Dr. Whitham

BACKGROUND REPORT ON SEISMICITY AND SEISMIC MONITORING IN EASTERN CANADA

by

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INTERIM REPORT

BACKGROUND REPORT ON SEISMICITY AND SEISMIC MONITORING IN EASTERN CANADA

INTRODUCTION

This report is presented as a background statement on the seismicity and seismic monitoring in eastern Canada under the terms of Contract No. NRC-04-79-180 for a Research Agreement entitled "Canadian Seismic Agreement" between the U.S. Nuclear Regulatory Commission (NRC) and the Canadian Commercial Corporation (CCC). The project, which commenced April 1, 1979, is under the direction of the Earth Physics Branch (EPB) of the Canadian Department of Energy, Mines and Resources and will be performed for CCC under the terms of a Memorandum of Understanding between these two agencies.

The purpose of the report is to provide a brief account of the present knowledge of the distribution of seismicity in eastern Canada, of the seismograph network that is currently operated by the EPB to monitor seismic activity in this region and of the proposed expansion of monitoring and data exchange that is foreseen during the agreement with NRC. Much of the background information on eastern Canadian seismicity and the existing seismograph network is available in EPB published reports and research papers. Therefore, the main text of this report on these subjects is restricted to a brief summary, with reprints or preprints of relevant reports attached as appendices to provide the reader with more complete and detailed information. The proposed expansion of the eastern Canadian seismograph network, to be undertaken during the NRC agreement, is given below in as much detail as possible at the time of preparation of this background statement, but should be considered tentative at this stage because of the large number

of factors, such as cost and site availability, that will govern the eventual configuration. Furthermore, continuing operation of the basic seismograph network depends upon continuing Canadian government financing. As the primary products of interest to NRC under the terms of the agreement are data and derived parameters on eastern Canadian earthquakes, a firm timetable is described below under which EPB will make this information available for the duration of the agreement.

HISTORICAL AND INSTRUMENTALLY-RECORDED SEISMICITY IN EASTERN CANADA

The basic earthquake data available for eastern Canada are from the two catalogues of Smith (1962, 1966) which cover the periods 1534-1927 and 1928-1959, respectively, and from annual catalogues published by the EPB since 1960. A list of these catalogues, to 1977, is given in Table 1. The current schedule for data reduction and publication of Canadian earthquake catalogues is described in a later section of this report.

The earthquake data for eastern Canada have been displayed on maps and discussed by many authors in recent years. The most recent study of this type by EPB staff is the paper by Basham et al. (1979), a preprint copy of which is attached as Appendix A. This paper includes a table of all earthquakes in eastern Canada with magnitudes ≥ 4.0. The magnitudes and/or epicentral coordinates of many of these earthquakes have been modified from previous catalogued values on the basis of reassessments of macroseismic and instrumental data. Appendix A also includes epicentral plots for eastern Canada in five time periods: 1661-1849, 1850-1899, 1900-1924, 1925-1949 and 1950-1975. These plots illustrate the increase of earthquake information with time, with the spread early settlements and the development of the seismograph networks.

Recent special studies of eastern Canadian earthquakes and earthquake zones have focussed on the Charlevoix zone in the St. Lawrence valley and on the Western Quebec zone north of the Ottawa River. Leblanc and Buchbinder (1977; attached as Appendix B) described the results of a field experiment that provided a clear delineation of the extent of microearthquake occurrences in the Charlevoix zone. P nodal solutions for six of the microearthquakes suggest that a thrust regime is along planes striking north or northeast. Stevens (1979; preprint attached as Appendix C) has reassessed the catalogued locations, using available instrumental data, of all Charlevoix zone earthquakes $M \geq 4.5$ since 1924. There is strong evidence to suggest that all of these earthquakes occurred within the zone of microearthquakes and, in fact, that they tend to cluster at each end of the 70 km long microearthquake zone.

(Appendix C includes an account of the instrumentation and peak response characteristics of the seismograph stations in eastern Canada and the northeastern U.S. during the first half of this century, information that will be of value in the study of instrumental data of twentieth century earthquakes throughout northeastern North America.)

Two earthquakes with magnitudes near 4 in western Quebec north of the Ottawa River, the Maniwaki earthquake of 1975 and the St. Donat earthquake of 1978, have been studied by Horner et al., (1978), attached as Appendix D, and (1979), preprint attached as Appendix E, respectively. Aftershock monitoring provided accurate hypocentral location for each of the main shocks, with an estimated uncertainty of about 2 km on all three hypocentral coordinates. The mechanisms for both of these earthquakes are shown by P-nodal and surface wave analysis to be thrusting with the deviatoric pressure axis nearly horizontal

in a southwest to south direction. This pair of earthquakes has also provided the first clear evidence of an increase in focal depth across the Western Quebec zone, from about 10 km north of Montreal to about 20 km north of Ottawa, 150 km to the west. This difference in focal depth is supported by the isoseismal data for these earthquakes and is apparent in the isoseismal data of other earthquakes in the zone for which accurate focal depths are not available.

SEISMOTECTONICS AND ZONES OF EARTHQUAKE OCCURRENCE IN EASTERN CANADA

Work is underway at EPB to expand the above described, rather isolated, results into a more comprehensive correlation of seismicity with other geological and geophysical parameters. At present, the understanding of important geological structures, neotectonics and causative stress field is not sufficient to delineate the eastern Canadian seismicity on the basis of "seismotectonic provinces" or geologically-controlled seismic source zones. Therefore, in the seismicity model developed for seismic risk estimation by Basham et al. (1979) (Appendix A) the "zones of earthquake occurrence" in the east are based principally on the distribution of historical and recent seismicity. The rationale for the zone boundaries, the derivation of magnitude recurrence relations and some sample risk calculations are described in Appendix A.

By necessity, the siting investigations and seismic design criteria for nuclear power stations in eastern Canada must also be based on this less-than-perfect understanding of the seismicity. A standard for seismic

qualification of CANDU nuclear power plants is under development by a Technical Committee of the Canadian Standards Association. A discussion of eastern Canadian seismicity and the combined probabilistic/deterministic approach to seismic risk estimation in the context of this standard is given in the Appendix A preprint.

SEISMOGRAPH OPERATIONS IN EASTERN CANADA

Seismograph operations in eastern Canada commenced with the installation of a Milne seismograph in Toronto in 1897 and a Bosch seismograph in Ottawa in 1906. A history of the subsequent development of the eastern Canadian network is given by Stevens (1979) (attached as Appendix C).

The current (May, 1979) configuration of the eastern Canadian network is shown in Figure 1. The four standard stations produce 3 short-period and 3 long-period photographic records daily. The ten regional stations produce short-period vertical hot stylus recordings; PBQ and POC regional stations also produce short-period horizontal recordings. The borehole seismograph, GAC, has a down-hole triaxial seismometer of the type used in the U.S. Seismic Research Observatory network; data are telemetered to Ottawa and recording is incorporated within the Eastern Canada Telemetered Network (ECTN). The ECTN currently consists of ten stations with data recording on-line at the Seismological Laboratory in Ottawa. Short-period vertical components of the Montreal (MNT) and Ottawa (OTT) standard stations form part of the ECTN. Also in operation, but not shown in Figure 1, is an array of seven radio-telemetered stations with FM tape recording in the Charlevoix area of the St. Lawrence (near LMQ and POC in Figure 1).

The EPB prepares an annual publication describing the Canadian seismograph operations. The most recently published edition (1977) is attached as Appendix F. This publication provides details of seismograph instrumentation, calibration curves, data distribution procedures, etc. A recent summary of seismological instrumentation and data processing in Canada by Hayman and Shannon (1979) is also attached as Appendix G.

The ECTN system is of particular interest in the context of the NRC agreement, so additional details are provided in the following paragraphs.

The remote stations each consist of a Geotech S13 seismometer, an amplifier with a bandpass of 1 to 20 Hz, a binary gain ranging analogue to digital converter, a serialiser and modem. Data are digitised at 60 samples per second in a format which includes a 9 bit mantissa and a 3 bit binary exponent to yield a dynamic range of 96 dB. The serialised digital data are transmitted to Ottawa over unconditioned leased phone lines at 1200 baud. Enchancements to the basic design in 1978 will permit greater dynamic range and the optional use of a UHF radio link for telemetry of the digital data on all future stations.

The Central Processor consists of dual PDP11 processors with up to 80 Mbytes of on-line storage, either of which can function as the event detector in a cold standby mode of operation. The system utilises the RSX11-M operating system and uses DECnet for interprocessor file transfer and for file exchange with the other EPB on-line seismic processors. Drum recorders with independent microprocessor controlled digital to analog converters are used to monitor key stations in the network.

A trigger algorithm continuously monitors the incoming data and when trigger conditions are satisfied creates an event file on the disc. The

trigger algorithm filters the data in the band 1.5 to 4 Hz and then short term (4.3s) and long term averages (512s) are compared. Typically trigger criteria are: STA > (2 to 4)* LTA. Currently there are no coincidence requirements in the algorithm due largely to the inhomogeneity of the network. A disc based ring buffer permits 60s of data to be saved ahead of the trigger.

A graphics terminal and a plotter are available for quick look and hard copies of the data. Digital event files are stored on 9-track 800 bpi tape reels in ANSI labelled format.

PLANNED EXPANSION OF THE EASTERN CANADA TELEMETERED NETWORK

Figure 1 shows the approximate locations of sixteen additional stations in eastern Canada that are planned for installation in the next two years. Table 2 shows the names of the settlements nearest to the planned locations. The locations numbered 1-12 are the tentative sites planned for new ECTN stations made possible by the NRC agreement. Locations numbered 13-16 are tentative sites for other stations planned by EPB, site 13 (Temiscaming) as an ECTN station, sites 14-16 as additional regional stations. Schedules for this latter expansion are not yet known.

In all cases, the planned station locations shown in Figure 1 should be considered as approximate. The final locations may be as much as 50-100 km from these sites and will depend on seismic noise conditions, data telemetery possibilities and costs (for ECTN stations) and the availability of local operators (for regional stations), as well as further considerations of overall network configuration and seismological requirements.

There are additional stations being planned for the north shore of Lake

Ontario and the upper St. Lawrence region of eastern Ontario. However, as neither the number of stations, their type, nor their planned locations are yet known, they have not been included in Figure 1.

The planned expansion made possible by the NRC agreement is shown as a total of twelve stations in Figure 1. This number should be considered as tentative at this time because it will depend on costs (instrumentation, installation, data telemetry, etc.) that are not known accurately. However, with this as a working plan, we describe in the following paragraphs the planned schedule for the development that will be undertaken. Considerable capability has already been developed on the ECTN, both in terms of completed R&D and in terms of installed excess capacity. Thus the overall strategy, at least during the first half of the 5-year period of the agreement, will be to install during each year as many stations as can be handled by the current system of hardware and software, and in parallel develop the additional capability in hardware and software to meet the installation needs of the subsequent year.

The planned installation program for the first year (April '79- March '80) includes the instrumentation purchase, site testing and installation of the stations numbered 1 through 6 in Figure 1. Station number 6 will replace MIQ and the net addition to the ECTN would be five stations. It is planned to use radio telemetry for stations 5 and 6, and perhaps 3, with repeaters at appropriate high elevations in eastern Ontario and western Quebec, and telephone line telemetry for the remaining stations.

During this first year most of the resources would be utilized on capital expenditure and non-recurring R&D costs. Within the Seismological Laboratory the development priorities include: analysis of throughput capabilities;

preparation of a network-independent event file format; improvement of graphics programs; further development of the trigger algorithm; evaluation of digital multiplexer options; and finalization of station location plans for the following year.

The planned installation program for the second year (April '80-March '81) includes the instrumentation purchase, site testing and installation of the remaining six stations, 7-12, in Figure 1. As stated above, this final configuration should be considered tentative because it will depend on planned optimum usage of available resources as well as other seismological considerations that may be brought to bear during the first year.

During the second year the available resources would be utilized on capital purchases, installations, maintenance and data telemetry line rental. Priorities within the Seismological Laboratory would include further hardware and software developments and the preparation of a report for publication on the overall ECTN system configuration and capabilities.

There would be no planned installation program during the third and successive years under the NRC agreement, but one or two station relocations may be necessary because of site characteristics or other seismological considerations. Resources would be utilized primarily on data telemetry line rentals, station maintenance and hardware and software maintenance in the Seismological Laboratory.

CANADIAN CONTRIBUTIONS TO NORTHEASTERN NORTH AMERICAN SEISMIC DATA EXCHANGE

A sample schedule for the determination of eastern Canadian seismicity is presented in Table 3, within the framework of the overall Canadian seismicity

data processing and bulletin preparation schedule. The table presents a sample schedule for the May-June, 1979 period and indicates all stages of data reduction and bulletin preparation, from the rapid telephone exchange for events of immediate interest to the preparation of the annual catalogue of Canadian earthquakes.

Rapid data exchanges by telephone are usually undertaken by EPB in Ottawa with the Lamont-Doherty Geological Observatory and/or the Weston Observatory following widely felt or scientifically interesting earthquakes in eastern North America. These rapid exchanges allow epicentre and magnitude to be derived from the largest possible data set for the occasional earthquake of immediate interest.

Data from the ECTN will be made available in the form of an ECTN Bulletin that will be prepared and distributed every two months. This Bulletin will show derived parameters (epicentres and magnitudes) as well as basic data (phase times, P first motions, ground amplitudes and periods) for all located earthquakes in or near Canada. In the sample schedule shown in Table 3 the May-June 1979 ECTN Bulletin will be prepared and distributed in August, 1979. Data from the northeastern U.S. networks will not normally be available in this time frame, so small earthquakes in the northeastern U.S. poorly recorded on ECTN will not be included. This ECTN Bulletin will be a new feature of Canadian seismicity data reduction and will be undertaken under the terms of the NRC agreement to make ECTN data available in advance of the preparation date of the Northeastern U.S. Seismic Network Bulletin.

The ECTN Bulletin will contain complete readings from ECTN stations for any eastern earthquakes that have been located during the two month period in question. It will also contain those reliable data that are available from

any other Canadian seismograph stations at the time of its preparation. These latter data however, will not be complete because the records from the non-ECTN stations will not have been thoroughly analysed. Similarly, preliminary northeastern U.S. network data that may be available will be incorporated.

Any revisions to the ECTN Bulletin file will be incorporated in the regular EPB bimonthly reports on Canadian earthquakes which are published approximately seven months after the earthquakes occur. In the sample schedule of Table 3 the bimonthly reports for the May-June 1979 period will be published in January, 1980.

The EPB bimonthly reports consist of three parts, a Summary list, a Bulletin list and a Current list. The Summary gives a chronological list of epicentres, magnitudes and other derived parameters of all earthquakes located in or near Canada. The Bulletin gives the same information but also includes the basic data used to derive the epicentres and magnitudes. Each list is divided into eastern, western and northern regions, so the eastern section of the regular EPB Bulletin, published in January, 1980 in the example, is equivalent to the ECTN Bulletin, published in July, 1979, but now contains a complete and final set of all Canadian seismic data. The Current list gives provisional epicentres and magnitudes for any earthquakes located in the approximately six-month period from the time period covered by the Summary to the date of its issue. The Current list thus provides an up-to-date account of the more interesting Canadian earthquakes, although the information given is necessarily provisional.

The EPB Summary and/or Bulletin are distributed in whole or in part to the operators of seismograph networks near to Canada, selected Canadian and

American universities, the U.S. National Earthquake Information Service, the International Seismological Centre and several private and public agencies that have an interest in Canadian earthquakes. Copies of the Summary and Bulletin will be distributed under the terms of the NRC agreement, to the NRC and to interested northeastern U.S. network operators.

The final publication containing information on Canadian seismicity is the annual catalogue of Canadian earthquakes. (The annual catalogues for past years are listed in Table 1.) In the Table 3 sample schedule, the 1979 Canadian earthquake catalogue is scheduled for preparation in November or December 1980.

The information contained in the Catalogue is essentially the same as that given in the six regular bimonthly Summaries for the year. Some late-arriving non-Canadian data may be added and some solutions may be modified to give a consistent interpretation to similar events throughout the year. The Catalogue will also include any isoseismal maps, P-nodal solutions or supplementary information that have been derived for any earthquakes during the year.

The 1978 and later Catalogues will contain only earthquakes for which the magnitude is 3 or greater. Earlier Catalogues had listed all events that could be located, but the expansion of the Canadian seismograph network in recent years has led to a marked increase in the number of very small earthquakes in some regions appearing in the Catalogues. The restriction to magnitude 3 or greater will be used in future to present a truer picture of the level of significant seismic activity throughout Canada. Information on the smaller earthquakes will continue to be documented in the bimonthly reports.

Epicentres, magnitudes and other related parameters for all known earthquakes in or near Canada are stored in a digital data file. Data for each new year are added to the file at the time the Catalogue is published. Any or all of the data are available on request for a routine nominal charge. The digital nature of the file allows for searches of special regions or time periods to be done easily and quickly.

The first ECTN Bulletin under the terms of the NRC agreement will be issued for the May-June, 1979 period in August, 1979. Information for the month of April, 1979 will be included, for this time only, to make the ECTN Bulletin complete from the commencement date of the NRC agreement.

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Basham, P.W., D.H. Weichert and M.J. Berry. Regional Assessment of Seismic Risk in Eastern Canada. Bull. Seis. Soc. Am., in press, 1979.

Hayman, R.B., and W.E. Shannon. Seismological Service of Canada: Instrumentation and Data Processing. Phys. Earth Planetary Interiors, 18, 95-104, 1979.

Horner, R.B., A.E. Stevens, H.S. Hasegawa and G. Leblanc. Focal Parameters of the July 12, 1975, Maniwaki, Quebec, Earthquake - an Example of Intraplate Seismicity in Eastern Canada. Bull. Seis. Soc. Am. 68, 619-640, 1978.

Horner, R.B., R.J. Wetmiller and H.S. Hasegawa. The St-Donat, Quebec, Earthquake Sequence of February 18-23, 1978. Can. J. Earth Sci., in press, 1979.

Leblanc, G., and G. Buchbinder. Second Microearthquake Survey of the St. Lawrence Valley near LaMalbaie, Quebec. Can. J. Earth Sci. 14, 2778-2789, 1977.

Smith, W.E.T. Earthquakes of Eastern Canada and Adjacent Areas, 1534-1927. Pub. Dom. Obs. 26, 271-301, 1962.

Smith, W.E.T. Earthquakes of Eastern Canada and Adjacent Areas, 1928-1959. Pub. Dom. Obs. 32, 87-121, 1966.

Stevens, A.E. Re-examination of some Larger La Malbaie, Quebec, Earthquakes (1924-1978). Bull. Seis. Soc. Am., in press, 1979.

TABLE 1

Catalogues of Eastern Canadian Earthquakes

Years	Authors	Publication
1534-1927	Smith	Pub. Dom. Obs., 26, 1962
1928-1959	Smith	Pub. Dom. Obs., 32, 1966
1960	Milne & Smith	Seis. Series Dom. Obs. 1960-2, 1961
1961	Milne & Smith	Seis. Series Dom. Obs. 1961-4, 1962
1962	Milne & Smith	Seis. Series Dom. Obs. 1962-3, 1963
1963	Milne & Smith	Seis. Series Dom. Obs. 1963-4, 1966
1964	Smith & Milne	Seis. Series Dom. Obs. 1964-2, 1969
1965	Smith & Milne	Seis. Series Dom. Obs. 1965-2, 1970
1966	Stevens, Milne, Wetmiller & Horner	Seis. Series E.P.B. No. 62, 1972
1967	Stevens, Milne, Wetmiller & Leblanc	Seis. Series E.P.B. No. 65, 1973
1968	Stevens, Milne, Horner, Wetmiller, Leblanc & McMechan	Seis. Series E.P.B. No. 71, 1976
1969	Horner, Milne & McMechan	Seis. Series E.P.B. No. 67, 1974
1970	Horner, Milne, McMechan	Seis. Series E.P.B. No. 69, 1975
1971	Horner, Milne & McMechan	Seis. Series E.P.B. No. 74, 1976
1972	Basham, Horner, Wetmiller Stevens & Leblanc	Seis. Series E.P.B. No. 76, 1977
1973	Wetmiller	Seis. Series E.P.B. No. 72, 1976
1974	Wetmiller	Seis. Series E.P.B. No. 73, 1976
1975	Wetmiller	Seis. Series E.P.B. No. 77, 1977
1976	Wetmiller & Horner	Seis. Series E.P.B. No. 79, 1978
1977	Horner, Stevens & Wetmiller	Seis. Series E.P.B. No. 81, 1979

TABLE 2

Planned Additional Stations for the Eastern Canadian Seismograph Network

Site No. (Figure 1)	Approximate Location
1	Sherbrooke, Quebec
2*	La Malbaie, Quebec
3	Cornwall, Ontario
4	Val d'Or, Quebec
5	Mont Tremblant, Quebec
6**	Grand Remous, Quebec
7	Chalk River, Ontario
8	Chicoutimi, Quebec
9	Matane, Quebec
10	Edmundston, New Brunswick
11	Sackville, New Brunswick
12	Salmon River, Nova Scotia
13	Temiscaming, Ontario
14***	St. Catherines, Ontario
15****	Kapuskasing, Ontario
16****	Geraldton, Ontario

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* telemetry from the LMQ or POC regional station

** will replace MIQ ECTN station

*** regional station will replace WNR

**** regional stations

TABLE 3

Sample Schedule for Determination of
Eastern Canadian Earthquakes

Date	Remarks
May-June 1979	Data months considered as example. During this period data exchange with northeastern US agencies by telephone will be undertaken as necessary for events of immediate interest, usually within two working days of the event occurrence.
August 1979	The May-June, 1979 ECTN Bulletin will be issued giving, for located events, a complete list of ECTN data plus other reliable data available at the time of publication.
November-December 1979	Data from all Canadian seismograph stations are analysed for the May-June, 1979 period. Additional Canadian and northeastern U.S. data are added to ECTN data.
January 1980	The regular EPB bimonthly Canadian Summary and Bulletin for the May-June, 1979 period are issued.
July 1980	Data analysis for the 1979 year is complete and the last regular bimonthly reports, for November-December 1979 issued.
October-November 1980	The data set for the 1979 year is finalized, confirmed blasts are deleted, similar events are given a consistent interpretation and any supplementary information such as isoseismals and P-nodal solutions are prepared. The 1979 Catalogue of Canadian earthquakes is prepared. Parameters for all located events are added to the EPB digital data file.

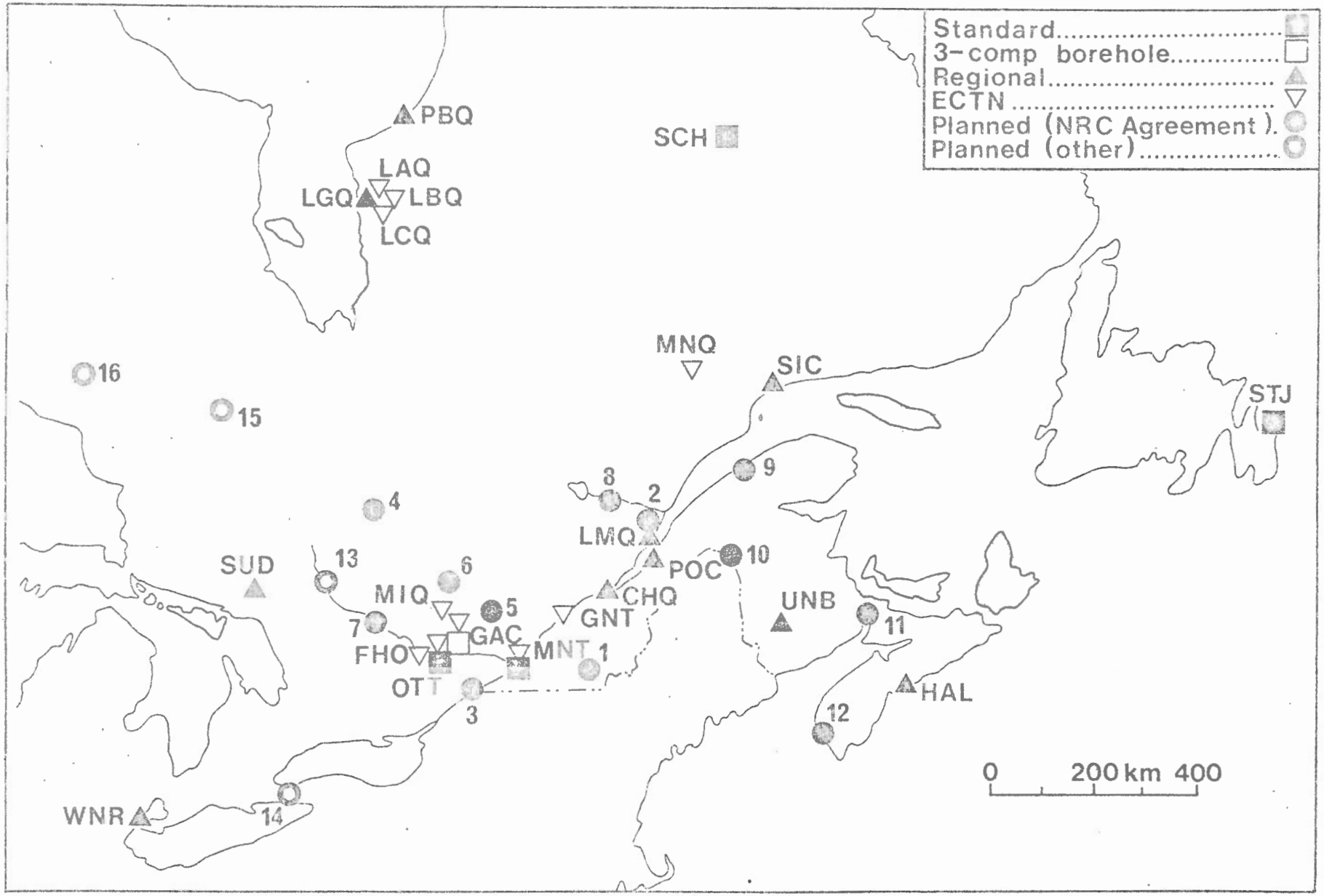

Figure 1. SEISMOGRAPH STATIONS IN EASTERN CANADA

APPENDIX A

Preprint: "Regional Assessment of Seismic Risk in Eastern Canada"

by P.W. Basham, D.H. Weichert and M.J. Berry

In press: Bulletin of the Seismological Society of America.

APPENDIX B

Reprint: "Second Microearthquake Survey of the St. Lawrence Valley near La Malbaie, Quebec"

by G. Leblanc and G. Buchbinder

Canadian Journal of Earth Sciences 14, 2778-2789, 1977.

APPENDIX C

Preprint: "Re-examination of some Larger La Malbaie, Quebec, Earthquakes (1924-1978)"

by A.E. Stevens

In press: Bulletin of the Seismological Society of America

APPENDIX D

Reprint: "Focal Parameters of the July 12, 1975, Maniwaki, Quebec, Earthquake - an Example of Intraplate Seismicity in Eastern Canada"

by R.B. Horner, A.E. Stevens, H.S. Hasegawa and G. Leblanc

Bulletin of the Seismological Society of America 68, 619-640, 1978

APPENDIX E

Preprint: "The St-Donat, Quebec, Earthquake Sequence of February 18-23, 1978"

by R.B. Horner, R.J. Wetmiller and H.S. Hasegawa

In Press: Canadian Journal of Earth Sciences.

APPENDIX F

Reprint: "Canadian Seismograph Operations - 1977"

by W.E. Shannon, R.J. Halliday, F. Lombardo and D.R.J. Schieman

Seismological Series, Earth Physics Branch No. 80, 1979.

APPENDIX G

Reprint: "Seismological Service of Canada: Instrumentation and Data Processing"

by R.B. Hayman and W.E. Shannon

Physics of the Earth and Planetary Interior 18, 95-104, 1979.