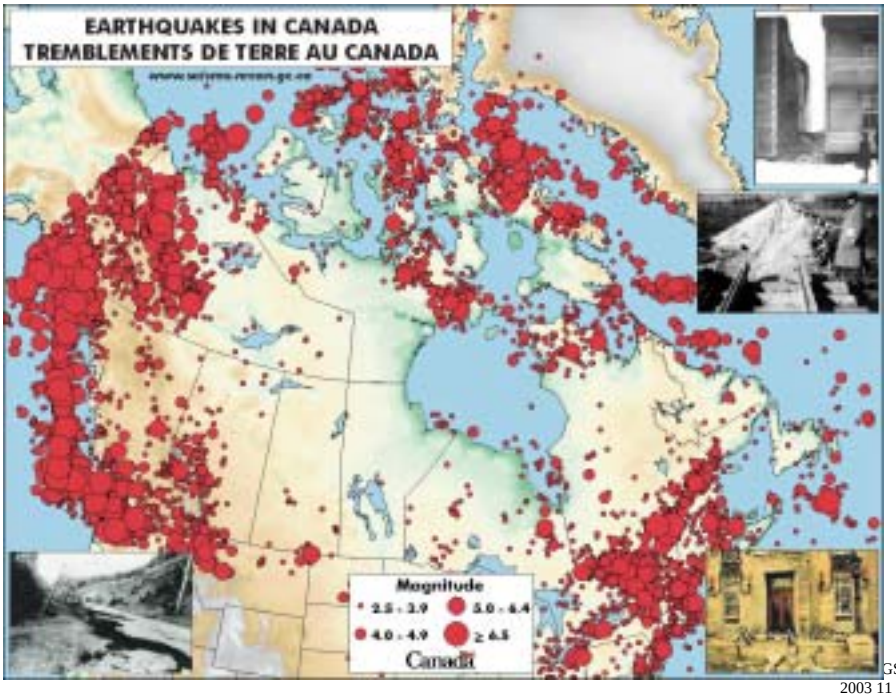
Overview of National Seismic Hazard Maps for the next National Building Code

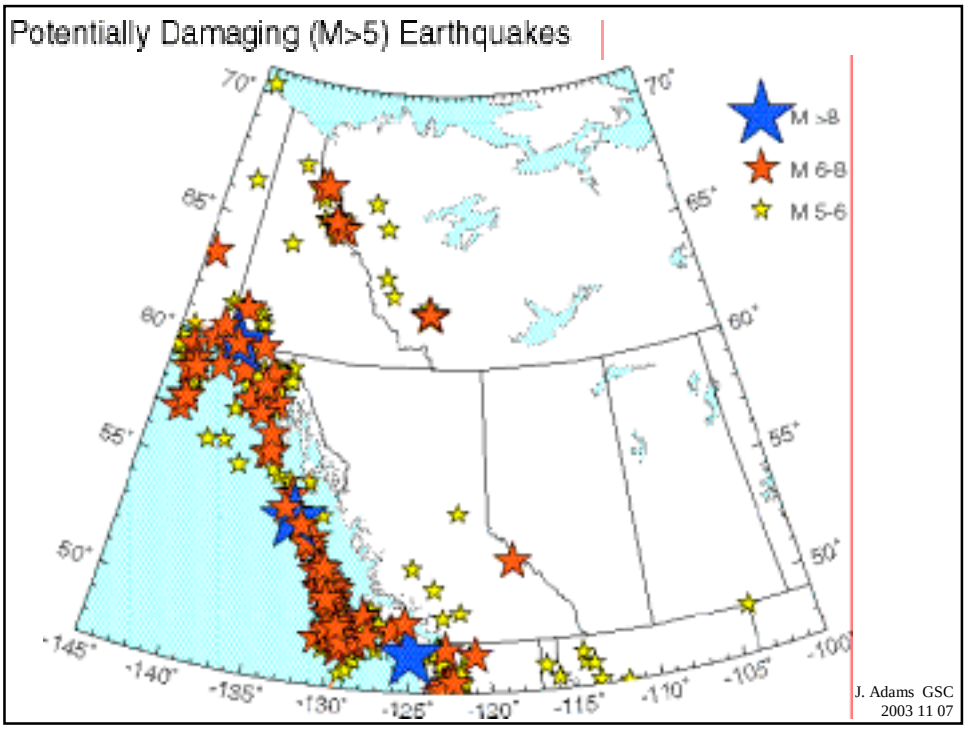
John Adams
Earthquakes Canada
Geological Survey of Canada

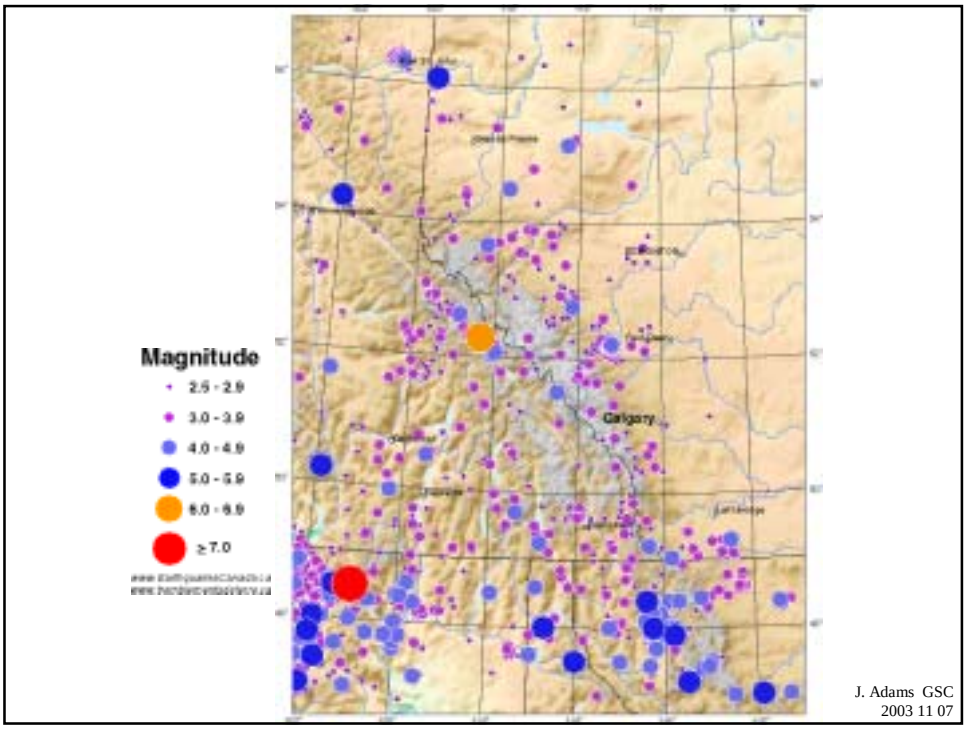
Natural Resources Canada
Ressources naturelles Canada

CSCE Workshop
2004 Jun 10

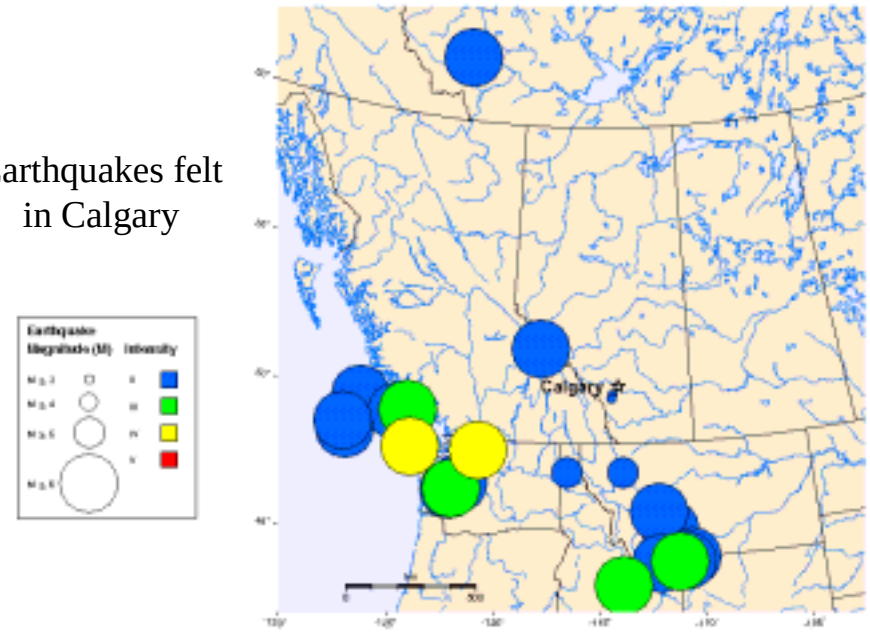


GSC
2003 11 07


Potentially Damaging (M>5) Earthquakes
M >8
M 6-8
M 5-6
70°
65°
60°
55°
50°
85°
-145°
-140°
-135°
-130°
-125°
-120°
-115°
-110°
-105°
-100°
J. Adams GSC
2003 11 07

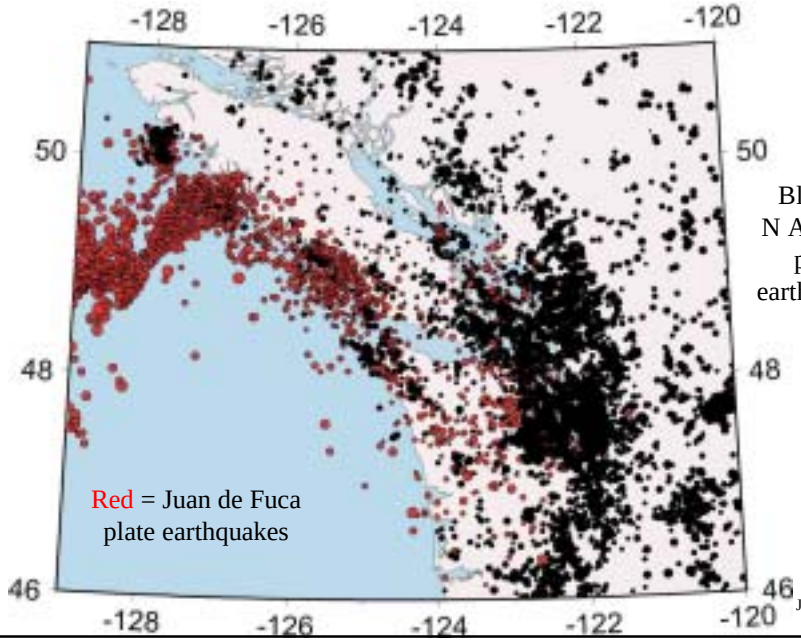

Magnitude
2.5 - 2.9
3.0 - 3.9
4.0 - 4.9
5.0 - 5.9
6.0 - 6.9
≥ 7.0
Calgary
J. Adams GSC
2003 11 07

Earthquakes felt in Calgary



J. Adams GSC
2003 11 07

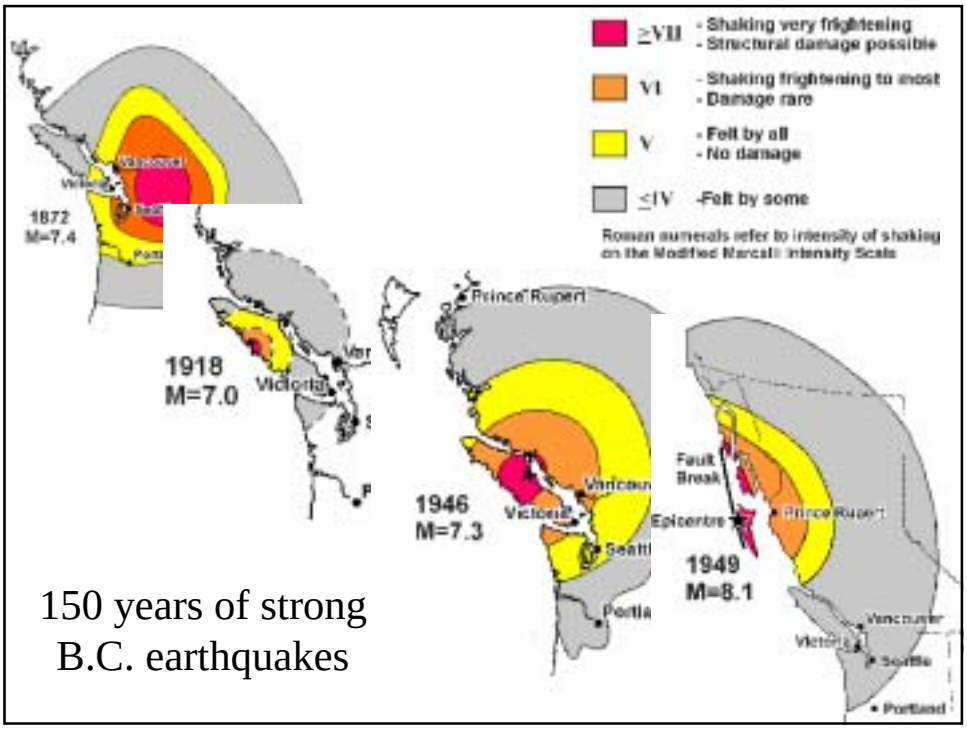
Cascadia Seismicity 1985-1999



Red = Juan de Fuca plate earthquakes

Black = N America plate earthquakes

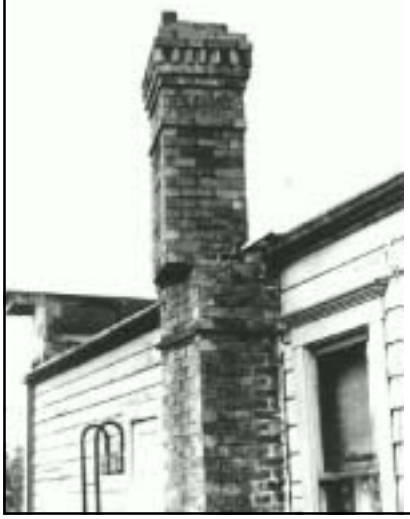
J. Adams GSC
2003 11 07



150 years of strong B.C. earthquakes

1946 earthquake

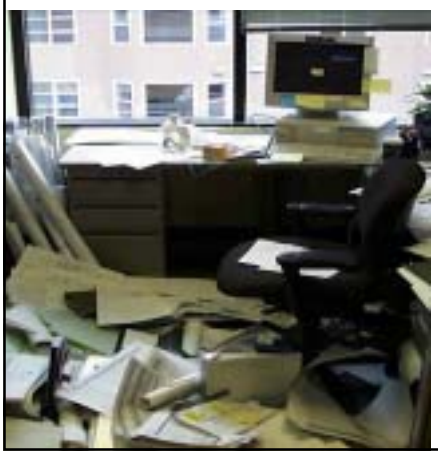
Vancouver Island



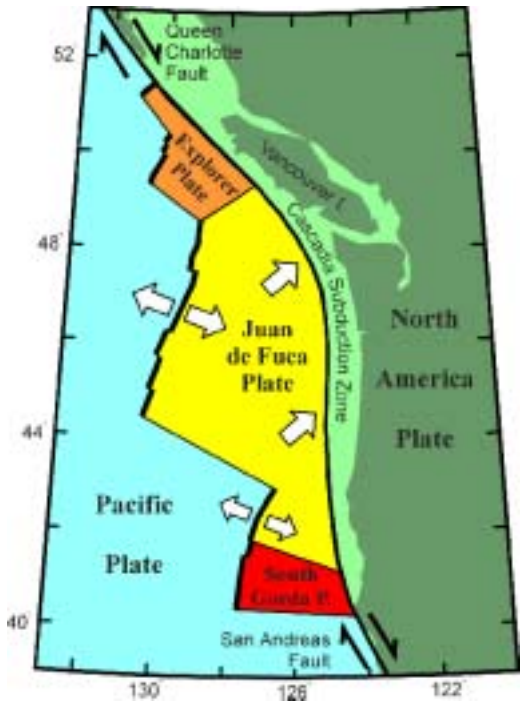
SC 07

Nisqually Earthquake, 2001
Opus East, Washington

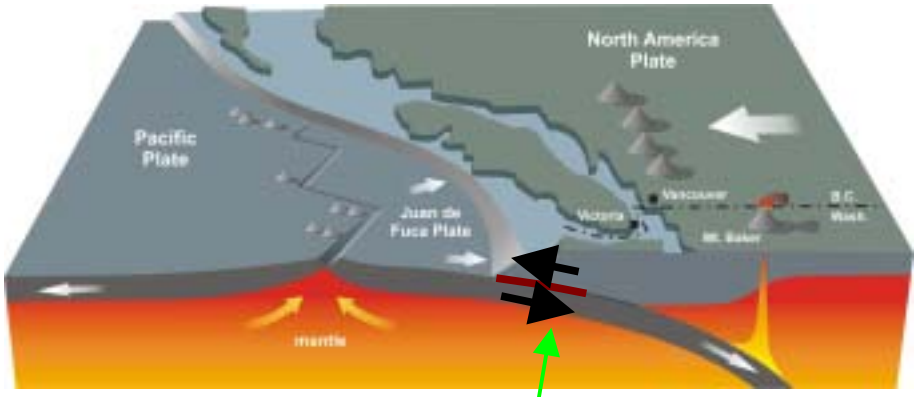
(on the fourth floor)



J. Adams GSC
2003 11 07



J. Adams GSC
2003 11 07



Megathrust Earthquakes

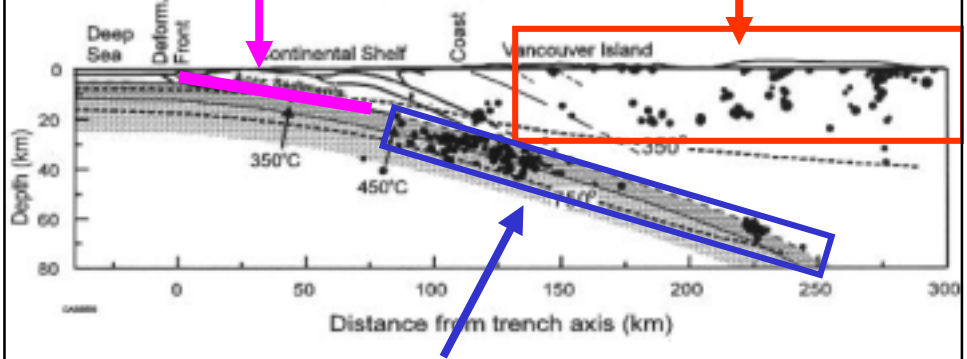
J. Adams GSC
2003 11 07

Subduction earthquakes

1700

Crustal earthquakes

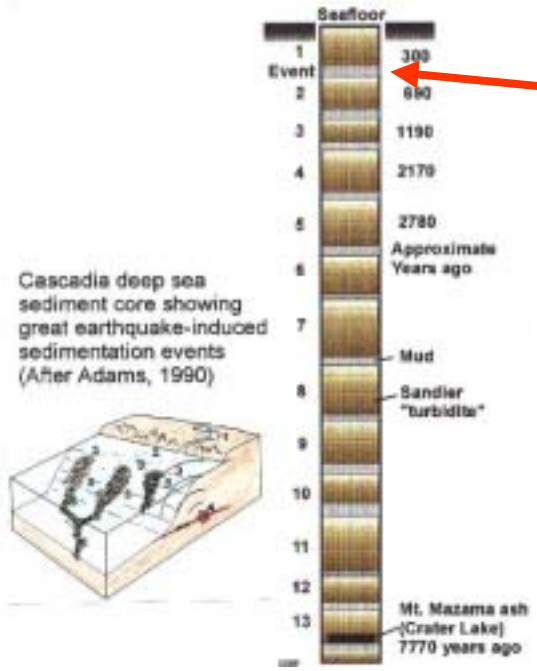
1872, 1918, 1946



Inslab (Sub-crustal) earthquakes

1949, 1965, 2001

J. Adams GSC
2003 11 07



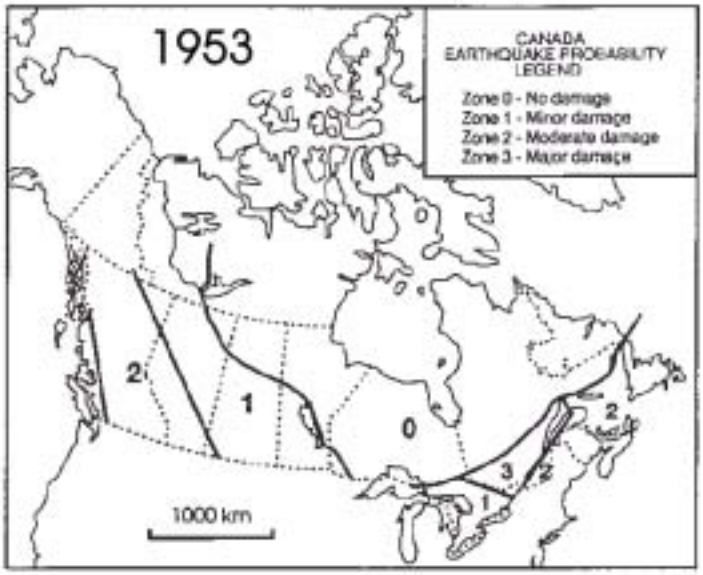
Cascadia deep sea sediment core showing great earthquake-induced sedimentation events (After Adams, 1990)

1700 A.D.

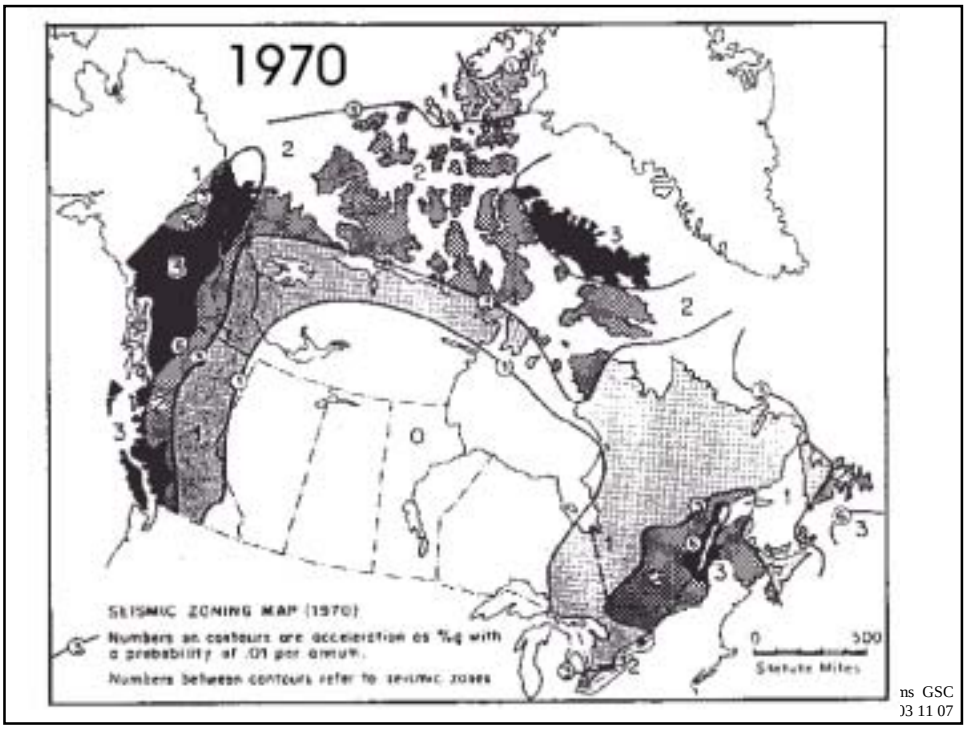
Once per 600 years

J. Adams GSC
2003 11 07

3 Previous Generations of Seismic Hazard maps

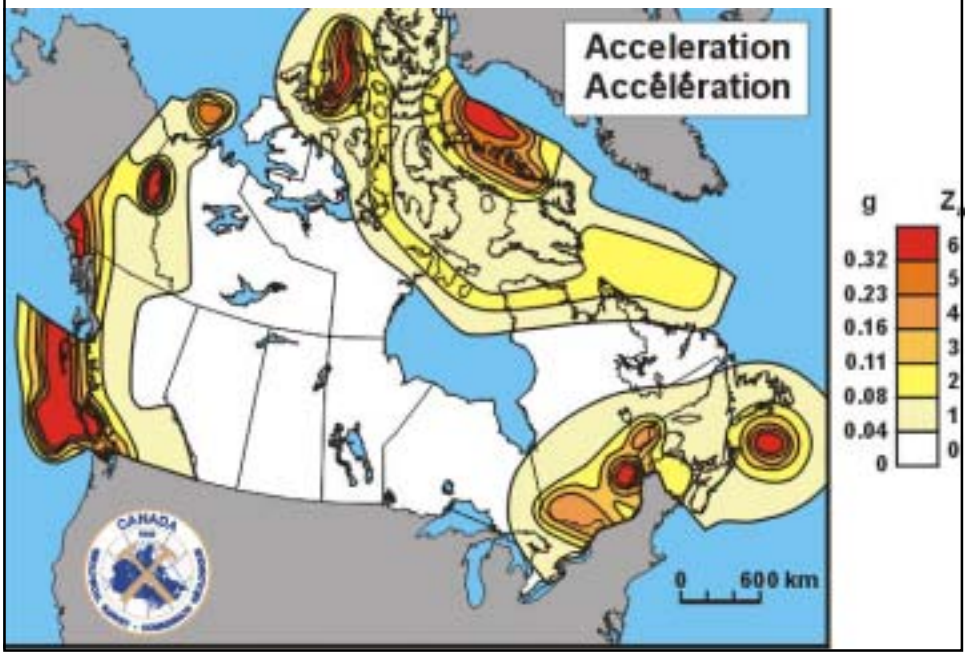


J. Adams GSC
2003 11 07

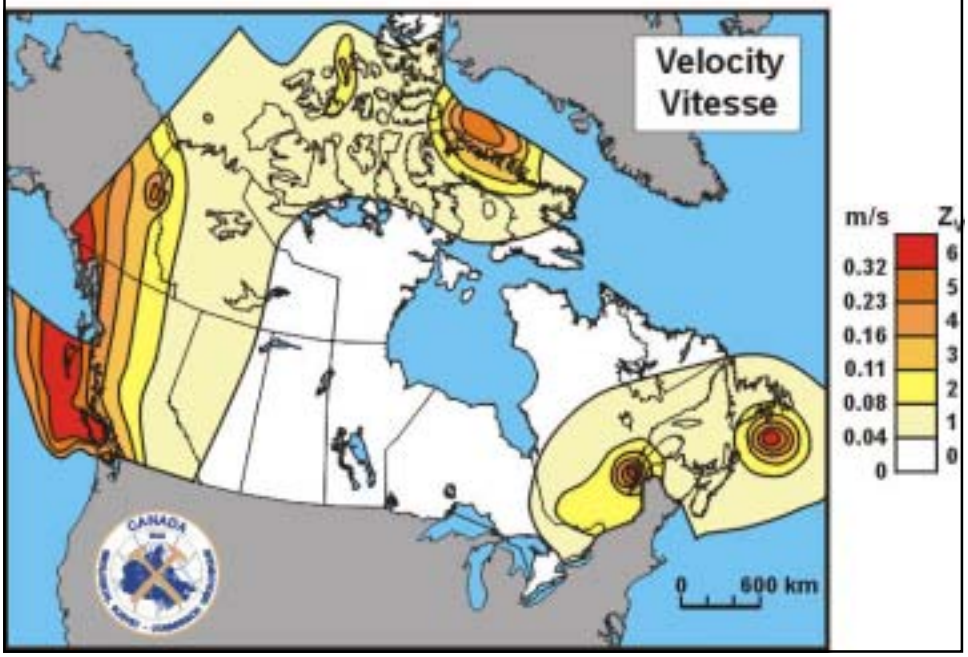


ns GSC
03 11 07

1985



1985



Seismic Hazard

shaking irrespective of consequence

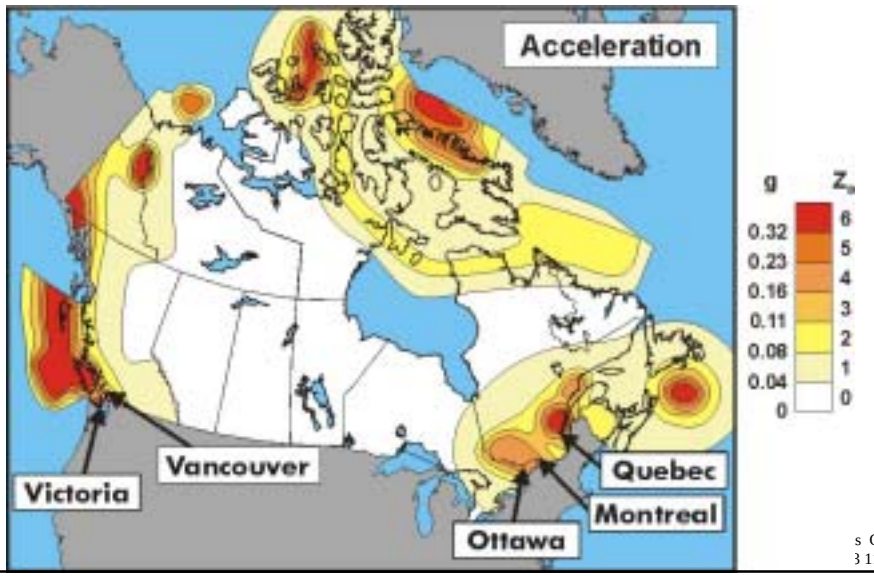
Seismic Risk

Hazard * Exposure

	hazard	exposure	risk
Baffin Island	high	low	low
Vancouver	high	high	high
Toronto	low	high	moderate

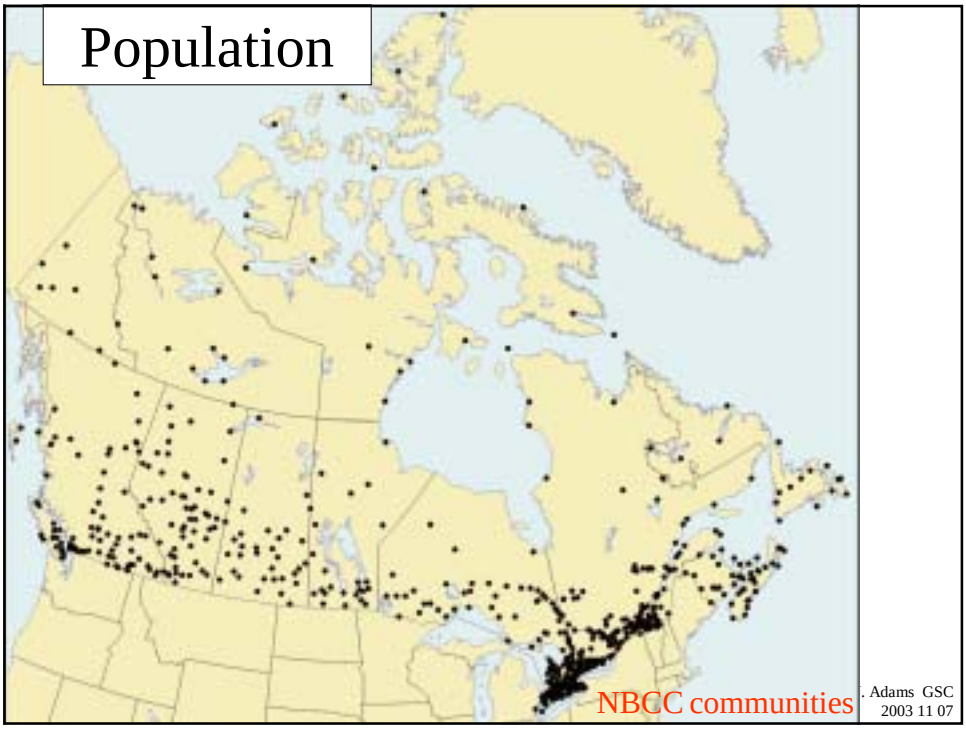
J. Adams GSC
2003 11 07

Hazard

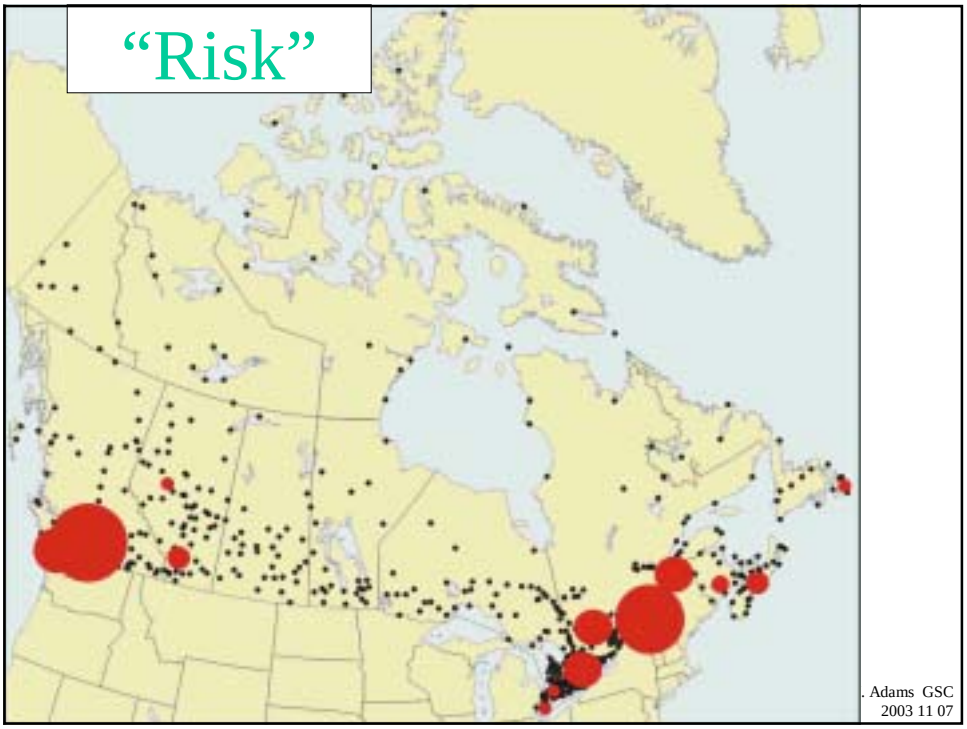


s GSC
3 11 07

Population



. Adams GSC
2003 11 07

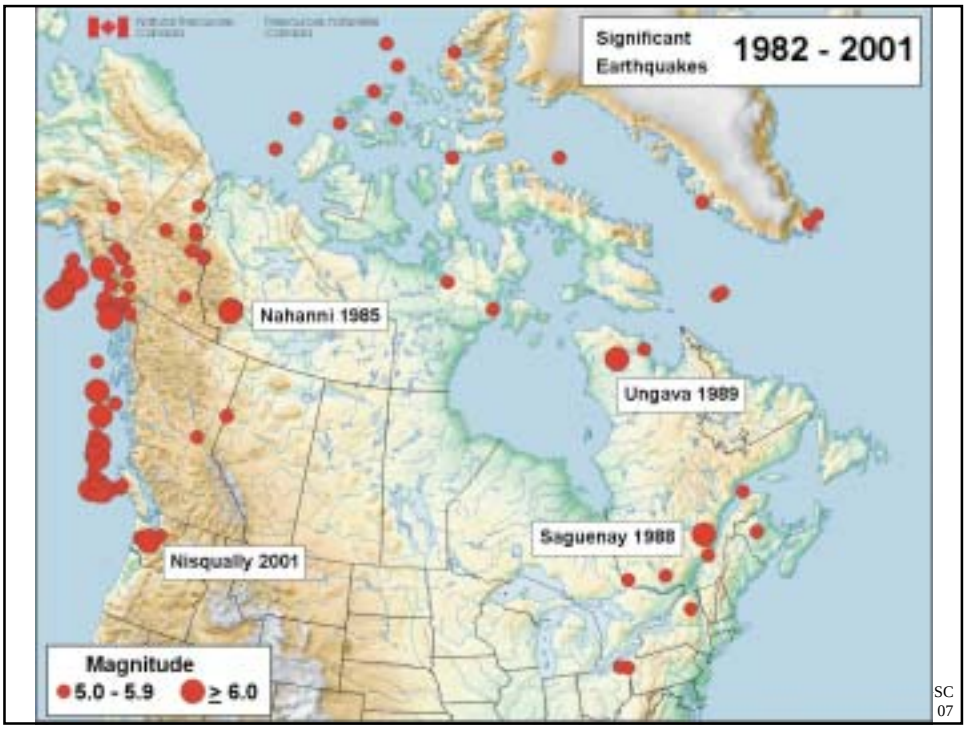


Need for New Seismic Hazard maps

Many improvements in methods since GSC's 1982 maps went into NBCC 1985

Thirty years of new earthquakes, including Nahanni, Saguenay, Ungava and Nisqually

J. Adams GSC
2003 11 07



GSC's 4th Generation maps
(Changes for NBCC 2005)

* New strong ground motion relations
New seismicity model
Robust hazard, not full probabilistic
New soil-condition factors
Spectral parameters, not peak
Median hazard plus uncertainty
Lower probability level - 2%/50 yr
Contours, not zones

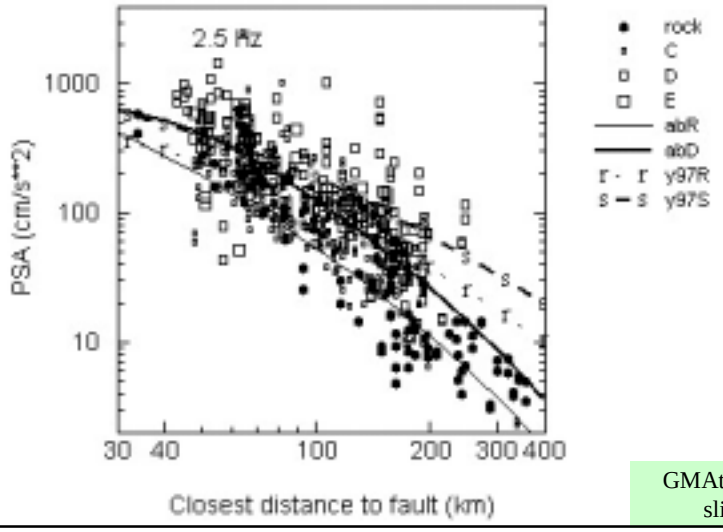
J. Adams GSC
2003 11 07

Main ground motion developments since 1985

- order of magnitude more ground motion data for western North America
- Ground motion data for eastern North America (for the first time!)
- Advancements in modeling ground motion
- → to new ground motion relations that profoundly influence hazard results

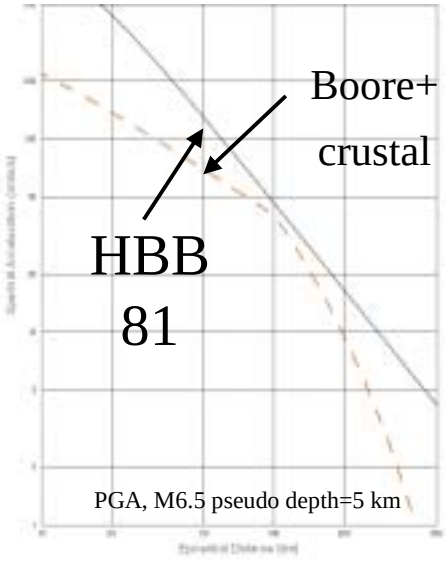
J. Adams GSC
2003 11 07

Recent data compared to inslab relations (M=6.8+/- 0.3)

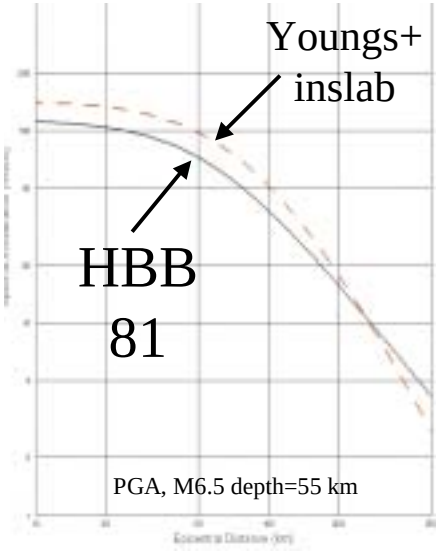


GMAtkinson slide

Replacement SGM relations



PGA, M6.5 pseudo depth=5 km



PGA, M6.5 depth=55 km

J. Adams GSC
2003 11 07

Summary

- Huge increase in ground motion data available for California as well as eastern and western Canada over last 15 years
- Better modeling capabilities allow good use of data to develop more reliable ground motion relations for all regions
- Main difference between ENA and western motions is enhanced high frequency content of ENA motions
- Significant uncertainties remain for ENA motions for large events and close distances, as well as for B.C. motions from all types of events

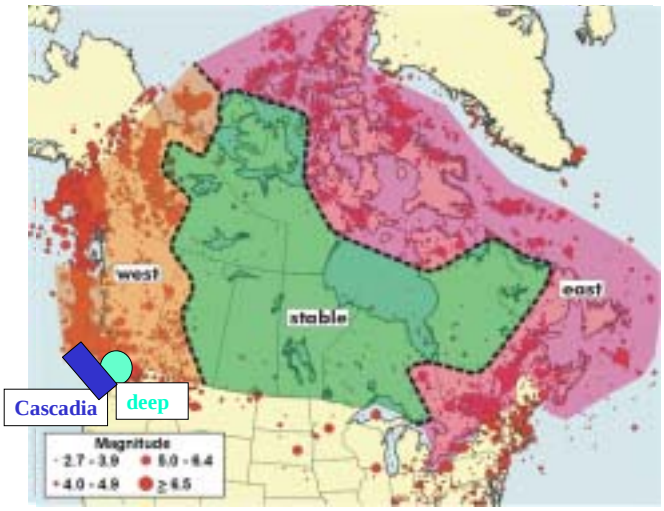
GMAtkinson slide

GSC's 4th Generation maps
(Changes for NBCC 2005)

New strong ground motion relations
* New seismicity model
Robust hazard, not full probabilistic
New soil-condition factors
Spectral parameters, not peak
Median hazard plus uncertainty
Lower probability level - 2%/50 yr
Contours, not zones

J. Adams GSC
2003 11 07

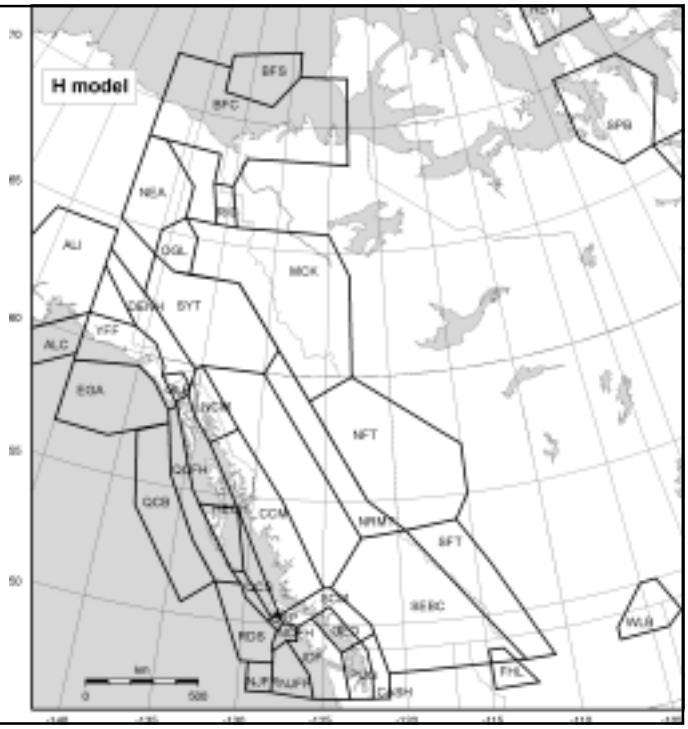
The main elements of the 4th Generation model



J. Adams GSC
2003 11 07

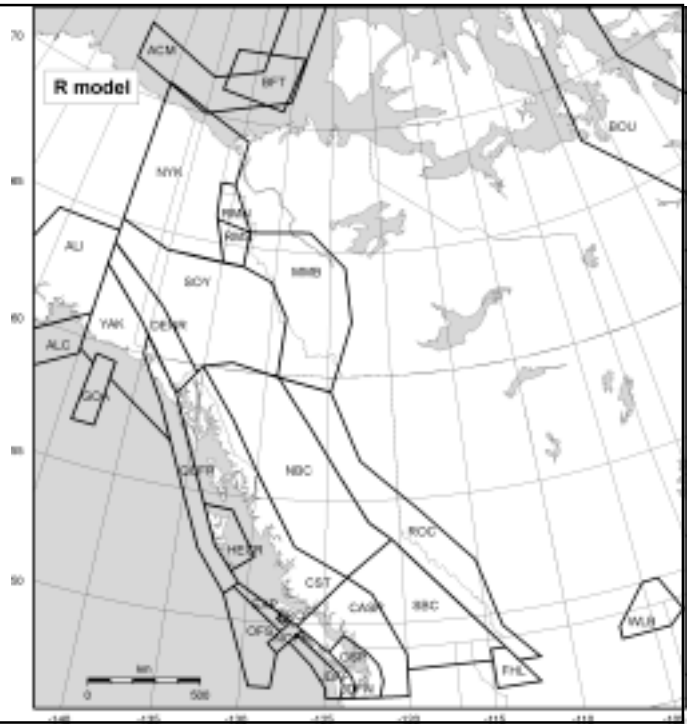
Seismic source zones

H model

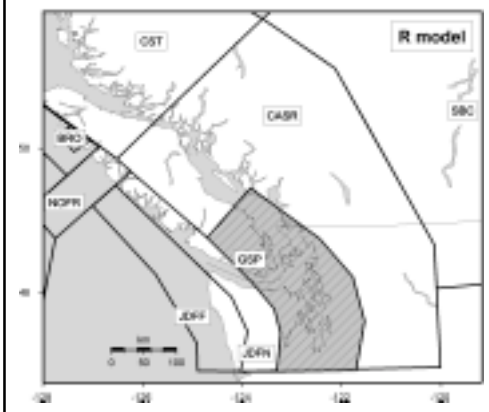


Seismic source zones

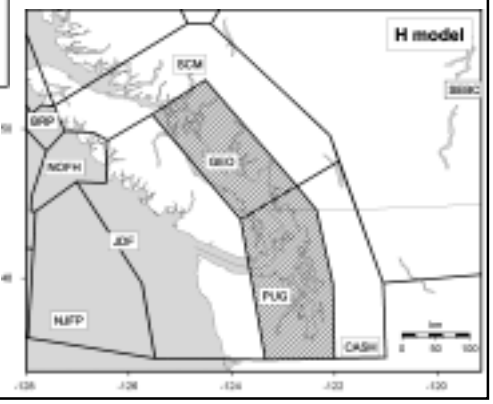
R model



Models for deep zones under SW B.C.

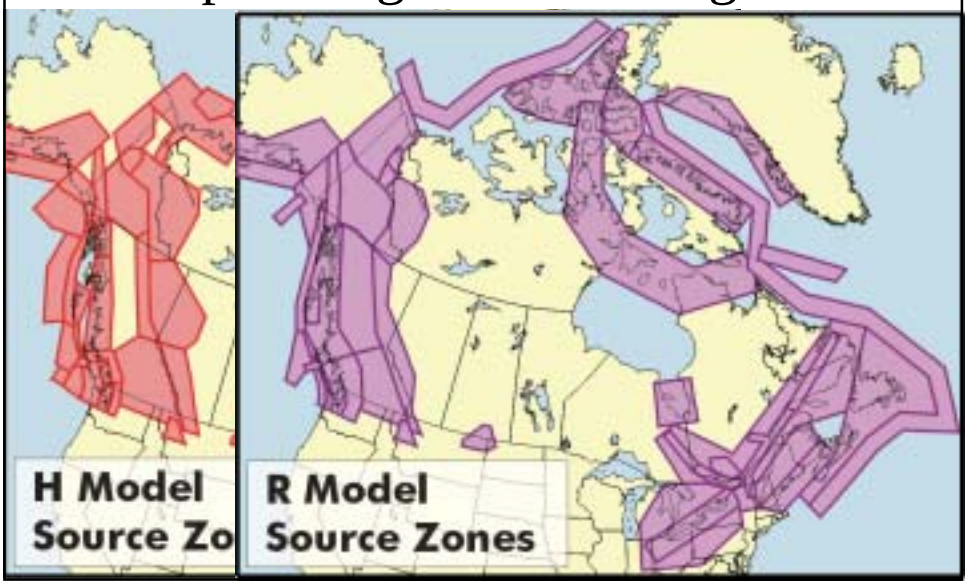


zone GSP lies beneath CASR

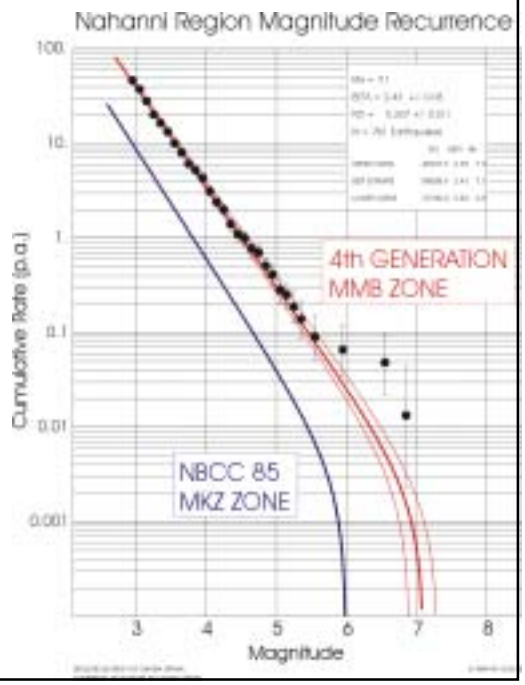


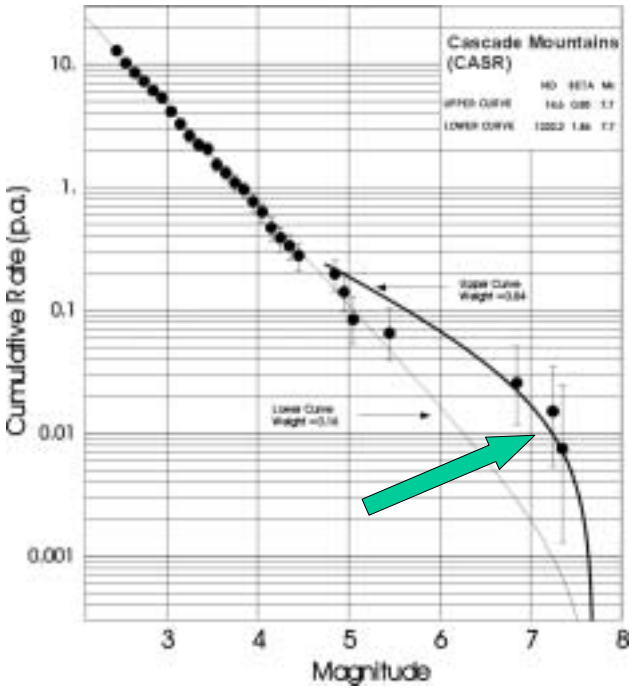
zone GEO lies beneath SCM
zone PUG lies beneath CASH

Two source zones span range in knowledge



Rates of activity, and sizes of the biggest events were underestimated

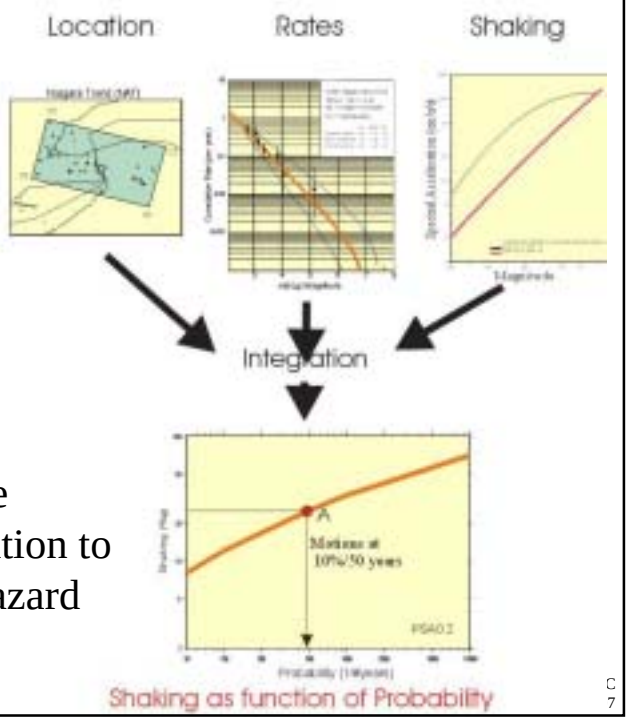




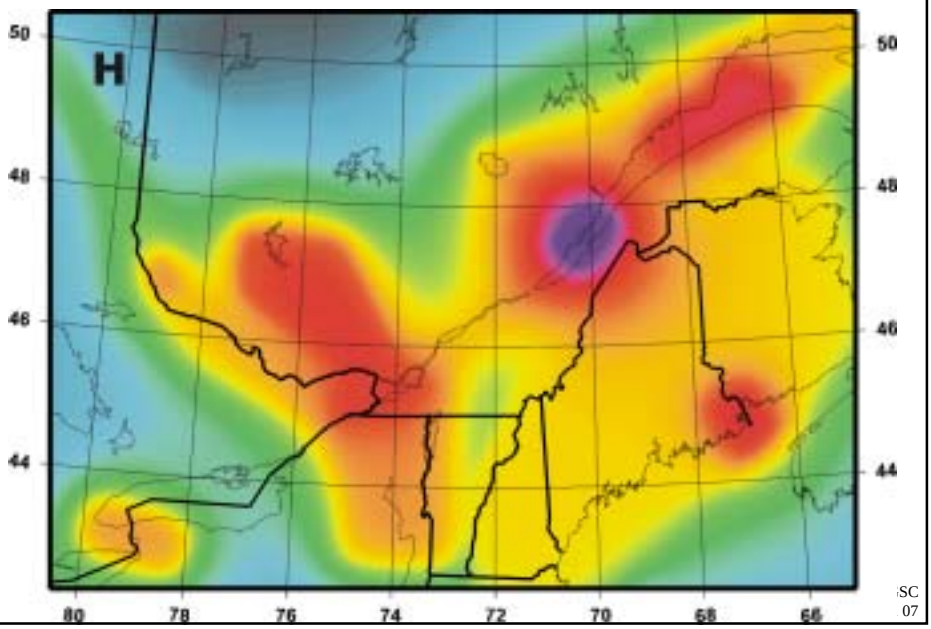
Some data do not appear to fit the simple model

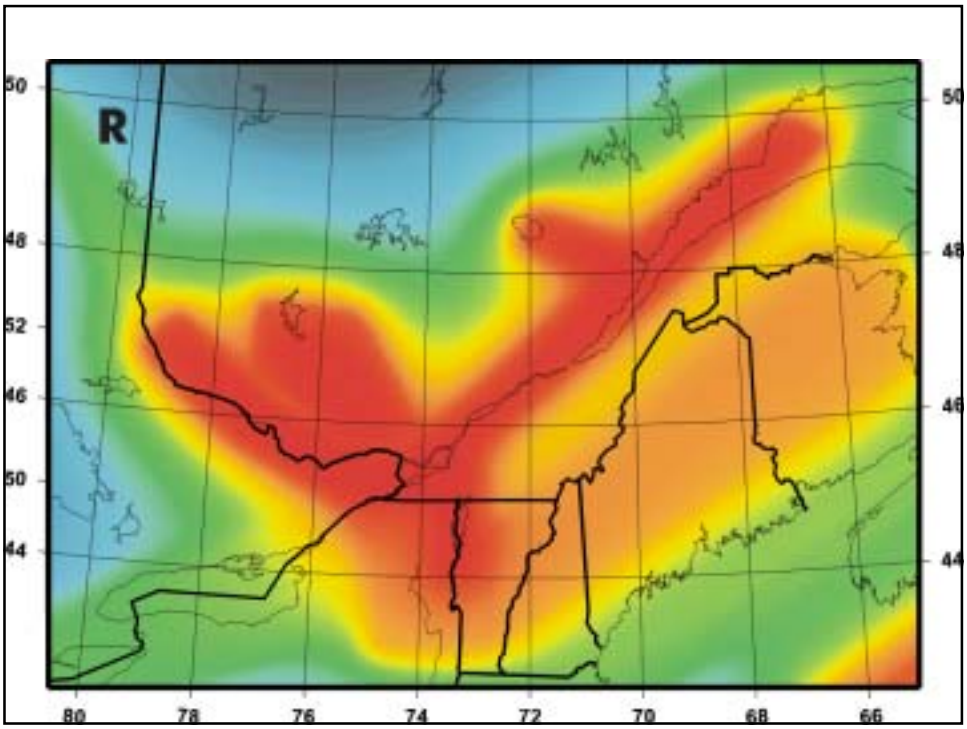
J. Adams GSC
2003 11 07

Probabilistic seismic hazard



Double integration to give hazard





Problem

- To use H would not reduce damage from future earthquakes elsewhere…

- To use R would reduce protection in historically-active regions

Solution: use the higher of the two values….

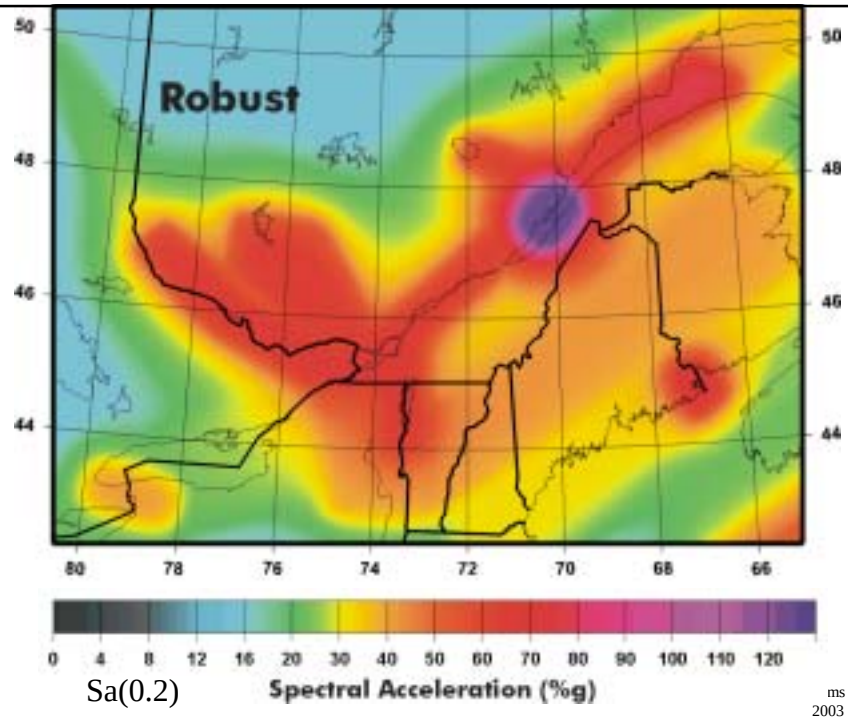
Robust method

J. Adams GSC
2003 11 07

GSC's 4th Generation maps
(Changes for NBCC 2005)

New strong ground motion relations
New seismicity model
* Robust hazard, not full probabilistic
New soil-condition factors
Spectral parameters, not peak
Median hazard plus uncertainty
Lower probability level - 2%/50 yr
Contours, not zones

J. Adams GSC
2003 11 07



Sa(0.2)

ms GSC
2003 11 07

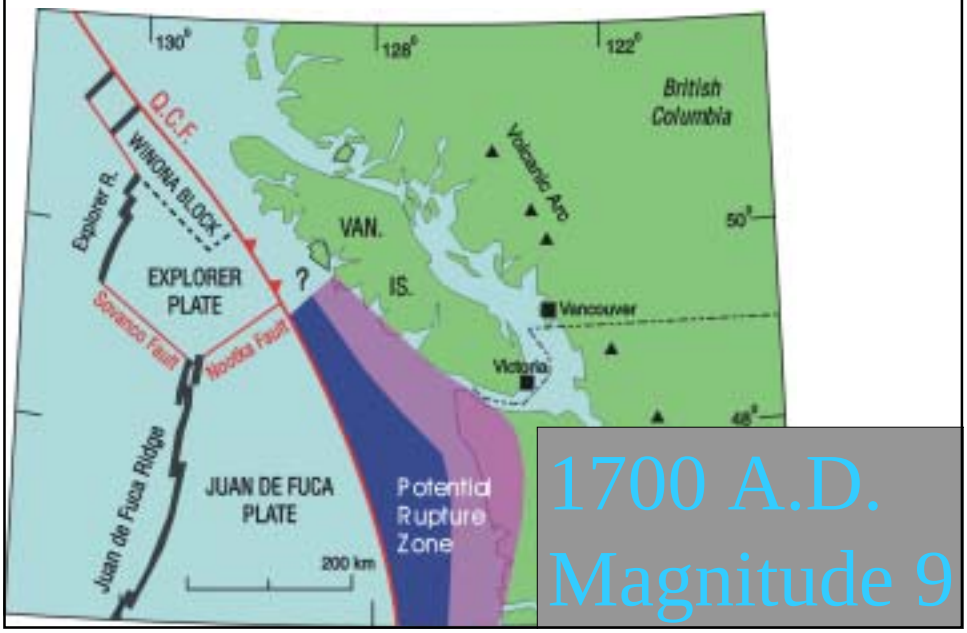
Full Robust Hazard Model

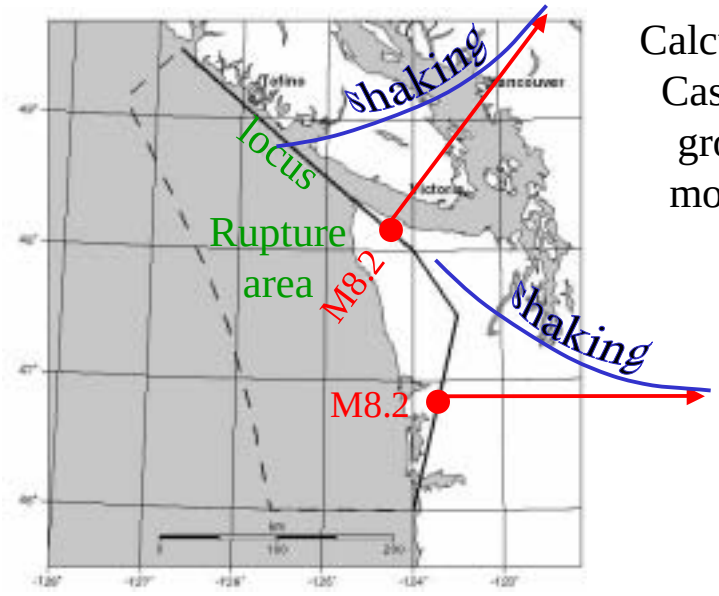
Highest value of:-

Probabilistic H model
Probabilistic R model
Deterministic Cascadia model
Probabilistic Stable craton model

J. Adams GSC
2003 11 07

Cascadia Subduction Zone

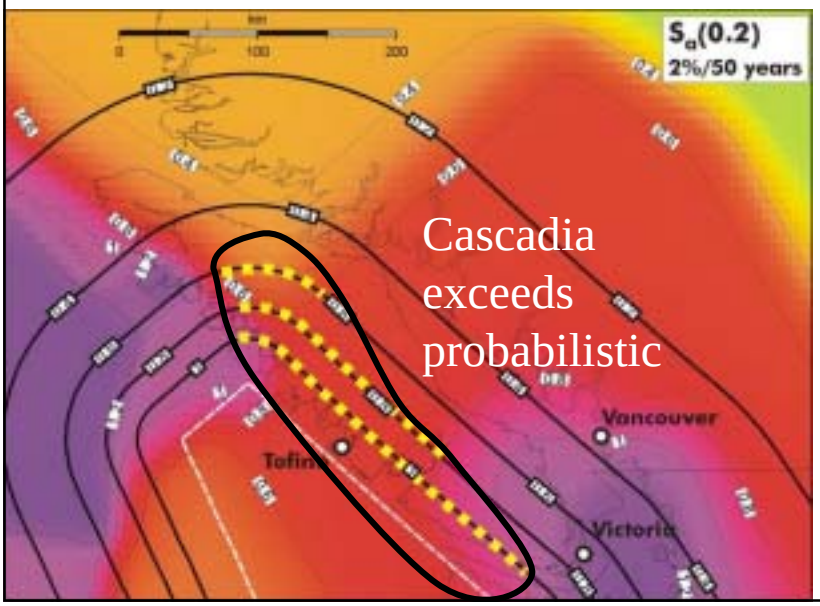




Calculating Cascadia ground motions

J. Adams GSC
2003 11 07

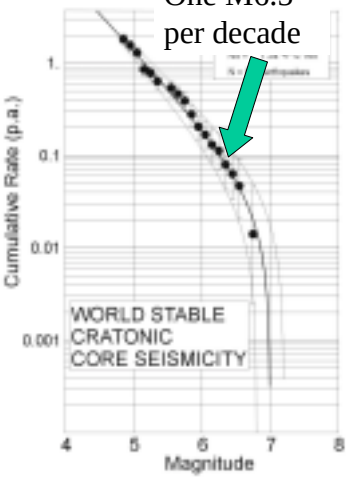
Deterministic Cascadia plus Probabilistic hazard



J. Adams GSC
2003 11 07

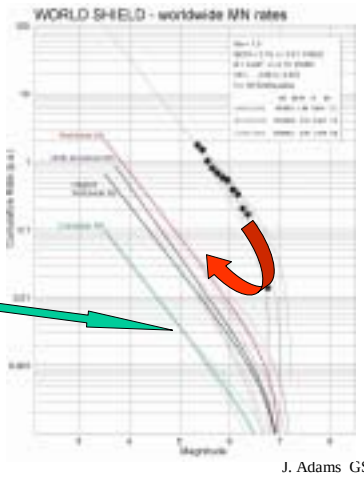
Stable Craton - No part of the world entirely lacks (big) earthquakes

One M6.5 per decade



J. Adams GSC
2003 11 07

A range of rate estimates…..



J. Adams GSC
2003 11 07

Floor Hazard estimates

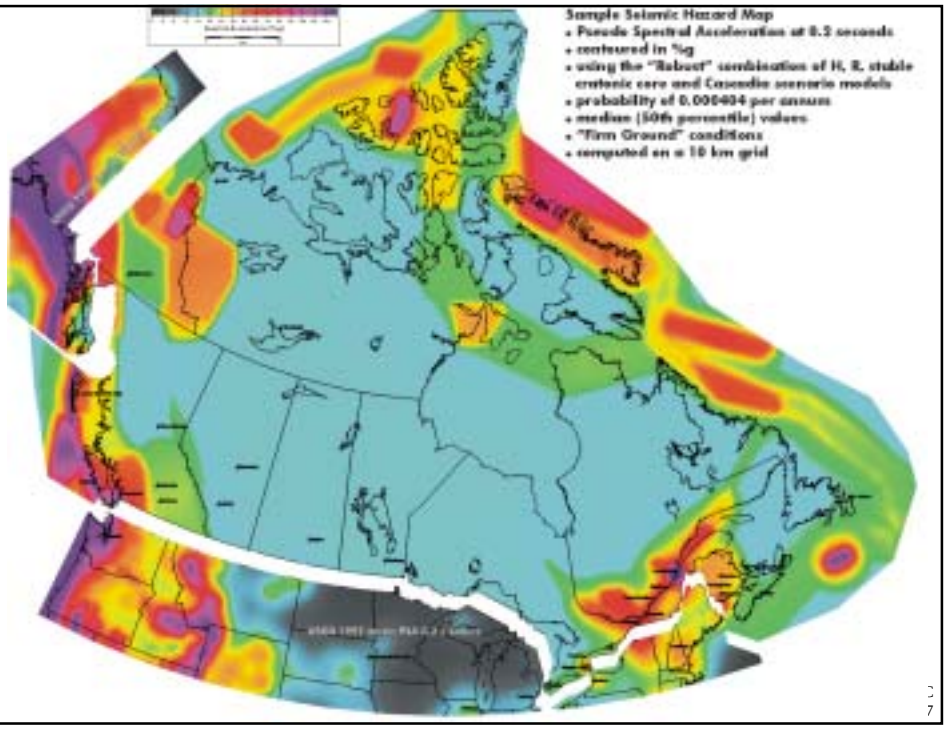
1985 Hazard estimates for central Canada came only from distant source zones – hazard from rare nearby earthquakes was neglected

2005 Hazard computed for centre of large zone with global rate

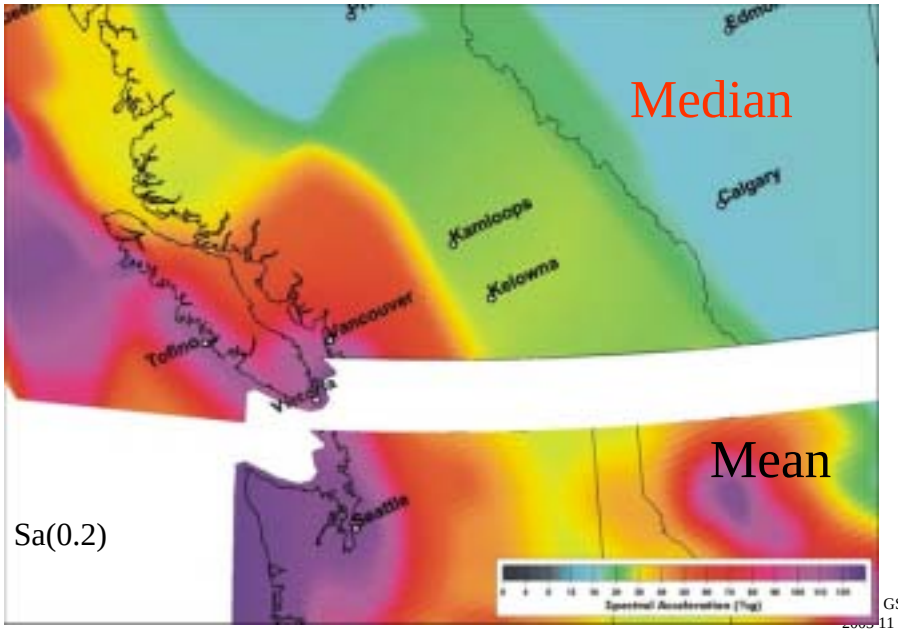
→ floor value (see Winnipeg values in Table)

10% in 50 year floor value is still below the lowest contour of the 1985 PGA map.

J. Adams GSC
2003 11 07



Southwestern Canada Hazard



GSC
2003-11-07

GSC's 4th Generation maps
(Changes for NBCC 2005)

New strong ground motion relations
New seismicity model
Robust hazard, not full probabilistic
* New soil-condition factors
Spectral parameters, not peak
Median hazard plus uncertainty
Lower probability level - 2%/50 yr
Contours, not zones

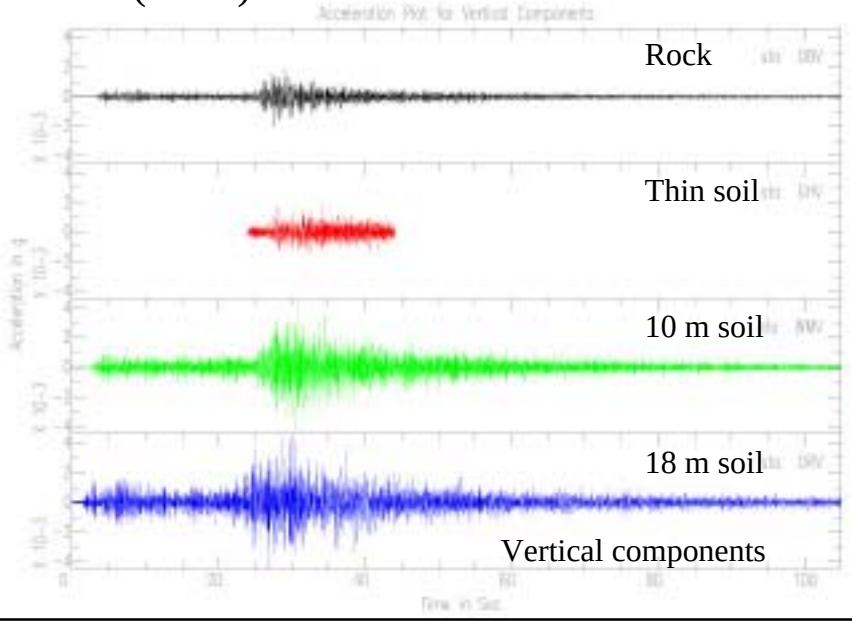
J. Adams GSC
2003 11 07

Foundation Factor

- Foundation soil amplifies wave motion as it propagates through it
- Amplification depends on
  - stiffness and depth of soil
  - ground motion intensity
- Foundation factor *F* in NBCC 1995 will be replaced by factor F_a for short periods and F_v for long periods

J Humar slide

2002 Au Sable Forks, N.Y., earthquake (M5.0) recorded at 4 Ottawa sites



GSC 11 07

Vancouver test demonstration of CUSP

ms GSC
03 11 07

Table 4.1.8.4.A.
Site Classification for Seismic Site Response
Forming Part of Sentences 4.1.8.4.(2) and (3)

Site Class	*Soil* Profile Name	Average Properties in Top 30 m as per Appendix A		
		***Soil* Shear Wave Average Velocity, V_s (m/s)**	**Standard Penetration Resistance, N_{60}**	***Soil* Undrained Shear Strength, s_u**
A	Hard *Rock*	$V_s > 1500$	Not applicable	Not applicable
B	*Rock*	$760 < V_s \leq 1500$	Not applicable	Not applicable
C	Very Dense *Soil* and Soft *Rock*	$360 < V_s < 760$	$N_{60} > 50$	$s_u > 100$kPa
D	Stiff *Soil*	$180 < V_s < 360$	$15 < N_{60} < 50$	$50 < s_u < 100$kPa
E	Soft *Soil*	$V_s < 180$	$N_{60} < 15$	$s_u < 50$kPa
E		Any profile with more than 3 m of *soil* with the following characteristics: • Plastic index PI > 20 • Moisture content w >= 40%, and • Undrained shear strength s_u < 25 kPa		
F	(1) Others	Site Specific Evaluation Required		

Notes to Table 4.1.8.4.A
(1) Other *soils* include:
a) Liquefiable *soils*, quick and highly sensitive clays, collapsible weakly cemented *soils*, and other *soils* susceptible to failure or collapse under seismic loading.
b) Peat and/or highly organic clays greater than 3 m in thickness.
c) Highly plastic clays (PI > 75) with thickness greater than 8 m.
d) Soft to medium stiff clays with thickness greater than 30 m.

J Humar slide

Credit for better sites

Table 1. Values of F_a as a Function of Site Class and T= 0.2 s Spectral Acceleration.

Site Class	Values of F_a				
	Sa(0.2)≤ 0.25	Sa(0.2) = 0.50	Sa(0.2) = 0.75	Sa(0.2) =1.00	Sa(0.2) = 1.25
A	0.7	0.7	0.8	0.8	0.8
B	0.8	0.8	0.9	1.0	1.0
C	1.0	1.0	1.0	1.0	1.0
D	1.3	1.2	1.1	1.1	1.0
E	2.1	1.4	1.1	0.9	0.9
F	Site specific investigation required				

Non-Linear effects on soft soils

Deamplification

J. Adams GSC
2003 11 07

Credit for better sites

Table 2. Values of F_v as a Function of Site Class and T= 1.0 s Spectral Acceleration.

Site Class	Values of F_v				
	Sa(1.0) < 0.1	Sa(1.0) = 0.2	Sa(1.0) = 0.3	Sa(1.0) =0.4	Sa(1.0) > 0.5
A	0.5	0.5	0.5	0.6	0.6
B	0.6	0.7	0.7	0.8	0.8
C	1.0	1.0	1.0	1.0	1.0
D	1.4	1.3	1.2	1.1	1.1
E	2.1	2.0	1.9	1.7	1.7
F	Site specific investigation required				

Non-Linear effects on soft soils

Less amplification

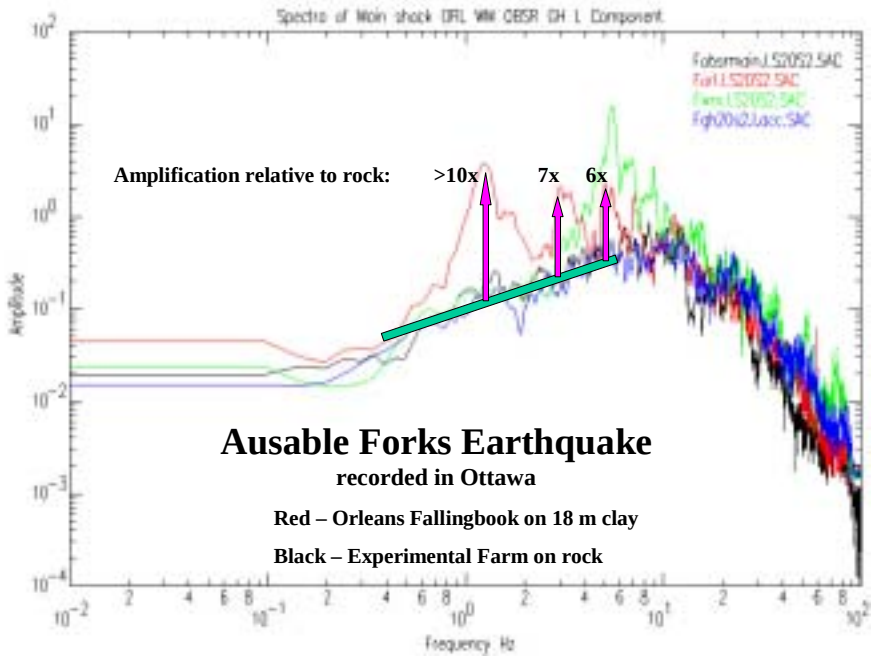
J. Adams GSC
2003 11 07

Design Spectral Acceleration

defined by 4 spectral hazard parameters
and 2 site factors

$$S(T) = F_a S_a(0.2) \quad \text{for } T \le 0.2\,\text{s}$$
$$= F_v S_a(0.5) \text{ or } F_a S_a(0.2)$$
whichever is smaller,
for $T = 0.5\,\text{s}$
$$= F_v S_a(1.0) \text{ for } T = 1.0\,\text{s}$$
$$= F_v S_a(2.0) \text{ for } T = 2.0\,\text{s}$$
$$= F_v S_a(2.0)/2 \text{ for } T \ge 4.0\,\text{s}$$

J. Adams GSC
2003 11 07



Ausable Forks Earthquake
recorded in Ottawa

Red – Orleans Fallingbook on 18 m clay

Black – Experimental Farm on rock

J. Adams GSC
2003 11 07

GSC's 4th Generation maps (Changes for NBCC 2005)

New strong ground motion relations
New seismicity model
Robust hazard, not full probabilistic
New soil-condition factors
* Spectral parameters, not peak
Median hazard plus uncertainty
Lower probability level - 2%/50 yr
Contours, not zones

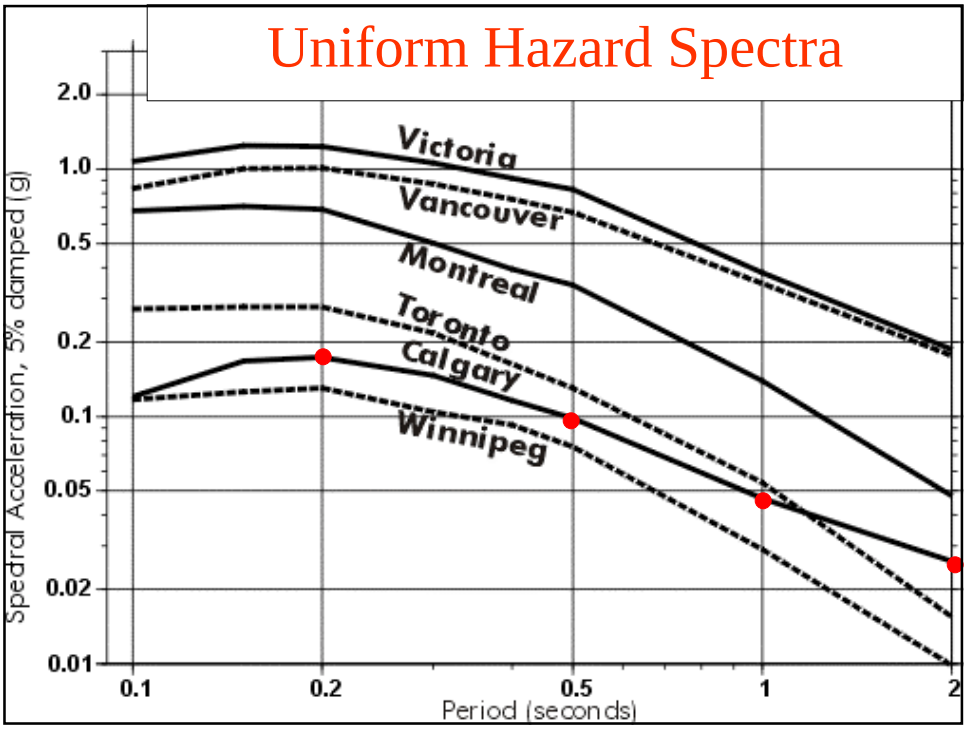
J. Adams GSC
2003 11 07

Spectral acceleration

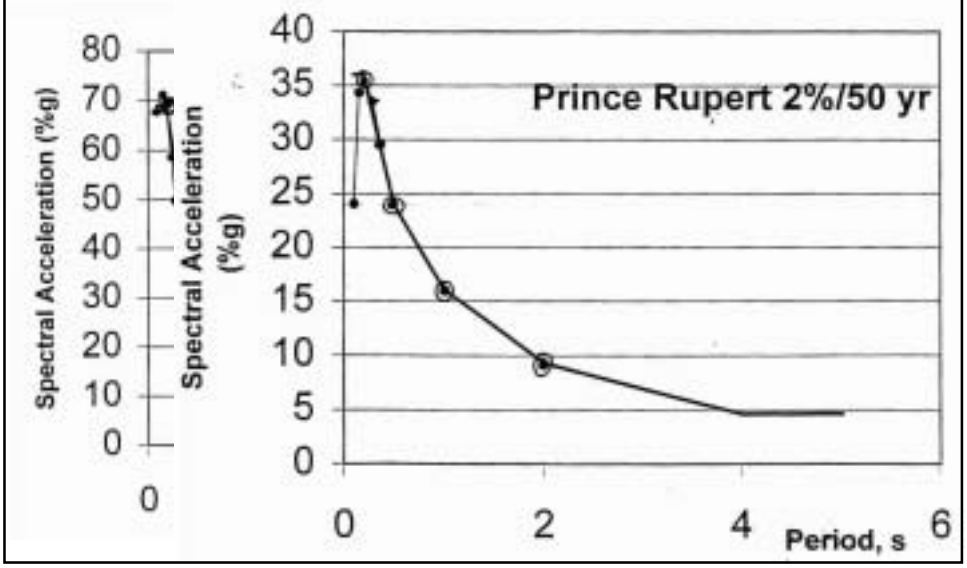
5% damped
on firm ground
units = g
periods of 0.2, 0.5, 1.0, and 2.0 s
plus (for foundation design)
Peak Ground Acceleration

J. Adams GSC
2003 11 07

Uniform Hazard Spectra



Approximation of UHS on Site Class C by four spectral parameters:-

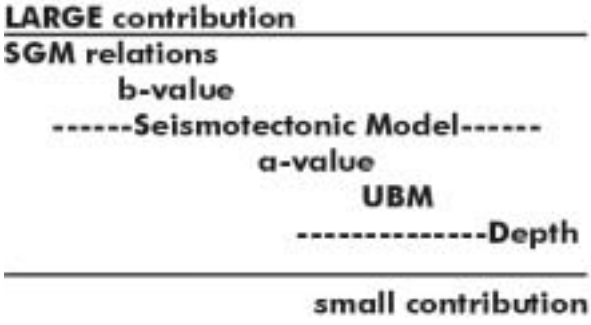


GSC's 4th Generation maps
(Changes for NBCC 2005)

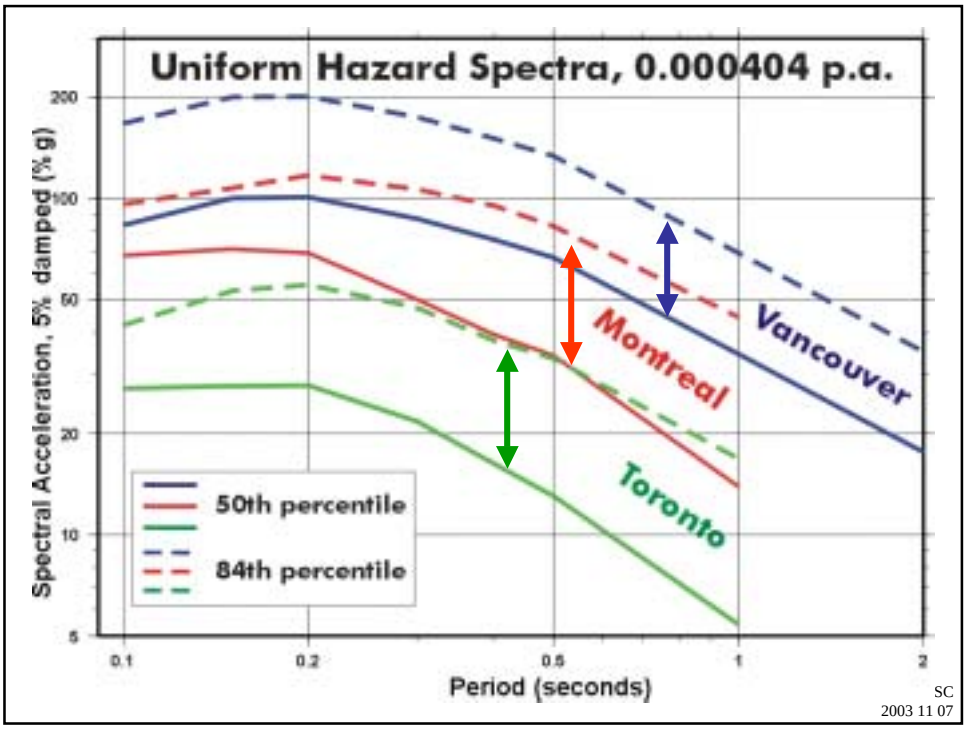
New strong ground motion relations
New seismicity model
Robust hazard, not full probabilistic
New soil-condition factors
Spectral parameters, not peak
* Median hazard plus uncertainty
Lower probability level - 2%/50 yr
Contours, not zones

J. Adams GSC
2003 11 07

First treatment of Uncertainty

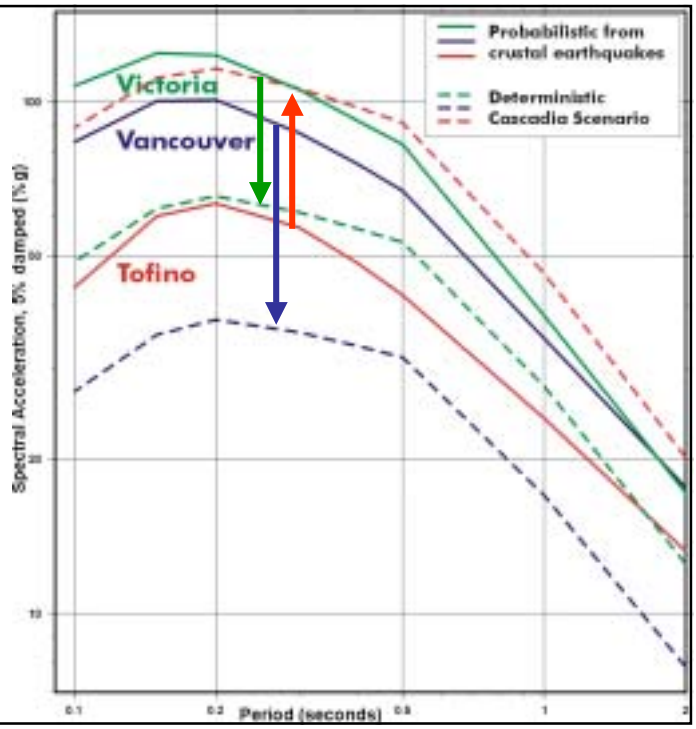


J. Adams GSC
2003 11 07



Uniform Hazard Spectra

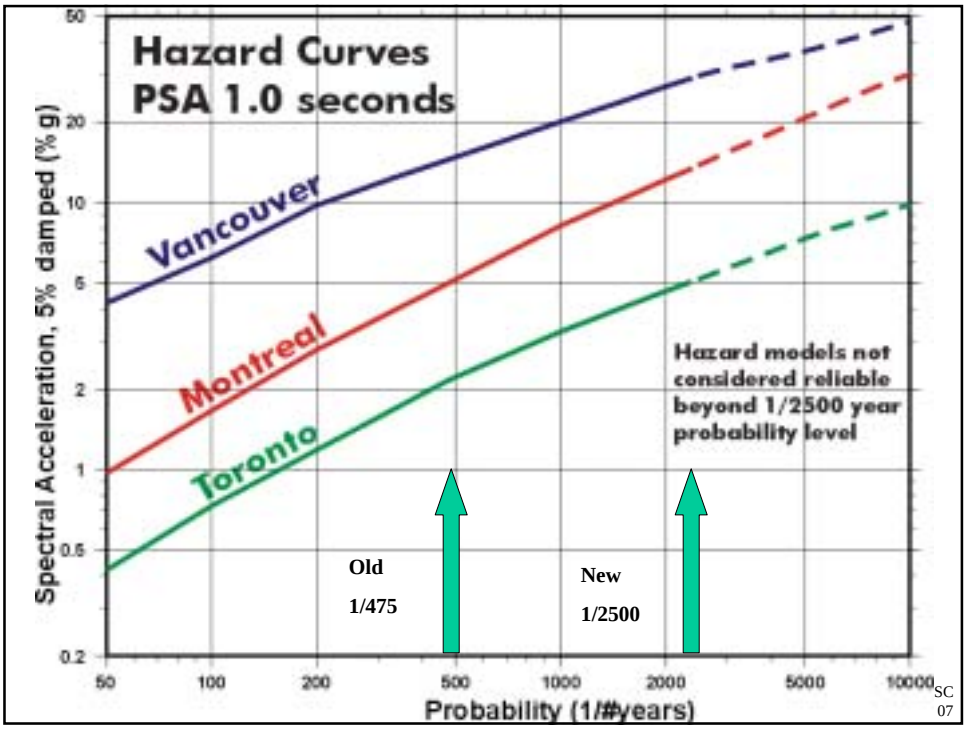
probabilistic and Cascadia

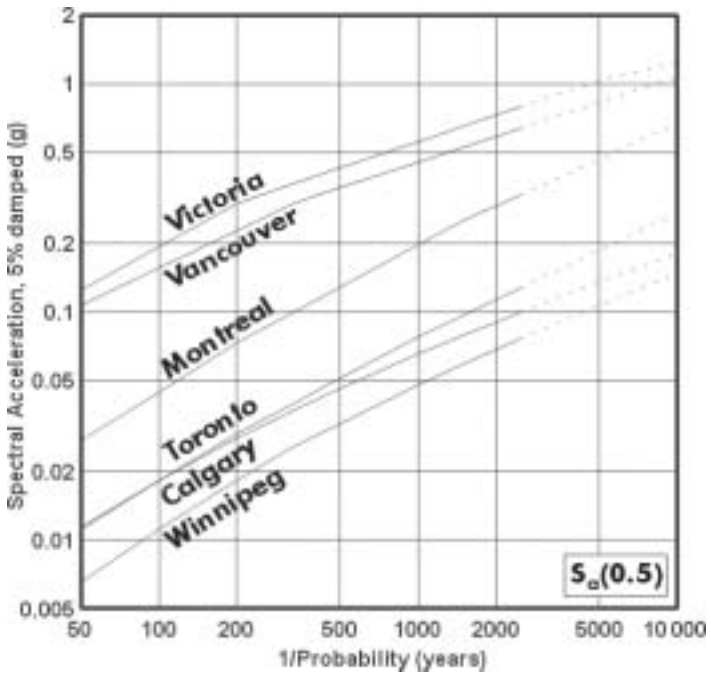


GSC's 4th Generation maps
(Changes for NBCC 2005)

New strong ground motion relations
New seismicity model
Robust hazard, not full probabilistic
New soil-condition factors
Spectral parameters, not peak
Median hazard plus uncertainty
* Lower probability level - 2%/50 yr
Contours, not zones

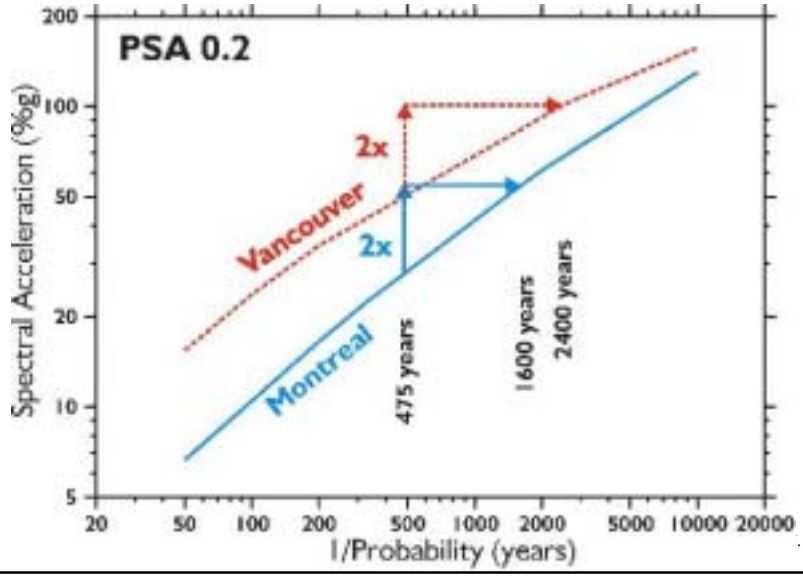
J. Adams GSC
2003 11 07





J. Adams GSC
2003 11 07

New probability level will lead to more uniform protection



. Adams GSC
2003 11 07

Results

City values: CJCE paper Table 1

Site values (climatic tables in NBCC) GSC Open File 4459

Uniform Hazard Spectra from site values

Soon: National hazard maps

Grid values for Canada

Hazard curves

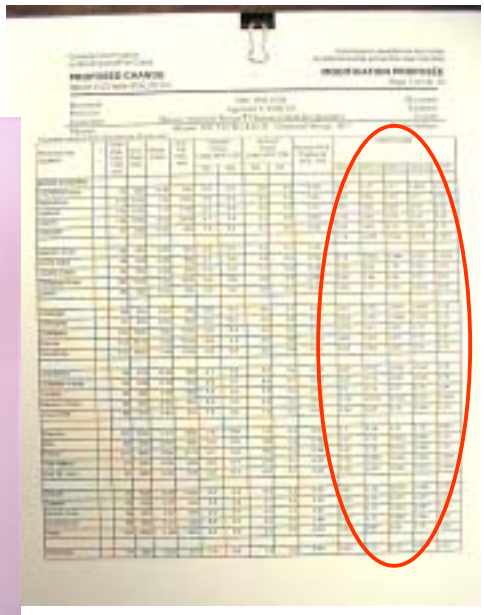
Deaggregated hazard

Measures of uncertainty

J. Adams GSC
2003 11 07

Download OF4459 from

earthquakesCanada.ca



J. Adams GSC
2003 11 07

Eastern Cities (PGA, 10%/50 yr)

	1985	2005	change	chief reasons
St. John's	0.054	0.036	down	1, 2
Halifax	0.056	0.057	slight	--
Moncton	0.085	0.072	down	2
Fredericton	0.096	0.094	slight	--
La Malbaie	0.70	0.59	down	2
Quebec	0.19	0.16	down	2
Trois Rivieres	0.12	0.18	up	3
Montreal	0.18	0.20	slight	--
Ottawa	0.20	0.20	slight	--
Niagara Falls	0.084	0.12	up	4, 5
Toronto	0.056	0.079	up	4, 5
Windsor	0.029	0.040	up	3, 5
Winnipeg	0.00	0.030	up	6

J. Adams GSC
2003 11 07

Reasons for changes

1. less impact of 1929 earthquake
2. new strong ground motion relations used
3. effect of R model
4. change in source zone boundary position
5. larger upper bound magnitudes used
6. effect of stable Canada model
7. Corrected coordinates to downtown
8. Less impact of 1946-type earthquakes

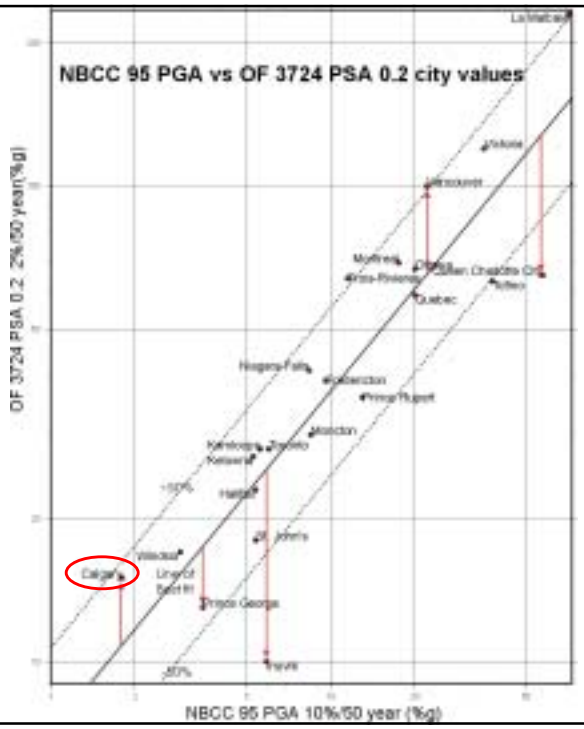
J. Adams GSC
2003 11 07

Western Cities (PGA, 10%/50 yr)

	1985	2005	change	chief reasons
Calgary	0.019	0.046	up	5
Kelowna	0.054	0.071	up	5
Kamloops	0.056	0.071	up	5
Prince George	0.034	0.033	slight	--
Vancouver	0.21	0.26	up	4
Victoria	0.28	0.34	up	7
Tofino	0.35	0.21	down	4, 8
Prince Rupert	0.13	0.092	down	2
Queen Charlotte City	0.57	0.22	down	2
Inuvik	0.06	0.032	down	2

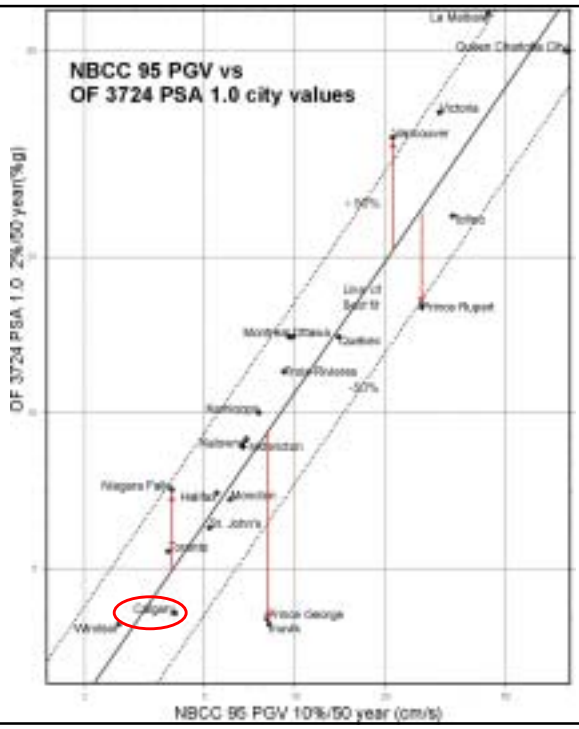
J. Adams GSC
2003 11 07

Short Period



J. Adams GSC
2003 11 07

Long Period



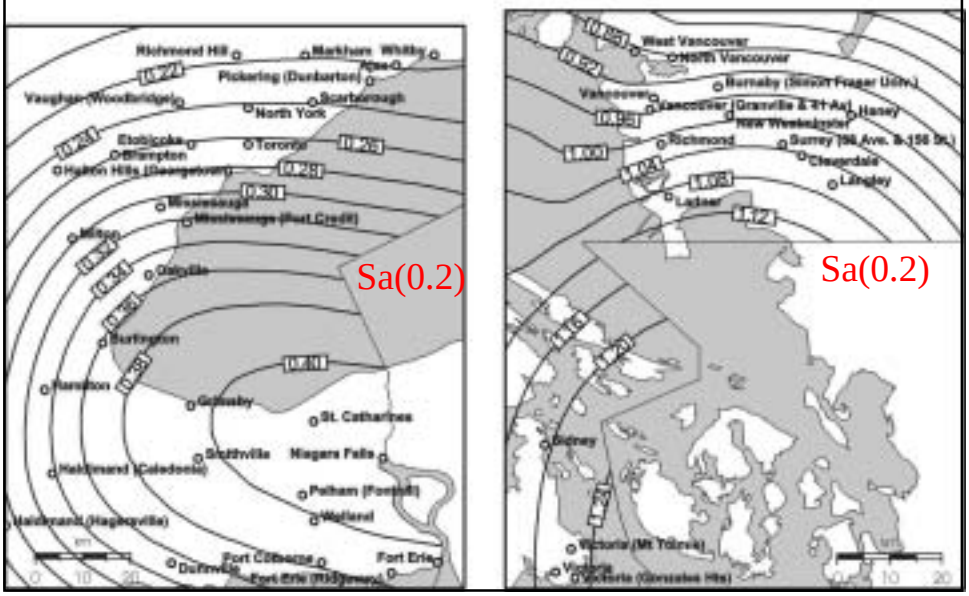
J. Adams GSC
2003 11 07

GSC's 4th Generation maps
(Changes for NBCC 2005)

New strong ground motion relations
New seismicity model
Robust hazard, not full probabilistic
New soil-condition factors
Spectral parameters, not peak
Median hazard plus uncertainty
Lower probability level - 2%/50 yr
* Contours, not zones

J. Adams GSC
2003 11 07

Gradients may become important, but no large steps as were in 1995 code



Contours, not zones

Typical Trigger values

IFaSa(0.2) = 0.2 g

IFaSa(0.2) = 0.35 g

IFaSa(0.2) = 0.75 g

IFvSa(1.0) = 0.25 g

for I=1, Site="C"=1 →contours

J. Adams GSC
2003 11 07

Contours, not zones

Trigger values (Importance, Foundation, Ground motion)

I Fa Sa(0.2) = 0.2 g

IFaSa(0.2) = 0.35 g

IFaSa(0.2) = 0.75 g

IFvSa(1.0) = 0.3 g

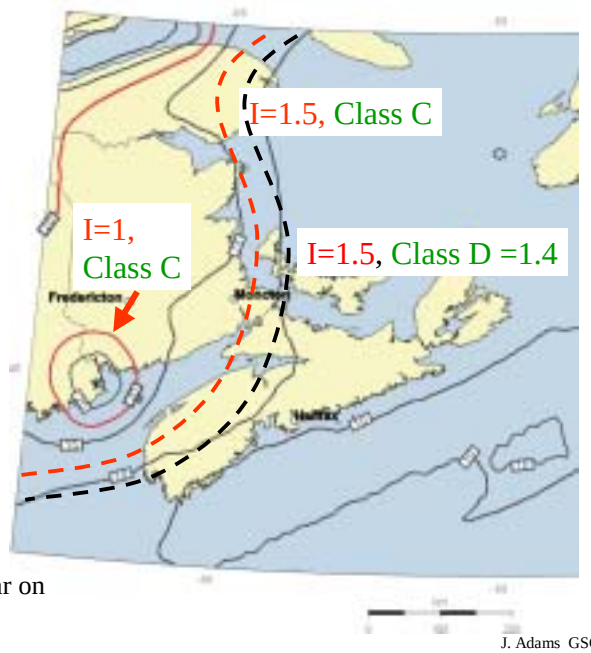
for I=1, Site="C"=1 → contours

J. Adams GSC
2003 11 07

Region affected by trigger levels depends on Importance

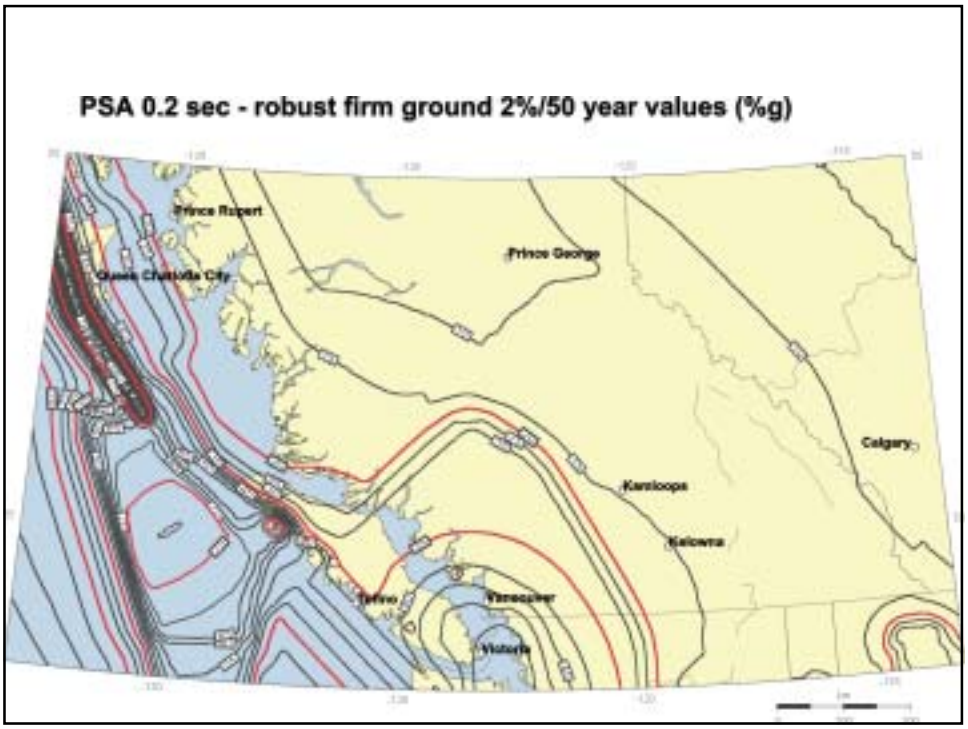
and

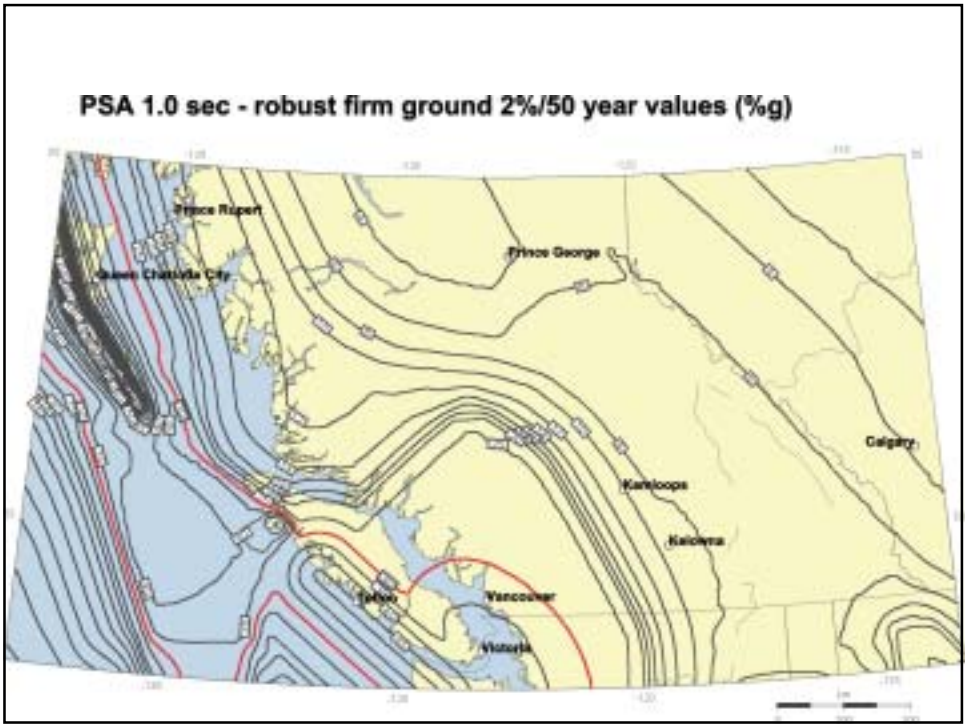
Soil Class



Sa(0.2) 2%/50 year on firm ground

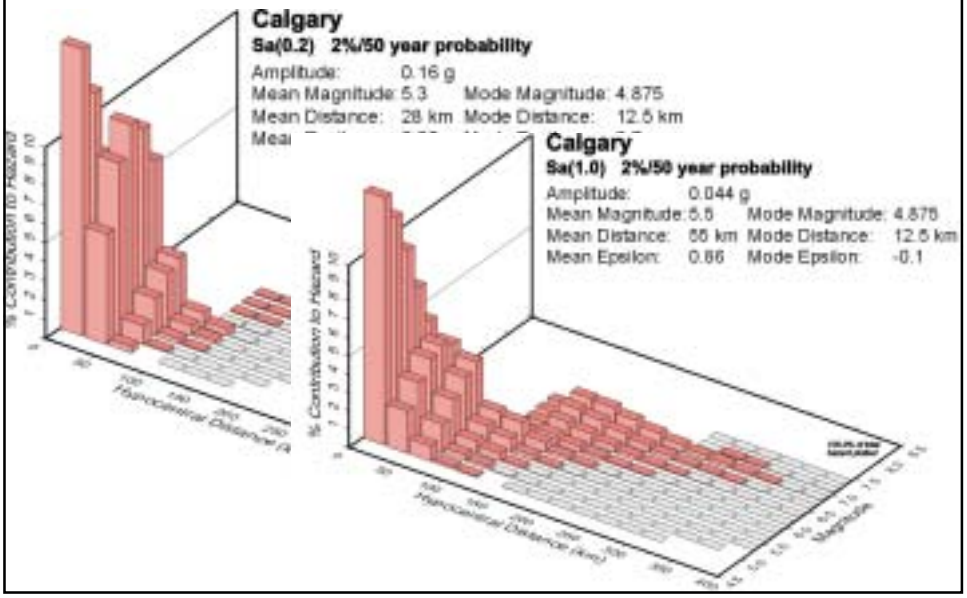
J. Adams GSC
2003 11 07


PSA 0.2 sec - robust firm ground 2%/50 year values (%g)
Prince Rupert
Prince George
Calgary
Kamloops
Kelowna
Vancouver
Victoria


PSA 1.0 sec - robust firm ground 2%/50 year values (%g)
Prince Rupert
Prince George
Calgary
Kamloops
Kelowna
Vancouver
Victoria

Deaggregation of hazard

contributions by magnitude and distance



Choosing Time histories

1. Deaggregation → identify the earthquake magnitude and distance pairs that contribute most to the hazard
2. Match UHS to synthetic or scaled-real spectra; typically close moderate earthquake and distant larger earthquake

→ choose time histories for dynamic design

J. Adams GSC
2003 11 07

NBCC Current Status

- New seismic hazard model finalized
- Results for 650 Canadian towns on Web
- Public comment on proposed Building Code discussed in September 2003
- Code to be adopted by Provinces and in effect by Spring 2005

J. Adams GSC
2003 11 07

www.EarthquakesCanada.ca

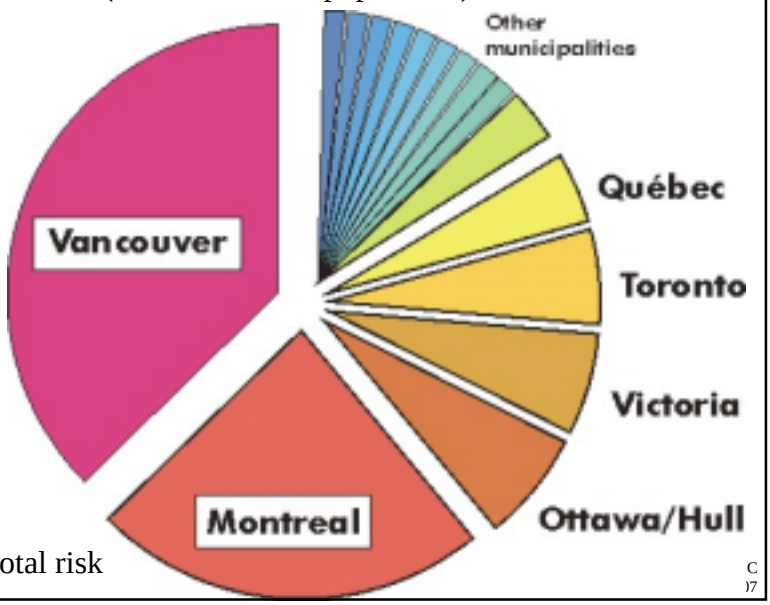
www.tremblementsdeterre.ca

info@seismo.nrcan.gc.ca

J. Adams GSC
2003 11 07

Final thought: Urban Seismic Risk

(2/3 of Canada's population)



6 cities = ¾ total risk