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EASTERN CANADA SEISMIC STUDIES JULY 1988 TO JUNE 1989

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EASTERN CANADA SEISMIC STUDIES
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1. INTRODUCTION

This open-file is a progress report of work carried out under the terms of a research agreement entitled *Canadian Seismic Agreement* between the U.S. Nuclear Regulatory Commission (USNRC), the Canadian Commercial Corporation and the Geophysics Division of the Geological Survey of Canada (GD/GSC) during the period from July 01, 1988 to June 30, 1989. The USNRC agreement supports generally the operation of various seismograph stations in eastern Canada and the collection and analysis of earthquake data for the purpose of mitigating seismic hazards in eastern Canada and the northeastern U.S. The specific activities carried out in this one-year period are summarized below under four headings; Eastern Canada Telemetred Network and local network developments, Datalab developments, strong motion network developments and earthquake activity.

Activities undertaken by the Geophysics Division (formerly the Earth Physics Branch) under this contract from 1979 to 1985 have previously been described in a Technical Report Covering 1979–1985 (NUREG/CR–4317 Vol. 1), in the previous Annual Reports of this series (NUREG/CR–4573 Vols. 1, 2 and 3), for 1985–86, 1986–87 and 1987–88 and in the regular quarterly reports issued under terms of this agreement. During the period of this report, the contract resources were spent on operation and maintenance of the Eastern Canada Telemetred Network (ECTN), development of special purpose local network systems, servicing and maintenance (by contract) of the strong-motion seismograph network in eastern Canada, operation and expansion of the Ottawa Datalab and earthquake monitoring and reporting. The development of the local networks for the Sudbury (SLTN) and Charlevoix (CLTN) areas are reported on here because they are closely linked to ECTN developments although they are supported in whole or in part by other sources.

In this time period eastern Canada experienced its largest earthquake in over 50 years when a magnitude (M) 6.0 event took place at 18:48 E.S.T. on Friday, November 25 near 48.12 ° N, 71.19 ° W just south of Chicoutimi, Québec. The tremor was felt over a very wide area of eastern North America, from Halifax west to Thunder Bay in Canada and as far south as Washington DC in the U.S., and caused some minor property damage in the Chicoutimi–Jonquière–La Baie area of the Saguenay valley and in the Québec City and Montréal areas. This earthquake, which has been christened the Saguenay earthquake, has provided a wealth of new data pertinent to earthquake engineering studies in eastern North America and is the subject of many continuing studies, which are presently being carried out at GD and elsewhere. The bibliography gives a summary of the scientific reports on earthquake or related studies that have been published or submitted for publication by GD staff in this period.

Finally, in this period a new modification to the Canadian Seismic Agreement has been completed which extends the agreement to March 31, 1990. It is expected that the modified Agreement will be renewed for another year.

2. ECTN AND LOCAL NETWORK DEVELOPMENTS

ECTN now consists of 21 short–period vertical outstations and one SRO–type borehole triaxial, short– and long–period outstation which monitor seismic activity in eastern Canada from north-eastern Ontario to eastern New Brunswick (Fig 1 and Table 1). One new outstation, DAQ at Lac Daran, Québec, was added to ECTN in this period. The outstations transmit seismic data in real time to a central processing facility in the Ottawa Datalab by either dedicated telephone lines (Fig. 2) or by UHF radio links (Fig. 3). Data are sampled at 60 Hz at each outstation (1 and 30 Hz. for the SRO station) using a 12-bit A/D converter with a four-stage gain-ranging scheme which gives a dynamic range of 96, 108 or 126 db depending on the type of outstation, Mark I, II or III.

ECTN data are now integrated with the data from two local digital telemetered networks, SLTN in Sudbury, Ontario and CLTN in La Pocatière, Québec, which are designed to provide enhanced seismic monitoring within their local areas. Each local network has a complete seismic processing facility located on site which can operate the array, store triggered event data and carry out routine analysis of the events independent of Ottawa.

SLTN was completed in April, 1987 as part of an expanded program of rockburst monitoring of 15 active mines in the Sudbury, Ontario area (Fig. 4) supported jointly by EMR, the Canadian mining industry and the Ontario provincial government. The array consists of three Mark III outstations sampling at 60 Hz. and linked by dedicated telephone lines to the local processor at the Science North Museum in the city of Sudbury. The processing facility forms part of a popular public display in the museum, featuring continuous monitors of the three outstations and and an automatic display of the last triggered event on the graphics terminal (Fig. 5). There is also a link provided to Laurentian University in Sudbury for inspection and acquisition of current events.

SLTN files follow the route

SUD73M ::::::::::::DEMSA0 ::::::::::::: MVAX3

to Ottawa where they are analyzed on MVAX3 concurrently with ECTN and CLTN events. DEMSA0 is a new communication server which has handled SLTN data since May 1989 and also handles DATAPAC connections to the computing facilities. In Ottawa SLTN files are systematically screened and noise files eliminated, location and magnitude are calculated for any well recorded events and P-nodal analyses are carried out. The affected mines are surveyed for information about the nature, depth and effects of the seismic events they have experienced and the information collected is stored in the seismicity database along with the hypocentral parameters. GD circulates comprehensive quarterly reports of all the information collected to the mining community.

CLTN became fully operational on October 30, 1987 replacing the older analogue array which had operated at the same sites since 1977. CLTN consists of 6 Mark III 3-component outstations (Fig. 6) each sampling at 80 Hz. and transmitting data to the local processor at La Pocatière, Québec via UHF radio-links. Each signal has a dynamic range of 126 db with a sample resolution of 2 nm/s per bit. A two-station coincidence requirement has been imposed on the CLTN trigger algorithm

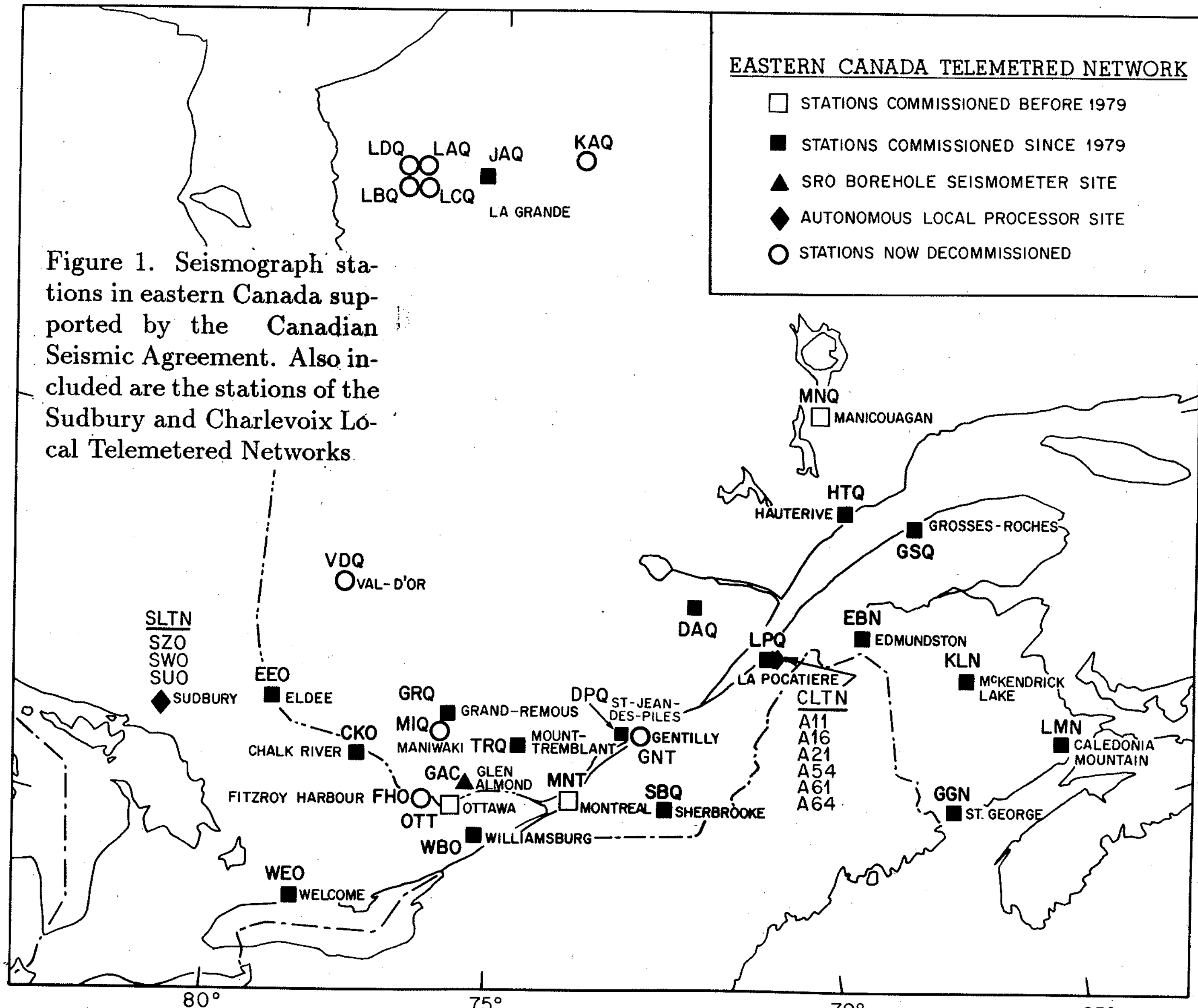


Figure 1. Seismograph stations in eastern Canada supported by the Canadian Seismic Agreement. Also included are the stations of the Sudbury and Charlevoix Local Telemetered Networks.

Table 1: Canadian Telemetered Networks 1988/89

STATION			LOCATION			OPERATING DATES
code	mark	name	N	W	m	start - stop
	ECTN					
OTT	I	Ottawa	45.3942	75.7167	077	02/24/74-04/25/78; 01/26/79-
MNT	II	Montréal	45.5025	73.6230	112	02/24/74-
MNQ	II	Manicouagan	50.5333	68.7744	564	11/27/74-
GNT	I	Gentilly	46.3628	73.3722	010	04/26/78-01/05/88
GAC	SRO	Glen Almond	45.7033	75.4783	062	10/26/79-
LPQ	III	La Pocatière	47.3408	70.0094	126	06/06/80-
SBQ	III	Sherbrooke	45.3783	71.9264	265	08/12/80-
VDQ	II	Val d'Or	48.2300	77.9717	305	12/09/80-04/17/86
WBO	II	Williamsburg	45.0003	75.2750	085	12/09/80-
CKO	II	Chalk River	45.9944	77.4500	190	01/12/81-
TRQ	II	Mont-Tremblant	46.2222	74.5556	853	03/16/81-
GRQ	II	Grand-Remous	46.6067	75.8600	290	03/16/81-
GSQ	II	Grosses-Roches	48.9142	67.1106	398	10/28/81-
EBN	II	Edmundston,	47.4620	68.2420	195	10/28/81-
GGN	III	St. George	45.1170	66.8220	030	10/28/81-
LMN	II	Caledonia Mt.	45.8520	64.8060	363	10/28/81-
KLN	II	McKendrick L.	46.8433	66.3717	411	01/28/82-
HTQ	II	Hauterive	49.1917	68.3939	123	04/15/82-
WEO	III	Welcome	44.0186	78.3744	149	04/30/82-
JAQ	III	La Grande-3	53.8022	75.7211	366	02/26/85-
EEO	III	Eldee	46.6411	79.0733	398	03/08/84-
DPQ	III	St-Jean-des-Piles	46.6804	72.7774	167	01/20/88-12/15/88; 02/27/89-
DAQ	III	Lac Daran	47.9644	71.2425	939	12/15/88-
	SLTN					
SUO	III	Chief L. Road	46.4027	81.0068	252	12/16/84-
SZO	III	Chicago Mine	46.4380	81.4960	312	01/24/87-
SWO	III	Joe Lake	46.7330	80.9990	372	05/27/87-
	CLTN					
A11	III		47.2430	70.1970	045	10-30-87-
A16	III		47.4680	70.0100	022	10-30-87-
A21	III		47.7040	69.6900	000	10-30-87-
A54	III		47.4570	70.4130	384	10-30-87-
A61	III		47.6940	70.0910	358	10-30-87-
A64	III		47.8270	69.8910	137	10-30-87-

mark - type of ECTN outstation GAC is a SRO-type borehole seismograph

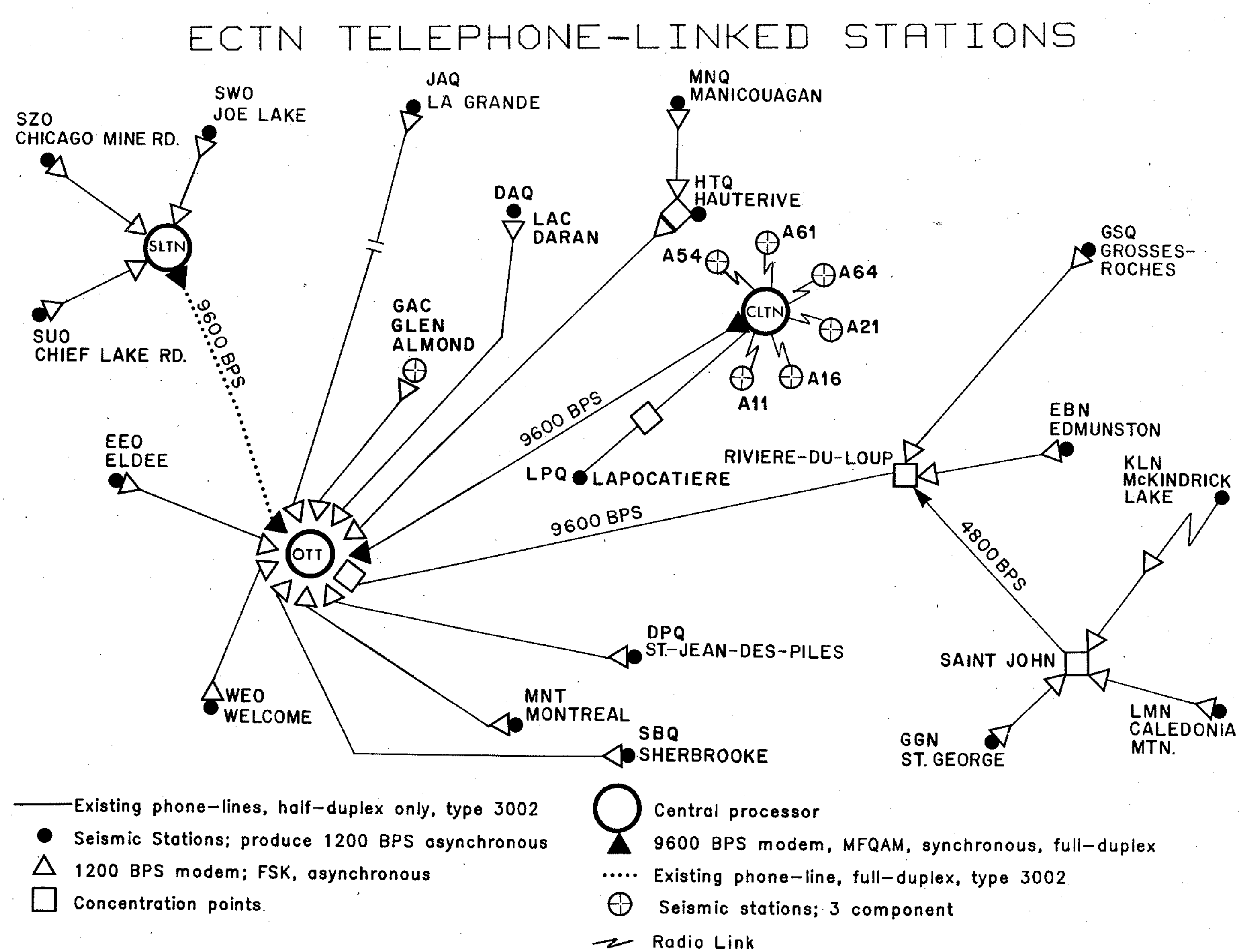


Figure 2. Block diagram of telephone-links for ECTN stations, SLTN stations and the CLTN processor. Short radio-links are employed at JAQ, KLN and the CLTN outstations.

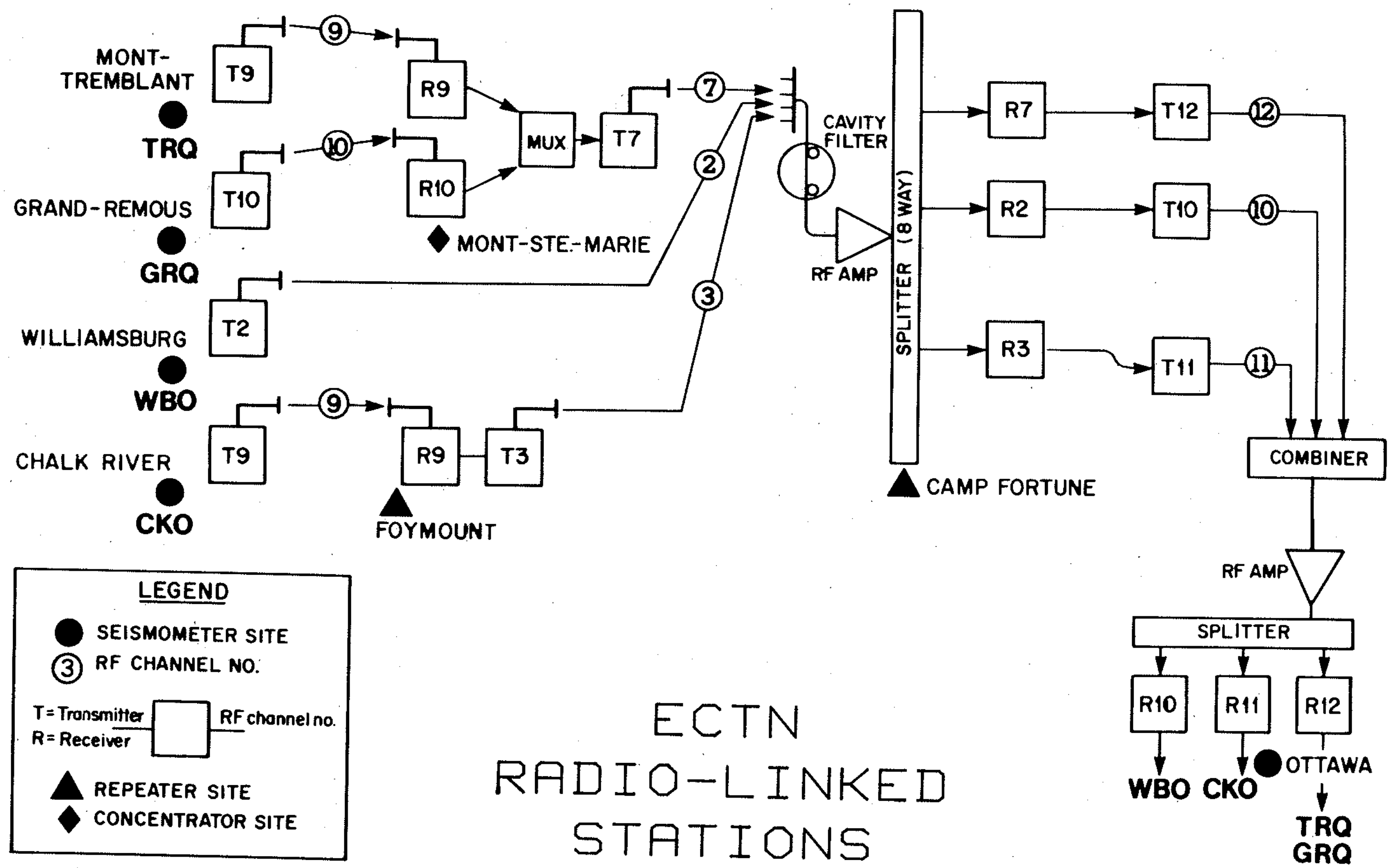


Figure 3. Block diagram of radio–links for ECTN stations.

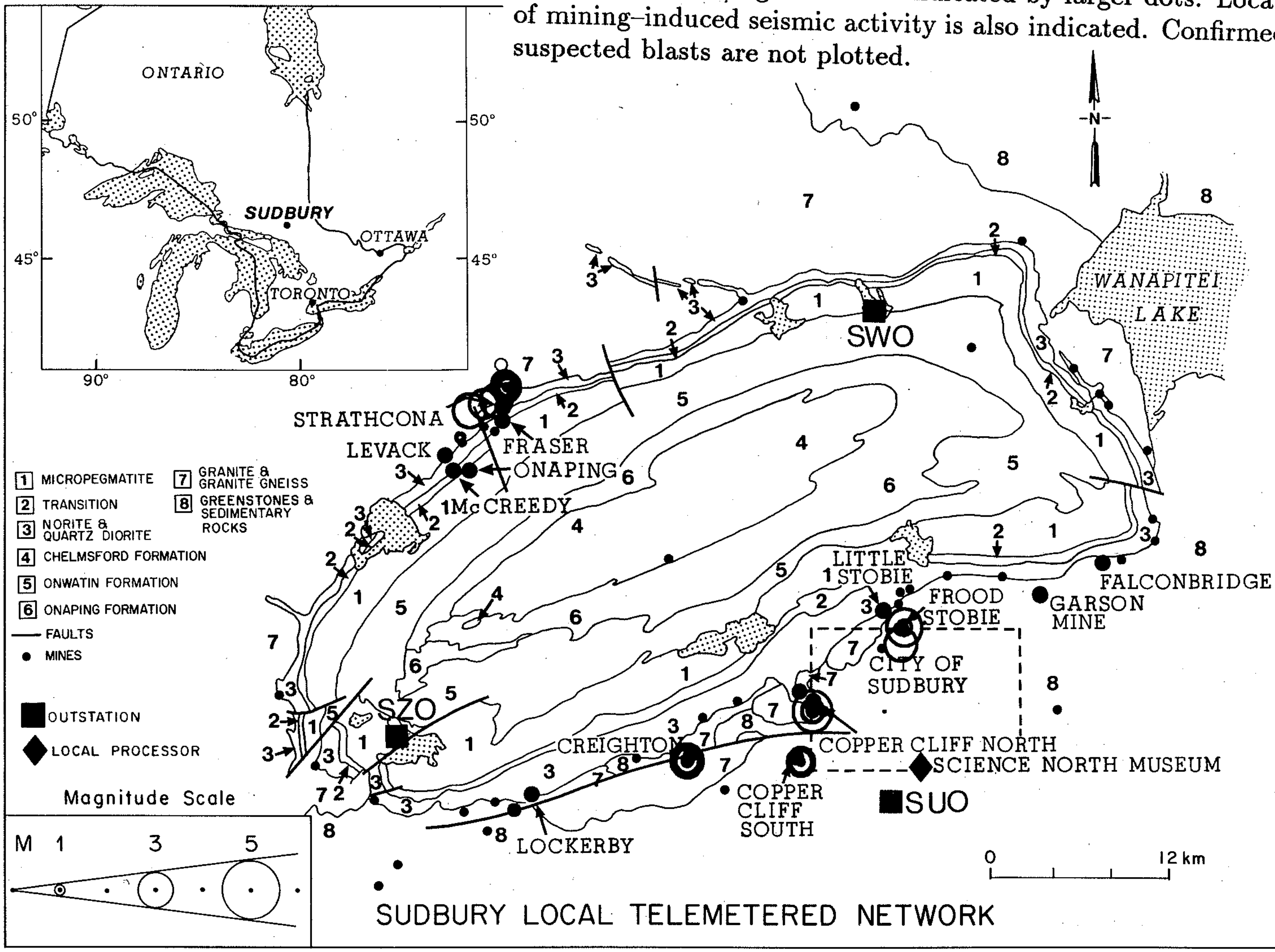


Figure 4. Map of the Sudbury Local Telemetered Network. Also shown are the simplified geology of the Sudbury Basin and the mine locations. Producing mines are indicated by larger dots. Location of mining–induced seismic activity is also indicated. Confirmed or suspected blasts are not plotted.

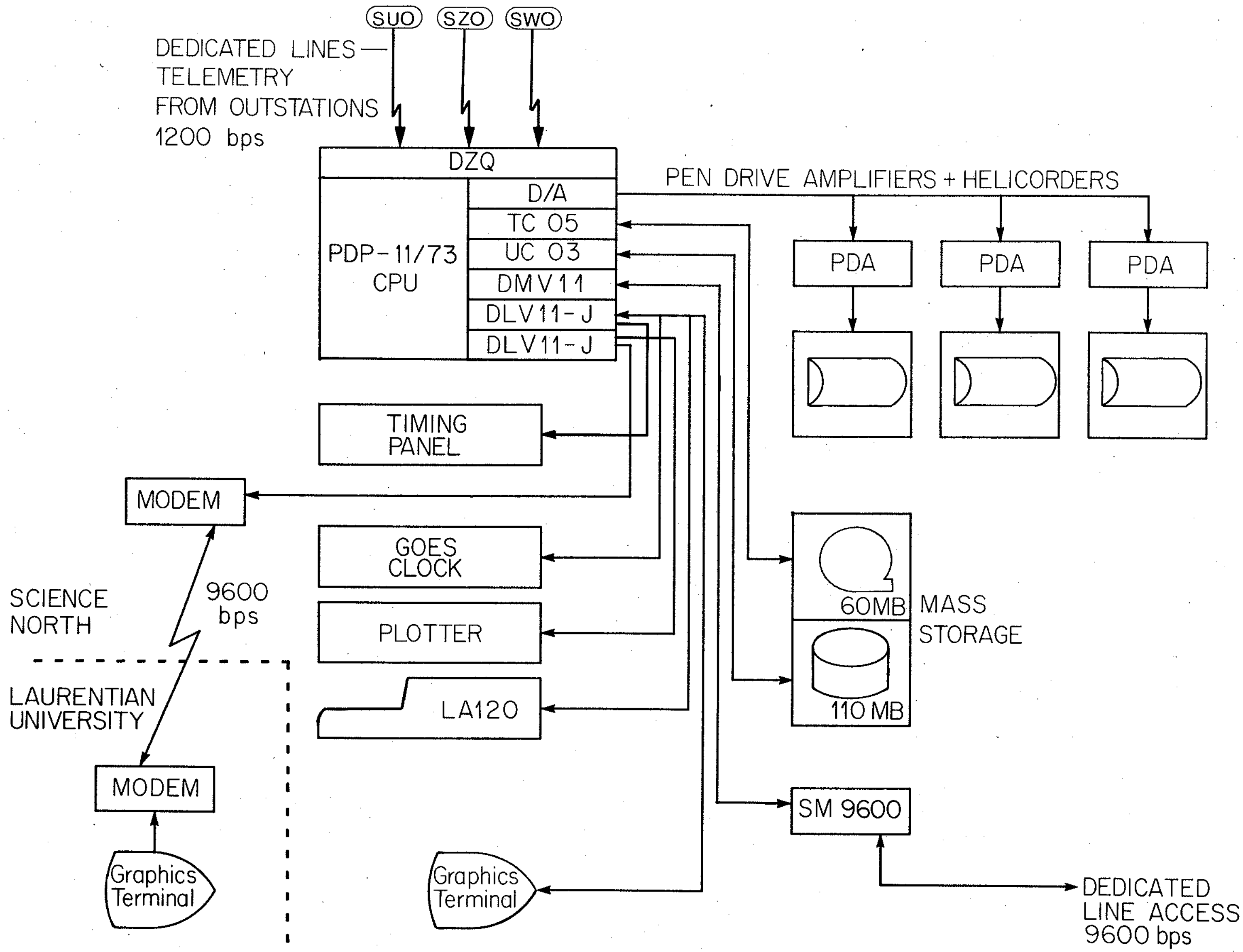


Figure 5. Block diagram of SLTN.

SUDBURY LOCAL
TELEMETRED NETWORK

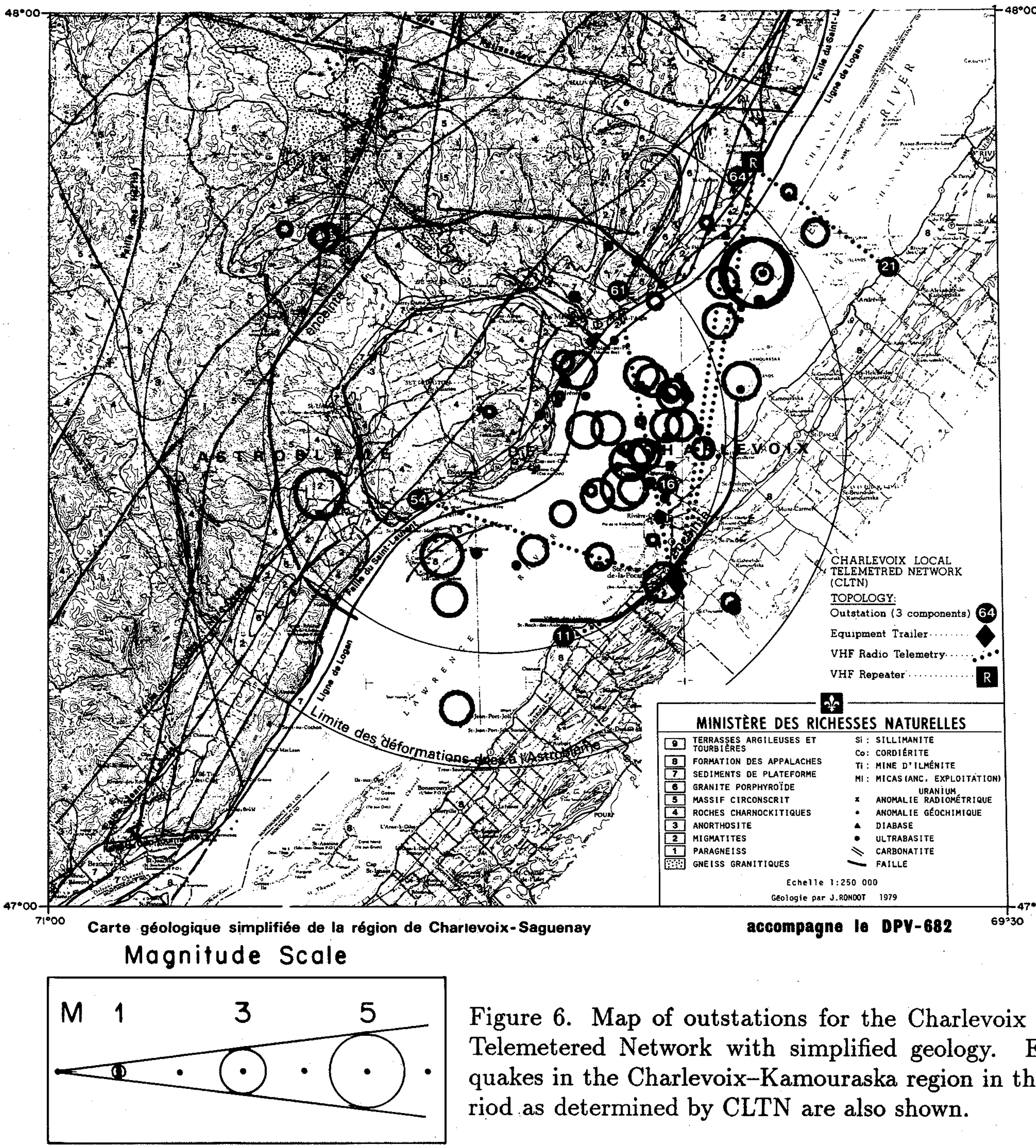


Figure 6. Map of outstations for the Charlevoix Local Telemetered Network with simplified geology. Earthquakes in the Charlevoix–Kamouraska region in this period as determined by CLTN are also shown.

in order to reduce the number of false alarm triggers. CLTN event files also have a 15-s pre-trigger buffer instead of the 60-s buffer used for ECTN files. Figure 7 shows the layout of the array.

CLTN event files are automatically transferred to Ottawa on a dedicated telephone line for analysis. The files follow the route

CHV73M::::::::::::OTTVAX:::::::::::::MVAX3

to Ottawa. CLTN event files, including teleseisms, are analyzed on MVAX3 concurrently with ECTN and SLTN files and are appended to any corresponding ECTN files in Ottawa before archiving. In the near future, CLTN data will be routed through DEMSA0 in the same manner as SLTN files, thus reducing the work load on OTTVAX.

ECTN Performance: The aggragate average up-time for the 21 ECTN components was 93.7% in this period. Details of the performance of each station are shown in Table 2. Telephone-linked stations generally performed better than radio-linked stations, because of the inherent problems with UHF radio communications, but JAQ had the largest down-time of 36% in this period because of power problems at that site. If it is not considered in the aggragate up-time statistics, then the aggragate average becomes 95.2%. The GAC borehole station, which had been converted from radio-link to a telephone-link at the start of this period, operated with an up-time exceeding 95% and was free from spiking.

Polarity of all vertical ECTN components was confirmed regularly in this period by systematically inspecting the first breaks of well recorded teleseisms or nuclear tests. No polarity reversals were found.

ECTN outstations generally performed without interruption during the Saguenay earthquake and produced some excellant records (Fig. 8). The exceptions were: LPQ whose signal was lost during the event due to the major power failure in eastern Québec caused by the earthquake; HTQ and MNQ which were affected by the same power failure; DPQ whose signal was clipped for some unknown reason during the event; and JAQ whose signal was spiky. However, most ECTN stations that recorded the event saturated on the S-phase; the exceptions were SBQ in southern Québec, KLN, GGN and LMN in New Brunswick and EEO and WEO in eastern Ontario. The local magnitude calculated for the Saguenay event from the unsaturated traces was MN 6.5, which is significantly higher than the mb magnitude value of 5.9 determined for this event by NEIS and indicates that the Saguenay earthquake radiated much more high-frequency shear-wave motion at regional distances than would have been expected from its teleseismic waveforms.

The peak ground motion at ECTN sites also provided important additional information about maximum vertical accelerations for the event that supplements the conventional accelerograph data described later. The peak values at ECTN sites varied from 0.07-0.76% g.

Telephone-linked Outstations: A new ECTN Mark III station, DAQ, was installed at the Hydro-Québec microwave relay site at Lac Daran, Québec in the epicentral area of the Saguenay earthquake

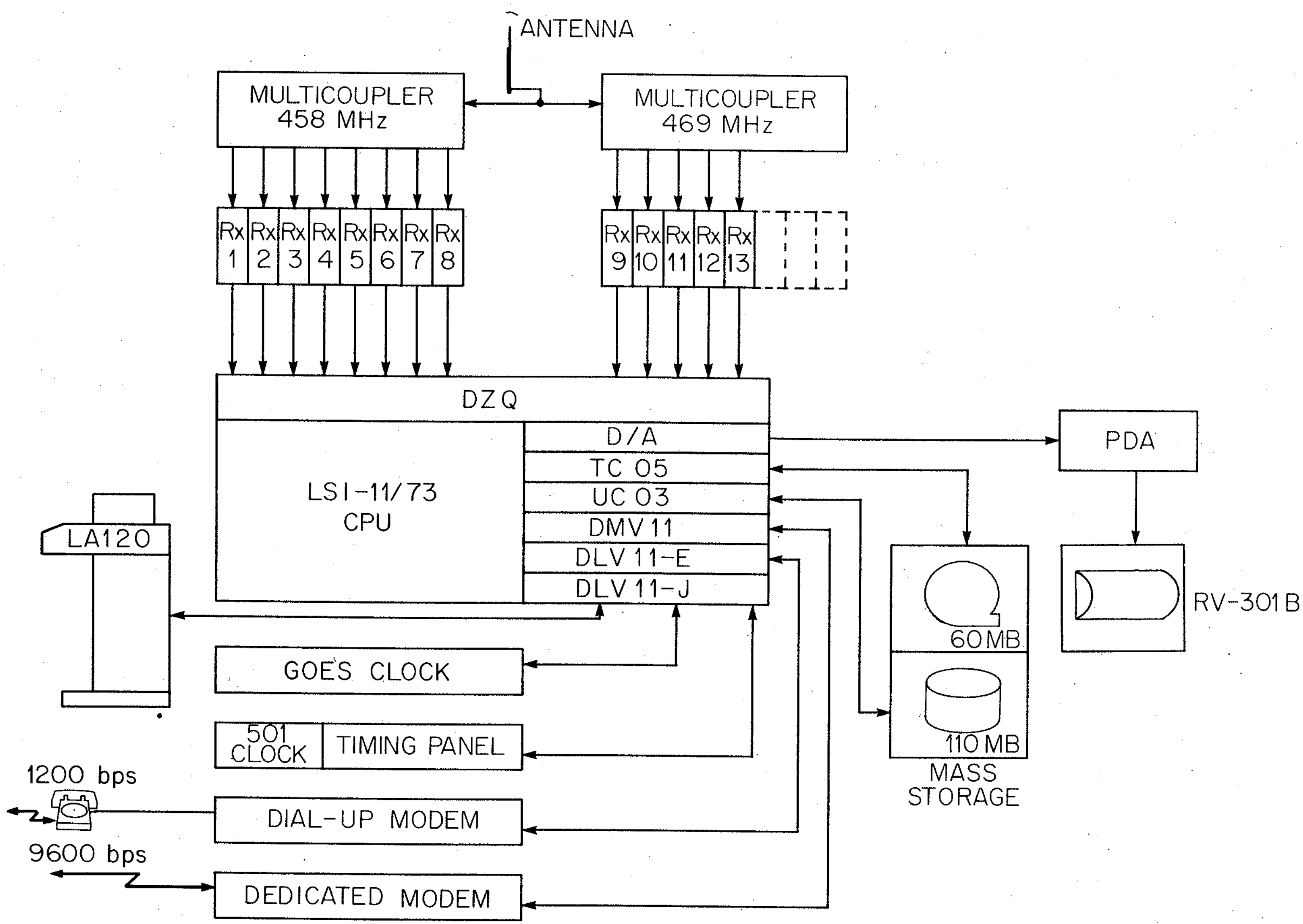


Figure 7. Block diagram of CLTN.

CHARLEVOIX LOCAL
TELEMETRED NETWORK

Table 2
Down-time for ECTN stations
1981-1987

STATION	% DOWN-TIME 88 87 86 85 84 83 82	COMMENT
	Telephone-linked Stations	
OTT	0.0 0.3 2.9 2.3 3.9 7.5 0.5	direct connection
MNT	0.1 0.1 0.2 0.4 0.1 0.8 1.0	direct line
SBQ	1.3 3.9 0.6 0.2 0.1 0.0 1.1	direct line
EEO	7.3 6.5 1.6 1.4 2.1	direct line
WEO	1.2 2.1 5.0 2.5 5.8 1.1 0.0	direct line
HTQ	0.6 0.3 15. 7.2 1.3 0.2 0.3	direct line
MNQ	0.6 7.8 24. 34. 1.8 0.4 0.0	via Hauterive
EBN	5.2 2.2 2.5 6.4 4.3 0.9 1.8	via Riv.-du-Loup
GSQ	1.8 1.8 3.7 2.6 2.1 0.6 1.6	via Riv.-du-Loup
LPQ	4.5 2.3 4.0 4.0 9.0 5.4 18.	via Riv.-du-Loup
LMN	1.8 1.9 2.2 8.4 13. 11. 32.	via St. John and Riv.-du-Loup
GGN	7.1 0.9 3.5 1.8 1.9 0.9 8.4	via St. John and Riv.-du- Loup
KLN	7.4 1.1 2.2 1.5 3.1 11. 5.4	short radio link via St. John and Riv.-du-Loup
JAQ	36. 6.8 3.0 11. 13. 5.0 1.3	short radio link
DPQ	8.4	direct line
GAC SPZ	3.4 3.6 2.5 5.5 4.2 2.8 2.3	direct line
	Radio-linked Stations	
CKO	7.3 5.2 15. 10. 32. 5.7 2.4	via Foymont and Camp Fortune
WBO	3.7 7.3 20. 10. 18. 5.8 0.2	via Camp Fortune
GRQ	19. 15. 20. 15. 10. 23. 23.	via Camp Fortune
TRQ	19. 15. 21. 22. 11. 54. 16.	via Camp Fortune

Séismogrammes du tremblement de terre du Saguenay (Québec), enregistrés par le réseau de télémétrie de l'est du Canada

Seismograms recorded by the Eastern Canadian Telemetered Network during the Saguenay Earthquake

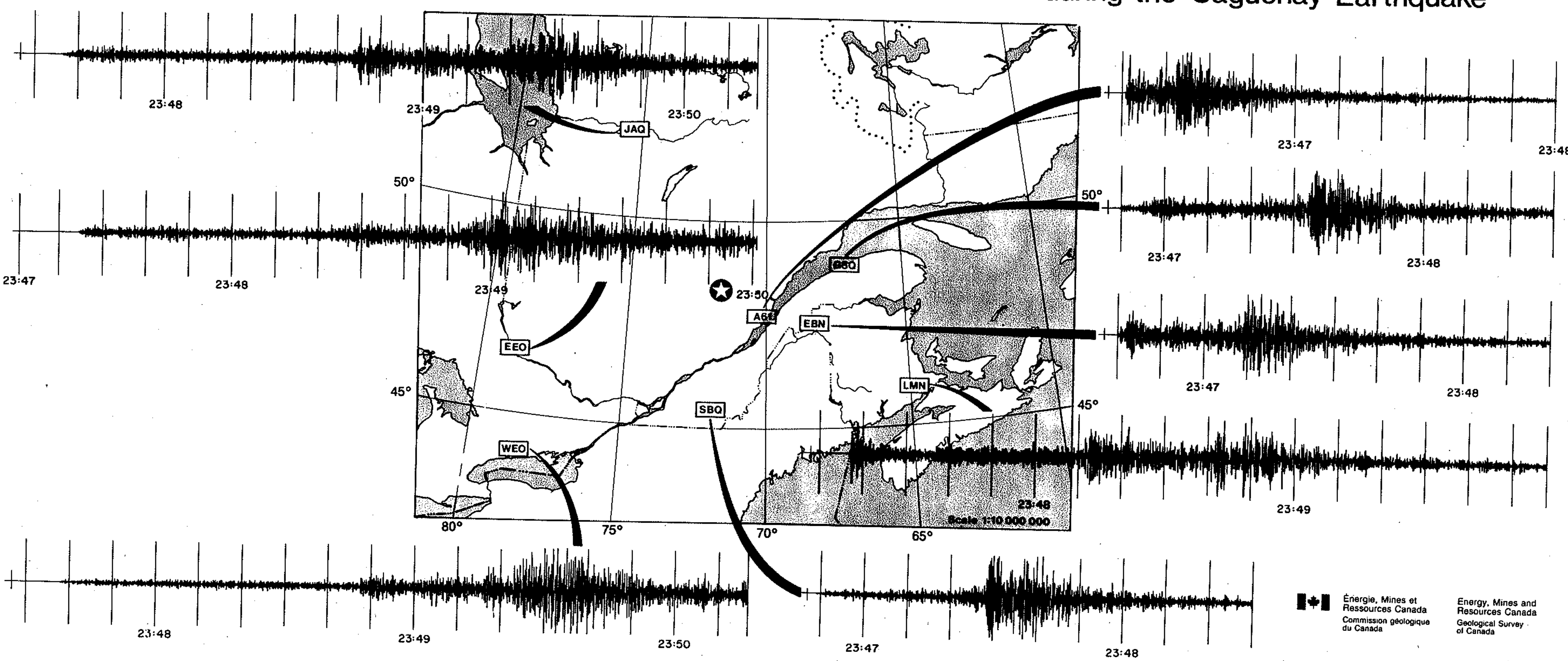


Figure 8. Some ECTN records of the Saguenay earthquake

on December 16. Details of the site are:

DAQ	47.9644 °N	71.2425 °W	939 m

In order to connect the DAQ signal to Ottawa as quickly as possible, the DAQ signal was put on the line used by DPQ and the DPQ station was temporarily closed on December 15. The firmware at DPQ was replaced in February to eliminate the clipping problem that had been experienced during the Saguenay earthquake and the station was calibrated. DPQ returned to service on February 17.

On January 16 LPQ was upgraded to a Mark III station. Both the old and new stations were calibrated. Data from LPQ were rerouted to Ottawa via Channel 1 of the supermodem used for CLTN. The CNCP commercial line carrying the LPQ signal from La Pocatière to Rivière–du–Loup and thence to Ottawa was cancelled thus saving its monthly line charge. However, noise spikes were experienced on the LPQ data coming by the new routing. The problem appeared to be centred in the CLTN supermodem and its synchronization with the rest of the system. The outstation, concentrator, computer and telephone line have all been eliminated as sources of the spiking. At this time spiking is still being experienced on the LPQ signal, and our efforts are continuing to identify the source and rectify the problem.

JAQ experienced a lengthy interruption in service during the latter part of 1988 when Hydro-Québec installed a new solar panel and appropriate batteries at the outstation. However, because of a rainy autumn with very few sunny days, the solar panels could not maintain the batteries and the station went dead. A second set of panels had to be installed and since then the station has run without any problems.

KLN, LMN and GGN experienced a lengthy interuption beginning on April 29, 1989 caused by failure of the supermodem in St. John, New Brunswick. The problem could not be corrected until July, 1989.

GGN and LMN were both serviced between October 17 and 21, new S-13 seismometers were installed and both stations were calibrated. GGN was upgraded to a Mark III station on June 16.

EEO was upgraded to a Mark III station on November 25, and calibrations were performed on both the new and old equipment.

GGN and EEO were also equipped with "Zap Trap" lightning arrestors.

The possibility of a misalignment of the horizontal components at GAC was investigated in this period by comparing the true and apparent azimuths of well located local earthquakes and blasts at GAC. The tests confirmed that any misalignment was small, less than 20°, and suggested that it was most likely counterclockwise.

The concentrator site at Rivière-du-Loup was repaired on September 06 following a microprocessor failure on September 02. Service from the six stations, KLN, EBN, GGN, LMN, GSQ and LPQ, that use that concentrator was interupted during this period.

A new Mark III concentrator, based on the IBM PC-XT, was designed in this period. The new concentrator will handle four–1200 baud Mark III input signals and output at 4800 baud using a Trailblazer asynchronous modem. The first unit will be installed at the HTQ concentrator in late 1989 and will be used to concentrate signals from a relocated HTQ station with those from MNQ and two new sites at Sept Îles (SIC) and Pointe-aux-Anglais (PAQ) in eastern Québec.

Radio-linked Outstations: All radio-linked ECTN stations were serviced and calibrated in the first quarter of this period, except TRQ. Several stations were hit by lightning, but no significant interuptions in service resulted.

SLTN Developments: SLTN generally operated routinely in this period without significant interuptions or problems. A major upgrade of the SLTN hardware and software was completed in December 1989. The EMULEX disk/tape cartridge subsystem was replaced and the hardware modifications to the processor required to handle the latest software revisions were completed. The firmware at the outstations was updated to prevent clipping on strong seismic events.

SWO was out of service for 3 days in November and again for 3 days in May.

On September 4, Mr. M. Plouffe, the part-time analyst seconded to GD by CANMET for SLTN data processing, was promoted to a full-time position at CANMET's Mining Research Laboratory in Elliot Lake, Ontario. Until the SLTN-analyst position at GD was restaffed, SLTN data were collected and stored by GD but not routinely analysed. Mr. S. Lapointe was hired as a temporary part–time analyst for SLTN data in February.

SLTN operated routinely in the July-September period. Data were analysed every other day in July and August, and on a monthly basis in September. In all, 240 seismic events in the Sudbury Basin were located, with magnitudes ranging from - 0.2 to 2.7. Most of the events were operation blasts at the 15 active mines in the Basin, but approximately 15% were rockbursts. Discrimination of the blasts and rockbursts was carried out in cooperation with the mine operators, and about 90% of the rockbursts in this period were confirmed by the mining operators. The remaining events were seismic activity in the mines that the mining operators could not detect by their conventional means.

During the October-December period approximately 150 seismic events with magnitudes between 0.2 and 2.7 were located by SLTN and about 75% of these events were confirmed to be mining-induced events by the mine operators. The largest event was a magntiude 3.3 rockburst at the Copper Cliff North mine on December 31.

The Saguenay event was recorded on scale on all three SLTN stations.

In the January-March period, 1622 seismic events were detected in the Sudbury Basin by SLTN, and 125 mining–induced seismic events were documented. The largest event in this period was a magnitude 2.3 event at the Fraser Mine in Sudbury.

In the April-June quarter approximately 110 mining-induced seismic events were analysed. The largest event was a magnitude 2.7 event at the Strathcona Mine on April 9, but the source of the event could not be confirmed because the mine's local seismic array was not operating at the time.

CLTN Developments: The operation of the CLTN processor was intensively monitored during this period to identify and rectify many problems that plagued the system during its initial year of operation. Numerous changes were made in the automatic file transfer procedures, which greatly improved their reliability, and a procedure was started whereby the CLTN console log was written to a local file. This facilitated an easier identification of the ongoing problems with the system. The problems were compounded by communication dropouts, which occurred 30 times per day on average on the CNCP commercial telephone line linking CLTN to Ottawa. On July 25 1988, the company finally corrected problems with the data circuit and reduced the average number of outages per day on the line from 30 to 3. Also, an improper termination of one of the radio-telemetry receiver lines was found and corrected on August 10. These changes effectively eliminated the problem with spiking in the CLTN data files and CLTN has performed well since about mid–August 1988. CNCP has given GD a 4–month credit as compensation for the frequent line outages experienced in the summer of 1988 as a result of their "line equalization" problems.

Seventeen local events with magnitudes ranging from 0 to 2.3 were located with CLTN data during the July-September period. Two events on July 15 and August 04, both magnitude 2.4, occurred while the network was down, and had to be located with ECTN data only.

CLTN data transmission was delayed several hours following the Saguenay earthquake when the communications line failed as a result of the power failure, which followed the earthquake in eastern Québec. The array continued to operate on backup power, however, and data files were triggered for the mainshock and all the larger aftershocks. Once the communication line was reconnected, the data files were automatically transferred to Ottawa in the normal manner. All CLTN components saturated on the S-phase of the mainshock.

Twenty-eight earthquakes were located by CLTN in the Charlevoix seismic zone during the October–December 1988 period. The largest was M 2.5 on December 18.

CLTN operated routinely throughout the January-March period. 31 earthquakes were located, ranging in magnitude from -0.4 to 4.3. The largest events were two magnitude 4.3 events on March 9 and 11, which are the earthquake doublet described in more detail in a later section. Aside from the doublet events, the distribution of activity in the seismic zone was not unusual.

In the April–June period, 19 earthquakes were located in the seismic zone by CLTN, the largest M 2.3 on May 25. The distribution of activity was not unusual, but no events occurred within 10 km of the doublet events.

3. DATALAB DEVELOPMENTS

ECTN data are received in the Ottawa Datalab by dual PDP-11/73 microcomputers (Fig. 9) where acquisition software demultiplexes the seismic data, produces formatted one-second data buffers of the network data, stores the data in a 5– minute ring buffer on disk and produces a number of continuous visual monitors of the signal channels on helicorders. A separate TRIGGER program

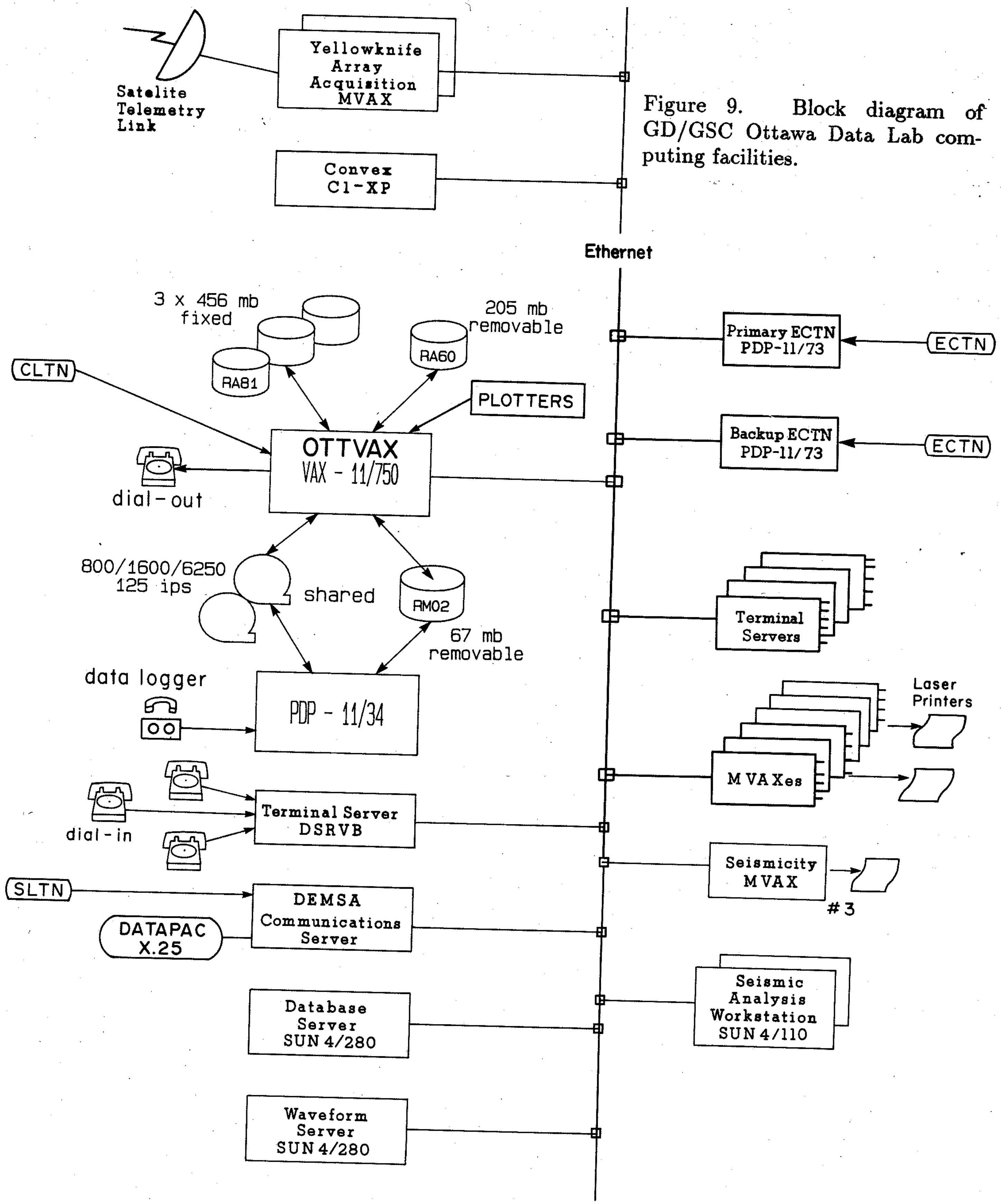


Figure 9. Block diagram of GD/GSC Ottawa Data Lab computing facilities.

continuously monitors the incoming data and, when the trigger conditions are satisfied for any single trace, creates an event file of the entire network data on disk. The overall process is controlled by a Network Configuration File (Table 3). The ECTN event files are then automatically scanned for noise files (typically those triggered by transmission glitches), which are segregated and the remaining files finally transferred via Ethernet to MVAX3 for analysis. The two 11/73 processors work independently of each other thus providing an important degree of redundacy for the acquisition system.

On MVAX3 (Fig. 10) the triggered event files are processed by a series of automatic programs (CAUSMO) which monitor the file transfers from the 11/73 processors, issue alerts on the computer systems for mutli-station-trigger files and plot and scale the transferred files for the network analysts' attention. Each networks' files, ECTN, CLTN and SLTN, go through a similar process. The analysts then identify all the valid seismic events in each day's files, including files containing teleseismic signals, and save them, combining the ECTN, CLTN and SLTN files for common events into one file as required in the process. Copies of all the saved files are returned to OTTVAX for archiving on magnetic tape while those containing local seismic events are analysed on MVAX3 using SAM to scale phase times and amplitudes and LOC to locate the hypocentres. The hypocentral data are stored in the database facility for future reference and for prepartion of the quarterly seismic bulletins which are distributed regularly to a wide variety of users both inside and outside of Canada.

The Saguenay earthquake put the earthquake analysis systems in the Ottawa Datalab to a real test. The computers continued to operate throughout the mainshock and power did not fail in Ottawa so no interruption of computer service was experienced. Despite some very chaotic conditions, preliminary location and magnitude of the tremor were determined within an hour of the event by GD staff using SAM and LOC and released to the press/media, emergency measures organizations, power utilities and the general public in an efficient manner. Interest in the event was intense and GD staff gave 28 television interviews, 130 radio interviews and responded to several hundred press enquiries in the days following the event.

GD subsequently carried out an intensity survey of the felt area of the tremor in Canada. The questionnaires were prepared and addressed and the replies analysed using the Datalab computer services particularly the relational database facilities on OTTVAX.

Hardware Developments: Figure 9 shows the current configuration of the Datalab computer network. During the year, a major procurement effort was undertaken to augment the processing facilities available to the Earthquake Seismology section. Although most interactive processing had been off-loaded to the MVAXes, and large numerical modelling jobs were moving to the CONVEX, the migration of more and more processing from the departmental mainframes to the in-house system had caused the central OTTVAX to become severely overloaded. The advent of continuous data via dedicated satellite telemetry link from the upgraded Yellowknife Seismic Array in late 1989, plus continuous satellite telemetry from the planned network of broad-band digital seismographs in 1990, clearly will bring a tremendous increase in the volume of data needing to be displayed, analyzed, classified, and archived on a daily basis.

Table 3

ECTN Network Configuration File: June 1989

NAME	ECTN	MAX. D/A CHANNELS	12	MAX. DZ UNITS	4
RING BUFFER (s)	300	PRE-EVENT BUFFER (s)	60	POST-EVENT BUFFER (s)	30
TRIGS. TO ENABLE SAVE	1	INITIAL LTSD	30	LTSD TIME CONSTANT	3
SYSTEM TIME BASE	60	RT CLOCK INTERUPT RATE	60	MULTI-PROCESSOR FLAG	A
MODE	P			CONSOLE LOGGING FLAG	3

L	C	SIGNAL	BD	D	SPS	F	TC ms	SENS nm/s	A	G	E	LVL	RAT	CF1 hz	R1	CF2 hz	R2	STC s	LTC m
1	1	OTT SZ	1200	2	60	2	-56	10.0			1	4.0	8	2.0	1.2	4.0	1.35	1.1	4.27
2	1	MNT SZ	1200	2	60	1	-60	10.0			1	4.0	20	2.0	1.2	4.0	1.35	1.1	4.27
3	1	EEO SZ	1200	2	60	5	-60	1.10	6	3		3.0	18	4.0	1.2	10.	1.80	1.1	4.27
4	1	DPQ SZ	1200	2	60	5	-61	1.10	7	1	1	3.0	20	4.0	1.2	10.	1.80	1.1	4.27
5	1	SBQ SZ	1200	2	60	5	-69	1.10			1	4.0	20	2.0	1.2	4.0	1.35	1.1	4.27
6	1	JAQ SZ	1200	2	60	1	-73	10.0	8	4		4.0	20	4.0	1.2	10.	1.80	1.1	4.27
7	1	WEO SZ	1200	2	60	5	-66	1.10	5	0	1	4.0	30	2.0	1.2	4.0	1.35	1.1	4.27
8	1	GAC SZ	1800	1	30	3	-62	0.70	9	0	1	2.5	40	1.0	1.2	2.0	1.35	2.2	8.54
8	2	GAC SN			30	3	-62	0.70			1								
8	3	GAC SE			30	3	-62	0.70			1								
8	4	GAC LZ		34	1	3	-62	0.20	10	0	1								
8	5	GAC LN			1	3	-62	0.20	10	0	1								
8	6	GAC LZ			1	3	-62	0.20	10	0	1								
9	1	MNQ SZ	2400	14	60	3	-98	10.0	1	3		3.0	18	4.0	1.2	10.0	1.80	1.1	4.27
9	2	HTQ SZ			60	3	-70	10.0	2	1	1	4.0	10	3.0	1.2	8.0	1.50	1.1	4.27
10	1	WBO SZ	1200	2	60	3	-62	10.0			1	4.0	15	4.0	1.2	10.0	1.80	1.1	4.27
11	1	CKO SZ	1200	2	60	3	-62	10.0			1	4.0	10	4.0	1.2	10.0	1.80	1.1	4.27
12	1	TRQ SZ	2400	14	60	3	-87	10.0	12	2	1	4.0	10	4.0	1.2	10.0	1.80	1.1	4.27
12	2	GRQ SZ			60	3	-87	10.0			1	4.0	10	4.0	1.2	10.0	1.80	1.1	4.27
13	1	GSQ SZ	4800	234	60	3	-216	10.0				4.0	8	3.0	1.2	8.0	1.50	1.1	4.27
13	2	EBN SZ			60	3	-216	10.0			1	4.0	30	3.0	1.2	8.0	1.50	1.1	4.27
14	1	GGN SZ	4800	234	60	5	-294	10.0	4	3	1	4.0	15	3.0	1.2	8.0	1.50	1.1	4.27
14	2	LMN SZ			60	3	-294	10.0			1	4.0	10	3.0	1.2	8.0	1.50	1.1	4.27
14	3	KLN SZ			60	3	-294	10.0	3	2	1	4.0	30	3.0	1.2	8.0	1.50	1.1	4.27
15	1	LPQ SZ	1200	2	60	5	-216	1.10	11	1	1	4.0	30	3.0	1.2	8.0	1.50	1.1	4.27
16	1	DAQ SZ	1200	2	60	5	-61	1.10			1	3.0	20	4.0	1.20	10.0	1.80	1.1	4.27

L: line number; C: component; BD: baud rate; D: packet code; F: format flag
SENS: bit resolution; DA: analog channel; G: analog gain; E: error log off; LVL: trigger level
RAT: trigger ration; CF: filter freq.; R: filter radius; STC: short-term constant; LTC: long-term constant

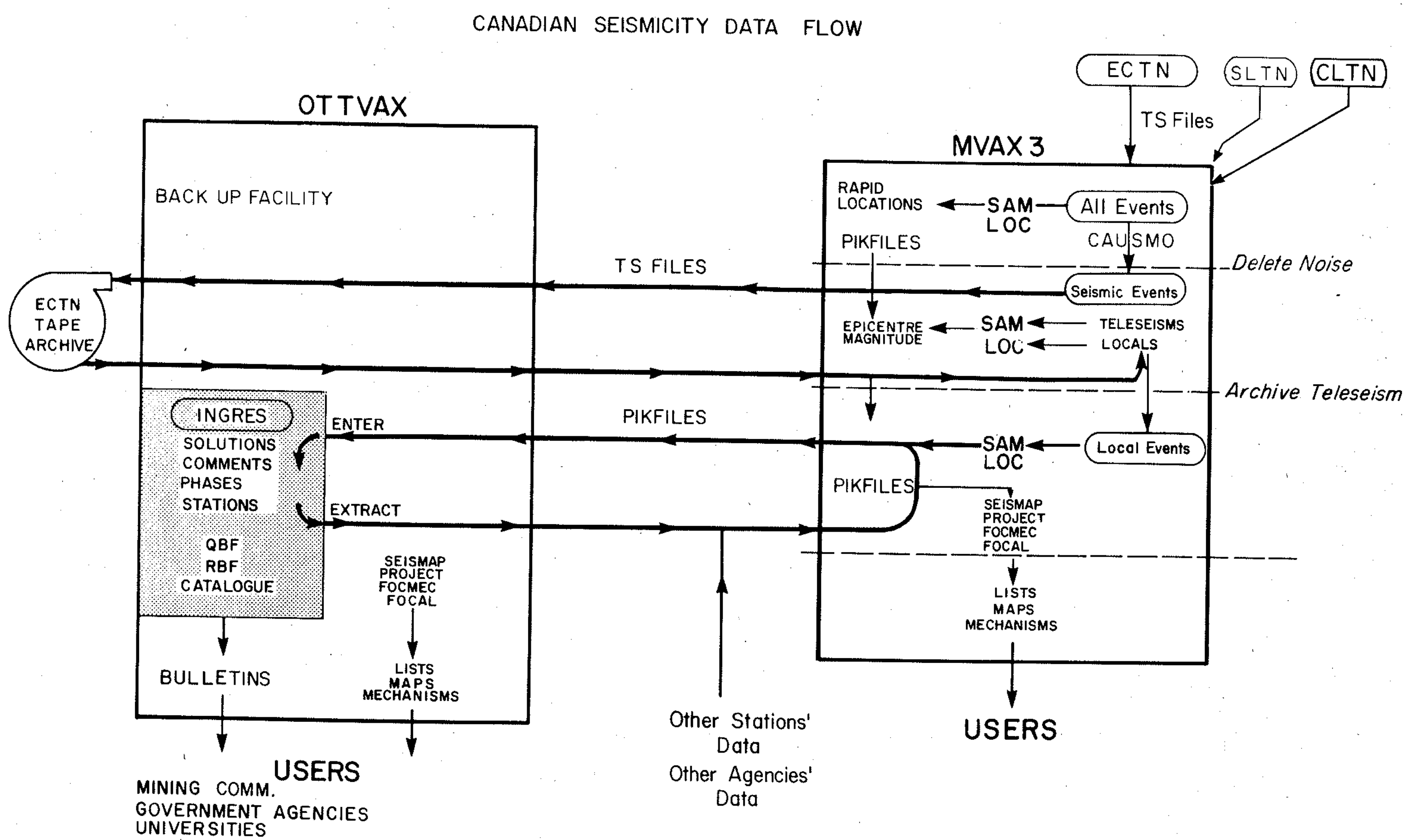


Figure 10. Block diagram of ECTN data flow.

It was clear, therfore, that the existing Datalab systems were incapable of meeting these needs in four critical areas:

- Data Base – development of the national Canadian Earthquake Database (CEDB), a relational database developed using the INGRES RDBMS package, was running out of steam on the overburdened OTTVAX host.

- Waveform Archive/PlayBack – a platform with significant I/O bandwidth was required to provide rapid centralized read/write access to digital time series stored on magnetic tape, 8mm Helical Scan cartridges, and 12" WORM optical disk.

- Automatic Seismic Processing (ASP) – a platform with sufficient CPU cycles available was needed to extend the relatively simple post-detection processing now being performed on MVAX3. With increased data volumes, it is anticipated that much more of the routine analysis will have to be automated.

- Seismic Analysis Workstations – to perform waveform display and seismic phase picking. The performance of the present interactive analysis system, comprising a Tektronix 4107/4209 colour graphics terminal or inexpensive monochrome Tek 4010/4014 emulator connected by serial line to a MVAX, simultaneously serving 6–8 other users, is barely adequate. In the near future, with potentially hundreds of events to be analyzed per day and no analogue recordings to help sort glitches and noise from *bona fide* seismic events, a much faster graphics display capability based on workstations was required.

In order to begin to satisfy some of these anticipated needs, the following new hardware items have been acquired:

- a SUN 4/280 Data Centre Server with nominal 10 MIPS CPU performance, 32 MB memory, 892 MB Winchester disk, and an Exabyte 2.3 GB Helical Scan cartridge tape to act as file server and waveform playback machine. Eventually, this machine will have shared access to the high-performance STC tape drives and the Aquidneck OAS 150/SONY 12" WORM optical disk playback subsystem acquired for playback of Yellowknife Array data.

- a second SUN 4/280 Data Centre Server with nominal 10 MIPS CPU performance, 32 MB memory, 892 MB Winchester disk, and an Exabyte 2.3 GB Helical Scan cartridge tape to act as INGRES Database server.

- two SUN 4/110 diskless workstations with nominal 7 MIPS CPU performance, 8 MB of memory, and 19" monochrome monitor to serve as prototype Seismic Analysis Workstations.

- a DEC DEMSA X.25/synchronous communications server to off-load from the OTTVAX the handling of national and international Datapac/X.25 communications and DECnet routing for the Local Telemetered Networks (SLTN and CLTN).

Acquisition Software: A major new release of the CDTSN central site acquisition software, dubbed

V4.2, was developed and put into production in this period. New features of V4.2 include:

- Support for 8-character station-band-component identifiers, including 5-character site codes. This makes the treatment of ASCII station names consistent throughout the entire software suite, from the input Network Configuration File, to the Time Series Files output by DEMUX, and throughout the VAX-based analysis software (SAM and LOC).

- Increased number of input signal telemetry ports from 16 to 24. This will permit planned network expansion up to the maximum processing capacity of the Mark IV hardware systems in a flexible manner.

- Combination of the separate "front-end" and "host" table data files, a carry over from the dual-processor Mark III configuration, into a single binary network configuration file, NCF.DAT. This reduces the number of subsidiary files required to operate the system and eases program maintenance.

- Creation of a new utility program, SHODAC, to map through dynamic memory and print a list of the current D/A converter (helicorder) station assignments and sensitivities. Previously, it was impossible to determine after the fact any *ad hoc* changes made with the DAC command.

In adition, the DEMUX program was further developed during the year. The method of spawning the DECnet utility (NFT) used to perform auto-transfer of detected event files over the network to MVAX3 was modified to circumvent a mysterious incompatibility with the RSX function of logging the real-time console output to a file. This latter feature was needed to provide improved performance monitoring and trouble shooting capabilities, especially for remote, unattended systems like CLTN that typically run without a hardcopy console connected.

Finally, the suite of routines used to specify and display the constants used in the pre-detection recursive digital filtering and long and short-term averaging in the TRIGGER program was modified so that the parameters are now specified directly in terms of centre frequencies, radii, and seconds. This is at once more intuitive and avoids the former intermediary step of running the desired values through an external conversion program. Table 3 gives an example of the new format for the filter parameters in the Network Configuration File.

In this period a systematic study of noise at all ECTN sites was conducted. As a result of that study, new filter and time constants were introduced into the TRIGGER program on the ECTN acquisition computers for some stations in January 1989 to improve their triggering performance.

In this period also, the discrimination routines for identifying ECTN files caused by tranmission glitches was migrated from MVAX3 where they were developed to the PDP 11/73 processors. This change allowed the noise files to be identified on the acquisition computers and thereby reduced the number of files that have to be transferred to MVAX3 daily for analysis.

Analysis Software: A new version of SAM was released which is capable of performing DC-remove, spike filtering, Butterworth filtering and marking observed/calculated arrivals, distances etc. on hardcopy plots. The new features are controlled by extra switches at the end of the HARDCOPY commands, HC, RHC, LC and RLC.

SAM has also been modified to log the total number of times that each command is called by users.

LOC was converted to use epochal time internally. This eliminated the problems that often arose when some of the phase times of a seismic event being located were on the day, month or year following the origin time. Provisions for loading arbitrary plane-layered velocity models into the program were also incorporated in LOC in this period and a new internal velocity model for the Saguenay region was defined. A new parameter, 'reading bias', defined as

$$bias = (weight \times residual/RMS)^2$$

was added to the output of LOC. The bias quantifies the influence of each residual on the calculated hypocentre and is usefull in error checking phase readings during an initial location.

Database Facilities: The Canadian Seismicity Database (CSDB) was used routinely in this period to store and update information about local earthquakes determined from ECTN. This database facility only contains the last two years of Canadian earthquake data and is optimized for current seismicity needs. The quarterly Bulletins and Summaries of earthquake activity distributed by GD were generated directly from this facility,

Work has continued on a major upgrade of the Canadian Earthquake Database (CEDB) to include information on instrument response, station location and history, network configuration, waveform and time-series indices, crustal models and unassociated arrivals as well as the standard local earthquake data. The new structure chart is shown in Figure 11. The design of the expanded database has been completed and a suite of new command procedures and programs have been created that can populate or update, either automatically or by hand, some of the database tables. We are continuing to populate those new database tables. Information on postal codes for post offices in eastern Canada was entered into the database in this period in order to be used routinely to address intensity reports for isoseismal surveys of widely felt earthquakes.

The Saguenay earthquakes marked the first time addresses for felt report questionnaires were generated directly from the database according to their geographic coordinates. In the process several new procedures and programs had to be created to handle the task. Despite these teething problems, over 2000 questionnaires were sent out in a timely fashion following the earthquake to the effected areas of Ontario, Québec, the Maritime provinces and Labrador.

Intensity information collected for the Saguenay earthquake in Canada was also entered into the database during the evaluation phase of the intensity survey. Similar data for the U.S. have been obtained from NEIS and loaded into the same tables and the combined dataset is being used to compile the final isoseismal map for the earthquake

Other developments in this period were:

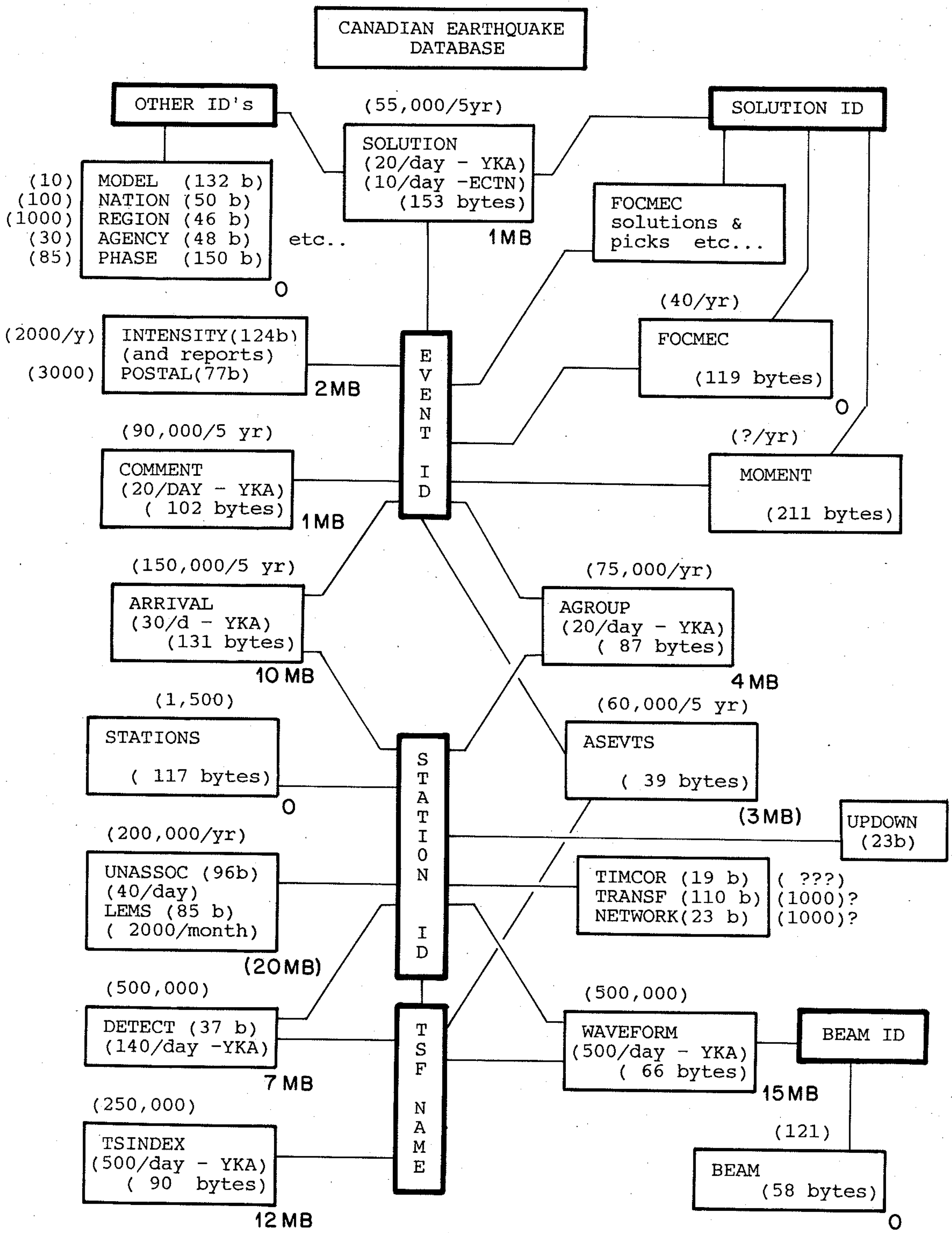


Figure 11. Block diagram of proposed new Canadian Earthquake Database. Estimated number of records and total amount of data (bytes) are given.

- Information for all ECTN and Yellowknife Array TSF tapes up to January 1989 has been entered into three tables: TSINDEX, WAVEFORM and DETECT. There were 240 tapes with more than 100,000 files.

- The CSDB has been moved (unloaded and reloaded through external ASCII files) from OTTVAX to SUNDBS. There is a significant performance improvement in INGRES on the dedicated SUN 4/280 processor compared to the VAX 750.

- A preliminary version of a new phase association program has been developed. It groups local earthquake phases read from Canadian seismograph stations by arrival time, identifies events of associated phases and searches the CEDB for existing information on the events and any available time–series.

- RDSEED, the standard file reader for the international Standard for Exchange of Earthquake Data (SEED) formatted time–series files, has been modified to work in the VAX environment. It now reads YKA data files in SEED format and outputs data files in ECTN Mark II format.

4. STRONG–MOTION NETWORK DEVELOPMENTS.

The Eastern Canada Strong Motion Seismograph Network, supported by the *Canadian Seismic Agreement*, consists of 19 sites centered around the Charlevoix region of Québec (Figure 12). The instruments are all Kinemetrics SMA–1 three–component analogue accelerographs (Table 4). Regular servicing of the network is carried out twice yearly by Geonetics Engineering Inc. of Ottawa under contract to GD.

The permanent network was serviced in October 1988, in early December 1988 and in May 1989. The next service trips are scheduled for October 1989 and May 1990.

The strong–motion network was found to be in excellent condition in October 1988. The original A–class time code generator was returned to site 16 (Chicoutimi–Nord). Time code generators were also replaced at site 10 (Rivière–Ouelle; suspect high current drain) and at site 18 (Rimouski; would not increment days or hours) where B-class units were installed.

No records were produced by the network in the period from the previous service trip in May of 1988 to November 1989.

Twelve instruments were triggered by the ground motion of the November 25 M6 Saguenay earthquake, one of which jammed and did not produce a usable record. The sites were:

Chicoutimi–Nord	St-André	Les Eboulements	Baie–St–Paul
La Malbaie	Tadoussac	St–Ferréol	Rivière–Ouelle
St–Pascal	Québec	Ste–Lucie	St–Eleuthière

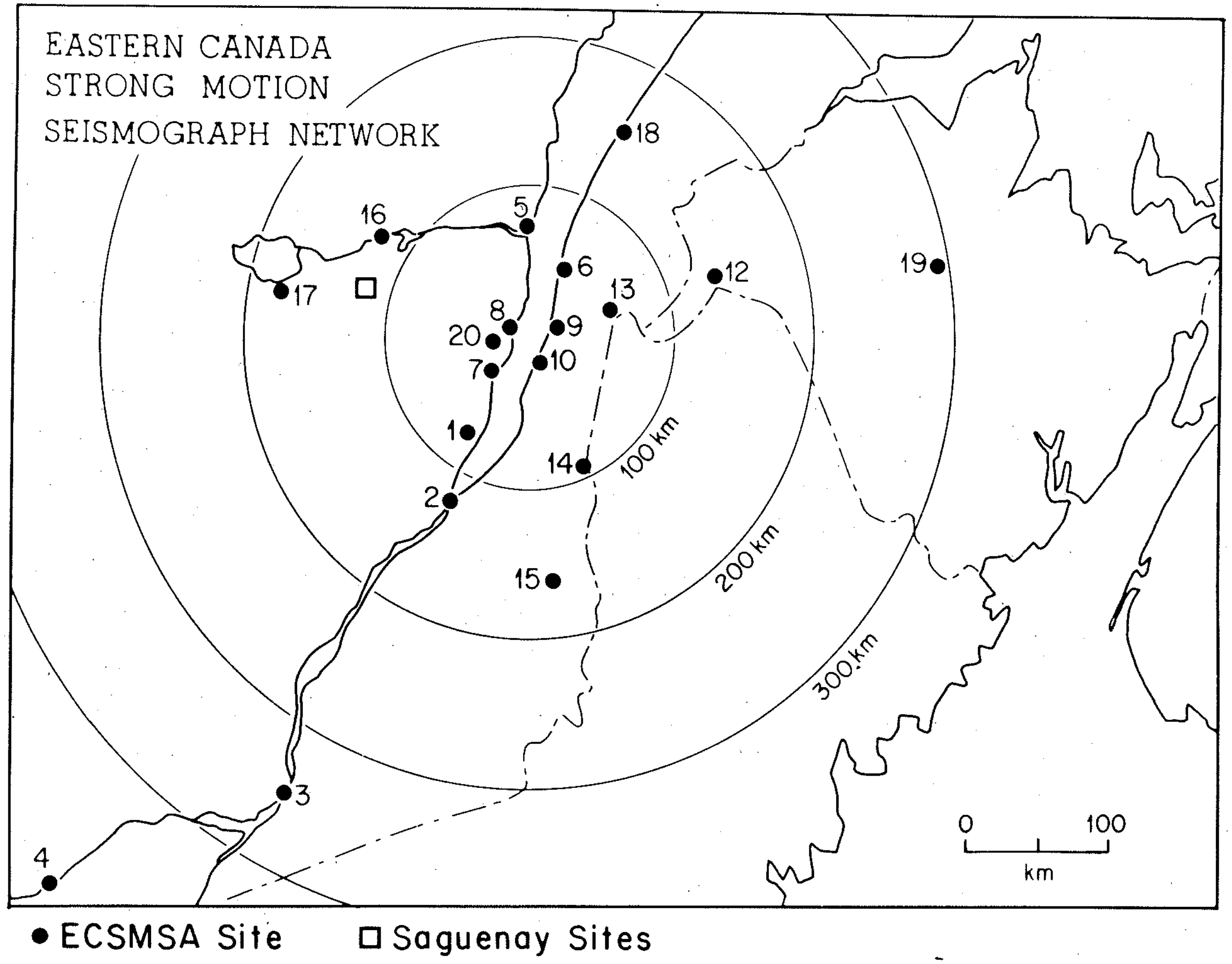


Figure 12. Strong–motion seismographs in eastern Canada supported by the Canadian Seismic Agreement

Table 4.
Eastern Canada Strong Motion Seismograph Network
June 1989

No.	Location	Date	Coord	Instr.	Sens.	Trigger	Building	Foundation
1.	St-Ferréol,Qué.	1/66	47.1256 70.8282	SMA-1 TCG-1B	1 g	0.0072 g	Underground seismic vault. Instrument on concrete pier.	bedrock
2.	Québec,Qué.	6/67	46.7782 71.2749	SMA-1 TCG-1A	1 g	0.0065 g	3-storey, reinforced concrete. Instrument on concrete pier on basement floor slab.	bedrock
3.	Montréal, Qué.	12/73	45.5025 73.6230	SMA-1 TCG-1A	1 g	0.0049 g	4-storey steel frame, curtain wall, poured concrete. Instrument in basement seismic vault.	bedrock
4.	Ottawa, Ont.	8/84	45.3942 75.7167	SMA-1 TCG-1A	1 g	0.0105 g	Underground seismic vault. Instrument on concrete pier.	bedrock
5.	Tadoussac, Qué.	5/79	48.1432 69.7189	SMA-1 TCG-1B	1 g	0.0101 g	Concrete pier to bedrock in crawl space of 1-storey bldg.	bedrock
6.	Rivière-du-Loup, Qué.	6/80	47.8356 69.5379	SMA-1 TCG-1B	1 g	0.0108 g	Two-storey reinforced concrete. Instrument on basement slab.	bedrock
7.	Baie-St-Paul, Qué.	10/82	47.4423 70.5069	SMA-1 TCG-1B	1 g	0.0090 g	Two-storey brick building. Instrument on basement slab.	alluvium valley
8.	La Malbaie, Qué.	9/67	47.6553 70.1527	SMA-1 TCG-1B	1 g	0.0112 g	1-storey steel frame, masonary walls. Instrument on concrete pier on basement floor slab.	bedrock
9.	St-Pascal, Qué.	10/69	47.5257 69.8045	SMA-1 TCG-1B	1 g	0.0050 g	1-storey reinforced concrete and masonary. Instrument on concrete basement floor slab.	bedrock
10.	Rivière-Ouelle,	8/84	47.4757 69.9961	SMA-1 TCG-1B	1 g	0.0108 g	Above ground seismic vault	bedrock
12.	Edmundston, N.B.	8/84	47.4614 68.2411	SMA-1 TCG-1B	1 g	0.0103 g	Above ground seismic vault	bedrock
13.	St-Eleuthère, Qué.	8/84	47.4950 69.3628	SMA-1 TCG-1B	1 g	0.0059 g	Above ground seismic vault	bedrock
14.	Ste-Lucie-de-Beauregard, Qué.	8/84	46.7414 70.0172	SMA-1 TCG-1B	1 g	0.0105 g	Above ground seismic vault	bedrock
15.	St-Georges, Qué.	8/84	46.1399 70.5799	SMA-1 TCG-1A	1 g	0.0132 g	Above ground seismic vault	bedrock
16.	Chicoutimi-Nord, Qué.	9/84	48.4902 71.0123	SMA-1 TCG-1A	1/2 g	0.0045 g	Outcrop in basement of two-storey wood frame house.	bedrock
17.	St-André-du-Lac-St-Jean, Qué.	9/84	48.3248 71.9917	SMA-1 TCG-1A	1 g	0.0054 g	Above ground seismic vault	bedrock
18.	Rimouski, Qué.	9/84	48.4452 68.4822	SMA-1 TCG-1B	1 g	0.0035 g	Above ground seismic vault	bedrock
19.	Miramichi, N.B. 'Loggie Lodge II'	10/86	46.9729 66.5293	SMA-1 TCG-1A	1 g	0.0105 g	Above ground seismic vault	bedrock
20.	Les Éboulements, Qué.	6/85	47.5496 70.3273	SMA-1 TCG-1B	1 g	0.0075 g	Above ground seismic vault	bedrock

For these records the following notes apply:

Tadoussac	The transverse sensor was dead
Baie–St–Paul	The unit shut off prematurely
Les Éboulements	The vertical sensor was completely undamped
St–Eleuthière	The unit triggered but jammed and did not record

The other eight instruments did not trigger. All the network stations were visited between December 4 and 8, the sites were inspected and any usable records were collected. The untriggered units had their basic operating parameters checked confirming that they all were operating according to specifications.

The original waveform data collected from the strong-motion network were presented in Open File Report No. 1976 of the Geological Survey of Canada (Munro and North 1988) and are reproduced in Figure 13. All eleven original accelerograms were digitized commercially using a computer–controlled trace–following laser scanner. The digitized data were processed using the AGRAM software package and the results were presented in Open File Report No. 1996 of the Geological Survey of Canada (Munro and Weichert 1989). This report contains plots of corrected acceleration, velocity and displacement, Fourier amplitude spectra of acceleration and pseudo–velocity response spectra. Both the raw and the evenly sampled processed digital data are available on 9–track magnetic tape.

A special network of eight strong–motion recorders (Figure 14) was set up in the epicentral area of the earthquake in the two weeks following the event. Five of the stations are operated by GD and three by LDGO. See Table 5.

In the period since the Saguenay earthquake of November 25, 1988, no records have been retrieved from either the permanent or the temporary strong-motion networks operated by GD in the Saguenay aftershock area. However, a M 3.6 aftershock on January 19, 1989 did trigger some of the strong–motion recorders operated by LDGO.

The GD SMA recorders will be kept in place until August of 1989 when they will be serviced and removed.

5. EARTHQUAKE ACTIVITY JULY 01 1988 TO JUNE 30 1989

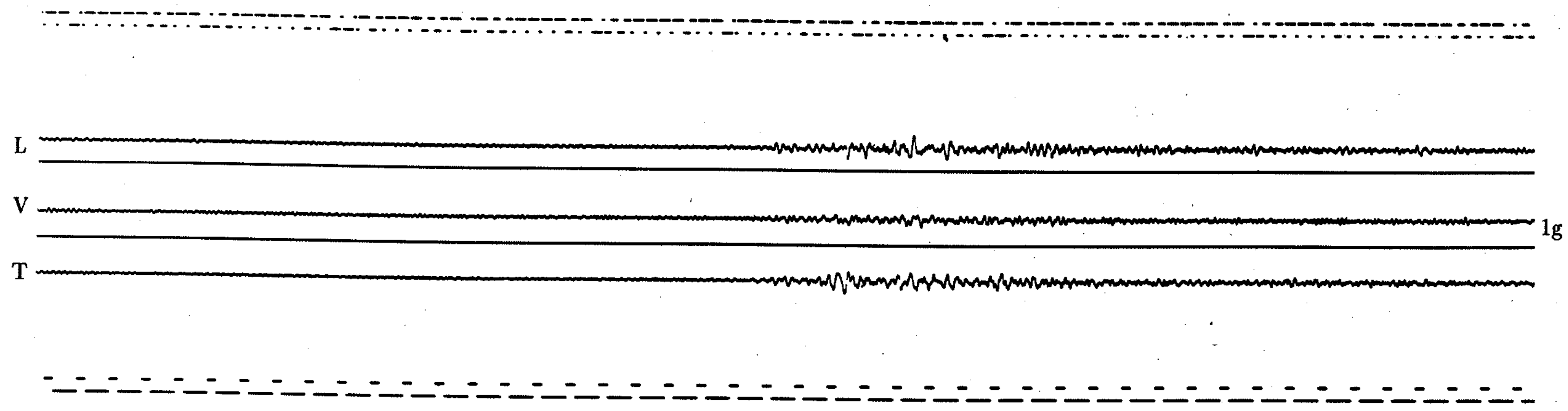
Under the terms of the Canadian Seismic Agreement, seismic data, provisional hypocentres and magnitudes for eastern Canadian and northeastern U.S. earthquakes are distributed quarterly to operators of the northeast U.S. seismic networks in the form of the ECTN Bulletin.

During the period July 1, 1988 to June 30, 1989, 312 earthquakes were analysed for location and magnitude (Figure 15). Thirty-nine earthquakes were magnitude 3.0 or greater, the largest being the M 6.0 Saguenay, Québec earthquake on November 25, 1988 (Table 6). Fourteen earthquakes were reported felt in Canada. Figure 15 shows that, aside from the Saguenay earthquake, the pattern of activity continued to be similar to that of previous years with activity occurring primarily in the recognized seismic zones of West Québec; Charlevoix, Québec; Lower St. Lawrence, Québec;

GEOLOGICAL SURVEY OF CANADA
STRONG MOTION PROGRAM
Saguenay Earthquake: 25 November, 1988.
Laurentides Provincial Park, Quebec, Canada.

COMMISSION GÉOLOGIQUE DU CANADA
PROGRAMME DE SECOUSSES FORTES
Tremblement de terre du Saguenay: le 25 novembre 1988.
Parc provincial des Laurentides, Québec, Canada.

Site 1: St–Ferréol, Instrument SMA-1 — Latitude 47.1256°N, +L=0° — Longitude 70.8282°W/O, Distance 114 km



Site 2: Québec, Instrument SMA-1 — Latitude 46.7782°N, +L=51° — Longitude 71.2749°W/O, Distance 149 km

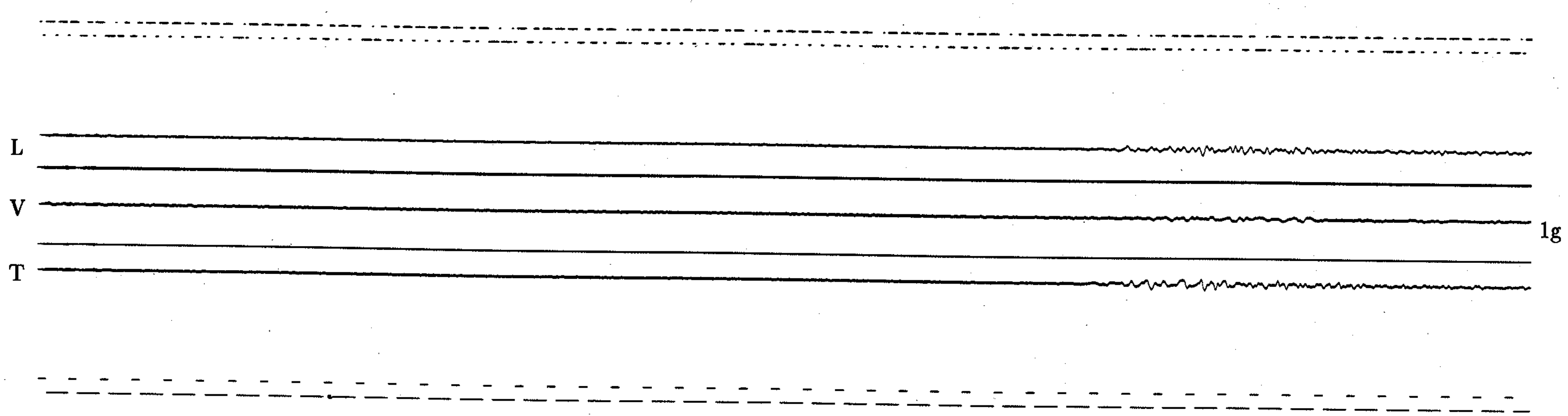


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Figure 13 a. Strong–motion accelerograms of the Saguenay earthquake

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Saguenay Earthquake: 25 November, 1988.
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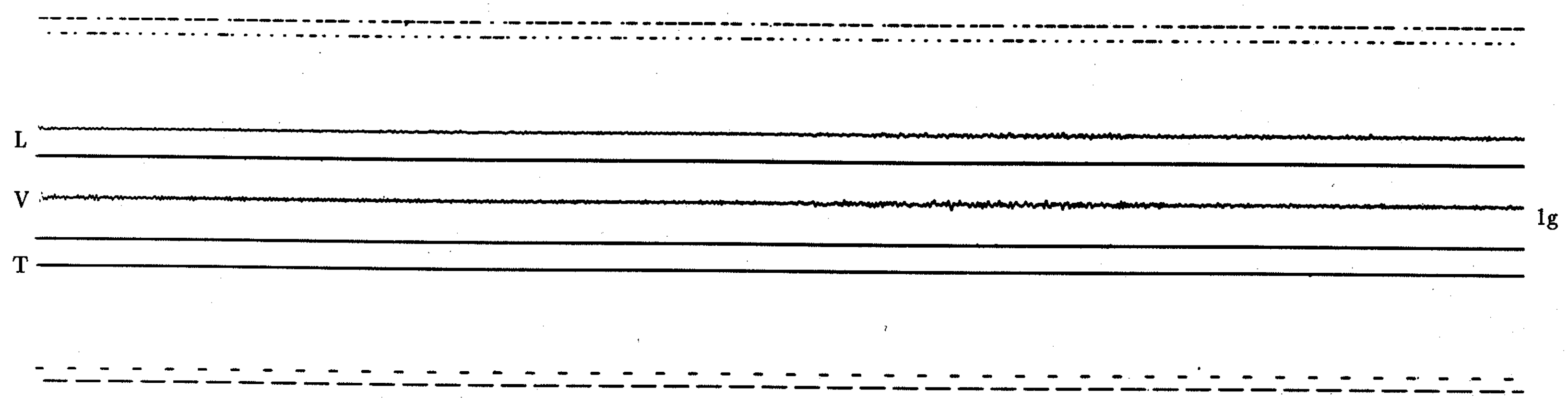
Site 5: Tadoussac, Instrument SMA-1, Latitude 48.1432°N, +L=97°, Longitude 69.7189°W/O, Distance 109 km



Site 7: Baie-St-Paul, Instrument SMA-1, Latitude 47.4423°N, +L=175°, Longitude 70.5069°W/O, Distance 91 km

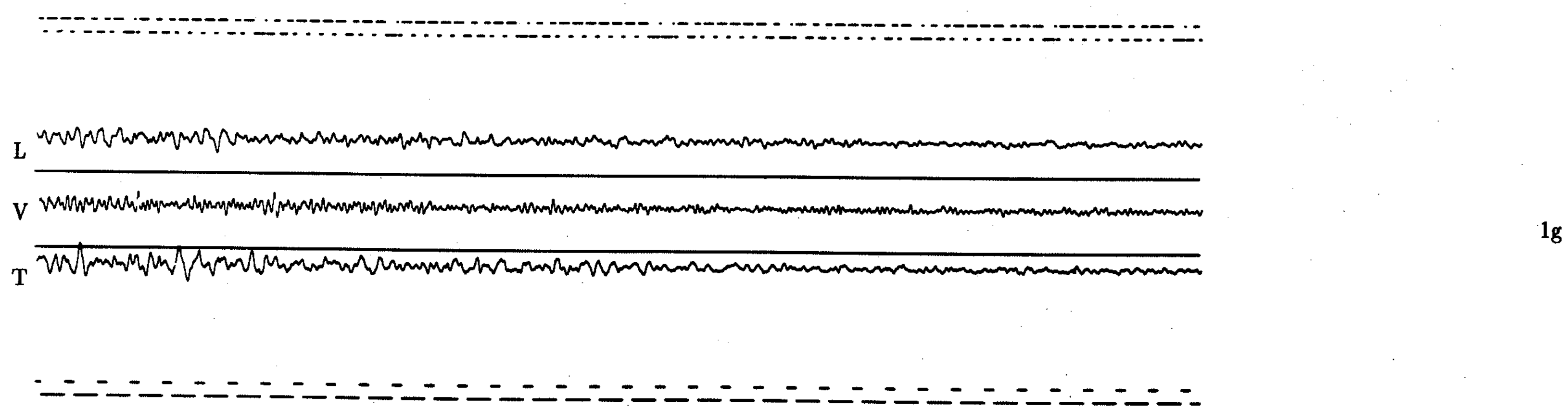


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Figure 13 b. Strong-motion accelerograms of the Saguenay earthquake

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STRONG MOTION PROGRAM
Saguenay Earthquake: 25 November, 1988.
Laurentides Provincial Park, Quebec, Canada.

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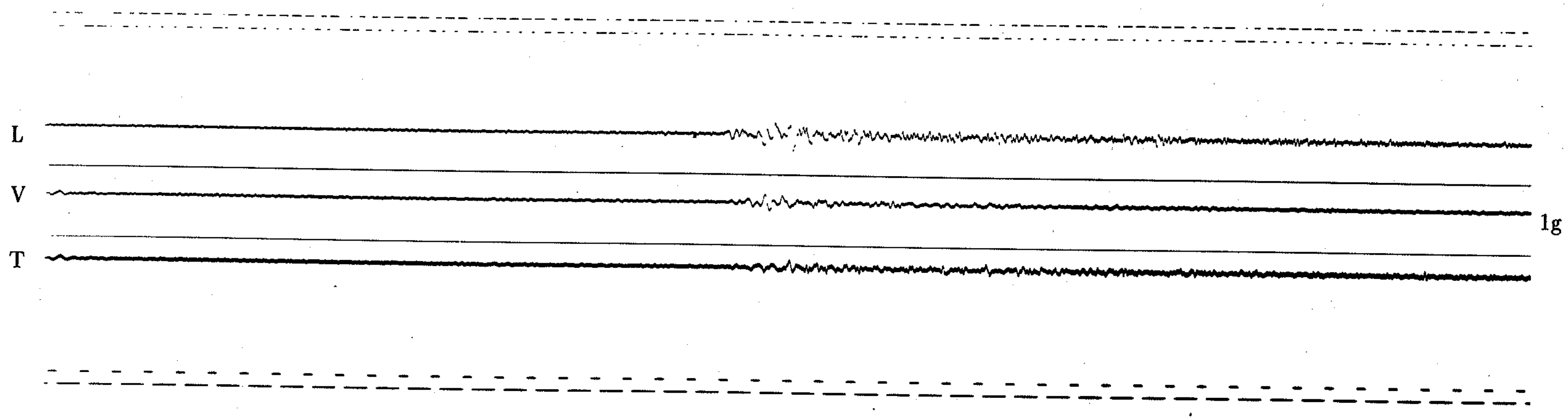
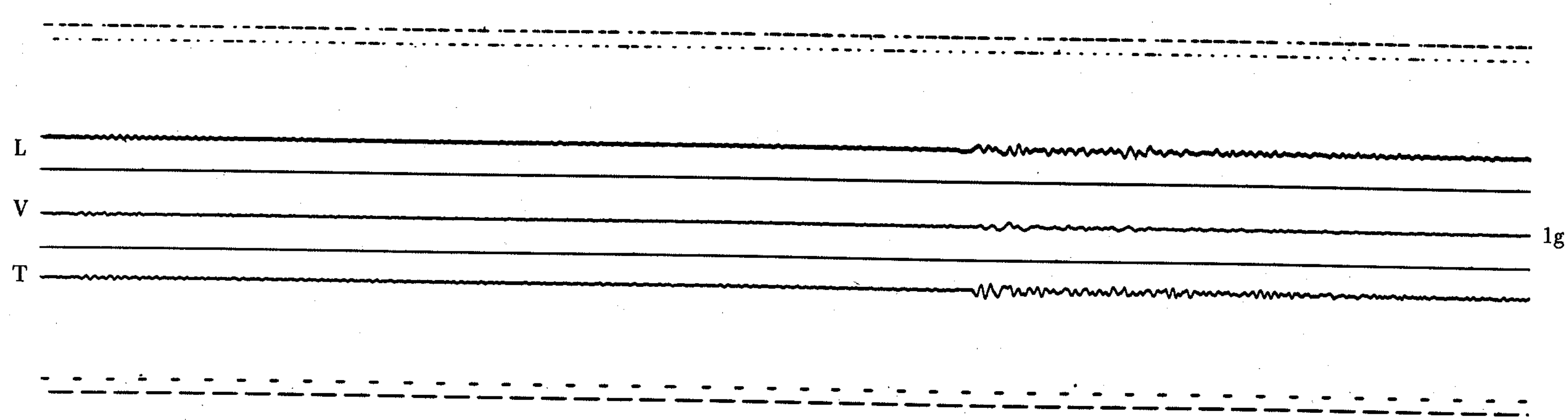
Site 8:	La Malbaie	Latitude 47.6553°N	Longitude 70.1527°W/O
	Instrument SMA-1	+L=251°	Distance 93 km



Site 9:	St–Pascal	Latitude 47.5257°N	Longitude 69.8045°W/O
	Instrument SMA-1	+L=0°	Distance 123 km



Canada

Figure 13 c. Strong–motion accelerograms of the Saguenay earthquake

GEOLOGICAL SURVEY OF CANADA
STRONG MOTION PROGRAM
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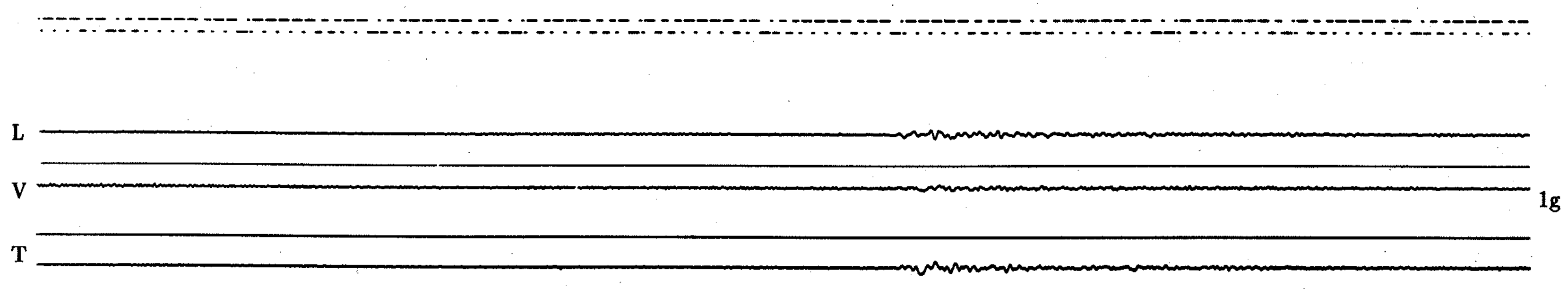
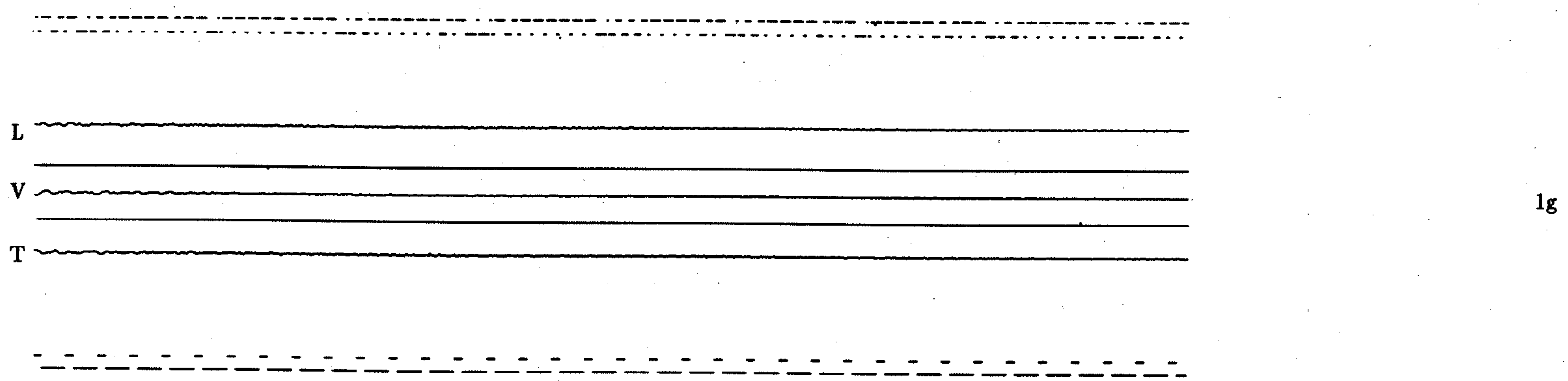
Laurentides Provincial Park, Quebec, Canada.

COMMISSION GÉOLOGIQUE DU CANADA
PROGRAMME DE SECOUSSES FORTES
Tremblement de terre du Saguenay: le 25 novembre 1988.
Parc provincial des Laurentides, Québec, Canada.

Site 10: Rivière–Ouelle, Instrument SMA-1 — Latitude 47.4757°N, +L=0° — Longitude 69.9961°W/O, Distance 114 km



Site 14: Ste–Lucie–de–Beauregard, Instrument SMA-1 — Latitude 46.7414°N, +L=0° — Longitude 70.0172°W/O, Distance 177 km



Canada

Figure 13 d. Strong–motion accelerograms of the Saguenay earthquake

GEOLOGICAL SURVEY OF CANADA
STRONG MOTION PROGRAM
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Laurentides Provincial Park, Quebec, Canada.

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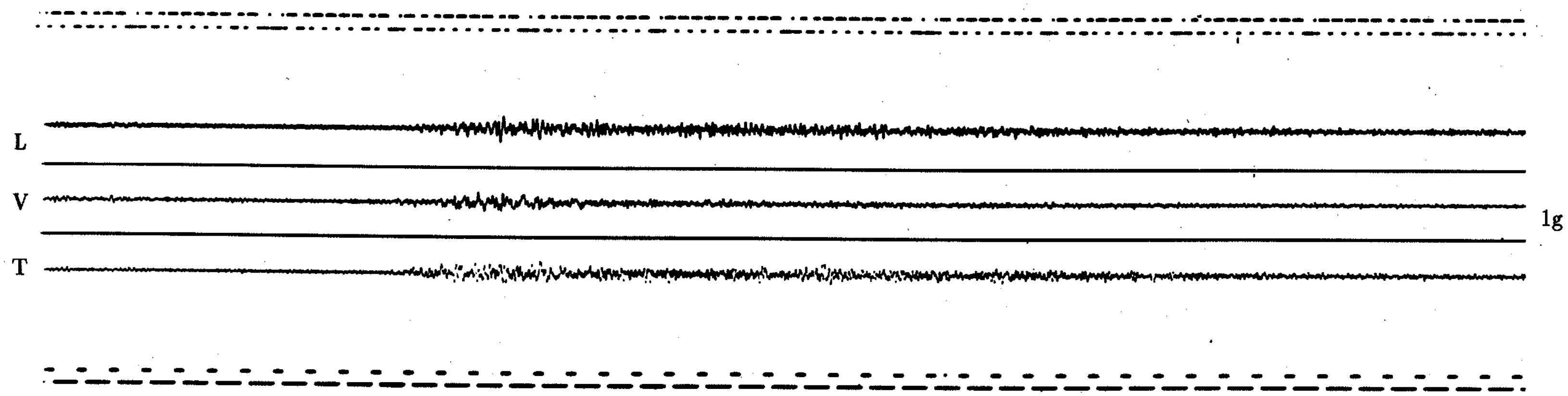
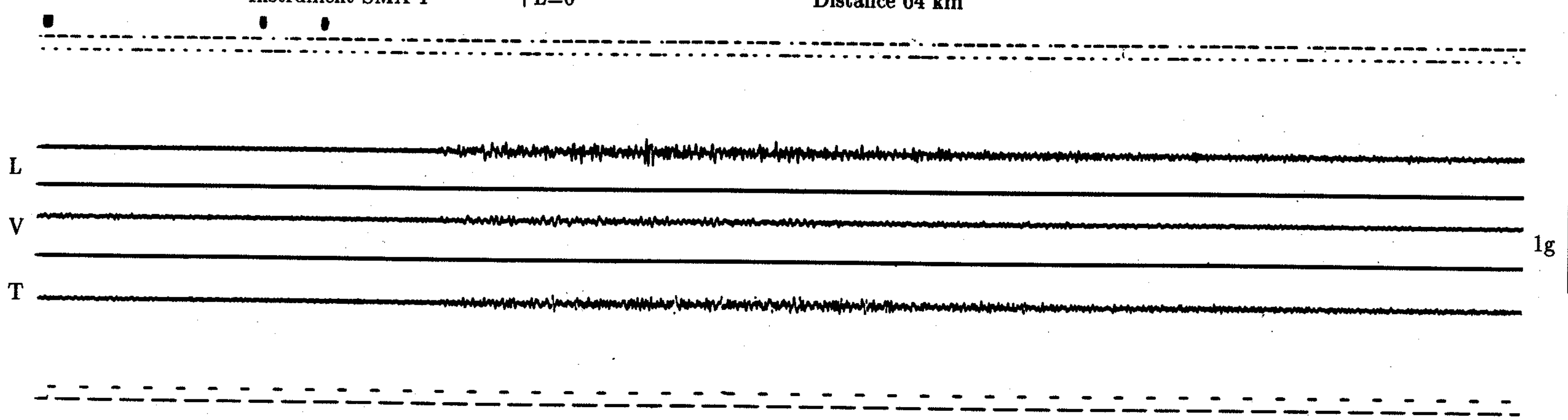
PROGRAMME DE SECOUSSES FORTES
Tremblement de terre du Saguenay: le 25 novembre 1988.
Parc provincial des Laurentides, Québec, Canada.

Site 16: Chicoutimi–Nord, Instrument SMA-1 — Latitude 48.4902deg N, +L=214° — Longitude 71.0123°W/O, Distance 43 km



Site 17: St–André–du–Lac–St–Jean, Instrument SMA-1 — Latitude 48.3248°N, +L=0° — Longitude 71.9917°W/O, Distance 64 km



Canadä

Figure 13 e. Strong–motion accelerograms of the Saguenay earthquake

GEOLOGICAL SURVEY OF CANADA
STRONG MOTION PROGRAM
Saguenay Earthquake: 25 November, 1988.
Laurentides Provincial Park, Quebec, Canada.

COMMISSION GÉOLOGIQUE DU CANADA
PROGRAMME DE SECOUSSES FORTES
Tremblement de terre du Saguenay: le 25 novembre 1988.
Parc provincial des Laurentides, Québec, Canada.

Site 20: Les Éboulements
Instrument SMA-1

Latitude 47.5496°N
+L=0°

Longitude 70.3273°W/O
Distance 90 km

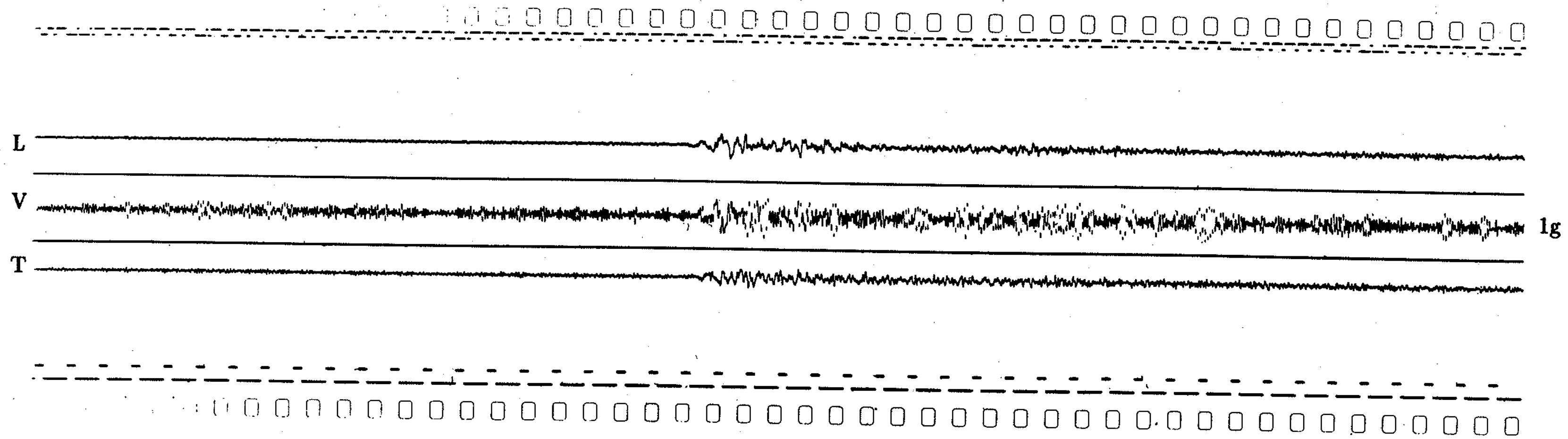


Figure 13 f. Strong–motion accelerograms of the Saguenay earthquake

Canadä

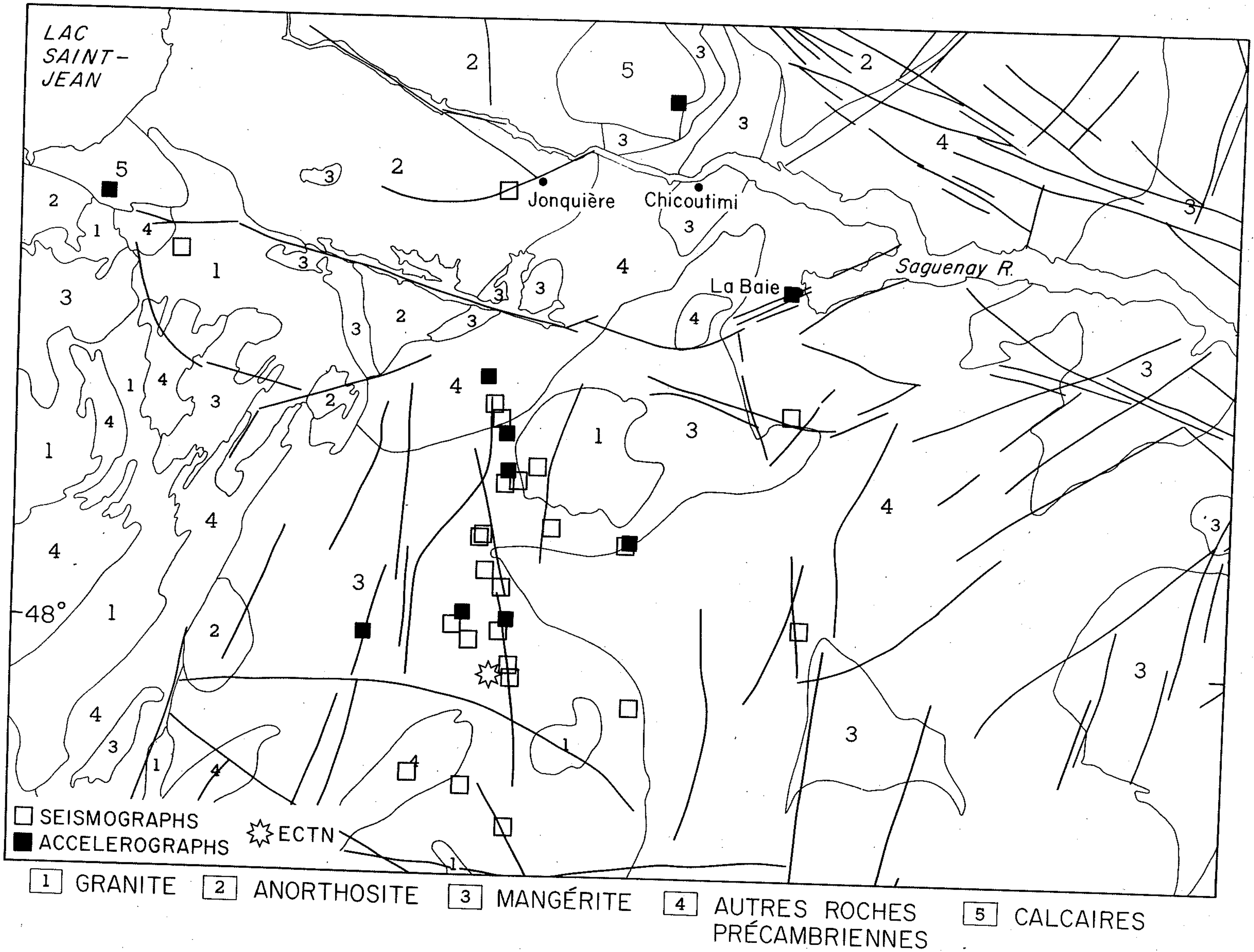


Figure 14. Simplified geology and seismograph sites in the Saguenay aftershock zor

Table 5.
Accelerograph Sites in the Epicentral Region of the Saguenay Earthquake
June 1989

No.	Location	Date	Coord.	Instr.	Sens.	Trigger	Foundation
				GD Stations			
1.	Lac Dumeaux, Qué.	11/88	48.0154 71.2279	SMA-1 TCG-1B	1 g	0.0063 g	bedrock
2.	Lac Levesque, Qué.	11/88	48.0198 71.2880	SMA-1 TCG-1B	1 g	0.0049 g	bedrock
3.	Lac Vaneau, Qué.	11/88	48.2351 71.2634	SMA-1 No TCG	1/2 g	0.0030 g	bedrock
4.	Lac Coupeau, Qué.	11/88	48.0883 71.0636	SMA-1 TCG-1A	1 g	0.0054 g	bedrock
5.	Lac Lecours, Qué.	11/88	48.1478 71.2398	SMA-1 TCG-1B	1/2 g	0.0054 g	bedrock
				LDGO Stations			
6.	Mont Apica, Qué.	11/88	48.999 71.419	SSA-1			bedrock
7.	La Baie, Qué.	11/88	48.318 70.8458	SSA-1			sediments
8.	Herbertville, Qué.	11/88	48.388 71.801	SSA-1			sediments

Miramichi, N.B.; and the Laurentian Slope.

There were several notable earthquakes recorded during the report period:

- A M4.7 foreshock to the Saguenay earthquake occurred on Wednesday, November 23 at 04:11 EST near 48.13 °N, 71.20 °W in the Laurentide provincial park of Québec. It was strongly felt in the Chicoutimi area and was felt widely in Québec City. A few people in Montréal and Ottawa also reported the tremor. GD dispatched a field team to the epicentral area that day and had recorders set up at three sites close to the epicenter of the foreshock by the following afternoon.

- On Friday, November 25, 62 hours after the foreshock, the M6.0 Saguenay earthquake took place in the same epicentral area. Its epicenter was only a few km from the foreshock's, and still within 10 km of the portable recorders deployed by the GD field crew. The local recorders allowed the depth of the start of the rupture to be calculated accurately and confirmed that the event occurred unusually deep within the crust at a depth of 29 km. No seismic activity with M greater than 1.0 had been detected by the portable recorders in the 24 hours prior to

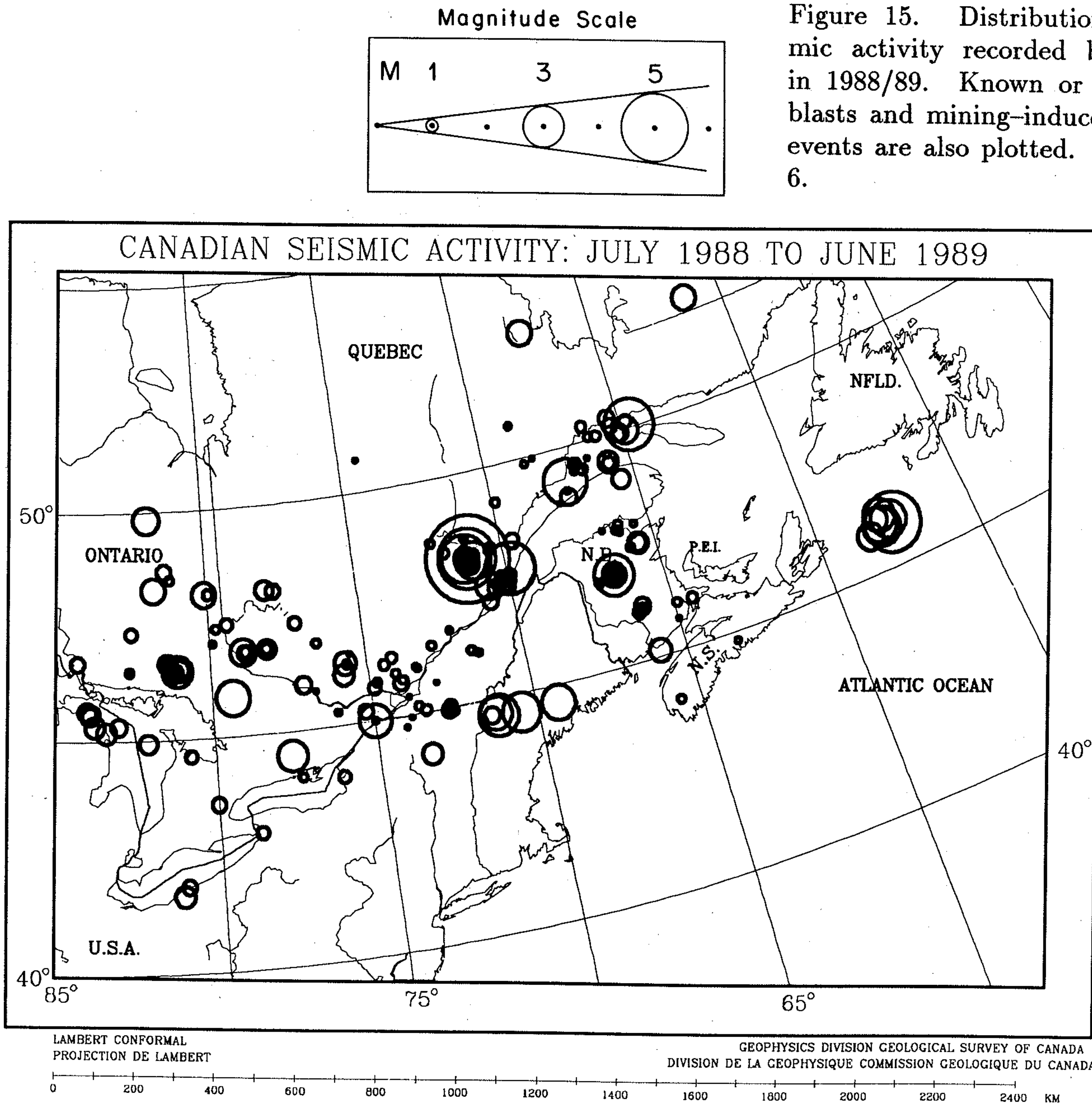


Figure 15. Distribution of seismic activity recorded by ECTN in 1988/89. Known or suspected blasts and mining-induced seismic events are also plotted. See Table 6.

TABLE 6 / TABLEAU 6
NATIONAL SUMMARY / SOMMAIRE NATIONAL
EASTERN CANADA / EST DU CANADA

EARTHQUAKES / TREMBLEMENTS DE TERRE
(3.0 ≤ MAG ≤ 10.0)
MIS EVENTS / EVENEMENTS LAM ++
(MAG ≥ 3.00)

35.00 ≤ LATITUDE ≤ 60.00
-95.00 ≤ LONGITUDE ≤ 0.00

JUL/JUIL 1988 - JUN/JUIN 1989

DATE H M S LAT LONG Z MAG Q

001 1988/08/09 00:16:45.5 47.463 -49.293 18.0 3.1ML *
RMS- 0.77 ERR- 0 0.195 0.120 G 0.0 NO- 5 8 2

002 1988/08/09 13:57:27.9 45.007 -74.989 7.7 3.4MN *
RMS- 0.26 ERR- 0 0.004 0.005 0.9 0.2 NO- 19 31 11
NEAR CORNWALL, ONT.
FELT BY MANY IN INGLESIDE AND
CORNWALL, ONT. ONE REPORT FROM KARS
AND ONE FROM MANOTICK.
FELT IN POTSDAM, MASSENA, MADRID,
WATINGTON AND SMALL COMMUNITIES IN
UPPER NEW YORK STATE.
PRES DE CORNWALL, ONT.
RESSENTI PAR PLUSIEURS A INGLESIDE ET
CORNWALL, ONT. UN RAPPORT DE KARS
ET UN DE MANOTICK.
RESSENTI A POTSDAM, MASSENA, MADRID,
WATINGTON ET DANS DE PETITES COMMUNAUTES
DU NORD DE L'ETAT DE NEW-YORK

003 1988/08/26 05:59:10.2 47.000 -66.600 5.0 3.8MN *
RMS- 0.00 ERR- G G G G 0.2 NO- 15 36 12
MIRAMICHI, N.B.
FELT AND HEARD IN BATHURST, N.B.
MIRAMICHI, N.-B.
RESSENTI ET ENTENDU A BATHURST, N.-B.

++ MIS EVENT/EVENEMENT LAM

IN THIS REPORT, THE TERM "MIS EVENT" IS THE ACRONYM FOR "MINING-INDUCED SEISMIC EVENT". IT REFERS TO ANY CONFIRMED SEISMIC EVENT OTHER THAN BLAST LOCATED AT A MINE SITE. IT DOES NOT IMPLY DAMAGE.

L'EXPRESSION "EVENEMENT LAM" UTILISEE DANS CE RAPPORT EST L'ACRONYME D'"EVENEMENT LIE A L'ACTIVITE MINIERE". ELLE DECRIT TOUT EVENEMENT CONFIRME AUTRE QUE DYNAMITAGE, LOCALISE DANS UN SITE MINIER. L'EXPRESSION N'IMPLIQUE PAS DE POSSIBLES DOMMAGES.

DATE H M S LAT LONG Z MAG Q

004 1988/09/02 12:15:14.7 48.282 -81.740 18.0 3.0MN *
RMS- 0.87 ERR- 0 0.026 0.042 G 0.2 NO- 7 15 8
NEAR TIMMINS, ONT.
PRES DE TIMMINS, ONT.

005 NEIS 09/07 02:28:12.1 38.100 -83.850 18.0 4.6MN *
RMS- 0.00 ERR- 0 0.573 0.666 G 0.1 NO- 6 12 5
MAG. MB 4.5 (NEIS)
FELT WIDELY IN KENTUCKY
BROKEN GAS LINE REPORTED
FELT IN NEIGHBOURING STATES
SAME LOCATION AS JULY 1980 MAG 5.2
KENTUCKY, U.S.A.
MAG. MB 4.5 (NEIS)
LARGEMENT RESSENTI AU KENTUCKY,
TUYAU DE GAZ BRISE
RESSENTI DANS LES ETATS LIMITROPHES
MEME LOCALISATION QUE JUIL. 1980 M.5.2
KENTUCKY, E.-U.

006 1988/09/29 16:46:56.2 46.823 -78.907 18.0 3.1MN *
RMS- 0.75 ERR- 0 0.038 0.018 G 0.2 NO- 10 18 8
TEMISKAMING REGION
NOT REPORTED FELT
REGION DE TEMISCAMING
PAS RAPPORTE COMME AYANT ETE RESSENTI

007 1988/10/20 13:09:52.8 44.639 -71.206 18.0 3.8MN *
RMS- 1.52 ERR- 0 0.042 0.028 G 0.2 NO- 18 35 13
NORTHERN NEW HAMPSHIRE, U.S.A.
FELT IN BERLIN, BRISTOL AND
PLYMOUTH, N.H.
NORD DU NEW HAMPSHIRE, E.U.
RESSENTI A BERLIN, BRISTOL ET
PLYMOUTH, N.H.

008 1988/11/12 19:56:49.7 43.954 -67.413 18.0 3.2MN *
RMS- 0.48 ERR- 0 0.046 0.019 G 0.2 NO- 6 12 2
GULF OF MAINE, WEST OF YARMOUTH

009 1988/11/14 06:15:47.9 44.603 -70.499 18.0 3.7MN *
RMS- 0.79 ERR- 0 0.039 0.027 G 0.1 NO- 15 34 14
NEAR DIXFIELD, MAINE.
PRES DE DIXFIELD, MAINE.

010 1988/11/23 09:11:27.3 48.132 -71.200 29.0 4.7MN *
RMS- 0.06 ERR- 0 0.006 0.007 G 0.4 NO- 4 7 18
SAGUENAY REGION, QUEBEC
IN LAURENTIDE PARK, QUEBEC
35 KM S OF CHICOUTIMI

```
#    DATE       H  M  S     LAT      LONG     Z    MAG    Q
              FORESHOCK OF M6.2 EVENT OF 25111988
              FELT IN THE SAGUENAY AND CHARLEVOIX
              REGIONS, QUEBEC CITY AND
              TROIS-RIVIERES, QUEBEC
              REGION DU SAGUENAY, QUEBEC
              DANS LA RESERVE FAUNIQUE DES
              LAURENTIDES. 35 KM AU SUD DE
              CHICOUTIMI.  PRECURSEUR DU MAG 6.0
              DU 25-11-1988.  RESSENTI AU SAGUENAY,
              DANS CHARLEVOIX, A QUEBEC ET A
              TROIS-RIVIERES.

011 1988/11/25 23:46:04.5  48.117  -71.183 28.9 6.0MS  *
    RMS- 0.04 ERR-  0  0.003 0.003  0.4 0.0 NO-  7 10  0
              SAGUENAY REGION, QUEBEC
              MAIN SHOCK
              MAG(PGC) 6.1 MS
              NEAR CHICOUTIMI, QUEBEC.
              FELT WIDELY IN EASTERN CANADA AND THE
              NORTHEASTERN UNITED STATES. SOME
              DAMAGE IN  CHICOUTIMI,  QUEBEC CITY,
              MONTMAGNY, MONTREAL AND CHARLEVOIX AREA.
              FORESHOCK ON 23 NOV 09:11:28 UT,
              MN 4.8.
              REGION DU SAGUENAY, QUEBEC
              MAG (PGC) 6.1 MS
              PRES DE CHICOUTIMI, QUE.
              LARGEMENT RESSENTI DANS L'EST DU
              CANADA ET LE NORD-EST DES ETATS-
              UNIS. DOMMAGES DANS LES REGIONS DU
              SAGUENAY, DE CHARLEVOIX, DE QUEBEC,
              DE MONTMAGNY ET DE MONTREAL.
              PRECURSEUR LE 23 NOV 09:11:28 T.U.
              MN 4.8

012 1988/11/26 03:38:08.2  48.142  -71.299 26.4 4.1MN  *
    RMS- 0.06 ERR-  0  0.004 0.006  0.6 0.2 NO-  7 10 13
              SAGUENAY REGION, QUEBEC
              LARGEST AFTERSHOCK
              FELT IN SAGUENAY AND CHARLEVOIX
              REGIONS
              REGION DU SAGUENAY, QUEBEC
              PLUS FORTE REPLIQUE
              RESSENTI AU SAGUENAY ET DANS
              CHARLEVOIX.

013 1988/12/28 06:28:47.3  44.627  -69.319 18.0 3.5MN  *
    RMS- 1.41 ERR-  0  0.089 0.068    G 0.2 NO- 11 20 10
              SOUTH OF DOVER FOXCROFT, MAINE

014 1988/12/31 06:53:50.4  46.490  -81.070  1.0 3.3MN  *
    RMS- 0.00 ERR-  0  0.003 0.005    G 0.2 NO-  3  6  7
              MIS EVENT
              COPPER CLIFF N MINE
              SUDBURY, ONT
```



```
#    DATE       H  M  S     LAT      LONG     Z    MAG    Q
              EVENEMENT LAM
              MINE COPPER CLIFF N

015 1989/01/01 17:55:53.6  49.254  -67.365 18.0 4.0MN  *
    RMS- 0.88 ERR-  0  0.016 0.026    G 0.2 NO- 16 36 12
              LOWER ST.LAWRENCE, QUE.
              NEAR GODBOUT, QUE.
              ON THE NORTH SHORE,
              FELT (IV) IN GODBOUT AND BAIE TRINITE
              AND (III) IN SEPT-ILES AND BAIE COMEAU
              ON THE SOUTH SHORE, FELT (III)
              IN MATANE, GROSSES-ROCHES,
              SAINT-ULRIC, LES MECHINS.
              BAS-SAINT-LAURENT, QUE.
              PRES DE GODBOUT, QUE.
              SUR LA COTE NORD,
              RESSENTI (IV) A GODBOUT ET BAIE TRINITE
              ET (III) A SEPT-ILES ET BAIE COMEAU.
              SUR LA RIVE SUD, RESSENTI (III)
              A MATANE, GROSSES-ROCHES,
              SAINT-ULRIC, LES MECHINS.

016 1989/01/16 02:33:55.4  47.000  -66.600  5.0 3.0MN  *
    RMS- 0.00 ERR-  G   G     G       G 0.3 NO-  8 17  7
              NOT REPORTED FELT
              MIRAMICHI, N.B.
              PAS RAPPORTE COMME AYANT ETE RESSENTI

017 1989/01/19 21:36:38.4  48.063  -71.008 24.8 3.6MN  *
    RMS- 0.10 ERR-  0  0.005 0.005  0.9 0.2 NO-  9 14 16
              SAGUENAY REGION, QUEBEC
              AFTERSHOCK
              REGION DU SAGUENAY, QUEBEC
              REPLIQUE

018 1989/01/23 21:16:06.5  48.140  -80.070  1.0 3.0MN  *
    RMS- 0.00 ERR-  0  0.025 0.039    G 0.3 NO-  8 15  9
              MIS EVENT
              MACASSA MINE
              KIRKLAND LAKE, ONT
              EVENEMENT LAM
              MINE MACASSA

019 1989/01/31 14:39:48.2  47.442  -70.671 19.7 3.1MN  *
    RMS- 0.11 ERR-  0  0.005 0.006  0.9 0.3 NO-  8 13 16
              CHARLEVOIX, QUEBEC
              FELT IN SAINT-HILARION,
              BAIE-SAINT-PAUL, LES EBOULEMENTS.
              CHARLEVOIX, QUE.
              RESSENTI A BAIE-SAINT-PAUL,
              SAINT-HILARION ET LES EBOULEMENTS.
```

```
  #    DATE       H  M  S     LAT      LONG    Z    MAG   Q

020 1989/02/02 01:19:07.8  57.500  -76.000 18.0 3.1MN
    RMS- 0.00 ERR-  0  0.000 0.000     G 0.0 NO-  1  3  1
          NORTHERN QUEBEC
          NORD DU QUEBEC

021 1989/02/02 15:40:46.4  45.927  -57.542 18.0 4.7ML  *
    RMS- 1.17 ERR-  0  0.065 0.082     G 0.2 NO- 11 21  7
          LAURENTIAN SLOPE
          TALUS LAURENTIEN

022 1989/02/10 01:04:24.2  50.069  -64.684 18.0 4.3MN  *
    RMS- 0.80 ERR-  0  0.020 0.034     G 0.2 NO- 25 43 16
          LOWER ST.LAWRENCE-NORTH SHORE, QUE
          FELT
          (IV) AT RIVIERE-SAINT-JEAN
          DISHES RATTLED, NOISE WAS HEARD,
          FELT STRONGER AND LONGER THAN SAGUENAY,
          (III-IV) MINGAN-LONGUE POINTE,
          VIBRATIONS LASTED 15 SEC.,
          (III) AT PORT MENIER,
          LASTED 5 SEC.
          (III) HAVRE-SAINT-PIERRE, SEPT-ILES,
          PORT-CARTIER.
          PREVIOUS EVENT IN THE AREA:
          JUNE 20, 1986 MN 3.4
          BAS-SAINT-LAURENT-COTE-NORD, QUE.
          RESSENTI
          (IV) A RIVIERE-SAINT-JEAN
          LA VAISSELLE A VIBRE, BRUIT FORT
          RESSENTI PLUS FORT ET PLUS LONGUEMENT
          QUE LE SEISME DU SAGUENAY.
          (III-IV) A MINGAN ET LONGUE-POINTE
          LES VIBRATIONS ONT DURE 15 SEC.
          (III) A PORT.MENIER, DURE 5 SEC.
          (III) HAVRE-SAINT-PIERRE, SEPT-ILES,
          PORT-CARTIER.
          DERNIER EVENEMENT DANS LA REGION:
          20 JUIN 1986, MN 3.4

023 1989/02/10 05:52:58.3  45.827  -58.364 18.0 3.1MN  *
    RMS- 2.27 ERR-  0  0.141 0.084     G 0.0 NO-  5 11  1
          EVENT OFFSHORE N.S.
          EVENEMENT AU LARGE DE LA N.-E.

024 1989/02/13 21:52:45.5  45.847  -79.343 18.0 3.5MN
    RMS- 1.23 ERR-  0  0.025 0.024     G 0.2 NO- 16 31 14
          SUNDRIDGE, ONT.
          FELT
          (IV) IN THE SUNDRIDGE AND
          SOUTH RIVER AREA.
          PEOPLE HEARD A LOUD RUMBLE.
          MORTAR DIPLACED FROM LOG CABIN.
```

```
  #    DATE       H  M  S     LAT      LONG    Z    MAG   Q
          ALSO FORESHOCK AT 21:34 MN 2.2,
          AND AFTERSHOCK AT 22:08 MN 2.6.
          SUNDRIDGE, ONT.
          RESSENTI
          (IV) DANS LA REGION DE SUNDRIDGE
          ET SOUTH RIVER.
          LES GENS ONT ENTENDU UN FORT GRONDEMENT
          DU MORTIER A ETE DEPLACE D'UNE CABANE
          EN BOIS ROND.
          AUSSI PRECURSEUR A 21:34 MN 2.2,
          ET REPLIQUE A 22:08 MN 2.6.

025 1989/02/16 00:16:05.7  45.937  -57.908 18.0 3.7ML  *
    RMS- 0.31 ERR-  0  0.025 0.039     G 0.1 NO-  5  9  2
          NORTHEAST OF LAURENTIAN SLOPE
          NORD-EST DU TALUS LAURENTIEN

026 1989/03/09 09:41:32.2  47.717  -69.861 10.9 4.3MN  *
    RMS- 0.09 ERR-  0  0.004 0.008  1.0 0.3 NO-  5 10 16
          CHARLEVOIX-KAMOURASKA, QUE.
          FELT IN LA MALBAIE (IV)
          AND BAIE-SAINT-PAUL.
          ALSO FELT ON THE SOUTH SHORE IN
          RIVIERE-OUELLE AND KAMOURASKA.
          CHARLEVOIX-KAMOURASKA, QUE.
          RESSENTI A LA MALBAIE (IV)
          ET BAIE-SAINT-PAUL.
          AUSSI RESSENTI SUR LA RIVE SUD A
          RIVIERE-OUELLE ET KAMOURASKA.

027 1989/03/09 18:36:03.2  49.977  -64.871 18.0 3.1MN  *
    RMS- 1.19 ERR-  0  0.059 0.104     G 1.8 NO-  4  8  4
          LOWER ST.LAWRENCE-NORTH SHORE
          BAS-SAINT-LAURENT-COTE-NORD

028 1989/03/11 08:31:52.1  47.718  -69.870 10.1 4.3MN  *
    RMS- 0.07 ERR-  0  0.003 0.006  0.8 0.3 NO-  6 11 17
          CHARLEVOIX-KAMOURASKA, QUE.
          FELT
          IN LA MALBAIE, BAIE-SAINT-PAUL,
          ILE AU COUDRE, CLERMONT,ST HILARION
          ON THE SOUTH SHORE
          AND IN THE SAGUENAY REGION.
          CLOSE TO MAG. 4.3 EVENT
          TWO DAYS EARLIER.
          CHARLEVOIX-KAMOURASKA, QUE.
          RESSENTI
          A LA MALBAIE, BAIE-SAINT-PAUL,
          ILE AU COUDRE, CLERMONT,SAINT-HILARION
          SUR LA RIVE-SUD,
          ET AU SAGUENAY.
          PRES DU SEISME DE MAG. 4.3 DEUX JOURS
          PLUS TOT.
```

#	DATE	H M S	LAT	LONG	Z	MAG	Q

029 1989/03/26 15:54:30.8 57.101 -58.979 18.0 4.1ML *
RMS- 1.45 ERR- 0 0.075 0.148 G 0.3 NO- 8 14 8
LABRADOR SEA
MER DU LABRADOR

030 1989/04/06 02:35:55.3 44.694 -71.278 18.0 3.4MN
RMS- 0.98 ERR- 0 0.045 0.021 G 0.3 NO- 20 36 20
NORTHERN NEW HAMPSHIRE
NORD DU NEW HAMPSHIRE

031 1989/04/06 13:15:29.0 49.832 -81.886 18.0 3.1MN *
RMS- 1.10 ERR- 0 0.021 0.026 G 0.2 NO- 16 31 9
NORTHERN ONTARIO

032 1989/04/27 16:47:50.0 36.100 -89.700 8.0 4.5MN *
RMS- 0.00 ERR- G G G G 0.2 NO- 5 8 3
NEW MADRID, U.S.A.

033 1989/05/08 22:04:05.2 45.987 -57.951 18.0 3.5MN *
RMS- 1.61 ERR- 0 0.090 0.102 G 0.4 NO- 8 19 7
OFFSHORE CAPE BRETON
AU LARGE DU CAP BRETON

034 1989/05/14 07:36:10.8 52.320 -61.332 18.0 3.0MN *
RMS- 1.24 ERR- 0 0.179 0.144 G 0.1 NO- 4 8 3
NORTH SHORE OF QUEBEC
LA COTE-NORD, QUEBEC.

035 1989/05/14 22:53:39.0 52.502 -34.944 18.0 5.9ML *
RMS- 1.39 ERR- 0 0.450 0.157 G 0.2 NO- 12 17 5
MID-ATLANTIC RIDGE
RIDE MEDIO-ATLANTIQUE

036 1989/05/16 07:24:00.8 46.024 -57.621 18.0 3.6ML *
RMS- 0.52 ERR- 0 0.034 0.053 G 0.4 NO- 10 20 8
OFFSHORE

037 1989/05/24 01:19:20.0 58.688 -60.350 18.0 4.4ML *
RMS- 0.86 ERR- 0 0.045 0.096 G 0.2 NO- 9 16 2
LABRADOR SEA
MER DU LABRADOR

038 1989/05/28 23:03:44.4 46.180 -57.859 18.0 3.4ML *
RMS- 0.80 ERR- 0 0.108 0.102 G 0.4 NO- 5 10 3
LAURENTIAN SLOPE
TALUS LAURENTIEN

#	DATE	H M S	LAT	LONG	Z	MAG	Q

039 1989/06/16 05:07:05.7 49.489 -66.231 18.0 3.3MN *
RMS- 0.31 ERR- 0 0.008 0.029 G 0.2 NO- 11 20 13
LOWER ST.LAWRENCE
NOT REPORTED FELT
BAS-SAINT-LAURENT, QUE.
PAS RAPPORTE COMME AYANT ETE RESSENTI

the mainshock.

- Two M 4 events in the Charlevoix–Kamouraska zone on March 9 and 11 were an earthquake doublet. The events had very similar relative times and waveforms on all the CLTN stations. Their hypocentre lay under the St.Lawrence river at a depth of 10 km at the northeast end of the seismic zone (Figure 6) in the same area where the last large earthquake of March 01, 1925 began. Earthquake doublets of any size in the Charlevoix–Kamouraska seismic zone have been exceptional events since detailed monitoring began in the zone in 1977. Only one or two other possible examples are known suggesting that a doublet of this magnitude has probably not occurred in the seismic zone at any time previously since as far back as 1925. For this reason and because of the notable location of the doublet, there has been some speculation that these events may be foreshocks to a larger event. However, the timing of the next large event is not obvious from the doublet and may not necessarily be immanent. Nevertheless, GD will be monitoring Charlevoix–Kamouraska seismicity closely with CLTN in the future looking for more unusual activity.

- The January-March 1989 period included one of the most unusual flurries of seismic activity experienced in eastern Canada in recent years. Starting with the Saguenay Earthquake on November 25, 1988 and continuing for approximately 4 months, exceptional earthquakes occurred in the Saguenay region, the lower St. Lawrence valley, the Atlantic margin, the Charlevoix region, the Labrador Sea, the Ungava region and the Labrador margin. The regions were widely separate and no obvious relationship could be seen between the activity in the different regions. Table 7 shows the sequence of exceptional events.

Table 7
Significant Events Following the Saguenay Earthquake

#	Area	Mag.	Days after	Comments
1	Saguenay	6.0	0	largest in 53 yr
2	Lower St.Lawrence	4.4	36	largest in 20 yr
3	Atlantic Margin	4.7	68	largest in 15 yr
4	Lower St.Lawrence	4.0	76	
5	Charlevoix	4.3	103	largest in 10 yr
6	Charlevoix	4.3	105	repeated event
7	Labrador Sea	5.3	108	largest in 20 yr
8	Ungava	5.7	110	largest in 30–50 yr
9	Labrador Margin	4.1	120	

The locations of the events are shown in Figure 16. Some of these events are outside the area usually covered in these reports and are not listed in Table 6 at the end. The rate of small magnitude activity also increased generally in this period.

- Another significant event, possibly another member of the flurry noted above, occurred in eastern Ontario, near Sunridge, on February 13, 1989. It was magnitude 3.5 and was felt with

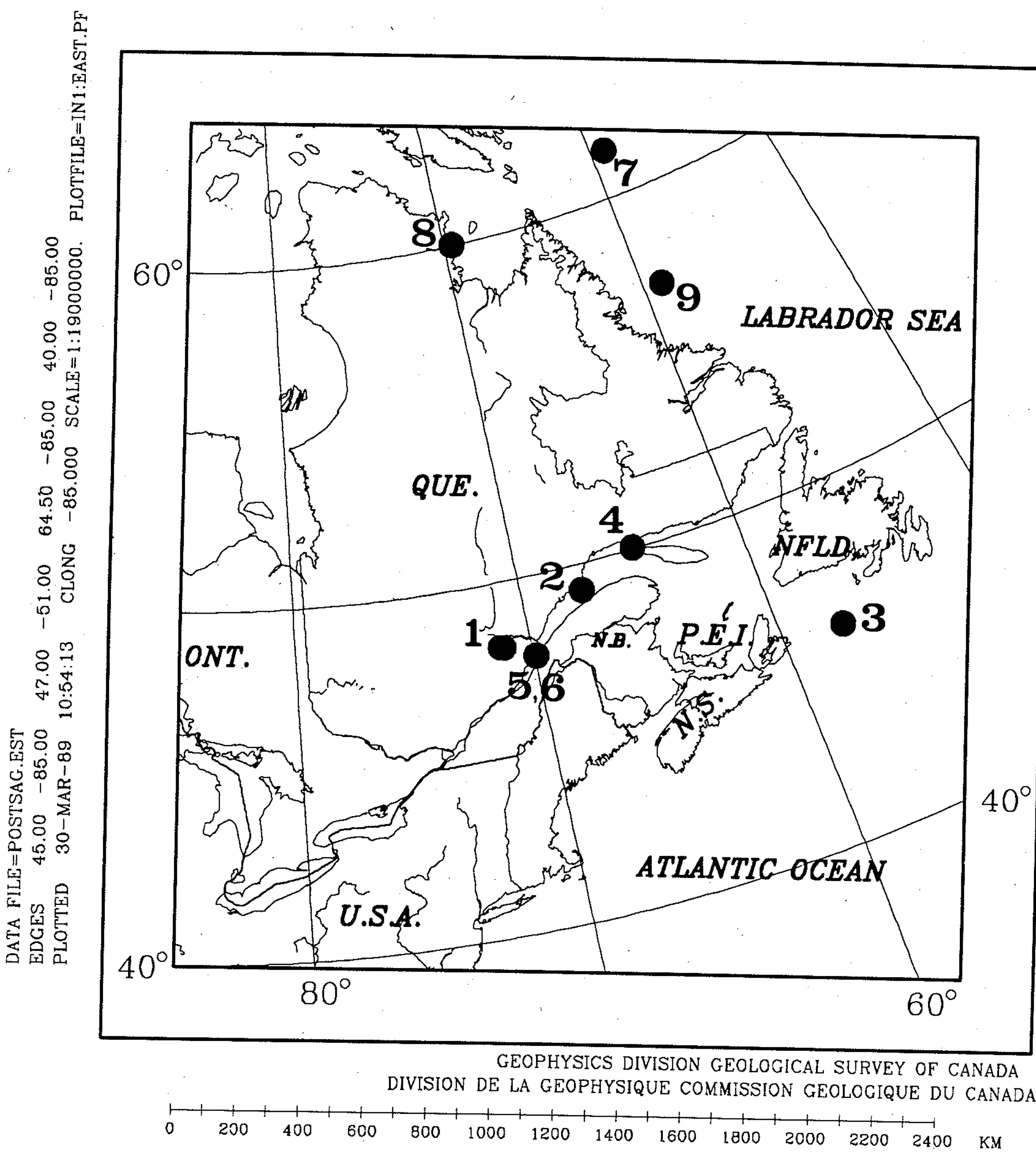


Figure 16. Distribution of exceptional earthquakes in eastern Canada, November 1988 to March 1989. See Table 7.

maximum intensity IV by local residents. The event took place in an area of historically low seismicity in northern Ontario, outside the bounds of the West Québec Seismic Zone, and was the largest event in the region in at least 44 years. Even more unusually it was preceeded by a magnitude 2.2 foreshock and followed by a magnitude 2.6 aftershock.

- On September 9, 1988 the first earthquake ever located in Prince Edward County on the northeastern shore of Lake Ontario was recorded. It was only magnitude 2.2, but is considered significant because Prince Edward County is crossed by some of the possible extensions of the Clarendon-Linden lineament from northern New York into Canada and the area has been recently selected as a study area for special enhanced multi-agency neotectonic investigations. The event was thoroughly investigated by GD and no source of blasting could be identified to explain it.

Field Studies of the Saguenay Earthquakes: In the weeks following the Saguenay earthquake a field program monitoring the aftershock activity begun by GD following the foreshock was greatly expanded with the assistance of Lithosphere and Canadian Shield Division (LCSD) of GSC, the University of Québec at Chicoutimi (UQAC) and the Lamont-Doherty Geological Observatory (LDGO). Seismic recorders, both analogue and digital, were set up at 23 different sites (Figure 14) throughout the epicentral area covering the aftershock zone. The locations of the sites were accurately determined by portable Global Positioning Systems. However, the aftershock activity declined remarkably quickly, and had almost ceased by December 10. Consequently, after that date, the field network was reduced to comprise four MEQ-800 seismographs operated by UQAC initially under contract to GD, a new ECTN station, DAQ, and the eight strong-motion accelerographs, which were described in the previous section. That reduced network continues to operate at this time. Data from the UQAC field recorders as well as from the ECTN and CLTN networks are being used to locate any aftershocks that occur. With this combined network, the detection threshold is approximately magnitude 0.5.

Eighty-six events in the Saguenay sequence from November 23, 1988 to June 30, 1989 varying in magnitude from M -0.2 to 6.0, were located with data from the field network and permanent networks where appropriate (Figure 17). Figure 18 shows typical waveforms of a Saguenay aftershock recorded by one of the field stations operated by GD.

The data set recoverd by the field network included all aftershocks with M greater than 1.0 and, because the network was partially in place at the time of the mainshock, the relationship of the aftershock activity to the mainshock is particularly well known, in contrast to most of the other large events in eastern Canada. The largest aftershock, M 4.3, occurred about four hours after the main event and was located about 10 km west of the mainshock. The next largest event was M 3.1 about 5 hours after the main event. There were no other M 3 aftershocks until January 19, 1989 when an event of 3.6 occurred accompanied by a few other smaller events. Since January 1989, however, there have been only two Saguenay events recorded attesting to the remarkably rapid decline in aftershock activity for this sequence. A preliminary analysis of the aftershock activity was carried out jointly by GD and LDGO in Ottawa in January, 1989 and the results of that study were presented at the Victoria meeting of the Seismological Society of America in April.

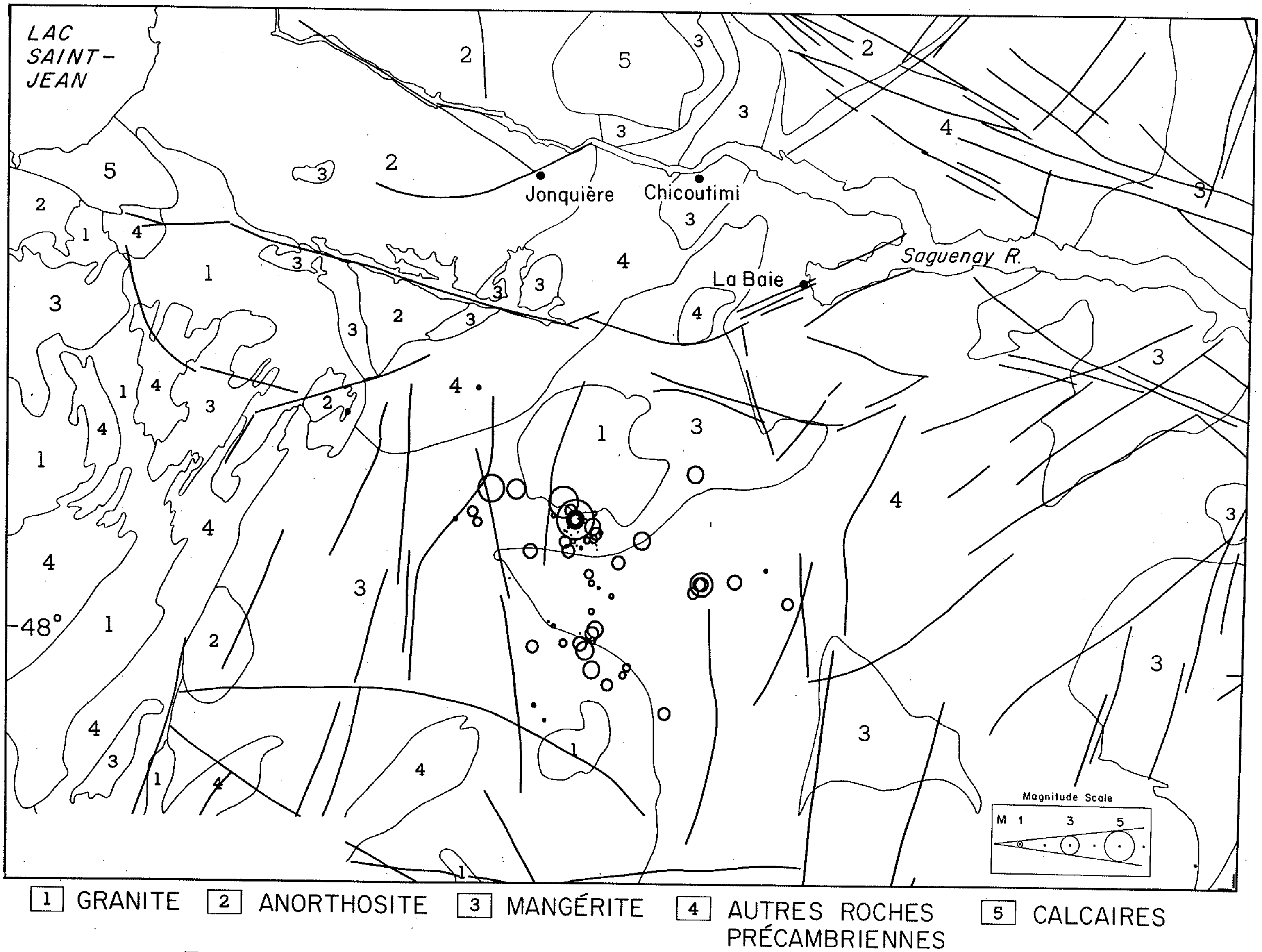


Figure 17. Distribution of Saguenay earthquake mainshock and aftershock sequence to June 1989.

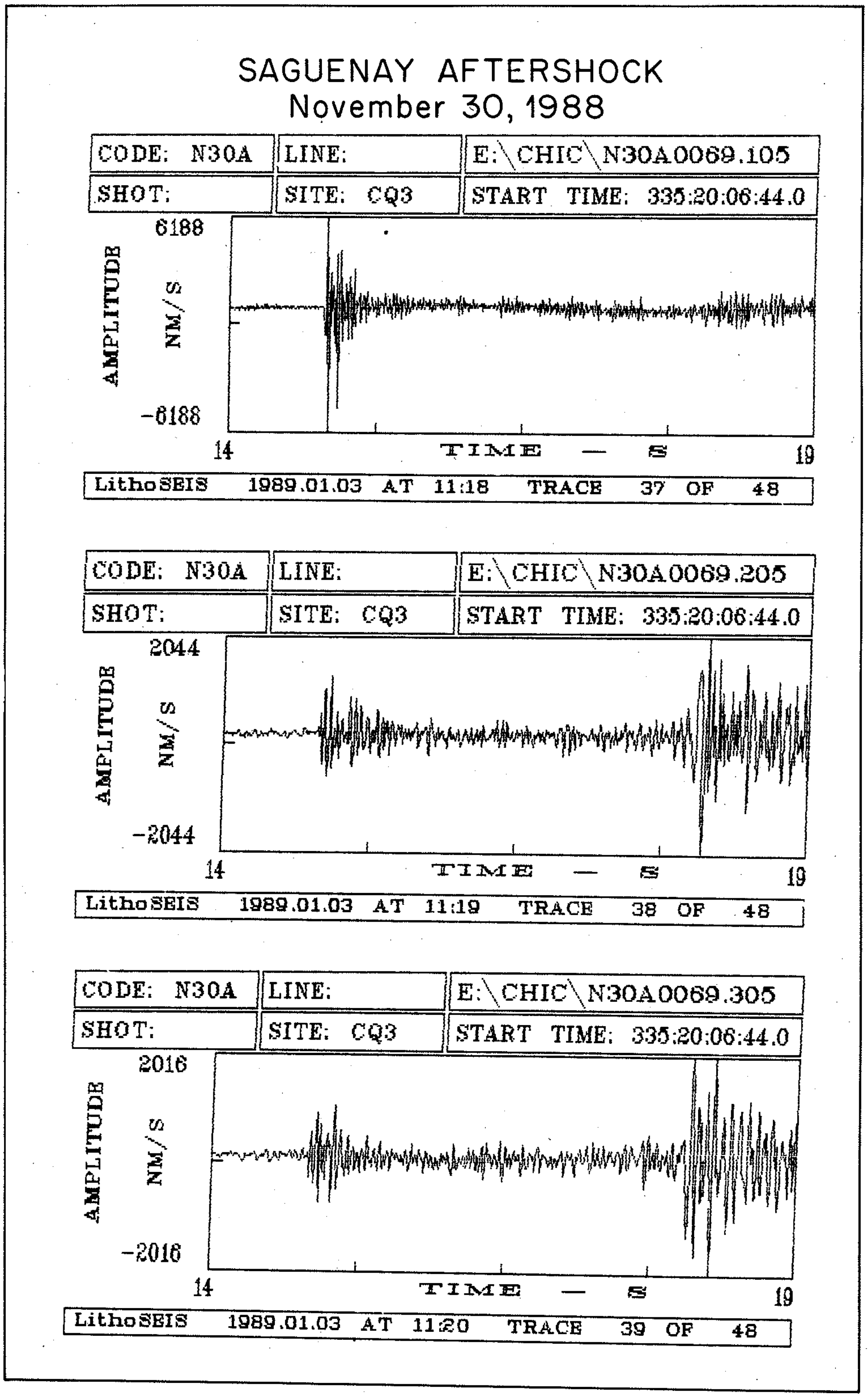


Figure 18. Waveforms of a Saguenay aftershock recorded by a portable recorder (EDA PRS-4) deployed in the field survey.

P-nodal mechanism solutions were calculated by GD for the Saguenay earthquake mainshock, foreshock and two largest aftershocks (November 25 and January 19) using ECTN, CLTN, SLTN and the field network data as appropriate. The solutions were all primarily thrust mechanisms with intermediate-dipping, north-trending planes (Figure 19).

Felt Events: Five events were felt in the period from July to November 1988. On July 27, a magnitude 2.8 earthquake occurred in northeastern New Brunswick, near the Chaleur Bay. The earthquake was felt in Bathurst and in the surrounding communities with a maximum intensity of III. On August 9, a magnitude 3.4 earthquake was felt in the Cornwall region of Ontario and in nearby communities in northern New York state. This event was well recorded by both the U.S. and Canadian networks. A magnitude 2.1 aftershock occurred two days later. A magnitude 3.8 earthquake centred in the Miramichi region of New Brunswick (where the magnitude 5.7 earthquake occurred in January 1982) was felt in Bathurst, New Brunswick on August 26. On October 8 a M 2.4 earthquake was recorded and felt near Buffalo, New York. It was not felt in Canada. Finally, on November 23 the M 4.7 foreshock to the Saguenay earthquake was felt strongly in the Saguenay region and throughout southern Québec as far as Trois-Rivières and felt mildly in Montréal and Ottawa.

The Saguenay earthquake on November 25 was felt with maximum intensity VII in the Chicoutimi-Jonquière-La Baie area, was felt strongly by most people within 500 km, felt by many within 1000 km and was perceptible by some people in special circumstances beyond 1000 km. The earthquake was felt south to Washington DC, north to Poste-de-la-Baleine, east to Goose Bay and Halifax, and west to Thunder Bay and Detroit. The total felt area appears to exceed 3 million square km. GD sent over 2000 questionnaires to rural postmasters in Québec, Ontario, the Maritime provinces and Labrador in order to determine the isoseismal distribution of the tremor. GD data has been combined with similar data collected by NEIS in the U.S. to produce the preliminary map of intensity distribution shown in Figure 20.

Minor sporadic property damage was experienced from the earthquake in the Saguenay communities within about 35 km of the epicentre including Chicoutimi, Jonquière and La Baie and at larger distances up to 350 km away in the major population centres of Québec City and Montréal. The damage was typically confined to cracks in masonary walls or fallen masonary blocks (Figure 21). The city hall in Montréal East experienced severe damage to masonary cladding (Figure 21), but the structure was located near the banks of the St. Lawrence River on a thick clay layer which probably contributed to the severity of the damage. Elsewhere in Montréal little or no damage due to the earthquake was reported. In addition, at least six highway embankment failures, two railway embankment failures and several natural slope failures were triggered by the earthquake (Figure 21). Finally, Hydro–Québec suffered significant damage in one of their older transmission stations in the Charlevoix region. The total bill for damage in the province of Québec caused by the earthquake is estimated to have exceeded $10 million.

Eight events were reported felt in the period from November 1988 to June 1989. In the Lower St.Lawrence region, earthquakes were felt on January 1 (M 4.0) and on February 10 (M 4.3). In the Charlevoix–Kamouraska region, the events were felt on January 31 (M 3.1) March 9 (M 4.3) and

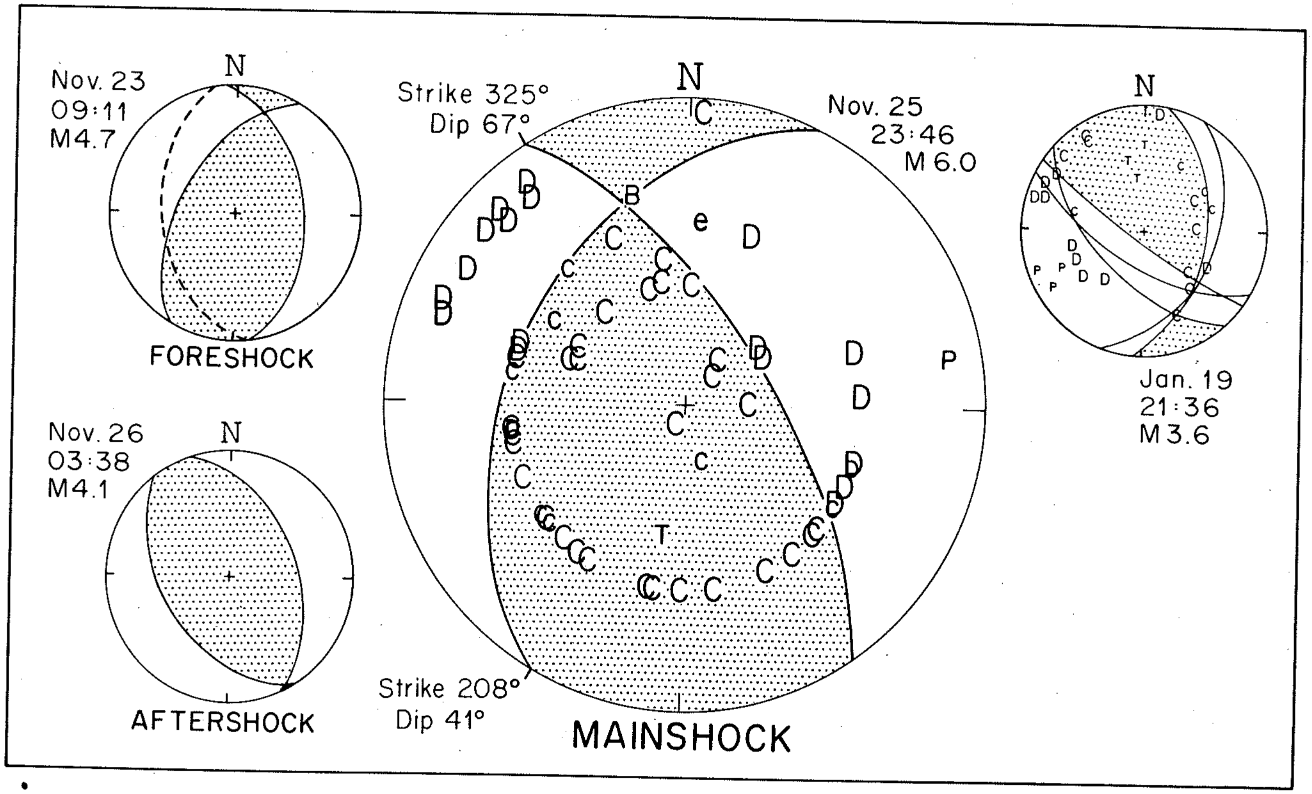


Figure 19. P–nodal mechanisms for the Saguenay earthquakes. Equal–area projection of the lower focal sphere is shown. Compressional quadrants are shaded. In some cases alternate equally likely solutions are indicated. P and T are the deviatoric pressure and tensional axes.

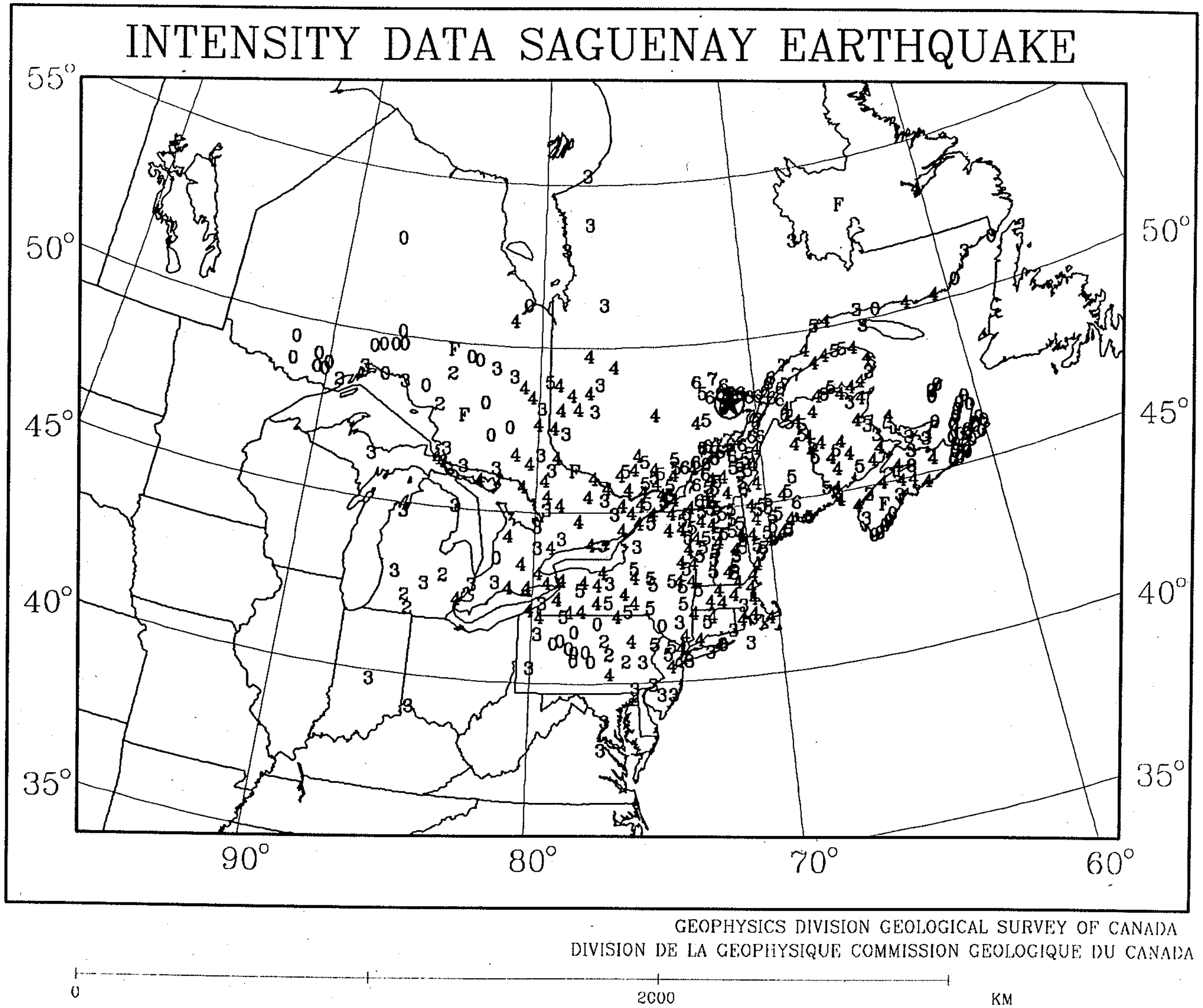


Figure 20. Intensity distribution for the Saguenay earthquake. U.S. data are from NEIS.

Diagonal cracks in brick wall of Notre–Dame Pavilion, Saint-François-d'Assise Hospital, Québec City

Debris from fallen masonry blocks in Dominique Racine Secondary School, Chicoutimi

Overall view of embankment failure (60 m long) near Ste-Anne-de-Beaupré

Loss of masonry cladding from clock tower of Montréal East City Hall

Figure 21. Examples of damage caused by the Saguenay earthquake

March 11 (M 4.3). The latter two events, which happened within two days of each other, caused some concern in the local population because the people there remembered that the Saguenay Earthquake was preceeded by two days by the magnitude 4.7 foreshock. In the Western Québec seismic zone, a tremor was felt on January 10 (M 2.9). On February 13, a magnitude 3.5 tremor was felt in northern Ontario. Only one earthquake was reported felt in Canada in the period from April to the end of June, 1989, a M 2.5 Saguenay aftershock on April 18.

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