EARTHQUAKES IN EASTERN CANADA: A THREAT THAT CAN BE MITIGATED

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RÉSUMÉ

Dans l'Est du Canada, plusieurs séismes peuvent être considérés significatifs, c'est-à-dire qu'ils ont causé des dommages aux édifices ou ont eu un impact sur l'environnement naturel (glissement de terrain, rupture en surface, liquéfaction, glissement sous-marin, avalanche de roches, glissement de remblai de chemin de fer et tsunami). Avec les séismes de plus faible magnitude, ces forts événements sont utilisés pour définir le taux de magnitude-récurrence pour les zones sismiques de l'Est du Canada. Ces taux et l'atténuation des ondes sismiques permettent de calculer les valeurs de mouvements de sol à différents niveaux de probabilité ce qui définit l'aléa sismique pour l'est du Canada – c.à-d. la probabilité qu'un séisme se produise avec un certain niveau de mouvement de sol. Notre société exige plus que l'aléa sismique, elle requiert une évaluation de l'impact potentiel des séismes. Pour cela, Ressources Naturelles Canada, en partenariat avec des universités et gouvernements locaux a défini deux projets qui examinent le potentiel d'amplification des ondes sismiques dans les régions d'Ottawa et de Québec. Utilisant les propriétés géotechniques des dépôts in situ, les rapports des mouvements horizontal sur vertical du bruit de fond et des mouvements sismiques enregistrés sur les dépôts non-consolidés et sur le roc, des cartes de microzonage sismique peuvent être définies.

ABSTRACT

In Eastern Canada, some earthquakes can be considered significant, i.e. they caused some damage to buildings or had an impact on the natural environment (landslides, rock falls, surface faulting, liquefaction, submarine slumping, rock avalanches, railroad embankment slides, and tsunami). Together with smaller magnitude earthquakes, these larger events have been used to define magnitude-frequency rates for the seismically active zones of Eastern Canada. These rates and the attenuation of seismic waves are used to compute values of ground motions at different probability levels which define the earthquake hazard for eastern Canada, i.e. the probability of an earthquake occurring with a given level of ground motion. Our society demands more than seismic hazard: it requires that we assess the potential impact of earthquakes. For this reason, Natural Resources Canada, in partnerships with universities and local governments, has defined two projects to examine the potential for amplification of seismic ground motions in the Ottawa and Quebec City regions. Using geotechnical properties of in situ deposits, ratios of horizontal to vertical background noise and ground motions recorded on unconsolidated deposits versus bedrock, microzonation maps are being defined.

1. INTRODUCTION

Although located in the middle of the North American plate, eastern Canada[1] has been subject to damaging earthquakes larger than magnitude (M[2]) 5. In the St. Lawrence and Ottawa River valleys, for instance, damaging earthquakes in the M 5 to 7 range have been documented in writing since the arrivals of the Europeans or recorded with seismographs since the early 20th century. Recently, a list of significant earthquakes of Canada was created with the most up-to-date descriptions of these events (Table 1; Lamontagne et al. 2007). This list helps define potential impacts of future eastern Canadian earthquakes and give direction to measures that could be taken to attenuate seismic risk.

Earthquakes will continue to affect the geological and man-made environments. The following sections review these four types of consequence in light of past eastern Canadian earthquakes. In the first section, it is seen that some M 5 to 7 eastern Canadian earthquakes have had a geological impact, such as surface faulting, liquefaction, submarine slumping, tsunamis, rock avalanches, rock falls, landslides, and railroad embankment slides. The second section overviews the efforts made in seismic hazard mapping. The third section examines some examples of past damage where buildings with unreinforced masonry elements and located on clay deposits were particularly susceptible to damage. This knowledge leads to defining urban areas that could be subjected to enhanced ground motions during a sizeable earthquake. In the fourth section, we examine cases of casualties, direct and indirect, due to eastern Canadian earthquakes. Finally, we conclude about future activities that should help attenuate the impact of sizeable earthquakes.

[1] In the text, eastern Canada is defined as the Canadian territory east of the Cordillera and south of latitude 60º.
[2] M is defined as the most widely accepted magnitude value (generally the moment magnitude or the felt area magnitude for historical earthquakes) for a given event.

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2. GEOLOGICAL EFFECTS

Geological effects of earthquakes include surface rupture, liquefaction, rock avalanches, rock falls, landslides and slumps in clay deposits, ground cracking, lateral spreading and liquefaction. Surface faulting excepted, all other impacts depend on the severity of ground motions. Surface faulting is directly related to the earthquake process and is described below.

Historically, only a few eastern Canadian earthquakes of magnitude greater than 5 had observed geological effects. For older earthquakes, this may be partly due to poor documentation: some events had very few written accounts and not all regions were populated. There are, however, many examples of geological effects. The 1929 M 7.2 Grand Banks earthquake triggered a submarine landslide that caused a deadly tsunami that came ashore on the southern coast of Newfoundland (27 victims). The 1935 M 6.2 Témiscaming earthquake caused minor rock falls and discolouration of lakes near the epicenter. Some 300 km from the epicenter, the vibrations also caused the failure of a railway embankment (Hodgson, 1945a). The 1989 M 6.3 Ungava earthquake occurred close to the surface and caused a 10-km long surface rupture, local liquefaction and lake-level change (Adams et al. 1991). It was the first documented rupture from a historical eastern North American earthquake, and possibly the first important displacement on a fault that was certainly not prominent at a regional level (Lamontagne and Graham, 1993). Smaller earthquakes in Canada did not have any geotechnical effects other than possible drying-up of some water wells (ex: 1944 M 5.6 Cornwall-Massena: Hodgson 1945b; 1982 M 5.7 Miramichi: Brinsmead 1982). Recently, two moderate size earthquakes on the U.S. side of the border have caused rock slides, the 2002 M 5.0 Au Sable Forks, New York (Pierre and Lamontagne 2004) and the 2005 M(Lg) 4.2 Bar Harbor, Maine (Ebel et al. 2008). In these two cases, it is surprising that rock slides were caused by these rather low magnitude events.

The 1988 M 6.0 Saguenay earthquake is special in the history of eastern Canadian seismicity since for the first time, the impact of a moderate eastern Canadian earthquake was well documented. Its effects were dramatic: liquefaction and rock falls in the epicentral region, and landslides as far as 200 km from the epicenter. At 30 km from the epicenter, for example, liquefaction caused extensive damage to local houses (Lefebvre et al. 1991; Boivin, 1992). There, evidence of older liquefaction and ground failure was found, possibly caused by older regional earthquakes (Tuttle et al. 1990). Other damage was seen as far as 170 km away from the epicenter where failures of railroad embankments were reported (Mitchell et al. 1990). Natural slope failures were also seen along the St-Maurice River (Lefebvre et al. 1992). For building design, it was a very useful earthquake: it was the first M 6 eastern Canadian earthquake recorded by strong ground motion instruments and has shown the high frequency content of earthquakes there (Munro and North 1989).

Not all moderate to large earthquakes have geotechnical impacts, a fact exemplified by the five M ≥ 6.0 of the Charlevoix-Kamouraska Seismic Zone (CSZ). Of these earthquakes, the 1663 event caused landslides in the epicentral region (Filion et al. 1991), and along the Saguenay and St-Maurice rivers, more than 200 km away (Legget and LaSalle, 1978; Desjardins, 1980). The 1663 event may have also produced a basin collapse in the Saguenay Fjord (Syvitski and Schafer 1996). The 1870 earthquake also had some dramatic consequences, including liquefaction and landslides in the epicentral region, and one possible rock fall along the Saguenay River (Lamontagne et al. 2007). A landslide, possibly indirectly linked with the earthquake, killed four people five days after the main shock (Lamontagne et al. 2007). Some submarine landslides of the Saguenay and St. Laurence rivers are also associated with some of these large CSZ earthquakes. Near Betsiamites on the Quebec North Shore, a subareal landslide occurred which continued offshore beneath the St. Lawrence River (Cauchon-Voyer et al. 2007). Another landslide scar potentially from the 1860 Charlevoix earthquake also exists there.

Our society can indirectly mitigate the potential impact of earthquakes by taking measures to minimize the risks associated with mass movements. From a probability point of view, the risk of surface rupture at any given point is negligible.

3. SEISMIC ZONING

In the past, destructive earthquakes have occurred in eastern Canada and similar events will undoubtedly happen in the future. The exact time and place of these events cannot be predicted but ongoing studies help us predefine areas most likely to be strongly shaken during an earthquake. Previous experience has stressed several lessons useful for seismic hazard and seismic risk studies. Due to the efficiency of the Canadian Shield to transmit seismic waves, moderate to large eastern Canadian earthquakes can be felt over large distances (more than 1000 km for magnitude 6 earthquakes) and damage is not constrained to the region near the epicenter. Since the 1950’s in Canada, some protection against the seismic ground motions has been included in the National Building Code of Canada. These provisions are updated according to the improved understanding of the potential location and strength of potentially damaging earthquakes. The low attenuation of eastern Canadian seismic waves has been considered.

Based on the last decades of seismographic recordings, seismologists can now characterize eastern Canadian earthquakes as well as their geographic distribution. It is known that most eastern Canadian earthquakes are upper- to mid-crustal earthquakes with mostly thrust (reverse) faulting mechanisms. The best studied seismic zone is the Charlevoix-Kamouraska area of Quebec. There, a seven-station seismograph network has monitored the earthquake activity since 1978. The hypocenters define active areas within the Precambrian basement that represent weak zones possibly correlated with the St. Lawrence paleorift system and in some cases to the Charlevoix impact crater structure. The possible correlation between earthquakes and paleorift faults there has a strong impact on the seismic zoning of eastern Canada.

The provisions of the National Building Code of Canada ensure that new buildings are resistant to seismic ground motions. The seismic provisions in the 2005 National Building Code of Canada use the larger of the ground motions derived from two different models. The first model assumes that the historical earthquake clusters denote areas that will continue to be active. The second model assumes a common geological framework for the seismicity cluster (i.e., passive Paleozoic rift faults) and regroups them into large source zones (Adams et al. 1995). In areas with historical damaging earthquakes, the hazard derived from the historical model dominates whereas in areas without significant activity but where rift faults are present, the hazard is dominated by the geologically-derived model.

4. SEISMIC MICROZATION STUDIES

The last few years have brought about a better understanding of the factors that determine the severity of ground motions. At a given location, the level of ground motions which partly controls damage depends on the earthquake itself, on attenuation of the seismic waves and on geological conditions at the point considered. In the near field, for instance, properties of the earthquake source (magnitude, stress drop, focal depth, focal mechanism, and directivity effects) all play a role in determining the ground motion characteristics. Remote from the epicentral region, crustal attenuation of the ground motions and the nature of the substratum underlying the point considered, become more important.

Damage can be locally enhanced by the type of overburden (Hodgson, 1945a; Paultre et al. 1993; Drysdale and Cajka, 1989). In almost all cases of earthquake damage, buildings were resting on soft soils (clay, sand, fill). For the Saguenay earthquake, 95% of all damage was associated with soft soils (53% with clay, 24% on multi-layer, and 18% on sand). It was also found that damage to buildings built on sandy foundations was restricted to 150 km epicentral distance, whereas for clay foundations, damage existed up to 350 km distance (Paultre et al. 1993). Dwellings in Les Éboulements were damaged during the 1870 Charlevoix earthquakes, but this could be due to the proximity to the epicentre and the possible focusing of strong ground motions (Lamontagne, 2008). Damage seen in historical earthquakes is likely to repeat during comparable future earthquakes. Widespread urban and industrial developments have taken place on soils now recognized as capable of amplifying earthquake ground motions.

In Quebec City, a search of historical documents has produced a database of locations where earthquake-related damage was reported (Lamontagne, 2008). Two groups of earthquakes caused damage to buildings, some larger ones from Charlevoix and the Saguenay and some smaller in the immediate region of Quebec City. The geographic distribution of damage shows a concentration in the lower town of Quebec City. Because the earthquakes occurred many decades apart, the area of Quebec City that was affected was not always the same (except for the old Quebec City part). The earthquake that caused the most intense damage was the 1870 earthquake that affected many buildings in the St-Roch neighbourhood (but the 1925 and 1988 earthquakes did not affect that area very much). A similar documentation of earthquake damage and felt reports is currently underway for the Ottawa region. This damage information layer can to be used to delineate areas of higher seismic hazards.

Damage is more common in buildings with unreinforced masonry elements (URM; i.e., without steel reinforcement) that rest on thick clay deposits. This aspect of damage distribution in eastern Canada was first recognized after the 1925 Charlevoix earthquake (Hodgson, 1945a) and confirmed subsequently in other eastern Canadian earthquakes. From photographic documentation of 20th century earthquakes, out-of-plane failure has been the most frequently reported form of damage to these buildings, in agreement with current knowledge on the behaviour of such structures (Bruneau and Lamontagne, 1994). In general, damage can be controlled by the quality of construction and the fastening of the exterior facade to the structure (Paultre et al. 1993). The recognition of the danger posed by these older buildings, especially if resting on thick unconsolidated deposits, should be central to any urban earthquake hazard mitigation program.

The presence of non-upgraded old buildings coupled with the population growth, particularly on sensitive soils, make earthquakes a potentially significant natural hazard in eastern Canada. Microseismic zonation of urban areas and improved account of soil amplification in the next National Building Code of Canada may provide partial reduction of the problem.

Our society demands more than seismic hazard: it requires that we assess the potential impact of earthquakes. For this reason, Natural Resources Canada, in partnerships with universities and local governments, has defined two projects to examine the potential for amplification of seismic ground motions in the Ottawa and Quebec City (Nastev et al. 2007) regions. Using geotechnical properties of in situ deposits Leboeuf and Nollet, 2006), ratios of horizontal to vertical background noise and ground motions recorded on unconsolidated deposits versus bedrock, microzonation maps are being defined. In the Ottawa region for instance, where the thickness of unconsolidated deposits can reach more than 100 m, ground motions can be amplified many times in areas compared with sites on bedrock (Crow et al. 2007). The maps can be used for land use planning as well as for quickly determining which part of a city was shaken most after a moderate to large earthquake.

5. CASUALTIES

In light of the number and the magnitude of some eastern Canadian earthquakes (Table 1), it is remarkable that only two possible cases of *direct* casualties are known. *Direct* casualties are those caused directly by the earthquake vibrations or the surface rupture and not by the consequences (such as landslides, fires, etc). In 1870, two children were likely killed in Les Éboulements, Québec, a village very close to the epicenter of the 1870 Charlevoix earthquake (Lamontagne, 2008).

For a time, two other earthquakes were supposed to have caused casualties, but these have been dismissed. For instance, it was suggested that the 20 October 1870 Charlevoix main shock, or one of its aftershock, caused a landslide that killed 4 people near Trois-Rivières, Québec. An analysis of official documents dismissed any relationship between the two events as they were found to be five days apart (Lamontagne et al. 2007). In 1732, the reported death of a girl caused by the M 5.8 Montreal earthquake is not supported by any official document (Leblanc 1981) and is now considered an unfounded rumor (Gouin, 2001).

The small number of *direct* casualties is probably due to two factors. The first one is the historically low population density of Canada, especially in the areas recognized as more active. Repeat of historical earthquakes in today's environment would likely have more impact due to the higher population and more inter-connected infrastructure. Moderate to large earthquakes being so infrequent, the awareness among the population remains relatively low making the population more at risk.

The second aspect is the robust construction practices in Canada. Since the 1950s, progressive upgrades to the seismic provisions of the National Building Code of Canada have provided protection against earthquake hazards in new buildings. The earthquake risk still exists partly due to our stock of old buildings and the urban growth on soft soils capable of amplifying ground motions. Quebec City, for instance, located some 100 km from the Charlevoix-Kamouraska Seismic Zone, has partly developed over soft deposits capable of amplifying strong ground motions (Chagnon and Doré, 1987). Much the same could be said of the Ottawa and Montreal regions, both located in the Western Quebec Seismic Zone.

In eastern Canada, there were some *indirect* casualties such as a few reported cases of heart attacks. More importantly, 28 people were indirect casualties of an earthquake when a tsunami hit the southern coast of Newfoundland in 1929. This tsunami was generated by a large submarine slump induced by the M 7.2 Grand Banks earthquake. Fortunately, Natural Resources Canada is now partnering with the Department of Fisheries and Oceans and potentially effected countries bordering the Atlantic Ocean to develop a storm surge and tsunami alert system (ESS, 2005). This effort should reduce the risk of another killer tsunami on the Atlantic coast.

6. CONCLUSIONS

Numerous moderate to large earthquakes have occurred in eastern Canada. Only one of these events is known to have been associated with a surface rupture. Some others had significant geological effects such as submarine slumping that induced a tsunami, rock avalanches, rock falls, landslides, railway embankment slides and liquefaction. The geological implications are as follows. First, the probability of earthquake-related surface ruptures is small because most earthquakes are too small or too deep. Second, liquefaction is possible but highly dependent on the characteristics of unconsolidated deposits in the areas affected by strong ground shaking. Third, rock falls can occur in regions of steep slopes. Fourth, landslides in clay deposits can occur depending on local conditions existing at the time of occurrence. Fifth, loosely compacted landfills, such as railway embankments, are sensitive to seismic ground motions even at large distances from the epicenter. Some of these earthquakes caused considerable damage to buildings with unreinforced masonry elements located on thick clay deposits. Finally, these events also had a strong psychosocial impact, due to the unpreparedness of the population. To reduce these earthquake impacts, new or upgraded programs should be developed to map areas most susceptible to mass movements, to define and upgrade buildings most at risk, and to educate the population about earthquake preparedness.

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Date	Time (U.T.)	Region	Lat	Lon	Mag	Landl side	Tsunami	Damage	Deaths	Description
1663-02-05	22:30	Charlevoix-Kamouraska, Quebec	47.6	-70.1	7	Yes	No	Yes	0	Epicenter most likely in the Charlevoix-Kamouraska Seismic Zone, Quebec; Felt in most of New France (Quebec City, Trois-Rivières, Montréal) and parts of New England (Boston) and New Amsterdam (New York City). Some damage to masonry in Quebec City, Trois-Rivières and Montréal. Landslides reported in the Charlevoix region, and along the St. Lawrence, Shipshaw, Betsiamites, Pentecôte, Batiscan and Saint-Maurice rivers. Numerous aftershocks felt in Quebec City during the following months.
1700-01-27	05:00	Cascadia Subduction Zone, British Columbia	48.5	-125	9	Yes	Yes	Yes (in Japan from tsunami)	Unknown; native villages destroyed according to oral traditions	Cascadia subduction zone, offshore of Vancouver Island, Washington and Oregon. Recorded widely in oral native accounts and by geological evidence for subsidence and a tsunami along the outer coast; confirmed by a tsunami record in Japan. Extent of damage unknown.
1732-09-16	16:00	Near Montreal, Quebec	45.5	-73.6	5.8	No	No	Yes	0	Probable epicenter near Montréal, Quebec. Felt in New France, from Louisbourg to the James Bay. Considerable damage in the city of Montréal where hundreds of chimneys were damaged and walls cracked. No injuries documented. Aftershocks felt in Montreal.
1791-12-06	20:00	Charlevoix-Kamouraska, Quebec	47.4	-70.5	6	No	No	Yes	0	Felt strongly in Charlevoix, Quebec, and in Quebec City. Damage to houses and churches in Baie-Saint-Paul, Les Éboulements and on Île aux Coudres.
1855-02-08	18:00	Moncton, New Brunswick	46.0	-64.5	5.2	No	No	Yes	0	Minor damage was reported for this earthquake. Chimney damage reported in Moncton, New Brunswick. In Hopewell,

										near the epicenter, the shock cracked the plastering of walls.
1860-10-17	11:15	Charlevoix-Kamouraska, Quebec	47.5	-70.1	6	No	No	Yes	0	Widely felt in Quebec and felt as far as New Brunswick, eastern Ontario and New England. Damage in the epicentral region on both shores of the St. Lawrence River: North Shore: Baie-Saint-Paul; La Malbaie; South Shore: Rivière-Ouelle. Also felt strongly in Quebec City.
1870-10-20	16:30	Charlevoix-Kamouraska, Quebec	47.4	-70.5	6½	Yes	No	Yes	Possibly 2 in Les Éboulements	Felt over most of the Province of Quebec, in Ontario, New Brunswick, and in New England. Considerable damage to houses in Charlevoix, especially in Baie-Saint-Paul, Les Éboulements and along the South Shore of the St. Lawrence River. Damage to chimneys reported in lower town in Quebec City. Possible rock slide along the Saguenay River.
1904-03-21	06:04	Passamaquoddy Bay, New Brunswick	45.0	-67.2	5.9	No	No	Yes	0	Strong earthquake 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.
1925-03-01	02:19	Charlevoix-Kamouraska, Quebec	47.8	-69.8	6.2	Yes	No	Yes	6 (heart attacks)	Charlevoix-Kamouraska Seismic Zone, Quebec, near Île aux Lièvres. The earthquake was felt over most of eastern Canada and northeastern U.S. It caused damage to unreinforced masonry (chimneys, walls) in the epicentral region on both shores of the St. Lawrence, and in Quebec City, (including damage to port facilities), Trois-Rivières and Shawinigan. Possible liquefaction near Saint-Urbain, Quebec. Numerous felt aftershocks followed.
1929-11-18	20:38	Laurentian slope, offshore	44.69	-56	7.2	Yes	Yes	Yes	28 (27 drowned	Laurentian Slope south of Newfoundland; offshore earthquake felt over most of the

		Newfoundland and Nova Scotia							by the tsunami, one child succumbe d to her injuries a few years later)	Maritimes, eastern Quebec and New England. On land, damage due to earthquake vibrations was limited to Cape Breton Island where chimneys were overthrown or cracked and where some highways were blocked by minor landslides. One chimney also fell in Fredericton, New Brunswick. The earthquake generated a massive submarine slump (landslide) and a large ocean wave (tsunami) which killed 27 people when it struck the Burin Peninsula. Total property losses were estimated at more than $1 million 1929 dollars (estimated as nearly $20 million 2004 dollars).
1935-11-01	06:03	Region of Témiscaming, Quebec	46.78	-79.07	6.1	Yes	No	Yes	0	The earthquake occurred approximately 10 km east of Témiscaming, Québec. This earthquake was felt west to Thunder Bay, Ontario, (then named Fort William), east to the Bay of Fundy and south to Kentucky and Virginia. Damaged chimneys were reported in Temiscaming, Quebec, and North Bay and Mattawa, Ontario. In the epicentral region, small rockfalls were observed as well as cracks in the gravel and sand at the edges of islands and borders of lakes. Some 300 km away from the epicenter, near Parent, Québec, earthquake vibrations triggered a 30 metre slide of railroad embankment. Numerous aftershocks were felt in Témiscaming and Kipawa during following months.
1944-09-05	04:38	Cornwall, Ontario-Massena New York.	44.96	-74.77	5.6	No	No	Yes	0	Cornwall, Ontario, region - New York border. Felt over most of eastern Ontario, southern Quebec and New England. Considerable damage to unreinforced masonry in both Cornwall, Ontario and Massena, New York. About 2,000 chimneys were damaged in Cornwall,

										Massena and several adjacent communities.
1982-01-09	12:53	Miramichi Highlands, New Brunswick	47.0	-66.6	5.8	No	No	Yes	0	First of two moderate earthquakes, Miramichi Highlands, New Brunswick. Because the epicentral area is unpopulated, damage was very slight: a few hairline cracks but no structural damage in buildings up to 100 km away. Followed by hundreds of aftershocks over the following months.
1985-10-05	15:24	North Nahanni River, Northwest Territories	62.21	-124.22	6.6	Yes	No	No	0	Felt in the western Northwest Territories, southeastern Yukon and northern Alberta and British Columbia. The earthquake caused large landslides, rockfalls and a major rock avalanche in the epicentral region. An estimated 5 to 7 million cubic metres of rocks crashed 1.6 km down from the crest to the toe of the slide. Felt strongly with slight damage at Wrigley, Fort Simpson and Fort Liard. Hundreds of aftershocks recorded in the following months.
1985-12-23	05:16	North Nahanni River, Northwest Territories	62.19	-124.23	6.9	Yes	No	No	0	Felt in the western Northwest Territories, southeastern Yukon and northern Alberta and British Columbia. Hundreds of aftershocks recorded in the following months.
1988-11-25	23:46	Saguenay Region, Quebec	48.12	-71.18	5.9	Yes	No	Yes	2 (heart attacks)	Laurentides Fauna Reserve, south of Saguenay (Chicoutimi), Quebec. Preceded by a foreshock 2½ days before. Damage caused to unreinforced masonry at Jonquière, Chicoutimi, La Baie, Charlevoix region, Montmagny, Quebec City, Sorel and Montreal-East. Liquefaction of soft soils in the Ferland-et-Boilleau area. Eleven cases of soil movements reported. Only one felt

										aftershock.
1989-12-25	14:24	Ungava Peninsula, Quebec	60.12	-73.6	6.3	No	No	No	0	The first earthquake in eastern North America to have produced surface faulting. No damage due to remoteness of epicenter from inhabited communities. Weakly felt in some northern Quebec communities.
1990-10-19	07:01	Mont-Laurier, Quebec	46.47	-75.59	5.0	No	No	No	0	Some minor damage in Mont-Laurier (cracked chimneys, water pipes broken). Widely felt up to distances of 500 km.