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REVIEW OF ROCKBURST INCIDENTS AT THE MACASSA MINE, KIRKLAND LAKE

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by

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ABSTRACT

Mines in the Kirkland Lake area have had a long history of rockbursts. In the past 50 years nearly 45% of all incidents in Ontario mines have occurred in these mines.

At the Macassa Mine of Lac Minerals Ltd., over 400 rockbursts ranging from "strain bursts" to "heavy bursts" were reported from a depth of 670 to 1935 m below surface. From 1984 to 1986, a number of significant events, with magnitudes from 2.2 to 3.1 M_N, were recorded on the national seismic network. Using available data an attempt was made to evaluate the ground problems encountered.

In the context of rockbursts, as the mining progressed to greater depth, high ground stresses and mining geometry as well as critical pillar configurations became significant factors. Pillar bursts were the most common rockburst mechanism which occurred both in the active and mined-out workings. In the pillar type of rockbursts, the change in potential energy of the wall rocks is probably the main source of the liberated energy. The presence of brittle, high-strength rock types as well as rocks of varying stiffness contributed to the occurrence of strain bursts in the development areas.

Rockburst incidents have increased both in number and severity at depths between 1400 to 1900 m.

Key words: Rockburst; Rock strength; Stress; Geological structure; Rock type; Mining geometry.

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Revue des coups de toit survenus à la mise Macassa de Kirkland Lake

par

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Résumé

Les mines de la région de Kirkland Lake ont été le siège de nombreux coups de toit. Au cours des 50 dernières années, 45 % de tous les coups de toit dans les mines ontariennes ont eu lieu dans les mines de cette région.

À la mine Macassa de Lac Minerals Ltée, plus de 400 coups de toit allant de "fractures de compression" à des "coups de toit majeurs" ont été signalés entre 670 et 1935 m de profondeur. De 1984 à 1986, des événements importants d'intensité comprise entre 2,2 et 3,1 M_N ont été enregistrés par le réseau sismique national. À partir des données disponibles, on a tenté d'évaluer les problèmes de terrain observés.

À mesure que les mines s'enfoncent dans le sous-sol, les contraintes de la roche, la géométrie de la mine et la configuration des piliers deviennent déterminantes pour les coups de toit. L'éclatement de piliers est la cause première des coups de toit survenus dans des chantiers tant actifs que déjà exploités. Dans ce type de coup de toit, la variation d'énergie potentielle des parois rocheuses est probablement la principale source d'énergie libérée. La présence de types de roche dure mais cassante et de roche de dureté variable a contribué aux fractures de compression dans les zones d'abattage.

Le nombre et la gravité des coups de toit ont augmenté entre 1400 et 1900 m de profondeur.

Mots clés : coup de toit; résistance de la roche; contrainte; structure géologique; type de roche; géométrie de la mine.

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There were seven operating mines in the Kirkland Lake camp but, since 1965, only the Macassa Mine continues to operate. The Lake Shore Mine, situated two properties east of Macassa, was re-opened in 1982 to recover remnant ore pillars left behind following the 1965 shutdown. Mines at Kirkland Lake have had a long history of rockbursts dating back to the early 1930's (1). Since 1935, nearly 45% of all recorded rockbursts in Ontario mines occurred in the Kirkland Lake area. The Wright-Hargreaves and Lake Shore mines were the most affected. In 1964, a large rockburst resulted in the immediate closure of Wright-Hargreaves Mine and, indirectly, the closure of the adjacent Lake Shore Mine. The ground problems were studied by various authors (2-4). It was suggested that the sequence of mining, the absence of backfill (Wright-Hargreaves Mine), the complex arrangement of structural weakness planes, and, to a certain extent, the variation in rock types were the major bursting factors encountered in these mines. A great deal of significance was given to the formation of a large number of isolated pillars which were gradually reduced in size and number. These resulted in the overstressing of several small pillars and the occurrence of violent pillar failure.

At the Macassa Mine, over 400 rockbursts, ranging from strain to heavy bursts were reported in the past 50 years of operation. But compared with the adjacent mines the rockburst problem and intensity has been less severe. However, some significant rockbursts have occurred during 1984, particularly in pillars (5).

In rockburst-prone areas, destressing has been practiced to alleviate ground failure, and an attempt has been made to identify possible rockburst potential areas by seismic velocity measurements (6).

Based on available data from visual inspections reported by the work crews, an attempt was made to review and evaluate the rockburst incidents at the Macassa Mine.

MINING BACKGROUND

The Macassa Mine property was developed by sinking four surface shafts and two internal winzes with lateral development drifts and sub-levels along the ore-bearing zones. The first mining development started about 400 m below surface in the eastern part of the property and extended down dip and towards the west. From 1933 to 1970, the main mining activities were concentrated in the eastern and central parts of the property. At present, mining operations range from between 700 to 1935 m below surface, with more than 80% of the mining activity concentrated at the west end of the mine. The western part of the mine has experienced a high ore expectancy at depth. Therefore, a new shaft was sunk to a depth of 2217 m to exploit ore reserves in this part of the property. The deepest working level is projected to be approximately 2150 m below surface.

The ore has been extracted with shrinkage and horizontal cut-and-fill mining methods. Levels are developed at 46 m vertical intervals, and, using cut-and-fill methods with waste development rock as a fill, the first 24 m height of a stope is mined. The remaining 22 m sill pillar is recovered using a modified Avoca method with 7.6 to 15.2 m long holes, again using waste development rock as fill.

GEOLOGICAL - STRUCTURAL SETTING

The Macassa Mine of Lac Minerals Ltd. is located in Kirkland Lake, Northern Ontario (District of Timiskaming). The geological setting of the deposit reflects a complex history of intermittent folding, intrusive activity, ore deposition, faulting or fracturing, and possible partial remobilization of the ore, dyke intrusion, and finally additional post ore faulting (7,8).

The principal gold-bearing zones occur along, or in close proximity to, one of several fault systems which has been designated as the Main Break, or Kirkland Lake Fault. This fault system traverses the entire length of the mine as a 0.30 to 6.0 m wide weakness plane marked by a zone of mylonitized and brecciated wall rock, chlorite schist and gouge. It is a thrust, or reverse, fault with an estimated displacement of about 460 m on the overlaying sediments.

The deeper levels of the mine exhibit a branching fault system with the development of an open split to the west forming a north and south branch to the Main Break. Another sub-parallel fault of major importance is the 04 Break which is connected to the north branch of the Main Break. The 04 Break is the main ore-bearing structure in the west part of the mine. Over the past 30 years, this fault and its allied structures have been the main source of ore in the mine. The fault systems have an east-west trend and generally dip steeply to the south.

Some post-ore fault systems with a northerly trend occur as steep dipping structures and are found to be associated with sub-parallel slips and faults exhibiting chloritization and brecciation. These cross-faults are designated as the Amikougami, Tegren, and Boundary Faults. These faults occur mainly at the west end of the mine workings. Post-ore faulting has not only affected the major EW ore-bearing Breaks, but has strongly affected both the Main Break and 04 Break subsidiary hanging wall veins. The displacement by post-ore fault systems on individual hanging wall veins reflects the large scale movement of rock masses on both the 04 Break and Main Break.

The nature of fracturing is not dependent on rock type and, in almost all cases, fractures transect all rock types. However, porphyry and particularly basic syenite contain some pronounced joint sets resulting in localized blocky masses of rock. Mineralization occurs throughout syenites, porphyry and tuff rocks as well.

Generally, wallrock alteration is confined to the major faults. Hydrothermal alteration, carbonatization, hematization, and silicification account for all the effects on the rock types in close proximity to the main faults and orebody. Often, intense discolouration is accompanied by structural deformation, i.e., crushing, brecciation and mylonitization.

REVIEW OF ROCKBURST INCIDENTS

An accurate record of source locations and the number of rockburst incidents is not possible. Since the mine does not have a microseismic monitoring system, the source locations of rockbursts are determined by the mine personnel with visual inspections. The recorded incidents are possibly only a part of the total which occurred, particularly in the old mined-out workings in the central and east areas of the mine.

In the following, rockbursts or any ground failures which have been recorded during the past 50 years of mine operation are reviewed and evaluated.

Until 1985, about 429 rockbursts were recorded, ranging from minor "strain bursts" to "heavy rockbursts". From 1936 to 1956, the rockburst incidents were not identified by location, and the data from 1975 to 1980 were not available. In Table 1, the information is given on rockburst type, frequency, and distribution by location, and the time of the incident before or after blasting underground. The distinction between strain bursts, light, medium or heavy rockbursts is arbitrary and is only based on visual observation and the amount of rock displacement involved. These local

Table 1 - Rockburst incidents by location and time, Macassa Mine.

Type of Burst	LOCATION OF BURST					TIME OF BURST			Total	Unidentified By Location or Time
	OREBODY			WASTE						
	Stope	Drift	Raise	By-Pass Dr.	Cross-cut	Before Blast	After Blast	Unknown		
Strain burst	118	26	9	6	15	100	34	40	174	49
(<5 ton)	67.8%	15%	5.2%	3.5%	8.6%	57.5%	19.5%	23.0%	51.2%	
Light burst	38	14	1	2	4	15	23	21	59	19
(5-15 ton)	64.5%	23.7%	1.7%	3.4%	6.7%	25.4%	39.0%	35.6%	17.4%	
Medium burst	44	10	2	1	7	20	31	13	64	15
(15-50 ton)	68.7%	15.6%	3.1%	1.6%	11.0%	31.3%	48.4%	20.3%	18.8%	
Heavy burst	26	11	-	1	5	12	24	7	43	6
(>50 ton)	60.5%	25.6%		2.3%	11.6%	27.9%	55.8%	16.3%	12.6%	
Total	226	61	12	10	31	147	112	81	340	89
Percentage	66.5%	18.0%	3.5%	2.9%	9.1%	43.2%	33.0%	23.8%	100%	—

classification terms are used throughout the report. Since the ore shoots occur on either side of the fault systems, the mining excavations are not confined to the hanging wall or footwall. Therefore, in most cases, a distinction was not made between the events which occurred in the hanging wall or footwall.

From reviewing the available data, it was found that the most affected areas were the pillars and the hanging walls/footwalls of large stopes. In most rockburst-prone areas, the strain bursts were usually followed by light, medium or heavy rockbursts. The strain bursts were the dominant type, which account for about 52% of all ground failures encountered. Nearly 18.2% of incidents can be identified as light and 18.4% as medium rockbursts. The remaining 11.4% were identified as heavy rockbursts. The volume of rock displacement involved in this type of burst ranged between 50 to over 1000 tons of rock.

According to the reported incidents, it appears that spalling and flaking in the excavation face, or some minor rockfalls, were often described as strain bursts.

A stope/pillar burst was the most common rockburst mechanism in the mining excavations. From 340 rockbursts which were identified by location, 70% occurred in the mined-out workings within the orebody, i.e., pillars and stope hanging walls or footwalls and raises. The remaining 30% were distributed in the development drifts, by-pass drifts or cross-cuts. The most common mining method at, or near, locations where rockbursts occurred was cut-and-fill.

The timing of rockburst events before or after blasting underground seems to be vague and nearly 23% are unknown. However, it was found that 57.5% of the strain bursts occurred before blasting and most of the light, medium and heavy rockbursts were observed after blasting.

Rockburst events were reported from a depth of 670 to 1935 m below surface with a preponderance between 1400 to 1650 m reflecting where most mining was taking place. Figure 1 shows the rockburst frequency by working levels. The highest frequency was concentrated in the proximity of the 1500 m level.

From 1984 to 1986, a number of significant rockbursts occurred at the Macassa Mine. These were recorded on the Eastern Canada seismic network. The events, which were concentrated mainly in the west end of mining developments, had magnitudes ranging from 2.2 to 3.1 M_N. Most of the damage was observed in the levels and sub-levels within the orebody. Generally, all events followed the previous rockburst activities observed in these areas. The most extensive rockburst, with a magnitude of 3.1 M_N, occurred in the pillars on the 6150 level, in the area between 61-38 and 63-38 stopes. After the event, about 130 m of the drift (61-04 Dr.) below the affected stoping area was closed. The estimated rock displacement was over 1000 tons. Some minor damage was observed in the cross-cuts and drifts around the rockburst area.

The remaining recorded rockbursts, pillar and strain bursts, occurred on the following working levels:

4600 level : 47-04 3D stope,
5300 level : 53-33 stope,
5725 level : 58-38 stope, inclined raise and 57-04 drift,
6025 level : isolated drift in the proximity of No. 3 shaft,
6300 level : 63-32 stope, 64-33 stope,
6450 level : 64-23 stope, sill pillar, drifts above and below the stope.

In these stopes, the majority of damage was concentrated in relatively limited areas. Predominantly the drifts in the immediate proximity of the large stopes, sill pillars, and the intersection of raises and the back of

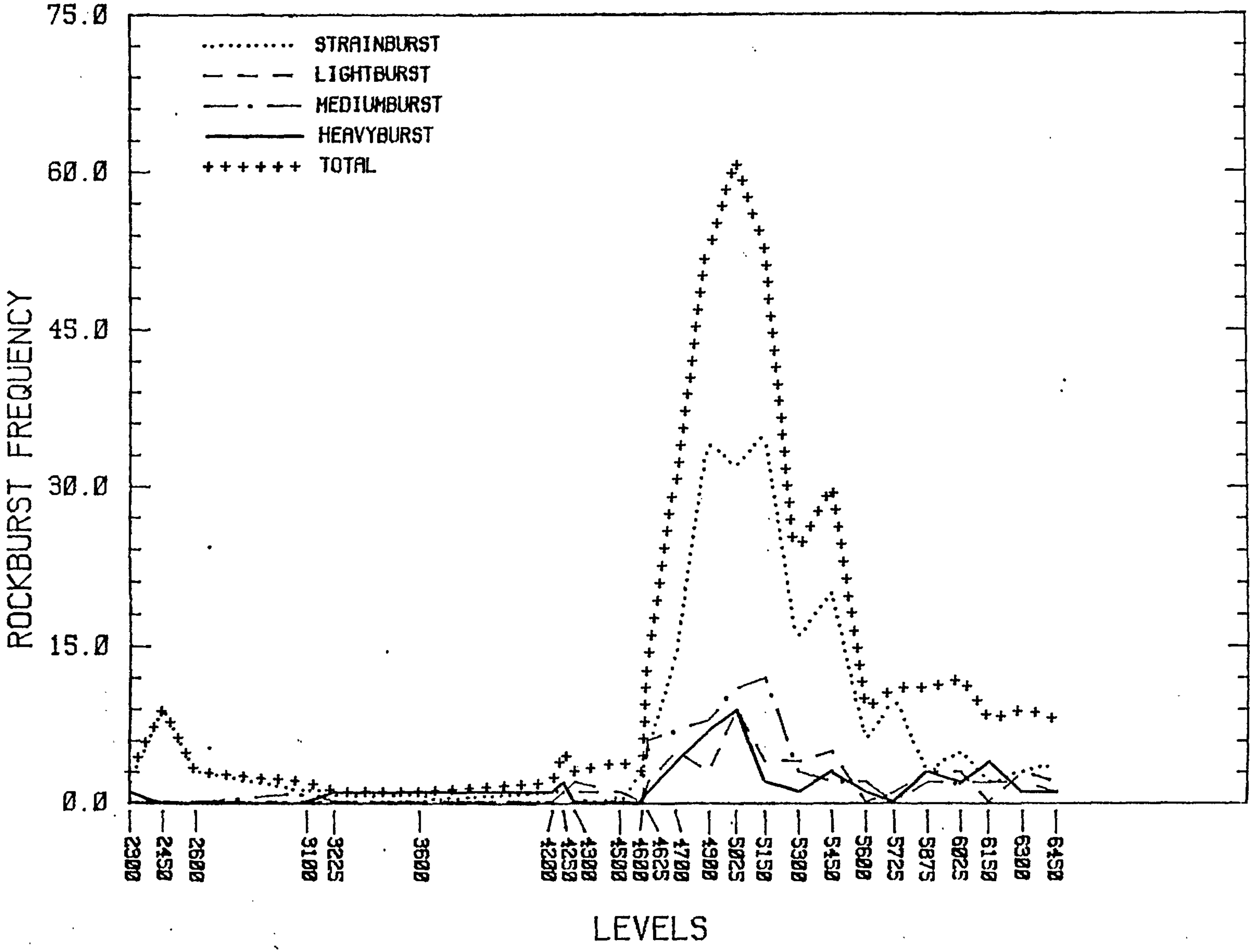

Fig. 1 - Distribution of rockbursts by working levels, Macassa Mine.

stopes were affected. Extensive slabbing and rock displacement, ranging from 5 to 50 tons, occurred in the affected locations, usually with no noticeable damage to the adjacent stopes. Most events were recorded after stope blasting.

Figure 2 shows the location of rockburst events recorded on the Eastern Canada seismic network, and the distribution of "heavy rockbursts" from visual observations.

Although useful information was gained on rockburst events from visual observations, the results indicated that a more quantitative scheme of data collection was desirable. Comprehensive data recording should include more details on the structural features and rock types.

DISCUSSION

For most mined-out workings in the central and east areas of the mine, direct field evidence for the ground failures is not available. The information is insufficient regarding mining geometry at the time of the events, the geological structural features, and the rock types. It was not possible to make an examination of old mine workings in order to obtain detailed information from the affected areas, therefore, the evaluations in these areas are based on the available data.

More background information, however, is available from the west end of the mining development where the recent rockburst events have been reported.

It is not within the scope of this report to deal in detail with the phenomenon of rockbursts. In the following, however, possible rockburst mechanisms and the parameters involved are briefly discussed:

a) Some local ground problems which accompanied mining developments appear to be structurally-controlled instabilities. The presence of unfavourably oriented major weakness planes with slips and pronounced multiple jointing

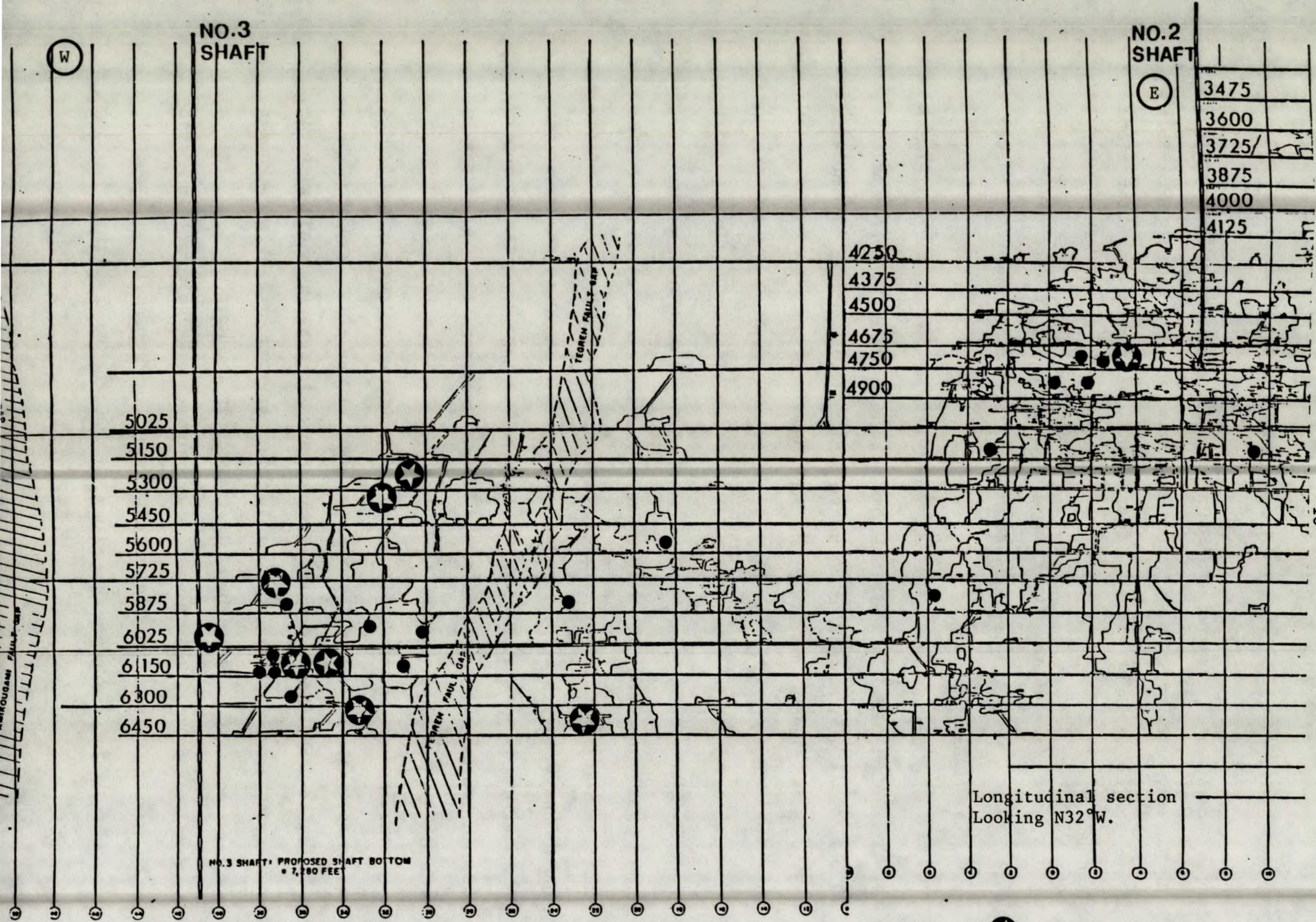

Fig. 2 - Location of rockbursts on the west and central area at the Macassa Mine. (✪) Recorded rockbursts, magnitude 2.2 to 3.1 MN. (●) observed "heavy rockbursts", rock displacement >50 tons.

can be intimately linked to deterioration and minor ground falls which have occurred in the development drifts, stope faces both in the hanging wall and footwall. The overall rock mass strength was controlled by the structural features which resulted in kinematic failures of potentially unstable wedges and blocks defined by weakness planes.

In general, structural features associated with any infilling, carbonatization, brecciation and alteration have, to a certain extent, influenced the mining stability in the immediate area.

b) The principal ore-bearing zones occur along the E-W trending faults (Main Break and 04 Break), and the mining is confined to the hanging wall and footwall of the fault system. Since the clamping stresses on the faults are considered to be large, it is unlikely that slippage will occur. No evidence of slippage has so far been observed along the northerly trending post-ore fault zones at the west area of the mine.

c) Mechanical rock property tests indicated that porphyry and tuff, compared to the syenite and siliceous basic syenite, were brittle and stiffer rock members at the mine. Uniaxial compressive strengths of porphyry and tuff ranged from 193 to 230 MPa, and the mean strength for the syenite rocks of about 145 MPa was determined. In addition, higher moduli of elasticity were obtained from tuff and porphyry rocks. Seismic velocity measurements, e.g., in the west area of the mine, showed some variations for different rock types (9).

With regard to high strength and modulus, and the variations observed, the function of mechanical rock properties are of some significance in the context of mining instability. This function can be defined as follows:

The strain energy stored in a rock is equal to:

$$U = \frac{1}{2E} [\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\upsilon(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_2\sigma_1)]$$

where, U is stored strain energy, per unit volume

σ_1, σ_2 and σ_3 are the principal stresses

E is deformation modulus,

ν is Poisson's ratio.

Hence, for constant stress levels the brittle high-modulus rock (e.g., tuff and porphyry) stores less energy than the soft low-modulus rock (e.g., syenites). This is counteracted, to a certain extent, in that a brittle rock has a higher compressive strength than soft rock. Perhaps a more important parameter than stored strain energy is the energy consumed in fracturing the rock. After failure, brittle rock rapidly reduces to zero stress with very little displacement, whereas with soft rock the stresses reduce more gradually with significant displacement. Consequently, most of the excess energy for soft rock is consumed in fracturing and compressing the rock which leaves little energy that can be released as seismic energy.

Where there is a contact between rocks with varying stiffness, brittle high-strength rock tends to fail violently, i.e., strain energy bursts. The inability of stress to be transferred across the contact to lower strength rock may be a contributing factor.

At the Macassa Mine, rockburst incidents indicate that ground failure is often associated with the co-existence of varying rock type properties. This condition most likely favoured the development of the strain type of bursts, and to some extent, violent release of energy.

Under comparable mining conditions, violent rockburst activities are very rare for the mines in the Timmins area. Compared with the high-strength and brittle rock types at the Macassa Mine, the weak serpentine rock, e.g., at the Porcupine Mine, can be considered as one of the major factors for the mine stability.

d) Ground stress determinations at the Macassa Mine, carried out at 1585 m and 1890 m depth below surface, indicated that the pre-mining vertical and horizontal stresses increase with depth (10). The pre-mining vertical stress, as well as the horizontal stresses perpendicular and parallel to the orebody, were determined as follows.

Vertical stress = 0.026 MPa/m

Horizontal stress perpendicular to orebody = 1.68 x vertical stress

Horizontal stress parallel to orebody = 1.27 x vertical stress.

Since the stresses increase with depth, high ground stress in conjunction with the mining geometry was the main contributing factor to the mine instability in the rockburst-prone areas.

e) At the east end of the mine, between 4675 and 5300 levels, horizontal cut-and-fill and rill stoping methods were employed with filling following closely on the mining of the ore. The stopes on these levels were mined without encountering any significant ground problems. But, when the stopes from the 5300 level had advanced to within close proximity of the levels above, frequent bursting occurred. However, the ground problems were confined to particular areas. These observations suggest that the sequence and rate of mining had an effect on the distribution and concentration of stress at critical locations.

f) At the west end of the mine with a mining depth ranging between 1500 to 1980 m, the stopes, e.g., 64-23, 64-33, 63-38, 61-38, 58-38 and 54-34, were the sites of some concentrated events situated in the hanging wall/footwall, sub-levels and sill pillars. Indicators of potential bursting were the formation of isolated pillars which were reduced in size and number. Consequently, overstressing of some pillars occurred as a result of unfavourable pillar configurations.

g) A relationship exists between generated seismic energy and detonation of high explosives in hard rocks (11). Under a high stress field at depth, the liberated energy can be considered as a triggering mechanism for the rockbursts which occurred at the time of, or closely following, underground blasting.

CONCLUSIONS

The main points from this evaluation of ground conditions are:

1. As the mining progressed to greater depths, high ground stresses and mining geometry, as well as critical pillar configurations, were significant factors in the context of rockbursts. Rockbursts increased in number and severity at a depth between 1400 and 1900 m.
2. Most damage occurred around the orebody, which points to pillar type of rockbursts with the change in potential energy being the major source of liberated energy. This is probably the main source of the rockbursts that occur both in the active and mined-out workings (e.g., sill pillars).
3. In a high stress field, the presence of brittle high-strength rock, as well as the contact between rocks of varying stiffness, contributed to the occurrence of strain bursts in the development areas.
4. Potentially unstable wedges and blocks defined by weakness planes were the main source of some local structurally-controlled instabilities.

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