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# PEAK PARTICLE VELOCITY FOR ROCKBURSTS IN SOME ONTARIO MINES

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# PEAK PARTICLE VELOCITY FOR ROCKBURSTS IN SOME ONTARIO MINES

by

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## ABSTRACT

Measurements of peak particle velocity have been made on 25 rockbursts at the Quirke and Denison mines at Elliot Lake and the Creighton Mine in Sudbury.

The relationship between peak particle velocity, $\hat{v}$, distance from source, R, and rockburst magnitude, M, was evaluated using seismology and blasting equation formats. By far the best fit is obtained with the blasting equation in the form:

$$\hat{v} = 4000\left(\frac{R}{10^{M/3}}\right)^{-1.6}$$

The measured velocities are considerably lower than those measured in South African gold mines, for comparable magnitudes and distances. Because of the fractured nature of the rock mass around Quirke and Creighton Mines the seismic signal is being attenuated at a rate proportional to $R^{-1.6}$ compared to $R^{-1.0}$ in South Africa.

Key words: Rockbursts; Blasting; Peak particle velocity.

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# VITESSE MAXIMALE DES PARTICULES PENDANT LES COUPS DE TOIT DANS CERTAINES MINES DE L'ONTARIO

par

D.G.F. Hedley*

RÉSUMÉ

On a mesuré la vitesse maximale des particules pendant 25 coups de toit aux mines Quirke et Denison situées à Elliot Lake ainsi qu'à la mine Creighton de Sudbury.

Pour évaluer la relation entre la vitesse maximale des particules, v, la distance à partir de la source, R, et la magnitude des coups de toit, M, on a fait appel à la sismologie et à l'équation de sautage. On obtient de loin le meilleur ajustement lorsque l'équation de sautage possède la forme suivante:

$$v = 4\,000 \left(\frac{R}{10^{M/3}}\right)^{-1,6}$$

Les vitesses mesurées sont beaucoup plus faibles que celles qui ont été obtenues dans des mines d'or d'Afrique du Sud, avec des magnitudes et des distances comparables. À cause de la nature fracturée de la masse rocheuse qui entoure les mines Quirke et Creighton, le signal sismique est atténué à un taux proportionnel à $R^{-1,6}$, comparativement à $R^{-1,0}$ en Afrique du Sud.

Mots clés : Coups de toit; sautage; vitesse maximale des particules.

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## INTRODUCTION

Peak particle velocity is generally the main criterion for assessing damage to underground workings and structures, both for blasting and rockbursts. Wagner (1984) used a relationship between rockburst magnitude, distance from source and peak particle velocity, developed by McGarr, et al. (1981), to assess damage in stopes and tunnels in South African gold mines. Guidelines were developed for support requirements and especially the yielding characteristics of the support.

As part of the Canada/Ontario/Industry Rockburst Project, strong-motion triaxial sensors are being installed around several rockburst-prone mines. These systems record the complete waveform of seismic events from which the vector sum peak particle velocity can be calculated.

## MONITORING SYSTEMS

In 1985/86 during testing of blast monitoring equipment at Denison Mine at Elliot Lake, three rockbursts were recorded from the adjacent Quirke Mine. The microseismic system at Quirke Mine gave the locations of these rockbursts and magnitudes were obtained from the Eastern Canada Seismic Network.

In 1986, INCO personnel recorded five seismic events, sometimes at multiple sites, at the Creighton Mine near Sudbury. The mine's microseismic system gave locations, and magnitudes were obtained from the National Network.

The same triaxial sensors velocity gauges with a frequency response of 2-250 Hz were used at both mines, installed on the floor of drifts and stopes.

A five unit macroseismic system was installed on surface above the rockburst area at Quirke Mine in March 1987. The design of the system has been described by Labuc, et al (1987). Initially, triaxial accelerometers were used, but after they were all destroyed by lightning, velocity gauges with a frequency response of 8-300 Hz were substituted. These sensors are grouted in boreholes about 4 m below surface, and on rock outcrops.

Since August 1987, 17 rockbursts from Quirke and the adjacent Denison Mine have been recorded by this system. Again microseismic systems at both mines are used for source location. Rockbursts of magnitude 1.8 and greater at Elliot Lake are normally recorded by the Eastern Canada Seismic Network. Rockbursts down to a magnitude of 0.8 are recorded on a local seismograph, which has been calibrated against the National Network, Rochon, et al. (1987).

## METHODS OF ANALYSIS

The first study on peak particle velocities from rockbursts was done by McGarr, et al. (1981) at the ERPM Mine in South Africa. The results were analyzed using the following format:

$$\log(R\hat{v}) = a\ M + b \qquad \text{Eq 1}$$

where, M = rockburst magnitude

R = distance from source

$\hat{v}$ = peak particle velocity

a and b = constants.

This relationship has continued to be used in the South African gold mines (Spottiswoode, 1984 and Gibbon, et al. 1986) generally in the form:

$$\log(R\hat{v}) = 0.5\ M + 2.81 \qquad \text{Eq 2}$$

In this equation $\hat{v}$ is expressed in mm/s and R in m.

An alternative method of analysis uses the relationship developed in blasting. For a spherical charge a cube root scaling factor is used:

$$\hat{v} = K\left(\frac{R}{W^{1/3}}\right)^{n} \qquad \text{Eq 3}$$

where, W = charge weight of explosive

n = attenuation or decay factor

K = constant.

The cube root factor is used so that the ratio of the distance R to the volume of explosive (equivalent to the weight, W) is dimensionless.

To use this relationship for rockbursts we have to substitute for the weight, W. The chemical energy contained in the explosive is directly proportional to its weight. Similarly, the magnitude of a rockburst is directly proportional to the logarithm of its seismic energy. Consequently, the format of Equation 3 for rockbursts can be expressed by:

$$\hat{v} = L\left(\frac{R}{10^{M/3}}\right)^{n} \qquad \text{Eq 4}$$

where, L is another constant.

Equation 1 can also be arranged into the same format and becomes:

$$\hat{v} = 10^{b}\left(\frac{R}{10^{aM}}\right)^{-1} \qquad \text{Eq 5}$$

and Equation 2 becomes:

$$\hat{v} = 645\left(\frac{R}{10^{M/2}}\right)^{-1} \qquad \text{Eq 6}$$

Elastic theory predicts that the attenuation of the peak particle velocity should decay with distance from the source at a rate of $R^{-n}$, where n is 2 near the source and 1 at greater distances (Dowling, 1985). It can be seen that Equation 5 represents this latter condition.

## PEAK PARTICLE VELOCITY SCALING

The magnitudes, peak particle velocities and distances for the 25 rockbursts recorded at Quirke, Creighton and Denison mines are listed in Table 1. In eastern North America, the Nuttli (1973) scale is used to determine magnitudes, which is similar to the Richter (1958) local magnitude scale used

Table 1 - Ground motion parameters

M - Magnitude (Nuttli); $\hat{v}$ - Peak particle velocity (mm/s); R - Distance (m)

| No. | Date | Mine | M | $\hat{v}$ | R | No. | Date | Mine | M | $\hat{v}$ | R |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | Quirke | 2.1 | 2.4 | 518 | 16 | Sept. 5/87 | Quirke | 0.9 | 0.42 | 688 |
| 2 | | Quirke | 2.5 | 27.8 | 122 | | | | 0.9 | 0.54 | 655 |
| 3 | Apr. 20/86 | Quirke | 1.8 | 0.58 | 750 | | | | 0.9 | 0.21 | 934 |
| 4 | Oct. 20/86 | Creighton | 2.3 | 75.0 | 72 | | | | 0.9 | 0.29 | 833 |
| | | | 2.3 | 22.4 | 152 | | | | 0.9 | 0.99 | 494 |
| | | | 2.3 | 12.7 | 169 | 17 | Sept. 6/87 | Quirke | 1.2 | 0.95 | 690 |
| 5 | Oct. 20/86 | Creighton | 2.9 | 55.6 | 392 | | | | 1.2 | 1.16 | 650 |
| | | | 2.9 | 9.1 | 467 | | | | 1.2 | 0.31 | 947 |
| 6 | Oct. 21/86 | Creighton | 2.2 | 3.6 | 429 | | | | 1.2 | 0.41 | 835 |
| | | | 2.2 | 3.3 | 398 | | | | 1.2 | 1.31 | 474 |
| 7 | Oct. 21/86 | Creighton | 2.3 | 7.4 | 401 | 18 | Sept. 6/87 | Quirke | 0.9 | 0.52 | 692 |
| 8 | Oct. 29/86 | Creighton | 3.3 | 45.2 | 333 | | | | 0.9 | 0.39 | 653 |
| 9 | Aug. 28/87 | Quirke | 0.9 | 0.15 | 997 | | | | 0.9 | 0.14 | 941 |
| | | | 0.9 | 0.10 | 972 | | | | 0.9 | 0.24 | 845 |
| | | | 0.9 | 0.06 | 1274 | | | | 0.9 | 0.64 | 494 |
| | | | 0.9 | 0.35 | 941 | 19 | Sept. 9/87 | Quirke | 1.1 | 0.16 | 1148 |
| | | | 0.9 | 0.42 | 655 | | | | 1.1 | 0.09 | 1091 |
| 10 | Aug. 28/87 | Quirke | 1.6 | 0.59 | 1096 | | | | 1.1 | 0.08 | 1446 |
| | | | 1.6 | 0.35 | 1064 | | | | 1.1 | 0.48 | 1115 |
| | | | 1.6 | 0.19 | 1375 | | | | 1.1 | 0.56 | 766 |
| | | | 1.6 | 1.01 | 1029 | 20 | Oct. 8/87 | Quirke | 1.4 | 0.80 | 908 |
| | | | 1.6 | 1.29 | 742 | | | | 1.4 | 0.38 | 1059 |
| 11 | Aug. 28/87 | Quirke | 1.4 | 0.26 | 1052 | | | | 1.4 | 0.67 | 615 |
| | | | 1.4 | 0.14 | 1020 | | | | 1.4 | 0.41 | 1108 |
| | | | 1.4 | 0.10 | 1332 | | | | 1.4 | 0.31 | 1284 |
| | | | 1.4 | 0.39 | 998 | 21 | Oct. 15/87 | Quirke | 1.1 | 0.62 | 675 |
| | | | 1.4 | 0.50 | 703 | | | | 1.1 | 0.95 | 574 |
| 12 | Aug. 28/87 | Quirke | 0.8 | 0.10 | 1105 | | | | 1.1 | 0.50 | 962 |
| | | | 0.8 | 0.07 | 1075 | | | | 1.1 | 0.20 | 921 |
| | | | 0.8 | 0.04 | 1381 | | | | 1.1 | 1.65 | 432 |
| | | | 0.8 | 0.20 | 1035 | 22 | Nov. 24/87 | Denison | 2.1 | 0.18 | 2424 |
| | | | 0.8 | 0.36 | 757 | | | | 2.1 | 0.06 | 2548 |
| 13 | Aug. 29/87 | Quirke | 2.3 | 0.78 | 1075 | | | | 2.1 | 0.14 | 2086 |
| | | | 2.3 | 0.43 | 1050 | | | | 2.1 | 0.10 | 2623 |
| | | | 2.3 | 0.44 | 1350 | | | | 2.1 | 0.08 | 2848 |
| | | | 2.3 | 1.28 | 1000 | 23 | Nov. 24/87 | Quirke | 1.8 | 1.63 | 751 |
| | | | 2.3 | 1.44 | 725 | | | | 1.8 | 0.64 | 856 |
| 14 | Aug. 31/87 | Quirke | 0.8 | 0.18 | 587 | | | | 1.8 | 1.46 | 860 |
| | | | 0.8 | 0.55 | 461 | | | | 1.8 | 1.61 | 650 |
| | | | 0.8 | 0.11 | 865 | | | | 1.8 | 1.09 | 722 |
| | | | 0.8 | 0.08 | 926 | 24 | Nov. 24/87 | Quirke | 0.8 | 0.32 | 730 |
| | | | 0.8 | 0.52 | 426 | | | | 0.8 | 0.08 | 834 |
| 15 | Sept. 4/87 | Quirke | 0.8 | 0.23 | 491 | | | | 0.8 | 0.24 | 831 |
| | | | 0.8 | 0.38 | 485 | | | | 0.8 | 0.40 | 661 |
| | | | 0.8 | 0.19 | 501 | | | | 0.8 | 0.18 | 722 |
| | | | 0.8 | 0.04 | 875 | 25 | Nov. 29/87 | Denison | 1.8 | 0.07 | 2446 |
| | | | 0.8 | 0.13 | 773 | | | | 1.8 | 0.06 | 2575 |
| | | | | | | | | | 1.8 | 0.13 | 2105 |
| | | | | | | | | | 1.8 | 0.09 | 2632 |
| | | | | | | | | | 1.8 | 0.05 | 2871 |

elsewhere. The recorded rockbursts ranged from 0.8 to 3.3 in magnitude, and the distance varied from 72 m to over 2800 m. The maximum peak particle velocity measured was 75 mm/s.

The relationship between peak particle velocity, distance and magnitude using the format of Equation 1 is shown in Figure 1. There is a clear trend but considerable scatter. The mean regression line gives:

$$\log(R\hat{v}) = 0.63\,M + 1.67 \qquad \text{Eq 7}$$

again $\hat{v}$ is expressed in mm/s and R in m.

The relationship generally used in South Africa (Equation 2) is also shown. All the measurements, except one, are well below this line.

The relationship using the blasting format (Equation 4) is shown in Figure 2. Again there is a clear trend, but considerably less scatter. A line representing,

$$\hat{v} = 4000\left(\frac{R}{10^{M/3}}\right)^{-1.6} \qquad \text{Eq 8}$$

gives a reasonable fit to the measurements. In this case an attenuation factor of 1.6 was deliberately chosen. The reasons for this are discussed next.

## COMPARISON OF ROCKBURSTS AND BLASTING

One of the objectives is to relate rockburst magnitude to an equivalent weight of explosive, using peak particle velocity as the common denominator. A blasting equation in fairly general use (Ambraseys and Hendron, 1968) is:

$$\hat{v} = 2080\left(\frac{R}{W^{1/3}}\right)^{-1.6} \qquad \text{Eq 9}$$

where, W = explosive weight in kg.

It can be seen that the attenuation factor of 1.6 is the same as in the rockburst Equation 8. Consequently, when combining the two equations the distance, R, disappears, and

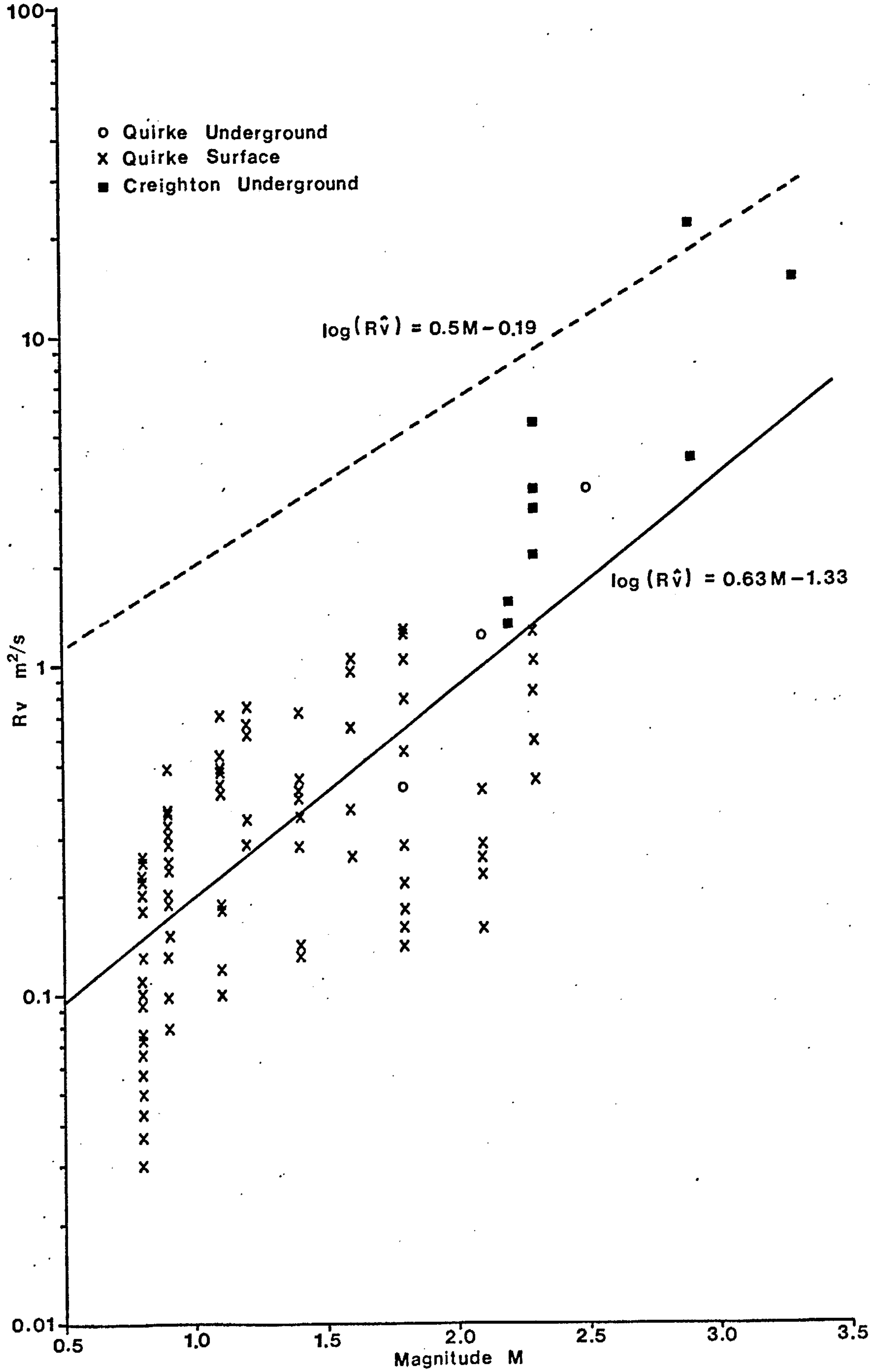


Fig. 1 - Scaled peak particle velocity as a function of rockburst magnitude, using a seismology format.

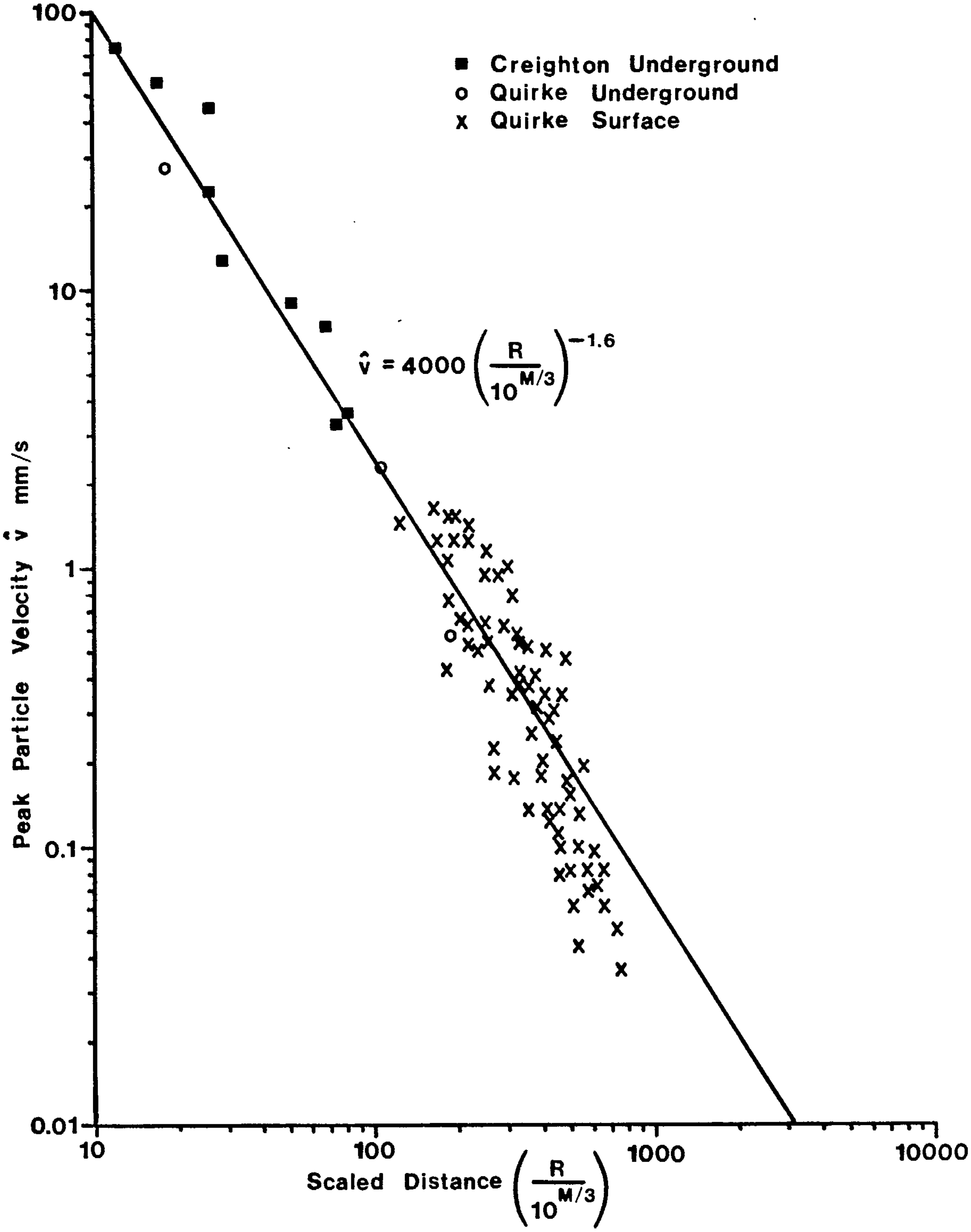


Fig. 2 - Peak particle velocity as a function of cube root scaled distance, using a blasting format.

$$\log W = M + 0.53 \qquad \text{Eq 10}$$

This relationship is shown in Figure 3. Some additional information is available from blasts used to calibrate part of the Eastern Canada Seismic Network in 1984. Explosive charges of 1600 kg and 2000 kg were detonated instantaneously in various sites in Northern Ontario which gave magnitudes of 2.6 to 2.9. These values are also plotted in Figure 3 and are in reasonable agreement with Equation 10.

## DISCUSSION

For Quirke. Creighton and Denison mines the peak particle velocity generated by rockbursts can be adequately expressed by:

$$\hat{v} = 4000 \left(\frac{R}{10^{M/3}}\right)^{-1.6}$$

Rearranging this equation and the one for South African mines (Eq. 6) gives,

$$\text{Ontario mines} \quad \hat{v} = 4000 \left(\frac{10^{.53M}}{R^{1.6}}\right)$$

$$\text{South African mines} \quad \hat{v} = 645 \left(\frac{10^{.5M}}{R^{1.0}}\right)$$

The constant factor is higher in Ontario, the factor involving magnitude (M) is similar, and there is a significant difference in the attenuation factor for distance (R). The two scales do overlap when the distance is about 25 m for magnitudes 1.0 to 3.0. Otherwise the measured velocities in Ontario mines are considerably leas for comparable distances and magnitudes. There may be valid reasons for this.

At Quirke Mine the hanging wall above the main rockburst area is extensively fractured through to surface (about 500 m). Diamond drilling encountered a number of open cracks up to 15 cm wide, which extend over a large area. Most of the measurements at Quirke were taken on the surface

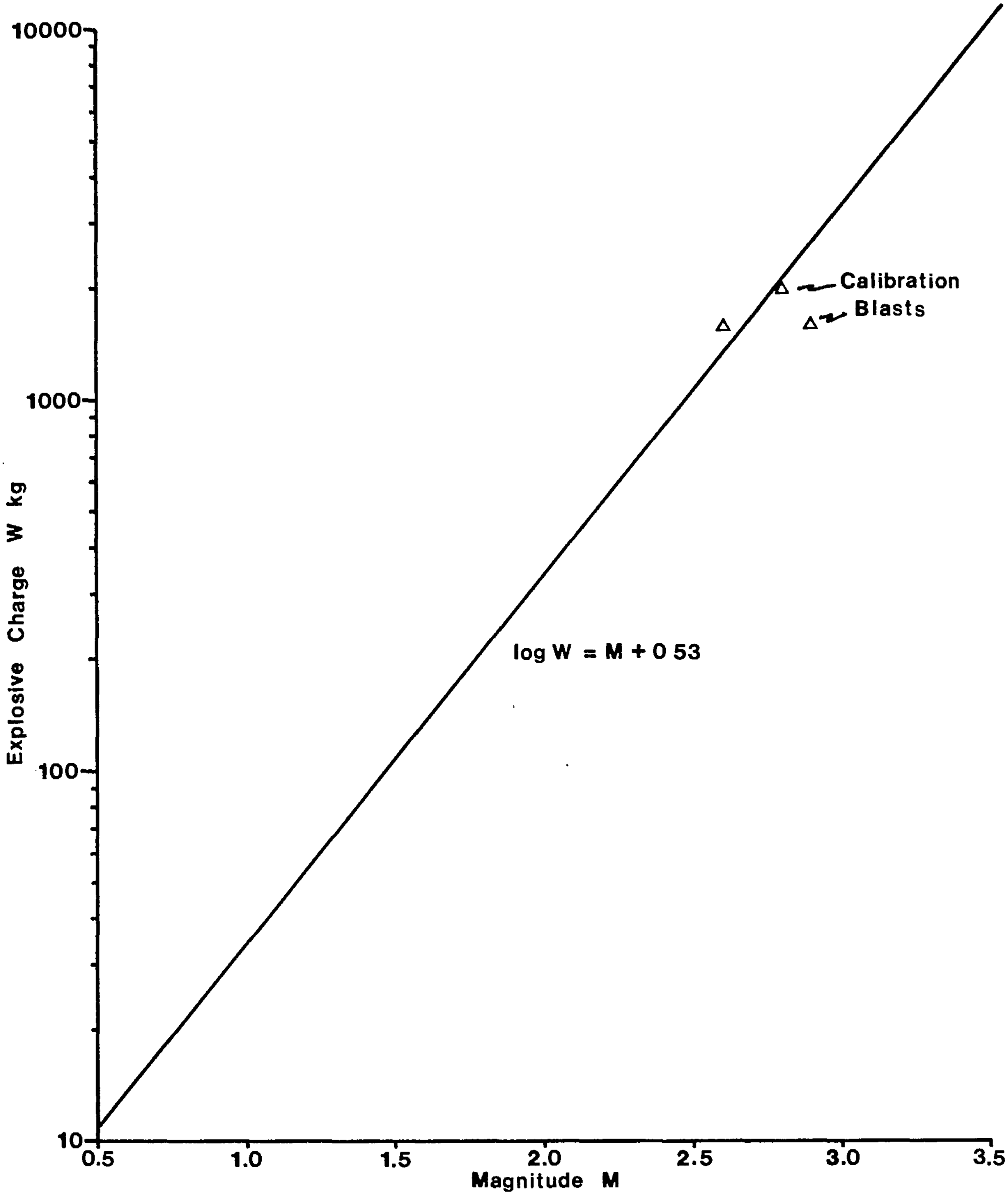


Fig. 3 - Rockburst magnitude compared to an equivalent weight of explosive.

geophones. Seismic signals from underground have to pass through this fractured rock mass and would be attenuated more than through solid rock. As can be seen in Figure 2. if only the surface readings at Quirke are examined the gradient of the line would have been steeper than 1.6.

At Creighton Mine, massive sulphide deposits, 400 m long by 60 m wide at a depth of about 2000 m, are being extracted by vertical retreat mining and mechanized cut-and-fill methods. A considerable fractured zone surrounds the mine excavations. Again the seismic signals have to pass through these fractured zones and would be attenuated.

In the near future additional macroseismic systems, using triaxial sensors, will be installed around the Creighton and Strathcona mines in Sudbury, the Campbell Mine at Red Lake, and the Macassa Mine at Kirkland Lake. These systems will provide considerably more data on the peak particle velocity generated by rockbursts.

Prediction of peak particle velocity is only half of the problem. Developing damage criteria for drifts, stopes and various support systems has still to be done.

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