Canadian strong motion seismograph networks*

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ABSTRACT: The Canadian strong motion seismograph network was started in 1963 and some 70 accelerographs are now in operation. Site selection is governed primarily by seismological rather than engineering priorities. The federal government networks are supplemented by privately-owned instruments in special engineered structures, mainly dams. In western Canada, 36 accelerographs are installed in the Vancouver-Victoria, Central Vancouver Island, and Queen Charlotte areas. The Vancouver-Victoria region is a high-density population centre, just inland from the Juan de Fuca subduction zone, which may be capable of large subduction earthquakes, while the latter two regions have a proven potential for large earthquakes (M8.1 and M7.3). Four earthquakes have yielded records of up to 0.06 g horizontal acceleration. In eastern Canada, 17 of the 19 accelerographs are now centered on the Charlevoix seismic zone, which has a long history of strong earthquakes. In 1982, an earthquake series in New Brunswick yielded the first significant near-source ground motions in eastern Canada of up to almost 0.6 g. Only one accelerograph was located in northern Canada until a series of strong earthquakes occurred in 1985 in the Northwest Territories. Instruments installed in the Nahanni aftershock zone recorded horizontal accelerations over 1 g and a vertical acceleration peak of over 2 g.

1 Introduction

Parts of Canada are strongly seismic. On the west coast, part of the circum-Pacific seismic belt, one M8.1 and several M7 earthquakes are known to have occurred in historical times. In eastern Canada, populated regions are known to have experienced magnitude 6 to 7 earthquakes as early as 1663, with three M6 or greater events since 1925.

This activity motivated the initiation of a modest strong motion program in western Canada by the Dominion Observatory, then a branch of the Department of Energy, Mines and Resources (EMR) and, almost concurrently, the National Research Council of Canada (NRCC) began to install a strong motion network in eastern Canada. Subsequent to some reorganization within the Canadian government, both networks are now under the direction of the Geological Survey of Canada (GSC) of the Department of Energy, Mines and Resources. This paper reviews the development, current status and proposed expansion of these networks, and tabulates the most notable strong motion records.

2 History

The first two instruments of the Canadian strong motion program were installed in early 1963 in Victoria and Vancouver. The early history of the network was described by Rogers, Milne and Bone (1970), and was reviewed by Rogers (1976). Most of the early instruments were located on the densely populated Lower Mainland and southern Vancouver Island. The locations were chosen to sample the response of the different soils and alluvial thicknesses of the Fraser valley deposits, and instruments were placed mostly in basements or ground floors of low-rise buildings.

The National Research Council of Canada (NRCC), through its Division of

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Building Research, installed the early strong motion network in eastern Canada, starting in 1966 (Rainer and Luctkar 1983). About a dozen accelerographs were placed in the large cities of Montreal and Quebec, and in the villages near the historical Charlevoix seismic zone, downriver from Quebec City.

In the late 70s there was a demand for seismic hazard estimation for a projected northern pipeline, and a few accelerographs were installed by EMR to capture ground motion on permafrost. Only one of these now remains in the Yukon Territory at Haines Junction.

Both EMR and NRCC also encouraged builders of large-scale engineered structures (mainly dams) to install their own accelerographs, and, in fact, the government agencies serviced these instruments for several years, until the industries took over this responsibility. Currently, four hydroelectric dams in British Columbia and three in Quebec are privately instrumented.

High on the list of Canadian concerns was the lack of good "free-field" ground motion relations for eastern Canada, where typical source parameters and attenuation are different from western North American earthquakes. This has been addressed in a network expansion in 1984. In western Canada, concerns are with the attenuation from earthquakes of about 50 km depth, and also with ground motion from very large earthquakes with spatially extended sources.

In 1982, a M5.7 earthquake in Miramichi, New Brunswick, provided a strong impetus for expansion of the eastern network, and, in cooperation with the U.S. Nuclear Regulatory Commission (USNRC), 8 accelerographs were deployed in the Miramichi aftershock area for 2 years. Some of these instruments captured the first significant near-source ground motions on bedrock in eastern Canada (Weichert et

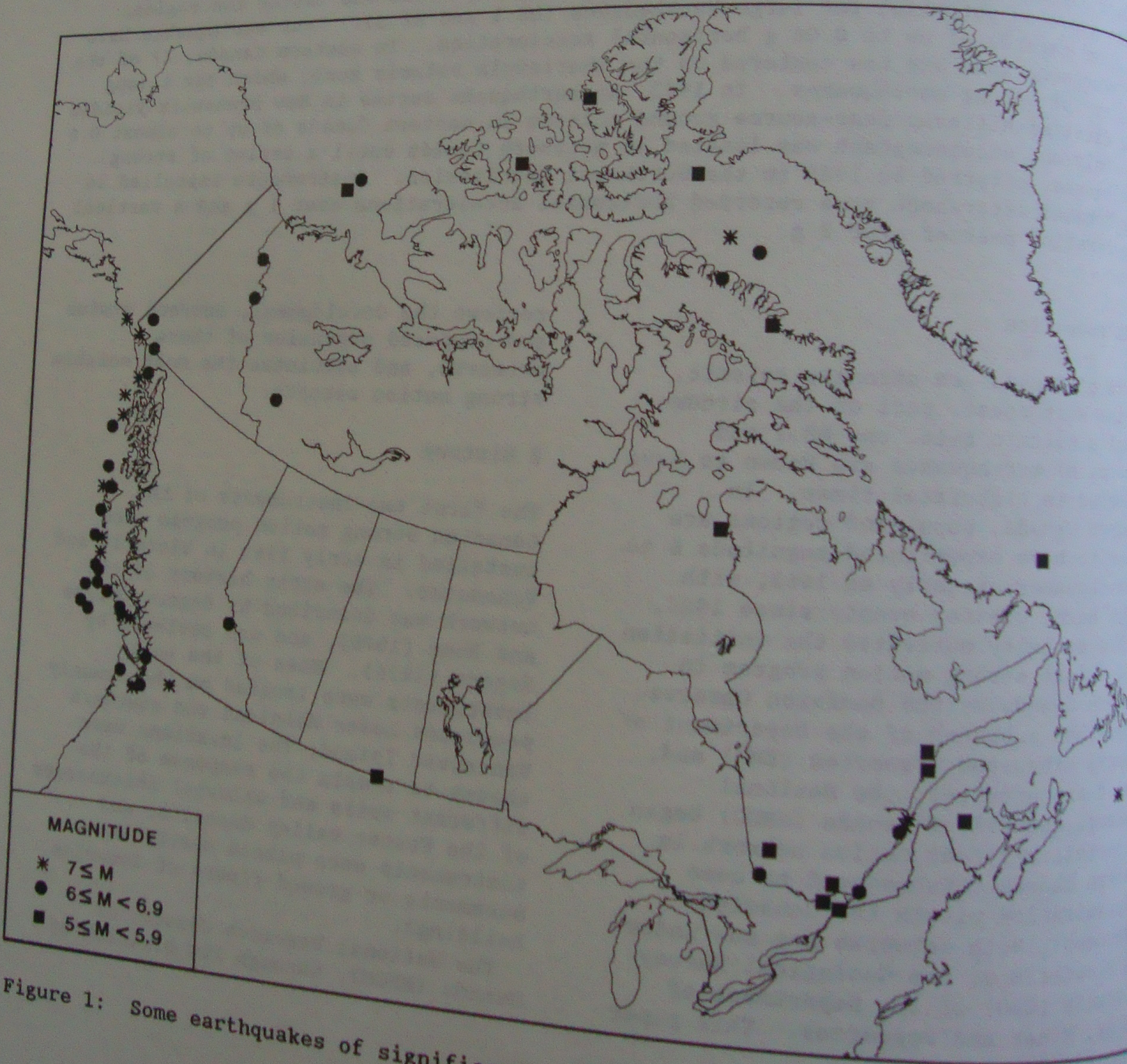

Figure 1: Some earthquakes of significance to Canada; 1663 to 1985.

al. 1982; also, see Table 1).

The eastern NRCC network was transferred to EMR in 1984 and was retrofitted and reconfigured using the decommissioned New Brunswick equipment and some new instruments. The number of instruments centered on the Charlevoix seismic zone more than doubled. Particular attention was paid to establishing "free-field" sites.

In 1985, a magnitude 6.6 earthquake occurred in the Mackenzie Mountains of the Northwest Territories. Three strong motion accelerographs were deployed during aftershock surveys and recorded very significant ground motion during a second large earthquake (M6.9). These and the 1982 Miramichi records will be described later (see Section 6 and Table 1).

A considerable number of seismoscopes had been installed in the earlier phases of the program (see Rogers 1976), but have now been removed because of servicing and cost/benefit considerations.

3 Instrumentation

The existing network of analog film recording accelerographs is still considered to be the best compromise of cost, reliability and data quality for the level of seismicity found in Canada, although a digitally recording accelerograph has been acquired. At present, most accelerographs in western Canada are 1 g Kinemetrics SMA-1 units, with six 1 g RFT- 250 units. In the east, most instruments are Kinemetrics SMA-1 1 g units with time code generators. The exceptions are three 1/2 g Kinemetrics SMA-1 units whose resonant frequencies are near 18 Hz, as compared to 25 Hz for the 1 g units; they are not considered to be appropriate for eastern Canada where higher than average ground acceleration frequencies and higher than 1/2 g amplitudes have been observed. Retrofit to 1 g is planned during 1987.

Detailed instrument and site data are given in the annual publication 'Canadian Seismograph Operations' of the Geological Survey of Canada. Through cooperation with the private operators, data on their stations are included in this publication.

Responsibility for the western strong motion stations, including the Yukon, lies with the Cordilleran and Pacific Margin Division of the GSC (Pacific Geoscience Centre, Sidney) and for the eastern stations with the Geophysics Division of the GSC (Ottawa). Maintenance is mainly by contract, with one scheduled visit every six months for all but the most remote sites, where visits are annual. Some of these stations have a simple monitor unit attached externally (see Rogers and Bennetts 1975). The curators of these instruments are contacted by mail a few times a year, and asked to record and send in the monitor readings. Abnormal readings may result in an early or unscheduled service trip.

Both offices of the GSC now have some spare instruments, which serve to maintain the networks and are readily available for deployment in aftershock zones of significant earthquakes.

4 Western Earthquake Potential and Networks

Canada's southwestern coast is part of the circum-Pacific seismic belt, comprised here of short ridge segments and transform faults separating the Pacific plate and the Juan de Fuca and Explorer platelets a few hundred kilometres offshore (Figure 2). These plate remnants are believed to subduct under Vancouver Island and the Lower Mainland of British Columbia where they give rise to earthquakes in the overlying crust and within the subducting plate (cf e.g. Keen and Hyndman 1979). Several earthquakes near and above M7 have occurred within a few hundred kilometres of the metropolitan centres of Vancouver and Victoria (Figure 1). Moreover, the potential of large thrust earthquakes on the Juan de Fuca subduction interface must be considered. Although not observed during historical times, evidence is mounting that such earthquakes may have occurred with average recurrence times of 400 to 500 years and magnitudes between 8 and 9 (Heaton and Kanamori 1984; Weichert and Rogers 1985).

Further north, the Pacific-North American plate boundary consists of the Queen Charlotte fault, a right-lateral strike-slip fault with a probable subduction component near the south end of the Queen Charlotte Islands. A magnitude 8.1 earthquake occurred in 1949 along this section of plate boundary.

All M5 and some M6 western earthquakes have been excluded from Figure 1 to avoid overcrowding the diagram.

4.1 The Vancouver-Vancouver Island Network

Figure 3 shows the current network and planned additions in the southwestern corner of British Columbia. The historical earthquake zone (Milne et al. 1978) extends from Seattle-Tacoma at the south end of the Puget Sound in the State of Washington, to about the 49th parallel, halfway between the two metropolitan areas of Vancouver and Victoria. The larger earthquakes here occur within the subducting plate. There is a relatively quiet zone just to the north of 49°N, followed by a zone of moderate earthquakes northwest of the Vancouver-Lower Mainland area. Large events with an epicentre in the Gulf

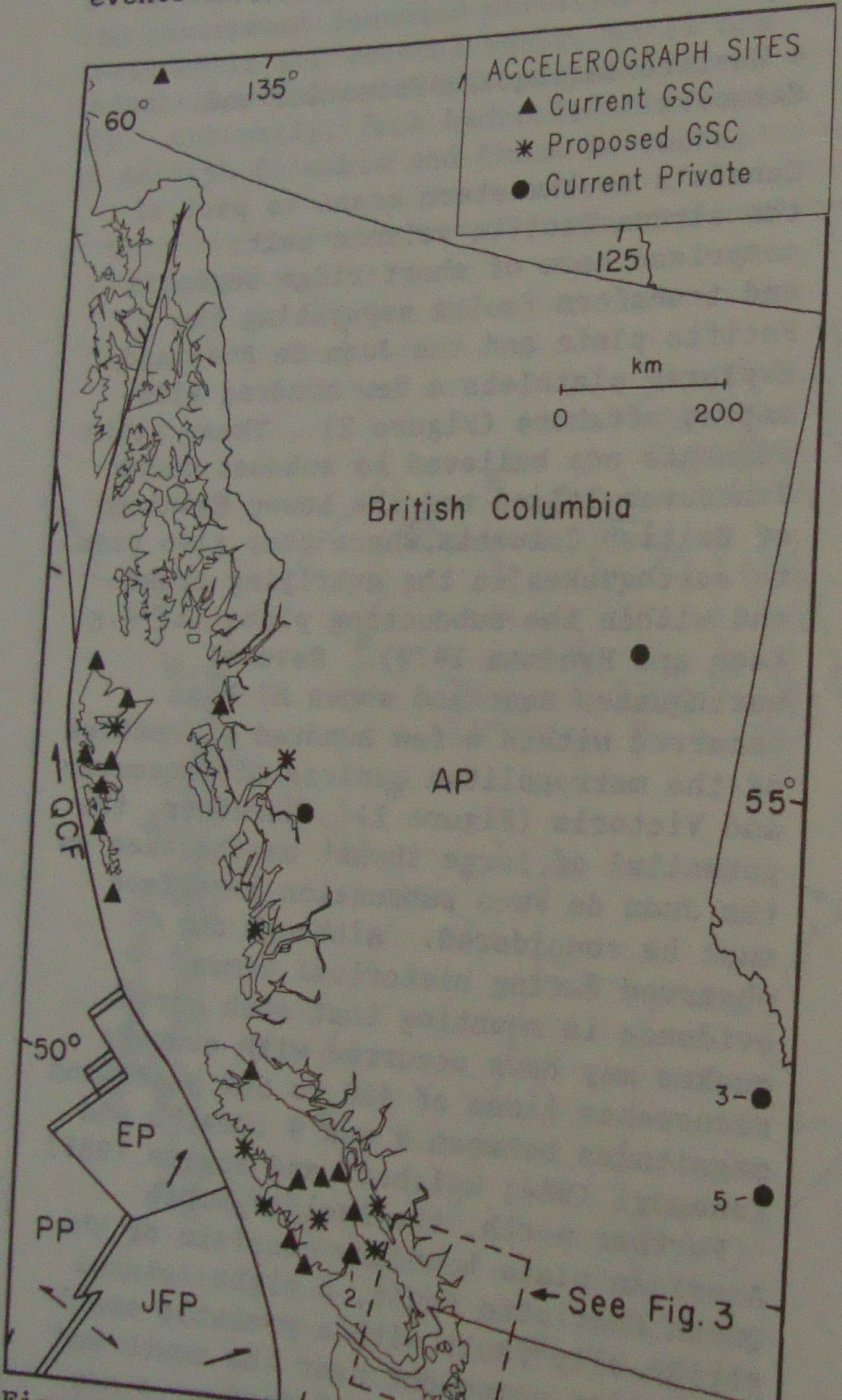

Figure 2: Accelerographs in western Canada - 1986 PP=Pacific Plate;AP=North American Plate; JFP=Juan de Fuca Plate; EP=Explorer Plate; QCF= Queen Charlotte Fault. Double bars at lower left represent transform faults; single-headed arrows show relative plate motion.

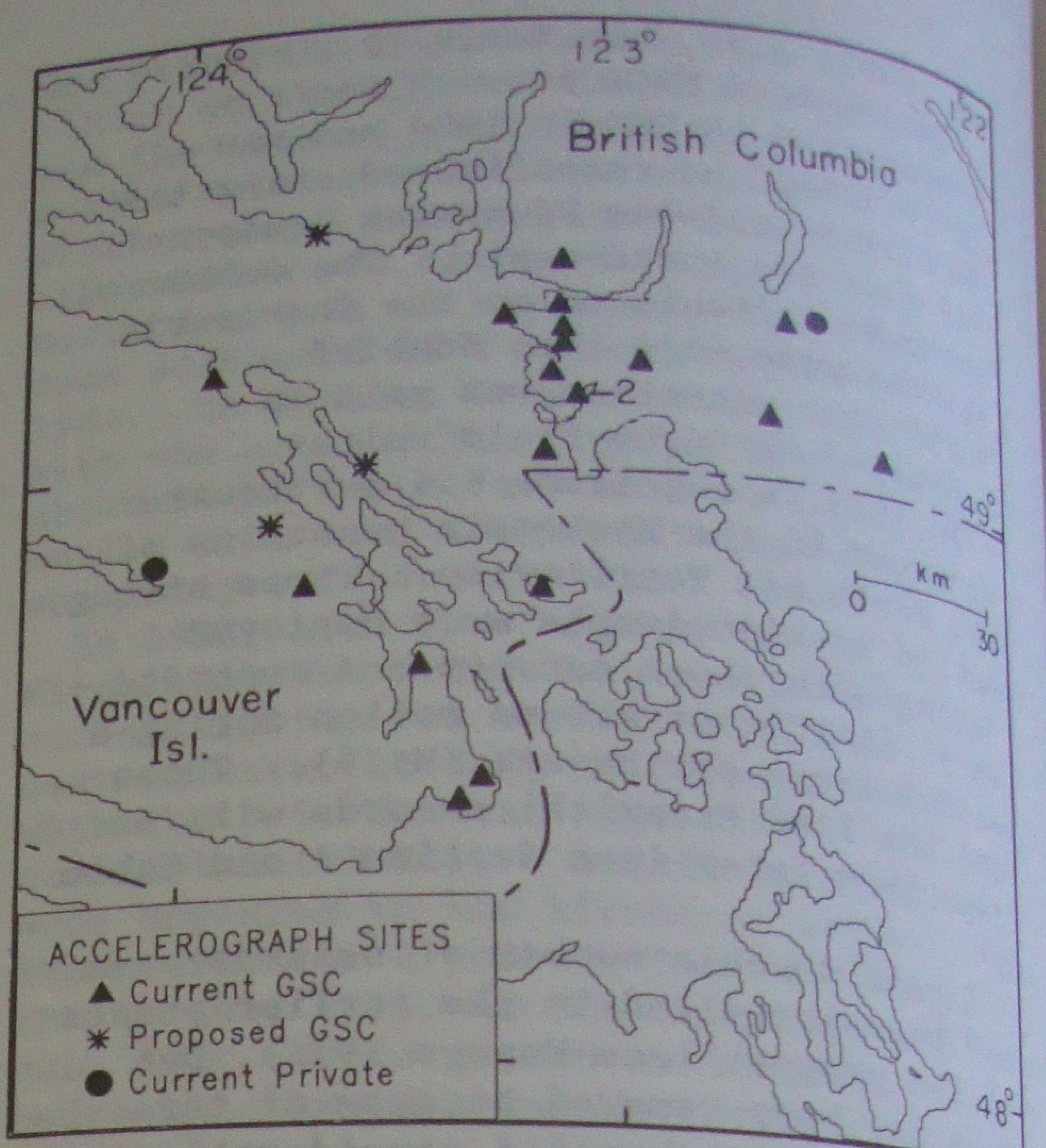

Figure 3: Accelerographs in the Vancouver-Victoria area - 1986.

Islands are considered to be the closest likely threat to the metropolitan areas. For this hypthetical epicentre the Vancouver-Lower Mainland network has one approximately north-south profile and a second profile approximately following the Fraser River with about 10 km spacing. Most accelerographs are on basement concrete slabs. Three of the sites along the northern profile are founded on bedrock while the east-west profile is founded mainly on alluvium, silt, sand or clay.

On the south side of the hypothetical epicenter, the accelerograph spacing is somewhat wider, a few tens of kilometers. All sites but one are on bedrock.

The siting of a few stations was influenced by engineering interests and instruments were located in structures of local importance and uniqueness. The southernmost example is an instrument at the coal shipping terminal on silt fill (Roberts Bank); another one is at the bottom of a tunnel under the Fraser River with a second "free-field" instrument a few hundred metres away. A third instrument is placed in the basement of a 22-storey concrete building in downtown Vancouver (B.C. Hydro) and a fourth is on the bedrock abutment of the Capilano concrete dam structure. One privately-owned instrument is located at Lake Cowichan (Teleglobe Canada) and another is at the Allouette dam on the

Fraser River.

Further to the northwest, central Vancouver Island has a high potential for a magnitude 7 event. Earthquakes occurred near the west coast of the island in 1918 (M7.0) and 1957 (M6.0), and in 1946 (M7.3) near the east coast. The currently existing and proposed accelerographs will cover the potential epicentral area well (see Figure 2), and completion of this network is expected by 1988. Remoteness and sparse population place restrictions on site selection; some instruments are not deployed in "free-field" conditions. The three proposed accelerographs for central Vancouver Island will be co-located with telemetred digital seismographs. This has potential advantages for data interpretation.

One instrument of the two in Port Alberni is located on a concrete floor built on a stiff cellular substructure of wood piles. This is a typical structure in forest product oriented west coast towns; a comparison with a nearby rock site would be highly relevant to engineering design.

4.2 The Queen Charlotte Network

Figure 2 shows the Queen Charlotte area network and Figure 1 indicates the high seismicity near the Queen Charlotte Islands. Instrument location is governed by the paucity of permanent settlements.

Instruments along the mainland coast are at a greater distance from the active principal Queen Charlotte fault zone, but seismic activity has been established to the east of the main fault between the Queen Charlotte Islands and the mainland. Accelerographs are located at the important seaport of Prince Rupert (GSC) and at the Kemano hydroelectric site (privately owned by ALCAN). Another accelerograph at the economically important location of Kitimat would be desirable.

4.3 B.C. Hydro Accelerographs

Cooperation between EMR and B.C. Hydro resulted in accelerograph installations in several dams in the early years of the EMR program. Ladore dam on Vancouver Island was instrumented by EMR in 1965, and the Mica Creek dam in the Rocky Mountain trench followed in 1972 (3 units, see Figure 2). More recently, B.C. Hydro has set up its own monitoring program and is expanding. Currently the utility company operates accelerographs at the Bennett dam in the Peace River area, Mica Creek dam, Revelstoke dam in the interior (5 units) and Allouette dam in the Lower Mainland. Other installations are planned (private communication, Tim Little, B.C. Hydro 1986).

5 Eastern Earthquake Potential and Networks

Seismicity in eastern Canada is well documented although not as well understood within the framework of modern plate tectonics (Basham et al. 1979). The Charlevoix seismic zone is historically the most active, with at least five earthquakes of magnitude 6 or greater (1663, 1791, 1860, 1870 and 1925). The 1925 event is the only earthquake with magnitude near 7 on land in eastern North America in the twentieth century. This source zone is considered to have the highest potential for strong ground motion and has had the highest priority for instrumentation.

Several other clusters of seismicity exist throughout eastern Canada, in which the activity is significantly higher than the general background. One of the most important is the western Quebec zone that contains the major population centers of Montreal and Ottawa. Past experience suggests that maximum magnitude earthquakes of at least M7 must be assumed here, but the

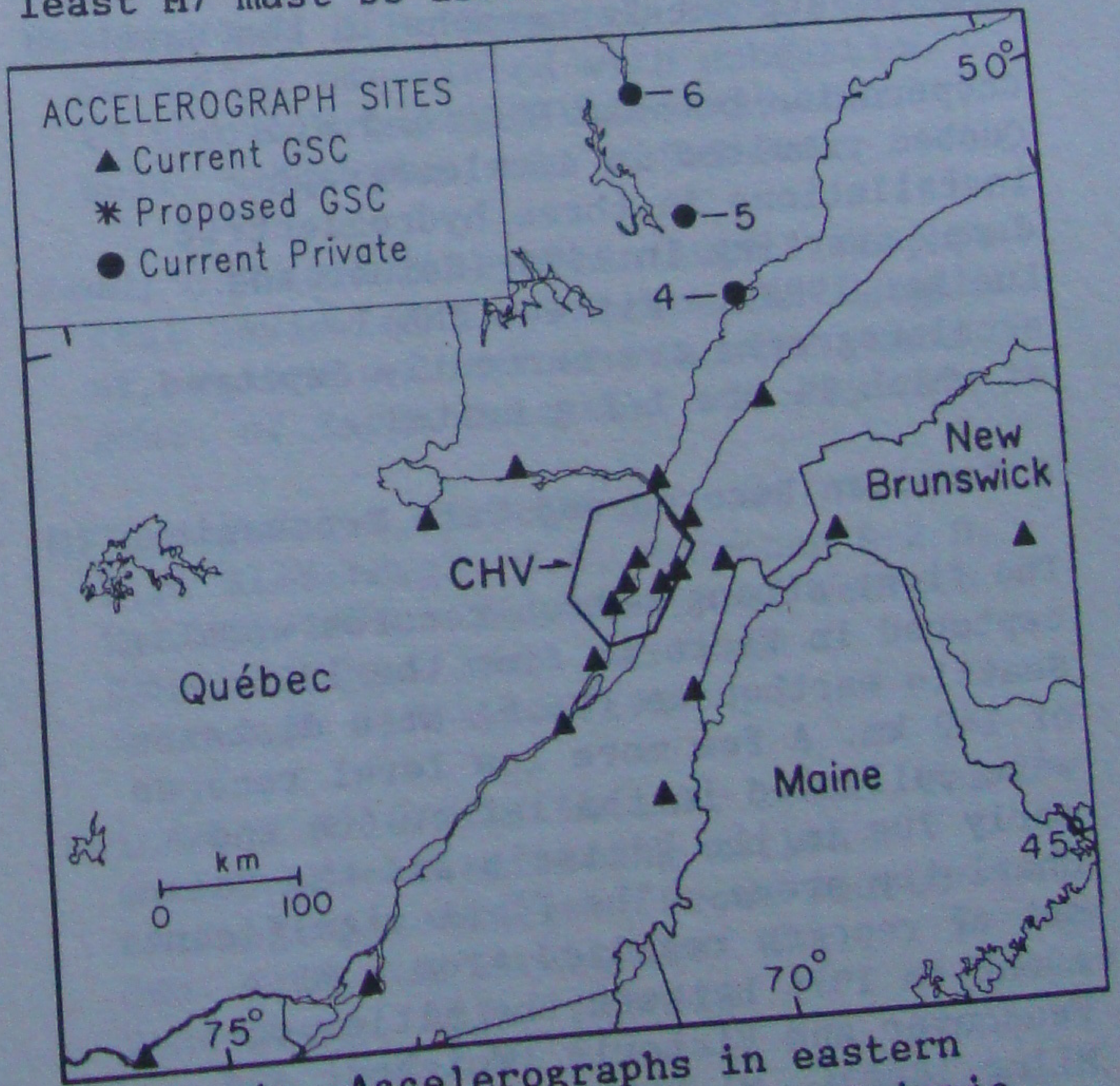

Figure 4: Accelerographs in eastern Canada - 1986. CHV=Charlevoix Seismic Zone.

probability for strong ground motion for these cities is smaller than for the Charlevoix zone.

Another source zone that includes one major historical event of M7.2 is a small area at the edge of the continental slope, at the mouth of the Laurentian Channel.

5.1 The Eastern Canadian Network

Figure 4 shows the eastern network, which comprises 19 sites and significantly improves the coverage of the Charlevoix seismic zone. The station layout approximates profiles both into the paleozoic terrain of the Northern Appalachians and into the Canadian Shield. Siting is constrained in the Shield region northwest of Charlevoix by a lack of villages. This configuration has two Northern Appalachian station profiles within Canada: one to the east ending at Miramichi, New Brunswick; and one to the south near the Quebec-Maine border.

The Charlevoix seismic zone shows activity over an epicentral region about 70 km by 30 km, centered along the river. A significant earthquake anywhere within this zone could trigger 5 strong motion seismographs within 50 km and 10 within about 100 km.

The single accelerographs in Montreal and Ottawa extend coverage into these densely populated and seismic areas.

5.2 Private Accelerographs in the East

Cooperation between NRCC and Hydro-Quebec resulted in accelerograph installations in three hydroelectric dams, starting in 1974 (Rainer and Luctkar 1983). Fifteen SMA-1 accelerographs are currently deployed, of which 11 are 1/2 g units.

6 Canadian Records and Data Processing

The first strong motion records were captured in Victoria from the 1965 Seattle earthquake (M6.5) at a distance of 140 km. A few more low level records were collected in the latter 60s and early 70s in the Victoria and the Queen Charlotte areas. The first significant set of records resulted from a M5.4 event in 1976 between the cities of Vancouver and Victoria (Weichert and Milne 1980). Eight accelerographs triggered, with maximum peak horizontal accelerations between 0.04 and 0.06 g at distances of about 30 to 60 km on various soil types.

In eastern Canada, the first accelerogram with maximum peak acceleration of about 0.01 g was obtained in 1979 from a shallow M5.1 event in the Charlevoix zone at a distance of 55 km. When the 1982 Miramichi, New Brunswick earthquake series started there were no nearby strong motion seismographs, until a temporary network was installed as mentioned earlier. A set of 19 records was captured from shallow earthquakes of M3.4 to M4.8 at distances from 4 to 30 km. Their significance lay in the high dominant frequencies (averaging 24 Hz) and high peak ground accelerations, up to almost 0.6 g (Weichert et al. 1982).

In northern Canada, the first set of records was captured after the M6.6 event of 5 October 1985. To the end of September, 1986, accelerograms had been recorded from over 80 smaller aftershocks and from a second large earthquake of M6.9 (23 December, 1985), at distances of approximately 8 to 30 km. The significance of these records are three-fold: they are the first strong motion records from a very large Canadian earthquake; the peak accelerations recorded are very high (1.32 g horizontal and greater than 2 g vertical), and the ground motions of the large December event are expected to be widely used for engineering design studies (Wetmiller et al. 1987).

Available Canadian records have been published in Open File Reports (Weichert and Milne 1980; Weichert et al. 1982; Weichert et al. 1986). Table 1 gives a selection of relevant ground motion parameters for the most important Canadian strong ground motion records captured to date. Shown are peak horizontal accelerations and velocities as well as the approximate 5% damped spectral levels of acceleration and velocity, together with earthquake magnitude and epicentral distance.

The earliest records were processed in-house. We now use commercial digitization facilities, and, in the last five years, the facilities and the programs of the U.S. National Strong Motion Data Centre of the USGS in Menlo Park (AGRAM Program Package, Converse, 1984) have been used. The processed data have been included in the USGS archive.

The digitized data from processed records are available on tape, at the

Table 1. Peak horizontal ground motion parameters of the most notable Canadian strong motion records.

Earthquake – site & condition	Nominal Dist. (km)	Acceler. (g)	Velocity (m/s)	5% damped response spectrum Acceler. (g)	5% damped response spectrum Velocity (m/s)
Miramichi M4.8					
31 March 1982					
– Holmes Lake, 5 m alluvium	6	0.34	0.014	0.6	0.05
– Mitchell Lake, bedrock	4	0.23	0.019	0.7	0.06
– Loggie Lodge, 5 m alluvium	6	0.56	0.041	0.8	0.06
– Indian Brook, gravel	3	0.42	0.031	0.8	0.06
Nahanni M6.9					
23 December 1985					
– Site 1, bedrock	8	1.32	0.46	3.0	1.0
– Site 2, bedrock	8	0.53	0.33	1.5	0.6
– Site 3, bedrock	25	0.19	0.06	0.7	0.1

user's expense. Requests should be made to the Head, Canadian Seismograph Network, Geophysics Division, Geological Survey of Canada, 1 Observatory Crescent, Ottawa, Ontario, Canada, K1A 0Y3.

7 Summary

The Canadian strong motion network started almost 25 years ago. The program is now the responsibility of the Geological Survey of Canada. Over 70 accelerographs are now in place, and large events in the Queen Charlotte, Central Vancouver Island, Vancouver-Victoria and Charlevoix areas should be adequately recorded. The GSC will continue to supplement permanent network data by deploying portable instrumentation in the aftershock zones of large events in these and other areas. In western Canada, the network should continue to grow to the outlined configuration before 1990. There are no expansion plans for the eastern network. Critical facilities should be instrumented by their owners; for example, the Canadian Standards Association provides guidelines on the installation of strong motion accelerographs in nuclear power plants (CSA-N289.5).

Recently captured strong ground motion records have a been received with great interest by the engineering community, emphasizing the socio-economic importance of maintaining a viable strong motion program in Canada.

8 Acknowledgements

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