Passive Seismic Methods for Site Assessment and Microzonation Mapping in Greater Vancouver

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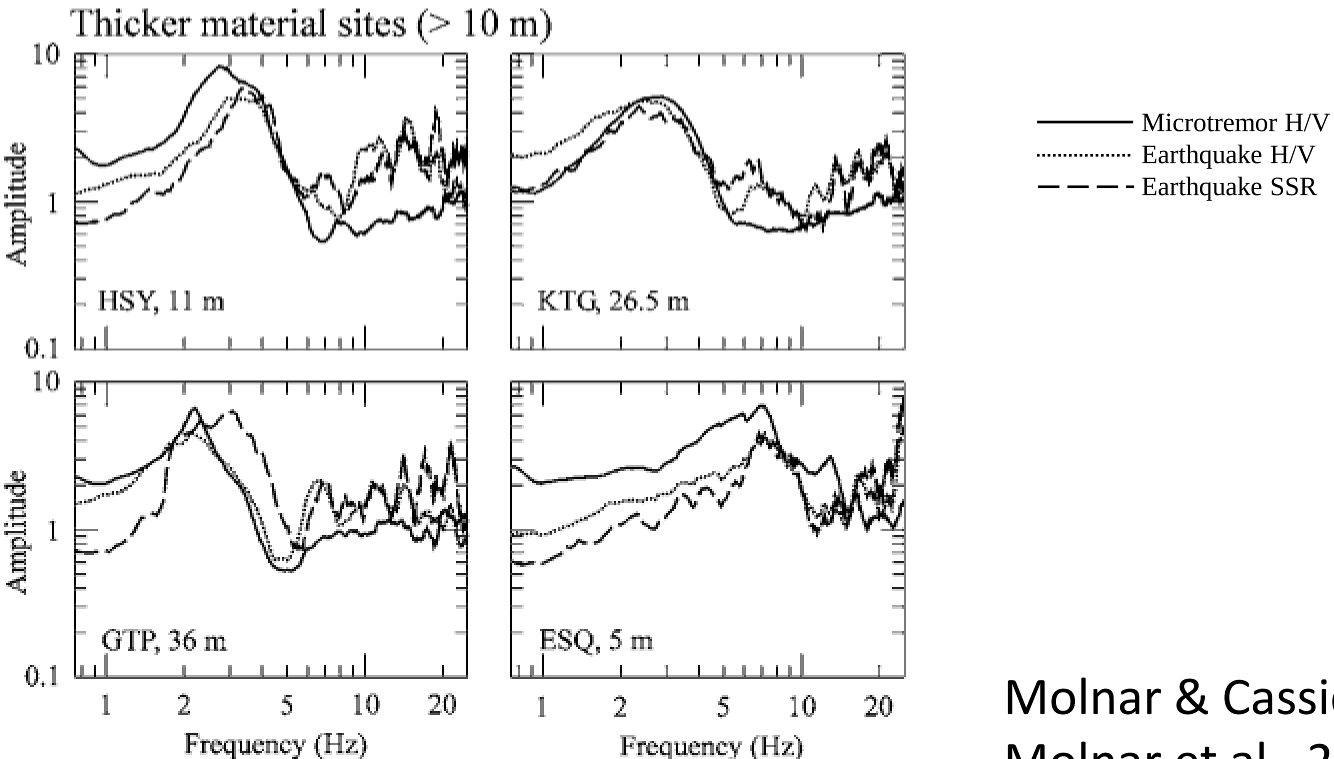
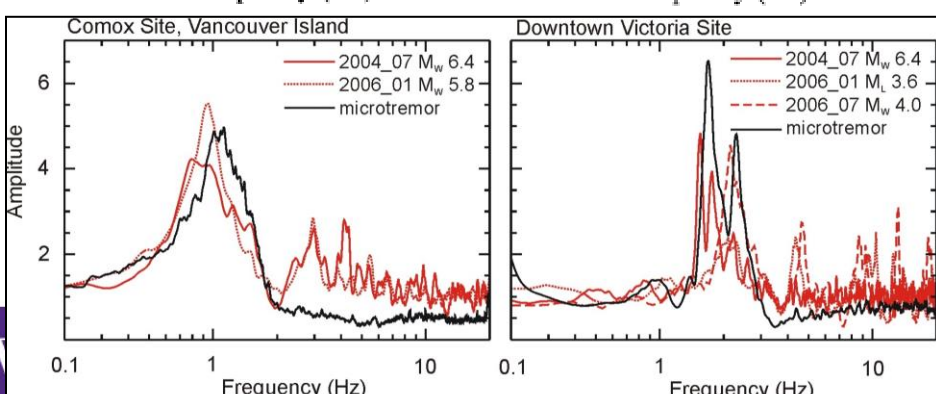
Passive seismic signals as useful as recorded earthquake shaking

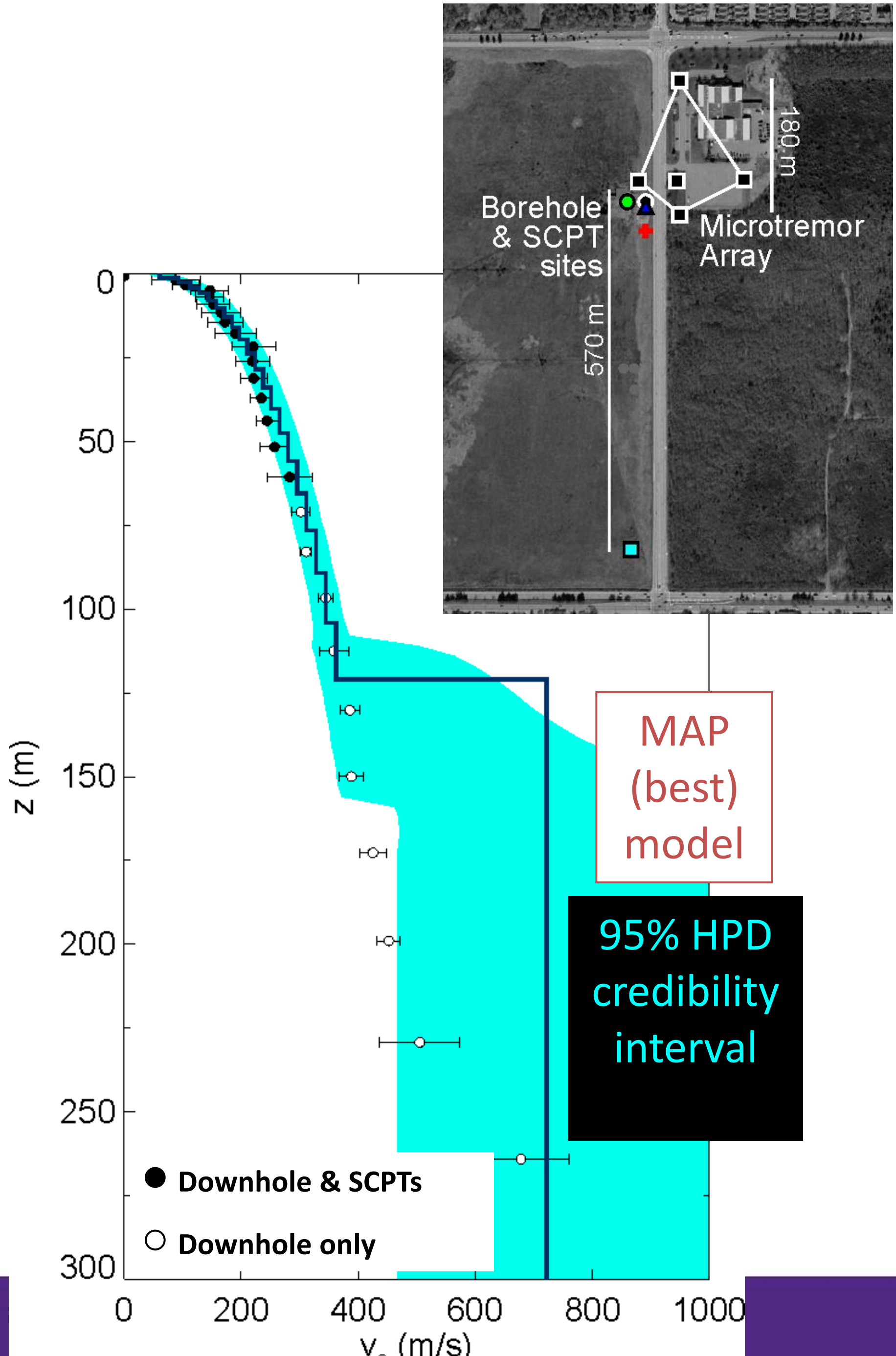


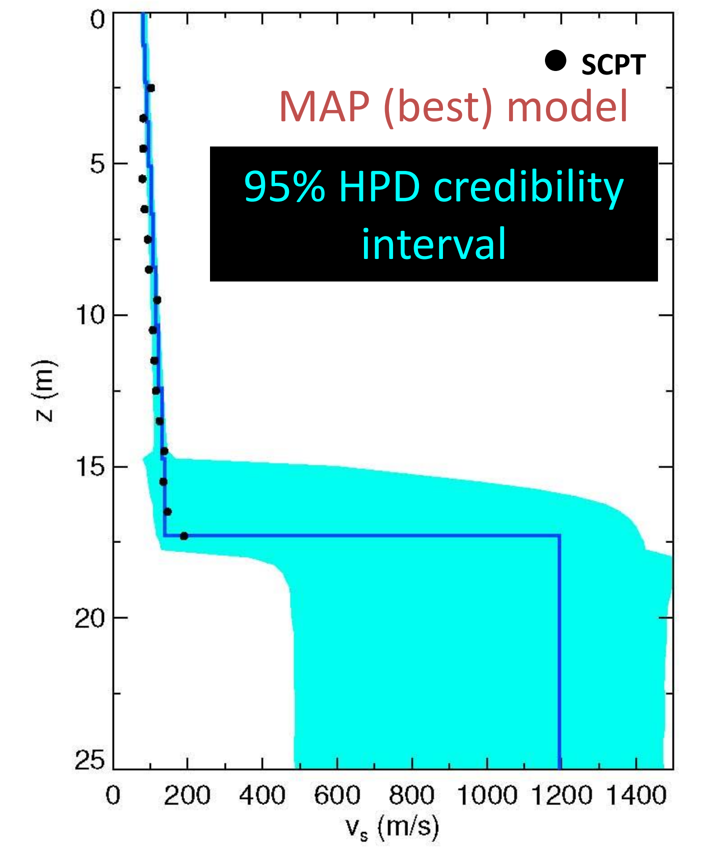


Molnar & Cassidy, 2006. *Eq. Spec*.
Molnar et al., 2007. 9CCEE.

Passive seismic signals provide accurate Vs profiles

Molnar, Dosso, Cassidy (2010) *GJI.*
Molnar, Cassidy, Dosso (2013) *Geophys*.





Why this talk? Why now?

Did you know?

1. There has been rapid development and application of passive seismic methods in the last ~20 years
2. There has been progress in standardized guidelines for non-invasive earthquake site characterization methods

Why should you care?

How this is filtering into Canadian geotech eng practice:

- Metro Vancouver seismic microzonation mapping project is using non-invasive methods for site classification → **EGBC guidelines for professional use of the maps** are under development
- GMMs starting to include peak frequency with Vs30 → Future seismic design codes may become less reliant on Vs_{30} and could include site period → **How to measure site period?**

Outline

Passive Seismic Methods for Site Assessment

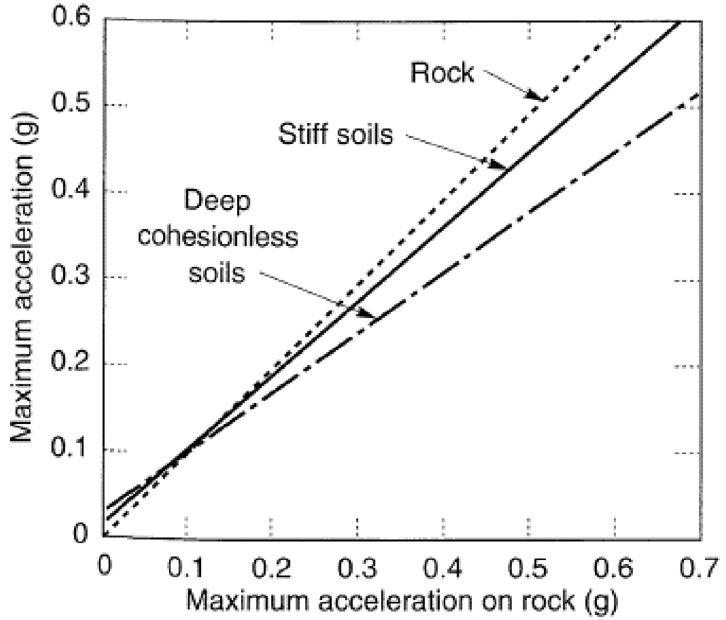
- NBCC site classification
- Passive seismology (ambient vibration, microtremor)
- Two main methods
- Reliable? Comparisons (blind-tests) with invasive methods

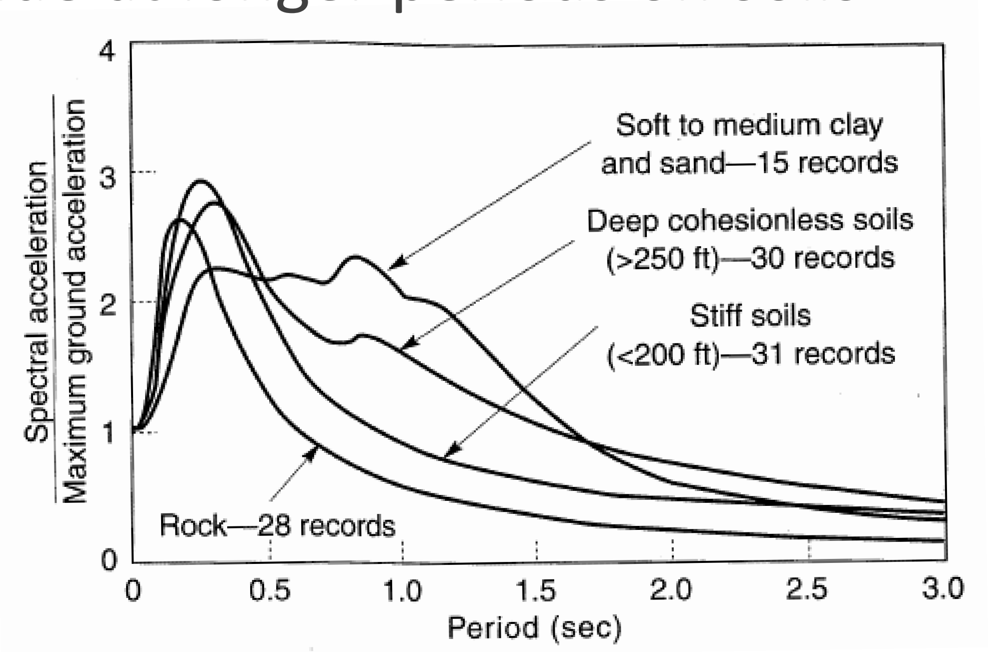
Microzonation Mapping in Greater Vancouver

- Project overview
- Development of geodatabase
- Preliminary non-invasive seismic testing results

Earthquake Site Assessment

- Higher shaking amplitude motion on soil vs. rock
- Higher shaking amplitude at longer periods on soils





Seed et al. (1976)
From Kramer 1996, Figs. 8.10 & 8.12

A single response spectrum shape for all site conditions is not appropriate → strongly influences dev. of bldg. codes & standards

Earthquake Site Assessment

- NBCC 1995: Site conditions compressed into four distinct site categories with associated amplification (foundation) factor, **F**

Table 1. Foundation factors, *F* (NBCC 1995).

$V_e = vSIFW$

Category	Type and depth of soil measured from the foundation or pile cap level	*F*
1	Rock, dense and very dense coarse-grained soils, very stiff and hard fine-grained soils; compact coarse-grained soils and firm and stiff fine-grained soils from 0 to 15 m deep	1.0
2	Compact coarse-grained soils, firm and stiff fine-grained soils with a depth greater than 15 m; very loose and loose coarse-grained soils and very soft and soft fine-grained soils from 0 to 15 m deep	1.3
3	Very loose and loose coarse-grained soils with depth greater than 15 m	1.5
4	Very soft and soft fine-grained soils with depth greater than 15 m	2.0

- First three factors based primarily on site effects reported by Seed et al. (1976) and Mohraz (1976).
- The factor *F* = 2.0 was added; large amplifications of earthquake motions in the clay deposits of Mexico City

Advantage: diff. soil categories → distinct ground response

Disadvantages: Lack of a quantitative site class measure, Factor not based on shaking intensity

Finn & Wightman 2003

Earthquake Site Assessment

- NEHRP 1994 Provisions from Borcherdt (1992, 1994):
  - Time-averaged Vs of upper 30 m (Vs_{30}) as quantitative continuous measure of site conditions

$$V_{S30} = \frac{30}{\sum \frac{h}{V_S}}$$

Table 2. Site classification for seismic site response (NEHRP 1994).

Site class	Site class name and generic description	Site class definition
A	Hard rock	$\overline{V}_{30} > 1500$ m/s
B	Rock	$760 < \overline{V}_{30} \le 1500$ m/s
C	Very dense soil and soft rock	$360 < \overline{V}_{30} \le 760$ m/s, $\overline{N} > 50$, or $\overline{S}_u > 100$ kPa
D	Stiff soil	$180 < \overline{V}_{30} \le 360$ m/s, $15 \le \overline{N} \le 50$, or $50 \le \overline{S}_u \le 100$ kPa
E	Soil profile with soft clay	$\overline{V}_{30} < 180$ m/s; plasticity index PI > 20, water content w > 40%, and $\overline{S}_u < 25$ kPa
F	Site-specific geotechnical investigations and dynamic site response analyses: (*i*) soils vulnerable to potential failure or collapse under seismic loading (liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils, etc.); (*ii*) peats and (or) highly organic clays (H > 3 m of peat and (or) highly organic clay, where H is thickness of soil); (*iii*) very high plasticity clays (H > 8 m with PI > 75); (*iv*) very thick "soft – medium-stiff clays" (H > 36 m)	

Earthquake Site Assessment

- NBCC 2005: Adopts NEHRP 1994 site classes and modifies foundation factors (**Fa**, **Fv**) to reference site class C
  - ✓ Quantitative continuous measure of site conditions
  - ✓ Factor based on intensity and period

Table 6. Values of F_a as a function of site class and spectral acceleration at T = 0.2 s ($S_{0.2}$).

	$S_{0.2}$				
Site class	≤0.25	0.50	0.75	1.00	≥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	—[a]	—[a]	—[a]	—[a]	—[a]

Note: Use straight-line interpolation for intermediate values of $S_{0.2}$.
[a]Site-specific geotechnical investigation and dynamic site response analyses should be performed.

Table 7. Values of F_v as a function of site class and spectral acceleration at T = 1.0 s.

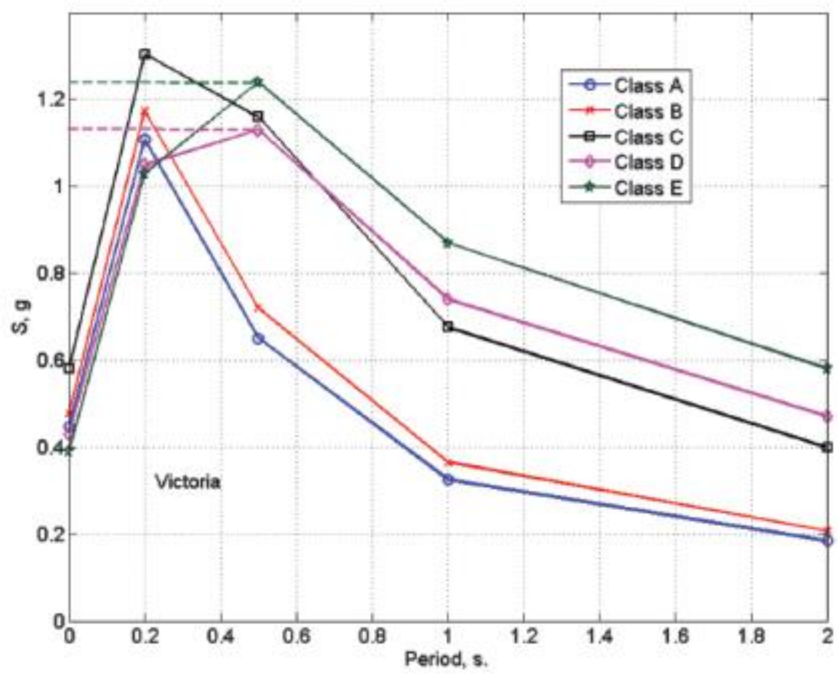
	$S_{1.0}$				
Site class	≤0.1	0.2	0.3	0.4	≥0.5
A	0.5	0.5	0.5	0.6	0.6
B	0.6	0.7	0.7	0.8	0.8
C	1	1	1	1	1
D	1.4	1.3	1.2	1.1	1.1
E	2.1	2	1.9	1.7	1.7
F	—[a]	—[a]	—[a]	—[a]	—[a]

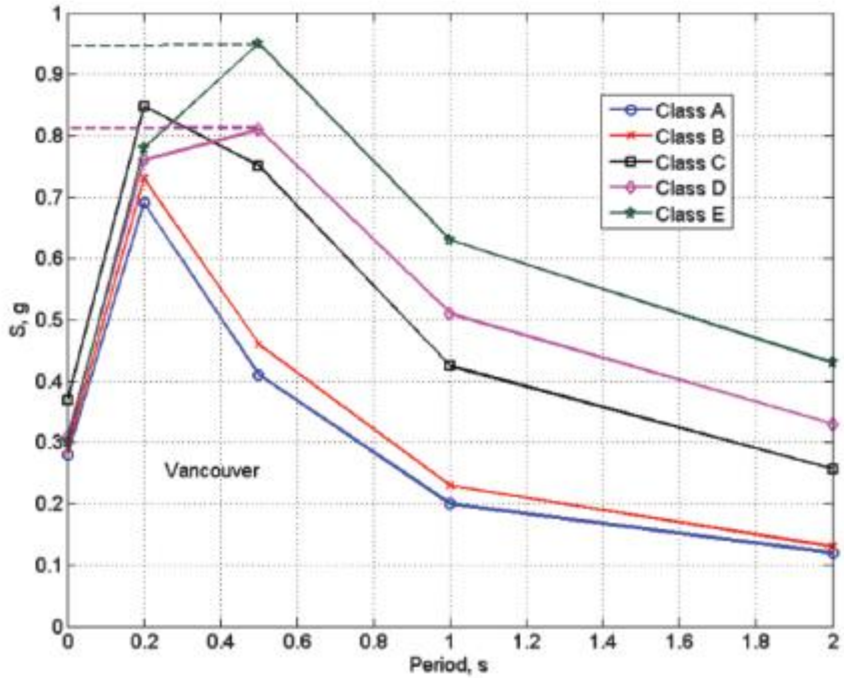
Note: Use straight line interpolation for intermediate values of $S_{1.0}$.
[a]Site-specific geotechnical investigation and dynamic site response analyses shall be performed.

Finn & Wightman 2003; Humar (2015) Can. J. Civ. Eng. **42**: 940–952

Earthquake Site Assessment

- NBCC 2005: Adopts NEHRP 1994 site classes and modifies foundation factors to reference site class C
- NBCC 2015: **F(T)** @ 0.2, 0.5, 1, 2, 5, and 10s





Finn & Wightman 2003; Humar (2015) Can. J. Civ. Eng. **42**: 940–952

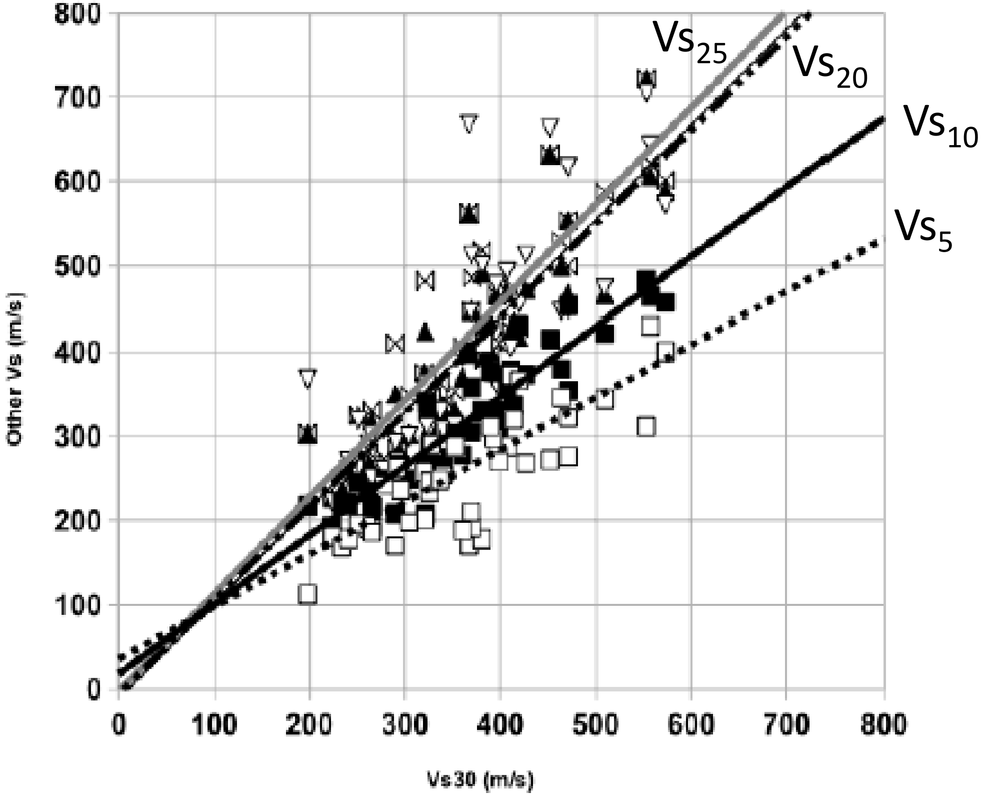
Earthquake Site Assessment

- NBCC 2020: Site Amplification Task Group of SC-ED has been evaluating F(T) approach for Vs_{30}–based site classes
  - Vs_{30} adopted in Canada, USA, Eurocode 8, Italy
- France: Vs, Vp, N_{60}, S_u, Dr
- China: Vs_{20} and soil thickness
- Turkey: Vs, h
- Japan: Vs, T_1, T_2, soil descrip.
- Mexico: Site period map of Mexico city
- New Zealand: Vs, (Vs_{30}, N_{60}, S_u), T_0, $H < 100$ m

Earthquake Site Assessment

- NBCC 2020: Site Amplification Task Group of SC-ED has been evaluating F(T) approach for Vs_{30}–based site classes

- Other metrics & combinations proposed:
  - Quarter Wavelength
  - Vs_{30} & basin depth
  - Vs_{10} & site period
  - Site period

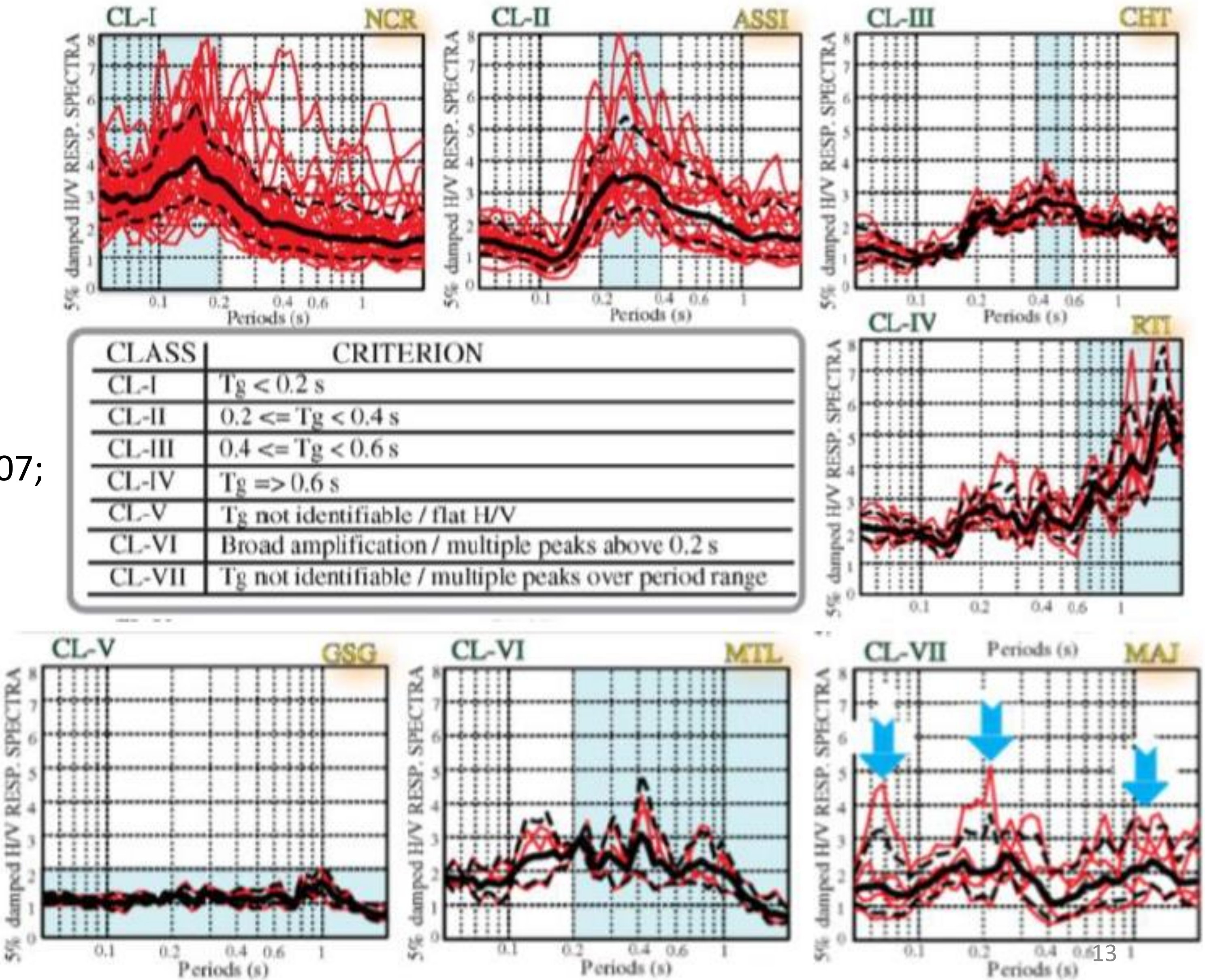


Gallipoli & Muccarelli (2009)

Earthquake Site Assessment

7 site period classes

Zhao et al. (2006);
Fukushima et al. 2007;
Zhao (2011);
Di Alessandro et al. (2012)



CLASS	CRITERION
CL-I	Tg < 0.2 s
CL-II	0.2 <= Tg < 0.4 s
CL-III	0.4 <= Tg < 0.6 s
CL-IV	Tg => 0.6 s
CL-V	Tg not identifiable / flat H/V
CL-VI	Broad amplification / multiple peaks above 0.2 s
CL-VII	Tg not identifiable / multiple peaks over period range

Earthquake Site Assessment

- NBCC 2020: Site Amplification Task Group of SC-ED has been evaluating F(T) approach for Vs_{30}–based site classes

  ? Use Vs_{30} directly and/or introduce site period ?

Would the geotechnical community be ready?

- What is the confidence in Vs measurements? As in, there are uncertainties in Vs within and between methods. Accuracy in Vs30 is within 50 m/s? 10 m/s? < 5 m/s?
- How do you reliably measure site period? (I’ve been doing it for 15 years; cases in geotechnical practice ?)

Passive Seismic Methods

V_S depth profiling methods
The best approach?

Combinations

Invasive Methods

- Vertical V_P, V_S profiling (XH, DH, PS logging)
- S/CPT
- SPT

Laboratory sample

- Bender Element

Non-invasive Methods

- Inversion of E/MHVSR
- Inversion of surface wave dispersion
  - Active-source methods
    - SASW, MASW, CSWS
  - Passive-source methods
    - Linear arrays: ReMi, IMASW
    - 2D arrays: MAM or AVA (hr/fk, M/SPAC, ESAC)

V_S depth profiling methods
The best approach?

Combinations

Invasive Methods

- Higher resolution
- Smaller volume
- Disturbs ground
- More expensive

Non-invasive Methods

- Lower resolution
- Larger volume (bulk)
- Non-disruptive to ground
- Less expensive

Growing popularity in passive methods
Method Standards or guidelines?

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7078

Shear Wave Velocity Measurement Guidelines for Canadian Seismic Site Characterization in Soil and Rock

J.A. Hunter and H.L. Crow
(Editors)

With Technical Contributions From:

J.-L. Arsenault, U. Atukorala, M.E. Best, D. Campos, C. Candy, L. Chouinard, M. Claprood, H.L. Crow, H. Dutrisac, J. Fleming, J.B. Harris, R. Hillman, J.A. Hunter, M. Karray, G. Lefebvre, M. Maxwell, S. Molnar, R. Paul, D. Perret, C. Phillips, S.E. Pullan, A.J.-M. Pugin, P. Rosset, J. Schmok, J.-J. Sincennes, S. Sol, I. Weemees, and D. Woeller

2012

Natural Resources Canada | Ressources naturelles Canada

Canada

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COSMOS Intl. Guidelines

- Canada Group Chair for Facilitation Committee (2015-2019) on **"International Guidelines for the Application of Non-Invasive Geophysical Techniques to Characterize Seismic Site Conditions"**

Lead organizer of MHVSR Chapter in guidelines

- Molnar et al. (2016). Application of MHVSR for site characterization: State-of-the-art, 16WCEE, Paper 4946.
- Molnar, Cassidy, Castellaro, Cornou, Crow, Hunter, Matsushima, Sanchez-Sesma, Yong (2018). **Application of MHVSR for site characterization: State-of-the-art**, *Surveys in Geophysics*.
- MHVSR Chapter by Oct. 2019; Guidelines for Dec. 2019

Passive Seismology

Recordings of background seismic noise, microtremors, or ambient vibrations using sensitive (low-noise-floor) seismometers

- 1900-1950’s: Seismometers developed & networks installed
- 1950’s: Correlation between microseisms and meteorological perturbations
- 1950-1970’s: Passive array analyses (i.e., nuclear test monitoring)
- Since 1970’s: Subsurface site characterization (site period, Vs depth profiling)

Origin of noise

Below 1 Hz	Close to 1 Hz	Above 1 Hz
↓	↓	↓
oceanic and large scale meteorological conditions	wind effects and local meteorological conditions	human activies

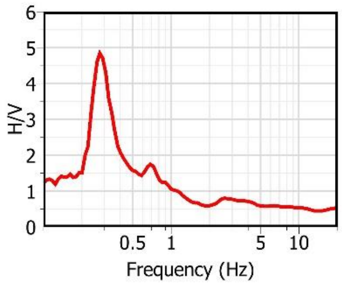
Microseisms **Microtremors**

Passive Seismic Methods

- The signal is "free", no extra cost
- Signals exist over a wide frequency range
  (0.03 to 100 Hz; 0.01 to 30 sec)
- Generally provides deeper investigation depths (longer wavelengths) than active-source seismic methods
- May not provide high frequencies, provides coarser resolution with depth or does not resolve thin layers
- Thus, use both active and passive techniques together
  - Vs profile from only MASW data? – that's old school !

Passive Seismic Methods

Single station

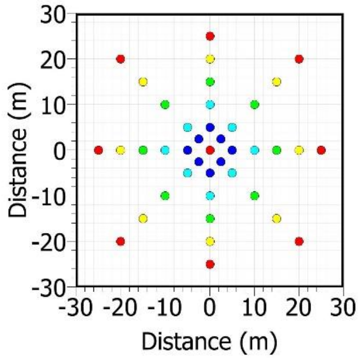


Y. Nakamura H/V technique

Ratio of horizontal to vertical spectrum

Measure of site period or peak frequency

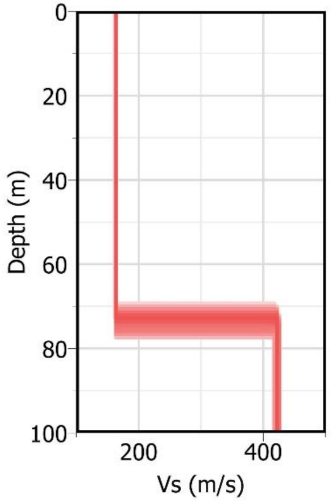
Array of stations (multiple synchronous recordings)



Wave propagation between motion sensors

Measures surface wave dispersion

Output: shear-wave velocity vs. depth



Passive Seismic Methods: MHVSR

$$\frac{\textit{Soil shear motion}}{\textit{Rock shear motion}}$$

Bedrock-to-surface

- Standard spectral ratio (SSR)
- Requires both soil & bedrock motion recordings
- Same event
- Same path (stations close together compared to eq. distance)
- Same instruments
- Left with only site response
- Borcherdt **1970**

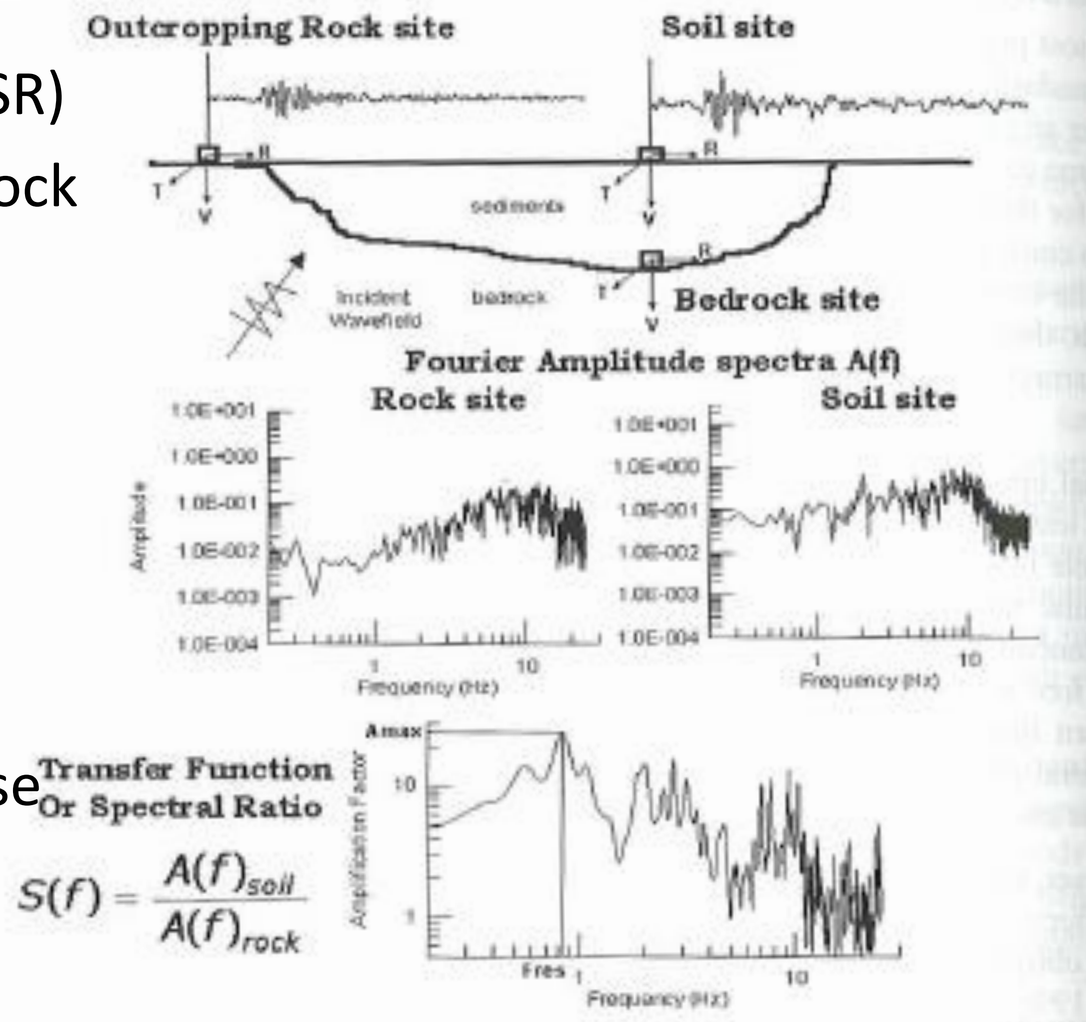


Fig. 5.4. General description of the Standard Spectral Ratio Technique (SSR)

$$\frac{Soil\ shear\ motion}{Soil\ vertical\ motion}$$

Horizontal-to-Vertical

- Vert. cmp does not record horizontal shear motions
  - Horiz. contains P-to-S conversions; Langston (1979) teleseismic P-wave receiver fcns
  - Rayleigh-wave microtremor HVSR method (Nakamura 1989)
- Advantage: only need one 3-cmp sensor
- Applied to eq. S-waves by Lermo & Chavez Garcia **1993**

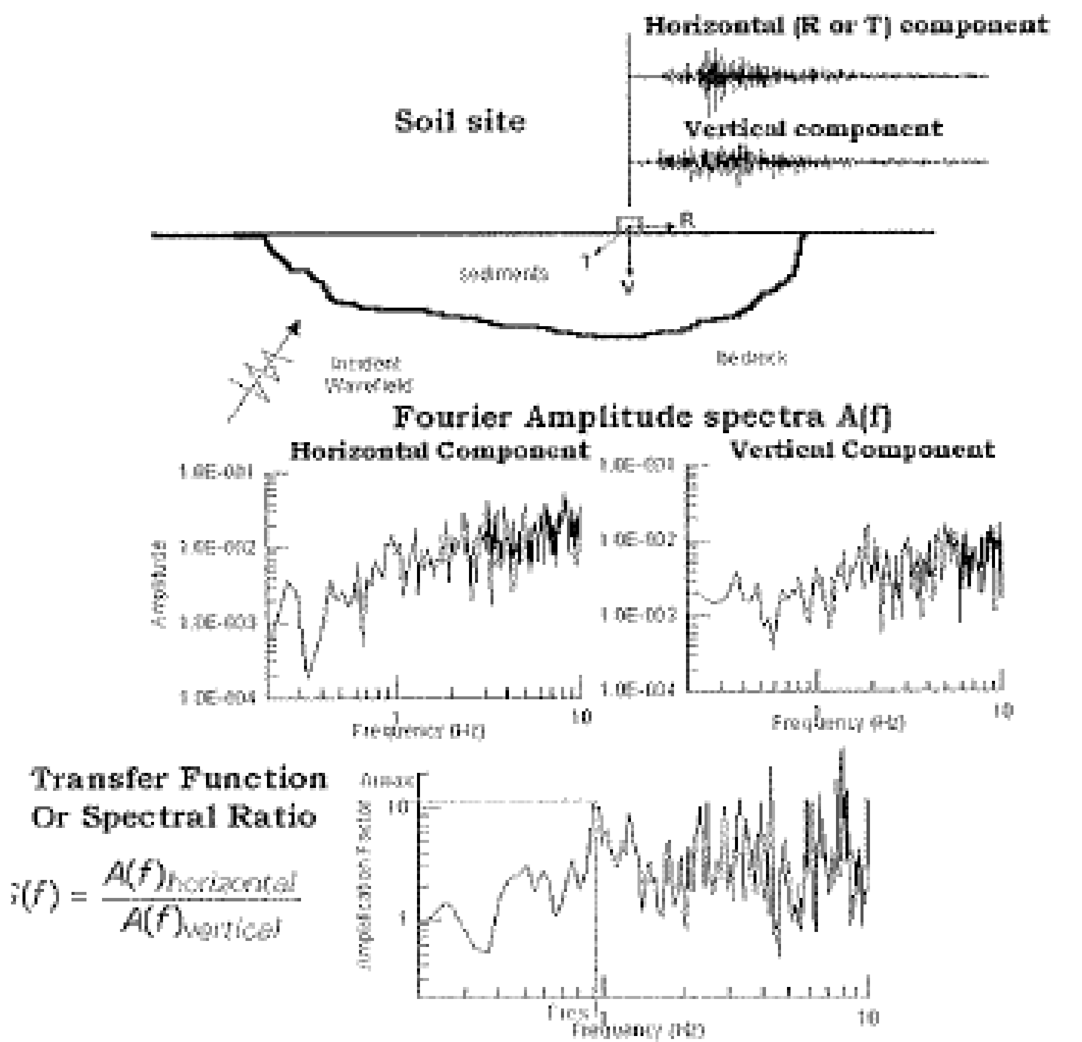


Fig. 5.5. Description of the Horizontal to Vertical Spectral Ratio Technique (HVSR)

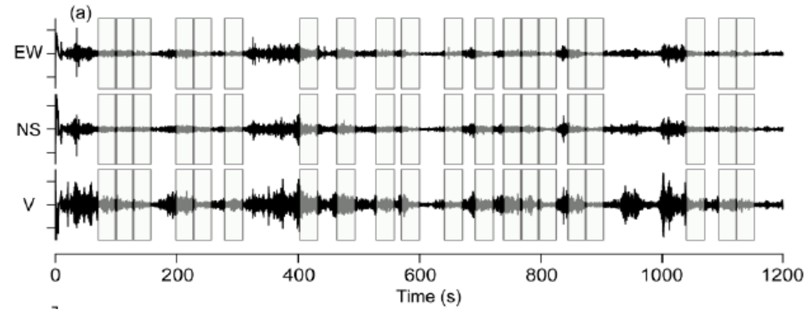
MHVSR method

Microtremor Horizontal-to-Vertical Spectral Ratio method
Nakamura (1989)

- Record vibrations for ~15-30 minutes with one tri-axial seismometer

MHVSR method

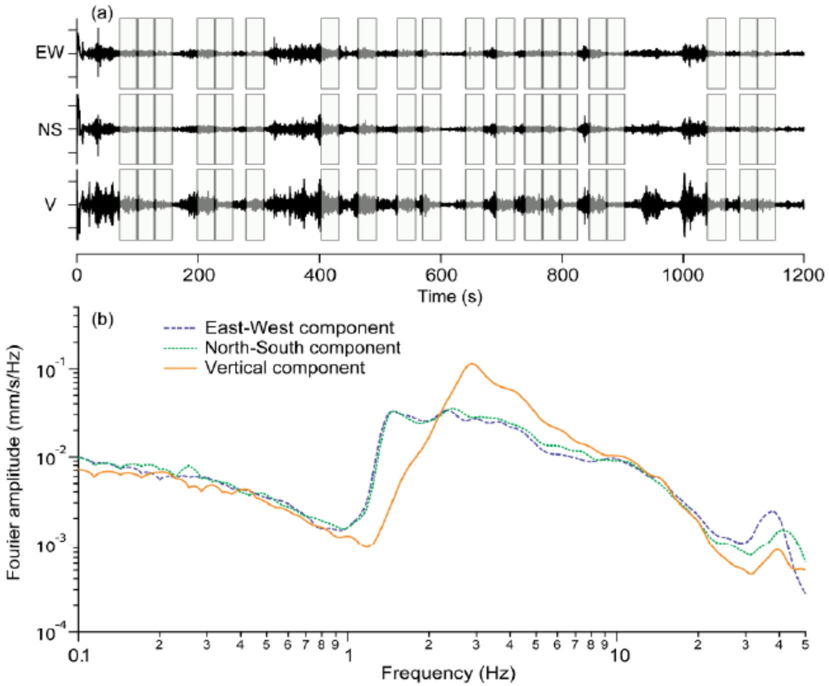
Microtremor Horizontal-to-Vertical Spectral Ratio method



20-min recording

MHVSR method

Microtremor Horizontal-to-Vertical Spectral Ratio method

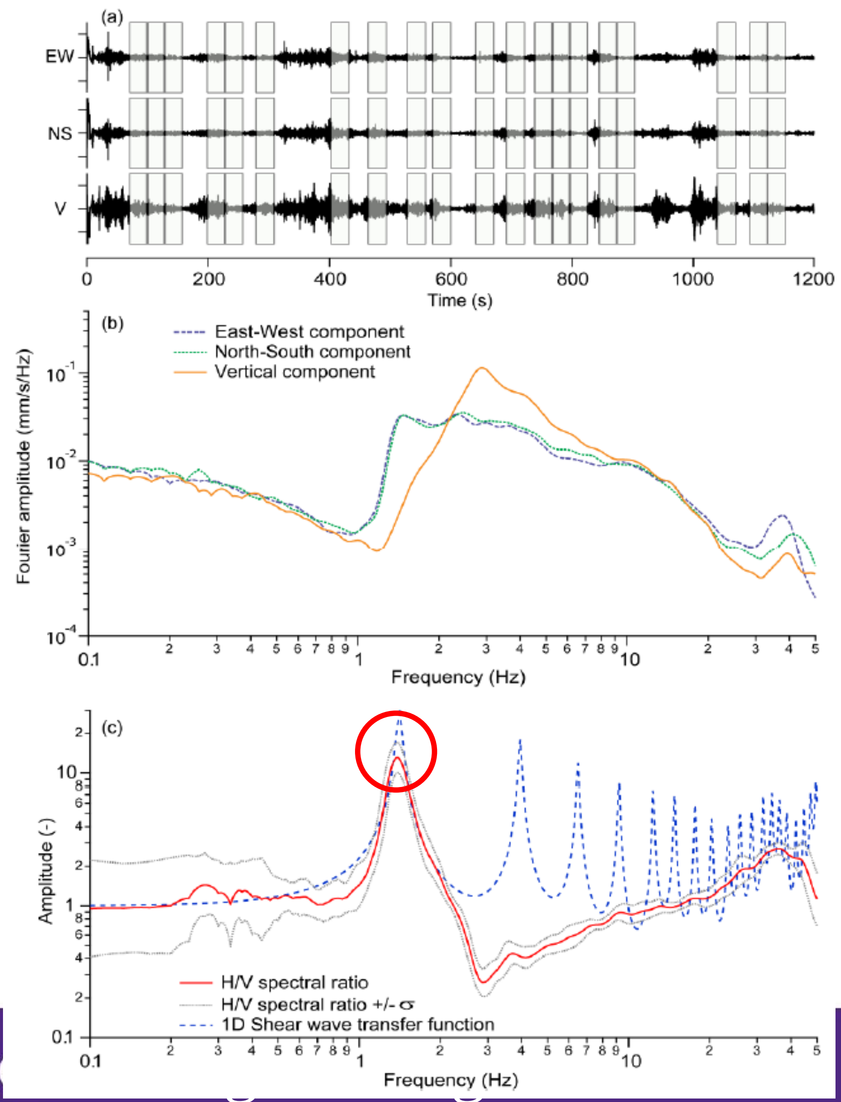


20-min recording

(Time-averaged) Fourier spectra

MHVSR method

Microtremor Horizontal-to-Vertical Spectral Ratio method



20-min recording

(Time-averaged) Fourier spectra

(Time-averaged) Horiz. Ave. HVSR

$$f = \frac{Vs}{4h}$$

If Vs = 200 m/s, then h = 30 m.

If h = 50 m, then Vs = 340 m/s.

H/V decomposition

$$\frac{H}{V} = \frac{H_{body} \square H_{Love} \square H_{Rayleigh}}{V_{body} \square V_{Rayleigh}}$$

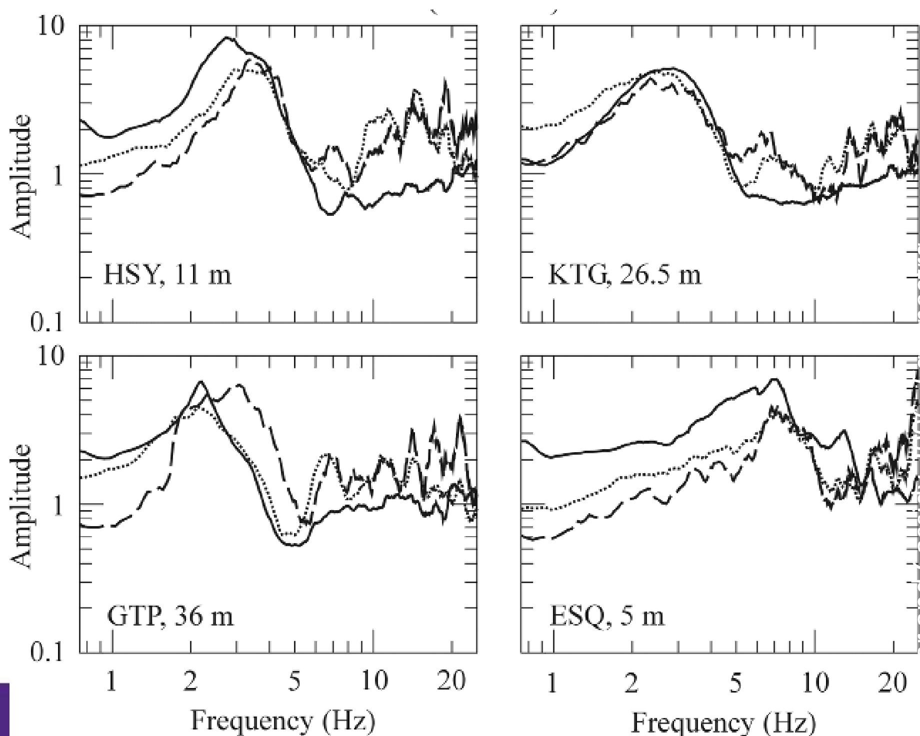
Body waves — Surface waves

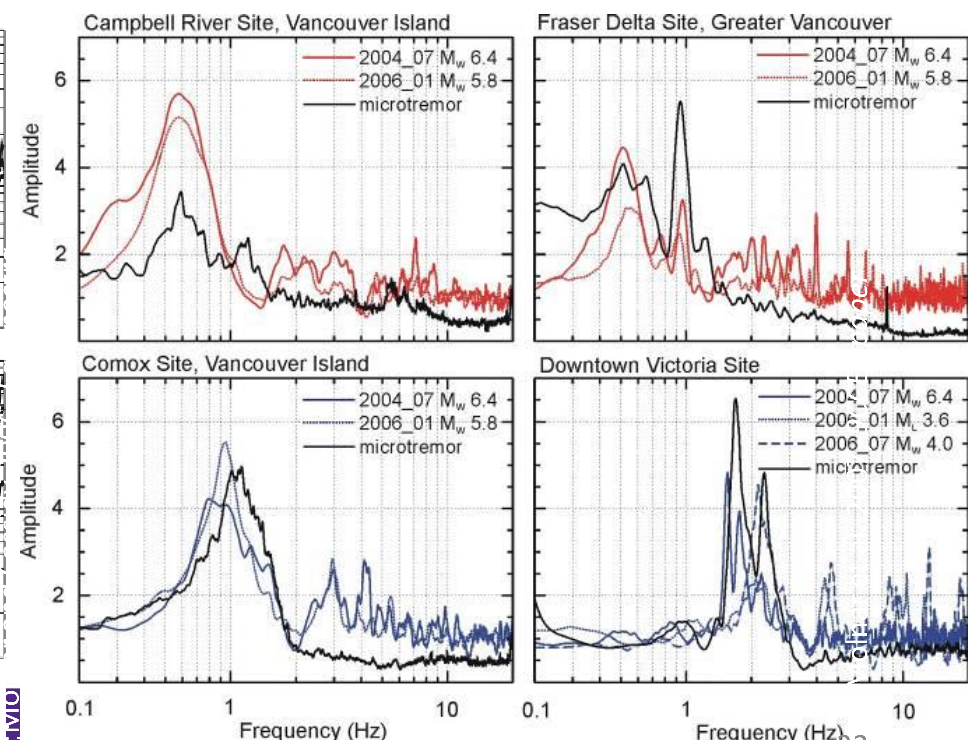
Impedance contrast	Composition
Strong ([4,∞[)	Rayleigh+Love
Moderate([3, 4])	Love+a bit of Rayleigh
Low (]∞,3])	Body waves+Love

After Bonnefoy-Claudet et al. (2008)

British Columbia

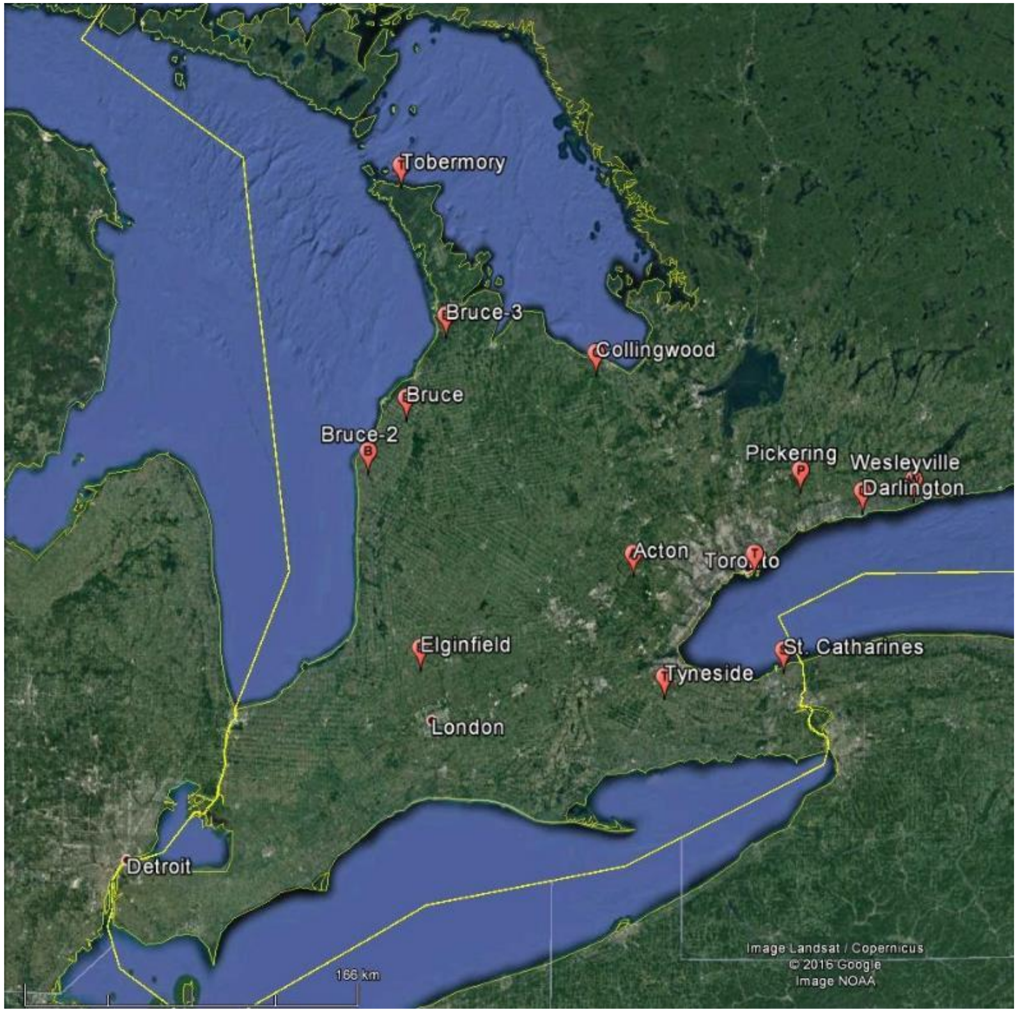
- Microtremor HVSRs replicate weak-motion earthquake site response (Molnar & Cassidy 2006)
- Amplification functions (MHVSR and/or EHVSR) determined at ~106 BC strong-motion stations
  - Cassidy et al. 1997, 1999, 2003; Onur et al.2004; Molnar et al. 2004, 2006, 2007;





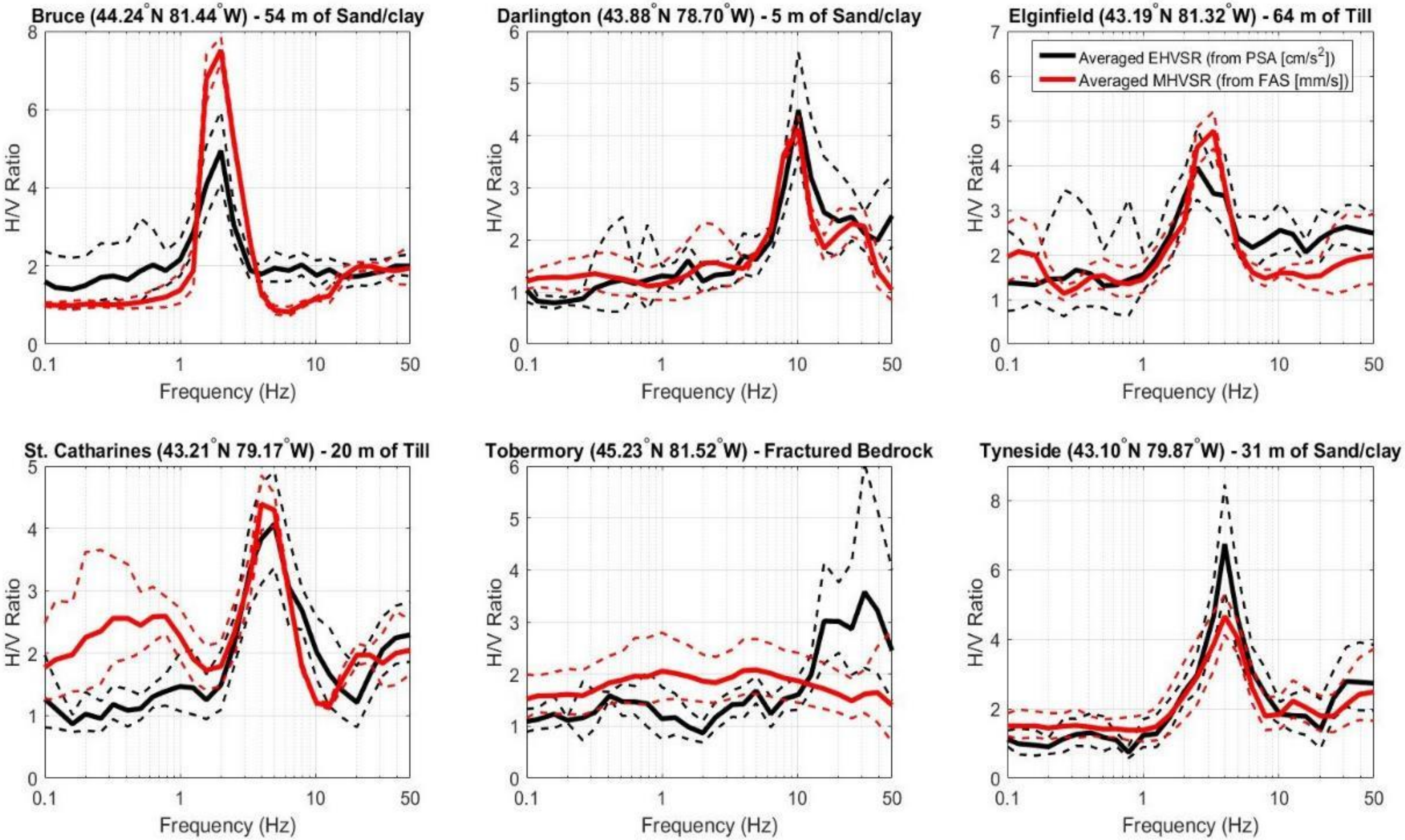
Ontario

- 15 seismograph stations surveyed during summer 2016 campaign across southern Ontario
- Purpose: inclusion of regional site amplification in ShakeMaps
- Stations occur on a variety of surficial site types, including: bedrock, glacial till, sand or clay and very soft organic sediment



Braganza, Atkinson, Molnar (2017) *SRL*

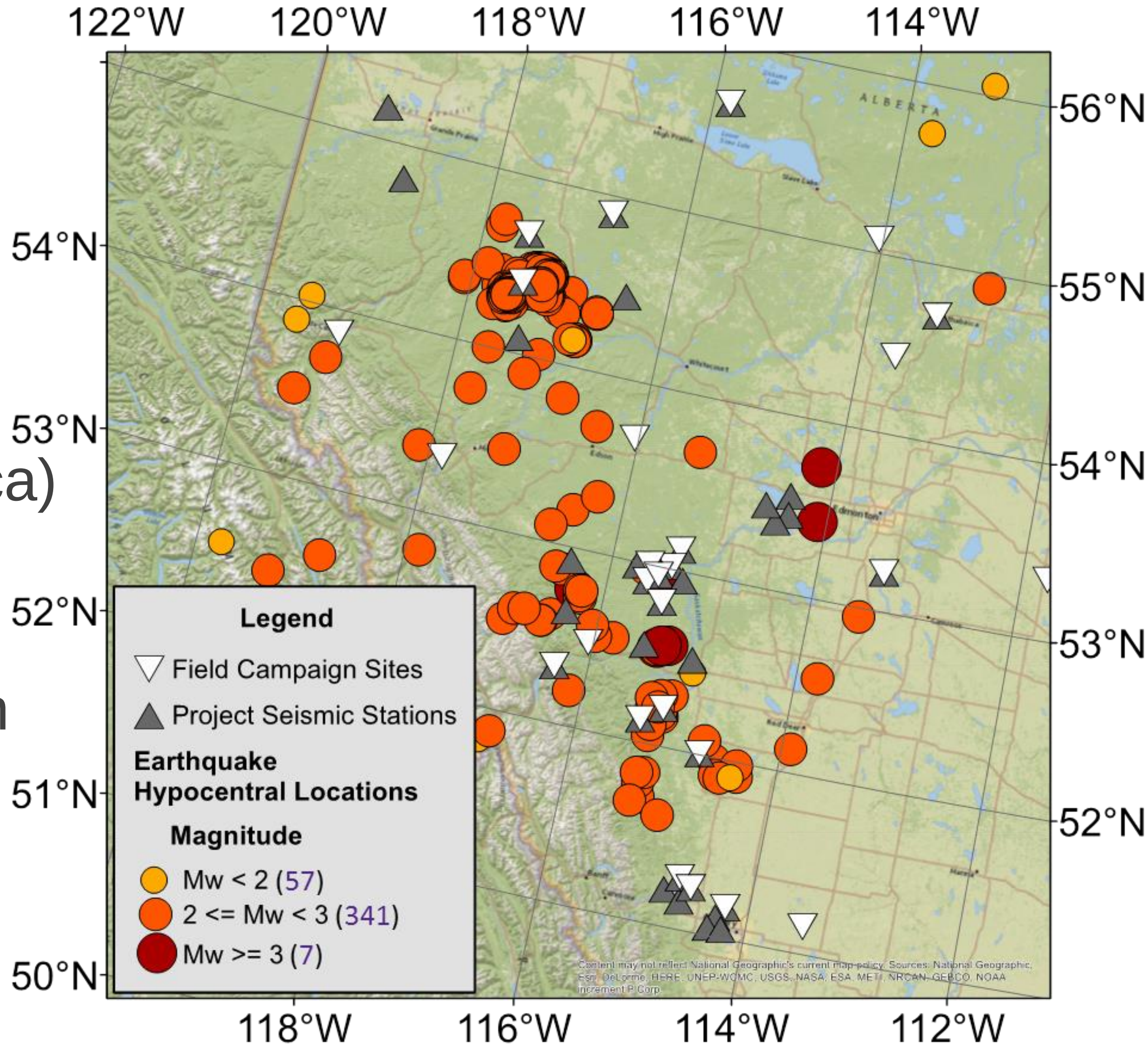
Agreement in f_{peak} of average microtremor and earthquake amplification response



Braganza, Atkinson, Molnar (2017) *SRL*

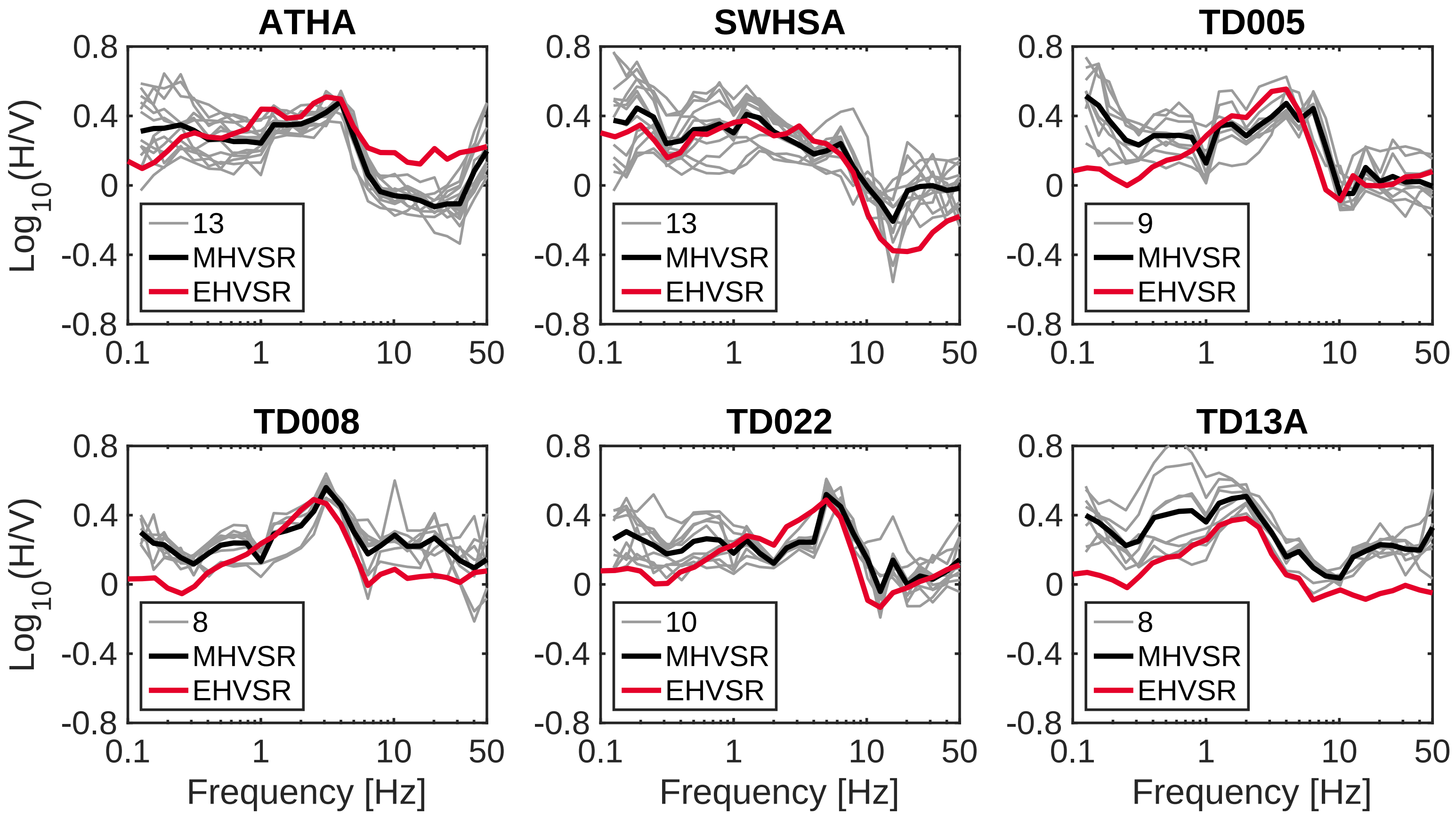
Alberta

- Canadian induced seismicity collaboration (inducedseismicity.ca)
- 26 seismograph stations visited in 2016 field campaign (white triangles)
- **405 earthquakes** (Sep 2013 – Feb 2016)



Farrugia, Molnar, Atkinson (2017) *BSSA*
Farrugia, Atkinson, Molnar (2017) *BSSA*

Alberta Agreement in peak frequency of average microtremor and earthquake amplification response (HVSRs)



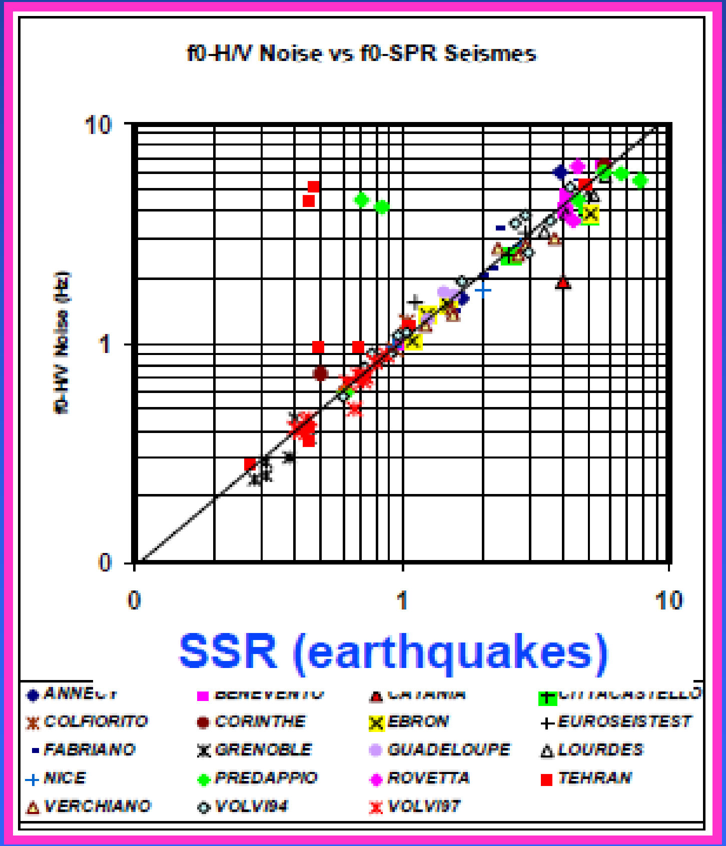
Farrugia, Molnar, Atkinson (2017) *BSSA*

Farrugia, Atkinson, Molnar (2017) *BSSA*

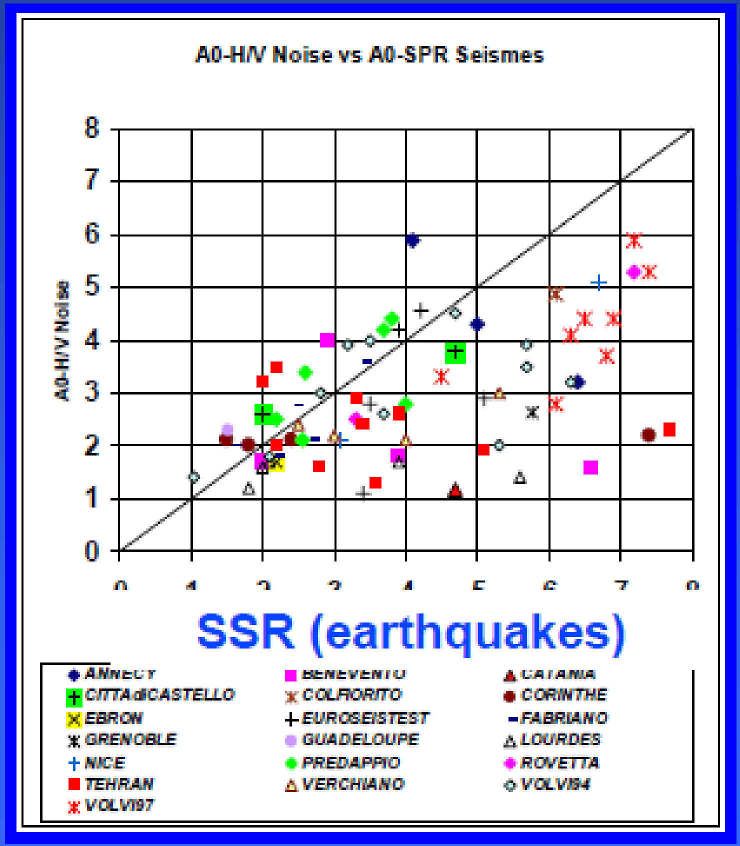
Interpretation of H/V measurements: Results from real data (SESAME results)

H/V (noise)

Frequency



Amplitude



Hagshenas, 2005

SSR vs. HVSR

Summary of empirical results:

e.g., Lachet & Bard 1994; Lachet et al. 1996; Field 1996; Field & Jacob 1996; Bard 1999; Horike et al. 2001; Bard et al. 2004;

- SSR consistent inter-event results; HVSR variable
- MHVSR f_0 agrees with Eq. SSR
- MHVSR amplitude lower than SSR
  - Few studies report agreement in SSR & MHVSR amplitude (Lermo & Chavez-Garcia 1994; Horike et al. 2001; Mucciarelli et al. 2003; Molnar & Cassidy 2006)

SSR vs. HVSR

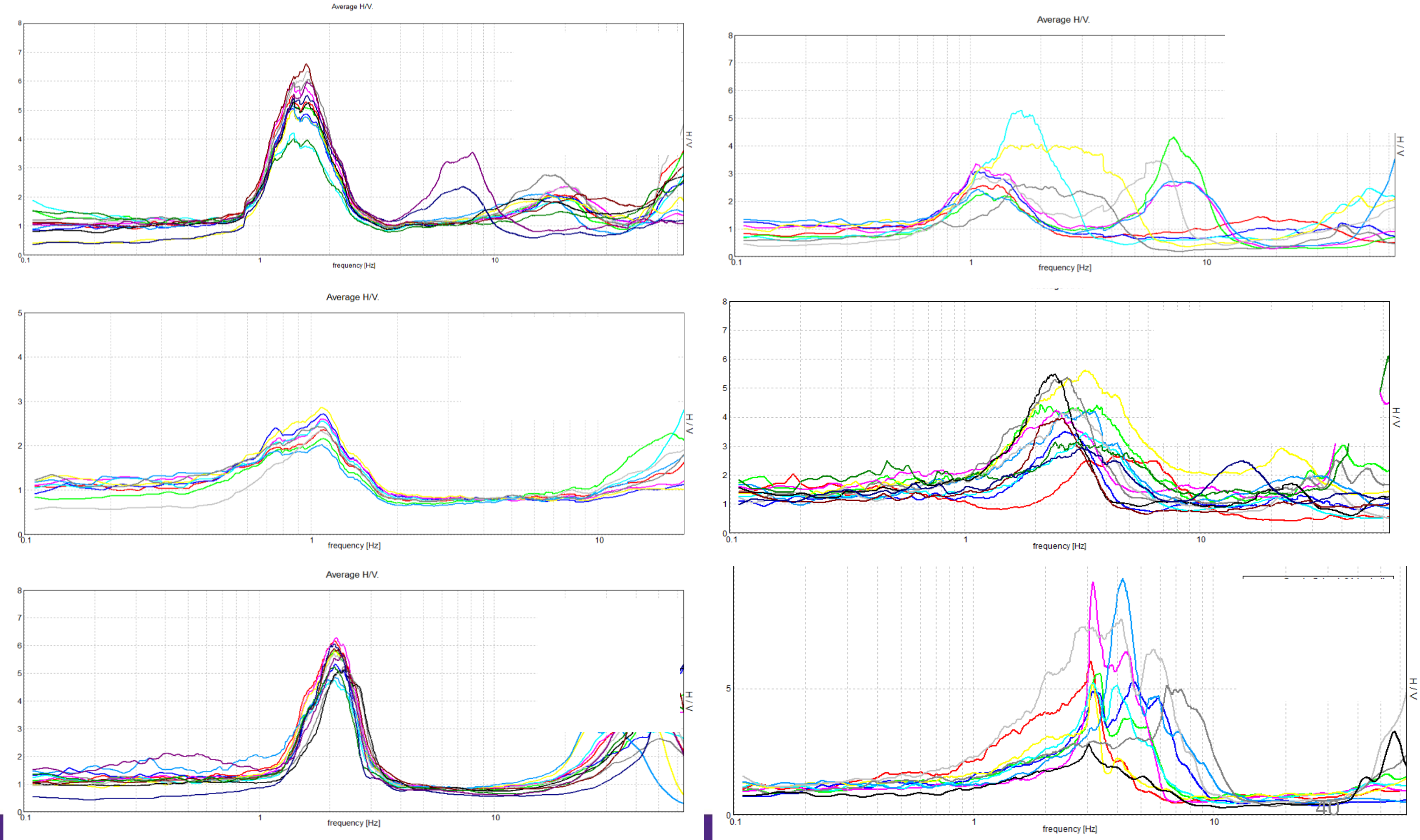
Summary of empirical results:

e.g., Lachet & Bard 1994; Lachet et al. 1996; Field 1996; Field & Jacob 1996; Bard 1999; Horike et al. 2001; Bard et al. 2004;

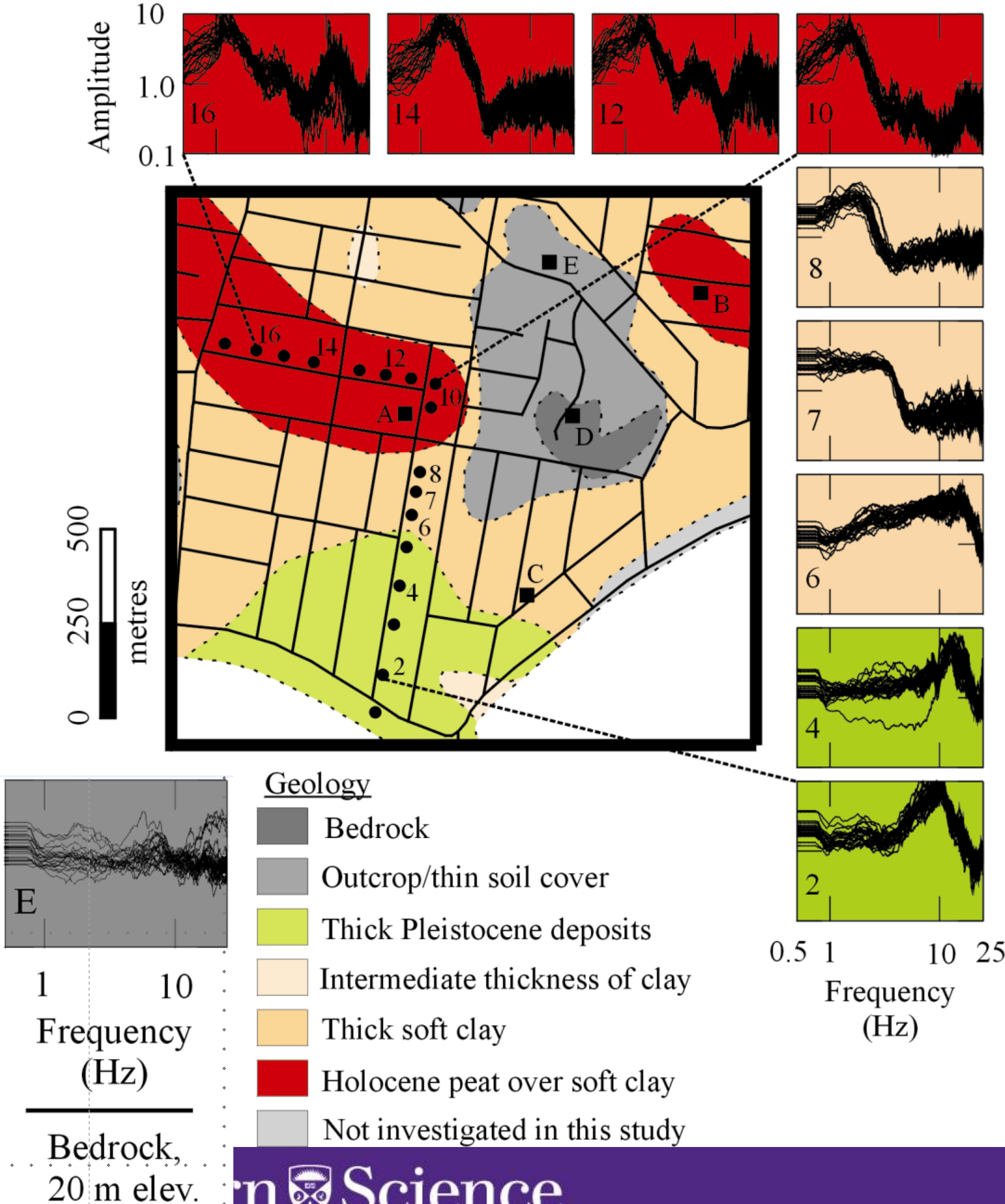
- SSR consistent inter-event results; HVSR variable
- MHVSR f_0 agrees with Eq. SSR
- MHVSR amplitude lower than SSR
  - Few studies report agreement in SSR & MHVSR amplitude (Lermo & Chavez-Garcia 1994; Horike et al. 2001; Mucciarelli et al. 2003; Molnar & Cassidy 2006)
- Eq. SSR → "true" measure of site amplification response
- E/MHVSR → reliable f_0, lower bound est. of amplification

Are we ready for site period in the NBCC ?

MHVSR for subsurface mapping (lateral changes in geology)



MHVSR for subsurface mapping



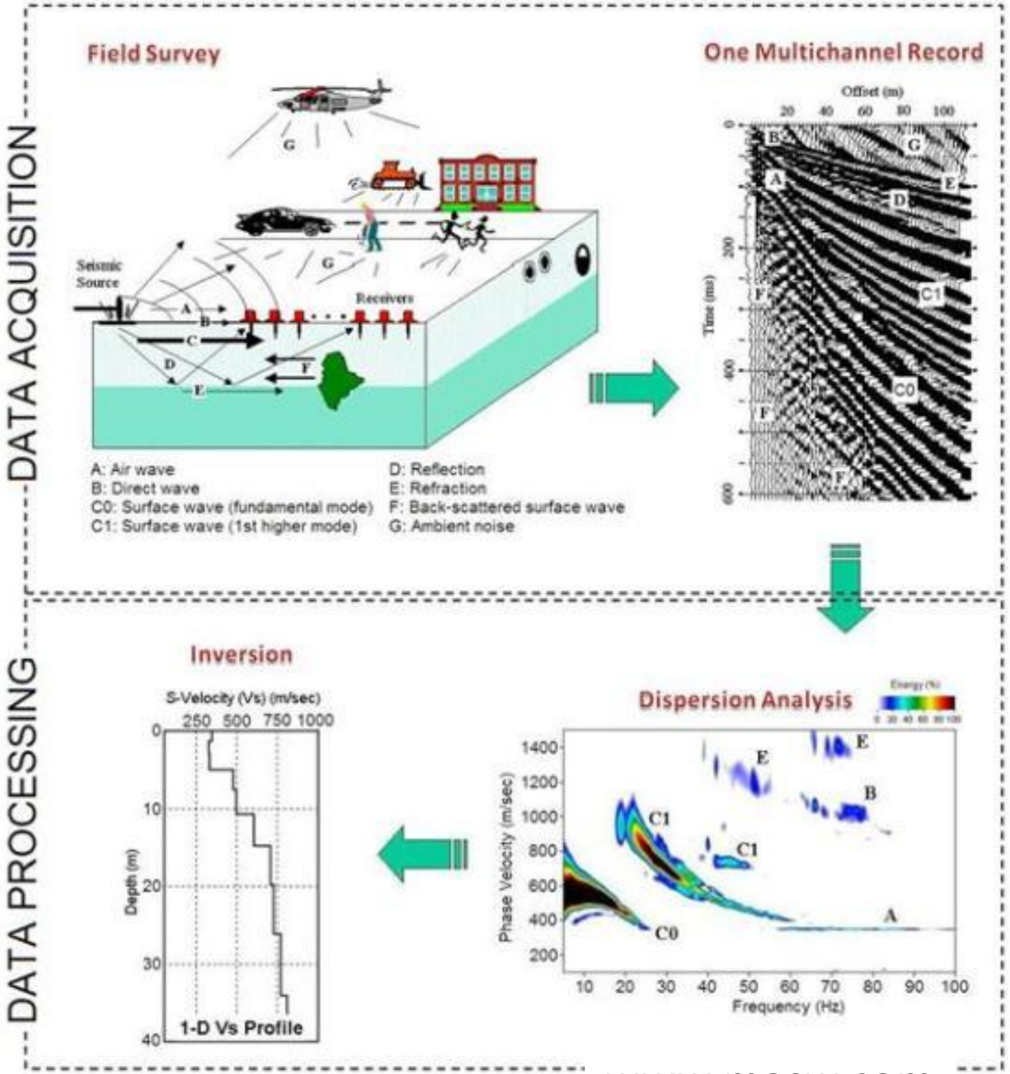
Soft site → high amplitude, low peak frequency

Stiff site → low amplitude, high peak frequency

Rock site → Flat response (no amplification in theory)

Passive Seismic Methods: Ambient Vibration Array (AVA)

Non-Invasive Methods



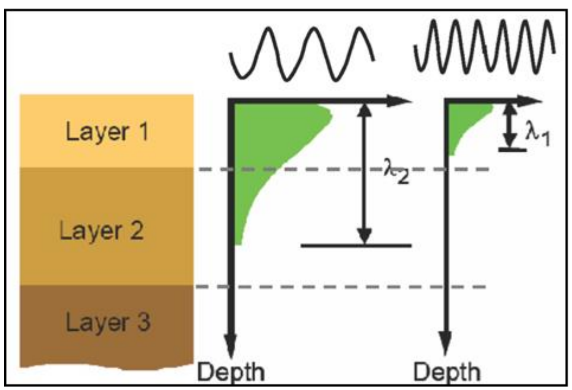
www.masw.com

Multi-sensor or array methods

- Body wave V_P, V_S
  - Refraction
- Surface wave dispersion
  - Active source
    - SASW, MASW, CSWS
    - Resolution depth 10's m
  - **Passive source**
    - **2D arrays; MAM or AVA (hr/fk, MSPAC, ESAC)**
    - Linear array; ReMi
    - Resolution depth 100's m

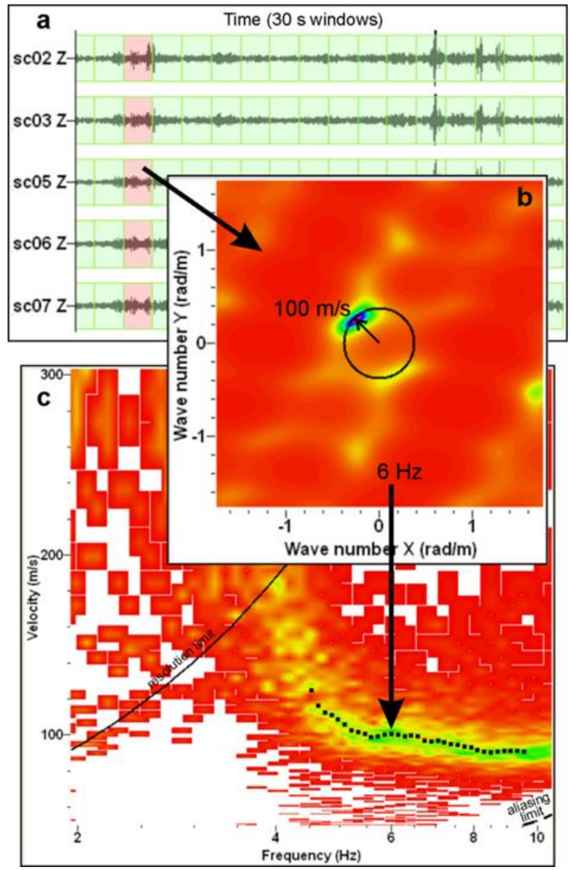
Microtremor array method (MAM; Aki, 1957)
Ambient vibration analysis (AVA)

1. Record ambient vibrations with seismic array

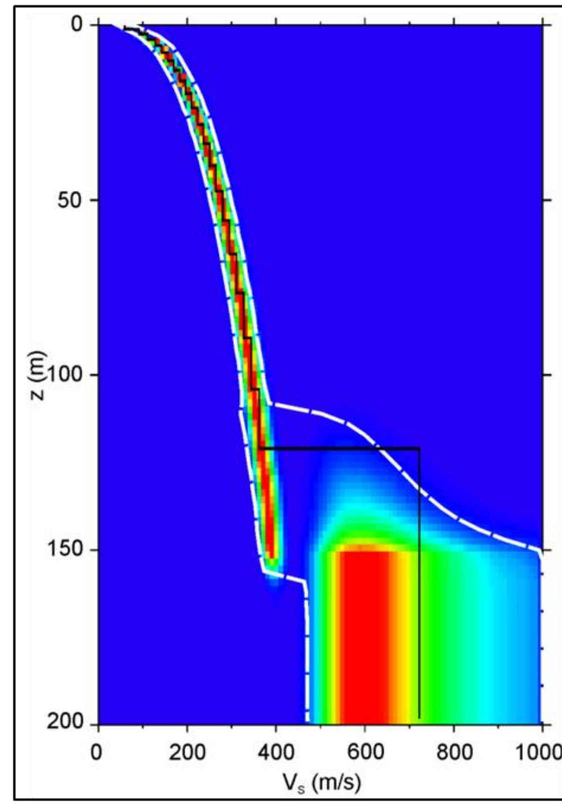


Vary array size to resolve different wavelength ranges (depth)

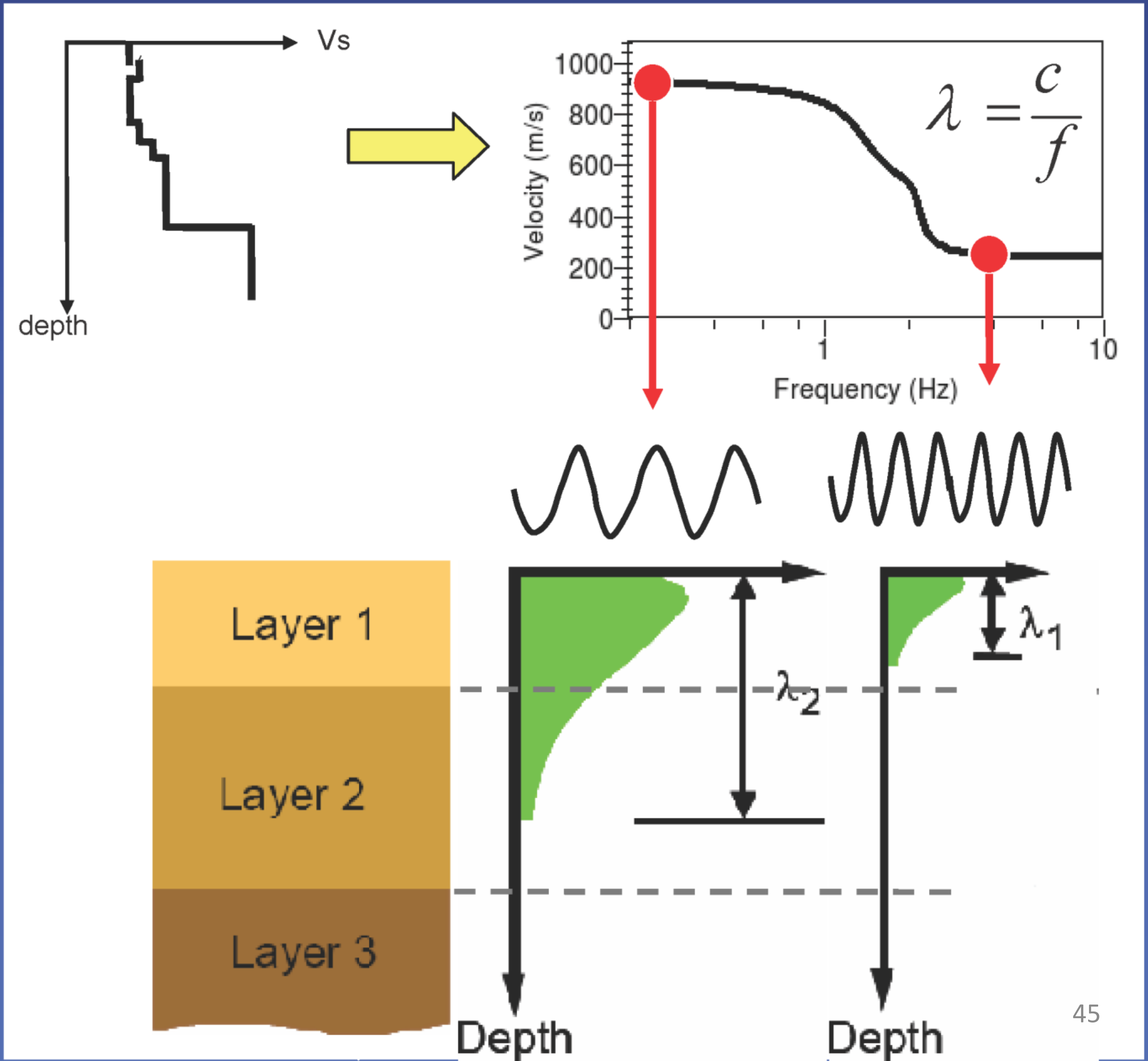
2. Extract dispersion curve



3. Invert for shear-wave velocity depth profiles



Links between subsurface structure and phase velocity of surface waves



Surface Waves

=

Dispersive Waves

velocity varies with frequency

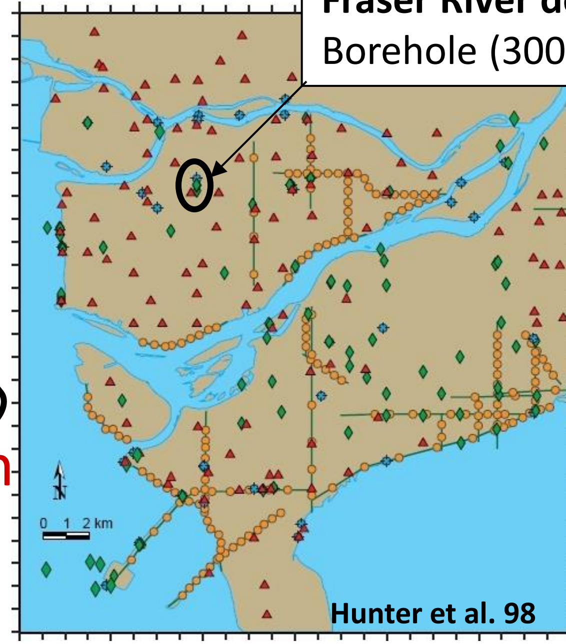
Passive Seismic Methods: Reliable Vs profiles or just reliable Vs30 ?

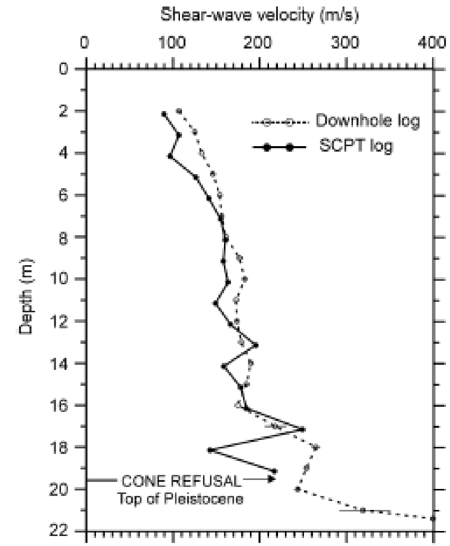
V_S-profiling history on the Fraser River delta

- Downhole logging
- Seismic cone penetration testing [SCPT]
- Surface reflection / refraction surveys
- Surface wave techniques
  - SASW or MASW
  - AVA

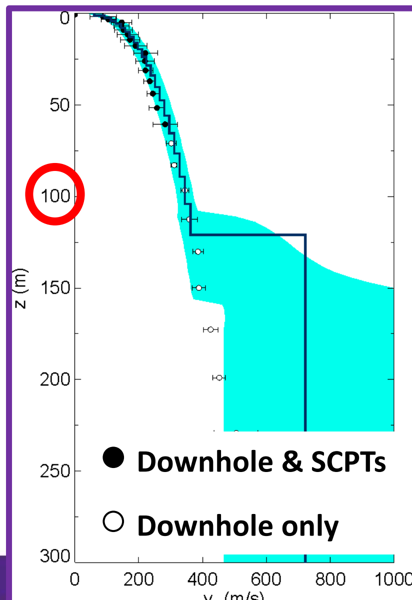
Inter-method variability in Vs is ≤ 25%

Fraser River delta site
Borehole (300 m), 4 SCPT (31-62 m)

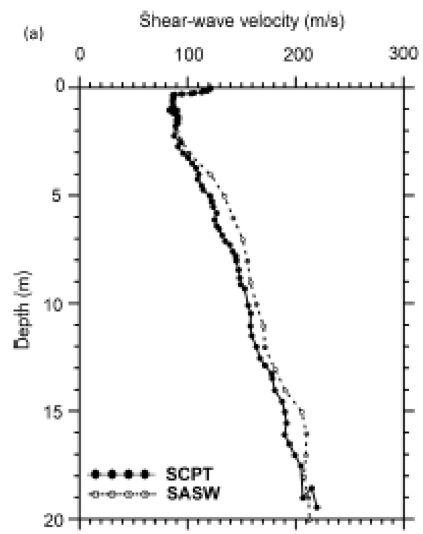




Hunter et al. 91

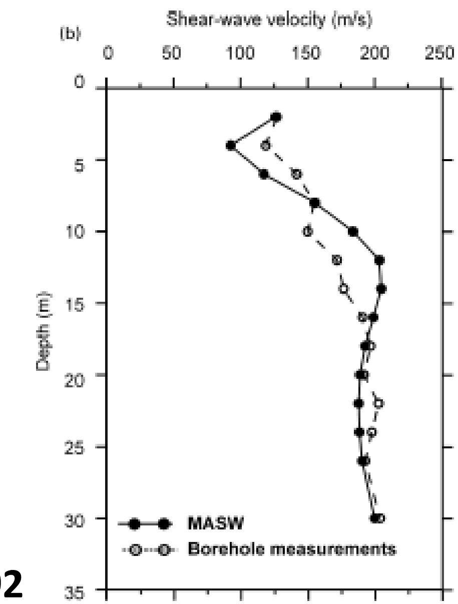


Molnar et al. 10



Addo & Robertson 92

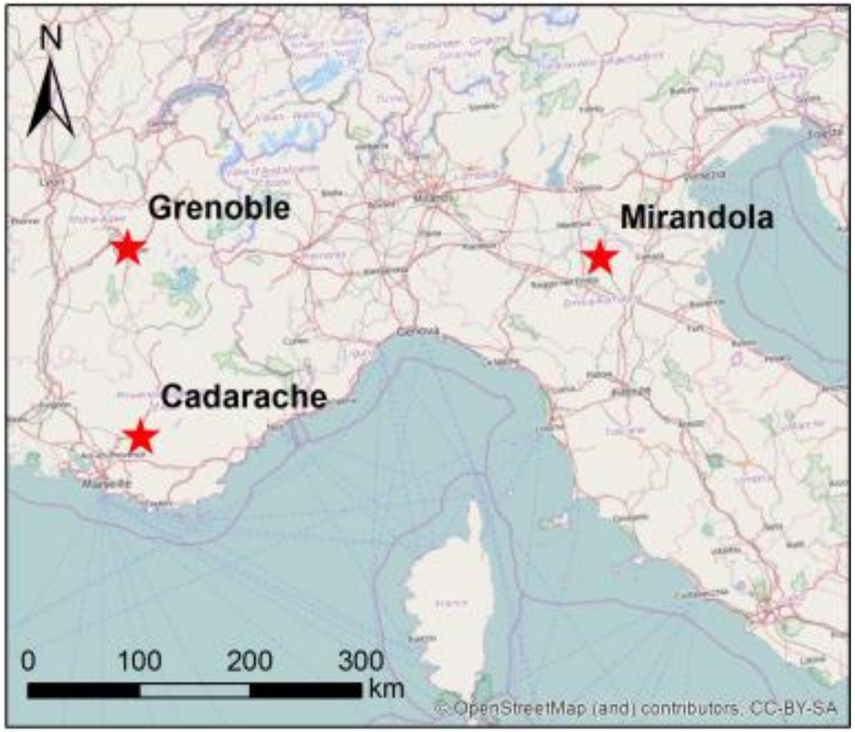
Woeller et al. 93



Xia et al. 00

InterPACIFIC project

- Intercomparison of methods for site parameter and velocity profile characterization
- Soft soil, Mirandola
  - 50-m sandy silty clay
  - 50-m Pleis. marine deposits
  - Pleis. rock-like deposits
- Stiff soil, Grenoble
  - 10's m recent alluvial deposits
  - over Qty clayey-marly deposit
  - Mesozoic bdrk at 500-800 m
- Rock outcrop – Cadarache
  - Cretaceous limestone

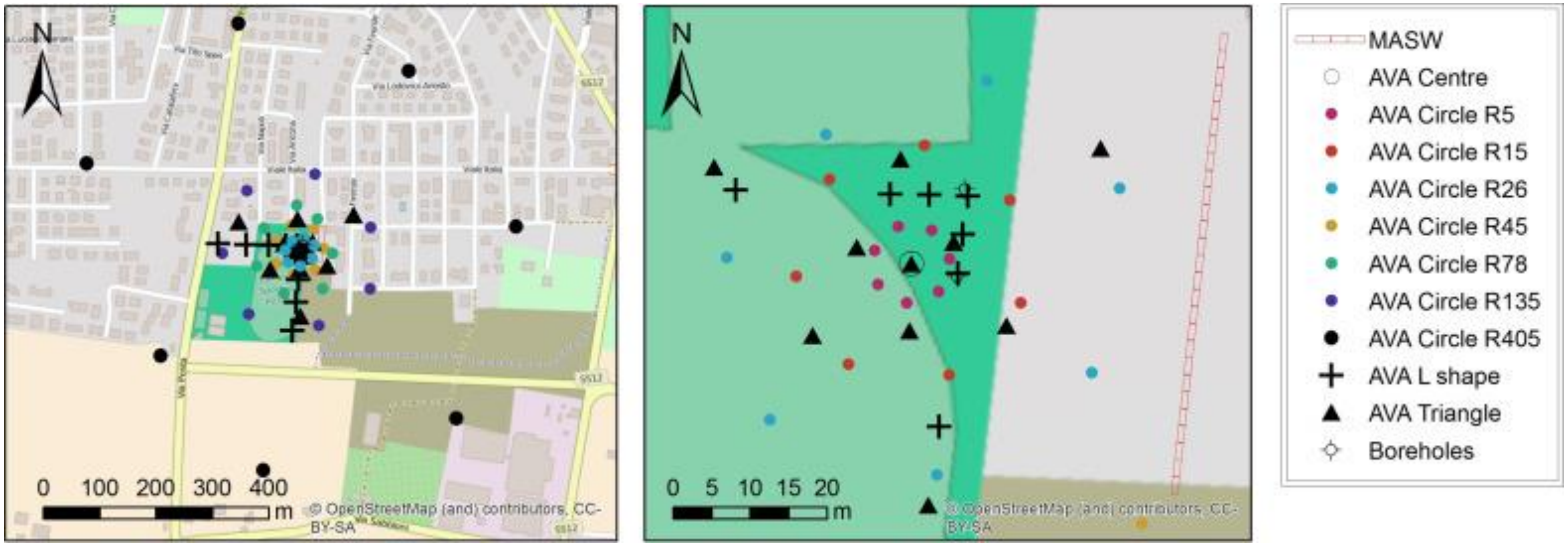


Garofalo et al. 2016, Part I: Intra-comparison of surface-wave methods

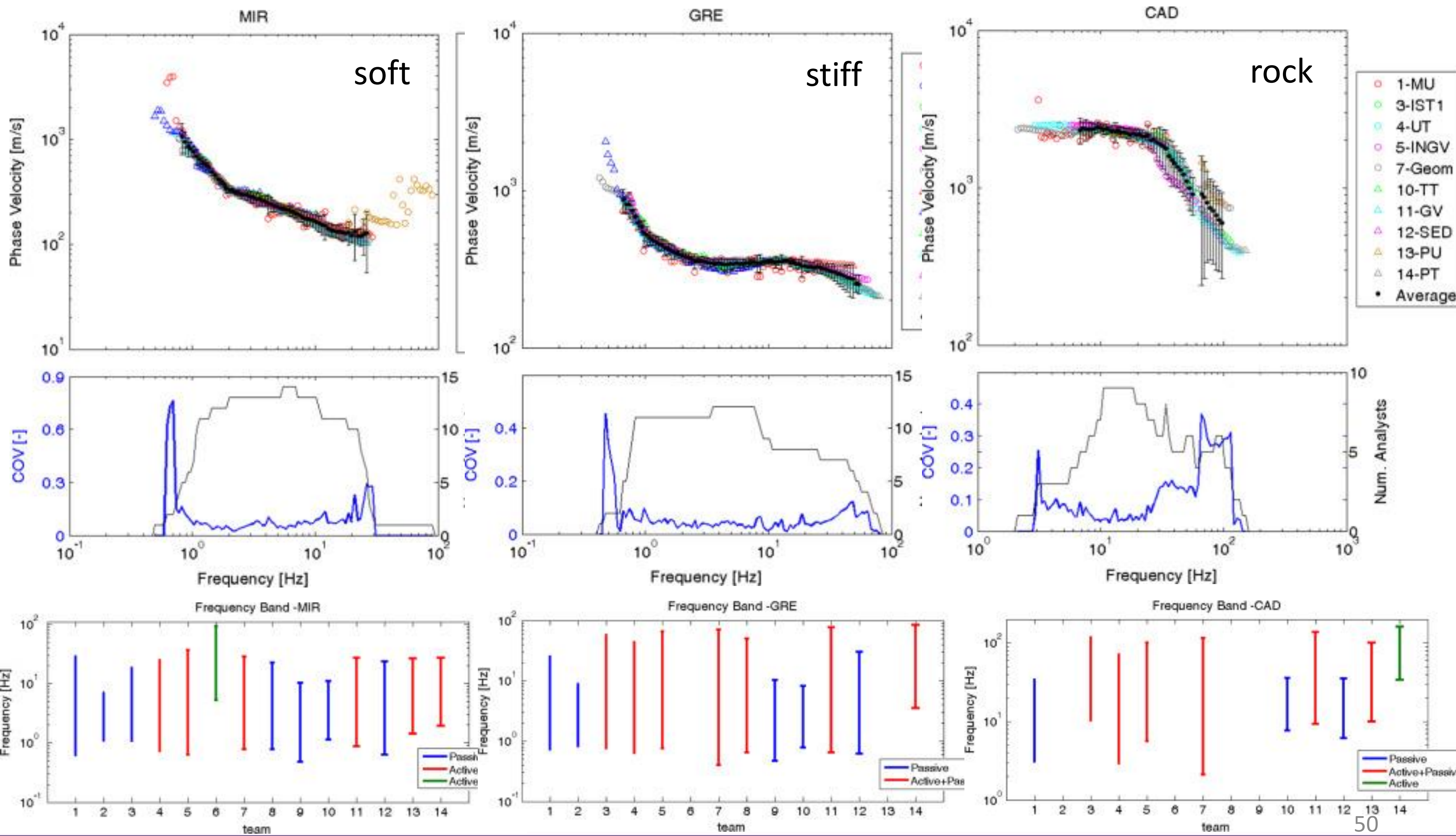
Intra SW methods comparison

- Suite of active & passive data collected at each site & provided to 14 expert-user teams
  - Free to adopt strategy and procedures each team considered the best to estimate a V_S profile
  - No requirements on investigation depth and resolution

Example of active & passive array recordings - Mirandola site

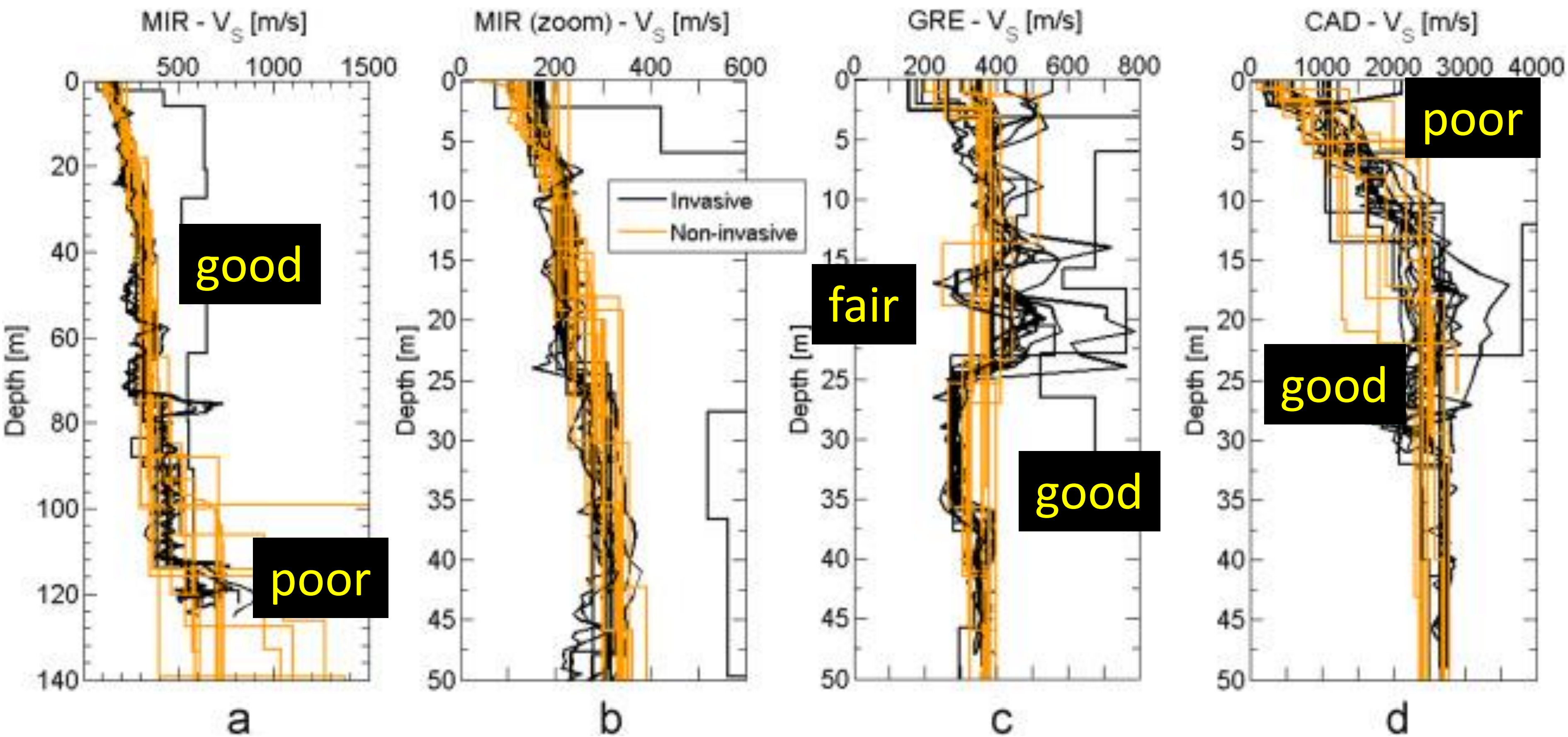


Intra SW methods comparison



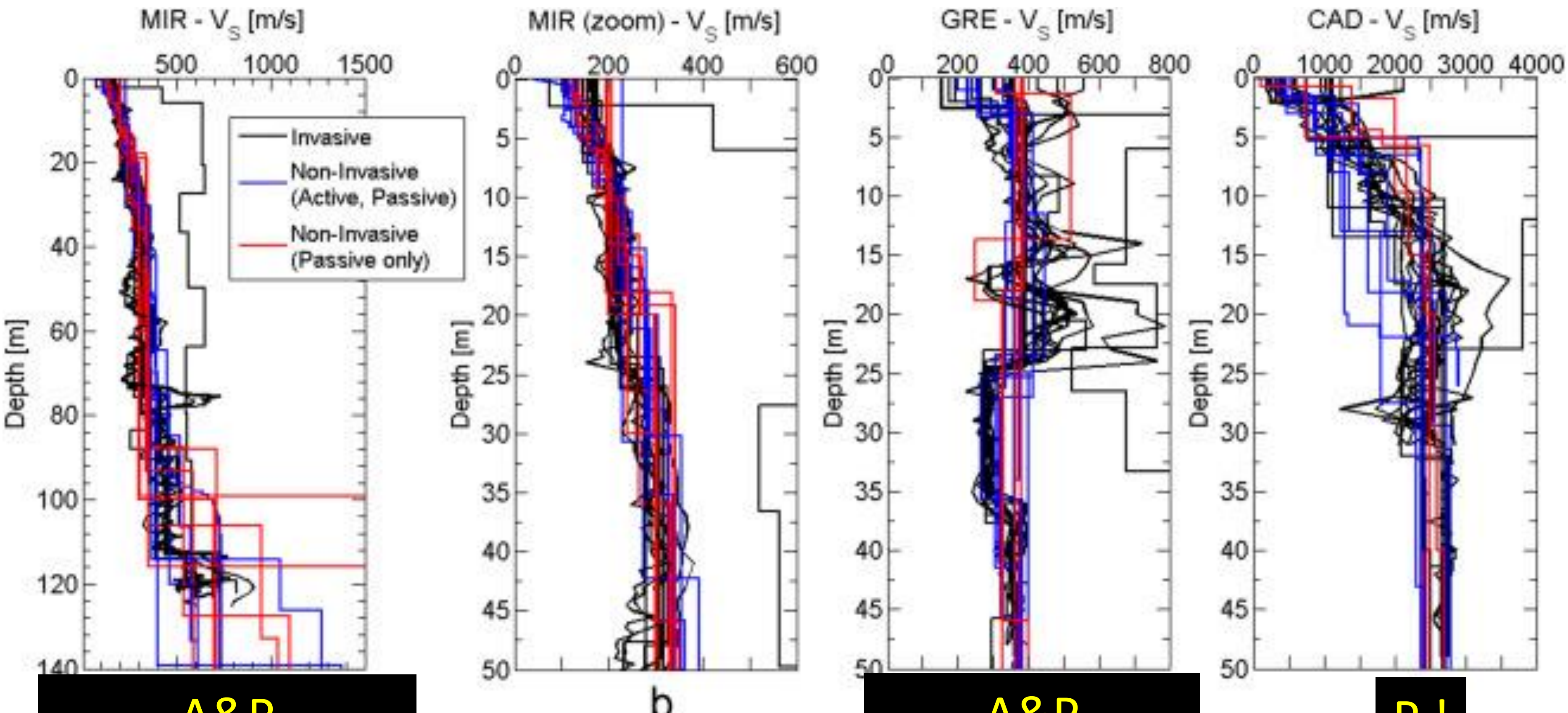
Garofalo et al. 2016, Part I: Intra-comparison of surface-wave methods

Inter-method comparison



Garofalo et al. 2016, Part II: Inter-comparison between surface-wave and borehole methods

Inter-method comparison



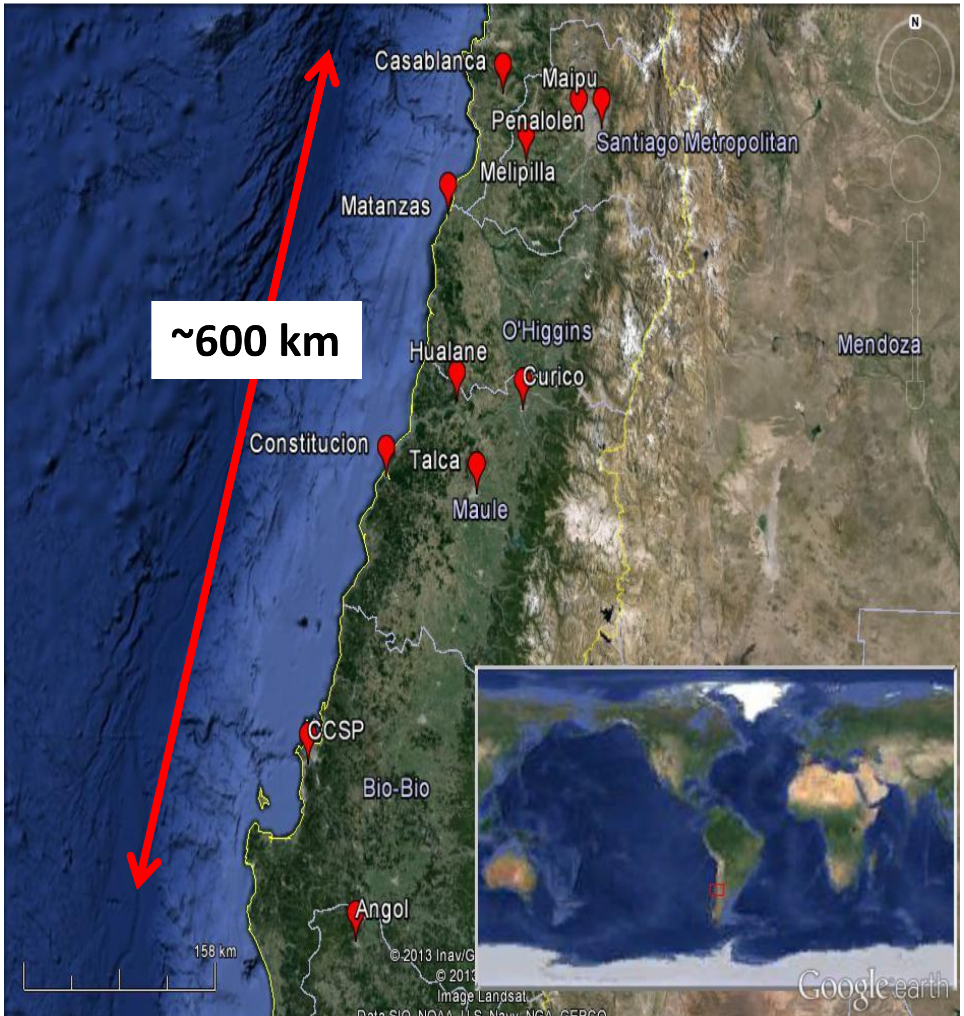
A&P
P only - Vs30 ok

A&P
P too uniform

P !

Garofalo et al. 2016, Part II: Inter-comparison between surface-wave and borehole methods

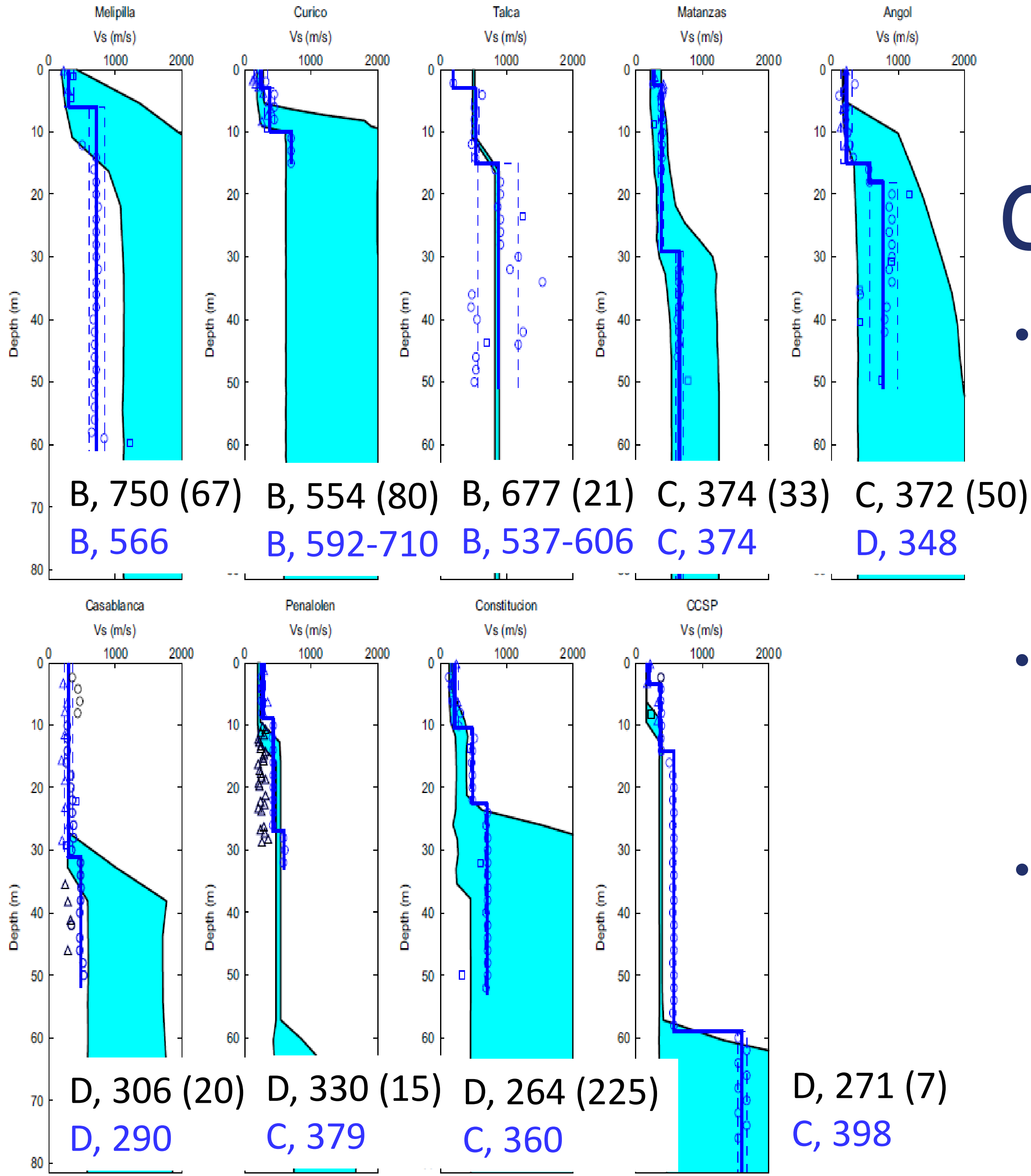
Case studies: Chile



Molnar, Ventura, Boroschek & Archila, 2015. SDEE.

- Requested to provide non-invasive $V_S(z)$ profiling at strong-motion instrument sites
- Part of a larger detailed site characterization project following the 2010 M8.8 Maule earthquake
- Single borehole drilled to 30-80 m depth at each site
- SPT, downhole v_S, & bender element v_S

Blind-Test Comparison



- Overall average relative difference in v_S is:
  - **~10% upper soil layers**
  - **~30% for bedrock layer**
- Site classification relatively consistent irrespective of methodology
- Exceptions:
  - MAM lower - Penalolen & CCSP
  - MAM higher - Angol

Passive Methods – Final Thoughts

- Reliable Vs30 values → Yes
- Reliable Vs profiles → Often, combined with active methods better in near-surface (for Vs30)

- You should ALWAYS observe the dispersion or MHVSR data and the model fit to this data
- You should NOT receive only Vs profile results
- You should NOT receive only a single Vs profile or Vs30 estimate – there is uncertainty, there should be a reported range in Vs and Vs30

Metro Vancouver Seismic Microzonation Mapping Project

Metro Vancouver
Seismic Microzonation Project

- **Generate comprehensive earthquake hazard maps** for the Metro Vancouver region of British Columbia.
- Involve the assessment and mapping of:
  - **Earthquake shaking hazard** (**amplification**, **site class**, **site period**)
  - **Liquefaction potential hazard**
  - **Landslide potential** or **slope instability hazard**
- At a **neighbourhood scale** with an initial focus in the western communities of Metro Vancouver

NEW!

BRITISH COLUMBIA | Emergency Management BC

Institute for Catastrophic Loss Reduction

Western UNIVERSITY · CANADA

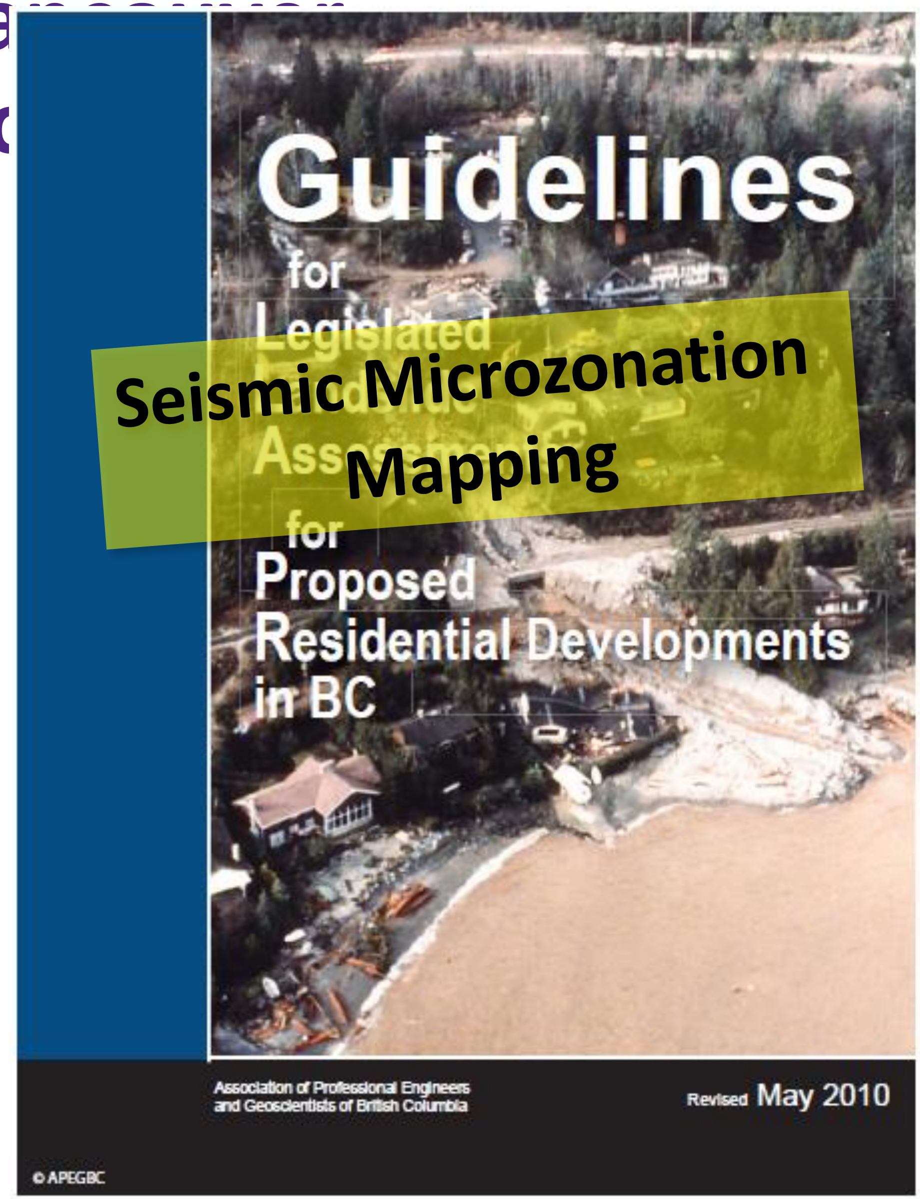
Metro Va
Seismic Microz

Additional funding supplied from EMBC Disaster Mitigation Branch for:

1. Hazard mapping of an additional community area
2. EGBC led Peer Review of project methodologies and analyses
3. EGBC Professional Practice Guidelines for Seismic Microzonation Mapping in BC

- One year extension, project completion: March 31 2023

ENGINEERS & GEOSCIENTISTS
BRITISH COLUMBIA



Geodatabase development

- BC does not have a public geo-database
- Other Vs databases
  - Greece,
  - USA
  - European seismic stations
- Geotechnical borehole data available online in Ontario
  - MTO and OGS

Bulletin of the Seismological Society of America, Vol. XX, No. xx, pp. –, – 2017, doi: 10.1785/0120160335

Development of V_S Profile Database and Proxy-Based Models for V_{S30} Prediction in the Pacific Northwest Region of North America

by Sean K. Ahdi, Jonathan P. Stewart, Timothy D. Ancheta, Dong Youp Kwak, and Devjyoti Mitra

Abstract Models for ergodic site response are frequently conditioned on time-averaged shear-wave velocity in the upper 30 m of a site (V_{S30}). However, in the Pacific Northwest (PNW) of North America, only 13% of the seismic recording stations contributing data to the Next Generation Attenuation-Subduction (NGA-Sub) project have measurement-based V_{S30} values. We present a shear-wave velocity (V_S) measurement

Bulletin of the Seismological Society of America, Vol. 104, No. 6, pp. 2827–2841, December 2014, doi: 10.1785/0120130331

Compilation of a Local V_S Profile Database and Its Application for Inference of V_{S30} from Geologic- and Terrain-Based Proxies

by Jonathan P. Stewart, Nikolaos Klimis, Alexandros Savvaidis, Nikos Theodoulidis, Elena Zargli, George Athanasopoulos, Panagiotis Pelekis, George Mylonakis,* and Basil Margaris

Abstract The time-averaged shear-wave velocity in the upper 30 m of a site (V_{S30}) is commonly used for ground-motion prediction. When measured velocities are unavailable, V_{S30} is estimated from proxy-based relationships developed for application on global or local scales. We describe the development of a local relationship for Greece, which begins with compilation of a profile database (PDB) from published sources and engineering reports. The PDB contains 314 sites; 238 have profile depths $\geq$ 30 m and 59 are within 100 m of accelerographs. We find existing relations for extrapolating a time-averaged velocity for depths less than 30 m to V_{S30} to over-predict V_{S30}. We present equations for these extrapolations.

Geodatabase

- **Initial Request for Geo Data, Nov. 2017**

How can you help?

To properly assess these hazards, knowledge of subsurface geology and its parameters are required which can be achieved by the collection and analysis of geophysical and geotechnical information.

If you or your organization (municipal engineering department, engineering firm, etc.) has any of the following geophysical or geotechnical information, please contact Dr. Sheri Molnar (smolnar8@uwo.ca). Preference is for information at depths greater than 10 metres and in digital file format. We will accommodate any confidentiality concerns.

- Stratigraphy or lithology at depths greater than 10 metres
- Groundwater level or monitoring
- Historical water channel (stream) maps and/or pre-construction aerial photos
- Compression-wave or shear-wave velocity measurements
- Standard penetration (blowcounts) or cone penetration (tip resistance, sleeve friction, etc.) measurements
- Soil mechanics laboratory testing including gradation, Atterberg limits, shear strength tests, etc.

Geodatabase

- **Procurement of available datasets (up to March 2018)**

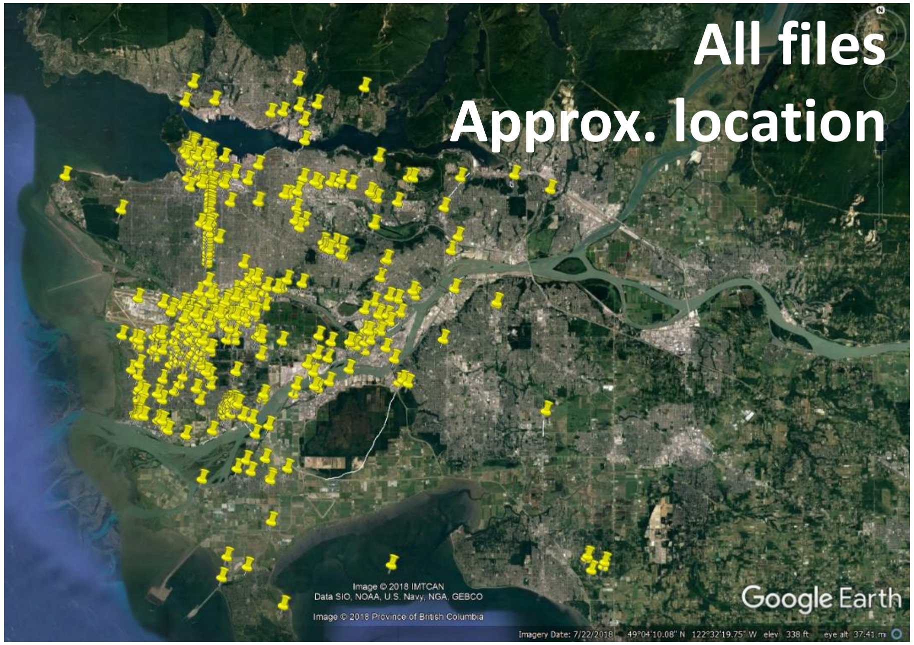
Agencies that have provided data

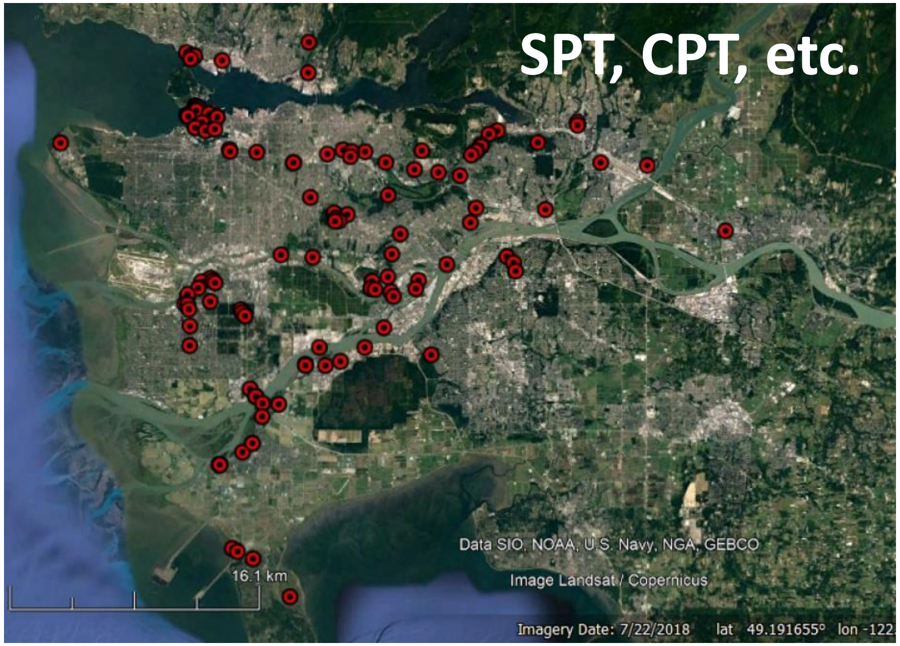
- **City of Coquitlam**
- **City of Delta**
- **NRCAN** (Vancouver)
- **Fortis BC**
- **Translink**
- **GeoPacific**
- **Pat Monahan**
- **City of Surrey**

- Met with several agencies in **July 2018** to obtain data access.
- A Western data sharing agreement was developed is available to share with agencies upon request.
- Got data you could share?

smolnar8@uwo.ca

Geodatabase





- **911 reports from 41 agencies obtained from 6 sources.**
- Tabulating data from the accumulated geo-files for our project analyses
- **Effort is ongoing in obtaining previous geodata from agencies and municipalities, by 2022**

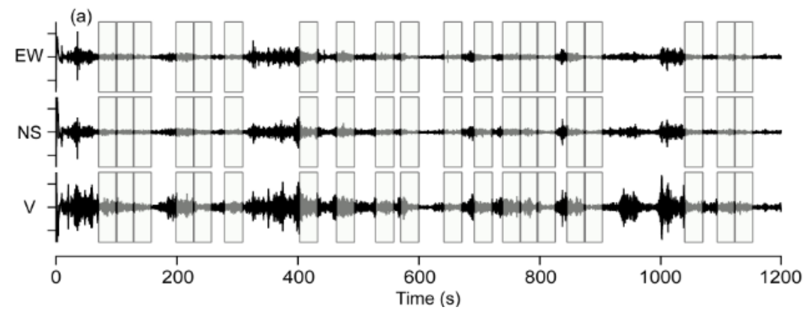
Methods

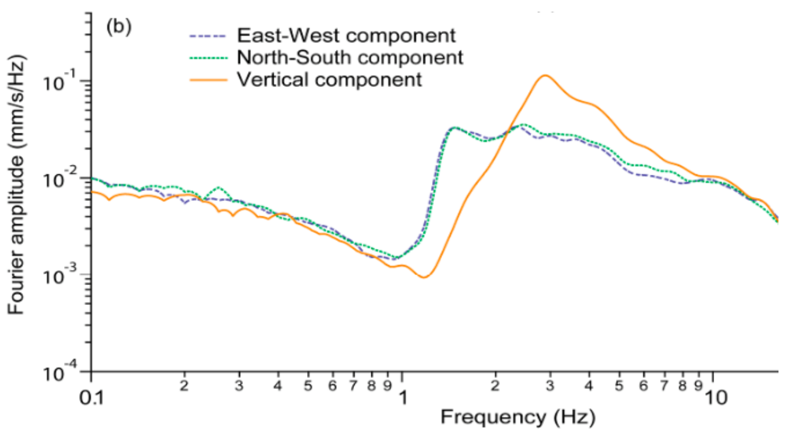
Two main methods:

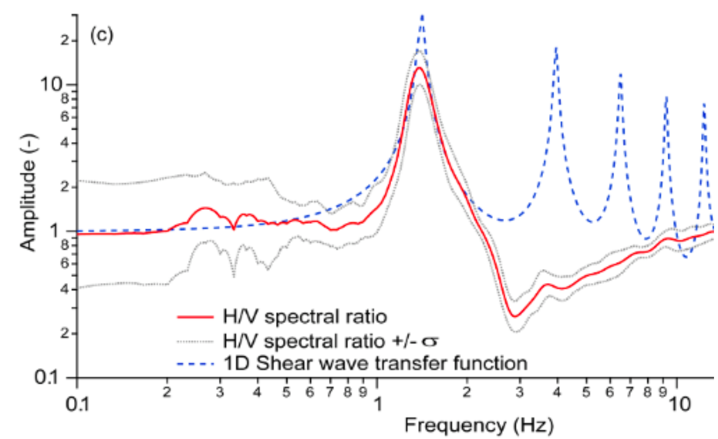
1. MHVSR

A single seismometer placed on ground for ~15 mins (deeper delta site for 30-45 mins.)

Calculate horizontal-to-vertical spectral ratio of microtremor recordings (MHVSR); a measure of ground stiffness and depth to impedance contrast or resonator (glacial till or bedrock)





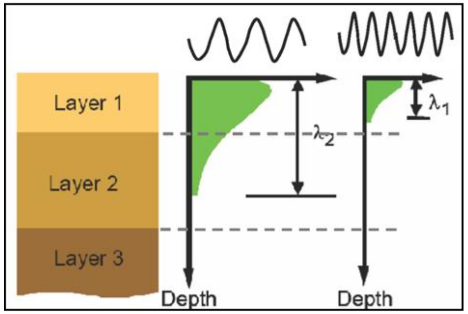


Methods

Two main methods:

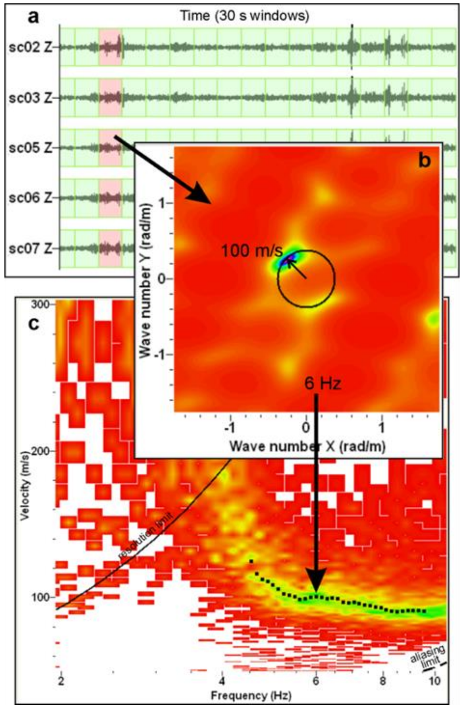
2. Arrays

1. Record ambient vibrations with seismic array

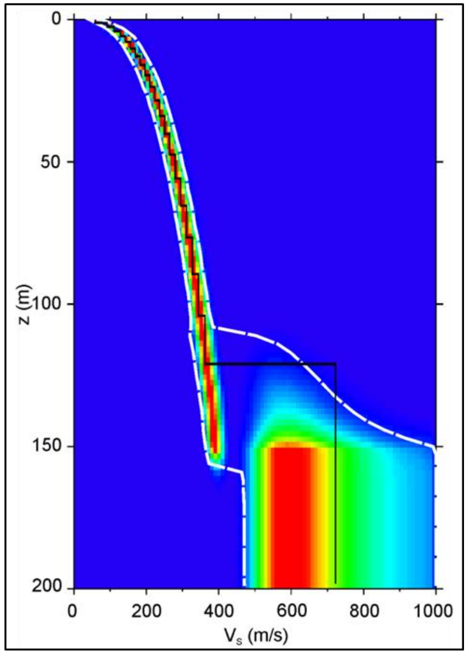


Vary array size to resolve different wavelength ranges (depth)

2. Extract dispersion curve

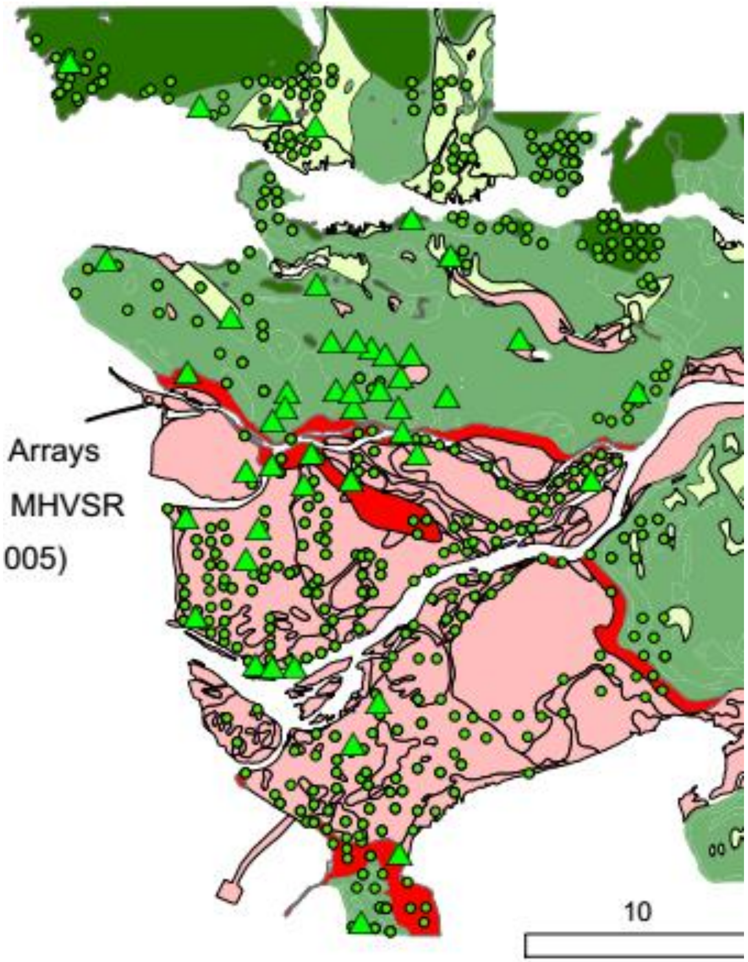


3. Invert for shear-wave velocity depth profiles



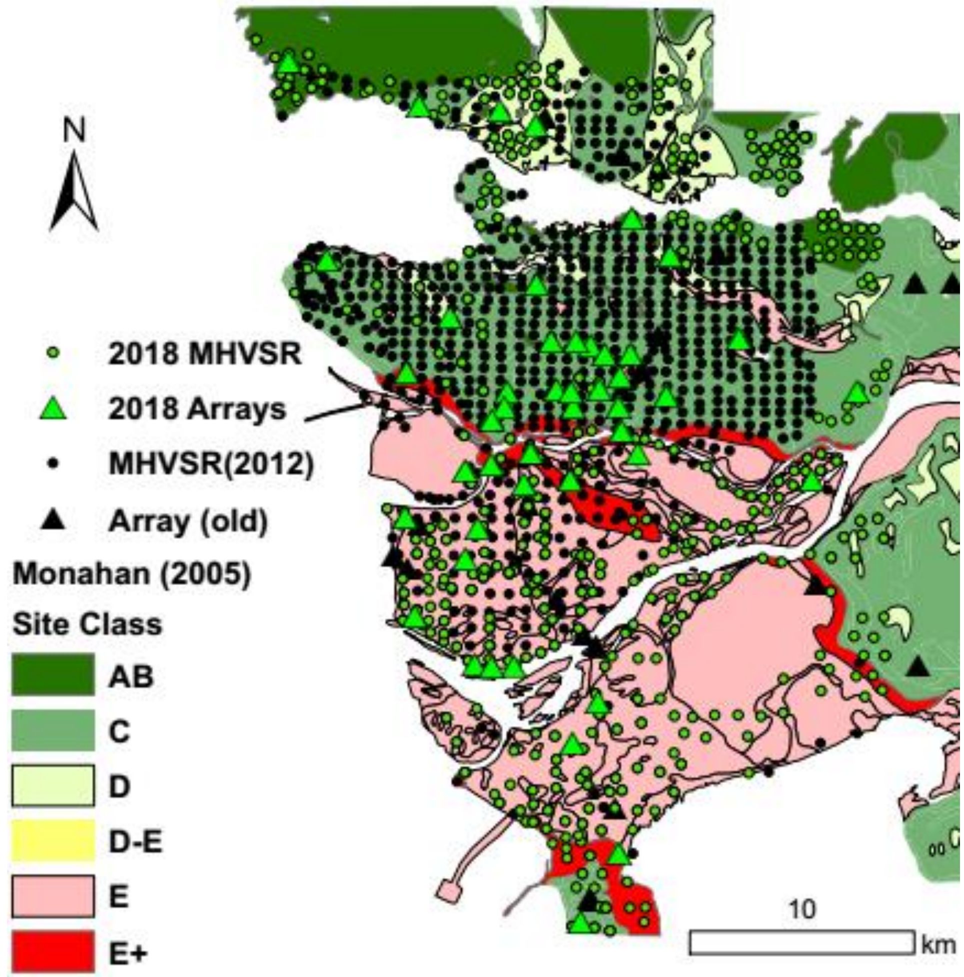
July 2018

- 401 MHVSR sites
- 44 Array sites



Cumulative dataset

- 1009 MHVSR sites
- ~54 Array sites



Metro Vancouver
Seismic Microzonation Project

- First successful seismic field campaign, three more to go
  - 401 MHVSR sites, 44 Array sites in 30 days
- Collection of previous geodata reports and files is ongoing through 2021
  - Lots of shallow borehole data, **need more geophysics (velocity, density) and geotechnical (soil strength, dynamic behaviour) reports**
  - A time intensive process but necessary
  - Current focus is lots of data processing!, prep. for next summer field tests

Western

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