Operational Procedures of Agencies Contributing to the ISC

Geological Survey of Canada: Canadian National Seismic Network

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International Seismological Centre

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5.1 Geological Survey of Canada: Canadian National Seismic Network

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5.1.1 Overview

The Geological Survey of Canada (GSC) has a mandate to monitor seismicity in Canada for the purposes of public safety and to mitigate hazard. This is primarily done with data from the national seismic network providing input into the National Building Code of Canada and through outreach and liaison activities with federal and provincial emergency preparedness organisations.

GSC is responsible for prompt issuance of earthquake notifications and for maintenance of the waveform archive and seismic catalogue. GSC mainly uses the seismic catalogue for input into the national hazard map and building codes and the waveform data to understand better the local conditions for disaster mitigation. The waveform and catalogue data are also widely used by universities and institutions worldwide to further the understanding of the earthquakes and earthquake hazard.

5.1.2 Seismicity and Hazard

Seismicity in Canada is concentrated in two distinct regions, as seen in Figure 5.1. Along the west coast the Pacific plate meets the North American plate, and a series of small plates comprising the Juan de Fuca plate system is caught between these two large plates. The stress associated with the Pacific-North American plate interaction extends inland into the Rocky Mountains and north along the boundary between the Yukon and Northwest Territories. In southwestern British Columbia (BC) the main Juan de Fuca plate is being subducted beneath the western edge of the North American plate. This western margin is thus the most seismically active region of Canada.

Eastern Canada also hosts significant seismicity. The St Lawrence River, which runs partially along the Canada-U.S. border on the east coast of the North American continent, follows a failed rift margin. This region and its surrounds have mainly been reactivated in response to intraplate stress and post-glacial rebound. Most of central Canada is relatively aseismic, which has led to a division of responsibility for catalogue production into the western and eastern halves, each managed out of the respective offices located in Sidney, British Columbia (BC), and in Ottawa, Ontario (ON). For the purposes of the archival

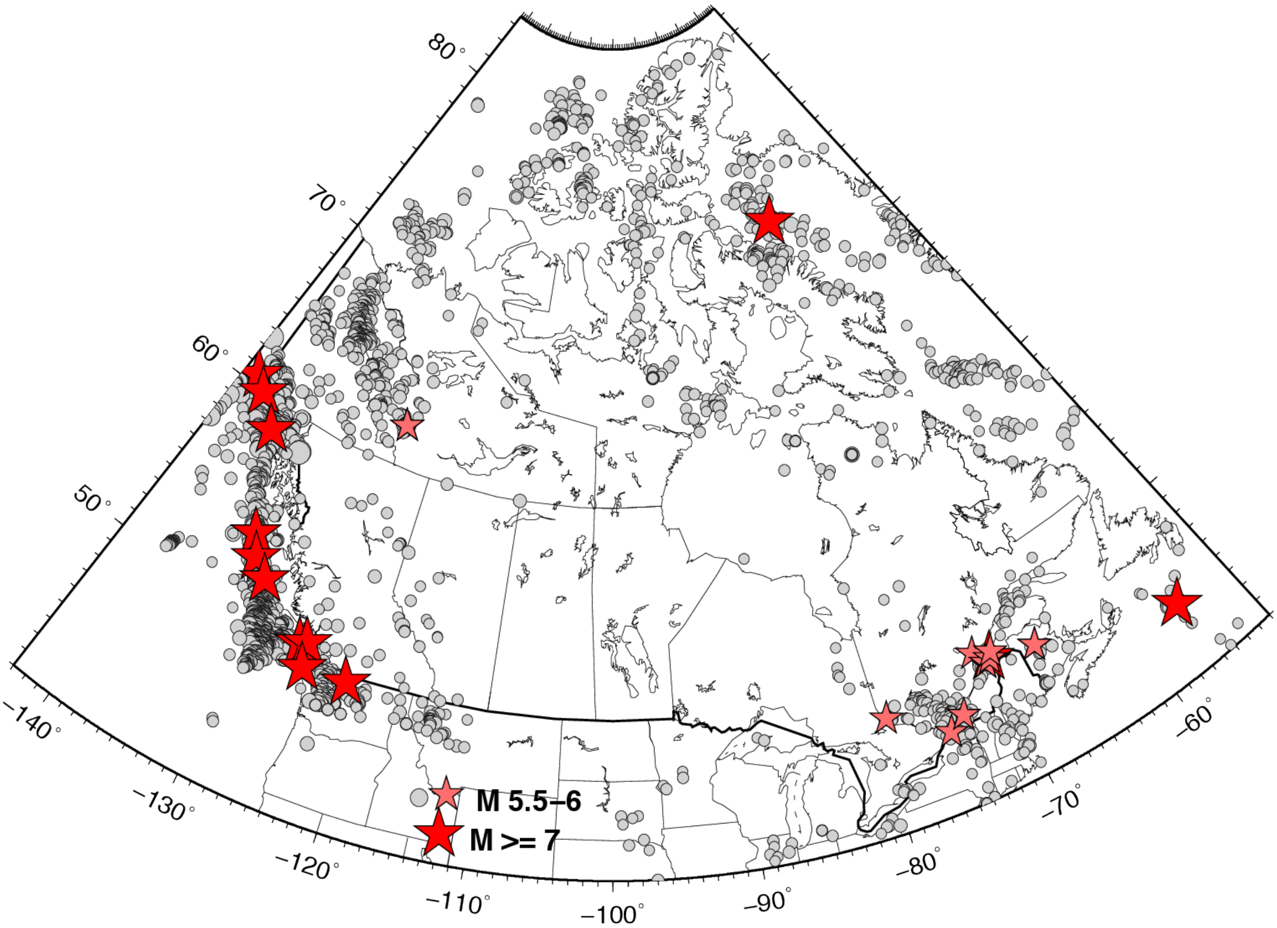

Figure 5.1: *Seismicity of Canada (grey dots: M≥3.5) and significant events (red stars). [Source: NRCan website.]*

database and website access, the information for these two halves is combined into a unified database, which is jointly updated by the two data centres.

Table 5.1 lists significant events that have occurred in Canada, which are also indicated on Figure 5.1. The 1770 January 26 M 9 earthquake, offshore from Vancouver Island in southwestern BC, was the largest event in Canadian history. This earthquake ruptured the entire Cascadia margin, approximately 1000 km from mid Vancouver Island to the Oregon-California border in the U.S., and caused a 10-80 m tsunami that destroyed native coastal villages and removed all trace of them (Rogers, 1991). On the eastern coast lives were lost on the Burin Peninsula in southern Newfoundland as a result of the tsunami associated with the 1929 November 18 M 7.2 Grand Banks earthquake.

5.1.3 Network and Catalogue History

The first-known Canadian seismogram is from a three-component velocity-sensitive Ewing seismograph recorded on a revolving smoked-glass plate at McGill University in Montreal, Quebec, on March 23 in 1897. This was not a continuous recording site, however, but it was soon followed in September 1897 by Canada's first permanent recording seismograph site in Toronto, Ontario, and in September 1898 by a second permanent recording seismograph site in Victoria, BC. The Toronto site was also the first seismograph station in North America with continuous and photographic recording.

Table 5.1: *Significant seismic events in Canada*
[Source: http://www.earthquakescanada.nrcan.gc.ca/historic-historique/map-carteeng.php]

Date	Lat	Lon	Mag	Location region
1663 Feb 5	47.60	-70.10	7.0	Charlevoix-Kamouraska Region 1663
1700 Jan 26	48.50	-125.00	9.0	Cascadia Subduction Zone
1732 Sep 16	45.50	-73.60	5.8	Western Quebec Seismic Zone, Montreal Region
1791 Dec 6	47.40	-70.50	6.0	Région Charlevoix-Kamouraska 1791
1860 Oct 17	47.50	-70.10	6.0	Région Charlevoix-Kamouraska 1860
1870 Oct 20	47.40	-70.50	6.5	Charlevoix-Kamouraska Region 1870
1872 Dec 15	48.60	-121.40	7.4	Washington-B.C. Border
1899 Sep 4	60.00	-140.00	8.0	Yukon-Alaska Border
1918 Dec 6	49.62	-125.92	7.0	Vancouver Island, British Columbia 1918
1925 Mar 1	47.80	-69.80	6.2	Charlevoix-Kamouraska region 1925
1929 Nov 18	44.50	-56.30	7.2	Atlantic Ocean, south of Newfoundland
1933 Nov 20	73.00	-70.75	7.3	Baffin Bay, Northwest Territories
1935 Nov 1	46.78	-79.07	6.1	Quebec - Ontario Border, Temiscamingue region
1944 Sep 5	44.97	-74.90	5.8	Cornwall region, Ontario-New York border
1946 Jun 23	49.76	-125.34	7.3	Vancouver Island, British Columbia 1946
1949 Aug 22	53.62	-133.27	8.1	Offshore Queen Charlotte Islands; now Haida Gwaii
1958 Jul 10	58.60	-137.10	7.9	Near the British Columbia-Alaska Border
1970 Jun 24	51.77	-130.76	7.4	South of Haida Gwaii, British Columbia
1979 Feb 28	60.59	-141.47	7.2	Southern Yukon-Alaska Border
1982 Jan 9	47.00	-66.60	5.7	Miramichi, New Brunswick
1982 Jan 11	47.00	-66.60	5.4	Miramichi, New Brunswick
1985 Oct 5	62.21	-124.22	6.6	Nahanni region; was Northwest Territories 1985-10
1985 Dec 23	62.19	-124.24	6.9	Nahanni region; was Northwest Territories 1985-12
1988 Nov 25	48.12	-71.18	5.9	Saguenay region
2012 Oct 28	52.55	-132.24	7.7	Offshore Haida Gwaii

During the 1960s the Canadian seismic network was expanded to monitor Canada uniformly with standardised instruments. The Canada-wide network was designed with a backbone of stations spaced approximately 500 km apart in a rough grid across Canada. On the west coast a small network of strong-motion seismometers was installed to capture on-scale recordings in the epicentral regions of large earthquakes.

J.H. Hodgson's 1956 seismic zoning map and, subsequently, Milne and Davenport's (1969) research on seismic hazard led, using data from this early network, to the development of Canada's first probabilistic hazard map (Whitham *et al.*, 1970), which was incorporated into the National Building Code of Canada in 1970. Updated editions have been produced as the network has developed.

The first digital stations were deployed in the mid-1970s. The number of stations slowly grew during the 1980s as telemetered seismic networks were developed in eastern and western Canada. The Eastern Canadian Telemetered Network (ECTN) and the Western Canadian Telemetered Network (WCTN) provided denser deployments of stations in areas of high seismicity and greater population density: the St Lawrence River valley region in southeastern Ontario and southwestern Quebec and along the Cascadia margin in southwestern BC. These networks were among the first true digital seismograph networks, as they had the digitizers sited at the seismic stations.

By 1985 the station coverage in southwestern BC was sufficiently dense that the number of earthquakes being routinely located in western Canada was increased significantly. In a later development, the early 1990s saw the first seismic data being transmitted by satellite in Canada. Today GSC operates 78 short-period sites, 285 broadband sites and 113 strong-motion (accelerometer) sites.

The Canadian Seismic Catalogue reflects the development of the main seismic network and the smaller sub-networks. This catalogue includes several historic earthquakes in the pre-1900s, several earthquakes in the late 1800s and 1900s located from phase reports from the sparse analogue seismic network in Canada and international phase reports, and then the greatly increased numbers of earthquakes at lower thresholds since the 1970s that were located using the significantly increased number of seismic stations and digital waveform technologies. As a result the level of catalogue completeness varies over time and space.

This combined catalogue has been corrected to M_w equivalent magnitudes and forms the basis for seismic zoning maps for the current 2015 National Building Code of Canada (NBCC). Research is also being carried out to understand the properties of earthquakes in various regions of Canada to improve and provide further advances in seismic provisions of the building code.

Current research using the GSC network includes studies of seismic tremor in the subduction zone along the west coast of Canada, investigations into Canadian tectonic plate margins and significant events such as the recent M_w 7.8 Haida Gwaii earthquake therein, the mechanics of oil and gas “fracking” and many other research activities such as investigations into temporal changes of earthquake characteristics.

5.1.4 Seismic Station Network and Waveform Data

GSC shares real-time waveform data with other co-operating agencies that have instruments sited in Canada: Canadian Universities, Plate Boundary Observatory (PB), Oceans Network Canada (NV) and USArray (TA); and with adjoining network neighbours: Alaska (AK), Washington (UW), Montana (MN), New York and New England (LD). GSC archives data for the Canadian Universities. GSC also offers assistance internationally to study earthquakes in other countries such as recently in Haiti, and Canada hosts several monitoring stations of the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO).

In a separate development, the Polaris Consortium was a collaborative project between Natural Resources Canada (NRCan), industry and universities conceived in 2000 and ending in 2014. Key Polaris stations have now been integrated into the Canadian National Seismic Network (CN) but with a number of the stations retaining their original network code (PO).

Currently the Canadian National Seismic Network (Figures 5.2 and 5.3) consists of a variety of instrument types from various manufacturers. Short-period seismometers include Teledyne-Geotech S13 and Mark Products L4 instruments. Broadband seismometers include Guralp CMG-3T, CMG-ESP, CMG-40T, Nanometrics Trillium and a few Streckeisen STS-1 instruments. Digitizers and data-loggers are a combination of GSC Geophysical Digitizers (spd, gd1, and gd2) and Nanometrics Taurus and Trident systems. The recent upgrade of the Yellowknife array included the installation of Guralp DM24 instruments.

The GSC Geophysical Digitizer was designed and built in-house in the late 1980s and early 1990s. It has since had one major upgrade, to gd2, primarily to provide greater sampling rates and to fulfil CTBTO IMS requirements. Currently the majority of the network stations sample at 100 samples/s but some gd1-based broadband stations sample at 40 samples/s. These ditgitizer/data-logger systems send CNSN-format packets that are archived to disc in CA-format files. Historically these CA-format files were 30-minute network-multiplexed files.

As of 2012 the waveform archive has been transitioned to one-channel-per-day files in CA-format. The purchase of the BRTT Antelope software package in 2005 now allows archiving in miniSEED format. Future plans involve converting the whole waveform archive to miniSEED format. Legacy software still requiring CA-format data is gradually being modified to work with the standard SEED or miniSEED data format now generally used by the seismological community.

Canada also has one teleseismic array and two smaller research arrays. The seismic array at Yellowknife in the Northwest Territories, NWT, was built by the British in the early 1960s. In 1962 responsibility for this medium-aperture array was transferred to the operators of the Canadian National Seismic Network, at that time the Department of Energy, Mines and Resources. The Yellowknife array is a 25 x 25 km cross-array of short-period (S13) seismometers together with a few broadband instruments and it is co-located with an infrasonic array.

Recently a compact PISA network of six seismometers was installed in 2010 near Sidney, BC, within an area of about one-square-kilometre for detection and location of seismic tremor at the subduction plate interface. In 2013 a local network of seismometers was installed in northern BC in conjunction with the Oil and Gas Commission to monitor fracking and in 2014 another local network was installed near Kitimat, BC, to monitor seismicity along a developing oil pipeline and shipping route.

Of the strong-motion sites, 113 have GSC internet accelerometer (IA) systems that calculate and send PGA, PGV, PGD and kSI parameters (for peak ground acceleration, velocity, displacement and spectral intensity measurements). These systems can store approximately 36 hours of data. In the advent of an earthquake, waveform data are requested and downloaded from the storage systems via the internet using in-house "JIA" software. Software providing an interface to the Antelope processing system is available in the Antelope contributed-data repository. The IA systems sample at 100 samples/s and communication channels are provided by combinations of internet, radio and satellite links. An additional 23 Kinemetrics Etna accelerographs in eastern Canada are triggered locally for events and record at 200 samples/s to local storage.

5.1.5 Data Processing

Digital data acquisition and exchange is organised using the BRTT Antelope system and the Nanometrics Apollo system. The seismic data are processed using legacy in-house software and the *genloc* location program (Pavlis *et al.*, 2004) via the BRTT *dbloc2* software package. GSC is currently moving all the seismic data processing to the BRTT Antelope system, though automatic locations are still determined using various systems. GSC is now also merging the systems used in the eastern and western offices to provide a uniform event processing system for Canada.

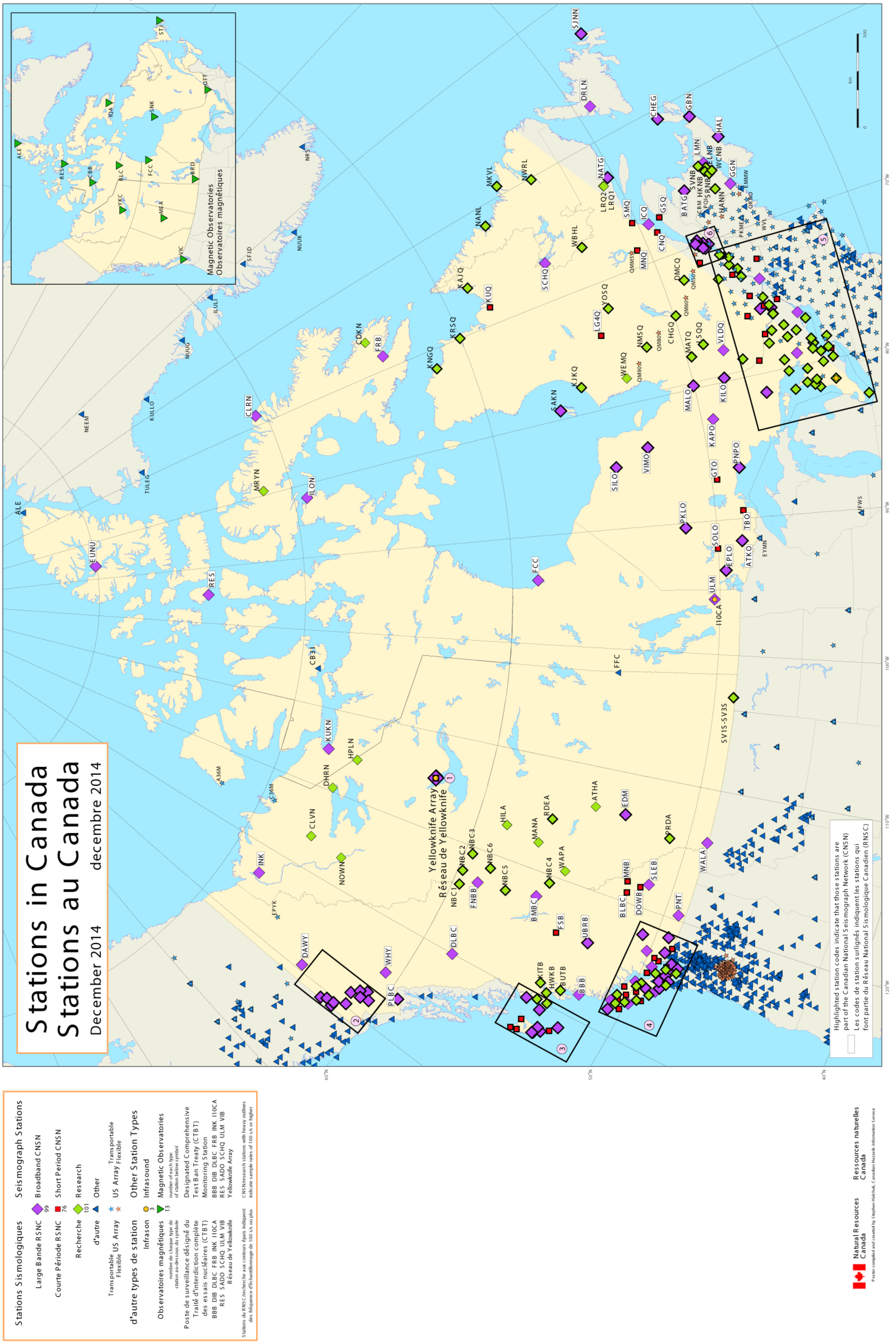

Figure 5.2: Overview of the Canadian seismic network and other contributing stations

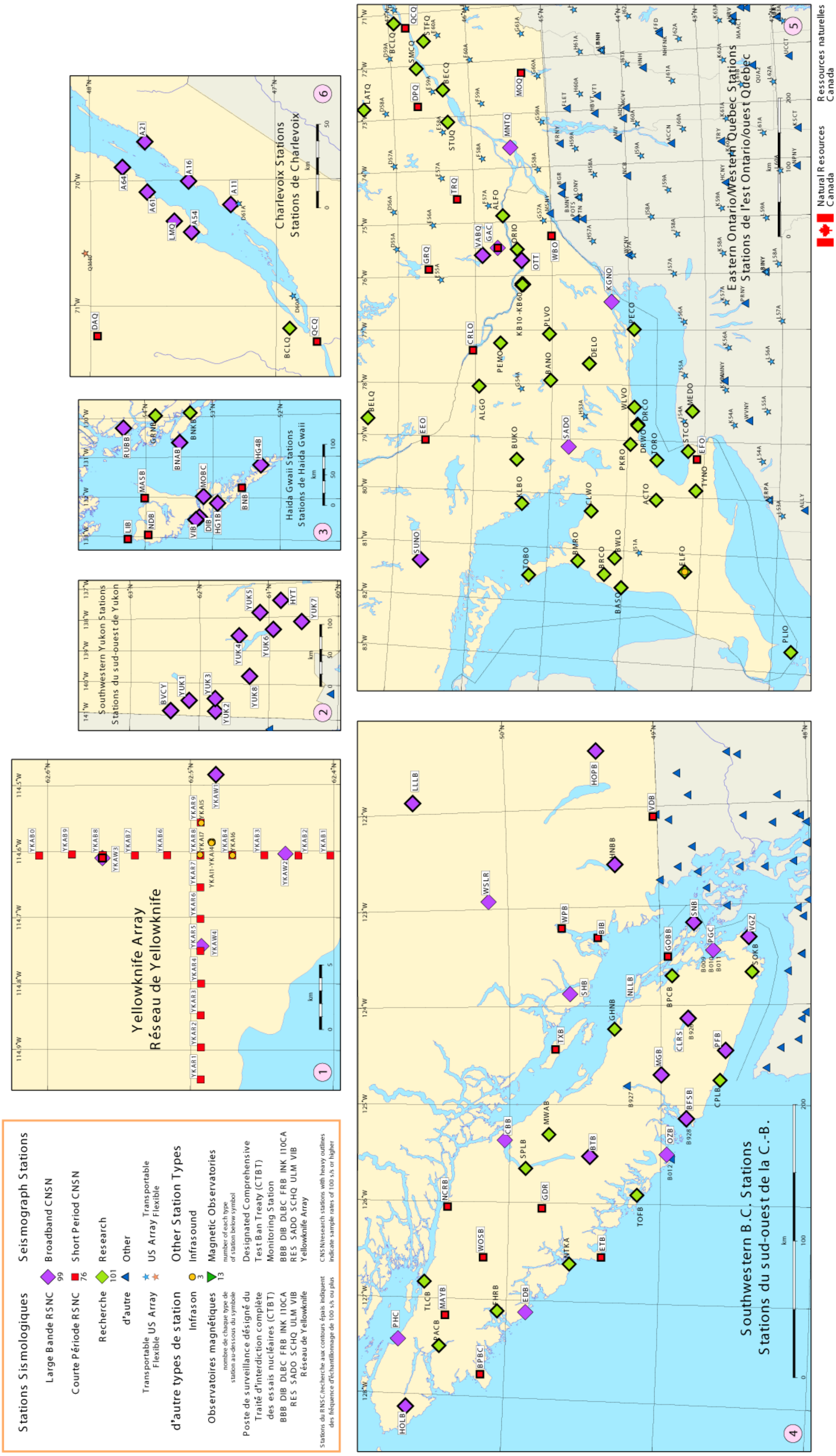

***Figure 5.3:** Details of Canadian sub-networks and other contributing stations*

Dataflow: Automatic Locations and Significant Event Notifications

For eastern Canada (Ottawa data-centre), software developed in-house by GSC is used. Detections are generated based on FFT frequency-band filtering of waveform packets. Four short-term-average/long-term-average (STA/LTA) frequency bands filter the summed power of each packet in the selected frequency bands in the FFT output. These detections are passed to the *Autoloc* processing software that generates automatic event locations. These *Autoloc* solutions are used for event alert purposes: the *Aneas* software package uses the *Autoloc* solutions to send out notifications, based on client criteria, to individual clients. Clients are notified by email, ftp, scp, fax, SMS or digital paging devices.

The STA/LTA detections are also passed to the ULF detection system. This system presents screened detections to analysts wherein waveforms are analysed by frequency, amplitude and coda shape to distinguish real-events from noise. This generates a daily ULF event-list, which drives the analyst processing system. Analysts inspect these events using the *DAN* location program. Noise detections are discarded and real events are located. The final event files are saved and the location parameters are loaded into the INGRES database for the Canadian Seismic Catalogue.

For western Canada (Sidney data-centre) event notifications are determined via the Antelope real-time system. Detections are based on STA/LTA thresholds in selected frequency bands for user-determined STA and LTA window-lengths. These detections are fed into a grid associator that formulates event hypotheses and retains those with a sufficient goodness-of-fit. These locations are then fed into the *genloc* location program with the final estimated location determined using the appropriate velocity model for the region.

These real-time detections, arrivals and origin determinations are written to a database. The automatic origins also drive the routine event-analysis system. Analysts inspect the origins, adjusting the automatic phase picks and adding new phase picks for real events and locating the events with the *genloc* program via the Antelope *dbloc2* module. The final data are kept in the Antelope Datascope database and the location parameters are loaded into the INGRES database for the Canadian Seismic Catalogue.

Canadian Seismic Duty personnel (the "on-call seismologists") carry cellular phones, by which they receive automatic locations from the above mentioned sources as well as from the United States Geological Survey (USGS) and the West Coast and Atlantic Tsunami Warning Center (WCATWC). Duty personnel are on duty for one week at a time and are available on an on-call (24/7) basis. Six duty personnel are mandated for rotating on-call duty at the Ottawa office and at the Sidney office. However, due to staffing shortages, it is not currently possible to maintain this complement of duty personnel. Details of earthquakes of magnitude four or more and all felt events are posted on the website soon after the event occurrences and significant event notices are sent to media and emergency response organisations as required.

Event Analysis – Seismic Catalogue

Events of magnitude 3.5 or more in the Canadian Seismic Catalogue were indicated in Figure 5.1, which showed the virtually aseismic region though the centre of Canada extending from the north-northwest to the south. Although estimations of the event locations and magnitudes are determined at the two data centres, west in Sidney and east in Ottawa, the resulting analyses are combined into the unified INGRES database to produce the Canadian Seismic Catalogue.

Daily Review

Analysts at either data centre process events on a daily basis during normal office hours. The daily routine involves the discrimination of earthquakes from mining and quarry blasts and noise events. Earthquakes and a small fraction of blast events have their locations determined but noise events are discarded. The waveforms are usually scanned for a subset of stations to search for any missed events, primarily small events recorded at three or fewer stations or events where adjacent recording stations are not yet incorporated into the automatic processing.

Monthly Review

Historically the monthly event review involves several tasks: checking for events above the completeness level for the seismic subregion but missing from the catalogue; maintaining consistency of the velocity models and event locations within those subregions based on defining stations and their distances from the hypocentral estimates; assessing general database health; and ensuring that event types are properly assigned.

Due to declining staff levels and the increasing numbers of stations that increase the workload, the analyst monthly review has regrettably languished over recent years. Some of these tasks are nevertheless accomplished using automatic database checks or by the increased diligence of analysts during the daily review. Furthermore, in-house research provides feedback on the state of the catalogue and the yearly reviews of the annual seismicity map and for seismic hazard provide valuable opportunities to address potential issues in the catalogue.

5.1.6 Magnitudes

The following magnitude types used in the Canadian Seismic Catalogue are listed below together with a short description of their domains:

M_L – western and northern Canada; select small events in eastern Canada for which mN cannot be calculated

$M_{L(Sn)}$ – offshore Vancouver Island, British Columbia, and offshore from the Atlantic coast

m_{bLg} – historically used for events in the Rocky Mountains and Alberta

m_N – eastern Canada.

M_S – teleseismic surface-wave determinations

M_w – events $>$ 3.5 - 4.0 Canada-wide, determined by interactive modelling of waveforms

Estimated M_w (M_w') – for events offshore from south-western Canada – a correction is applied to the $M_{L(Sn)}$ value obtained for these events, based on Risteau *et al.*, 2007

5.1.7 Data Availability

Data and resource material are available through the NRCan website:

http://www.earthquakescanada.nrcan.gc.ca

5.1.8 References

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