Natural Resources Canada / Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8772

Macroseismic and landslide information on the 1663 moment magnitude (M) 7 earthquake, Charlevoix, Quebec

M. Lamontagne and J. Locat

2021

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8772

Macroseismic and landslide information on the 1663 moment magnitude (M) 7 earthquake, Charlevoix, Quebec

M. Lamontagne[1] and J. Locat[2]

[1]Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario
[2]Faculty of Science and Engineering, Université Laval, 1065 Avenue de la Médecine, Québec, Québec

2021

Permanent link: https://doi.org/10.4095/328121

This publication is available for free download through GEOSCAN (https://geoscan.nrcan.gc.ca/).

Recommended citation
Lamontagne, M., and Locat. J., 2021. Macroseismic and landslide information on the 1663 moment magnitude (M) 7 earthquake, Charlevoix, Quebec; Geological Survey of Canada, Open File 8772, 1 .zip file. https://doi.org/10.4095/328121

Publications in this series have not been edited; they are released as submitted by the authors.

Macroseismic and landslide information on the 1663 moment magnitude (M) 7 earthquake, Charlevoix, Quebec

M. Lamontagne and J. Locat

Abstract

The February 5, 1663, magnitude 7 Charlevoix earthquake occurred at approximately 5:30 p.m. local time (February 5, 1663, 22:30 U.T.). This earthquake is one of five known moment magnitude 5.5-7 events that occurred in the Charlevoix Seismic Zone (CSZ) between 1663 and the present. Due to the sparse population at the time, the exact position of the epicenter and the magnitude are still debated. The Charlevoix Seismic Zone is generally assumed as the epicentral region based on its historical earthquakes and its sustained lower magnitude earthquake activity. Given that this earthquake occurred in the mid 1600's and far from the few existing towns, felt accounts are limited in number. Available historical documents reveal that it was felt by the then 2500 inhabitants of New France mostly concentrated in three towns (Quebec City, Trois-Rivières, Montréal), and by other inhabitants of New England and New Holland.

The macroseismic information is augmented by landslides (subaqueous and terrestrial) and sedimentation events which likely were triggered by the 1663 earthquake. Most of these mass movements are dated using either C^{14} or sedimentation rate methods. These mass movements are used as proxies to estimate both the magnitude of the earthquake and its epicentre.

This Open File Report presents the macroseismic information and its ratings on the Modified Mercalli Scale for a total of eight locations for Canada. For each

locality, the felt information is rated on the Modified Mercalli intensity (MMI) scale and tabulated in a Microsoft Excel sheet. The text of some of the newspaper accounts are reproduced. The Open File also provides a GoogleEarth kmz file that allows the felt information reports to be viewed in a geographic visualization tool.

Dedication

This Open File Report is dedicated to the memory of the late Father Pierre Gouin who has spent years of his later life documenting earthquakes of the Province of Quebec. His findings and analyses can be found in Gouin (2001). Many interpretations of macroseismic effects in this Open File are largely based on his dedicated work.

Reverend Pierre Gouin, S.J. 1917-2005

Introduction

The February 5, 1663 Charlevoix earthquake is significant because it is the strongest earthquake ever felt in continental Eastern Canada. Its epicenter is assumed to be in the Charlevoix Seismic Zone (CSZ) (Figure 1) where five earthquakes rated at moment magnitude (**M**) 5.5 or more are known to have occurred: 1663 (**M** ~ 7); 1791 (**M** ~ 5.5); 1860 (**M** ~ 6.1); 1870 (**M** ~ 6.6); and 1925 (**M** 6.2; Bent, 1992; Bent, 2009). Due to the

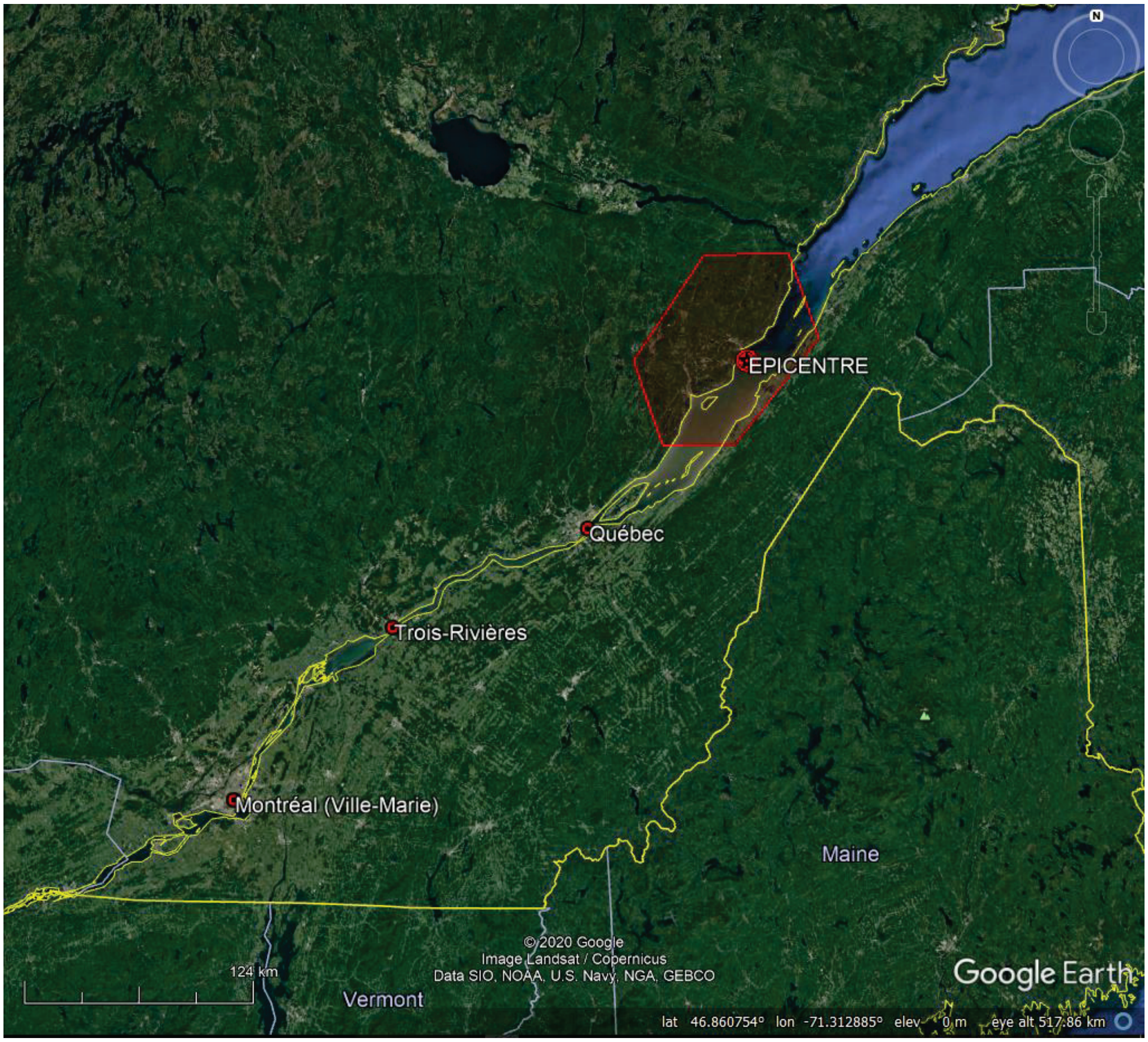

Figure 1: Location map of the CSZ (red hexagon), of the assumed epicenter of the 1663 earthquake and of cities that existed in 1663. Boundaries are the current ones.

its number of damaging earthquakes and its frequent lower magnitude earthquakes, the CSZ is recognized as the most active seismic zone of Eastern Canada (Basham et al., 1982).

The main shock occurred on February 5, 1663 at about 5:30 p.m. local time (February 5 at 22:30 U.T.). At the time, no permanent settlement existed within the CSZ, and most inhabitants of New France were concentrated in Quebec City, Trois-Rivières and Montréal (Gouin, 2001; the original text is found in Gouin(2001)_e.pdf and Gouin(2001)_f.pdf). The CSZ is generally assumed to be the epicentral region based on its historical damaging earthquakes and its sustained lower magnitude earthquake activity. The assumed epicenter position is 47.6ºN by 70.1ºW which is approximately the centre of the CSZ. Due to the poor constraints on the position of the epicentre, an uncertainty of at least 50 km is warranted. Locat (2011) discusses the position of the epicentre and, based on the landslides to the north of the CSZ, suggests an epicentre within the Canadian Shield, somewhat closer to the epicentre of the 1988 Saguenay earthquake. As a consequence, caution must be exercised in considering the epicentral distances which are calculated from the assumed epicentre (the spreadsheet entries are described below).

MMI values were assigned based on macroseismic descriptions, as these are not found in Gouin (2001). There was chimney damage reported in Quebec City, Trois-Rivières, Montréal, and possibly near Boston (Roxbury). We assigned MMI VII where chimney damage was reported: "Damage … considerable in poorly built or badly designed buildings, …old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent" (see full description in Appendix 1). For Quebec City, the MMI values and descriptions are from Lamontagne (2007; 2009).

The three main objectives of this Open File are:

1) To centralize in a table the felt reports and interpreted intensities on the Modified Mercalli scale for that earthquake.
2) To provide the text of the original reports in newspapers and other documents that described the impact of the earthquake.
3) To provide a map that shows the distribution of macroseismic reports for that earthquake.

Magnitude

Rating the magnitude of the 1663 earthquake is difficult and controversial: this OF is not examining this question in depth. Estimating the magnitude of a pre-instrumental felt earthquake can be based on the felt area, the maximum amount of damage, the impact at distance compared with more recent earthquakes, the impact estimated from intensity attenuation prediction or as briefly discussed below, from landslide information.

Since no instrumental data exist, using intensity data to rate the magnitude of the 1663 earthquake will always be confronted to these facts: very few contemporary felt reports exist and they are poorly distributed over the territory. In the Canadian earthquake catalogue, this earthquake is rated as **M** 7.0 (Bent, 2009; Lamontagne et al., 2018). For matter of simplicity, we are using this value in this OF. However, we must recognize that this value is a very approximate conversion from the assumed local magnitude 7.0 (M_L) in the Canadian earthquake catalog of Smith (1962), which was interpreted from the macroseismic effects. For seismic zoning purposes, the GSC value uses **M** 7.0 while EPRI lists it as Mw 6.7 based on maximum intensity. Bent (2009) reminds us of the large uncertainty to the magnitude value and that it is doubtful that this value could ever be refined further. She estimates the uncertainty range to be **M** 6.7 to 7.5. The reader is referred to Bent (2009) for a discussion on the various approaches used to estimate **M.**

There also is Ebel (2011), who estimated **M** based on the damage information at distance. Using various lines of evidence, including the observation of chimney damage at Roxbury (Danforth, 1880) and a cracked masonry wall in Boston, MA, Ebel (2011) estimates the size of the 1663 earthquake as **M** 7.5 ± 0.45, a mean value significantly larger than the **M** 7.0 of the GSC catalogue. Whereas Danforth (1880) is a contemporary observation, the cracked masonry wall was assumed to be due to the 1663 earthquake by oral tradition. On the other hand, Gouin (2001) warns of giving too much weight on the damage reports in Boston:

"Williams in 1785 (ed. 1785, I, pp. 263-264) gave information on what happened at Boston during the main shock. He told his readers of authors mentioning that the earthquake was felt in New England, of the accompanying noise, of houses oscillating, of « pewters falling from their shelves ... », etc. In reading his report, we have the impression that information from Canada and from New England are rather mixed up. The reader cannot know which effect belongs to which part of North America.

Based on interpretations of other secondary sources, Mather et al. (1927) estimated the intensity to be at Boston VII (RF), i.e. VI (MM). We do not believe that the original documents authenticate these conclusions. They suggest a much lower intensity."

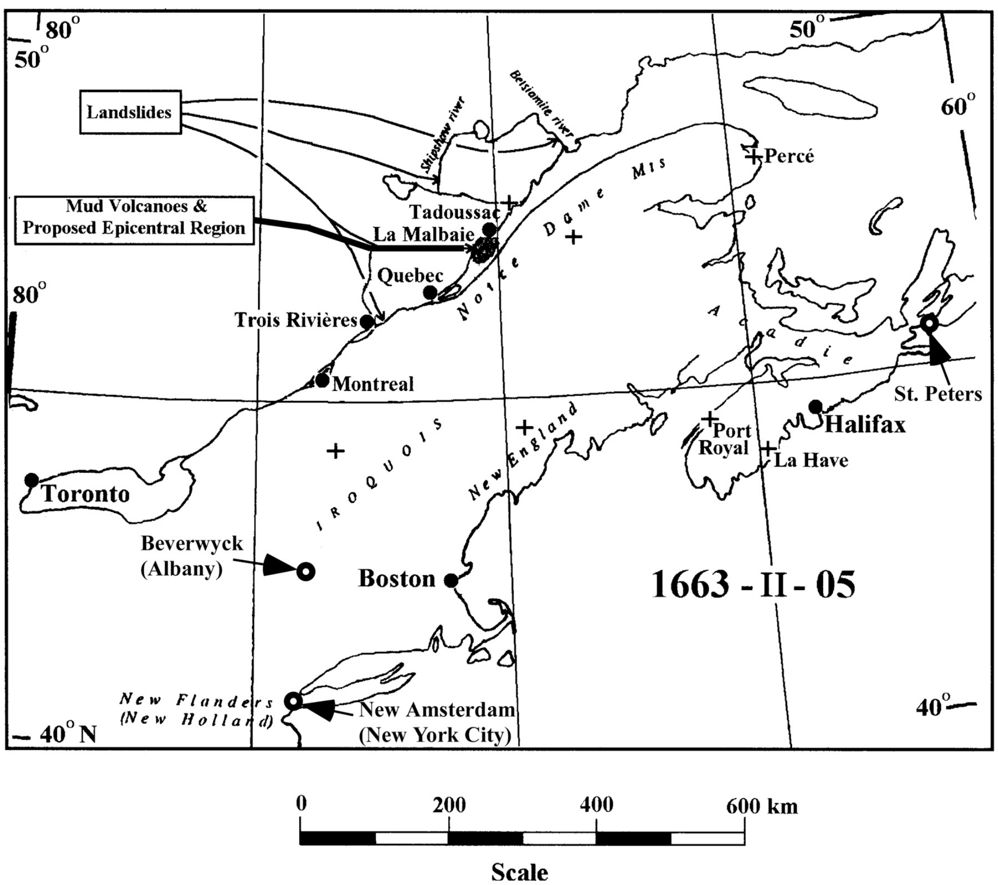

Figure 2. Locations of felt reports and landslide occurrences after Gouin (2001).

Another source of information contained in this OF is the landslide data. From the analysis of landslide-related data and using empirical methods for magnitude estimation, Locat (2011) estimates a minimum magnitude **M** of 7.2 ± 0.2 and a maximum magnitude that would be close to the maximum for the Charlevoix area, which has been previously estimated at **M** = 7.8 ± 0.6.

Landslides

Hodgson (1928, p. 333), in his evaluation of the magnitude of the 1663 earthquake, was aware of landslides as reported by Lalemant (1663) but, among other things, considered that : *"The documentary reports, while undoubtedly coloured by the excitement and terror of the early settlers, may be accepted to a much greater degree if we consider the possibilities of landslides earthquake."* Gouin (2001) includes a number of contemporary descriptions of mass movements as described by Lalemant (1663). Since the work of Hodgson (1928), and particularly since the early 1970's, a significant database on landslides has been established (terrestrial or subaqueous) and even more since the advent of LiDAR (terrestrial) and multibeam side scan sonar (underwater) technologies. Locat (2008, 2011) compiled most of the mass movements related to the 1663 earthquake, including the work of Doig (1986, 1990 and 1998) and Ouellet (1997), to assess the magnitude and location of the earthquake using a method developed at the USGS by Keefer (1984). Keefer (1984) proposed various empirical correlations linking known earthquake epicenters with the farthest distance of a related mass movement (landslide or rockslide). This dataset was expanded by Rodríguez et al. (1999). The mass movements used by Locat (2011) for this exercise are included in the excel file.

Smith (1962) assigned a maximum MMI value of X to the event, probably based on the triggering of large landslides (MMI X: "Landslides considerable from river banks and steep slopes"; see Appendix 1). Rating secondary effects, such as landslides and liquefaction, on the MMI scale is difficult. An interesting observation coming out of the work of Locat (Figure 10 in Locat 2011) is that the empirical relationship of Keefer (1984) would indicate that the minimum intensity of an earthquake which can triggered a landslide would correspond to a MMI of VII.

Gouin (2001) discusses the reports of sand volcanoes from which he determines a maximum MMI of VIII. Sand volcanoes have been identified near Baie-St-Paul but they are related to the 1870 earthquake. The positions of the interpreted liquefaction reports are unknown. Considering their reported dimensions and impact, one may wonder if these were grossly overestimated.

Intensity Reports

This Open File Report documents all felt, damage and landslide information related to the 1663 earthquake in Canada and in the United States. For this, we include for each locality, the felt information rated on the MMI scale tabulated in a Microsoft Excel sheet. The Open File also provides a GoogleEarth kmz file that allows the felt information reports to be viewed in this geospatial tool.

Data and results

The included spreadsheet contains the basic information on the felt accounts. The MMI ratings of Gouin (2001) are provided.

Fields of the Tables

Using Microsoft Excel, a spreadsheet was created that includes some 29 entries (rows) with macroseismic and landslide information. The columns are the same as those published in Lamontagne and Burke (2018), except for two additional columns with Dating methods of the landslides (English and French). We also include a sheet with additional descriptions of the landslides from Locat et al. (2011).

The columns of the Excel sheet for the macroseismic information are:

1. CEEF: A date and time that could eventually refer to entries in the Canadian Earthquake Epicentre File (CEEF)
2. Date.time (UTC): date and time of the earthquake in Universal Time
3. Year_event: Year of the event (YYYY) (Universal Time)
4. Month_event Month of the event (MM) (Universal Time)
5. Day_Event: Day of the event (DD) (Universal Time)
6. Hour-Event: Hour of the event (HH) (Universal Time)
7. Minute-Event: Minute of the event (mm) (Universal Time)
8. Second-Event: Second of the event (ss.s) (Universal Time)
9. MMI Location: Community where earthquake was felt. In the case of landslides, the current name of the nearest community is used.
10. Address: Address where the earthquake was felt (if known)
11. Prov/State: Province or State of the community where the earthquake was felt; NB: New Brunswick; NS: Nova Scotia; PE: Prince Edward Island; QC: Quebec; ME: Maine (USA); MA, Massachusetts (USA) and NH: New Hampshire (USA).
12. Country: Canada or the USA
13. Postal/Zip: Postal Code or Zip Code of the community where the earthquake was felt (if known). In this Open File, no attempt was made to populate this field.
14. Latitude (°N): Latitude of the community where the earthquake was felt; taken from the original felt reports or more rarely obtained from GoogleEarth. Some latitude coordinates of Gouin (2001), which were reported with only one digit, were modified by the first author.
15. Longitude (°W): Longitude of the community where the earthquake was felt; taken from the original felt reports or, more rarely, obtained from GoogleEarth. Some longitude coordinates of Gouin (2001), which were

reported with only one digit, were modified by the first author.

16. Epicentral Distance (km): Epicentral distance in km between the earthquake source and the community where the earthquake was felt. The cell calculates the distance using the formula:

    Epicentral Distance (km) = ACOS(COS(RADIANS(90-(lat. site))) *COS(RADIANS(90-(lat. of epicentre))) +SIN(RADIANS(90-(lat. of site))) *SIN(RADIANS(90-(lat. of epicenter))) *COS(RADIANS(Lon of site - (Lon of epicentre)))) *6371

    We used the epicenter of Lamontagne et al. (2017), i.e. Latitude 47.6°N and Longitude 70.1°W, as listed in the second sheet of the Excel file.
17. Final Numeric MMI: Based on the felt report, interpreted Intensity on the Modified Mercalli Scale of 1931. Although MMI is defined using Roman numerals, we decided to convert them to Arabic numerals for ease of use.
18. Basis for MMI (English): Aspects of the felt report in English (if available) that were used to rate the MMI (in Arabic numerals).
19. Basis for MMI (French): Aspects of the felt report in French (if available) that were used to rate the MMI (in Arabic numerals).
20. Source of felt report: Source of felt report.
21. Precision of location (km): In some cases, it is possible to estimate the radius of uncertainty of the location. We did not use this field in this report.
22. Minimum MMI: The minimum value of MMI for a felt report that is interpreted to lie within a range of intensities (ex: MMI 3-4; in Arabic numerals).
23. Maximum MMI: The maximum value of MMI for a felt report that is interpreted within a range of intensities (ex: MMI 3-4; in Arabic numerals).
24. Interpreter: Author who made the interpretation.
25. Additional notes: Comments of interest on the felt report or its publication.
26. Dating method: Method of dating for the landslide
27. Méthode de datation: French version of Column 26.

Landslides Sheet

1. Number used in Locat (2011): Reference to Table 1 of Locat (2011)
2. Community/Location nearest to mass movement: Current location point
3. Latitude: Latitude of the centre point of the mass movement
4. Longitude: Longitude of the centre point of the mass movement
5. Dating method: Method used to date the mass movement
6. Type of mass movement:
7. Material type: The material that failed
8. A (km^2): Surface area of the mass movement in squared kilometers
9. V (Mm^3): Volume of the mass movement in Mega cubic meters
10. Reference: Original reference of work
11. Brief description
12. Description (français)
13. Short description

GoogleEarth file

To ease the consulting of the data and put them in a geographic context, a kml file is included in the Open File. This and can be viewed using the GoogleEarth software that can be downloaded at https://www.google.com/earth/ . A static image of the Google Earth display is shown in Figure 2.

Conclusions and recommendations

A new digital repository of felt accounts for the 1663 Magnitude 7 Charlevoix earthquake was created. We are confident that this Open File includes all available information on how this earthquake was felt in the Province of Quebec and on the landslides caused by this earthquake, but it will be amended if new information is uncovered. We anticipate that it will be useful for research on this earthquake as well as on other intraplate earthquakes.

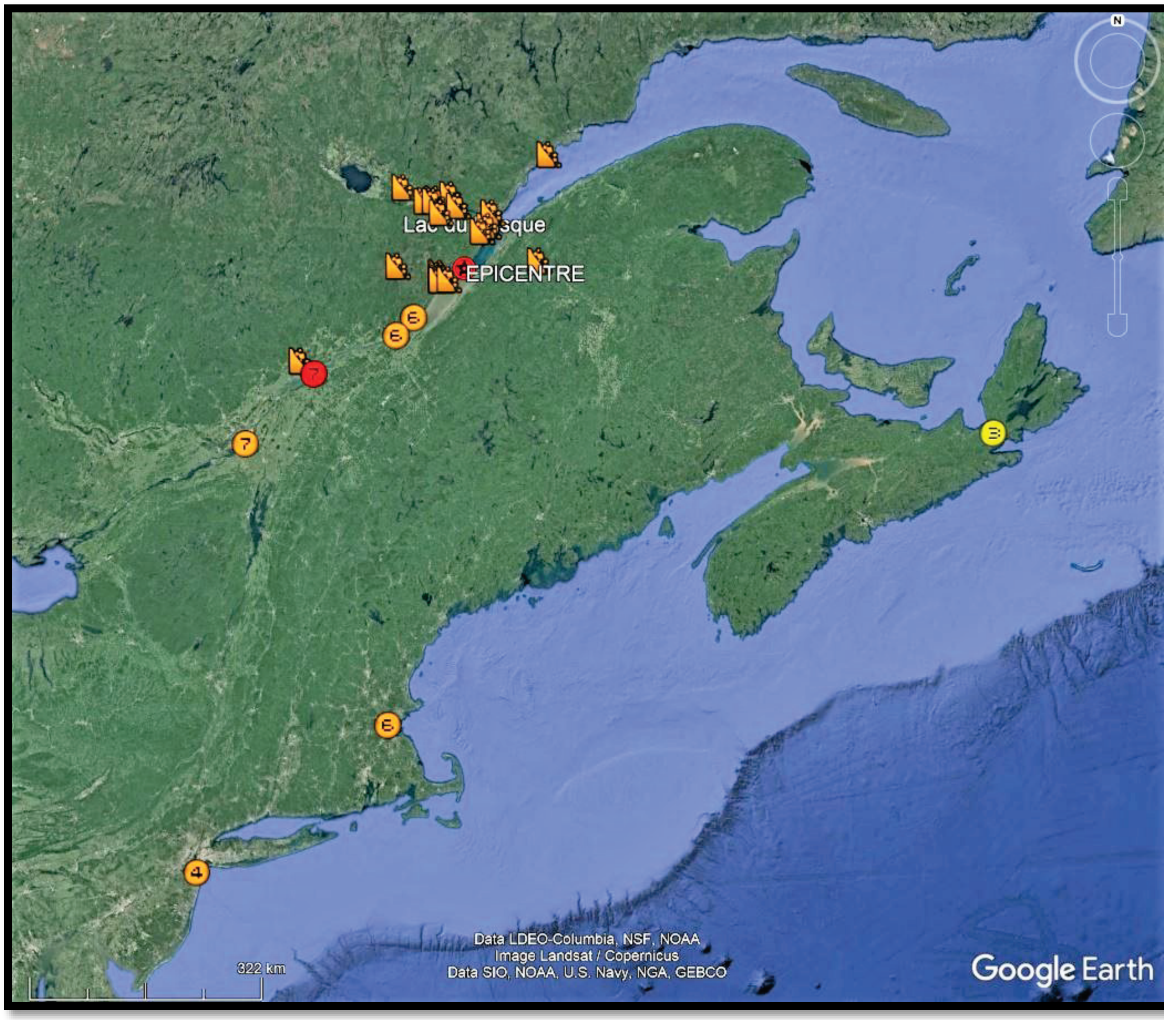

Figure 2. Static image of Google Earth view showing distribution of felt reports included in this Open File and generated from the kml file.

Acknowledgments

We thank Ms. Laura Olson for reformatting some felt information and our GSC colleague Dr Greg Brooks for his review of this Open File.

References (Note: some only appear in the spreadsheet)

Basham, P. W., Weichert, D.H., Anglin, F.M., and Berry, M.J. 1982. New probabilistic strong ground motion maps of Canada: a compilation of earthquake source zones, methods and results. Publications of the Earth Physics Branch Open File Report 82-33, (Energy, Mines and Resources, Canada). https://doi.org/10.4095/8869 (Open Access)

Bent, A.L., 1992. A re-examination of the 1925 Charlevoix, Quebec, earthquake. Bulletin of the Seismological Society of America, 82: 2097 - 2113.

Bent, A.L., 2009. A moment magnitude catalog for the 150 largest eastern Canadian earthquakes, Geological Survey of Canada, Open File 6080, 23 pages.

Cauchon-Voyer, G. 2011. Mouvements de masse en milieu côtier : le cas des grands glissements du delta de la Rivière Betsiamites, Québec, Canada. Thèse de doctorat, Université Laval, Québec, Qc.

Cauchon-Voyer, G., Locat, J., Demers, D., Robitaille, D., et Locat, P. 2008a. Morphological and stratigraphic analysis of the Colombier landslide area, Quebec. In : 4th Canadian Geohazards conference, Québec city, J. Locat, D. Perret, D. Turmel, D. Demers and S. Leroueil Eds, Presses de l'Université Laval, Québec, Qc. p. 271–278.

Cauchon-Voyer, G., Locat, J., et St-Onge, G. 2008b. Late-Quaternary morpho-sedimentology and submarine mass movements of the Betsiamites area, Lower St. Lawrence Estuary, Quebec, Canada. Marine Geology, 251(3–4): 233–252. doi:10.1016/j.margeo.2008. 03.003.

Cauchon-Voyer, G., Locat, J., Leroueil, S., St-Onge, G., and Demers, D. 2011. Large-scale subaerial and submarine Holocene and recent mass movements in the Betsiamites area, Quebec, Canada. Engineering Geology, 121(1–2) : 28–45.

Danforth, S. (1880). Journal of Rev. S. Danforth, Roxbury, Massachusetts, New England Hist. and Gen. Reg. 34, 84–89, 162–166, 297–301, 359–362.

Desjardins, R. 1980. Tremblement de terre et glissements de terrain : corrélation entre les datations au 14C et des données historiques à Shawinigan, Québec. Géographie physique et quaternaire, 34 : 359–362.

Doig, R. 1986. A method for determining the frequency of large magnitude earthquake in lake sediments. Canadian journal of Earth Sciences, 23: 930–937. doi:10.1139/e86-094.

Doig, R. 1990. 2300 yr history of seismicity from silting events in Lake Tadoussac, Charlevoix, Quebec. Geology, 18(9) : 820–823. doi:10.1130/0091-7613(1990)018<0820:YHOSFS>2.3.CO;2.

Doig, R. 1998. 3000-year paleoseismological record from the region of the 1988 Saguenay, Quebec, earthquake. Bulletin of the Seismological Society of America, 88(5) : 1198–1203.

Dubé, S. 1998. Analyse de l'écroulement rocheux du Mont Éboulé, Québec. Mémoire de maîtrise, Département de géologie et de génie géologique, Université Laval, Québec, Qc.

Ebel., J. 2011. A new analysis of the magnitude of the February 1663 earthquake at Charlevoix, Quebec. Bulletin of the Seismological Society of America, Vol. 101, No. 3, pp. 1024–1038, June 2011, doi: 10.1785/0120100190

Filion, L., Quinty, F., and Bégin, C. 1991. A chronology of landslide activity in the valley of Rivière du Gouffre, Charlevoix, Québec. Canadian Journal of Earth Sciences, 28(2) : 250–256. doi:10. 1139/e91-024.

Gouin, P. 2001. Tremblements de terre historiques au Québec: de 1534 à mars 1925, identifiés and interprétés à partir des textes originaux contemporains / Historical earthquakes felt in Quebec : from 1534 to March 1925, as revealed by the local contemporary literature. Montréal : Guérin, 1491 pp.

Halchuk, S; Allen, T I; Rogers, G C; Adams, J; 2015. Seismic Hazard Earthquake Epicentre File (SHEEF2010) used in the fifth generation seismic hazard maps of Canada. Geological Survey of Canada, Open File 7724, 2015, 21 pages, https://doi.org/10.4095/296908

Hodgson, E.A. 1928. The probable epicenter of the Saint-Lawrence earthquake of February 5th 1663. Journal of the Royal Canadian Astronomical Society, 22: 325–334.

Keefer, D.K. 1984. Landslides caused by earthquakes. Geological Society of America Bulletin, 95(4): 406–421.

Lalemant, J. 1663. Relation de ce qui s’est passé ... en Nouvelle France, és années 1662 & 1663. Chapter II: Universal Earthquake in Canadas, and its marvellous effects. In Jesuit Relations, XLVIII, pp. 41-57.

Lamontagne, M., Keating, P. and Perreault, S. 2003. Seismotectonic characteristics of the Lower St. Lawrence Seismic Zone, Quebec: insights from geology, magnetics, gravity, and seismics. Canadian Journal of Earth Sciences, 40(2): 317-336.

Lamontagne, M. 2007. Les dommages dus aux tremblements de terre dans la région de Québec entre 1608 and 2006. Geological Survey of Canada Open File 5547.

Lamontagne, M. 2009. Description and analysis of the Earthquake damage in the Quebec City region between 1608 and 2008, Seismological Research Letters, 80: 514-524.

Lamontagne, M., and Burke, K.B.S. 2018. The 1929 magnitude 7.2 Grand Banks earthquake: felt reports from the dominions of Canada and Newfoundland and islands of Saint-Pierre and Miquelon, France; Geological Survey of Canada, Open File 8353, 1 .zip file. https://doi.org/10.4095/306961

Lamontagne, M., Halchuk, S., Cassidy, J.F. and Rogers, G.C. 2018. Significant Canadian Earthquakes 1600-2017. Open File 8285, 2018, 37 pages, https://doi.org/10.4095/311183.

Lasalle, P., et Chagnon, J.-Y. 1968. An ancient landslide along the Saguenay, River, Quebec. Can. J. Earth Sci., 5(3) : 548–549. doi:10.1139/e68-049.

Levesque, C., Locat, J., et Leroueil, S. 2006. Dating submarine mass movements triggered by earthquakes in the Upper Saguenay Fjord, Quebec, Canada. Norwegian Journal of Geology, 86: 231–242.

Locat, J. 2008. Localisation et magnitude du séisme du 5 février 1663 (Québec) revues à l'aide des mouvements de terrain. In : 4th Canadian Geohazards conference, Québec city, J. Locat, D. Perret, D. Turmel, D. Demers and S. Leroueil Ed Géorisques IV : des causes à la gestion, Québec, Qc., mai 2008, Presses de l'Université Laval, Québec, Qc. p. 429–443.

Locat, J. 2011. La localisation et la magnitude du séisme du 5 février 1663 (Charlevoix) revues à l'aide des mouvements de terrain. Canadian Geotechnical Journal, 48 : 1266-1286.

Locat, J., Dubé, S., and Couture, R. 1997. Analyse de l'écroulement rocheux du Mont Éboulé, Québec. Proceedings of the 50th Canadian Geotechnical conference, Ottawa, BiTech Publishers Ltd., Richmond, C.-B. p. 118–126.

Locat, J., Martin, F., Locat, P., Leroueil, S., Levesque, C., Konrad, J.-M., 2003a Submarine mass movements in the Upper Saguenay Fjord (Quebec, Canada), triggered by the 1663 earthquake. *In*: Submarine mass movements and their consequences. J. Locat and J. Mienert Eds, Kluwer Series on Natural and Technological Hazards. Kluwer Academic Publishers, Dordrecht, Pays-Bas. Vol. 19, p. 497–508.

Locat, P., Locat, J., Leroueil, S., and Duchesne, M.J. 2003b. Characterization of a submarine flow-slide at Pointe-du-Fort, Saguenay Fjord, Quebec, Canada. *In* : Submarine mass movements and their consequences, J. Locat and J. Mienert Eds. Kluwer Series on Natural and Technological Hazards. Kluwer Academic Publishers, Dordrecht, Pays-Bas. Vol. 19, p. 509–518.

Locat, J., Locat, P., and Leroueil, S., 2007. Linking geotechnical and rheological properties from failure to post-failure: the Pointe-du-Fort slide, Saguenay Fjord, Quebec. In Submarine mass movements and their consequences. Lykousis, D. Sakellariou, and J. Locat Eds, Springer, Dordrecht, Pays-Bas. p. 181–189.

Locat, J., Turmel, D., Habersetzer, M., Trottier, A.-P., Lajeunesse, P., and St-Onge, 2016. Earthquake-induced landslides in Lake Éternité, Québec, Canada. In: Submarine Mass Movements and their Consequences, *Advances in Natural and Technological Hazards Research* 41, pp.: 361-370

Ouellet, M. 1997. Lake sediments and Holocene seismic hazard assessment within the St. Lawrence Valley, Québec. Geological Society of America Bulletin, 109: 631–642. doi:10.1130/0016-7606(1997)109<0631:LSAHSH>2.3.CO;2.

Potvin, J., Pellerin, F., Demers, D., Robitaille, F., La Rochelle, P., and Chagnon, J.-Y. 2001. Revue et investigation complémentaire du site du glissement de Saint-Jean-Vianney. Proceedings of the 54th Canadian Geotechnical Conference, Calgary, Calgary, 16–19 septembre 2001, M. Mahmoud, R. van Everdingen and J. Carss, Eds. BiTech Publishers Ltd., Richmond, C.-B. p. 792–800.

Quilliam, L., and Allard, M. 1989. Évolution géomorphologique du glissement de terrain et du marais littoral de Saint-Joseph-de-la-Rive, Charlevoix, Québec. Géographie physique et quaternaire, 43 : 367–376.

Rodríguez, C.E., Bommer, J.J., and Chandler, R.J. 1999. Earthquake induced landslides: 1980–1997. Soil Dynamics and Earthquake Engineering, 18: 325–346. doi:10.1016/S0267-7261(99) 00012-3.

Ruffman, A. 2013. Comment on "A New Analysis of the Magnitude of the February 1663 Earthquake at Charlevoix, Quebec" by John E. Ebel. Bulletin of the Seismological Society of America, 103, No. 5, 2894–2896.

Shilts, W.W., Rappol, M., and Blais, A. 1992. Evidence of late and postglacial seismic activity in the Témiscouata–Madawaska Valley, Quebec – New Brunswick, Canada. Canadian Journal of Earth Sciences, 29(5) : 1043–1069. doi:10.1139/e92-085. areas: 1534–1927.

Smith, W.E.T, 1962. Earthquakes of Eastern Canada and Adjacent areas 1534-1927, Publications of the Dominion Observatory, Vol. 26, no. 5. (https://doi.org/10.4095/8704)

St-Onge, G., Mulder, T., Piper, D.J.W., Hillaire-Marcel, C., and Stoner, J.S. 2004. Earthquake and flood-induced turbidites in the Saguenay Fjord (Québec): a Holocene paleoseismicity record. Quaternary Science Reviews, 23(3–4): 283–294. doi:10.1016/j. quascirev.2003.03.001.

Syvitski, J.P.M., and Schafer, C.T. 1996. Evidences for an earthquake triggered basin collapse in Saguenay Fjord, Canada. Sedimentary Geology, 104(1–4): 127–153. doi:10.1016/0037-0738(95)00125-5.

Urgeles, R., Locat, J., Lee, H., and Martin, F. 2002. The Saguenay Fjord, Quebec, Canada: integrating marine geotechnical and geophysical data for spatial seismic slope stability and hazard assessment. Marine Geology, 185(3–4): 319–340. doi:10.1016/S0025-3227(02)00185-8.

Wood, H.O. and Neumann F. 1931. Modified Mercalli Intensity of 1931. Bulletin of the Seismological Society of America, 21: 277-283.

Appendix 1: Modified Mercalli Intensity Scale (Verbatim from Wood and Neumann, 1931)

I. Not felt -- or, except under especially favorable circumstances.

Under certain conditions, at and outside the boundary of the area in which a great shock is felt:

- sometimes birds, animals, reported uneasy and disturbed;
- sometimes dizziness or nausea experienced;
- sometimes trees, structures, liquids, bodies of water, may sway; doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive or nervous persons.

Also, as in grade I, but often more noticeably:

- sometimes hanging objects may swing, especially when delicately suspended;
- sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly;
- sometimes birds, animals, reported uneasy and disturbed;
- sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration.

- Sometimes not recognized to be an earthquake at first.
- Duration estimated in some cases.
- Vibration like that due to the passing of light or lightly loaded trucks or heavy trucks some distance away.
- Hanging objects may swing slightly.
- Movements may be appreciable on upper levels of tall structures.
- Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few.

- Awakened few, especially light sleepers.
- Frightened no one, unless apprehensive from previous experience.

- Vibration like that due to the passing of heavy or heavily loaded trucks.
- Sensation like heavy body striking building or falling of heavy objects inside.
- Rattling of dishes, windows, doors; glassware and crockery clink and clash.
- Creaking of walls, frame, especially in the upper range of this grade.
- Hanging objects swung, in numerous instances.
- Slightly disturbed liquids in open vessels. Rocked standing motor cars noticeably.

V. Felt indoors by practically all, outdoors by many or most: outdoors direction estimated.

- Awakened many, or most.
- Frightened few -- slight excitement, a few ran outdoors.
- Buildings trembled throughout.
- Broke dishes, glassware, to some extent.
- Cracked windows -- in some cases, but not generally.
- Overturned vases, small or unstable objects, in many instances, with occasional fall.
- Hanging objects, doors, swing generally or considerably.
- Knocked pictures against walls, or swung them out of place.
- Opened, or closed, doors, shutters, abruptly. Pendulum clocks stopped, started, or ran fast, or slow.
- Moved small objects, furnishings, the latter to slight extent.
- Spilled liquids in small amounts from well-filled open containers.
- Trees, bushes, shaken slightly.

VI. Felt by all, indoors and outdoors.

- Frightened many, excitement general, some alarm, many ran outdoors.
- Awakened all.
- Persons made to move unsteadily.
- Trees, bushes, shaken slightly to moderately.

- Liquid set in strong motion.
- Small bells rang -- church, chapel, school, etc.
- Damage slight in poorly built buildings.
- Fall of plaster in small amount.
- Cracked plaster somewhat, especially fine cracks; chimneys in some instances.
- Broke dishes.
- Fall of knick-knacks, books, pictures.
- Overturned furniture in many instances.
- Moved furnishings of moderately heavy kind.

VII. Frightened all -- general alarm, all ran outdoors.

- Some, or many, found it difficult to stand.
- Noticed by persons driving motor cars.
- Trees and bushes shaken moderately to strongly.
- Waves on ponds, lakes, and running water.
- Water turbid from mud stirred up.
- Incaving to some extent of sand or gravel stream banks.
- Rang large church bells, etc.
- Suspended objects made to quiver.
- Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc.
- Cracked chimneys to considerable extent, walls to some extent.
- Fall of plaster in considerable to large amount, also some stucco.
- Broke numerous windows, furniture to some extent.
- Shook down loosened brickwork and tiles.
- Broke weak chimneys at the roof-line (sometimes damaging roofs).
- Fall of cornices from towers and high buildings.

- Dislodged bricks and stones.
- Overturned heavy furniture, with damage from breaking.
- Damage considerable to concrete irrigation ditches.

VIII. Fright general -- alarm approaches panic.

- Disturbed persons driving motor cars.
- Trees shaken strongly -- branches, trunks, broken off, especially palm trees.
- Ejected sand and mud in small amounts.
- Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters.
- Damage slight in structures (brick) built especially to withstand earthquakes.
- Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling.
- Fall of walls.
- Cracked, broke, solid stone walls seriously.
- Wet ground to some extent, also ground on steep slopes.
- Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers.
- Moved conspicuously, overturned, very heavy furniture.

IX. Panic general.

- Cracked ground conspicuously.
- Damage considerable in (masonry) structures built especially to withstand earthquakes:
- threw out of plumb some wood-frame houses built especially to withstand earthquakes;
- great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames;
- serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks.

- Landslides considerable from river banks and steep coasts.
- Shifted sand and mud horizontally on beaches and flat land.
- Changed level of water in wells.
- Threw water on banks of canals, lakes, rivers, etc.
- Damage serious to dams, dikes, embankments.
- Severe to well-built wooden structures and bridges, some destroyed.
- Developed dangerous cracks in excellent brick walls.
- Destroyed most masonry and frame structures, also their foundations.
- Bent railroad rails slightly.
- Tore apart, or crushed endwise, pipe lines buried in earth.
- Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material.

- Broad fissures, earth slumps, and land slips in soft, wet ground.
- Ejected water in large amount charged with sand and mud.
- Caused sea-waves ("tidal" waves) of significant magnitude.
- Damage severe to wood-frame structures, especially near shock centers.
- Great to dams, dikes, embankments, often for long distances.
- Few, if any (masonry), structures remained standing.
- Destroyed large well-built bridges by the wrecking of supporting piers, or pillars.
- Affected yielding wooden bridges less.
- Bent railroad rails greatly, and thrust them endwise.
- Put pipe lines buried in earth completely out of service.

XII. Damage total -- practically all works of construction damaged greatly or destroyed.

- Disturbances in ground great and varied, numerous shearing cracks.

- Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive.
- Wrenched loose, tore off, large rock masses.
- Fault slips in firm rock, with notable horizontal and vertical offset displacements.
- Water channels, surface and underground, disturbed and modified greatly.
- Dammed lakes, produced waterfalls, deflected rivers, etc.
- Waves seen on ground surfaces (actually seen, probably, in some cases).
- Distorted lines of sight and level.
- Threw objects upward into the air.