SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Final Project Report

Title: ANALYSIS OF ROCKBURST AND ROCKFALL ACCIDENTS IN RELATION TO CLASS OF STOPE SUPPORT, REGIONAL SUPPORT, ENERGY OF SEISMIC EVENTS, AND MINING LAYOUT

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SUMMARY

For assessing the safety risk, the analysis of falls of ground (FOG) has to be made. From the documents "Reports of delay in production due to FOG" and " Estimate and Actual Efficiency Sheets Stoping" a database was created with 244 records. The database covered the time span 1991 and 1992 of one mine.

The multivariate analysis was used to obtain a correlation between mining production and accident parameters. The following parameters were under investigation: volume of the mined rock per month, length of the active face over a month, average face advance per month, delay in production due to FOG, number of reportable accidents and linear extent of damage. There is a lack of direct correlation between monthly production figures and the number of reportable accidents.

The relationship between number of FOGs and production delay is very simple, and therefore it should be easy to forecast a loss in production due to FOG. Expose of the section of a mine to delays in production can be measured using model parameters. Investigations were conducted using different mining layouts and support. Parts of mine with backfill and other types of support have the same proportion of large to small FOG. The reportable accidents occurred during FOGs cause relatively small production delays. In available data set FOGs causing large damage in mine were not responsible for accidents.

Examination of number of the FOGs versus the linear extent of damage indicates the existence of the three following classes of FOGs: (1) FOG with the lengths varying from 0.5 m to 16 m, and fractal dimension $D \approx 0.67$; (2) FOG with the lengths varying from 16 m to about 90 m, and fractal dimension $D=1.51$ and (3) FOG with the length greater than 90 m. Each class of FOGs has its own mechanism and therefore should be treated separately. Class 1 is associated with the spatial distribution of the exposed site. Class 2 reflects the fracture geometry, which can be associated with geological feature. Class 3 is highly irregular.

Periodicity of reportable accidents is analysed. The spectra of rate of reportable accidents have the most dominant peaks associated with a 7 day cycle as well as a 7/2 and a 7/3 day cycle. All spectra have small but well defined peaks for the period of 204 days.

DEPARTMENT OF MINERAL AND ENERGY AFFAIRS
DETAILED SIMRAC FINAL REPORT

1. DATA COLLECTION

A For assessing the safety risk, the analysis of all falls of ground (FOG) has to be made. This means FOGs which cause reportable accidents and the ones which do not. I was given an access to reports of the delays in production due to FOG in a mine, which covered the time span 1991 and 1992. From those reports a database was created with 244 records. Parameters of each FOG are kept in database records. Table 1 shows list of parameters describing FOG.

B During a course of the project it was seen that there was a need to compare the FOG data with mining production parameters. To this end an access to mining data was derived from the document " Estimate and Actual Efficiency Sheets Stoping". From this bulletin the following parameters were available: volume of the mined rock per month, the length of the active stope over a month and the average face advance per month.

C In the first quarter of 1993, a separate analysis of periodicity of reportable accidents was done with a data set obtained from the South African Reportable Accident Statistics System Associated with Rockbursts and Rockfalls.

TABLE 1

STRUCTURE OF THE RECORD FOR EACH FOG

1. working place
2. level/line
3. year, month, day, time
4. production delay in days
5. production loss in tons
6. number of fatal accidents
7. number of injuries
8. presence of geological structure
9. extent of fall: width,thickness,length
10. permanent support: type, distance from face, spacing
11. temporary support: type, distance from face, spacing
12. magnitude of seismic event, if such was recorded

2. DEVELOPMENT OF METHODOLOGY TO ANALYSE DATA

2.1 The multivariate analysis

The correlation between mining production and accident parameters was analysed in detail. The object of data analysis was to examine the interdependence of parameters. Data was collected on a monthly basis and the following parameters in Table 2 were under investigation:

Table 2

volume of the mined rock per month	Volume
length of the active face over a one month period	Active F
average face advance per month	Rate
delay in production due to FOG	Delay
number of reportable accidents and fatalities	Accident
linear extent of damage	Damage L

The multivariate method procedures were used in the examination of data from both longwall mining and shaft pillar extraction. The correlation and partial correlation analysis procedure was used.

The correlation analysis generated a matrix of correlation coefficients for a set of observed values. It provided a preliminary view of the relationships amongst the variables. Correlation coefficients provided a normalized measure of the association between two variables. The coefficient values fell between -1 and 1. A positive correlation indicated that the variables varied in the same direction whilst a negative correlation indicated that the variables varied in the opposite direction. Statistically independent variables are expected to have a correlation coefficient of zero.

The partial correlation analysis estimates partial correlation coefficients for a set of observed values. A partial correlation coefficient measures the relationships between two variables whilst controlling the effects of other variables. These effects were controlled by removing the linear relationship with some variables before calculating the correlation coefficients between the two variables of interest. Partial correlation is useful for uncovering hidden relationships and detecting spurious relationships.

EXAMPLE 1

Table 3 and 4 contains the result of the correlation and partial correlation analysis for a longwall mining operation in a specific section. Data were collected during 16 months period. The length of active face varied from 287m to 760m and the average face advance per month varied from 3.5m to 7.9m.

Table 3
Correlation matrix

	Active Face	Rate	Delay	Accident	Damage length
Volume	0.62	-0.03	-0.36	-0.55	-0.55
Active F	1	-0.78	-0.25	-0.50	-0.42
Rate		1	0.15	0.26	0.20
Delay			1	0.54	0.70
Accident				1	0.74

Table 4
Partial Correlation matrix

	Active Face	Rate	Delay	Accident	Damage length
Volume	0.94	0.92	-0.26	-0.05	-0.21
Active F	1	-0.97	0.29	-0.16	0.12
Rate		1	0.29	-0.11	0.13
Delay			1	0.09	0.46
Accident				1	0.50

The results of analysis are reflected by the values of the coefficients. In several cases the values of the coefficients change significantly from Table 3 to Table 4. Therefore, a joint interpretation of the correlation and partial correlation matrixes is not simple.

By concentrating on the non-controversial facts there is, as expected, a very strong correlation between volume of rock removed and length of active face. In addition the correlation between the linear extent of damage and the number of reportable accidents is convincing. The relationship between linear extent of damage and delay in production due to the damage is also clearly evident.

EXAMPLE 2

The identical analysis (Table 5 and Table 6) was performed for another section of longwall mining. In this case the length of active face varied from 601 m to 1310 m and the available data covered a period of 10 months. The conclusions are similar with the exception that the correlation between linear extent of damage and the number of reportable accidents is only 0.37.

Table 5
Correlation matrix

	Active Face	Rate	Delay	Accident	Damage length
Volume	0.73	0.85	-0.67	0.26	-0.06
Active F	1	0.28	-0.13	0.58	0.08
Rate		1	0.05	-0.07	-0.10
Delay			1	-0.09	0.71
Accident				1	-0.11

Table 6
Partial Correlation matrix

	Active Face	Rate	Delay	Accident	Damage length
Volume	0.94	0.98	-0.14	-0.07	-0.05
Active F	1	-0.88	-0.02	0.29	0.21
Rate		1	0.21	-0.02	-0.04
Delay			1	0.28	0.76
Accident				1	0.37

EXAMPLE 3

The third set of data (Table 7 and Table 8) covers 20 months of observation in a shaft extraction with backfill support. The length of active stope varied from 263m to 443m. For the most part the correlations remain similar, with the one exception that there are no observed correlations between production parameters and the number of reportable accidents.

Table 7
Correlation matrix

	Active Face	Rate	Delay	Accident	Damage length
Volume	0.69	0.90	0.01	0.29	-0.07
Active F	1	0.37	-0.09	0.19	-0.21
Rate		1	0.23	0.23	0.19
Delay			1	0.08	0.74
Accident				1	-0.13

Table 8
Partial Correlation matrix

	Active Face	Rate	Delay	Accident	Damage length
Volume	0.93	0.98	-0.31	0.24	-0.46
Active F	1	-0.89	0.30	-0.21	0.35
Rate		1	0.31	-0.20	-0.48
Delay			1	0.29	0.48
Accident				1	-0.12

INTERIM CONCLUSIONS

A correlation between the number of reportable accidents and linear extension of damage during the FOG was observed in longwall mining, but it not appear to be significant in shaft extraction.

There is no clear correlation between the volume of the mined rock or a length of the active face and delay in production or length of face damage during the FOG.

The most important conclusion is a lack of direct correlation between monthly production figures (the volume of mined rock, active face length or average face advance) and the number of reportable accidents.

It is a common practice in industry to calculate the number of accidents versus production parameters. It appears that those correlations do not exist on a smaller scale where +/- 2000 m of active stope is involved. This can lead to an optimistic conclusion that an increased rate of production does not mean an increase of fatalities.

The low values of correlation coefficients associated with accidents suggest that any mathematical model which is going to describe accidents should involve more than one parameter.

2.2 Examination of number of the FOG versus delay in production for different mining layouts and support

The statistical properties of the occurrence of FOG have not been studied in a systematic way. The space distribution of the FOG were examined in order to better understand the FOG generation process and - thereby - possibly assist in forecasting a loss of production. The created database gives an opportunity to analyse the relationships between the frequency of FOG and a delay in production, as well as the frequency of FOG versus production delay. All of these could be assessed for different mining layouts and support conditions.

Figure 1 presents the cumulative number (N) of FOGs with production delay (d) for a total set of data. It came as a surprise that with the exception of 3 FOGs all 244 lay on a straight line using a log - linear scale. The empirical relation satisfies the following equation:

$$\log N(d) = A - B d,$$

where A and B are constants. The B constant reflects proportion of large to small falls in a given set. The larger B, the more the system is dominated by small FOGs. The constant A may be considered a coefficient of FOG intensity.

Figures 2, 3, 4 and 5 show frequency-production delay relation for the following conditions:

- longwall mining (Figure 2.)
- shaft extraction (Figure 3.)
- longwall mining with backfill support (Figure 4.) and
- longwall mining with no backfill support (Figure 5.).

The values of A and B corresponding to analysed mining conditions are given in Table 9. Stability of the ratio between the number of large and small FOGs can be seen in the all situations. A slightly higher value of B in shaft extraction compared to the longwall mining is observed. It may also be noticed, that the value of B is the same with backfill or other types of support (Table 9). This could imply that the mechanism of energy release is the same.

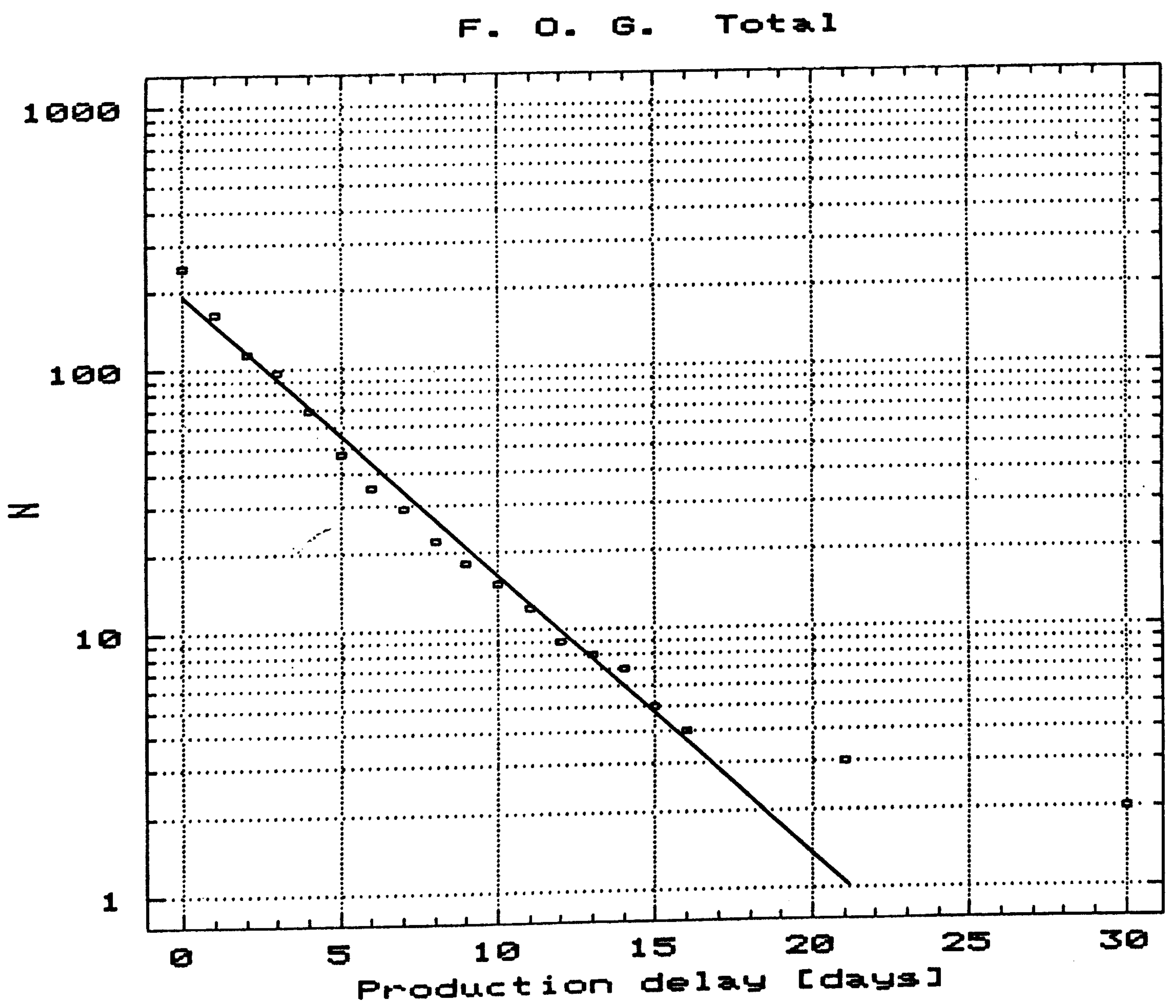
F. O. G. Total
1000
100
10
1
N
0
5
10
15
20
25
30
Production delay [days]

Figure. 1.

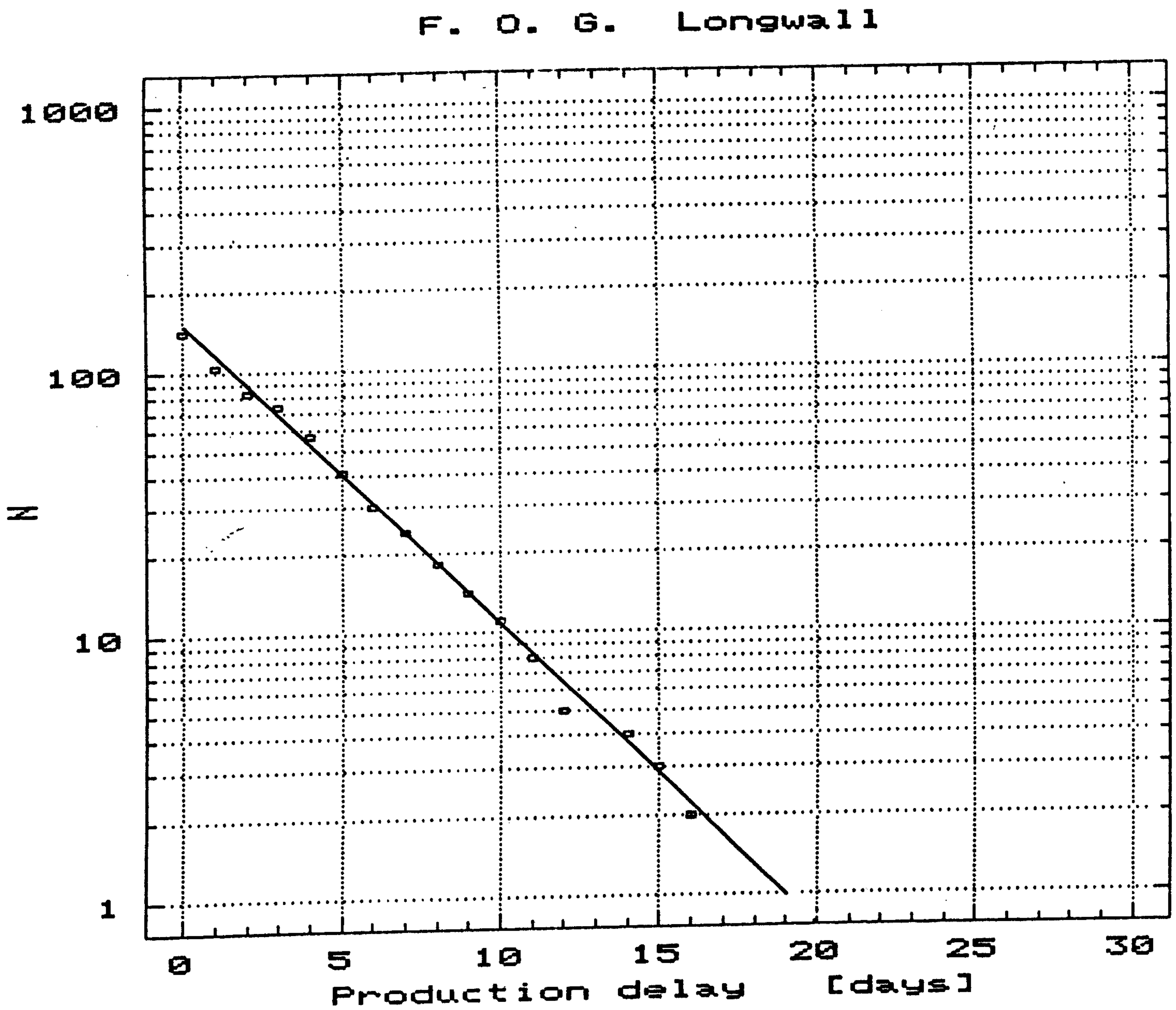
F. O. G. Longwall
1000
100
10
1
N
0
5
10
15
20
25
30
Production delay [days]

Figure. 2.

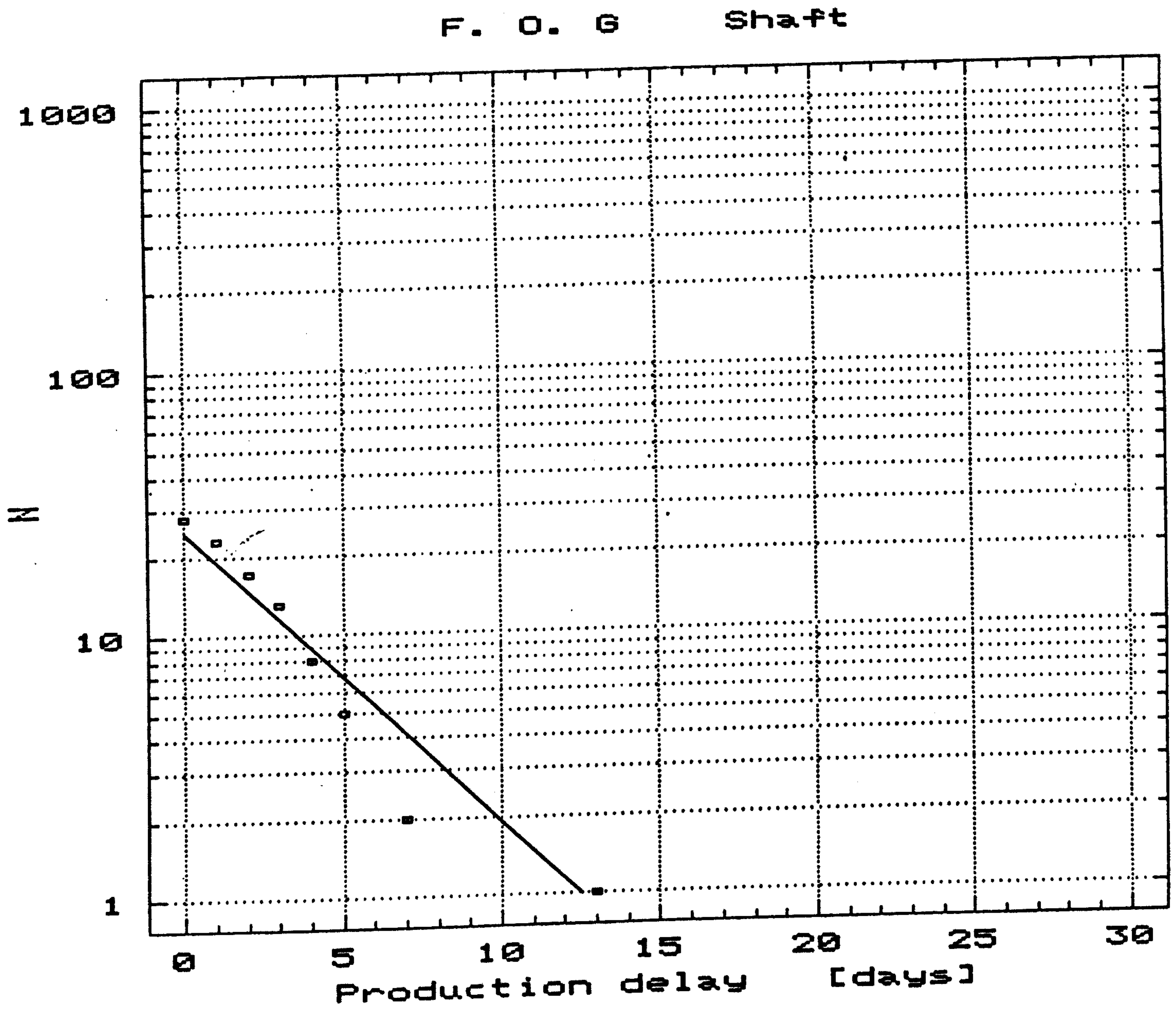
F. O. G Shaft
N
1000
100
10
1
0
5
10
15
20
25
30
Production delay [days]

Figure. 3.

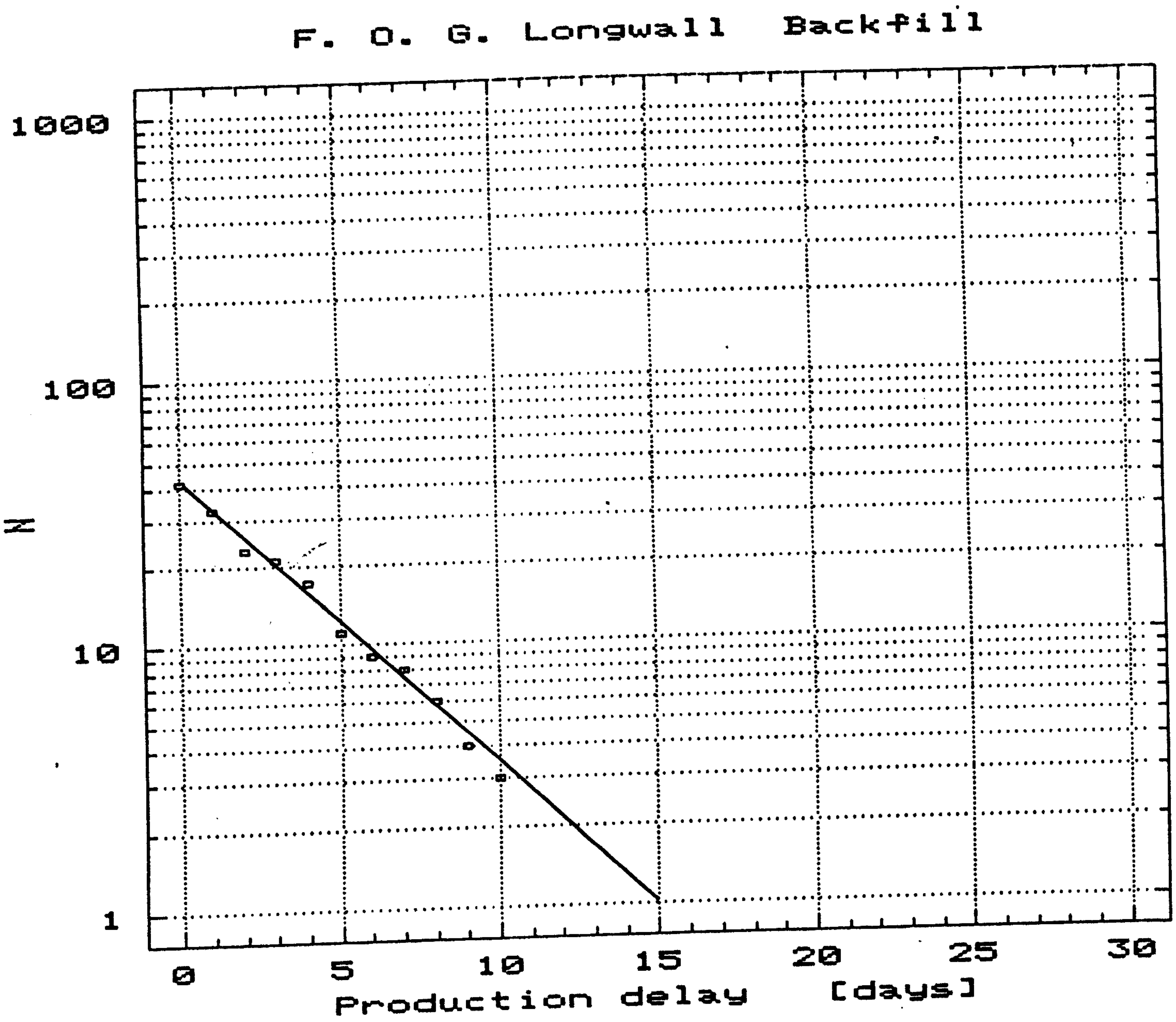
F. O. G. Longwall Backfill
1000
100
10
1
N
0
5
10
15
20
25
30
Production delay [days]

Figure. 4.

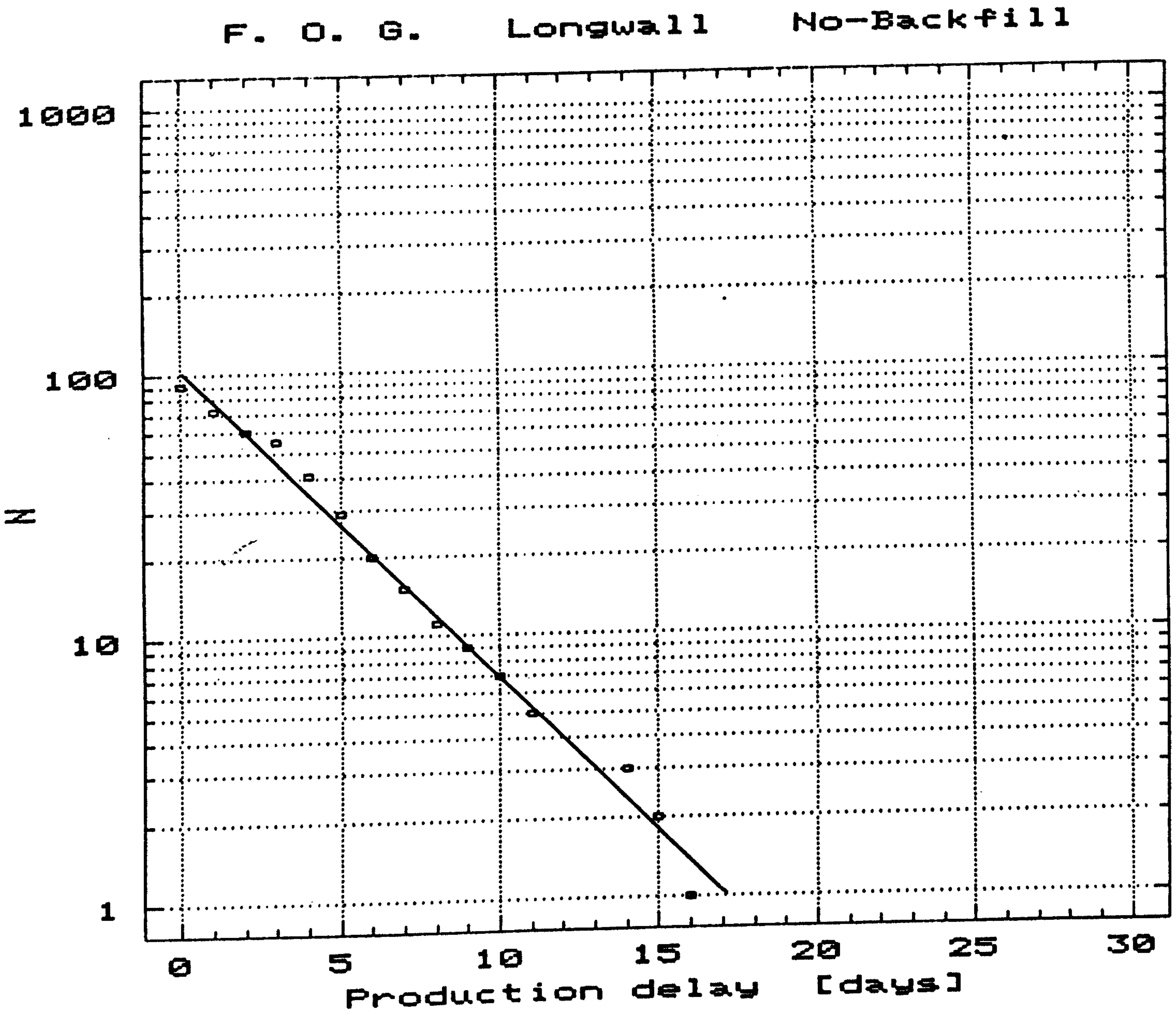
F. O. G. Longwall No-Backfill
1000
100
10
1
N
0
5
10
15
20
25
30
Production delay [days]

Figure. 5.

TABLE 9

Region	Number of FOG	B	A	Correl Coeff
Total	244	0.1074+/-0.002	2.27	0.995
Longwall	142	0.1151+/-0.0019	2.17	0.998
Longwall- BF	42	0.1114+/-0.0035	1.63	0.998
Longwall-no BF	91	0.1176+/-0.0037	2.02	0.994
Shaft Ext- BF	28	0.1663+/-0.0108	1.53	0.984

INTERIM CONCLUSIONS

The relationship between number of FOGs and production delay is very simple. The applied model has only two parameters, therefore it should be easy to forecast a loss in production in a specific region. Expose of the section of a mine to a delay in production due to FOG can be measured using model parameters A and B.

Section of mine with backfill and other types of support has the same proportion of large to small FOGs.

2.3 Examination of the Number of the Reportable Accidents Versus Delay in Production

Access to the data set that contained all the FOGs was used to analyse the type of FOG which caused the accident. The first question to answer was whether accidents spread proportionally across all types of FOGs ,or if more accidents were associated with some particular type of FOG. The comparison focused on two parameters of FOG: injury and production delay.

Table 10 illustrates a statistical summary of the data. The most prominent feature of data is that almost all accidents are associated with FOG, which caused delay in production of 0, 1 or 2 days. 60% of FOG's, which cause production delays of less than three days are responsible for 94% of accidents.

TABLE 10

Production delay [days]	Number of FOG's	Fatal accidents	Injury
0	81	10	73
1	49	2	36
2	17	-	23
3	28	-	3
4	22	-	4
5	12	1	1
6	6	-	-
7	7	-	-
8	4	-	-
9	-	-	-
10	9	-	-
11	-	-	-
12	1	-	-
13	1	-	-
14	2	-	-
15	1	-	-
16	1	-	-
21	1	-	-
30	2	-	-
TOTAL:	244	13	140

INTERIM CONCLUSIONS

All reportable accidents occurred during FOGs caused relatively small production delay. FOGs which caused large damage were not responsible for any accidents. If this result could be confirmed in another mine it would be very important indicator of an area with a safety problem.

2.4 Examination of the Number of the FOG Versus Linear Extent of Damage in Production for Different Mining Layouts (and support)

The relation between number of the FOGs and the linear extent of damage was investigated. This relation was analysed for the following conditions: longwall mining, shaft extraction, longwall mining with backfill and longwall mining with no backfill. The experimental relation between the cumulative number (N) of FOGs with the linear extent (L) was plotted on a double logarithmic scale. Figure 6 clearly shows three linear trends and thus fractal concept can be applied to the statistical distributions of the linear dimension of damage.

A fractal is a family of irregulars or fragmented shapes. Fractal geometry is the description of forms more complex than the standard shapes, ie points (dimension D=0), lines (D=1), planes (D=2), and solids (D=3). To describe the departure of the shapes from a simple form, the fractal dimension is used. One way to obtain the fractal dimension, D, is to obtain the slope of the graph (see Figure 6). If the number of FOG, N(L), with a linear dimensions greater than L satisfies the relation

$$\log N(L) = A - D \log L,$$

the fractal distribution is defined and A and D are the constants. In physical applications there are upper and lower limits on the applicability of the fractal distribution.

A relationship between a length of FOG and a number of FOG indicates the existence of three following classes of FOG:

1 FOG with the lengths varying from 0.5 m to 16 m, and D =0.67
2 FOG with the lengths varying from 16 m to about 90 m, and D=1.51
3 FOG with the lengths greater than 90m

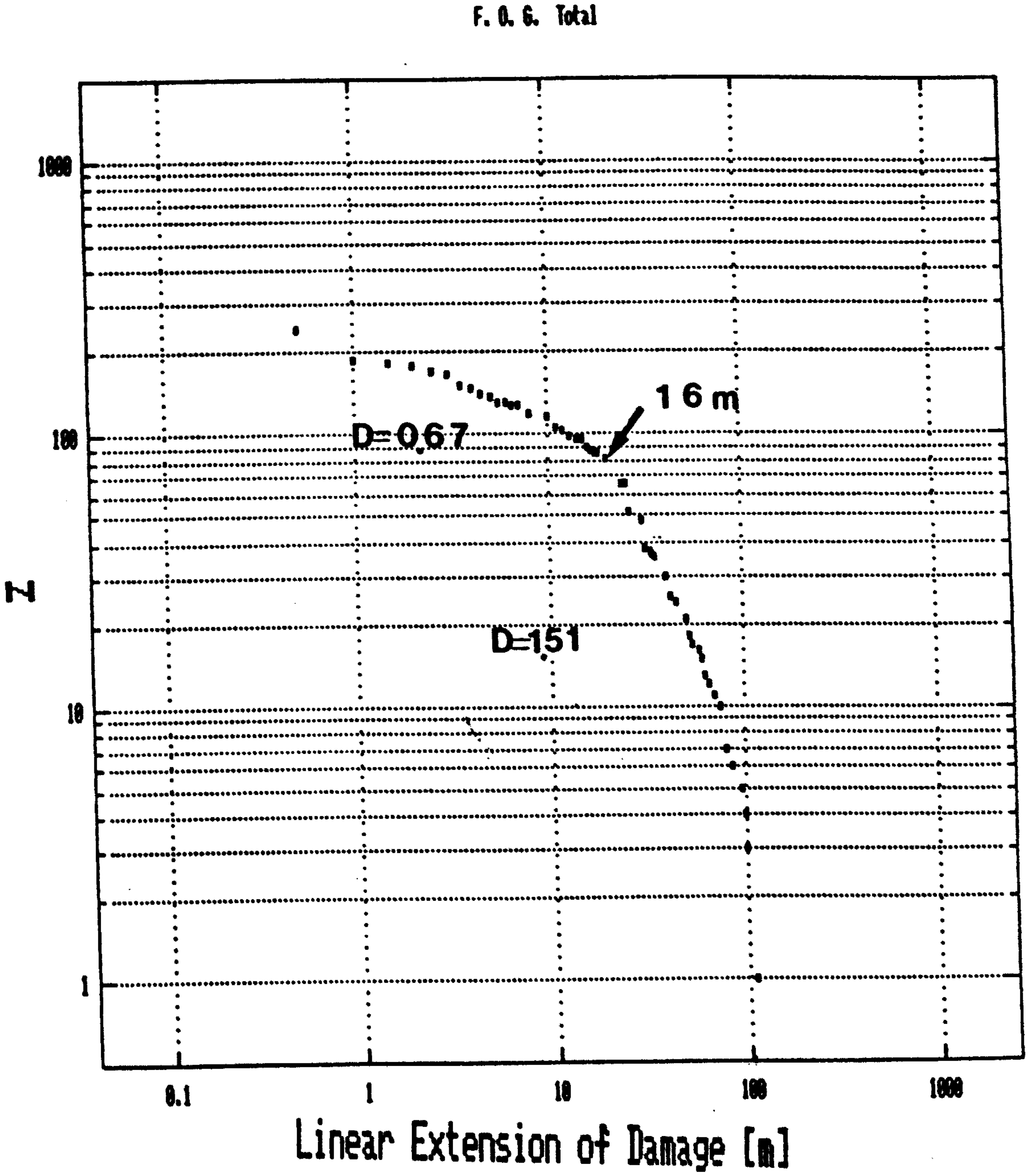
F. O. G. Total
N
1000
100
10
1
0.1
1
10
100
1000
Linear Extension of Damage [m]
D=0.67
16 m
D=1.51

Figure 6

INTERIM CONCLUSIONS AND DISCUSSION

Classes 1 and 2 of FOG have fractal distributions. The limit of 16 m is imposed by FOG data, and not by the geometry of the mining. An interesting feature is that the length of an average panel of 30 m is not a boundary limit for the class's.

Each class of FOG's has its own statistic and perhaps its own mechanism and therefore should be treated separately. What is meant by the word "mechanism" is that each class of FOG is controlled by a different set of parameters (or have different causes)

Topological dimensions of L is 1 (D=1). Fractal dimensions when D=0.67, should be treated partly as points (D=0) and partly as finite lengths (D=1). Therefore, class 1 is concerned not with the geometry of the fracture system but with the spatial distribution of the planes of weakness.

Fractal dimension D = 1.51 should be treated partly as a finite length (D=1) and partly as a plane (D=2). Class 2 reflects the fracture geometry, which can be associated with geological features. The distribution of FOGs is likely to be related to the distribution of pre-existing planes of weakness in the rock.

The occurrence of damage with lengths greater than 90 m appears to be highly irregular. Therefore, to understand its mechanisms (causes) will be a difficult task.

CONCLUSION OF A VERY GENERAL NATURE

Analysis of the above model of FOG in a gold mine is identical to that used to describe catastrophic patterns, for example on a stock market or in an ecosystem. Researchers in those fields agree, that when a catastrophe strikes, blame is attached to a combination of powerful mechanisms. Those mechanisms may well be correct. But a large, interactive systems such as rock mass in mine, stock market or ecosystem can break down not only under the force of a mighty blow, but also at the drop of a proverbial pin.

2.5 Periodicity of reportable accidents

In the first progress report I analysed the periodicity of reportable accidents. Several spectra of the rate of reportable accidents have been obtained (see Figure 7). The spectra cover time intervals from 1 to 5 years. The most dominant peaks are associated with a 7 day cycle as well as both 7/2 day and 7/3 day cycles. These peaks are relatively easy to explain, as they are harmonics related to a 7 day cycle in mines. On the basis of these data, a model of an average rate of accidents has been built, using non - linear inversion techniques (see Figure 8). All spectra have small but well defined peaks for a period of 204 days.

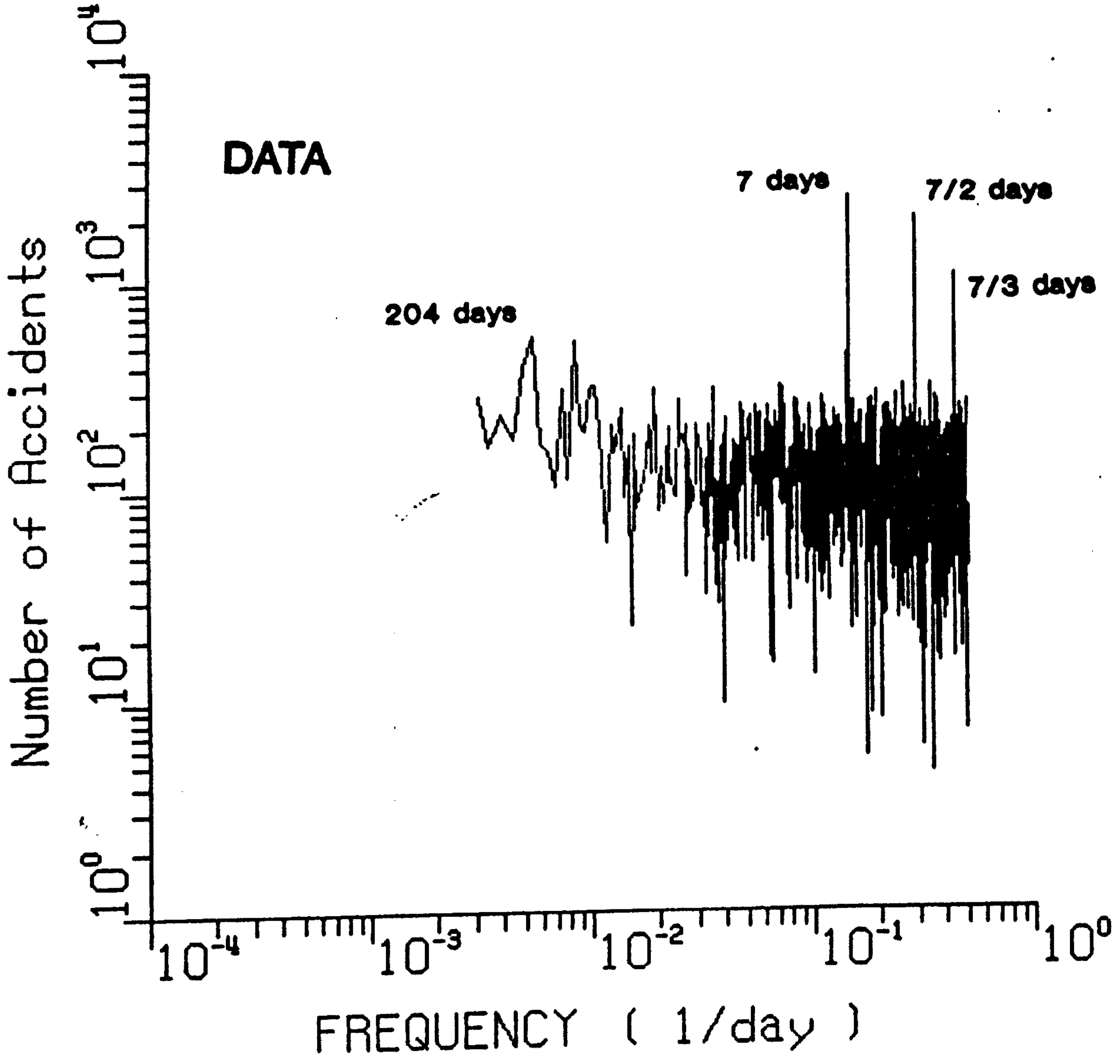
DATA
204 days
7 days
7/2 days
7/3 days
Number of Accidents
10^0
10^1
10^2
10^3
10^4
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
FREQUENCY (1/day)

Figure 7

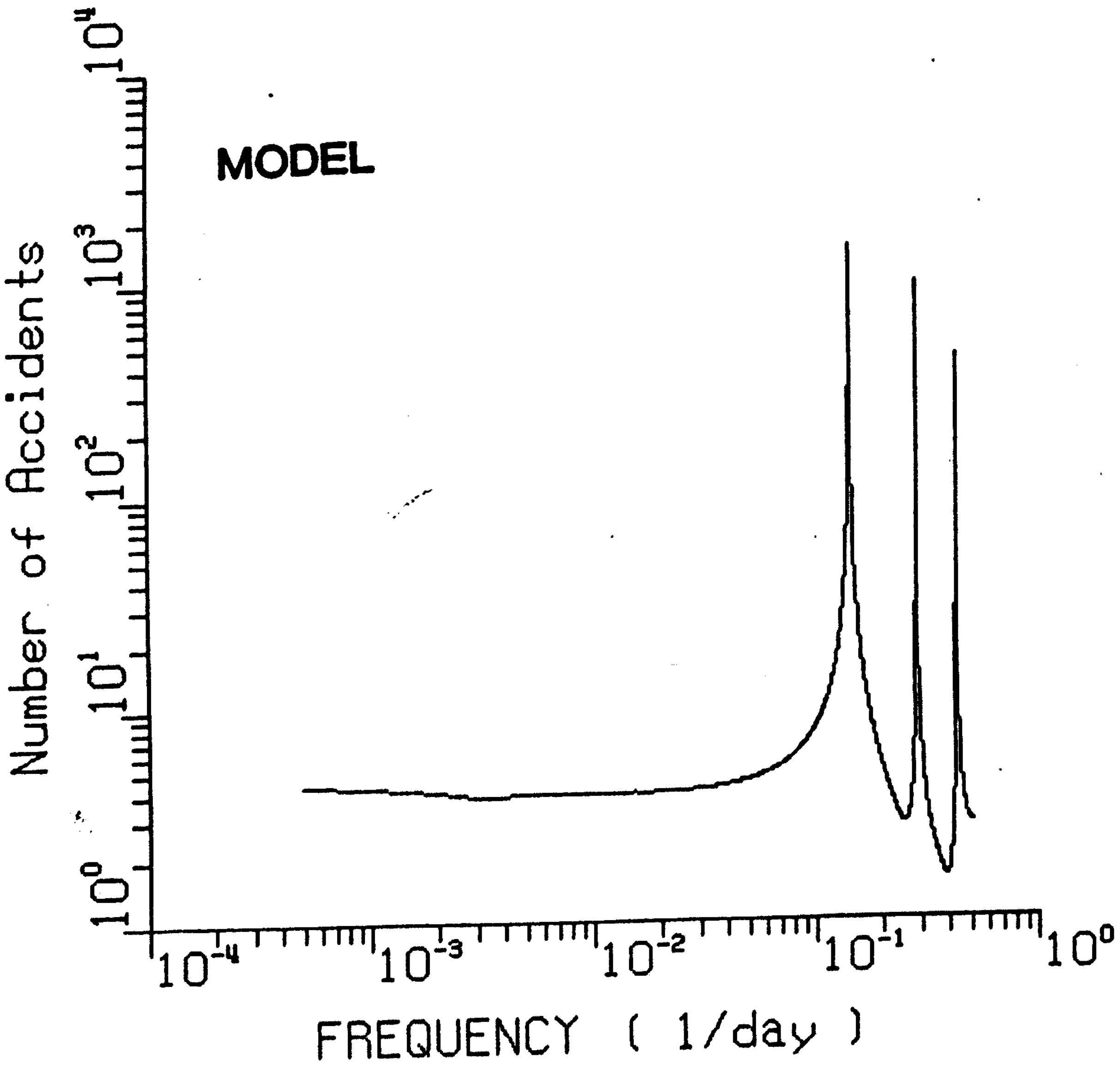
MODEL
Number of Accidents
10^0
10^1
10^2
10^3
10^4
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
FREQUENCY (1/day)

Figure 8

APPENDIX 1
LIST OF PROJECT'S ENABLING OUTPUTS WITH BRIEF STATEMENTS OF OUTCOME

ENABLING OUTPUTS

1 Data collection
2 Development of methodology to analyse data
3 Preparation of report with a conclusion

BRIEF STATEMENTS OF OUTCOME

2.1 The Multivariate Analysis

The most important conclusion is a lack of direct correlation between monthly production figures (a volume of the mined rock, active face length or average face advance) and the number of reportable accidents. It is a common practice in industry to calculate the number of accidents versus production parameters, however it appears that those correlations do not exist on a smaller scale, where +/- 2000 m of active stope is involved. This can lead to an optimistic conclusion that an increased rate of production does not mean an increase of fatalities.

The low values of correlation coefficients associated with accidents suggest that any mathematical model which is going to describe accidents should involve more than one parameter.

2.2 Examination of the Number of the FOG Versus Delay in Production for Different Mining Layouts and Support

The relationship between number of FOGs and production delay is very simple. The applied model has only two parameters, therefore it should be easy to forecast a loss in production in a region.

Section of mine with backfill and other type of support has the same proportion of large to small FOGs.

2.3 Examination of the Number of the Reportable Accidents Versus Delay in Production

All reportable accidents occurred during FOGs caused relatively small production delays. FOGs which caused large damage in mine were not responsible for any accidents.

2.4 Examination of the Number of the FOG Versus the Linear Extent of Damage in Production for Different Mining Layouts (and support):

A relationship between a length of FOG and a number of FOGs indicates the existence of the three following classes of FOGs:

CLASS 1: FOGs with lengths varying from 0.5 m to 16 m, and fractal dimension D =0.67

CLASS 2: FOGs with lengths varying from 16 m to about 90 m, and fractal dimension D=1.51

CLASS 3: FOGs with lengths greater than 90 m

The limit of 16 m is not a characteristic length associated with the mining geometry, so consequently one can speculate that it is imposed by a rock property. An interesting feature is that the panel of 30 m length is not a boundary for the class's. Each class of FOG's has its own mechanism and therefore should be treated separately. Class 1 is concerned with the spatial distribution of the exposed sites. Class 2 reflects the fracture geometry, which can be associated with a geological feature. The distribution of FOGs is likely to be related to the distribution of pre-existing planes of weakness in the rock. The occurrence of damage with lengths greater than 90 m is highly irregular Therefore, to understand its mechanism (cause) will be difficult.

2.5 Periodicity of the Reportable Accidents

The spectra of the rate of reportable accidents have the most dominant peaks associated with a 7 day cycle as well as a 7/2 and a 7/3 day cycles. All spectra have small, but well defined peaks for a period of 204 days.

APPENDIX II

LIST OF INTERIM REPORTS,PAPERS,PUBLISHED ON THE PROJECT

1 Statement of progress: April 1993
2 Mid-year Progress Report
3 Statement of progress: October 1993
4 Paper in preparation