

**SEISMIC HAZARD, FAULTS AND EARTHQUAKES  
DIGBY NECK, BAY OF FUNDY**

**Prepared by**

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(a) H model; (b) R model. ACM, Arctic Continental Margin; CASR, Cascade Mountains; CHV, Charlevoix; ECM, Eastern Continental Margin; IRM, Iapetan Rifted Margin; NAT, Niagara–Attica. From Adams and Atikson, (2003).

## Introduction

This report provides an assessment of the seismic hazard for the area of the proposed basalt quarry and marine terminal on Digby Neck as well as the regional and local distribution of faults and earthquakes. Within Canada, the Bay of Fundy area occurs within the Northern Appalachian Seismic Zone (NAN). Figure 1 below shows the historical seismicity in eastern Canada and Figure 2 is a more detailed map of the location of seismicity in NAN.

Figure 1

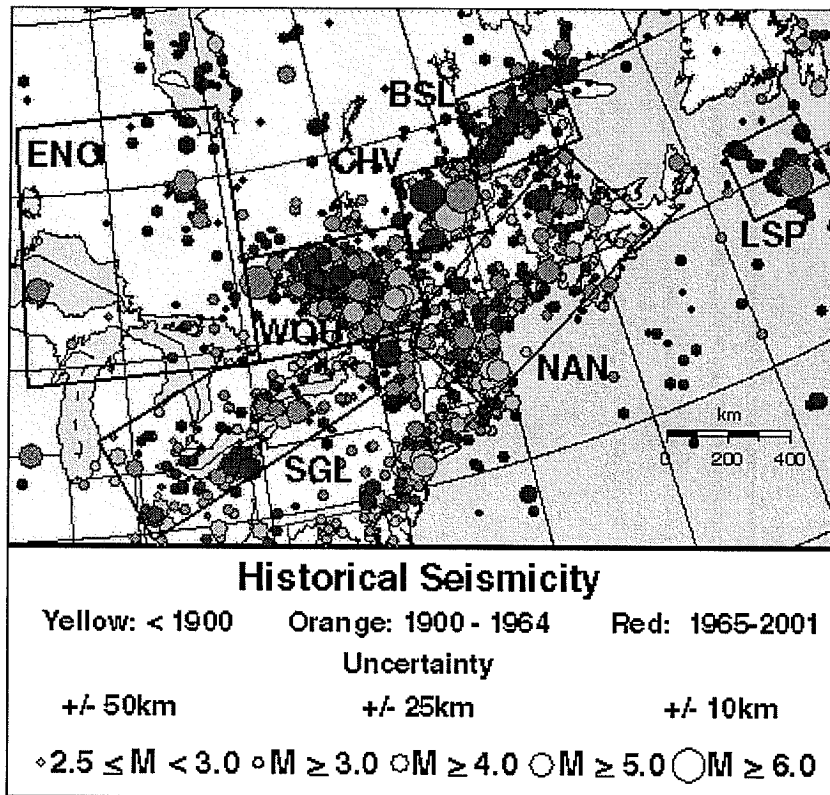


Figure 2

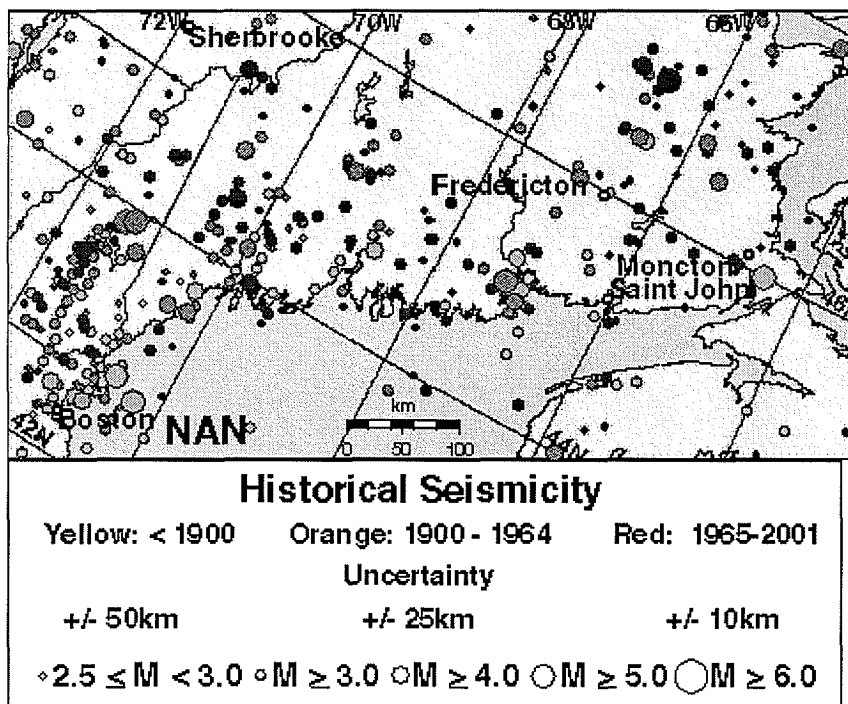


Figure 2

The Northern Appalachians Seismic Zone (NAN) includes most of New Brunswick and extends into New England. It shows the locations of a few earthquakes to the northeast of Digby with a magnitude of 3 or less. None occur on Digby Neck, Nova Scotia.

The National Building Code of Canada (1995) is the present document that provides the control on building design for various earthquake loads. A new seismic hazard model, the fourth national model for Canada, is presently being developed by the Geological Survey of Canada (Adams and Atkinson, 2005) to update Canada's current (1985) seismic hazard maps. The new proposed model incorporates data from recent earthquakes and includes a number of other improvements. This report will summarize the 1995 building code as it pertains to southeastern Canada as well as review the proposed changes for 2005.

In Canada, the evaluation of regional seismic hazard for the purposes of the National Building Code is the responsibility of the Geological Survey of Canada and this report draws from their web site and many published documents. The seismic zoning maps prepared by the Geological Survey are derived from analysis of past earthquakes and from knowledge of Canada's tectonic and geological structure. Seismic hazard is expressed as the most powerful ground motion that is expected to occur in an area for a

given probability level. Contours on the maps delineate zones likely to experience similarly strong ground motions.

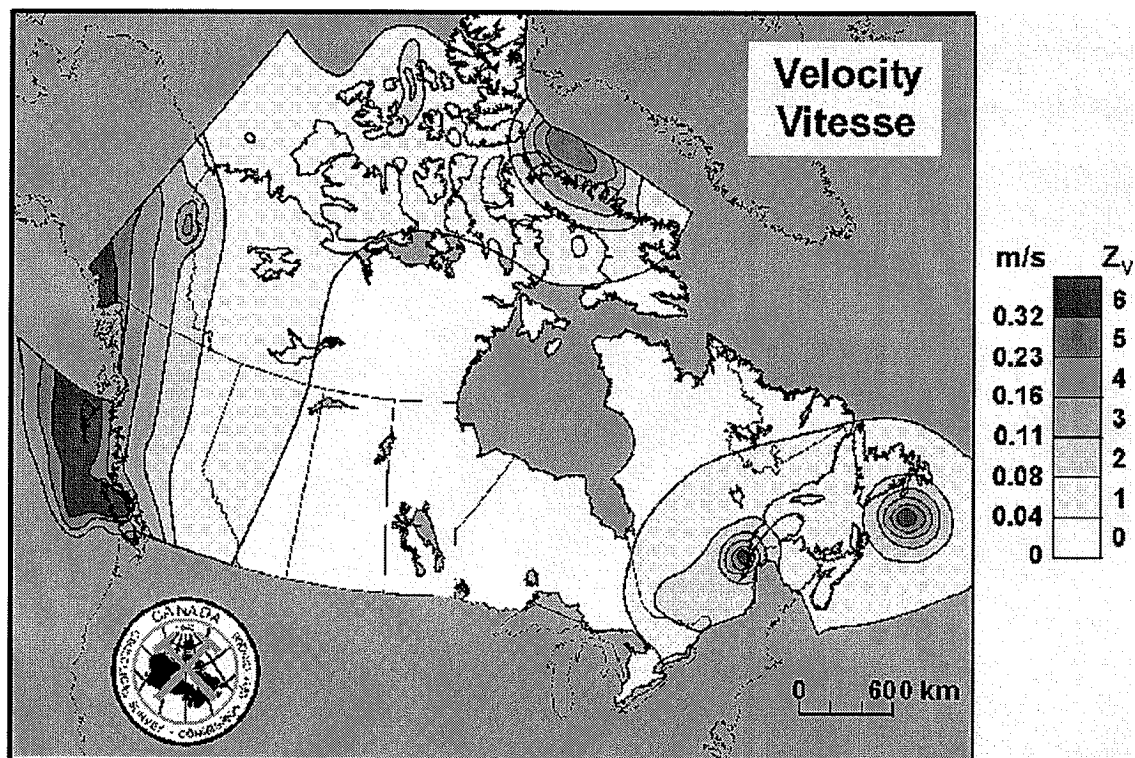
The seismic zoning maps and earthquake load guidelines included in the National Building Code are used to design and construct buildings and other structures to be as earthquake proof as possible. The provisions of the building code are intended as a minimum standard and are meant to prevent structural collapse during major earthquakes and to protect human life.

### **Seismic Hazard Information in the 1995 National Building Code**

Building design for earthquake loads is addressed in sections 4.1.9, 9.20.17 and 9.24.1.5 of the 1995 National Building Code of Canada. The seismic zoning maps are found in Chapter 4, Commentary J, Figures J-1 and J-2 of the User's Guide to the 1995 edition. In addition, a table in Appendix C starting on page 483 of the Code, provides ground motion design values for many communities across Canada. While the National Building Code is chiefly intended for new buildings (Subsection 1.2.1), appendix A (Section A-1.1.2.1) outlines the principles by which the code should also be applied to the use and modification of existing buildings.

The two seismic zoning maps each divide Canada into seven zones of ground motion. Figure 3 has been prepared on the basis of probable ground velocity and Figure 4 according to acceleration. Velocity is given in metres per second; acceleration is expressed as a fraction of gravity.

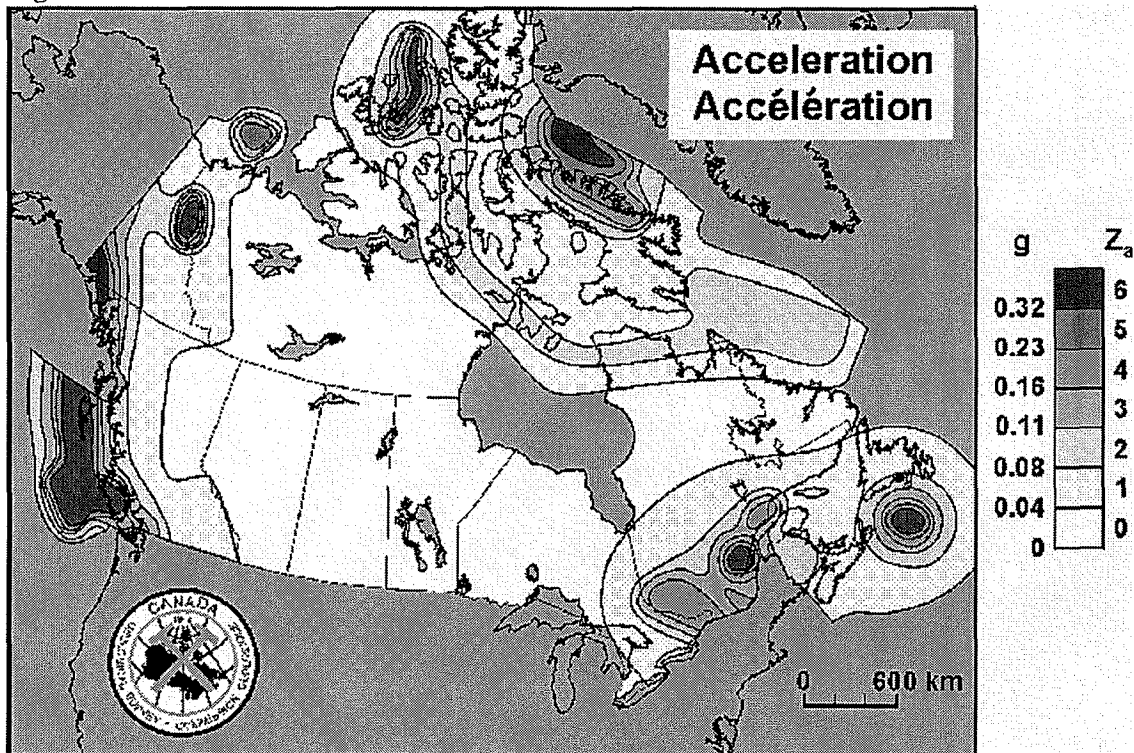
Figure 3



### Velocity Seismic Zoning Map

This map first appeared in the Supplement to the 1985 National Building code. The map is appropriate for large structures (e.g., 10-story buildings).

Figure 4



### Acceleration Seismic Zoning Map

This map first appeared in the Supplement to the 1985 National Building code. It is appropriate for small structures (e.g., 1-2 story buildings).

Ground motion probability values are given in terms of probable exceedence, that is the likelihood of a given horizontal acceleration or velocity being exceeded during a particular period. The probability used in the National Building Code is 0.0021 per annum, equivalent to a 10-per-cent probability of exceedence over 50 years. This means that over a 50-year period there is a 10-per-cent chance of an earthquake causing ground motion greater than the given expected value.

Most buildings are well-designed to withstand vertical forces, but the horizontal component of ground motion is critical to earthquake-resistant building design. In the urban areas of coastal British Columbia, for example, 20-per-cent gravity is a typical seismic load at an appropriate probability for buildings. A building, designed to tolerate a sideward pushing force equal to 20 per cent of its own weight, should prove earthquake resistant.



## **Earthquakes and Seismicity**

The area of Canada east of the Cordillera (western area), extending north from the United States to the Arctic Ocean, comprises about two-thirds of the stable craton of the North American plate. Much of this area appears to be substantially aseismic, although it contains several zones of significant seismicity and a few other regions of lower-level seismicity. The seismicity of the southern part, together with the adjacent United States, was compiled comprehensively by Smith (1962, 1966), who collected earthquake reports compiled by others, analysed original records where possible, and decided on the best location and magnitude for each earthquake. Further earthquake analysis, including spatial distribution, recurrence rates, and relationship to geological structure was modified by Basham et al. (1982). The latter paper, although the most thorough seismicity compilation to date, was compiled for an engineering seismic hazard study and the conclusions were published in Basham et al., (1985).

Using P-wave polarities, Sv/P amplitude ratios, and the program FOCMEC, the focal mechanisms of 21 recent earthquakes in southeastern Canada have been determined. The mechanisms show systematic thrust faulting throughout eastern Canada from nearly-horizontal compression. Local differences in the direction of compression and the strike of the fault planes provide valuable insights into the seismotectonics of the western Quebec, Charlevoix, Lower St Lawrence, and northern Apalachian regions.

The continual shifting of large segments of the earth's crust (called tectonic plates) causes more than 97% of the world's earthquakes. Eastern Canada is located in a stable continental region within the North American Plate and has a relatively low rate of earthquake activity. Nevertheless, large and damaging earthquakes have occurred here in the past and will inevitably occur in the future.

## **Rate of Earthquake Activity**

Approximately 300 earthquakes occur yearly in eastern Canada. Four will exceed magnitude 4, thirty will exceed magnitude 3, and about fifteen events will be reported only as felt. A decade will, on average, include three events greater than magnitude 5. A magnitude 3 event is sufficiently strong to be felt in the immediate area, and a magnitude 5 event is generally the threshold of damage. The seismograph network of the Geological Survey of Canada can detect all events exceeding magnitude 3 in eastern Canada and all events magnitude 2.5 or greater in densely populated areas.

## **Earthquake Causes**

The causes of earthquakes in eastern Canada are not well-understood. Unlike plate boundary regions where the rate and size of seismic activity is directly correlated with plate interaction, eastern Canada is part of the stable interior of the North American Plate which extends across the western Atlantic Ocean to the mid-ocean ridge. Seismic activity in these areas is thought to be related to regional stress fields, with the earthquakes concentrated in regions of crustal weakness. Although earthquakes can and

do occur throughout most of eastern Canada, years of instrumental recordings have identified clusters of earthquake activity.

### **Calculation of Seismic Hazard**

The seismic hazard for a given site is determined from numerous factors. Canada is divided into earthquake source regions based on past earthquake activity and tectonic structure. The relationship between earthquake magnitude and the average rate of occurrence for each region is weighed, along with variations in the attenuation of ground motion with distance.

The acceleration and velocity seismic zoning maps show levels of ground shaking over different frequency ranges: centred near 5 hertz (oscillations per second) for the acceleration map and near 1 hertz for the velocity map. This is important because different buildings are susceptible to different frequencies of earth motion, and damage is frequently associated with a resonance between earthquake ground motion and the building's own natural frequency. Low brick buildings for example can be severely damaged by a moderate (magnitude 5.5) local earthquake that has most of its energy in the high-frequency range. High-rises may be affected more acutely by larger, more distant sources. In building construction and design, not only the size of a probable earthquake should be considered, but also the nature of the ground motion most likely to occur at the site. Seismic hazard calculations provide part of this information. As the understanding of earthquakes and of their effects on engineered structures continues to develop, the seismic provisions of the National Building Code are revised to enhance public safety and minimize earthquake losses.

### **Proposed 2005 National Building Code of Canada**

A new seismic hazard model, the fourth national model for Canada, has been devised by the Geological Survey of Canada (Adams and Atkinson, 2005) to update Canada's current (1985) seismic hazard maps. The model incorporates new knowledge from recent earthquakes, new strong ground motion relations to describe how shaking varies with magnitude and distance, the newly recognized hazard from western Canadian Cascadia subduction earthquakes, and a more systematic approach to reference site conditions. Other new innovations are hazard computation at the 2% in 50 year probability level, the use of the median ground motions, the presentation of results as uniform hazard spectra, and the explicit incorporation of uncertainty via a logic-tree approach. These new results provide a more reliable basis for characterizing seismic hazard across Canada and have been approved by the Canadian National Committee on Earthquake Engineering (CANCEE) as the basis of the seismic loads in the proposed 2005 edition of the National Building Code of Canada.

The seismic hazard maps in the current NBCC (1995) were developed in the early 1980s. Since that time, there have been significant advances in our understanding of seismicity (Fig. 1) and ground motions in Canada and corresponding advances in methodologies to assess seismic hazard. The following is a discussion of the advances

and how they have shaped the new seismic hazard maps intended for use in the proposed 2005 edition of the NBCC extracted from Adams and Atkinson (2005).

Seismic hazard analysis has been an element of good engineering design practice through the NBCC for many decades. Since 1970, seismic hazard maps have been developed for building code applications based on a probabilistic approach. The current code maps were developed using the well-known Cornell–McGuire probabilistic approach (Cornell 1968; McGuire 1976; Basham et al. 1982, 1985). In this method, the spatial distribution of earthquakes is described by seismic source zones, which may be either areas or faults; the source zones are defined based on seismotectonic information. The spatial distribution of earthquakes within each source is assumed to be random (i.e., uniformly distributed), and the temporal distribution of events as a function of magnitude is specified from historical seismicity supplemented by geologic or geodesic data where practicable. The exponential relation of Gutenberg and Richter (Richter 1958), asymptotic to an upper bound magnitude ( $M_x$ ), is used to describe the magnitude–recurrence statistics. Magnitude ( $M$ ) in this work is intended to be equivalent to moment magnitude, the standard measure of earthquake size and the magnitude type used in most strong ground motion relations. An alternative magnitude scale,  $mbLg$ , is used for eastern earthquakes and then converted to moment magnitude using an empirical relationship (Atkinson and Boore 1995). The link between earthquake occurrence within a zone and ground motions experienced at a site is provided by ground motion relations. These are equations specifying the median (50th percentile) amplitude of a ground motion parameter, such as peak ground acceleration (PGA) or spectral acceleration ( $S_a(T)$ , where  $T$  is the period in seconds), as a function of earthquake magnitude and distance, and the distribution of ground motion amplitudes about the median value (i.e., variability). To compute the probability of exceeding a specified ground motion amplitude at a site, hazard contributions are integrated over all magnitudes and distances, for all source zones, according to the total probability theorem (in practice, sensible limits are placed on the integration range for computational efficiency). Calculations are performed for a number of ground motion amplitudes, and interpolation is used to find the ground motions associated with the chosen probability levels. The basic procedures are described by the EERI Committee on Seismic Risk (1989) and the NRC Committee on Seismology (1988). Because of its ability to incorporate both seismicity and geologic information, the Cornell–McGuire method is the most widely used seismic hazard evaluation technique in North America and perhaps the world.

Another important change in the new maps is the lowering of the probability level from 10% in 50 years (0.002 per annum) to 2% in 50 years (0.000404 per annum) (Adams et al. 1999). This change was motivated by studies over the last 10–20 years that have shown that the best way to achieve uniform reliability across the country is by basing the seismic design on amplitudes that have a probability close to the target reliability level (Whitman 1990).

## **Seismic source parameters**

### **Source models for Canada**

The 1985 hazard maps described the distribution of seismicity using a single set of seismic source zones. Since then, two decades of additional knowledge about earthquakes have revealed clearer epicentre patterns in some places but “unexpected” events in others. This has led to a better understanding of the seismotectonics behind the seismicity, but also an appreciation that much is unknown about how the future pattern of seismicity will resemble or differ from the historical pattern. For eastern Canada, the credible range of models was represented by two philosophically distinct probabilistic models: the H (historical seismicity) model uses relatively small source zones drawn around historical seismicity clusters, whereas the R (regional) model establishes larger, regional zones (Fig 5).

In eastern Canada, the R model often combines a number of seismicity clusters that are inferred to have a common cause into large source zones, the larger of which are the Arctic Continental Margin (ACM), the Eastern Continental Margin (ECM), and the Iapetan Rifted Margin (IRM). For each, the R model zone implies that currently aseismic regions between adjacent seismicity clusters (e.g., the St. Lawrence valley near Trois-Rivières) are capable of large earthquakes. Over the long run, the rate of activity along these extensive tectonic zones (e.g., at any place along the continental margin) may be constant; the current seismicity “hot spots” may be just a temporary clustering, speculatively representing prolonged aftershock sequences.

Contour maps of hazard computed using the R model have long “ridges” of moderate hazard and lack the “bull’s eyes” of high hazard produced by the H model (and that exist in the 1985 maps). If only the R model hazard were implemented in a building code, it would reduce the seismic protection significantly in regions of high historical seismicity while increasing protection only slightly in other places. A probabilistic combination of the two models would involve their weighted sum, but any weight given to the R model would reduce the protection in regions of high historical seismicity. This dilemma is addressed by performing calculations for both models, then adopting the more conservative result, the so-called “robust” approach, as described.

### **Strong Ground Motion Relations**

Ground motion relations are a key component of any seismic hazard model, as they control the amplitudes of motion predicted for any magnitude and distance. No matter how accurate the seismotectonic source models, the reliability of the final hazard values is highly dependent on the reliability of the strong motion relations and on the extrapolations within them, as observational data from large earthquakes in Canada are sparse. The different physical properties of the crust in eastern and western Canada require the use of separate strong ground motion relations for different regions, as was the case for the 1985 maps, which used the eastern and western relations of Hasegawa et al. (1981).

### **Eastern Canada**

For eastern Canada, ground motion relations are a major source of uncertainty in seismic hazard estimation because of the paucity of observations in the magnitude–

distance range of engineering interest. Consequently, eastern ground motion relations may change significantly as new events are recorded. For example, the recordings of the 1988 Saguenay earthquake caused ground motion modellers to revise their prior relationships to account for its unexpectedly large short-period motions. Deliberations of the Senior Seismic Hazard Analysis Committee (SSHAC) suggested an emerging consensus. On that basis the GSC adopted a suite of relationships with their aleatory uncertainty (the base relations of Atkinson and Boore 1995), and their epistemic uncertainty (Atkinson 1995), consistent with that consensus (Adams and Atkinson, 2005). These represent the available published ground motion relationships, but there is considerable controversy in this field (Atkinson and Boore 1997, 2000a). The Atkinson–Boore suite of relationships was derived to fit observational data on hard-rock seismometer sites and so needs adjustment to represent the ground motions on the “firm ground” reference ground condition chosen for Canada .

#### **Summary of the New Seismic Hazard model**

The seismic hazard results generated from a new national model will provide a more reliable basis for seismic design of new buildings across Canada. They provide an updated depiction of hazard across Canada, including its variability with spectral period. The spectral parameters used will describe the expected shaking better than the peak motion parameters used in the 1995 NBCC. Understanding of the new results will be aided by new ways of presenting the information, such as deaggregation. The model is planned to be released in late 2005.

#### **Earthquakes In New Brunswick**

A summary of the historical earthquake activity in the province of New Brunswick is extracted from a report by Burke, (2005). The first recorded account of an earthquake in New Brunswick is from the *Royal Gazette* published in Halifax, on December 13th, 1764, "We hear from St John's (Saint John) in this province that on the 30th of September last, about 12 o'clock noon, that a very severe shock of an earthquake was felt there". Since then many hundreds of earthquakes have been reported or recorded in the province. In fact, most of New Brunswick lies within the Northern Appalachian Zone (NAN), as shown on the map of earthquakes in Eastern Canada and has experienced several earthquakes in the magnitude 5 to 6 range. The exception is the northwestern part of the province with a few smaller magnitude earthquakes, which lies within the Eastern Background Zone. New Brunswick has also felt the effects of larger events from the Charlevoix-Kamouraska Zone, Lower St. Lawrence Zone and the Laurentian Slope Zone.

A more detailed map of the Northern Appalachian Zone shows epicentres distributed throughout New England and New Brunswick. Epicentres for many of the twentieth century earthquakes have been determined from the analysis of seismograph records, but some of the lower magnitude events and the pre-1900 events have been assigned epicentres based on historical accounts in newspapers and journals. Reports of effects of the earthquakes in different communities allow Modified Mercalli intensity values to be determined and an isoseismal map can then be constructed. The epicentre is chosen to be at the place where the most severe effects are felt, or at the centre of the felt area, if only limited information is available. Magnitude values can be calculated from

the felt area (Nuttli and Zollweg, 1974 and Street and Lacroix, 1979), the area contained within the IV isoseismal, (Street and Turcotte, 1977) or a combination of intensity and felt areas (Sibol *et al.*, 1987).

In New Brunswick, epicentres cluster in three regions (Burke, 1984); Passamaquoddy Bay region, Central Highlands (Miramichi) region, and the Moncton region. Earthquakes have been more frequent in these regions and sometimes of a size to be potentially damaging (larger than magnitude 5).

### **Passamaquoddy Bay Region.**

Since the Passamaquoddy region is the area with the largest reported earthquakes closest to the Digby Neck area of Nova Scotia it is important to assess the nature of seismic activity in that region. Passamaquoddy Bay was identified as a seismically active region by Barosh (1981), who stated that more than 50 earthquakes had been reported from the area since 1870. He reports that after a network of seismograph stations was installed in southeastern Maine in 1975, an average of 7 earthquakes per year had been recorded with a magnitude range of 1 to 3.2. A search of the Canadian National Seismological Database for dates between 1800 and October 1, 1999 found 77 earthquakes for the region (44.5°N to 45.5°N; 66.5°W to 67.5°W). Twelve unlisted events found by scanning of local newspapers await evaluation for inclusion in the database (Burke *et al.*, 1987 and Burke and Comeau, 1988).

The largest historically reported event in this region was in the early morning hours (2:04 a.m. local time) on March 21st, 1904, when a strong earthquake was felt throughout the Maritime Provinces, the St Lawrence Lowlands and the New England states. Minor damage to buildings was reported from several communities along the coasts of New Brunswick and Maine and chimneys were thrown down at St Stephen in southwestern New Brunswick and Eastport in southeastern Maine. Using the area within the IV isoseismal, Leblanc and Burke (1985) estimated a felt area IV magnitude of 5.9, although there is a lack of intensity information from the Atlantic Ocean to the south. However, the earthquake has been given a magnitude of  $m_N = 5.9$  in the Canadian National Seismological Database. A possible foreshock was reported felt from Camden in southern Maine at midnight on March 20th, 1904 (*Camden Herald*, March 25th, 1904) and aftershocks reported felt at Bar Harbour in southern Maine and Fredericton in central New Brunswick at 5 am (local time) on March 21st, 1904. (*Bar Harbour Record*, March 23rd, 1904 and *Daily Herald*, March 21st, 1904). There is also a report of several aftershocks being felt at West Gouldsboro, on the southern coast of Maine, in the days following the earthquake (*Bar Harbour Record*, March 30, 1904). These reports of a foreshock and aftershocks from widespread communities are not too useful in pinpointing an epicentre for this earthquake, but the activity confirms that a sizeable main shock occurred. Smith's estimate of the epicentre at 45.0°N, 67.2°W, based on the location of the strongest intensities (Smith, 1962), is the epicentre adopted in the Canadian National Seismological Database.

An earthquake at 5:45 am (local time) on October 22<sup>nd</sup>, 1869 was found to have a similar isoseismal map to the 1904 earthquake. This earthquake was relocated to Passamaquoddy Bay and given a magnitude of 5.7 based on the area within the IV isoseismal by Leblanc and Burke, (1985). It has now been assigned an epicentre of 45.0°N, 67.2°W and a magnitude of  $m_N = 5.7$  in the Canadian National Seismological Database. Minor damage to chimneys and walls were reported from a widespread distribution of communities; e.g. Eastport in southeastern Maine, Fredericton and Woodstock in central New Brunswick, Newcastle (Miramichi City) in northern New Brunswick and Saint John, along the southern coast of New Brunswick. This wider distribution of masonry damage than with the 1904 event probably reflects the poorer construction practices and state of repair in the nineteenth century. Damage and changes to spring water flow at more northerly locations, e.g. Newcastle (Miramichi City), suggest the possibility of an epicentre in the Central Highlands (Leblanc and Burke, 1985). This idea is also supported by reports of possible aftershock activity felt in the Fredericton area and possible foreshocks felt in the Tobique valley, in northwestern New Brunswick, (from a letter to the editor in the October 30, 1869 issue of the *Carlton Sentinel* " .....It is said by some that there was a shock some six hours previous to the one spoken of, and also another on Friday noon, but they were slight.) The similarity of the isoseismal map of the 1869 earthquake to that of the 1904 earthquake is strong evidence of this being a Passamaquoddy Bay event.

A May 22<sup>nd</sup>, 1817 event was for many years assigned to a central Maine location, but a study of newspaper and journal accounts by Leblanc and Burke (1985) clearly identifies this as another Passamaquoddy Bay earthquake. The same study assigned a magnitude between 4.5 and 5 based on the area enclosed within the IV isoseismal. This earthquake is now listed at an epicentral position of 45.0°N, 67.2°W and given a magnitude of  $m_N = 4.8$  in the Canadian National Seismological Database. Newspapers and diaries of the day gave accounts of violent shaking of houses from Calais in southern Maine, Grand Manan Island in the Bay of Fundy and St Stephen in southwestern New Brunswick, but no damage was reported. An interesting reference to this earthquake was found recently in a collection of letters from the 1780s to 1830s, purchased by the University of New Brunswick from a Sotheby's auction in London in 1994 (Kathryn Hilder, personal communication, June 20th, 1994). This was in a letter from a Jane Moore, who was living in St Mary's, then a small community just north of Fredericton, written on June 3rd, 1817 to her sister, Elizabeth Moore, in New Town, New York "*I was very much alarmed a few nights ago at the shock of an earthquake it awoke me out of a soun(sic) sleep when I found the house and bed where I slept in the most violent motion it appeared to rock as if it was upon rockers it lasted however but a short time*".

Plots of epicentres on a geological map of the Passamaquoddy Bay region in the 1970s suggested that earthquake activity might be related to movement on the Oak Bay Fault (Rast *et al.*, 1979). This north to northwest trending fault offsets Silurian and Devonian rock units with areg ional strike direction of northeast and shows a major discontinuity in aeromagnetic and gravity contours associated with these units. However, a Triassic dyke that crosses the fault in the St Croix River is not offset by the Oak Bay Fault, showing that there has been no recent movement along the fault, (Burke and

Stringer, 1993). Glacial striations checked at twenty-four locations showed no sign of postglacial displacement and no disturbances of Quaternary sediments were found along the faults examined on land. However, a marine geophysical survey, in 1988, did map pockmarks (gas escape craters) and plumose structures (linear erosional features) on the bottom of Passamaquoddy Bay and the northwestern alignment of some of the pockmarks (pockmark chains) may be associated with northwest trending faults (Pecore and Fader, 1990). Recent movement along these faults may have allowed the release of gas that created the pockmarks in the soft sediments. Other workers have related the earthquake activity to a general subsidence of Passamaquoddy Bay with accompanying minor movements on the faults in the area, (Barosh, 1981).

### **Faulting in the Bay of Fundy Region**

The most widespread and significant fault or fault zone in the Bay of Fundy region is a westward extension of the Chedabucto-Cobequid fault system in Nova Scotia. It is part of a much larger transform fault system that extends from the Grand Manan area of the Bay of Fundy, north of Minas Basin, across Nova Scotia, through Chedabucto Bay to the Laurentian Channel. The name "Glooscap Fault System" has been proposed for this system (King and MacLean, 1976). They further proposed that it might join with the Newfoundland fracture zone in deep water to the east and involve oceanic crust in this area. The fault system is essentially Triassic and earlier in age but there is evidence for additional faulting in Cretaceous time and perhaps recent activity on the eastern Scotian Shelf and in the adjacent Laurentian Channel. Map 812H (King and Maclean, 1976) shows the distribution of faults of the Glooscap Fault System in the Bay of Fundy. It consists of a linear continuous – discontinuous fault that extends from Ile Haut in the east, westerly to a few kilometers off the coast of New Brunswick at Cape Spencer where it changes direction and continues southwesterly to Grand Manan. There it joins a series of other faults bordering pre-Pennsylvanian acoustic basement. North of this western area of the fault, the Triassic sediments are structurally disturbed in a broad zone that continues to the Passamaquoddy Bay region in the north. As reported in King and MacLean 1976, in the disturbed zone the aeromagnetic data shows considerable variation in contrast to the typically smooth signature of the Triassic rocks through the remainder of the basin.

Fader (1989) conducted a high-resolution seismic reflection survey over the northern part of the disturbed zone to determine if any of the faults had affected the Quaternary overlying sediments in order to assess recent activity. The faulted Triassic sediment is overlain by thick glaciomarine stratified sediments that would record any activity on the faults below. The survey showed that the overlying sediments were not disturbed in any way indicating no activity of the faults over the past 15 – 18 000 years. This is contrast to the eastern Scotian Shelf where north of Banquereau, both glaciomarine Emerald Silt and LaHave Clay Holocene sediments are faulted and contorted along the same fault system.

The closest mapped faults to Digby Neck are a series of oblique short faults that offset the basalt ridge of North Mountain along its length. These occur in Digby Gut, on



Digby Neck and between Digby Neck, Long and Brier Islands. They do not extend into the Triassic sediments that occur a few km offshore and are interpreted to be inactive (Map 812H). Most of these faults are associated with offsets in the trend of North Mountain. Later erosion appears to have removed considerable basalt from these offsets and has resulted in the location of coves and or flooded marine passages.

**Whites Point Site Assessment**

At the request of the quarry developers an assessment of the site has been evaluated against the 1995 National Building Code of Canada by the Geological Survey of Canada. Provisional 2005 NBCC values for the site have also been provided although these values are intended to form the basis of the 2005 edition of the National Building Code of Canada, they have yet to be formally adopted and are subject to change. The next National Building Code of Canada is expected to be adopted in the third quarter of 2005. Peak and spectral hazard values are determined for an exceedence of 2%/50 years. Values are for "firm ground" (NBCC 2005 soil class C - average shear wave velocity 360-750 m/s). Median (50th percentile) values are given in units of g for peak horizontal and 5% damped spectral horizontal acceleration.

Latitude N and Longitude W are latitude (decimal degrees North) and longitude (decimal degrees West), respectively. Peak Ground Acceleration (PGA) and spectral acceleration (Sa(T), where T is the period in seconds) values are tabulated.

Located at 44.43 North 66.20 West

**Zoning for Above Site**

Acceleration zone	Za = 1	Zonal acceleration	0.05 g
Velocity zone	Zv = 1	Zonal velocity	0.05 m/s

**Ground motions for selected probability levels for above site**

Probability of exceedence per annum	0.010	0.005	0.0021	0.001
Probability of exceedence in 50 years	40%	22%	10%	5%
Peak horizontal ground acceleration (g)	0.036	0.050	0.075	0.099
Peak horizontal ground velocity (m/s)	0.017	0.030	0.054	0.084

**1995 NBCC seismic zones  
probability level: 10% in 50 years**

g or m/s	0.00	0.04	0.08	0.11	0.16	0.23	0.32
ZONE	0	1	2	3	4	5	6*
zonal value	0.00	0.05	0.10	0.15	0.20	0.30	0.40

\* zone 6: nominal value 0.40;  
site-specific studies suggested for important projects

**Proposed 2005 National Building Code of Canada hazard values**

Site values at a probability of 0.000404 p.a.  
50th PERCENTILE values tabulated  
Lat N Lon W Sa(0.2) Sa(0.5) Sa(1.0) Sa(2.0) PGA  
44.433 66.200 0.298 0.153 0.073 0.022 0.165

The Geological Survey of Canada discourages the use of the "peak horizontal ground acceleration" measure of hazard and suggests using the spectral parameter most relevant to the period of the proposed facility. The proposed 2005 seismic hazard values should not be used with the 1995 NBCC.

**Summary and Conclusions**

Seismic zoning maps for Canada are derived from analysis of past earthquakes, and from advancing knowledge of Canada's tectonic and geological structure. Canada is divided into earthquake source regions based on past earthquake activity and tectonic structure. The relation between earthquake magnitude and the average rate of occurrence for each region is considered, along with variations in the attenuation of ground motion with distance. In calculating seismic hazard, scientists consider all earthquake source regions within a relevant distance of the proposed site. In the building code there are two seismic zoning maps for Canada - one showing maximum horizontal ground velocity (appropriate for large structures), and the other showing maximum horizontal ground acceleration (appropriate for small structures)

Both seismic hazard maps are probabilistic maps. They provide the likelihood of a given horizontal acceleration or velocity being exceeded during a particular time period. The probability used in the National Building Code is 0.0021 per annum, equivalent to a 10-per-cent probability of exceedance over 50 years. This means that over a 50-year period there is a 10-per-cent chance of an earthquake causing ground motion greater than the given expected value (or a 90-per-cent chance of non-exceedance). On the maps,

seismic hazard is expressed as the maximum ground motion that is expected to occur in an area with a given probability. Contours delineate zones likely to experience similar intensities of shaking.

Digby Neck is located within the Northern Appalachian Seismic Zone (NAN). Maps of seismic risk in the 1995 code show the area occurs within Z one 1 and is considered to have a low earthquake risk. In fact, Canada to the east of the Cordillera, extending north from the United States border to the Arctic Ocean, comprises about two-thirds of the stable craton of the North American plate. Much of this large area appears to be substantially aseismic, although it contains several zones of significant seismicity and a few other regions of lower-level seismicity. The areas of high seismicity appear to occur in zones of horizontal compression associated with thrust faulting.

Historically, earthquakes in this Digby Neck region have been infrequent and of small magnitude. The nearest zone of earthquake activity is across the Bay of Fundy in the Passamaquoddy Bay region. The Oak Bay Fault is considered to be the site of the activity for that region. Two small earthquakes epicenters have been reported to the northeast of Digby.

A new seismic hazard model, the fourth national model for Canada, has recently been devised by the Geological Survey of Canada (Adams and Atkinson, 2005) to update Canada's current (1985) seismic hazard maps and is planned to be implemented in late 2005.

## Figures

Figure 1. A map of the historical seismicity in eastern Canada.

Figure 2. A more detailed map of the location of seismicity in the NAN area of eastern Canada.

Figure 3. A seismic zoning map of Canada which has been divided into seven zones of ground motion. It has been prepared on the basis of probable ground velocity. Velocity is given in metres per second.

Figure 4. A seismic zoning map of Canada prepared according to acceleration. Acceleration is expressed as a fraction of gravity.

Figure 5. Source zones used in the H and R models. Certain shaded zones show how small clusters of seismicity in the H model are combined into large zones in the R model. Seismicity for relatively aseismic regions outside of zones is accounted for by the stable Canada model: (a) H model; (b) R model. ACM, Arctic Continental Margin; CASR, Cascade Mountains; CHV, Charlevoix; ECM, Eastern Continental Margin; IRM, Iapetan Rifted Margin; NAT, Niagara-Attica. From Adams and Atkinson, (2003).

## References

Adams, J., Weichert, D.H., and Halchuk, S. 1999. Lowering the probability level — Fourth generation seismic hazard results for Canada at the 2% in 50 year probability level. *In* Proceedings of the 8th Canadian Conference on Earthquake Engineering, 13–16 June 1999, Vancouver, B.C. Canadian Association for Earthquake Engineering. pp. 83–88.

Adams, J. and Atkinson, G., 2003, *in* Canadian Journal of Civil Engineering Special Issue, Volume 30, Number 2, April 2003, Proposed Earthquake Design Requirements of the National Building Code of Canada, Development of seismic hazard maps for the proposed 2005 edition of the National Building Code of Canada 2005 edition -National Research Council Canada Research Press

Atkinson, G.M. 1995. Ground motion relations for use in eastern hazard analysis. *In* Proceedings of the 7th Canadian Conference on Earthquake Engineering, 5–7 June 1995, Montréal, Que. Canadian Association for Earthquake Engineering, Montréal, Que. pp. 1001–1008.

Atkinson, G.M., and Boore, D.M. 1995. New ground motion relations for eastern North America. *Bulletin of the Seismological Society of America*, **85**: 17–30.

Atkinson, G., and Boore, D.M. 1997. Some comparisons of recent ground motion relations. *Seismological Research Letters*, **68**: 24–40.

Atkinson, G., and Boore, D.M. 2000a. Reply to Comment on ‘Evaluation of models for earthquake source spectra in eastern North America’. *Bulletin of the Seismological Society of America*, **90**: 1339–1341.

Basham, P., Weichert, D., Anglin, F., and Berry, M. 1982. New probabilistic strong seismic ground motion maps of Canada — a compilation of earthquake source zones, methods and results. Energy, Mines and Resources Canada, Earth Physics Branch, Open-file Report 82-33.

Basham, P.W., Weichert, D.H., Anglin, F.M., and Berry, M.J. 1985. New probabilistic strong seismic ground motion maps of Canada. *Bulletin of the Seismological Society of America*, **75**: 563–595. Bazzurro, P., and Cornell, C.A. 1999. Disaggregation of seismic hazard. *Bulletin of the Seismological Society of America*, **89**: 501–520.

Barosh, P.J. 1981: Seismicity and tectonics of the Passamaquoddy Bay area, Maine and New Brunswick, Abstracts with Programs, Geological Society of America, v. 13, p. 122.

Burke, K.B.S. 1984: Earthquake activity in the Maritime Provinces, Geoscience Canada, v. 11, p. 16-22.

Burke, K.B.S., Slauenwhite, S. and Bidiscombe, P. 1987: Historical seismicity of the Passamaquoddy Bay region of New Brunswick for the period 1811-1900, Contract Report 23222-6-3421 01-ST for Geophysics Division, Geological Survey of Canada, Ottawa, 93 p.

Burke, K.B.S., and Comeau, R. 1988: Historical seismicity of the Passamaquoddy Bay region of New Brunswick for the period 1900-1961, Contract Report 23233-7-3720 01-SZ for Geophysics Division, Geological Survey of Canada, Ottawa, 80 p.

Burke, K. S. 2005, A summary of the historical earthquake activity in the province of New Brunswick. University of New Brunswick Web Site.

Cornell, C. 1968. Engineering seismic risk analysis. Bulletin of the Seismological Society of America, **58**: 1583–1606.

Fader, G. B. J., 1989, Cruise Report 88-018, Phase 4 and 88-018, Phase 5, M.V. Navicula - Passamaquoddy Bay and Bay of Fundy, 22 p.

Hasegawa, H.S., Basham, P.W., and Berry, M.J. 1981. Attenuation relations for strong seismic ground motion in Canada. Bulletin of the Seismological Society of America, **71**: 1943–1962.

King, L. H. and MacLean, B., 1976. Geology of the Scotian Shelf, Geological Survey of Canada paper 74-31. 31 p., enclosure Map 812H.

Leblanc, G. and Burke, K.B.S. 1985: Re-evaluation of the 1817, 1855, 1869 and 1904 Maine-New Brunswick area earthquakes, Earthquake Notes, v. 56, p. 107-123.

McGuire, R. 1976. FORTRAN computer program for seismic risk analysis. U.S. Geological Survey, Open-file Report 76-67.

National Building Code of Canada, 1995. NRCC no. 38726; section 4.1.9.1 sentence 5 and Appendix C: Climatic Information for Building Design in Canada

Nuttli, O.W. and Zollweg, J.E., 1974: The relation between felt area and magnitude for central United States earthquakes, Bulletin of Seismological Society of America, v. 64, p. 1189-1207.

Pecore, S.S. and Fader, G.B.J., 1990: Surficial geology, pockmarks and associated neotectonic features of Passamaquoddy Bay, New Brunswick, Canada, Geological Survey of Canada, Open File 79-20, 7 p.

Rast, N., Burke, K.B.S. and Rast, D., 1979: The earthquakes of Atlantic Canada and their relationship to structure, Geoscience Canada, v. 6, p. 173-180.

Richter, C. 1958. Elementary seismology. W.H. Freeman and Co., New York.

Sibol, M.S., Bollinger, G.A. and Birch, J.B., 1987: Estimation of magnitudes in central and eastern North America using intensity and felt area, Bulletin of Seismological Society of America, v. 77, p. 1635-1654.

Smith, W.E.T. 1962: Earthquakes of Eastern Canada and adjacent areas 1534-1927, Publication of the Dominion Observatory, Ottawa, Canada, v. XXVI, p. 271-301.

Smith, W.E.T. 1966: Earthquakes of Eastern Canada and adjacent areas 1928-1959, Publication of the Dominion Observatory, Ottawa, Canada, v. XXXII, p. 87-121.

Street, R.L. and Lacroix, A.V. 1979: An empirical study of New England seismicity: 1727-1927, Bulletin of Seismological Society of America, v. 69 p. 159-175.

Street, R.L. and Turcotte, F.T. 1977: A study of northeastern North America spectral moments, magnitudes and intensities, Bulletin of Seismological Society of America, v. 67, p. 599-614.

Whitman, R.V. (*Editor*). 1990. Proceedings of the Workshop on Ground Motion Parameters for Seismic Hazard Mapping, 17- 18 July 1989, Buffalo, N.Y. Technical Report NCEER-89-0038.

Figure 5

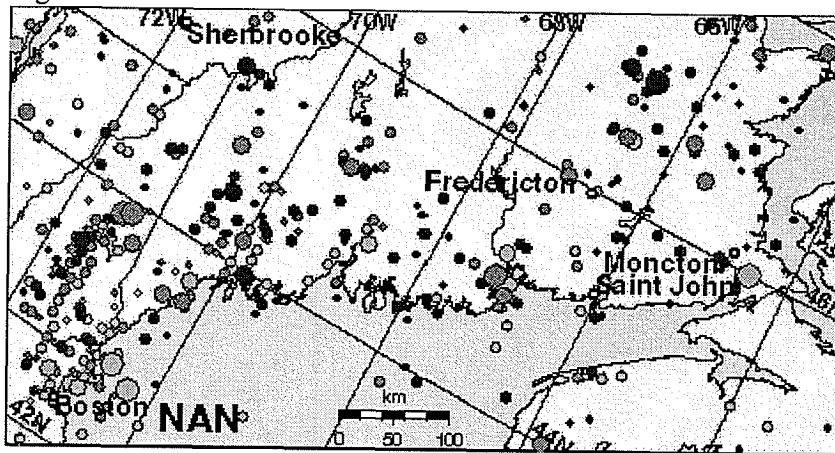


Figure 6  
Continental Margin; IKM, Iapetan Killec Margin; NAT, Niagara-Natchez.

