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ROCKBURSTS IN ONTARIO MINES DURING 1985

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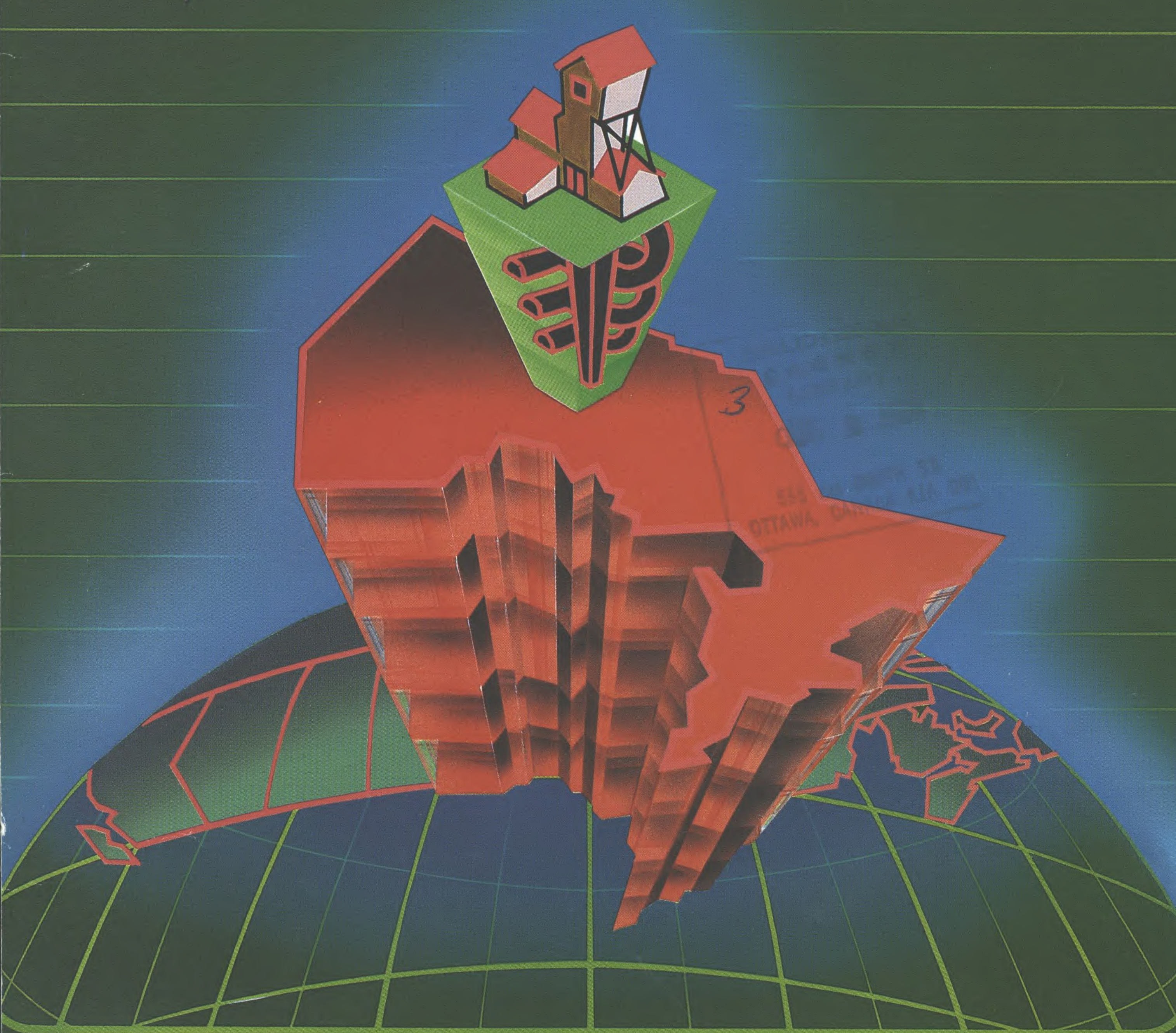

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D.G.F. Hedley

Elliot Lake Laboratory

Mining Research Laboratories

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ROCKBURSTS IN ONTARIO MINES DURING 1985

D.G.F. Hedley*

Abstract

During 1985, 127 rockbursts occurred in ten mines in Ontario, which was a 20% increase from the previous year. The number of large rockbursts, of magnitude 3.0 and greater, however, decreased from ten to three.

These rockbursts were recorded on the Eastern Canada Seismic Network operated by Energy, Mines and Resources Canada, and, in most cases, on the microseismic systems installed in the mines.

Key words: Rockbursts; Microseismic monitoring; Ontario.

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COUPS DE TOIT DANS LES MINES DE L'ONTARIO EN 1985

D.G.F. Hedley*

Résumé

En 1985, 127 coups de toit se sont produits dans 10 mines de l'Ontario, ce qui représente une augmentation de 20% par rapport à l'année précédente. Le nombre de coups de toit importants, soit d'une magnitude de 3,0 ou plus, a baissé de 10 à 3.

Ces coups de toit ont été enregistrés par le Réseau de télémétrie de l'est du Canada exploité par Énergie, Mines et Ressources Canada et, dans la plupart des cas, par des systèmes microsismiques installés dans les mines.

Mots-clés: Coups de toit; surveillance microsismique; Ontario.

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CONTENTS

TABLES

FIGURES

INTRODUCTION

This report is the second in a series of annual reviews of rockburst activity in Ontario mines. The first report covered the 1984 rockburst incidents (1). The same classification system is used, with the main criterion being magnitude. These values are obtained from the Eastern Canada Seismic Network operated by the Geophysics Division of Energy, Mines and Resources Canada. In addition, rockbursts are classified by location and type. Location includes hanging wall, orebody, or footwall and is determined from mine microseismic systems or visual observation. Type defines the likely mechanism involved, being either strain energy, pillar, or fault-slip bursts. Rock type, depth below surface, and mining method are also recorded.

During 1985, four additional microseismic systems were installed in Ontario mines, bringing the total number to eight. These new installations were in Rio Algom's Stanleigh Mine at Elliot Lake, and Falconbridge's Lockerby, Strathcona, and Fraser mines in the Sudbury area.

In 1984, multiple rockburst activity occurred in four mines: Campbell Red Lake Mine, Rio Algom's Quirke Mine, Falconbridge's No. 5 Shaft, and Inco's Creighton Mine. In 1985, this major rockburst activity continued in Quirke Mine and a series of 14 rockbursts occurred throughout the year in Falconbridge's Strathcona Mine. The other rockbursts were isolated and occurred in Denison Mine at Elliot Lake; in Campbell and Dickenson mines at Red Lake; Falconbridge, Lockerby, Creighton, and Garson mines at Sudbury; and in Macassa Mine at Kirkland Lake.

ROCKBURST STATISTICS

Rockbursts recorded during 1985 at Elliot Lake, Red Lake, Sudbury, and Kirkland Lake are listed in Tables 1, 2, 3, and 4 respectively. All these rockbursts were recorded by Energy, Mines and Resources Canada, except for the events at Red Lake for which the records of the nearby seismic station operated by Sandia National Laboratories were used.

Table 1 - Recorded rockbursts in Ontario mines in 1985 - Elliot Lake area

No.	Date	Time*	Magnitude	Mine	Type	Place	Rock	Depth, m	Mining method
1	Jan. 2	04:31	2.5	Quirke	Pillar	Orebody	Qtz. conglomerate	520	Stope and pillar
2	Jan. 3	03:26	2.5	"	"	"	" "	420	" " "
3	Jan. 6	14:32	3.0	"	"	"	" "	425	" " "
4	"	17:00	2.8	"	"	"	" "	475	" " "
5	"	22:23	2.7	"	"	"	" "	425	" " "
6	Jan. 8	05:48	2.8	"	"	"	" "	435	" " "
7	Jan. 9	19:35	2.0	"	"	"	" "	545	" " "
8	Jan. 10	03:20	1.9	"	"	"	" "	555	" " "
9	"	14:59	2.2	Denison	"	"	" "	560	Room and pillar
10	Jan. 11	07:29	2.4	Quirke	"	"	" "	475	Stope and pillar
11	"	23:04	2.6	Denison	"	"	" "	670	" " "
12	Jan. 15	07:34	2.2	Quirke	"	"	" "	420	" " "
13	"	21:13	2.2	"	"	"	" "	475	" " "
14	Jan. 16	07:59	2.2	"	"	"	" "	375	" " "
15	Jan. 23	02:51	1.8	"	Fault slip?	H.W.?	Quartzite	465	" " "
16	Jan. 24	16:18	2.5	"	Pillar	Orebody	Qtz. conglomerate	420	" " "
17	Jan. 27	17:43	2.4	"	"	"	" "	465	" " "
18	Feb. 3	15:28	2.7	"	"	"	" "	420	" " "
19	Feb. 5	01:37	2.1	"	"	"	" "	380	" " "
20	"	14:28	2.0	"	"	"	" "	435	" " "
21	"	21:50	2.6	"	"	"	" "	390	" " "
22	Feb. 9	07:07	2.9	"	"	"	" "	375	" " "
23	"	07:44	1.2	"	"	"	" "	365	" " "
24	"	08:00	2.8	"	"	"	" "	365	" " "
25	"	10:51	2.2	"	"	"	" "	560	" " "
26	"	12:20	2.8	"	"	"	" "	365	" " "
27	"	13:02	2.2	"	"	"	" "	375	" " "
28	"	15:39	2.2	"	"	"	" "	340	" " "
29	"	20:16	2.8	"	"	"	" "	475	" " "
30	Feb. 10	00:46	1.9	"	"	"	" "	375	" " "
31	"	03:46	2.0	"	"	"	" "	470	" " "
32	"	13:54	2.0	"	"	"	" "	375	" " "
33	"	23:33	2.3	"	"	"	" "	450	" " "
34	Feb. 12	11:24	2.2	"	"	"	" "	365	" " "
35	Feb. 13	12:08	2.6	"	"	"	" "	360	" " "
36	Feb. 15	09:59	2.5	"	"	"	" "	410	" " "
37	"	10:40	2.0	"	"	"	" "	425	" " "
38	"	16:53	2.0	"	"	"	" "	365	" " "
39	Feb. 16	19:29	2.0	"	"	"	" "	360	" " "
40	Feb. 17	06:54	2.1	"	"	"	" "	345	" " "
41	"	10:01	2.2	"	"	"	" "	470	" " "
42	"	13:31	2.4	"	"	"	" "	425	" " "
43	"	15:32	2.1	?	?	?	?	?	" " "
44	"	21:03	3.0	Quirke	Pillar	Orebody	Qtz. conglomerate	375	" " "
45	Feb. 18	03:14	2.3	"	"	"	" "	460	" " "
46	Feb. 27	17:38	2.4	Quirke	Pillar	Orebody	Qtz. conglomerate	365	Stope and pillar
47	Mar. 5	04:38	1.8	"	Fault slip?	H.W.?	Quartzite	420	" " "
48	Mar. 10	17:15	1.9	"	Pillar	Orebody	Qtz. conglomerate	360	" " "
49	Mar. 11	00:36	2.1	"	"	"	" "	470	" " "
50	Mar. 12	12:05	2.6	"	"	"	" "	370	" " "
51	Mar. 14	01:38	2.1	"	"	"	" "	525	" " "
52	"	23:01	2.0	"	"	"	" "	420	" " "
53	Mar. 16	02:27	2.2	"	"	"	" "	570	" " "
54	Mar. 23	11:18	2.5	"	"	"	" "	470	" " "
55	Mar. 24	04:43	2.2	"	"	"	" "	420	" " "

Table 1 (Cont'd)

No.	Date	Time*	Magnitude	Mine	Type	Place	Rock	Depth, m	Mining method
56	Apr. 1	21:14	2.0	"	Pillar	Orebody	Qtz. conglomerate	390	Stope and pillar
57	Apr. 2	02:55	2.4	"	"	"	" "	385	" " "
58	Apr. 4	09:22	2.8	"	"	"	" "	525	" " "
59	Apr. 5	01:49	1.5	"	"	"	" "	525	" " "
60	"	22:04	2.8	"	"	"	" "	430	" " "
61	"	22:08	1.9	"	"	"	" "	450	" " "
62	Apr. 6	23:38	1.8	"	Fault slip?	H.W.?	Quartzite	435	" " "
63	Apr. 13	10:57	2.0	"	Pillar	Orebody	Qtz conglomerate	375	" " "
64	Apr. 15	05:40	2.0	"	"	"	" "	380	" " "
65	Apr. 18	22:49	2.2	"	"	"	" "	450	" " "
66	Apr. 20	18:26	2.1	"	Fault slip?	H.W.?	Quartzite	435	" " "
67	Apr. 25	08:38	2.2	"	Pillar	Orebody	Qtz conglomerate	365	" " "
68	May 21	04:17	2.2	"	"	"	" "	375	" " "
69	"	04:41	2.2	"	"	"	" "	345	" " "
70	May 31	21:31	2.2	"	"	"	" "	520	" " "
71	June 5	14:13	2.1	"	Fault slip?	H.W.?	Quartzite	495	" " "
72	June 20	01:28	2.5	"	Pillar	Orebody	Qtz conglomerate	420	" " "
73	June 23	21:45	2.2	"	"	"	" "	470	" " "
74	July 16	13:41	2.2	"	"	"	" "	570	" " "
75	July 19	02:00	1.8	"	"	"	" "	570	" " "
76	"	08:41	1.9	"	"	"	" "	570	" " "
77	Aug. 8	06:47	1.9	"	Fault slip?	H.W.?	Quartzite	405	" " "
78	Aug. 20	11:11	2.5	"	Pillar	Orebody	Qtz conglomerate	550	" " "
79	Aug. 25	22:41	2.0	"	"	"	" "	390	" " "
80	Sept. 3	22:07	2.4	"	"	"	" "	570	" " "
81	Sept. 15	21.10	2.0	"	"	"	" "	535	" " "
82	Sept. 17	06:06	1.6	"	Fault slip?	H.W.?	Quartzite	465	" " "
83	"	06:46	2.0	"	Pillar	Orebody	Qtz conglomerate	460	" " "
84	Oct. 29	02:30	2.1	"	"	"	" "	570	" " "
85	Nov. 8	10:06	2.3	"	"	"	" "	405	" " "
86	Nov. 17	10:16	2.2	"	Fault slip?	H.W.?	Quartzite	405	" " "
87	Nov. 27	19:36	2.0	"	Pillar	Orebody	Qtz conglomerate	395	" " "
88	Nov. 29	08:27	1.9	"	"	"	" "	420	" " "

* EST & EDT

H.W. - Hanging wall

Table 2 - Recorded rockbursts in Ontario mines in 1985 - Red Lake area

No.	Date	Time*	Magnitude+	Mine	Type	Place	Rock	Depth, m	Mining method
1	Mar. 20	12:28	2.0	Dickenson	Pillar	Orebody	Andesite	750	Cut-and-fill
2	Apr. 26	12:33	2.3	Campbell	"	"	"	840	" " "
3	Aug. 8	03:48	1.9	Dickenson	?	?	?	?	?
4	Dec. 2	16:51	1.5	"	Pillar	Orebody	Andesite	555	Old shrinkage
5	Dec. 7	22:27	2.0	"	"	"	"	540	"

* CST & CDT

\+ Magnitude estimated from Sandia records

Table 3 - Recorded rockbursts in Ontario mines in 1985 - Sudbury area

No.	Date	Time*	Magnitude	Mine	Type	Place	Rock	Depth, m	Mining method
1	Feb. 6	13:33	2.6	Strathcona	?	?	?	?	?
2	Feb. 17	12:05	1.7	"	?	?	?	?	?
3	Feb. 23	00:05	2.4	"	?	?	?	?	?
4	Mar. 8	16:49	2.6	Creighton	Pillar	Orebody	Sulphides	1800	Cut-and-fill
5	Mar. 24	06:33	1.6	Garson	"	"	"	1100	Vert. retreat blast
6	Apr. 10	17:24	2.5	Strathcona	Strain	F.W.	Gneiss	625	Cut-and-fill
7	Apr. 17	01:20	2.0	Falconbridge	Fault slip	"	Norite	1540	" " "
8	"	01:23	1.7	"	" "	"	"	1455	" " "
9	May 2	04:16	1.9	Strathcona	Pillar	"	Gneiss	720	Blasthole
10	May 6	10:02	2.2	"	Fault slip	"	"	720	"
11	June 9	07:15	2.3	Lockerby	Strain	H.W.	Granite	1035	"
12	"	07:33	2.6	"	"	"	"	1035	"
13	"	11:23	1.3	"	"	Orebody	Sulphides	1035	"
14	June 27	21:54	1.9	Garson	"	F.W.	Norite	1220	Vert. retreat blast
15	July 4	03:06	1.8	Creighton	"	H.W.	"	1645	Undercut-and-fill
16	Aug. 6	11:15	1.7	Garson	Shear	F.W. contact	"	1100	Vert. retreat blast
17	Aug. 29	01:08	2.8	Creighton	Pillar	Orebody	Sulphides	2070	Cut-and-fill
18	Sept. 10	00:31	2.6	"	Strain	F.W.	Granite	1525	Undercut-and-fill
19	Sept. 18	04:14	1.7	"	Pillar	Orebody	Sulphides	1705	Cut-and-fill
20	Nov. 2	01:35	2.9	"	"	"	"	1830	" " "
21	"	07:44	2.0	"	Strain	F.W.	Granite	1585	Vert. retreat blast
22	"	08:39	2.5	"	"	"	"	1585	" " "
23	Nov. 9	05:41	2.2	Strathcona	"	"	Gneiss	650	Cut-and-fill, Blasthole
24	Nov. 17	09:56	2.7	"	Fault slip	"	"	700	Blasthole
25	Nov. 19	11:45	2.2	"	" "	H.W.	Norite	580	Cut-and-fill
26	Dec. 18	05:46	2.3	"	Strain	F.W.	Gneiss	650	" " "
27	Dec. 20	02:41	2.5	Creighton	Pillar	Orebody	Sulphides	1890	" " "
28	Dec. 21	15:32	3.1	Strathcona	Fault slip	F.W.	Gneiss	700	Blasthole
29	Dec. 24	18:40	1.8	"	" "	"	"	790	"
30	"	20:02	1.5	"	" "	H.W.	Norite	750	"
31	Dec. 26	02:25	2.1	"	" "	F.W.	Gneiss	750	"

* EST & EDT

F.W - Footwall

H.W. - Hanging wall

Table 4 - Recorded rockbursts in Ontario mines in 1985 - Kirkland Lake area

No.	Date	Time*	Magnitude	Mine	Type	Place	Rock	Depth, m	Mining method
1	May 23	06:54	2.4	Macassa	Pillar	Orebody	Tuff/	1950	Cut-and-fill
2	Sept. 24	02:05	2.4	"	"	"	Syenite/	1745	" " "
3	Dec. 8	04:22	1.8	"	?	?	Porphyry	?	" " "

* EST & EDT

In all, 127 rockbursts were recorded, ranging in magnitude (2) from 1.2 to 3.1. The events in the Quirke Mine at Elliot Lake continued to dominate the statistics, accounting for 70% of the total (cf. 55% in 1984). Pillar bursts in thin tabular orebodies (i.e., in Quirke, Denison, Campbell, Dickenson, and Macassa mines) are still the most common rockburst mechanism, representing 70% of the events. Fault-slip-type rockbursts are thought to have occurred in Strathcona Mine and in the hanging wall above Quirke Mine, and to represent about 15% of the total. Six rockbursts recorded on the regional seismograph network could not be located by either the microseismic system or visual observations in the mines.

All the rockbursts in Quirke and Denison mines at Elliot Lake occurred in the old, mined-out workings and relate to past mining practice. All the rockbursts at Red Lake, Sudbury, and Kirkland Lake mines occurred in active mining areas and relate to present mining practice.

The frequency of rockbursts of varying magnitude (M_N) is plotted as a semi-log relationship in Figure 1 together with the curve for the 1984 rockbursts. The straight-line relationship between M_N = 2.1 to 3.5 observed in the 1984 results is only evident between M_N = 2.1 to 2.7 in 1985. The sections of the mines (i.e., Falconbridge No. 5 Shaft and Creighton) that experienced large rockbursts in 1984 were closed down immediately after those occurrences. Consequently, neither mine contributed to the 1985 activity, which could explain some of the decrease in the number of large rockbursts.

For earthquakes, the relationship between frequency and magnitude comes from naturally occurring seismologic forces, whereas for rockbursts the forces are mining-induced and this type of relationship may not always apply.

ROCKBURSTS AT ELLIOT LAKE MINES

Rockburst activity in 1985 at Rio Algom's Quirke Mine was a continuation of that which began in September 1984. All the 59 events of 1984 and the 88 events of 1985 (see Table 1) are plotted on a partial plan of Quirke Mine and the adjacent Denison Mine in Figure 2. Both companies are mining the same gently dipping conglomerate reefs using a stope (or room) and pillar layout.

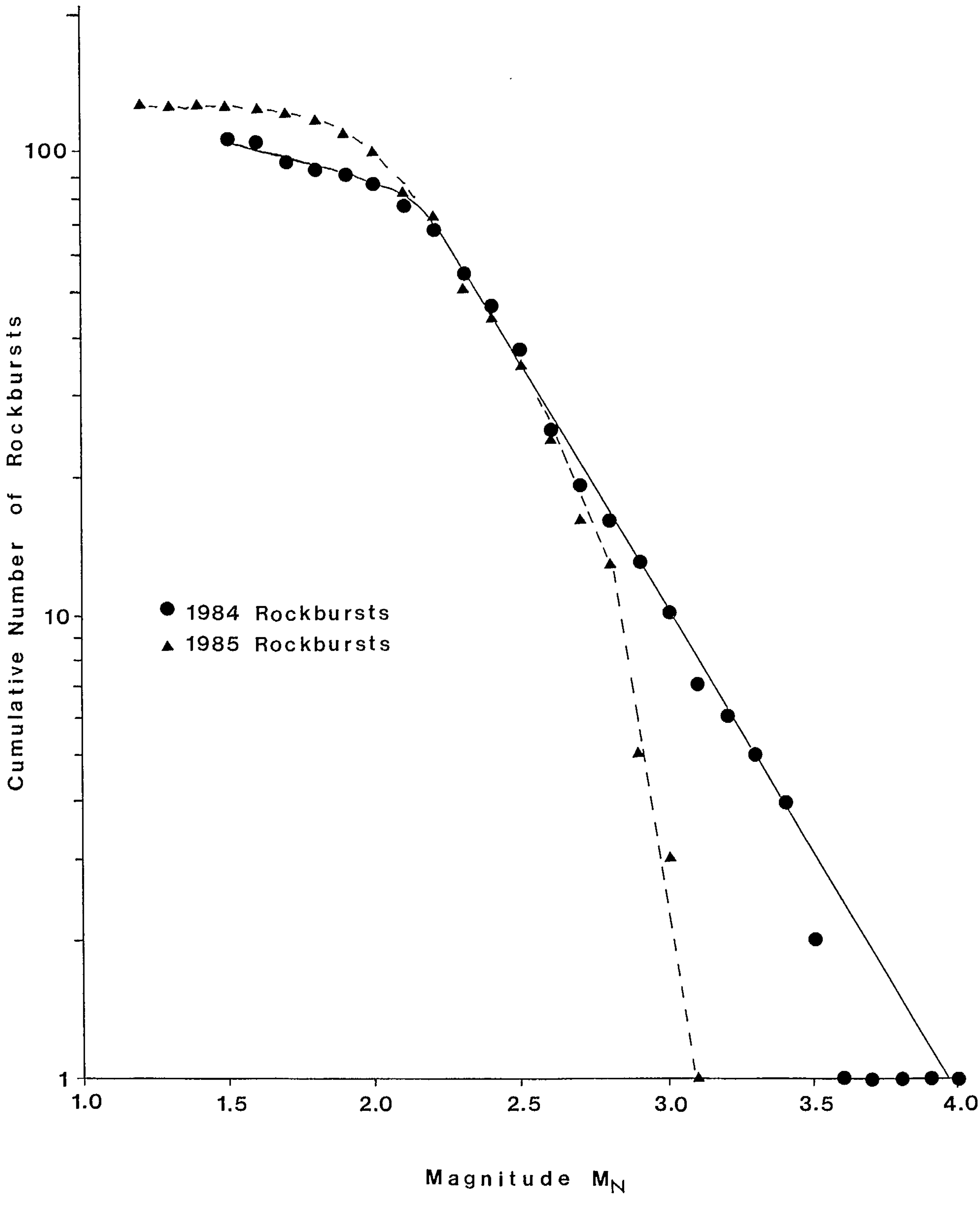

Fig. 1 - Frequency-magnitude relationships

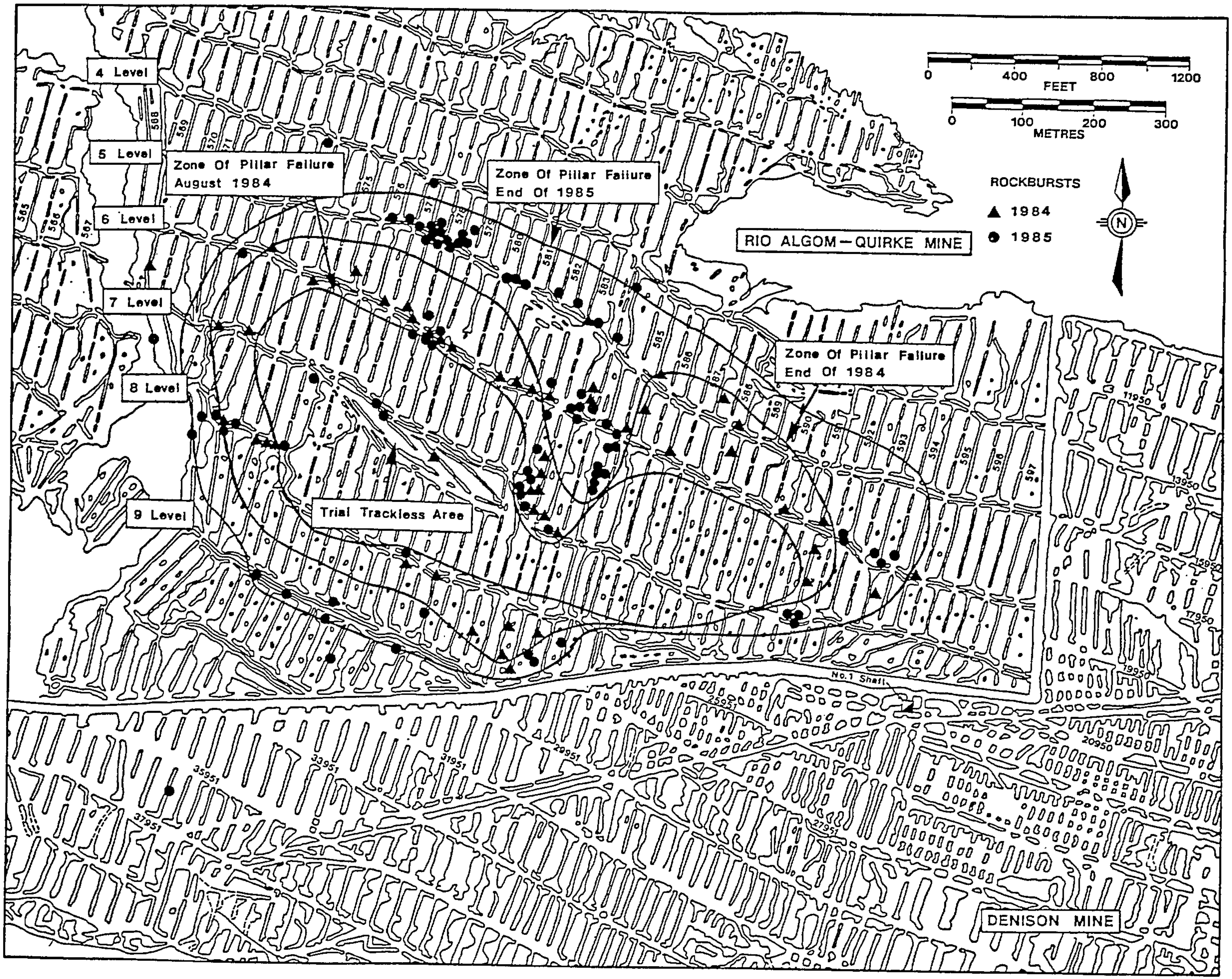

Fig. 2 - Partial plan of Quirke and Denison mines showing 1984/85 rockburst locations

Rockbursts first occurred in the east part of Quirke Mine during March 1982. Seismic activity has continued since then with varying intensity. In August 1982, a 16-channel, ElectroLab microseismic system was installed for locating seismic events. This system was subsequently expanded to 32 channels and is shared with Denison Mine to obtain better coverage of the boundary pillar area between the two mines.

By August 1984, it was estimated that the zone of pillar failure at Quirke Mine extended 870 m on strike by 300 m on dip (see Fig. 2). Some large pillars just to the northeast of a trial trackless area were holding back failure in this area. At that time, it was still considered that the main roof was spanning the failure zone without major breakdown.

Major rockburst activity in the pillars occurred again in September 1984, and continued almost without interruption until April 1985, and sporadically after that. First, the sill pillars on the 6 level failed, increasing the span on dip to 420 m. In February 1985, the 5 level sill pillars failed, increasing the span to 520 m, and, during August and September 1985, the 9 level sill pillars failed, increasing the span to 600 m on dip. The affected area also expanded to the east and west, and there was a large concentration of rockbursts around the large pillars northeast of the trackless area. By the end of 1985, the estimated zone of pillar failure extended about 1100 m on strike by 600 m on dip (see Fig. 2).

Two isolated rockbursts occurred in Denison Mine during January 1985. One of these is plotted on Figure 2 south of Quirke Mine; the other occurred about 1200 m east of Quirke Mine.

The pattern of rockburst activity during 1984-85 was predominantly a spreading-out of the affected area with violent pillar failures occurring around the periphery. However, a few rockbursts occurred near the centre of the affected area. The first of these, during December 1984, was located in the centre of the trial trackless area. Visual observations, during July 1982, had indicated that the pillars had failed. Consequently, it was suspected that the rockburst had occurred in the hanging wall. During 1985, additional rockbursts occurred in the same area (i.e., those inside the zone of pillar failure, end of 1984), including some on the 6 level sill which had failed during September 1984. All these rockbursts in the central zone were intermediate in size, with magnitudes of 1.6 to 2.2.

Additional evidence of breakdown of the hanging wall came from the increase in water flowing from the rockburst area. In February 1985, the inflow increased from 1.3 L/s to 4.2 L/s, with a large increase to 17 L/s in April 1985. Since that time, the water flow has fluctuated between 15 L/s and 19 L/s. Also on surface, almost directly above the rockburst area, the water level of a beaver pond dropped by about 4 m sometime between April and December 1985, which represented a loss of about 75 million litres of water.

Both the seismic and water inflow data suggested that the hanging wall had fractured above the rockburst zone, centred on the trial trackless area. The first major breakdown probably occurred during December 1984, when the partially supported span on dip was 420 m. This breakdown accelerated in February 1985, when the span increased to 520 m and, in September 1985, to 600 m. The average depth below surface in this area is about 500 m. It is interesting to note (see Fig. 2) that no rockbursts have been recorded at the centre of the eastern part of the rockburst zone. The partially supported span on dip is about 360 m in this area.

ROCKBURSTS AT RED LAKE MINES

Five rockbursts occurred in 1985 at Red Lake mines; four at Dickenson Mine and one at Campbell Mine (see Table 2). This number was a significant decrease from the 26 rockbursts recorded in 1984.

The rockburst at Campbell Mine occurred in the 'L' ore zone in a pillar between a haulage drift and an overlying cut-and-fill stope. A steeply dipping fault along the axis of this orebody also runs through the pillar. Considerable microseismic activity is monitored in the area after each mining step in the stope.

The first rockburst at Dickenson Mine, on 20 March 1985, occurred at the east end of the mine in a sill pillar above a cut-and-fill stope. Originally this stope was developed for sub-level longhole stoping but was converted to cut-and-fill because of ground control problems. Widespread sloughing was observed in a nearby access drift.

The event on 8 August 1985 was felt on surface but could not be located underground. Campbell's microseismic system picked up the event but it was too far away for accurate source location.

The two rockbursts in Dickenson Mine, during December 1985, occurred near old, mined-out shrinkage stopes next to the boundary pillar with Campbell Mine (Fig. 3). These stopes were not backfilled. The most likely trigger of these rockbursts was the mining in cut-and-fill stope 1302-El on Campbell's side of the boundary, some 50 m to 90 m from where the rockbursts occurred. Campbell's microseismic system gave reasonable source locations using a "Block Solution." However, the source could not be verified because of lack of access on the Dickenson side.

ROCKBURSTS AT SUDBURY MINES

Thirty-one rockbursts occurred in Sudbury mines during 1985 (see Table 3), almost double the occurrences of the previous year. Nineteen of these rockbursts occurred in Falconbridge's mines (Strathcona, Lockerby, and Falconbridge No. 5 Shaft) and 12 in Inco's mines (Creighton and Garson).

In 1984, the Falconbridge No. 5 Shaft experienced a series of major rockbursts associated with slippage along prominent faults in the footwall, as a consequence of which the mine was closed. However, minor seismic activity continued to be monitored on the mine's microseismic system. On 17 April 1985, two rockbursts of magnitude 2.0 and 1.7 occurred within three minutes of each other. They were located on the 4775 and 5050 levels and in one of the prominent fault structures (i.e., Ore Pass Fault) which played a major role in the 1984 incidents. However, they were much deeper than the previous seismic activity, which was mainly confined to between the 3325 and 4200 levels. It is not known what triggered these 1985 rockbursts because no mining had taken place during the previous ten months.

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*With contributions by D. Morrison, Falconbridge Ltd., and P. MacDonald, Inco Ltd.

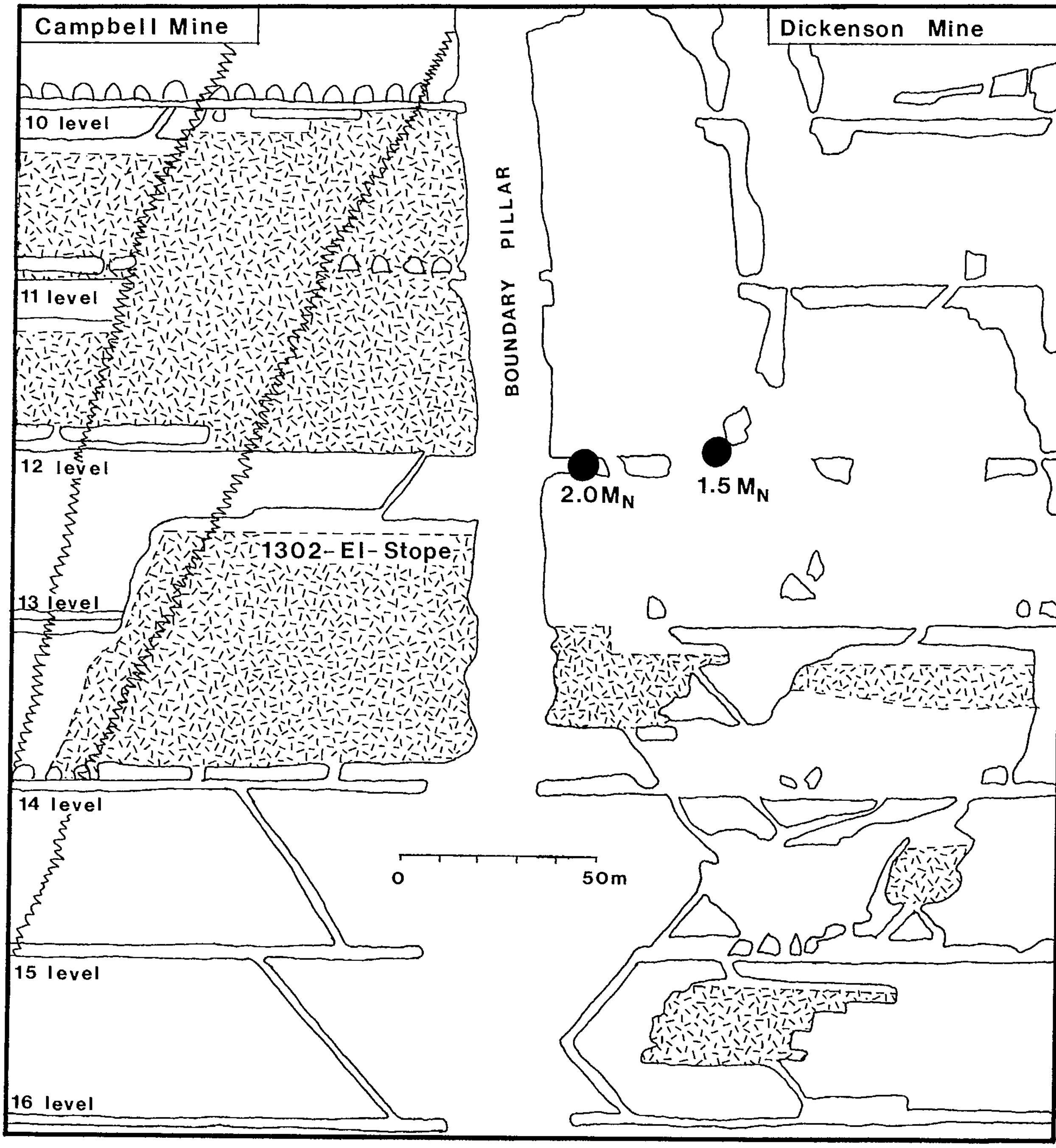

Fig. 3 - Rockbursts around the boundary pillar between Campbell and Dickenson mines

Falconbridge's Lockerby Mine is located on the southwest rim of the Sudbury Basin. The almost-vertical, lenticular orebody, up to 55 m wide, extends to a depth of 1300 m. A blasthole stoping method with delayed cemented backfill is used. A 16-channel, microseismic monitoring system was installed at the mine in early 1985. On 9 June 1985, three rockbursts of magnitude 2.3, 2.6, and 1.3 occurred within four hours, accompanied by many microseismic events. Most of this activity occurred in the hanging wall granites near the 34 level (1035 m depth). The first two rockbursts were located near an ore/waste pass system about 40 m into the hanging wall and significant damage was observed around these passes. Just 15 days previously part of a pillar directly opposite the ore/waste passes had been blasted, which would have altered the stress distribution. The mechanism could have been either strain energy resulting from high stress concentrations around the passes or slippage along prominent joint sets dipping at about 30° towards the orebody. The third smaller rockburst occurred in a pillar at the extremity of the orebody and was probably associated with a changing stress pattern resulting from the first two rockbursts.

Falconbridge's Strathcona Mine lies on the northwest rim of the Sudbury Basin. The orebody is about 800 m along strike and lies between 500 and 930 m depth. It varies in width from 30 m in the west, where it dips 70° to the south, to more than 300 m in the east where the dip is about 40°. Mineralization is in the late granite breccia which lies between the hanging wall norites and the footwall feldspathic gneisses.

Production began in 1968 using cut-and-fill techniques, but, by the mid-1980's, about half of the 1 million tons per year came from blasthole stoping with delayed backfill. The major ore reserves are in a large sill pillar between the 2250 and 2500 levels (685 m to 760 m depth).

Minor seismic activity dates back to the early 1970's, but increased significantly in the fall of 1984. In February 1985, three rockbursts of magnitude 2.6, 1.7, and 2.4 were felt throughout the mine. Although some damage was found, they could not be definitely located. This uncertainty led to the installation of a 32-channel, microseismic system which became operational in June 1985. In addition, new support techniques and restrictions on time of blasting were introduced.

The microseismic system identified that a 1-m-wide, olivine diabase dyke at the west end of the orebody was the major source of seismic activity. This dyke dips at about 70° to the northeast and cuts diagonally across the orebody. It consists of many slickensided planes and smaller dykes branch off at an acute angle, although the latter have limited continuity. Cut-and-fill stopes intersected by the dyke experienced poor ground conditions and were converted to blasthole stopes.

Figure 4 is a longitudinal section of the west end of the orebody showing the blasthole layout for mining the main sill pillar. The main diabase dyke intersects the 23-200 panel, which was one of the first stopes mined in this block. Figure 5 is a plan of the undercut level for the 23 level stopes, showing the blasting sequence in the 23-200 panel. In addition, the main and branch dyke systems are shown, together with the locations of major damage.

In the 23-200 panel, the drop raise was completed in April 1985, and the first production blast took place on October 11. Seismic activity immediately following the production blast was in the pillars to the east and along the branch dyke into the hanging wall. The production blast on October 17 produced a similar pattern of seismic activity. However, after the blasts on October 25 and November 1, seismic activity shifted to the main dyke itself, into the footwall, and still in the pillars to the east.

About 90 minutes after the production blast on November 8 a major rockburst of magnitude 2.2 occurred. Damage was found on the footwall ramp and minor water seepage was observed on the branch dyke where it intersects the 23-179 stope. Blasting was stopped in the 23-200 panel to rehabilitate the ramp area. On November 17, a rockburst of magnitude 2.7 occurred, which caused more damage to the ramp and to 179 undercut. However, the 200 panel and the intersection of the main dyke with the ramp were not affected. Additional rockbursts of magnitude 2.2 and 2.3 on November 19 and December 18 occurred in the same area.

On December 21, a 3.1-magnitude rockburst completely destroyed the ramp over a distance of 50 m with caving extending up to 10 m above the original roof. The entire area was subsequently abandoned and the damaged area was backfilled, including the 23-200 panel.

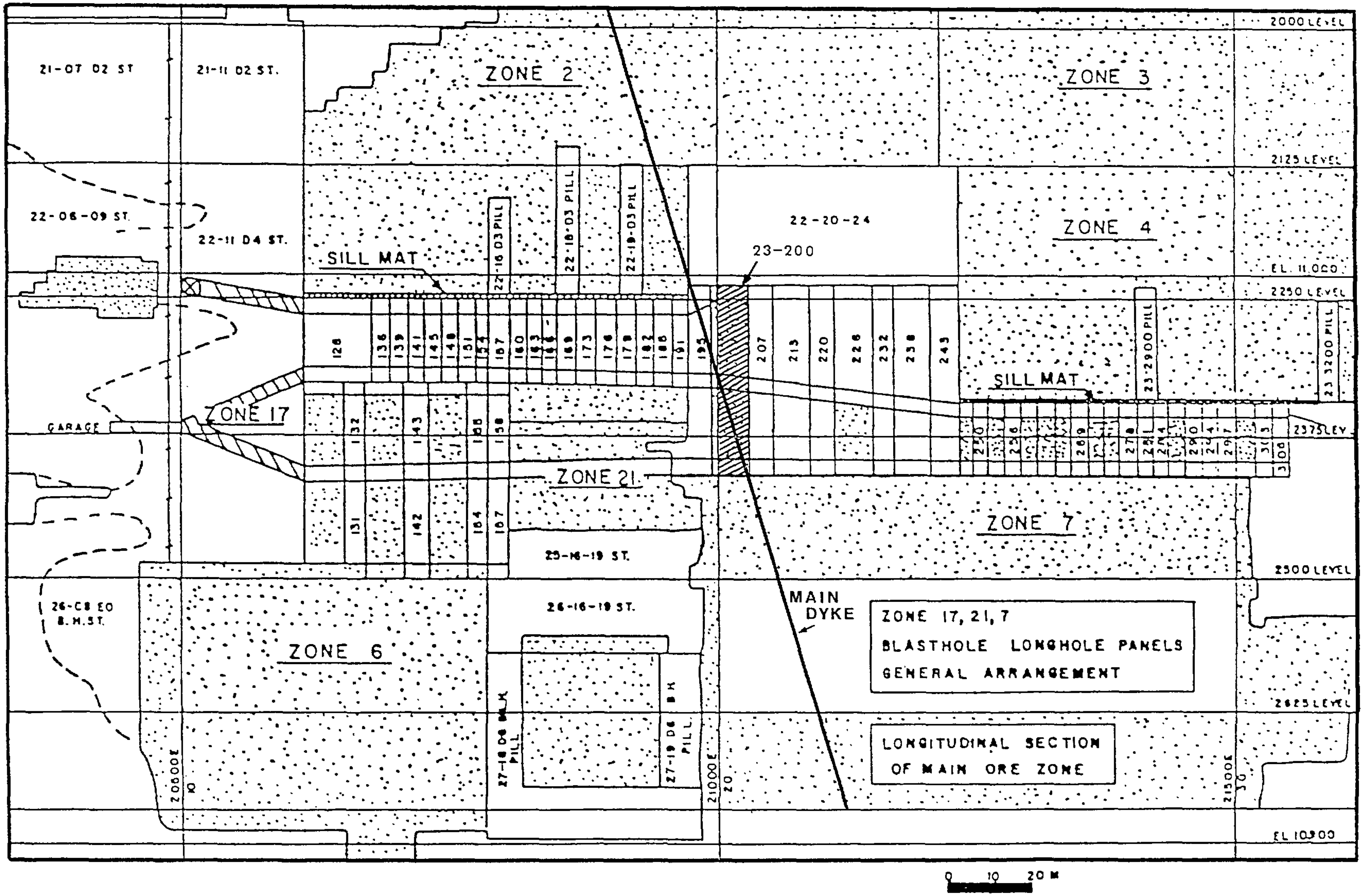

Fig. 4 - Longitudinal section of Strathcona Mine with blasthole layout

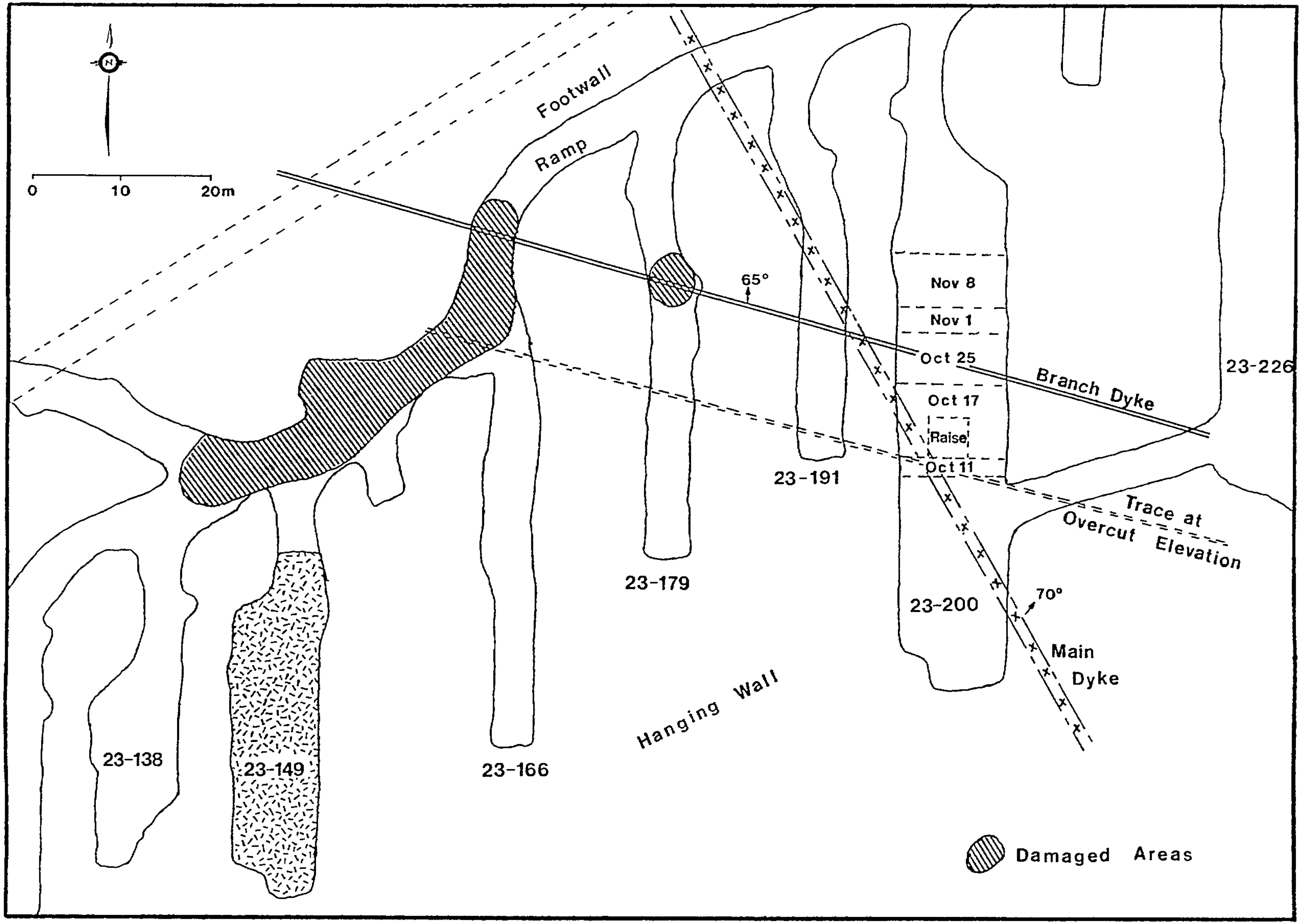

Fig. 5 - Plan of 23 level undercut showing geologic structure, blasting sequence and damage

It appears that the main mechanism of rockbursts at the Strathcona Mine is fault slippage. The main- and branch-dyke systems can be considered as a shear plane with associated tension gashes. Mining the 23-200 panel altered the stress regime on the main dyke and allowed minor stick-slip on the slickensided planes. Accumulated slippage along this dyke would eventually reactivate the branch dykes. On the hanging wall side damage occurred in a series of small seismic events, whereas on the footwall side the magnitude and damage was much greater.

On 6 July 1984, a series of rockbursts occurred at Inco's Creighton Mine. The first rockburst in the series had a magnitude of 4.0, the largest recorded in two decades. These bursts were located in the middle section of the mine between depths of 975 and 1220 m. In addition, in 1984, two isolated rockbursts occurred in the deeper levels. During 1985 nine rockbursts were recorded (see Table 3), all located in the deeper levels between 1520 m and 2070 m.

At depth, the main orebody (400) strikes east-west over a length of about 400 m, with an average width of 60 m, dipping about 65° to the north. It extends to a depth in excess of 2200 m. The ore consists of massive sulphides at the footwall grading to disseminated sulphides at the hanging wall. Mechanized cut-and-fill is the predominant method of extraction.

A secondary orebody (403) strikes north-south over a length of about 140 m. Width varies from 30 m to 60 m and the dip is almost vertical. This orebody extends from 1460 m to 1900 m depth. It is separated by about 150 m from the east end of the 400 orebody. The ore is mainly disseminated sulphides and vertical retreat mining (VRM) is the principal method used.

Both orebodies have a history of seismicity including rockbursts resulting from the high stress conditions encountered at depth. The locations of eight of the nine 1985 rockbursts, as determined from the microseismic system, are plotted in Figure 6. Six of the rockbursts occurred in the 400 orebody and three in the 403 orebody.

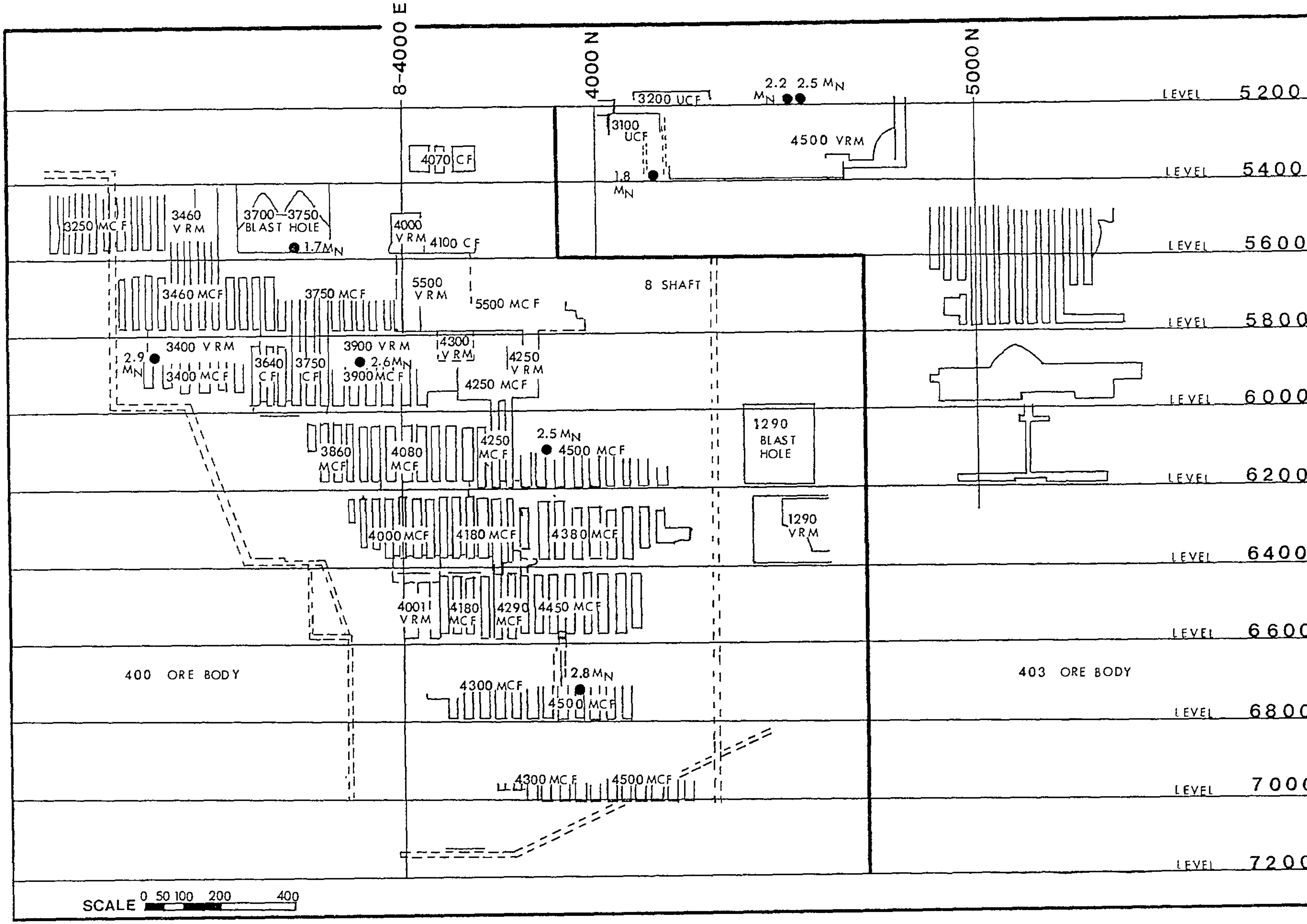

Fig. 6 - Composite longitudinal section showing location of rockbursts at Creighton Mine in 1985

Most of the rockbursts in the 400 orebody were located in the backs of cut-and-fill stopes, which had progressed at least half their height to the level above. These could be seen as bursting of the crown pillars, and the magnitudes were relatively high; 2.5 to 2.9. The 2.6-magnitude event on the 5000 level was located where a quartz diorite dyke intersects a footwall drift. On the 5600 level, a 1.7-magnitude rockburst occurred in the drawpoint of a blasthole stope.

In the 403 orebody a 1.8-magnitude event was located in the chutes of an undercut-and-fill stope. On 2 November 1985, two rockbursts occurred within an hour of each other on the 5200 level and 2 1/2 hours after a blast in the crown pillar of an adjacent VRM stope. Coincidentally, a rockburst of 2.9 magnitude occurred in the 400 orebody some 6 hours earlier. All the 1985 rockbursts at Creighton Mine took place near active mine workings and the mining activity was probably the triggering mechanism.

The three rockbursts at Inco's Garson Mine, of magnitudes 1.6 to 1.9, occurred at depths of 1100 m to 1200 m near VRM stopes.

ROCKBURSTS AT KIRKLAND LAKE MINES

Only three rockbursts were recorded at Macassa Mine in 1985 (see Table 4), which was a decrease from five in the previous year. No damage could be found for the third rockburst, hence its location is unknown. The first two rockbursts, both of 2.4 magnitude, occurred in sill pillars above cut-and-fill stopes, at depths of 1745 m and 1950 m (Fig. 7).

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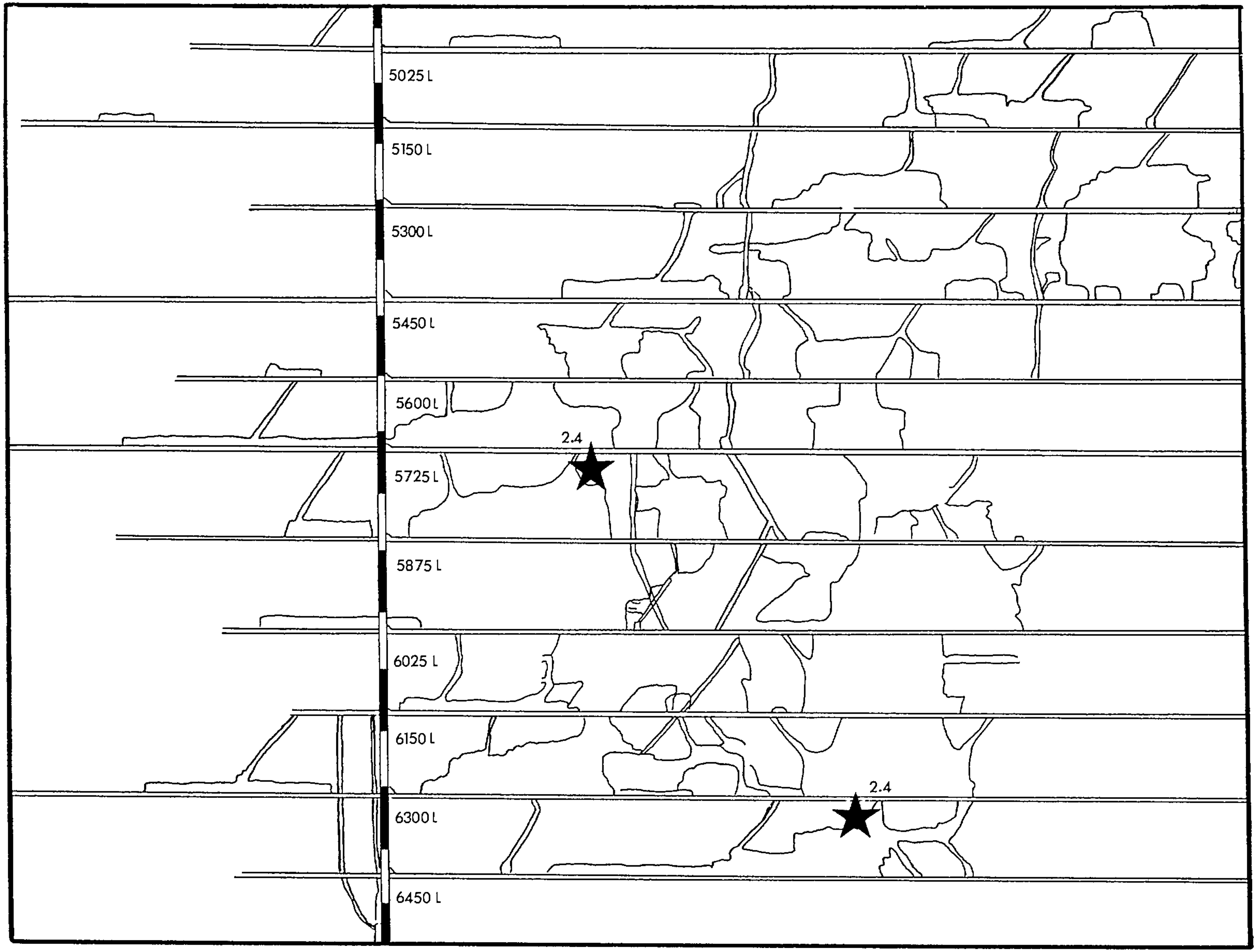

Fig. 7 - Longitudinal section of the west end of Macassa Mine showing locations of 1984 rockbursts

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