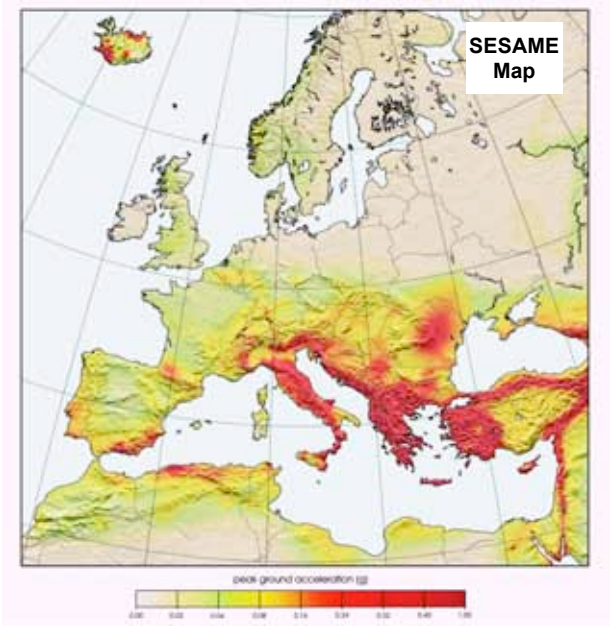


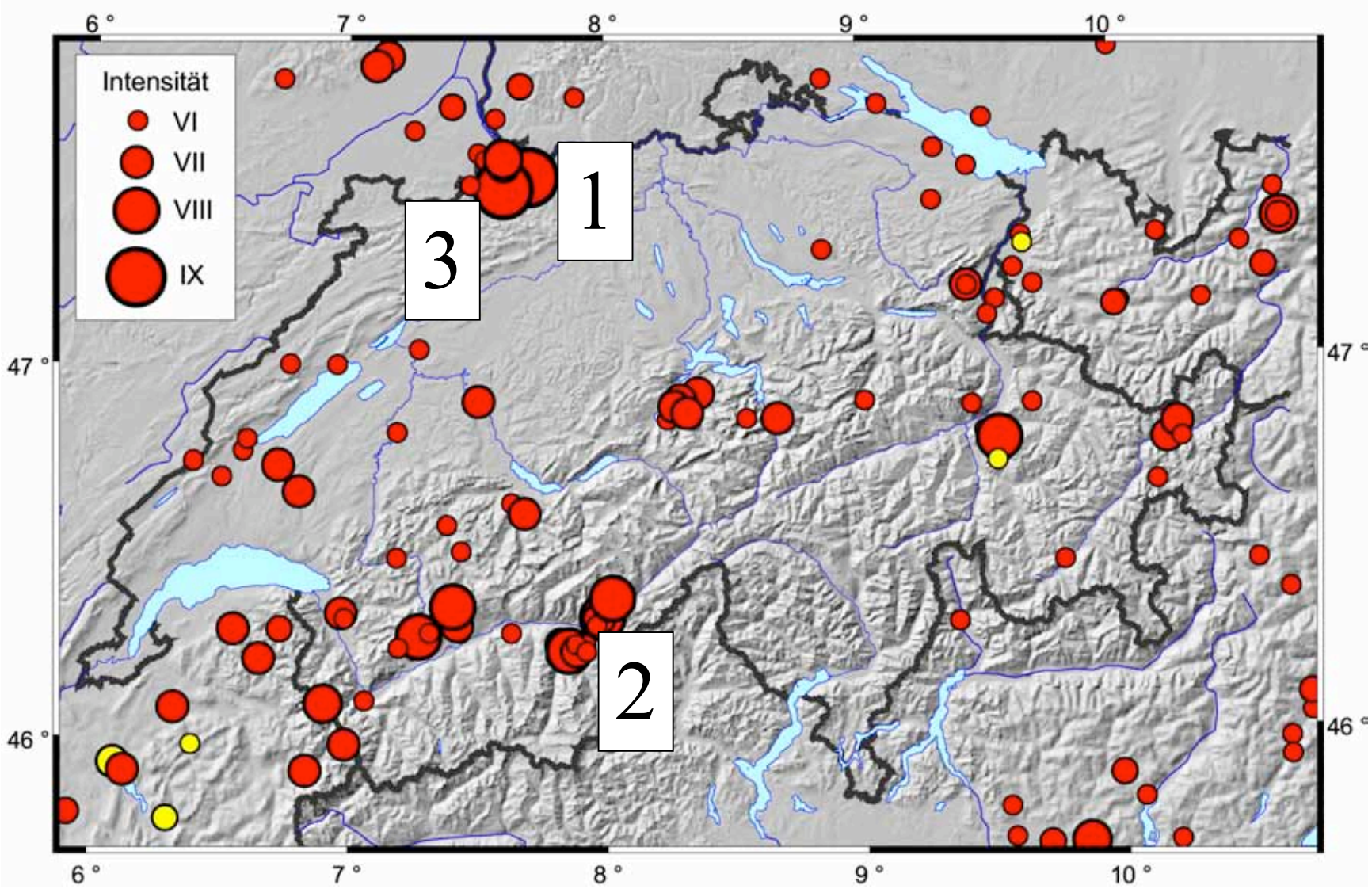
Evaluating Site Effects in Areas of Low Seismicity

Donat Fäh

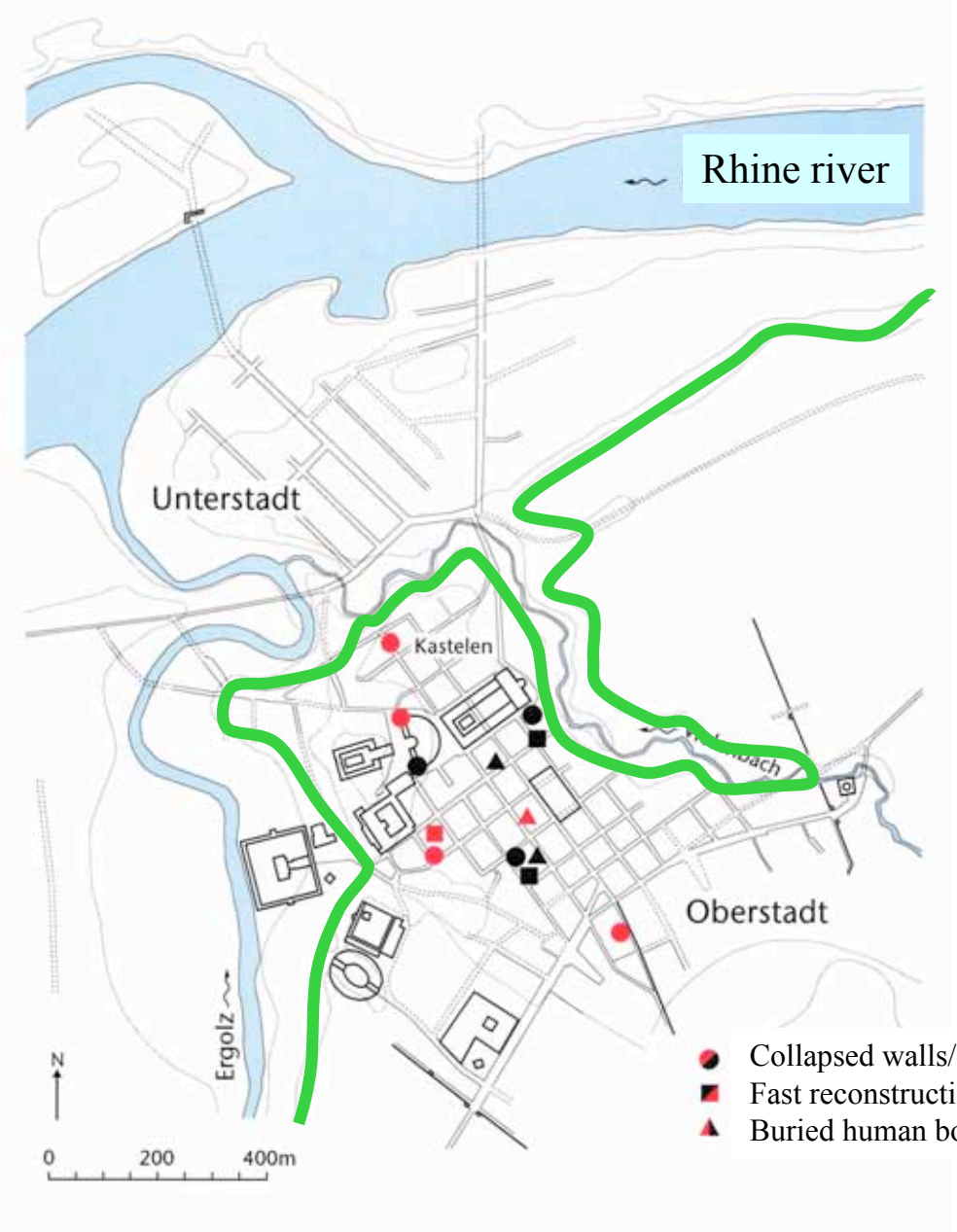
Swiss Seismological Service

ETH Zurich

Known Earthquakes with Damage

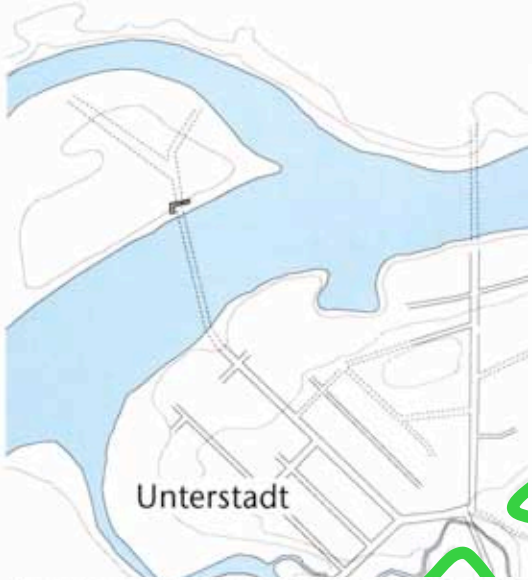


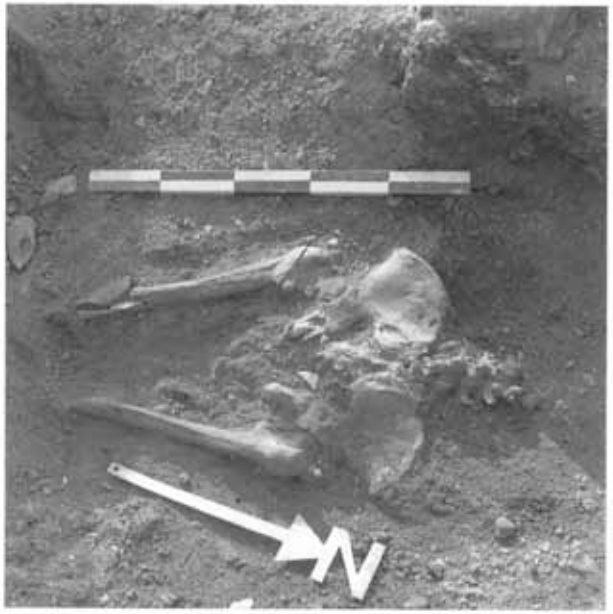
Augusta Raurica 250
(An earthquake?)



River Terrace

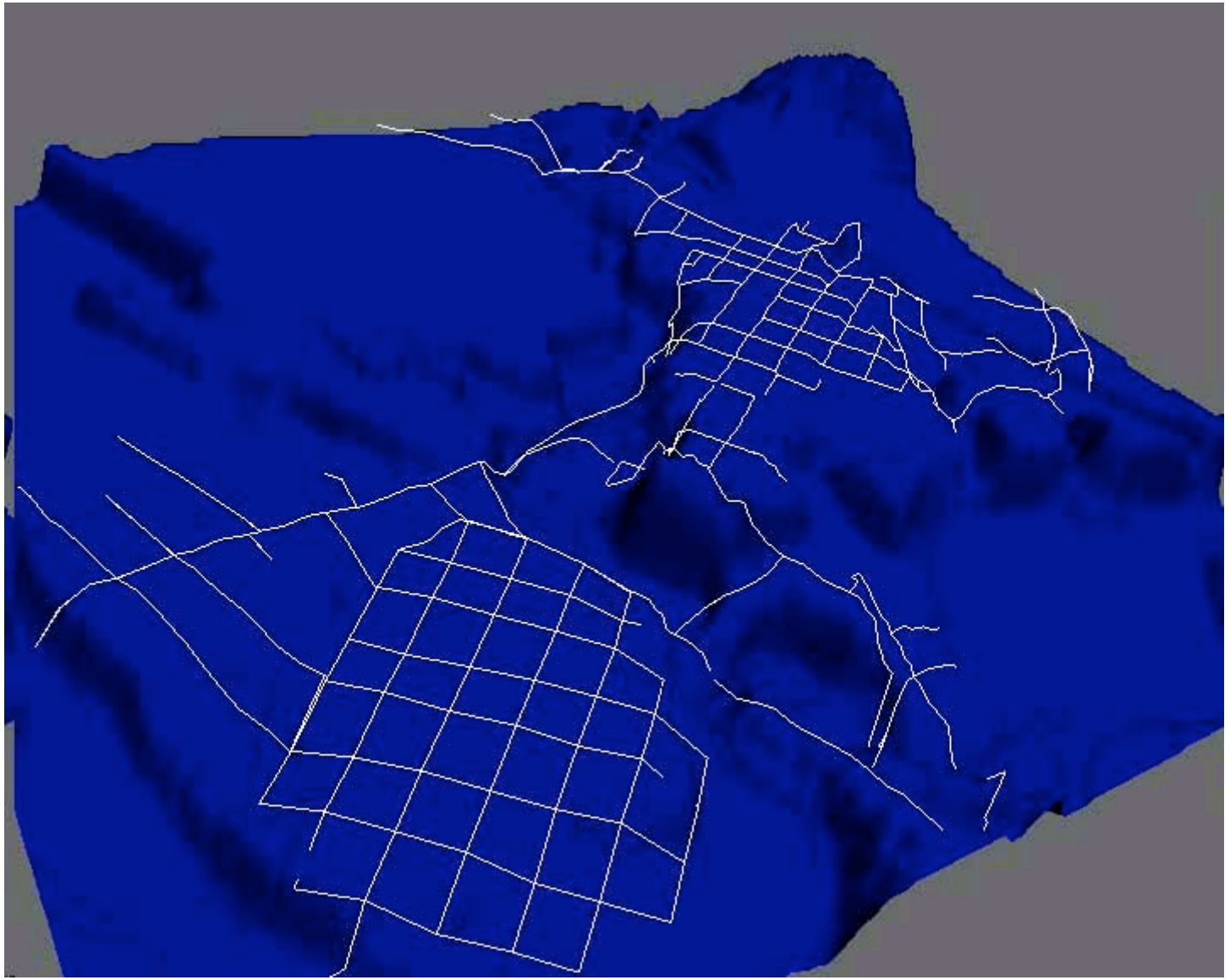
- Collapsed walls/ Fallen sections of columns
- Fast reconstruction
- Buried human bodies


Unterstadt


N

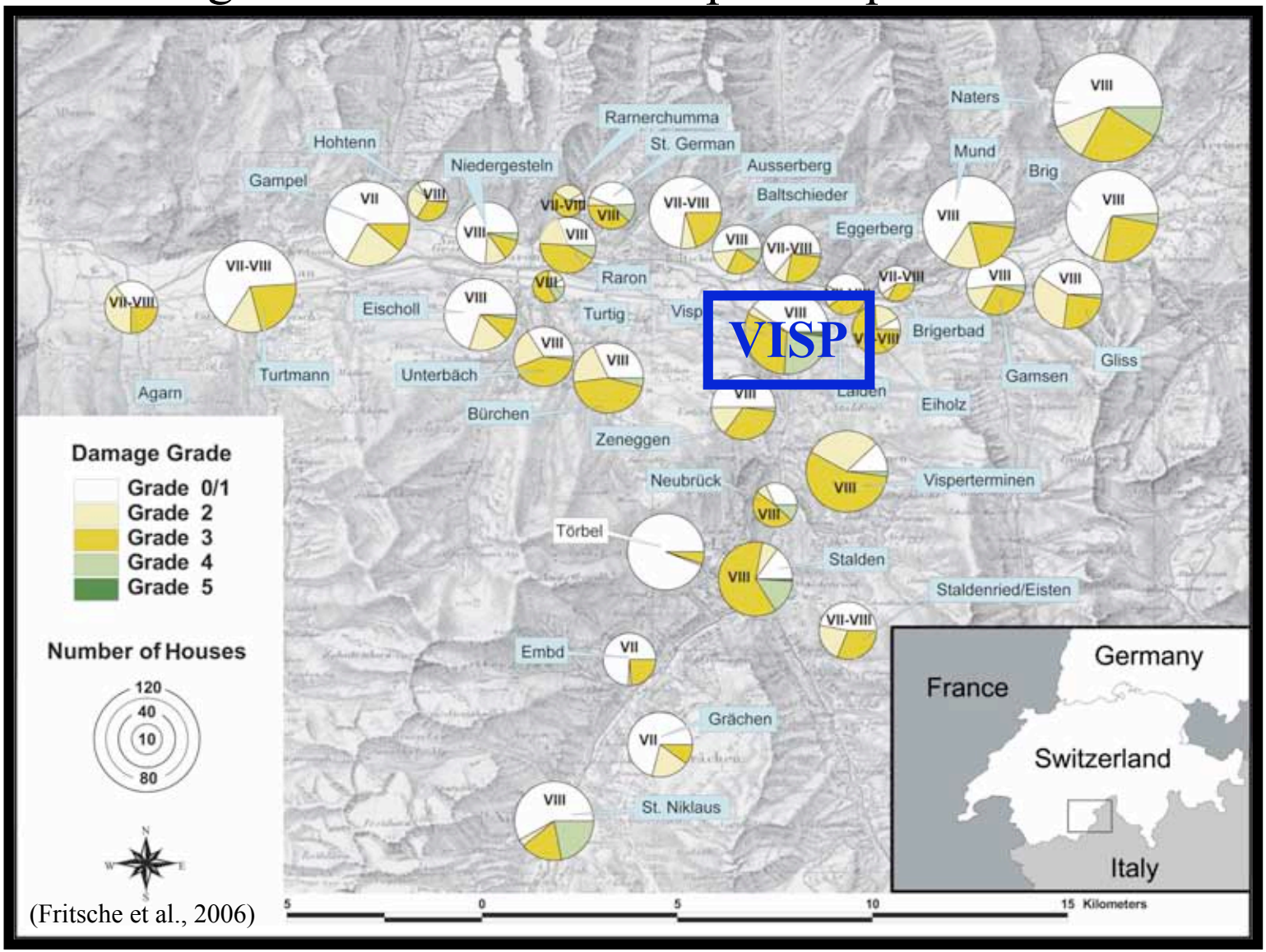

N

A 3D site effect in the city ?

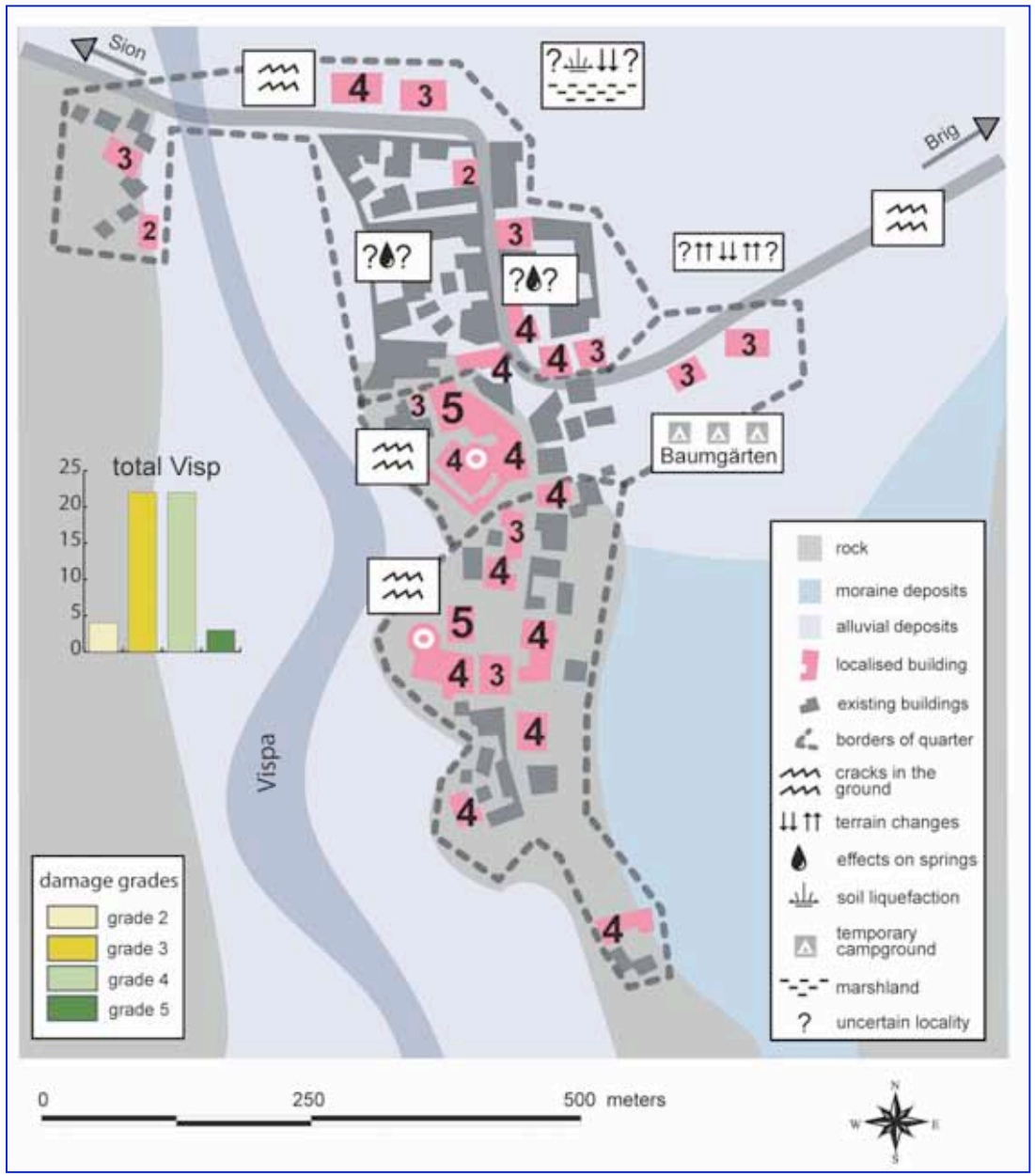


(Oprsal and Fäh, 2006)

Damage field of the 1855 Visp earthquake Mw=6.4



(Fritsche et al., 2006)

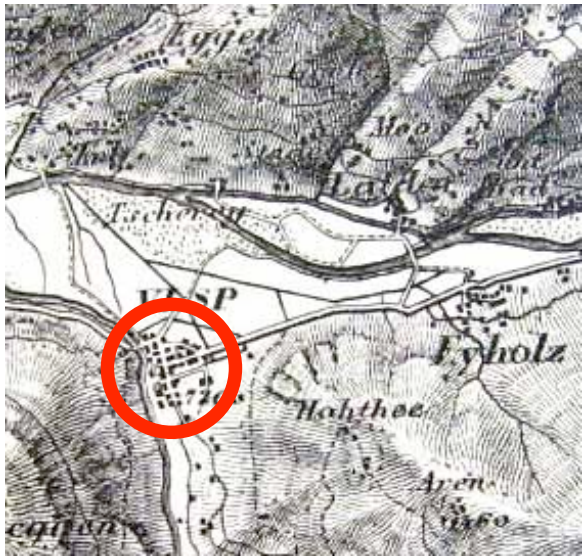


Site Visp
1855 Earthquake

(Fritsche et al., 2006))

What would happen today?

Visp



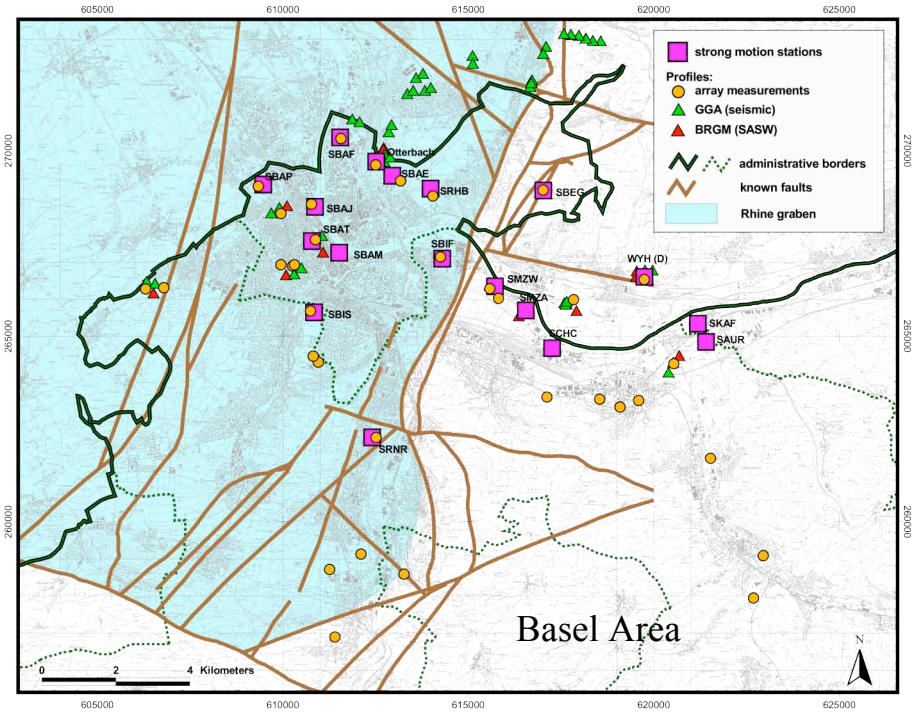
1850

1940

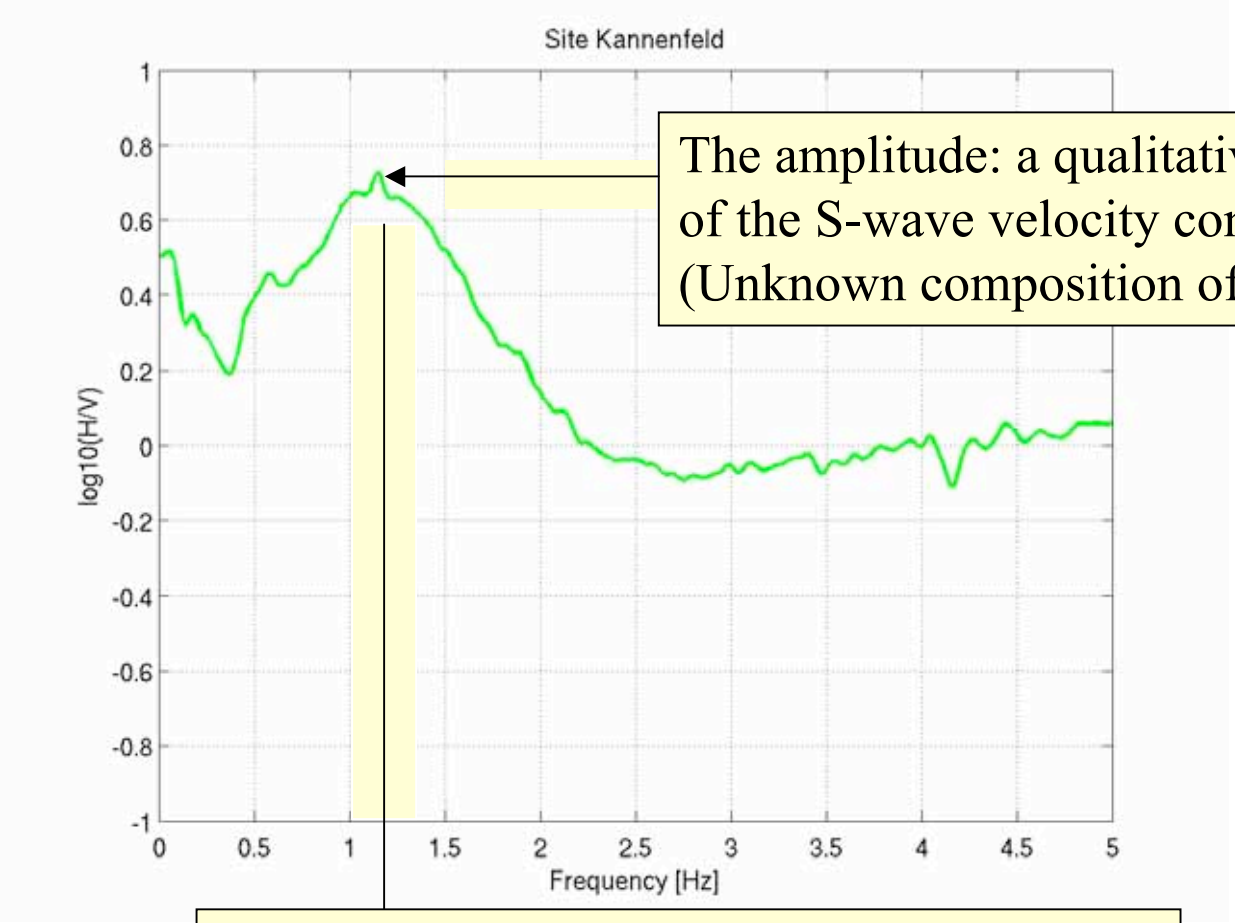
1980

Methods to quantify site effects

- Ambient vibration H/V spectral ratios
- Ambient vibration array techniques
- Active geophysical methods
- Numerical modelling
- Records of small earthquakes



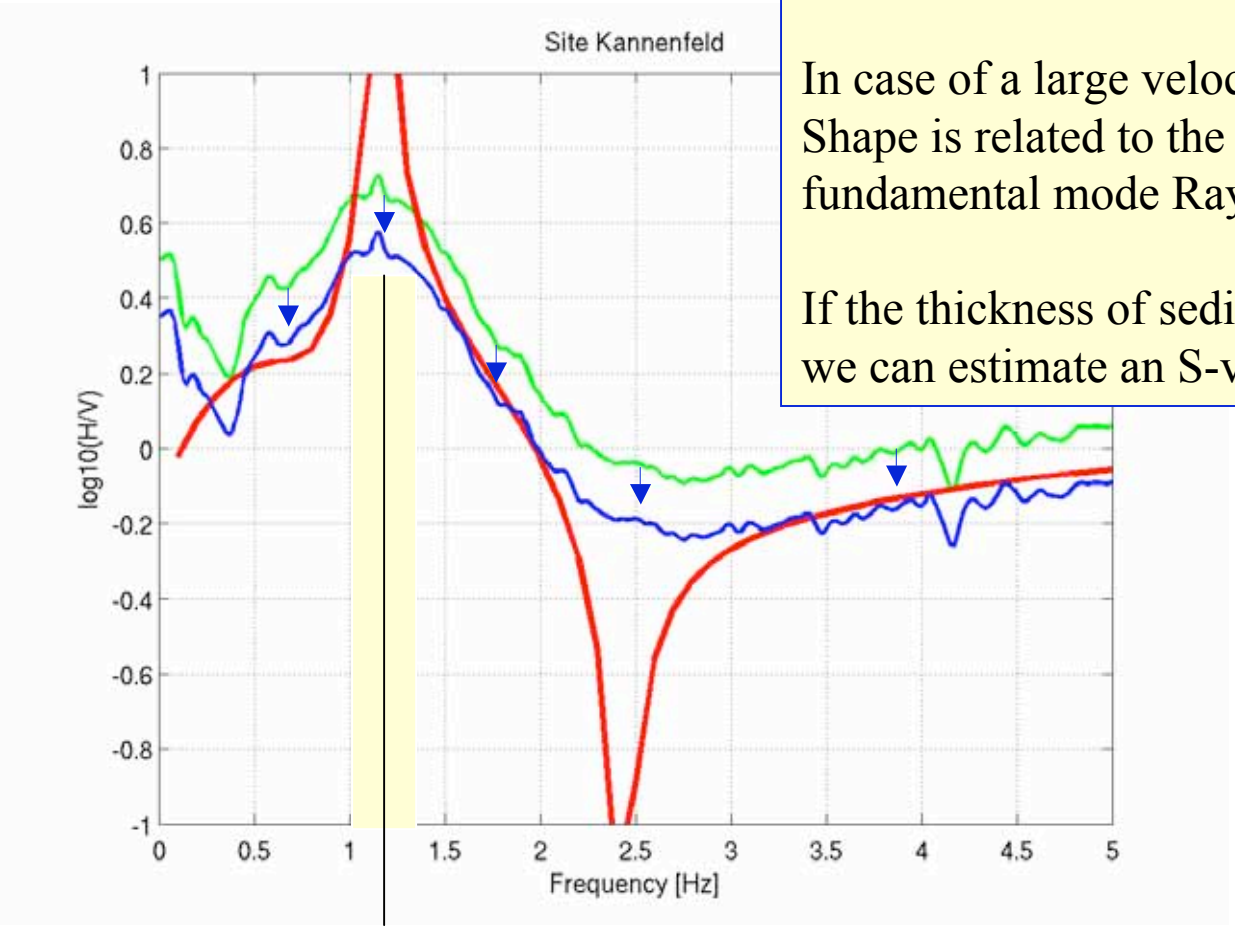
Ambient vibration H/V spectral ratios: anatomy



The amplitude: a qualitative measure of the S-wave velocity contrast (Unknown composition of wavefield)

Peak is at fundamental frequency f_0 of the sediments (Considerable Uncertainty)

Ambient vibration H/V spectral ratios: anatomy

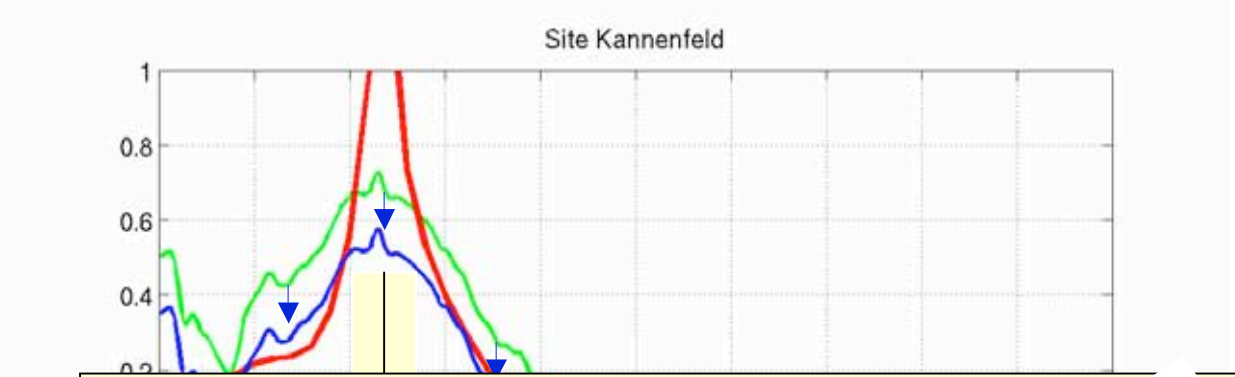


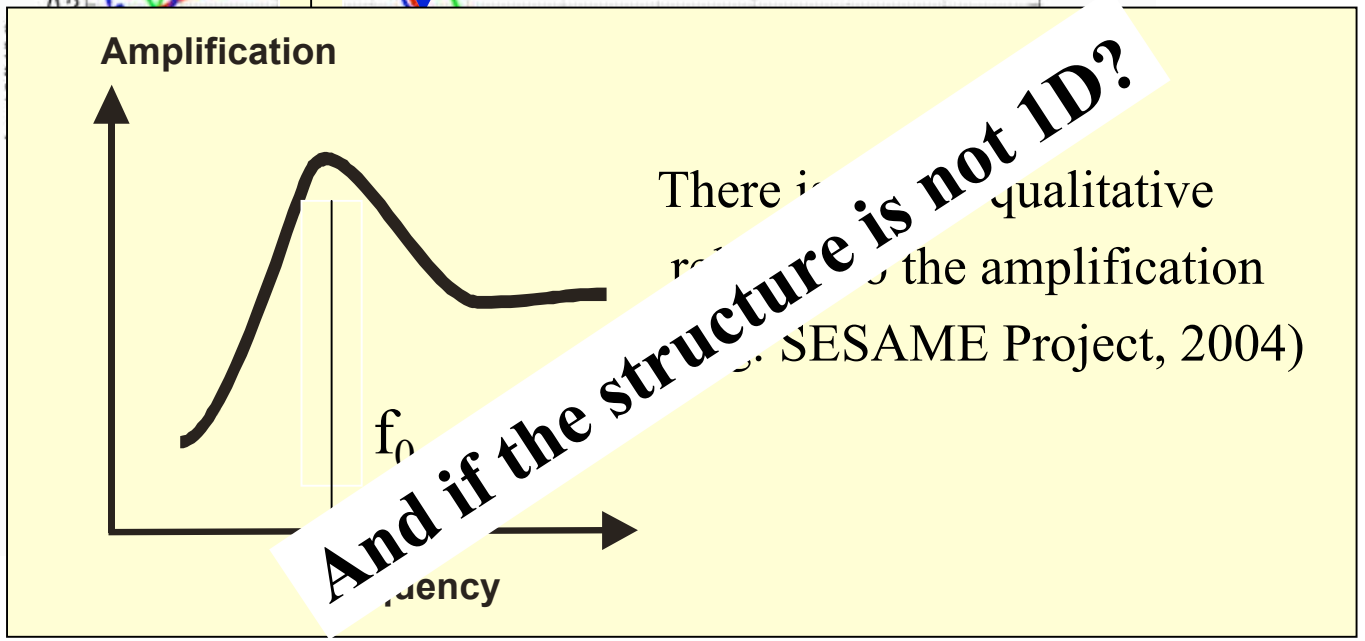
- Remove the SH-wave part.....

In case of a large velocity contrast: Shape is related to the ellipticity of the fundamental mode Rayleigh wave.

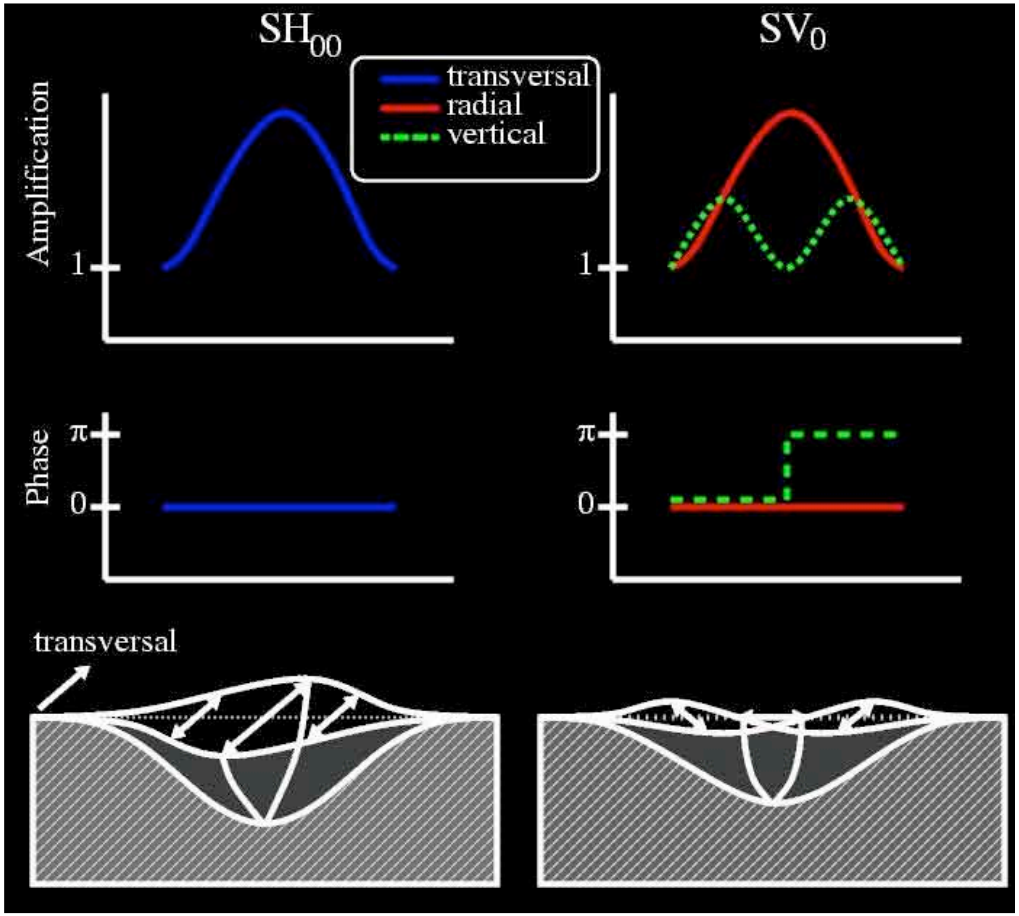
If the thickness of sediments is known, we can estimate an S-velocity profile.

Ambient vibration H/V spectral ratios: anatomy

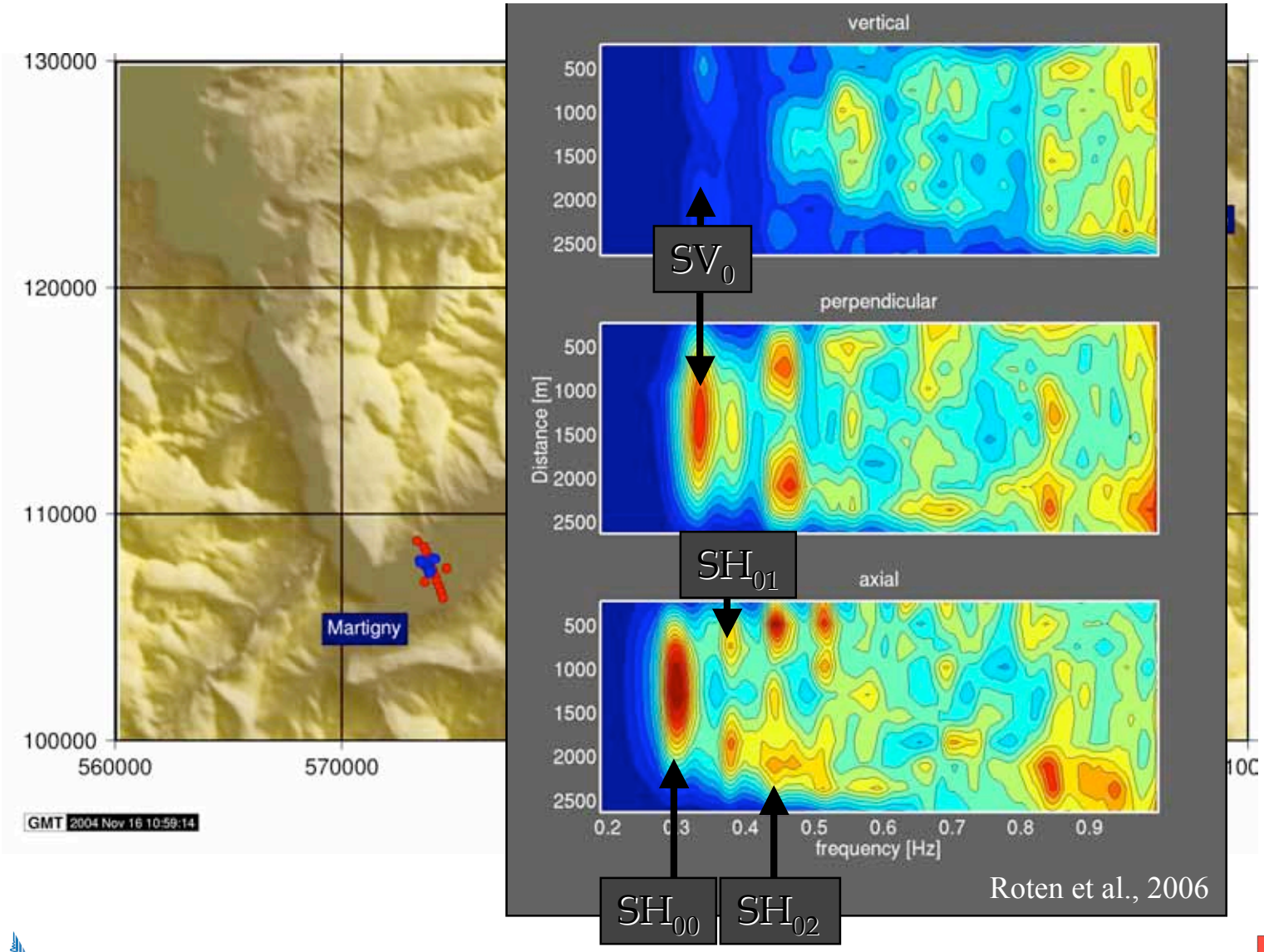




Identification of resonances in 2D structures using ambient vibration recordings

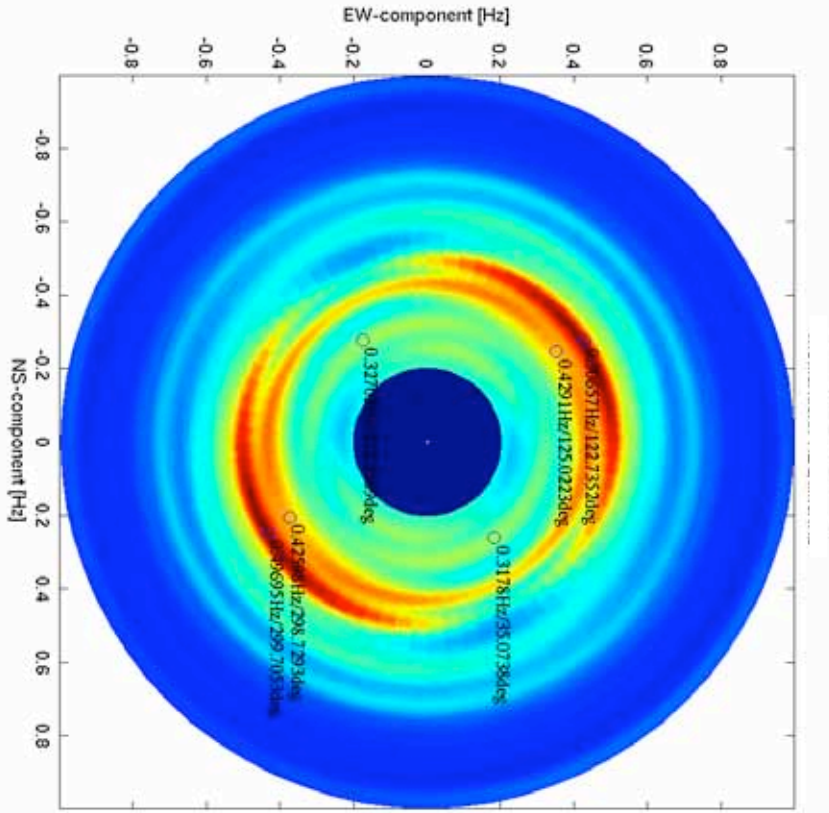


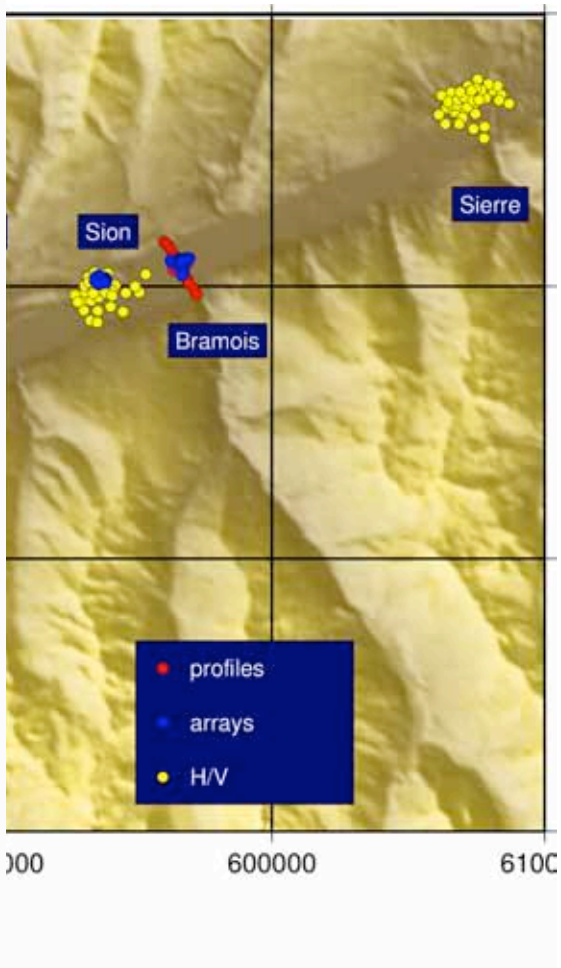
Reference-station-method using ambient vibration signals
Alpine valleys: the Valais case



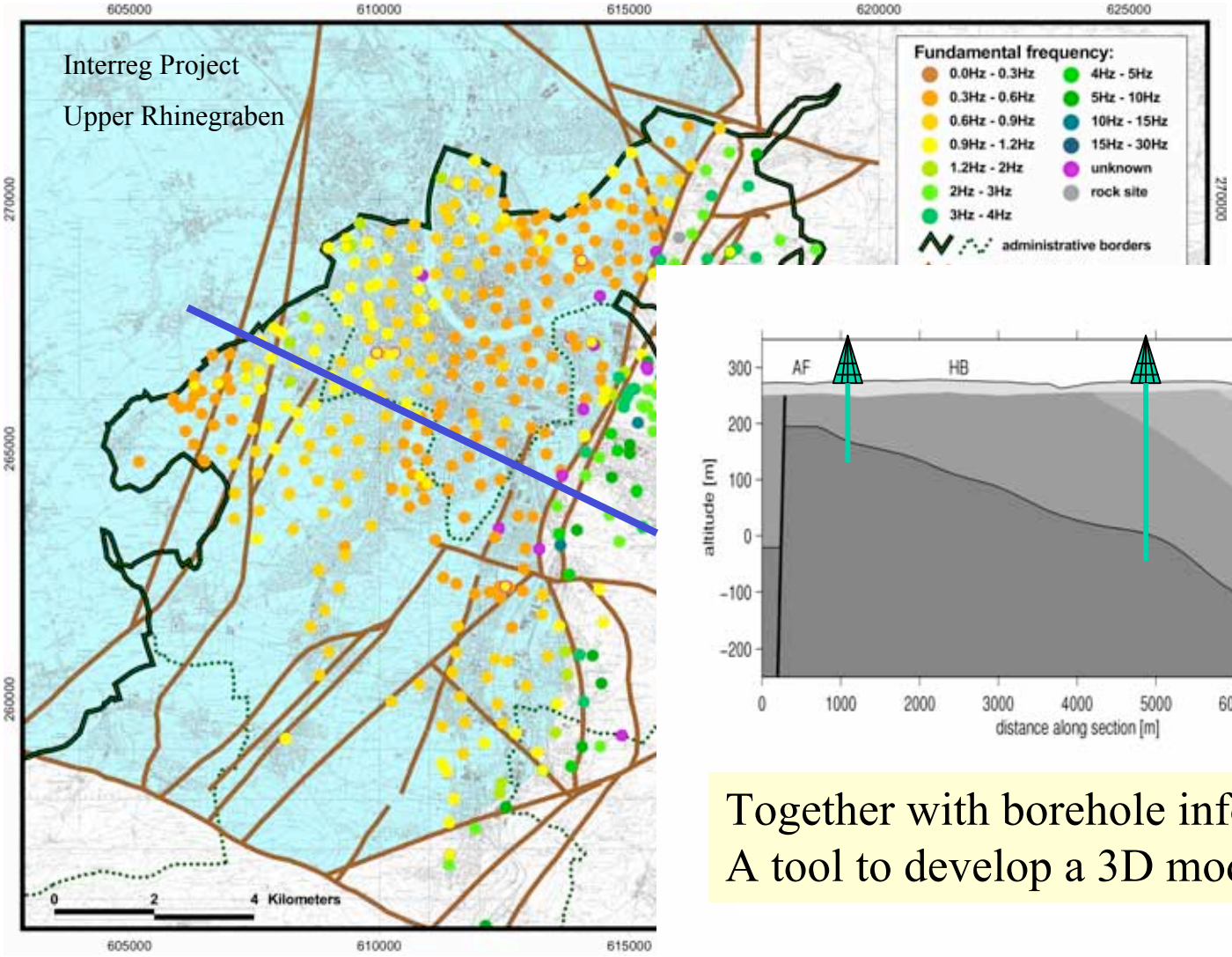
H/V spectral ratios as a function of the azimuth
Alpine valleys: the Valais case

Sion



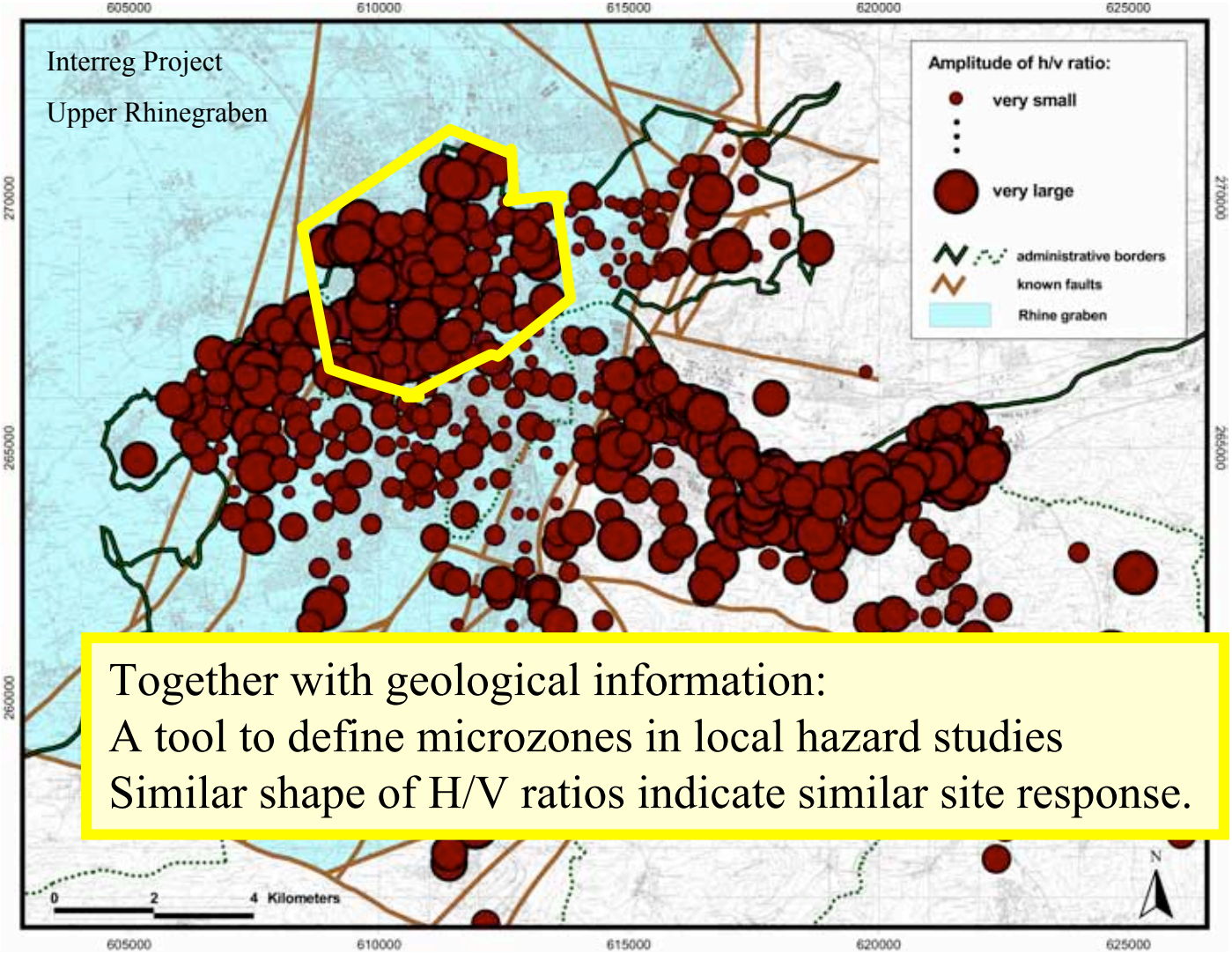


Map of the fundamental frequencies of resonance of the sediments



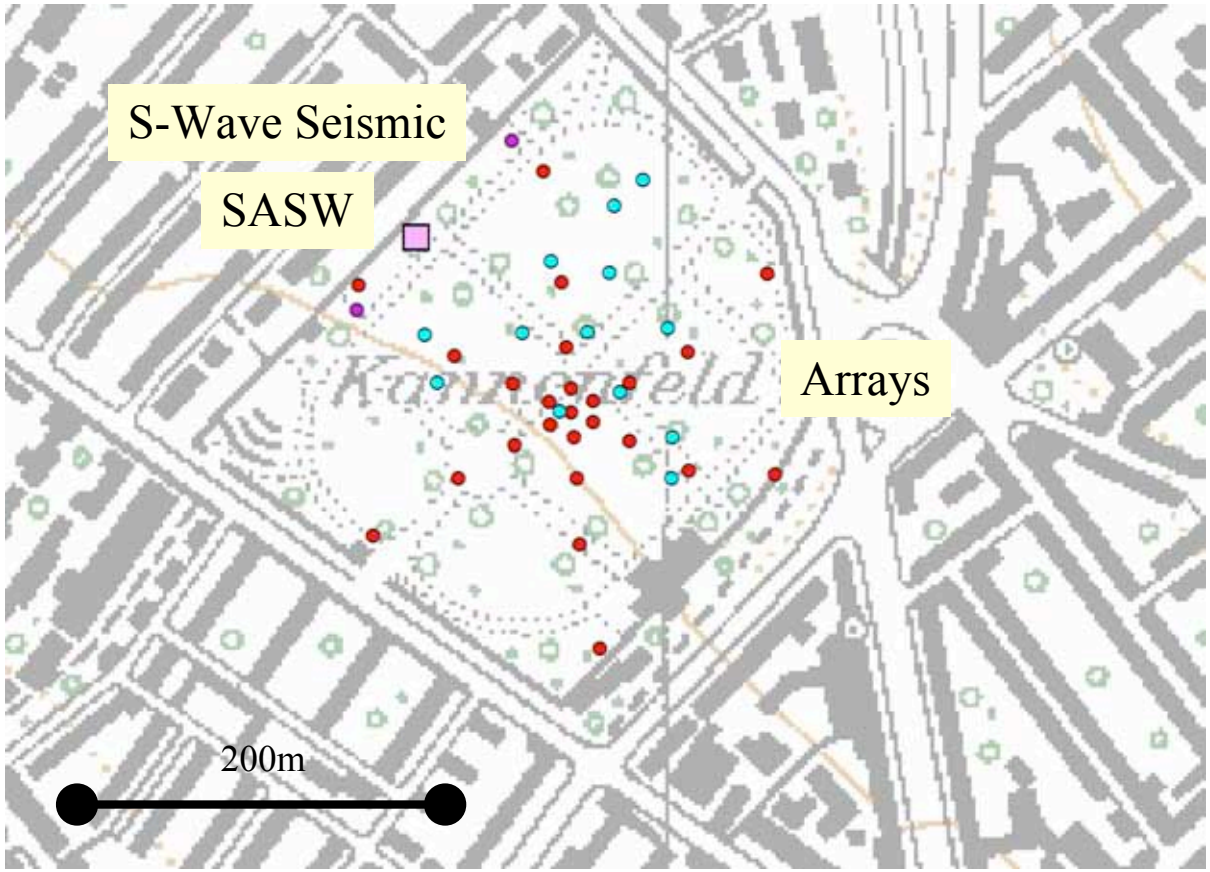
Together with borehole information:
A tool to develop a 3D model

Amplitude of H/V spectral ratios:
Qualitative map of the S-wave velocity contrast between sediments and bedrock



Together with geological information:
A tool to define microzones in local hazard studies
Similar shape of H/V ratios indicate similar site response.

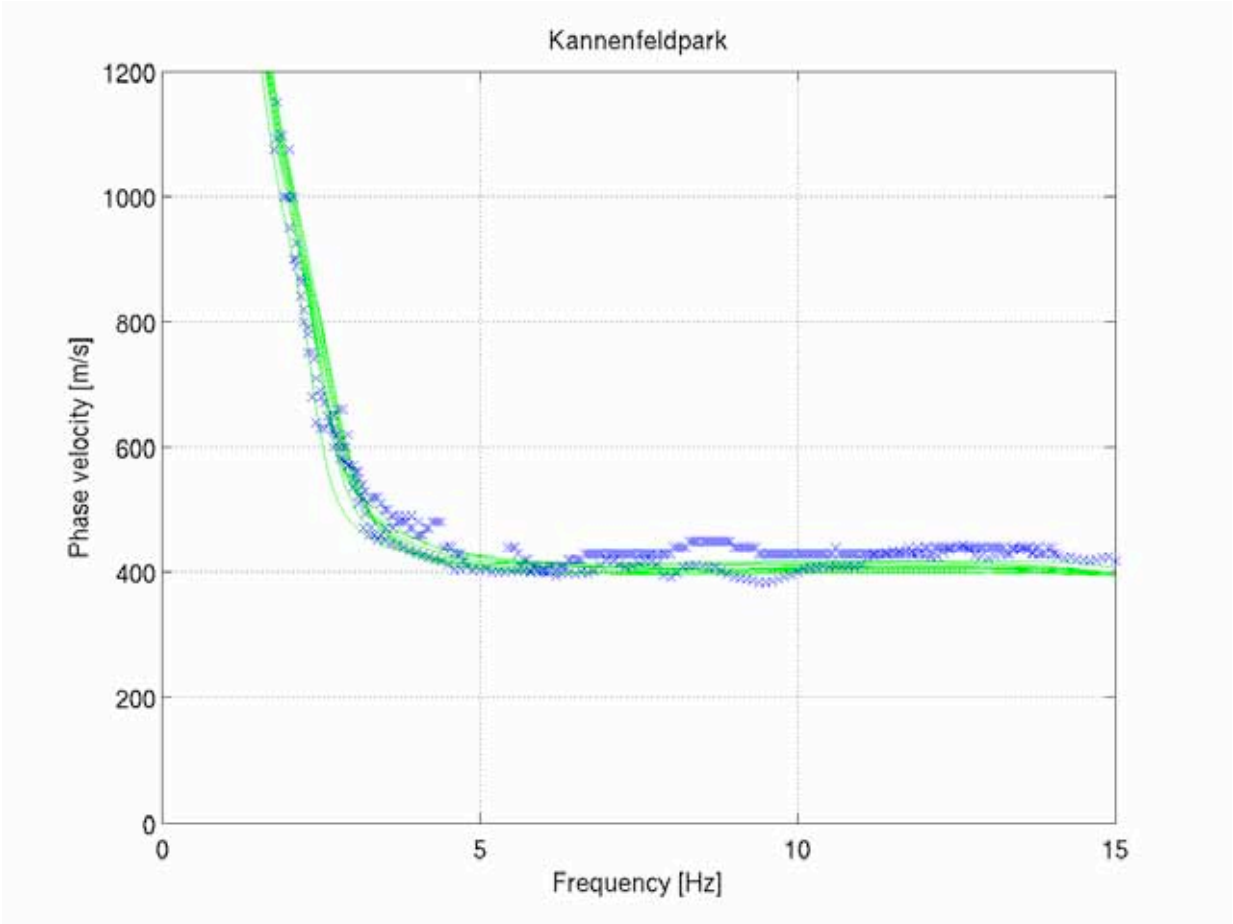
Ambient vibration array techniques and active techniques:
(FK, HRBF, SPAC, SASW, SEISMICS,.....)

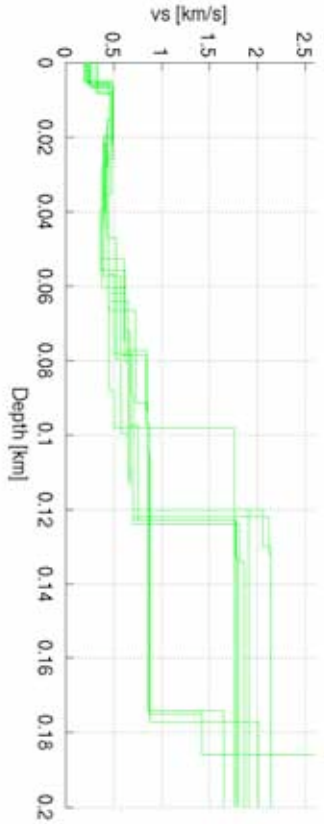


A complex case!

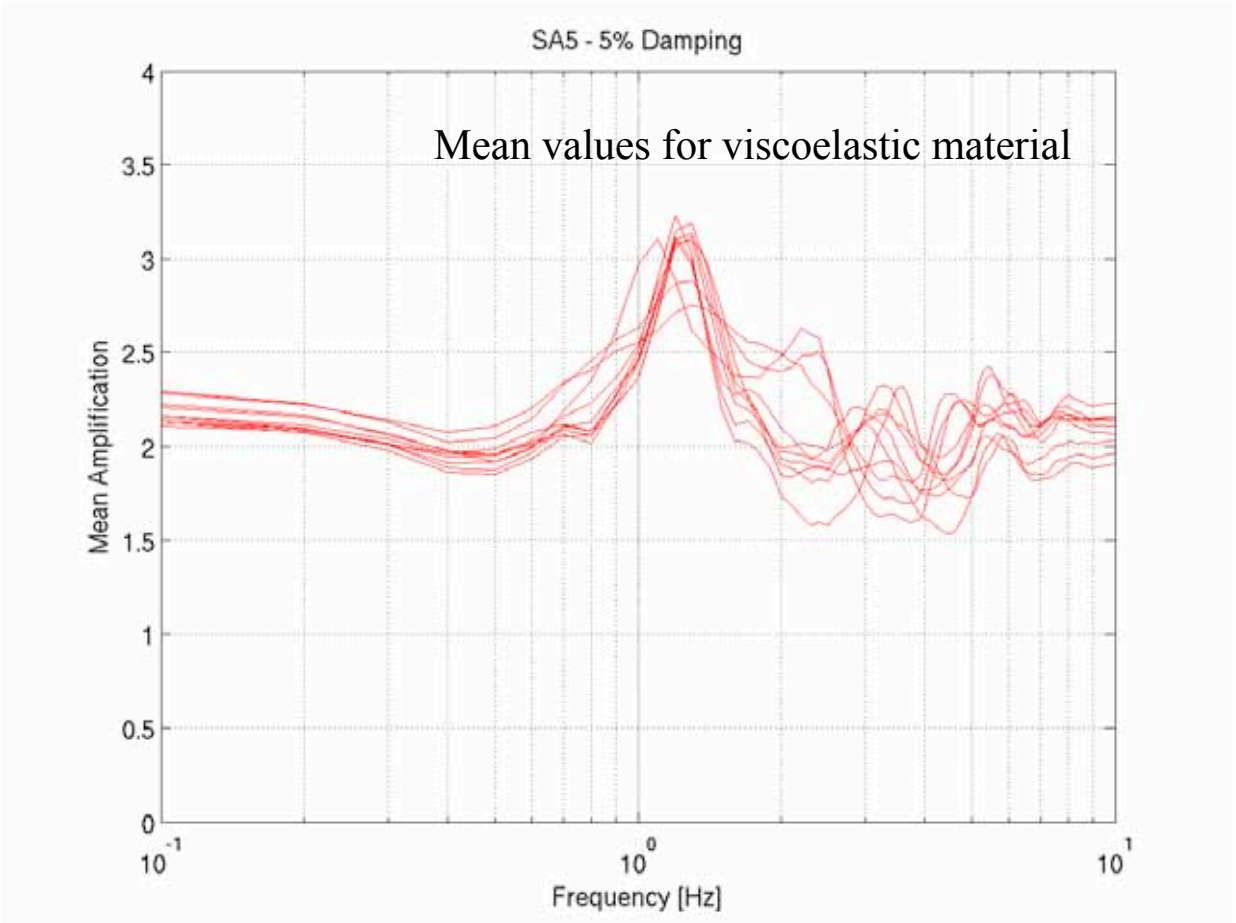
Ambient vibration array techniques :

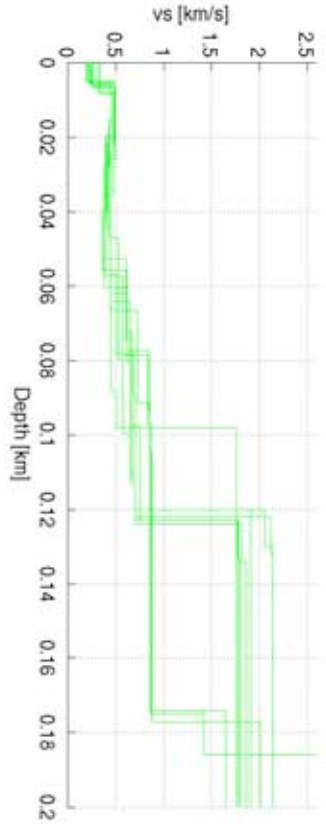
Dispersion curves from the vertical components & ellipticity





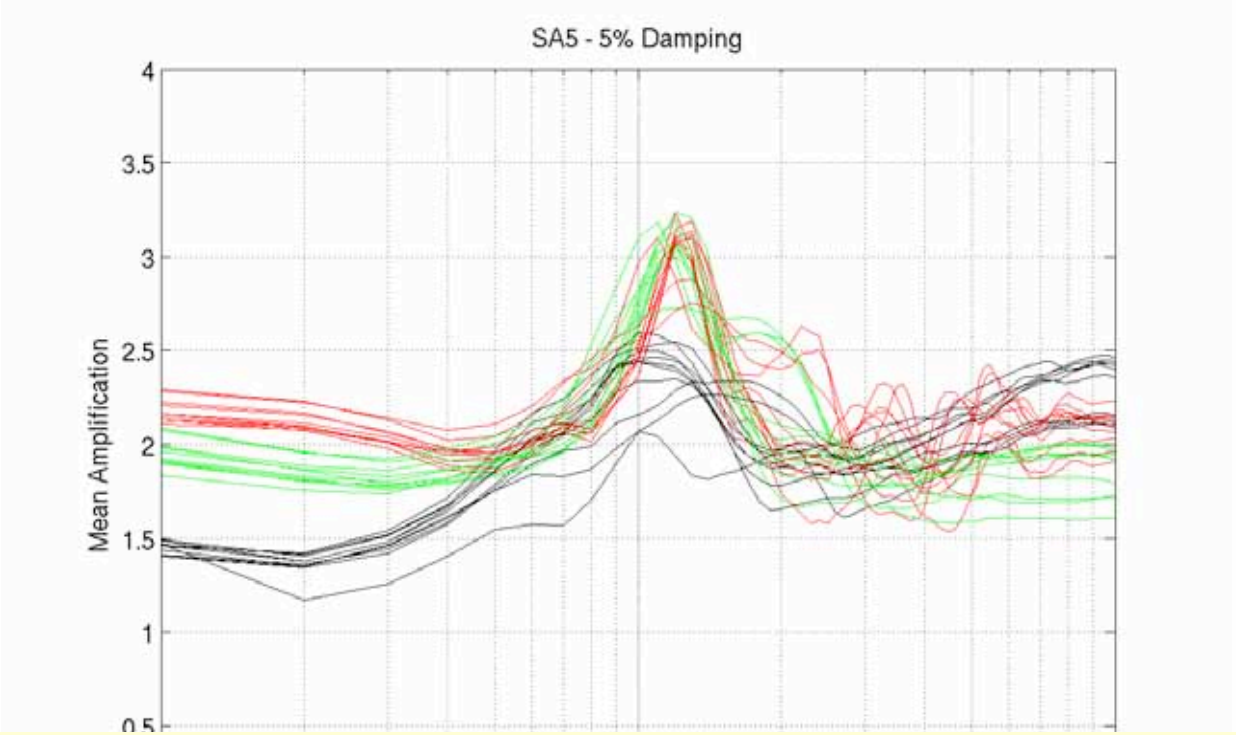
Best comparison of models: Difference in the site response

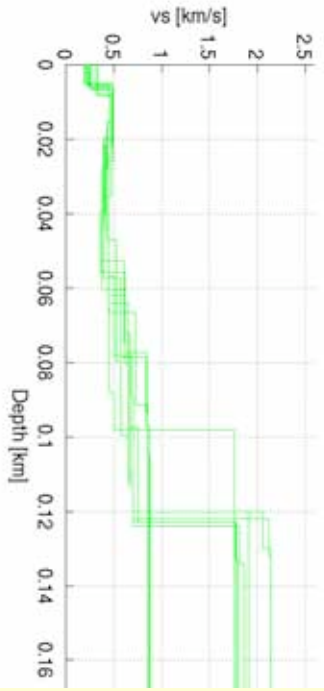




SH-wave, vertical incidence: Mean for 512 synthetics (point sources, scaled to Mw 6)

Modelling needs some approximations: the choices are important

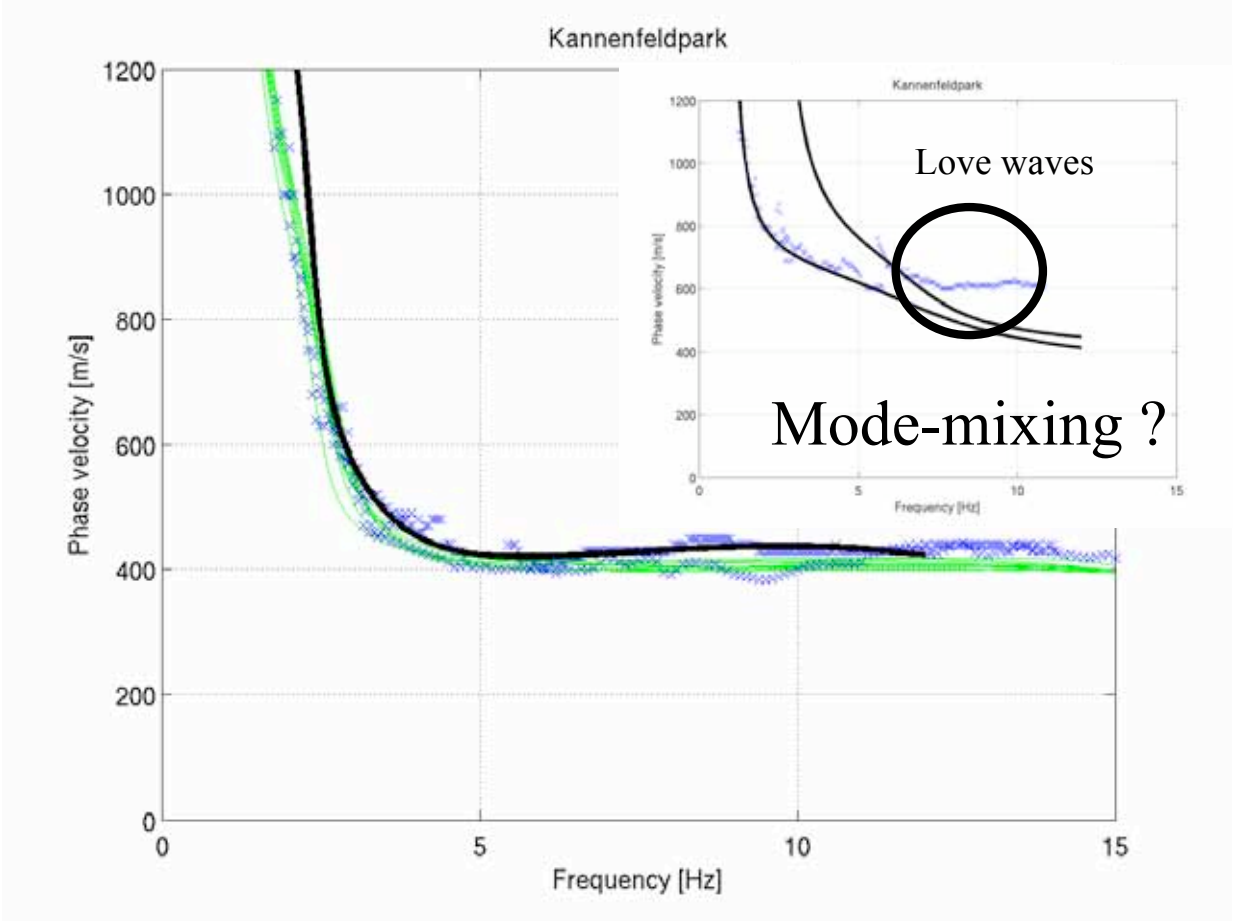


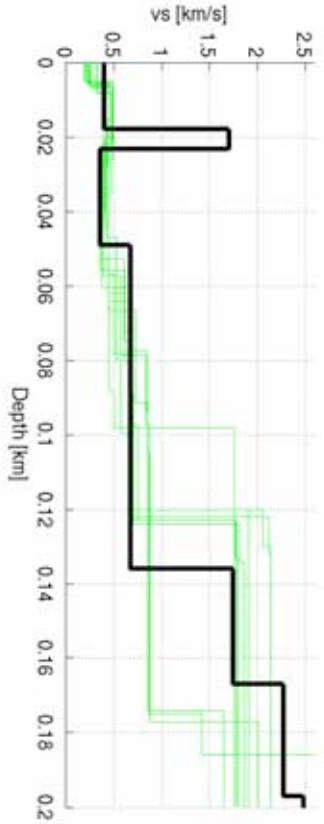


The modelling techniques we can apply :

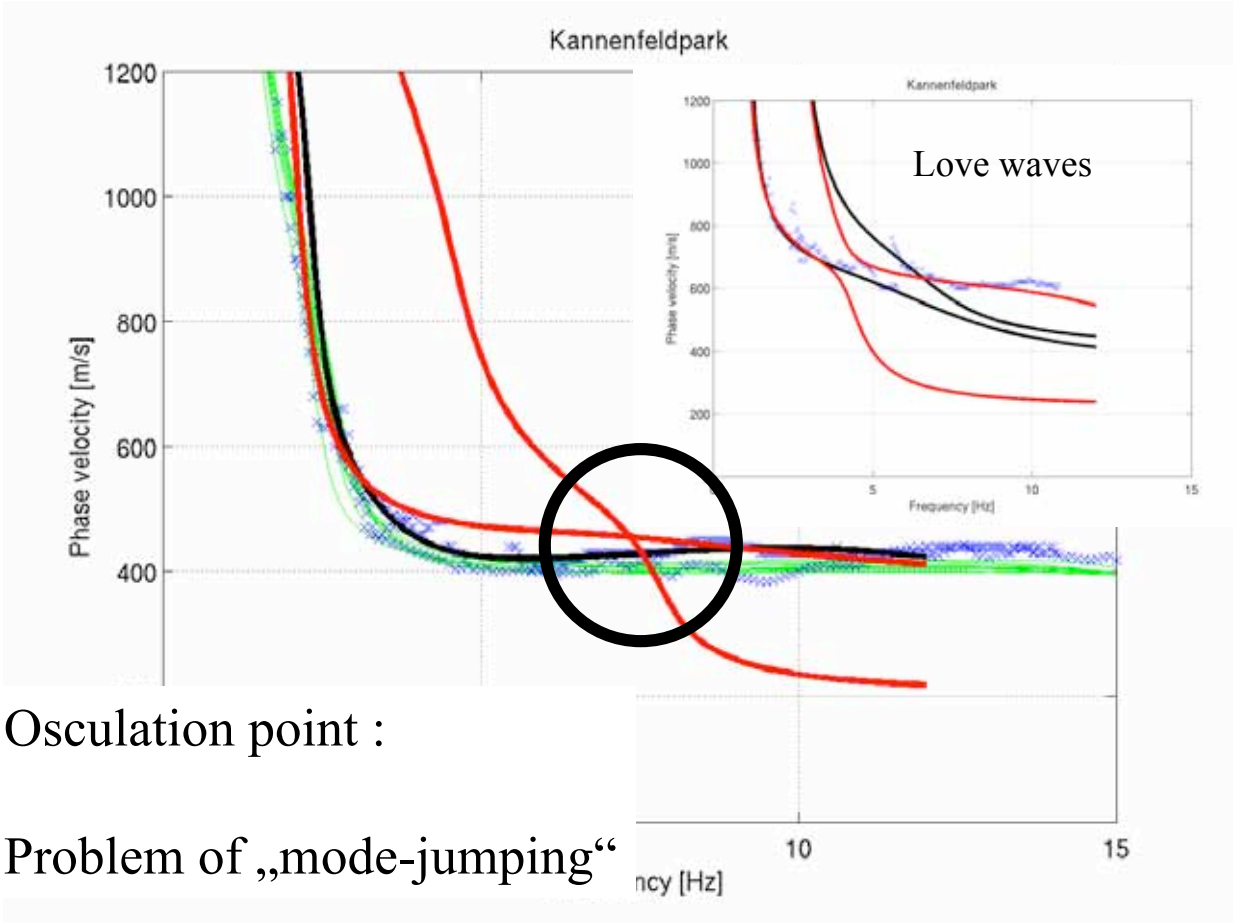
- 1D (SH, P-SV), 2D (SH, P-SV), 3D
- elastic, visco-elastic, non-linear material behaviour
- plane waves vertical or obligue incidence, realistic sources (point, extended)

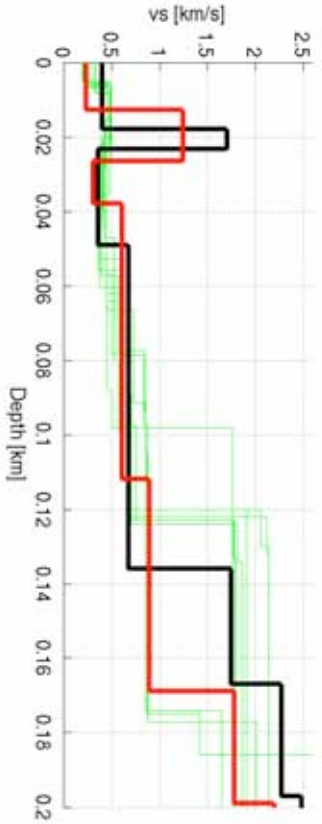
Ambient vibration array techniques :
Adding the Love wave information





Ambient vibration array techniques :
Dispersion curves and mode jumping





Osculation point :

Problem of „mode-jumping“

Ambient vibration array techniques and non-invasive active techniques:

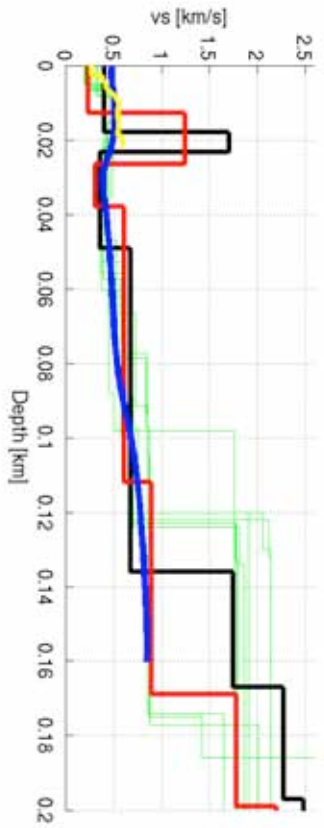
Comparison for a complex case

Possible Problems

SASW (active):
Depth resolution limited to 20-30m
Limited to 1D structures (smooth models)
Problems with urban noise

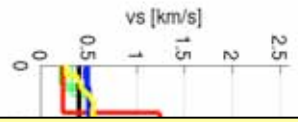
S-wave seismic (active):
Frequency range outside the range 0.5-10Hz
Problems with urban noise

Ambient vibration array technique (passive):
Limited to 1D structures (Smooth models)
Possible „mode jumping“



Ambient vibration array techniques and non-invasive active techniques:

Comparison for a complex case



What are the reasons for possible differences:

The method?

The analyst?

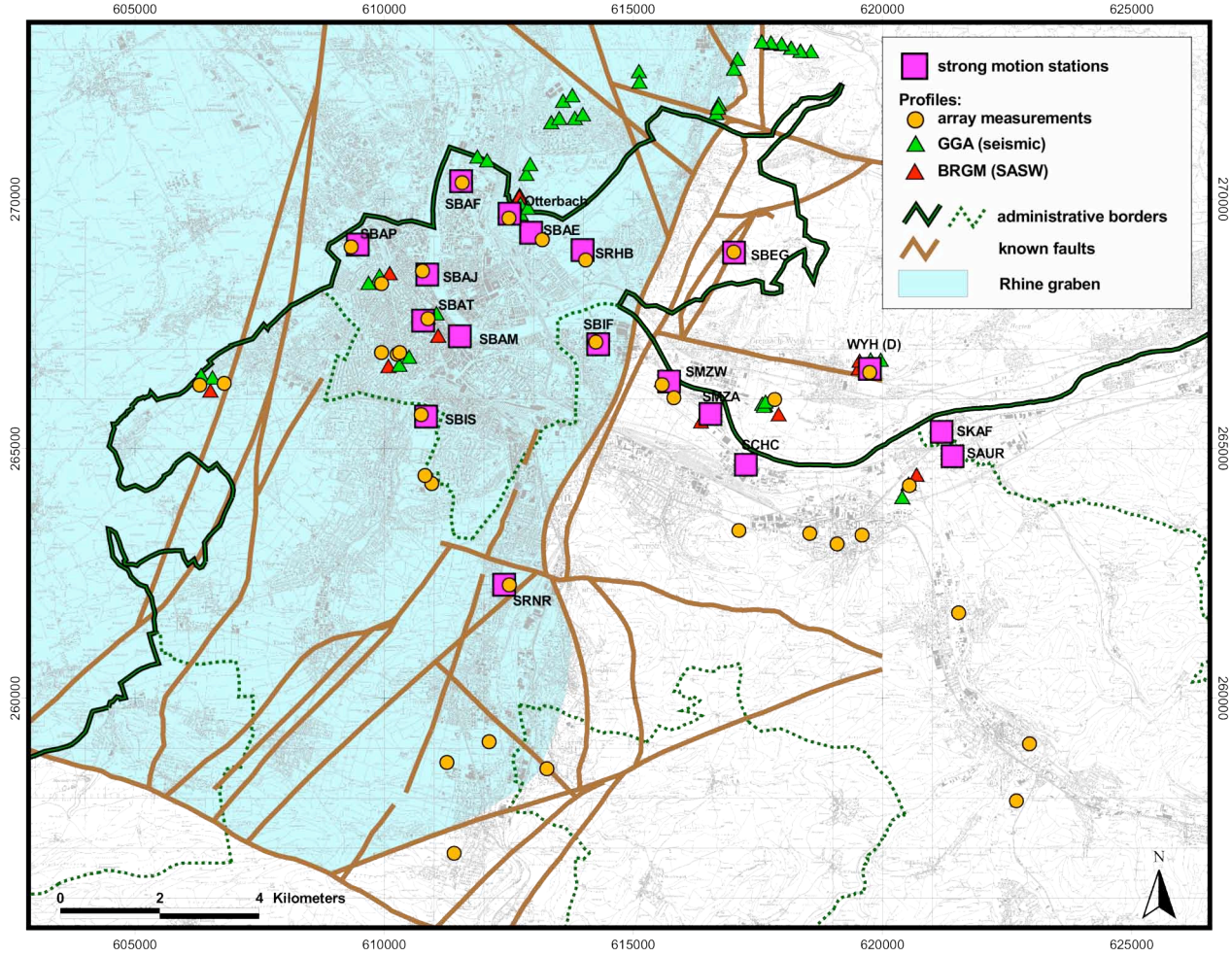
Lateral variation of the soil condition
(not the same site)?

A good solution is the combination of different techniques

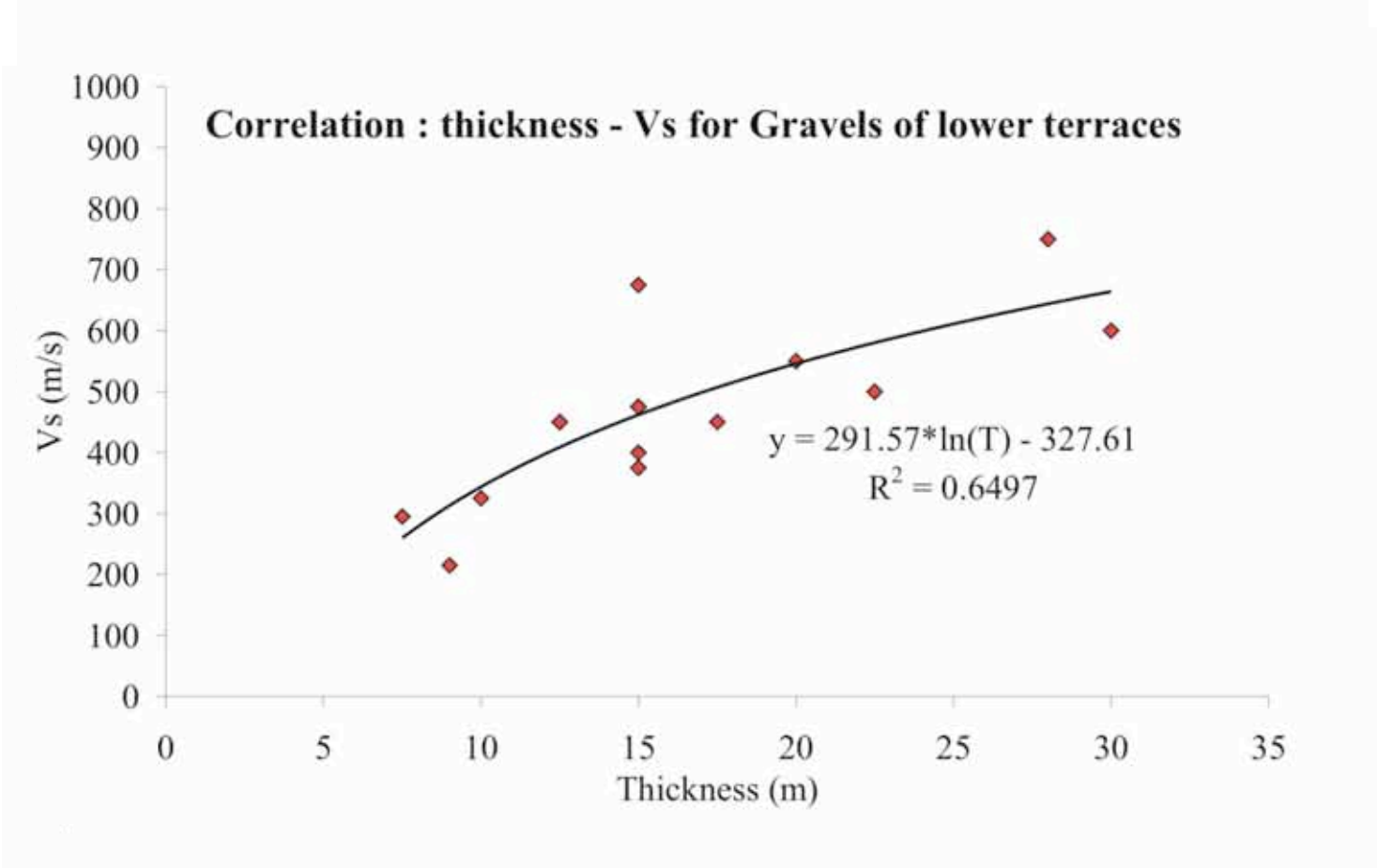
(ESG 2006 Grenoble, ambient vibration array blind test)

Ambient vibration array techniques and active techniques:

From single measurements to soil characterization

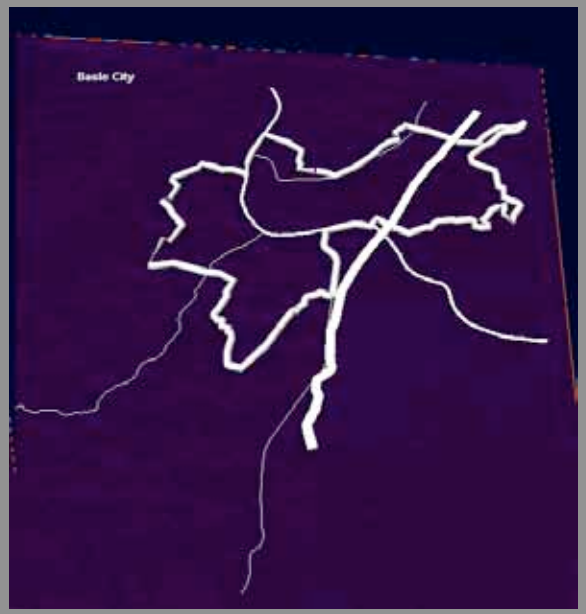


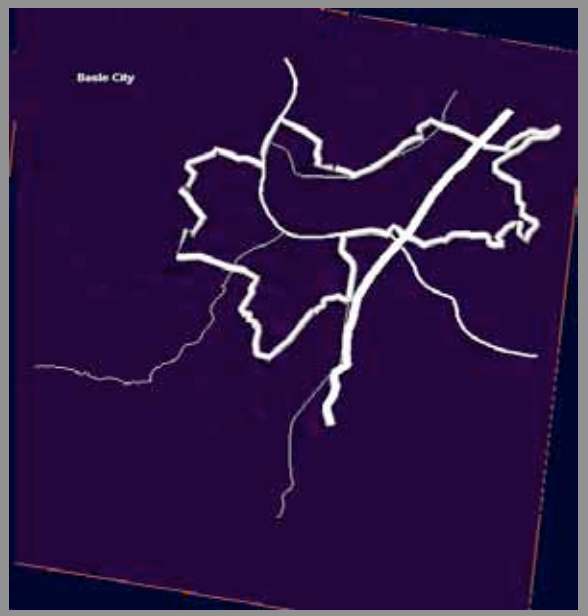
Ambient vibration array techniques and active techniques:
From a single measurements to soil characterization

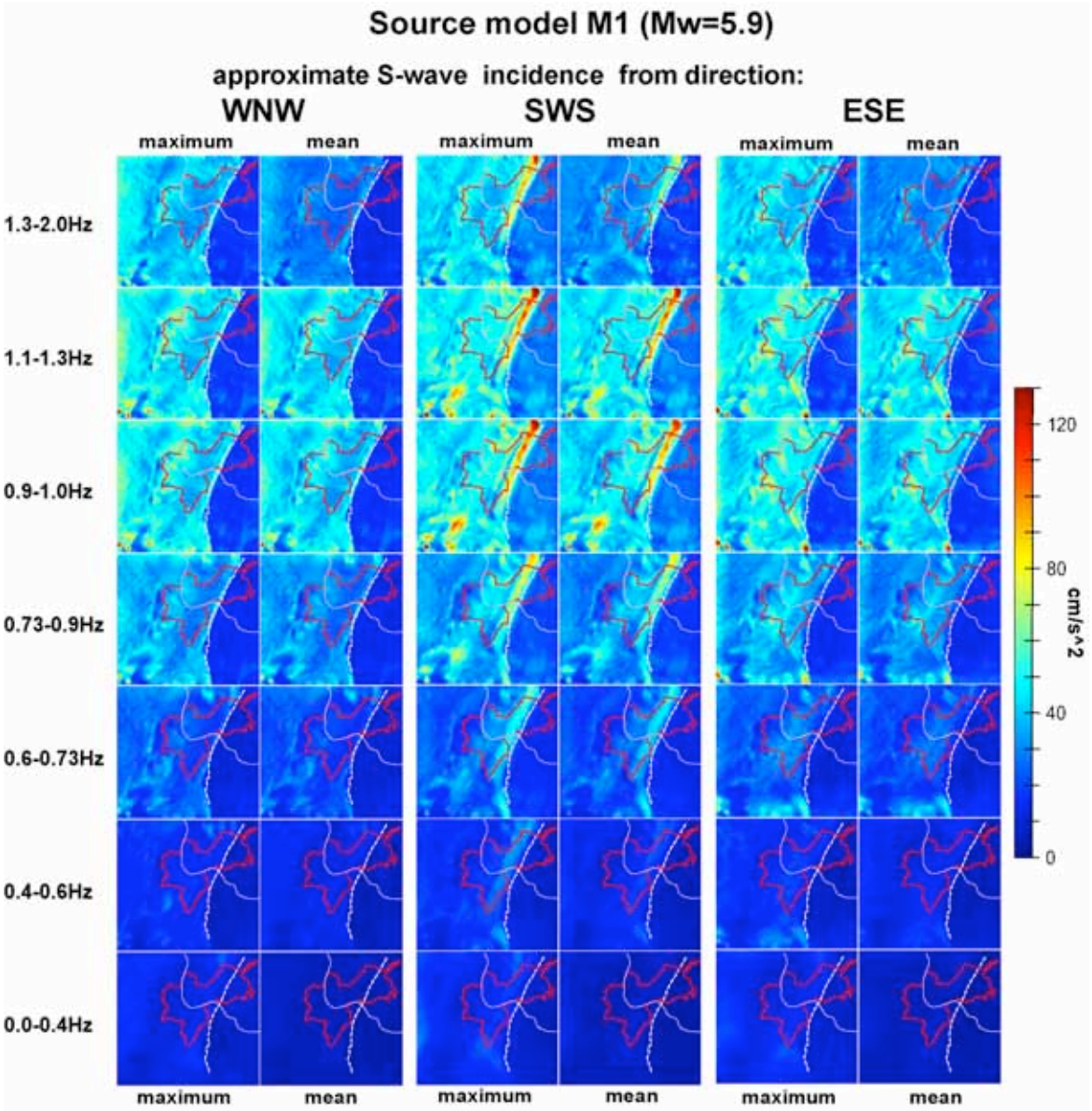


Havenith et al., 2006

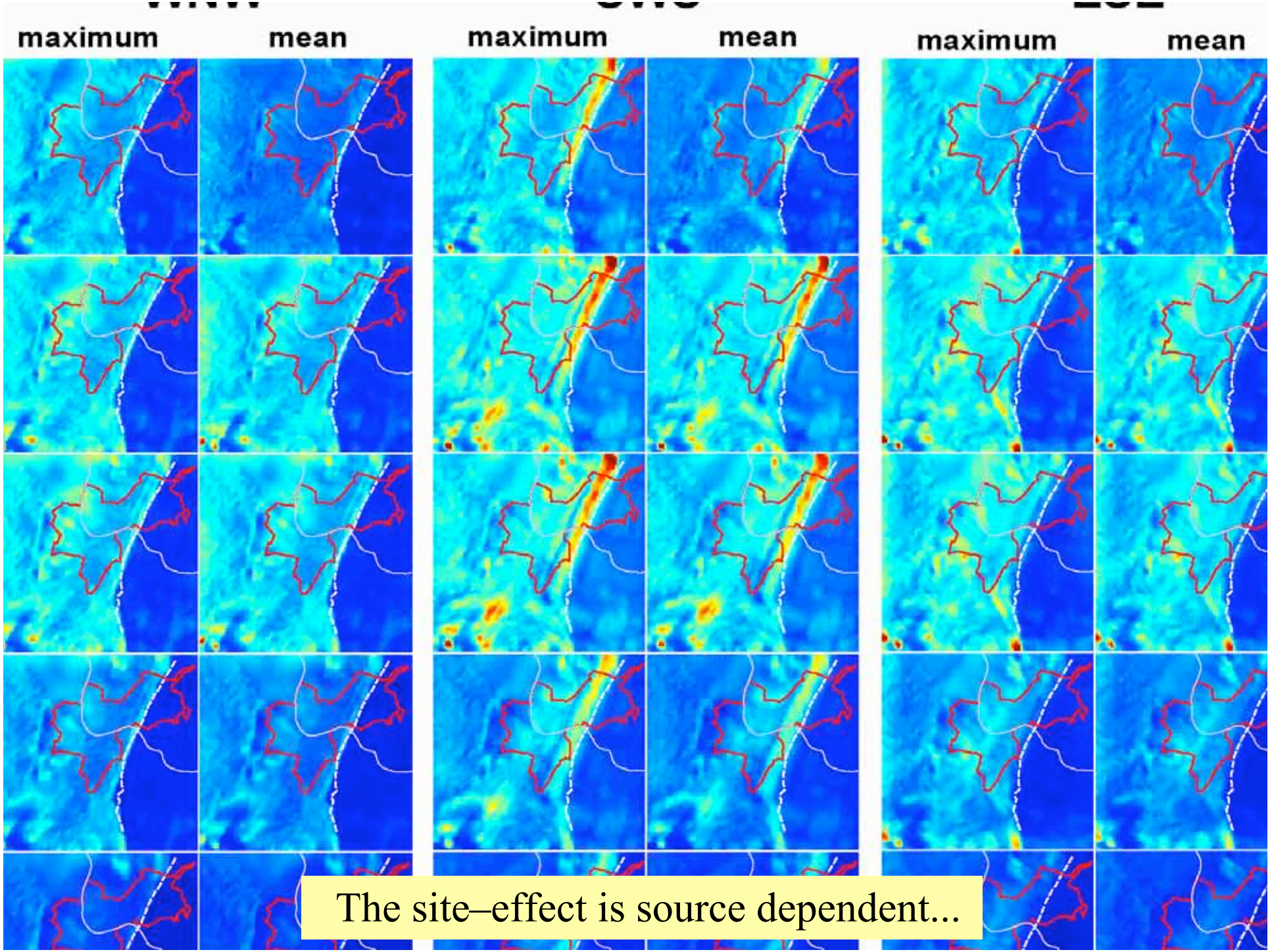
Numerical modelling (3D)





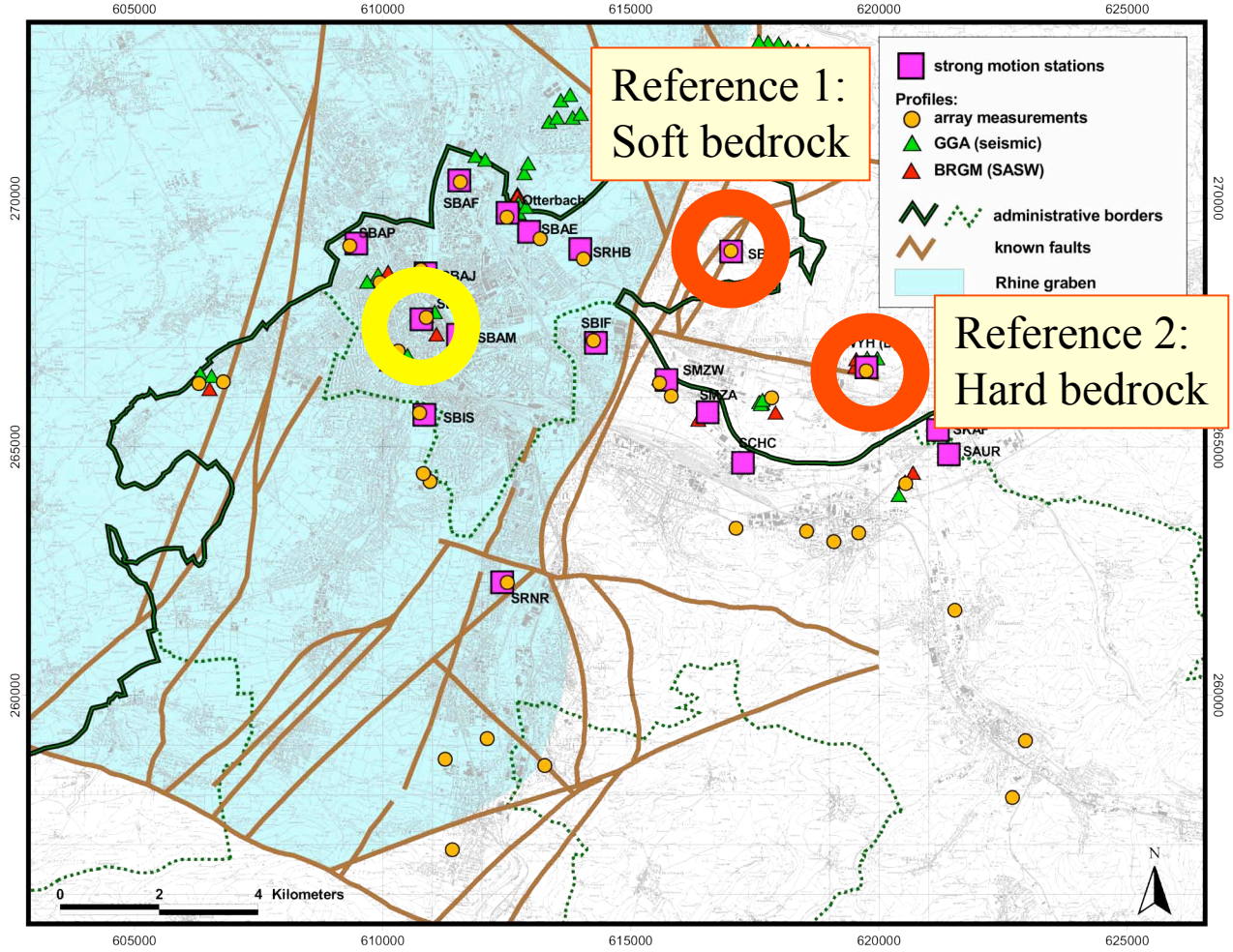


Oprsal et al., 2005


maximum
mean
maximum
mean
maximum
mean
The site–effect is source dependent...

Testing numerical models with observations:

The problem of the reference site conditions: What is „bedrock“ ?



Testing numerical models with observations:

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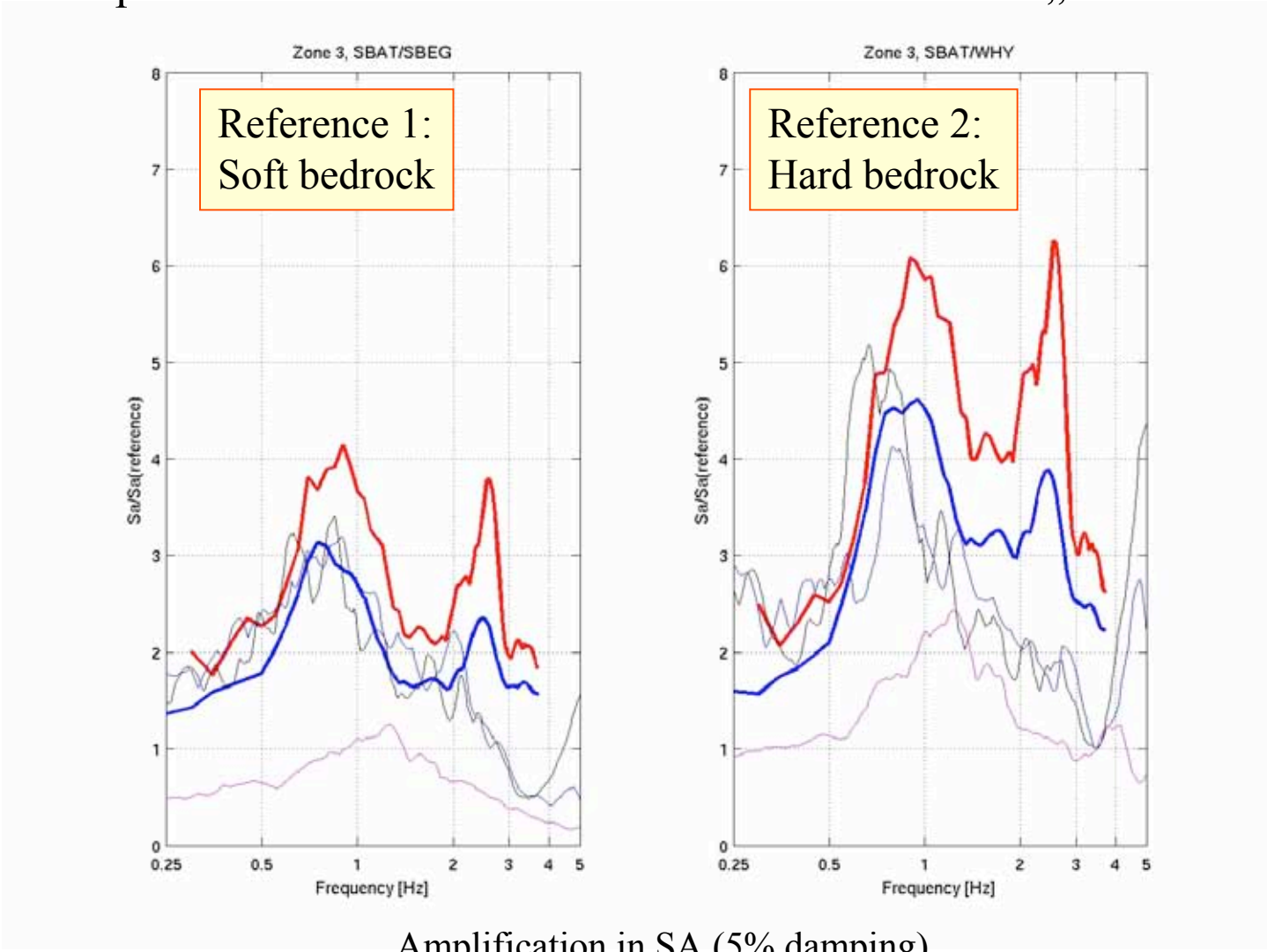
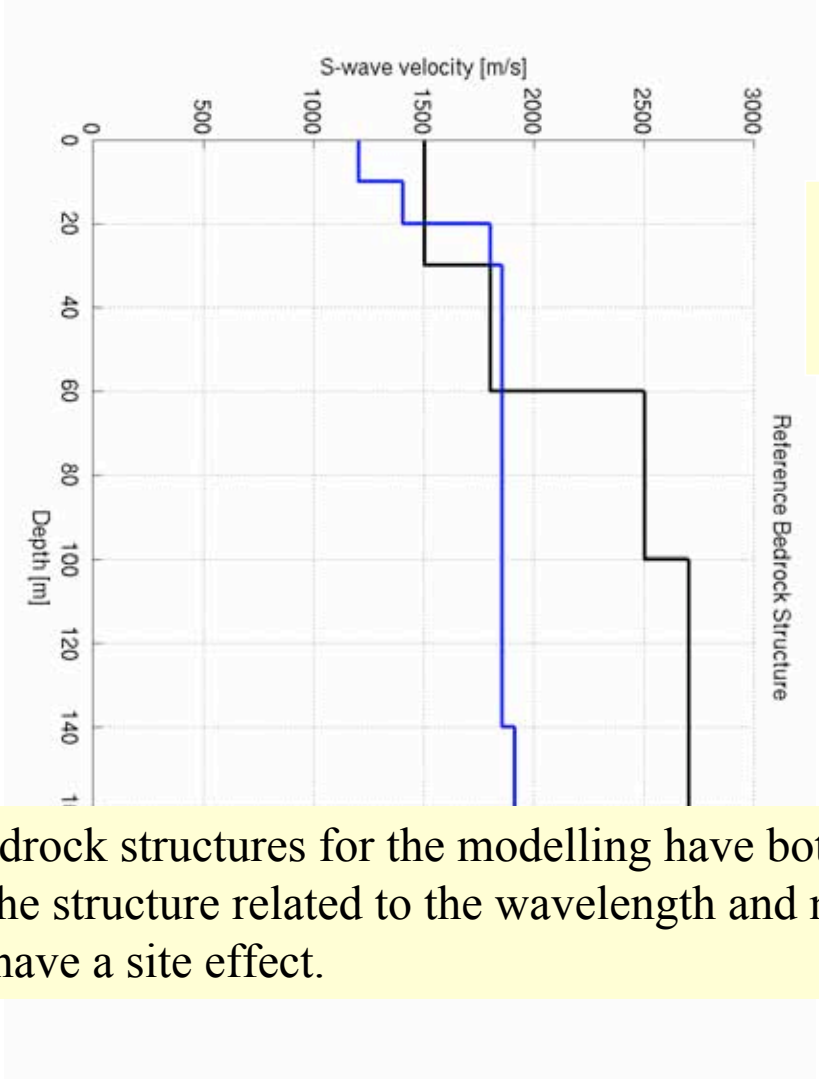


Amplification in SA (5% damping)

Reference Bedrock

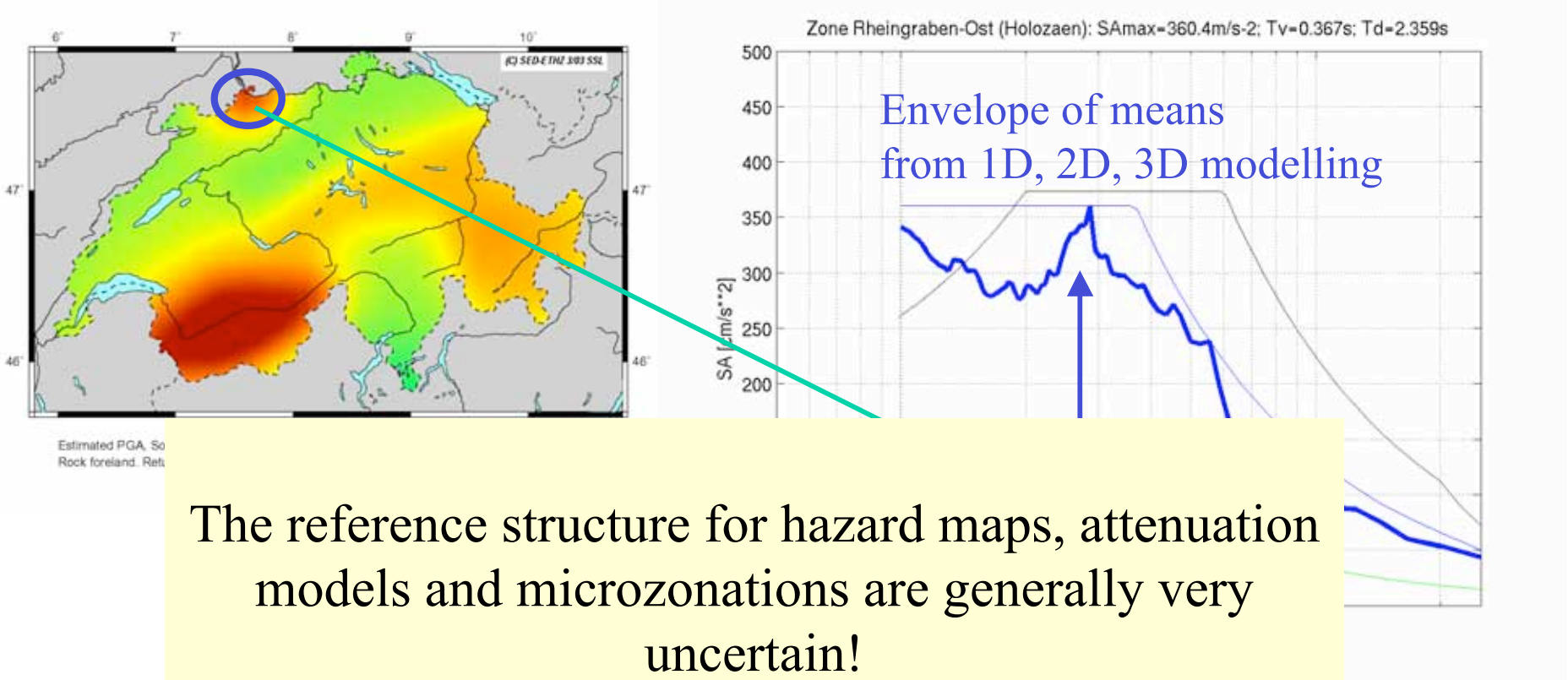


Soft bedrock
(Hazard reference)
Hard bedrock

The 2 reference bedrock structures for the modelling have both a vs30 of about 1500 m/s!

- The waves see the structure related to the wavelength and not only the upper 30m.
- Rock sites also have a site effect.

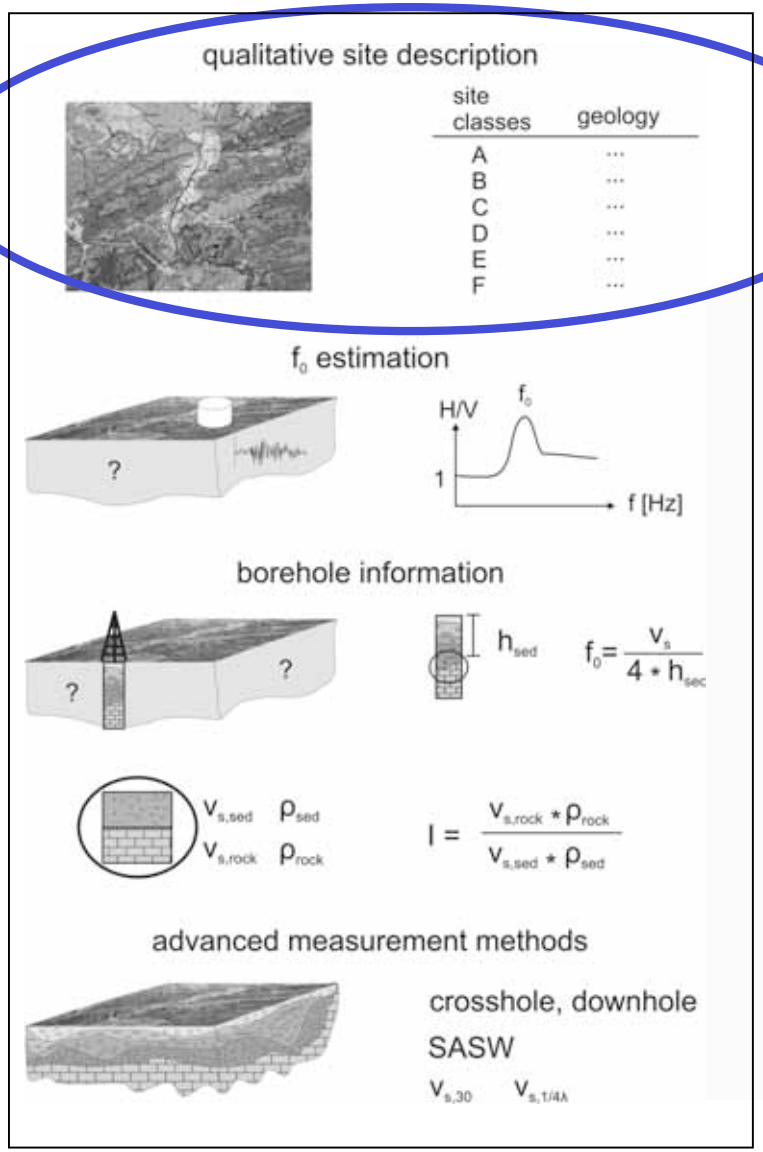
Reference Bedrock?



The reference structure for hazard maps, attenuation models and microzonations are generally very uncertain!

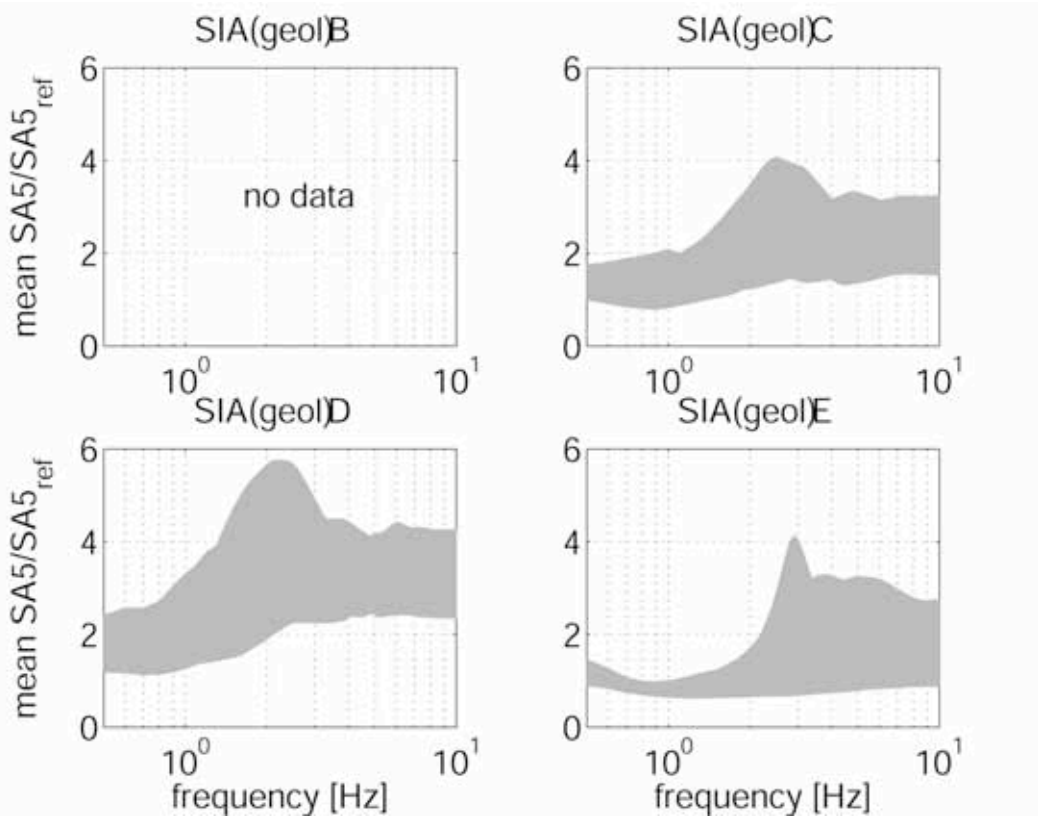
This can be improved by characterizing the sites of the seismological stations (vs, vp profiles)!

(Geological) Site classification in building codes:



(Steimen, 2004)

Mean spectral amplification (5% damping) using geology for site-classification (Swiss sites)



Summary:

- Some more work is needed to make our field techniques more robust.
- The choices in the numerical modelling strongly affect the results.
- Observations (strong & weak motion) are necessary to confirm the modelling. There is a need for dense accelerometric networks.
- Site characterization of the seismic stations is required to reduce uncertainties.
- Building codes: site classification schemes can be improved (microzonation, use of f_0, quarter-wavelength velocity...)

Topics that I have not addressed:

- How to go from weak motion to strong motion estimates
- non-linear behaviour, liquefaction and other secondary phenomena

Thank you for your attention!

Acknowledgments:
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B.Steiner, F.Matter, P.Suhadolc, G.Panza, W.Brüstle,
U. Polom, A.Roulle, P.Huggenberger, E.Fäh
M.Mueller, R.Meier and many others