Earthquakes in Canada
Accompanying Notes to "Shake It Up!"

J.M. Aylsworth
Geological Survey of Canada, Natural Resources Canada

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Where do earthquakes happen?

- Earthquakes occur all over the world; however, a significant trend is obvious.
- Ninety-five percent of the world's earthquakes occur on active faults that form the boundaries of the major tectonic plates of the Earth.
- The "Ring of Fire", circling the Pacific Ocean, and including Canada's west coast, is one of the most active areas of earthquake and volcanic activity in the world.

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Tectonic Plates

- The earth's outermost layer of crust and upper mantle is fragmented into a number of "tectonic plates".
- Due to the heating and cooling of the rock below these plates, the resulting convection causes the adjacently overlying plates to move, and, under great stress, deform. The rates of plate movements range from about 2 to 12 cm per year.
- 95% of earthquakes occur on active faults that form the boundaries of the major tectonic plates of the Earth.

What causes earthquakes?

- Earthquakes are the result of a sudden release of energy when rocks under stress slide abruptly past one another along a break (fault) in the Earth's crust. Earthquakes are caused by the slow deformation of the outer, brittle portions of tectonic plates. Sometimes, tremendous energy can build up within a single, or between neighbouring plates. If the accumulated stress exceeds the strength of the rocks making up these brittle zones, the rocks can break suddenly, releasing the stored energy as an earthquake.

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Movement of tectonic plates
The arrows on the map indicate the direction of plate movement.
There are 3 types of movement:

1. **Divergent**: Plates move away from each other along a zone of upwelling convection. E.g. Mid-Atlantic Ridge
2. **Convergent**: Plates move towards each other, causing one plate to override the other one, forcing it to descend ('**subduct**') towards the interior of the Earth and melt back into the mantle. E.g. Juan de Fuca Plate is subducting beneath the North American Plate.
3. **Transform**: Plates move in opposing directions past each other.

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What happens?

- The location within the Earth where the break or rupture occurs is called the **FOCUS**.
- The **EPICENTRE** is the location on the Earth's surface directly above the focus.
- A **fault** is a zone of fractures or breaks in rocks where movements occur. Some faults may reach the surface and, in a large earthquake, displacements of the ground may sometimes be observed along the fault at the surface.
- Earthquake **waves** radiate outwards from the focus. What we feel during an earthquake is the vibration of these waves on the surface.

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What are earthquake (seismic) waves?

- During an earthquake, seismic waves are the vibrations that are initiated by fracturing of the Earth's crust and radiate outward from the point of fracture.
- There are several different kinds of seismic waves, and they all move in different ways:
  1. **Body waves:** These can travel through the interior of the earth. P-waves and S-waves are body waves.
     - The **P-wave** can move through solid rock or liquid.
     - The **S-wave** can only move through solid rock, not through any liquid medium. *It is this property of S-waves that led seismologists to conclude that the Earth's outer core is a liquid.*
  2. **Surface waves:** These are created when body waves reach the surface. They move only over the surface of the Earth, like ripples on water. Rayleigh and Love waves are surface waves.

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Seismic Waves

- **Body Waves**
  1. The **P-wave** (**primary or compressional) wave** is the fastest seismic wave, and, the first to 'arrive' at a seismic station. The P-wave can move through solid rock or liquid. It moves by pushing and pulling the medium that it moves through, (*just like sound waves push and pull the air*.) Subjected to a P-wave, particles move in the same direction in which the wave is moving (the direction in which the energy is traveling.) Usually people can only feel the bump and rattle of these waves.
  2. ***S-WAVES*** - The **S-wave** or **secondary wave** is the second wave you feel in an earthquake. The S-wave is slower than a P-wave and can only move through solid rock, not through any liquid medium. S-waves move rock particles up and down, perpendicular to the direction that the wave is traveling.
- **Surface waves**
  Surface waves are restricted to the Earth's surface and do not pass through the interior of the Earth.
  1. The **Love wave** is the fastest surface wave and moves the ground from side-to-side. Confined to the surface of the crust, Love waves produce entirely horizontal motion.
  2. A **Rayleigh wave** rolls along the ground just like a wave rolls across a lake or an ocean. Because it rolls, it moves the ground up and down, and side-to-side in the same direction that the wave is moving. Most of the shaking felt from a large earthquake is due to the Rayleigh wave, which can be much larger than the other waves.

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Seismograms

- Earthquake vibrations are recorded on seismographs and shown on seismograms. Because each type of wave travels at a distinctive velocity, the first arrival of each wave can be distinguished on the seismogram.
- Seismograms are used to locate the epicentre and calculate the magnitude.

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Seismograms are used to:
Locating the Epicentre

Because the velocity of P and S-waves are known, seismologists can use the difference in their arrival times at a recording station to calculate the distance of that station from the epicentre. With values from 3 different recording stations, the location of the epicentre can be determined, as shown on this map. Circles representing the calculated distance to the epicentre from the station are drawn on a map. The epicentre lies at the intersection of the 3 circles.

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Magnitude & Amplitude

- Seismograms are also used to calculate the magnitude of an earthquake.
- By measuring the time interval between the arrivals of the P and S wave groups seismologists are able to calculate the distance between the seismograph and the origin of the earthquake. Magnitude is then derived from the amplitude of the waves on the seismogram and the distance of the earthquake from the seismograph.

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Magnitude

- Magnitude is a unique number that represents the strength of an earthquake at its epicentre.
- The seismogram diagrams on the right can be used to illustrate a logarithmic scale. Each is 10 times greater than the previous.
- Stress to the students that, when talking about an earthquake being a (e.g.) 5 or a 6 on the magnitude scale, there is a great difference between a magnitude 5 earthquake and a magnitude 6 earthquake and this will be apparent in the damages associated with each.
- The magnitude of an earthquake is proportional to the length of the rupture zone.

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Magnitude

- Each year there are thousands of earthquakes of magnitude 1 to 3.5, but their vibrations are rarely felt. Large magnitude, damaging earthquakes occur much less frequently.
- **The largest earthquake ever recorded was a magnitude 9.5 in Chile in 1960.**
- Canada's largest recorded earthquake (magnitude 8.1) occurred along the Queen Charlotte Fault in BC in 1949.
- **Canada's largest earthquake was a magnitude 9.0, Cascadia subduction zone earthquake offshore of Vancouver Island, Washington and Oregon on Jan. 26, 1700.** This event was widely recorded in native oral accounts and confirmed by geological evidence for both surface subsidence and a tsunami along the outer coast. The date was confirmed by a tsunami record in Japan of a tsunami with an unknown source (no earthquake was felt).

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Intensity

- Earthquakes are measured in two ways:
    1. Magnitude is a measure of the amount of fault movement at the source of the quake.
    2. **Intensity is what we feel** when an earthquake occurs and it varies from place to place.
- There is only one magnitude but there can be many different intensities, depending on how far we are from the source and our local geological conditions.
- Intensity is measured on the Modified Mercalli Intensity Scale.

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Intensity

- The Modified Mercalli Intensity Scale is based on personal reports of what was felt and observed at each location. Intensity is a more useful way of evaluating the impact of an earthquake.

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Intensity

- Intensity values from many reports can be plotted on a map to illustrate the earthquake's impact over a large region.
  (Note : the colour scale on these images is slightly different than the one on the previous slide.)

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Amplification effects

- **Shaking intensity depends on**
  1. the **size** of the earthquake (magnitude),
  2. the **distance** from the epicentre, and
  3. **the underlying geology**. Soft soils (sand, silt and clay) experience longer and greater shaking than do bedrock or stiff soils (hard glacial till). When the earthquake waves pass from stiff soil to soft soil, their velocity decreases dramatically. When velocity decreases, wave amplitude must increase, resulting in stronger shaking at the surface. The effect is augmented by resonance effects – the wave reaches the surface and returns, only to bounce back off the impedance layer of stiff soil, creating a resonance effect between the surface and impedance layer, and resulting in longer shaking at the surface.

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Impact:

- Many earthquakes are not felt or, although felt, cause no damage.
- In strong earthquakes buildings and bridges may be damaged or collapse.
- Even when no structural damage occurs to buildings, falling objects present a major hazard inside a building.

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Impact:

- Tsunamis can follow a large earthquake if there has been a significant ground movement on the ocean floor.
- Unusual retreat of the sea often precedes the arrival of the tsunami wave.
- In the deep ocean, tsunami waves are barely distinguishable, with a very long wavelength and small wave amplitude. As it approaches shore, the wave slows, wavelength decreases and amplitude greatly increases, causing the wall of rushing water at the shore.
- Although rare, Canada has experienced tsunamis that were triggered by earthquakes and landslides.

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Recent Earthquake Disasters – Haiti, 2010

- A major disaster – the fourth deadliest earthquake in world history - ~230,000 deaths
- Source of information : IRIS http://www.iris.washington.edu/hq/

Slide 23
Haiti – Regional Tectonics

- Motion between the Caribbean and North American plates occurs along two major east-west trending, strike-slip fault systems.
- The earthquake was a left-lateral strike slip faulting on the southern fault system. This fault system moves about 7 mm/yr.

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Haiti – History

- The dots locate epicentres of earthquakes that occurred in the last 20 years. (Colours indicate depth of focus.)
- Most earthquakes are associated with the northern fault system.
- The January 12, 2010 earthquake occurred in the southern fault system.

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Haiti - Shaking intensity map
Why was the Haiti earthquake only lightly felt in neighbouring countries (Dominican Republic, Cuba)?

- The areas subjected to extreme (red) to strong (yellow) shaking are restricted to a small region because only a relatively short length (70 km) of the fault actually ruptured.

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Haiti – Aftershock

- 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. 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.

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Haiti – Impact

- **In the top 10 list of deadliest earthquakes in world history.**
- About 230,000 deaths. Widespread destruction in Southern Haiti.
- Damages were so great because:
    1. A densely populated city, Port-au-Prince, is close to the epicentre and experienced an intensity of 8+.
    2. Many buildings were poorly constructed and collapsed.

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Chile, 2010 - A "Great" Earthquake

- Seismologists estimate that the earthquake was so powerful that it may have shortened the length of the day by 1.26 microseconds and moved the Earth's figure axis by 8 cm or 2.7 milliarcseconds.
- Preliminary measurements show that the entire South American Plate moved abruptly westward during the quake. Researchers from Ohio State University and other institutions have found, using GPS, that the earthquake shifted Santiago (28 cm) to the west-southwest and moved Concepción at least 3 meters to the west. The earthquake also shifted other parts of South America. For example, it moved Buenos Aires, Argentina, about 2.5 cm to the west. (Source: Wikipedia)
- The source for much of this information on Chile earthquake section is taken from a "Teachable moment" powerpoint prepared by IRIS (Incorporated Research Institutes for Seismology) at this url:http://www.iris.edu/hq/retm/event/962

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Chile - Tectonics

- The earthquake occurred as thrust-faulting on the interface between the Nazca and South American plates, with the Nazca plate moving landward and downward below the South American plate. This is a subduction zone.
- The red star on the map shows the epicentre of the earthquake while the arrows show the direction of motion of the Nazca Plate toward the South American Plate.
- At the location of this earthquake, the two plates are converging at a rate of about 8 cm/yr.
- The rupture extended about 700 km along the length of the fault, and from the Earth's surface to depths of over 50 km.
- The largest amounts of rupture occurred in the first 60 seconds but smaller displacements continued for up to 200 seconds after the start of the earthquake.

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Chile – History

- **The length of the 2010 rupture was ~700 km,** ten times greater than the Haitian rupture length. It occurred just north of the 1960 rupture which produced the strongest quake ever measured.

- **History: The 1960 Valdivia Quake (magnitude 9.5) was the strongest quake ever measured in the world.**
  - The 1960 earthquake occurred beneath the Pacific Ocean off the coast of Chile. Ground motion from this earthquake destroyed and damaged many buildings, leaving about 2,000,000 people homeless. Because it occurred in mid- afternoon and was preceded by a powerful foreshock, people were frightened from their buildings, placing them outside when the main earthquake occurred. Casualty estimates for this earthquake, range as high as 6000 people.
  - It generated a series of tsunamis. These waves swept over areas of coastal Chile moments after the earthquake occurred, destroying buildings and drowning many people. The tsunami impacted the entire Pacific Ocean; fatalities occurred as far away as the Philippines, Japan and Hawaii.

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Chile – Impact 2010

- Building destruction was not as widespread in Chile as in Haiti because Chile builds to the earthquake standards of a national building code. Hence there were fewer fatalities, although the shaking was more severe in Chile.
- Note that masonry falling off the facade of buildings presents a hazard.
- The earthquake triggered a tsunami which devastated several coastal towns in south-central Chile. A 2.34 m high tsunami wave hit Talcahuano, a port city near Concepción. The tsunami caused serious damage to port facilities and lifted boats out of the water. In the fishing town of Dichato, which has 7,000 residents, it was the third tsunami wave that ended up being the most damaging.
- Tsunami warnings were issued in 53 countries. Minor tsunami damage occurred in the San Diego area of California and in the Tōhoku region of Japan.

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Japan 2011

- Magnitude 9 earthquake, one of the largest in Japanese history, followed by a catastrophic tsunami.
- See this URL for more information on the earthquake and tsunami in Japan, March 2011:
- http://www.iris.edu/hq/retm/event/1328

Slide 39 Could it happen in Canada?

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Yes, Canada has earthquakes !

- Map shows the earthquakes that occurred over a 30 day period. (A current update of this map can be found at Earthquakes Canada at http://earthquakescanada.nrcan.gc.ca/index-eng.php)

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Canada

- About 4000 earthquakes per year occur in or near Canada (~11 per day!), but only 50-55 are reported as ‘felt’.
- The majority of these felt earthquakes are too small to cause any damage.
- Since 1900, about 20 earthquakes have caused significant damage in Canada.
- **Canada’s largest recorded earthquake** (magnitude 8.1) occurred along the Queen Charlotte Fault in BC in 1949.
- **Canada’s largest earthquake was a magnitude 9.0, Cascadia subduction zone earthquake offshore of Vancouver Island, Washington and Oregon on Jan. 26, 1700**. This event was widely recorded in native oral accounts and confirmed by geological evidence for both surface subsidence and a tsunami along the outer coast. The date was confirmed by a tsunami record in Japan.
- As seen on the map, earthquakes occur in specific zones. They are most frequent off the west coast. They are very rare in the interior of Canada.

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Where do most of the earthquakes happen in Canada?

1. Earthquakes along **Canada's west coast** occur at or near the margins of slowly moving tectonic plates. (Offshore B.C., SW Yukon, Richardson Mountains and Mackenzie Valley)
2. In **Eastern Canada** earthquakes are not at the edge of a tectonic plate. They are in regions of crustal weakness. The slow movement of the North American Plate away from the Mid-Atlantic Ridge may activate old zones of weakness and faults such as the St. Lawrence Valley.
3. In the **Arctic**, earthquakes also seem to be associated with plate margins and older geological features, but may also be related to stresses produced as the land continues to rise following melting of the heavy ice sheets from the last continental glaciation.

- Although a region may have earthquakes, human **risk** is slight if few people live there. The Southern Cordillera and the St. Lawrence Lowlands have the greatest risk of earthquakes.

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Significant* Earthquakes Affecting Canada

#	Date**	Magnitude	Description
1	**1663**, Feb. 5	M 7.0	Charlevoix-Kamouraska region, QC.
2	**1700**, Jan. 26	M 9.0	Cascadia subduction zone, offshore of Vancouver Island, Washington and Oregon.
3	**1732**, Sept. 16	M 5.8	Near Montreal, QC.
4	**1791**, Dec. 6	M 6.0	Charlevoix-Kamouraska region, QC.
5	**1860**, Oct. 17	M 6.0	Charlevoix-Kamouraska region, QC.
6	**1870**, Oct. 20	M 6.5	Charlevoix-Kamouraska region, QC.
7	**1899**, Sept. 10	M 8.0	Yukon-Alaska border.
8	**1904**, Mar.21	M 5.9	Passamaquoddy Bay, NB.
9	**1909**, May 15	M 5.3	Near the Saskatchewan border in Montana.
10	**1918**, Feb. 4	M 6.0	Revelstoke, BC.
11	**1918**, Dec.6	M 6.9	Vancouver Island, BC.
12	**1920**, Jan. 23	M 5.5	Gulf Islands, BC.
13	**1925**, Feb. 28	M 6.2	Charlevoix-Kamouraska region, QC.
14	**1929**, May 26	M 7.0	Just south of Haida Gwaii, BC.
15	**1929**, Nov. 18	M 7.2	Atlantic Ocean, south of NL. Tsunami.
16	**1933**, Nov. 20	M 7.3	Baffin Bay, Nunavut.
17	**1935**, Nov. 1	M 6.1	Quebec-Ontario border.
18	**1944**, Sept. 5	M 5.6	Eastern Ontario-New York border.
19	**1946**, Jun. 23	M 7.3	Central Vancouver Island, BC.
20	**1949**, Aug. 21	M 8.1	Off Haida Gwaii, BC. Canada's largest historical earthquake.
21	**1964**, Mar. 27	M 9.2	Near Anchorage, Alaska. Tsunami.
22	**1970**, Jun. 24	M 7.4	South of Haida Gwaii BC.

23	**1979**, Feb. 28	M 7.5	Southern Yukon-Alaska border.
24	**1982**, Jan. 9	M 5.8	First of two moderate earthquakes, Miramichi Highlands, NB.
25	**1985**, Dec. 22	M 6.9	Nahanni region, NWT.
26	**1988**, Nov. 25	M 5.9	Saguenay region, QC.
27	**1989**, Dec. 25	M 6.3	Ungava Peninsula, QC.
28	**2010**, Jun. 23	M 5.0	Val-des-Bois, QC.

**Significant events are defined as magnitude greater than or equal to 6, or widely felt, or causing significant damage from shaking or tsunami waves, or it is scientifically interesting.*
*** Date is the local date.*

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West Coast

- **Cascadia Subduction zone**. Juan de Fuca plate is subducting beneath the North American plate.
- Also associated with volcanic activity

Slide 45
West Coast : The Cascadia Subduction Earthquake, 1700

- At 9PM on January 26, 1700 one of the world's largest earthquakes occurred along the west coast of North America. The undersea Cascadia thrust fault ruptured along a 1000 km length, from mid Vancouver Island to northern California in a great earthquake, producing tremendous shaking and a huge tsunami that swept across the Pacific. The Cascadia fault is the boundary between two of the Earth's tectonic plates: the smaller offshore Juan de Fuca plate that is sliding under the much larger North American plate.
- The earthquake shaking collapsed houses of the Cowichan people on Vancouver Island and caused numerous landslides. The shaking was so violent that people could not stand and so prolonged that it made them sick. On the west coast of Vancouver Island, the tsunami completely destroyed the winter village of the Pachena Bay people with no survivors. These events are recorded in the oral traditions of the First Nations people on Vancouver Island. The tsunami swept across the Pacific also causing destruction along the Pacific coast of Japan. It is the accurate descriptions of the tsunami and the accurate time keeping by the Japanese that allows us to confidently know the size and exact time of this great earthquake.
- The earthquake also left unmistakeable signatures in the geological record as the outer coastal regions subsided and drowned coastal marshlands and forests that were subsequently covered with younger sediments. The recognition of definitive signatures in the geological record tells us the January 26, 1700 event was not a unique event, but has repeated many times at irregular intervals of hundreds of years. Geological evidence indicates that 13 great earthquakes have occurred in the last 6000 years.
- We now know that a similar offshore event will happen sometime in the future and that it represents a considerable hazard to those who live in southwest B.C. However, because the fault is offshore, it is not the greatest earthquake hazard faced by major west coast cities. In the interval between great earthquakes, the tectonic plates become stuck together, yet continue to move towards each other. This causes tremendous strain and deformation of the Earth's crust in the coastal region and causes ongoing earthquake activity. This is the situation that we are in now. Some onshore earthquakes can be quite large (there have been four magnitude 7+ earthquakes in the past 130 years in southwest B.C. and northern Washington State). Because these inland earthquakes can be much closer to our urban areas and occur more frequently, they represent the greatest earthquake hazard. An inland magnitude 6.9 earthquake in 1995 in a similar geological setting beneath Kobe, Japan caused in excess of $200 billion damage.

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East Coast : The 1929 Magnitude 7.2 "Grand Banks" earthquake and tsunami

- On November 18, 1929 at 5:02 pm Newfoundland time, a major earthquake occurred approximately 250 km south of Newfoundland along the southern edge of the Grand Banks. This magnitude 7.2 tremor was felt as far away as New York and Montreal. 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. A few aftershocks (one as large as magnitude 6) were felt in Nova Scotia and Newfoundland but caused no damage.
- The earthquake triggered a **large submarine landslide** (an estimated volume of 200 cubic kilometres of material was moved on the Laurentian slope) which ruptured 12 transatlantic cables in multiple places (locations of cable breaks can be seen as small circles on the map). The huge landslide generated a **tsunami** (a large induced sea wave). The tsunami was recorded along the eastern seaboard as far south as South Carolina and across the Atlantic Ocean in Portugal.
- Approximately 2 1/2 hours after the earthquake the tsunami struck the southern end of the Burin Peninsula in Newfoundland as three main pulses, causing local sea levels to rise between 2 and 7 metres. At the heads of several of the long narrow bays on the Burin Peninsula the momentum of the tsunami carried water as high as 13 metres. This giant sea wave claimed a total of 28 lives – 27 drowned on the Burin peninsula and a young girl never recovered from her injuries and died in 1933.
- More information: http://earthquakescanada.nrcan.gc.ca/histor/20th-eme/1929/1929-eng.php

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What Can We Do?

- The National Building Code – Canadian buildings are designed to withstand earthquake shaking. However old buildings may not meet the code – many have been retrofitted (fixed up to code).

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What should you do during an earthquake?

- **If you are indoors, stay there.**
  Do not run outside: you could be hit by flying debris or bits of glass. Take cover under, and hold on to a sturdy desk, a table, or a bed. Avoid windows and tall furniture.
- **If you are outdoors, stay there.**
  Keep away from power lines and buildings. (House chimneys are likely to topple during a strong earthquake).
- **If you are in a vehicle**, stop and park away from buildings, bridges and overpasses.
- **If you are in a low coastal area, go to high ground.**

Slides 51 to 57
Personal Safety

- These slides provide more detailed information on what to do **during** and **after** an earthquake.
  Source : http://www.getprepared.gc.ca/knw/ris/eq-eng.aspx#a4