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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8285

Significant Canadian earthquakes 1600–2017

M. Lamontagne, S. Halchuk, J.F. Cassidy, and G.C. Rogers

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Canada

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Significant Canadian earthquakes 1600–2017

Abstract

This Open File provides the most up-to-date information on the significant earthquakes of Canada for the period 1600 to 2017 inclusively. In addition to slight adjustments to a previously published Open File (Lamontagne et al., 2007), the current Report adds some significant earthquakes that occurred between 2007 and 2017 inclusively. In light of ongoing research, a number of updates were also included, together with the justifications for the changes. When available, maps based on macroseismic surveys or Did-You-Feel-It reports were also joined. As in the previous Open File Report, earthquakes are considered significant if their magnitude, estimated from felt reports or scaled from records, exceeded 6.0 on the Richter scale or if they had been felt by many Canadians at Modified Intensity VI or stronger. A total of 172 events were selected for the period 1600-2017. The information is provided in a Microsoft Excel sheet that provides for each event: the source information (Origin Time, Latitude, Longitude, Depth, Region, Magnitude); the impact (associated landslide(s), tsunami, damage to buildings, deaths, Maximum Modified Mercalli Intensity in Canada); a description of the event; the source of information and web links for additional information in English and French.

Objective

This Open File (OF) Report provides the most up-to-date information on significant Canadian earthquakes between 1600 and 2017. Publishing the results and methodology in this Open File Report is a means of properly documenting each earthquake and insuring peer-review by Geological Survey of Canada seismologists. This OF updates OF 5539 that covered the time period 1600 to 2006 (Lamontagne et al., 2007). In light of ongoing research, a number of updates were also included, together with the justifications for the changes. Methodologies are similar. When the information previously published in OF5539 is updated, the cell in the spreadsheet is highlighted in yellow for eastern Canadian earthquakes or orange for western Canadian earthquakes.

We are confident that the information contained in this table will be used in a number of other applications, notably web sites on earthquakes. We encourage users of this information to read the field descriptors to avoid possible pitfalls or misconceptions about certain seismological aspects. The list itself is presented as a Microsoft Excel spreadsheet. We have also added two sheets: one with events that because of new magnitude estimates, do not meet the selection criteria and the other one with the original descriptions of Lamontagne et al. (2007). The following sections explain how to use the information it contains. To ease the consulting of the data and put them in a geographic context, a kmz file is added and can be viewed using the GoogleEarth software that can be downloaded at: https://www.google.com/earth/download/ge/

Static images of the Google Earth displays are shown as Figures 1, 2 and 3.

Selection of earthquakes

To decide if an earthquake is "significant", criteria such as number of deaths, damage, magnitude or maximum intensity could be used. Each category sets limits on the number of events and on the completeness of the list. Since the list will be used to enhance the awareness of the Canadian public to earthquake hazards, the authors decided to choose events that caused some minimal damage, or could have caused damage had they occurred close to inhabited regions. For this reason, the authors selected known earthquakes larger than *magnitude*[1] 6.0 (estimated from felt reports or scaled on records) as well as some smaller ones felt by many Canadians.

Each earthquake of the list met one or more of the following criteria.

1. The preferred magnitude (either instrumental magnitude, or estimated magnitude from damage or felt-area information) is 6.0 or greater. See the discussion below on the choice of the preferred magnitude.

[1] Most seismological terms are defined in the glossary at the end of the Open File.

2. The earthquake had some impact on the built environment (starting from light damage such as broken pipes or chimneys, i.e. Modified Mercalli Intensity VI) or on the natural environment (liquefaction, landslides, rock falls, tsunamis).

3. The earthquake was felt by a significant number of Canadians.

4. The earthquake occurrence is supported by paleoseismological evidence (only the 1700 Cascadia earthquake met this criterion, since other paleo-earthquakes are too uncertain in location, origin time and magnitude).

In addition to these criteria, we subjectively qualified the significance of the earthquake from damage information and magnitude. We rated them from major (***), moderately significant (**), significant (*), or weakly significant < ~ > (generally remote from inhabited areas, weakly or not felt).

Completeness and Precision of Source Information

The list is not and cannot be complete for the whole of the Canadian territory for the entire period 1600-2017. This list of significant Canadian earthquakes is as complete as possible at the time of writing. It is possible that future studies will reveal hitherto unknown events or will modify our knowledge of some of these events. Due to the nature of documenting earthquakes, such modifications to the list are more probable for pre-instrumental data.

Prior to the introduction of seismographs in the late 19th century, earthquake occurrences were only known through historical accounts (felt information). If an earthquake was sufficiently large or sufficiently close to inhabited regions, it could be reported in personal accounts, diaries or newspapers. This implies that pre-instrumental earthquakes are only known if they had been felt by people who reported what they felt in documents that were preserved and indexed. Consequently, our knowledge of pre-instrumental earthquakes depends entirely on how the population with written history (as opposed to the oral tradition) was distributed as a function of time. This explains the more numerous pre-1850's earthquake occurrences in eastern Canada

versus western and northern Canada. These information sources were used to create a series of earthquake catalogues which we used to define our list.

Towards the end of the 19th century, seismographs were progressively installed in Canada. These early instruments were not very well adapted to recording local events and could only detect large, distant earthquakes (teleseisms). They were insensitive to earthquakes of magnitude less than about 5. More sensitive, short-period seismographs only began regular operations at the beginning of 1928 (Smith, 1962). Slowly, the number of stations increased and the ability to record local earthquakes increased. It is only after 1950 that that all earthquakes of magnitude 6.0 or larger could be detected over the whole Canadian territory (Basham et al., 1982).

Source parameters

In a manner similar to the completeness of earthquake reporting, the precision of the source parameters of the selected earthquakes has improved over the years. The sections below examine in more detail the uncertainty of the source parameters; origin time; location (latitude and longitude, depth) and magnitude.

1. **Origin Time**

The list provides both the origin time of earthquakes in local and in Universal Coordinated Time.

Historical earthquakes of the 17th, 18th and 19th centuries are reported with their approximate local time. In some cases, the best estimate of the origin time is the part of the day (day, morning, afternoon, evening, night). Burke (2007) discusses a method to calculate approximate Universal Time for earthquakes of the Pre-standard time era. Telegraphs associated with railroads were to improve the situation.

Events after the early 20th century were recorded by one or more seismographs and are reported according to Coordinated Universal Time (UTC). Most dates (year/month/day) and times (hour:minute:seconds) are listed in UTC. This is the modern equivalent of Greenwich Mean

Time (GMT) and is 5 hours later than Eastern Standard Time (EST), 8 hours later than Pacific Standard Time (PST). The difference is 4 and 7 hours respectively when compared with Daylight Saving Time, a concept that started during the First World War without being consistently applied since then or across Canada. To help readers, the local time is also provided for events that were largely felt. This leaves out numerous offshore events that were too small or too distant to be felt by human beings. Please note that it is possible that the date of origin of an event is different in local time and universal time (for example the 1925 Charlevoix earthquake occurred on February 28 at 21:19 local time and is listed as March 1st at 02:19 U.T.).

For a lack of clarity in the written documents, it is difficult for some pre-instrumental earthquakes to assign a definite the local time (and as a consequence an universal time). For these, no local or U.T. is given and the field is left blank..

2. Location (Region, Area, Latitude, Longitude, Depth)

The location of an earthquake refers to the position of its *epicentre* (latitude and longitude). To give readers a quick reference to the location of the epicentre, we have defined, for each event, a region of Canada (E: East; N: North; W: West) and a geographic area. The regions of Canada are: East- Ontario and provinces to the east; West- Manitoba and provinces to the west; North- territories. Epicentres are given in terms of geographic latitude (decimal degrees North) and longitude (decimal degrees West). Since we included events with impact in Canada, some earthquakes have their epicentres on the U.S side of the border or in international waters. The epicentres of pre-20th century earthquakes are generally not as well defined as the more recent or instrumentally-recorded earthquakes. For pre-instrumental earthquakes, locations are approximated from felt information (where the epicentre is the centre of the felt area) or reports of damage (where the epicentre is generally the region of most significant damage).

Instrumentally-recorded earthquakes are located using the arrival times of seismic waves. As the precision of these locations depend on the density and characteristics of the seismograph stations, more recent earthquakes are generally better located than older ones. In some cases, the location of aftershocks with a temporary network of seismographs provided an indirect means to locate

the main shock with increased precision. Figures 1 provides the location of the epicentres, with more detailed views in Figures 2 and 3 for Western and Eastern Canada respectively.

The epicentres listed are chiefly those found in the Canadian Earthquake Database used for seismic hazard calculations (Halchuk et al., 2015). This database has some earthquakes not listed in the latter: events that did not meet the completeness criteria of Halchuk et al. (2015) and those for which a revision was warranted by recent research. We have tried to list the best assumed epicentre, taken either from the earthquake database or representing the most recent review of the epicentre. In addition, the authors subjectively defined a qualifier to define an approximate precision of the epicentre: Quality A refers to ± 5 km or better, B: ± 10 km, C: ± 20 km; D: ± 50 km or worse. Quality A is generally assigned to earthquakes that occurred within a dense network of stations or to earthquake locations that were refined due to an aftershock survey.

One should note that large earthquakes (with magnitude larger than 8) are not point sources and should not be represented simply by the point that represents their epicentres. Instead, it is preferable to represent the earthquake source of these large events as a fault surface for the 1700 megathrust earthquake or as a fault line for the 1949 Queen Charlotte Islands earthquake (Figure 2).

Focal depth can only be estimated from instrumental data and for this reason, only earthquakes recorded after the early 20th century have this information. Depth of the focus (hypocentre) is given in kilometers below sea level. In general, all eastern and northern Canadian earthquakes occur in the upper 30 kilometers of the Earth's crust. Beneath British Columbia, earthquakes can occur within the continental crust as well as well below the continental crust. If the exact focal depth cannot be determined, it is fixed to a value representative of events in the area and given with (F). An 'x' means that the exact value is unknown.

3. Magnitude (Preferred Magnitude, Magnitude Type, Other magnitudes)

The magnitude of an earthquake is a convenient way of representing the size of an earthquake. First formulated in 1935, the local magnitude (M_L) scale was defined for moderate-size ($3 < M_L < 7$) earthquakes in southern California that occurred within 600 km of a Wood-Anderson seismograph. The M_L scale corresponds to the "Richter scale". All of the currently used scales for rating earthquake magnitudes (duration (m_D); surface-wave (M_S), body-wave (m_b), moment (M_w or **M**), etc.) yield results that are only consistent with M_L over a limited range of magnitude. The most consistent estimate of earthquake size across a wide range of magnitudes is the moment magnitude (M_w or **M**). This magnitude is based on the seismic moment which, unlike most scales derived from seismic phase amplitudes, does not saturate with earthquake size. For this reason, the moment magnitude best quantifies an earthquake. In eastern North America, a specific magnitude, m_b(Lg) was defined by Otto Nuttli based on the largest body wave amplitude (Lg) seen on vertical seismograms for continental paths. In eastern Canada, the GSC uses a variation of the m_b(Lg) scale, called the Nuttli magnitude (M_N). Historical earthquakes, not recorded on seismographs, are sometimes scaled on the felt area magnitude (m_{FA}) or given a corresponding m_N value estimated from empirical felt area- m_N relationship.

In this list, several magnitude types are used:

- M_L - Local, or Richter magnitude.
- M_N - Nuttli, or body wave magnitude (m_b(Lg)). Used for earthquakes in eastern Canada.
- M_w or **M** - Moment magnitude.
- m_B and M_S - Compressional body wave by Gutenberg and surface wave magnitudes.
- m_{FA} and M_f (IV) - felt area magnitude and magnitude based on the Modified Mercalli Intensity IV area.

There are numerous magnitude scales and for this reason, it is difficult to give the best magnitude rating for an event. The authors have chosen to use the Moment Magnitude rating as the primary magnitude when available. If the moment magnitude was unknown (for pre-instrumental events for example) the magnitude chosen was the best estimate from the information available. For some historical events, the authors chose not to use decimal units but rounded off the magnitude to the nearest ½ magnitude unit to reflect the very approximate

magnitude value. For earthquakes prior to about 1955, earthquake magnitudes were not calculated on a routine basis and only a few were studied in detail to determine their magnitude ratings. For most, the magnitude rating is approximate and is identified as other (OT). This includes some events for which the magnitude is estimated by comparing felt effects with more recent earthquakes in the same region.

4. Area

The Area descriptor is a general term that refers to the epicentral region of the earthquake.

5. Impact

Three fields related to the impact of earthquakes are defined: landslides, tsunamis and damage to buildings and structures. In general, we refer to the impact in Canada unless identified as damage in the USA. Landslides include any mass movement triggered by the earthquake-generated ground vibrations, such as earth flows, rock avalanches, rock falls, rotational landslides, slumps, etc. For convenience, liquefaction and sand expulsions are included in this group. Tsunamis are sea waves generated by the motion of the sea floor through direct rupture or by mass movement induced by the ground vibrations or by co-seismic rupture. Damage to buildings and structures includes any type of building/structure damage from light damage (cracks in plaster of walls for example) through cracked chimneys, up to collapse of buildings or other structures.

6. Deaths and Cause of deaths

There are no known documented cases of deaths directly caused by Canadian earthquakes, although two deaths are suspected to have occurred during the 1870 Charlevoix-Kamouraska earthquake (Lamontagne, 2008). There were however, indirect deaths, such as those caused by the Laurentian slope earthquake of 1929. The earthquake generated a massive submarine slump (landslide) that induced a large ocean wave (tsunami) which killed 27 people when it struck the Burin Peninsula of Newfoundland (plus one person who died from her injuries years later).

Native oral traditions also tell of entire villages on Vancouver Island being drowned by the tsunami caused by the year 1700 earthquake. The 1946 Vancouver Island earthquake caused one death in Canada: one person drowned when a small boat capsized in a landslide-generated wave (Hodgson, 1946). Other indirect casualties include people who die of heart attacks but their numbers are generally poorly known.

7. Maximum Intensity on the Mercalli Scale

The maximum intensity provided herein is that which was experienced on Canadian territory. It is not necessarily the maximum intensity recorded for that earthquake, most notably for earthquakes with epicentres located on US territory.

Although many intensity scales exist, the Modified Mercalli Intensity (MMI) Scale is the most commonly used for North American earthquakes (Appendix 1). The MMI scale is designated by Roman numerals that range from no perceptible shaking (I) to catastrophic destruction (XII). Please note that "not felt" can also be rated as (0). Although intensity values are related to ground shaking levels, the MMI scale does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects. Intensity scales differ from the magnitude scales in that the effects of an earthquake of a given magnitude vary greatly from place to place, so there may be many intensity values (e.g.: IV, VII) determined from one earthquake. For that earthquake, there is only one value of a given type.

The MMI scale and isoseismal maps are not ideal to describe all possible consequences of an earthquake. First, rating intensity can be subjective since any level covers a range of effects on humans, structures and the natural environment. Some analysts look for many effects before assigning the level, whereas others consider the maximum level witnessed in a given area. Second, intensity reports only come from inhabited areas, which leave out many sparsely populated areas. In the 20th century, questionnaires were mailed to town postmasters who could only describe what they knew of the local impact. Nowadays, anyone who feels an earthquake can fill out internet-based questionnaires, providing a better sampling of the maximum local

impact. When the only descriptor was felt or felt widely, without damage, MMI III was assigned.

8. **Description**

The description provides basic information on the earthquake itself or on its consequences.

9. **Sources**

For each earthquake, the sources of information are provided. The list is not exhaustive.

10. **Links (English)**

Readers are referred to these links on the Earthquakes Canada website (EarthquakesCanada.ca) for more information on specific earthquakes in or near Canada (including photographs of damage and isoseismal maps). More extensive information on earthquakes in the neighbouring United States can be found on the United States Geological Survey's Earthquakes Hazard Program site at earthquake.usgs.gov

Differences from existing earthquake catalogues

Readers may find that the current list of significant earthquakes is different from previous earthquake catalogues. Here are some differences and the rationale behind these changes.

1. **False events**

There are a few instances of false or 'ghost' events. One of them is the 1534 pseudo-earthquake that was supposed to have occurred between the two voyages of Jacques Cartier in Canada (1534-1535). This possibility was discarded by Gouin (1994). This 'ghost' event does not appear in the list.

2. New events and modified information on events

The works of Gouin (2001) for Quebec and of Burke (2004) for New Brunswick have brought to light new information on many pre-instrumental earthquakes. Numerous epicentres, magnitudes and origin times were re-evaluated.

An event was previously listed as 1831-07-14. According to Gouin (2001), no earthquake occurred on that date (contrary to Smith, 1962). In this table, it is listed as 1831-07-07 or 1831-07-08 since it occurred during the night without any indication of the time of occurrence.

For the event on 1842-11-07: according to Gouin (2001), the earthquake occurred on 1842-11-07 not on 1842-11-09 (contrary to Smith, 1962). There are reports written on Nov. 07 for this earthquake.

The event on 1869-10-22 was formerly located at Passamaquoddy Bay, New Brunswick (45.0N, 67.2W) but Burke (2004) suggests a more central New Brunswick location which we used in this table.

The earthquake of 1880-11-29 was wrongly listed as 1880-11-28 in Dawson and in Smith (Gouin, 2001).

The epicentre of the earthquake of 1872-12-15 was modified slightly from that of Bakun et al. (2002) based on information in Brocher et al. (2017).

The following earthquakes have magnitudes < 6.0 and were not reported felt in Canada. Since they were in Lamontagne et al. (2007), we have decided to list them but out of the main Excel sheet. Their information was corrected to the new values and their fields were moved to the other sheet entitled “other-earthquakes”.

1. 1917-07-01 Calculations from Victoria Seismograph log books estimate 53, -133 and M about 5.5.

2. 1917-12-23 Calculations from Victoria Seismograph log books estimate 53.5, -133 and M about 5.0.
3. 1935-07-06 Location from Doser (2001) together with felt information suggest a magnitude of about 5.
4. 1939-02-08 ISC-GEM V5 calculates magnitude Mw 5.91 +/- 0.37.
5. 1941-10-01 Magnitude estimated at about 5.5.
6. 1941-11-06 Magnitude estimated at about 5.
7. 1947-04-30 Magnitude estimated at about 5.5.

GoogleEarth file

To ease the consulting of the data and put them in a geographic context, a kmz file is added and can be viewed using the GoogleEarth software that can be downloaded at: https://www.google.com/earth/download/ge/

Static images of the Google Earth displays are shown as Figures 1, 2 and 3.

Conclusion

The list of earthquakes provides the most up-to-date compilation of significant Canada earthquakes and of their impact for the period 1600-2017. In addition to slight adjustments to a previously published Open File (Lamontagne et al., 2007), the current Report adds some significant earthquakes that occurred between 2007 and 2017 inclusively.

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Appendix 1: Modified Mercalli Intensity Scale (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.

Glossary

Active fault:

A fault along which slip has occurred in recent geological time, or where earthquake foci are located.

Aftershock:

An earthquake that occurs after a "mainshock" (or larger earthquake). Aftershocks occur in the same general region as the "mainshock" and result from readjustments of stress at places along the fault zone. For great earthquakes (M=8) aftershocks may occur over hundreds of kilometres. Depending on the size, and depth of the earthquake, aftershocks may occur for many months after the mainshock. However, both the size, and the rate of aftershock activity dies off quickly with time.

Body wave:

A seismic wave that can travel through the interior of the earth. P-waves and S-waves are body waves.

Body-wave magnitude:

Magnitude of an earthquake as estimated from the amplitude of body waves.

Coda:

The concluding train of seismic waves that follows the principal waves from an earthquake.

Crust (of the Earth):

The layer of rock located immediately below the earth's surface. Beneath continents, it is typically about 35 km thick, and composed of granite. Under the ocean, the crust is about 5-10 kilometres thick and composed mainly of basalt.

Continental shelf:

Part of the continental margin between the coast and the continental slope.

Depth of an earthquake:

The value given is the depth below the surface of the mean spheroid.

Earthquake:

The sudden release of stored elastic energy caused by the sudden fracture and movement of rocks along a fault. Some of the energy released is in the form of seismic waves, that cause the ground to shake.

Earth's crust:

The layer of rock located immediately below the earth's surface. Beneath continents, it is typically about 35 km thick, and composed of granite. Under the ocean, the crust is about 5-10 kilometres thick and composed mainly of basalt.

Elastic wave:

A wave that is propagated by some kind of elastic deformation, that is, a change in shape that disappears when the stresses are removed. A seismic wave is a type of elastic wave.

Epicentre:

The point on the earth's surface directly above the focus (hypocentre) of an earthquake.

Fault:

A zone of fractures or breaks in rocks where movements occur. Earthquakes often occur along faults because they can be weak zones in the rock.

First arrival:

The first recorded signal attributed to seismic wave travel from a source.

Foreshock:

An earthquake that is smaller than, and precedes, a "mainshock". Foreshocks tend to occur in the same area as the mainshock.

Great Earthquake:

An earthquake having a magnitude of 8 or greater.

Hypocentre:

The subsurface location (focus) at which the energy of an earthquake is released. Earthquakes generally occur at depths less than about 30 km, but may occur to a depth of 600 km or more in some areas.

Intensity:

The Modified Mercalli Scale is a numerical scale used to categorize earthquakes based on descriptions of how the earthquake was felt. These effects may range from I (not felt except by a very few under a especially favorable conditions) and XII (total damage).

Interplate earthquake:

Earthquake with its focus on a plate boundary. Offshore earthquakes of western Canada are of this type.

Intraplate earthquake:

Earthquake with its focus within a tectonic plate. Eastern Canadian earthquakes are of this type.

Landslide:

An abrupt movement of geological materials downhill in response to gravity. Landslides can be triggered by an earthquake or other natural causes. Undersea landslides can cause tsunamis, such as the one triggered by the 1929 Grand Banks earthquake.

Latitude:

The location of a point north or south of the equator. Latitude is shown on a map or globe as east-west lines parallel to the equator.

Liquefaction:

The process in which a granular solid (soil) takes on the characteristics of a liquid as a result of an increase in pore pressure and a reduction in stress. In other words, solid ground looses cohesion and starts flowing like a liquid.

L_g Wave:

A surface wave which travels through the continental crust. This wave type is the one which causes damage during large Eastern Canadian earthquakes.

Longitude:

The location of a point east or west of the prime meridian. Longitude is shown on a map or globe as north-south lines left and right of the prime meridian, which passes through Greenwich, England.

Mainshock:

The largest earthquake in a "cluster" of earthquakes. Mainshocks are sometimes precede by "foreshocks", and generally followed by aftershocks.

Major Earthquake:

An earthquake having a magnitude of 7 to 7.9.

Magnitude:

Magnitude is a measure of the amount of energy released during an earthquake. All magnitude scales are calibrated to the original magnitude scale defined by Richter. See text for more details.

Mantle (of the Earth):

The main bulk of the Earth, between the crust and the core, ranging from depths of about 40 to 3470 kilometers. It is composed of dense silicate rocks and divided into a number of concentric shells. Under Eastern Canada, it can be found at around 40 km depth and west of the Rocky Mountains it is at a depth of about 30 km.

Moderate earthquake:

An earthquake having a magnitude of 5 to 6 on the Richter scale.

Modified Mercalli Intensity Scale:

The Mercalli scale rates the intensity of shaking from an earthquake. The ratings vary from I (felt only under especially favourable circumstances) to XII (total destruction). See Appendix 1 for details.

Moment (Seismic moment of earthquakes):

A measure of earthquake size related to the leverage of the forces (couples) across the area of the fault slip. The rigidity of the rock times the area of faulting times the amount of slip. Dimensions are dyne-cm (or Newton-meters).

Moment magnitude (M_W):

Magnitude of an earthquake estimated by using the seismic moment.

Origin time:

The exact time at which an earthquake occurred.

P wave:

Also called primary, longitudinal, irrotational, push, pressure, dilatational, compressional, or push-pull wave. P waves are the fastest body waves and arrive at stations before the S waves, or secondary waves. Their velocity in the crust varies between 5.0 and 7.0 km/s. The waves carry energy through the Earth as longitudinal waves, moving particles in the same line as the direction of the wave. P waves can travel through all layers of the Earth. P waves are generally felt by humans as a bang or thump.

Passive margin:

Continental margin formed during initial rifting apart of continents to form an ocean; frequently has thick sedimentary deposits.

Paleoseismology:

The study of ancient (prehistoric) earthquakes from their geological evidences.

Phase: (seismic)

The onset of a displacement or oscillation on a seismogram indicating the arrival of a different type of seismic wave.

Plates and plate tectonics:

The crust and upper mantle of the earth are made up of about a dozen large plates and several smaller ones that are constantly moving. The movements are very slow - only a few centimetres per year. Where the plates rub against one another, strain builds up, especially at the edges. When the strength of the rock is exceeded, the earth's crust may break and suddenly shift causing an earthquake.

Precursor:

A change in the geological or geophysical conditions that is a forerunner to earthquake generation on a fault. Precursors have not been reliably recognized as such beforehand.

Runup height:

The elevation of the water level above the immediate tide level when a tsunami runs up onto the coastal land.

Rupture Zone:

The area of the Earth through which faulting occurred during an earthquake. For very small earthquakes, this zone could be a few millimeters long, but in the case of a great earthquake, the rupture zone may extend several hundred kilometres in length and tens of kilometres in width.

S wave:

Also called shear, secondary, rotational, tangential, equivoluminal, distortional, transverse, or shake wave. These waves carry energy through the Earth in very complex patterns of transverse (crosswise) waves. These waves move more slowly than P waves, but in an earthquake they are usually bigger. S waves cannot travel through fluids, such as air, water or molten rock.

Seiche:

A free or standing wave oscillation of the surface of water in an enclosed basin that is initiated by local atmospheric changes, tidal currents, or earthquakes. Similar to water sloshing in a bathtub.

Seismic:

Having to do with earthquakes or elastic waves.

Seismic moment:

See **Moment** (of earthquakes).

Seismic Sea Wave:

A tsunami (see below) generated by an undersea earthquake.

Seismic Zone:

A region in which earthquakes are known to occur.

Seismicity:

The occurrence of earthquakes in space and time.

Seismogram:

Recording of ground motions made by a seismograph.

Seismograph:

A very sensitive instrument used to record and measure earthquakes. During an earthquake, vibrations initiated by fracturing of the earth's crust radiate outward from the point of fracture and are detected by seismographs. The visual record produced is called a seismogram. Seismographs have become increasingly more sensitive through time.

Seismology:

The study of earthquakes, seismic sources, and wave propagation through the Earth.

Seismometer:

The sensor part of the seismograph, usually a suspended pendulum.

Seismotectonics:

The study of earthquakes and their relationships with faults.

Slip (fault):

The relative motion of one face of a fault relative to the other.

Soil amplification:

Increase in the amplitude of earthquake ground motions when seismic waves pass from rock into less rigid material such as soil. This amplification generally lessens as the shaking becomes stronger.

Strike of fault:

The line of intersection between the fault plane and the surface of the Earth. Its orientation is expressed as the angle west or east of true north.

Strong ground motion:

The shaking of the ground near an earthquake source made up of potentially damaging seismic waves of various types.

Subduction Zone:

A region where the earth's plates collide, with one plate sliding beneath the other. The world's largest earthquakes occur along this type of plate boundary. The Cascadia subduction zone, extending from northern California to the north end of Vancouver Island, is one such area. The subducting oceanic plate is about 40 km beneath Victoria, BC, and about 70 km beneath Vancouver.

Surface Waves:

Waves that move along the surface of the Earth. Rayleigh and Love waves are surface waves.

Surface-wave magnitude: M_S

Magnitude of an earthquake estimated from measurements of the amplitude of surface waves.

Swarm: (or Earthquake swarm)

A series of minor earthquakes, none of which may be identified as the main shock, occurring in a limited area and time.

Teleseism:

An earthquake that is distant (usually more than 2000 km) from the recording station.

Tidal wave:

See **Tsunami**.

Transform fault:

A strike-slip fault connecting the ends of an offset in a midoceanic ridge, an island arc, or an arc-ridge chain. Pairs of plates slide past each other along transform faults.

Tsunami:

(Japanese for "Harbour Wave"). A series of huge ocean waves caused by a rapid, large-scale disturbance of the sea water, such as a major earthquake beneath the seabed that causes large vertical movements. In deep water, tsunami waves are less than a metre high, but they can travel at speeds exceeding 800 kilometres per hour and can easily cross an entire ocean basin. When they reach shallow water or narrow inlets the waves slow down and the height builds up which can cause devastation on shore. The term “tidal wave” is sometimes incorrectly used to describe this phenomenon. Tsunamis are not tidal in nature.

Unconsolidated:

Loosely arranged, not cemented together, so particles separate easily.

UTC:

Coordinated Universal Time. A modern continuation of the Greenwich Mean Time (GMT), which is the mean solar time on the meridian of Greenwich, England. UTC is referenced to atomic clocks and is the international standard on which civil time is based.

Figure captions:

Figure 1: Significant earthquakes in or near Canada 1663-2017. This is a static image of the Google Earth displays; users should use GoogleEarth with the file SigEQ.kmz to get enhanced views of the seismicity.

Figure 2: Significant earthquakes in or near southwestern Canada, 1700-2017 with dates of earthquakes with some impact. The fault ruptures of the M9 1700 Cascadia earthquake is shown as a white surface. The surface ruptures of the 1899 M 8.0 Yakutat and the M 8.1 1949 Queen Charlotte earthquake are shown as red lines. This is a static image of the Google Earth displays; users should use GoogleEarth with the file SigEQ.kmz to get enhanced views of the seismicity.

Figure 3: Significant earthquakes in or near southeastern Canada, 1663-2017 with dates of earthquakes with some impact. This is a static image of the Google Earth displays; users should use GoogleEarth with the file SigEQ.kmz to get enhanced views of the seismicity.