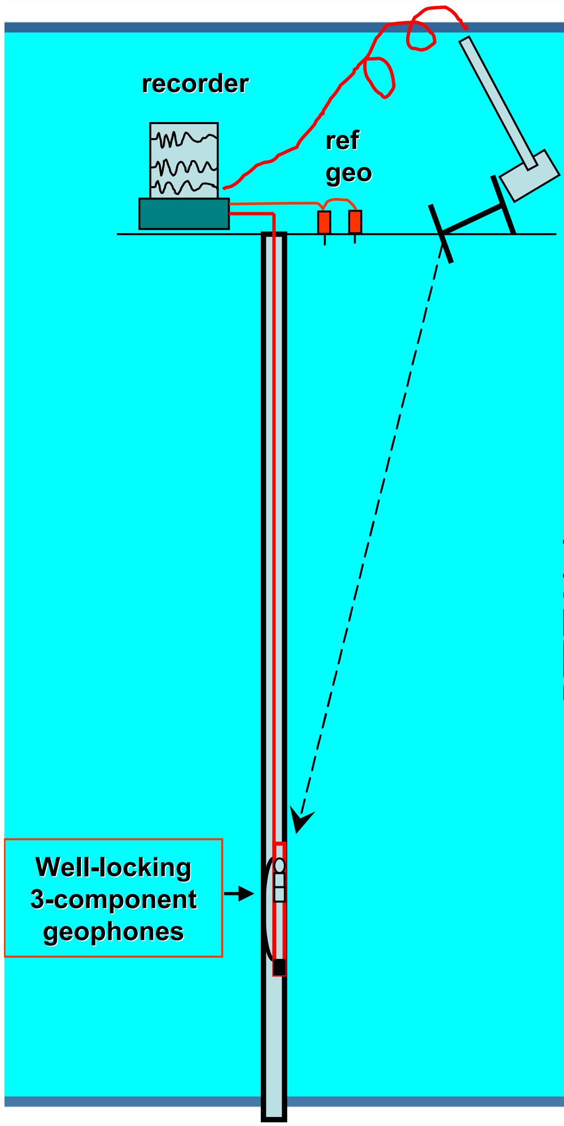
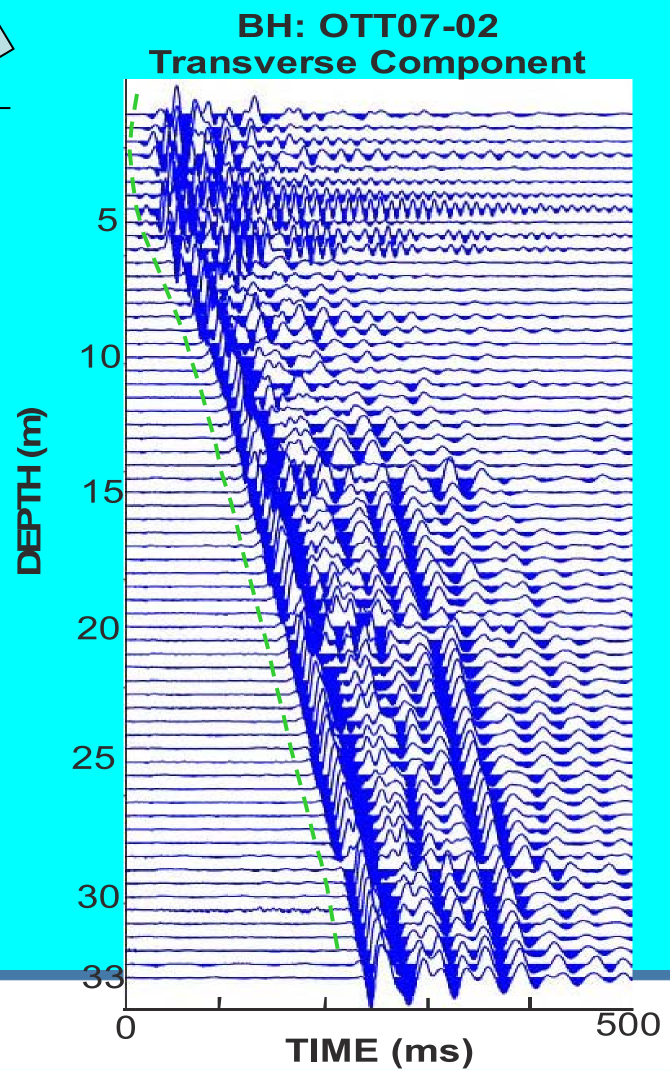
URBAN SEISMIC HAZARD MAPPING USING GEOPHYSICAL TECHNIQUES

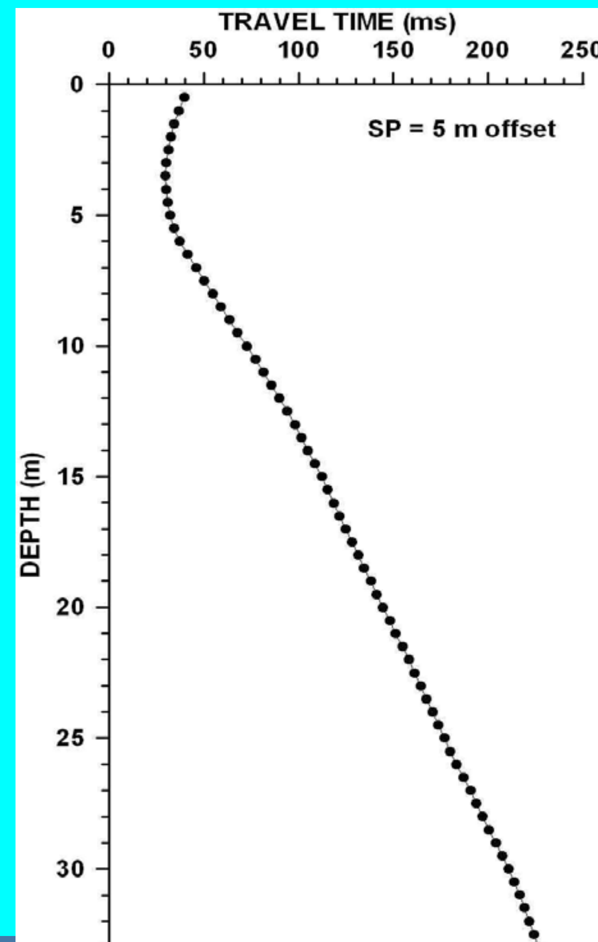
Jim Hunter

Geological Survey of Canada

VSP: DOWNHOLE SHEAR WAVE MEASUREMENTS (in cased boreholes)

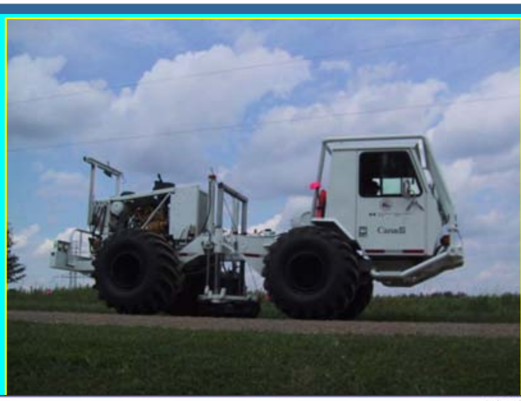




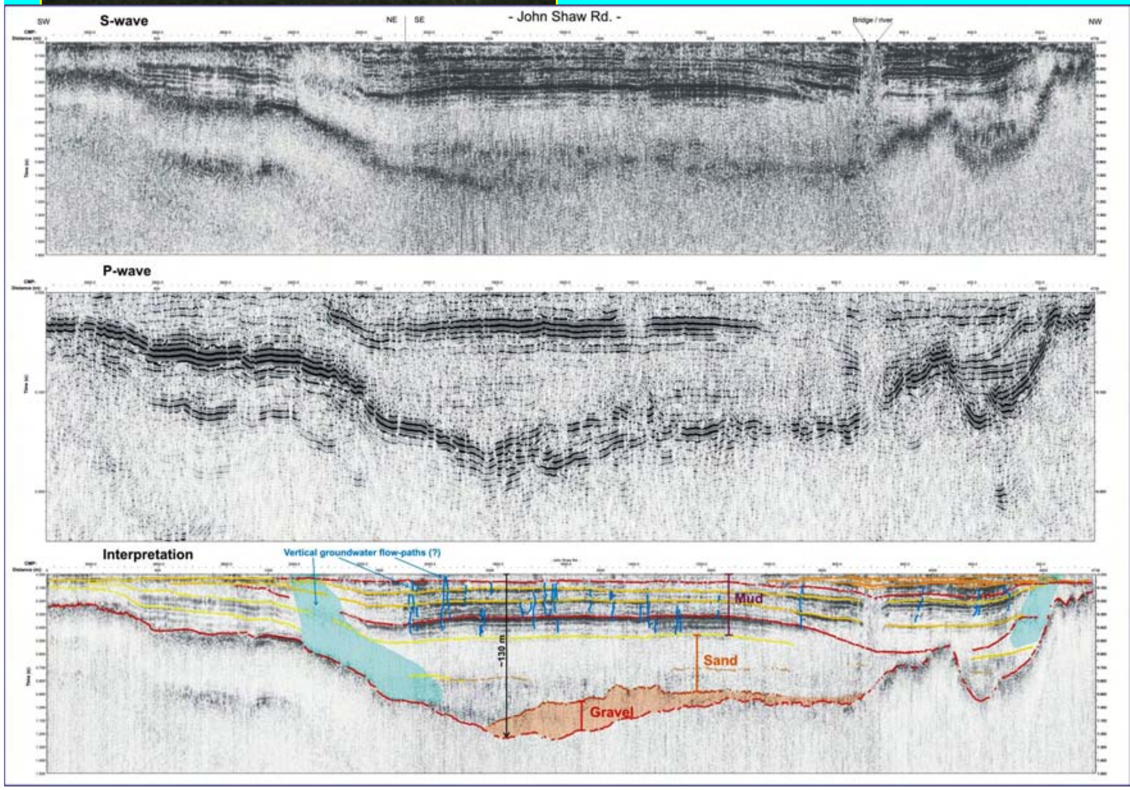


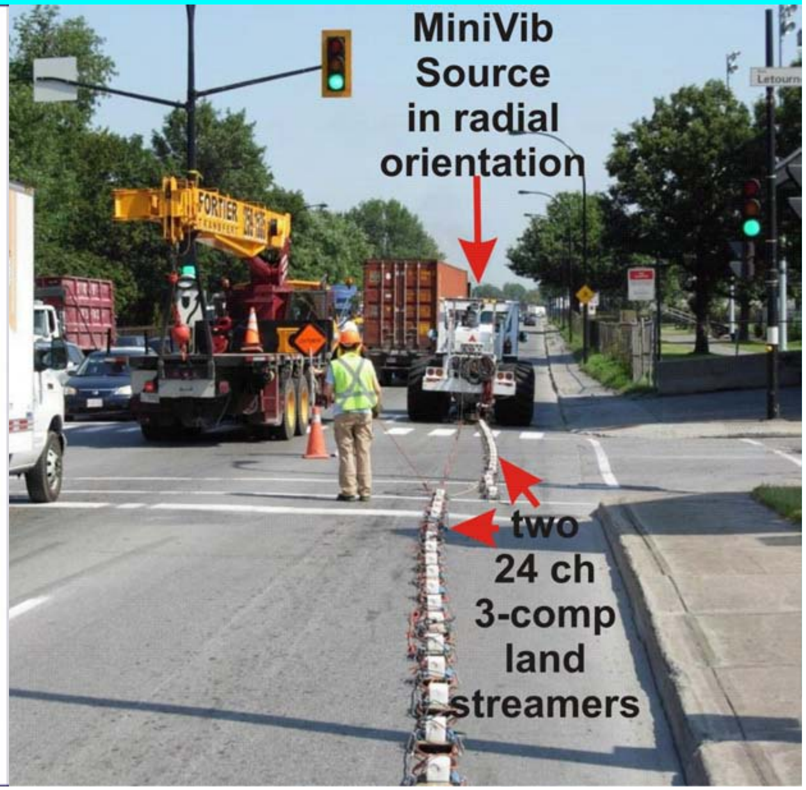
Surface Reflection/Refraction Site Analyses and MASW

Landstreamer Array with Vibratory Source



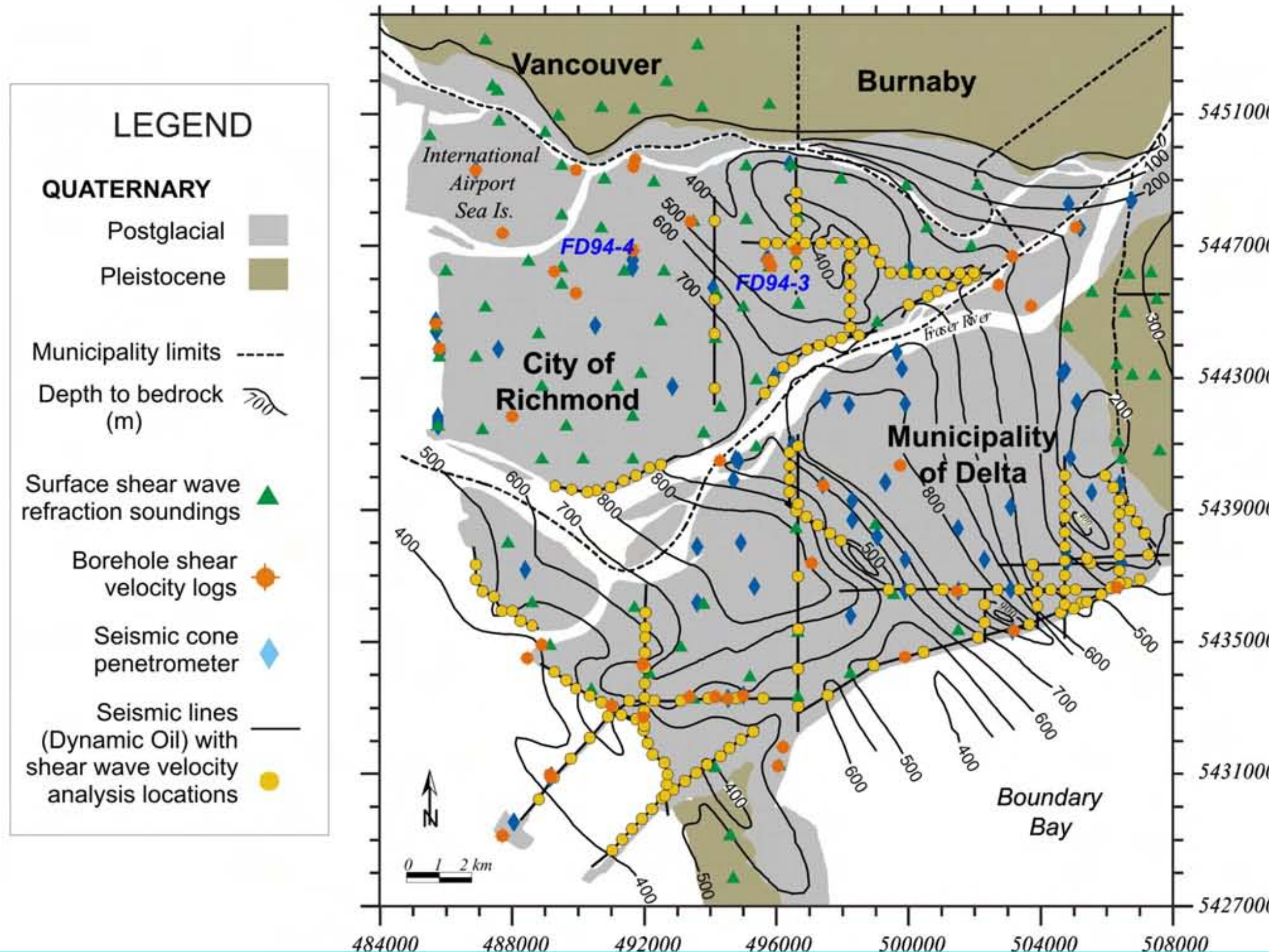
Shear wave reflection profiling.
Notre-Dame Est, Montreal

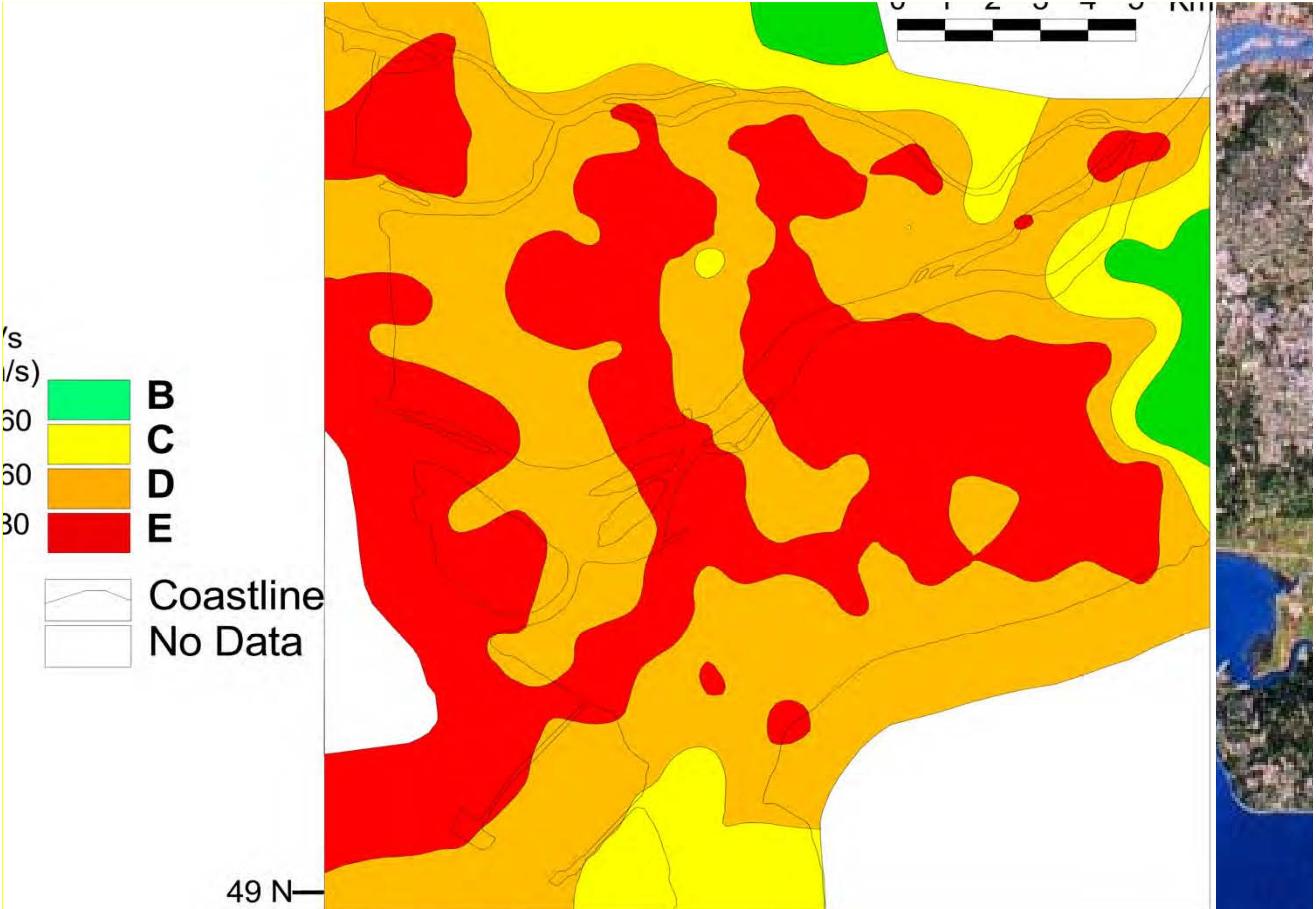




Downtown Vancouver
firm soil and rock
Approximate edge of delta
Vancouver International Airport (dyked)
Industrial area
electric power substations
Industrial area
Surrey Uplands (firm soil)
City of Richmond (dyked)
Massey Tunnel Highway 99
Municipality of Delta (dyked)
Electric cable corridor to Vancouver Island
Coalport Terminal
Ferry Terminal
Tsawwassen Uplands (firm soil)

Fraser River Delta, British Columbia
Shear Wave Velocity Site Locations





NEHRP SITE CLASSIFICATIONS

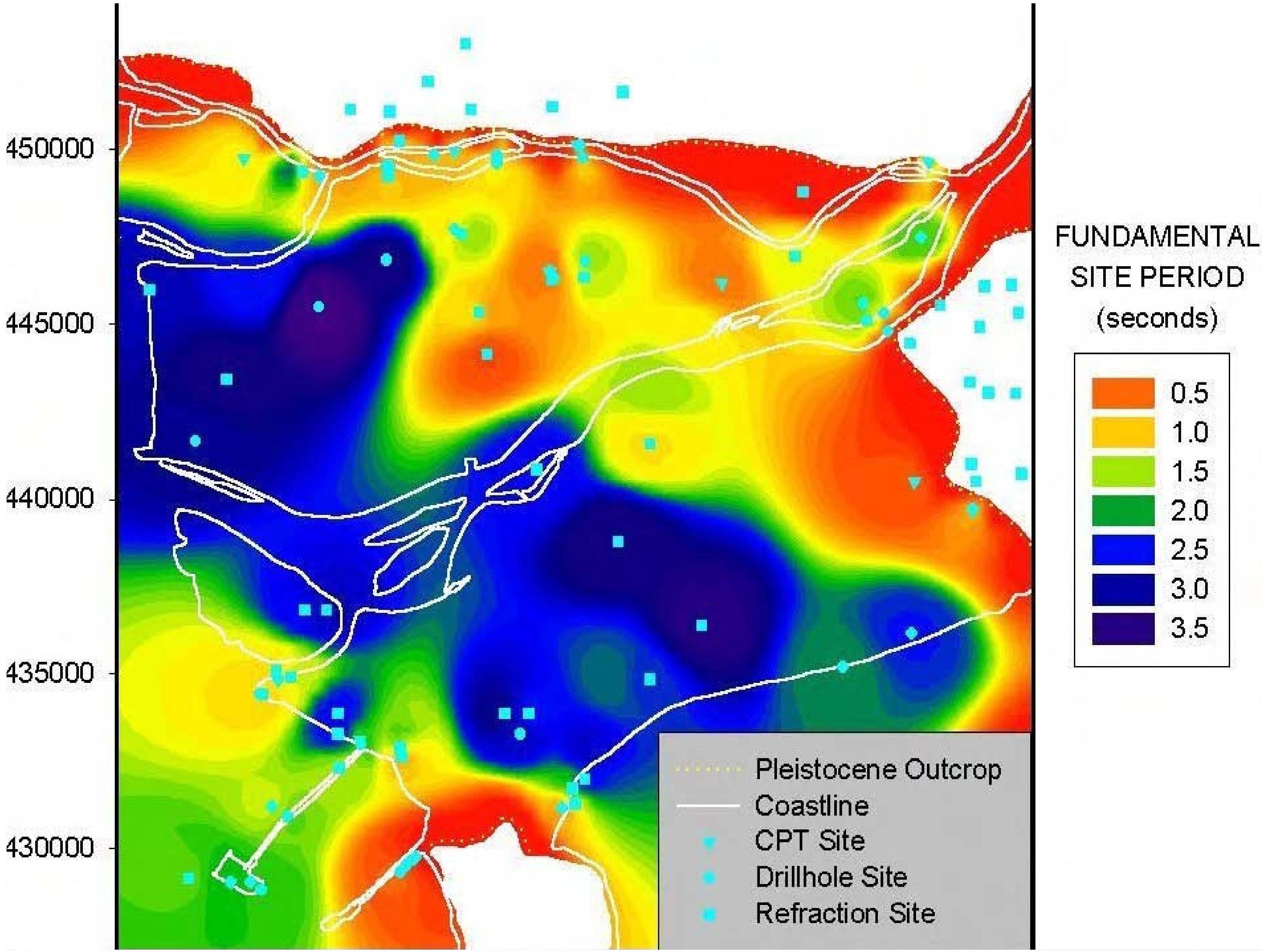
Ground Resonance

Equally important as Vs30 mapping –
should be used together for site interpretation

Rule of Thumb

13 stories=0.1 s x 13 stories = 1.3s structure period

If fundamental site period of the ground also ~1.3s, then increased resonance of structure could occur


450000
445000
440000
435000
430000
FUNDAMENTAL
SITE PERIOD
(seconds)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Pleistocene Outcrop
Coastline
CPT Site
Drillhole Site
Refraction Site

Zonation of Ottawa, Ontario

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Carleton University (CSRN)

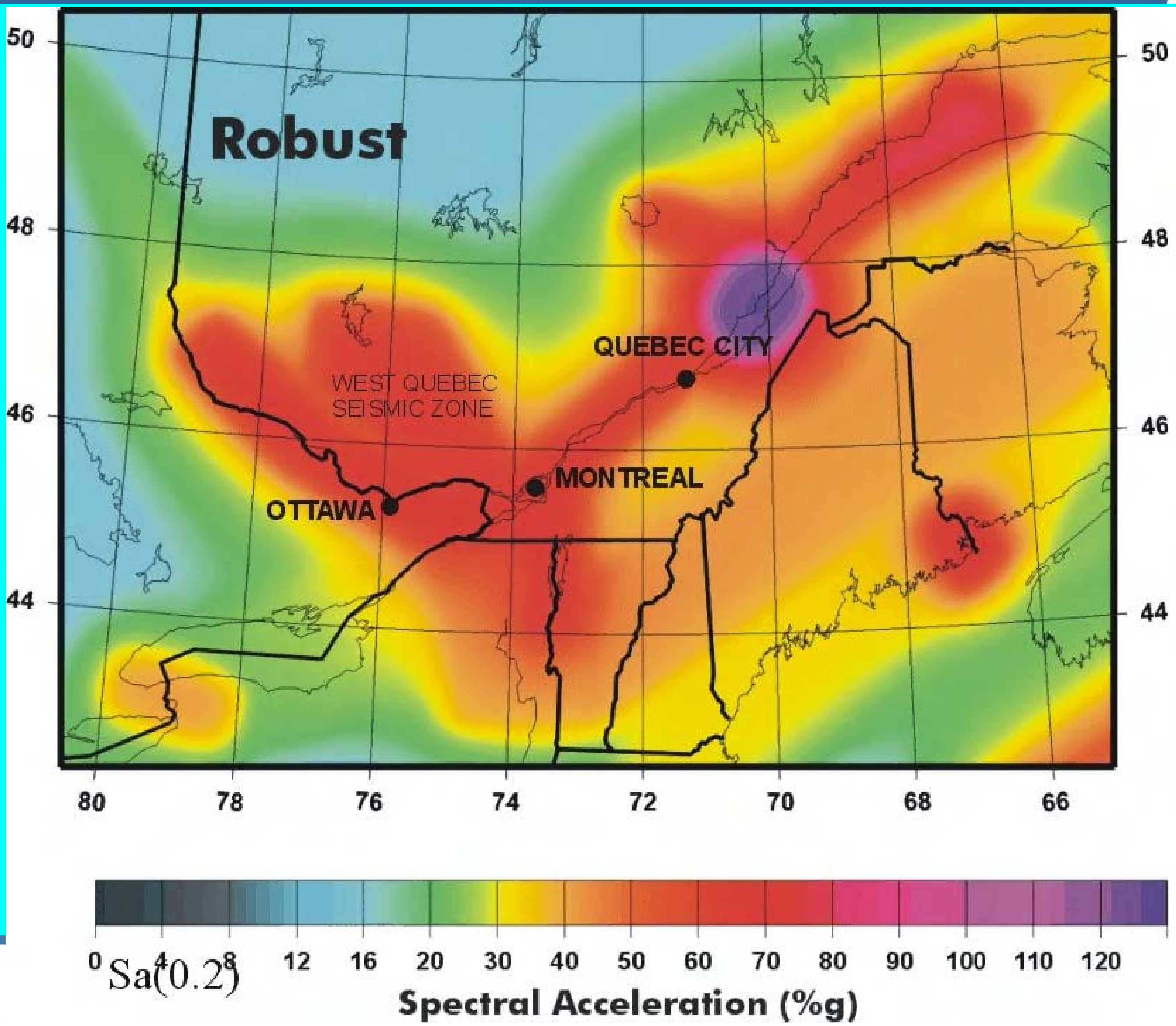
Dr. Jim Hunter, GSC
Dr. Andre Pugin, GSC
Dr. Susan Pullan, GSC

EXTENT OF CHAMPLAIN SEA SEDIMENTS

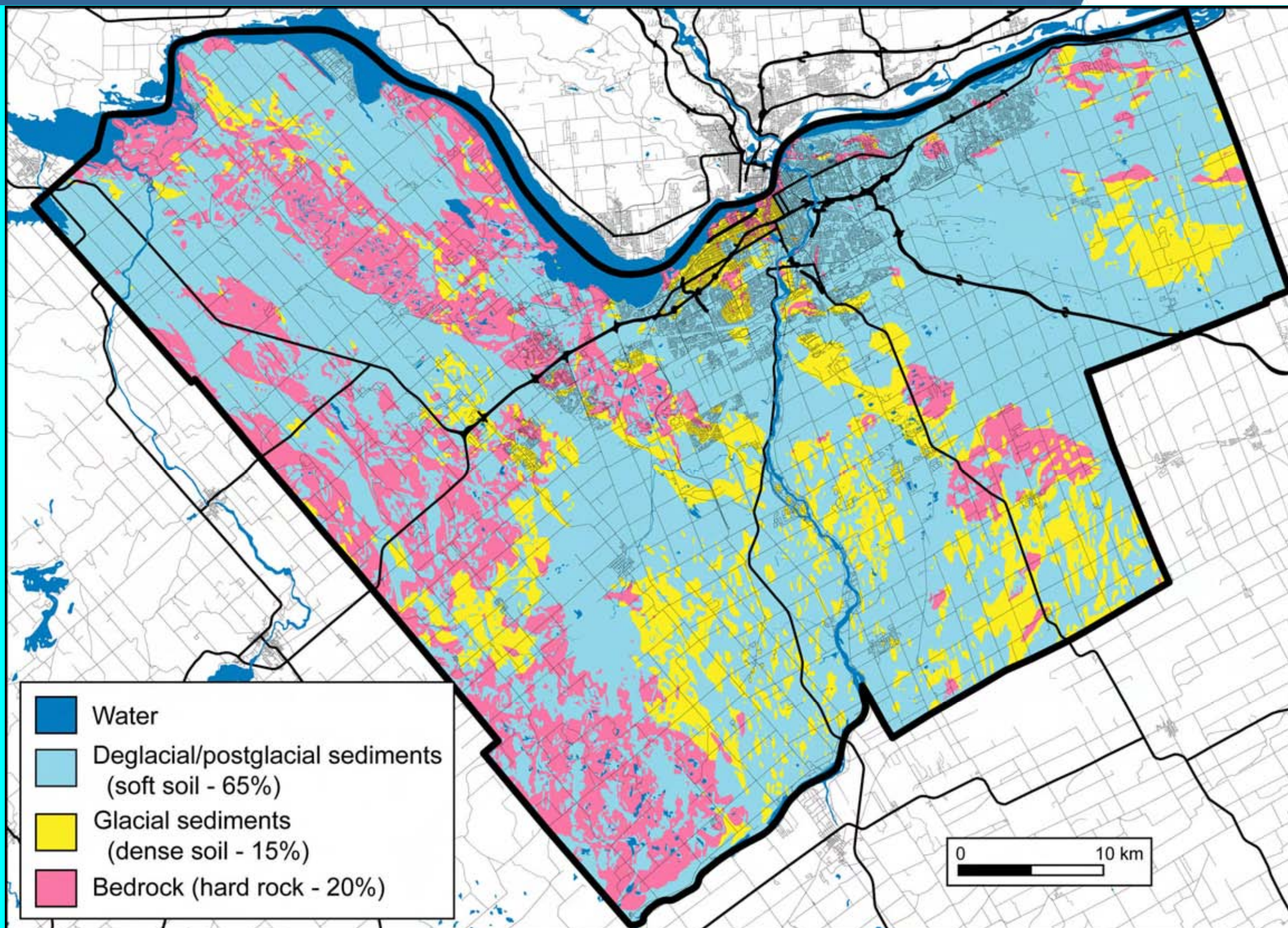
-soft sediments up to 130 m thick

-low Vs overlying high Vs glacial sediments and rock

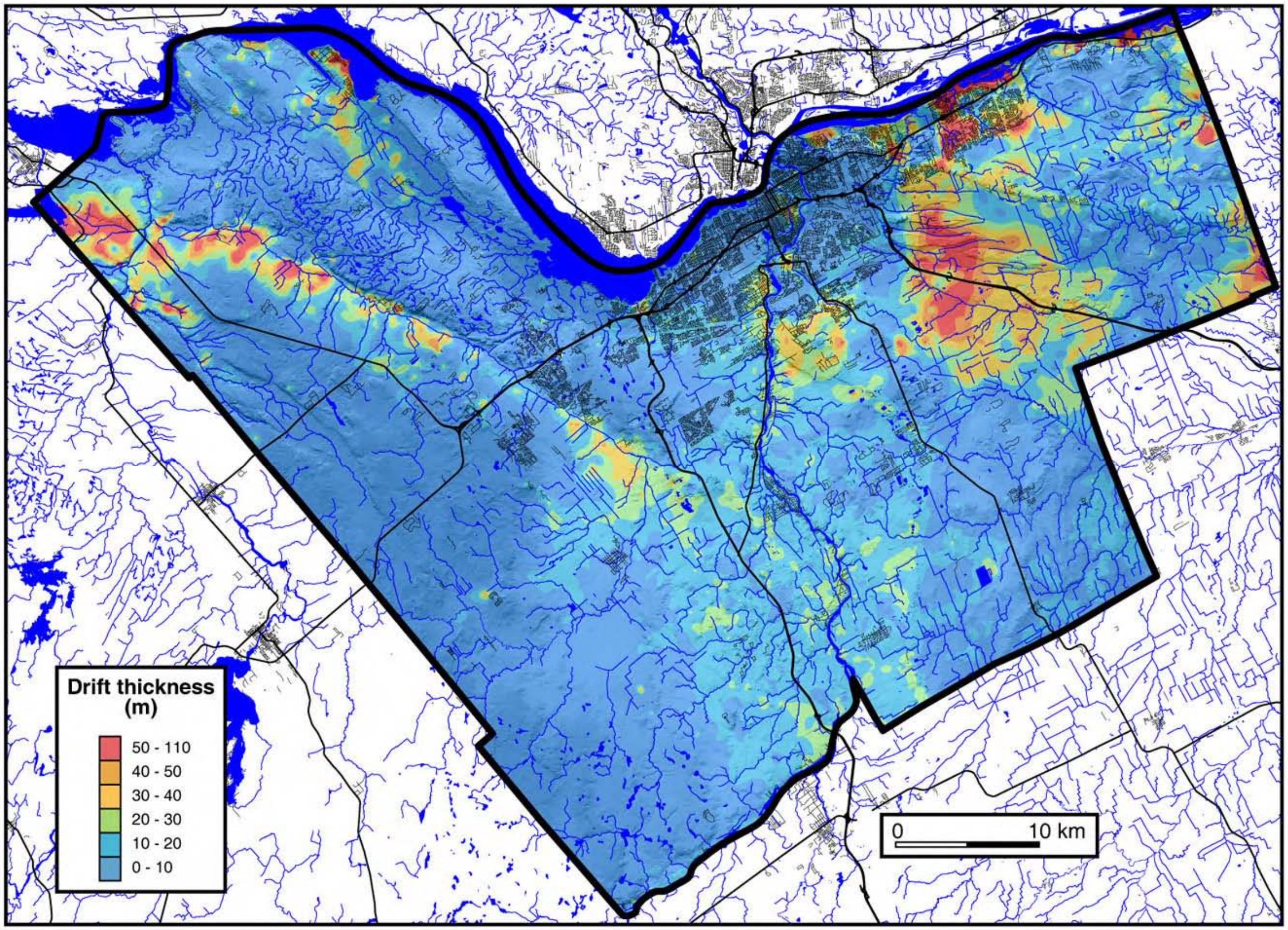
NBCC High Seismic Hazard Areas of Eastern Canada (Sa = 0.2 seconds)



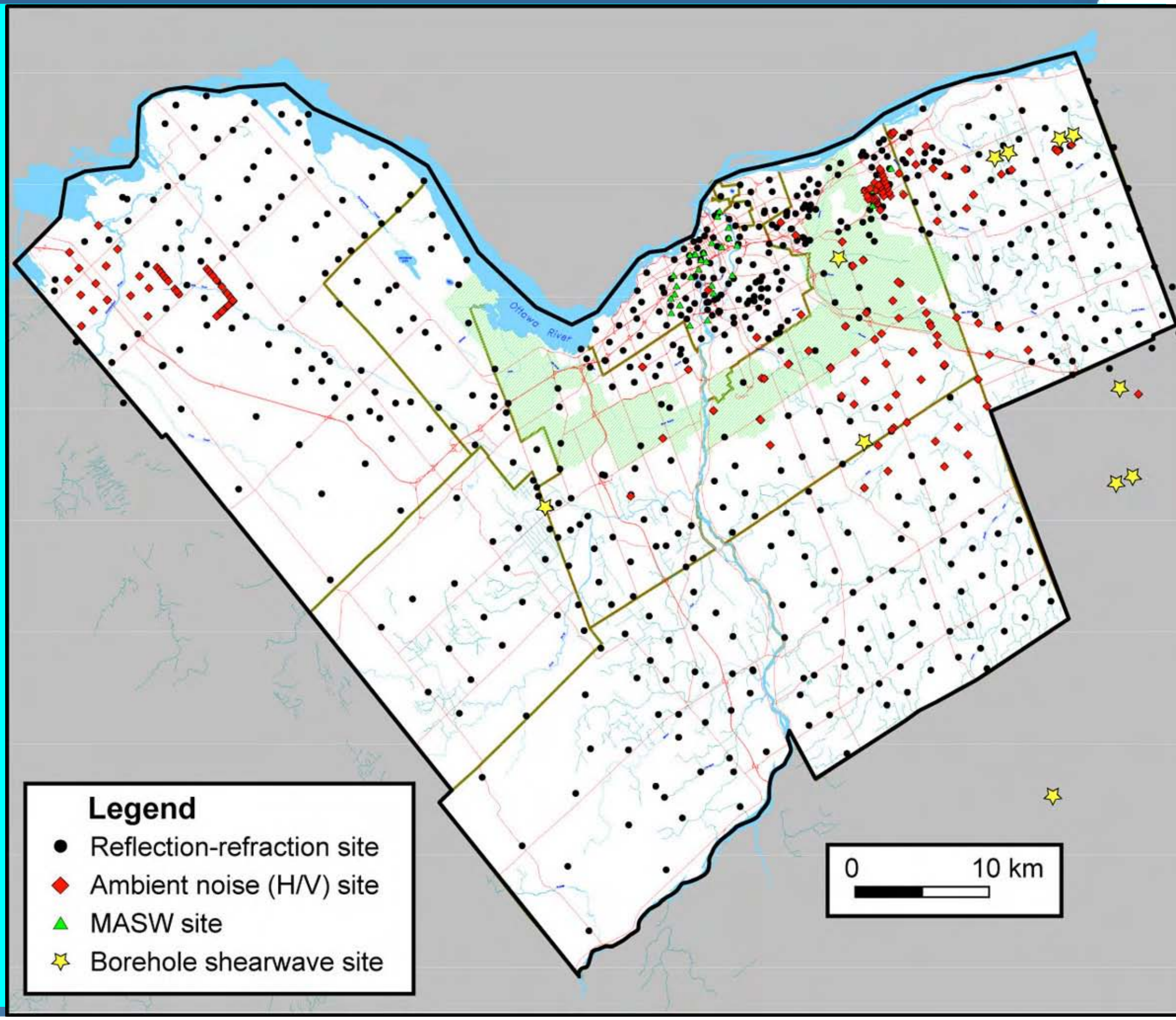
Simplified Surficial Geology



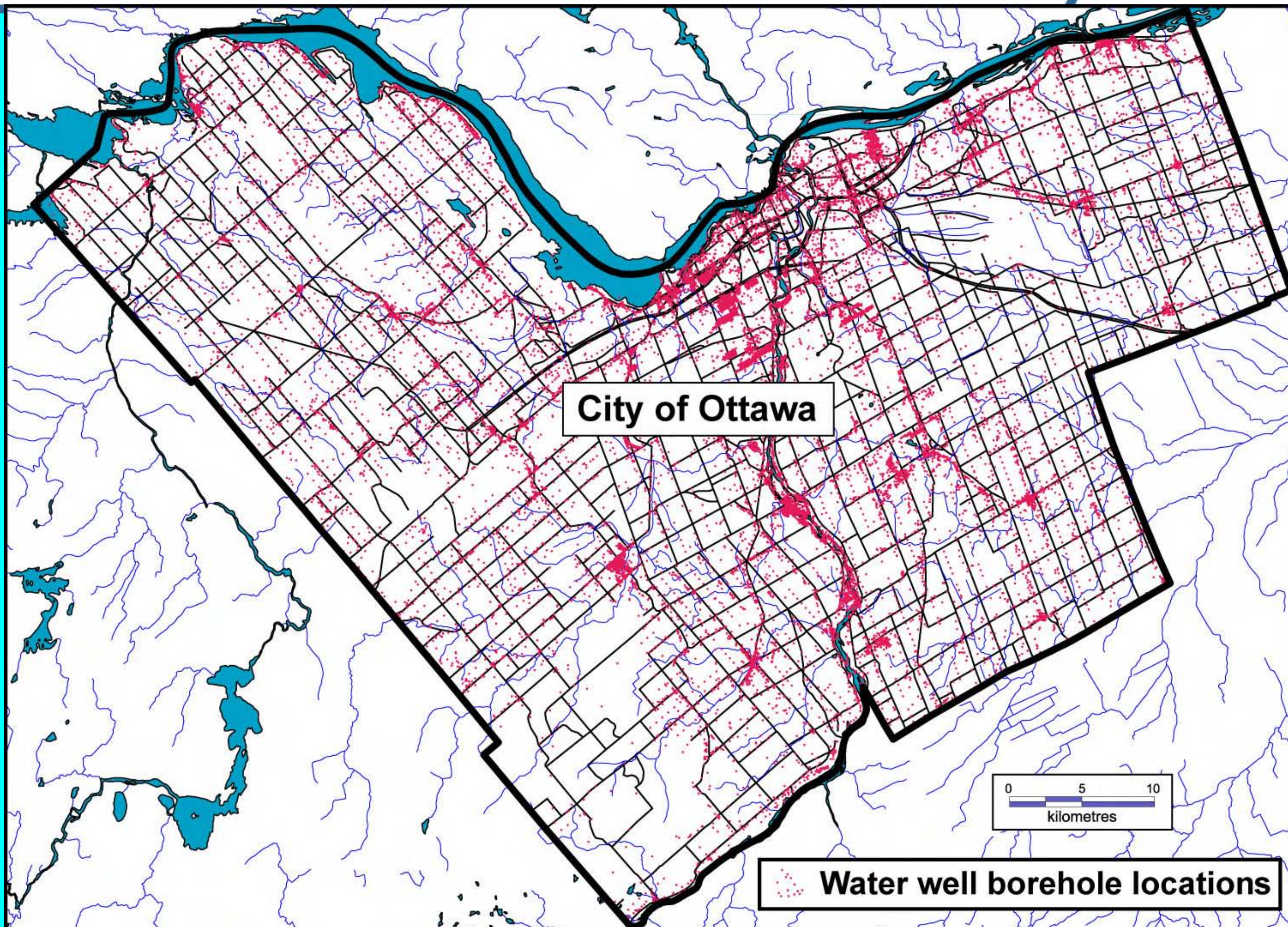
City of Ottawa
Overburden Thickness Map



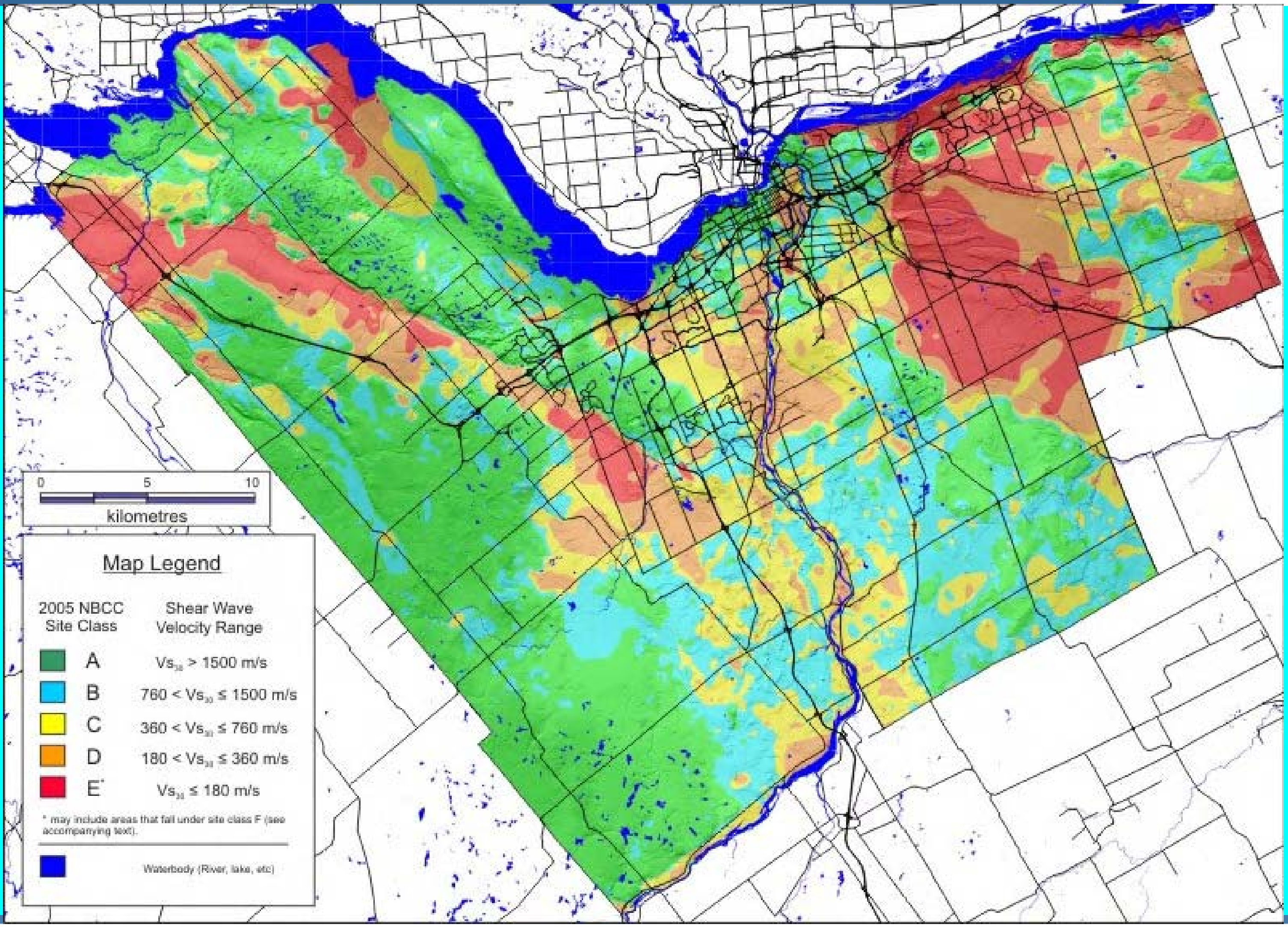
Data sources – 685 surface geophysics sites
10 geohysical boreholes
25 line-km of Landstreamer



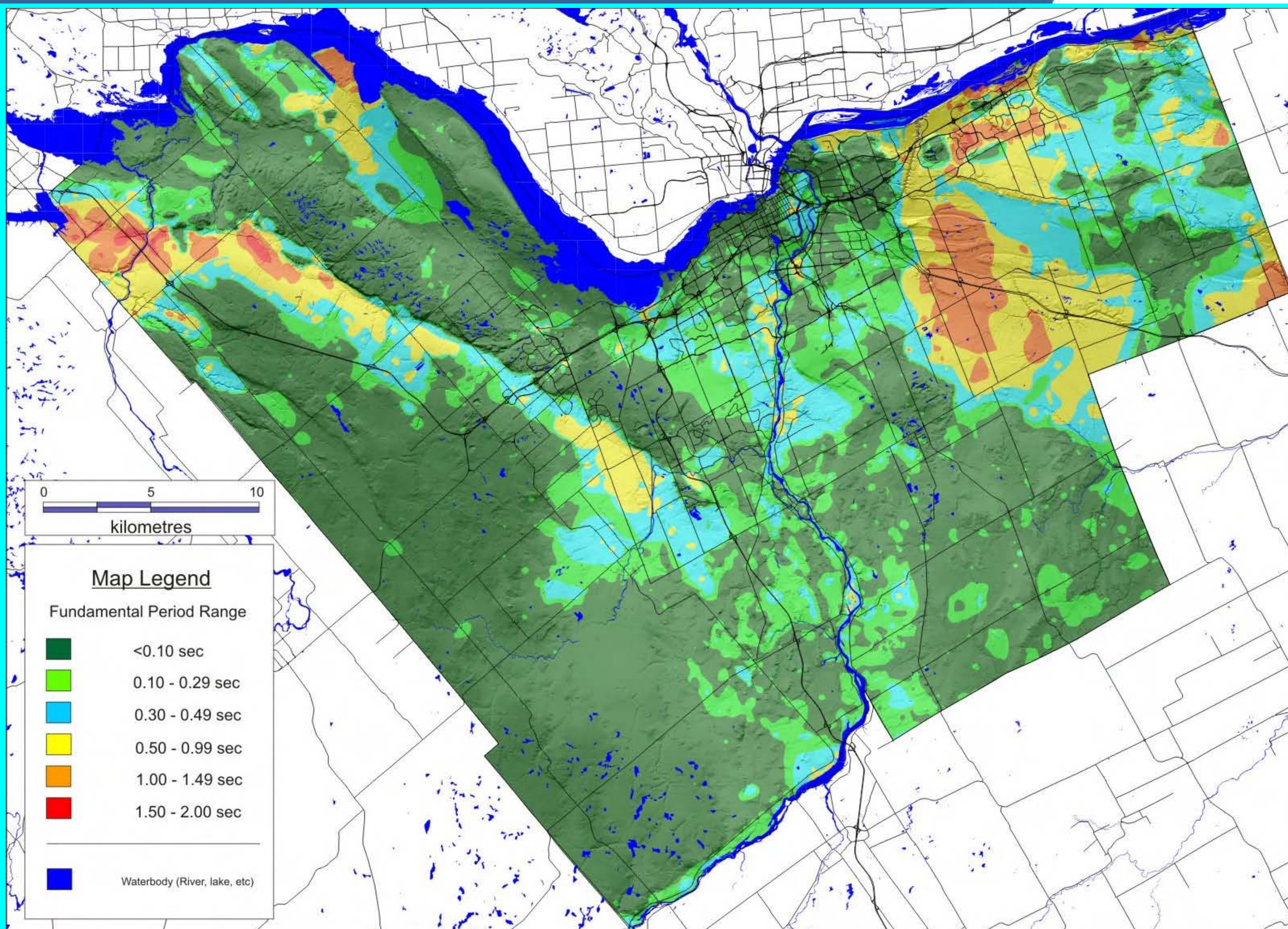
Data sources – 21,000 water wells and engineering boreholes



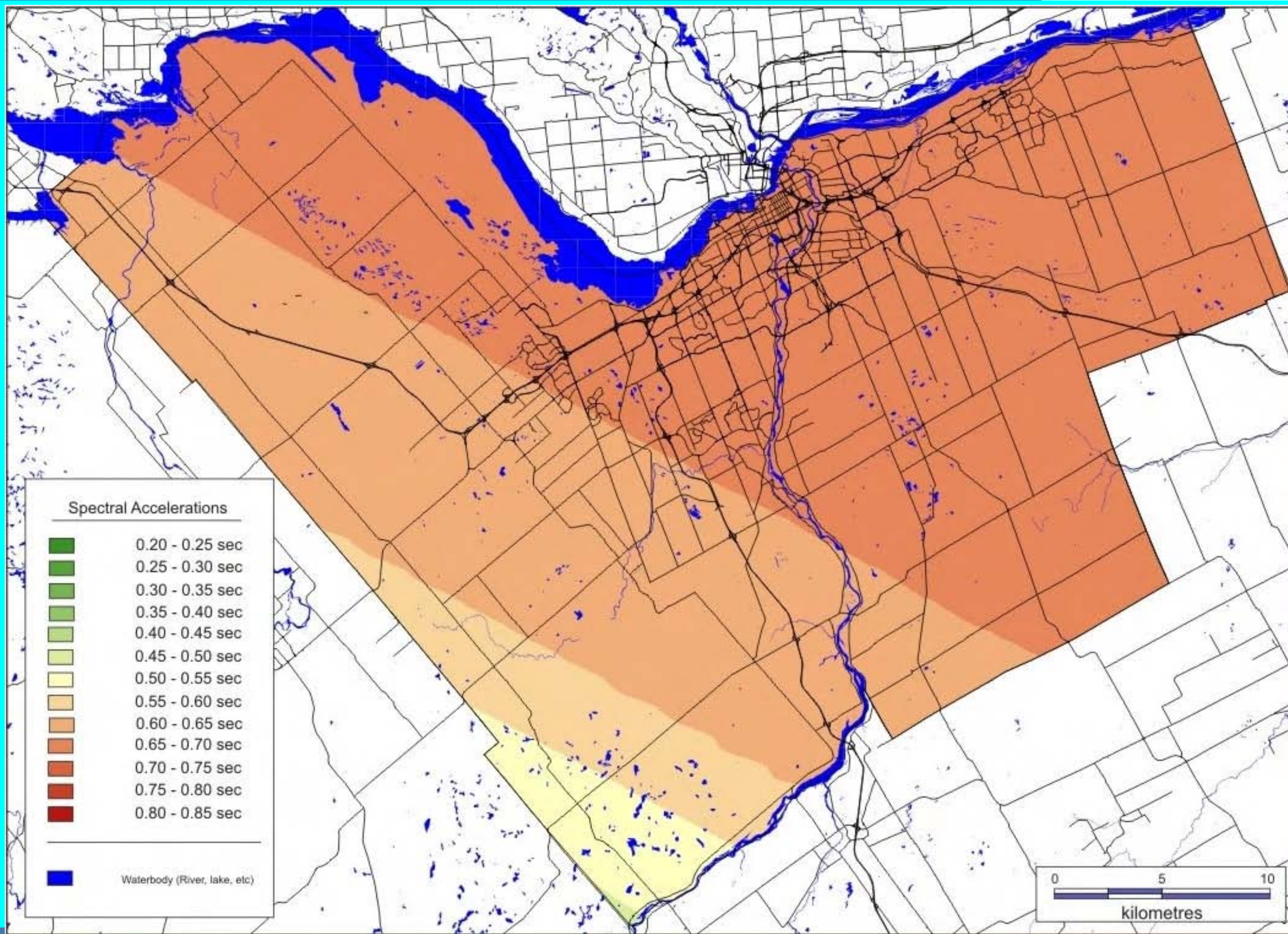
Ottawa NEHRP Zonation Map based on Vs_{30} measurements



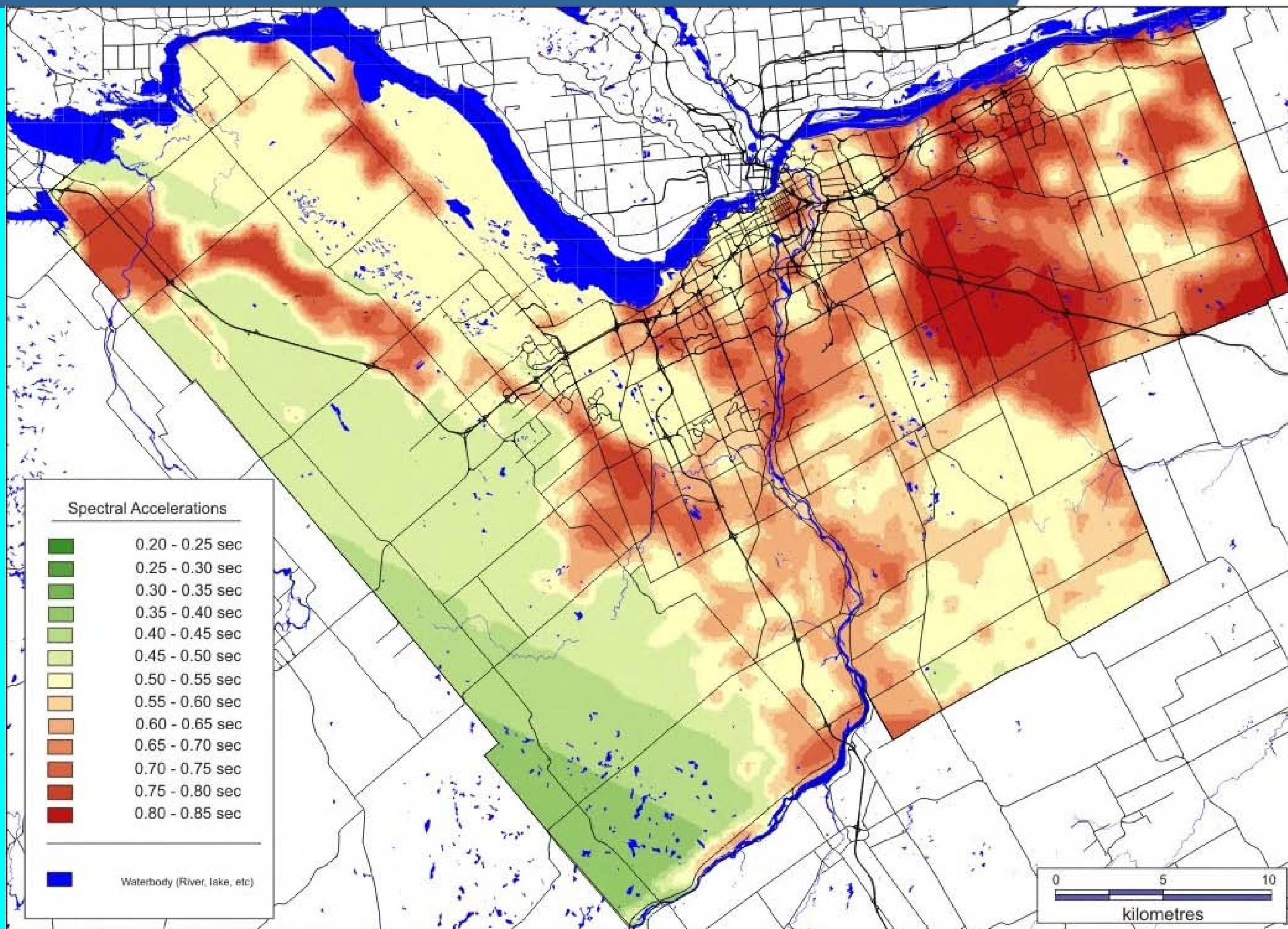
Ottawa Fundamental Site Periods based on soil thicknesses and Vs velocities



Variation of Sa(0.2) values for NEHRP C across the City of Ottawa for the “design” earthquake



Variation of Sa(0.2) values for the "design" earthquake after accounting for differing NEHRP zones across the City of Ottawa



Applications of the maps

Office of Emergency Management:

- maps help to predict areas of City where the greatest shaking may occur
- maps will be used during upcoming review of the City's comprehensive vulnerability analysis
- maps will be used in prioritizing City's response for the affected neighbourhoods during a significant earthquake event
- City will be seeking NRCan's advice about:
  - Conducting a hazard assessment using the maps
  - Public education of earthquake hazards

Applications of the maps

Planning and Infrastructure Department:

- **Building Code Services**:
  - maps are used on a daily basis as part of screening process for assessment of potential developments
  - information for out-of-town developers on the variability of soil conditions in the Ottawa area
  - Map information may lead to the stipulation of increased level of geotechnical analysis for building permit approval

Future applications

- **Quantitiative risk analysis**
  - Microzonation maps add a critical **framework** layer that represents the variability of the seismic hazard
- **Emergency management exercises**
  - Ottawa seismic site categories map being incorporated into **SHAKEMAP** by **CHIS** for improved earthquake modeling
- **Planning city growth**
  - High-level tool for siting critical infrastructure (can avoid terrains prone to greater shaking)

The End!

Thank you for your attention!

Jim Hunter

Hazard Mapping is the Framework for Risk Assessment

Urban Seismic Hazard Mapping

Shear Wave Velocities of Soils and Rock
are Key Measurements
In the Hazard Framework
(shear wave velocities to be defined shortly)

Urban Seismic Hazard Mapping

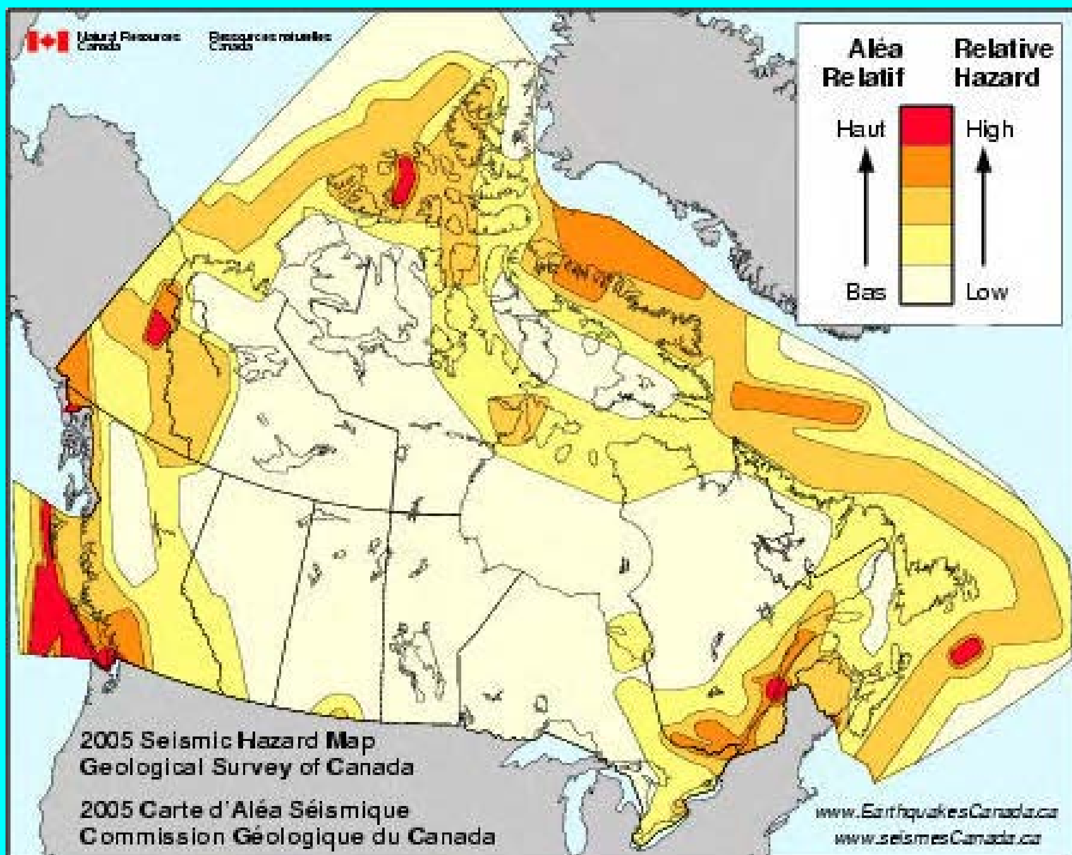
Thick <u>Soft Soils</u>

Having Low Shear Wave Velocities

Are Associated With

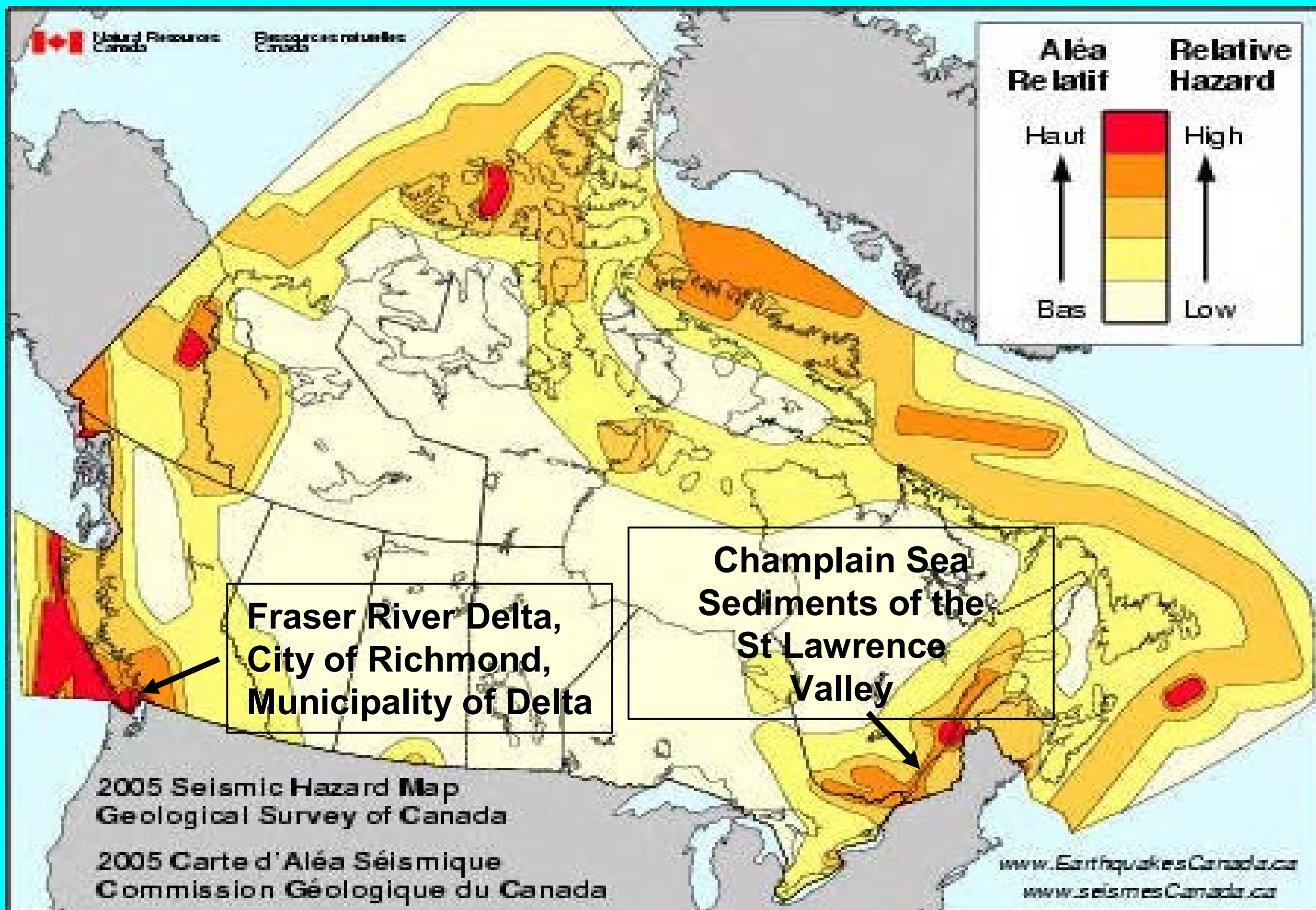
Increased Shaking and Damage

Q: IS SOFT SOIL A PROBLEM IN HIGH HAZARD ZONES IN CANADA?



A: Yes

Q: IF SO, WHERE ARE THESE ZONES?
(with respect to population density)



Q: HAS THERE BEEN PREVIOUS EVIDENCE OF MAJOR EARTHQUAKE DAMAGE? (close to population centers today)

A: <u>East</u> – Charlevoix QC, 1663 AD M7.0,

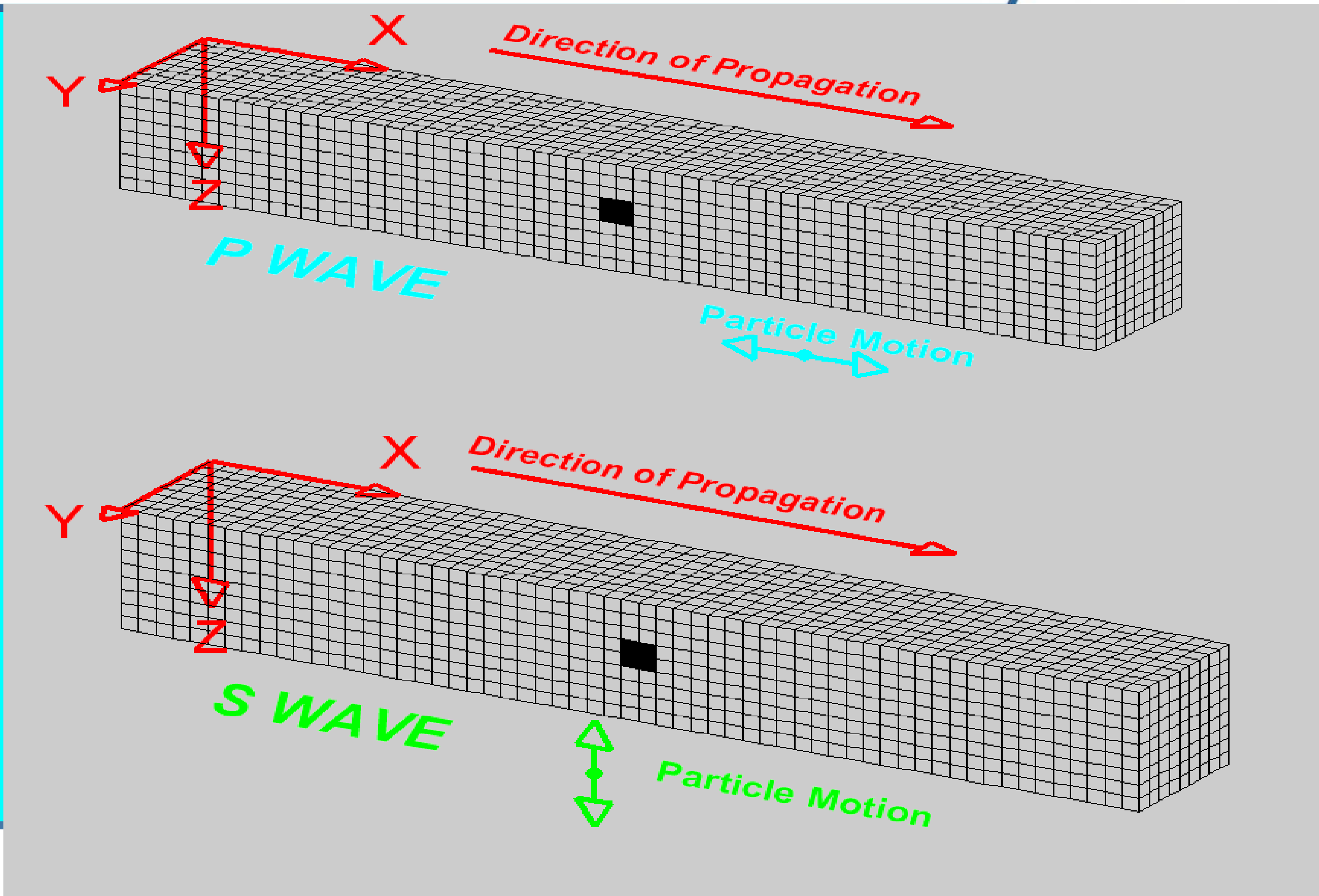
Lefevre Ont 7050 ybp M 6.5-7.0,

Bourget Ont 4550 ybp M6.0-6.5

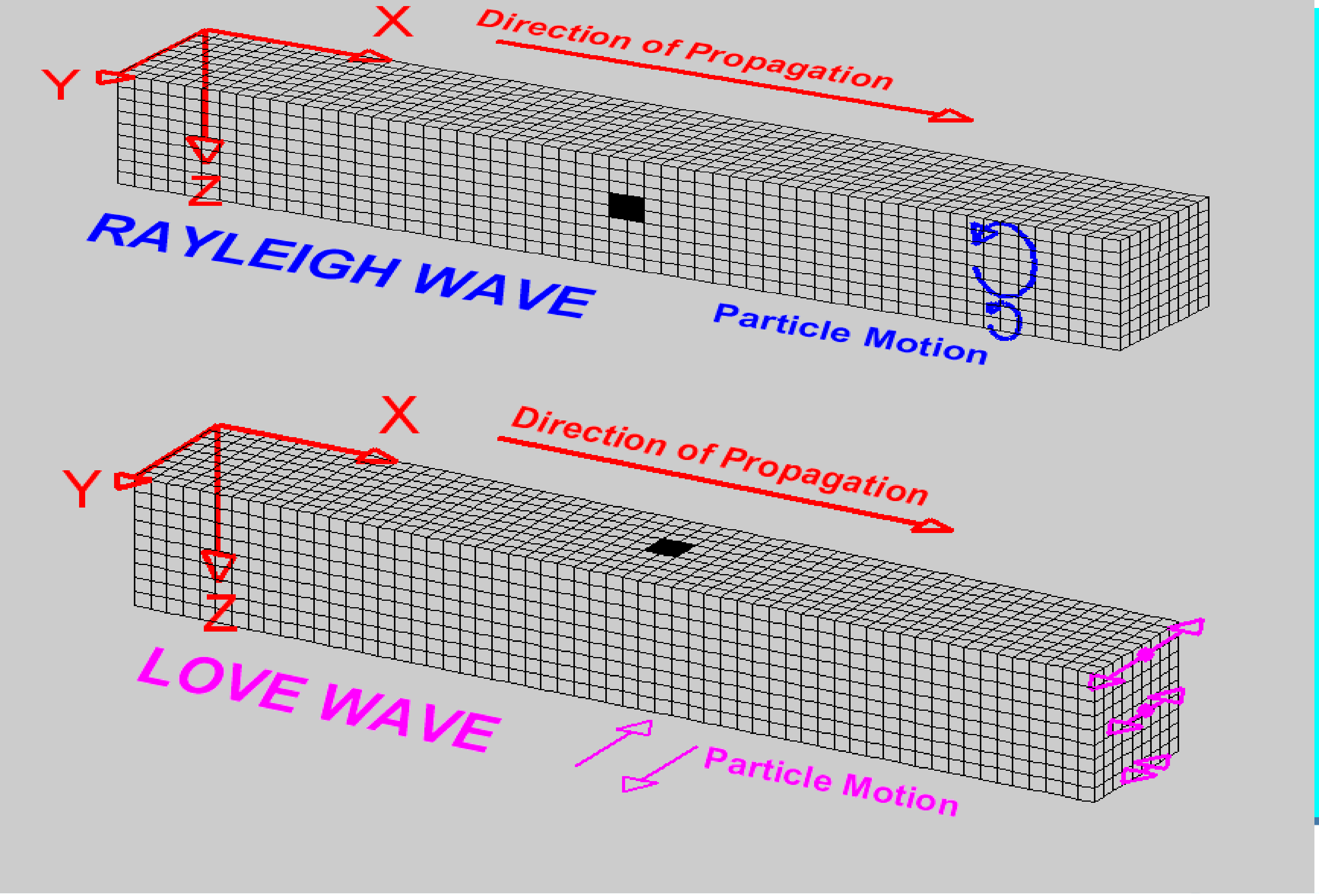
<u>West</u> – several large events in the geological record,

the last major event on the west coast was 1700 AD, M8-9

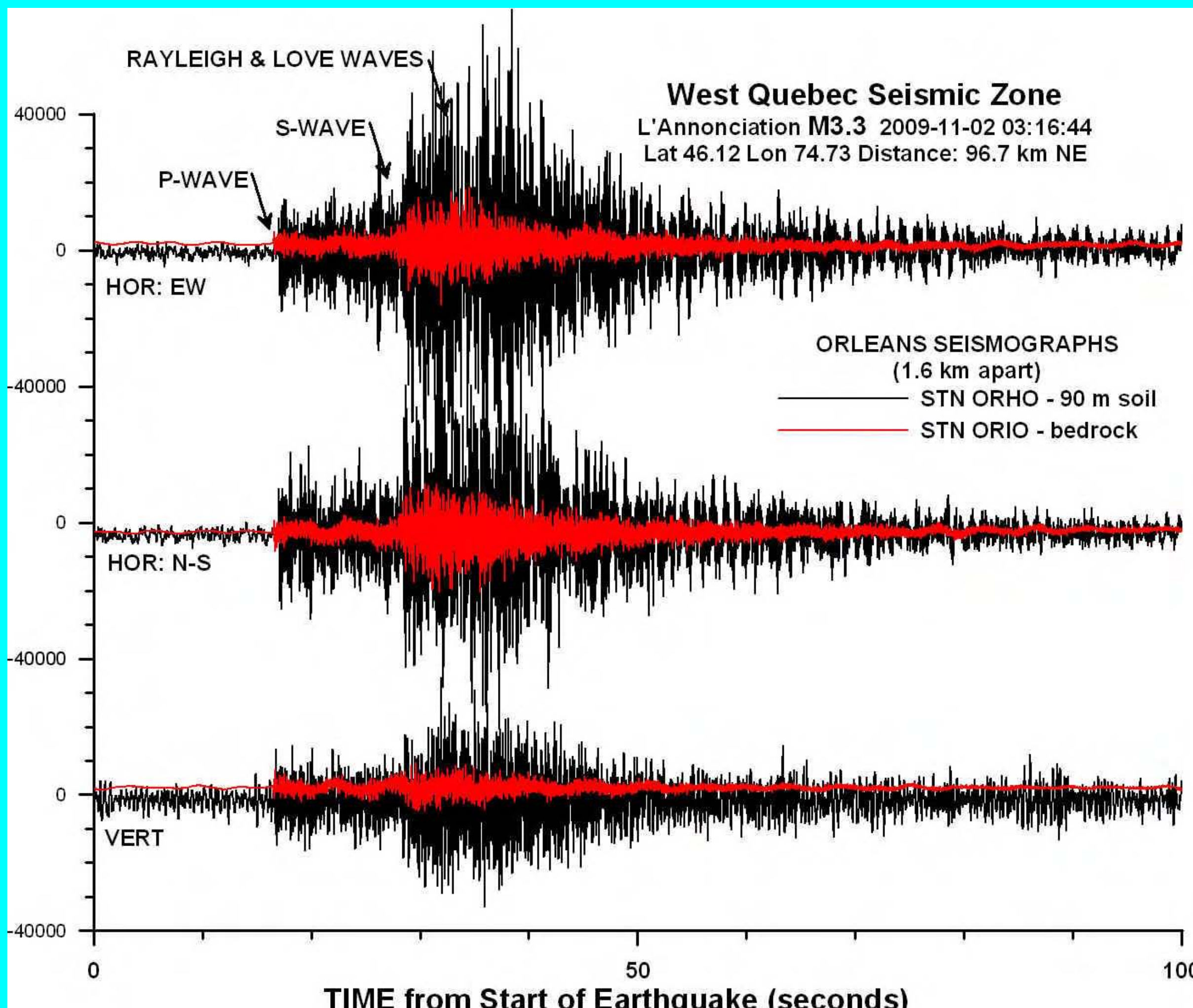
EARTHQUAKE BODY WAVES



EARTHQUAKE SURFACE WAVES



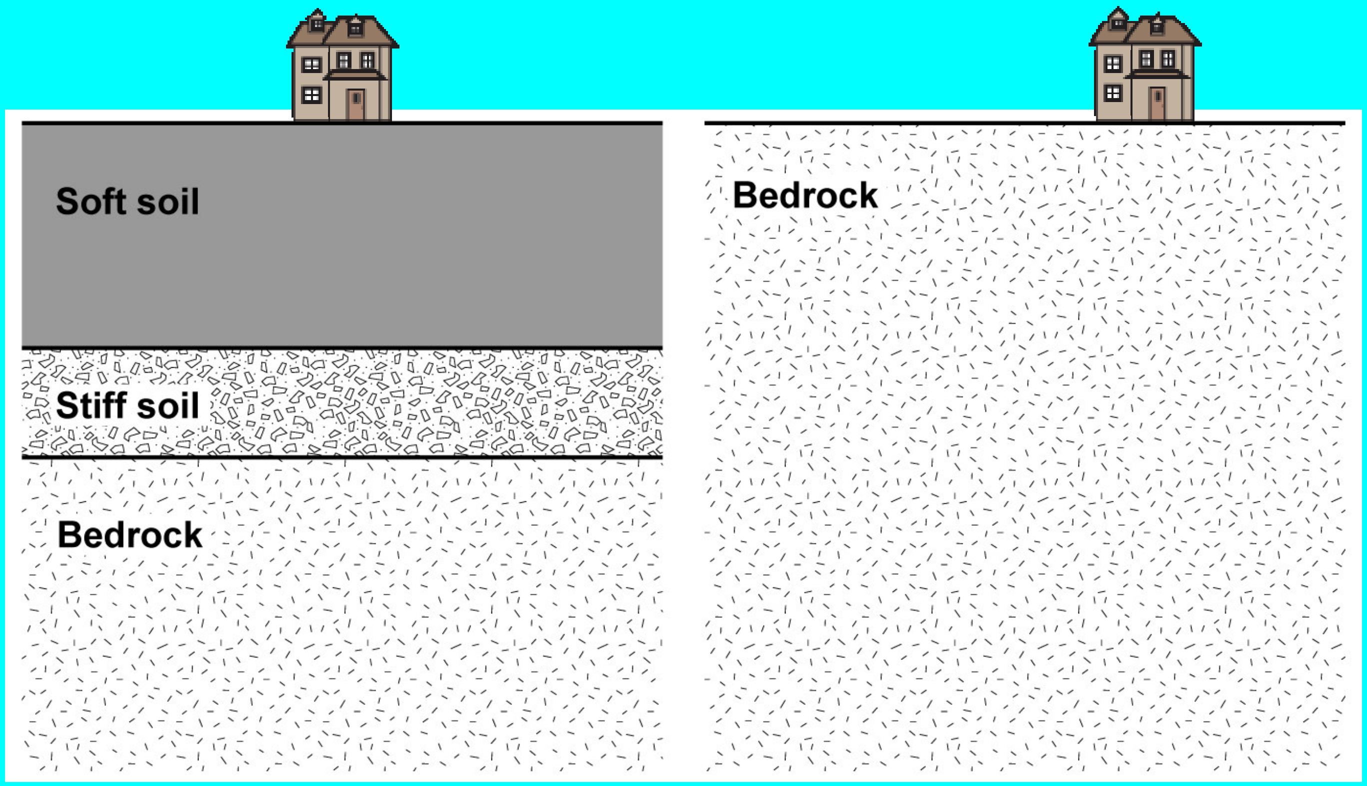
Example Seismic Record of a Local Earthquake
The epicentre was north of Ottawa and Montreal



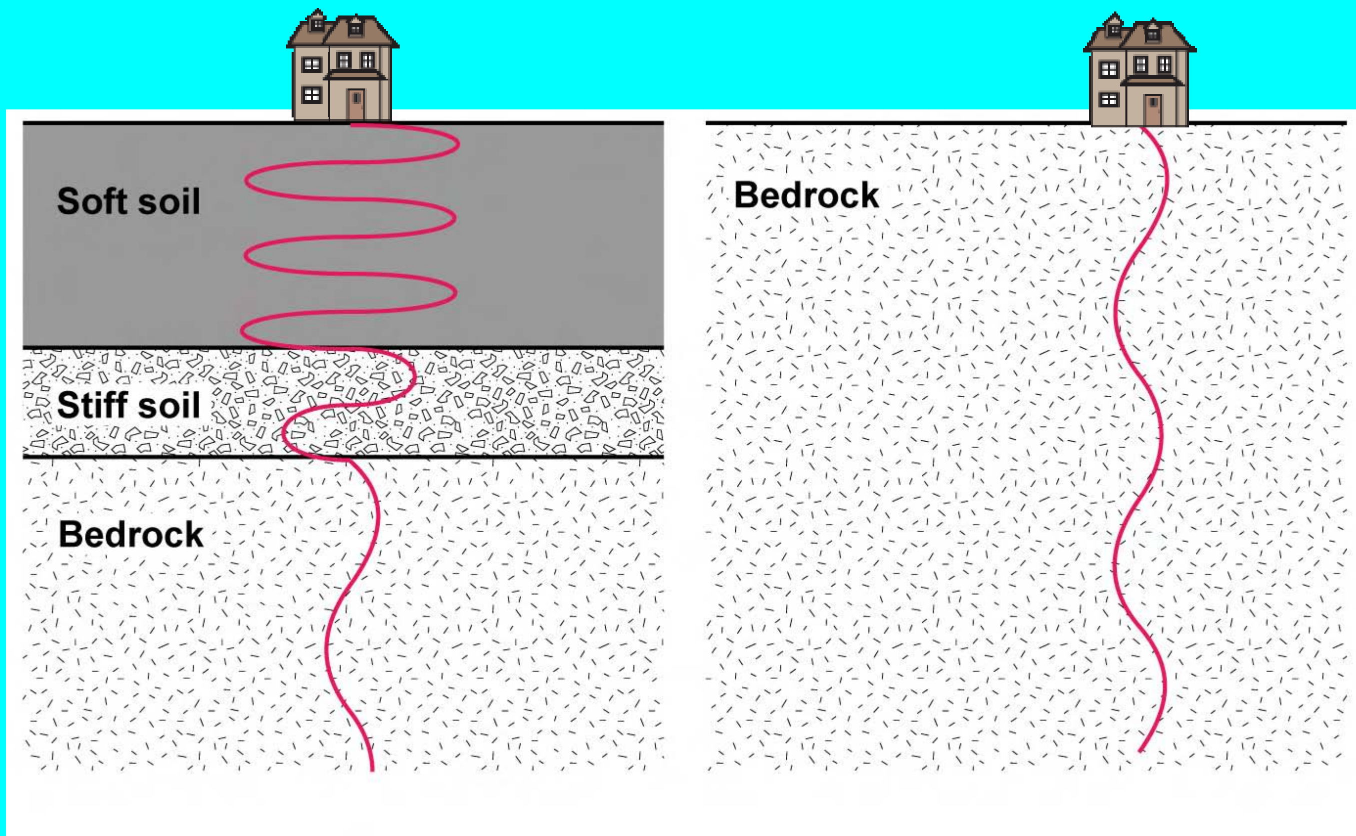
What happens to earthquake waves in soft soils to cause the concern?

- the seismic waves slow down passing through soils
- the wavelengths get shorter, but have the same energy per wavelength, hence,
- the amplitude of shaking increases

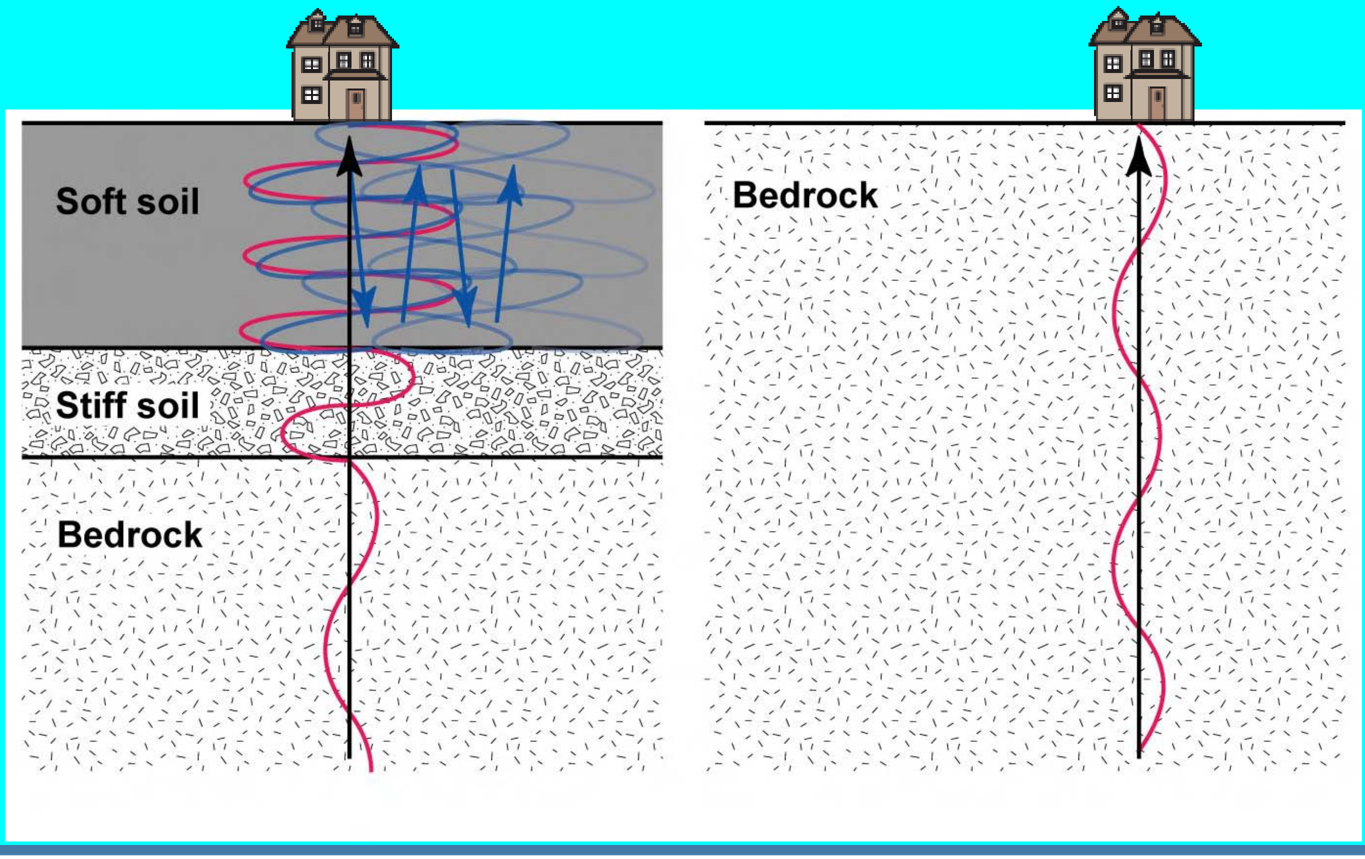
Impedance Contrast Amplification



Impedance Contrast Amplification

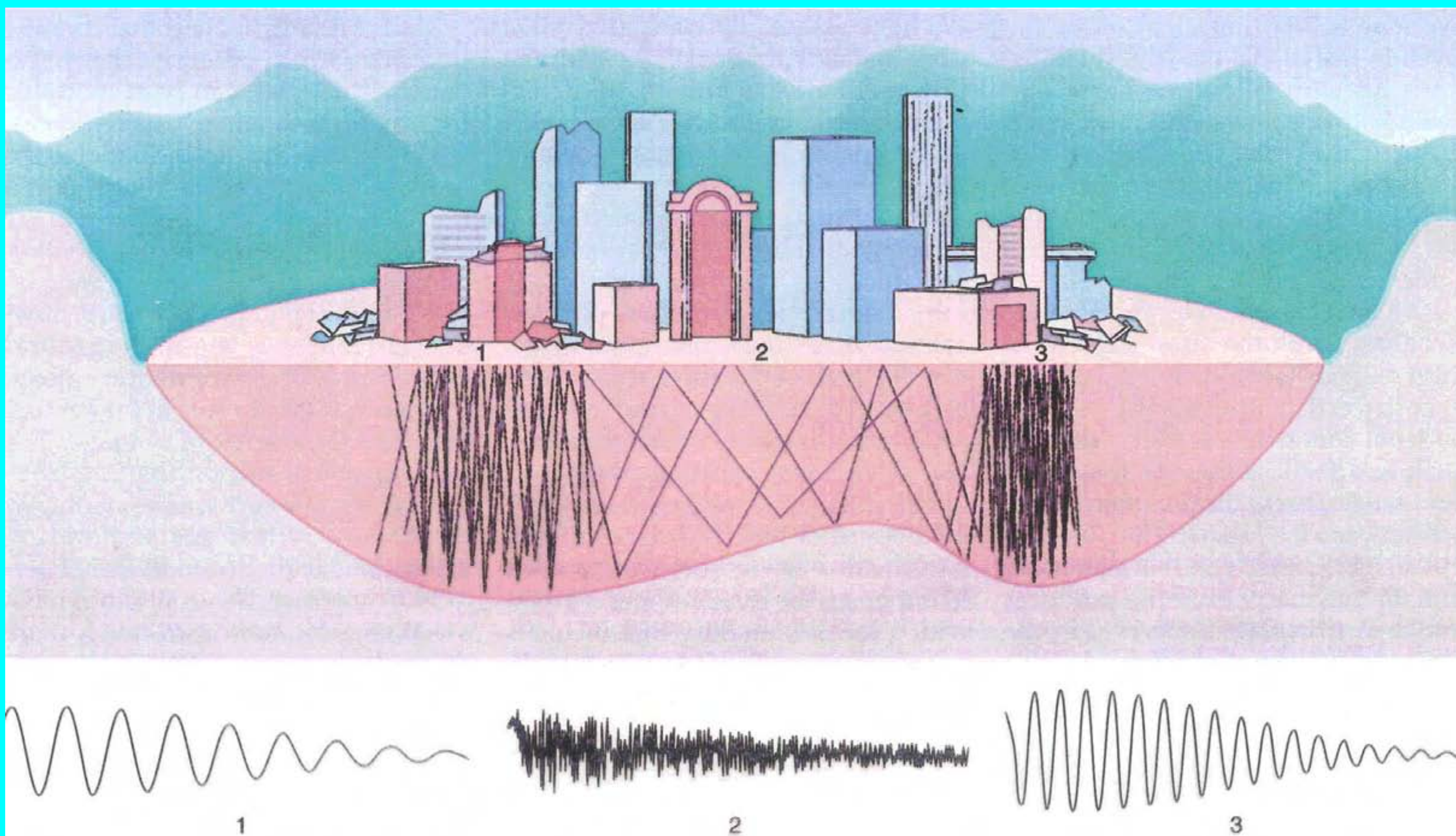


Resonance Amplification Added



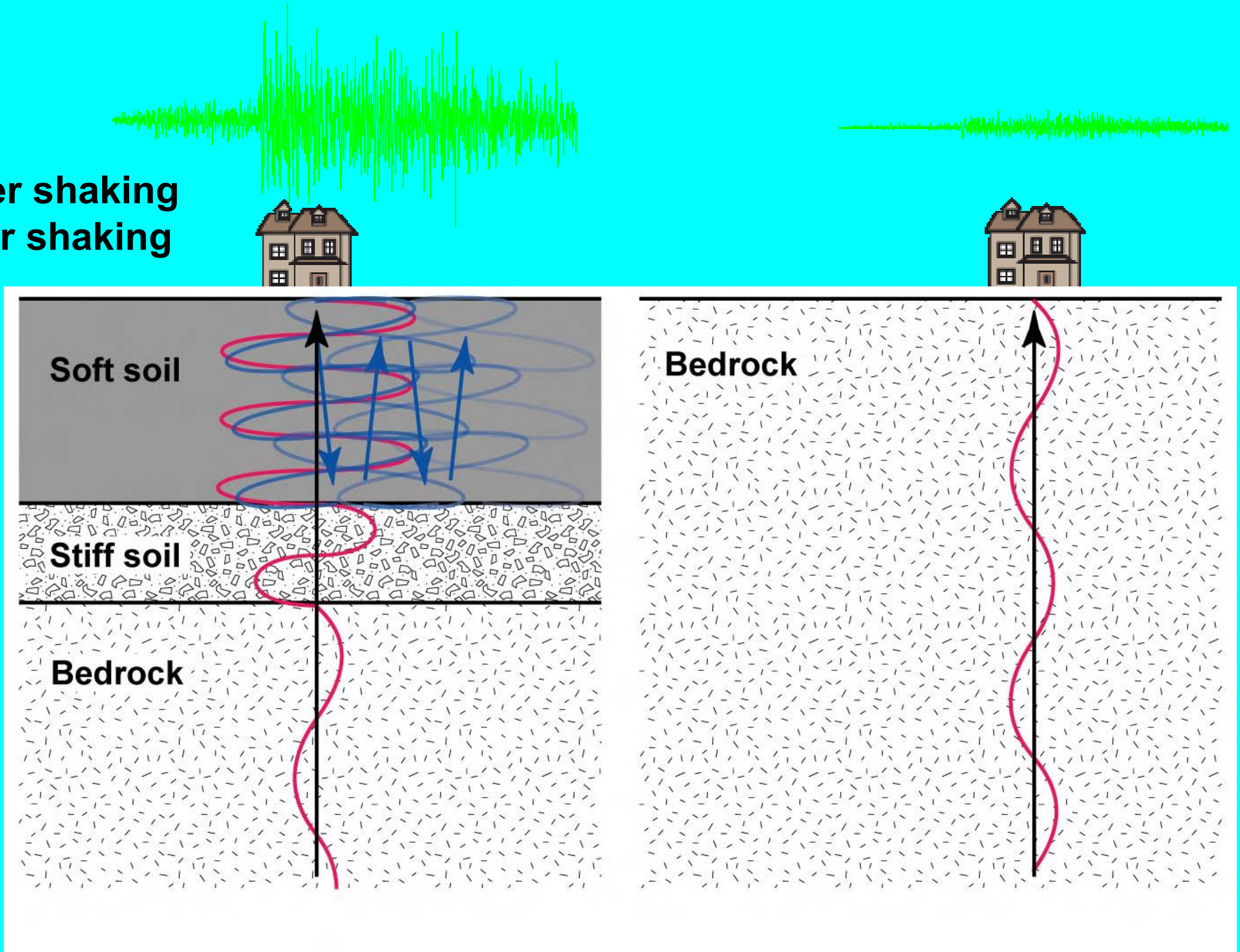
Basin Effects: focussing, defocussing

Mexico City, 1985 after Rial et al., 1992

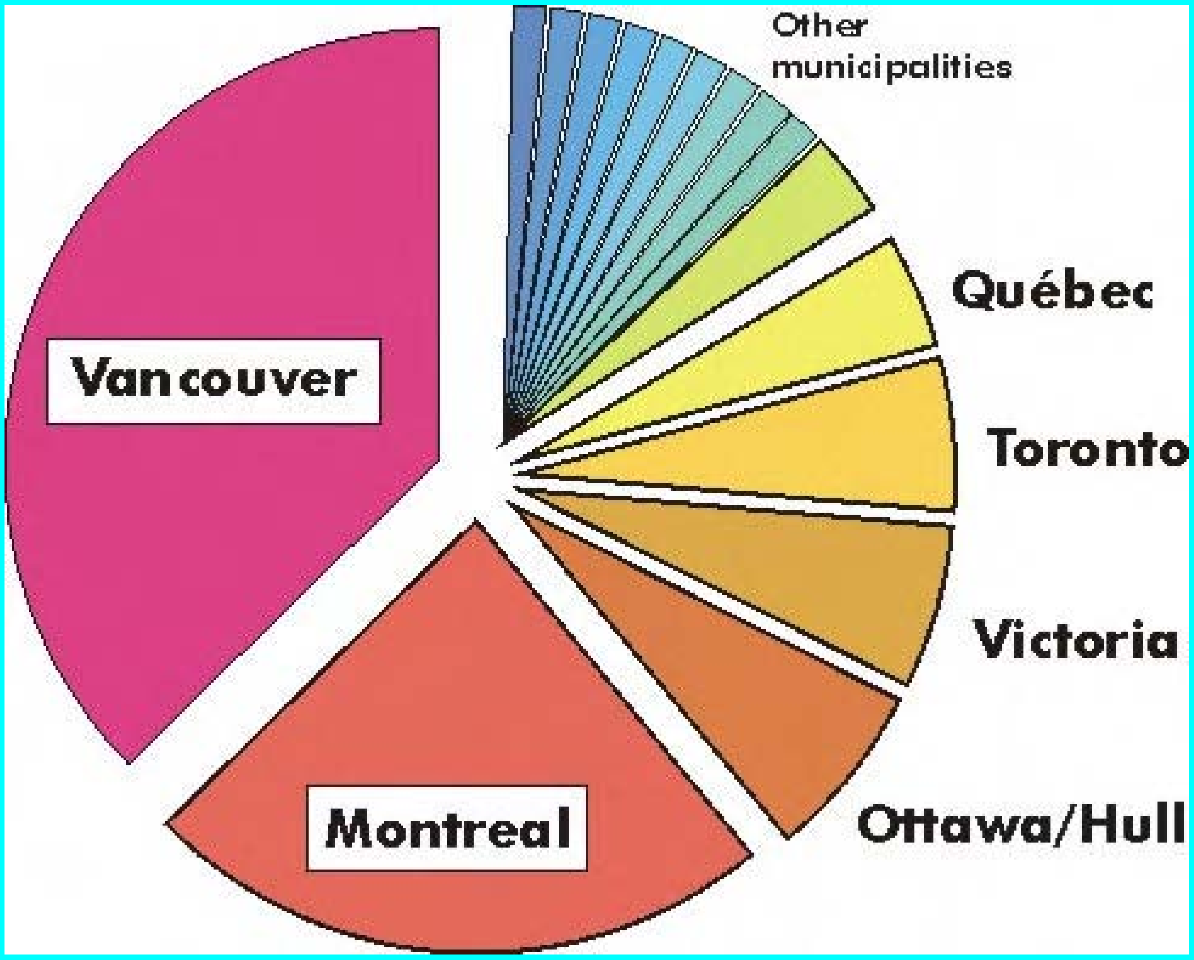


Combined soft soil effects

Greater shaking
Longer shaking



Canadian Urban Seismic Risk



NBCC seismic site categories (NEHRP)

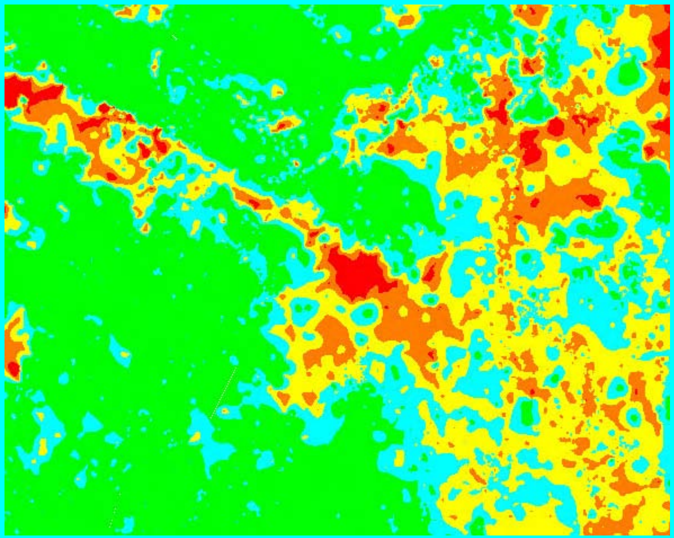
Site Class	Soil profile name
A	Hard rock (e.g., granite)
B	Rock (e.g., limestone)
C	Very dense soil or soft rock (e.g., till or shale)
D	Stiff soil (e.g., gravel)
E	Soft Soil (e.g., marine clay)
F	Others

NBCC seismic site categories (NEHRP)

Site Class	Soil profile name	Defined based on geotechnical properties of the upper 30 m		
		Soil average shear wave velocity, V_s (m/s)	Standard penetration resistance, N_{60}	Soil undrained shear strength, S_u (kPa)
A	Hard rock (e.g., granite)	$V_s > 1500$	na	na
B	Rock (e.g., limestone)	$760 < V_s < 1500$	na	na
C	Very dense soil or soft rock (e.g., till or shale)	$360 < V_s < 760$	$N_{60} > 50$ (blow counts)	$S_u > 100$
D	Stiff soil (e.g., gravel)	$180 < V_s < 360$	$15 < N_{60} < 50$ (blow counts)	$50 < S_u < 100$
E	Soft Soil (e.g., marine clay)	$V_s < 180$	$N_{60} < 15$ (blow counts)	$S_u < 50$
F	Others	Site specific evaluation required		

NEHRP Zone Mapping

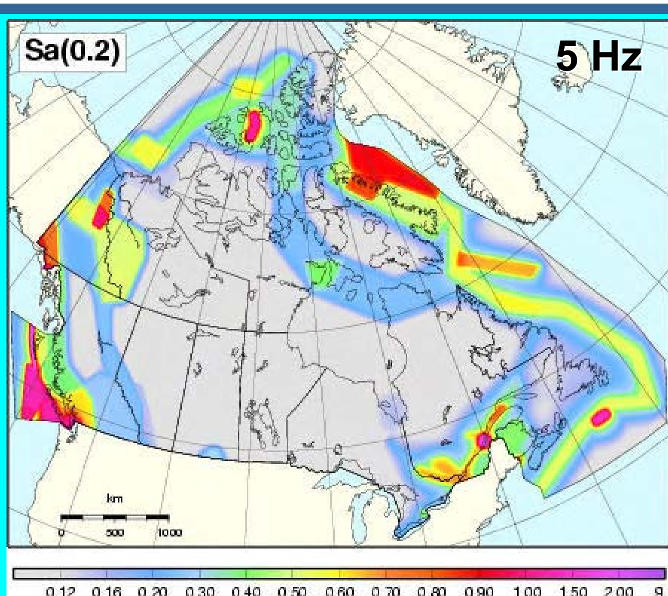
Resulting Interpolated Site Class map

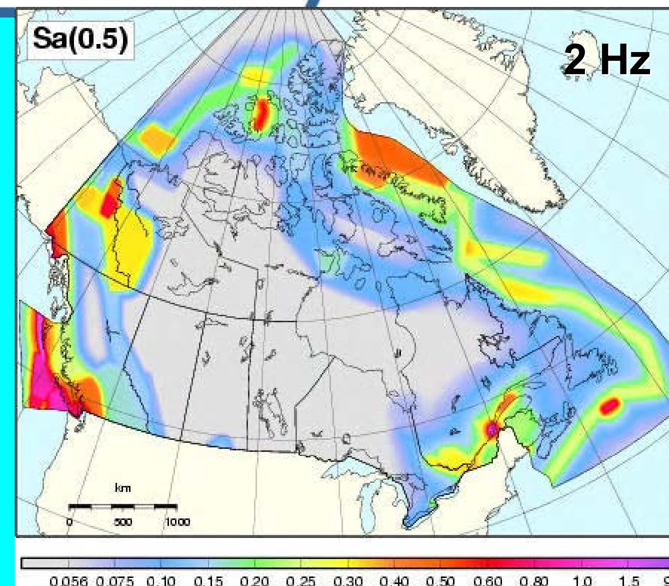


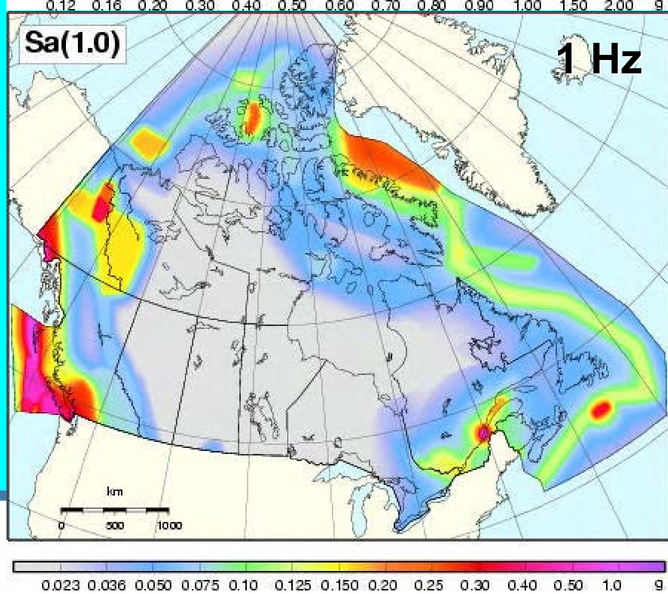
2005 NBCC

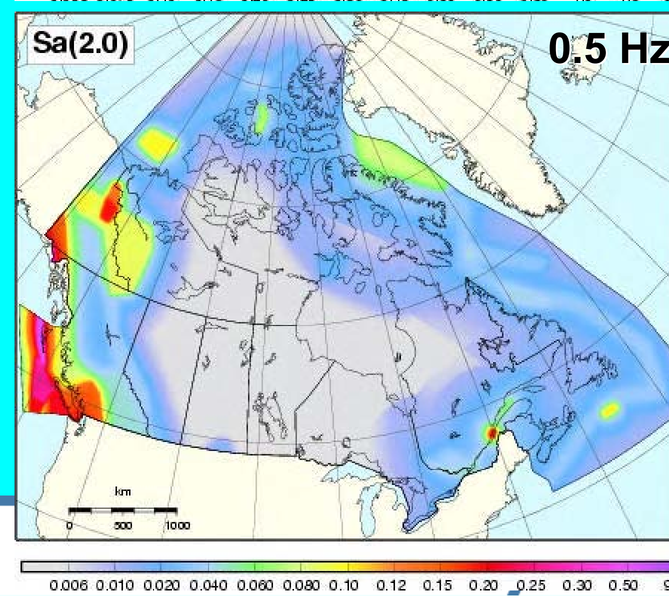
Site Class	Soil profile name	Defined based on geotechnical properties of the upper 30 m		
		Soil average shear wave velocity, V_s (m/s)	Standard penetration resistance, N_{60}	Soil undrained shear strength, S_u (kPa)
A	Hard rock (e.g., granite)	$V_s > 1500$	na	na
B	Rock (e.g., limestone)	$760 < V_s < 1500$	na	na
C	Very dense soil or soft rock (e.g., till or shale)	$360 < V_s < 760$	$N_{60} > 50$ (blow counts)	$S_u > 100$
D	Stiff soil (e.g., gravel)	$180 < V_s < 360$	$15 < N_{60} < 50$ (blow counts)	$50 < S_u < 100$
E	Soft Soil (e.g., marine clay)	$V_s < 180$	$N_{60} < 15$ (blow counts)	$S_u < 50$
F	Others	Site specific evaluation required		

Ground Acclerations for NEHRP Zone C for the “1 in 2500” year event









NBCC Amplification Factors
Look-up tables

Table 2. Values of F_a as a Function of Site Class and T= 0.2 s Spectral Acceleration.

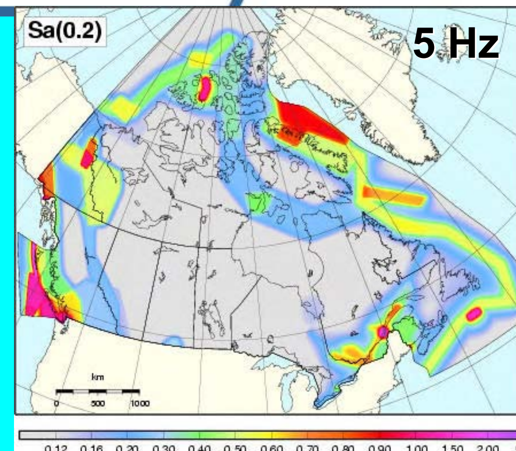
Credit for better sites

Ottawa

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



AMPLIFICATION FACTORS TO NEHRP ZONE C (FIRM GROUND) FOR CANADIAN SITES

Table 3. Values of F_v as a Function of Site Class and T= 1.0 s Spectral Acceleration.

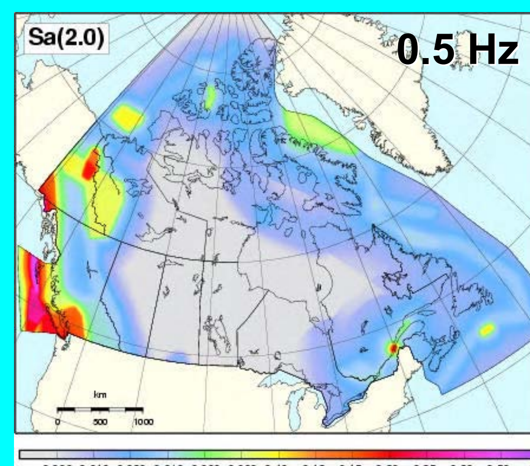
Credit for better sites

Ottawa

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



Shear Wave Measurement Techniques

-Seismic Cone Penetrometer (SCPT)

-Downhole Seismic Profile (VSP)

-Surface Refraction/Reflection Site Analyses

-Seismic Landstreamer profiling

-Multi-channel Analysis of Surface Waves (MASW)

SEISMIC CONE PENETROMETER - SCPT
(Conetec Investigations Ltd)