillar life. The existing methods are both crude and suspect, but indications are that predictions are possible.

3. The consequences of pillar failure can be devastating to workers underground and to the general public.

In the concluding remarks it was pointed out that the failure of coal pillar mining systems is a world wide problem and not restricted to South Africa. In overseas countries the effect of such failure has led to several problems with surface stability.

Although it is claimed that pillars are designed with provision for the effects of time, this is seemingly not so and current design methods do not make provision for the effect of time. Not only the pillars themselves are suspect but the whole pillar mining system. Although the present methods are believed to be inadequate, it is believed that a solution could be obtained albeit with some effort.

As vast reserves are locked up in old pillars, and presently working mines do not only consist of new pillars, the problem is not only one that has direct influence on workers but also on the availability of the reserves of a mine.

The main problem identified is the uncertainty that exists with regard to these pillars. This results in inadequate decisions with regard to the long term stability of pillars and could result in a safety hazard for workers underground and land users on surface.

3.4   **J. W. Oberholzer**. Results of the workshop and questionnaire to determine the consequences of the decay in pillars. (Full report presented as Appendix 4)

3.4.1   Workshop

A workshop was held with delegates identified by the working group of this project. Although certain of the delegates could not attend, there were sufficient present to allow the consequences of pillar decay to be identified.

During the workshop the following consequences were identified as the most important ones. (Presented descending in order of importance.)

1.   Loss of mining reserves
2.   Loss of confidence in rock mechanics design
3.   Risky re-opening of older mines
4.   Loss of equipment - Dangerous recovery
5.   Dangerous gases escaping into the workings
6.   Violent collapse of the workings
7.   Surface effects - subsidence and structural damage
8.   Gradual collapse of the pillars
9.   False sense of security

Apart from the safety aspect it is evident that the group in the workshop identified wider issues than those applicable to the underground environment. The most important consequence was seen to be the loss of mining reserves. To enable safety to be maintained overdesign of the pillars could occur which would lead to an unnecessary loss in reserves. The importance given to loss of confidence in rock mechanics design also supports this issue.

From the results of the workshop it is evident that the uncertainty surrounding the time that pillars remain stable could seriously affect not only the basis for pillar design but the whole rationale upon which the choice of mining systems is based. This could lead to an unjustified loss of confidence in the whole process used to design pillars and the mining systems in which they are used.

3.4.2   Modified Delphi questionnaire

Using the consequences identified by the workshop a questionnaire was drawn up and sent by fax to the respondents identified by the workshop. The respondents formed a significantly wider representation than that of the workshop.

The process used, a modified Delphi process, lends itself to greater consensus. (By presenting the results of the workshop, the respondents had a good indication of the overall opinion of the group.) Only if a respondent is aware of facts not known to the other respondents are anomalous results indicated.

From the results of the questionnaire the following consequences were ranked by the group, as being the most important, in terms of severity and probability of occurrence.

1.   Unsafe pillar extraction
2.   Loss of safety factor-margin
3.   Flooding and spontaneous combustion in shallower mines
4.   Roof instability (in workings)
5.   Old areas risk of methane explosions
6.   Violent collapse of workings
7.   Risky re-opening of older mines
8.   Gradual collapse of the pillars
9.   Gas- water influx in multi-seam workings
10.   Increased problems with mining operations

From these results it can be seen that the perception of the consequences differs between the focused group of the workshop and the group of respondents consisting of a broader spectrum of disciplines. There is a more direct focus on safety and less of a focus on the implications.   The hazards are more directed at the effects of mining and the dangers that could be caused by pillar weakening.

This supports the overall consensus that pillar decay has a serious effect on the safety of underground workers. However the broader focus should also be considered. As efforts will be directed to keep workers safe, the effect of pillar weakening will thus also be manifested in a severe loss of mining reserves, as a result of over design of either the pillars themselves or the type of mining method used. It is not the decay of pillars that is the problem but rather the lack of information regarding predictability of decay.

In considering the effects of collapsed pillars on the surface the questionnaire respondents focused on the specifics such as the flooding and spontaneous combustion whereas the workshop-group identified broader effects on the surface that included public safety.

4   TECHNOLOGY NEEDS

The following presents the technology needs as identified by the various contributors:

Dr. J.N. van der Merwe

1.   Strength of fresh coal pillars in different areas and seams
2.   Rate of strength decay for these circumstances
3.   Modes of pillar system failure (roof , floor , pillar slabbing)
4.   Rates of stability decay for different modes of pillar failure

B. Madden

1.   An understanding of the factors that cause the coal seam deterioration
2.   The rates at which individual seams deteriorate
3.   The change in rates, over time, at which spalling occurs
4.   The influence of petrology of the coal in pillars on its long term strength
5.   The occurrence and variation of clay minerals in and between seams

G.S. Esterhuizen

1.   Techniques to assess the potential of the decay of a given coal seam
2.   Techniques to assess the degree of decay of coal and roof strata
3.   Techniques to assess the strength of old pillars prior to pillar extraction

J. Oberholzer

1.   The need to determine the potential for pillar collapse over longer periods so that the effect on surface stability and the land use of the overlying surface can be determined for longer time periods

5   RESEARCH NEEDS

The following summarizes the research needs identified by the contributors:

Dr. J.N. van der Merwe

1. Completion of project to determine the fresh strength of pillars
2. Empirical determination of rates of decay of bord and pillar systems in different areas and seams
3. Determination of factors governing rates of coal pillar decay;

    Chemical - Influence and effects of the petrographical composition of the coal in the pillars on the rates of decay

    Mechanical - Relationship between geometry and rates of decay

    Relationship between derived parameters (load , safety factor etc.) and rates of decay
4. Determination of the chemical and mechanical factors' influence on roof and floor decay

It is foreseen that the work would lead to the formulation of relationships between the immediate strength , the strength at a point in time after excavation, probabilities of failure after a period of time and the influence of factors that still need to be identified.

B. Madden

1. Identification of the factors at the hand of laboratory tests and other testing methods
2. Determination of the extent of scaling of the individual coals seams
3. Petrographical analysis of the contents of seams on the vertical and horizontal axis

G.S. Esterhuizen

1. Develop the techniques to assess the potential for time dependant decay for a given coal seam, to assess the degree of decay of a given pillar or roof strata and the strength of old pillars, especially where pillar extraction is to be conducted.
2. Quantify the time dependent behaviour of coal materials.
3. Quantify the long term strength of coal pillars.
4. Develop safe methods of extracting old pillars with low safety factors.

J. Oberholzer

1.   Determine a probabilistic forecast of time related stability of the surface overlying bord and pillar workings, with specific reference to subsidence that could cause damage to structures and cause changes in the use of the land.

6   CONCLUSIONS

Identified needs

This project's output was to present the rationale for pursuing research into the field of decaying pillars. From the study conducted it has become evident that there is a need to research the time related decay of pillars to reduce the uncertainty of when pillars become unstable or unsafe. By reducing this uncertainty the main concern, that of keeping workers and the public safe, can be addressed without significant losses in mining reserves or increased difficulty in extracting the coal.

Technology needs

It is evident that the greatest technology needs are related to the uncertainty regarding the rate of decay of pillars and the factors that influence this decay.

There is a need to be able to predict the life of pillars in various circumstances based on the prevailing circumstances. The circumstances will include both the physical and chemical characteristics of the coal as well as the geometric size and placement of the pillar (coal seam) in the strata.

With this information pillars can be designed to be stable for required periods and the safety of pillars that have to be extracted can be determined.

Research needs

Methods for the determination of the fresh strength of pillars need to be established. This will form the basis according to which decay and the life of pillars will be evaluated.

The factors that affect decay will have to be identified, how they influence the rate of decay will also have to be determined. This work will have to be done for all the major seams being mined at present.

The aforementioned work could then form the basis for predicting the life of pillar, or the time period that it is stable, in a probalistic way.

This will allow the evaluation of the suitability for extraction of older pillars as well as the assessment of the risk of failure in older pillars.

7   RECOMMENDATIONS

It is recommended that a longer term project be established to investigate the extent of pillar decay and the influence of the causative factors leading to the decay of pillars in coal mines.

Once the factors have been identified and an indication obtained of how they influence the decay of pillars, can further projects be identified. It is foreseen that later projects will have to more specifically address the time influence of the individual factors.

The ultimate output from this project should enable pillar lifetimes to be forecast, based on the prevailing characteristics of the coal and the conditions under which the pillars were formed.

APPENDIX 1

DETERMINATION OF THE EFFECT OF THE AGE OF COAL PILLARS ON ACCIDENTS AND CONDITION OF THE PILLARS

Prepared for CSIR: Division of Mining Technology

by

P J J van Vuuren and G S Esterhuizen

Department of Mining Engineering
University of Pretoria

June 1997

SYNOPSIS

A pilot study was carried out to determine the effect of the age of coal pillars on the accident rate in underground pillar extraction sections and on the condition of the pillars. Accident statistics of a 10 year period were studied and visits were made to mines which were extracting pillars at the time of the investigation. The data base of accidents was small and poor correlation was obtained between accidents and age of pillars. However, the following conclusions were made:

- there is an increasing trend in the fall of ground accident rate as the age of pillars being extracted increases;

- pillar conditions at the stooping line deteriorate more rapidly as the age of the pillars being extracted increases;

- mine personnel do not perceive the age of the workings as contributing to the hazard of pillar extraction;

- the initial factor of safety of pillars being extracted has a dominating effect on the condition of the pillars at the stooping line;

- most of the fall of ground accidents occurred at the stooping line, where deterioration is also the most severe.

- the sensitivity of pillar conditions to the initial factor of safety and to their age results in increased hazards when extracting old pillars which have low factors of safety.

It is recommended that further research should concentrate on the extraction of old pillars with low factors of safety.

CONTENTS

DETERMINATION OF THE EFFECT OF THE AGE OF COAL PILLARS ON ACCIDENTS AND CONDITION OF THE PILLARS

1.0 INTRODUCTION

South African coal mines have been extracting coal for more than a century using underground mining methods. The most common method of underground coal mining is the bord-and-pillar method. As a result, large undermined areas are standing on coal pillars which were mined many years ago. Many of these areas have collapsed. Since all the collapses did not take place immediately after the pillars had been formed, it is clear that time dependant deterioration of the pillars occurred.

Concern has been expressed over the decay of pillars with time which could lead to a reduction of their strengths, collapses of old workings and an increase in the rock fall hazard where persons work in or travel through old workings.

CSIR Miningtek was awarded a SIMRAC project to determine the need to research the long term stability of coal pillar workings, (Project COL 439). A part of the research was sub-contracted to the University of Pretoria and is presented in this report.

The research presented in this report entailed a study of accident statistics to determine whether there is a relationship between fall of ground accidents and age of workings where pillar extraction is done. In addition, several coal mines were visited as part of a pilot study to establish whether pillar conditions were worse when extracting old pillars compared to the extraction of newer pillars.

2.0 INVESTIGATION PROCEDURES

The pilot study was focused on accident statistics and pillar conditions in mines where pillar extraction was being practised. The procedure adopted was to compare accident statistics and pillar conditions in workings where old and new pillars were being extracted so that the effect of time related decay of the pillars could be established.

An extract of the safety statistics of the past 10 years was obtained from the Department of Mineral and Energy Affairs. From these statistics the data of reportable and fatal fall of ground accidents, related to pillar extraction, were extracted.

Letters were written to the managers of the mines concerned, requesting further detail of these accidents. Most of the mines responded and the data thus collected could be examined

The mines where the accidents occurred, and other mines where pillar extraction was being done, were visited during March and April 1997 to collect additional data. Informal discussions were also held with officials involved in the extraction operations to obtain their views on the behaviour of the pillars and the difficulties experienced during extraction.

The data collected concerning the pillars were classified according to condition, age, safety factor and other relevant parameters.

3.0 FALL OF GROUND ACCIDENTS ASSOCIATED WITH PILLAR EXTRACTION

Data of 27 fall of ground accidents, which occurred over the 10 year period, were obtained and analysed. It was understandably not possible to visit the panels where these accidents occurred and only the relevant data such as the age of the workings could be collected from the mines in addition to the data on the accident reports.

The accidents occurred at 7 mines and totalled 29 fatalities and 23 reportables. Further information namely depth of workings, age of the pillars, safety factor, whether the accident occurred at the pillar being extracted or elsewhere in the section and approximate monthly production tonnages were recorded. The data and associated locality plans were tabulated and are presented in Appendix 1.
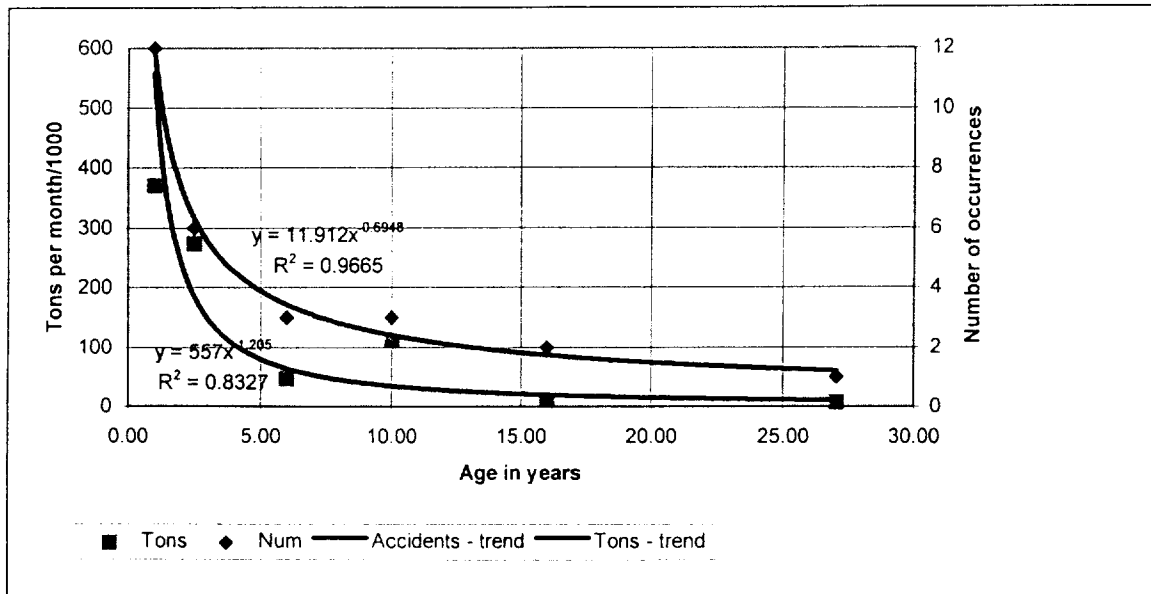
Effect of age of workings

Table 1 is a summary of the number of accidents related to age and the relative monthly tonnages produced from these sections in the periods prior to the occurrences. Each

Table 1 Relationship between pillar age, occurrence of accidents and production

Pillar age (Years)	Number of Occurrences	Sum of production rates (thousand ton per month)
Less 1	12	370
1 - 4	6	274
4 - 8	3	48
8 - 12	3	111
12 - 20	2	11
+ 20	1	8

occurrence of an accident is recorded as a single event, regardless of the number of persons involved.

The statistics in table 1 are presented graphically in figure 1. The results suggest that the frequency of occurrences are not directly related to the age of the pillars. It rather indicates that pillars are being extracted in areas where the age of the pillars are less than four years and

Figure 1 Graph showing statistics of age of workings against number of accidents and tonnage produced in panels where fall of ground accidents occurred

very frequently less than one year. The percentage of occurrences in areas where the age is less than 4 years equals to 60 % with the tonnage produced in the period before the accidents occurred amounted to 78 % of the relevant tonnages. This was also found to be the case where pillar extraction was being done during the investigation period, where more than 60% of the tonnage was being mined from panels younger than four years.

Statistically the sample is not large enough and the tonnages too erratic, due the physical mining conditions at different mines, to try and relate the occurrence of individual accidents to age or production rates. As a result, the relationship between the trend lines shown in figure 1 were used to calculate the accident rate per ton produced, shown in figure 2. It can be seen that there is an increasing trend in accidents per ton mined as the age of the pillars increases.
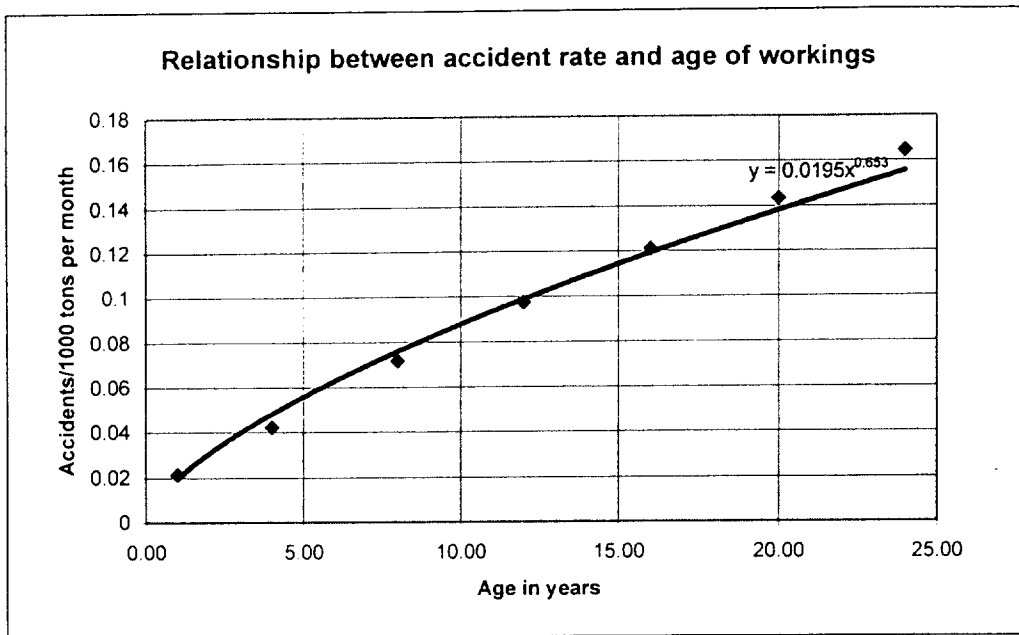
Figure 2 Graph showing trend of accident rate against age of workings in pillar extraction panels where fall of ground accidents occurred

Effect of factor of safety of workings

A further possible contributing factor to the occurrence of fall of ground accidents is the safety factor in the areas where the accidents occurred. The safety factors ranged from 1,6 to about 6,0 and the distribution of frequency against safety factor and related tonnages produced are shown in Table 2. Details are presented in appendix 1.

Table 2 Statistics of accidents and factors of safety in pillar extraction workings where accidents occurred

Safety Factor	Frequency of occurrences	Thousands of tons produced per month
1,0 - 1,5	0	0
1,5 - 2.0	7	262
2,0 - 2,5	16	523
2,5 - 3,0	1	6
3.0 - 4,0	1	5
4.0 +	2	14

The statistics presented in table 2 are shown graphically in figure 3. It can be seen that the accident frequency does not relate to the factor of safety , but rather to the tons produced. The results rather indicate that most of the tonnage from the pillar extraction panels was mined at factors of safety of between 1,5 and 2,5 which is also the range within which most of the accidents took place. Approximately 85% of the accidents took place at safety factors between 1,5 and 2,5 whilst 97% of the tonnage was produced in this range. Owing to the low number of data points and the different mining conditions, ie low seam and high seam mining, no further analysis of the effect of the factor of safety was carried out.

Relationship between fall of ground accidents, production rate and factor of safety of pillars
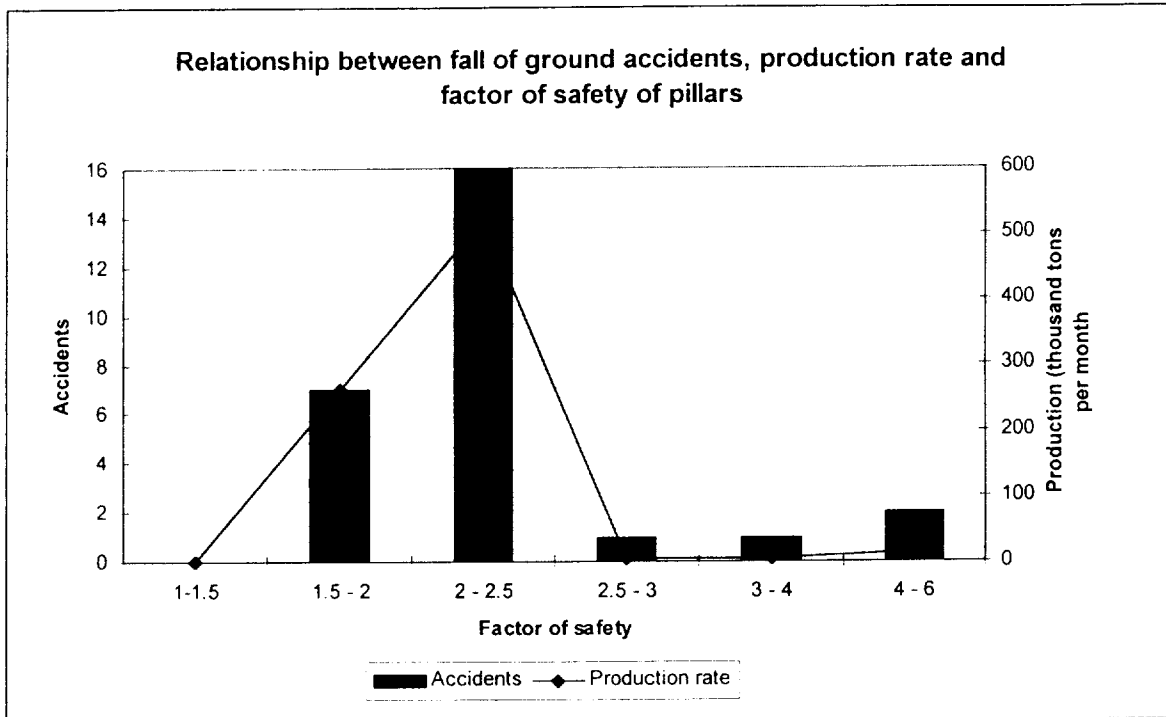
Figure 3 Relationship between fall of ground accidents, production and factor of safety in panels where accidents were recorded

Location of accidents

The location of the accidents could either be in the area where pillars were actually being extracted or elsewhere in the section. The accident reports indicated that 23 (85 %) of accidents occurred in the area directly related to an actual pillar extraction operations and 4, (15 %), elsewhere in the section. These dramatic figures indicate that the major fall of ground hazard is the area where the pillar extraction is actually being done.

4.0 CONDITIONS OF PILLARS IN CURRENT PILLAR EXTRACTION SECTIONS.

In this exercise a number of the mines where accidents had occurred and other mines where pillar extraction or partial pillar extraction was being done were visited and the condition of the pillars and roof in these sections were recorded and analysed. Altogether seven mines, including 15 panels were visited.

Data collection method

The method of recording the conditions of pillar workings based on the method developed by CSIR Miningtek, was used, see appendix 2. As the object of this exercise was to rate specifically the pillar conditions, a simplified method assessment was used. The assessment made use of a rating system as follows:

1 - None	:	no visible fracturing, scaling or deterioration
2 - Slight	:	fracturing with occasional scaling of ribsides and corners to a depth of 0 - 100 mm.
3 - Moderate	:	scaling of ribsides and corners to a depth of 100 - 300 mm.
4 - Severe	:	severe scaling of ribsides and corners to a depth of 300 - 700 mm.
5 - Very Severe	:	general scaling of ribsides and corners, original pillar shape difficult to observe, scaling in excess of 700mm.

At the mines visited all the parameters required were observed and additional data obtained from the survey and geological departments. Where possible three rows of pillars were examined at the following locations: adjacent to the goaf line, pillars about 100 meters further back and finally pillars about 200 meters outbye. At each location three pillars were evaluated.

Being close to the working faces, most of the pillars had been fairly recently stonedusted, hence slight pillar fracturing could not be observed unless the stonedust was removed. This was not normally done and only where scaling occurred was fracturing observed and recorded.

Effect of mining method

From the site visits it become clear that pillars older than 5 years had mainly been developed by means of conventional drilling and blasting and the more recent pillars had been developed by continuous miners, either drum type or, roadheader type. All pillar extraction was done by continuous miners of the same type used during development.

Although the ribsides which had been blasted were more uneven then those cut by continuous miner, the general pillar conditions were dominated by the local geology and stress levels rather than the mining method. Cases where no scaling was present were observed in both drill and blast panels as well as continuous miner panels. The absence of scaling could therefore not only be attributed to the mining method. Where moderate and severe scaling occurred it was irrelevant of the original mining method.

The conditions of the pillars in stooping panels were usually typical for the specific mine. At two locations the typical degree of scaling was "slight" to "moderate", prior to pillar extraction. At all the other mines scaling was non existant and any observed scaling was the result of low factors of safety and/or age of the pillars during stooping.

Roof conditions

Roof conditions away from the stooping line were generally good. The roof support ranged from no support during initial development, with 1-1,5 meter roof bolts installed at intersections, re-roofbolting when pillaring, or w-straps in the roads and 5 meter - 40 ton cable anchors on the intersections. The stability of the roof was not included in the rating of the pillar conditions.

Opinions of mine personnel working in pillar extraction

From the informal discussions held with the personal involved in pillar extraction, the most important factors affecting the safety of pillar extraction could be identified. Probably the

most important factors are the training, local knowledge and discipline of the team of

workers doing the pillar extraction. In addition to this, the safety factor, general condition of

the area and the adequacy of support is of major concern for the safe extraction of these

pillars. The age of the workings was not a particular concern, provided the general conditions

were good.

Observed pillar conditions

The data collected, descriptions of the pillar extraction sections visited and plans as at the

date of the visits are presented in appendix 3. Table 3 summarises the pillar ratings carried

out in the 15 panels examined. Figure 4 illustrates the effect of age of pillars on their

Table 3 Condition of pillars in pillar extaction panels

PANEL	AGE	SAFETY	DETERIORATION		
No	YEARS	FACTOR	FIRST PILLAR	100m BACK	200m BACK
1	0,5	6,0/1,5*	None	None	None
2	1,5	2,5/0,8*	None	None	None
3	23,0	2,4/0,7*	Slight	Slight	Slight
4	0,3	2,0	None	None	None
5	0,8	1,8	Very severe	None	None
6	0,1	2,2	None	None	None
7	22,0	1,4	Very severe	Very severe	Slight
8	26,0	1,6	Moderate	Slight	Slight
9	0,1	2,1	Moderate	Slight	None
10	2,3	2,1	Moderate	Slight	Slight
11	17,0	1,7	Severe	None	None
12	14,0	5,6/±2,5*	Slight	None	None
13	3,0	4,1/±2.0*	None	None	None
14	8,0	5.1	None	None	None
15	37,0	1,6	Moderate	None	None

* Final factor of safety where partial pillar extraction is done by pillar splitting.

condition at the stooping line. There is a wide scatter of results, but a fitted linear trend line

indicates an upward trend (poorer conditions) with age. It can be concluded that age only has

a slight influence on the pillar rating away from the goaf line. Near the goaf line the older

pillars appears to be scaling slightly more than newer pillars with the same safety factors.
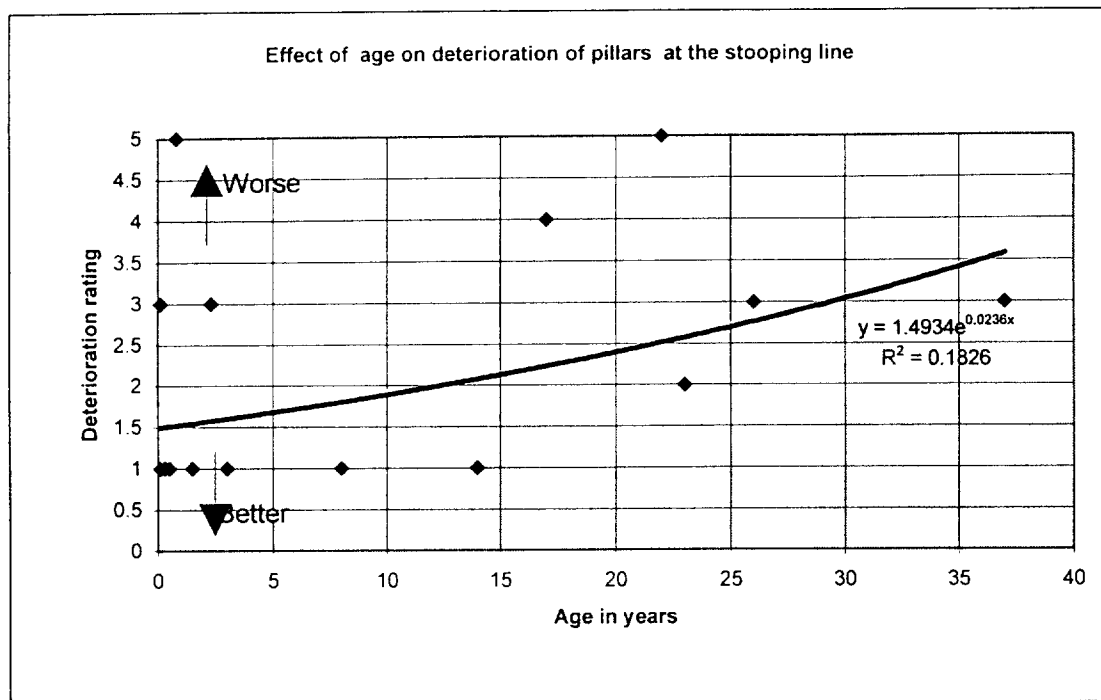

Figure 4 Effect of age on pillar conditions at the stooping line

As far as the effect of the safety factor is concerned, the row of pillars next to the stooping line is severely effected when the safety factors are low, as shown in figure 5.

There are two panels of specific interest. Panel number 5 where the age was less than one

year and the safety factor is around 1.8. all the pillars deteriorated dramatically as the goaf

line moved forward. Close to the barrier pillar the scaling was less severe but towards the
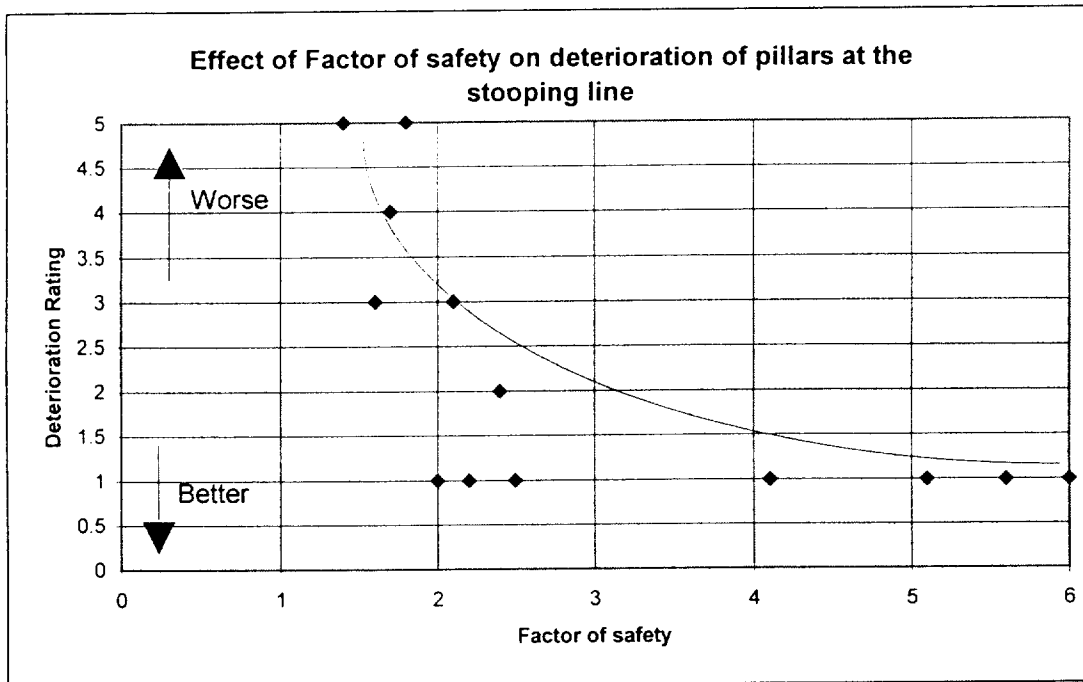
Figure 5 Effect of factor of safety on pillar conditions at stooping line

centre and specifically where there was an apex the scaling of the pillars was very severe.

This scaling reduced drastically from the second line of pillars. It in fact became almost zero.

The roof conditions remained stable.

The second panel of interest is one where the original mining was done 22 years ago, and

there are goafs on either side of this panel. The area is also overlain by a 37 meter dolerite sill

which might not have been broken. Stooping was started in this panel but was soon

adjourned due to a serious intersection collapse which covered the continuous miner. The

scaling of the ribsides was very severe up to a point further back, coinciding with the limits of
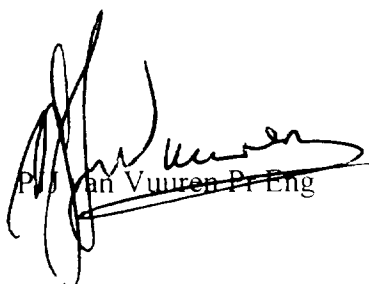
the adjacent goafs.

5.0 CONCLUSIONS

The data base of fall of ground accidents is small and consequently low correlation coefficients were obtained in the study. Nevertheless, it is concluded that an increased age of coal pillars increases the rock fall hazard in pillar extraction operations. The reasons for this conclusion are as follows:
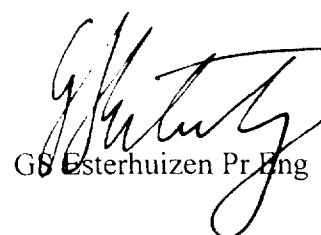
a) The accident statistics indicate an increasing trend in fall of ground accidents per ton mined as the age of pillars being extracted increases.

b) Observations in pillar extraction panels showed that pillar conditions at the stooping line tend to deteriorate more rapidly as the age of the pillars being extracted increases.

The study also resulted in the following conclusions being drawn:

c) Mine personnel currently working in pillar extraction panels do not perceive the age of the workings as contributing to the hazard of pillar extraction.

d) It was found that during pillar extraction the initial factor of safety of the pillars had a major effect on pillar conditions near the stooping line.

e) Most of the fall of ground accidents in pillar extraction sections (85%) occured at the stooping line. It is in this area that pillar deterioration is also the most severe. Further research into the hazards of pillar extraction should therefore be concentrated on the stability of the workings at the stooping line.

f) The sensitivity to factor of safety, combined with sensitivity to the age of pillars, will result in an increased hazard of fall of ground accidents when extracting old pillars with low factors of safety. The effects are most noticeable near the stooping line, where most accidents occur. The extraction of old pillars with low factors of safety is a topic which requires further research.

PJ van Vuuren Pr Eng

GS Esterhuizen Pr Eng

STATITICS ON SERIOUS AND FATAL ACCIDENTS DUE TO PILLAR

EXTRACTION OPERATIONS IN RSA COAL MINES - 1988 TO 1996.

ACCIDENT NR	DEPTH (M)	AGE - YEARS	SAFETY FACTOR	PRODUCTION (000 TPM)	CASULTIES	AT PILLAR EXTRACTED	AT ADJACENT LOCALITY
1	47	2,0	2,5	44	1 - Fatal	Yes	No
2	147	2,0	2,5	44	1 - Injury	Yes	No
3	258	0,5	1,6	36	1 - Injury	No	Yes
4	258	0,4	1,8	42	1 - Injury	No	Yes
5	237	1,0	1,6	29	1 - Fatal	Yes	No
6	266	3,5	1,7	36	2 - Injury	Yes	No
7	203	1,0	1,8	36	1 - Injury	No	Yes
8	161	1,2	2,5	40	1 - Injury	Yes	No
9	156	0,6	2,3	39	5 - Injury	Yes	No
10	177	5,5	2,1	51	1 - Fatal	Yes	No
11	168	0,5	2,1	49	1 - Fatal	No	Yes
12	160	10,0	2,3	41	1 - Injury	Yes	No
13	166	0,4	2,4	36	1 - Injury	Yes	No
14	156	0,2	2,0	64	1 - Fatal	Yes	No
15	155	1,2	2,3	72	4 - Injury	No	Yes
16	145	1,4	2,1	59	1 - Injury	Yes	No
17	95	1,0	2,2	66	1 - Fatal	Yes	No
18	137	23,0	5,9	08	1 - Fatal	Yes	No
19	254	0,2	2,1	05	1 - Fatal	Yes	No
20	267	13,2	3,0	06	1 - Fatal	Yes	No
21	68	12,3	3,9	05	1 - Fatal	Yes	No
22	197	1,0	2,3	15	10 - Fatal	Yes	No
23	50	8,0	4,1	06	1 - Injury	Yes	No
24	290	5,0	2,1	06	1 - Fatal	Yes	No
25	55	0,4	2,3	02	1 - Fatal	Yes	No
					2 - Fatal	Yes	No
					1 - Injury	Yes	No
26	62	9,0	1,7	19	2 - Fatal	Yes	No
					1 - Injury	Yes	No
27	65	2,5	2,3	15	3 - Fatal	Yes	No
					1 - Injury	Yes	No

ACCIDENT NUMBER 1

DATE: 1993-08-30

CASUALTY : 1 FATALITY

DEPTH   : 147 METER

AGE   : 2,0 YEARS

SAFETY FACTOR : 2,5

PRODUCTION : 44 000 TPM
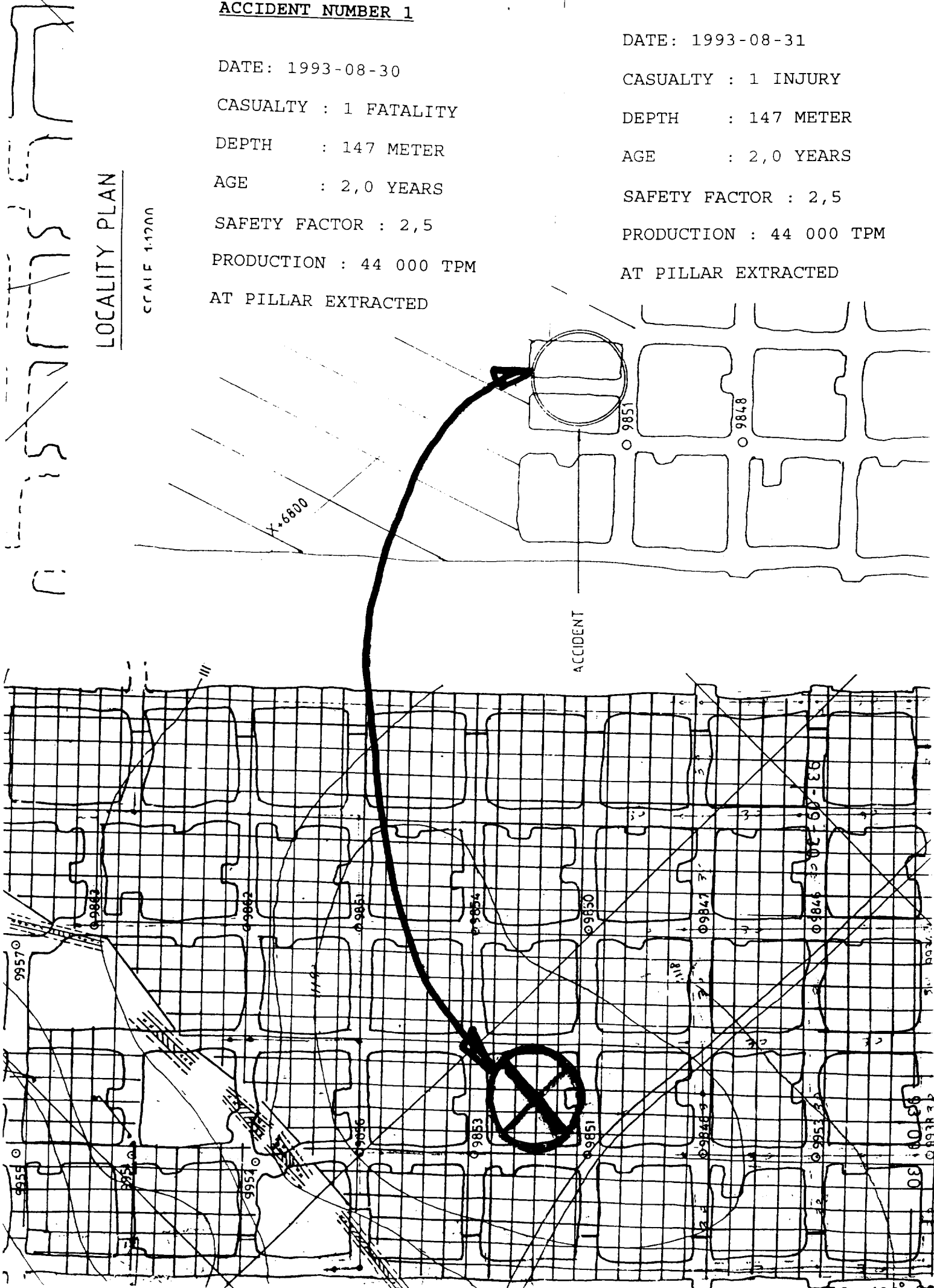
AT PILLAR EXTRACTED

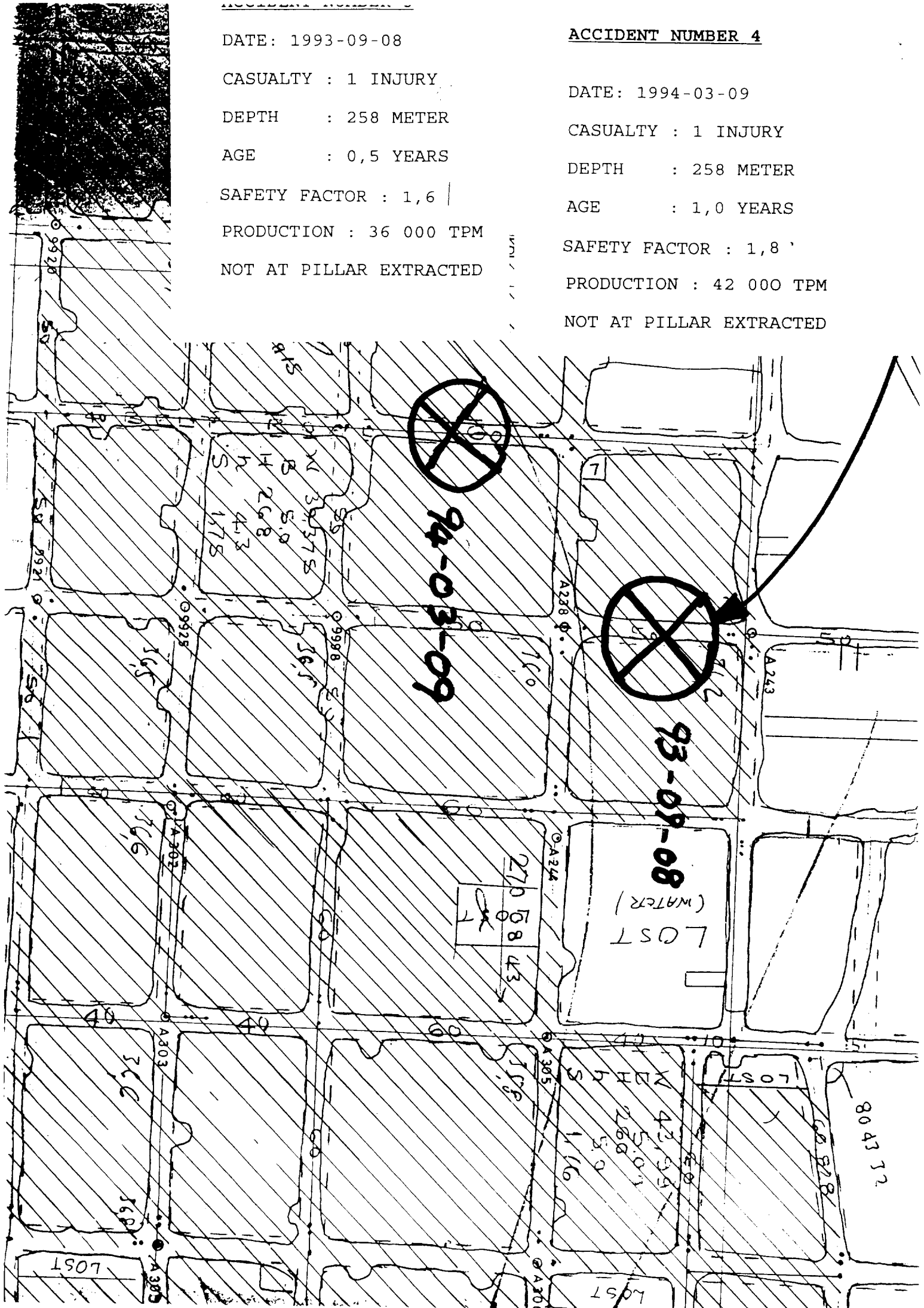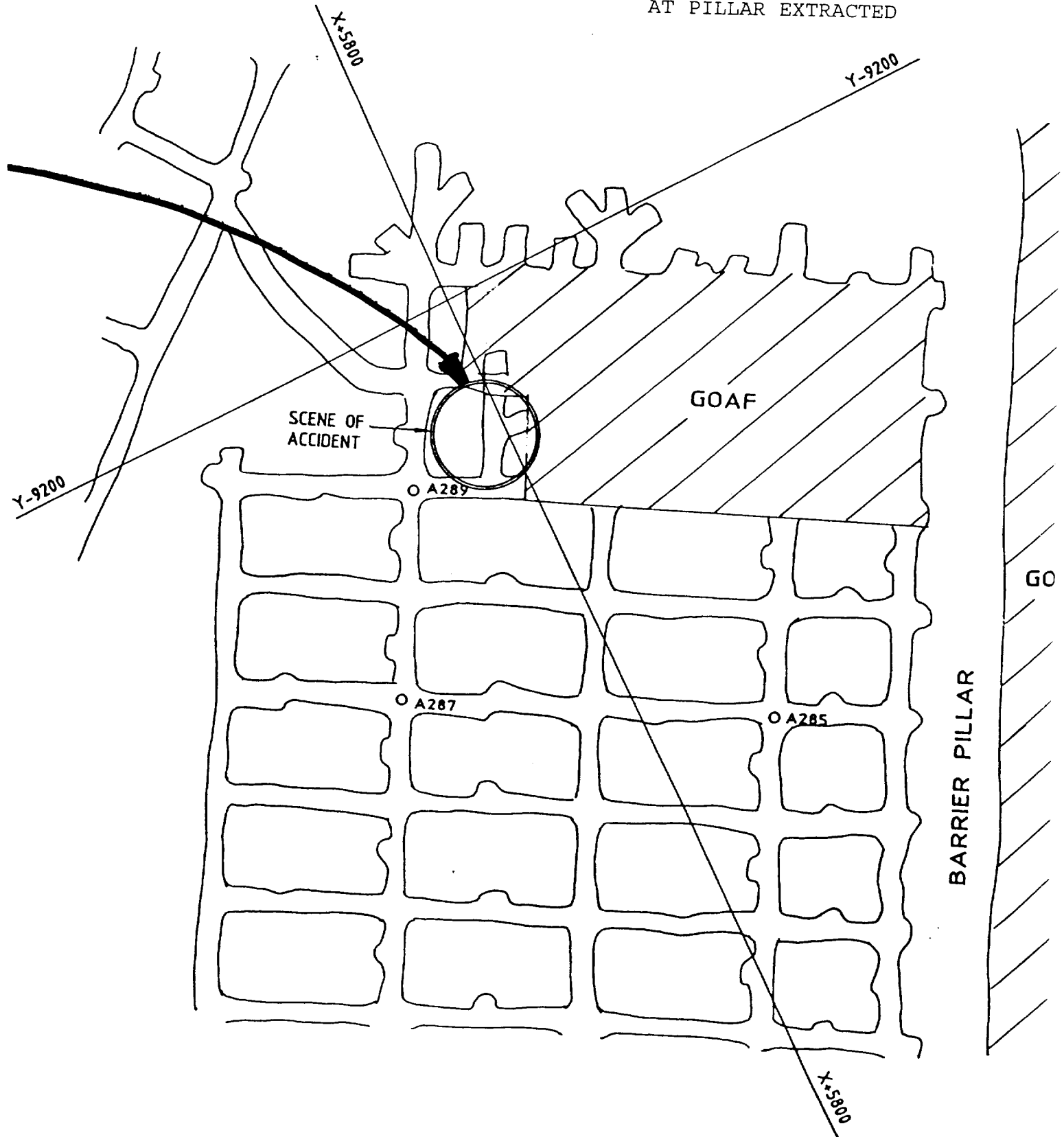## ACCIDENT NUMBER 2

DATE: 1993-08-31

CASUALTY : 1 INJURY

DEPTH   : 147 METER

AGE   : 2,0 YEARS

SAFETY FACTOR : 2,5

PRODUCTION : 44 000 TPM

AT PILLAR EXTRACTED

LOCALITY PLAN

SCALE 1:1200

ACCIDENT NUMBER 3

DATE: 1993-09-08
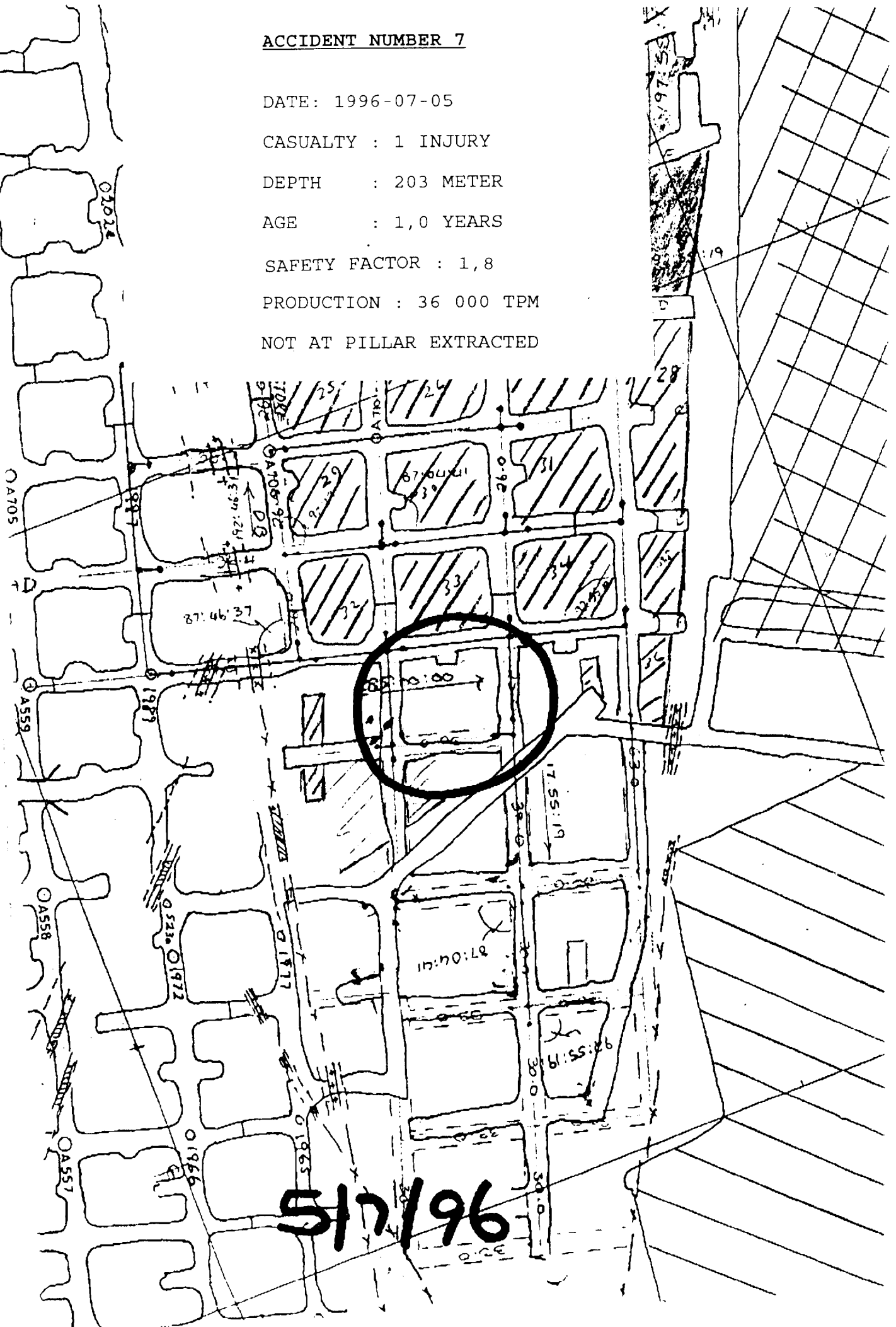
CASUALTY : 1 INJURY

DEPTH   : 258 METER

AGE   : 0,5 YEARS

SAFETY FACTOR : 1,6

PRODUCTION : 36 000 TPM

NOT AT PILLAR EXTRACTED

ACCIDENT NUMBER 4

DATE: 1994-03-09

CASUALTY : 1 INJURY

DEPTH   : 258 METER

AGE   : 1,0 YEARS

SAFETY FACTOR : 1,8

PRODUCTION : 42 000 TPM

NOT AT PILLAR EXTRACTED

DATE: 1992-11-12

CASUALTY : 1 FATALITY

DEPTH   : 237 METER

AGE   : 0,4 YEARS

SAFETY FACTOR : 1,6

PRODUCTION : 29 000 TPM

AT PILLAR EXTRACTED
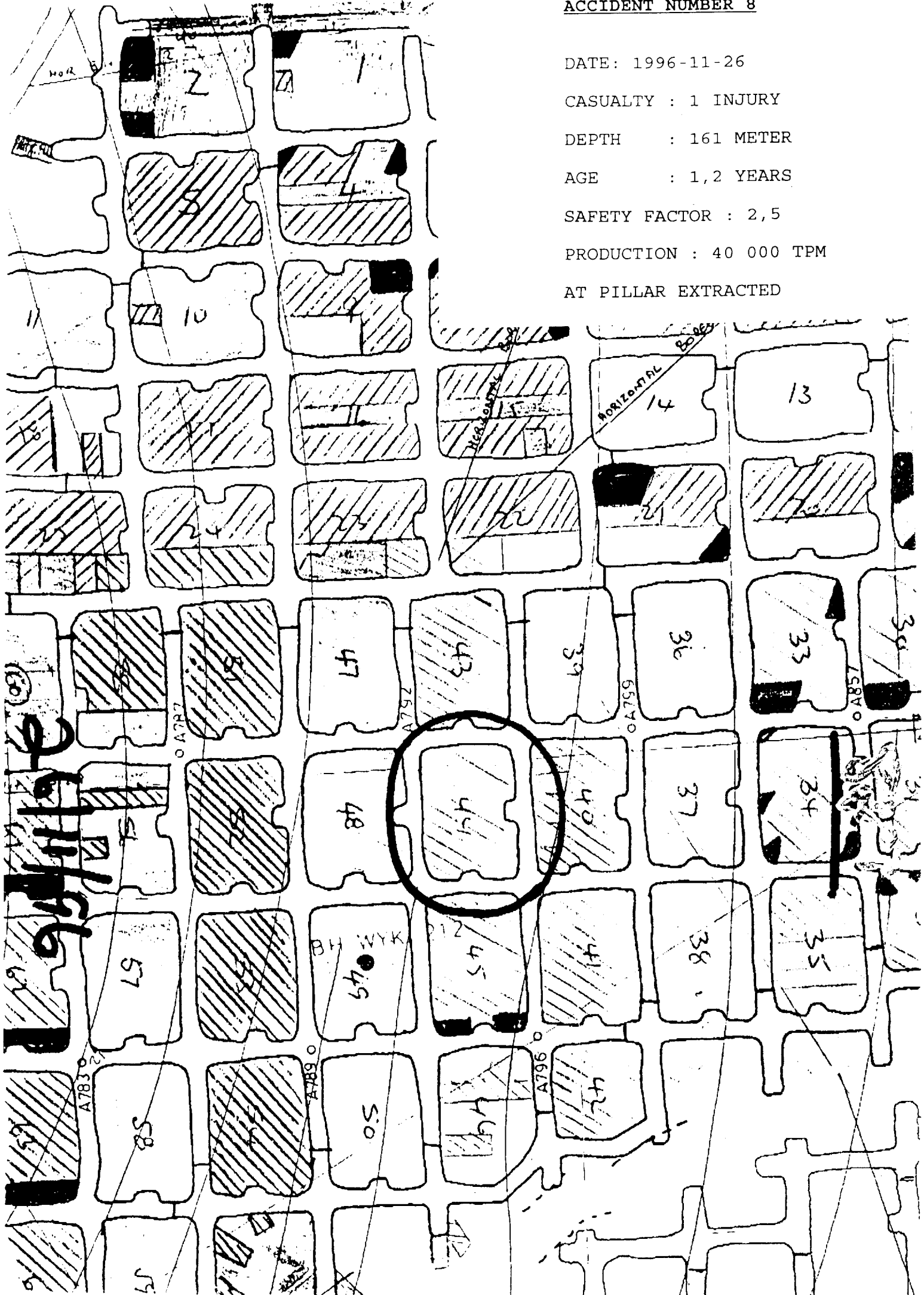
ACCIDENT NUMBER 6

DATE: 1994-08-24

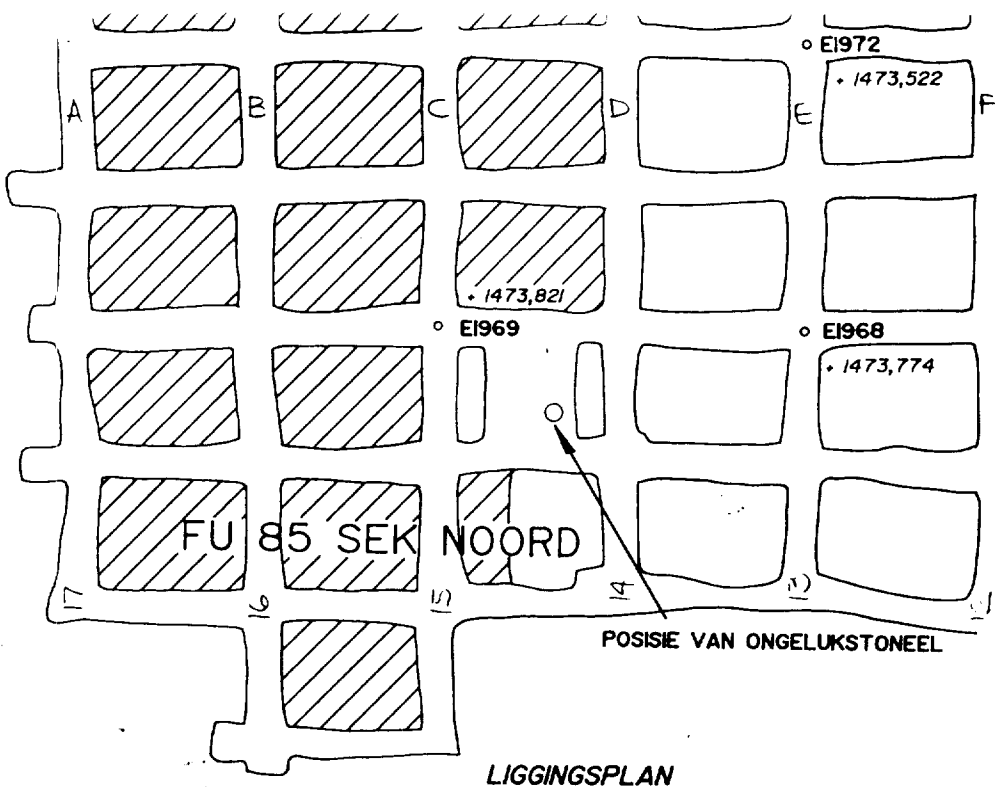CASUALTY : 2 INJURIES

DEPTH   : 266 METER

AGE   : 2,5 YEARS

SAFETY FACTOR : 1,7

PRODUCTION : 36 000 TPM

AT PILLAR EXTRACTED
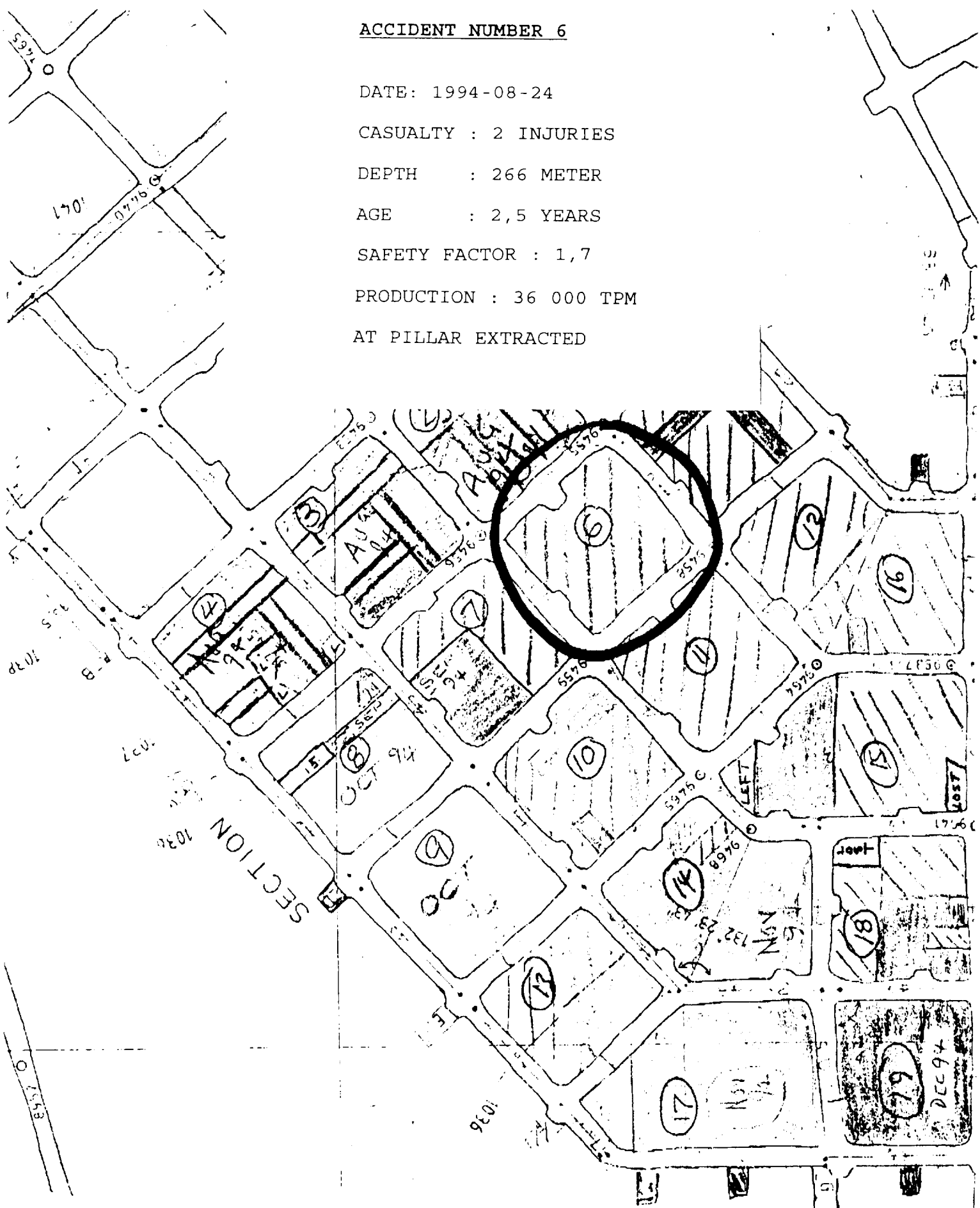
24/8/94

ACCIDENT NUMBER 7

DATE: 1996-07-05

CASUALTY : 1 INJURY

DEPTH   : 203 METER

AGE   : 1,0 YEARS

SAFETY FACTOR : 1,8

PRODUCTION : 36 000 TPM

NOT AT PILLAR EXTRACTED

517/96

ACCIDENT NUMBER 8

DATE: 1996-11-26

CASUALTY : 1 INJURY

DEPTH : 161 METER

AGE : 1,2 YEARS

SAFETY FACTOR : 2,5

PRODUCTION : 40 000 TPM

AT PILLAR EXTRACTED

DATE: 1988-02-15

CASUALTY : 5 INJURIES
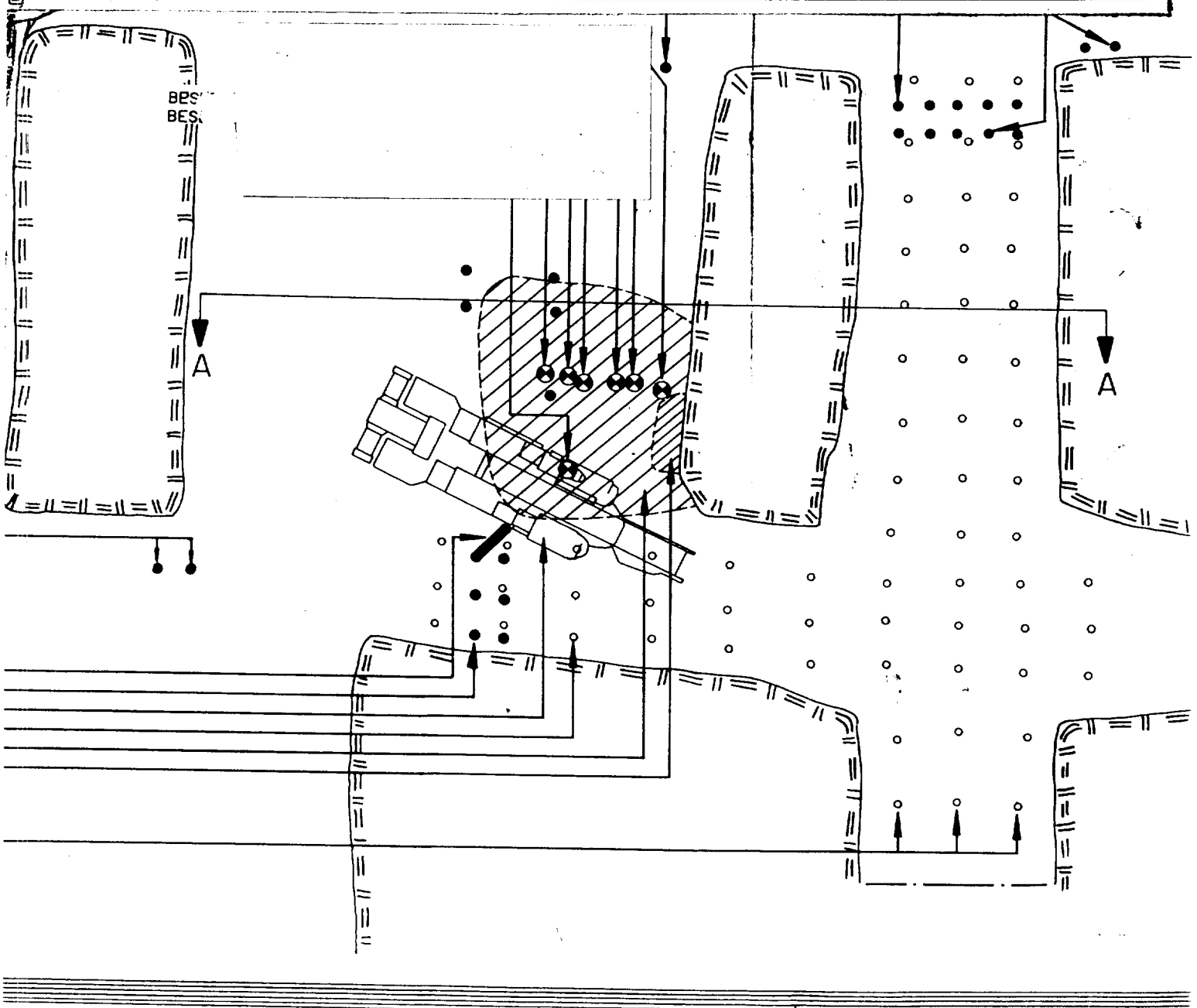
DEPTH : 156 METER

AGE : 0,6 YEARS

SAFETY FACTOR : 2,3

PRODUCTION : 39 000 TPM

AT PILLAR EXTRACTED

○ EI972
• 1473,522

• 1473,821

○ EI969

○ EI968
• 1473,774

FU 85 SEK NOORD

POSISIE VAN ONGELUKSTONEEL

LIGGINGSPLAN

Skaal 1/1500

A

A

BES
BES

A

A

ACCIDENT NUMBER 10

DATE: 1990-10-05

CASUALTY : 1 FATALITY

DEPTH : 177 METER

AGE : 5,5 YEARS

SAFETY FACTOR : 2,1

PRODUCTION : 51 000 TPM

AT PILLAR EXTRACTED

PUN

PUN

PUN

BREKERLYN

DAKBOUTE (OORSPRONKLIK)

DELWER

KLIKSTOKKE NA ONGELUK

POSISIE VAN MYNER

95mm KRAG-TOEVOER KABEL

PUIN BESTAANDE UIT KLIP EN 67 OF

PUIN BESTAANDE UIT KLIP EN SIG

KLIKSTOKKE

,300 meter

POSISIE VAN ONGELUK

46 47 48 49 50 51 52 53 54 55

L 83

○ 985

FM 76/15 FM76/17 FM76/19 FM76/21 FL83/1 FL83/3 FL83/5 FL83/7 FL83/9 FL83/11

A

○ 986 B L84 ○ 2202

E1247 2343 L85 ○ 2283

◎ 1474.405 ○ C

948 L86 ○ 2284

D ○ 2285

E1248 E1302

◎ 1473.805 E E1305

FM76/40 FM76/42 FL76/2 FL76/4 FL76/6 FL76/8 FL76/10 FL76/12 FL76/14

◎ 1475.259 ◎ 1472.785 ◎

SEK

N

LIGGINGSPLAN

Skaal 1/500

ACCIDENT NUMBER 11

DATE: 1990-04-19

CASUALTY : 1 FATALITY

DEPTH : 168 METER

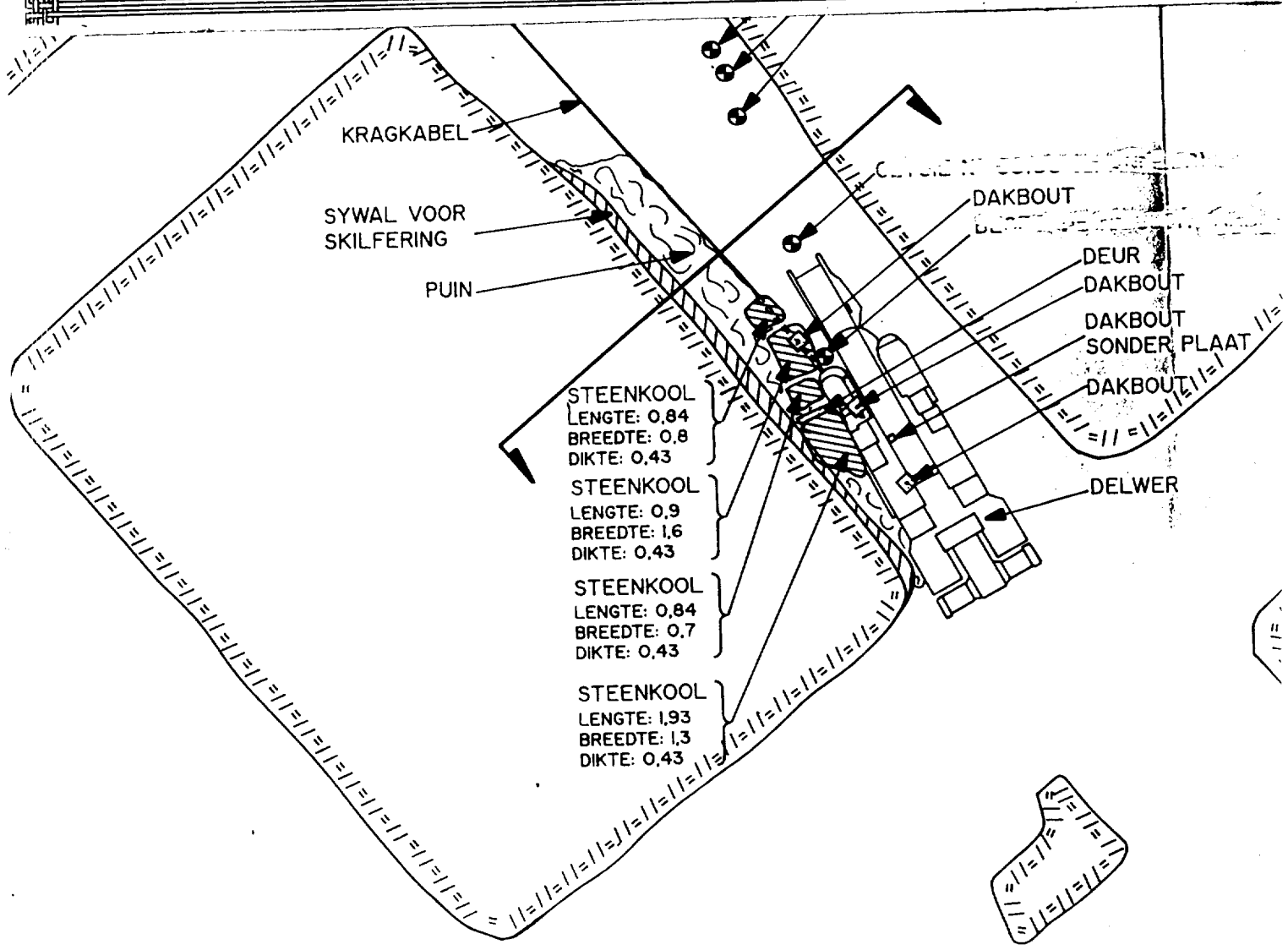AGE : 0,5 YEARS

SAFETY FACTOR : 2,1

PRODUCTION : 49 000 TPM

NOT AT PILLAR EXTRACTED

E2322
4075
4113

POSISIE
VAN
ONGELUK
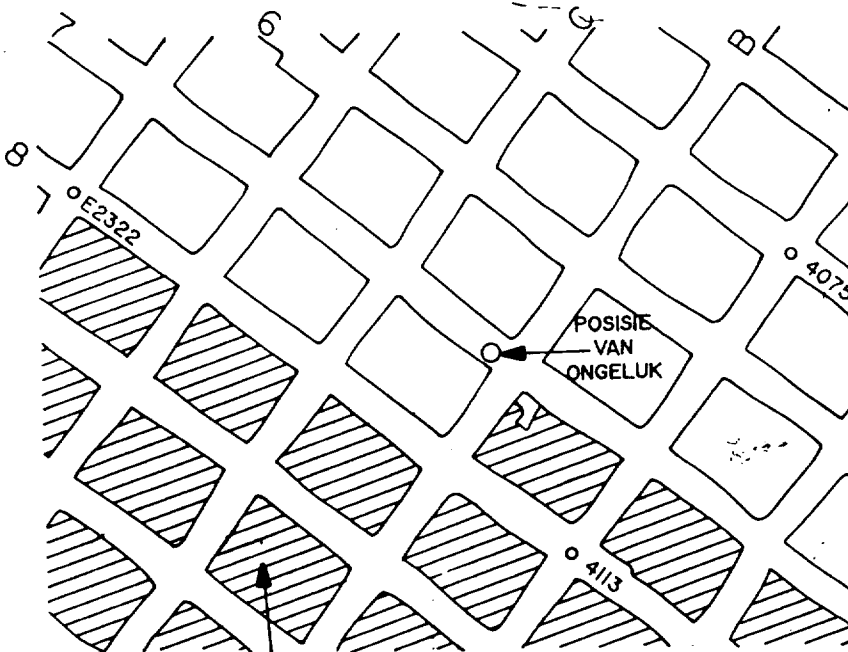
GEBIED WAAR DAK GEVAL HET

LIGGINGSPLAN

Skaal 1/1500

KRAGKABEL

SYWAL VOOR
SKILFERING

PUIN

DAKBOUT

DEUR
DAKBOUT

DAKBOUT
SONDER PLAAT

DAKBOUT

STEENKOOL
LENGTE: 0,84
BREEDTE: 0,8
DIKTE: 0,43

STEENKOOL
LENGTE: 0,9
BREEDTE: 1,6
DIKTE: 0,43

STEENKOOL
LENGTE: 0,84
BREEDTE: 0,7
DIKTE: 0,43

STEENKOOL
LENGTE: 1,93
BREEDTE: 1,3
DIKTE: 0,43

DELWER

DATE: 1991-08-30

CASUALTY : 1 INJURY

DEPTH   : 160 METER

AGE   : 10,0 YEARS

SAFETY FACTOR : 2,3

PRODUCTION : 41 000 TPM

AT PILLAR EXTRACTED

±7m

±9m

8m

5,5m

POSISIE VAN ONGELUK

A   B   C   D   E   F   G

E931

-1478,415

24

22
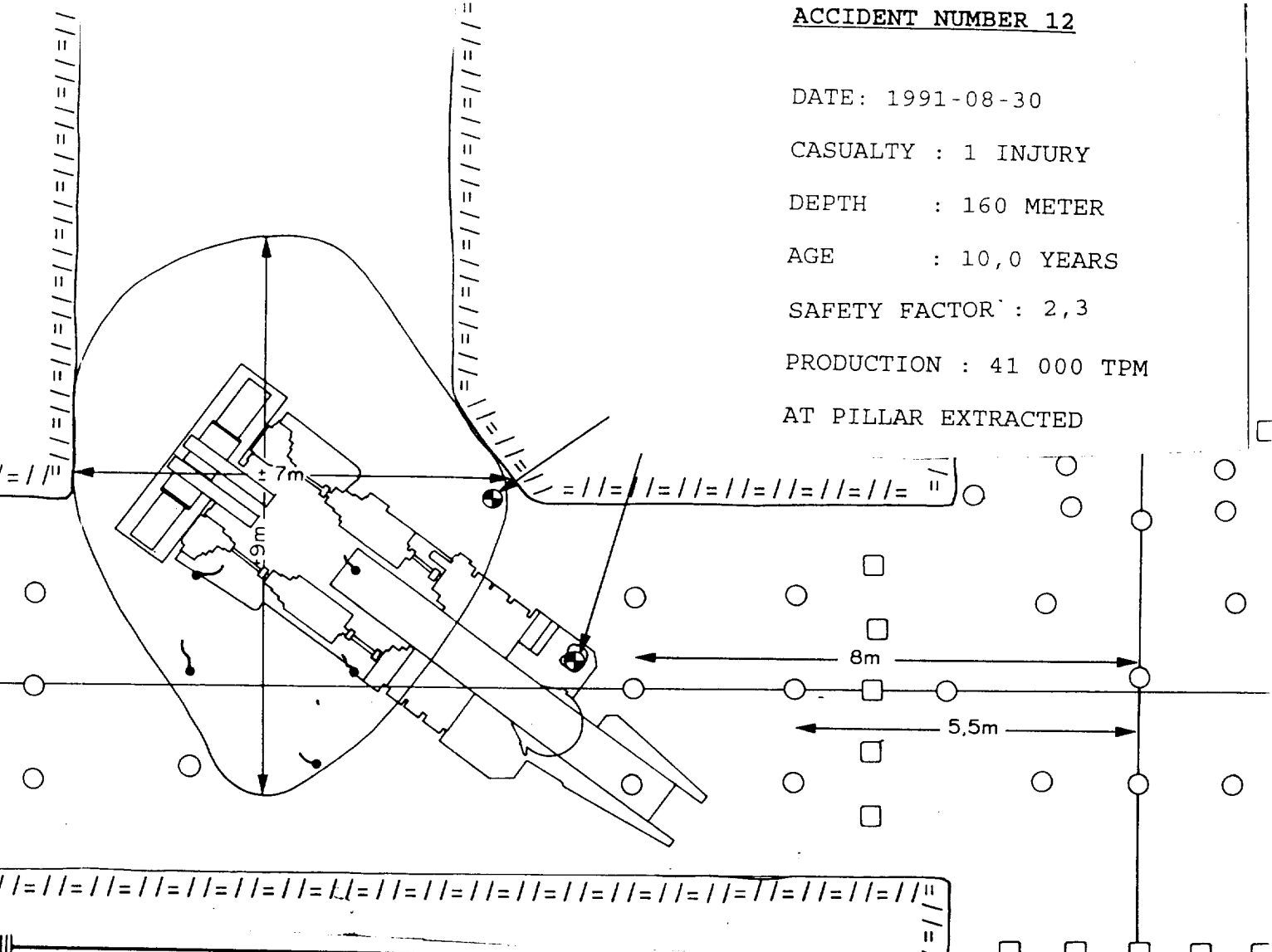
7 SÊKONDER

LIGGINGSPLAN

Skaal 1/1500

PUIN

ACCIDENT NUMBER 13

DATE: 1992-01-04

CASUALTY : 1 INJURY

DEPTH   : 166 METER

AGE   : 0,4 YEARS

SAFETY FACTOR : 2,4

PRODUCTION : 36 000 TPM

AT PILLAR EXTRACTED

GETUIE 1

GETUIE 2

POSISIE VAN
ONGELUK

13

12

10

E2697
-474,373
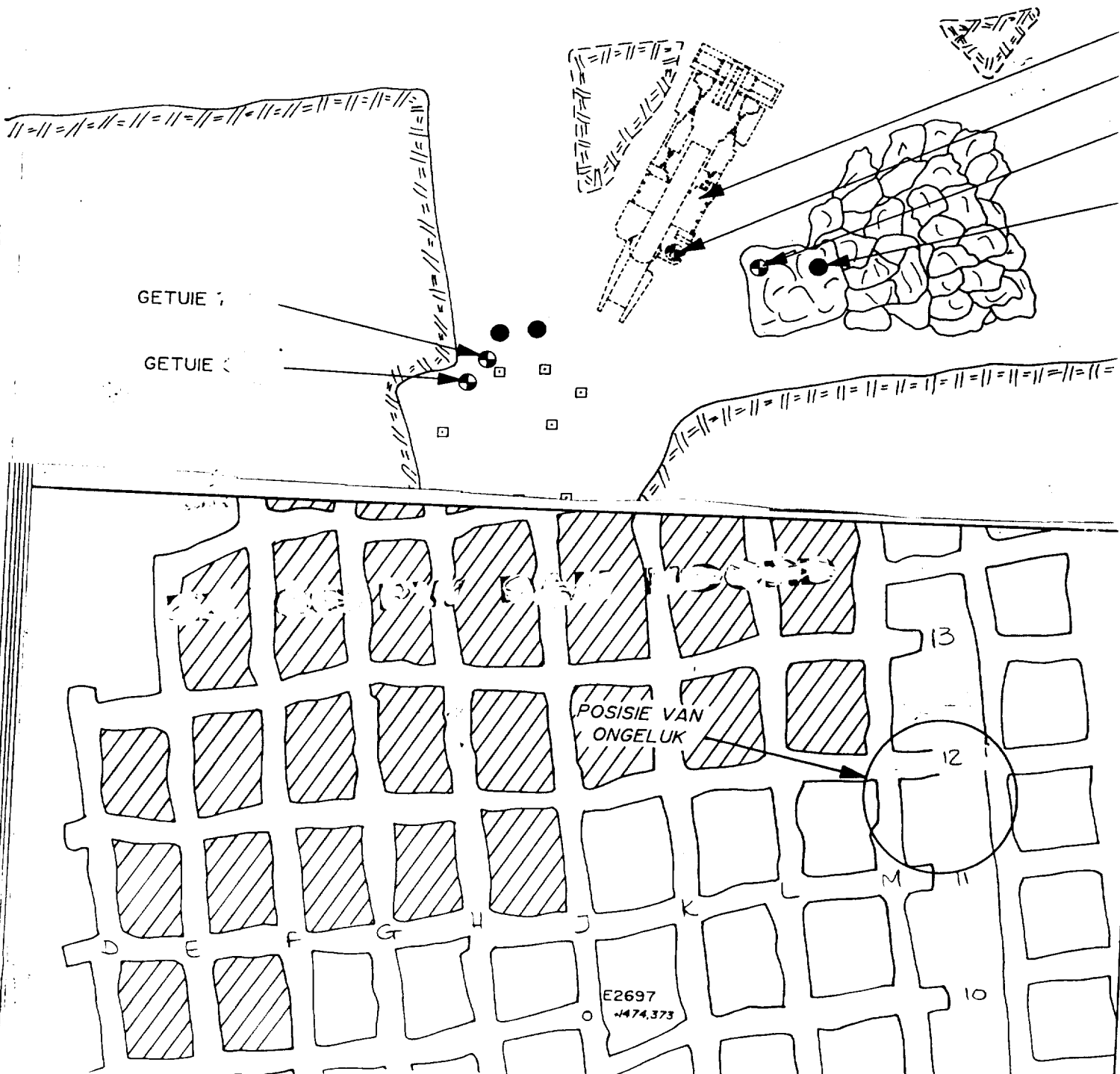
ACCIDENT NUMBER 14

DATE: 1992-05-15

CASUALTY : 1 FATALITY

DEPTH   : 156 METER

AGE   : 0,2 YEARS

SAFETY FACTOR : 2,0

PRODUCTION : 64 000 TPI

AT PILLAR EXTRACTED

Posisie
van
Ongeluk

o E27748

C D E F G H J

STOEL
KLIP 0,6 × 0,45 × 0,3

KLIP 0,6 × 0,4

HARDEHOED
KLIP 0,5 × 0,3

METAANMETER

KRAGKABEL

WATERPYP

A

A

KLIP : WYDTE 4,2m
GEMIDDELDE DIKTE 1,3m
LENGTE KAN NIE GEMEET WORD NIE

KLIP : WYDTE 3,5m
GEMIDDELDE DIKTE 1,3m
LENGTE KAN NIE GEMEET WORD NIE
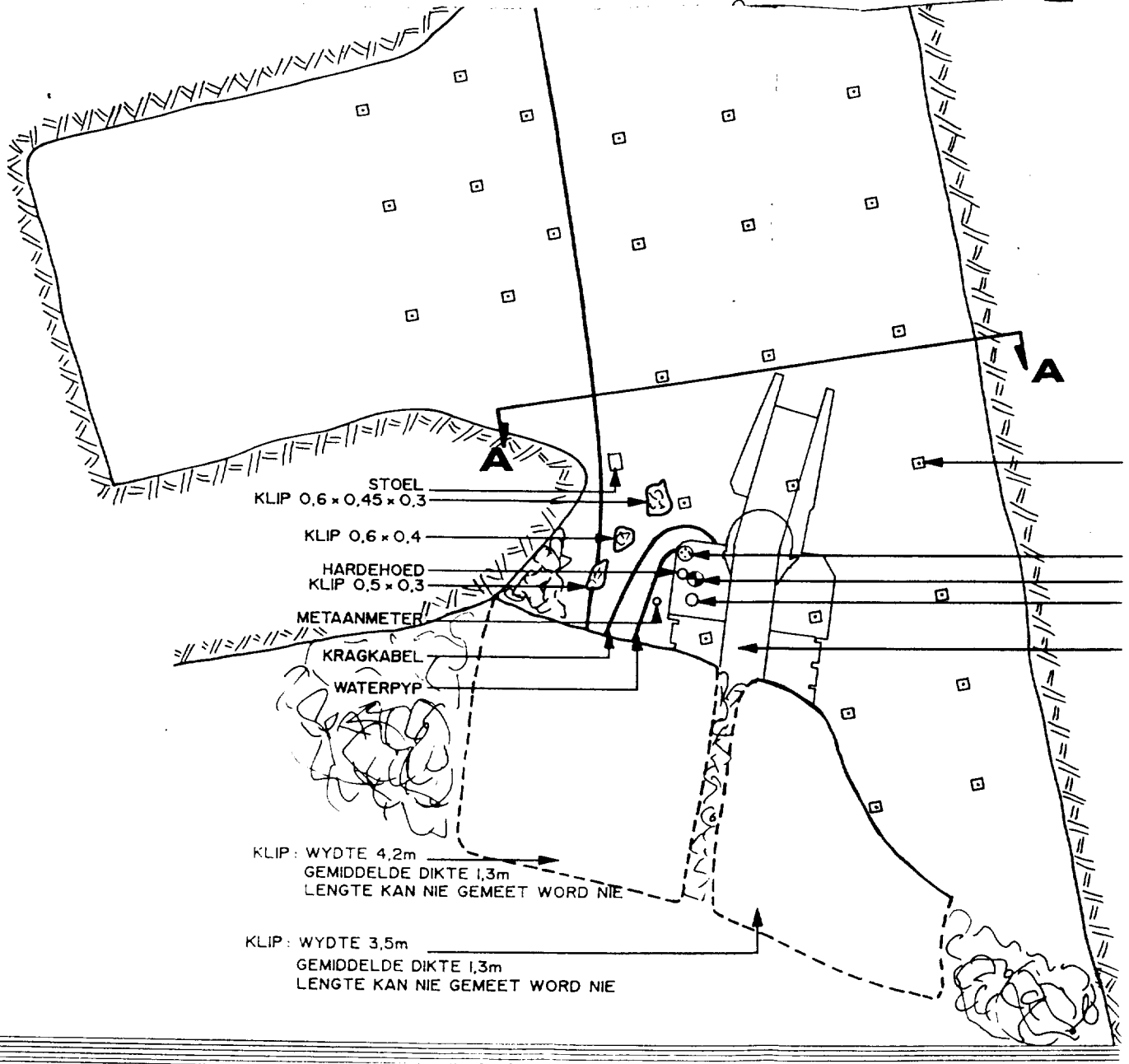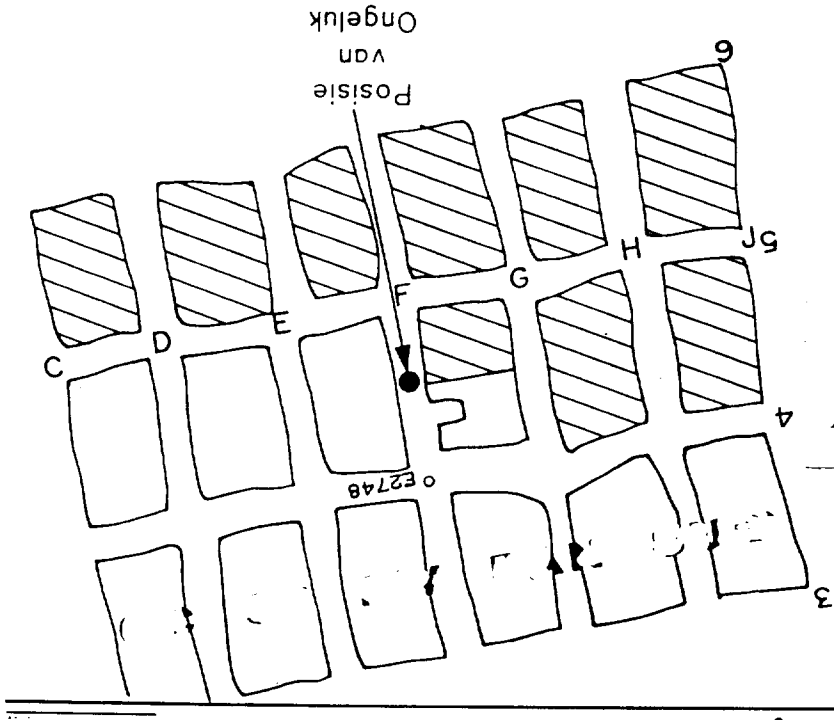
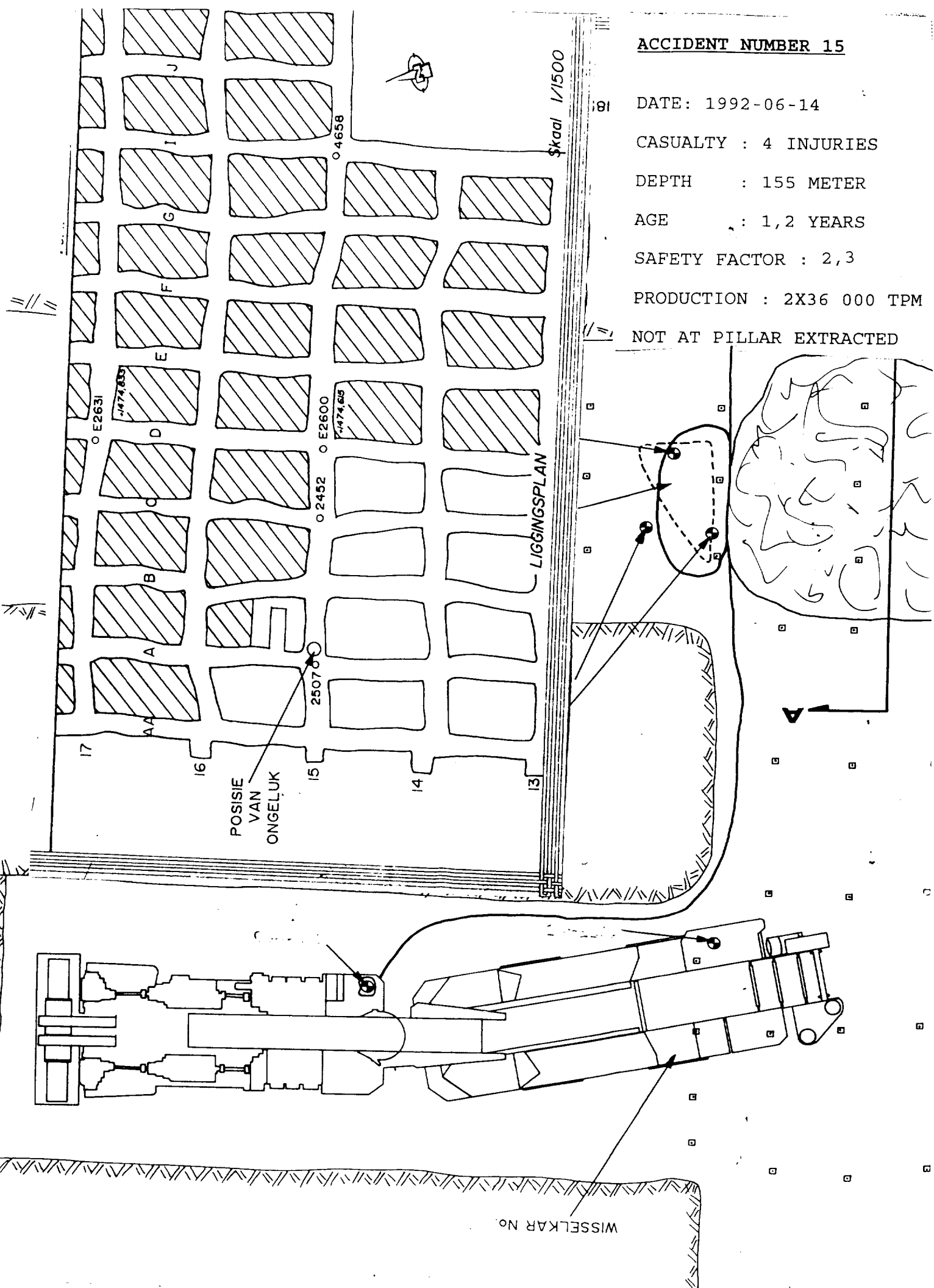ACCIDENT NUMBER 15

DATE: 1992-06-14

CASUALTY : 4 INJURIES

DEPTH : 155 METER

AGE : 1,2 YEARS

SAFETY FACTOR : 2,3

PRODUCTION : 2X36 000 TPM

NOT AT PILLAR EXTRACTED

Skaal 1/1500

LIGGINGSPLAN

POSISIE VAN ONGELUK

WISSELKAR No.

ACCIDENT NUMBER 16

DATE: 1994-06-15

CASUALTY : 1 INJURY

DEPTH : 145 METER

AGE : 1,4 YEARS

SAFETY FACTOR : 2,1

PRODUCTION : 59 000 TPM

AT PILLAR EXTRACTED
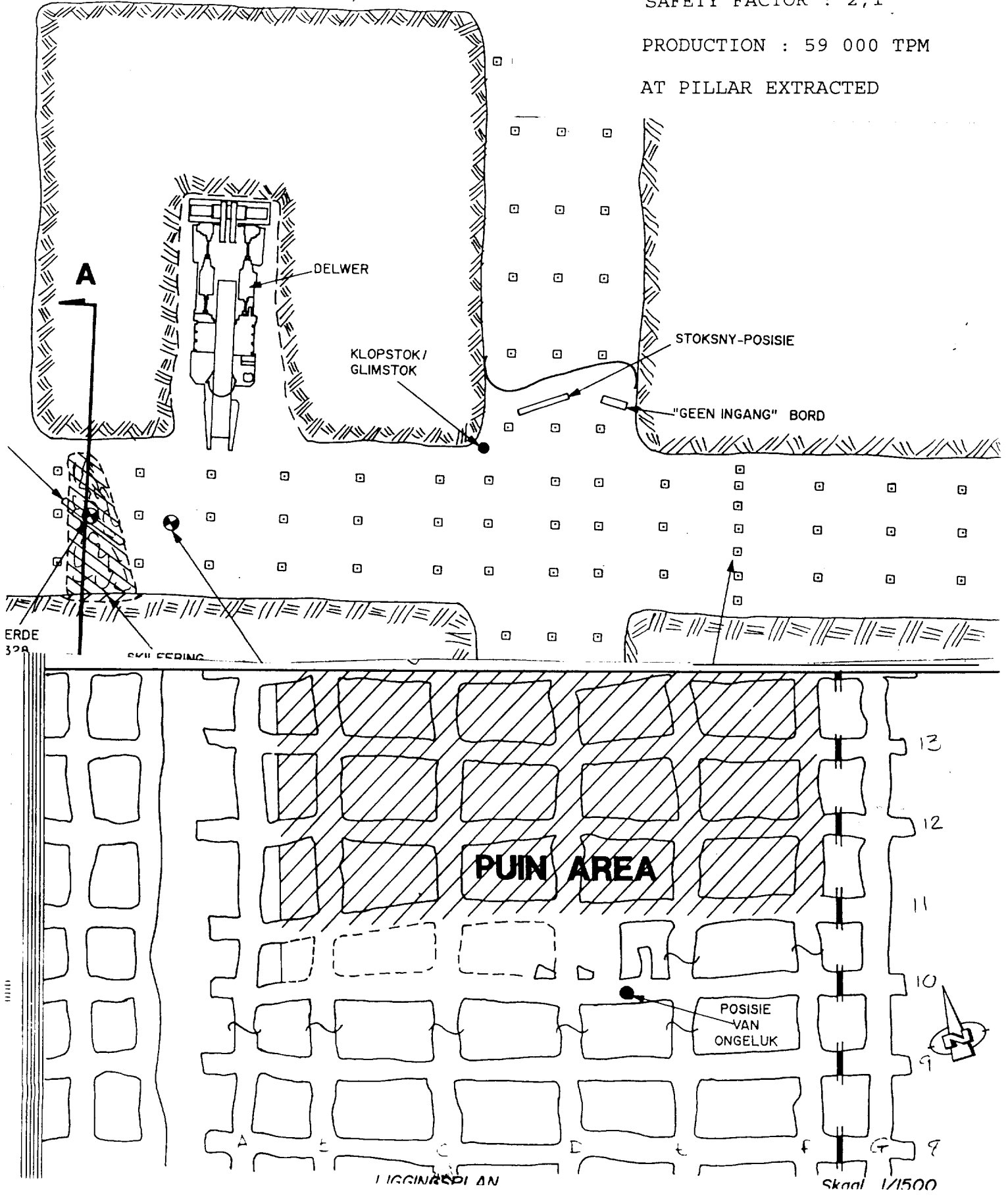
A

DELWER

KLOPSTOK/
GLIMSTOK

STOKSNY-POSISIE

"GEEN INGANG" BORD

ERDE
32A

SKILFERING

PUIN AREA

POSISIE
VAN
ONGELUK

13

12

11

10

9

A   B   C   D   E   F   G

LIGGINGSPLAN   Skaal 1/1500

7131

7132

7133

WW 1746

H406,230

7134

7136

NR 56A PANEEL WES

POSISIE VAN ONGELUK

10

7

6

5

LANGSLYN

VOORLAASTE PUINLYN

LAASTE PUINLYN

GETUIE

GLIMSTOK

GETUIE K/No.

NAAT

DELWER

OORLEDENE

KABELHANTEERDER K

KABEL

WATER

VOORLAASTE PUINLYN

(BENADERDE) DAKBOUT UIT

(BENADERDE) C

(BENADERDE) DAKBOUT GEBREEK

PUIN VOOR OPRUIMING

SPER PILAAR

PLAN

ACCIDENT

ROCK

ROCK
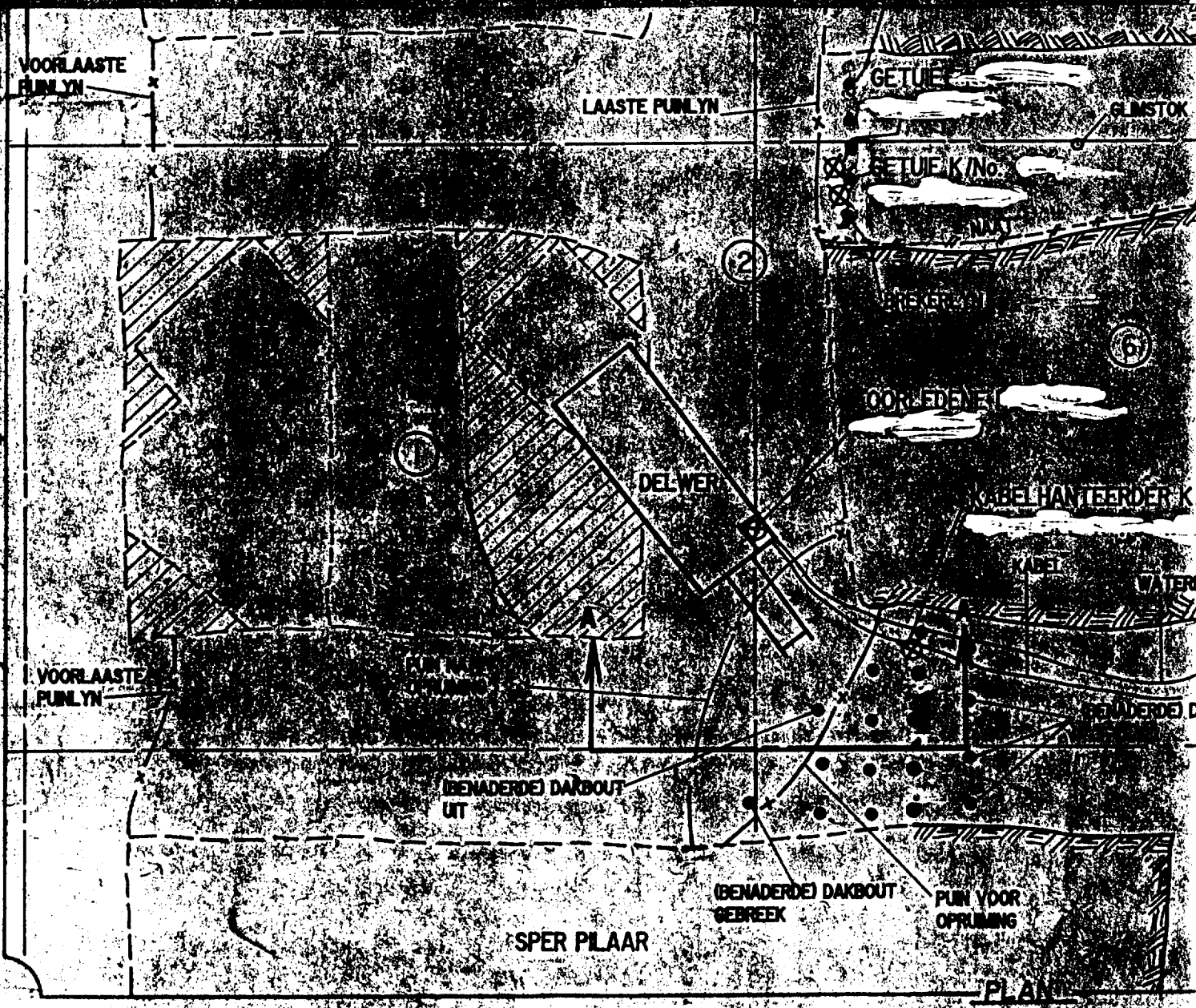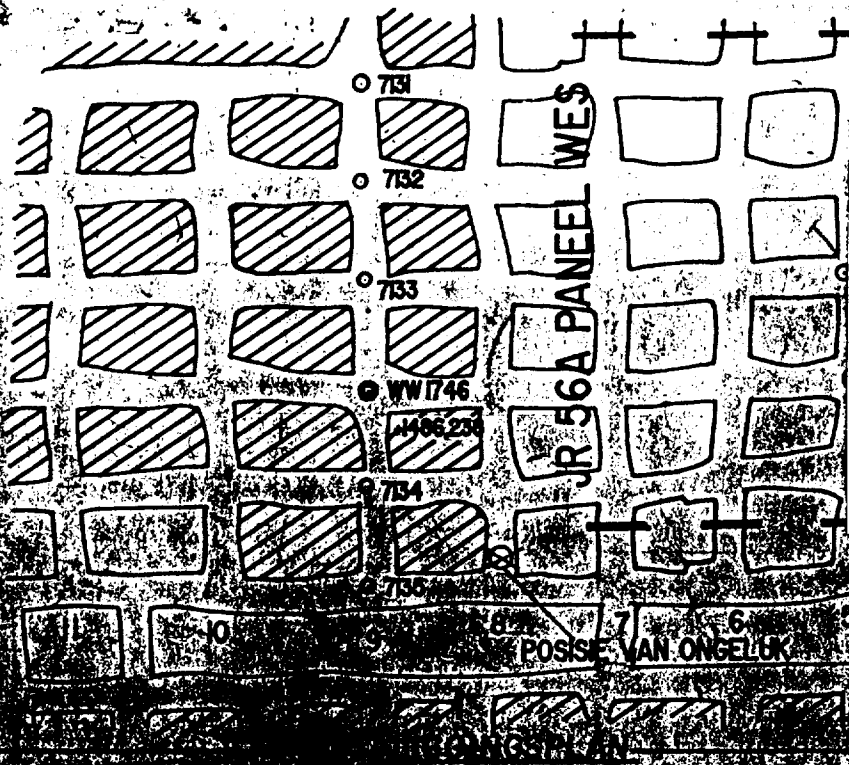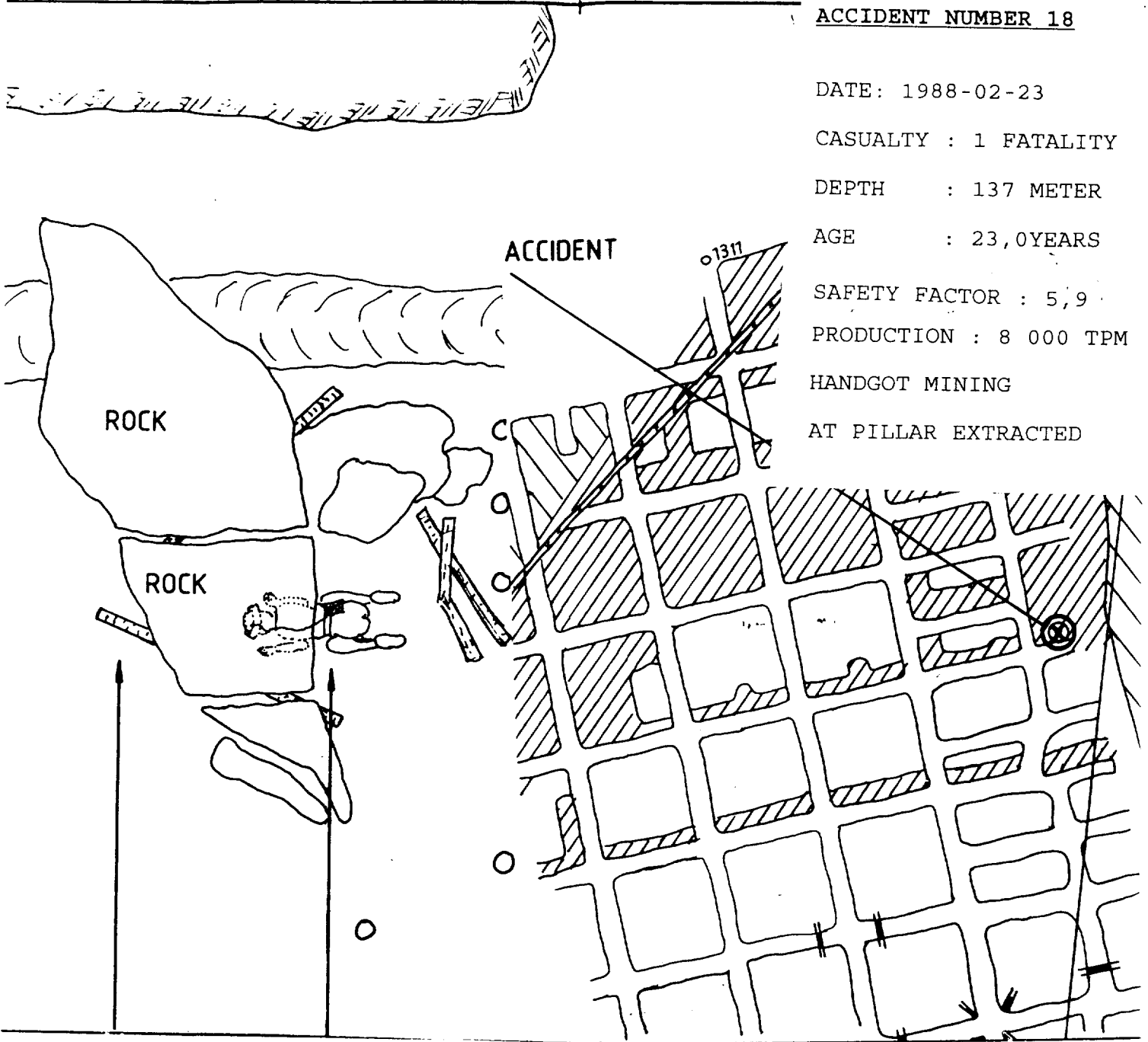
SECTION A-A
SCALE 1 : 50
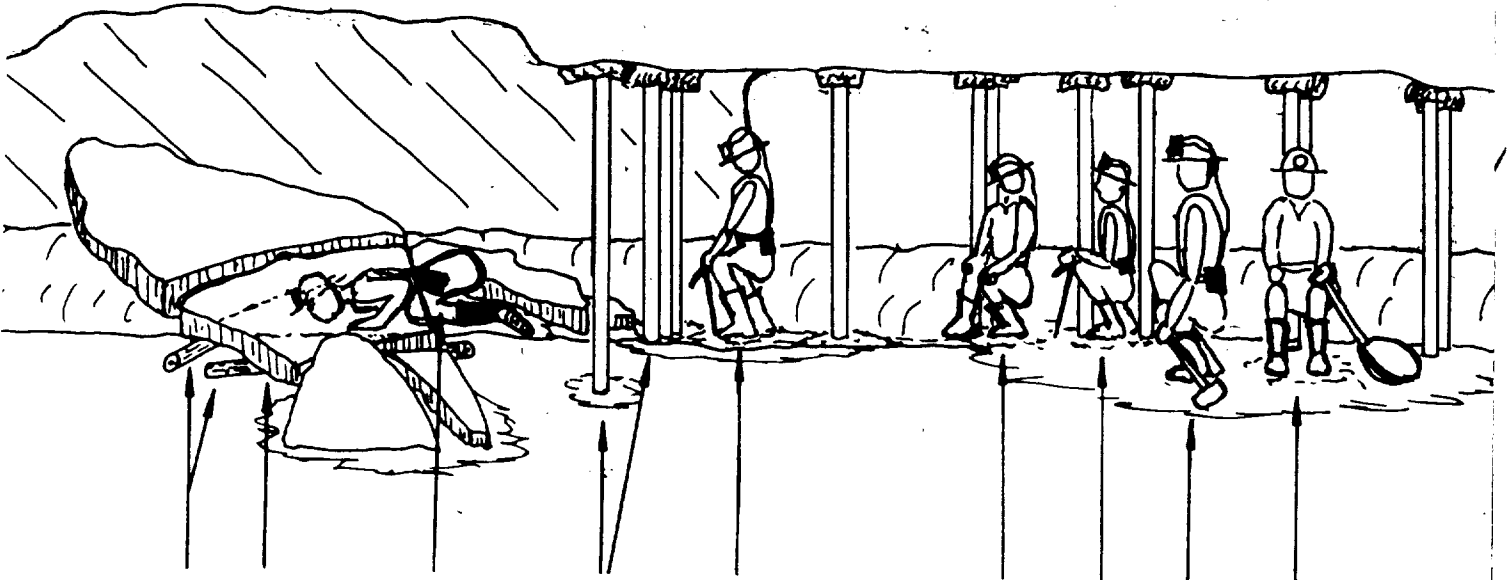
DATE: 1991-11-26

CASUALTY : 1 FATALITY

DEPTH   : 254 METER

AGE   : 0,2 YEARS

SAFETY FACTOR : 2,1

PRODUCTION : 5 000 TPM

HANDGOT MINING

AT PILLAR EXTRACTED

BLASTED SNOOK

FD POSITION
K DURING
ION

SOLID SNOOK

ORIGINAL
PILLAR EDGE

SUPPORT TAPE

SCENE OF ACCIDENT
2nd LEFT COMPANION

BS141   BS142   BS143

C2876

BS036   BS035   BS034   BS033   C2875   BS031   BS032

LOCALITY PLAN
Scale 1 : 1500

N
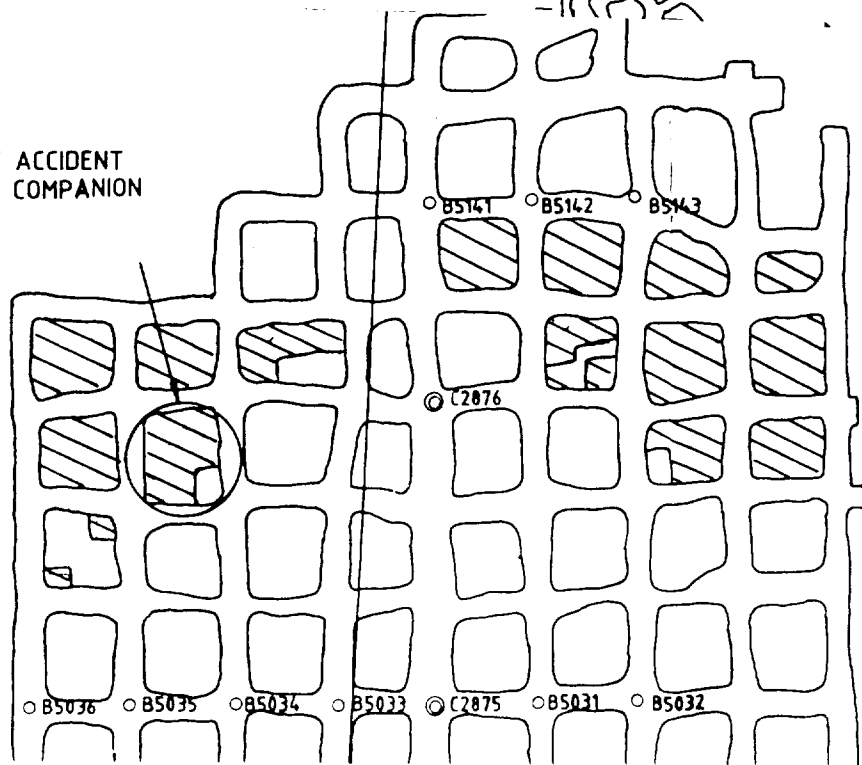
DATE: 1996-05-07

CASUALTY : 1 FATALITY

DEPTH : 267 METER

AGE : 13,4 YEARS

SAFETY FACTOR : 3,0

PRODUCTION : 6 000 TPM

AT PILLAR EXTRACTED

3,30m

DECEASED

A

A

PLAN SCALE 1:100

Y+1000

Y+900

X+1000

SCENE OF ACCIDENT

B1950

0,33m

X+1100

B1862

B18

B1863

B1F

BELT ROAD

B1861

B
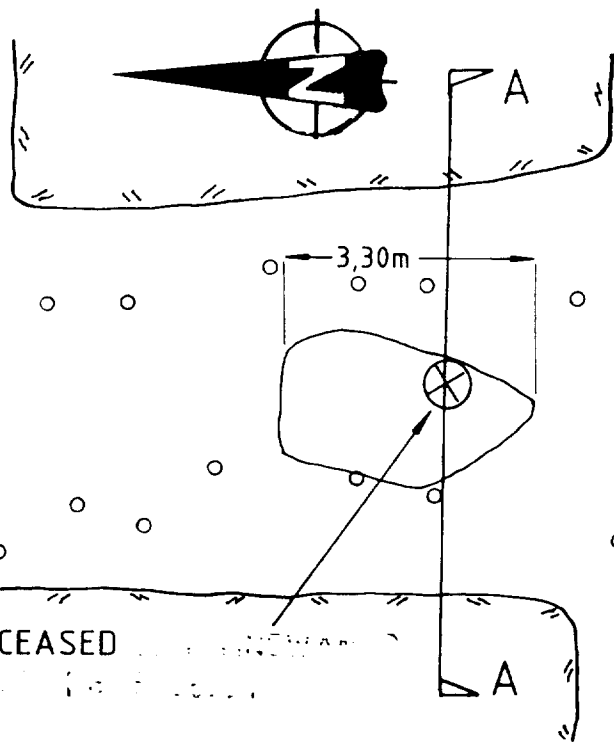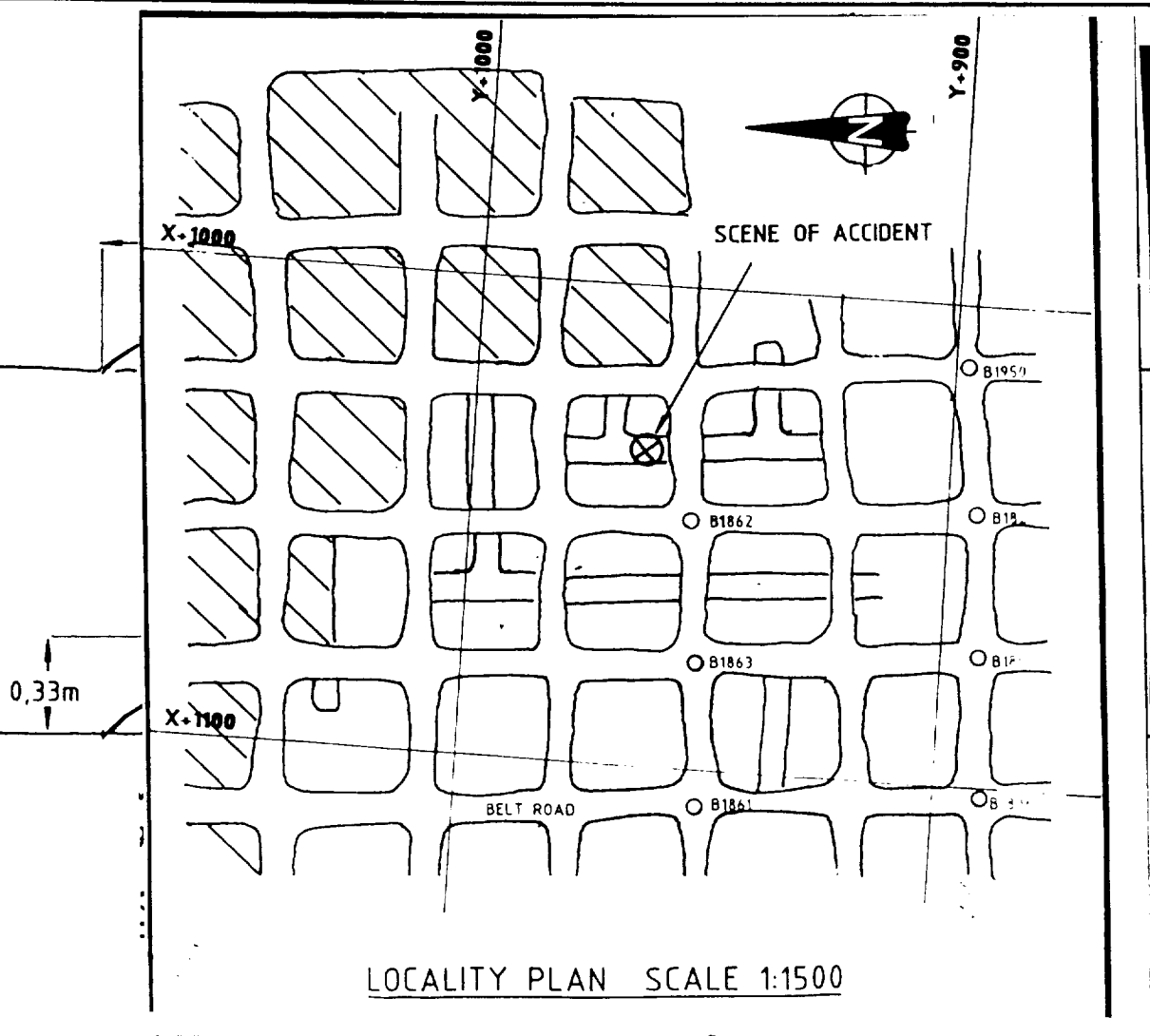
LOCALITY PLAN SCALE 1:1500

ACCIDENT NUMBER 21

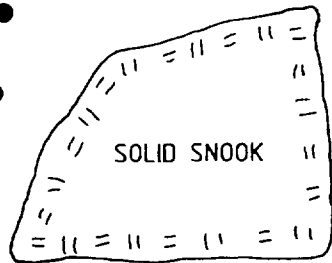DATE: 1996-09-25

CASUALTY : 1 FATALITY

DEPTH : 68 METER

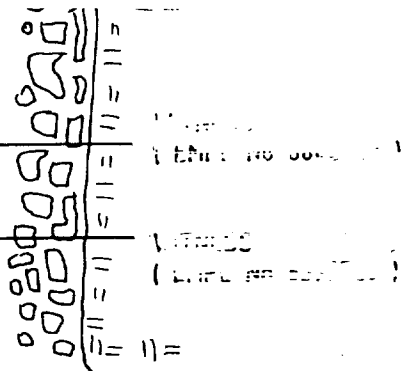AGE : 12,3 YEARS

SAFETY FACTOR : 3,9

PRODUCTION : 5 000 TPM

HANDGOT MINING

AT PILLAR EXTRACTED

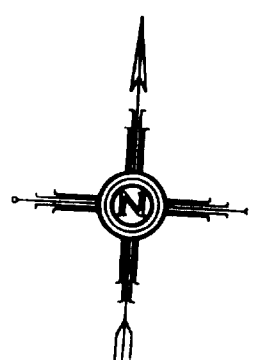POSITION WHERE ROCK DISLODGED FROM ROOF

FINAL POSITION OF ROCK ON FLOOR

APPROXIMATE LINE WHERE COAL IN FLOOR STARTED

2,5m

2,8m

3,0m

ROOF BOLTS

ROCK SIZE: LENGTH 3,7m
WIDTH 1,25m
THICKNESS 0,18m TAPERING
TO FEATHER EDGE

BREAKER LINE

TIMBER

NE

ALLEDGED POSITION OF ACROPROPS ON LARGE BLOCKS OF FOG ACROPROPS WERE INSTALLED AFTER 1st FOG

ESTIMATED ROOF POSITION

GENERAL POSITION OF DECEASED & INJURED

SO IN B

POSITION OF HOLE

1st FOG

ROADHEADER
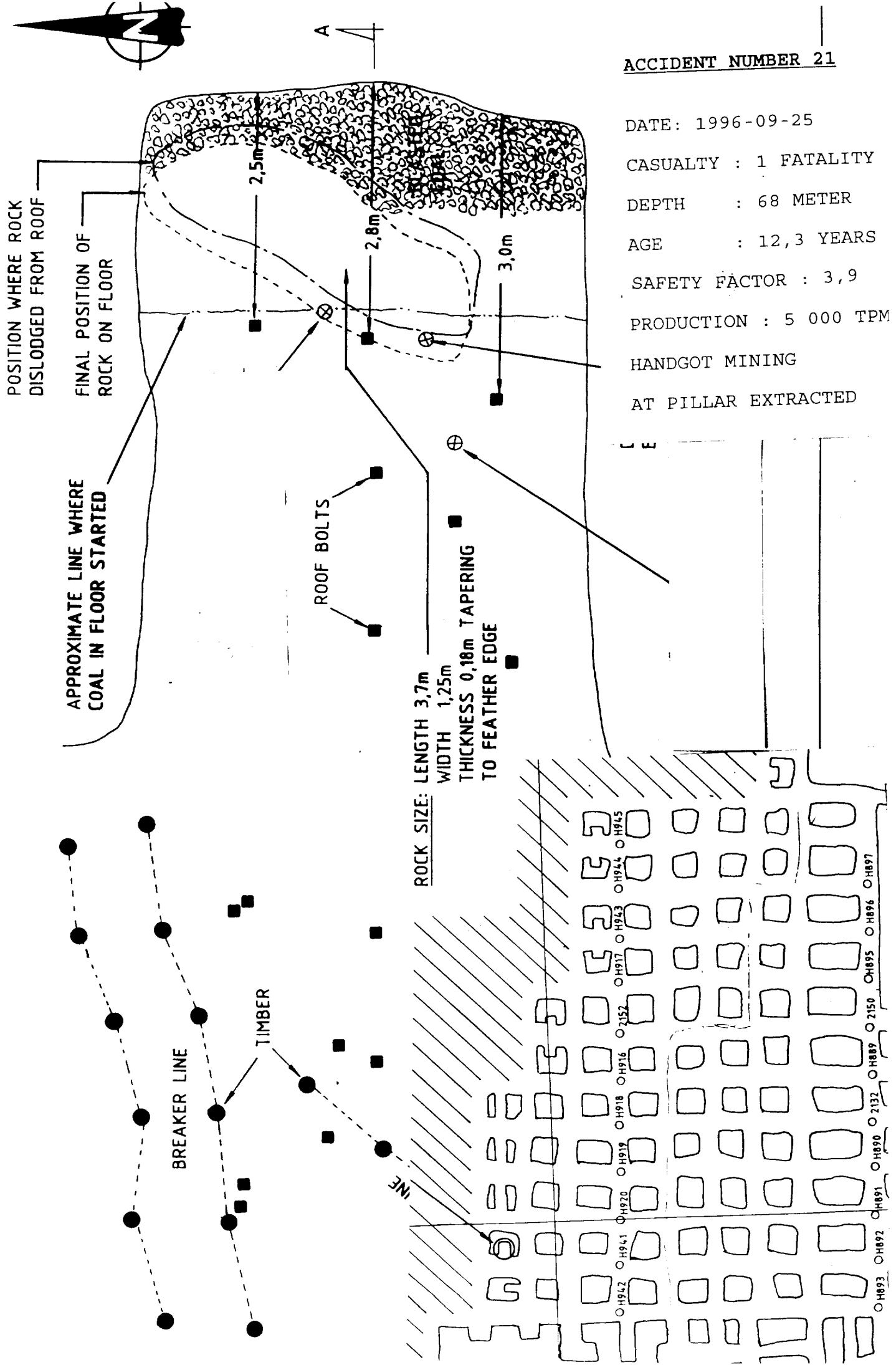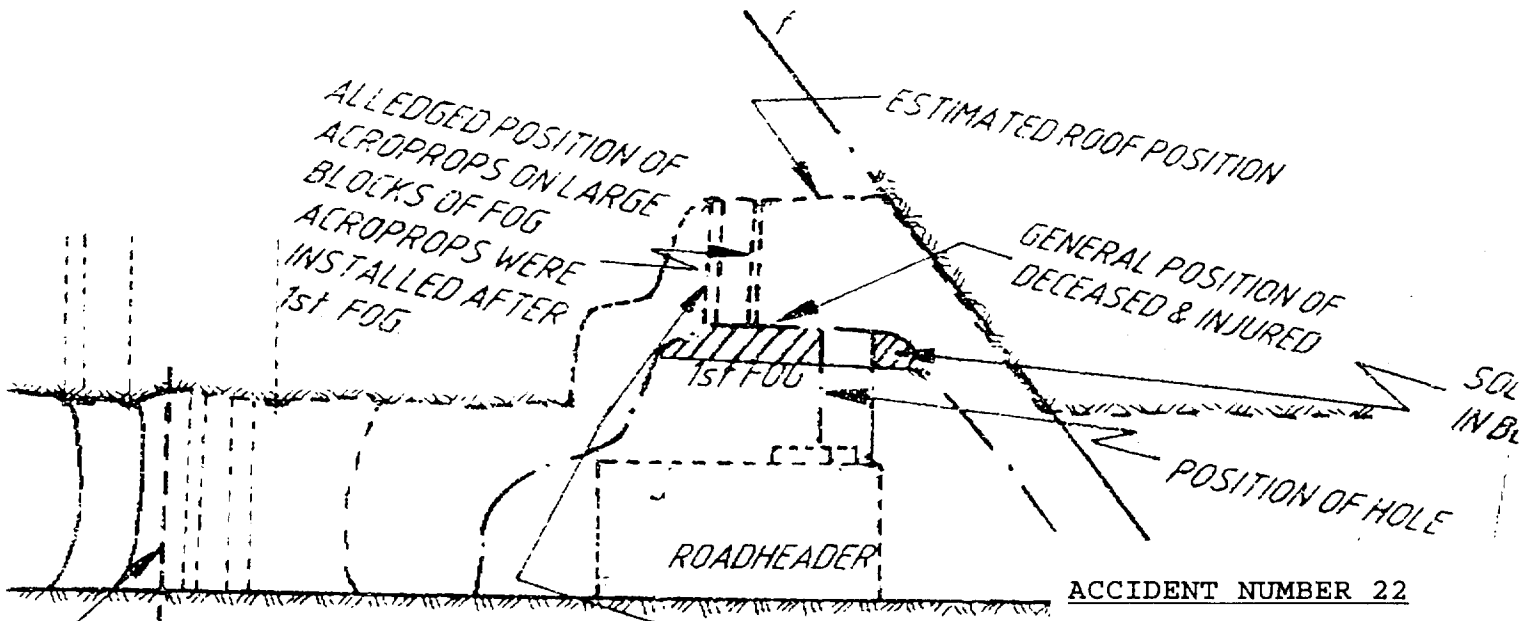
EMENTS PAST THIS TO BAD ROOF CONDITIONS.

ALLEDGED POSITION OF TIMBER POLE SUPPORT.

ACCIDENT NUMBER 22

DATE: 1996-03-25

CASUALTY : 10 FATALITIES
            1 INJURY

DEPTH   : 197 METER

AGE   : 1,0 YEARS

SAFETY FACTOR : 2,3

PRODUCTION : 15 000 TPM

AT PILLAR EXTRACTED

GOAFED AREA

SCENE OF ACCIDENT

GOAF LINE

DYKE

CUT

CUT

CUT ROAD B

CUT 20

D

E

4   3   2   1

LOCALITY PLAN

SCALE 1:1500

ACCIDENT NUMBER 23

DATE: 1993-08-30

CASUALTY : 1 FATALITY

DEPTH : 50 METER

AGE : 8,0 YEARS

SAFETY FACTOR : 4,1

PRODUCTION : 6 000 TP

AT PILLAR EXTRACTED

ROOF FALLEN

2,0 TO 3,0 METRES

ACCIDENT

COY NO.
COY NO.
COY NO.

B

HT 2,2

B

A

'C'

A

ROOF FALLEN

0,3 TO 0,7 METRES

SANDSTONE

3,0 × 1,0 × 0,6 METRES

WITNESS COY NO. 2182

HT 2,1

FEEDER

PILLAR

BREAKERLINE

BREAKERLINE

CONTINUOUS MINER

HT 2,3

HT 2,0

PLAN OF ACCIDENT
SCALE 1: 250

SURFACE CONTOUR

SCENE OF ACCIDE

2044

947

2169

1440,211
1438,311

2122

1440,989
1438,619

1643,082
1640,812

957

2485

2150

2215

EST. POSITION OF
TIMBERS PRIOR TO
ACCIDENT

BREAKER LINE
DISLODGED BY GOAF

GOAF

POSITION OF DECEASED

DRILL AUGER

GOAF

TIMBER

BROKEN TAPE

BREAKER
LINE

B

CENTRE TIMBERS

POSITION OF MINER

TNESS

D

ACCIDENT NUMBER 24

DATE: 1996-04-23

CASUALTY : 1 FATALITY

DEPTH   : 290 METER

AGE   : 5;0 YEARS

SAFETY FACTOR : 2,1

PRODUCTION : 6 000 TPM

HANDGOT STOOPING

AT PILLAR EXTRACTED

SECTION 103

SCENE OF ACCIDENT

D

C
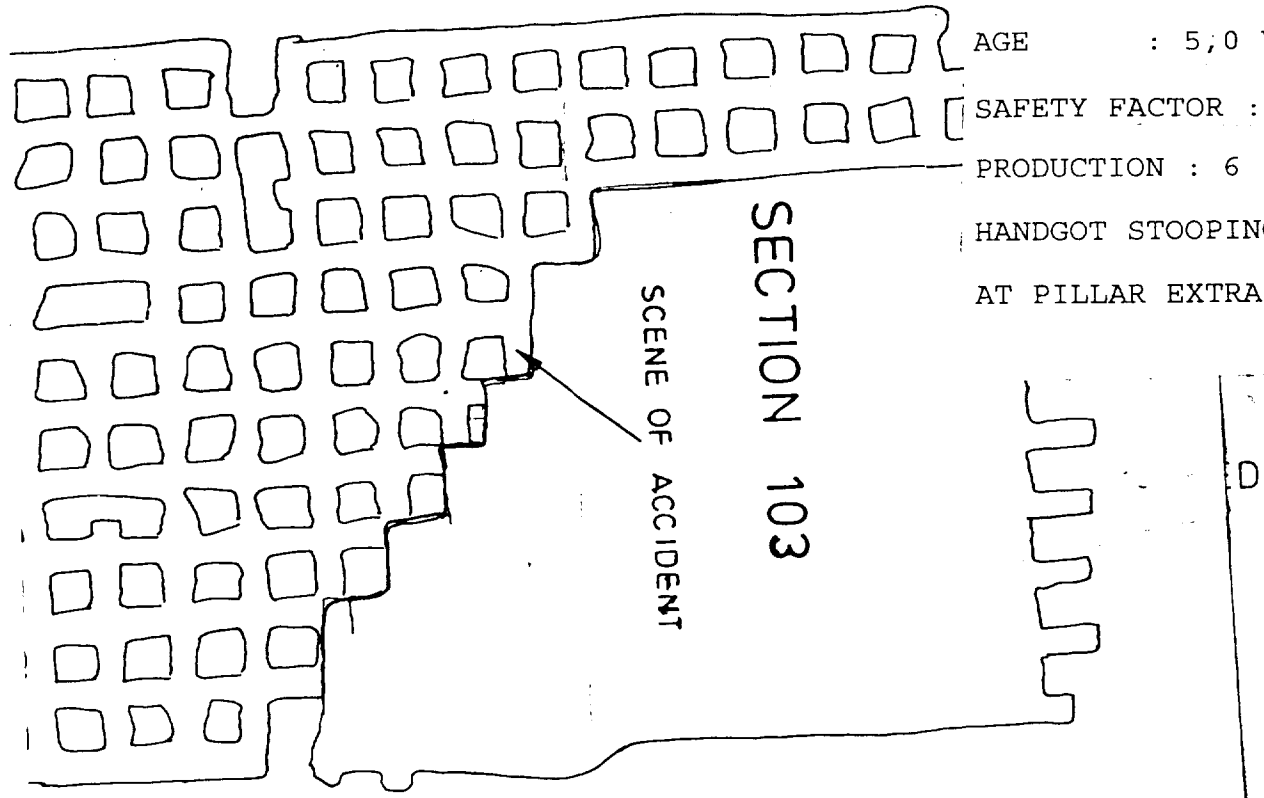
ACCIDENT NUMBER 25

DATE: 1995-08-07

CASUALTY : 2 FATALITIE.
           1 INJURY

DEPTH   : 55 METER

AGE   : 0,4 YEARS

SAFETY FACTOR : 2,3

PRODUCTION : 2 000 TPM
(JUST STRARTED)

AT PILLAR EXTRACTED
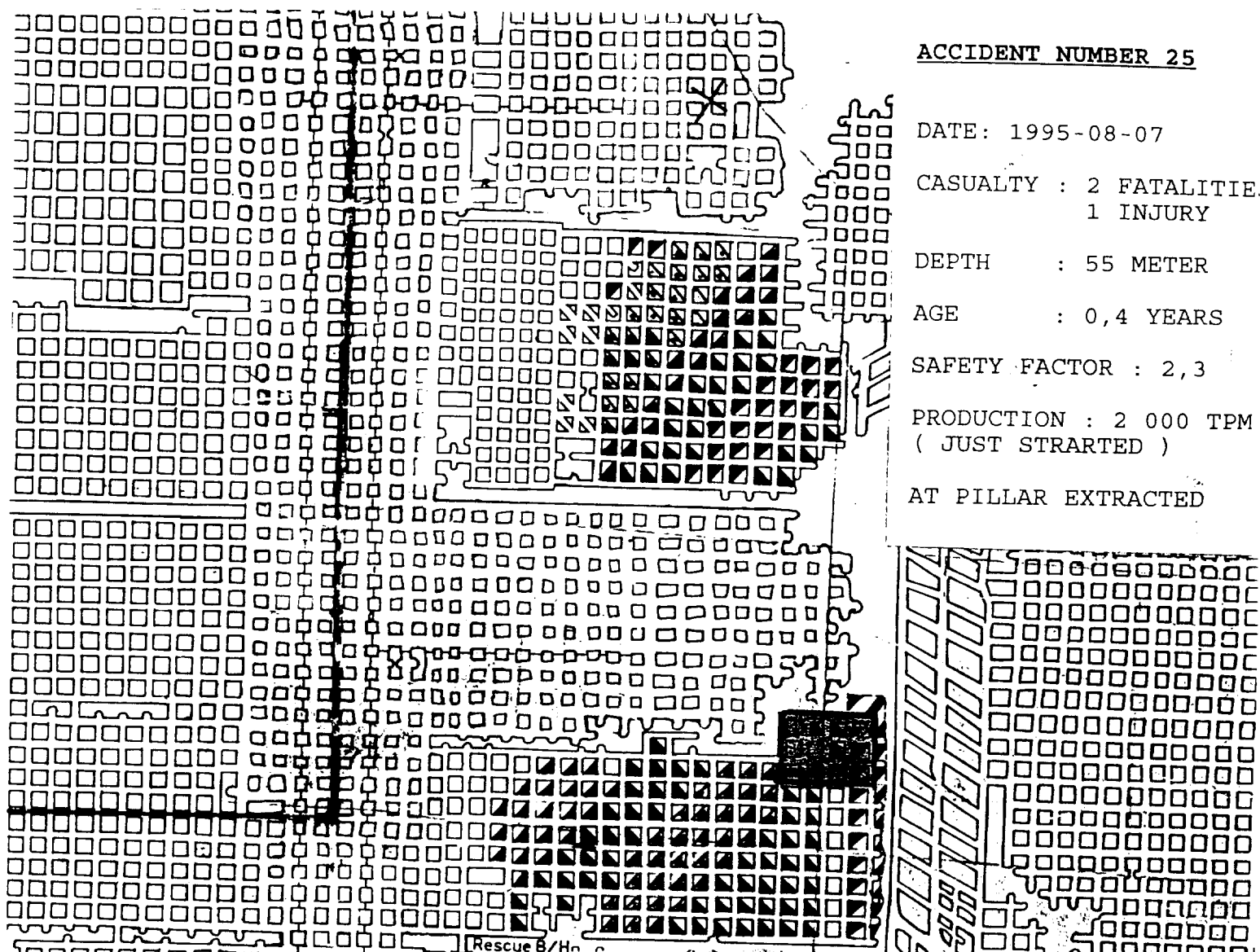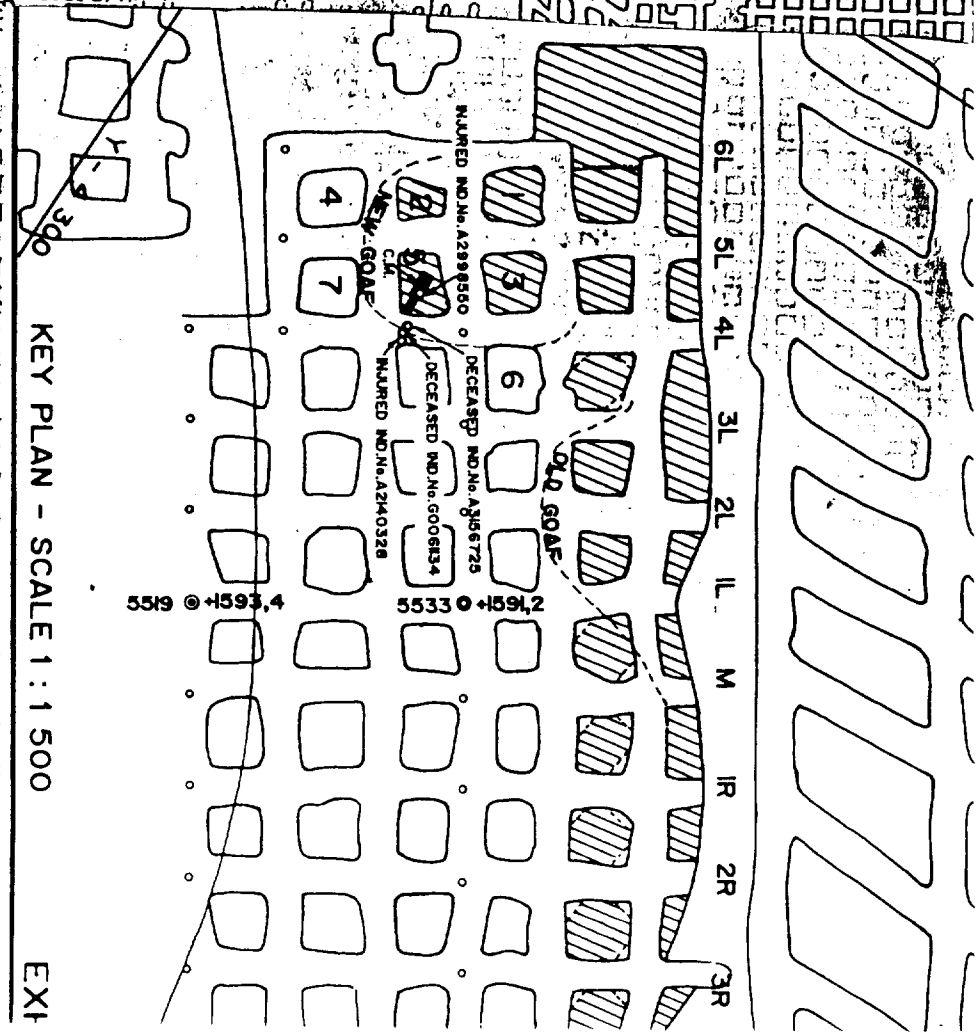
KEY PLAN - SCALE 1 : 1 500

Rescue B/H

INJURED IND.No.A2908560
DECEASED IND.No.A3367725
INJURED IND.No.A2140328
DECEASED IND.No.G006134

NEW-GOAF
OLD GOAF

5519 ⊛ +1593,4   5533 ○ +1591,2

ACCIDENT NUMBER 26

DATE : 1989-09-19

CASUALTY : 2 FATALITIES
1 INJURY

DEPTH : 62 METER

AGE : 9,0 YEARS

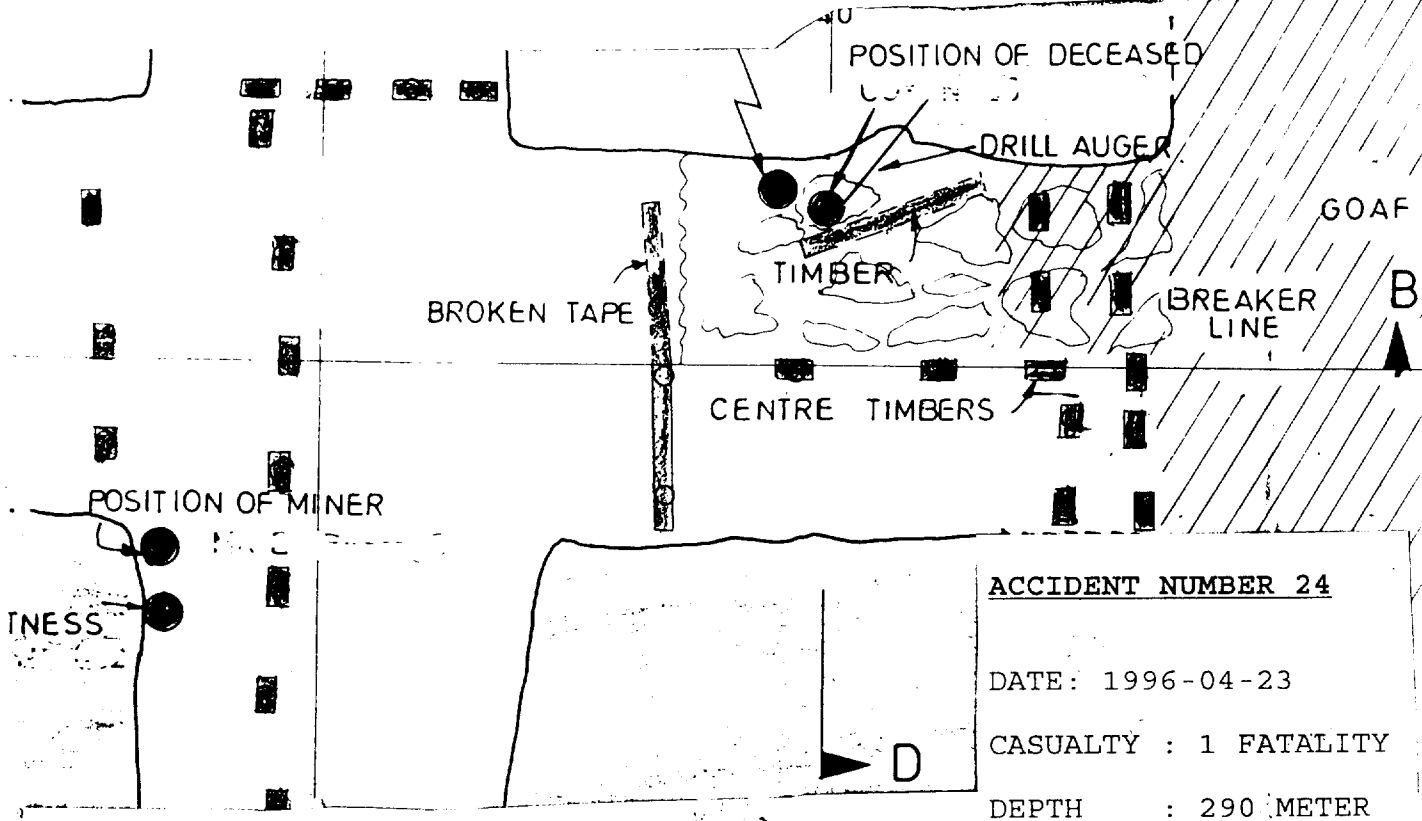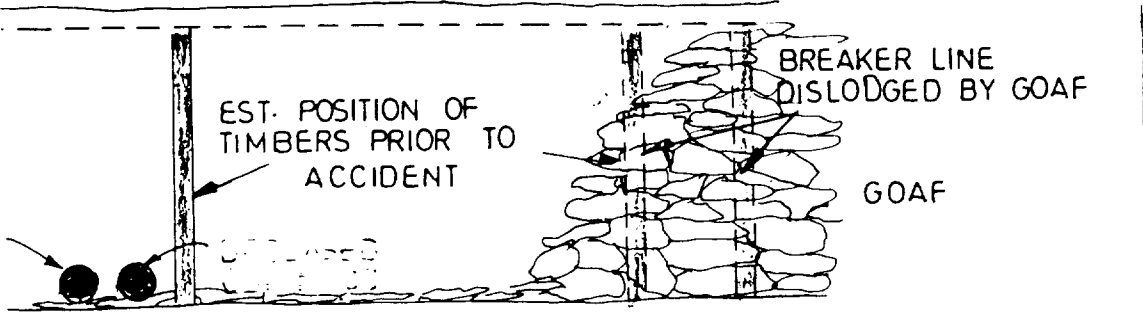SAFETY FACTOR : 1,7

PRODUCTION : 19 000 TPM

AT PILLAR EXTRACTED
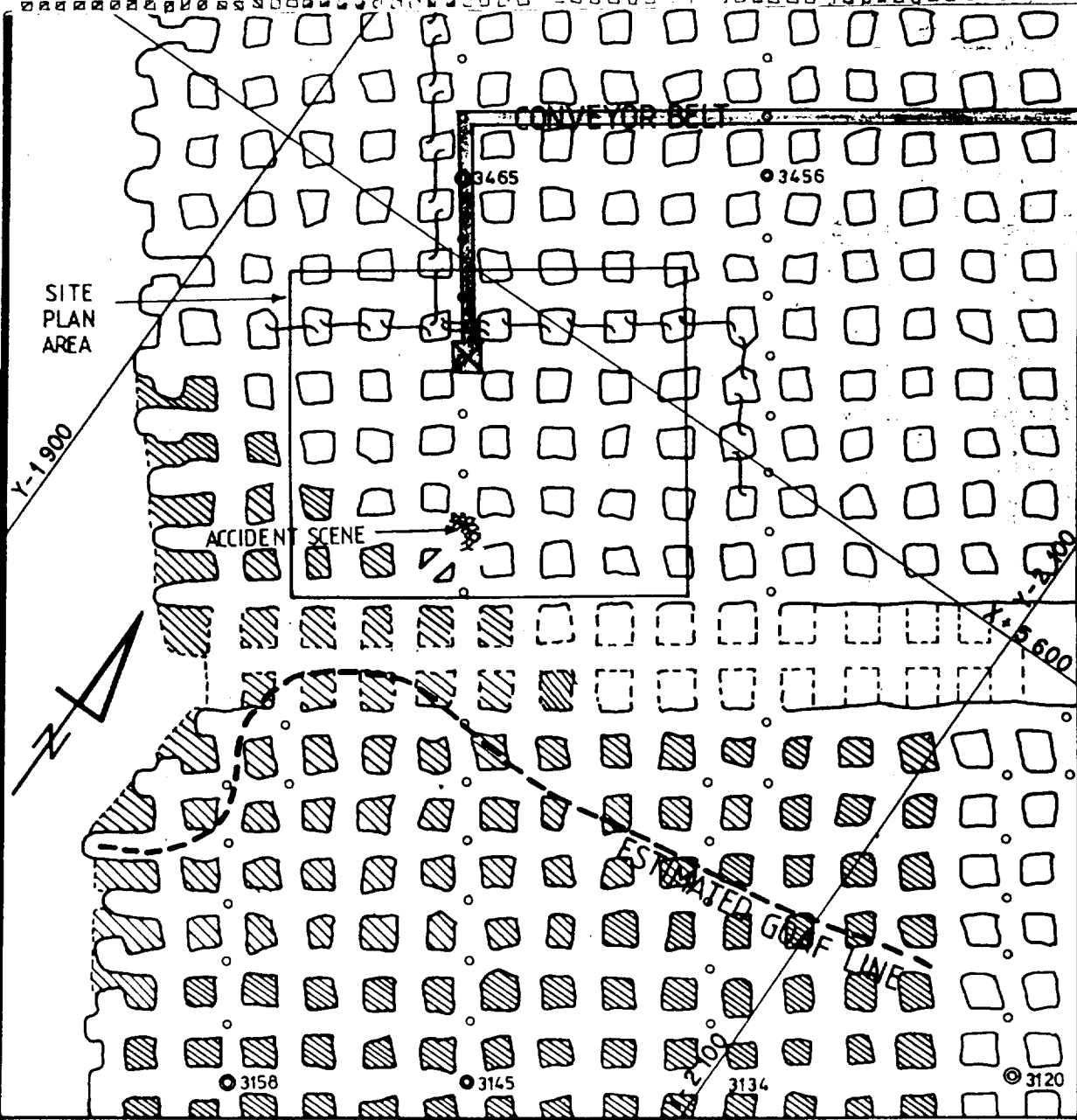
KEY PLAN — SCALE 1:1500   19-09-89.

ACCIDENT NUMBER 27

DATE: 1993-08-30

CASUALTY : 3 FATALITIES
           1 INJURY

DEPTH   : 65 METER

AGE   : 2,5 YEARS

SAFETY FACTOR : 2,3
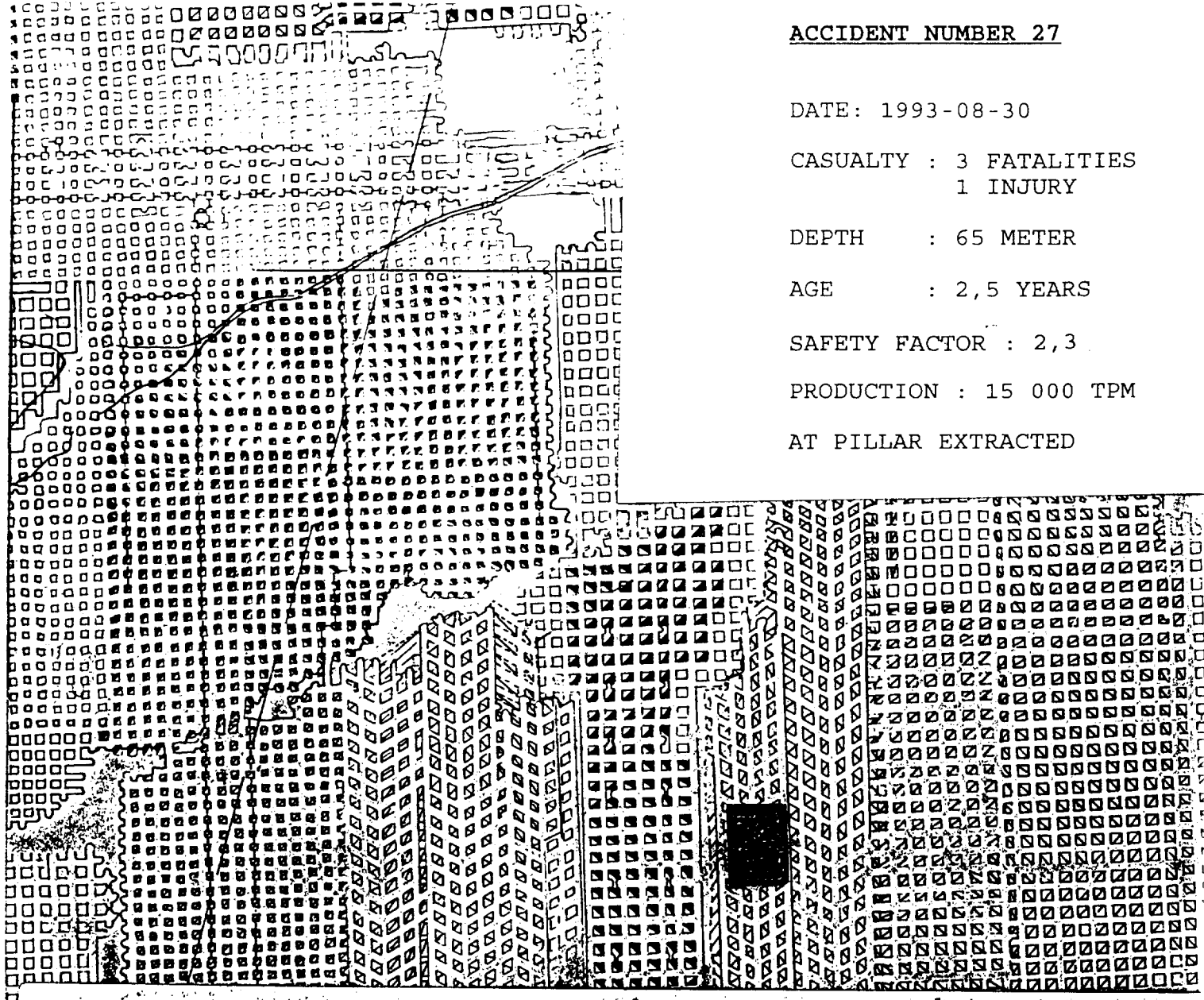
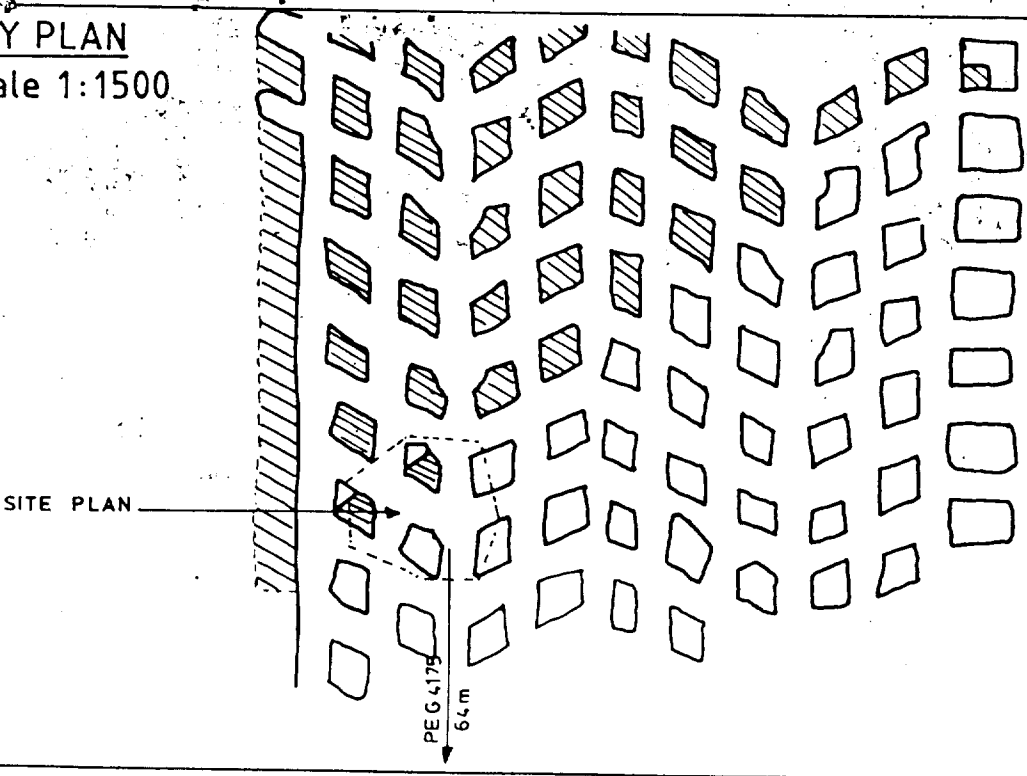PRODUCTION : 15 000 TPM

AT PILLAR EXTRACTED

EY PLAN

:ale 1:1500

SITE PLAN

PEG 4175

64 m

EXHIBIT "A"

T/N

APPENDIX 2

Title: COAL PILLAR DETERIORATION

Author: B J Madden
Research

Agency: CSIR: Division of Mining Technology

June 1997

1. Introduction

Collapse of coal pillars have been known to occur up to 50 years after mining. Examination of the designed dimensions of some 90 pillar collapses known to have occurred in South Africa has shown probable reasons for some of the collapses. However, several collapsed cases have occurred where the design of the pillar dimensions were according to the current South African guidelines for pillar design, yet pillar collapse occurred.

This report summarises three cases where deterioration of the coal pillar has been observed. The reason for the deterioration is not understood and requires study so that long term stability of standing pillars is obtained for the safety of the underground workforce.

2. Background

Figure 1 shows the frequency of the collapsed pillar cases versus their designed safety factor. Several observations can be made from the figure. Firstly, pillar collapses have occurred with very high, up to 5,6 designed safety factor. In fact 35 of the 90 pillar collapse have occurred with safety factors in excess of a designed value of 1,6. Secondly, the majority of the collapsed pillar cases occur in Salamon's original empirical range of 1967 and have a designed safety factor of less than 1,6. In eight cases the pillars stood between 30 and 50 years at designed safety factors of between 0,91 and 1,37 before failing.

It should be noted that the majority of coal produced underground in South Africa comes from the Witbank and Highveld Coalfields. In these coalfields Salamon's strength formula is performing well in the design of stable pillar systems. However, coal is produced underground in a variety of coalfields with varying conditions. Examination of the collapsed cases with higher designed safety factors than 1,6 suggests that they can be broadly grouped into geographic areas.

For example some 29 collapsed pillar cases occur in the Vaal Basin Coalfield since 1967. Some of these cases failed with high safety factors due to some form of deterioration over time, van der Merwe (1993). Madden (1991) excluded 19 cases from the Vaal Basin Coalfield in the re-evaluation of pillar design conducted in 1988. The mechanism resulting in pillar deterioration is not understood and requires further research.

3. Observed pillar deterioration
3.1 Case A

A study of fracturing into pillars and measurement of bord widths was conducted by Madden (1987). Of the four panels investigated in the original study, three were revisited in 1996 and the bord widths and fracture depths remeasured. All sections were open to ventilation for the full period and although the incline shaft was closed, the workings were accessed by a ventilation shaft.

A12 Section's pillars were mined by continuous miner. The pillar sides had spalled and cutter marks and stone dusting were not observed. The scaling occurred throughout the panel but the pillar condition could be described as good.

Figures 2 - 4 shows the frequency of bord widths measured during the investigation of 1982 and again in 1996.

Table 1 summarises the change in bord widths measured in 1982 and 1996 from the original surveyor's offset measurement from the surveyor record books. Included in the table is an estimate of the rate of pillar spalling over time. The time scale has been calculated between the original date of mining until 1982 and also 1996 as well as between 1982 and 1996. The rates of scaling in 1982 could be anomalous as the time between the surveyed offset and the 1987 study has been taken as 3 months. In Section A12 a slightly lower average 6.65 m was measured compared to 6.72 m from the

original surveyor's offsets, measured 5 years earlier. The scaling commenced after this 5 year period.

Table 1. Increase in bord width and rate of scaling

SECTION	CHANGE (m) (from original - 1982)	RATE (m/y)	CHANGE (m) (1982-1996)	RATE (m/y)	CHANGE (m) (from original - 1996)	RATE (m/y)
A1 (D & B)	0.47	0.094	0.97	0.069	1.44	0.076
A12 (CM)	-0.07	-0.014	0.46	0.033	0.39	0.021
F17 (D & B)	0.03	0.120	0.55	0.039	0.58	0.041

Figure 5 shows the average bord width measurements taken in Sections A1, A12 and F17 in 1996, 1982 and from the original surveyor's offsets normalised to the same starting date. All three sections have shown an increase in bord width over time, however the scaling varied in each section.

The rate of pillar scaling for Section A1 decreases from 0,094 m/yr for the first 5 years to 0,069 m/yr for the next 14 years. The rate of scaling of Sections A12 and F17 between 1982-1996 are within about 20 per cent at 0,046 and 0,055 m/yr respectively. This rate is approximately half that of Section A1.

From Table 1 the following points can be obtained:

I.   Initial scaling of the drill and blast workings is rapid but reduces over time.

II.   Deterioration of the continuous miner formed pillars commenced only after at least 5 years.

III. There is more deterioration of the drill and blast pillars than the continuous miner formed pillars.

IV.   Section A1 is scaling at a rate twice that of F17.

In all cases the increase in bord width exceeds the 1982 average depth of fracture suggesting that fracturing is extending into the pillar with time, Table 2.

The rate of scaling observed in the sections could be due to a number of factors including: material properties. skin stress, discontinuities, and environmental factors such as changing humidity. temperature and moisture content. Van der Merwe (1993)

discussed the rate of scaling of pillars in the Vaal Basin. The required scaling of a pillar, Figure 6, necessary to reduce the pillar width such that the calculated safety factor will be reduced to ensure failure was given as,

$$d = w - [0,2232 \, k^{-0,4065} \, S^{0,4065} \, H^{0,4065} \, h^{0,2683} \, (w+b)^{0,813}] \quad (1)$$

where, d is the required scaled distance (m)

   w is the original pillar width (m)

   k is the pillar strength (MPa)

   S is the safety factor at failure

   H is the depth below surface (m)

   h is the mining height

   b is the bord width

Table 2. Fractures recorded in pillar side observation holes in 1982 and 1996

DATA	PANEL	HOLES WITH FRACTURES OBSERVED OVER TOTAL No. HOLES	% HOLES WITH FRACTURES	MAX. FRACTURE DEPTH (mm)	AVERAGE FRACTURE DEPTH (mm) (for holes with fractures)	INCREASE IN BORD WIDTH (m)
1982	F17	20 / 61	33%	460	270	0,03
1982	A1	27 / 57	48%	520	170	0,47
1982	A12	7 / 56	12,5%	55	44,2	-0.07
1996	F17	32 / 61	53%	300	130,5	0,55 (1982-1996)
1996	A1	38 / 57	67%	270	71,7	0,97 (1982-1996)
1996	A12	32 / 56	57%	230	72,5	0,46 (1982-1996)

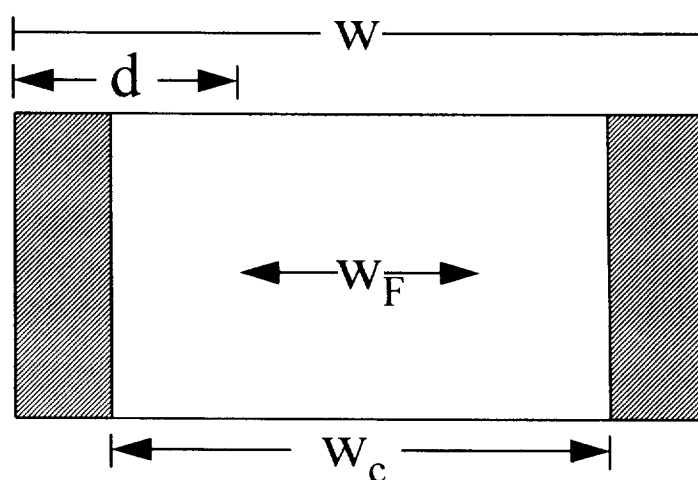
Figure 6. Required Amount of Scaling

Given that k is 7,2 MPa and that pillar failure will occur when the safety factor is 0,5 the original dimensions were used in equation (1). For Section A1 scaling of 4,166 m from the pillar was required. Assuming a linear rate of scaling of 0,069 m/yr, based on the increase in bord width during the period 1982 to 1996, pillar failure could occur in approximately 60 years from the time of the formation of pillars, as this was 19 years ago failure would be anticipated in about 40 years time.

The assumption of a linear scaling rate may be incorrect because as the pillar scales the load on the skin of the sidewall increases hence an accelerated scaling rate may occur, alternatively a reduction in scaling rate due to confinement of slabbed material may occur. This latter point may have happened in Section A1 as, over the first 5 years the rate was estimated to be 0,094 m/yr and this decreased to 0,069 m/yr over the next 14 year period.

Similarly the time until failure for A12 was estimated to be about 90 years and F17 about 50 years from 1996. While these are estimates further work on the known pillar failures and rate of scaling could be of significance as far as long term stability of coal pillars is concerned.

The 1987 report described the pillars in Section A12, mined by continuous miner five years earlier, as having cutter marks clearly seen on all pillars. The report further stated that "the pillar conditions of all four panels could be described as very good even though 0,25 m of spalling was observed in the panel mined by drill and blast methods five years earlier". The report commented that " at the depths of the workings under investigation, pillars in older workings should have reached an equilibrium and should therefore, reflect the full extent of the blast-induced damage". In the light of the 1996 observations the continued scaling of pillars in all panels questions the adjustment of the safety factor of continuous miner formed pillars. While the rate of scaling is lower for the continuous miner formed pillars scaling into the pillar occurs in all panels over time.

A detailed study is required into the long term pillar deterioration as the above results are from only three panels in one colliery. However, the implication of continued pillar

deterioration could have far reaching effects not only for safety but also for future environmental impacts.

3.2 Case B

An examination of a pillar collapse effecting a surface structure was undertaken. To gain access to the workings a ventilation wall had to be holed. Figure 7 shows the conditions on both sides of the wall. The difference in pillar and roof condition can only be attributed to the atmosphere or climatic conditions altering the strata in an unknown manner as the pillars on either side of the ventilation wall were mined at the same time and to the same dimensions using the same equipment.

This area was remote from the pillar collapse and was not effected by the collapse.

3.3 Case C.

This case was reported in the final project report COL 021A entitled "A Reassessment of Coal Pillar Design Procedures" by BJ Madden, I Canbulat, B Jack and G Prohaska.

Long term pillar stability affects the safety of the mine personnel in several ways. Firstly, pillar deterioration occurring in main developments could potentially lead to the isolation of crews. While larger pillars designed to higher safety factors in main developments are industry standards this effect should be investigated. Of greater potential risk is the intended extraction of previously formed pillars. Extensive reserves exist wherein the nominal safety factor was designed to the accepted norm of 1,8. The effect of the passage of long periods of time on pillar strength is required to be known as the extraction of seemingly suitable pillars standing for several decades will be increasingly contemplated in the future.

In October 1995 pillars in the No. 2 Seam, Witbank Coalfield, were inspected at Colliery C. In one panel the pillars were mined in 1958 prior to the introduction of Salamon's safety factor design formula. The pillars were formed to a calculated safety factor of 1.21. In a report dated July 1988, some 30 years after mining, Dr Carmbly stated that "after very many years the conditions are still excellent." At this stage, 1988, the pillars showed little sign of deterioration. Observations in 1995 however, revealed considerable scaling of the pillars in conjunction with roof falls. Obviously some trigger occurred between 1988 and 1995 to account for the deterioration in panel condition. Mining of an adjacent area did occur in 1991 with a substantial 24 m wide barrier between the panels. To examine the possible influence of mining on the older pillars, numerical simulations using BEPIL, MAP3D and MINLAY were conducted. All models showed very small (0,1-0,2 MPa) increases in load on some of the pillars next to the barrier. It was concluded that the mining probably was not the reason for the deterioration.

4.   Conclusion

Long term pillar stability affects the safety of the mine personnel in several ways. Firstly, pillar deterioration occurring in main developments could potentially lead to the isolation of crews. While larger pillars designed to higher safety factors in main developments are industry standards this effect should be investigated. Of greater potential risk is the intended extraction of previously formed pillars. Extensive reserves exist wherein the nominal safety factor was designed to the accepted norm of 1,8. The effect of the passage of long periods of time on pillar strength is required to be known as the extraction of seemingly suitable pillars standing for several decades will be increasingly contemplated in the future.

References

Madden B.J. and Canbulat I. (1996). Reassessment of Coal Pillar Design Procedures. *SIMRAC Symposium.*

Carmbly, H. (1988). Unpublished report.

Madden, B.J. (1991). A Re-assessment of Coal Pillar Design. *J. S. Afr. Inst. Min. Metall., vol. 91, no.1, pp. 27-37. January.*

van der Merwe, N. (1993). Revised Strength Factor for coal in the Vaal Basin. *J.South African Inst. Min. Metall.* March. Vol. 93, no 3. pp. 71-77.

PILLAR RATINGS

PILLAR SIDES (side wall spalling)

- [ ] A Straight cutter marks
- [ ] B Slight undulations 0,1 m
- [ ] C 0,1 - 0,3 m spalling
- [ ] D 0,3 - 0,7 m
- [ ] E > 0,7 m spalling

CORNERS (corner spalling)

- [ ] A Square
- [ ] B 0 - 0,5 m
- [ ] C 0,5 - 1,0 m
- [ ] D 1,0 - 1,5 m
- [ ] E > 1,5 m

PILLAR FRACTURING

- [ ] A Tight < 1,0 mm
- [ ] B Open 1,0 - 3,0 mm
- [ ] C Moderatly wide 3-10 mm
- [ ] D Wide 10-30 mm
- [ ] E Very wide > 30 mm

STONE DUSTING

- [ ] A Complete 80 - 100 %
- [ ] B Well 60 - 80 %
- [ ] C Moderate 40 - 60 %
- [ ] D Slight 20 - 40 %
- [ ] E None 0 - 20 %

TIME SINCE LAST DUSTING

- [ ] A One day
- [ ] B One week (1day-7days)
- [ ] C One month (1week-1month)
- [ ] D One year (1month-1year)
- [ ] E More than one year

PILLAR - ROOF CONTACT

- [ ] A Very good No signs of gap
- [ ] B Good Slight gap 2,0 mm
- [ ] C Fair 2,0 - 10,0 mm
- [ ] D Poor > 10,0 mm
- [ ] E Very poor spalling due to contact

STONE LAYER/WEAKNESS IN THE PILLAR

Type of stone layer/weakness
_____

Thickness
_____

Height from the floor
_____

WEAKNESS IN THE PILLAR

- [ ] A None No sign
- [ ] B Slight 0,1 m
- [ ] C Moderate 0,1 - 0,3 m
- [ ] D Severe 0,3 - 0,7 m
- [ ] E Very severe 0,7 m

COMPOSITION OF ROOF/FLOOR

Roof
_____

Thickness
_____

Floor
_____

Thickness
_____

COMMENTS ON ROOF AND FLOOR CONDITIONS

FOUNDATION FAILURE

Pillar punching/heave (Y/N?) _____

Description _____

ROOF TYPE AND ROOF SUPPORT

ROOF

ROOF COMPETENCE

- [ ] A No falls/cracks
- [ ] B No falls but cracks
- [ ] C Occasional minor falls
- [ ] D Falls to a competent layer
- [ ] E Falls to an incompetent layer

HEIGHT OF FALLS

- [ ] A None
- [ ] B Slight   0,1 m
- [ ] C Moderate 0,1 - 0,5 m
- [ ] D Severe   0,5 - 2,0 m
- [ ] E Very sev. > 2,0 m

DENSITY OF FALLS

- [ ] A None
- [ ] B Occasional on a slip/dyke
- [ ] C Assoc.with slip/dyke
- [ ] D Intersections only
- [ ] E Intersections and bords

SKETCH THE SUPPORT PATTERN

SUPPORT

SUPPORT TYPE

- [ ] A None
- [ ] B Roof bolt
- [ ] C Timber
- [ ] D Other

ROOF BOLTS

- [ ] A Full column
- [ ] B Mechanical
- [ ] C Resin point anch.

Length of bolt _____

Support density _____

SUPPORT EFFICIENCY

- [ ] A Very efficient 80 - 100 %
- [ ] B Efficient   60 - 80 %
- [ ] C Moderate   40 - 60 %
- [ ] D Inefficient < 40 %

SUPPORT PATTERN

Number in a row _____

Distance apart _____

INSTALLATION

- [ ] A None
- [ ] B Intersections
- [ ] C Bords & Intersections
- [ ] D Pillars

1.1 DEVELOPMENT

This panel was developed by a continuous miner about 6 months prior to the date of visit.

The coal seam was at a depth of 134 meters with the dolerite sill situated from surface to a depth of 40 meters.

The panel consisted of three roads with pillars mined at 48m x 48m centres and with a bord width of 5,7 meters and mining height of 2,6 meters gave a safety factor of about 4,0.

1.2 SECONDARY MINING

Secondary mining was done with a continuous miner and consisted of pillar quartering and floor lifting on the retreat as shown on the attached panel plan.

With floor lifting the total height came to 4,0 meter and with the quartering the safety factor was reduced to $\pm$ 1.4. The panel retreated for 100 meter and production was $\pm$ 40 000 tons per month.

1.3 SUPPORT

Support during developed was by means of rows of 4 x 1,8 meter bolts per row with rows at 1,2 meters apart.

Secondary support consisted of W-straps installed with 4 x 2,3 meter resin bolts at 1,5 meter apart.

1.4 CONDITION OF PILLARS

At the face line the condition of the pillars was as developed with no scaling near the present working faces as well as further back.

PANEL 1

2.1 DEVELOPMENT

The original development was done in the straight panel on four roads with a continuous miner at 36m x 36m centres. The dolerite sill was located at 18 meters to 61 meters from surface. The depth of the coal seam was 159 meters, the bord with 5,2 meters and with a mining height of 2,9 meters the safety factor was 2,5

2.2 SECONDARY MINING

Secondary mining consisted of mining to the geological limits of the block and then doing further extraction with a herringbone system as shown on the attached panel plan. In this method 6,0 meter wide roads are advanced to a depth of about 15 meters and leaving a 3,0 meter wide rib which gave a crush pillar with a safety factor of ± 0.7. These pillars crushed out as the panel retreated and the area goafed. The panel retreated about 200 meter and the production was ± 40 000 tons per month.

2.3 SUPPORT

The support during development consisted of rows of 4 x 1,8m resin bolts with rows at 1,5m apart.

Prior to secondary mining W-straps were installed in between the rows of roofbolts with 4 x 2,3 meters resin bolts. Finger line mine poles were installed in the centre of the newly cut herringbone roads.
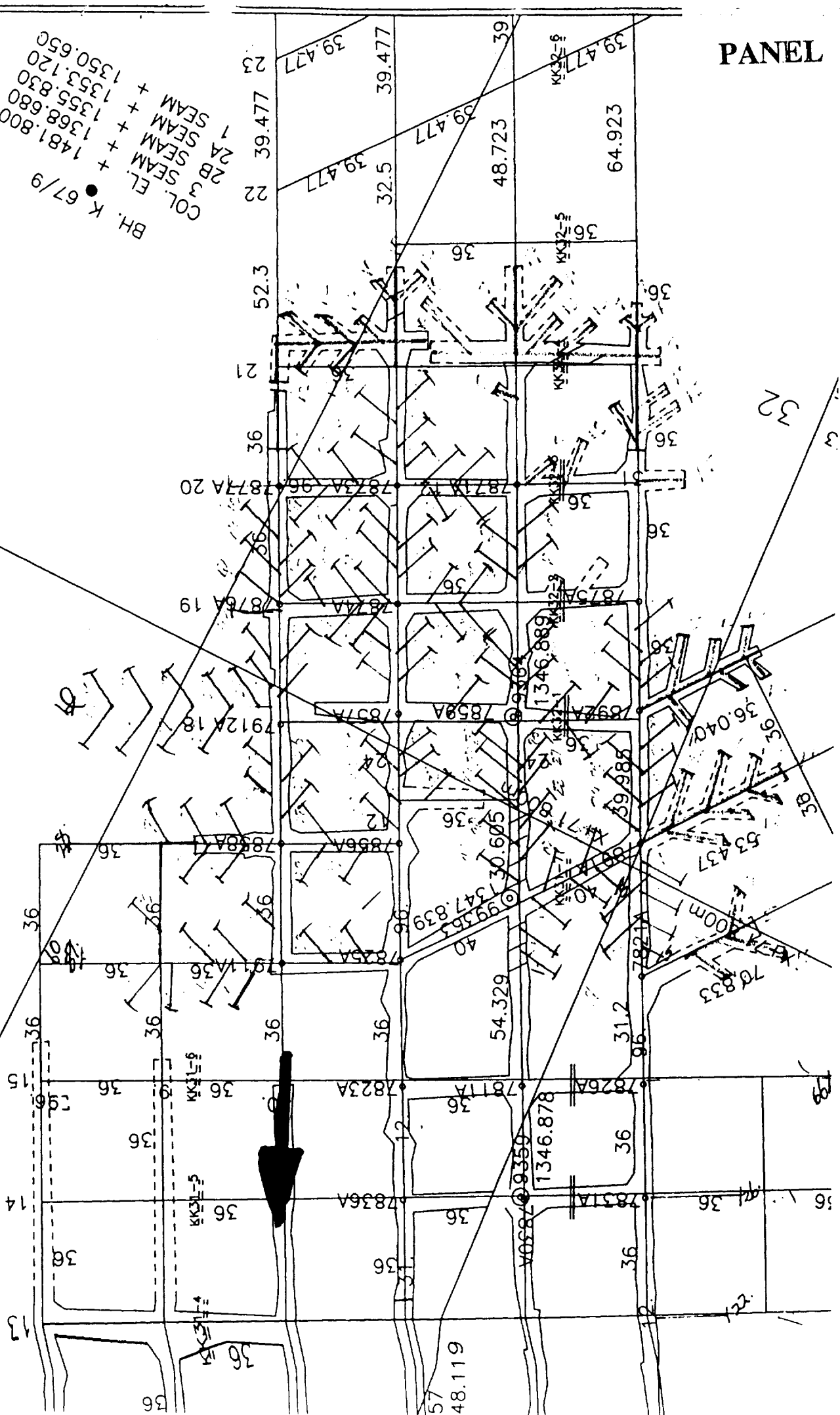
2.4 CONDITION OF THE PILLARS

Pillars where secondary mining was not yet done showed no signs of deterioration or scaling. Further back there was slight scaling at a few places.

The fenders left after the herringbone mining showed rapid deterioration with crushing and goafing from the second line of pillars back.

PANEL 2

3.1 DEVELOPMENT

The original development consisted of 7 roads mined by conventional drilling, blasting and mechanised cleaning. The pillar sizes were 20m x 20m and the coal seam was 114 meters deep with the dolerite sill situated at 13 meters to 54 meters from surface. With a bord width of 4,8 meters and a mining height of 3,1 meters the safety factor was 2,4

3.2 SECONDARY MINING

The secondary mining consisted of a mixture of floor coaling and herringbone mining with a continuous miner to reduce the size of the pillars. The latter ± 150 meter of the panel was mined by herringbone mining. The roads were mined at 6,0 meters wide to holing since the pillar sizes were about 15,0m x 15,0m. Crushing fenders of about 3,0 wide were left with an approximate safety factor of 0,7. These fenders crushed from about the second pillar back and the area goafed. a total distance of 150 meter was mined this way at the date of the visit and the production was ± 40 000 tons per month.

3.3 ROOF SUPPORT

The original roof support was with rows of 4 x 1.8 meter mechanical anchored bolts with the rows 1,5 meter apart. Due to slight roof scaling a fair percentage of these bolts were ineffective.

Secondary support consisted of rebolting with 1,8 meter roof bolts and wire meshing where considered necessary. Finger lines of mine poles were installed along the newly developed roads with breaker lines at the pillar corners. The breaker lines were pulled out once the splitting of the pillar was completed.

3.4 CONDITION OF THE PILLARS

No substantial scaling of the pillars near the face line or further back was observed. Slight corner scaling was observed at a few places with also slight occasional scaling (Coal) off the roof but no falls were observed.

Few rolls in the floor was present near the face causing accumulation of water.
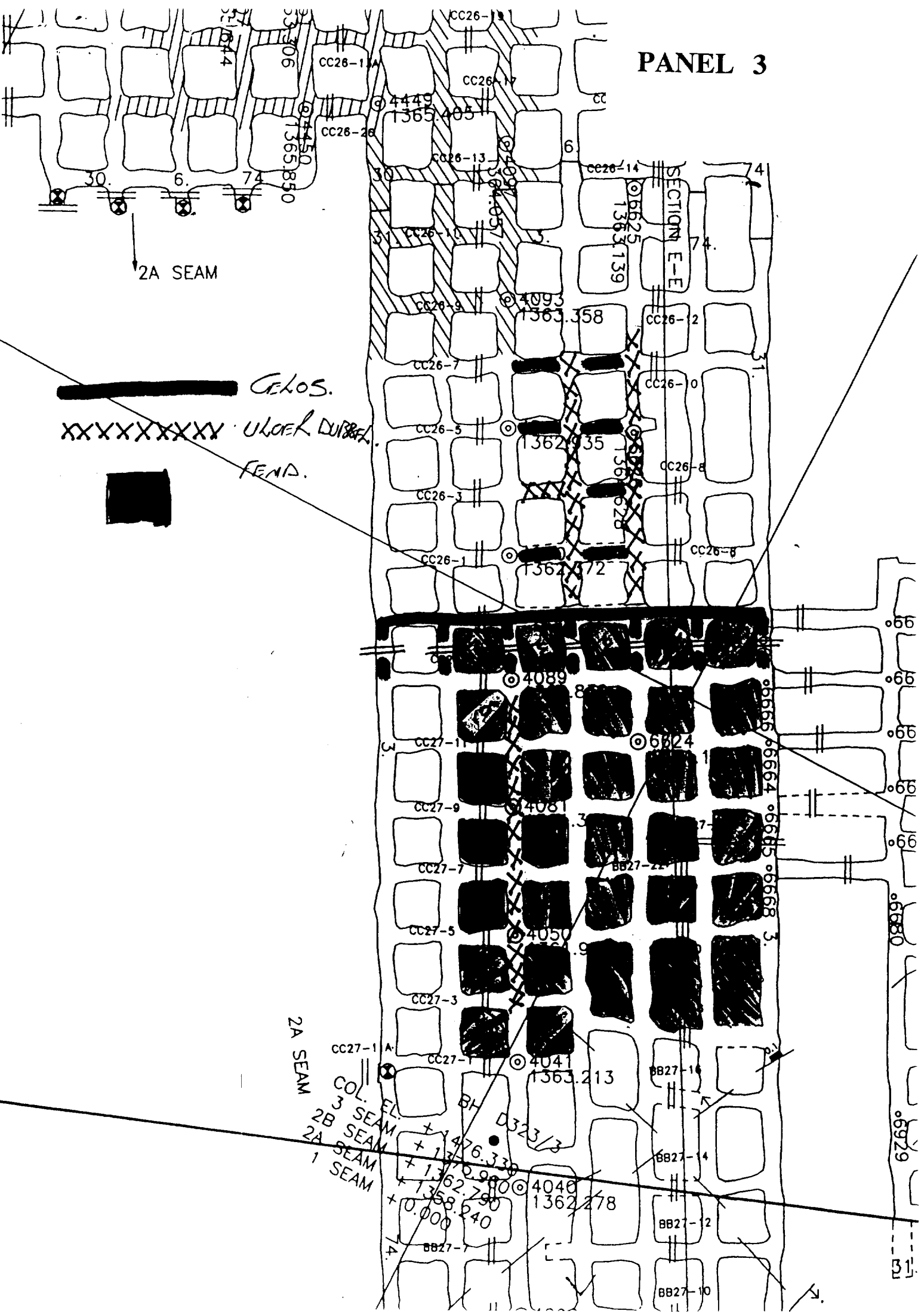
PANEL 3

2A SEAM

CC26-19
CC26-18A
CC26-17
CC26-26
4449
1365.405
30 6. 74
1365.850
CC26-13
CC26-14
CC26-11
CC26-9
4093
1363.358
CC26-12
CC26-7
CC26-10
CC26-5
1362.935
CC26-8
CC26-3
CC26-1
1364.472
CC26-6

CELOS.
XXXXXXXX ULOER DURBEL.
FEMP.

SECTION E-E
6625
1363.139

66
66
6666
66
6664
66
6665
6668
66

4089
CC27-11
CC27-9
4081
CC27-7
6624
BB27-22
CC27-5
4050
CC27-3
BB27-16
CC27-1 A
CC27-1
4041
1363.213
BB27-14

2A SEAM
COL. EL.
3 SEAM
2B SEAM + 1476.330
2A SEAM + 1370.98
1 SEAM + 1362.790
+1358.840
+0.000.840
4040
1362.278
BH D323/3
BB27-12
BB27-10
BB27-7

6929
6680
31
31

4.1 DEVELOPMENT

The panel was developed by two continuous miners with 9 roads at 24m x 24m centres. The coal seam is 98 meters deep and the dolerite sill is located at 13 meters to 35 meters from surface. The bord widths were 6,9 meters and the mining height 3,6 meters which resulted in a safety factor of 2,1.

The development was done about four months prior to the date of visit and when the limit of the panel was reached stooping commenced immediately

4.2 SECONDARY MINING

The secondary mining was pillar extraction with two continuous miners in the panel. The panel was divided in two and the faces of the continuous miner working on the right side of the panel lagged by one to two pillars. The pillars were split lengthwise forming two 18m x 6m smaller pillars. These pillars were then extracted one by one mining diagonal lifts of three meters wide. Snooks of various sizes were left but they soon crushed out.

The panel advanced about 70 meters at the date of the visit and initial goafing was limited. Production from the two continuous miners were 90 000 tons per month.

4.3 SUPPORT

The support during development consisted of rows of 3 x 1,2 meter sandex roofbolts with the rows spaced at 3,0 meters apart.

During pillar extraction additional 1,2 meter sandex roofbolts are installed where considered necessary.

Breaker lines consisted of two rows of 5 x 1,2 meter sandex roofbolts with a few warning mine poles installed at selected points.
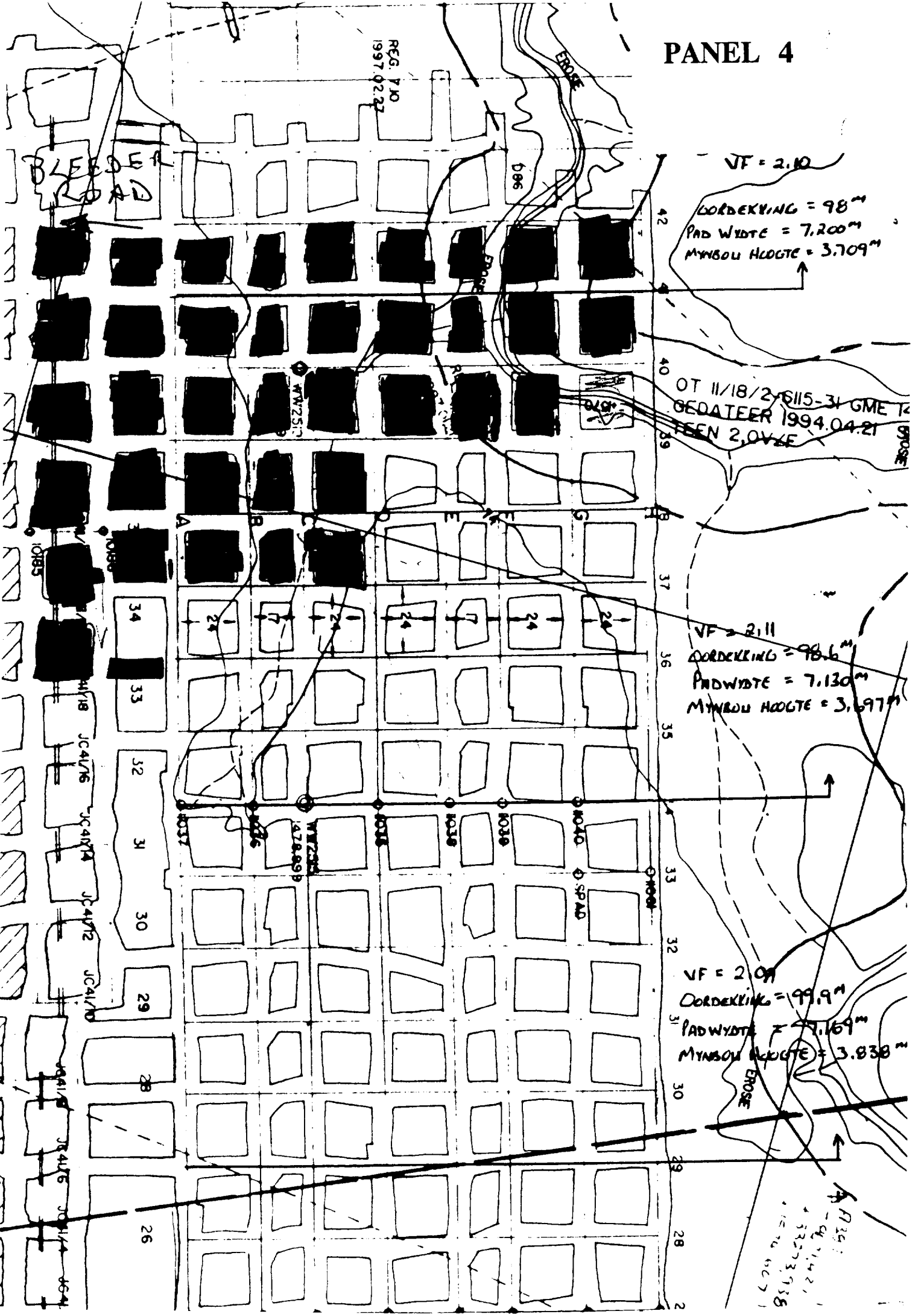
The immediate roof was competent sandstone or shaly sandstone.

A typical mining and support standard for this type of pillar extraction for two different sizes of pillars were as shown on attached drawing.

4.4 CONDITION OF PILLARS

No scaling was observed of the pillar sidewalls or corners either near the goaf line or further back. The roof also showed no deterioration at that stage.

PANEL 4

VF = 2.10
ØORDEKKING = 98ᴹ
PAD WIDTE = 7.200ᴹ
MYNBOU HOOGTE = 3.709ᴹ

VF = 2.11
ØORDEKKING = 98.6ᴹ
PADWIDTE = 7.130ᴹ
MYNBOU HOOGTE = 3.697ᴹ

VF = 2.0ᴹ
ØORDEKKING = 99.9ᴹ
PADWYDTE = 7.169ᴹ
MYNBOU HOOGTE = 3.838ᴹ

SNYVOLGORDE IN 'N 24 x 24m SENTER (18 x 18m) PILAAR TYDENS WINNING
PILLAR EXTRACTION CUTTING SEQEUNCE IN A 24 x 24m CENTRE (18 x 18m) PILLAR

NIE VOLGENS SKAAL
NOT TO SCALE

PUN
GOAF

PUN
GOAF

PUN
GOAF

PUN
GOAF

SOLIED
SOLID

SOLIED
SOLID

SOLIED
SOLID

SOLIED
SOLID

DAKBOUT BREKERLYN
ROOFBOLT BREAKERLINE

DAKBOUT BREKERLYN
ROOFBOLT BREAKERLINE

DAKBOUT BREKERLYN
ROOFBOLT BREAKERLINE

DAKBOUT BREKERLYN
ROOFBOLT BREAKERLINE

KLIKSTOK
POLICEMAN

4 m

6 m

1 m

RIGTING WAARIN PILARE ONTTREK WORD
DIRECTION OF PILLAR EXTRACTION

VORM45/LEV4
1994.10.24
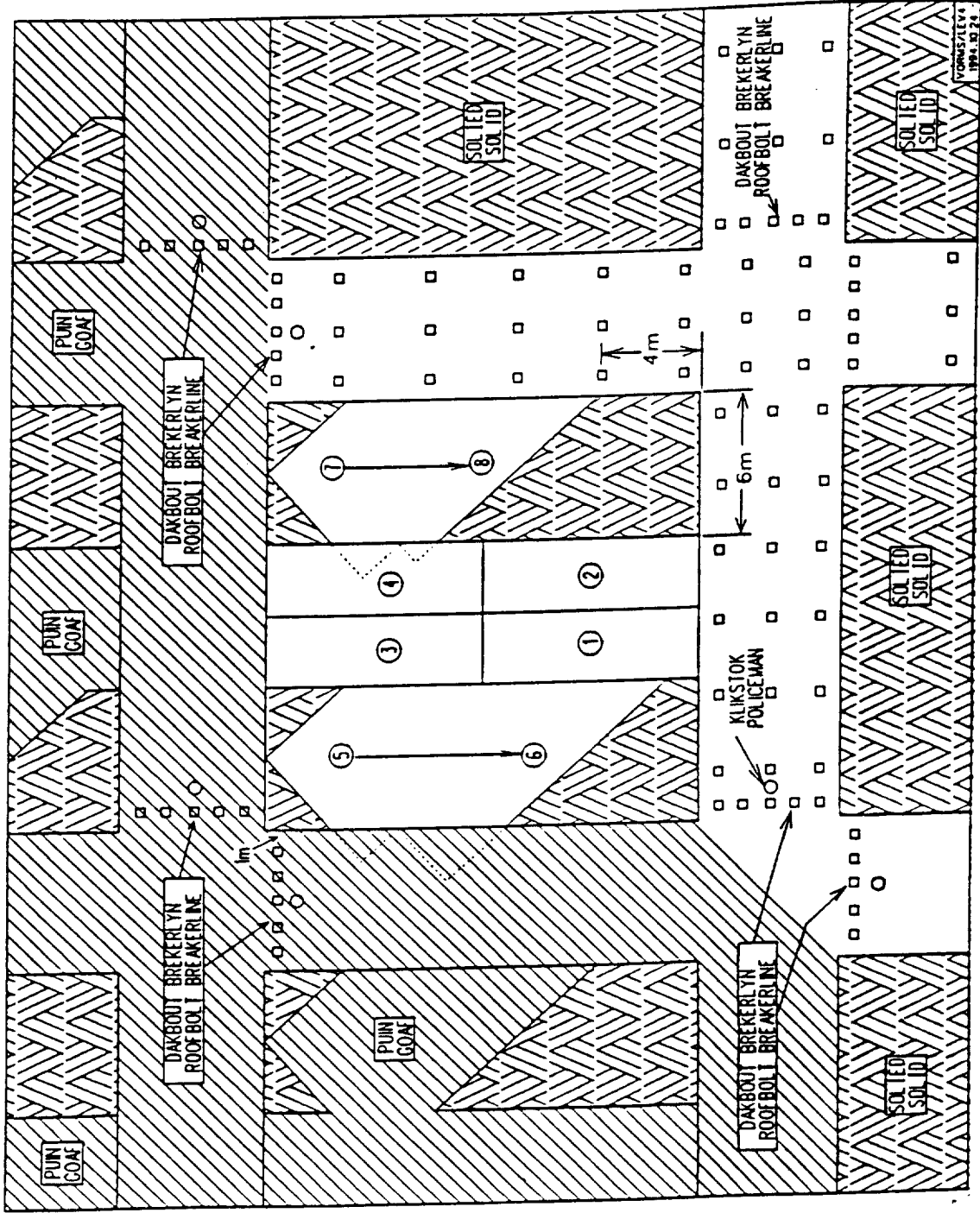
SNYVOLGORDE IN 'N 36 x 24m SENTER (30 x 18m) PILAAR TYDENS WINNING
PILLAR EXTRACTION CUTTING SEQEUNCE IN A 36 x 24m CENTRE (30 x 18m) PILLAR
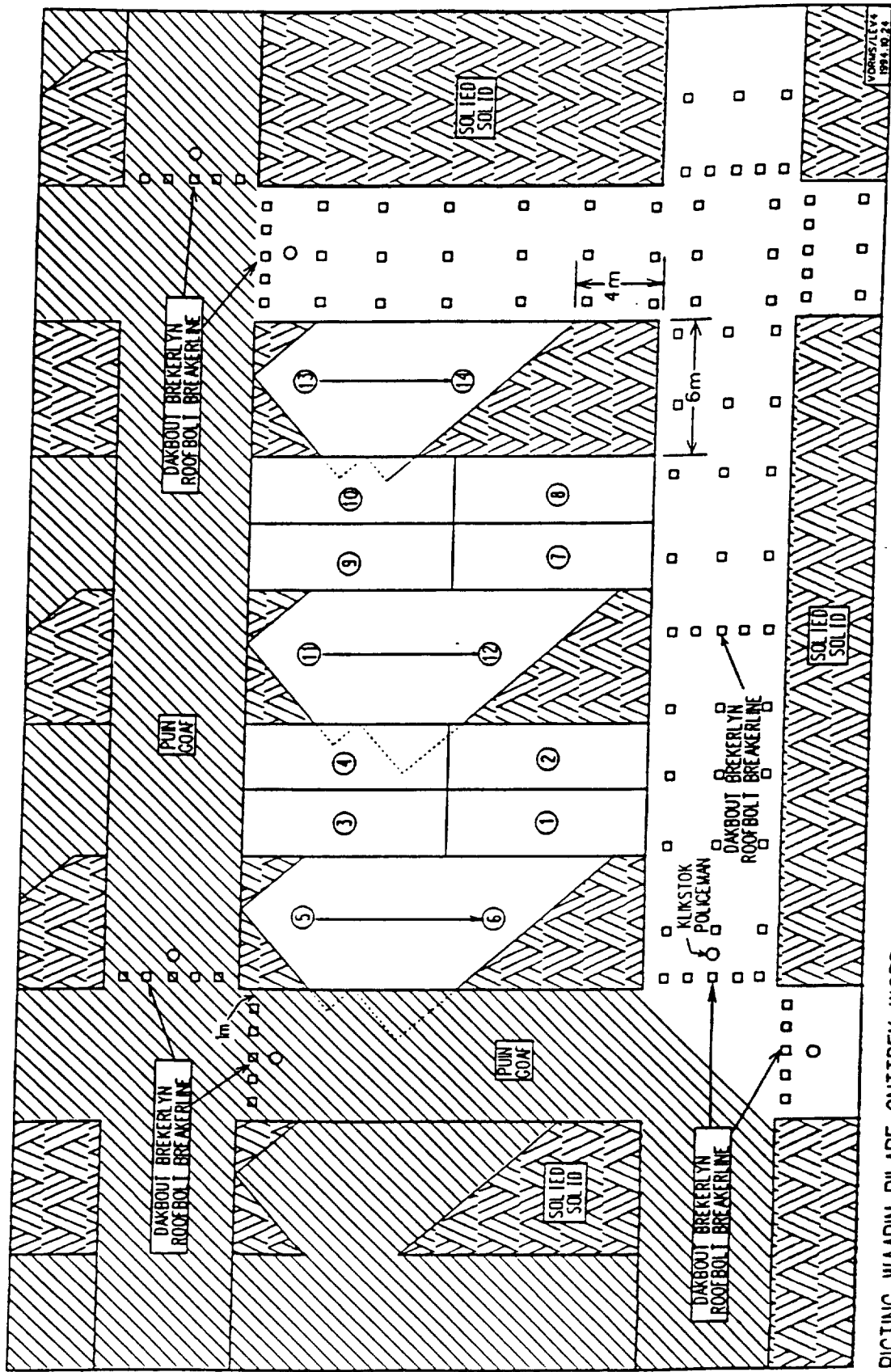
NIE VOLGENS SKAAL
NOT TO SCALE

BYLAE G
ANNEXURE G

RIGTING WAARIN PILARE ONTTREK WORD
DIRECTION OF PILLAR EXTRACTION

5.1 DEVELOPMENT

The cross panel development and back stooping of this panel to the point of inspection was done during the preceding 9 months.

The cross panel consisted of 11 roads and the secondary development panel where stooping just started consisted 9 roads. (Refer to attached panel plan 5(a)). The depth was 153 meters with the dolerite sill located from 70 meter to 83 meter below surface. The pillar centres were 24m x 27m and the development was done with two continuous miners. With the road widths of 6,4 meters and mining height of 3,8 meters the safety factor was around 1,8.

5.2 SECONDARY MINING

At the time of the visit problems were experienced and one continuous miner was shifted to the adjacent cross panel where it started with the development of that panel. The second continuous miner completed the extraction of the cross panel pillars and the secondary development would be retreated to a point opposite the last road of the adjacent panel.

Pillar extraction was done by splitting the pillar lengthwise forming two pillars of about 6m x 21m. these pillars were then mined out in turn lifting them off in the standard way , leaving small snooks which crushed out with the increased stresses. The area goafed very well.

The distance of goaf from the secondary development was 150 meters and the production with the one continuous miner just prior to the visit was $\pm$ 50 000 tons per month.

5.3 SUPPORT

Support during development consisted of rows of 3 x 1,2 m resin bolts with the rows spaced 2,4 meters apart.

During pillar extraction secondary roofbolts were installed where considered necessary. Two rows of 5 x 1,2m resin bolts were installed as the breakerline with a few warning poles installed at selected points.

5.4 CONDITION OF THE PILLARS

The condition of the pillars in this panel was of specific interest. The panel was visited twice about two weeks apart. The approximate goaf lines at the days of the

visits were as shown on panel plans 5(a) and 5(b) respectively.

During the first visit it was found that the pillars immediately in front of the goaf line showed very severe scaling, sloping from the roof to the footwall. The road widths at the start of the pillar, the goaf, was in excess of 8 meters and back towards the first through road the width was about 7 meters.

Corner scaling adjacent to the goaf line was also very severe. The corners of the pillars at the first thought road showed moderate scaling of 10cm to 30cm.

No apparent deterioration of the roof was observed but there was occasional scaling of ± 100 mm. No falls were observed.

These conditions were also observed for the pillars of the bleeder road.

Because of this significantly important situation the panel was visited again about two weeks later. Due to problems, water and other the production and advance of this panel was not as anticipated. The face positions were approximately as shown on panel plan 5(b).

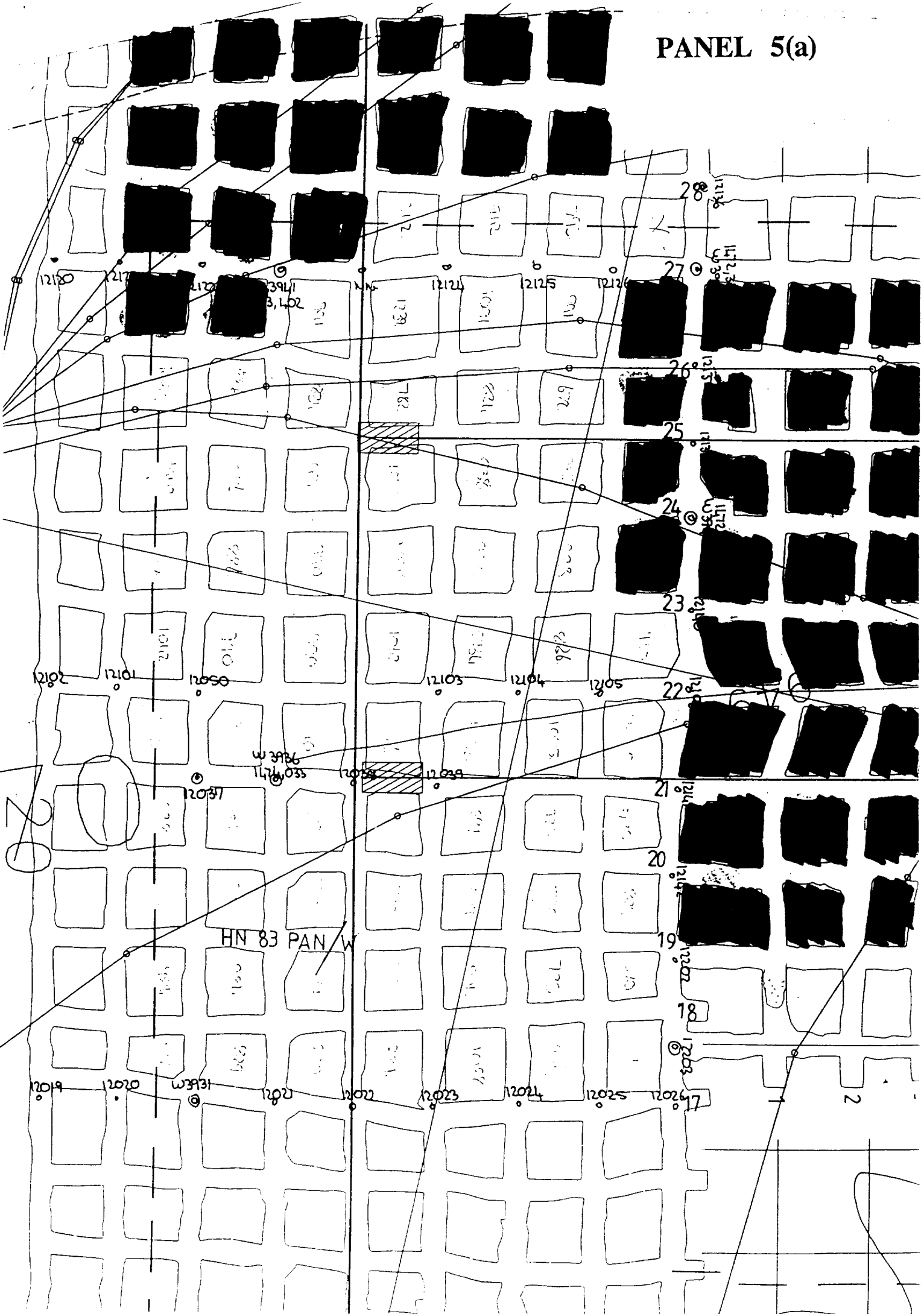The condition of the pillars nearest to the goaf line started from left to right were noted carefully.

It was found that nearest to the barrier pillars on either side the scaling was considerable less than towards the centre of the panel [refer to points 1 & 2 and 8 & 9 on panel plan 5 (b)]. The scaling became progressively worse towards the apex of the goaf line [refer to points 4, 5 and 6 on panel plan 5(b)] and was very severe on the pillar opposite point 5.

This increase of scaling illustrated the increase of stress on these pillars from the barrier to the centre of the panel.

Moving away from the goaf line there was a rapid decrease in scaling. In the last through-road the scaling on the further sidewalls and corners were considerably less, in fact only slight, compared to the severe scaling of the sidewalls and corners towards the goaf. The pillars further away from the goaf were as mined and no deterioration was observed.

The significance and danger of critical pillar sizes which defines the safety factor was well illustrated by the pillar behaviour of this panel. The stress distribution on the pillars rapidly reduced from the first to the second line of pillars from the goaf.
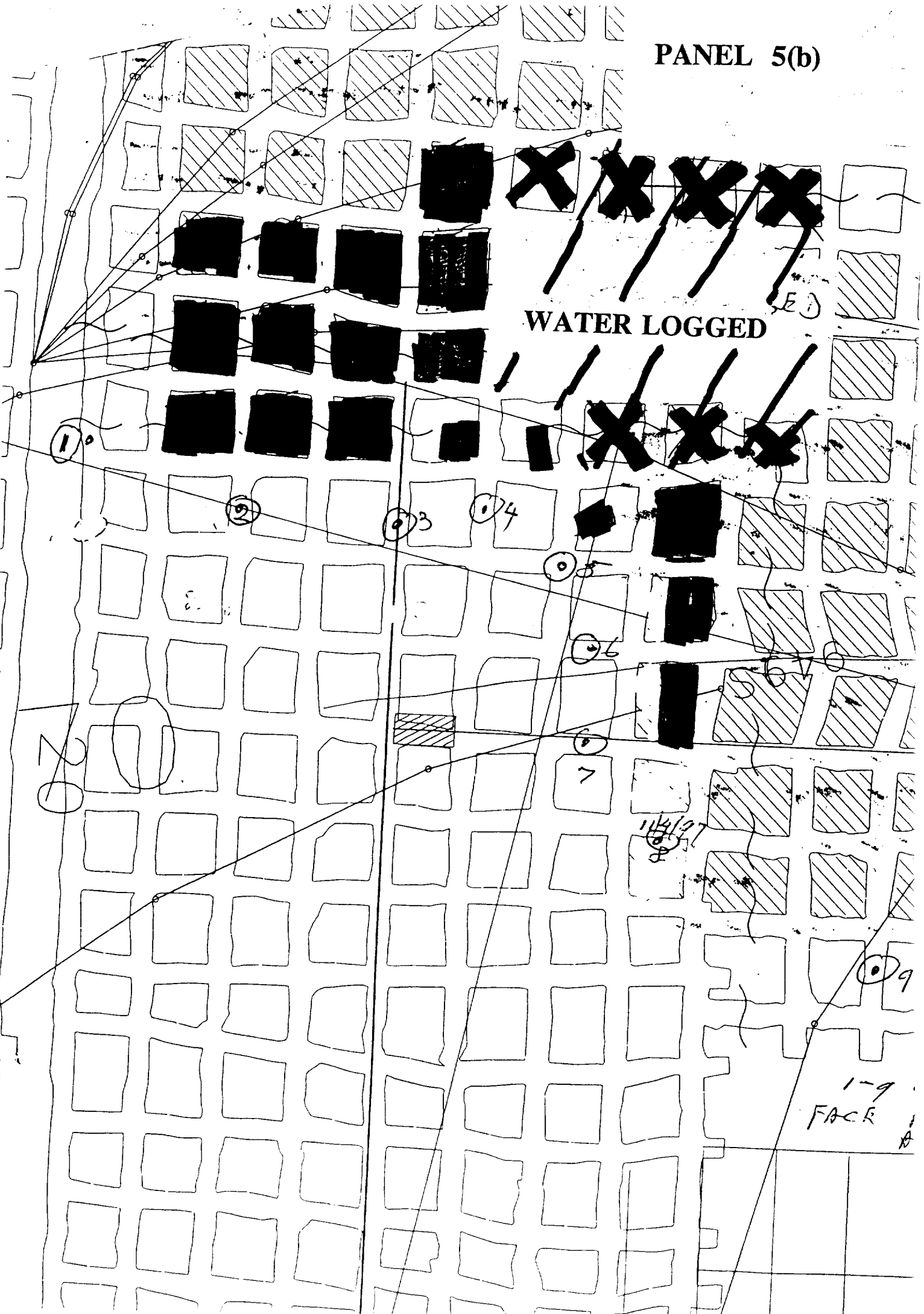
PANEL 5(a)

HN 83 PAN/W

28
27
26
25
24
23
22
21
20
19
18
17

12120   12117   12123   12941   12124   12125   12126
3, L02   NN

12102   12101   12050   12103   12104   12105

W 3936
1474 033   12038   12039
12037

12019   12020   W3931   12021   12022   12023   12024   12025   12026

PANEL 5(b)

WATER LOGGED

6.1 DEVELOPMENT

This panel was developed with six roads with a continuous miner. The depth was 185 meters with the dolerite sill situated from 51 meters to 91 meters from surface. The pillar centres were 27m x 27m. The road widths were 6.1 meters and the mining height was 2,8 metres which gave a safety factor of 2,2. Production during development averaged at about 40 000 tons per month.

6.2 SECONDARY MINING

Pillar extraction had just started and will be done on the standard way for the specific mine.

6.3 SUPPORT

Support during development consisted of rows of 3 x 1,2 meter resin bolts with the spacing of the rows at 2,5 meters apart.

6.4 CONDITION OF WORKINGS

The pillars throughout the panel were as cut with no scaling of either the sidewalls or the corners.

As a result of the limited seam height no coal was left in the roof during mining. The immediate roof consisted of $\pm$ 20cm shaly sandstone which tend to dislodge in places. This could cause some problems during pillar extraction. At places lateral cracks were also formed in the centre of the roads which would require additional roofbolts and barring.

EP 68

EP 68
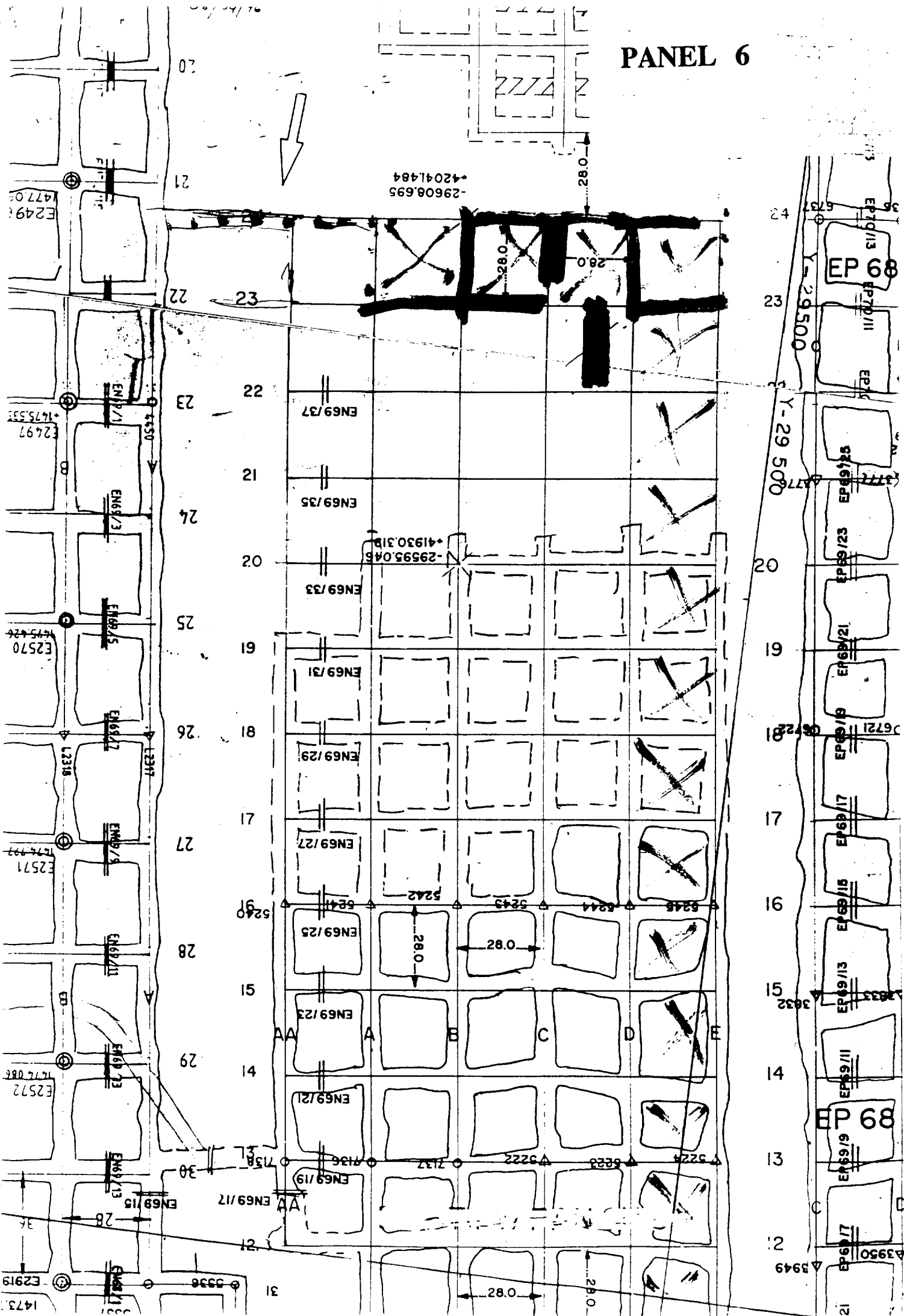
7.1 DEVELOPMENT

Development of this panel was done some 22 years ago by conventional drilling, blasting and mechanical cleaning. The depth was 274 meters and the dolerite sill was located from 65 meters to 88 meters below surface.

There were four roads which were designed at 30m x 30m centre pillars with 6.0 meters wide roads and a mining height of 3,6 meters which would give a safety factor of about 1.6. With calculations after mining it was found that the safety factor equates to 1,4.

7.2 SECONDARY MINING

Two attempts were made to commence pillar extraction with a Voëst type continuous miner in this panel but premature goafing necessitated withdrawal.

With the second attempt a fall to a height of about 15 metres buried the machine and it had to be dug out.

7.3 SUPPORT

The support for development consisted of rows of 4 x 1,8 meter mechanical anchored roofbolts with the rows spaced 1,2 meters apart.

In preparation for pillar extraction W-straps were installed with 4 x 2,4 resin bolts at 1,4 meter spacing. At the intersections 5 x 5 meter at 400 kN cable anchors were installed. To protect workers against sidewall scaling wooden dowels and nylon lacing were installed along the sidewalls.

7.4 CONDITION OF THE PILLARS

Due to scaling the roadways widened to the extend that at places they were in excess of 10 meters and the safety factor reduced to about 1,1 (Mine figure).

The condition of the pillars in the panel cannot be attributed to in-panel pillar extraction but due to other factors.

These external factors caused very severe scaling of the pillars and a number of collapses of roof in the panel it selves. The possible factors could be:

1)   The safety factor although adequate appear to be marginal. Conditions further back in the panel (± 200 meter) appeared to be normal.

2)   A geological disturbance ahead of the collapsed area could have caused some
        deteriorating influence of the coal and the roof strata.

3)   Abutment stresses due to a stooped out area on the one side, a mined longwall
        panel on the other side (refer to panel plan 7) and the dolerite which might
        not have broken.

Beyond the possible influence of these stresses ($\pm$ 200 meter back) the condition of
the pillar sidewalls were almost normal for the specific mine.

The condition of the pillars in this panel illustrated the possible consequences of
marginal safety factors and not allowing for possible additional abutment stresses.

PANEL 7
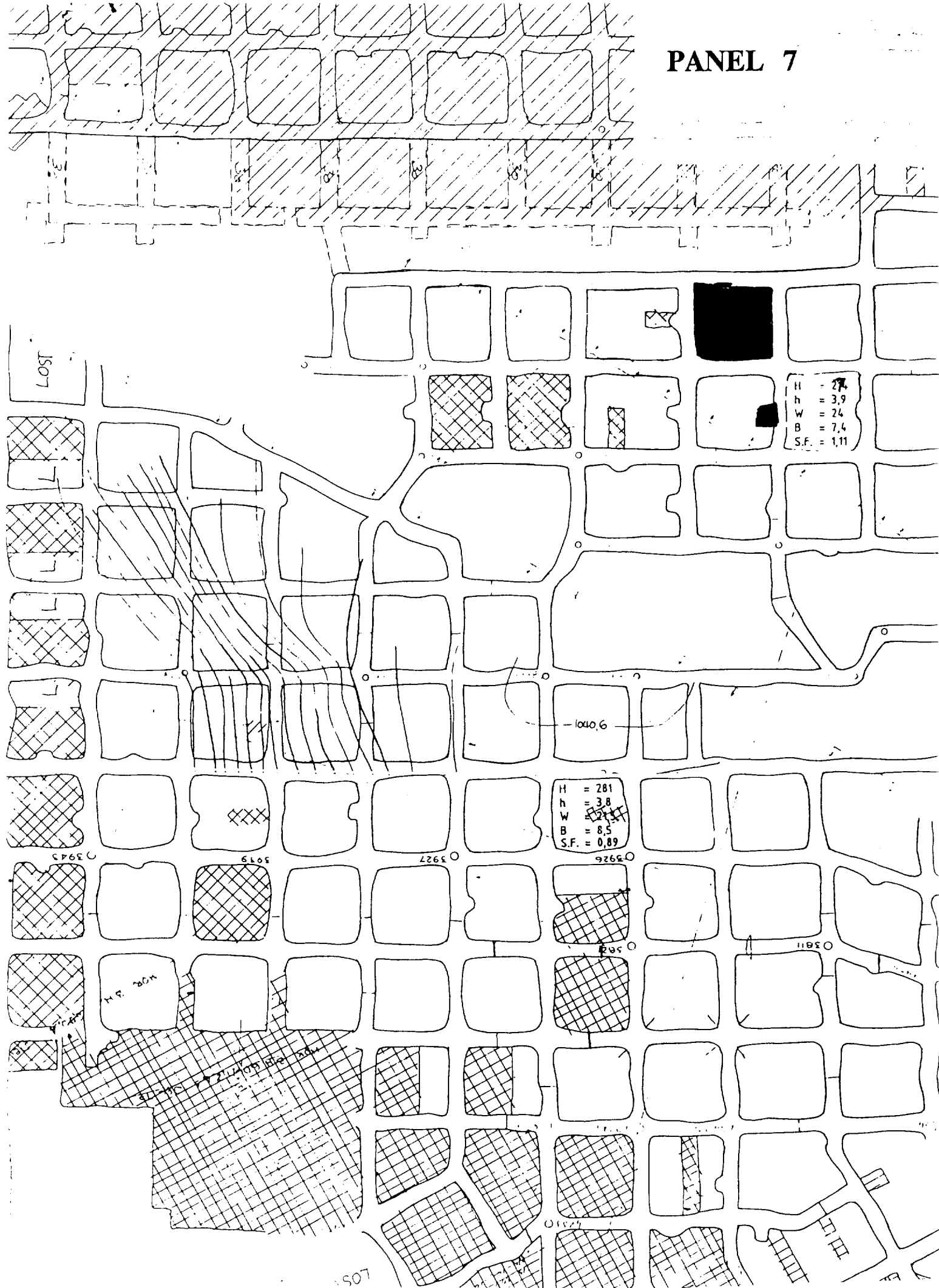
H = 27
h = 3,9
W = 24
B = 7,4
S.F. = 1,11

H = 281
h = 3,8
W = 2?,??
B = 8,5
S.F. = 0,89

1040,6

8.1 DEVELOPMENT

The development of this secondary development panel was done some 26 years ago with conventional drilling, blasting and mechanical cleaning. The panel layout was four roads at 30m x30m centres. Subsequently a small triangular block of coal was also developed on the same pillar centre layout. The depth was 216 meter and the dolerite sill is located at 72 meters to 120 meters below surface. With a bord width of 5,8 meter and a mining height of 3,2 the safety factor was 1,4

8.2 SECONDARY MINING

Secondary mining done was pillar extraction with a road header type continuous miner. Pillars were split lengthwise to form two smaller pillars of about 8m x 24m. These pillars were then mined out in sequence in the standard way practised on that mine. (See attached drawings to panel 8 plan)

Due to the general ground conditions the maximum advance before support was installed was about 12 meters. When splitting a pillar the spilt was advanced for halve the pillar distance when the machine was withdrawn and support installed before completing the split. Whilst installing the support the machine was moved to an adjacent face where cutting continued. Goafing was very good and tight to the line of pillars. The extend of the goaf was some 150 meters far and production was ± 46 400 tons per month on a three shift basis.

NOTE:
None-standard size pillars were mined suitably and safely by a modified method.

8.3 SUPPORT

The support during development consisted of rows of 4 x 1,8 meter roofbolts installed at 1,2 meter apart.

For pillar extraction the section was re-bolted with W-straps installed with 4 x 2,3 meter resin bolts at 1,2 meter apart and 5 x 5 m x 400 kN cable anchors installed at intersections. To protect the workers against sidewall scaling wooden dowels and nylon lacing were installed along the pillar sidewalls.

8.4 CONDITION OF THE PILLARS

Moderate scaling of the pillar sidewalls and corners occurred on the row of pillars adjacent to the goaf line. The depth of scaling ranged from 10cm to 30 cm. Scaling

of the roof was very slight but required barring at places and rebolting.

Further back the sidewall scaling was slight and the sidewalls were mainly as mined.

PANEL 8

25X25 1/11.N 3

25×25 M. PILLARS

9065

9065 0

0

35 x 25
PILLARS
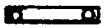
SYSTEMATIC ROOF SUPPORT - ROADHEADER PILLAR EXTRACTION

SISTEMATIESE DAKBESTUTTING - TONNELDELWER PILAARSLOPING

GOAF/DAKPUIN

GOAF/DAKPUIN

1.5m

A

5.0m

1.5m

1.5m
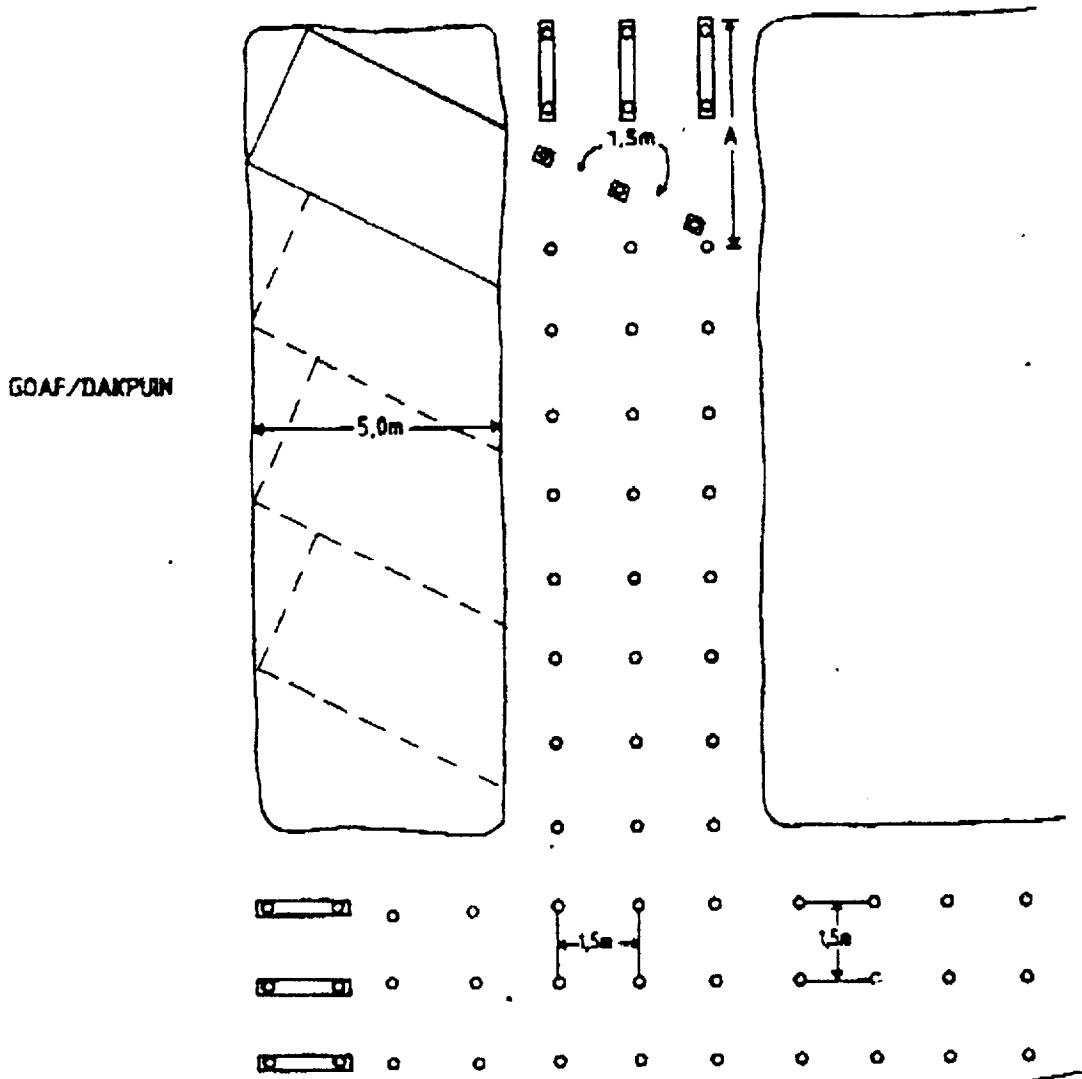
LEGEND/VERKLARING

A = LAST 5,0m - NO ROOFBOLTS/LAASTE 5,0m - GEEN DAKBOUTE

▭ BREAKERLINE/BREEKLYN

o ROOFBOLT/DAKBOUT

▣ FINGER LINE SUPPORT WOODEN PROP WITH HEADBOARD

9.1 DEVELOPMENT

Development of this six road panel was done less than a month prior to the date of visit and once the limit of the block of ground was reached pillar extraction started immediately.

Development was done with a Voëst type road-header at a depth of 199 meters and the dolerite sill located at 72 to 123 meters from surface. With pillars at about 30 meter centres, a road width of 5,3 meters and a mining height of 3,2 meters the safety factor was about 2,0.

9.2 SECONDARY MINING

Pillar extraction has just started and would be carried out on the standard way for that mine and pillar centres. Production was ± 40 000 ton per month on a three shift basis. Goafing was well even with only one line of pillars removed.

9.3 SUPPORT

Support during development consisted of rows of 4 x 1,9m resin bolts with the rows 1,2 meter apart.

For pillar extraction the section was re-bolted with W-straps installed with 4 x 2,3 meter resin bolts at 1.2 meters apart and 5 x 5m at 400 kN cable anchors at the intersections. To protect workers against sidewall scaling wooden dowels and nylon lacing were installed along the sidewalls of the pillars.

9.4 CONDITION OF THE PILLARS

Even with the limited span due to only one line of pillars removed the deterioration of the last row of pillars to the stooping line was already apparent. Scaling of the sidewalls of the pillars and corners was moderate (100mm to 300 mm). No deterioration of the roof was observed.

Further back no signs of scaling or fracturing of the pillars were observed.

PANEL 9

10.1 DEVELOPMENT

The panel was developed 2,3 years back with a Voëst type road-header on 30m x 40m centres. The panel consisted of four roads.The depth was 197 meters, with a road width of 6,1 meters and mining height of 4,0 meters the safety factor was 2,1

10.2 SECONDARY MINING

Secondary mining consisted of pillar extraction with a Voëst type road-header. The pillars were split twice leaving three 8m x 24m pillars. The lift was advanced for ± 12 meters when the machine was with-drawn for roofbolting. After holing the narrow pillars formed were mined out one after the other in the standard way of lifting.

Production was ± 41 000 tons per month on a three shift basis. The panel was mined to a distance of 300 meters back and goafing of the roof good. The panel sloped towards the goaf and no water was encountered.

10.3 SUPPORT

Support during development was with rows of 4 x 1,9 meter bolts with 60 cm wooden blocks because of the friable roof. The rows were spaced 1,3 meters apart.

In preparation for pillar extraction W - straps were installed at 4 x 2,3 resin bolts at 1,4 meters apart and 5 x 5m at 400 kN cable anchors were installed at intersections. Wooden dowels and nylon lacing was installed along the pillar sidewalls to protect workers against slabbing.

10.4 CONDITION OF THE PILLARS

The condition of the pillars nearest to the goaf line was moderate to severe. Pillar sidewall scaling was up to 70 cm at places. Even the roof was fairly poor and slabbing up to 20cm occurred at places. No major falls was observed.

Further back the conditions were as mined with occasional minor sidewall scaling
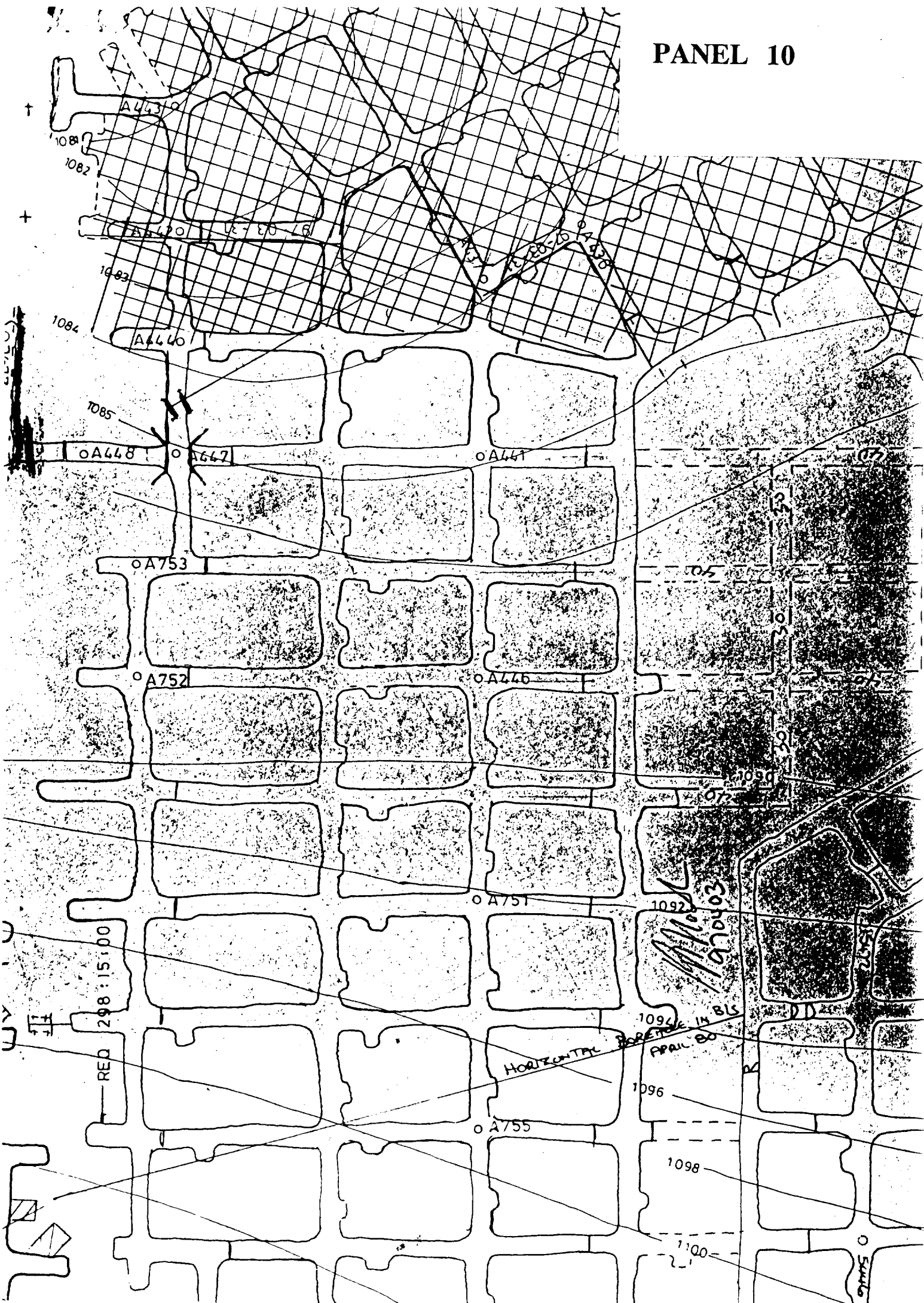
11.1 DEVELOPMENT

The development of the panel was done some 17,0 years ago with conventional drilling, blasting and mechanised coal cleaning. The panel consisted of six roads. The depth was 247 meters with the dolerite sill located at 71 meters to 116 meters from surface. The pillar centres were 30m x 30m, with a road-width of 5,3 meters and a mining height of 3,4 meters the safety factor was about 1,7

11.2 SECONDARY MINING

Pillar extraction was done with a Voëst type road-header by splitting the pillar lengthwise, retreating after ± 12 meters advance for roofbolting and then completing the remainder of the split. The two ± 8m x 24m pillars thus formed was extracted by lifting in the standard manner. Production was 31 000 tons per month on a three shift basis and goafing was very good. The panel retreated for a distance of 150 meters. The footwall in the area at the time of the visit was very uneven causing accumulation of water and footwall crushing which made tramming difficult.

11.3 SUPPORT

Support for development consisted of rows of 4 x 1,9 mechanical anchored roofbolts with 600mm wooden blocks due to the friable roof. The rows of roofbolts were spaced at 1,3 meters apart.

For pillar extraction re-roofbolting was done with W-straps and 5 x 5m at 400 kN cable anchors at intersections. Along the pillar sidewalls wooden dowels and nylon lacing were installed to protect workers against pillar slabbing.

11.4 CONDITION OF THE PILLARS

The condition of the first row of pillars from the goaf was bad with scaling of sidewalls and corners up to 70cm. The roof remained in tact with no scaling.

Further back the pillars were as mined and unaffected by the stooping operations in front.

PANEL 11

Y-8
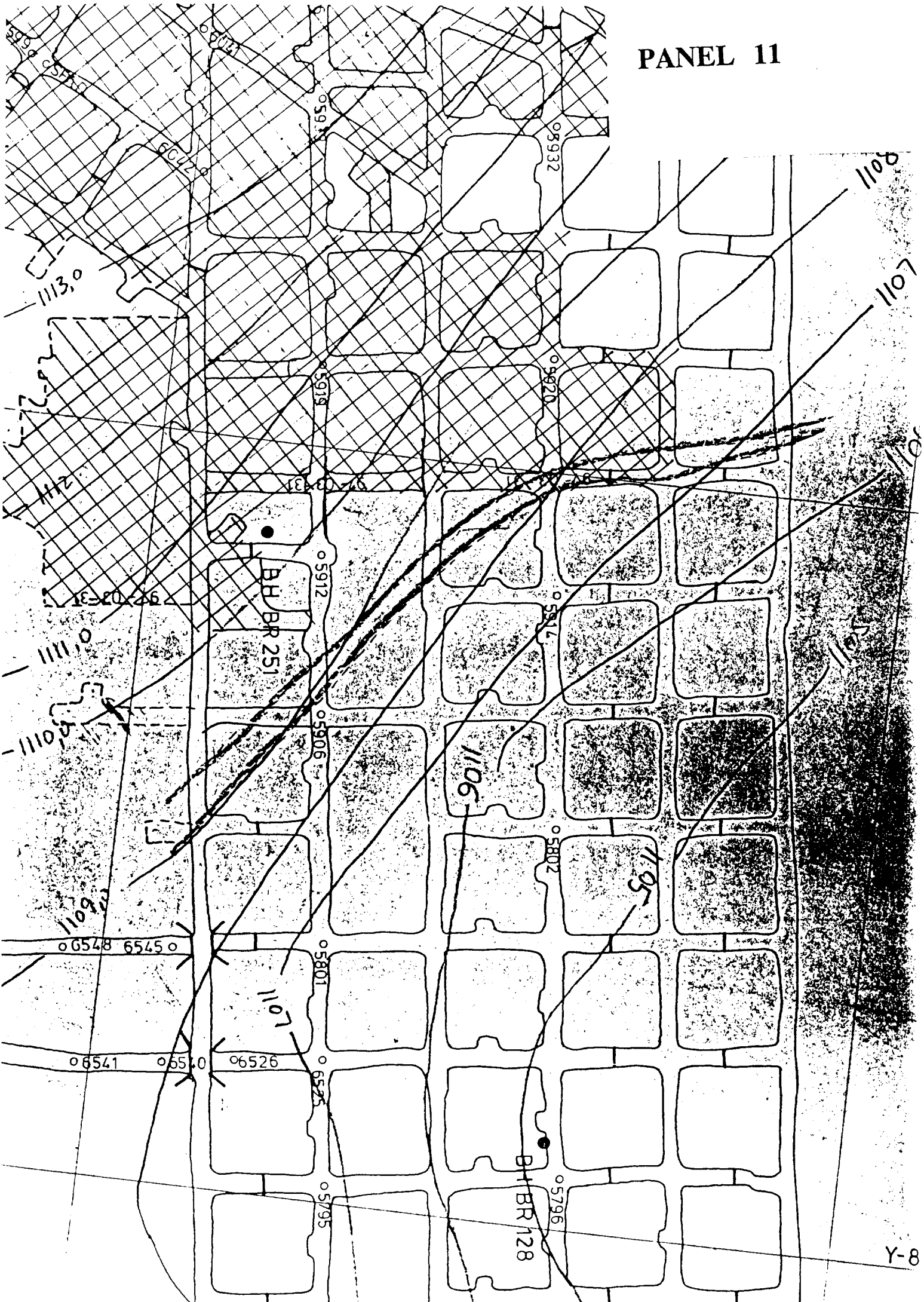
12.1 DEVELOPMENT

This short panel was mined towards the sub-outcrop 1,4 years ago with a continuous miner. The panel consisted of 9 roads with pillar centres of 16m x 16 m, the depth was ± 30 meters and with road widths of 5,5 meters and mining height of 2,4 meters the safety factor when developed was about 5,6.

12.2 SECONDARY MINING

The secondary mining was done by splitting the pillar with two adjacent lifts of 3,0 meters wide each with a continuous miner and leaving two triangular pillars with an apex thickness of about 3 meters. The "safety factor" with this configuration was calculated to be 2,5 (By the mine). The production was 35 000 tons per month on a double shift basis. The advance on the retread was 100 meters.

12.3 SUPPORT

Support on development consisted of occasional roofbolts at the intersections.

Prior   to splitting 9 x 1,2 meter resin bolts were installed on the intersections and elsewhere only where slips occurred.

Finger lines of mine poles were installed where the first lift of the split was mined.

12.4 CONDITION OF THE PILLARS

The condition of the first line of pillars moderate scaling of pillar sidewalls and corners of 100mm to 300mm was observed.

The small pillars left did, as far as could be observed from a distance, not show significant scaling. The roof remained unaffected.

Further back the condition of the pillars were good with no scaling observed.

13.1 DEVELOPMENT

This panel is situated at the slope of a mountain and the depth varied from 68 meter to 125 meter. Original mining was done some three years earlier by conventional drilling, blasting and mechanised cleaning. The pillar sizes of this extensive panel were about 20m x25m centres, the road-widths were 4,9 meters and the mining height of 2,4 meters. The safety factor as developed was around 4,0.

13.2 SECONDARY MINING

Secondary mining consisted of pillar splitting by a continuous miner. The pillars were split roughly diagonally by two or more splits, depending on the actual size of the individual pillar, at 3,0 meters wide. The fenders left were $\pm$ 3,0 meter wide. The safety factor after splitting was calculated to be about 2,0 (By the mine).

Production was 26 000 per month and the completed area retreated were about 150 meters.

13.3 SUPPORT

Support during development consisted of occasional roofbolts at intersections.

Prior to splitting 9 x 1,2m resin bolts were installed at intersections and where slips occurred.

Finger lines of mine poles were installed where splitting was done.

13.4 CONDITION OF THE PILLARS

The pillars adjacent to the secondary mining were visually unaffected by the reduced sizes of pillars. No scaling of pillar sidewalls, corners or roof was observed.
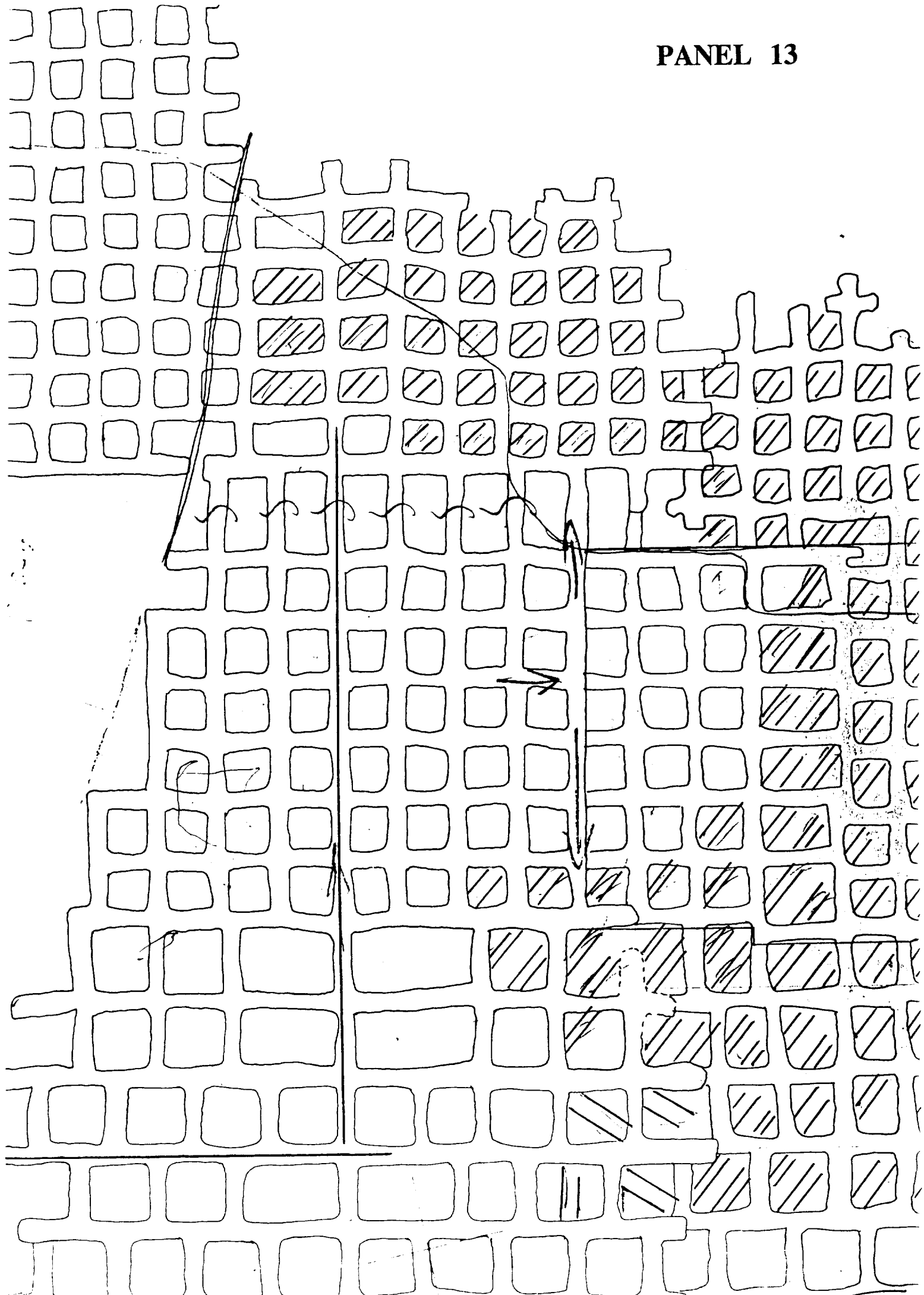
14.1 DEVELOPMENT

The area was developed some 9.0 years ago by conventional drilling, blasting and mechanised cleaning at a depth of 33 meters. The area was extensive with only occasional barrier pillars. The pillar centres were 15m x 15m, the road-widths were 6,1 meter and mining height 1,8 meters which gave a safety factor of about 5,0.

14.2 SECONDARY MINING

The extraction "panel" consisted of 8 roads and straddled a barrier pillar. This barrier pillar was mined to equal sizes pillars and then extracted with the panel pillars. The pillar extraction was done on a 45 degree line extracting the pillars from left to right with a drum type continuous miner.

Being small ($\pm$ 9m x 9m) the pillars were mined by a sequence of lifting at a $\pm$ 60 degree angle and leaving small supporting snooks. (Refer to attached mine standard sequence). The last snook if too large was drilled and blasted out.

A surface pipeline had to be protected and a line of two pillars were left intact to satisfy the d/2,7 requirement.

Production was 24 000 tons per month and the panel retreated for a distance of 200 meters from the panel end. Goafing was to about 20 meters from the face line.

14.3 SUPPORT

During development support consisted of rows of 3 x 1.0 meter roofbolts with the rows 1.8 meters apart. Slight occasional scaling of $\pm$ 100 mm made some of the roofbolts ineffective.

For stooping secondary roofbolting, consisting of 1,0 meter resin bolts, was installed where necessary.

Sets of two rows of 5 timber breaker lines were installed at the pillar being extracted. As soon as the pillar extraction was completed the timber poles were pulled out with the continuous miner

14.4 CONDITION OF THE PILLARS

The condition of the first line of pillars adjacent to the goaf line did not show any degree of scaling of the pillar sidewalls or corners and they were observed to be as

mined. Along the roof occasional scaling of a ± 100 mm false layer was observed.

Further back the conditions were observed to be similar with no scaling of the pillar sidewalls and corners but still some slight scaling of the roof. As far as could be seen with the limited vision no scaling occurred at the pillars left to protect the pipeline.
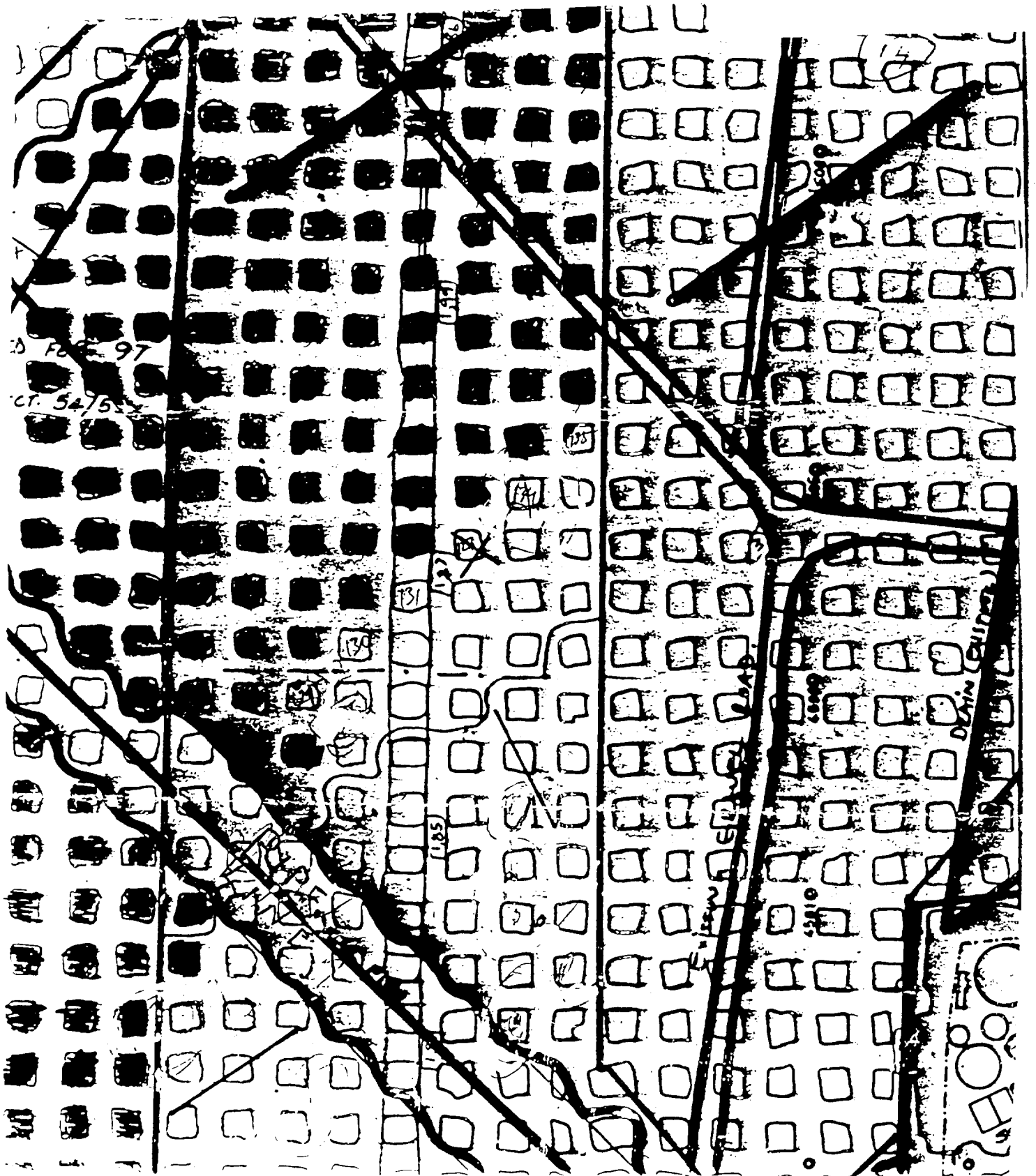
PANEL 15

15.1 DEVELOPMENT

Development of this area was done on a panel configuration of 12 roads some 37 years ago. Mining was done with conventional drilling, blasting with mechanical loading.

The depth was 64 meters and with pillars of 15m x 15m centres, road widths of 6,8 meters and a mining height of 3,5 meters the safety factor was about 1,6

15.2 SECONDARY MINING

The secondary mining consisted of pillar extraction on 3 pillars mining at an angle of 45 degrees from right to left. This means that the goaf line was approximately straight with the 45 degree three pillar face line moving from right to left.

Due to the size of the pillars they were extracted by lifting from the goaf side and leaving two corner snooks and small fringe snooks. If the last corner snook was too large it was drilled and blasted.

Production was 46 000 tons per month and the total production from that shaft came from the single section. The total distance stooped was 200 meters. Goafing was very good.

A system of dumping was adopted to accommodate frequent machine or belt stoppages. Dumping was done when the continuous miner was working and the belt stopped. When the belt was running and the machine stopped, either for maintenance or a breakdown, the dumped coal was loaded with a gathering arm mechanical loader and transported by shuttlecar to the belt. In this way about 2/3 of the production came directly from the face and 1/3 from dumped coal.

15.3 SUPPORT

During development about a meter of coal was left in the roof and almost no roofbolts were installed.

In preparation for stooping the area was roofbolted with 5 x 1,5 meter resin roofbolts per intersection and elsewhere only where considered necessary.

As breakerline consisting of two rows of 5 x 1,5 meter resin bolts were installed. In addition two rows of three each mine poles were also installed at the breaker line position. These mine poles were pulled out when the pillar had been extracted.

15.4 CONDITION OF THE PILLARS

The pillars adjacent to the goaf line showed slight to moderate scaling of the sidewalls and corners of up to 300 mm. Along the roof slight scaling of coal was observed. Barring needed to be done in preparing for the next stooping line. At the second row of pillars and further back almost no scaling was observed.

STOPPED

FREQUENCY

0 1 2 3 4 5 6 7 8 9 10

SAFETY FACTOR

0.5-0.6
0.7-0.8
0.9-1.0
1.1-1.2
1.3-1.4
1.5-1.6
1.7-1.8
1.9-2.0
2.1-2.2
2.3-2.4
2.5-2.6
2.7-2.8
2.9-3.0
3.1-3.2
3.3-3.4
3.5-3.6
3.7-3.8
3.9-4.0
4.1-4.2
4.3-4.4
4.5-4.6
4.7-4.8
4.9-5.0
5.1-5.2
5.3-5.4
5.5-5.6

Shallow depth

Vaal Basin

Soft floor

Klip River
Slips and joints

Very shallow depth
and weak roof

Legend:
- Salamon Data 1904-1967
- Madden Data 1967-1988
- New Data Post 1988
- Data not used by Madden 1967-1988
- Data not used by Salamon 1904-1967
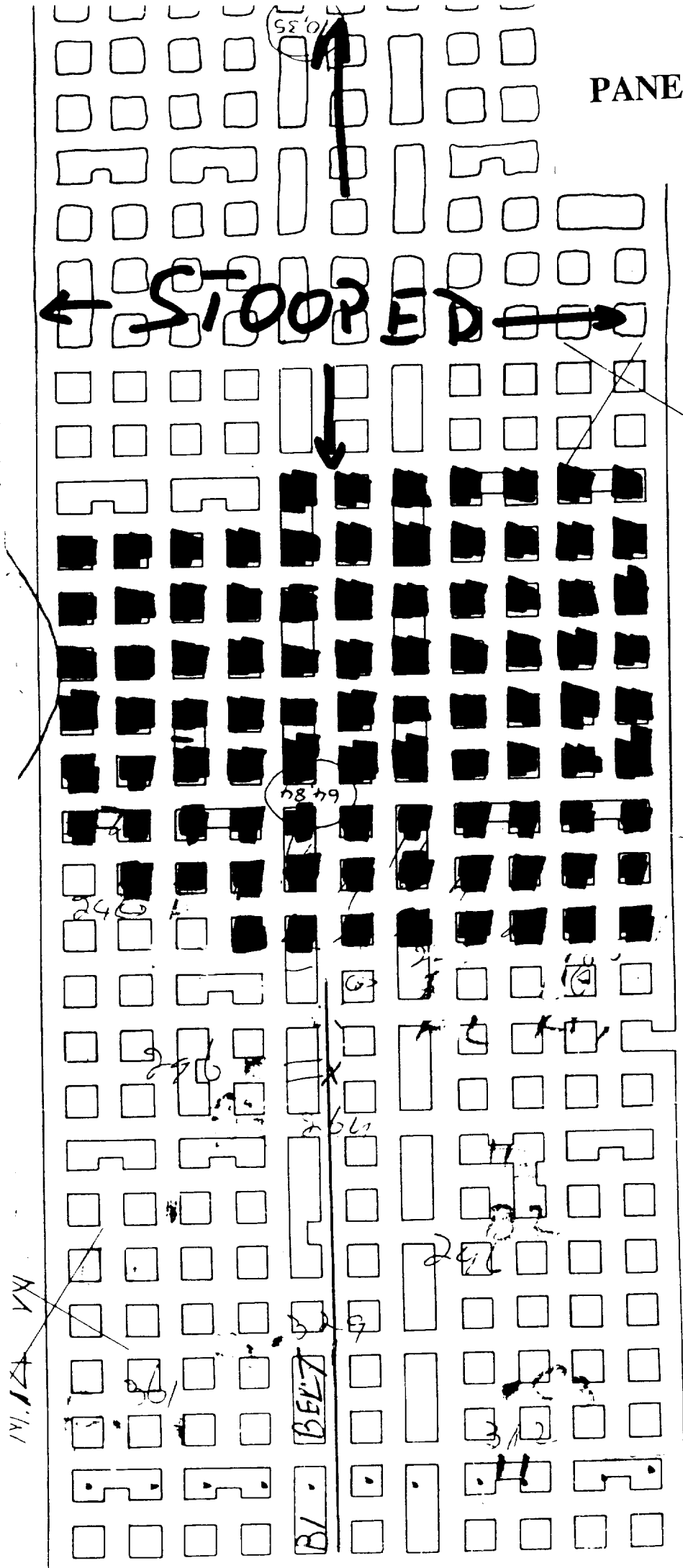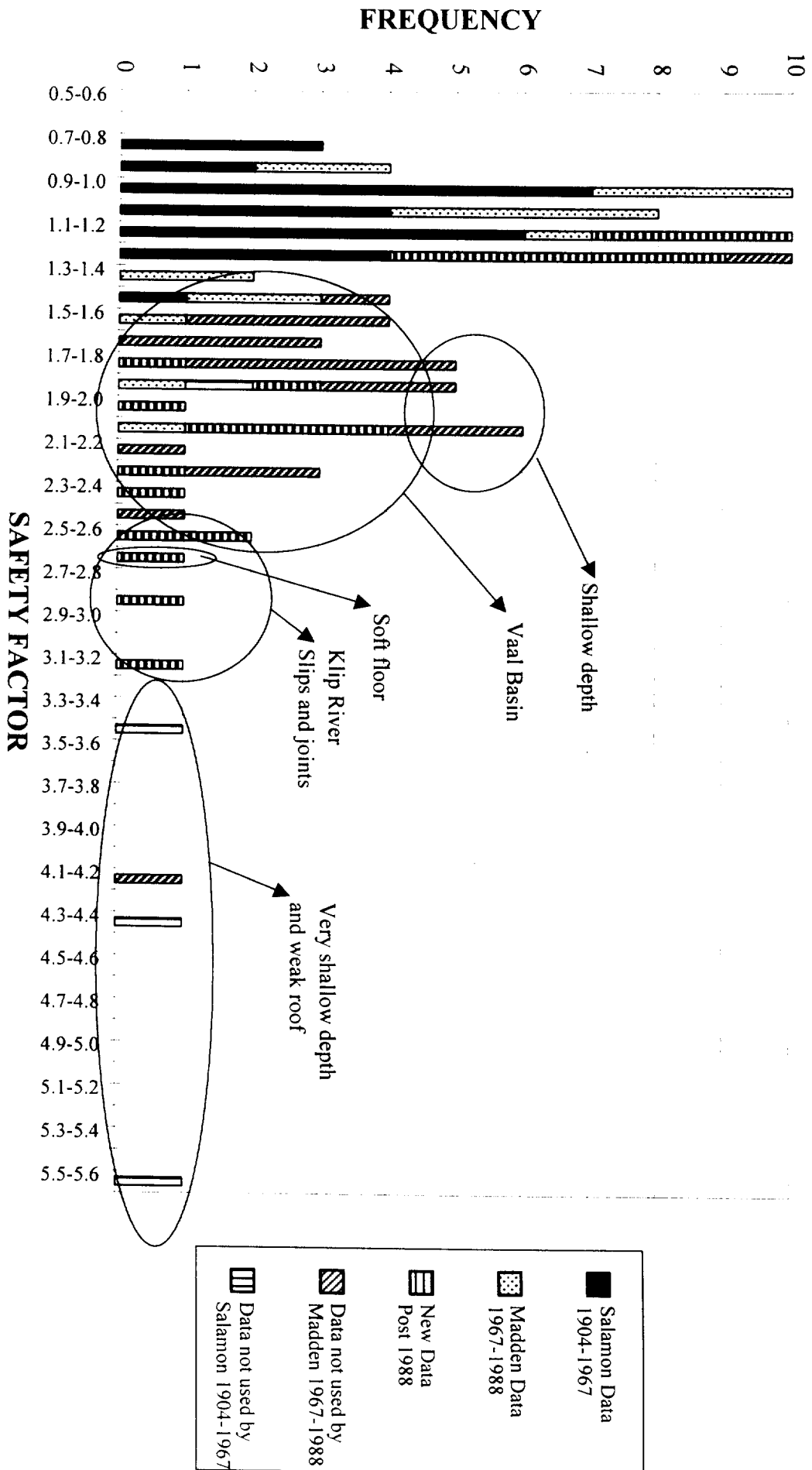
Figure 1. Frequency of Pillar Collapses versus the Design Safety Factor

Note: Broad Categories of Possible Reasons for Collapse

COMPARISON BETWEEN THE OLD AND NEW MEASURED DATA
(A1 SECTION) (D & B OLD)

MEAN (old) = 6,72 m

MEAN (new) = 7,69 m

FREQUENCY

BORD WIDTH (m)

new data
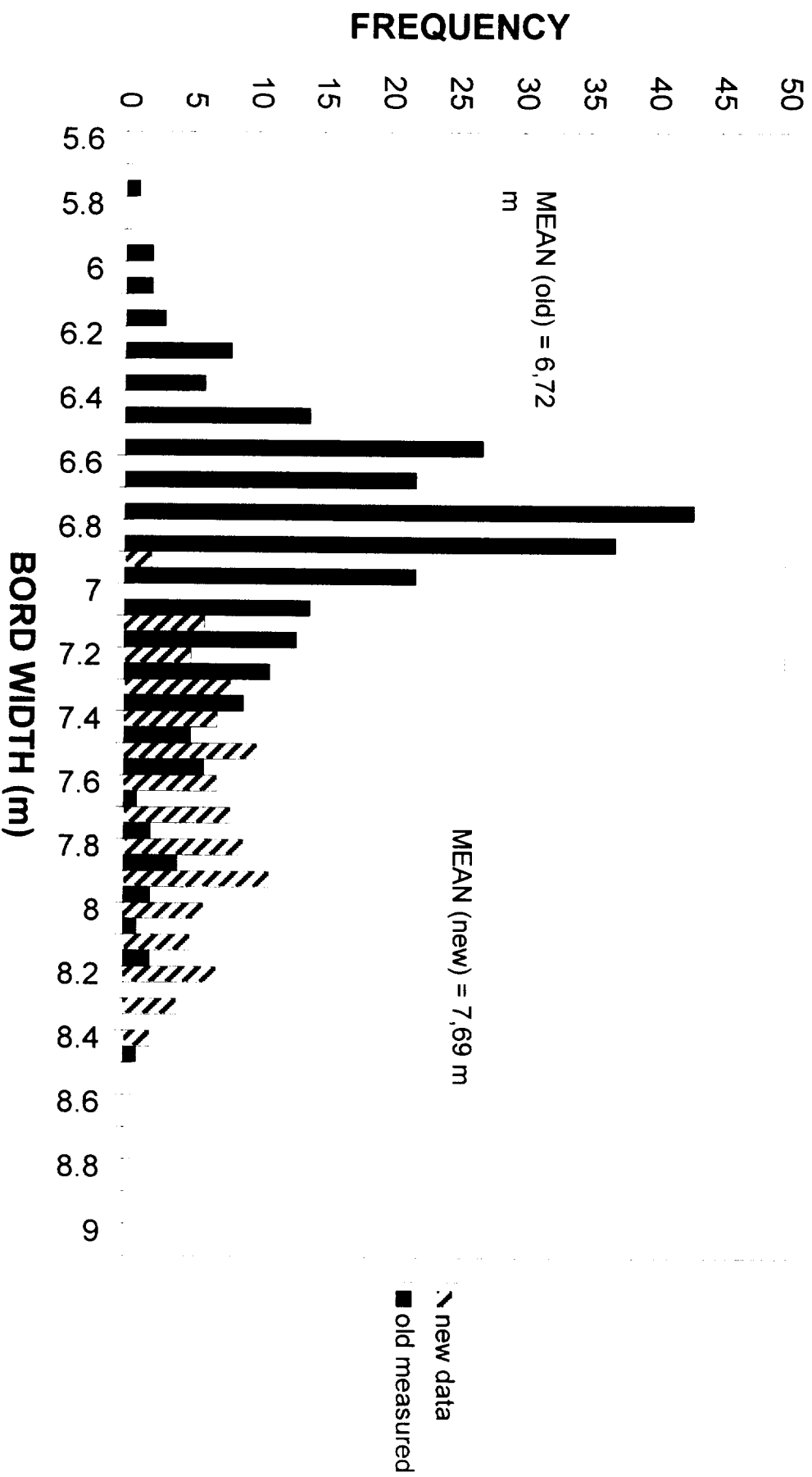
old measured

Figure 2. Frequency of Bord Width Measured in Section A1 (Drill and Blast old) 1987 and 1996

COMPARISON BETWEEN THE OLD AND NEW MEASURED DATA
(A12 SECTION) (CM OLD)

FREQUENCY

MEAN (old)= 6,65 m

MEAN (new) = 7,11 m

new data
old measured
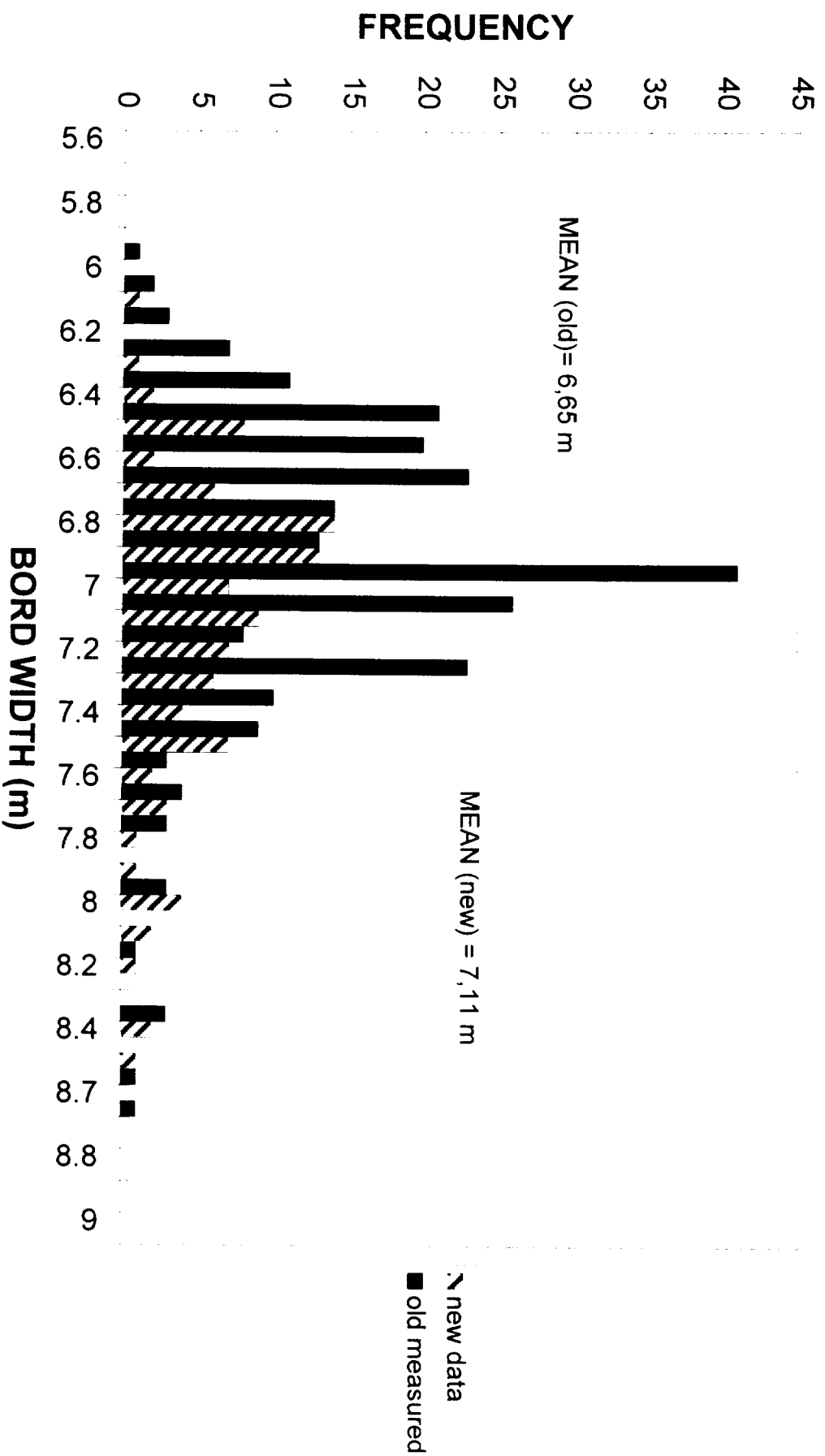
BORD WIDTH (m)

Figure 3. Frequency of Bord Width Measured in Section A12 (CM old) 1987 and 1996

COMPARISON BETWEEN THE OLD AND NEW MEASURED DATA
(F17 SECTION) (D & B RECENT)
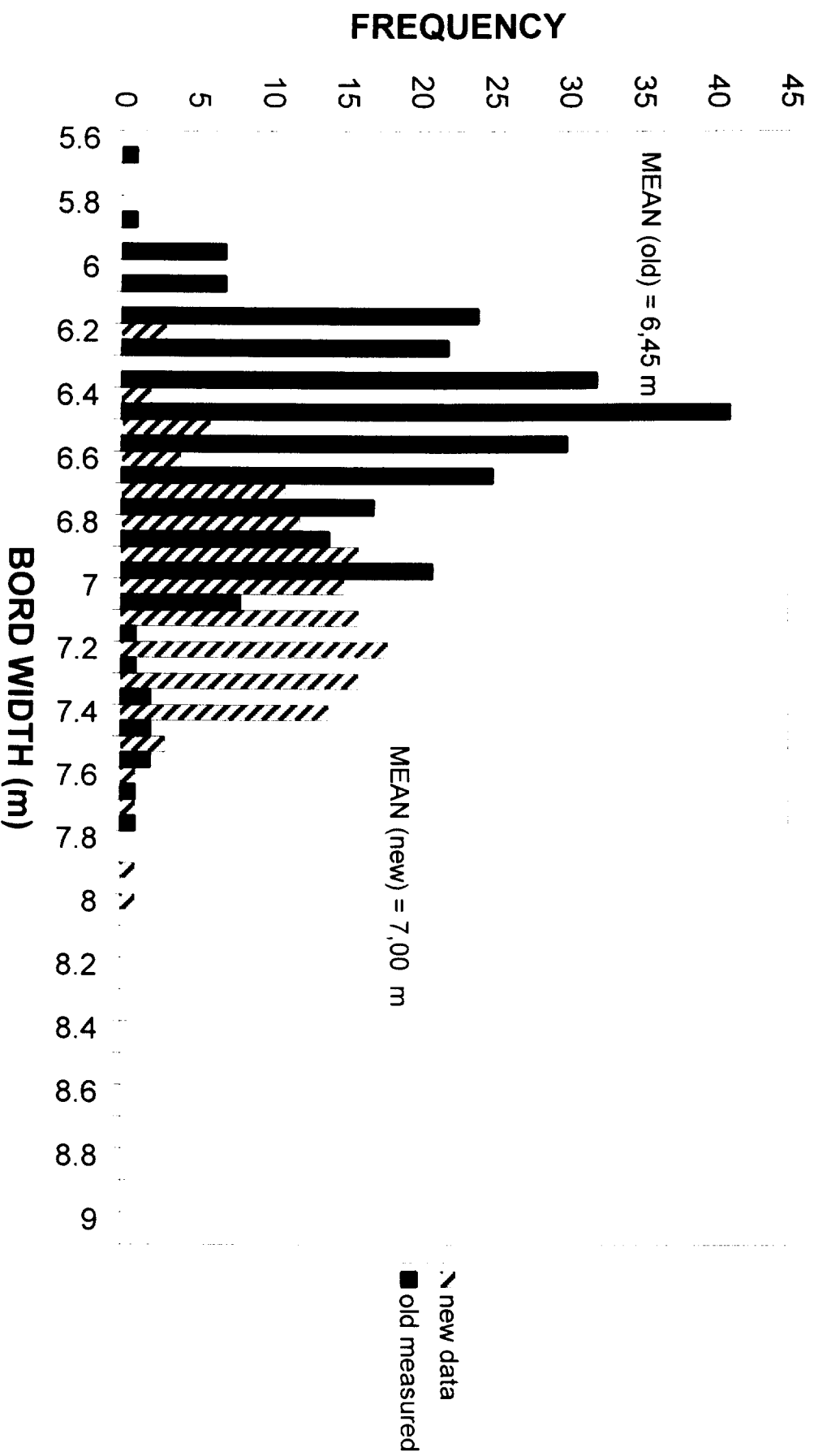
Figure 4. Frequency of Bord Width Measured in Section F17 (Drill and Blast old) 1987 and 1996

BORD WIDTH INCREASE (m)

TIME (years)

— ■ — A1 SECTION (1977)
— ● — A12 SECTION (1977)
- ▲ - F17 SECTION (1982)
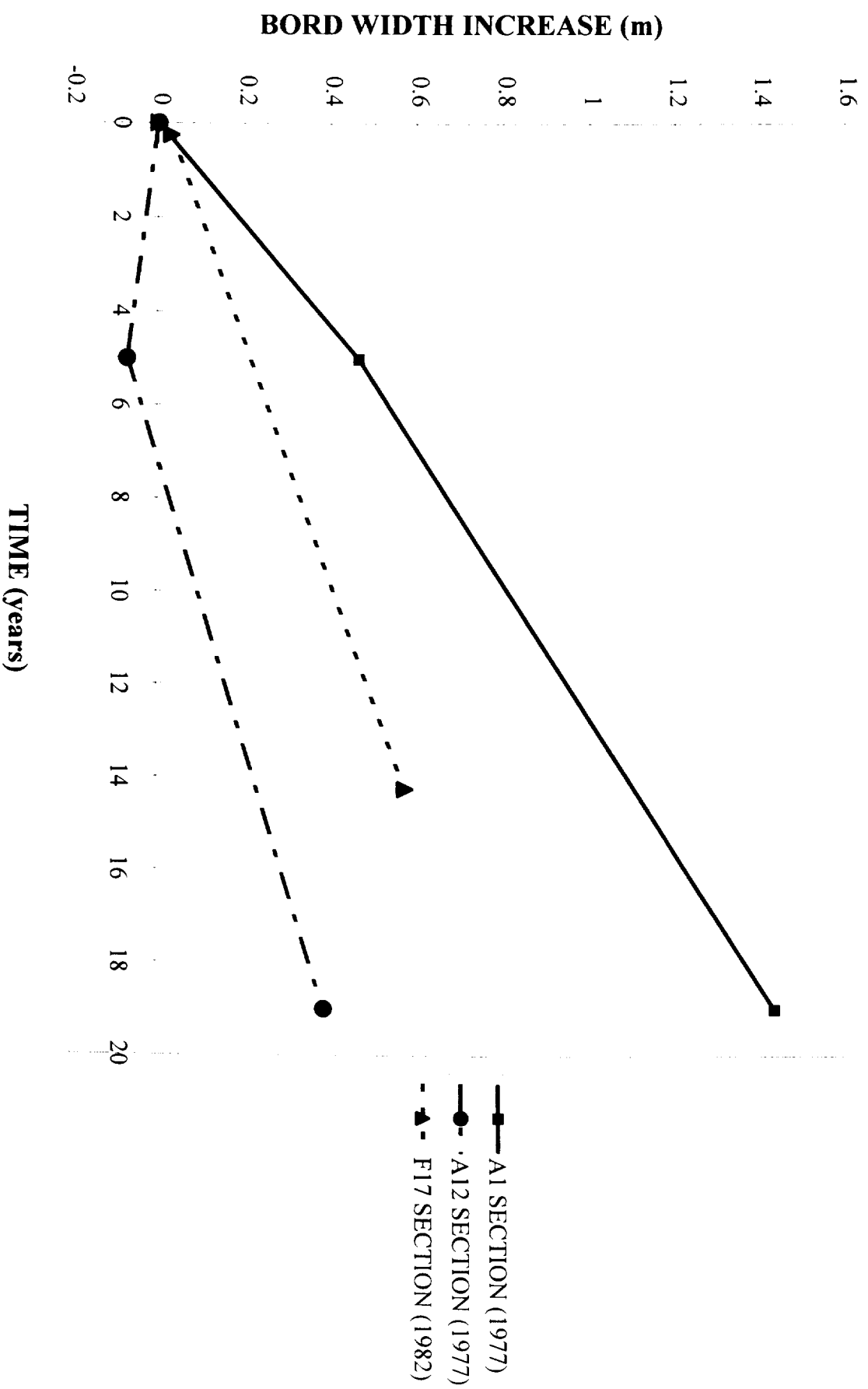
Figure 5. Bord Width Measurements of 1996, 1987 and at the time of Mining Normalized to the same time Since Mining
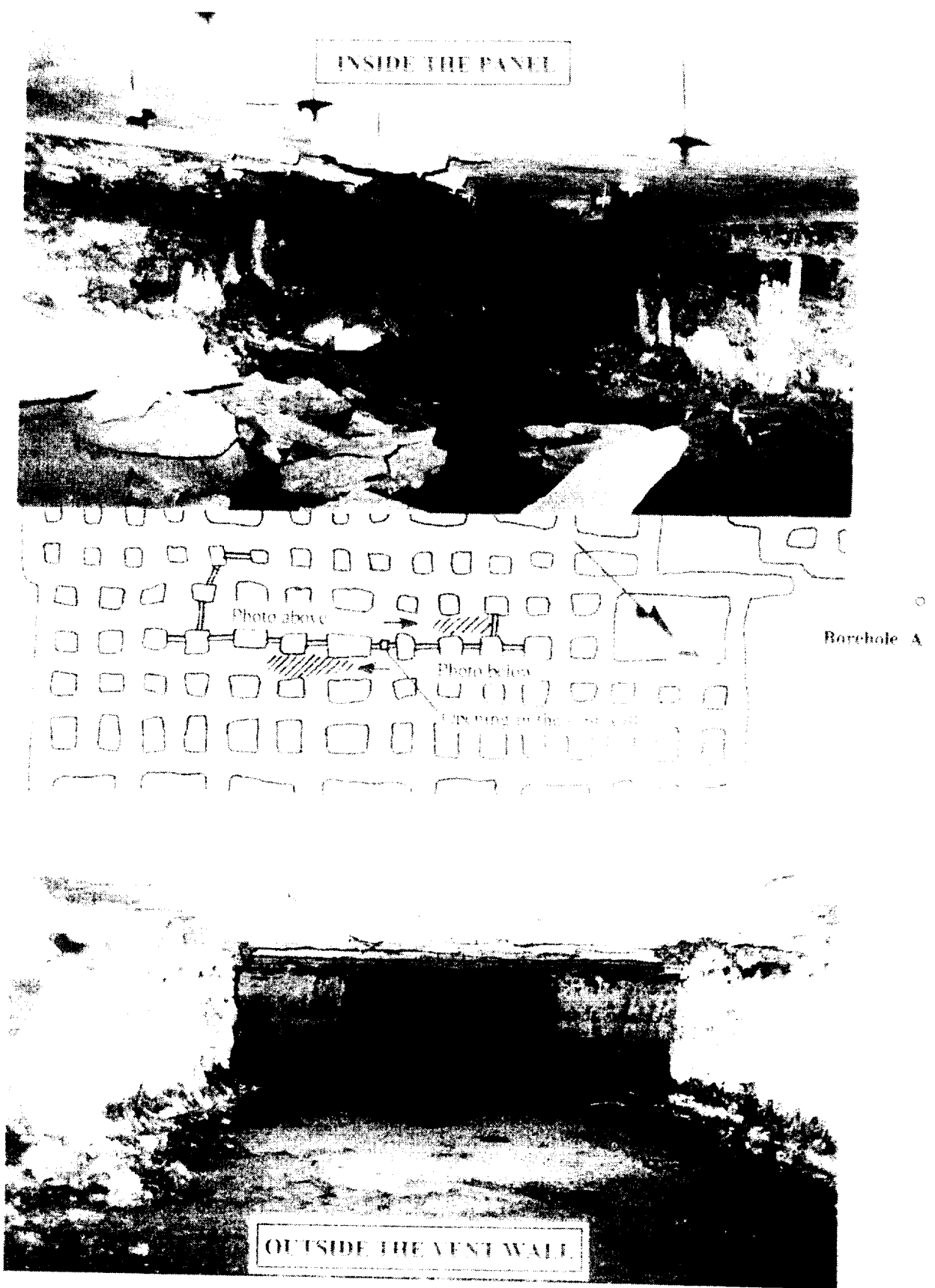
Figure 7. Comparison of Conditions Either Side of the Vent Wall

APPENDIX 3

ITASCA AFRICA (PTY) LTD

THE NEED TO RESEARCH TIME RELATED STRENGTH CORROSION OF COAL PILLARS IN SOUTH AFRICA

(Sub Contracted Contribution to Research Project COL 439 awarded to CSIR: Division of Mining Technology)

Report prepared by: Dr J N van der Merwe

June 1997

1 Introduction

This report is in the form of a sub contracted contribution to SIMRAC Research Project COL439, awarded to Miningtek. It covers two aspects of the overall investigation, namely a review of published material and an experience based description of the risks inherent to mining old pillars, or even to mine new areas while being exposed to the risks caused by much older pillars in the infrastructure of an old mine.

To an experienced rock mechanics engineer, the aspect of time related strength corrosion poses a very old problem, one which has been believed to be too complex to attend to in the past. That a potential problem exists has been taken for granted for a very long time. There are two potential pitfalls in reporting on this aspect to the less initiated decision makers :

- the first is to leave out detail which is believed to be "obvious", forgetting that the audience has not been exposed to the intricate details of the rock engineering science, especially on a subject like this which has not received public exposure ;

- the second is to go beyond the point of saturation by providing too much detail which is really obvious.

An attempt will thus be made to balance these two aspects in order to provide the SIMRAC decision makers with the information which is necessary to decide whether or not this aspect requires attention.

2 Quotes on pillar failure from literature

For several years the problem of time related effects on geological materials has been recognised in the inner circles of science. Professor Syd S Peng, head of the Mining Engineering department of the University of West Virginia in Morgantown, USA, a noted expert internationally in coal mining rock engineering, states in his most recent book on coal mining induced subsidence[1] the following in the introduction:

> "There have been many surface subsidence cases that occurred long after mining. Some do and others do not relate to the abandoned coal mines."

Then, on page 127 of the same book, he states the following:

"The US Bureau of Mines estimates that there are over 8 million acres of undermined land due to the extraction of coal, metals and non metals. Subsidence has affected more than 2 million acres, and more than 99% of the subsidence is related to underground coal mining. There is reason to believe that some of the remaining 6 million acres of the undermined land have a high potential to subside."

Further on the same page, the following description is given:

"The progressive deterioration of pillars, mine floors and mine roofs after long exposure to air and water may later result in the collapse of strata over the mine entries, the crushing of the remaining coal pillars or the bearing failure of the mine floor beneath the coal pillars."

This is followed by the comment :

".................subsidence over abandoned coal mines receives little attention by the researchers, mainly because it is difficult to predict and takes place decades after mining has ceased."

This statement is found on page 128, again from the same book :

"The basic mechanism is the gradual deterioration and final failure of the roof, floor and coal pillars. The time for the occurrence of subsidence above abandoned coal mines depends on the rate of deterioration. Generally speaking, time dependant or delayed subsidence is difficult to predict and, in a sense, difficult to control."

The following was stated by JN van der Merwe[2] in a keynote address about a critical review of the rock engineering science at the First North American Rock Mechanics Symposium in 1994 :

"It is known that over time, due to several reasons, pillar strength will deteriorate. The inclination of nature is to create a situation of stability, and true stability in mining is only reached once the cavities are no longer there. Whether nature will repair man's damage by failing the pillars, collapsing the roof or causing the pillars to punch into the floor is a matter of circumstances.

The question is not whether a cavity will fail, but when. Is it not time to express stability in terms of the passage of time rather than a ratio of strength to load, both of which are time dependant anyway ?"

The phenomonen of "creep" in rocks has been well described in principle. This is one possible mechanism for time related failure. Creep merely means that under the influence of a constant load, rock will continue to deform slowly. Depending on the magnitude of the load, this may or may not result in failure after a long period. The principle is well documented in a number of highly regarded publications, like Jaeger and Cook[3] or Obert and Duvall[4]. In a 1969 Research Report Prof M.D.G. Salamon[5] refers to creep when he states that :

> *"Sometimes the failure of rock will not take place immediately, but after the lapse of some, often quite considerable, time from the start of loading."*

There does not appear to be any immediately accessible data on the specifics of coal material creep characteristcs. Other materials like rock salt, marble, slate, etc appear to be better covered.

Pillar failure is but one possible mechanism of the failure of a bord and pillar mining system, and for pillar failure creep is but one mechanism. Another possibility is weathering, the effects of which have often been described but almost never quantified. A report by the CSIR in 1960[6] on compression tests on coal contains the following observation on p6 :

> *"(2) The strength of <u>fresh coal</u> from the various collieries does not vary appreciably.*
>
> *(3) The weathered coal samples from Coalbrook North (Samples 414 and 434) disintegrated during the sawing process. No specimens could be prepared from these samples."*

(Author's Note : I assume that Dr Madden will expand on this by including the Matla 5 Seam case.)

In their classical 1967 paper on pillar strength Salamon and Munro[7] have the following to say about their data base :

> "The data are divided into two groups, that is current and collapsed workings. In the remainder of the paper, the current mining geometries are treated as stable workings. This is a somewhat arbitrary assumption. It must be remembered, however, that the so-called 'current' workings were worked at least 18 months prior to the analysis and that none of them has collapsed in the intervening period. Admittedly, a few of these areas may collapse in the future, but these changes are not likely to affect the outcome of this analysis materially. The period which elapsed between the dates of mining and collapse, in the other group of data, varies from a few weeks to 32 years. While, undoubtedly, this variation is of great practical significance, the number of cases in this group is not sufficient to allow consideration of the time effect."

If the subsequent collapse of cases which were treated as stable in this analysis does not affect the outcome materially, it is saliently implied that the new collapses will be compensated for by a new batch of younger stable cases. Consequently, there will be this passage through time of the distinction between older collapsed cases and younger stable ones, which in turn implies that the strength formula is only valid for a period of time, ie the period between mining and collapse. The implication of this line of argument is that the strength formula is not an indicator of time dependant stability - it is in the purest sense only unconditionally valid for the period of stability that was evident in the data which the authors at the time had available to them, ie 18 months plus the three intervening years between 1967 and 1964 (when data gathering was assumed to be initiated), or say five years. In the final sentence of the quoted passage the authors state that they could not consider time effects. This argument alone should be sufficient to indicate that, at the very least, the issue of time related pillar stability should be re-investigated in the light of the passage of the thirty years since the publication of the original paper.

Conclusion 1: Pillar systems which are stable initially may fail over time.

3   Attempts to predict the time of failure

There are several safety factor formulae for coal mine pillars the world over. Almost all of the authors of the empirical formulae have at some stage or another claimed that their particular formula was based on cases

which included very old pillars and therefore the time effects are implicitly incorporated. This argument is invalid, as inclusion of the time effect should either guarantee stability forever or it should have a method by which the time of failure can be predicted. It is not sufficient to point to a set of pillars which are more than say fifty years old and therefore assume that the pillars must live to five hundred years. The very essence of nature is change, and the only correct statement to make regarding the stability of fifty year old pillars is that they are now fifty years closer to failure.

(Author's note : Again I assume that Dr Madden will add that there is no correlation between safety factor and time of failure, based on the well known plot of Safety Factor vs Pillar Age at Failure.)

A literature search yielded three attempts at predicting the time of failure.

3.1 The pillar stress method

In a paper published in 1988, the authors van Besien and Rockaway[8] published the following formula:

$$D_{sag} = 148 - 32.5S_p + 2.1S_p^2,$$ [1]

where S_p is the pillar stress in Mpa and D_{sag} is the time delay in years between mining and the onset of subsidence, implying pillar system failure. The formula was based on the observation of 42 subsidence cases over old bord and pillar workings in the eastern states of the USA. The time delay is the maximum time delay, in other words subsidence could occur from time zero to the time predicted with the formula. This formula is purely empirical, there is no reference to the failure mode.

3.2 The floor safety factor method

In 1992 the authors Hao and Chug[9] published the results of an analysis of 24 bord and pillar subsidences in Ilinois. They concluded that failure of the floor was the most likely subsidence mechanism and then came up with the following formula to predict the pillar life (or "incubation period") at failure :

$$IP = -174\ln(1 - \frac{FSF}{3}) - 15,$$ [2]

where *FSF* is the floor safety factor (not given in the paper) and *IP* is the incubation period between mining and failure in years.

3.3   The mining height method

Van der Merwe[10] observed and analysed pillar failures in the Vaal basin and concluded that progressive pillar scaling was the mode of pillar failure. He found a correlation between mining height and the rate of scaling. Combined with the scaling distance required to reduce the safety factor to a value of 0,3 (the minimum value at which all the failed pillars in the data base had failed), this yielded a method to predict the Pillar Life *Index*, specifically not called a pillar *life* because of the restrictions of the method. He used the following equations :

$$d = w - [0,0742h^{0,268} H^{0,407} (w + B)^{0,813}] ,$$ [3]

$$R = 0,015h^{3,7}$$ [4]

and

$$PLI = \frac{d}{R}$$ [5]

where *d* is the required scaling distance, *h* the mining height, *H* the mining depth, *w* the original pillar width and *B* the bord width. The scaling rate is denoted by *R* and *PLI* is the Pillar Life Index.

The PLI yields the *minimum* pillar life, ie it may be said that a pillar will not fail before PLI years have elapsed. This has to be so because on the same mine at the time of analysis there were hundreds of pillars of similar dimensions and under similar conditions which had not failed.

As with the other two methods, this is empirical and has all the shortcomings of an empirical method. As more data becomes available over time, the results of the analysis may change. Factors like atmospheric conditions were not taken into account. There was no attempt to explain why only certain pillars failed and why others under the same conditions remained more or less stable. The method is only valid for the Vaal Basin. At the time of analysis there were exploratory attempts to derive similar formulae for other mining districts which indicated significantly lower rates of

scaling, but due to a lack of data it was not pursued to the same extent as the Vaal Basin cases.

3.4   Comparison of the methods

The Floor Safety Factor Method (FSF) is excluded from this comparison because there is insufficient information on the calculation of the FSF in the quoted reference to allow examples to be calculated.

Figure 1 shows the results of the remaining two methods, the Stress and Mining Height methods, applied to pillars at increasing depth. For the example, a pillar size of 18 m, bord width of 6,6 m and mining height of 2,5 m were chosen. Both methods display a shorter predicted life as the depth increases, but the magnitudes differ significantly. There are several potential explanations for the difference, one being that the Mining Height method is restricted to a particular mode of failure while the Stress method isn't. They were derived with different data sets in different countries. The Stress method relies on one variable only, namely the pillar stress, while the mining height method is a function of pillar stress, strength, etc. Equation [3] incorporates the safety factor.

However, one intriguing fact remains : the Stress method claims to provide a **maximum** period before failure (ie if a pillar system hasn't failed before the predicted life has expired, it won't fail), while the Mining Height method claims to provide a **minimum** life (ie a pillar certainly will not fail before the predicted life has expired). The life predicted by the Stress method is always greater than that predicted by the Mining Height method - is it for instance possible that the two curves describe the upper and lower boundaries of a "life envelope" for pillar systems ?

It is granted that the probability of this being true is slim indeed, but the fact remains that research is required into this aspect to at least test the possibility.

Conclusion 2 :   There have been attempts to predict pillar life. The existing methods are both crude and suspect, but it has at least been shown that the possibility to enter this field exists. It is not impossible to do this work.
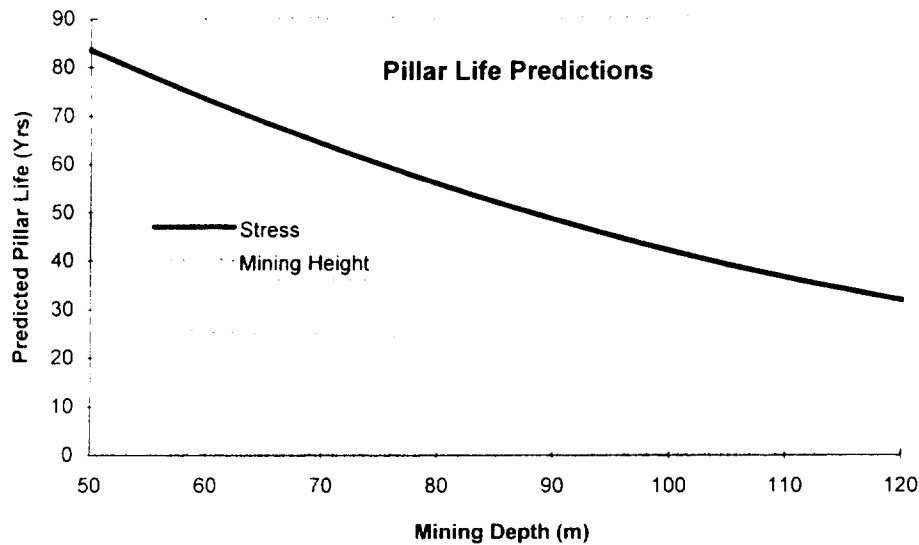
Figure 1. Comparison of two methods to predict the life of pillar
mining systems

4 Consequences of pillar failure

Because SIMRAC has a duty to allocate research funds to areas where
the greatest risk to workers exists, it is necessary to indicate the extent to
which pillar system failure poses a risk to underground workers. This
particular aspect has received attention in another section of the
investigation in the form of the identification of potential risks by engineers
and managers from industry.

To indicate that those risks are real, what will be presented here are the
results of a similar exercise on an existing operating mine where pillars
are in the process of failing. As a result of the exercise, a number of
action plans were implemented, one of them being to close the
underground section of the mine sooner than planned because the high
risk areas were considered unsuitable for further exploitation.

4.1 Brief description of the mine

The mining depth varies from about 40 m below surface to
aproximately 180 m. There are three minable seams and in some
areas multi seam extraction was done. The mining height is
nominally 3 m. Mining methods include bord and pillar (both

conventional and continuous miner), pillar extraction and longwalling. The mine is over 40 years old.

The current operating sections are at the extremities of the shaft system. The access routes for people and the underground coal conveying route to those sections pass through the old areas of the mine. A number of pillar failures have occurred in the past and continue to occur. Areas of active pillar scaling are monitored and where possible, treated by either pillar wrapping or where surface structures are at risk, by back filling.

The major risk to workers arise from the effects of pillar failure in the old areas of the mine. The next section describes the most important specific risks which were identified.

4.2 Brief descriptions of the major identified risks

4.2.1 Gas inflow from upper seam into current workings

Part of the access route to the current workings is on a lower lying seam in an area where the upper seam has also been mined. There is slow combustion on the upper seam in an area further away, but connected to the area overlying the access route via old goafs. Should the parting between the two seams fail, carbon monoxide will have direct entry into the intake airway of the current sections. The parting has failed in the past in other areas.

(Note : This risk has been addressed by continuous monitoring, rerouting the ventilation intake and by supporting the lower seam workings intensively.)

4.2.2 Flooding

Low lying portions of the access routes are flanked by underground dams in certain areas. Should the pillars in the dams fail, the dam walls could be blown out, flooding the access routes and trapping the workers in the sections.

(Note : This risk has been addressed by emptying the dams.)

4.2.3 Trapping workers by old pillars failing

This is an obvious danger, as vast distances of the access routes traverse old areas of the mine. There is the direct danger of people being in an area where pillars fail, like maintenance personnel on roads and conveyors or workers en route to sections. The second danger is that workers in the sections could be trapped by collapses in the old areas. This danger is not restricted to the accessible pillars only, as failure on the upper seam could cause an overload on the bottom pillars and cause secondary failure in the access routes.

(Note : This risk is managed by monitoring pillars in the access routes, stepped up maintenance of the rescue bays, restrictions on the number of people on maintenace in old areas, the provision of a rescue hole close to working sections, etc.)

4.3 Risk to other parties

It is not only underground workers who are at risk when pillar systems fail. Pillar failure will in most cases result in surface subsidence and there will be some effect at the very least to surface users. If all else fails, the risk to underground workers can be avoided simply by closing the mine. This will not only be ineffective as a method to minimize the risk to third parties, it will in fact increase that risk because there will be no pre-warning of impeding failure and access to the underground for the implementation of preventive measures will be lost.

SIMRAC is not concerned with a risk to the safety of the public as a result of mineworkings, but that risk in the case of pillar failure is so great that no evaluation of this nature can be complete without considering the side benefits to public safety of addressing the phenomonen of pillar system failure.

Vast areas of the country have been mined by coal. Mining cannot proceed without continouosly increasing that area. It can only get larger. At the same time, the population grows both in numbers and sophistication and the surface area required for human

habitation and for infrastructure like roads, railway lines, etc inrease all the time. It will not be possible to avoid interaction between the two forever by geographical seperation.

This is already apparent. Consider the example of the town and surrounding areas of Witbank, and the areas to the east of Brakpan and Springs, pock marked by subsidences. Long distances of the N12 freeway connecting Witbank to Gauteng are over old coal workings, as are areas of the main railway line to Mozambique, a gas pipeline, power pylons, etc. When will those pillars fail ? Will they be stable forever ?

Of course, the situation at Witbank is aggravated by several underground fires. But fire is not the only cause of pillar failure. Consider the examples of the well known failures in the Vaal basin and more recently at Matla Colliery which were certainly not caused by fire. They were not merely caused by the pillars being too small, either - those areas were mined after the implementation of the Salmon-Munro safety factor formula.

Conclusion 3   The consequences of pillar failure can be devastating to workers underground and to the general public.

5   Discussion and conclusions

The failure of coal pillar mining systems is a world wide problem. It is not restricted to South Africa. The surface manifestation of such failures have been studied extensively in several countries and entire symposia and conferences have been devoted to it. In the USA the problem is so severe that the Federal Government has set up an agency to handle the problem - the Office of Surface Mining and Reclamation Enforcement (OSM). There are several insurance schemes in place to redress losses suffered by the public - see van der Merwe[11]. Pillar systems do fail over time.

Pillars are designed with the aid of safety factor formulae, not one of them making explicit provision for the time effect, although their creators claim that time is included in the formulae. If that were in fact so, pillars designed with them should either never fail or the time of failure (or at the very least, a type of "guarantee period") should be known. Neither condition is true and one can therefore conclude that the current design methods do not make provision for the time effect.

It is not only the pillars themselves that are suspect, but rather the entire pillar mining system. Failure can occur as a result of failure of the pillar material due to progressive fracturing of the material, degradation of the inherent strength of the material due to weathering, or any number of other hitherto unknown causes. Over time, the floor may fail and pillars may punch into the floor. Or the roof could fail extensively. Either or both of the last two effects can and probably will have an adverse effect on the strength of the pillars themselves. This is a system problem, the components of the system being inter linked and mutually dependant.

While the analytical study of time effects is complex enough to discourage most researchers, some have taken the easier route of empirical study. Not one of the currently available results can be described as satisfactory, but at least it has been shown that there are ways of addressing the problem. It is not an impossible task, even though it cannot be expected to be easy.

The risks posed by pillar system failures are severe. The general perception is that only very old pillars in abandoned mines will fail and that mineworkers will not be exposed to risk, and that consequently the problem should be addressed by an agency other than SIMRAC. This is not true. Older, currently operating mines are also at risk, and by implication, so are the people working in them. As the mines get older, the risk increases. More and more mines will be at greater risk each year. The problem at the moment is that it is impossible to state which mines where will be at the greatest risk, simply because at this stage, the time effects on pillar mining systems cannot be quantified.

There are vast reserves locked up in the pillars of older mines. As current "easy" reserves get depleted, the temptation to re-open those mines and to extract the pillars grows. The only problem is, no-one knows whether it can be done safely. In the end, the choice is a simple one. Either assume that it will be too dangerous and lose those valuable reserves, or assume that it will be safe and perhaps find out too late that the pillars have been weakened too much to allow safe extraction. Or, the third choice, be scientifically responsible and find out whether it can be mined safely. This is the choice before SIMRAC.

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#	Parameter	9	10	11	12	13	14	15
1	PANEL NUMBER	9	10	11	12	13	14	15
2	DEPTH - Meters	199	197	247	30	13	33	64
3	DOLERITE - Thickness (M)	72 to 123	Nil	71 to 116	68 to 125	Nil	Nil	Nil
4	PILLAR SIZE - (Meter)	23,4 x 23,4	24,0 x 34,0	25,4 x 25,4	10,2 x 10,2	14,0 to 19,0	8,8 x 8,8	8,4 x 8,4
5	ROADWIDTH - (Meter)	5,3	6,1	5,3	5,5	4,9	6,1	6,8
6	MINING HEIGHT - (Meter)	3,2	4,0	3,4	2,4	2,4	1,8	3,5
7	SAFETY FACTOR: DESIGN / ACTUAL / FINAL	2,1 / 2,0	2,1 / 2,1	1,7 / 1,6	5,6 / 2,5	4,1 / 2,0	5,1 / 5,4	1,8 / 1,6
8	AGE OF PILLARS - Years	0,1	2,3	17,0	1,4	3,0	9,0	37,0
9	MINING METHOD:	B & P : CM Stooping	B & P : CM Stooping	Drill & Blast Stooping	B & P : CM Splitting	Drill & Blast Splitting	Drill & Blast Stooping @ 45°	Drill & Blast Stooping
10	DISTANCE OF SECONDARY MINING - (Meters)	2nd Line	300	150	100	150	250	200
11	PRODUCTION - Ton/Month	± 40 000	±1 000	31 000	35 000	26 000	24 000	± 46 000
12	ROOF SUPPORT a) Development	4 x 1,9m @ 1,3m	4 x 1,9m @ 1,3m	4 x 1,9m @ 1,3m	Occational	Occational	3 x 1,0m @ 1,3m	All most Nil
	b) Stooping	W-Strap / Cable	W-Strap / Cable	W-Strap / Cable	9 x 1,2m lns	9 x 1,2 lns	Rebolt 1m	5 x 1,5 lns
	c) Breaker Line	Nylon lacing Timber	Nylon lacing Timber	Nylon lacing Timber	Finger Line	Finger Line	Timber	Roofbolts & Timber
13	CONDITIONS AT FACE LINE: a) Pillars	Moderate	Severer	Severe	Moderate	None	None	Moderate
	b) Corners	Moderate	Moderate	Severe	Moderate	None	None	Moderate
	c) Roof	None	Moderate	None	None	None	Slight	Slight
	100m BACK: a) Pillars	Slight	Moderate	None	None	None	None	None
	b) Corners	Slight	As mined	None	None	None	None	None
	c) Roof	None	None	None	None	None	None	None
	200m BACK: a) Pillars	None	Slight	Slight	None	None	None	None
	b) Corners	None	As mined	None	None	None	None	None
	c) Roof	None	None	None	None	None	Slight	None
14	RATING: a) At Face Line	Moderate	Severe	Severe	Moderate	Severe	None	Moderate
	b) 100m Back	Slight	Slight	None	None	None	None	None
	c) 200m Back	None	Slight	None	None	None	None	None

EVALUATION OF CONDITION OF PILLARS WITH RESPECT TO AGE

#		1	2	3	4	5	6	7	8
1	PANEL NUMBER	134	159	114	98	153	185	274	216
2	DEPTH - Meters	0 to 40	18 to 61	13 to 54	13 to 35	70 to 83	51 to 91	65 to 88	72 to 120
3	DOLERITE - Thickness (M)								
4	PILLAR SIZE - (Meter)	42 x 42	30 x 30	15 x 15	16.8 x 16.8	19.0 x 22.0	21.0 x 21.0	21.0 x 21.0	24.0 x 24.0
5	ROADWIDTH - (Meter)	5.7	5.2	4.8	6.9	6.4	6.1	6.0	5.8
6	MINING HEIGHT - (Meter)	2.6 / 4.0	2.9	3.1	3.9	3.8	2.8	3.6	3.2
7	SAFETY FACTOR: DESIGN	1.5	2.5	2.4	2.0	1.8	2.2	1.6	1.6
	ACTUAL / FINAL	1.4	0.7	0.7	2.1	1.6	2.2	1.1	1.4
8	AGE OF PILLARS - Years	0.5	1.5	23.0	0.5	0.8	0.1	22.0	26.0
9	MINING METHOD: a) Primary	B & P : CM	B & P : CM	Drill & Blast	B & P : CM	B & P : CM	B & P : CM	Drill & Blast	Drill & Blast
	b) Secondary	Quarter + Floorlifting	Hering Bone	Herringbone	Stooping	Stooping	Started	Stooping / Stop	Stooping
10	DISTANCE OF SECONDARY MINING - (Meters)	100	200	100	70	150	First line / 0	Nil	150
11	PRODUCTION - Ton/Month	± 40 000	± 40 000	± 40 000	2 x 45 000	50 000	40 000	46 400	46 400
12	ROOF SUPPORT a) Development	4 x 1.8m @ 1.2m	4 x 1.8m @ 1.5m	4 x 1.8m @ 1.5m	3 x 1.2m @ 3m	3 x 1m @ 2.4m	3 x 1.2 @ 2.5m	4 x 1.8m @ 1.2m	4 x 1.8m @ 1.2m
	b) Stooping	W-Straps	W-Straps	Rebolt	Where necessary	Where necessary	Rebolt	W-Strap / Cable	W-Strap / Cable
	c) Breaker Line	None	Timber	Timber	Rootbolts	Rootbolts	Rootbolts	Nylon lacing No Stooping	Nylon lacing Timber
13	CONDITIONS AT FACE LINE: a) Pillars	None	None	None	None	Very Severe	None	Very Severe	Moderate
	b) Corners	None	None	Slight	None	Very Severe	None	Very Severe	Moderate
	c) Roof	None	Slight	Slight	None	Slight	Slight	Slight / Falls	Slight
	100m BACK: a) Pillars	None	None	None	None	None	None	Slight	Slight
	b) Corners	None	None	None/Slight	None	None	None	Slight	As mined
	c) Roof	None	None	Slight	None	None	Slight	Slight	None
	200m BACK: a) Pillars	None	None	None	None	None	None	Slight	As mined
	b) Corners	None	None	None/Slight	None	None	None	Slight	As mined
	c) Roof	None	None	None	None	None	None	Slight	None
14	RATING: a) At Face Line	None	None	None	None	Sides Very Severe	None	Very Severe	Moderate
	b) 100m Back	None	None	None	None	None	None	Slight	Slight
	c) 200m Back	None	None	None	None	None	None	Slight	Slight

APPENDIX 4

Title: RESULTS OF THE WORKSHOP AND QUESTIONNAIRES TO DETERMINE THE CONSEQUENCES OF THE DECAY OF PILLARS

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Research

Agency: CSIR : Division of Mining Technology

Project No.: COL 439 Revised

Date: July 1997

CONTENTS

CONTENTS (continued)

LIST OF TABLES

1   INTRODUCTION

This report presents the findings of the exercise done to determine the hazards that could flow out of the decay of coal mine pillars. In terms of the project definition it was required that a risk assessment type of exercise was carried out to determine the hazard, or consequences, that could flow out of pillars decaying.

This report does not cover the other issues that were identified in the project proposal and should be read with the other reports submitted in fulfilment of the project requirements.

2   PROCESS

The determination of the consequences were done in such a way that the widest input could be obtained in the most cost effective manner. The first step in identifying the consequences was to hold a workshop with invited delegates. These delegates were chosen in terms of both their expertise in the field, as well as their experience with matter pertaining to weakened or weakening pillars.

The main purpose of this workshop was to identify those consequence that were deemed to be important. Although not in the scope of this project, some issues, that did not directly impact on health and safety, were also included to give the whole picture, as well as to indicate the relative importance of health and safety issues in terms of the overall problem. The consequences were identified using a nominal group technique, thereby ensuring that no cross pollination of ideas or influencing of any of the delegates' ideas occurred.

Once the consequences were identified they were listed in the form of an questionnaire and sent out to a larger group of people in the industry, as well as DME and unions members. By using a process where the probability, as well as the severity was evaluated, on an individual basis, a ranking of the issues could be done.

During the workshop the most important issues were also identified but so as not to bias the feedback from the wider group, these values were not presented with the questionnaire.

The results of the first set of returned questionnaires were calculated and sent, together with the second round questionnaires to all the relevant people. In the event of any person wanting to change his results from that of the groups they were requested to re-submit the form. In the

event that they concurred with the group, they were requested not to send a return. Returns not received would, therefore, be deemed to be in agreement with the results.

The averages of the returns were then compiled again, and the consequences then ranked using the product of the severity and the probability as an indicator of the importance of the consequence.

3   DESCRIPTION OF IDENTIFIED CONSEQUENCES

The consequences that were identified during the workshop, as well as a short description of each are presented below. It should be noted that these consequences are not ranked in any order of importance, but in the order that the group identified them.

3.1   Dangerous Gases Escaping into the Workings

This hazard occurs when either flammable gas or poisonous gas flows into the accessible workings from sealed off areas following a collapse of pillars. This can be caused by the displacement of volume behind the sealed off area. On the other hand, the area where the seals are placed can be damaged and the integrity of the seals effected, thereby allowing the release of gas.

3.2   Violent Collapse of Workings (Safety)

With the continued decay of pillars it can safely be assumed that they will ultimately fail after a period of time, either singulary or in multiples. When this occurs a certain point is reached when the workings become unstable and a violent collapse over a significant larger area, than where the pillars have decayed, could occur.

3.3   Fatalities (Single Multiples and Disaster) (Safety)

The most severe consequence of pillars failing are when workers are present during the collapse which could lead to either single or multiple fatalities.

3.4   Loss of Mining Reserves (Non-safety)

When the safety factor of mine workings have to be adapted to compensate for a reduction in the safety factor over a period of time, mineable reserves will be lost. In a similar fashion when main access routes are destroyed through the collapse of pillars, or pillars become so unstable that they pose a threat, the reserves that are accessed by these travelling ways will be lost.

3.5 Roof Instability (in workings) (Safety)

When pillars decay with time their structural integrity is reduced. At the same time the size of the pillars are diminished by the effects of scaling. On the one hand, the primary support given by the pillars are reduced, and, on the other hand, the roadway span is increased to a point where it is too much for the overlying strata to be contained by the installed roof support systems. In both cases the outcome will be unstable roofs in the working and back areas.

3.6 Increased Problems with Mining Operations (Safety)

This is actually the culmination of other factors all of which lead to an overall problem in which the activity of mining safely is made more difficult. This consequence is deemed to be a safety issue as it deals with the deterioration of a situation where both safety and productivity are involved.

3.7 Overdesign of Pillars (Non-safety)

Because of the uncertainty of the rate at which the strength of pillars decay and to ensure safety of workers it can be assumed that an overdesign of pillars will occur. This overdesign might not be warranted during the time that the workings are accessible to workers or have an influence on other accessways. Loss of reserves could, thus, be unnecessarily be incurred.

3.8 Gradual Collapse of the Pillars (Safety)

The consequence of pillars decaying over time is that they will eventually lose their strength and start to collapse. This consequence is an requirement for some of the other consequences to occur.

3.9 Serious Injury to Workers (Safety)

In the event of dangerous roof and pillar instability and collapse, workers are subject to injury. This consequence is similar to consequence no. 3, only less in severity.

3.10 Dangerous Maintenance of Weakened pillars (Safety)

In the event of pillars decaying to the point where they have to be maintained or strengthened, it would lead to a hazard as the work would have to be done under dangerous conditions.

3.11 Present Mining Methods will come under Scrutiny (Safety)

There was a feeling in the group, especially under those members more familiar with the science of strata control, that the decay of pillars and the resultant reduction in stability would cause doubts to be cast on the ability of the practitioners to design mining layouts. As the designs are based on design criteria that have been proven, any doubt that is created in the validity of such criteria will automatically create doubts with regard to the mining designs. The methods presently used would then come under scrutiny and to maintain safety other extraction methods might have to be used.

3.12 Regional Stability will be Threatened (Safety)

When pillars start failing a point can be reached where such a decrease of support has occurred that the remaining pillars cannot support the area. In such a case the whole area or region could be subjected to stability problems.

3.13 Flooding and Spontaneous Combustion in Shallower Mines (Non-safety)

In shallower mines the subsidence caused by pillar failures will lead to passages through the overlying strata to the surface. These passages can lead to an increased inflow of water into the underground workings. The ingress of air can lead to the initiation and the maintaining of fires caused by spontaneous combustion.

3.14 Trapping of Persons and Equipment (Safety)

In the event of pillars failing, especially in the older areas of the mines, entries to the working can be damaged. When these entries are damaged there is a danger that it could occur when workers and equipment are inbye of this point, leading to them becoming trapped.

3.15 False Sense of Security (Safety)

If pillars decay over time and their strength diminishes, a false sense of security will be created. As the rate at which these pillars decay, as well as the factors leading to such decay, is not fully understood, the people working in the mine would not be aware of the extent of the hazard that they are subjected to.

3.16 Loss of Equipment - Dangerous Recovery (Safety)

As there is an increased hazard when extracting older pillars, as well as the possibility of trapping equipment, it is foreseen that the recovery of this equipment would constitute a unnecessary and hazardous operation.

3.17 Damage to Infrastructure Critical to Inbye Workers (Safety)

In the event of pillars in the access ways of the mine becoming unstable and collapsing, the infrastructure, like ventilation passages, water, travelling routes, all which are critical to workers inbye from the occurrence, will become damaged.

3.18 Surface Effects-Subsidence and Structural Damage (Non-safety)

With the collapse of pillars, surface effects will be caused due to the strata becoming unstable.

3.19 Choked Airways (Safety)

As the pillars decay an amount of scaling, to a lesser or larger degree, occurs. This scaling occurs in the older parts of the mine that are used for the return airways, and would constrict or choke the flow of air through these passages.

3.20 Loss of Safety Factor-Margin (Safety)

With decay of the pillars it loses its strength. The loss of strength will cause a commensurate decrease of the safety factor of the pillar and the section.

3.21 Unsafe Pillar Extraction (Safety)

It would be significantly more hazardous to extract pillars that have decayed, than to extract pillars that are still close to their original strength.

3.22 Loss of Confidence in Rock Mechanics Design (Non-safety)

In the event of pillars, that were initially designed with a sufficient margin of safety, becoming unstable due to decay, questions, around the whole design process, could be raised. This will cause a loss of confidence in the both the way that pillars have, and, are being, designed, and in the whole

safety margin situation in the coal mines. Although this is a non-safety issue, the implications of these consequences occurring would have widespread implications.

3.23 Flooding (Safety)

In the event of pillar decay leading to unstable strata, the risk of an inflow of water from both underground and overlying aquifers, as well as other ground water, is possible.

3.24 Fires Underground (Safety)

Due to the spalling and break-up of the pillars, loose coal could accumulate, which could be prone to spontaneous combustion, causing a mine fire to start in the older workings.

3.25 Loss of Capital Investment-Mine (Non-safety)

When main entries and large parts of the mine become inaccessible due to older pillars becoming unstable, the mine, which is a large capital investment, could become unsafe to the degree that operations have to cease.

3.26 Gas-Water Influx in Multi-Seam Workings (Safety)

In the event of strata collapse due to pillars failing, an influx of water and gas from the higher seams could flow into the underlying seams.

3.27 Multi-Seam Reserve Losses (Non-safety)

When the pillars in underlying seams, designed to protect the overlying seams, become unstable due to decay, the overlying seam reserves will be lost.

3.28 Need to Protect Surface-Dangerous Remedial Work (Safety)

When pillars, due to decay, become so unstable that work has to be conducted to safeguard the surface, it can be anticipated that this work will be done under dangerous conditions.

3.29 Dangerous Rescue Operations (Safety)

In event of rescue work having to be done to rescue either men or machinery after collapses, due to pillar decay, it can be anticipated that such work will be done under extremely dangerous conditions.

3.30 Loss/Reduced Productivity (Non-safety)

In the event of pillars becoming unstable it can be foreseen that the extraction of coal will become more hazardous. This, in turn, will lead to a lower level of productivity in the affected sections.

3.31 Pillar Decay Mop-up Increases Risk (Safety)

One of the manifestations of pillar decay is the side-wall spalling of coal, which means there will be a need to clear this coal. This work will have to be done in the older workings under more hazardous conditions than would be the case regarding younger pillars.

3.32 Old Areas Risk of Methane Explosions (Safety)

In the older workings methane accumulations can be ignited by the fall of roof material . These ignitions could be caused by rock striking roofbolts or by rock striking rock.

3.33 Underdesign of Pillars (over longer time scale)

As the pillars decay they will lose their original designed, strength meaning that, with the passage of time, pillars that were then designed correctly, will now be underdesigned.

3.34 Risky Re-opening of Older Mines

If pillars decay with time, then pillars in older mines would most likely be unstable. This means that to open an older mine, with the intent of extracting reserves, will be an hazardous operation.

3.35 Fatalities Lower Pillar Failure

This consequence was forwarded by only one respondent, and the precise nature of what was meant is not clear.

4   EVALUATION OF IDENTIFIED CONSEQUENCES

During the workshop that was held to determine the possible consequences of the decay of pillars, a nominal group technique was used to determine those aspects that were considered to be the most important issues. Table 1 reflects the consequences that were considered the most important by the group as well as the average score that was obtained for each consequence.

Table 1   RANKING OF CONSEQUENCES BY IMPORTANCE (WORKING GROUP)

		CONSEQUENCE OF THE DECAY OF PILLARS	IMPORTANCE
	1	Dangerous gases escaping into the workings	7.5
	2	Violent collapse of workings	7.4
	3	Fatalities (single Multiples and disaster)	
	4	Loss of mining reserves	9.0
	5	Roof instability (in workings)	
	6	Increased problems with Mining operations	
	7	Overdesign of pillars	
	8	Gradual collapse of the pillars	7.0
	9	Serious injury to workers	
	10	Dangerous maintenance of weakened pillars	
	11	Present mining methods will come under scrutiny	
	12	Regional stability will be threatened	
	13	Flooding and spontaneous combustion in shallower mines	
	14	Trapping of persons and equipment	
	15	False sense of security	6.5
	16	Loss of equipment - Dangerous recovery	8.4
	17	Damage to infrastructure critical to inbye workers	
	18	Surface effects - subsidence and structural damage	7.2
	19	Choked airways	
	20	Loss of safety factor - margin	
	21	Unsafe pillar extraction	
	22	Loss of confidence on rock mechanics design	8.6
	23	Flooding	
	24	Fires underground	
	25	Loss of capital investment - mine	
	26	Gas-water influx in multiseam workings	
	27	Multiseam reserve losses	
	28	Need to protect surface - dangerous remedial work	
	29	Dangerous rescue operations	
	30	Loss/reduced productivity	
	31	Pillar decay mop-up increases risk	
	32	Old areas risk of methane explosions	
	33	Undersign of pillars (over longer time scale)	
	34	Risky reopening of older mines	8.4

Table 2 and Table 3 sets out the results obtained from the questionnaire sent out to a broader spectrum of respondents. In Table 4 the severity and probability have been combined to give an indication of the importance of each consequence.

Table 2   AVERAGE RESULTS FROM THE RESPONSES OF THE FIRST ROUND OF THE
QUESTIONNAIRES

	CONSEQUENCE OF THE DECAY OF PILLARS (Not in order of importance)	Team	
		Probability	Severity
1	Dangerous gases escaping into the workings	5.8	5.7
2	Violent collapse of workings	6.2	7.9
3	Fatalities (single Multiples and disaster)	4.3	8.0
4	Loss of mining reserves	6.5	5.3
5	Roof instability (in workings)	7.6	6.5
6	Increased problems with Mining operations	7.3	6.0
7	Overdesign of pillars	4.6	3.2
8	Gradual collapse of the pillars	7.7	5.8
9	Serious injury to workers	4.5	6.8
10	Dangerous maintenance of weakened pillars	6.5	5.5
11	Present mining methods will come under scrutiny	7.8	4.7
12	Regional stability will be threatened	6.6	6.3
13	Flooding and spontaneous combustion in shallower mines	7.3	7.0
14	Trapping of persons and equipment	5.7	6.8
15	False sense of security	6.3	5.7
16	Loss of equipment - Dangerous recovery	5.6	6.5
17	Damage to infrastructure critical to inbye workers	5.9	6.2
18	Surface effects - subsidence and structural damage	6.9	5.5
19	Choked airways	6.3	6.1
20	Loss of safety factor - margin	8.2	6.3
21	Unsafe pillar extraction	8.0	7.5
22	Loss of confidence on rock mechanics design	7.2	6.0
23	Flooding	5.3	6.3
24	Fires underground	5.2	7.5
25	Loss of capital investment - mine	4.8	5.6
26	Gas-water influx in multiseam workings	6.3	7.0
27	Multiseam reserve losses	6.6	5.1
28	Need to protect surface - dangerous remedial work	5.5	4.4
29	Dangerous rescue operations	5.3	6.6
30	Loss/reduced productivity	6.4	4.9
31	Pillar decay mop-up increases risk	7.0	5.1
32	Old areas risk of methane explosions	5.9	8.3
33	Undersign of pillars (over longer time scale)	6.9	6.3
34	Risky reopening of older mines	7.4	6.3
35	Fatalities lower pillar failure	3.0	9.0

Table 3   AVERAGE RESULTS FROM THE RESPONSES OF THE SECOND ROUND OF
THE QUESTIONNAIRES

	CONSEQUENCE OF THE DECAY OF PILLARS	Team	
	(Not in order of importance)	Probability	Severity
1	Dangerous gases escaping into the workings	5.8	5.7
2	Violent collapse of workings	6.2	7.9
3	Fatalities (single Multiples and disaster)	4.3	8.0
4	Loss of mining reserves	6.5	5.3
5	Roof instability (in workings)	7.6	6.5
6	Increased problems with Mining operations	7.3	6.0
7	Overdesign of pillars	4.6	3.2
8	Gradual collapse of the pillars	7.7	5.8
9	Serious injury to workers	4.5	6.8
10	Dangerous maintenance of weakened pillars	6.5	5.5
11	Present mining methods will come under scrutiny	7.8	4.7
12	Regional stability will be threatened	6.6	6.3
13	Flooding and spontaneous combustion in shallower mines	7.3	7.0
14	Trapping of persons and equipment	5.7	6.8
15	False sense of security	6.3	5.7
16	Loss of equipment - Dangerous recovery	5.6	6.5
17	Damage to infrastructure critical to inbye workers	5.7	6.2
18	Surface effects - subsidence and structural damage	6.9	5.5
19	Choked airways	6.3	6.1
20	Loss of safety factor - margin	8.2	6.3
21	Unsafe pillar extraction	8.1	7.5
22	Loss of confidence on rock mechanics design	7.1	6.0
23	Flooding	5.3	6.3
24	Fires underground	5.1	7.5
25	Loss of capital investment - mine	4.9	5.6
26	Gas-water influx in multiseam workings	6.2	7.0
27	Multiseam reserve losses	6.5	5.1
28	Need to protect surface - dangerous remedial work	5.5	4.4
29	Dangerous rescue operations	5.4	6.6
30	Loss/reduced productivity	6.6	4.9
31	Pillar decay mop-up increases risk	6.9	5.1
32	Old areas risk of methane explosions	5.9	8.3
33	Undersign of pillars (over longer time scale)	7.1	6.3
34	Risky reopening of older mines	7.4	6.3
35	Fatalities lower pillar failure	3.3	9.0

Table 4   RANKED CONSEQUENCES FROM THE RESULTS OF THE SECOND
QUESTIONNAIRE RETURN

RANK	CONSEQUENCE OF THE DECAY OF PILLARS	VALUE
1	Unsafe pillar extraction	60.0
2	Loss of safety factor - margin	52.1
3	Flooding and spontaneous combustion in shallower mines	51.2
4	Roof instability (in workings)	49.5
5	Old areas risk of methane explosions	49.4
6	Violent collapse of workings	48.7
7	Risky re-opening of older mines	46.2
8	Gradual collapse of the pillars	44.2
9	Gas-water influx in multiseam workings	44.2
10	Increased problems with Mining operations	43.8
11	Undersign of pillars (over longer time scale)	43.8
12	Loss of confidence on rock mechanics design	43.4
13	Regional stability will be threatened	41.3
14	Trapping of persons and equipment	38.9
15	Fires underground	38.7
16	Choked airways	38.4
17	Surface effects - subsidence and structural damage	38.1
18	Damage to infrastructure critical to inbye workers	36.5
19	Loss of equipment - Dangerous recovery	36.5
20	Present mining methods will come under scrutiny	36.3
21	Dangerous maintenance of weakened pillars	36.0
22	False sense of security	35.7
23	Pillar decay mop-up increases risk	35.6
24	Dangerous rescue operations	34.9
25	Fatalities (single Multiples and disaster)	34.5
26	Loss of mining reserves	33.9
27	Multiseam reserve losses	33.6
28	Flooding	33.6
29	Dangerous gases escaping into the workings	33.1
30	Loss/reduced productivity	31.4
31	Serious injury to workers	30.6
32	Loss of capital investment - mine	27.1
33	Need to protect surface -dangerous remedial work	24.5
34	Overdesign of pillars	14.6

The most important consequence identified by this study is that of unsafe pillar extraction. The importance attached to this issue is indicated by the difference between the obtained value and the next lower value (7.9). Having very similar values, the next two consequences deal with the loss of the safety factor margin and the possibility of flooding and spontaneous combustion in shallower mines. This is followed by the consequence of a violent collapse of the workings. The next two important issues are roof instability and the risk of methane explosion in older workings. The re-opening of older mines is then ranked, and below this lies the gradual collapse of the pillars, followed by the influx of water and gas into the workings.

In considering these consequences, it is evident that the consequences of the decay of pillars, meaning the weakening of pillars over time, is seen to have an influence on the safety of workers. This will be manifested in unsafe conditions when pillars are extracted, as well as when old mines are re-opened. There is an increased risk to mine workers due to the loss in the safety margin, which would lead to some of the other consequences that were ranked high, e.g. the gradual collapse of the pillars and a violent collapse of the workings. Similarly an inrush of water and gas in both shallow and deeper mines are seen to be resultant hazards.

5   CONCLUSIONS

On the whole it can be concluded that the consequences of a decay in pillars will detrimentally affect the safety of workers. Mining operations would become more difficult, as well as hazardous, especially where higher extraction methods are used. The maintaining of the safety levels would lead to the loss of reserves or an increased amount of operational efforts and cost.

It is not the primary effect of decaying pillars that poses a hazard but rather the secondary effect when pillars have failed. Trapping of workers and equipment, inrush of water and gases, and surface effects are all deemed to be hazardous.

The hazards posed by the decay of pillars will not only influence the underground workers, but also have an influence on the surface, where it can cause damage through subsidence.

From the results of the workshop and questionnaire it seems that it is not only the consequences of the decay of pillars that constitute a hazard, but also the uncertainty of when these pillars decay to an unacceptable state.