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The Sudbury local telemetered seismograph network

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ABSTRACT: During the last four years in the Sudbury mining area, rockbursts have caused four casualties and millions of dollars in damages and lost production. These problems led to the creation of the Canada-Ontario-Industry Rockburst Project in 1985. One of its first actions was the deployment of a state-of-the-art three-station digital seismograph network (SLTN) around the perimeter of the Sudbury Basin with data telemetered to a central processing facility at Sudbury. The network provides uniform coverage of any seismic activity throughout the basin to magnitude 1.5 mN $\pm$0.5. All triggered event files are automatically copied to the national seismological laboratory in Ottawa where they are analyzed along with regional earthquake data. In collaboration with the mining industry, seismic events at each mine are discriminated. Afterwards, the data are stored in a database and reported in a comprehensive bulletin. SLTN now detects more than 550 triggers per month. Approximately 30% of these events can be located inside the basin and are related to mining activities. Of these, approximately 25 mining-induced seismic events are detected each month and an average of 10 are confirmed by the mines. SLTN provides the raw data for a variety of seismological studies of the rockburst phenomena which will eventually lead to a better understanding of rockburst source properties and help to mitigate their effects.

INTRODUCTION

The Sudbury Basin is one of the major mining centres in Canada with nickel and copper as the principal base-metal products. The Sudbury Structure includes the Early Proterozoic elliptical Sudbury Igneous Complex and the Whitewater Group within the intrusion and some brecciated Archean and Proterozoic rocks (Figure 1) (Pye et al. 1984). The region is subjected to high horizontal east-west directed stresses (Herget 1980). The mines located around the rim of the basin use a variety of mining methods such as cut-and-fill, vertical retreat blast, undercut-and-fill, and blasthole (Hedley and Wetmiller 1985; Hedley 1987). A telemetered regional three-station seismograph network around the Sudbury Basin monitors the seismic activity in 15 mines owned by two major mining companies: INCO Ltd. and Falconbridge Ltd. This network is linked to the Canadian National Seismological Laboratory of the Geophysics Division, Geological Survey of Canada, Energy, Mines and Resources Canada, at Ottawa where data analysis is performed.

HISTORY

Since the mid-1930's many mines in the Sudbury Basin have had rockburst problems (Morrison 1942; Hodgson 1958). In 1984 an unusually high level of rockburst activity, in a short period of time, attracted attention from the public, the mining industry and government agencies. At least 120 rockbursts occurred over an eight-month period. The more important events were:

- On June 20 rockbursts occurred at Falconbridge's No. 5 shaft resulting in 4 deaths and the permanent closure of the mine.
- A major series of rockbursts occurred at INCO's Creighton Mine during summer shutdown; the largest one (mN = 4.0) was felt throughout the Sudbury area.
- In September a series of rockbursts started at Rio Algom's Quirke Mine at Elliot Lake.

In light of these events, a first proposal was written (Udd 1984) emphasizing the need for improvement of seismic-monitoring equipment for more accurate source location of events. In June 1985, a formal project was announced: the Canada-Ontario-Industry Rockburst Project (Hedley and Udd 1987). Its goals were to develop capabilities in rockburst monitoring, analysis and prevention. Its estimated cost was $4.2 million over 5 years. The tripartite project was divided as follows:

- From Canadian government through CANMET (Canada Centre for Mineral and Energy Technology): staff to operate the project, training, and maintenance of the equipment.
- From Ontario government: funds for equipment and services.
- From the mining industry: continuing supervision of the existing microseismic-monitoring systems and assistance with the installation of new equipment.

One of the first tasks was to:

"Enlarge the regional seismic network in the Sudbury Basin from one to three stations (connected to Science North ..), to increase the range for recorded rockbursts and to improve the source location of previously unlocated rockbursts". (Brehaut and Hedley 1986).

To achieve these goals, the Sudbury Local Telemetered Network (SLTN) was developed by the Geophysics Division using the same kind of high resolution digital seismic equipment employed to monitor earthquake activity (Basham et al. 1985; Wetmiller et al. 1986, 1987). In addition to the installation of the first outstation (SUO) on March 8th, 1984, two outstations (SZO and SWO) were added to complete the network on January 24th and May 27th, 1987, respectively (Figure 1).

OUTSTATION DESCRIPTION

The three outstations consist of a vertical single-component short period Teledyne-Geotech S13 seismometer located in a surface vault, and a 60 Hz digitizing package. The latter equipment is mounted indoors, out of direct sunlight to prevent direct solar radiation from heating the equipment case. In winter, no heating is required since the equipment is designed to operate reliably at -40^{o}C.

All outstations have 16-bit data samples produced by 12-bit A/D digitizer with a minimum detectable

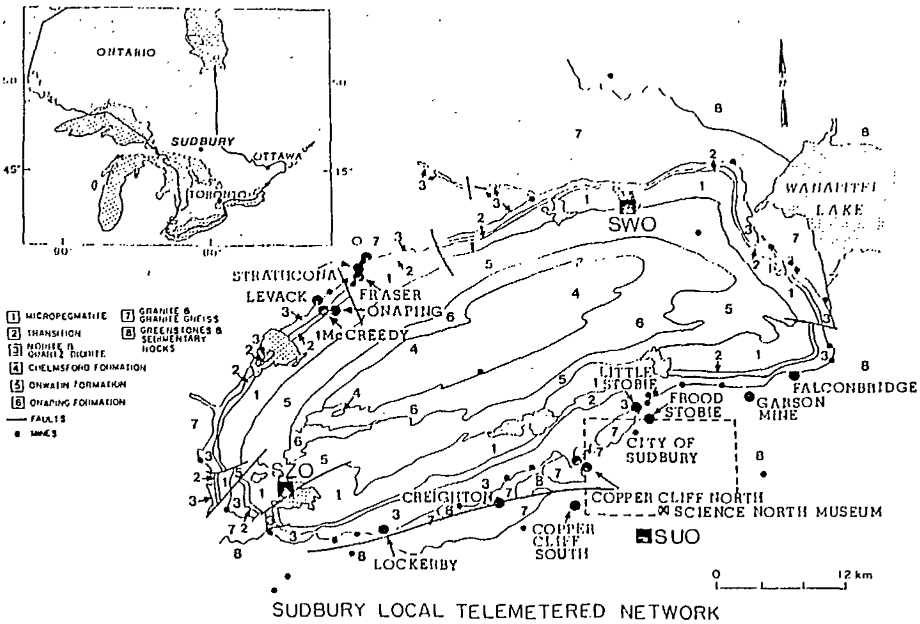

Figure 1. Map of the Sudbury Basin showing the location of the three SLTN seismographs (filled squares).

ground motion of 2 nm/s (Wetmiller et al. 1987). This resolution of 2 nm/s is equivalent to the amplitude of a magnitude 1.5 event located at 100 km. As the dynamic range is 126 dB (Figure 2), the magnitude range is about 6 for events located at 100 km. The frequency range is 1 to 16 Hz.

Calibration is performed daily on SLTN. For each outstation, a series of sinusoidal signals is automatically applied to the S13 seismometer calibration coil to drive the mass at a known peak velocity, typically 10 μm/s, over a frequency range from 0.167 Hz to 25.0 Hz. Triggered event files are produced during the calibration and a velocity response curve is determined periodically. Analog records are used to monitor progress of the calibration procedure but are not used to produce response curves.

SUDBURY PROCESSOR

The outstations are linked via dedicated phone lines to a central processing facility at Science North. Science North is a museum located in Sudbury, opened to the public in 1984, where the processor and monitors form a popular public display (Figure 3).

A PDP 11/73 processor receives continuous data from the three outstations and saves triggered event files with a simple STA/LTA (short-term average/long-term average) trigger algorithm (Figure 4). The computer has a disk capacity of 110 megabytes and can store approximately two months of network events and is equipped with software to display traces, pick phases and to locate events. It stores the daily event data on site, produces continuous visual monitors of each outstation at Science North (Figure 3) and automatically transfers events to Ottawa via a dedicated 9600 baud telephone line for analysis. Should the automatic process fail, the SLTN processor keeps all triggered events until the link reopens. In addition, a remote workstation including graphics terminal, printer/plotter, modem and dedicated communications line was opened at Laurentian University to display and plot waveform data.

DATA PROCESSING

At the Geophysics Division, all SLTN data are merged with data recorded by the Eastern Canada Telemetered

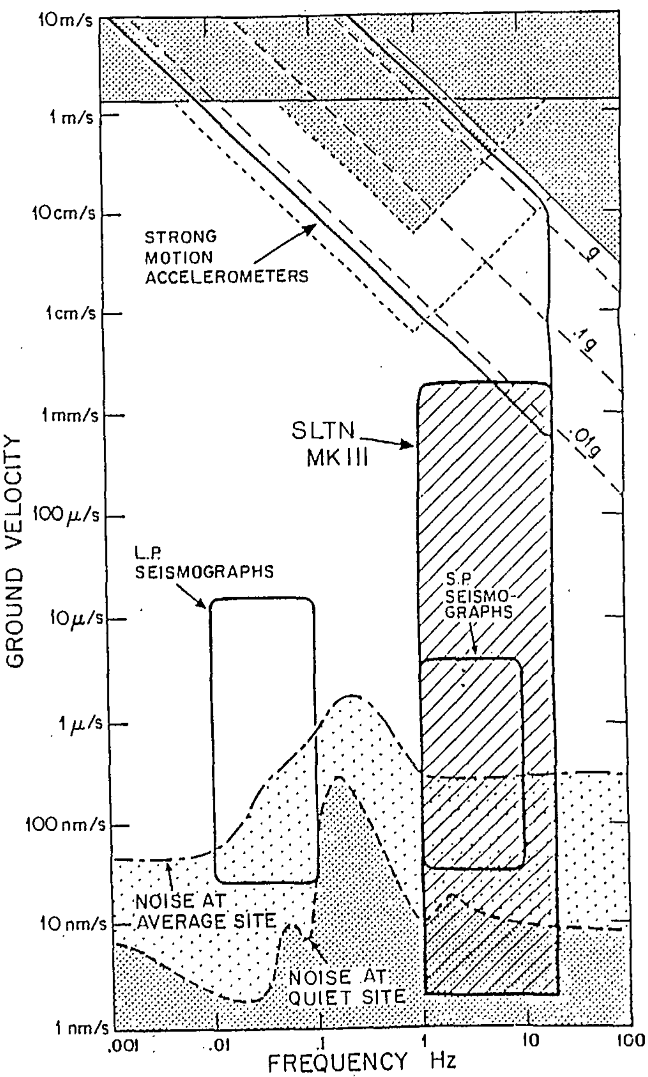

Figure 2. Seismic ground motion spectrum.

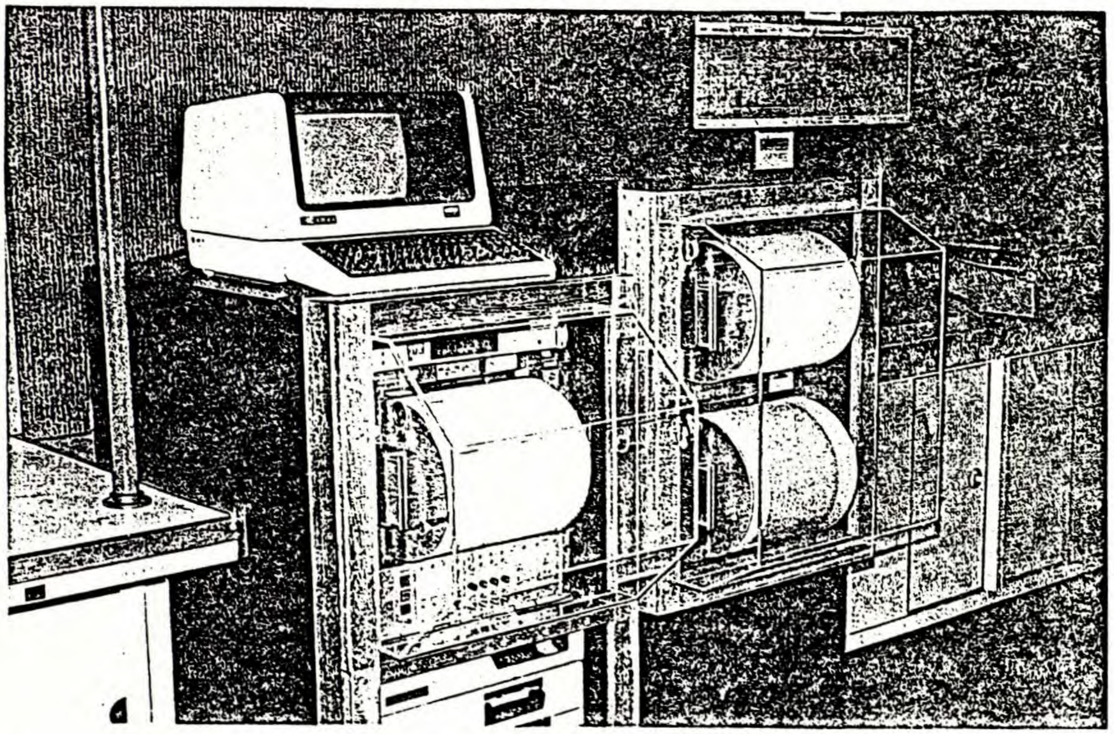

Figure 3. Present display as shown at Science North, Sudbury.

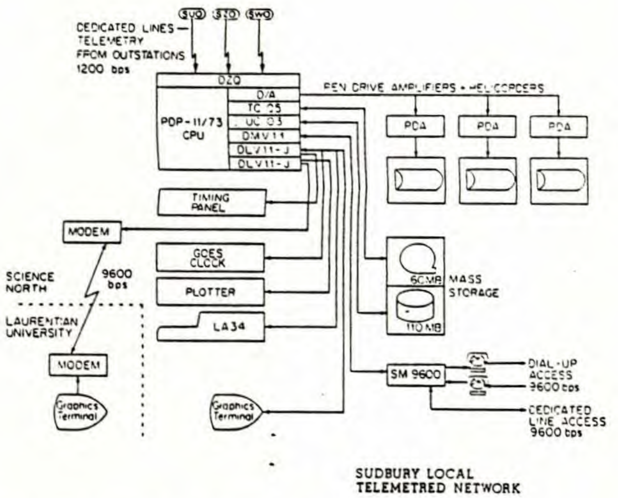

Figure 4. Block diagram of SLTN.

Network (ECTN). SLTN event files are appended to ECTN event files for regional earthquakes and teleseisms as appropriate. All files are then archived onto 6250 bpi magnetic tape.

The main computer for seismic analysis of the Sudbury network is a MicroVAX II computer system. It consists of a KA630 CPU with 9 megabytes of memory, a DHV-11 8-port DMA terminal multiplexer, a RD53 71 megabytes system disk with RQDX3 controller and two Fujitsu M2333 280 megabytes user disks with an EMULEX QD32 controller and a DEQNA Ethernet controller.

The Canadian Automated Seismic Monitor (CAUSMO) program is used to discriminate noise, local seismic events and teleseisms on a daily routine. CAUSMO classifies new triggers by type, identifies P-phases of seismic events, calculates times of well defined P-onsets and plots the information. CAUSMO now automatically deletes SLTN calibration pulse files, unless wanted, and plots time series files. Better algorithms to discriminate between noise, blasts and mining-related events, especially when the noise level is high or for small events, are being developed to improve automation of the process and to release diskspace with a minimal risk of losing important seismic data.

A variety of interactive processing programs are available to the analysts. The Seismic Analysis Monitor (SAM) package is used to display (Figure 5), filter and scale waveforms. The PIK command generates ASCII data for input to the location program, LOC, which calculates hypocentre and magnitude parameters. Other routines are available for P-nodal mechanism and seismic source property analysis and discrimination (Figure 6).

In collaboration with the mining industry, mining-induced seismic events at each mine are identified. After confirmation by mine operators, the data are stored in the Canadian seismicity database (CSDB) along with earthquake data using the INGRES relational database package. Fortran programs in EQUEL/FORTRAN have been developed to allow analysts to enter, extract or update information in CSDB.

From the database, a program called CATALOGUE allows the compilation of comprehensive reports on Canadian seismic activity. A quarterly report issued by the Geophysics Division, lists mining-induced seismic events for concerned parties such as mining industries, government agencies and universities, and is a summary of mining-induced activity in Canada, particularly northern Ontario. This report is the result of a collaboration among CANMET, Atomic Energy of Canada Ltd. (which funds the operation of six seismograph stations in northern Ontario), and the Geophysics Division. It is hoped coverage will become more national with increased interest from concerned parties.

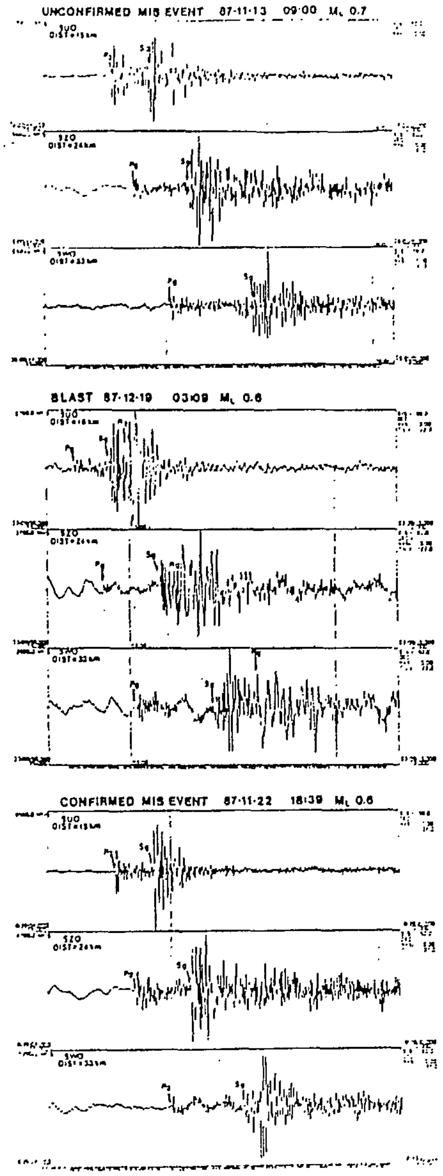

Figure 5. Plots of events time series (all coming from the same mine) using SAM and showing the wave arrivals.

ACTIVITY REPORT

Since 1984, the number of recorded mining-related seismic events has increased each year, especially since September 1987 (see Table 1), as improvements to the network has lowered the detection threshold and increased the coverage. Prior to the installation of the SWO and SZO outstations, the detection threshold was about 1.5 to 1.7 mN. At the present time, it is around 1.0.

Since September 1987, SLTN detects about 550 triggers per month. A large number (47%) of these detections are noise and calibration pulses. Ten per cent of the triggers are from seismic events originating outside the Sudbury Basin. Roughly half are Canadian seismic events and half are teleseisms. The Canadian events can be divided into two main groups: induced seismic events from nearby mining districts of Elliot Lake, Kirkland Lake and Manitoulin Island, and natural seismic events from the Western Quebec seismic zone. Table 2 shows the event distribution for the period between September 1987 and February 1988, the first six-month period of systematic analysis. All numbers in brackets in the Table are provisional.

Out of the 43% (242) triggers remaining per month originating in the Sudbury Basin, 64% can be located. Blasts represent 84% of the latter number. Each month, approximately 10 mining-induced seismic events are now located and confirmed by mine operators by comprehensive monthly mailed lists. The remaining located events (approximately 15 per month) represented unexplained and hitherto unnoticed seismic activity in the vicinity of mining operations. None of these events has been large enough to cause any damage in the mines.

In our reports, the term "mining-induced seismic event" (MIS event) is used to designate any seismic activity induced by mining, other than confirmed blasts. The term "rockburst" is generally reserved by the mining community or by Ontario legal statute to designate seismic events which cause damage to mine workings. As such, the term "rockburst" only represents one class of seismic activity associated with mining.

SLTN thus has shown that a significant number of seismic events occur every month which are not blasts and which are unable to be confirmed by the mine operators. These events possibly represent seismic activity induced by the mining operations away from the active mine workings. Such activity is difficult to detect by conventional in-mine monitoring systems. However, it appears significant in the Sudbury Basin and must be considered when trying to understand and predict any seismic activity induced by mining. Conventional cataloguing techniques, such as in-mine monitoring or visual damage criteria, which ignore these unnoticed events are incomplete.

CONCLUSION

At the present time, it is possible to locate more than 150 events per month around the Sudbury Basin. Complete coverage for magnitude greater than 1.5 has now been achieved. However, conventional documentation/monitoring mine methods only permit the confirmation of an average of 10 MIS events per month, besides the numerous blasts. The significant number (15 per month) of unconfirmed MIS events provides a new aspect, previously unknown, of the induced seismic activity in the basin and confirms the need to develop new location techniques and networks.

With the forthcoming operation of two CANMET macroseismic networks surrounding Falconbridge's Strathcona mine and INCO's Creighton Mine (Makuch 1986), location accuracy will increase, especially with respect to mining-induced seismic events occurring outside the existing mines' microseismic networks. These networks will add to the SLTN coverage so as to lower the detection threshold within those mines.

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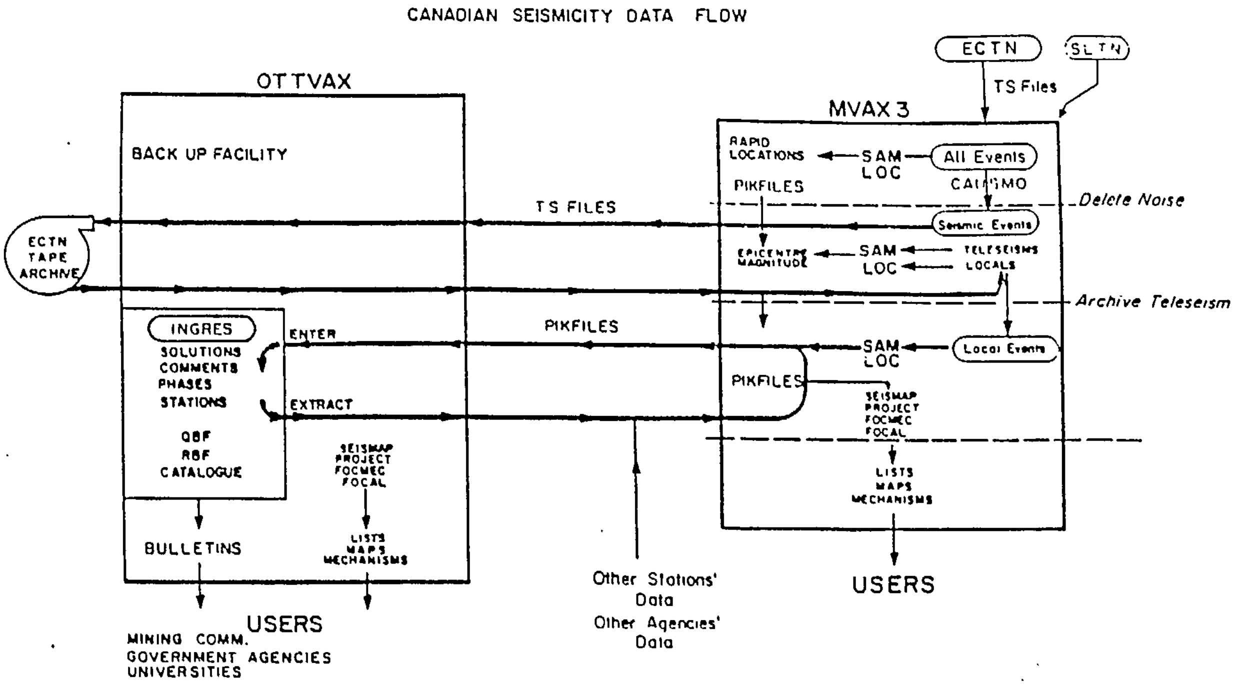

Figure 6. Block diagram of the Canadian seismicity data flow between the two main seismicity computers MVAX3 (for MicroVax II) and OTTVAX (for Vax 750).

Table 1. Performance of mining-induced seismic events in the Sudbury area.

Year	Month	No.	Confirmed No.	Confirmed Magnitude Range	Unconfirmed No.	Unconfirmed Magnitude Range
1984		16	16	1.5-4.0 mN		
1985		32	31	1.3-3.1 mN	1	1.9 mN
1986		53	45	1.4-3.3 mN	8	1.7-2.5 mN
1987	Jan.-Mar.	17	9	1.5-2.9 mN	8	1.5-2.2 mN
1987	Apr.-June	28	12	1.5-2.7 mN	16	1.5-2.2 mN
1987	July-Sep.	(35)				
1987	Oct.-Dec.	(102)				
1988	Jan.-Feb.	(27)				

Table 2. Network performance.

Month	Year	Triggers	Teleseisms and Canadian Events	Noise and Calibration	Sudbury Events	Blasts	MIS
Sept.	1987	492	44	167	281	(123)	(24)
Oct.	1987	652	64	258	330	(138)	(35)
Nov.	1987	616	56	275	285	(154)	(31)
Dec.	1987	600	49	330	221	(118)	(36)
Jan.	1988	467	58	251	158	(99)	(18)
Feb.	1988	564	89	296	179	(141)	(7)
Total:		3391	360	1577	1454	(773)	(151)
Mean:		565	60	263	242	(129)	(25)
Percentage:		100%	10%	47%	43%	(84)%	(16)%

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