

Montreal Shakes – Local earthquakes in their Canadian context

John Adams

Canadian Hazards Information Service
Natural Resources Canada, Ottawa, Canada

IASPEI Opening Ceremony
Montreal, Friday July 12 2019

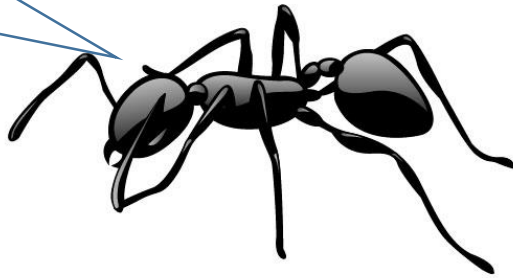


Copyright. Her Majesty the Queen in Right of Canada, 2019

Adams2019

Why are we here?

That's a
pretty big
question!



Why are we here?

Perhaps I
can answer
that...



Why Montreal?

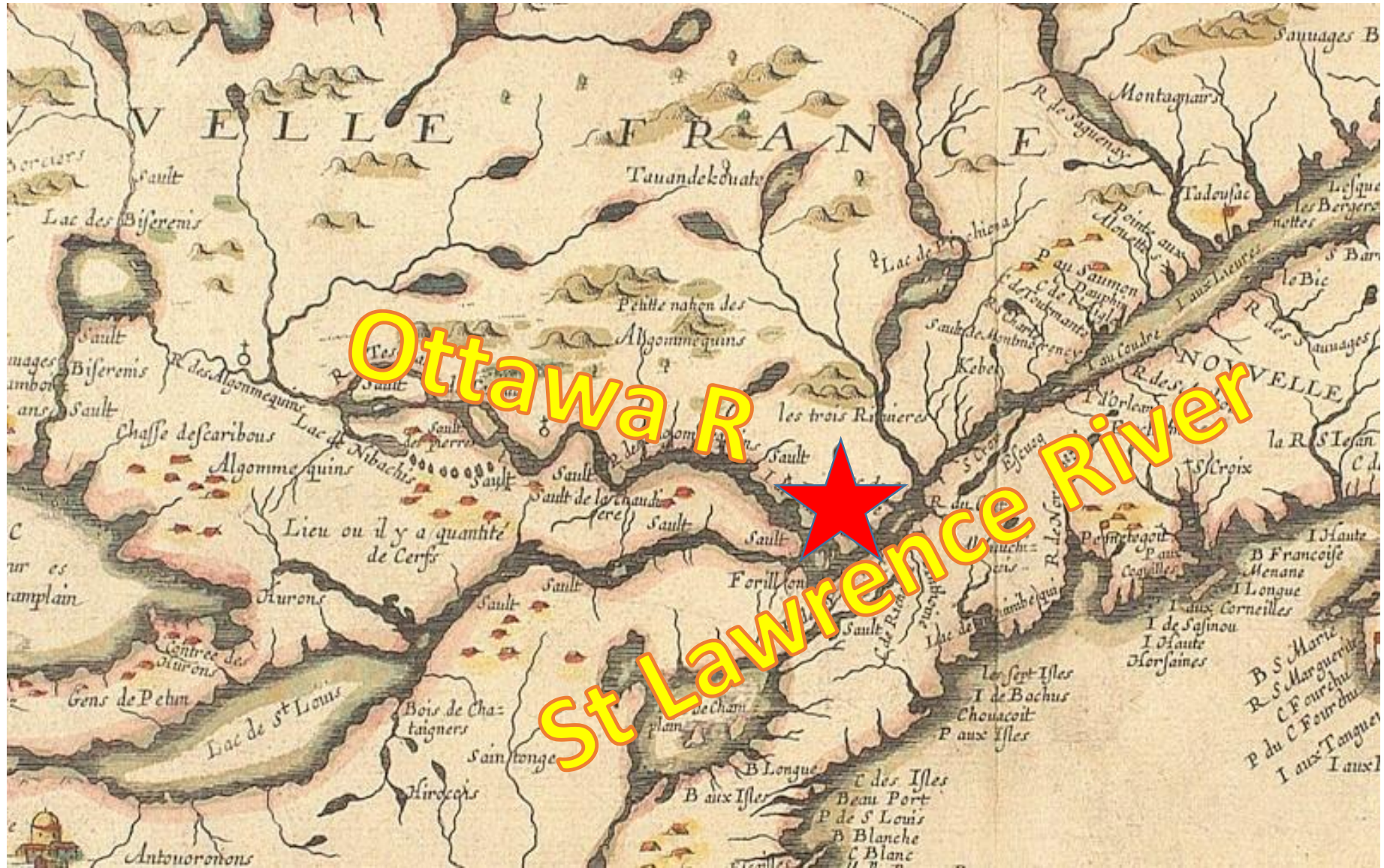
Now that's
a long story



If you flew
here, you
might not
have realized
you are on an
island in a
river.....



1643 map by Jean Boisseau



<http://digital.library.mcgill.ca/pugsley/IMAGES/3%20-%20300%20DPI%20JPGs/Pugs04.jpg>



Our First Canoe.



The short cut

Niagara Falls

To Europe

To Great Lakes

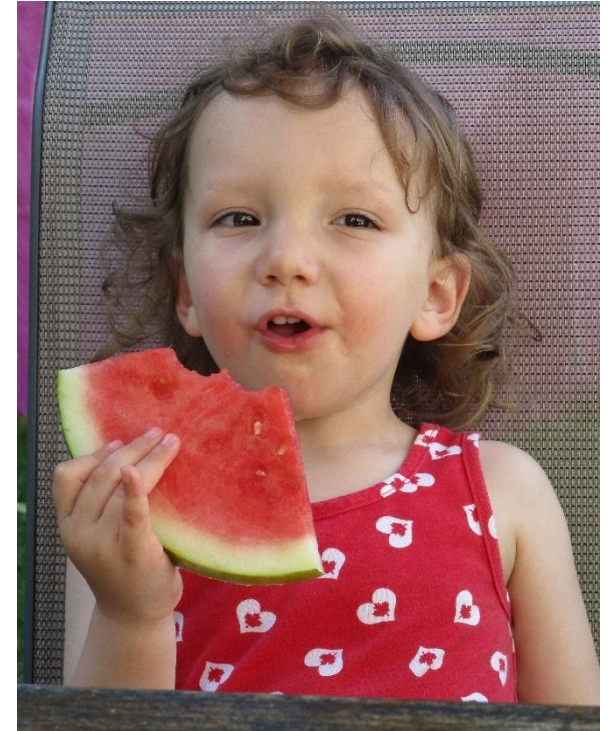
Legend

So, Montreal started as a trading hub because of the rivers



Our Park, Canada

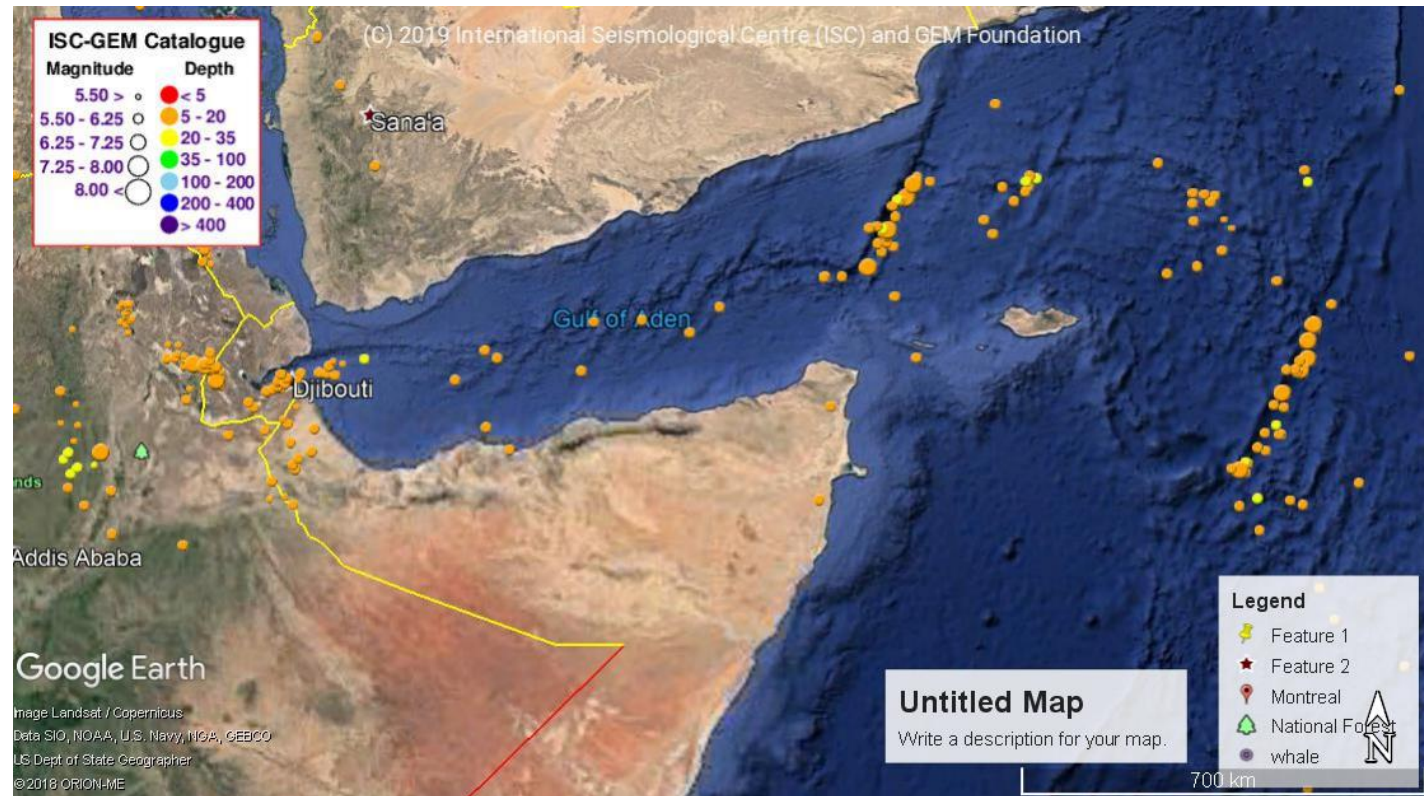
Why are the rivers here?



Ancient rifting earthquakes

Analogy: Red Sea / Gulf of Aden

The southeast shore rifting from the northwest shore to form the Iapetus Ocean

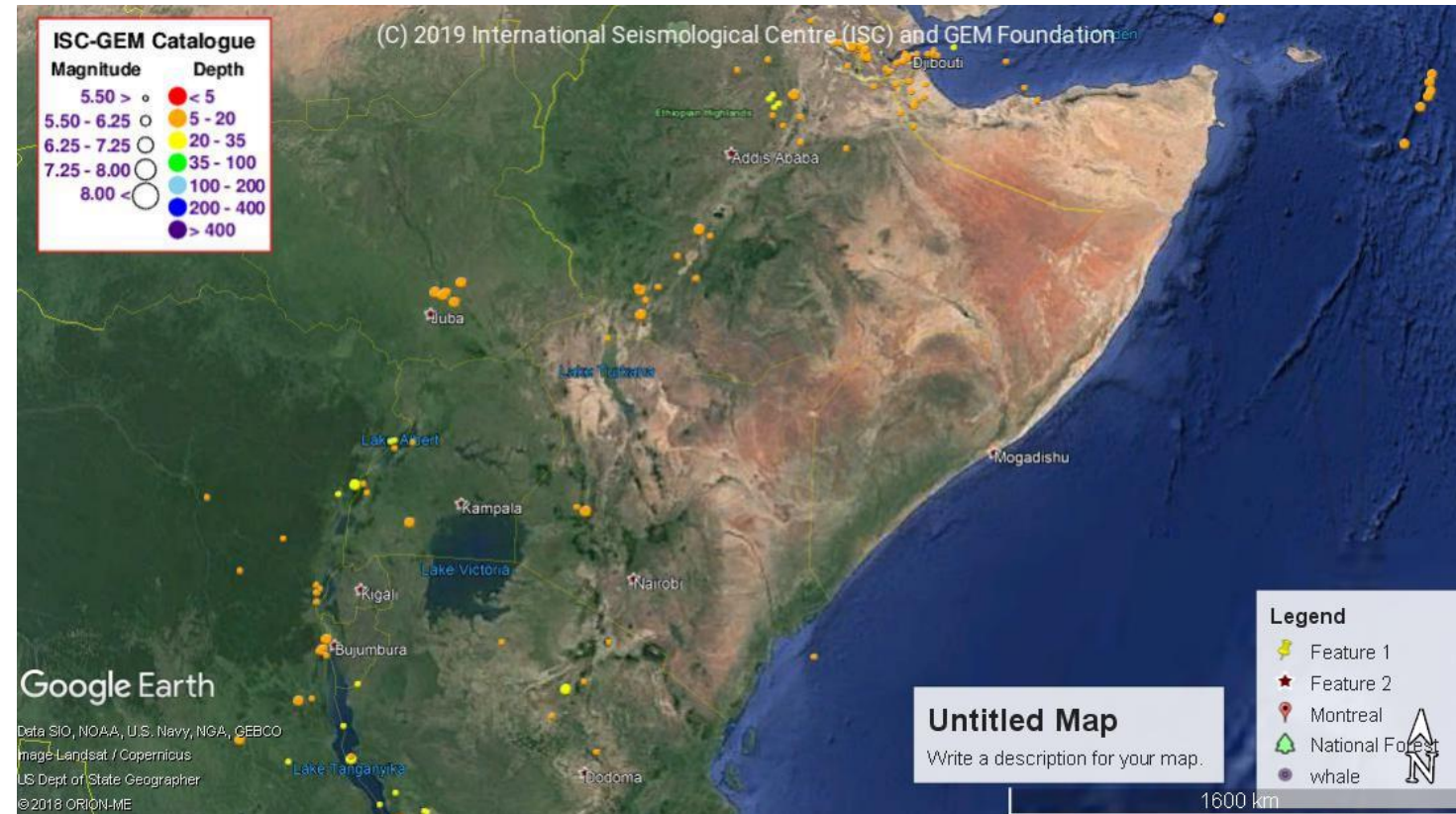


International Seismological Centre, ISC-GEM Earthquake Catalogue, <https://doi.org/10.31905/d808b825>, 2019

Ancient rifting earthquakes

Analogy: East African Rift

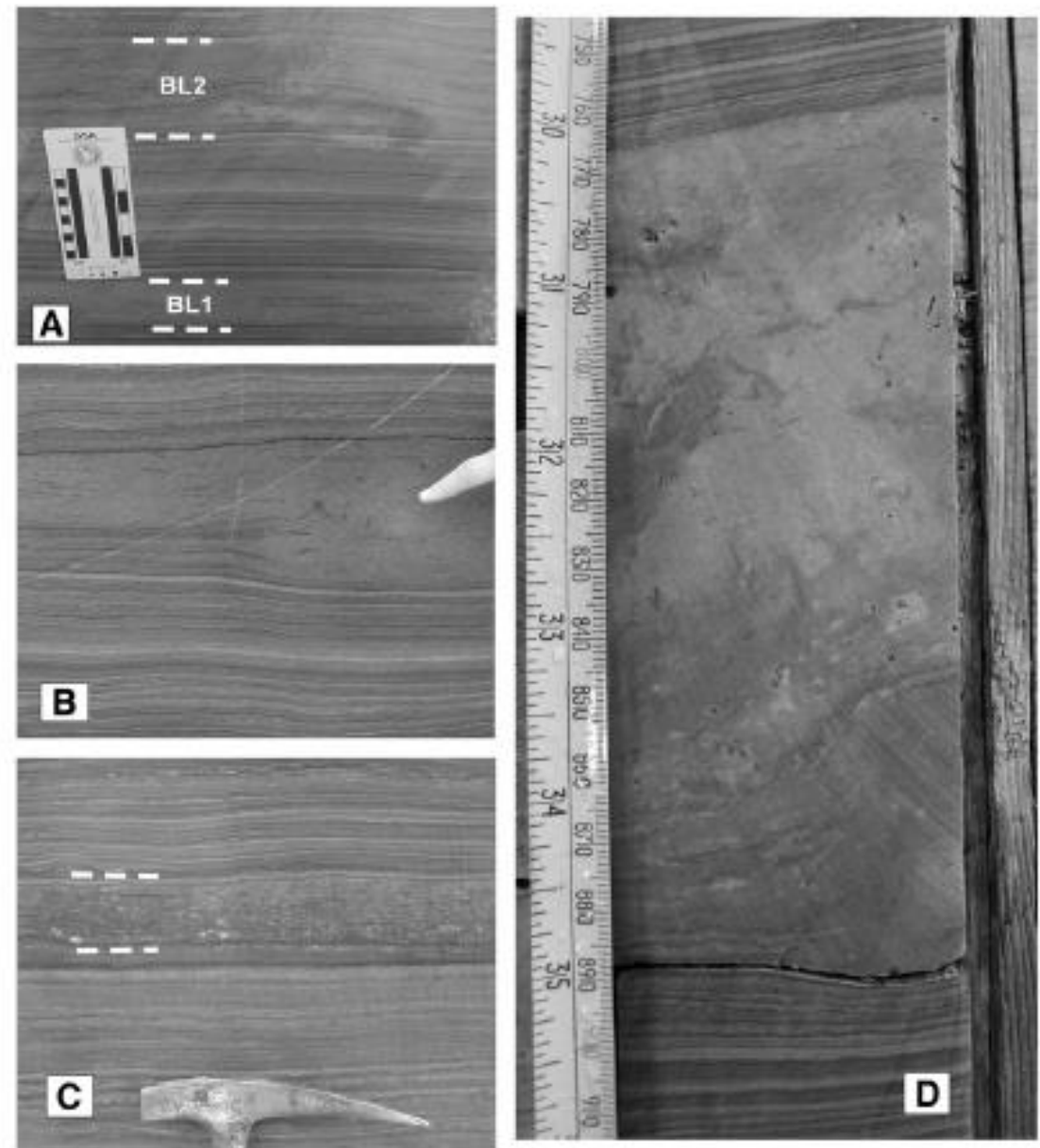
Rifted grabens opened up along the Ottawa and Saguenay river valleys, but failed to become oceans



International Seismological Centre, ISC-GEM Earthquake Catalogue, <https://doi.org/10.31905/d808b825>, 2019

The shores of the ocean
were covered by thick
platform sediments in the
Ordovician and Devonian

We see paleo-earthquakes in those
finely-banded sediments (now
limestone) disrupted by deformed
layers - probably recording
intraplate earthquakes

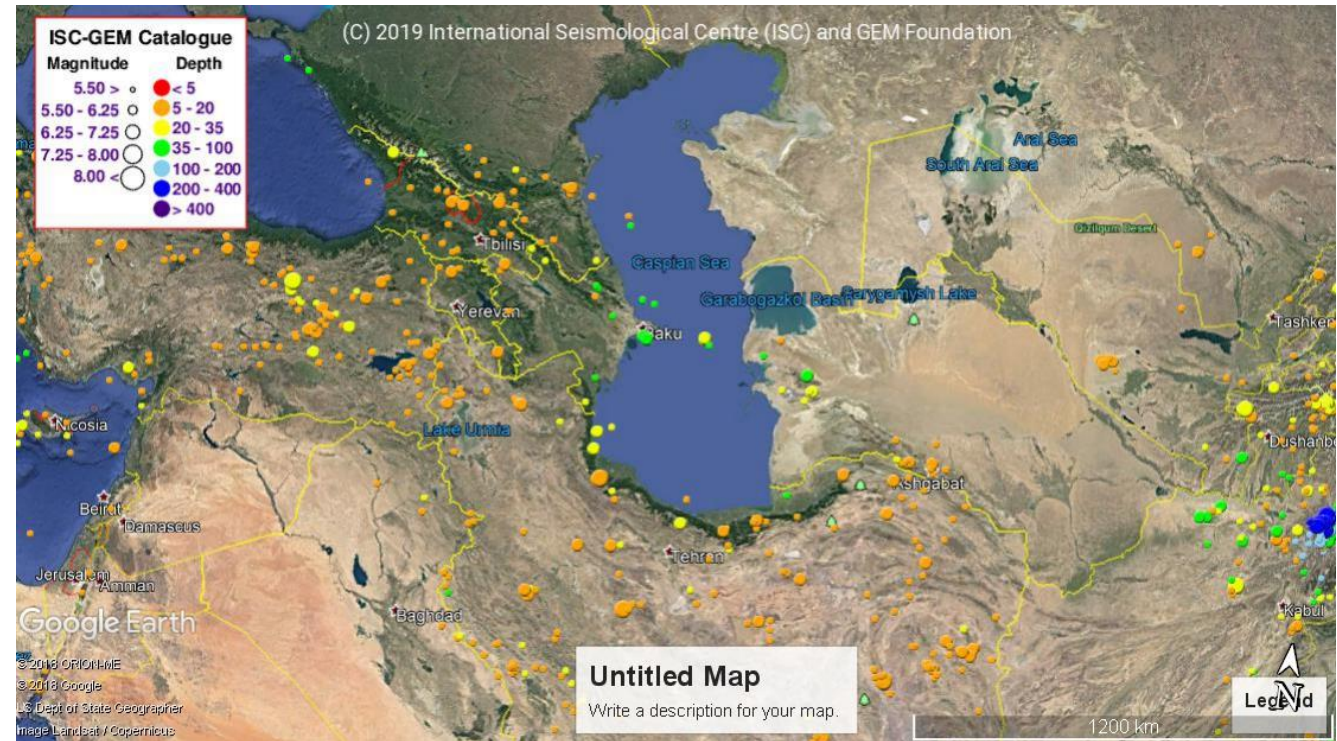


Wallace and Eyles: Seismites within Ordovician–Silurian carbonates and clastics of Southern Ontario, Canada and implications for intraplate seismicity. *Sedimentary Geology* 316 (2015) 80–95 12

About 450 million years ago Iapetus closed, with the wedge of continent that is the Appalachians being thrust over the platform rocks, and (near Montreal) almost over the rift faults

Ancient continental collision earthquakes

Analogy: Northern Iran



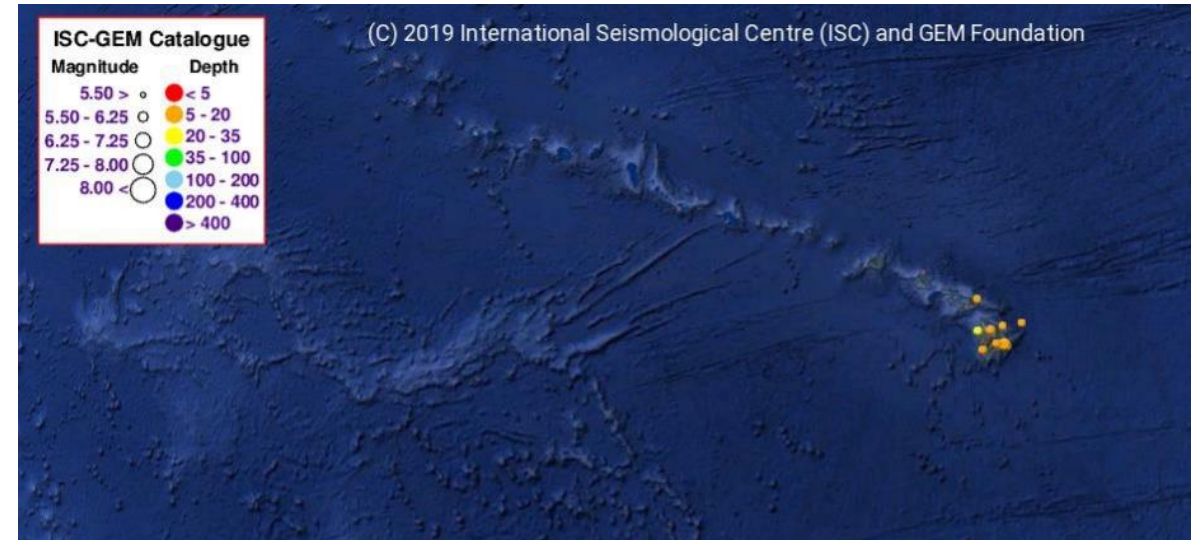
International Seismological Centre, ISC-GEM Earthquake Catalogue, <https://doi.org/10.31905/d808b825>, 2019

Then in the Cretaceous ~110-90 m.y, Montreal moved over a hotspot (Great Meteor)

The crust was thermally lifted; volcanoes broke through, and sediments were eroded from the top

There was about 1 km of Devonian sediments above Montreal (since eroded) because clasts are found in the volcanic throats

Ancient hotspot earthquakes Analogy: Hawaii



International Seismological Centre, ISC-GEM Earthquake Catalogue, <https://doi.org/10.31905/d808b825>, 2019



The roots of the volcanoes (tops were eroded away)
are clearly visible in the topography and vegetation
pattern

Mont Royal (a short walk away) is the closest of these



From the Place Ville Marie observation deck you can see some of the others to the southeast....



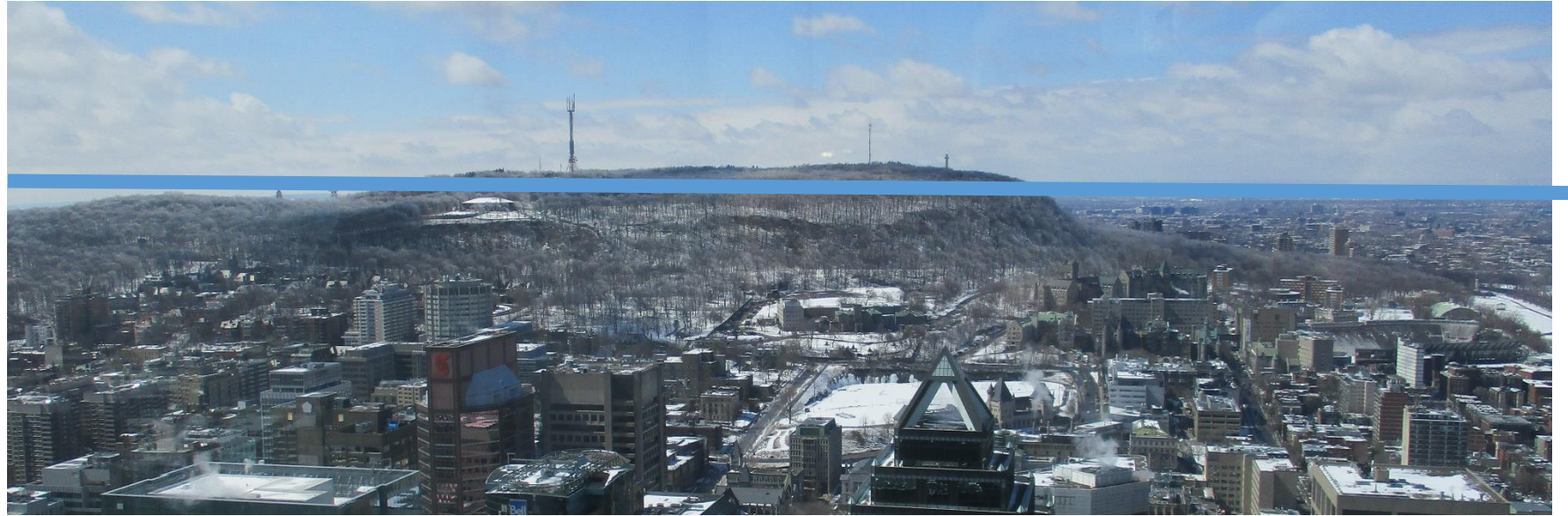
Then we had a period of continental
glaciation 1-2 m.y. ago

When the ice melted 12,000 years ago
Montreal was ~180 m underwater



but the sea quickly receded as the land
rebounded

but the sea quickly receded as the land rebounded



Today the St Lawrence river at Montreal is about 6 m above sea level, and there are rapids just upstream

Another reason why (in this instant of time) Montreal is here

Adams2019

5000 years ago explorers might have sailed past Montreal

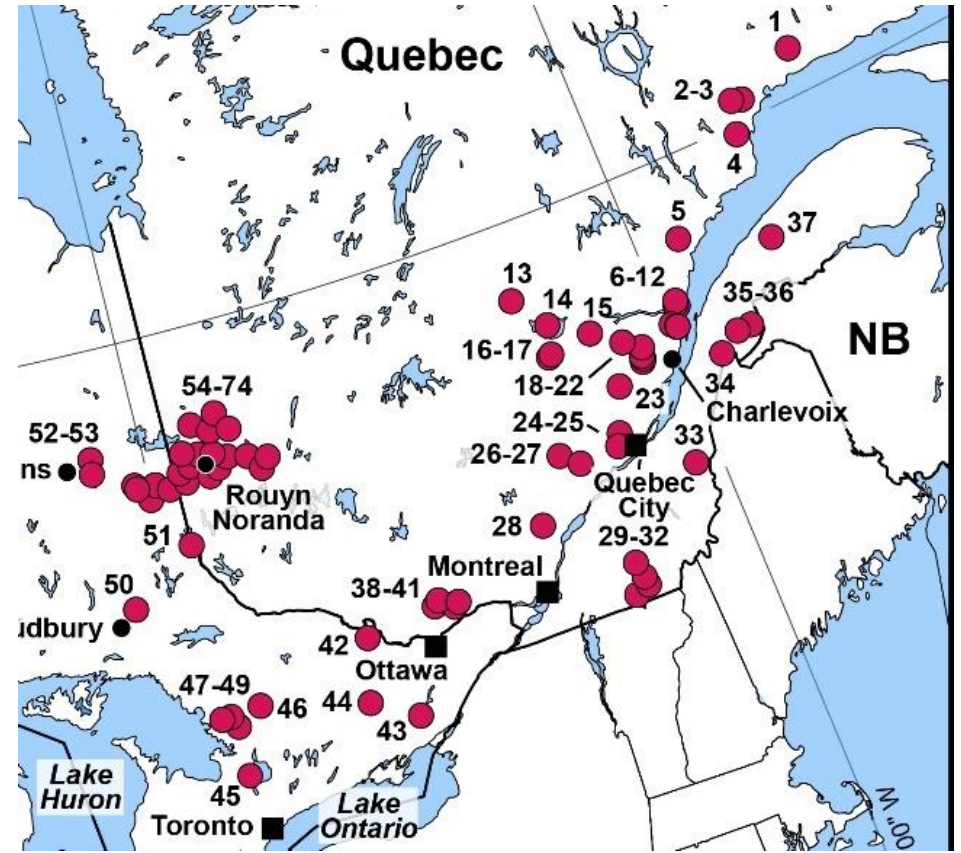
Future rebound will strand Montreal above direct access to ocean ships

Ancient deglacial earthquakes recorded by buried landslides within many lakes

At the time of deglaciation we
probably had lots of earthquakes
for a thousand years or so

releasing strain energy stored up
while the vertical load of the ice
inhibited thrust earthquakes

Analogy: Fennoscandia (but we
haven't found the fault scarps
yet...)



A review of evidence of glacially-induced faulting and seismic shaking in southeastern Canada. Gregory R. Brooks^{1*} and John Adams² submitted to QSR 2019

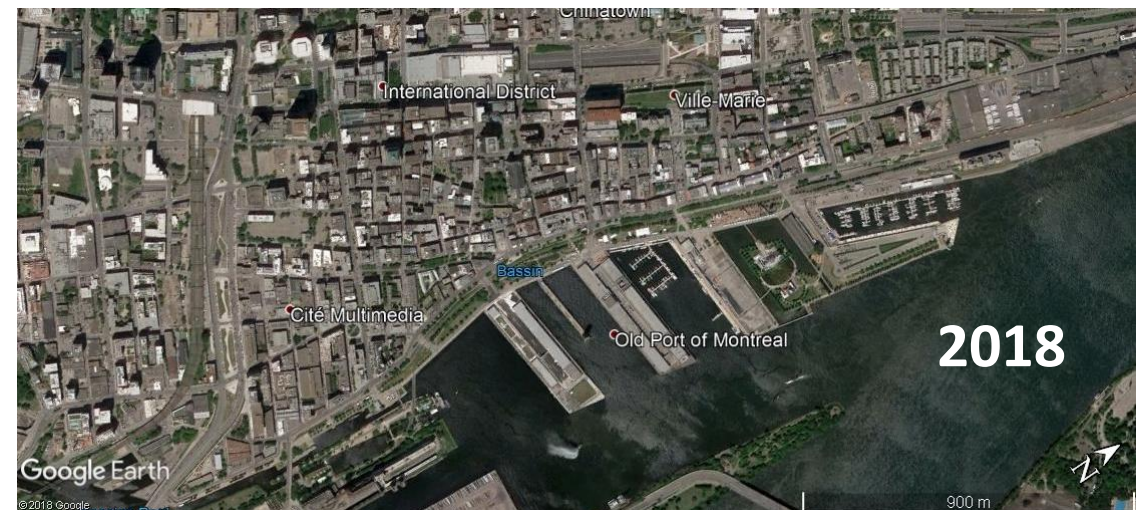
So, the river system echoes the
crustal weaknesses caused by
generations of ancient large
earthquakes

and hence the founding of
Montreal by those using the rivers
for exploration and commerce.

That same geological history
controls the seismicity and seismic
hazard for Montreal today



https://archive.org/details/McGillLibrary-rbnc_plan-town-montreal_G3454_M65_1758_J4-16675



Written history - Historical earthquakes

1663 M~7 Charlevoix about 350 km NE of Montreal

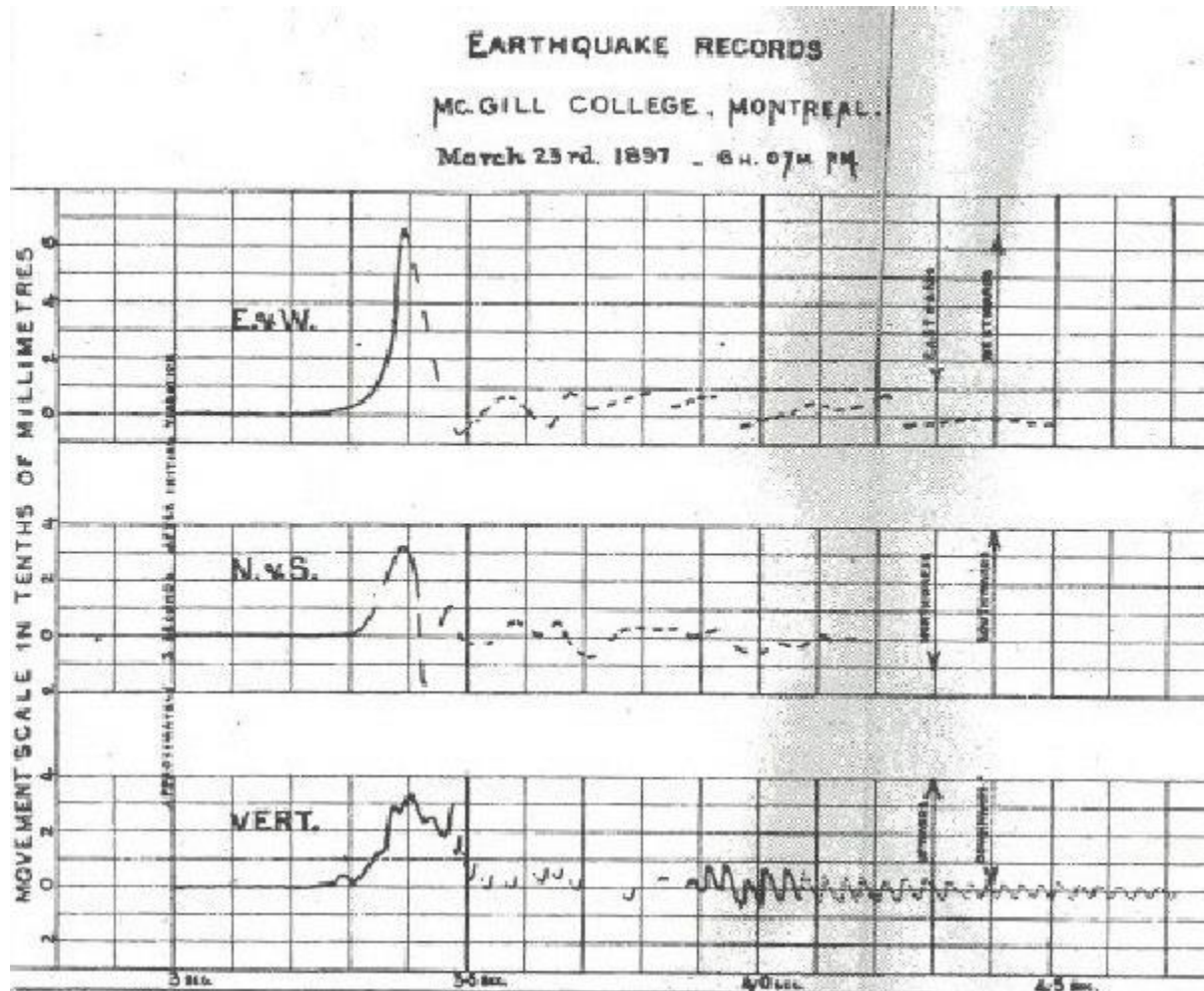
possibly M7.3-7.6 according to Ebel (2011): A New Analysis of the Magnitude of the February 1663 Earthquake at Charlevoix, Quebec. BSSA 101 (3): 1024-1038.

1732 Mw 6.3, Island of Montreal (Stevens, 1991 6th Can Conf Eq Eng)

- comprehensive building code introduced 1727 “durable and safe”
- Population was ~3000
- ½ buildings were stone
- 567 chimneys damaged, at 2/house implies 50% of houses damaged
- 3 large stone buildings damaged
- Losses much less than fires of 1695, 1721, 1734

First Canadian seismogram Montreal 1897

Currently considered to be Mw 4.6 on the
Island of Montreal



By McLeod and Callendar (1897) of McGill University, made on a 3-component Ewing seismograph and stated, Their Ewing seismograph was configured to start automatically by the force of a shock, and it only operated on occasion.

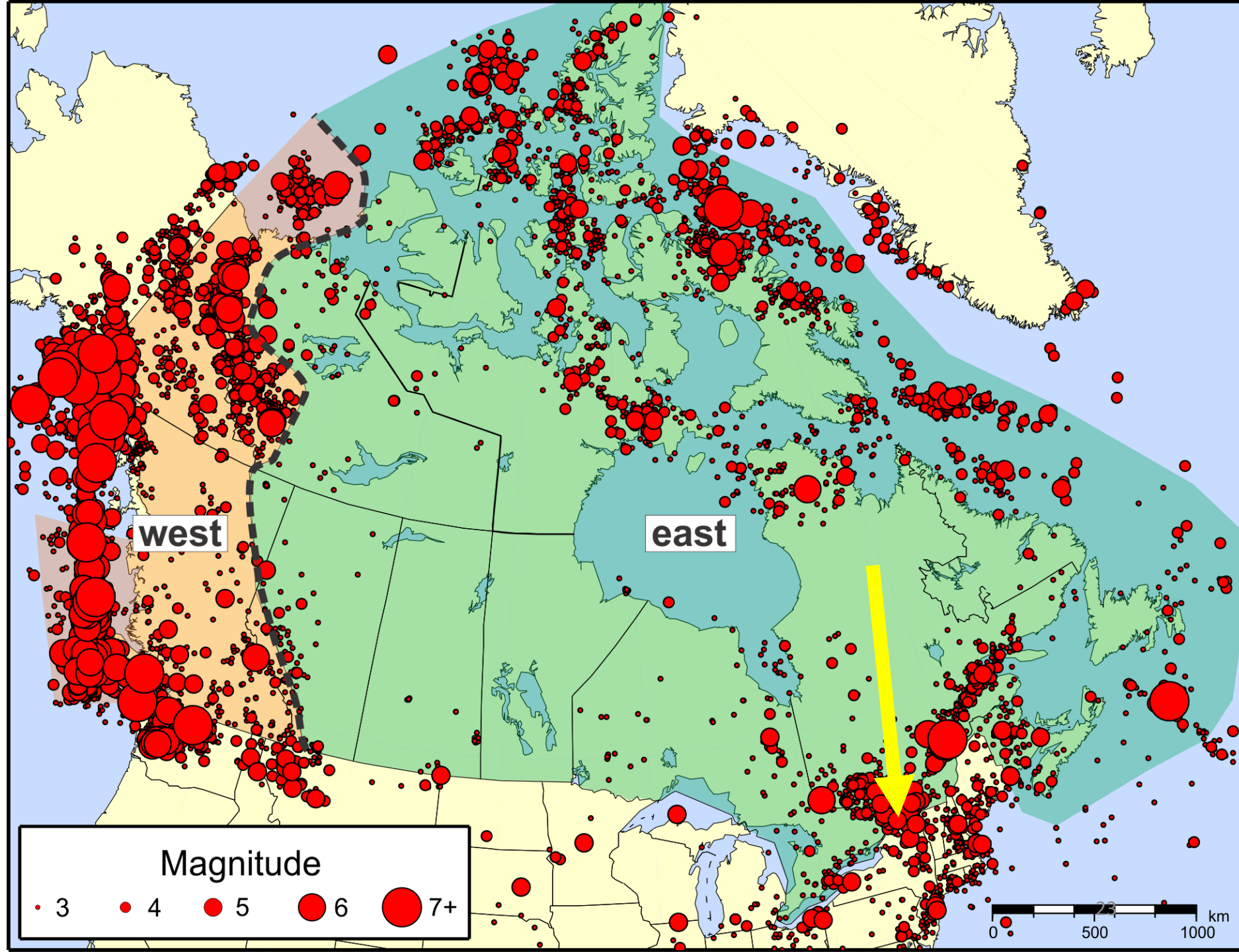
Prior recording? Dawson (1870) says “Note: A slight shock of earthquake was felt at Hawkesbury on the Ottawa on the 3rd January (1871). Dr. Smallwood states that though not appreciable in Montreal, it was indicated by the seismometer. No further information about this instrument could be found. *Early History of the Canadian Seismograph Network* www.earthquakesCanada.ca

Montreal in Canadian earthquake context

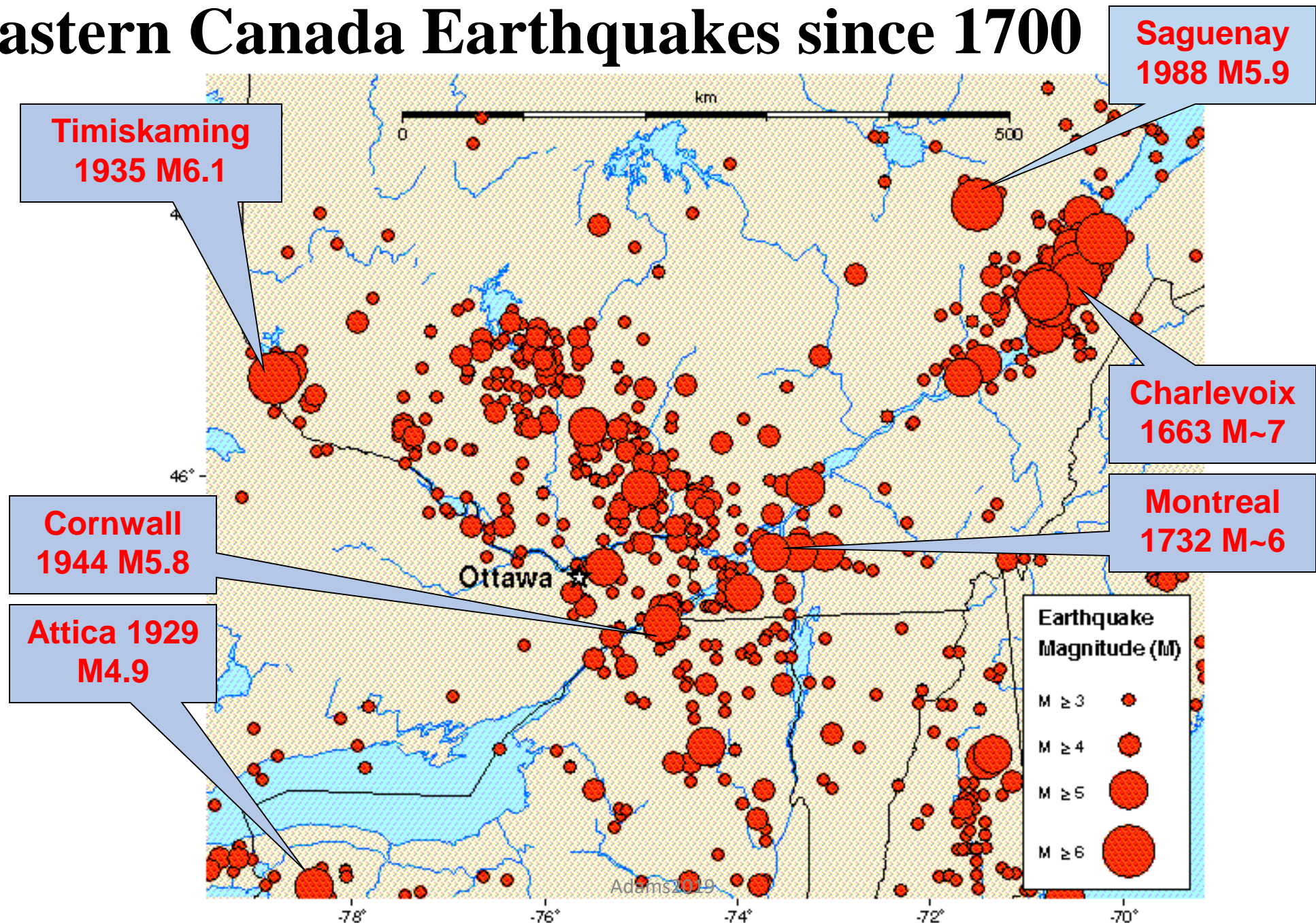
Central Canada – low seismicity

Southeastern Canada & Arctic - moderate, localized seismicity

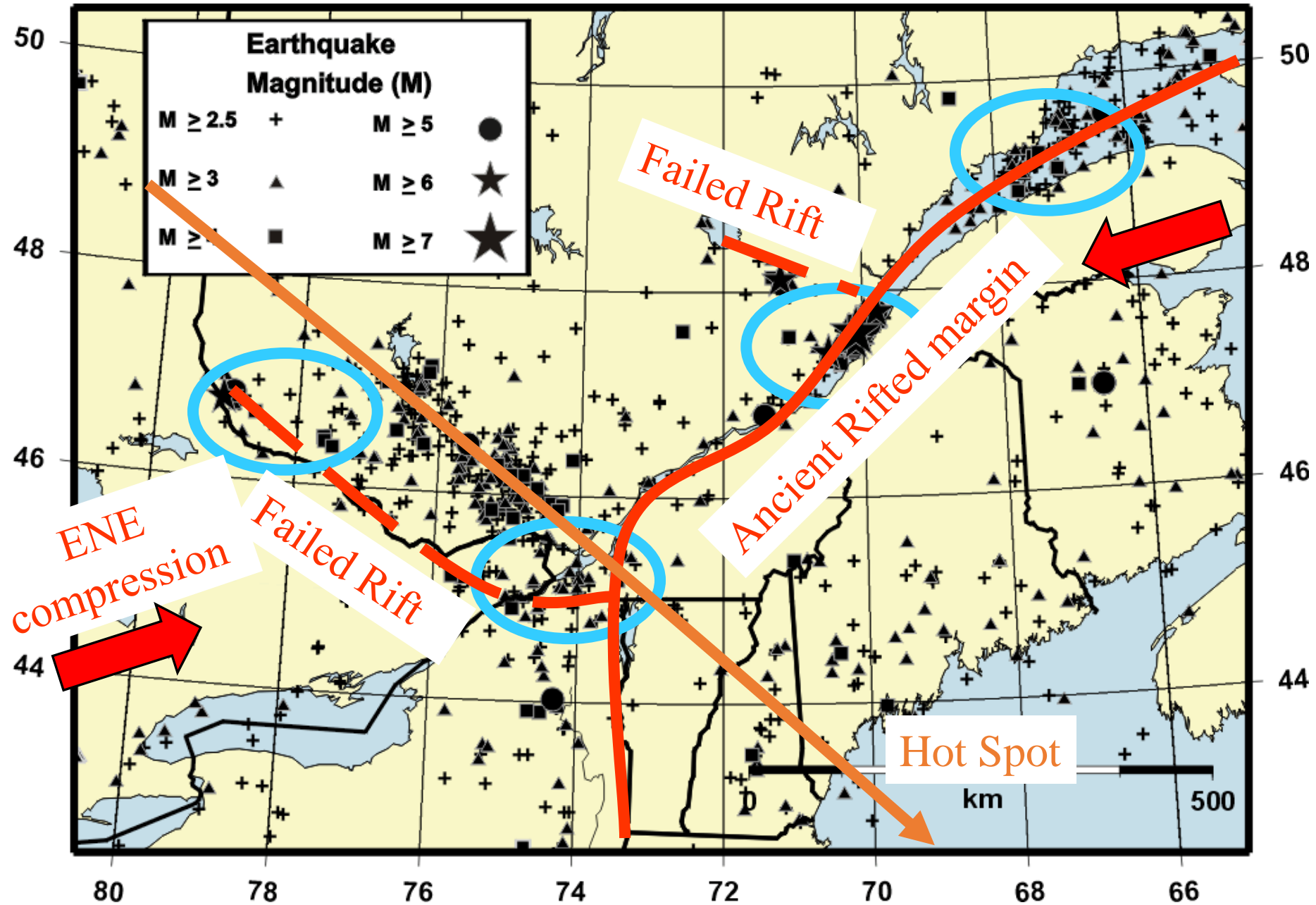
Western Canada - high seismicity related to plate boundaries

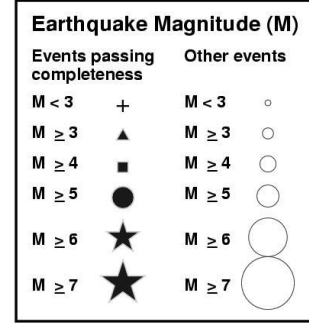


Southeastern Canada Earthquakes since 1700



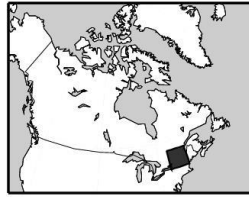
Why do earthquakes happen here?





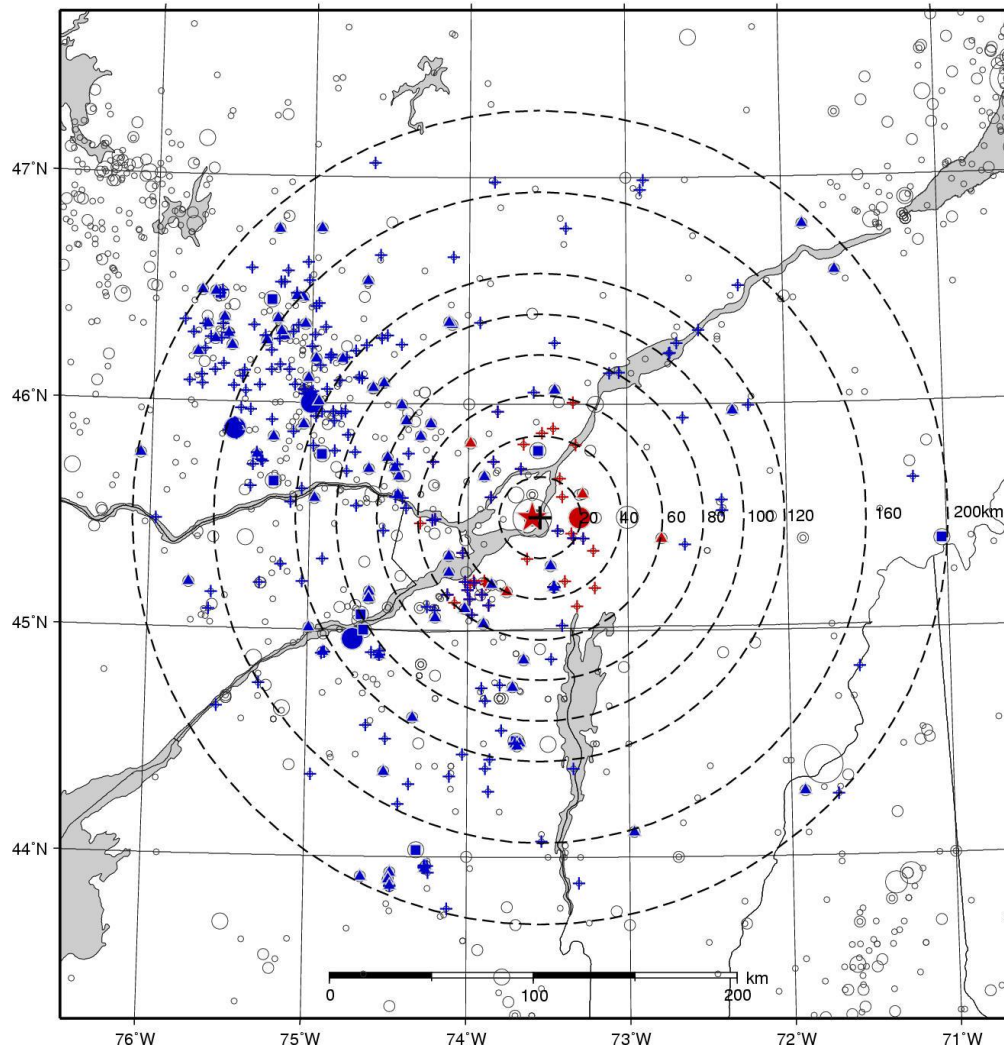
Port of Montreal regional seismicity

earthquakes larger than magnitude	are complete from the year
5.95	1660 1850
5.35	1730
4.75	1880 1900
4.25	1900 1928
3.75	1928 1938
3.25	1938
2.75	1963 1963
2.35	1968 1975
2.05	1982

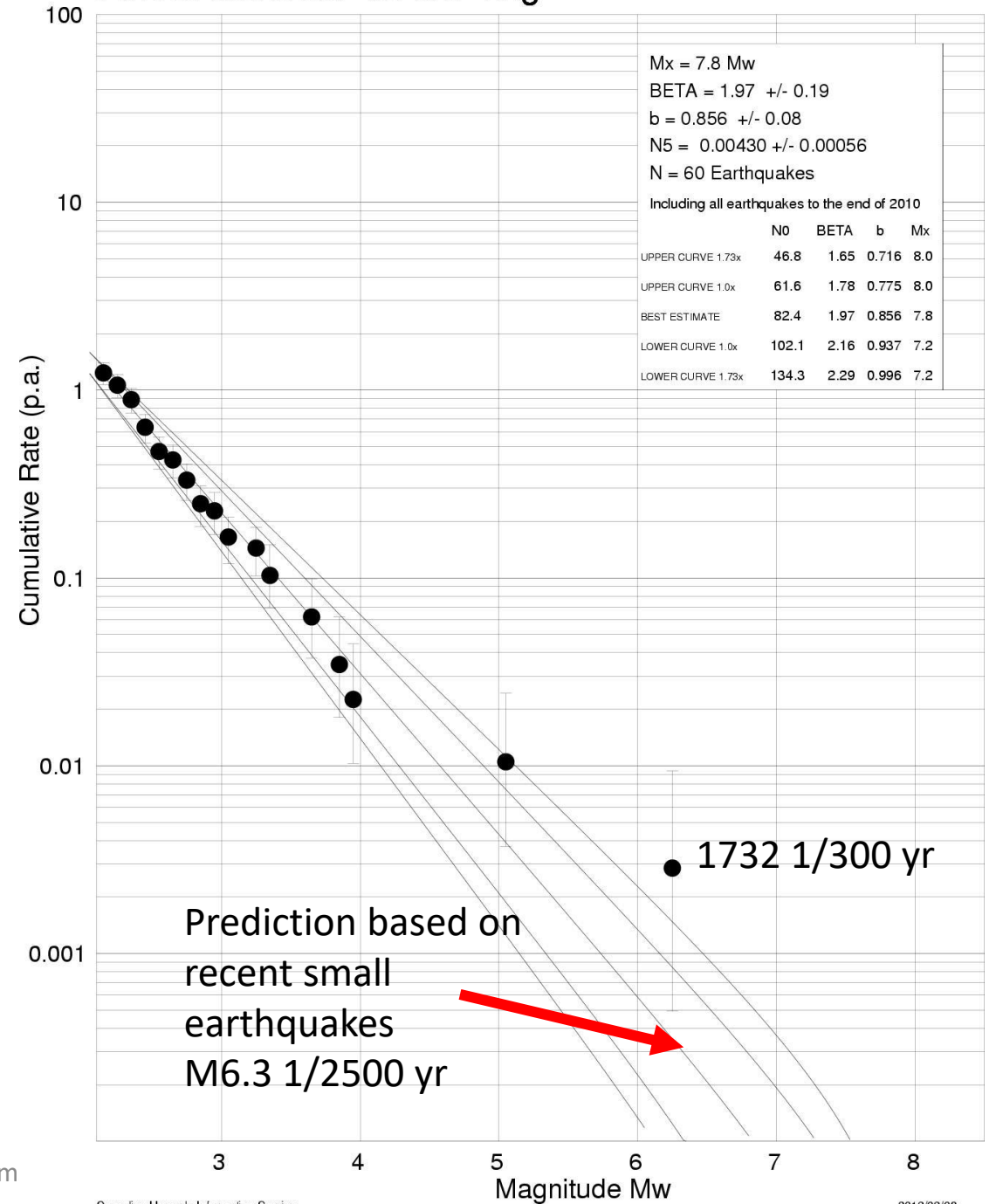


Canadian Hazards Information Service
Geological Survey of Canada
March 7 2013

All known earthquakes M ≥ 2.5 or Mw ≥ 2.1 are plotted to the end of 2010



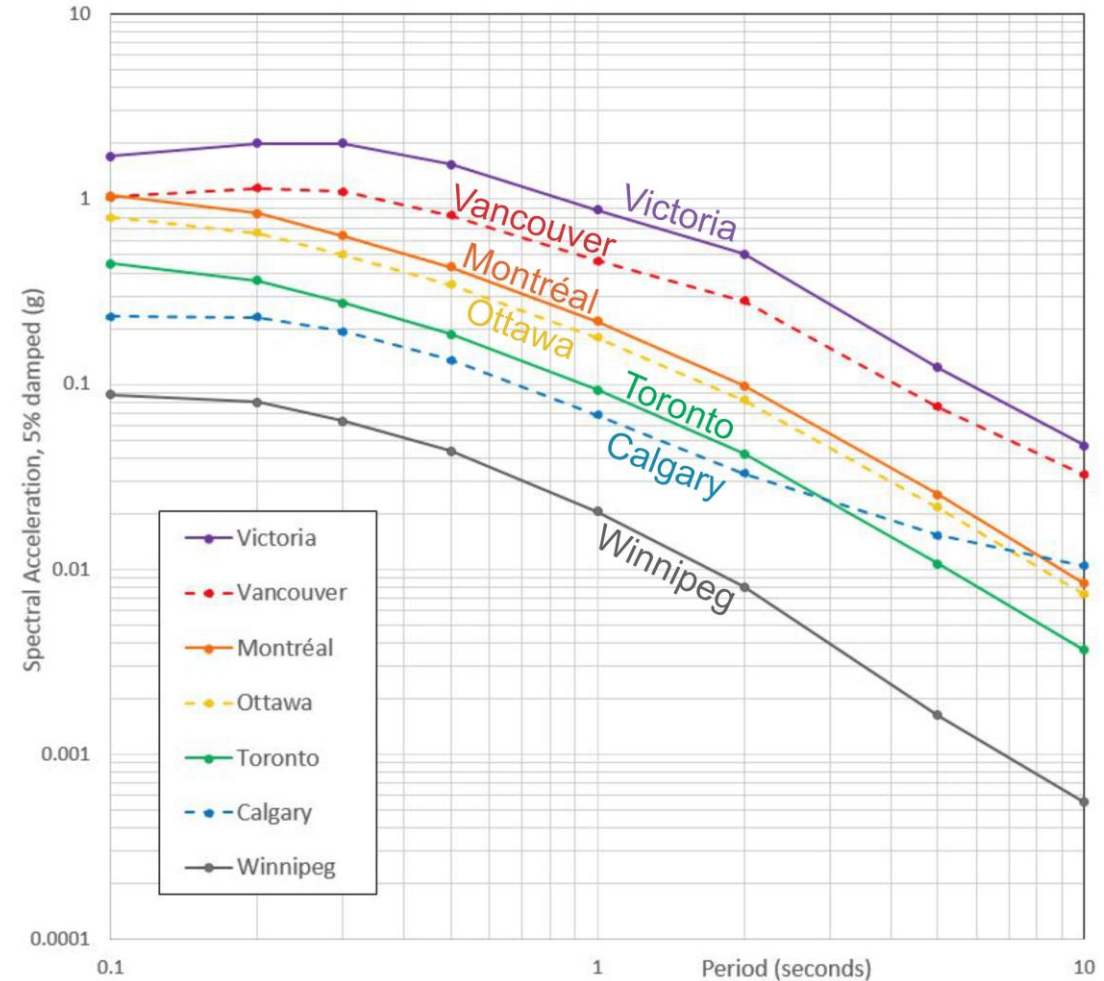
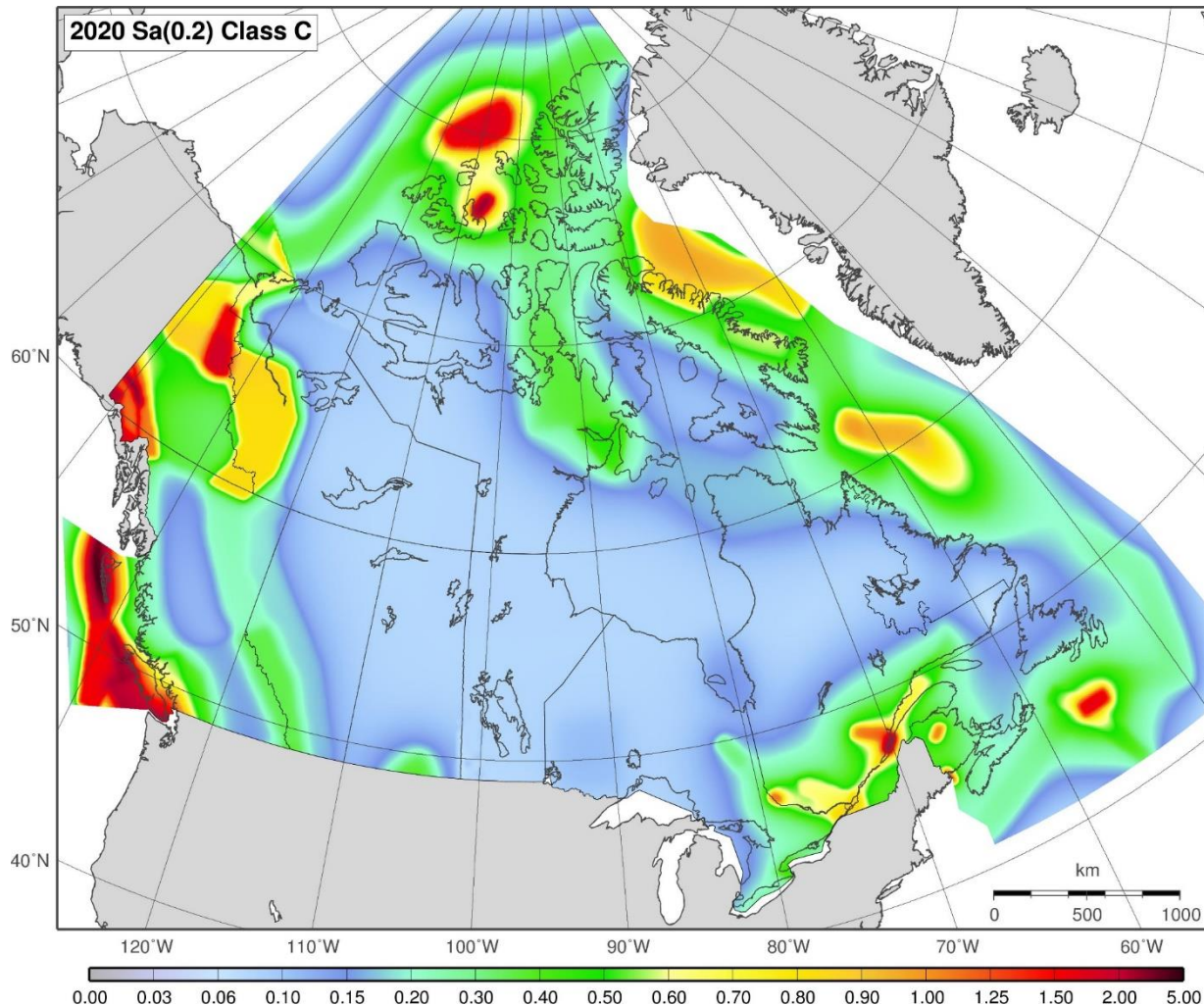
Port of Montreal 60 km "ring"



Adam

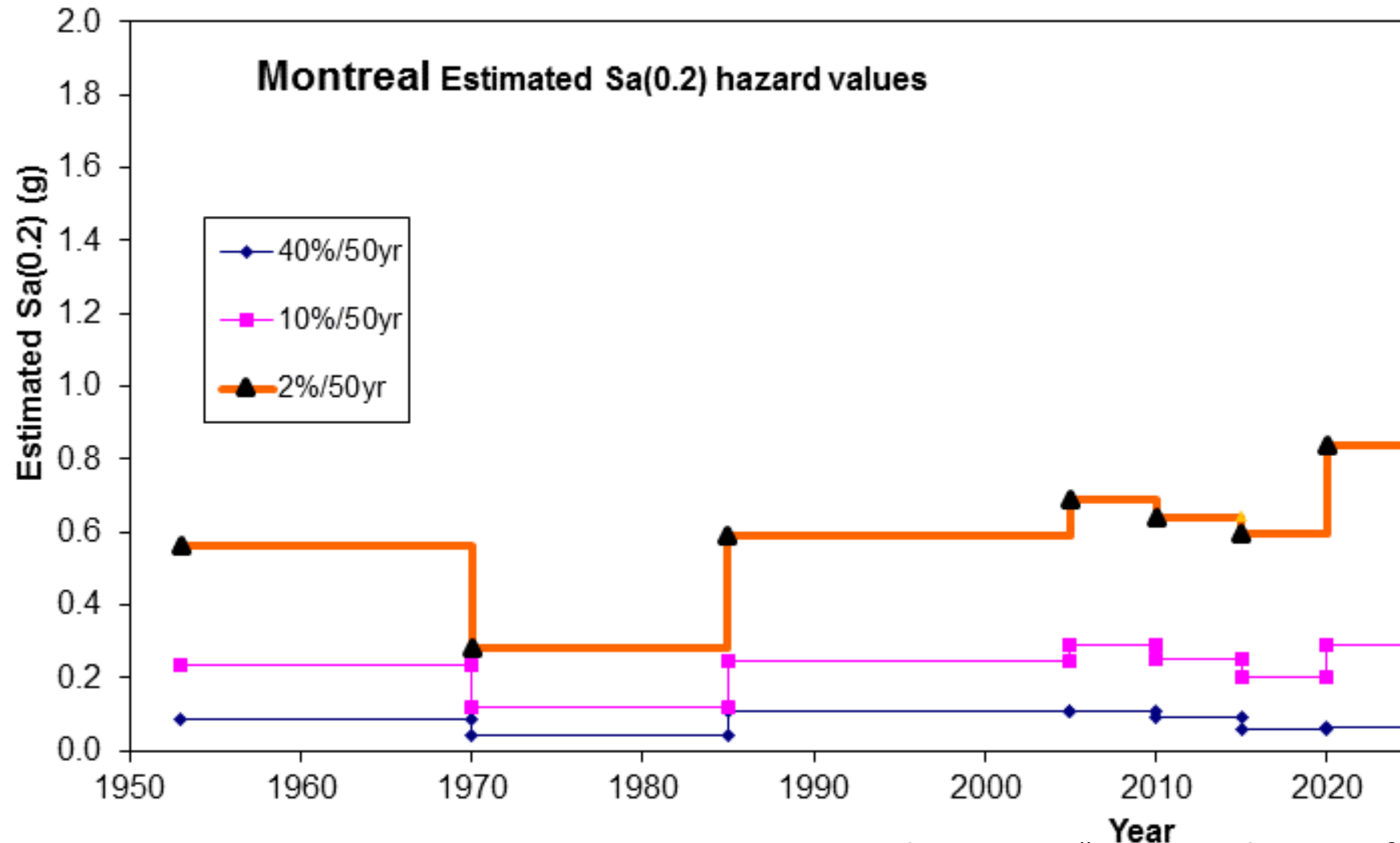
Earthquake rate and shaking models

→ Seismic Hazard estimates, for 2020:



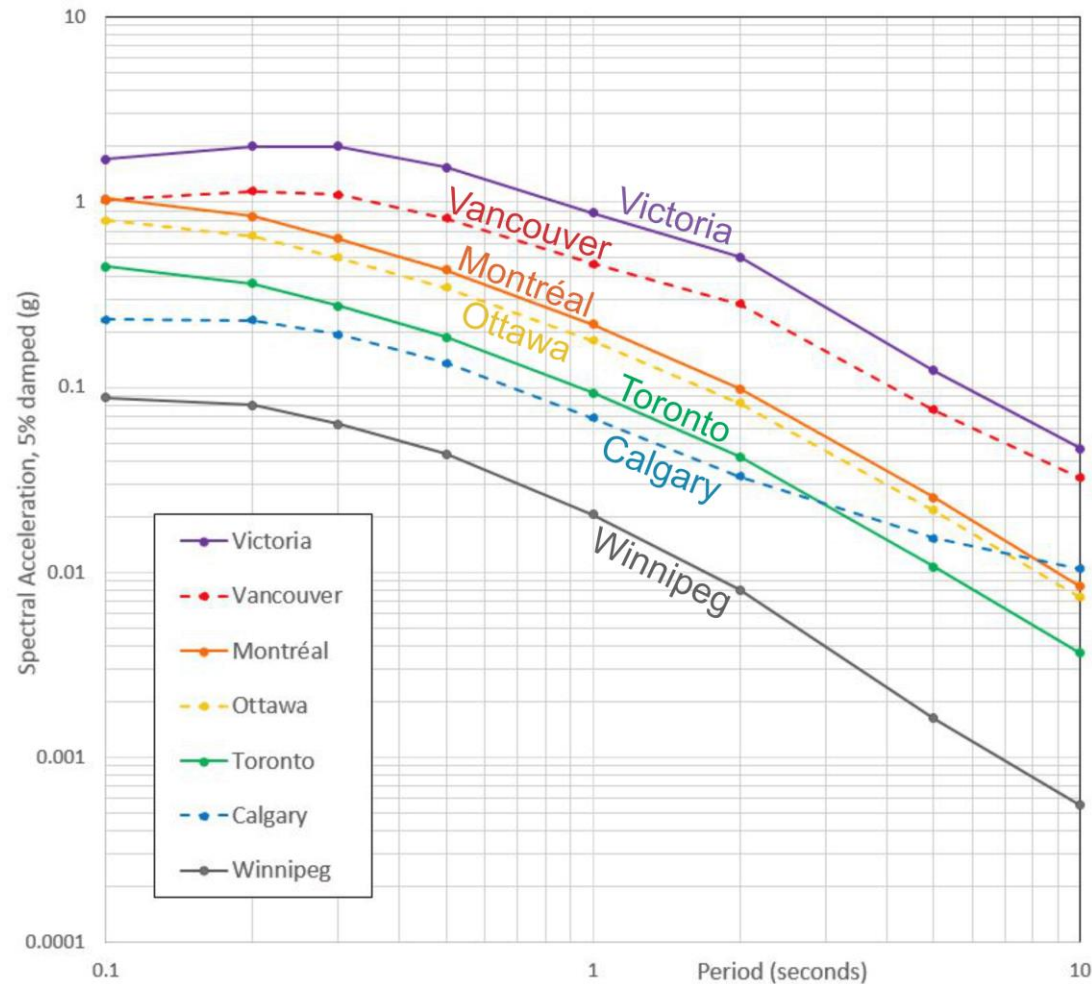
Adams et al. 2019 "Canada's 6th Generation Seismic Hazard Model, as Prepared for the 2020 National Building Code of Canada". 12th Can Conf Eq Eng

Here's how the seismic hazard estimates for Montreal have changed with time:



Adams 2019 "A 65-year history of seismic hazard estimates in Canada". 12th Can Conf Eq Eng

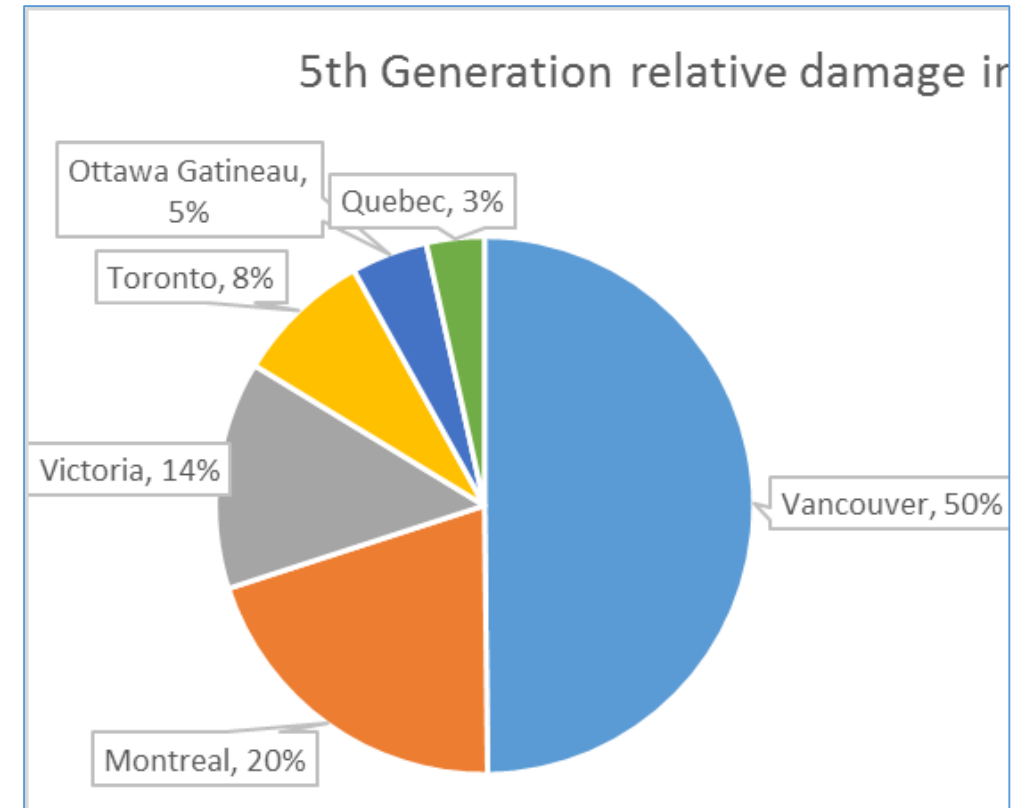
That's the seismic hazard for Montreal.....



Adams2019

What about the seismic risk?

Here's relative risk for Canadian cities, estimated using hazard*population



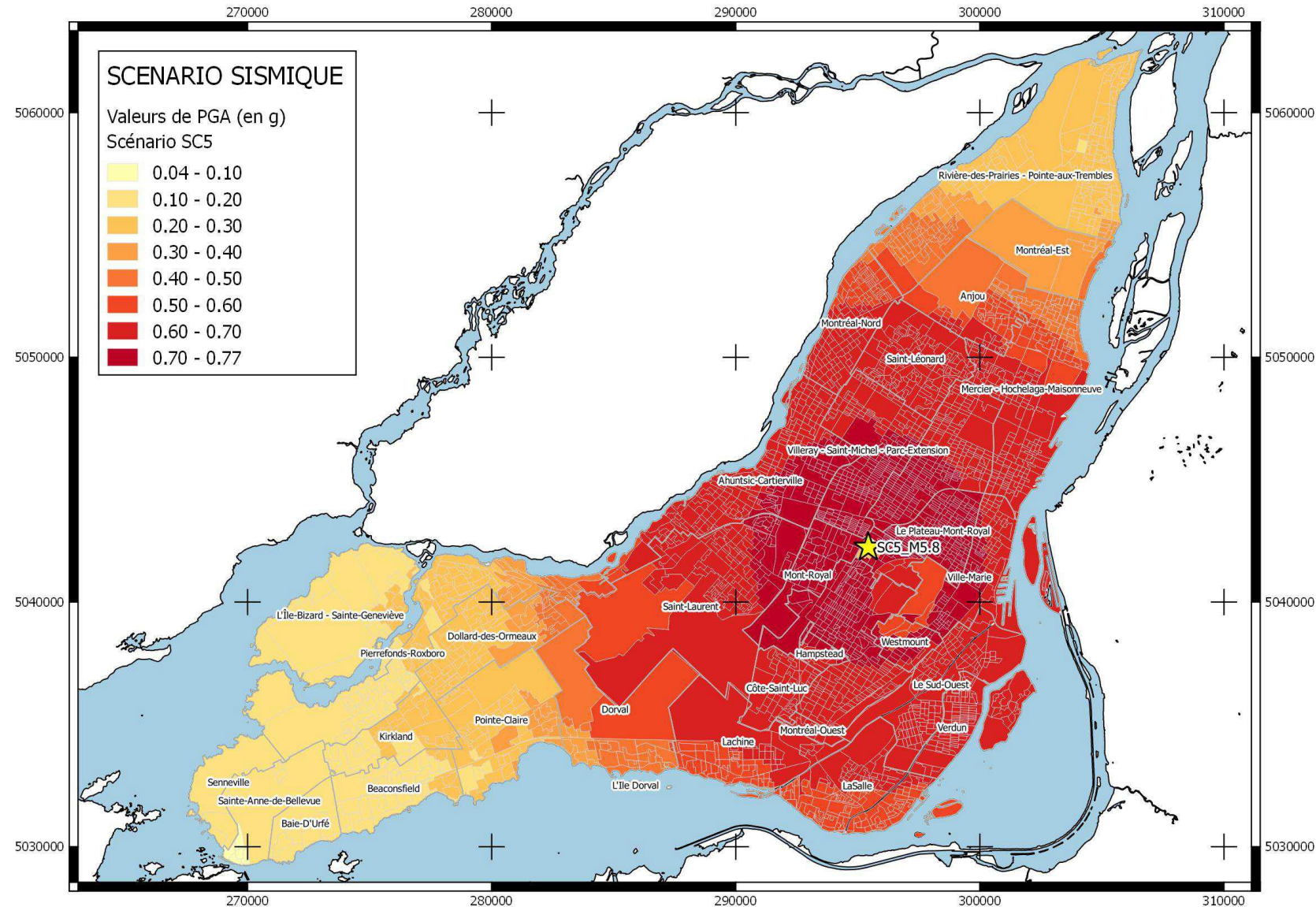
29

Scenario analysis:

Repeat of 1732

but magnitude taken
as 5.8

Strong shaking on
the island of
Montreal

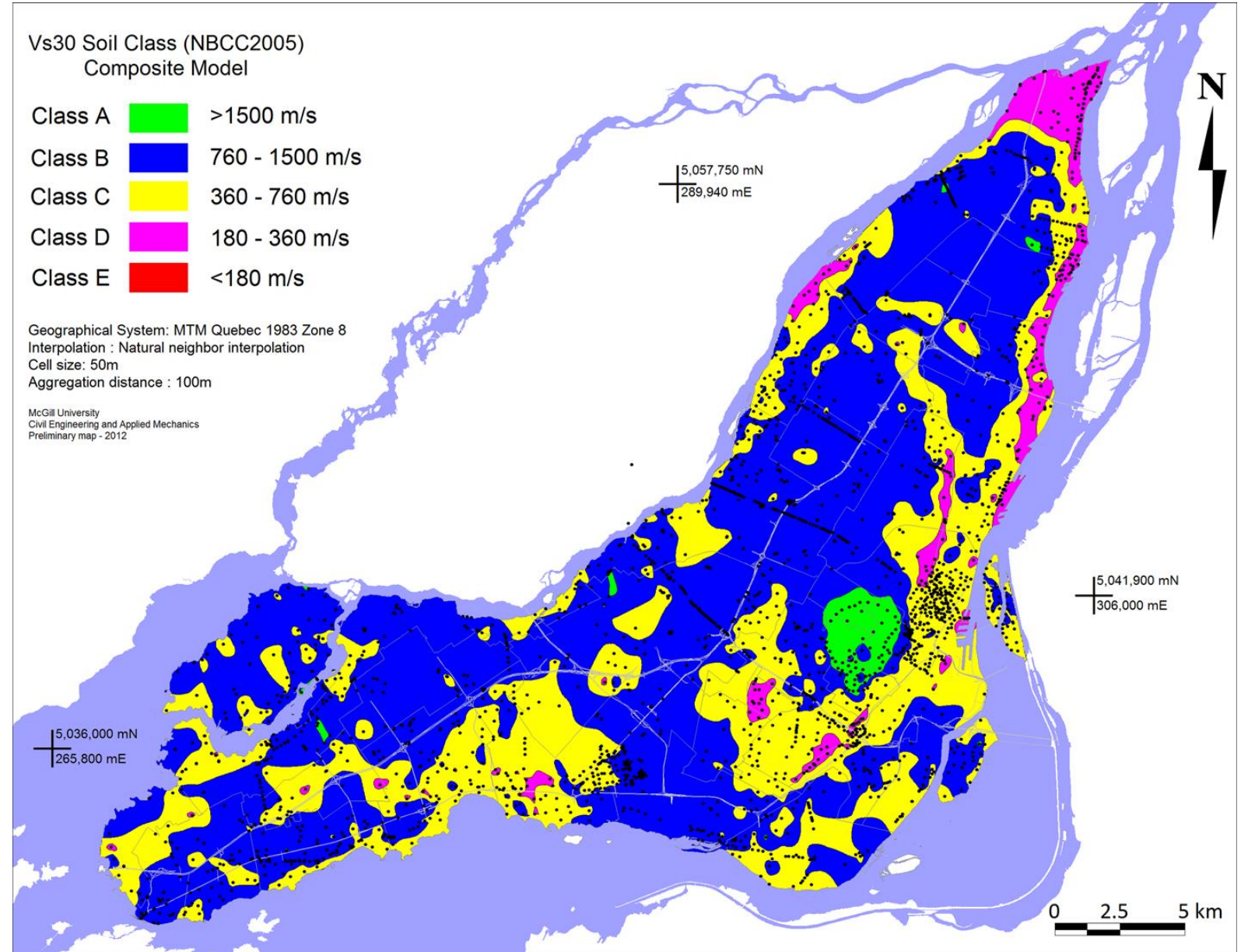


Philippe Rosset 2019 Could Montreal residential buildings suffer important losses in case of major earthquakes? 12th Can Conf Eq Eng

Soil conditions in Montreal

— not too bad, but some basins of thick soft soil, deposited soon after deglaciation in a shallow sea

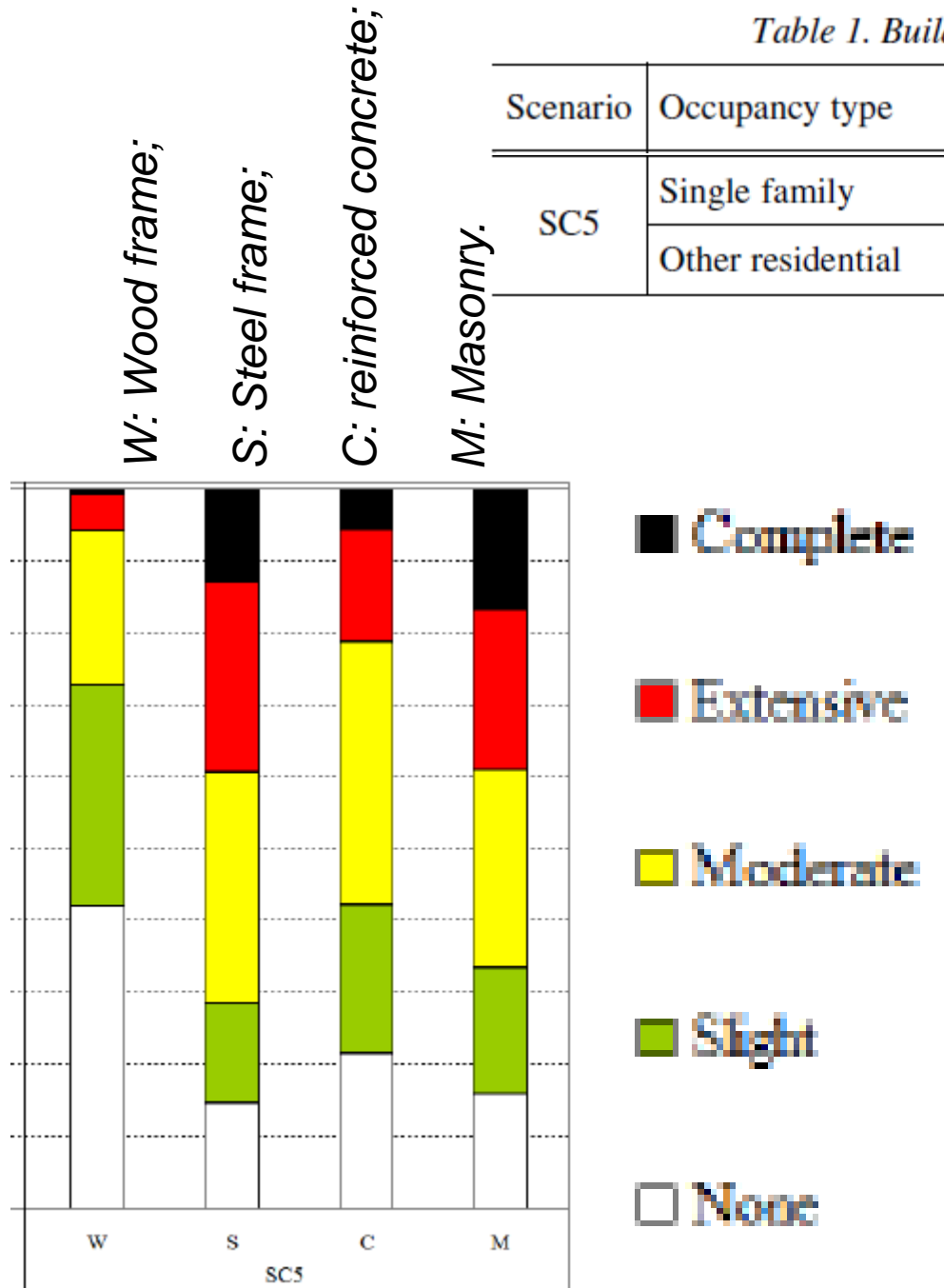
Soft soil amplifies earthquake shaking and increases damage



Rosset et al 2015: Microzonation models for Montreal with respect to VS30. Bull Earthquake Eng (2015) 13:2225–2239

Table 1. Building damage distribution (in %) by occupancy types and scenarios.

Scenario	Occupancy type	None	Slight	Moderate	Extensive	Complete	Number of buildings
SC5	Single family	48.0	28.4	17.9	4.5	1.3	196,640
	Other residential	23.5	27.8	28.7	13.1	6.9	153,676



Scenario →
Heavy residential
building losses,
particularly
masonry ones

Philippe Rosset 2019 Could Montreal residential
buildings suffer important losses in case of major
earthquakes? 12th Can Conf Eq Eng

Summary

1. Montreal is here because the rivers meet here
2. The rivers are here because of geological events
3. Those geological events resulted from ancient large earthquakes
4. Today's earthquakes are related to the old faults
5. Seismic hazard is moderate in Montreal
6. Seismic risk is appreciable in Montreal, even if it is not Japan, Peru, Indonesia.....
7. And you are here because.....?

Thank You!

All interested participants are invited to attend a presentation given by John Adams from 09:30-10:00 on July 12.

Speaker: John Adams, Canadian Hazards Information Service, Natural Resources Canada

Title: Montreal Shakes – Local earthquakes in their Canadian context

Abstract: Montreal benefits from past earthquakes and may suffer from future earthquakes. The establishment of Montreal at the junction of the Ottawa and St. Lawrence rivers arose from events 560 Ma ago with the rifting and later collision of continents. Montreal passed over a hotspot 110 Ma ago and left the roots of ancient volcanoes as pimples on today's landscape – Mont Royal and others. The river system echoes the crustal weaknesses left by past events and the earthquakes that accompanied them, and hence the founding of Montreal by those using the rivers for exploration and commerce. Those same ancient faults are the source of today's earthquakes. Descriptions of some larger historic earthquakes and their effects will set the scene for a talk about today's earthquakes, the seismic hazard they represent for 2020, and the consequences should a rare large earthquake occur near Montreal.