Seismic Hazard Maps for the National Building Code of Canada – past, present and future

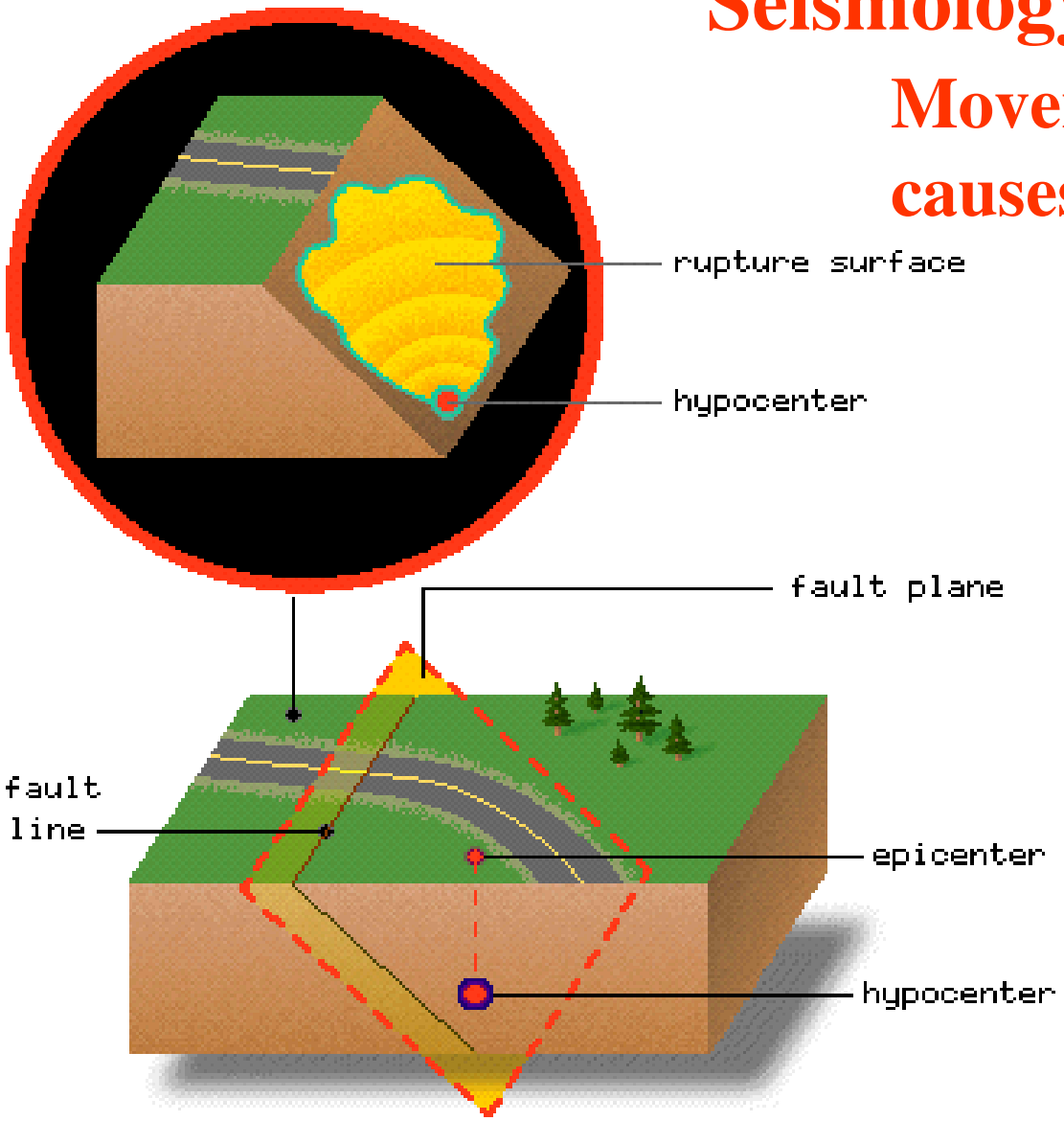
John Adams

Geological Survey of Canada,
Natural Resources Canada, Ottawa,
CSRN 2011 Workshop
2012 Jan 13

Natural Resources Canada
Ressources naturelles Canada

Seismology Background

Movement on a fault plane causes vibrations…



The larger the area on which there is slip (rupture)…

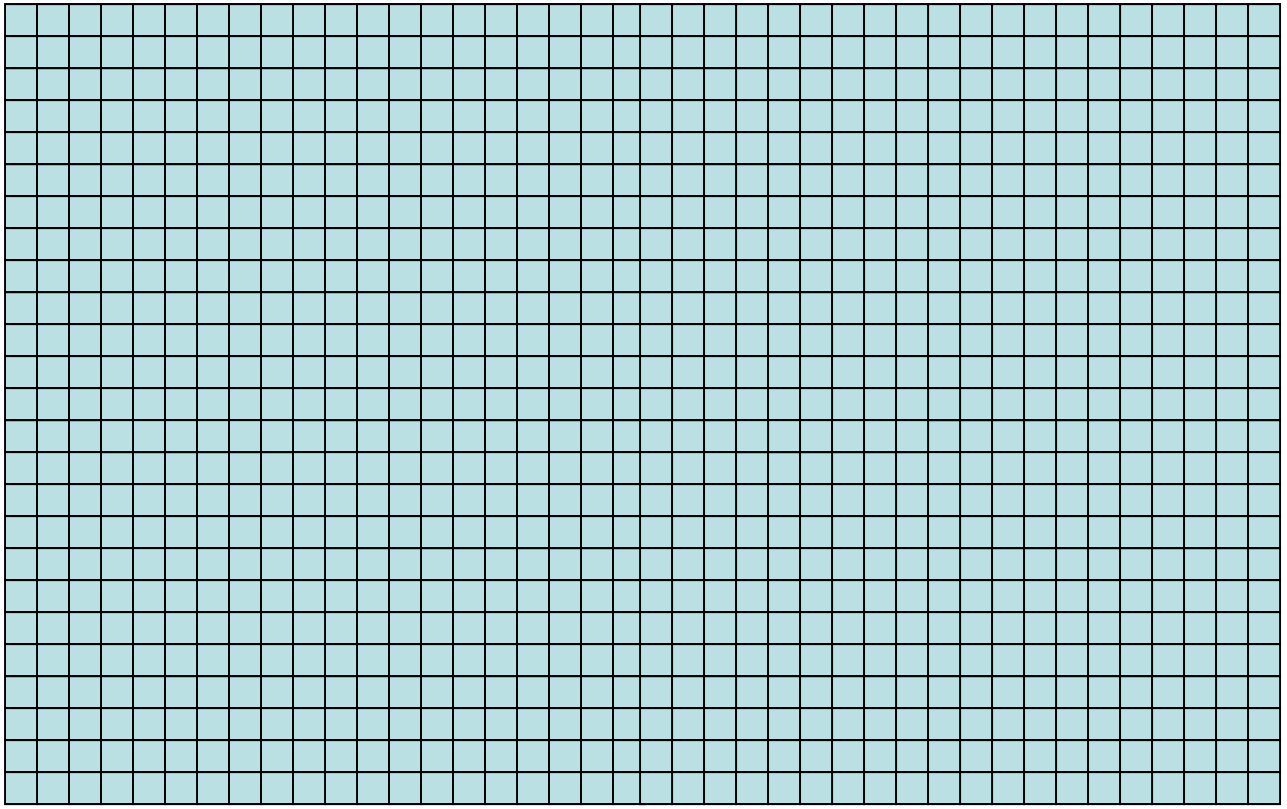
the larger the <u>magnitude</u> of the earthquake

Relative fault areas

Haiti 2010 M7.0

M6.2

Japan 2011 M9.1



~ 1000 times larger than M7.0

Magnitude

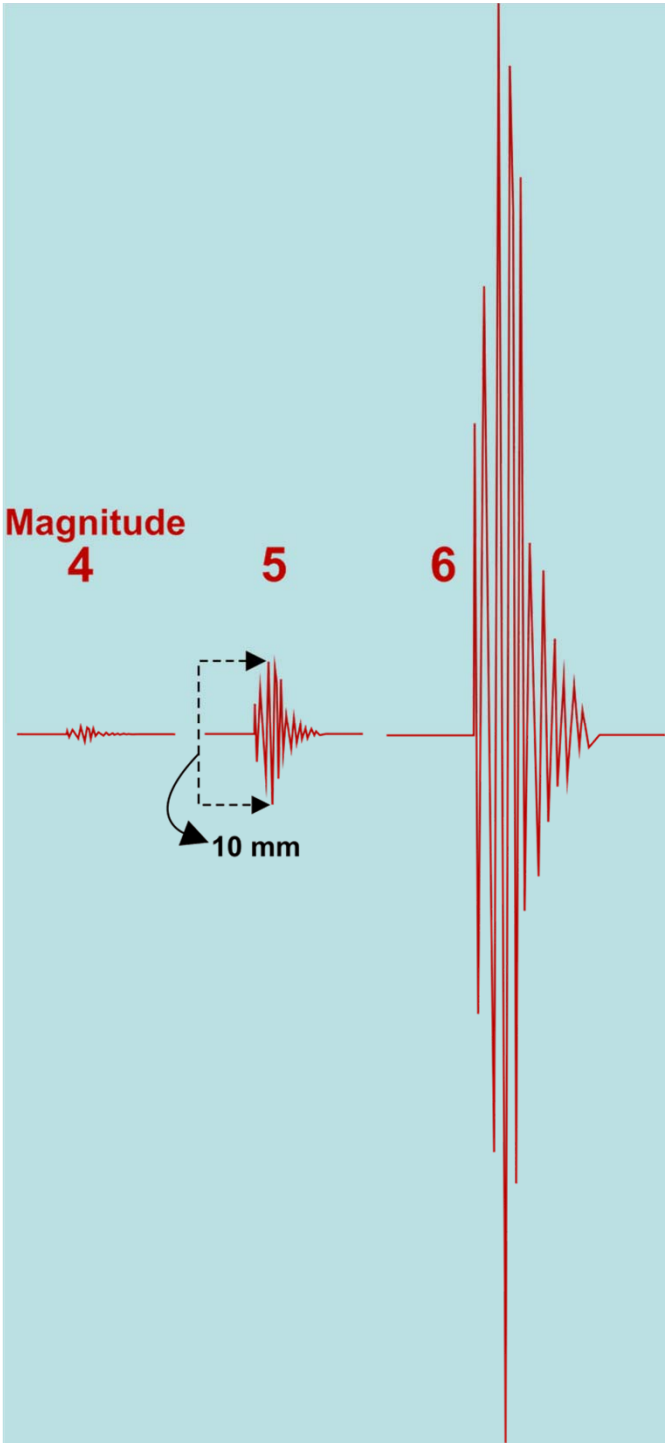
Magnitude
– depends on the size of the reactivated fault surface;
– as magnitude increases, the strength of ground shaking, duration, and area impacted increases very quickly.

Ground shaking
Increases by 10 times for every magnitude unit

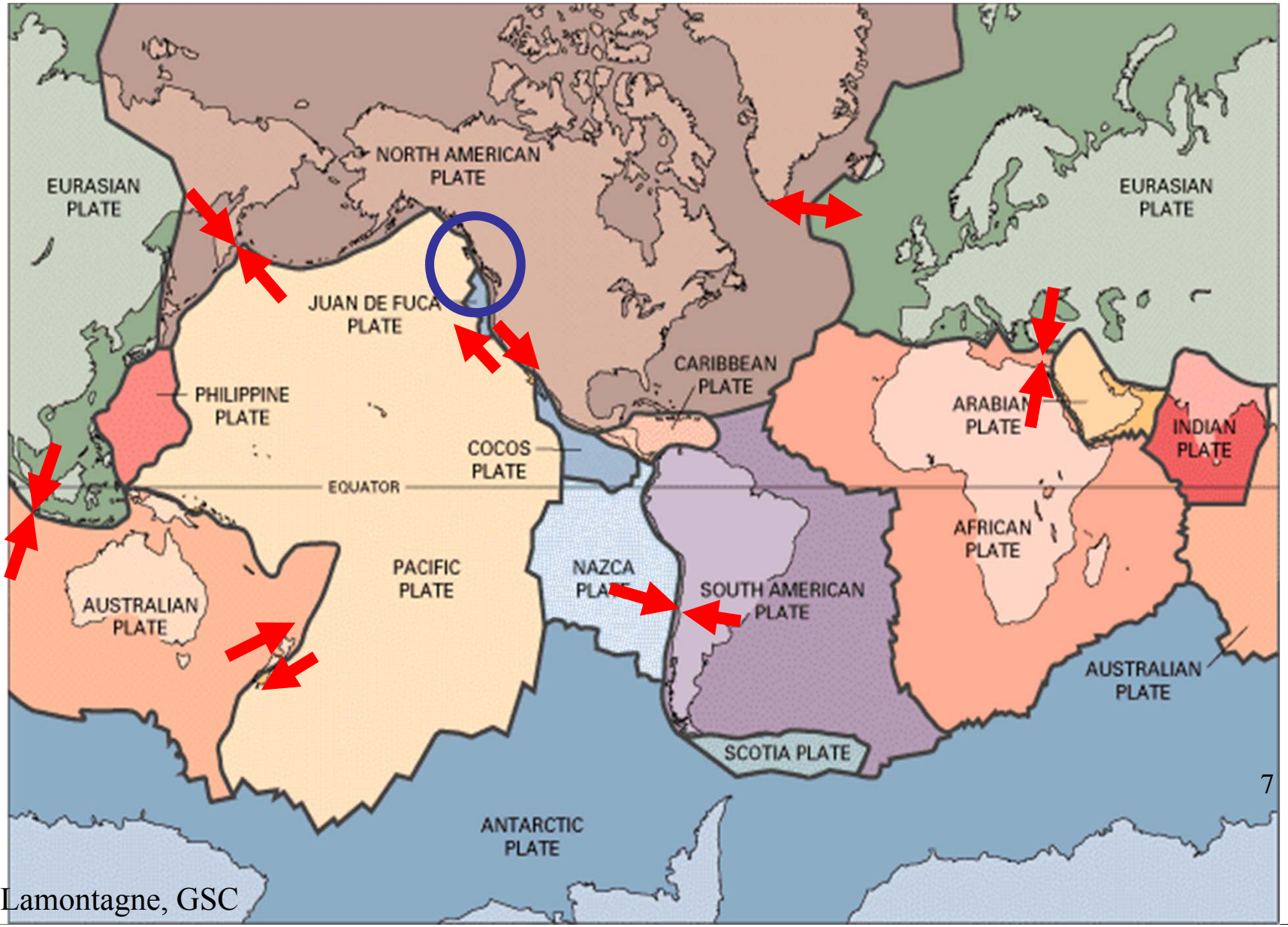
Energy released
Increases by 32 times for every magnitude unit

Duration of shaking

From a few seconds (M 4) to several minutes (M 9)

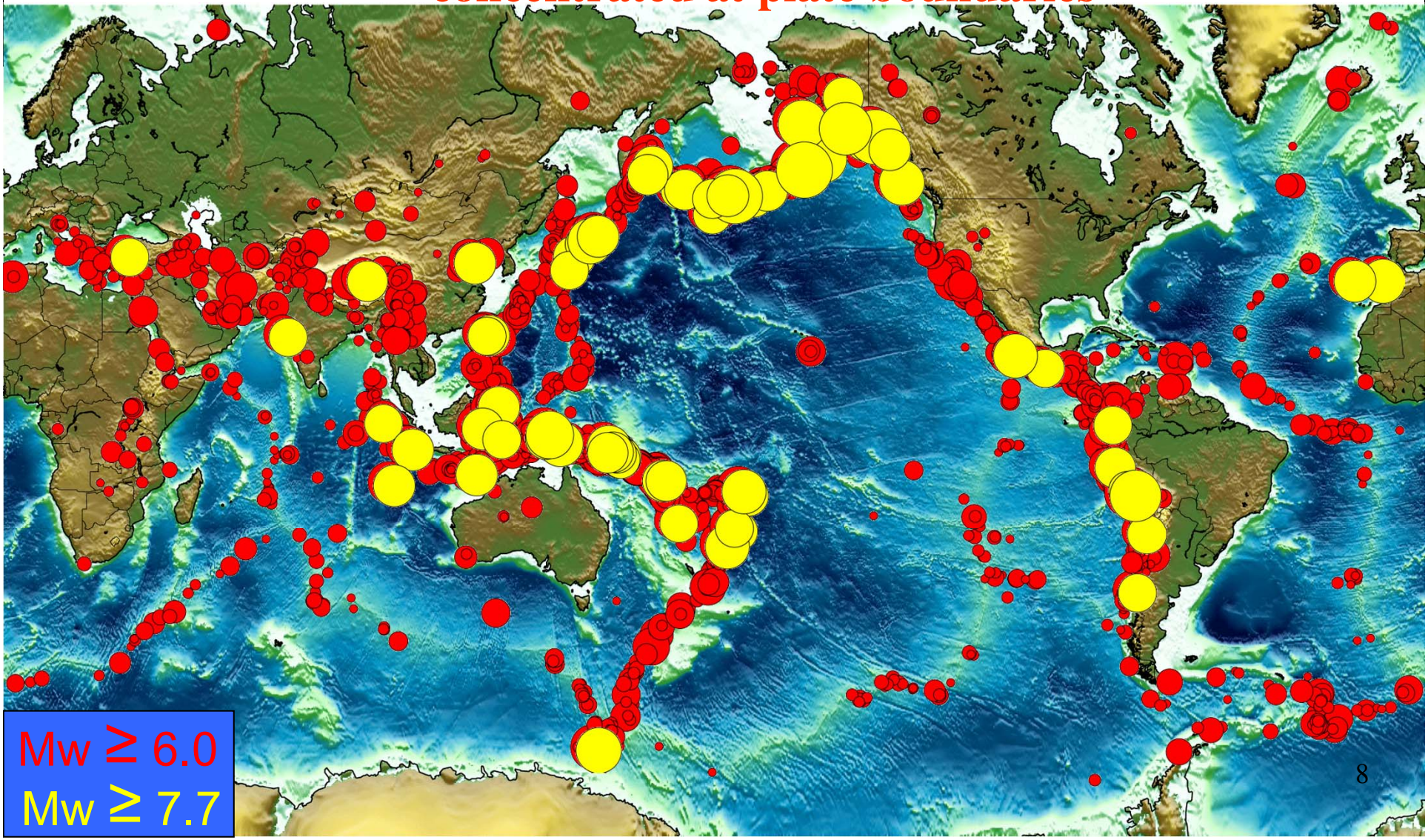


Major earthquakes are related to movements at Plate Boundaries



M Lamontagne, GSC

Global Seismicity over 20 years: concentrated at plate boundaries



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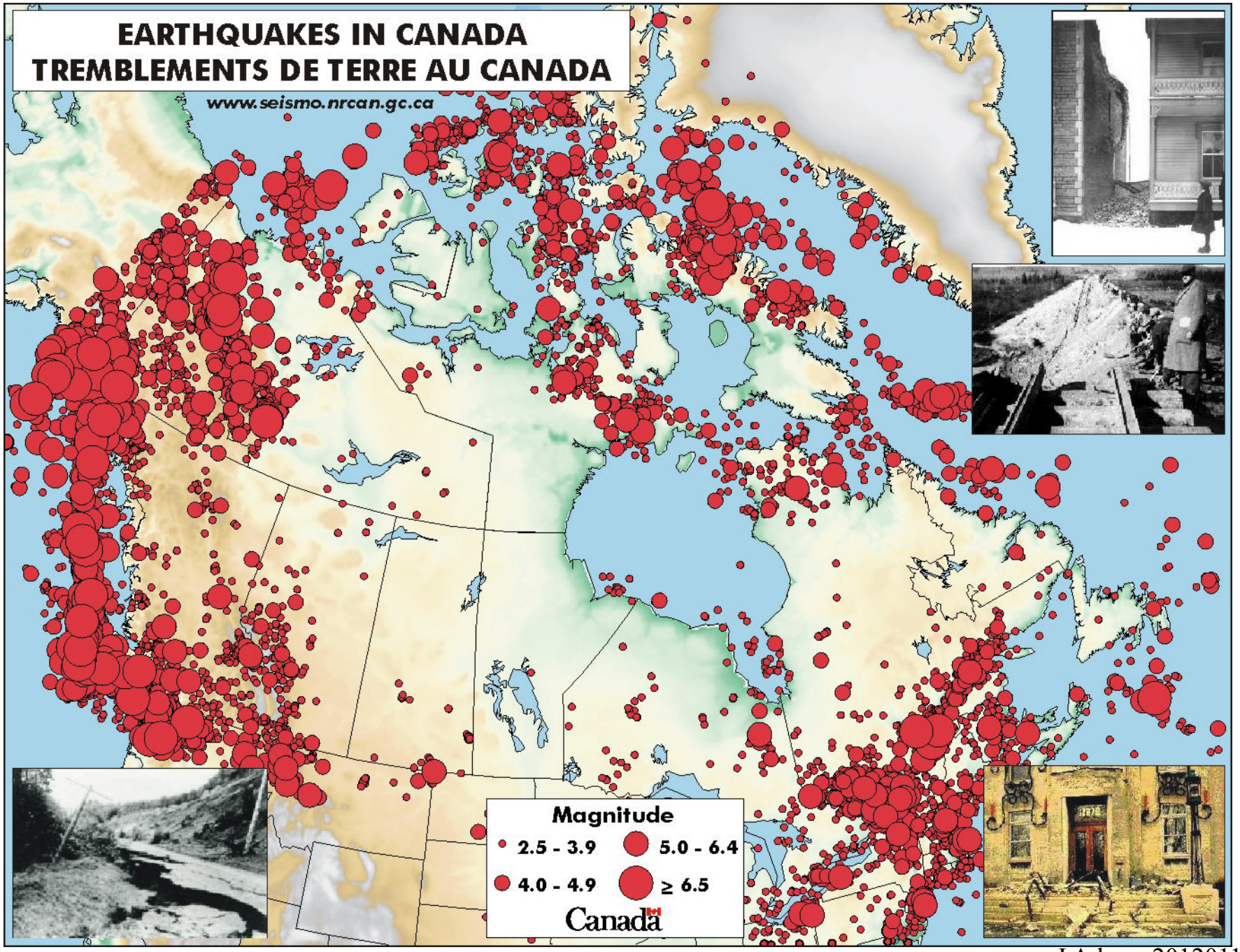

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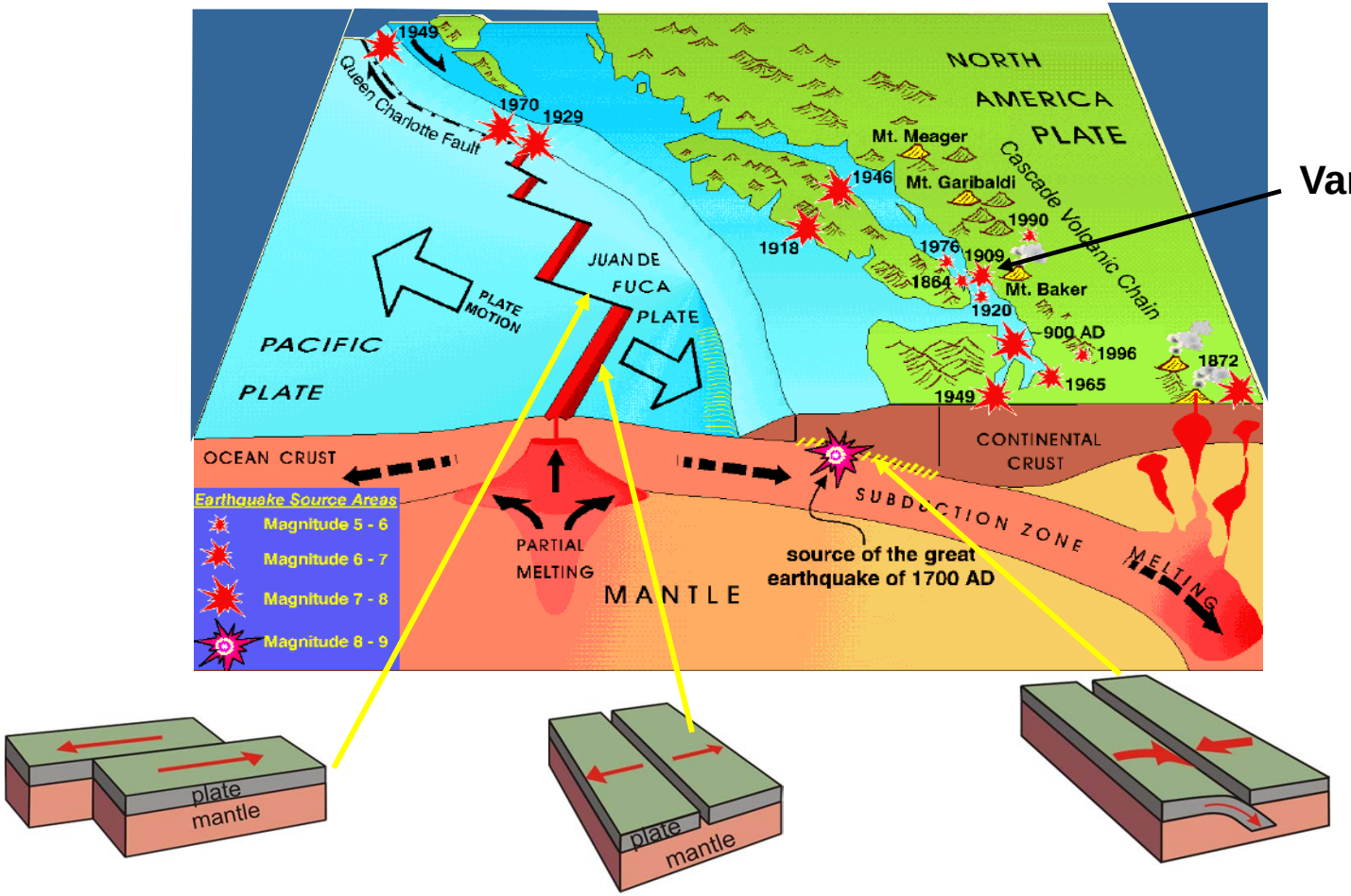
Tectonic Context of Canada's West Coast



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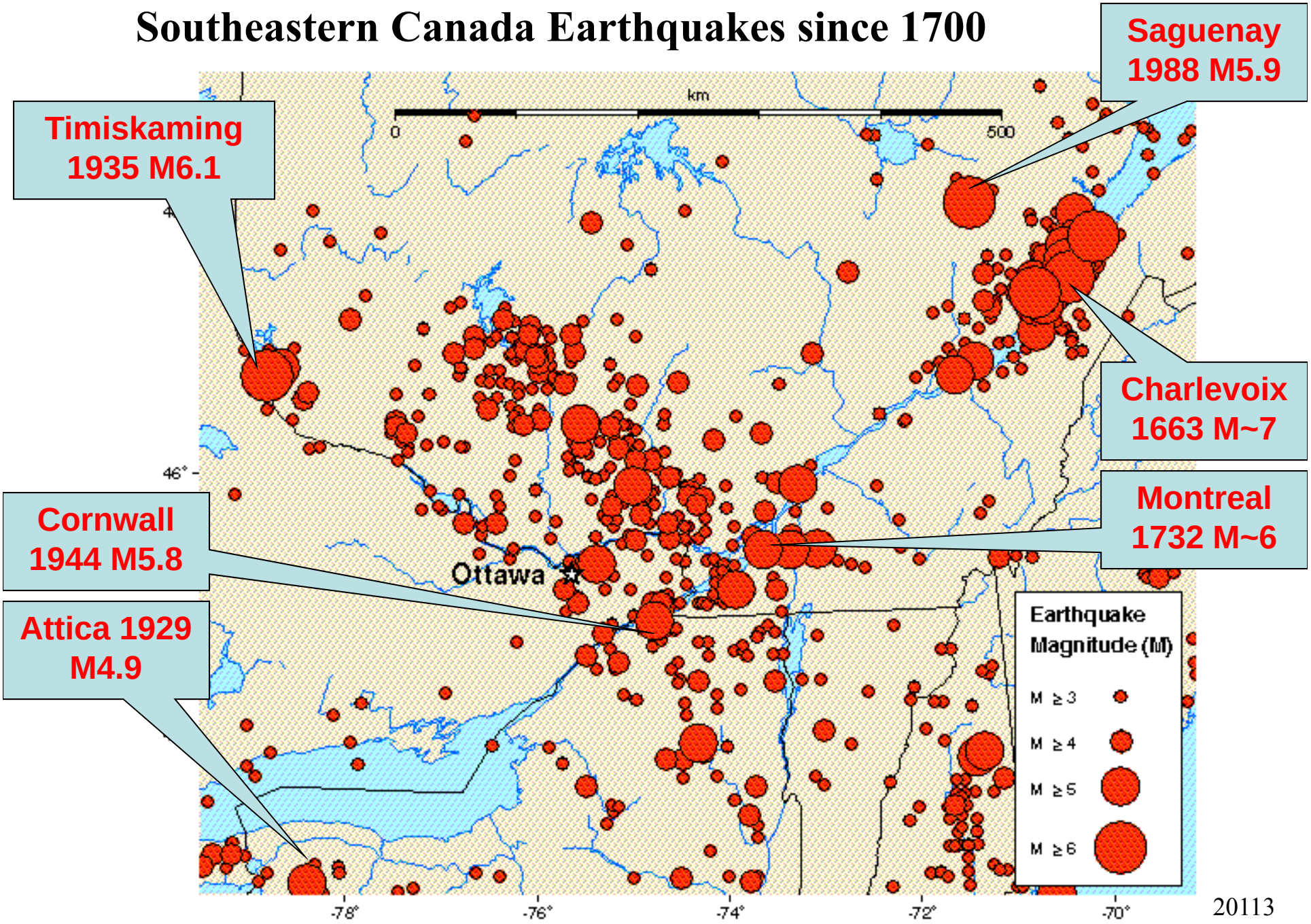
Southeastern Canada Earthquakes since 1700



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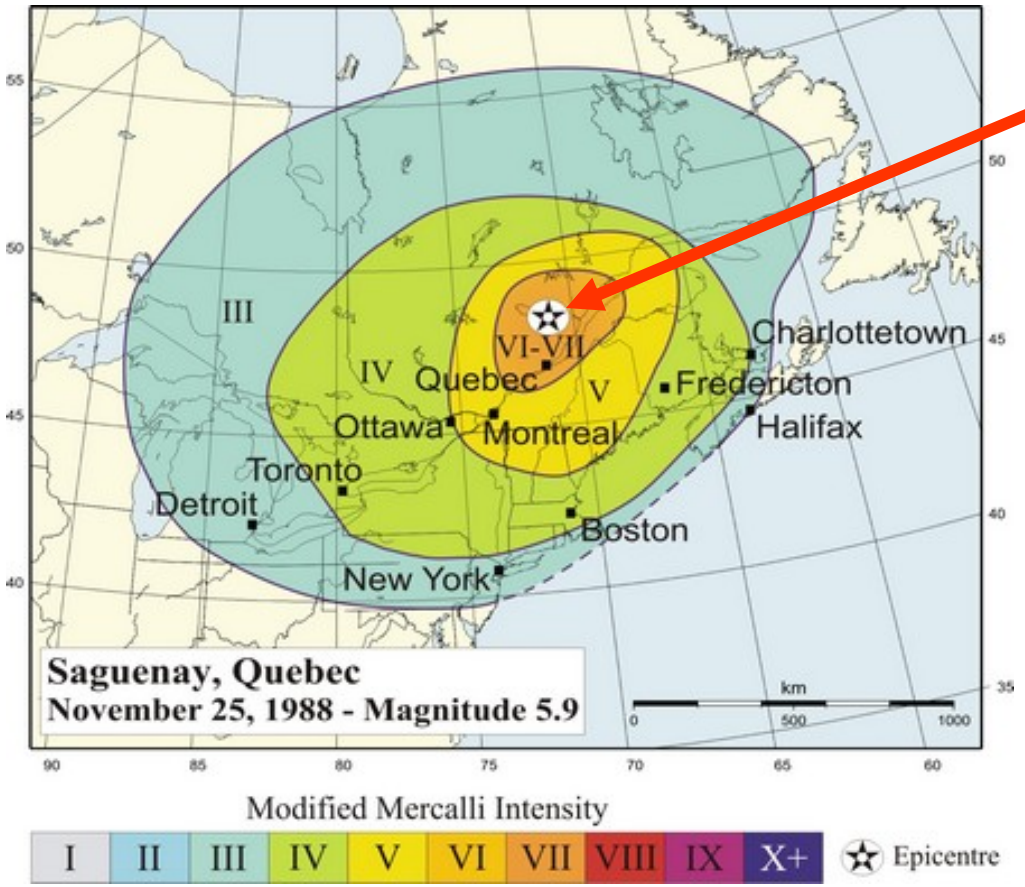
Size described by magnitude (**one magnitude per earthquake!**)

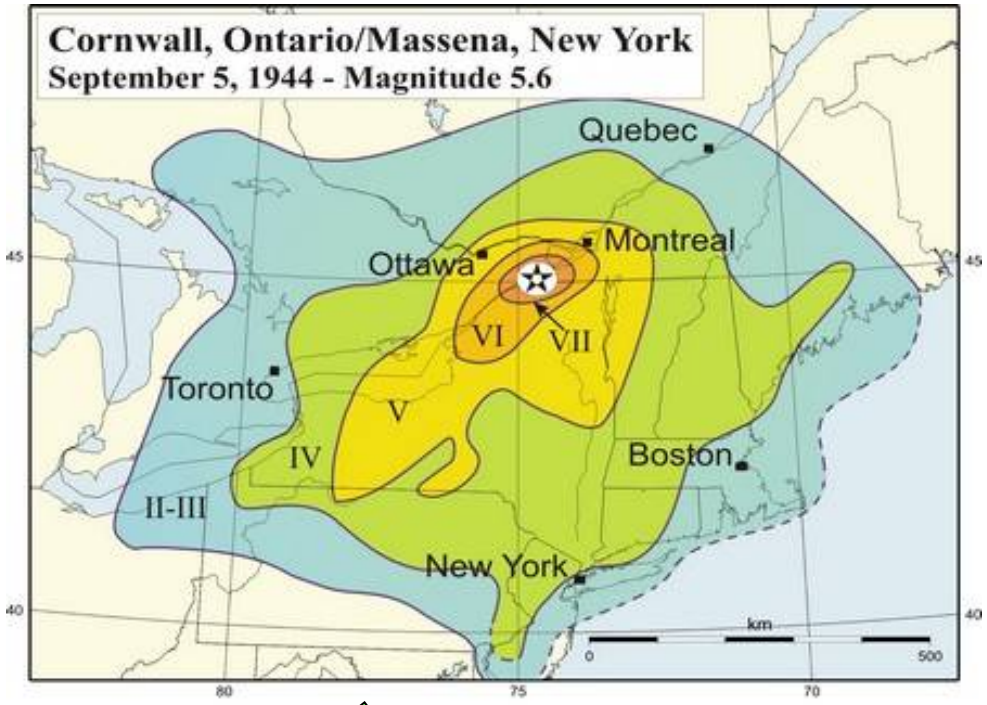
Effects described by shaking intensity (Modified Mercalli scale: IV, VII)



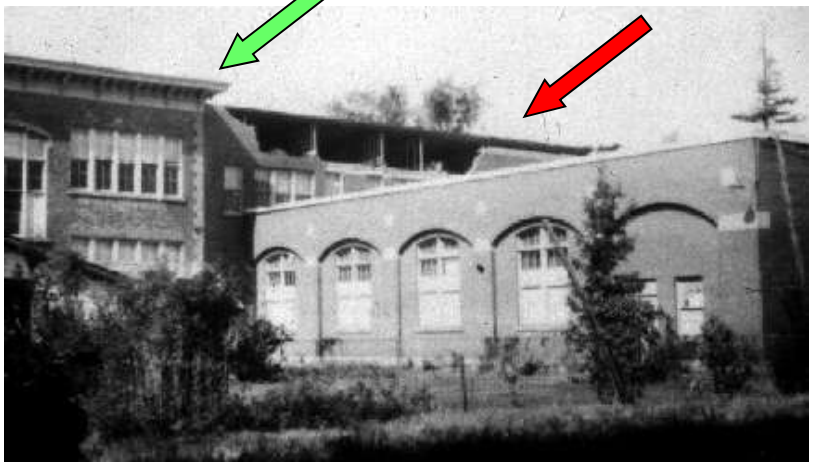
Magnitude 5.9 Saguenay
1988 Nov 25 suppertime

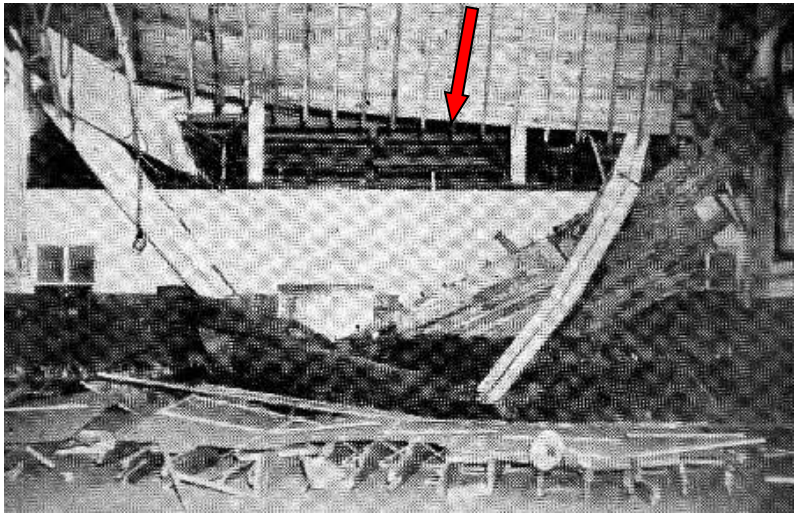
Damage in Montreal 250 km away

Cornwall 1944 Mw 5.7



Masonry damage





School Gymnasium

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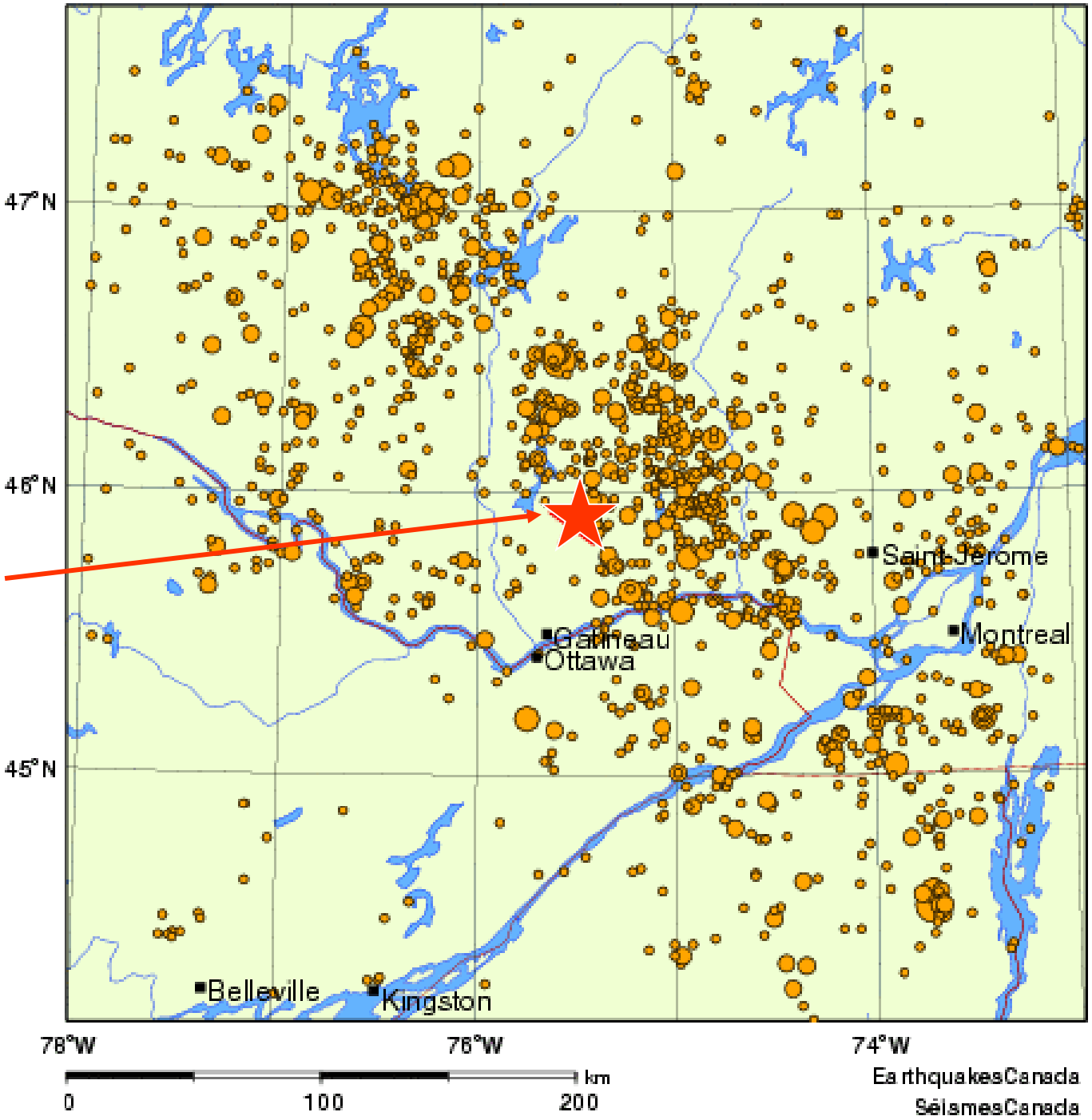
Most recent sizable earthquake

Val-des-Bois
Mw 5.0
June 2010

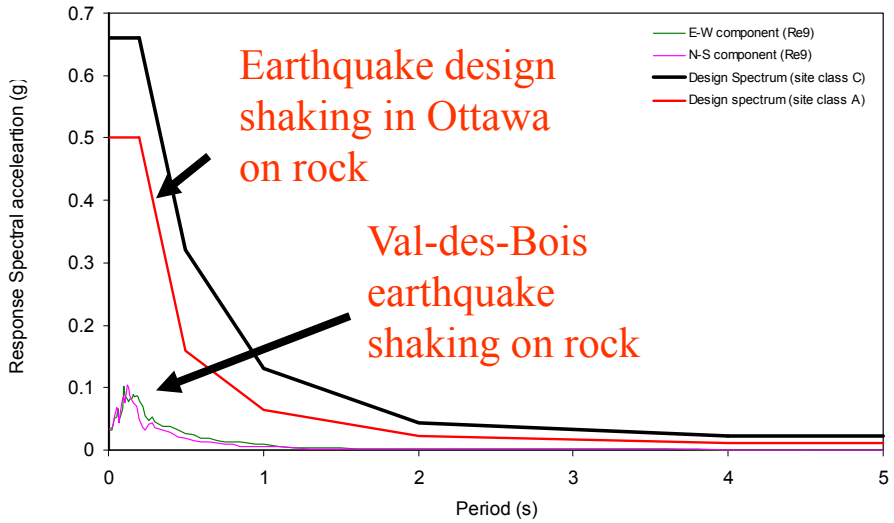


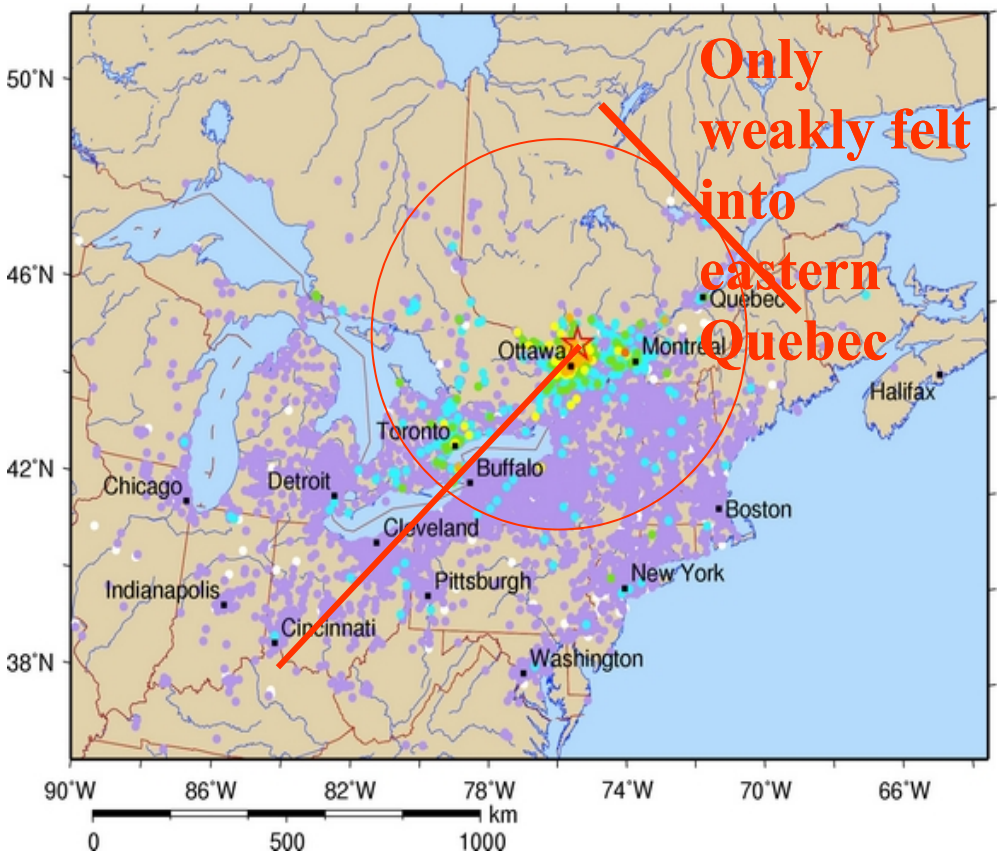
Earthquakes magnitude 2.0 and larger, 1980 - present

Val-des-Bois Earthquake

June 23rd shaking in Ottawa was

- strongest in Ottawa's history
- once-in-150-year level of shaking
- only 1/5th as strong as current building code requires





Potentially felt by about 19 million people

Web reports from 59,000 people

Felt much farther to the southwest than to the northeast

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Examples of Val-des-Bois earthquake effects

At less than 70 km

While in Toronto, 400 km away …….

www.zazzle.com

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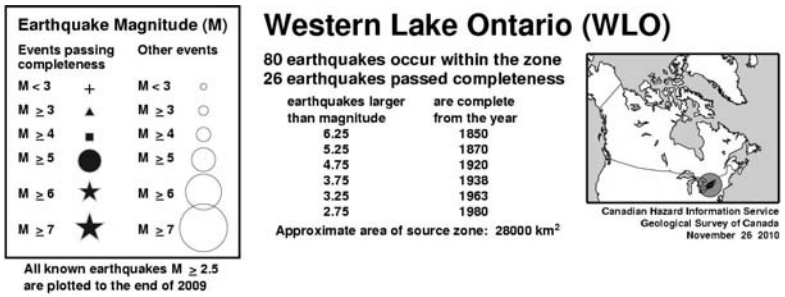
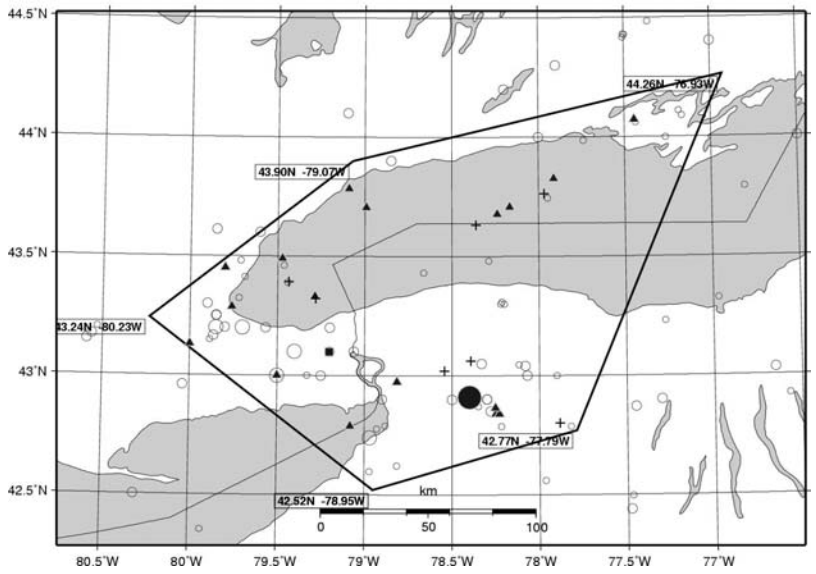
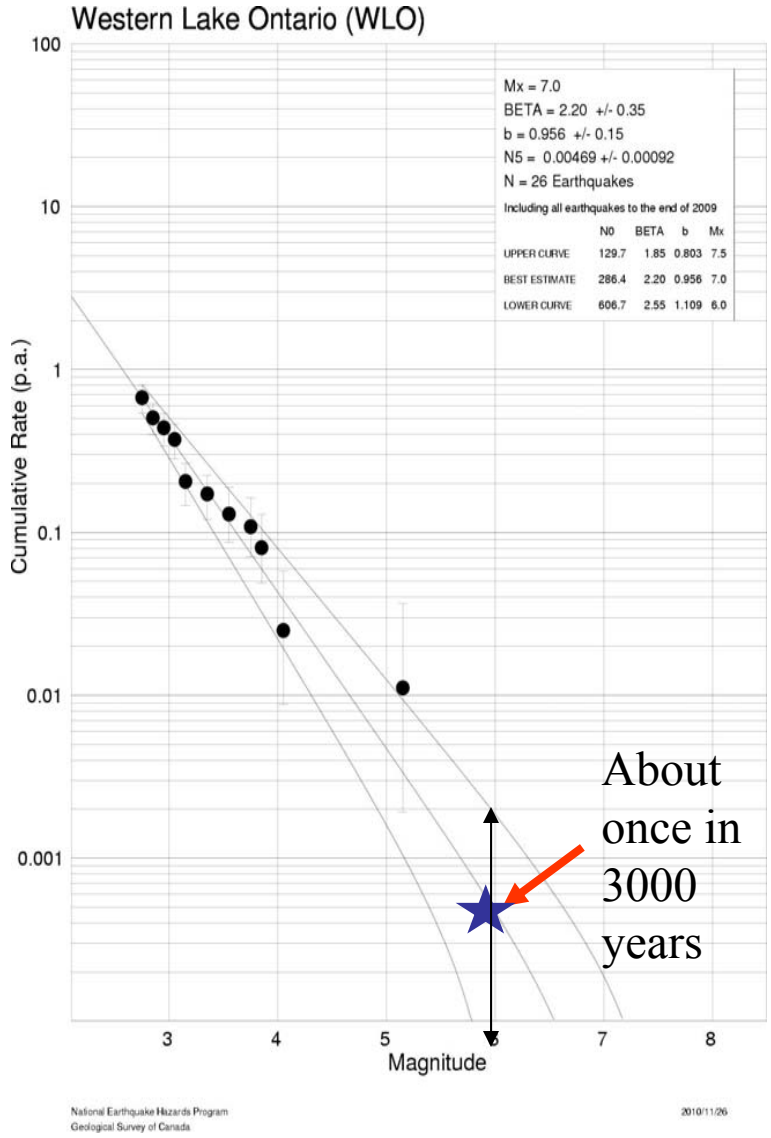
How often do earthquakes happen?

Magnitude-recurrence statistics near Toronto







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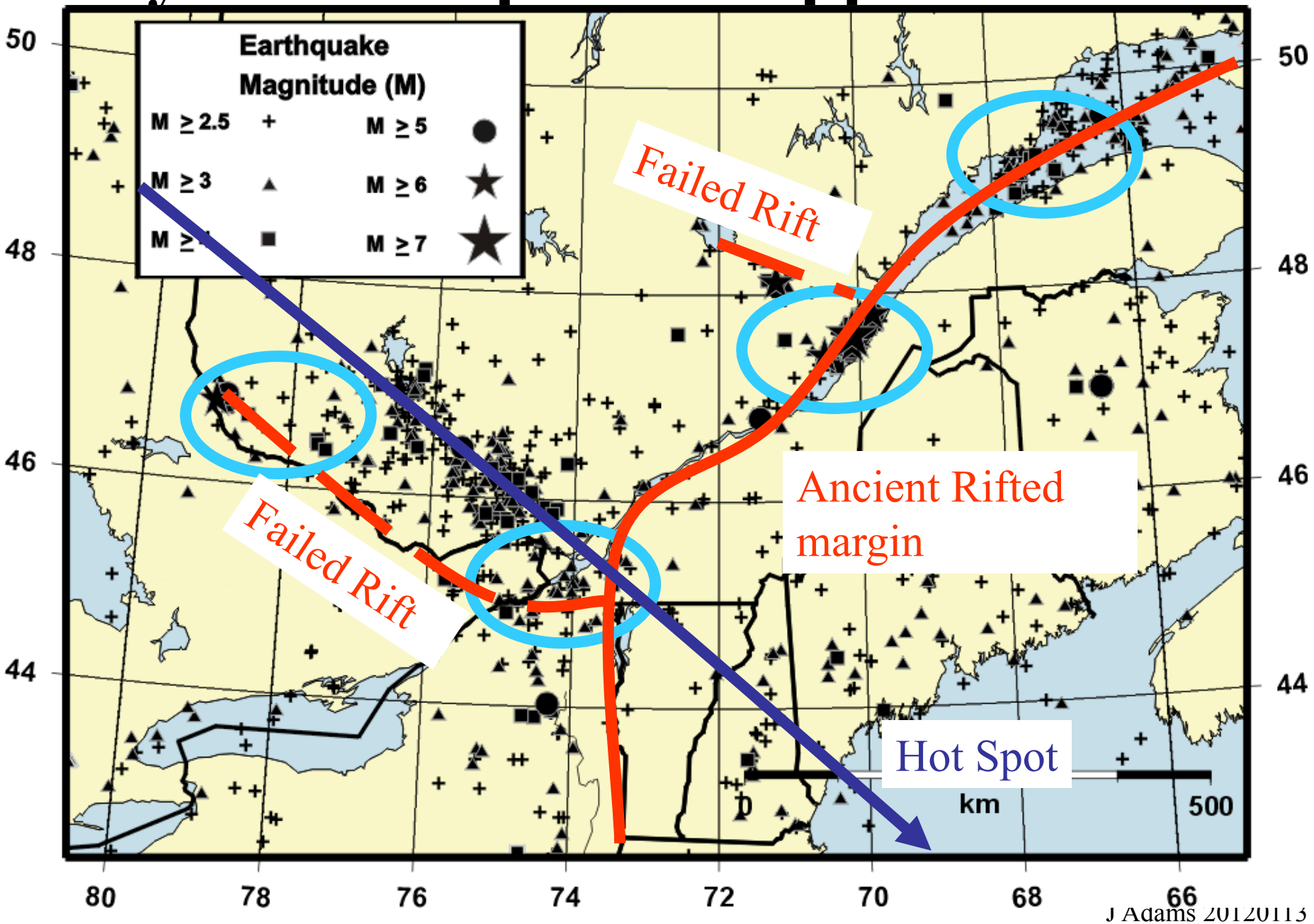
Why do earthquakes happen here?

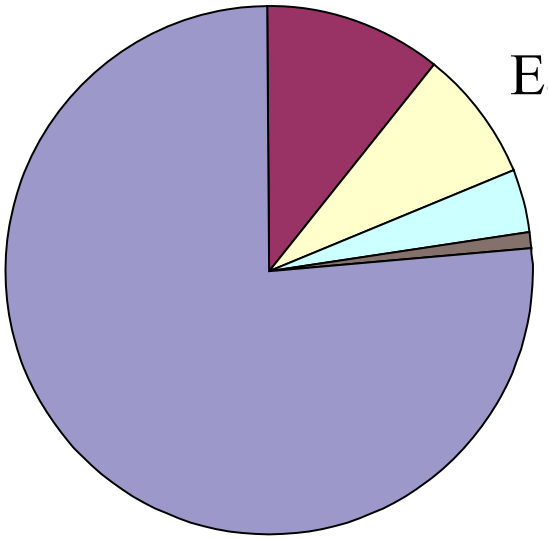


We can't stop earthquakes
We can't forecast them in a useful way (yet!),

So we must mitigate their effects

Globally most deaths in earthquakes are from:

People killed in collapsing buildings 77%



Tsunamis 11%

Earthquake-triggered landslides 8%

Fire 4%

Liquefaction; heart attacks ~1%

2.6 million fatalities, 1900-2010
Source: Daniell 2011, Figure 10

We <u>have</u> done something about collapsing buildings, through Canada's National Building Code

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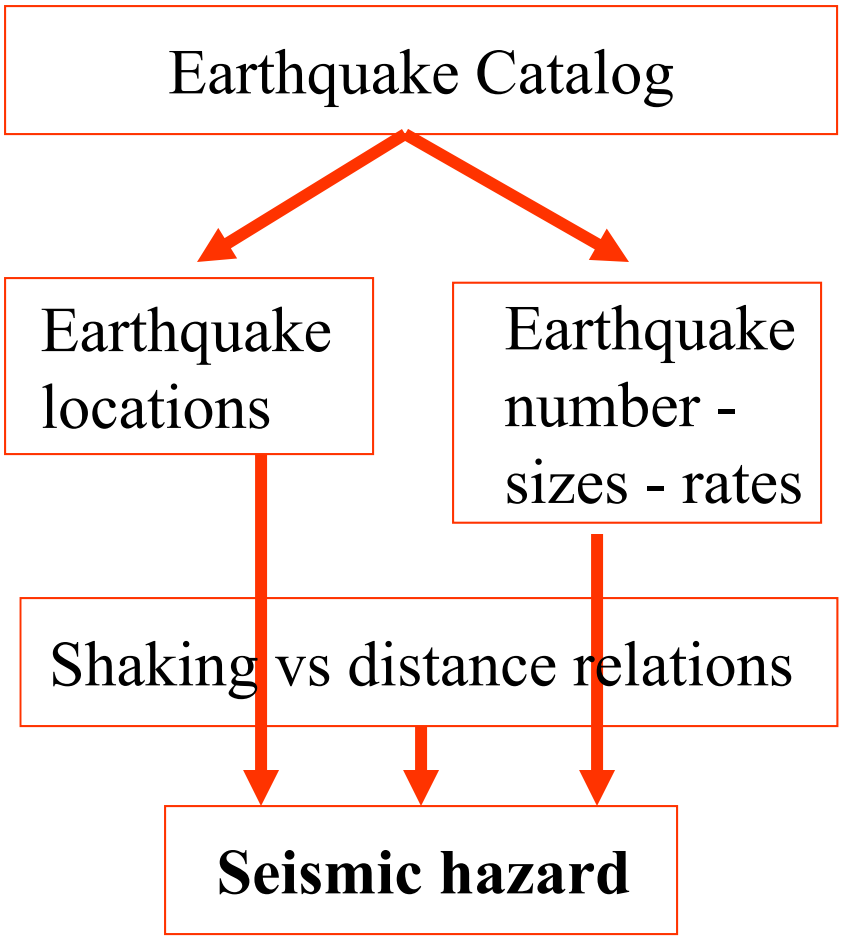
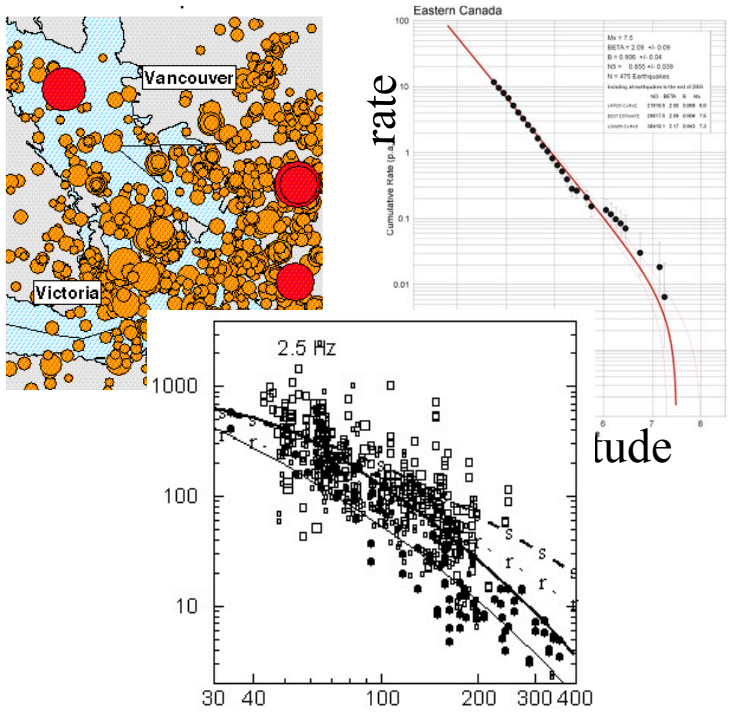
National Building Code

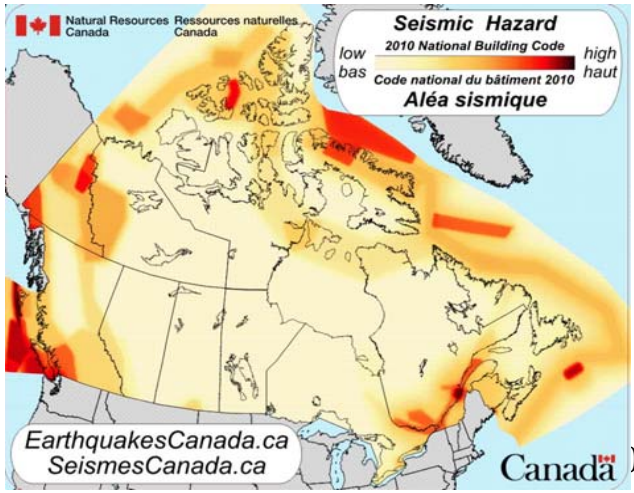
The minimum standard to protect the life and safety of building occupants and the general public as the building responds to strong ground shaking

Expected shaking comes from seismic hazard maps

Probabilistic seismic hazard







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National Building Code

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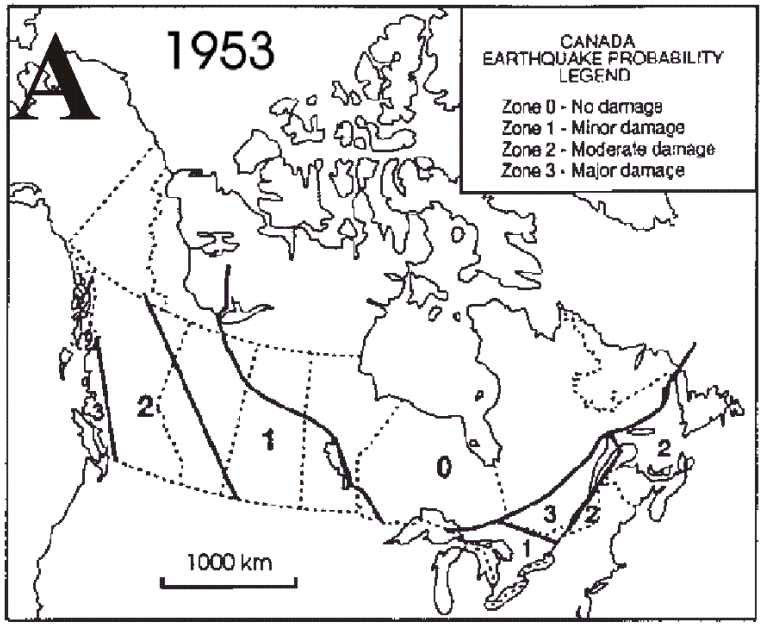

1953

One map

Primarily a zoning map

Peak Acceleration for 4 zones

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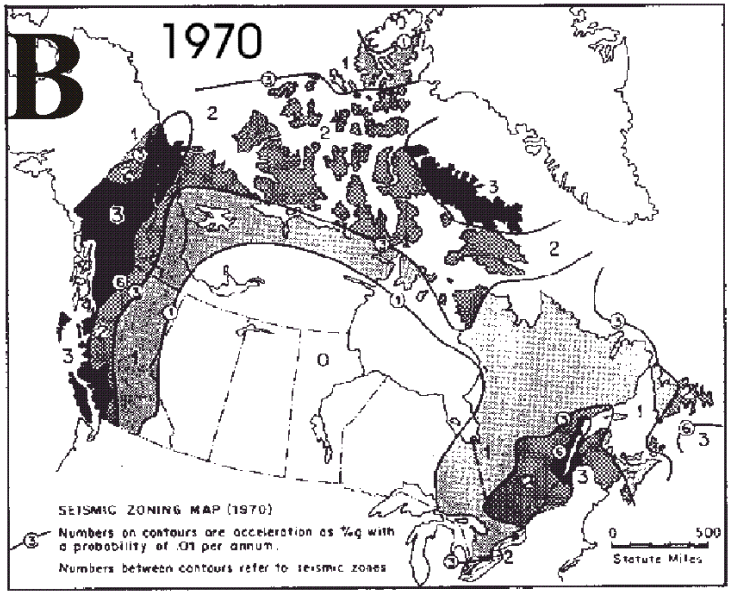
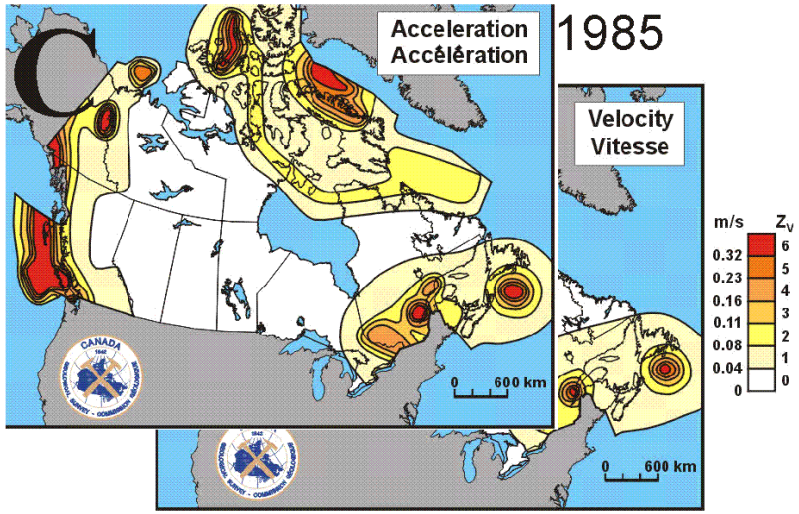


1970

One map

Peak Acceleration for 4 zones

Probabilistic at 1/100 years



1985

Two maps

Peak Acceleration & Velocity

7 zones

Rock and Firm Ground

Probabilistic 10% /50 years

= 1/475 years

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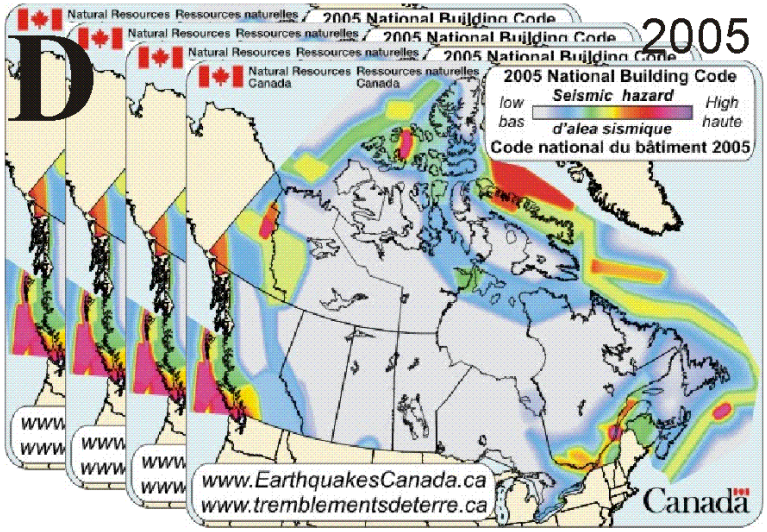

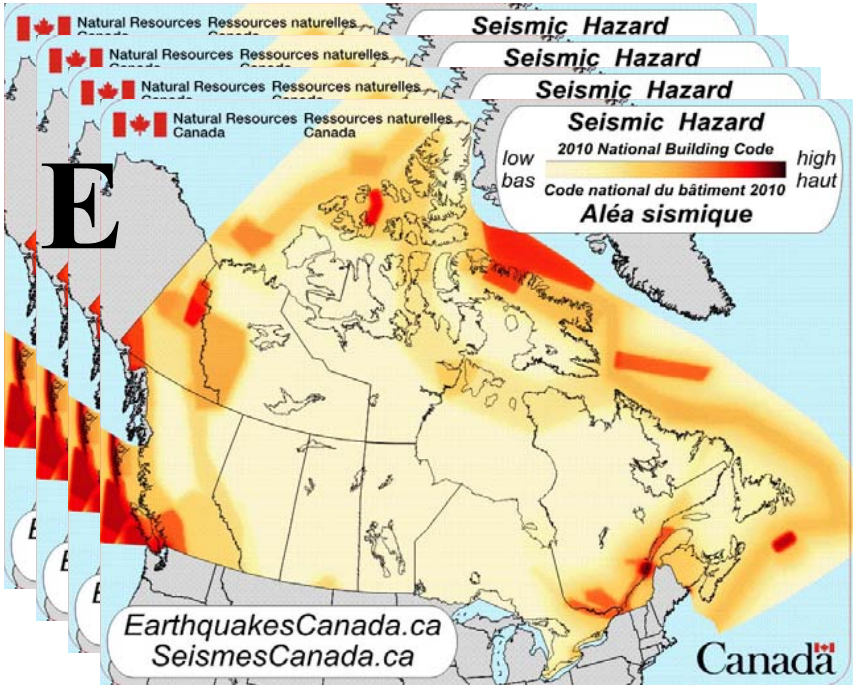

2005

Four maps

Spectral Acceleration

(plus Peak Acceleration)

No zones

Firm Ground (Site Class C)

Probabilistic at 2%/50 years

= 1/2475 years

2010

Similar to 2005

(see next slide)

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NBCC 2010

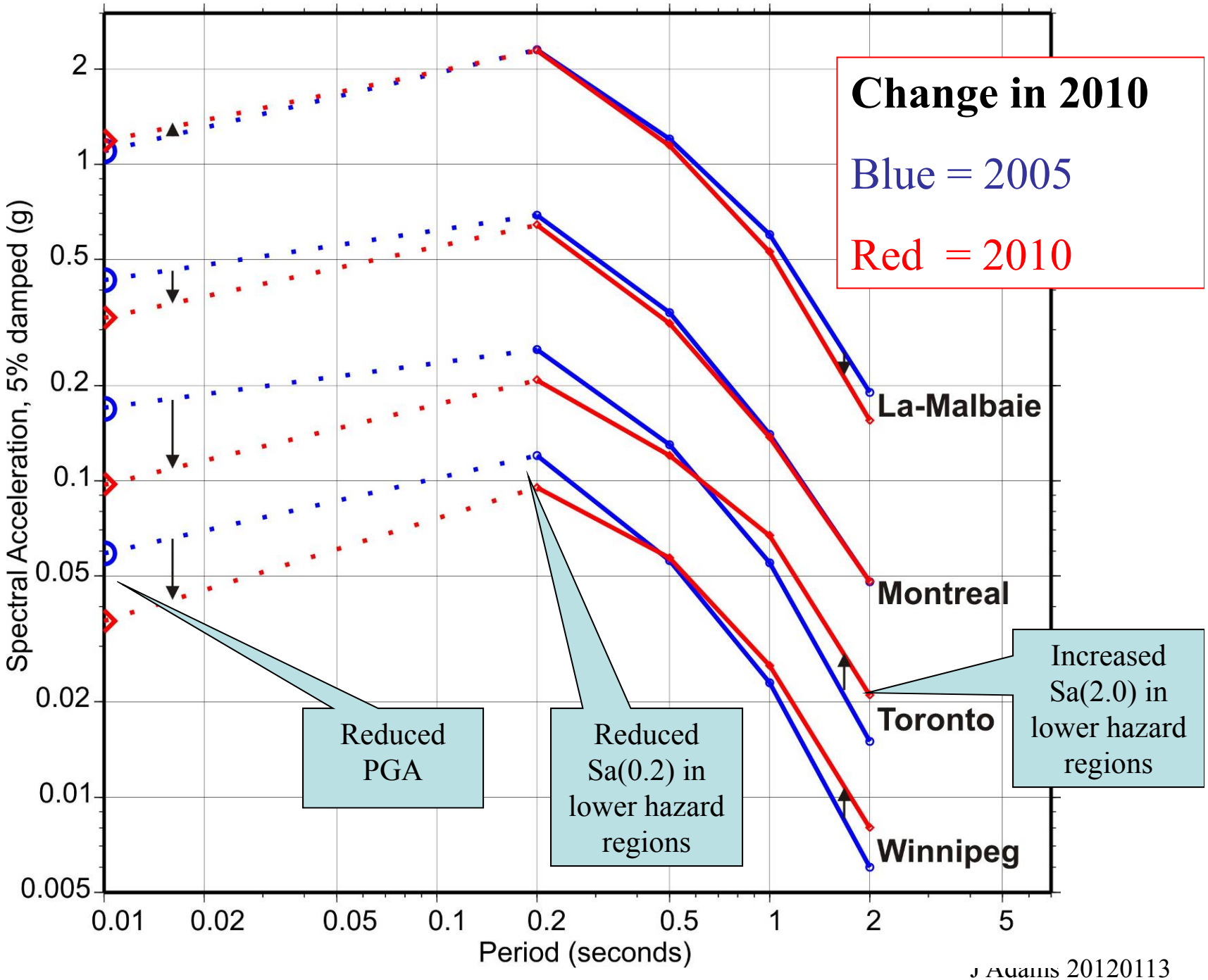
Issued at end of 2010

In process of being adopted by Provinces and Territories

Similar parameters to 2005

Chief seismic difference: model for eastern ground motion shaking changed from Quadratic to 8-parameter fit because this reduced unnecessary conservatism

- Reduced hazard at short periods in low-hazard zones
- Increased hazard at long periods in low-hazard zones
- Reduced PGA (still used in geotechnical designs)
- Spectra tilted from the changes



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NRCan website for seismic hazard calculations

www.EarthquakesCanada.ca

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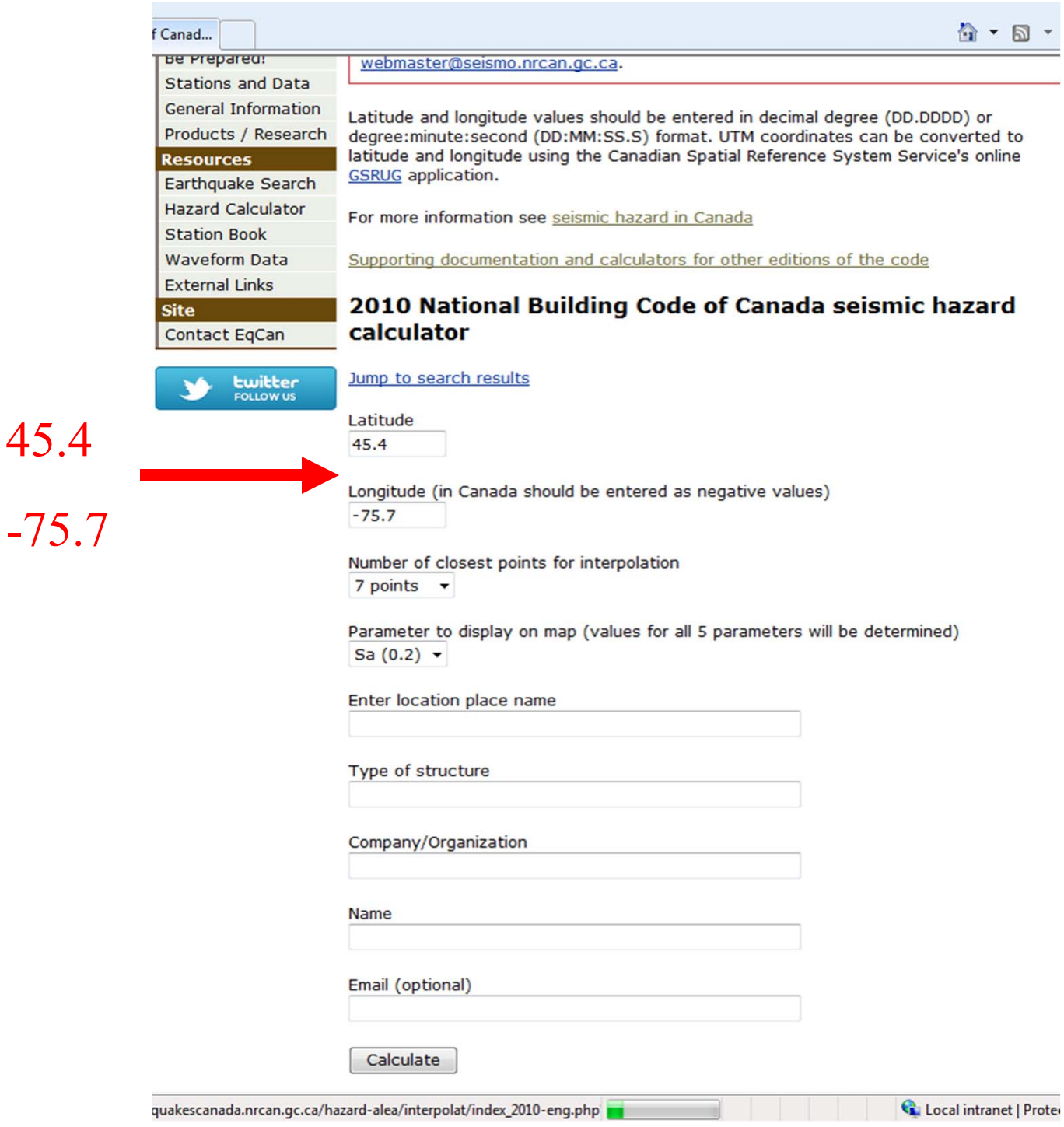

45.4

-75.7

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Web output plus single-page pdf

NBCC probability

Other probabilities

2010 National Building Code Seismic Hazard Calculation

INFORMATION: Eastern Canada English (613) 995-5548 français (613) 995-0600 Facsimile (613) 992-8836
Western Canada English (250) 363-6500 Facsimile (250) 363-6565

Requested by: ,

December 14, 2011

Site Coordinates: 45.4 North 75.7 West

User File Reference:

National Building Code ground motions:
2% probability of exceedance in 50 years (0.000404 per annum)

Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)	PGA (g)
0.635	0.308	0.137	0.046	0.324

Notes. Spectral and peak hazard values are determined for firm ground (NBCC 2010 soil class C - average shear wave velocity 360-750 m/s). Median (50th percentile) values are given in units of g. 5% damped spectral acceleration (Sa(T), where T is the period in seconds) and peak ground acceleration (PGA) values are tabulated. Only 2 significant figures are to be used. ***These values have been interpolated from a 10 km spaced grid of points. Depending on the gradient of the nearby points, values at this location calculated directly from the hazard program may vary. More than 95 percent of interpolated values are within 2 percent of the calculated values.***

Ground motions for other probabilities:

Probability of exceedance per annum	0.010	0.0021	0.001
Probability of exceedance in 50 years	40%	10%	5%
Sa(0.2)	0.089	0.249	0.386
Sa(0.5)	0.043	0.122	0.186
Sa(1.0)	0.017	0.056	0.087
Sa(2.0)	0.006	0.018	0.028
PGA	0.039	0.122	0.201

References

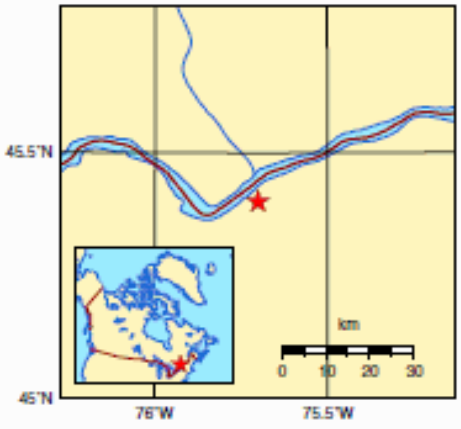
National Building Code of Canada 2010 NRCC no. 53301; sections 4.1.8, 9.20.1.2, 9.23.10.2, 9.31.6.2, and 6.2.1.3
Appendix C: Climatic Information for Building Design in Canada - table in Appendix C starting on page C-11 of Division B, volume 2

User's Guide - NBC 2010, Structural Commentaries NRCC no. 53543 (in preparation)
Commentary J: Design for Seismic Effects

Geological Survey of Canada Open File xxxx
Fourth generation seismic hazard maps of Canada: Maps and grid values to be used with the 2010 National Building Code of Canada (in preparation)

See the websites *www.EarthquakesCanada.ca* and *www.nationalcodes.ca* for more information

Aussi disponible en français



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NBCC 2015: 5th Generation Seismic Hazard Maps

Trial results: focus is on computing and understanding the hazard values for populated SE and SW Canada – main cities

Main changes

- Catalog
  - 18 years more earthquakes
  - Moment magnitude catalog
- Replacement of Robust approach
  - Replacement of H and R models
    - East
    - West
  - Probabilistic treatment of Cascadia
  - Integrated treatment of Floor source
- New Ground Motion relations
- New spectral values (shorter and longer periods)
- Adjusted reference ground condition

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New earthquakes

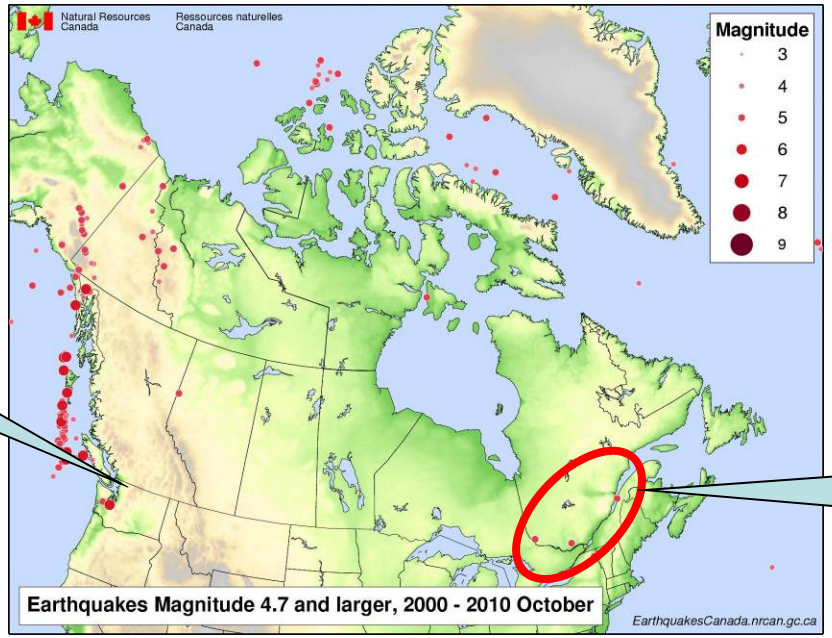
Last model used earthquakes up to 1990/1991

Now will add earthquakes up to end of 2010

Adds lots of smaller earthquakes (GSC used to locate 1500 earthquakes a year, now locates 4500+ per yr)

Adds a number of significant earthquakes in the last decade
(Denali, Nisqually, Queen Charlottes, Val-des-Bois…)

New data for inslab earthquakes



New data for moderate M5 earthquakes

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Improved catalog in Moment magnitude (Mw)

For 2015:

largest events have had Mw assigned by inspection of data and publications

Events smaller than Mw~4.7 converted from catalog values

Sensitivity tests:

East: centre of Gatineau zone

Sa(0.2) = 0.26 g from mN catalog

0.25 g from Mw catalog

West: Prince Rupert

Sa(0.2) = 0.37 g from mN catalog

0.33 g from Mw catalog

Sensitivity test: Not much effect on onshore hazard

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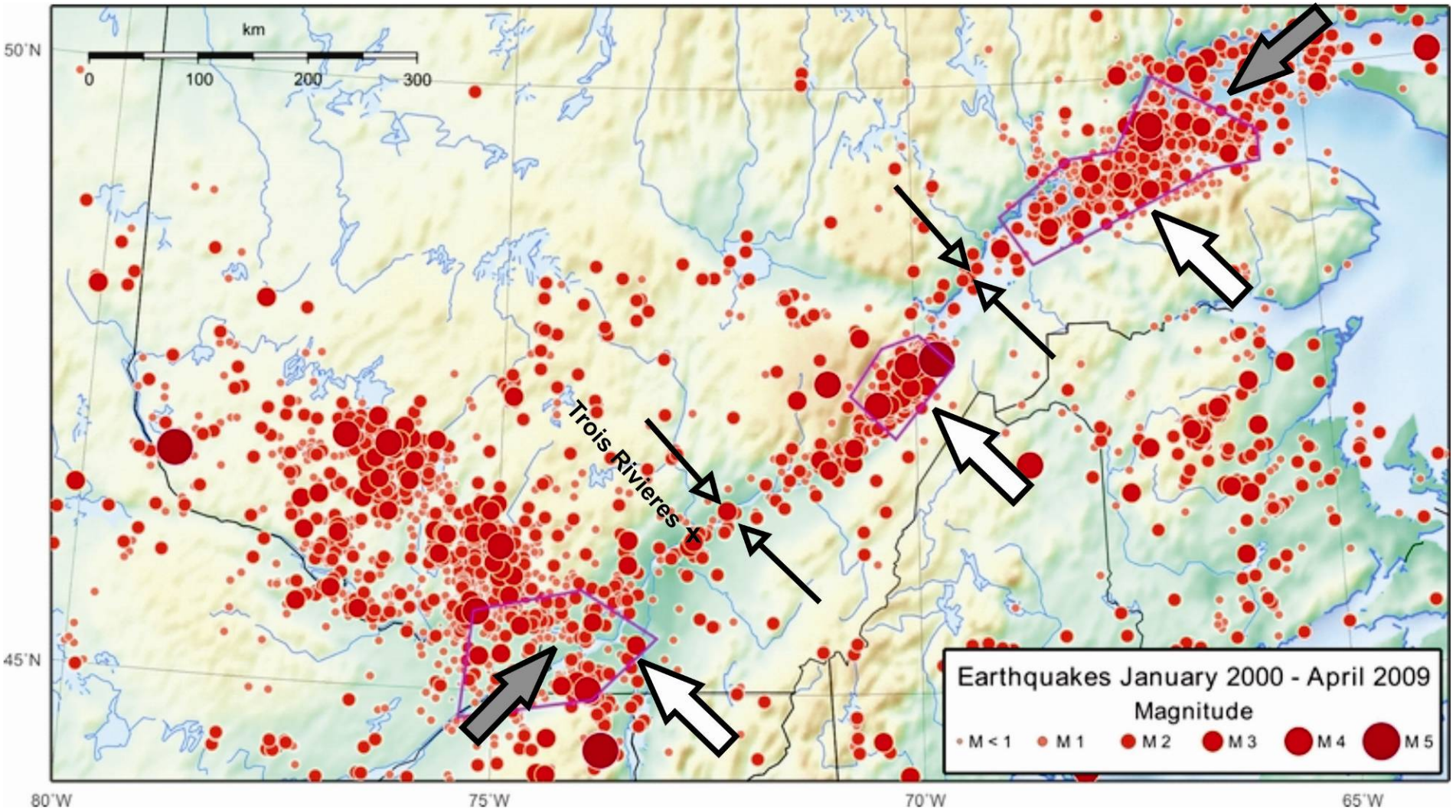
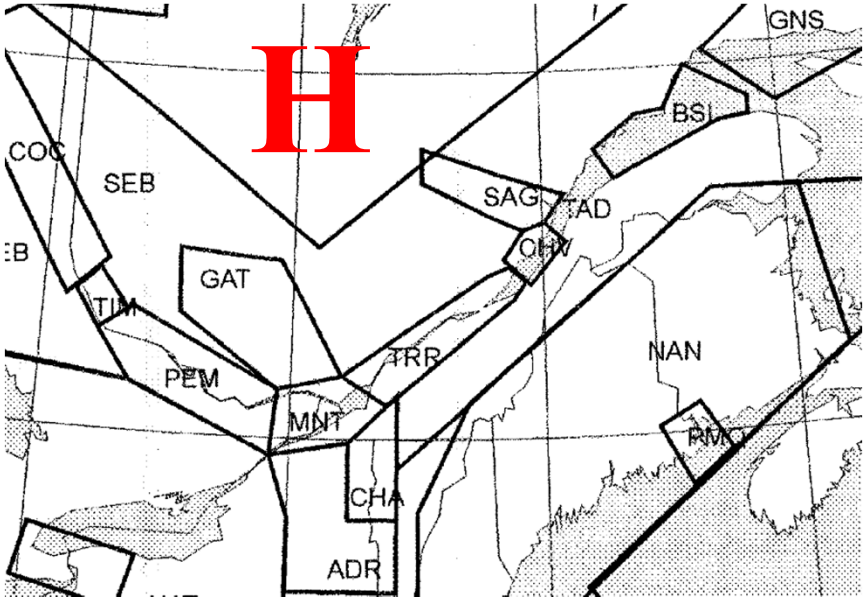
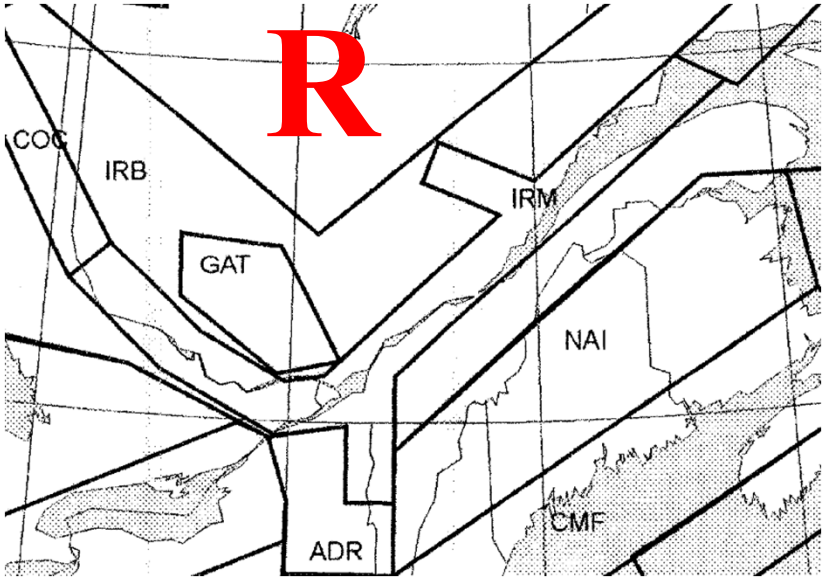
Eastern source zones: Replacement of Robust approach

The issue:



2005/2010 approach





Locations very different in H model, reflecting local earthquake activity

Locations rather similar in R model

Sa(0.2) in cm/s/s	2005 H	2005 R
La Malbaie	2300	660
Quebec City	520	590*
Trois Rivieres	350	640
Montreal	580	690
Ottawa	450	670

* Low because IRM zone boundary badly placed

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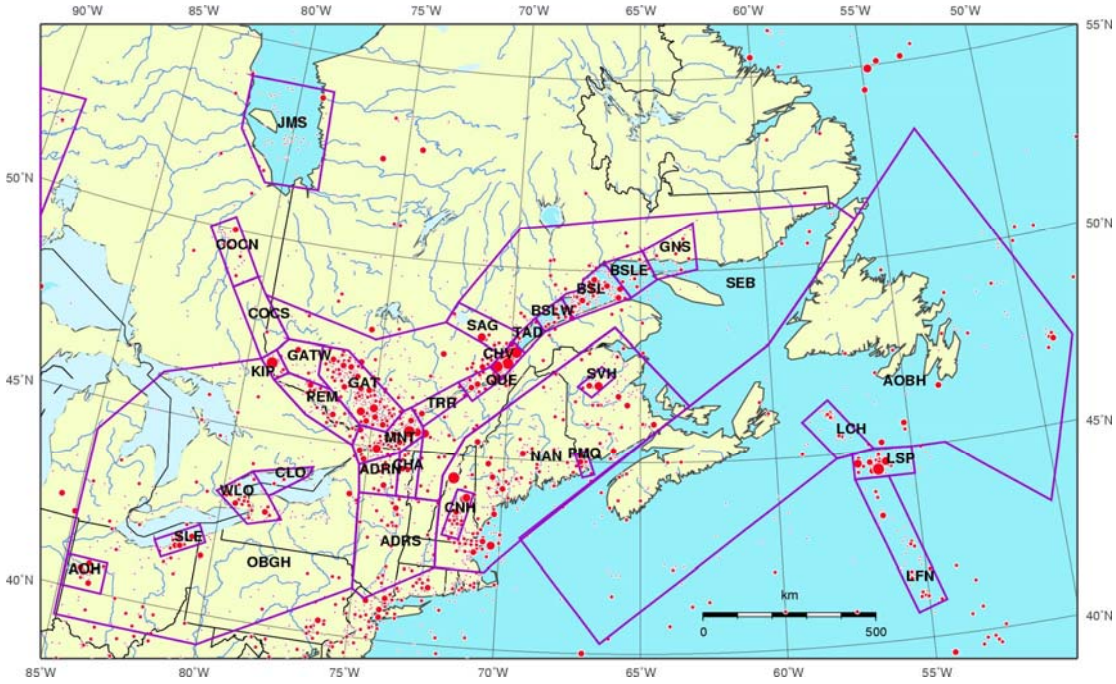
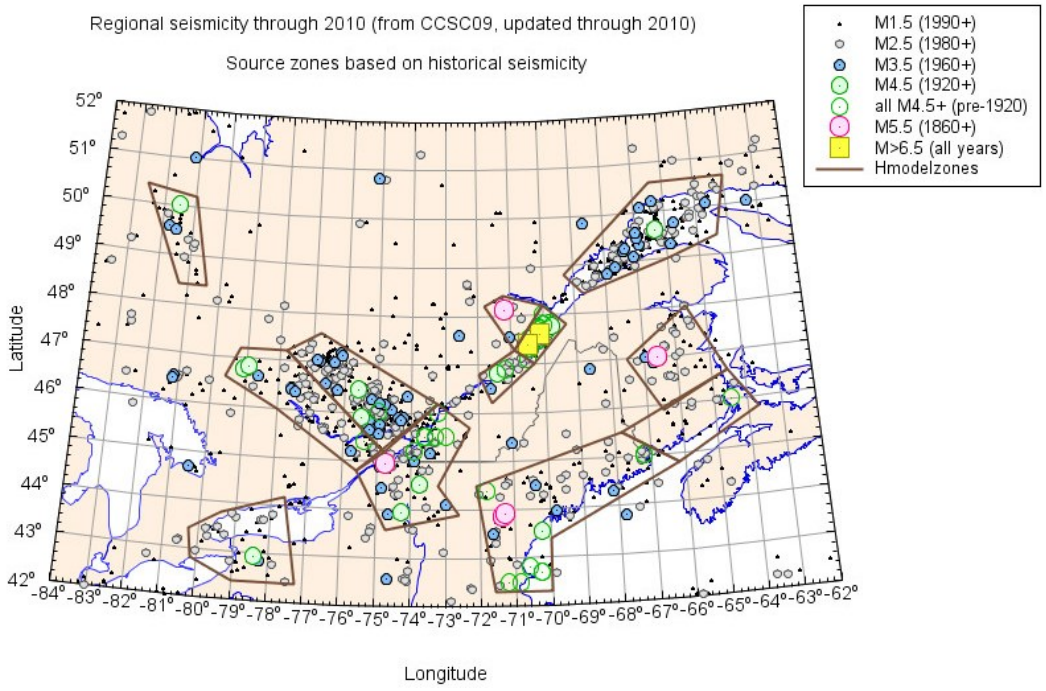
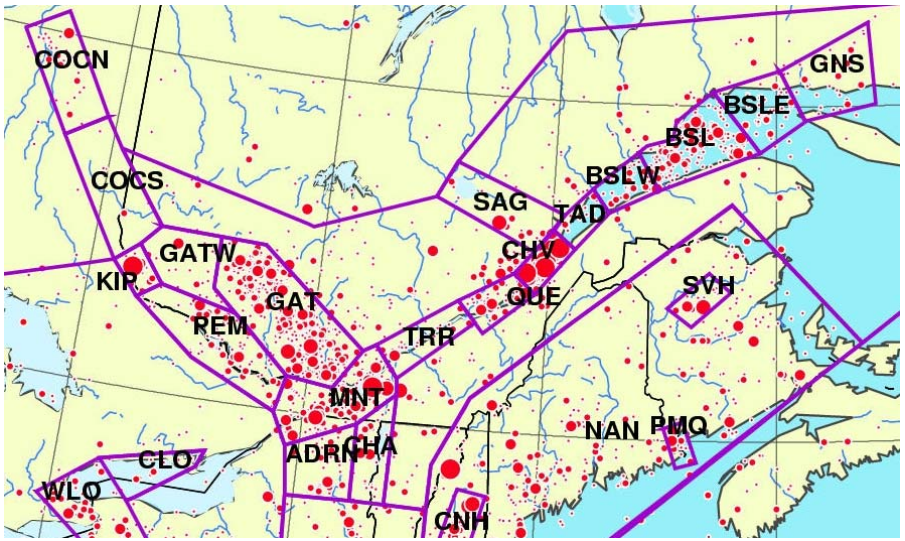
2015 draft Historical seismic source models

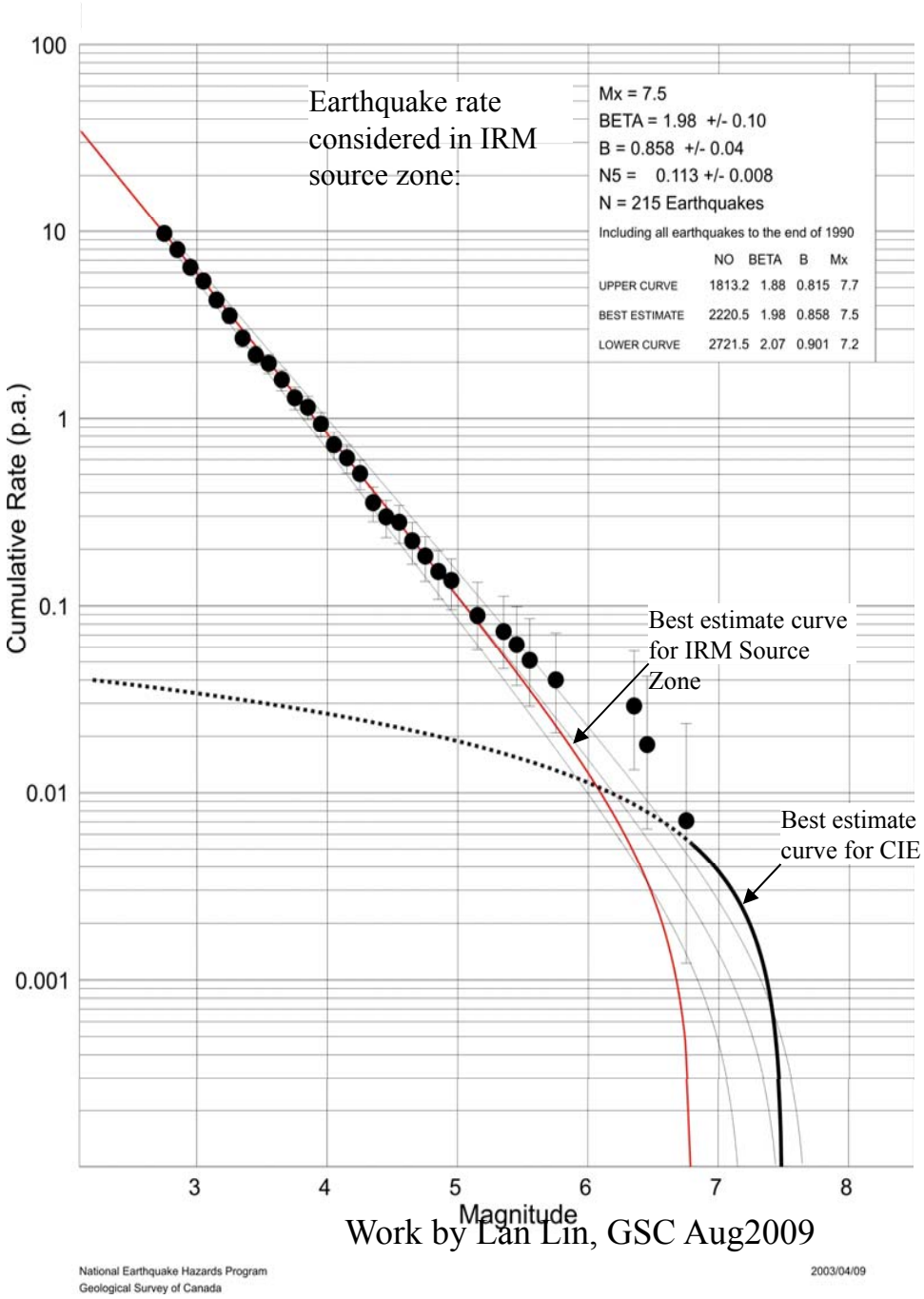
GSC 2011



Atkinson







Work by Lan Lin, GSC Aug2009

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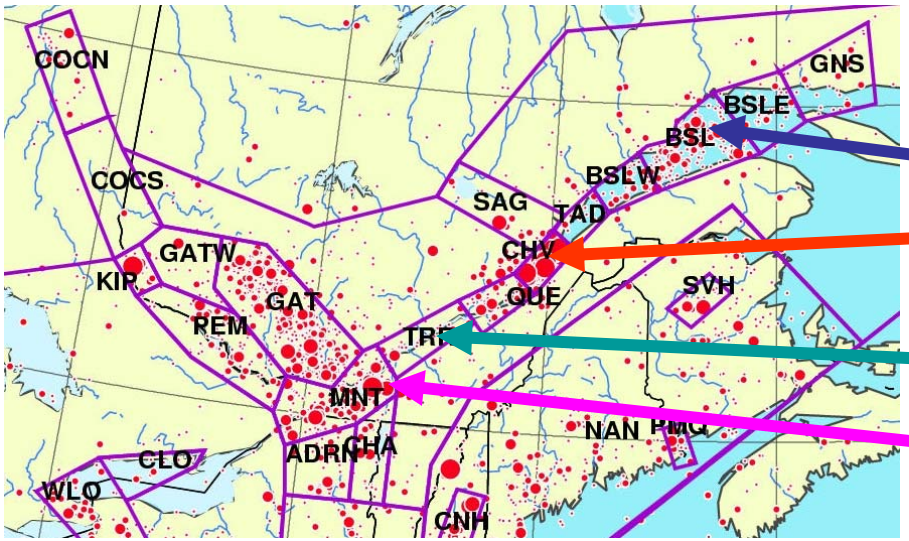

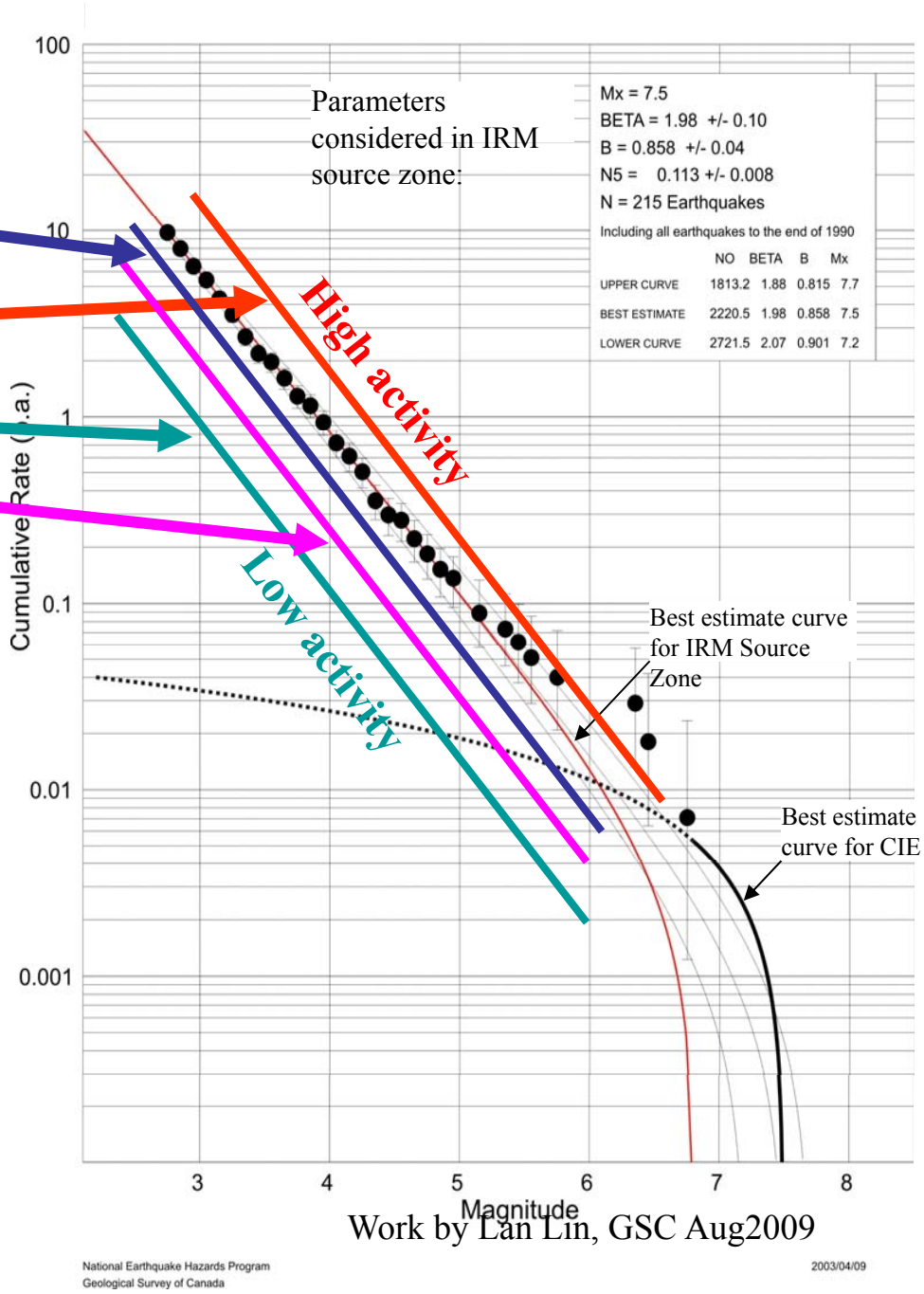

Work by Lan Lin, GSC Aug2009

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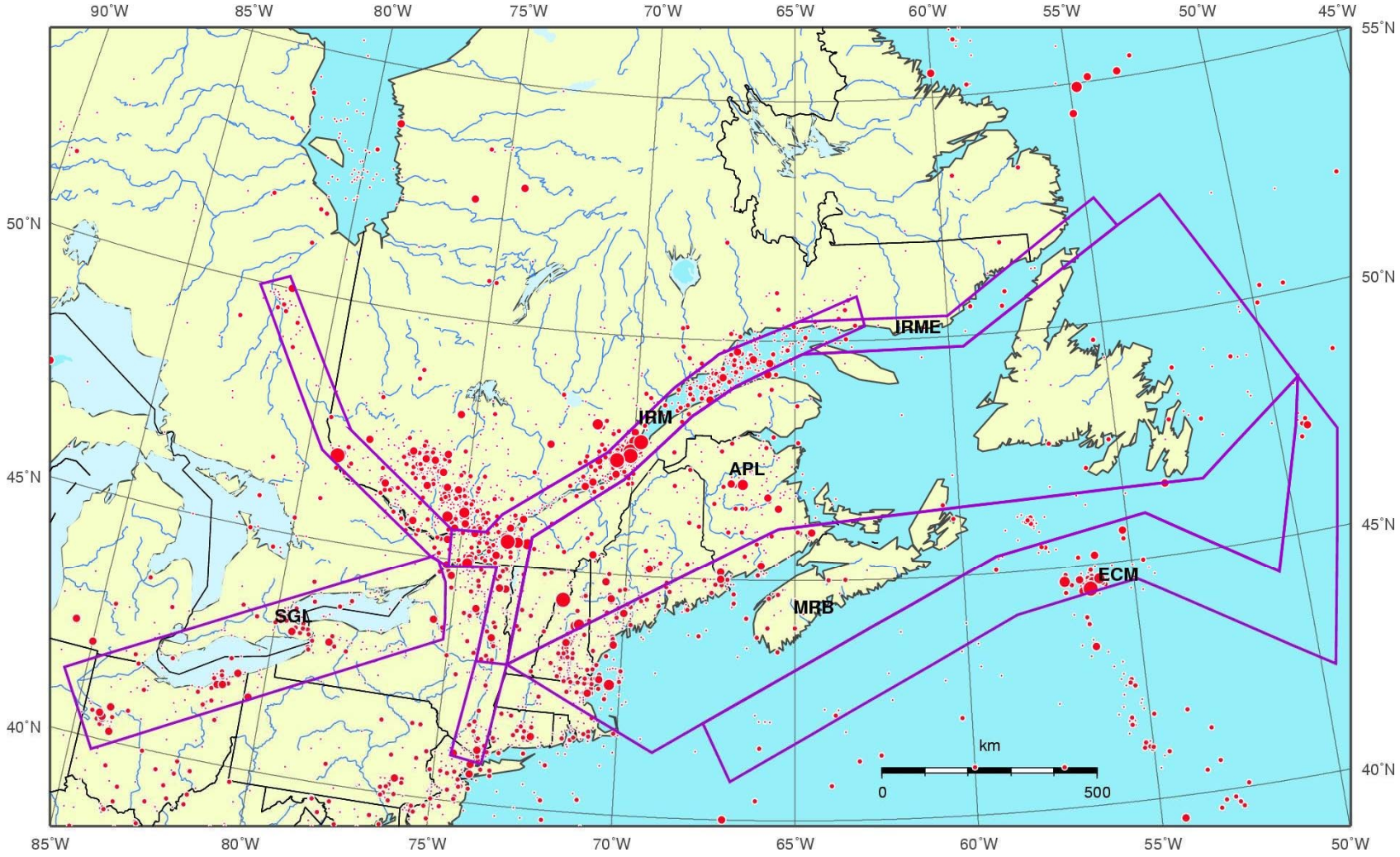
Seismotectonic seismic source model from GSC

5 large zones as sources for Random Big Earthquakes (RBE)



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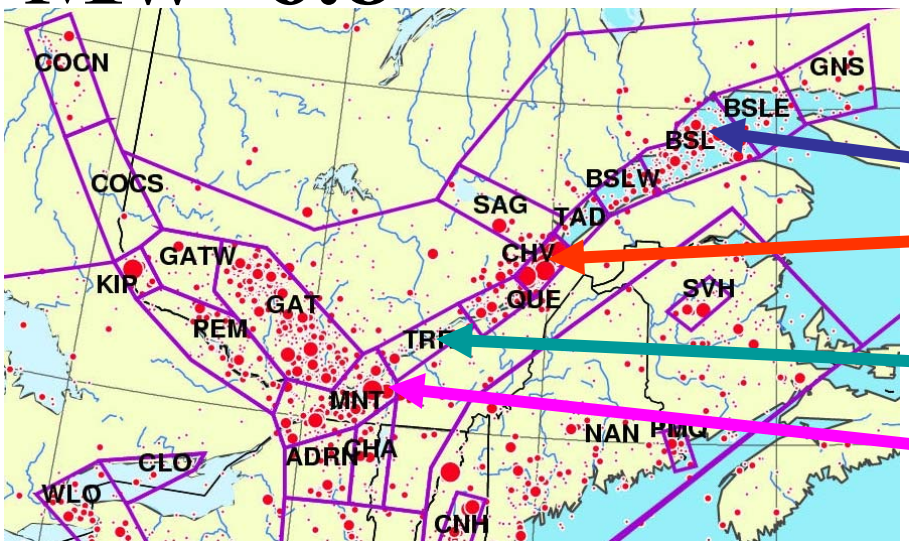
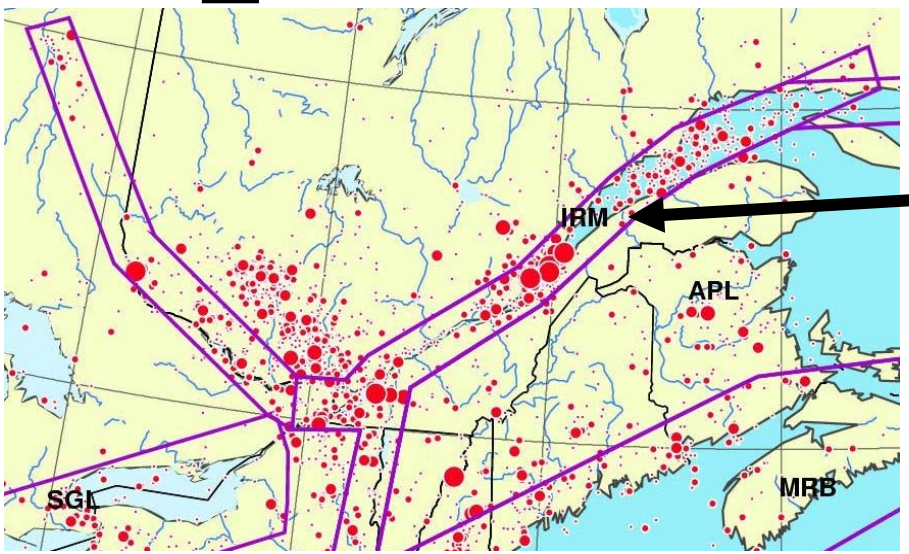
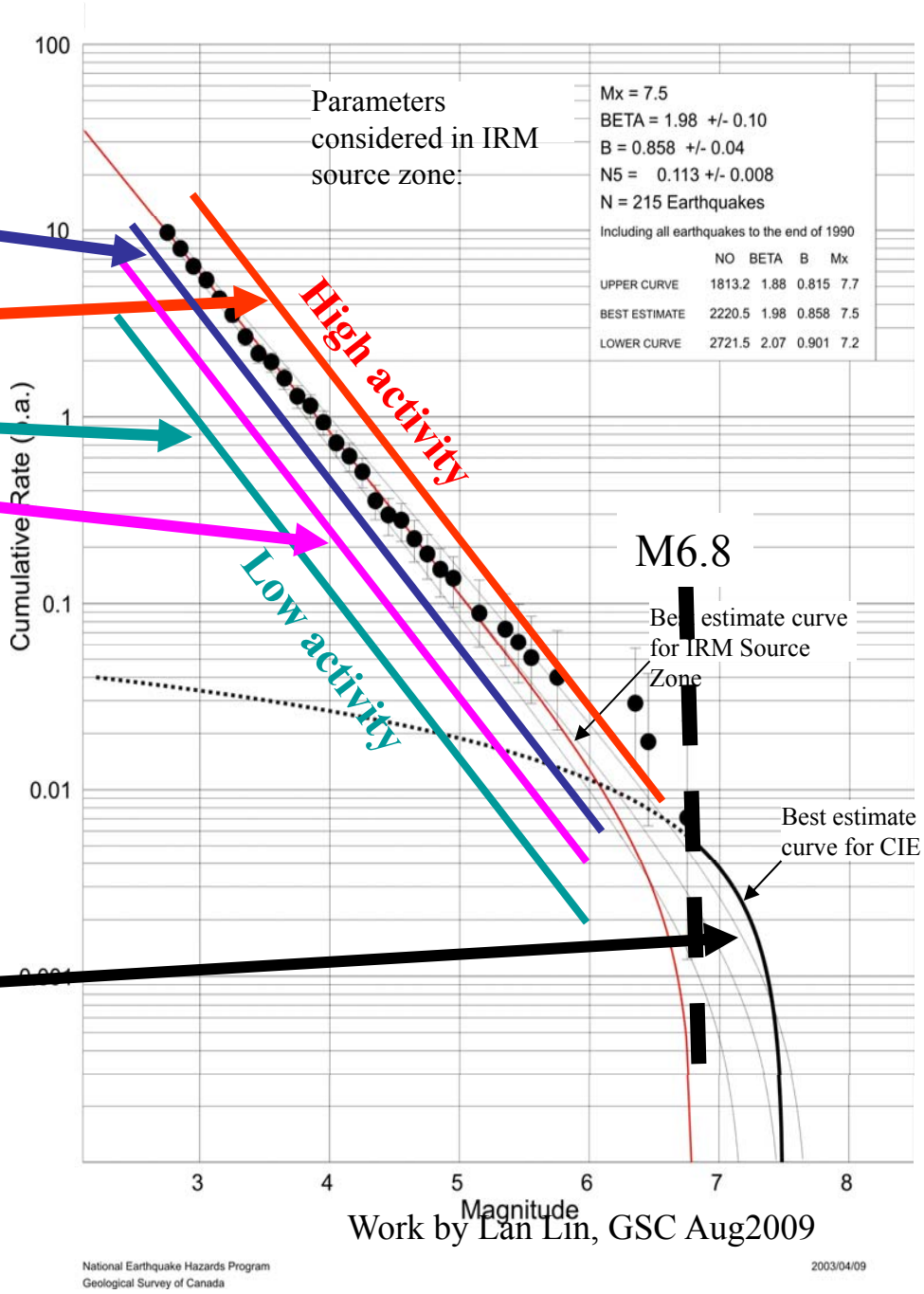
Mw<6.8



Composite seismic source model

Mw≥6.8





Work by Lan Lin, GSC Aug2009

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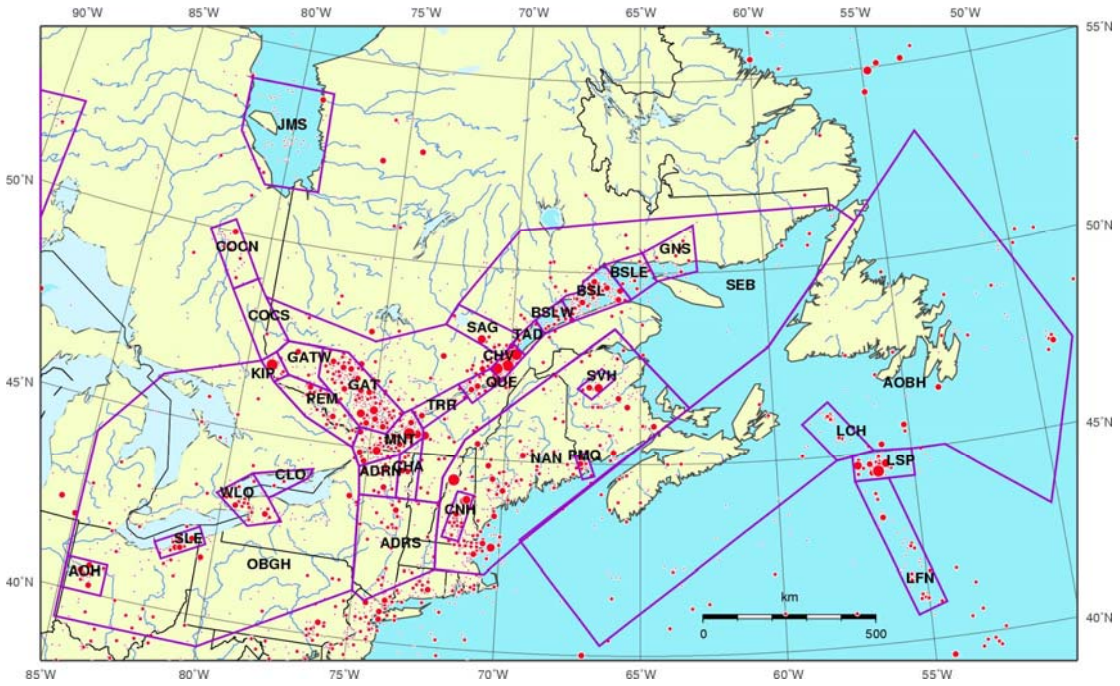
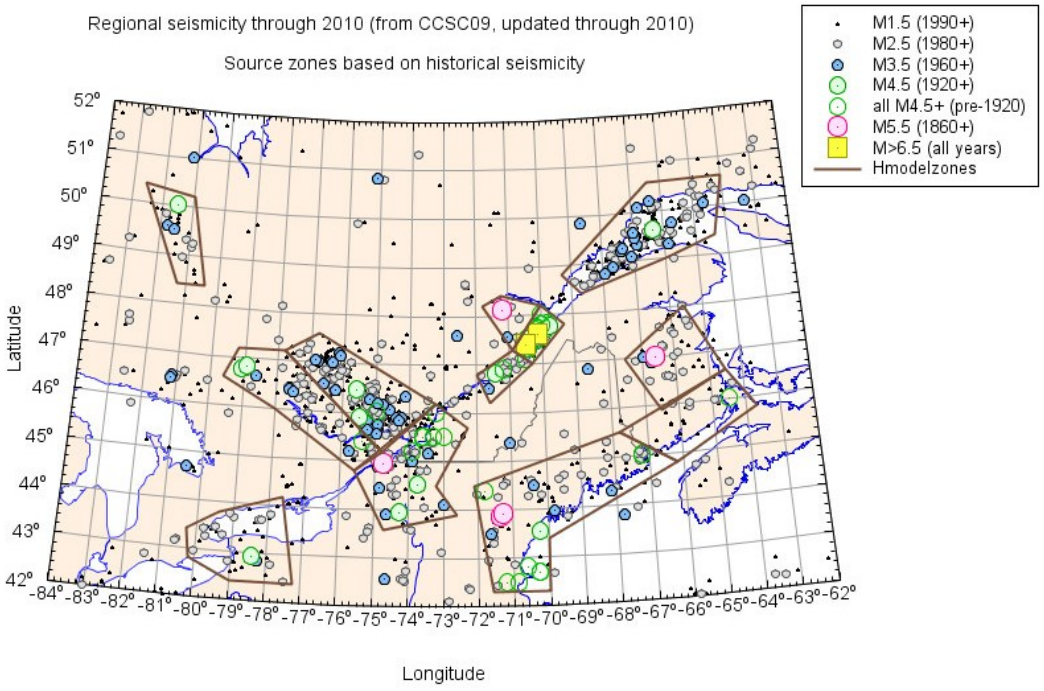
Historical seismic source models → Composite Model

We can use the "H" models directly, or <u>composite</u> with the RBE model

The transition magnitude used doesn't matter very much





What rates for Random Big Earthquakes?

Very little constraints from data, paleoseismic or otherwise

St. Lawrence rift source: expect one Mw≥6.8 per 300 years

Other "best" rates for Mw≥6.8 by judgement based on relative seismicity levels

Large uncertainty – taken as factor of 3 up and down

Can infer unreasonable maximum rates from history (used to additionally constrain upper limits in blue)

1/1000 years

1/300 years

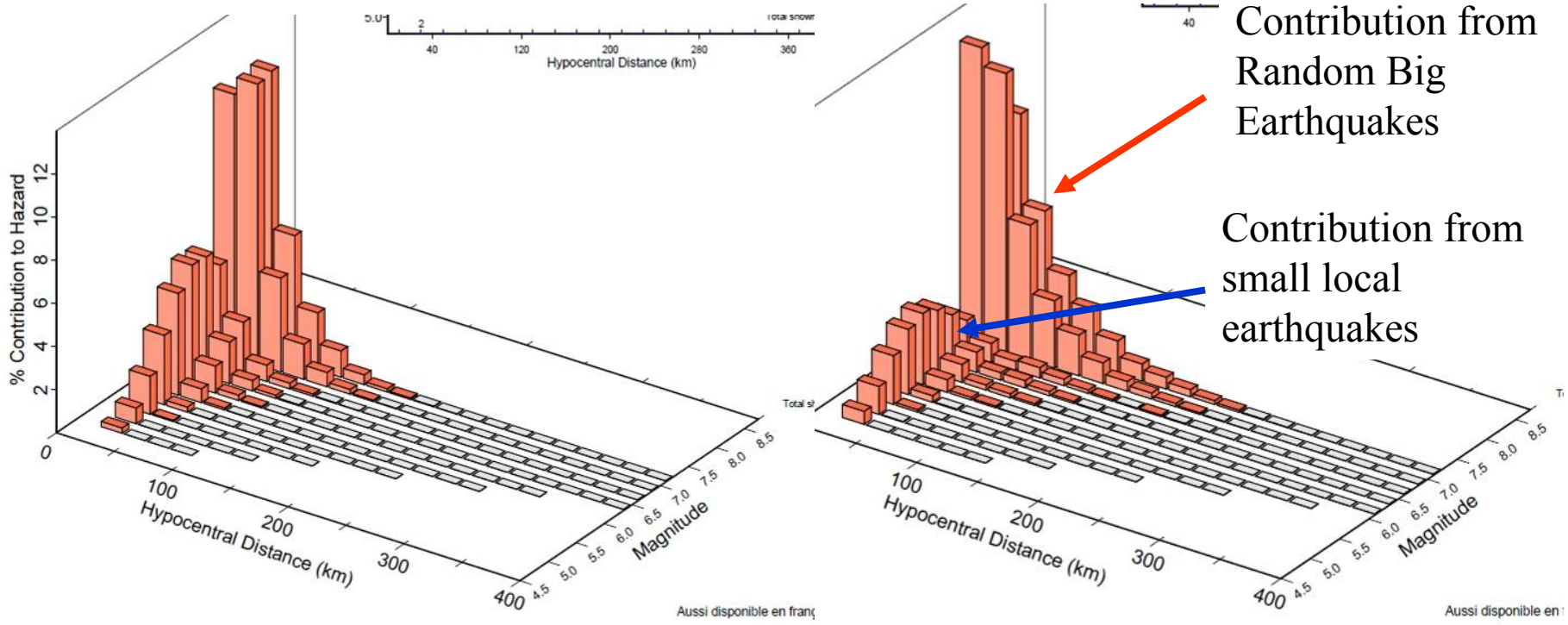
1/3000 years

	APL	ECM2	IRM	MRB	SGL
best N(6.8)	0.0010000	0.0030000	0.0030000	0.0003000	0.0003000
upper N(6.8)	0.0032000	0.0060000	0.0060000	0.0009200	0.0009200
lower N(6.8)	0.0003200	0.0009200	0.0003200	0.0000920	0.0000920
N_0 (best)	36.8	110.3	110.3	11.0	11.0
N_0 (upper)	117.6	220.5	220.5	33.8	33.8
N_0 (lower)	11.8	33.8	11.8	3.4	3.4

Effect of Composite model is more evident in low seismicity regions like Trois Rivieres

Montreal

Trois Rivieres



Change in hazard still being modelled, but….

- Montreal not the same as Ottawa
- Trois Rivières lower than Montreal and Quebec City
- Charlevoix still high, but less high than before

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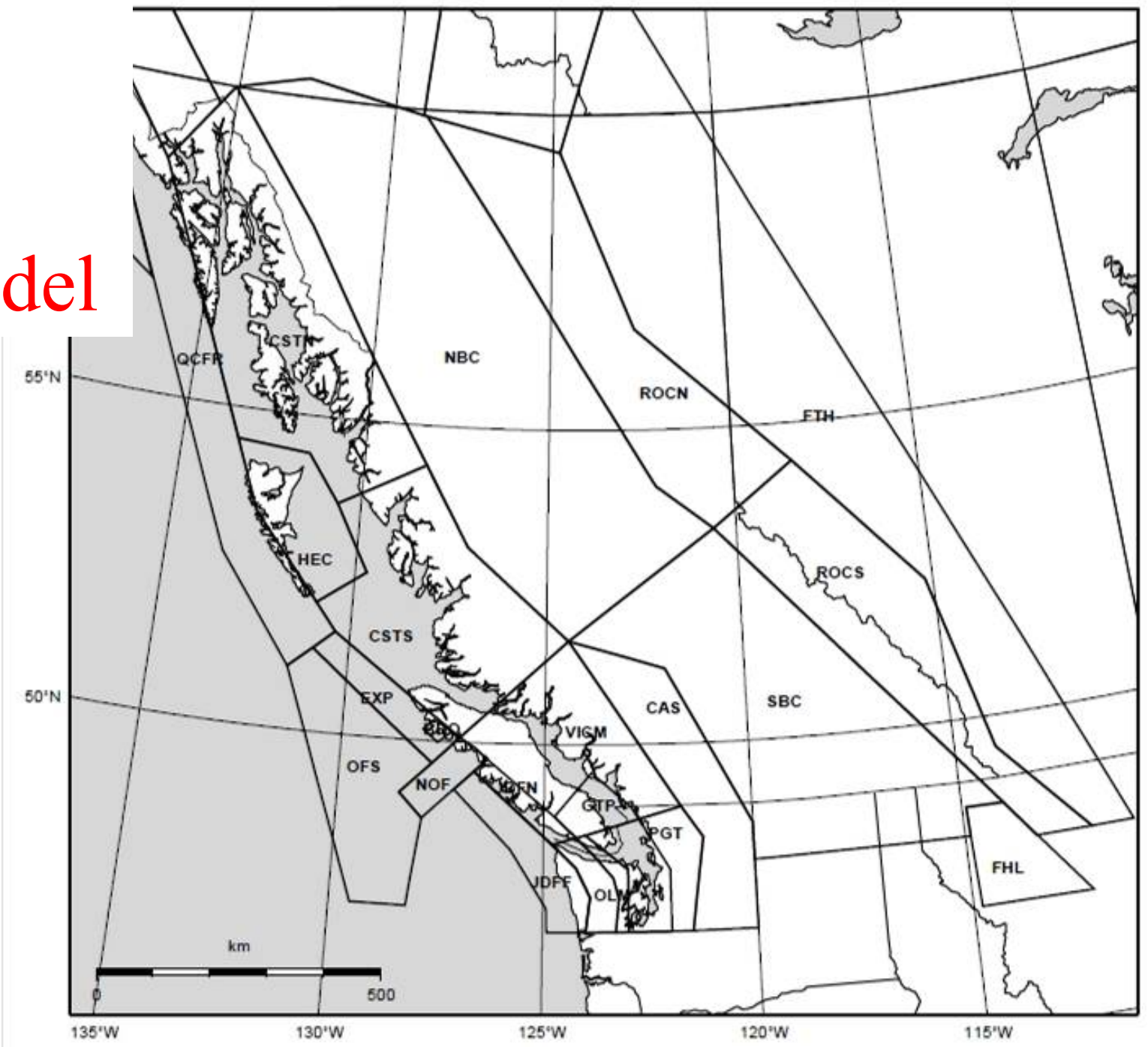
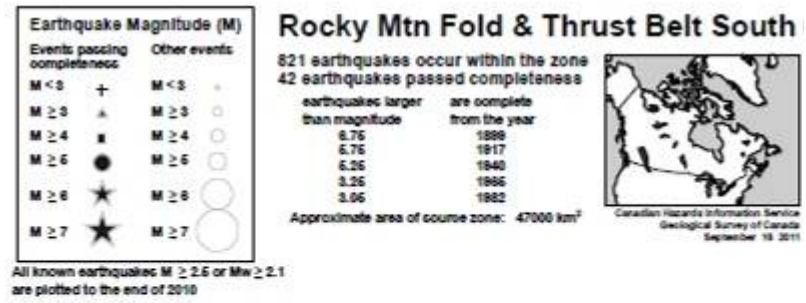
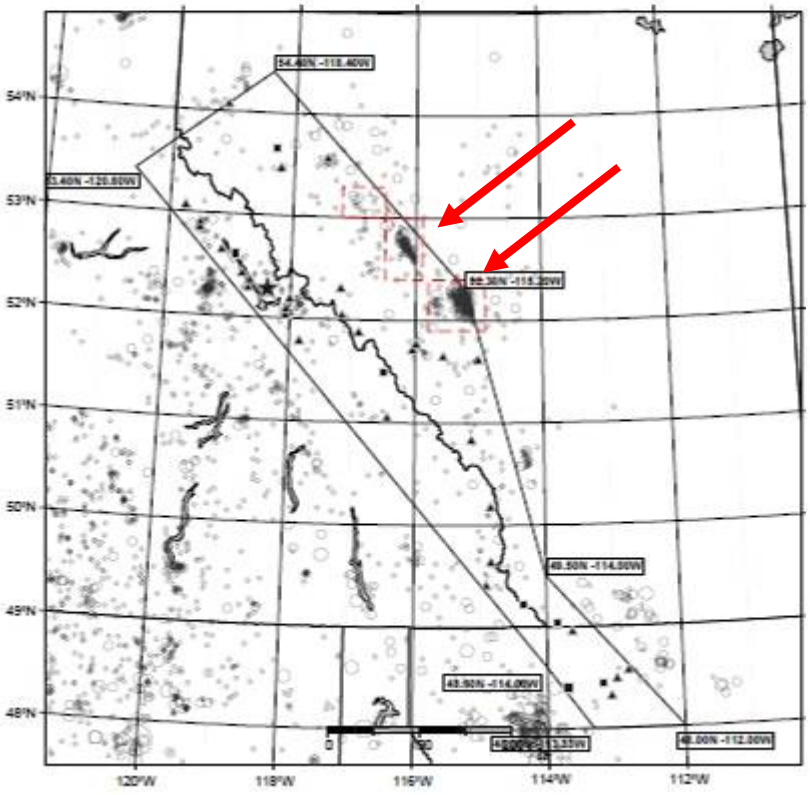
Western sources

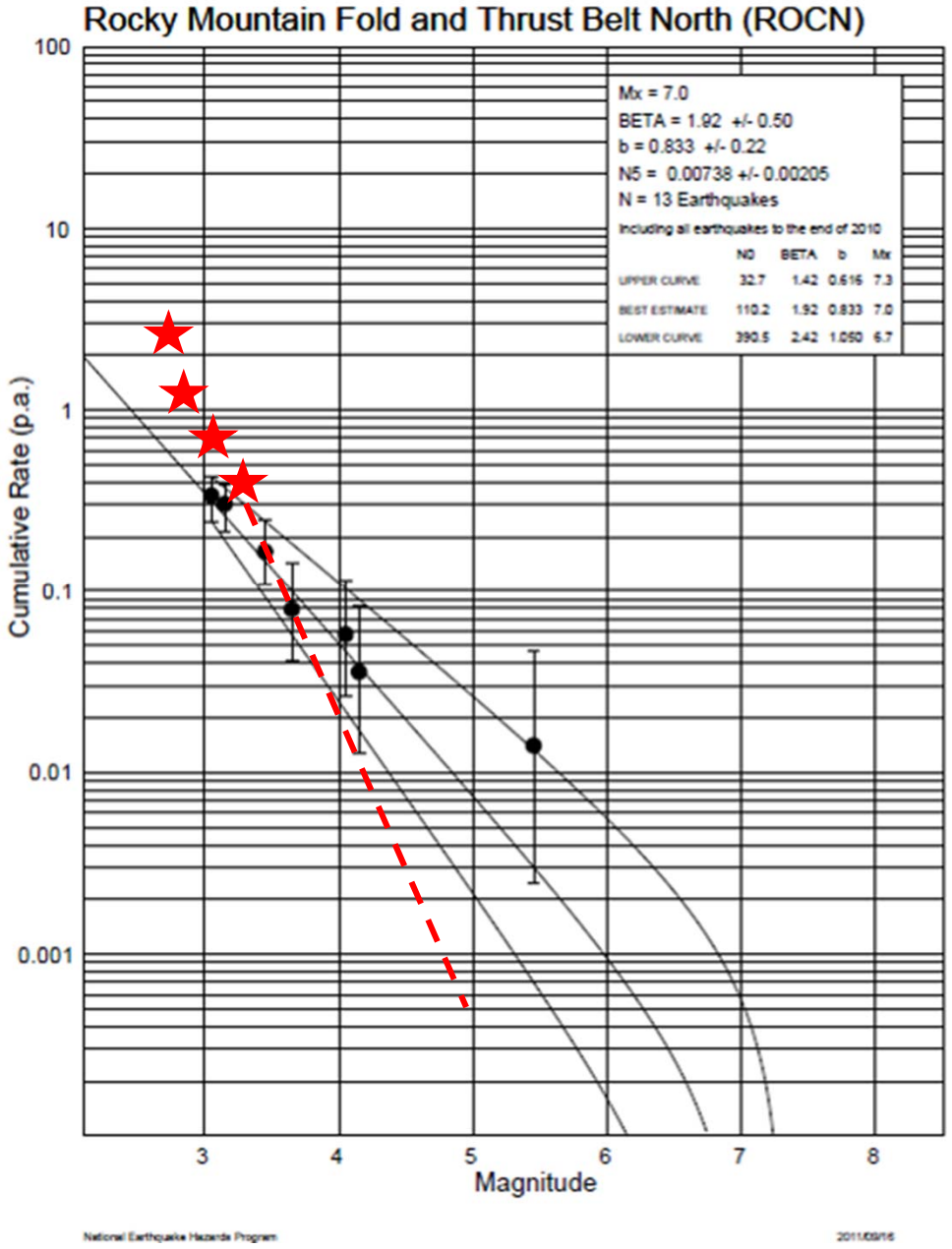
2011 model



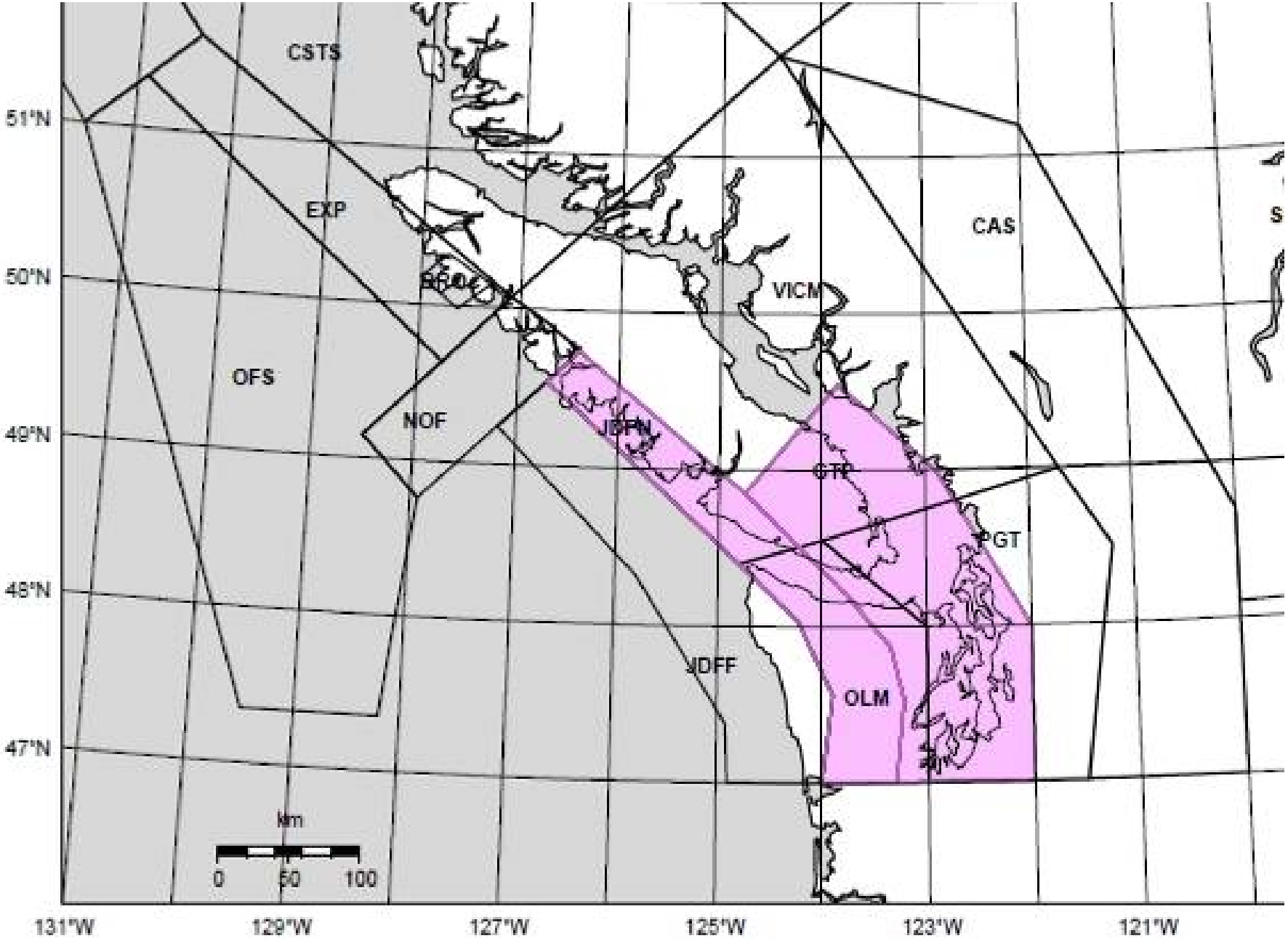
Will remove areas of obvious <u>induced</u> events





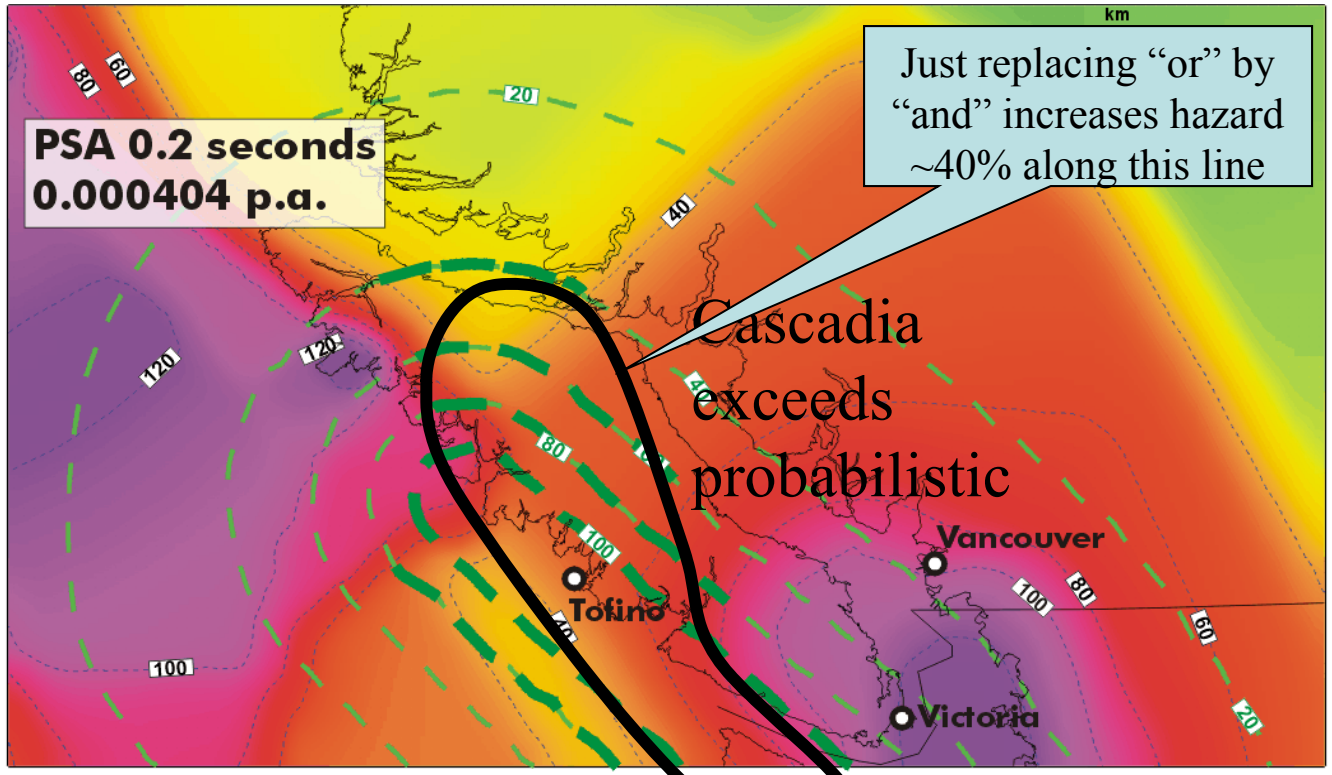


Crustal and sub-crustal (mauve) sources



Probable replacement of 2010 deterministic Cascadia approach by 2015 probabilistic fault model

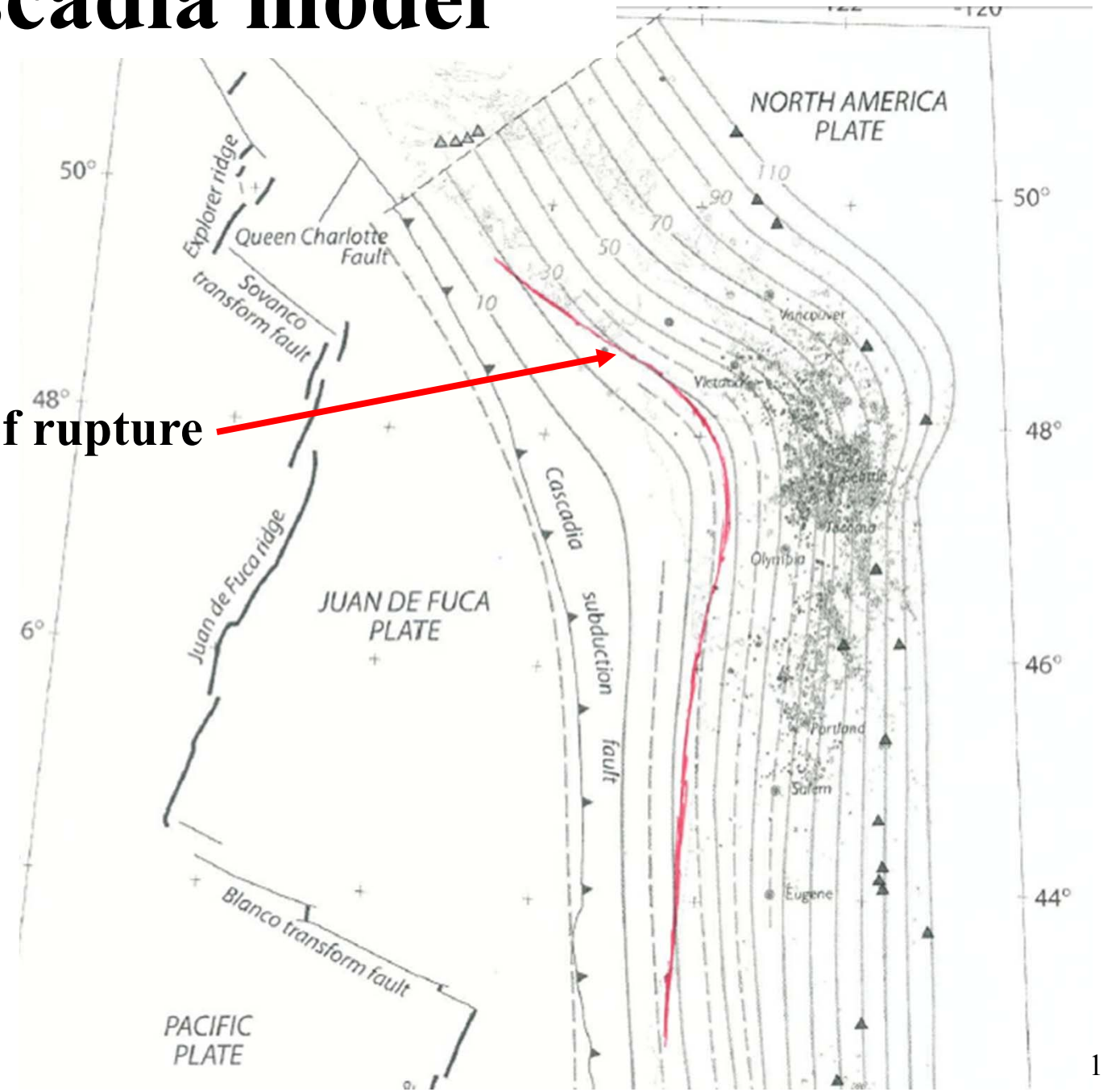
2010



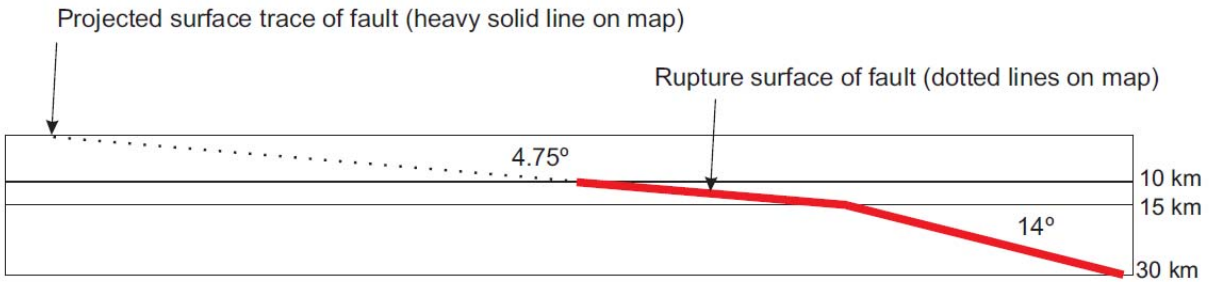
Cascadia scenario earthquake contours in green (heavier where this model dominates) superimposed on robust H and R model shaded contours

2015 Cascadia model

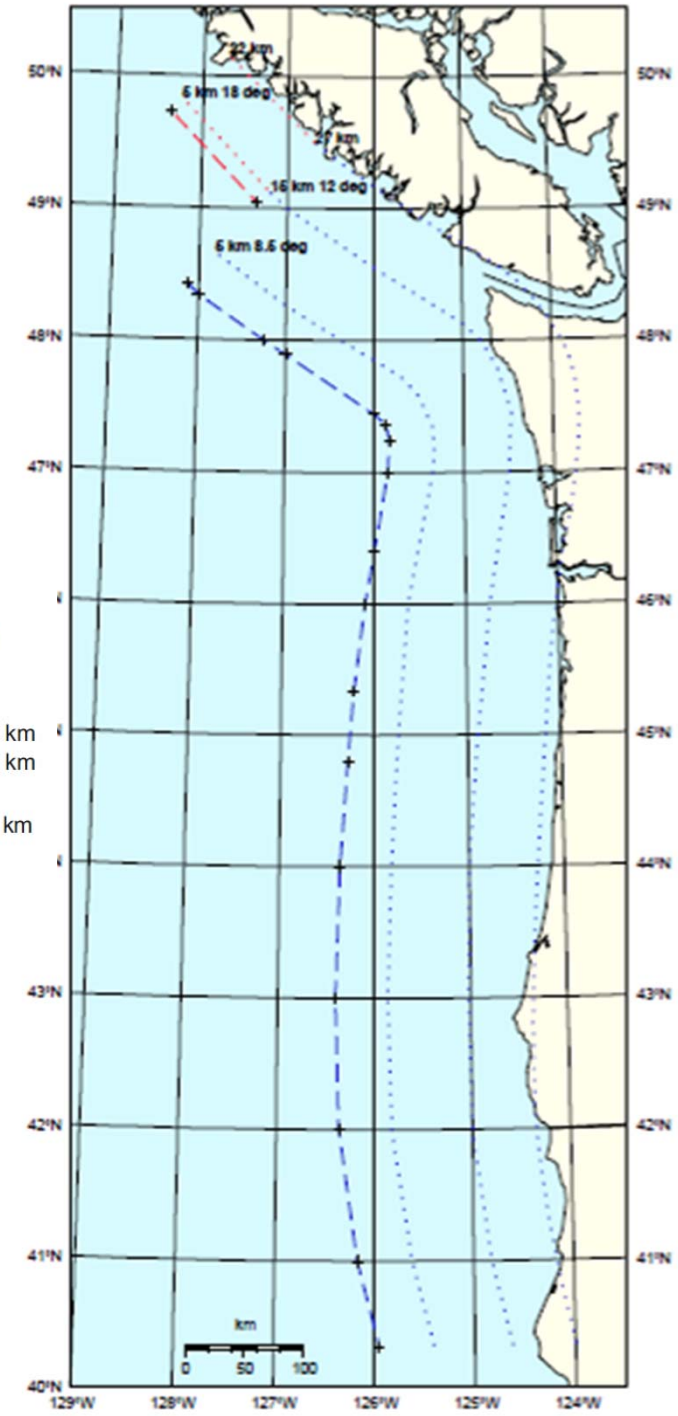
Inboard edge of rupture

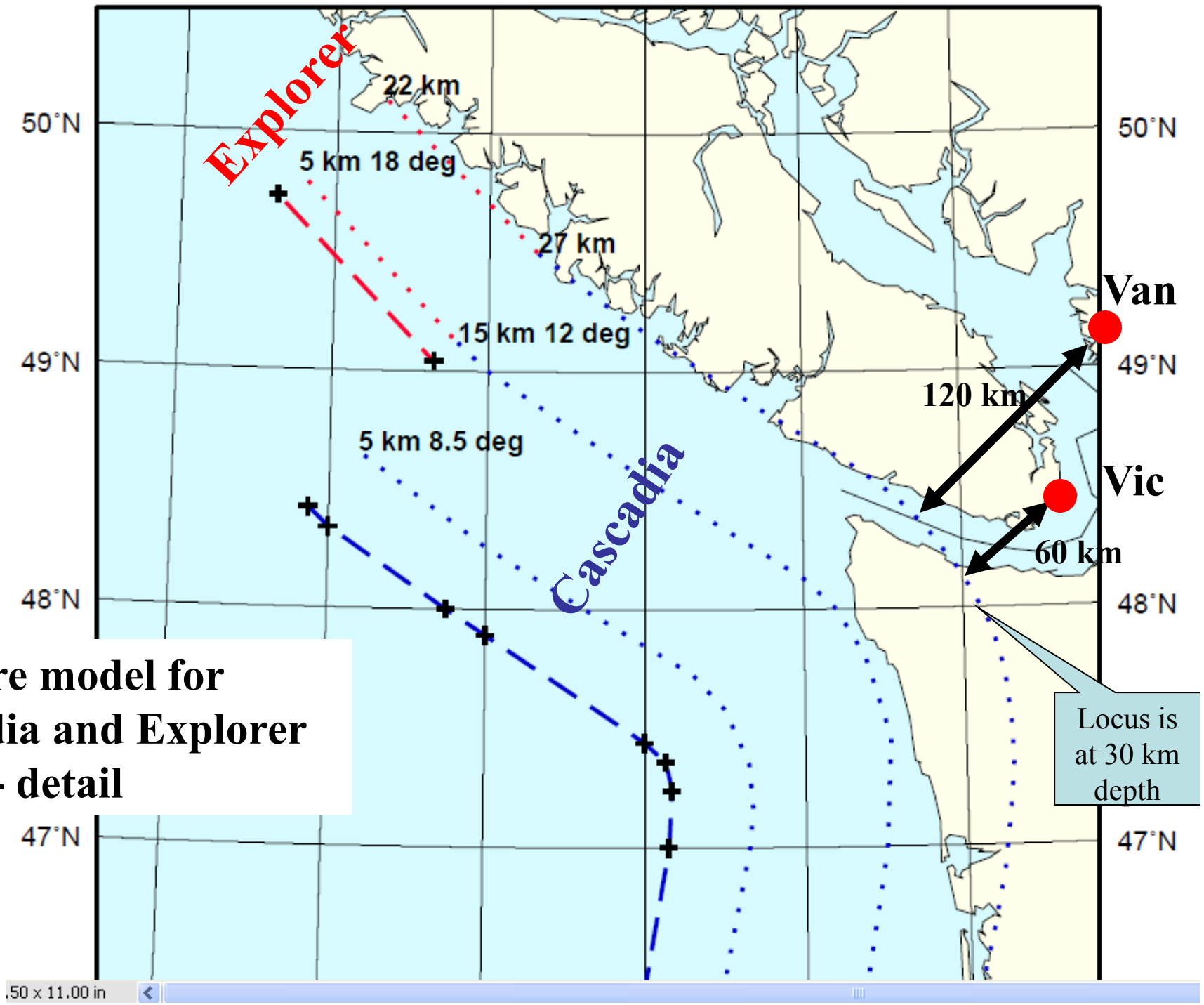


Rupture model for Cascadia and Explorer plates



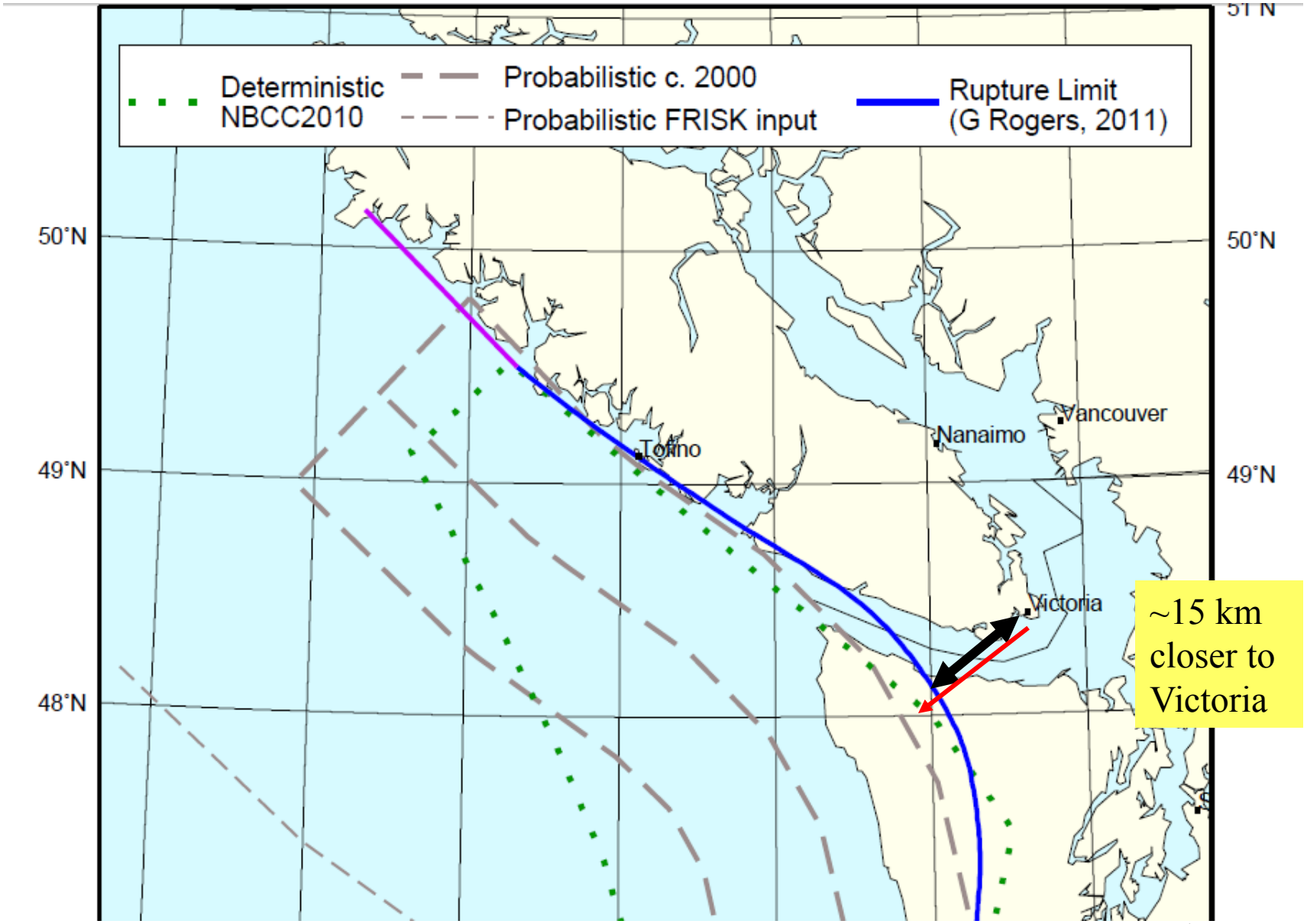
Cascadia probabilistic model, developed for Penrose conference, ca. 2000
for use with FRISKGSC program





Rupture model for Cascadia and Explorer plates - detail

Comparison of Cascadia inboard loci (best estimates)



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Paleohistory of Great Cascadia Events – after Goldfinger et al 201X

Table 9. Magnitude calculated from time interval, plate motion and rupture zone dimensions

Turbidite number	mean age	northern margin following interval years	northern margin slip from following time (m)	southern margin interval years	southern margin slip from time (m)	average northern & southern slip	Segment name	rupture length km	rupture width km	seismic moment	Mw
1	250					16.0	A	1000	83	398.4E+27	9.00
2	412	162	5.9	162	5.9	4.6	A	1000	83	113.6E+27	8.64
2a	579			167	6.1	4.7	C	450	55	55.8E+27	8.43
3	784	373	13.6	205	7.5	8.1	A	1000	83	202.7E+27	8.81
3a	1062			278	10.2	7.8	B	660	75	69.0E+27	8.50
4	1189	405	14.8	127	4.6	7.5	A	1000	83	186.5E+27	8.78
4a	1364			175	6.4	4.9	C	450	55	71.2E+27	8.50
5	1626	437	16.0	262	9.6	9.8	A	1000	83	245.1E+27	8.86
5a	1818			193	7.0	5.4	B	660	75	164.7E+27	8.75
5b	2121			303	11.1	8.5	C	450	55	72.1E+27	8.51
5c	2386			265	9.7	7.5	C	450	55	40.8E+27	8.34
6	2536	911	33.3	150	5.5	14.9	A	1000	83	372.2E+27	8.98
6a	2767			230	8.4	6.5	C	450	55	91.9E+27	8.58
7	3105	568	20.8	338	12.4	12.8	A	1000	83	318.1E+27	8.94
7a	3350			245	9.0	6.9	B	660	75	128.7E+27	8.68
8	3587	482	17.6	237	8.7	10.1	A	1000	83	252.2E+27	8.87
8a	3946			359	13.2	10.1	D	250	55	39.9E+27	8.34
9	4211	624	22.8	265	9.7	12.5	A	1000	83	311.8E+27	8.93
9a	4509			299	10.9	8.4	D	250	55	53.1E+27	8.42
10	4861	650	23.8	352	12.9	14.1	A	1000	83	351.4E+27	8.97
10a	5159			299	10.9	8.4	C	450	55	29.3E+27	8.25
10b	5267			108	3.9	3.0	C	450	55	80.7E+27	8.54
10c	5564			297	10.9	8.4	C	450	55	5.4E+27	7.76
10d	5584			20	0.7	0.6	D	250	55	3.0E+27	7.59
10e	5604			20	0.7	0.6	D	250	55	10.4E+27	7.95
10f	5673			69	2.5	1.9	C	450	55	60.8E+27	8.46
11	5897	1036	37.9	224	8.2	17.8	A	1000	83	442.1E+27	9.03
12	6476	579	21.2	579	21.2	16.3	A	1000	83	406.5E+27	9.01
12a	6893			417	15.3	11.7	D	250	55	36.6E+27	8.31
13	7136	659	24.1	243	8.9	12.7	A	1000	83	316.4E+27	8.94
14*	7625	489	17.9	489	17.9	13.8	A	1000	83	343.4E+27	8.96
14a	7968			343	12.6	9.7	D	250	55	32.3E+27	8.28
15	8182	557	20.4	214	7.8	10.9	A	1000	83	270.5E+27	8.89
15a	8552			370	13.6	10.4	D	250	55	57.4E+27	8.44
16	8933	751	27.5	380	13.9	15.9	A	1000	83	396.8E+27	9.00
16a	9094			161	5.9	4.5	D	250	55	3.7E+27	7.55
17	9119	186	6.8	25	0.9	3.0	A	1000	83	74.0E+27	8.52
17a	9284	165	6.0	165	6.0	4.7	A	1000	83	115.8E+27	8.65
18	9817	534	19.5	534	19.5	15.0	A	1000	83		
n=39											
total time		9817		9817							
total slip		353	350.2		350.2	350.7					
total plate boundary slip											
scale factor	0.77										

* = age constrained by Mazama ash age from Zdanowicz et al., 1999

Intervals for complete rupture events

Dates for past events (10,000 year history)

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Cascadia Magnitude-recurrence for complete rupture events

10,000 year history (we have one sample of the 1/10,000 year event!)

Assume that each rupture of interest to Canada is complete, end-to-end

(i.e. all M~9, not some M9 + many M~8)

Use time interval * plate tectonic rate to get the slip per event →magnitude

Protypical event happens every 550 years, ruptures length of 1020 km and width of 125 km, has slip of 25 m and has magnitude of 9.3

Events range in magnitude from 8.5 - 9.1 or 8.9 - 9.5 depending on input assumptions

– but nearby seismic hazard is not very sensitive to exact magnitudes when earthquakes get this big

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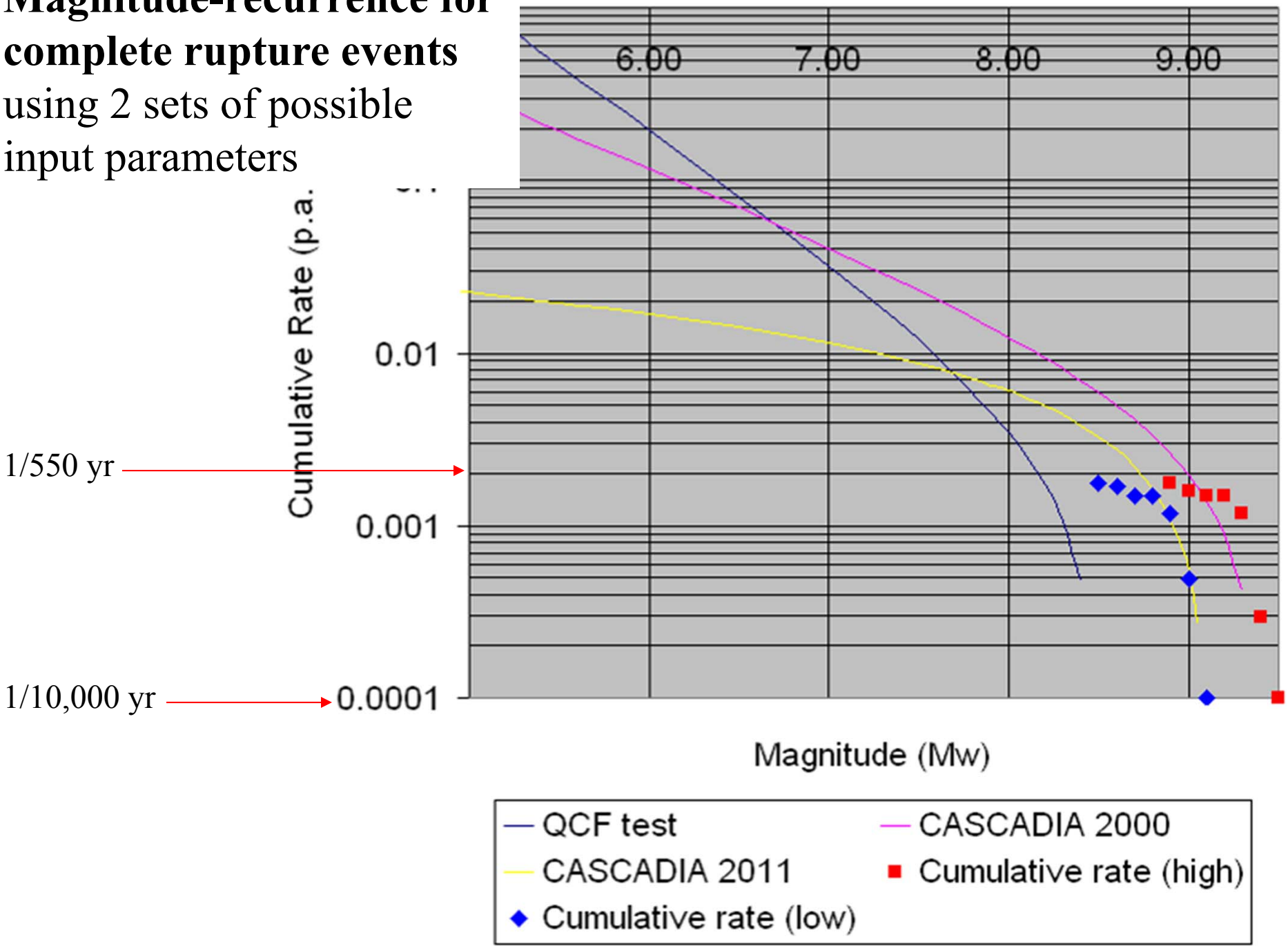
Magnitude-recurrence for complete rupture events using 2 sets of possible input parameters



Trial run

Probabilistic Cascadia motions

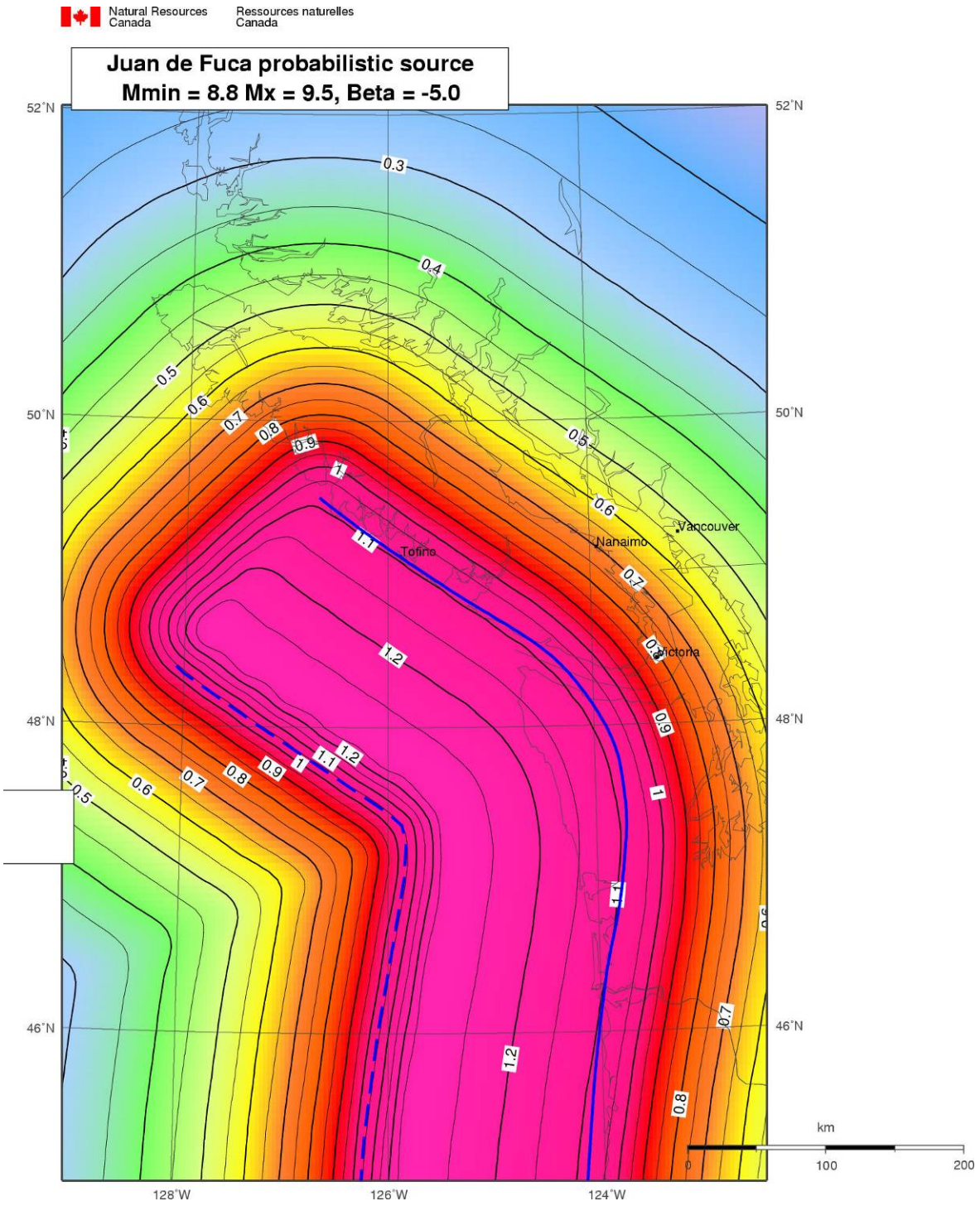
Sa(0.2) for 2%/50 years

2011 geometry

Youngs' GMPE

Results indicative only

Locus is uncertain by ~20 km, and results in ~15% change in hazard



Floor region and Maximum earthquake

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

A record of stable continental region earthquakes from Western Australia spanning the late Pleistocene: Insights for contemporary seismicity

Mark Leonard [a,*], Dan Clark [b]

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[b] Geoscience Australia, Australia

Mmax in non-extended-SCR is M**7.25±0.1** and

in extended-SCR is M**7.65±0.1**

ABSTRACT

In plate boundary regions moderate to large earthquakes are often sufficiently frequent that fundamental seismic parameters such as the recurrence intervals of large earthquakes and maximum credible earthquake (Mmax) can be estimated with some degree of confidence. The same is not true for the Stable Continental Regions (SCRs) of the world. Large earthquakes are so infrequent that the data distributions upon which recurrence and Mmax estimates are based are heavily skewed towards magnitudes below M_w5.0, and so require significant extrapolation up to magnitudes for which the most damaging ground-shaking might be expected. The rarity of validating evidence from surface rupturing palaeo-earthquakes typically limits the confidence with which these extrapolated statistical parameters may be applied. Herein we present a new earthquake catalogue containing, in addition to the historic record of seismicity, 150 palaeo-earthquakes derived from 60 palaeo-earthquake features spanning the last >100 ka of the history of the Precambrian shield and fringing extended margin of southwest Western Australia. From this combined dataset we show that Mmax in non-extended-SCR is M7.25 ± 0.1 and in extended-SCR is M7.65 ± 0.1. We also demonstrate that in the 230,000 km^2 area of non-extended-SCR crust, the rate of seismic activity required to build these scarps is one tenth of the contemporary seismicity in the area, consistent with episodic or clustered models describing SCR earthquake recurrence. A dominance in the landscape of earthquake scarps reflecting multiple events suggests that the largest earthquakes are likely to occur on pre-existing faults. We expect these results might apply to most areas of non-extended-SCR worldwide.

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Integrated Treatment of Floor source

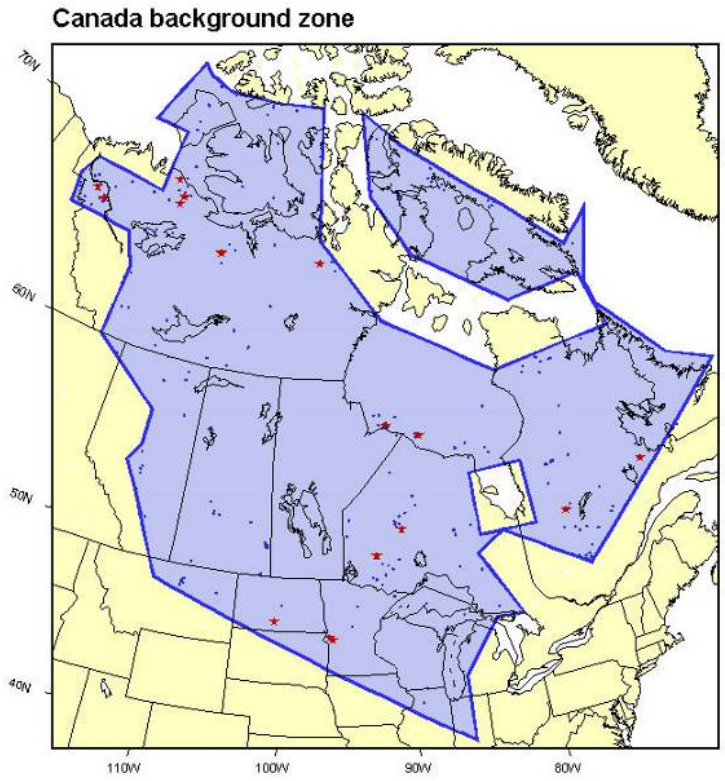
Will add as a source to the eastern and western models

Will use two alternative models (probably 4th Gen and Martens-Atkinson models, equally weighted)

Will allow Mmax to 7.2 + (Leonard & Clark, 2011)

Expect hazard to drop in centre of country, may increase it at margins, near other earthquake sources (e.g. Calgary, Sudbury)

May still need a floor value?



New Ground Motion Prediction Equations

Gail will talk about these

Evolution of spectral periods

In 1985 it was PGA and PGV

In 2005/2010 Sa at 0.2, 0.5, 1.0, 2.0 seconds

For 2015 may add 0.15, 5, 10 seconds

Important for very short rigid structures

Important for tall buildings and bridges

Not yet certain how these periods would be used in the Code

Adjusted reference ground condition

In 1985 it was Rock or Firm Ground

In 2005 Fa and Fv factors were introduced

- reference condition = Site Class C
- reduction factor of 20-50% for being on rock

For 2015 the reference ground condition is likely to be the boundary between site class B and site Class C ("B/C" = BslashC) for consistency with all recent Ground Motion relations

Probably no design level implications

(though the Fa and Fv values will change)

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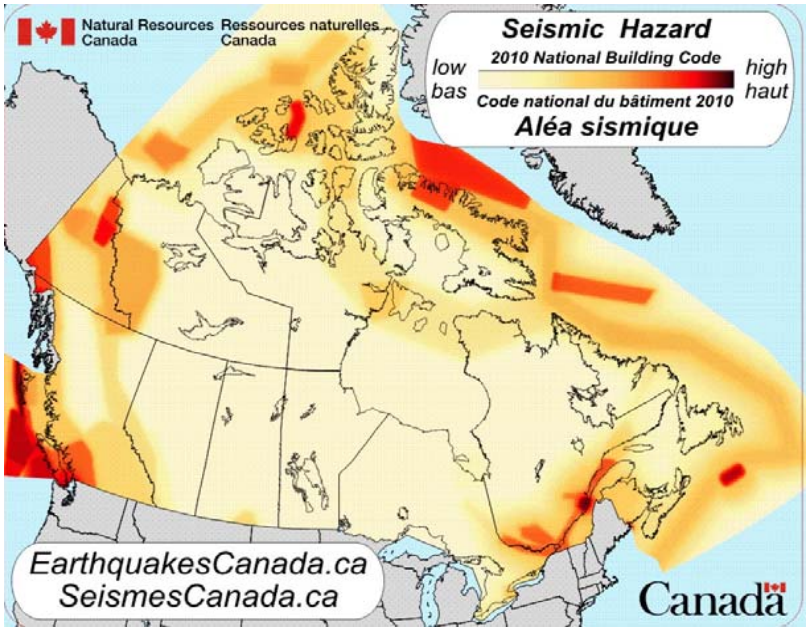
Summary

Seismic hazard estimates are improving

More data leads to improvements and increased confidence in our estimates

2015 estimates will provide an improved basis for the distribution of engineering anti-seismic measures across Canada



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Thank You

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