Using Ambient Vibration Array Techniques for Site Characterisation

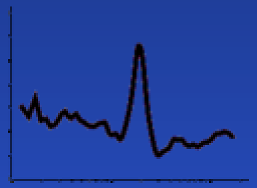
Physical background of ambient vibrations

C. Cornou with many contributions and slides from
S. Bonnefoy-Claudet, P.-Y. Bard and
the SESAME partners.

December 6-12th 2008, Thessaloniki, Greece

Using Ambient Vibration Techniques for Site Characterisation

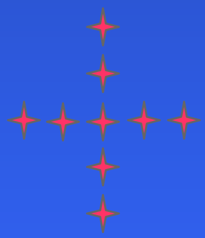
Single station



H/V method

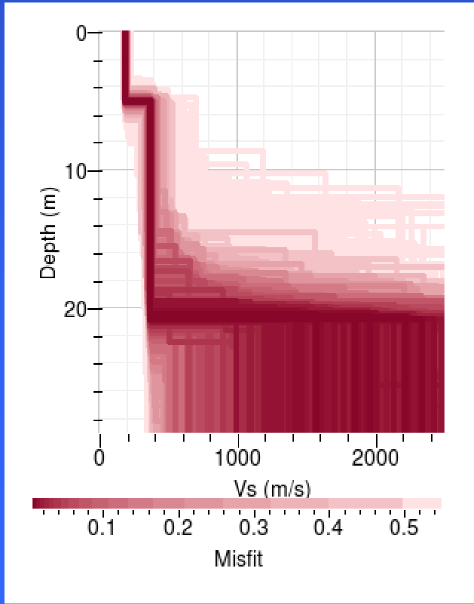
Ratio of horizontal spectrum over vertical spectrum

Array of stations (with synchroneous records)



Study wave propagation between motion sensors

Output: shear wave velocity vs. depth



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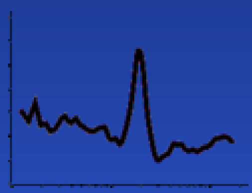
Single station



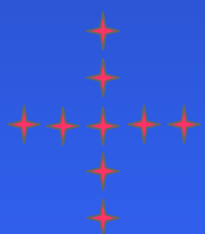
H/V method

Ratio of horizontal spectrum over vertical spectrum

1

SURFACE WAVES

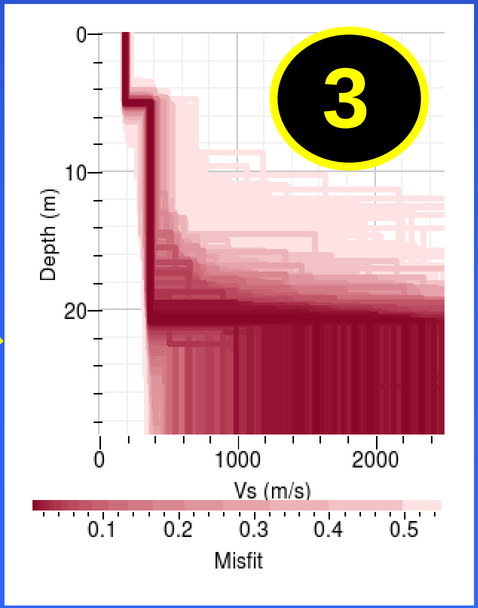
Array of stations (with synchrone ... rds)



Study wave pr ... n between
motion sens ...

2

Output: shear wave velocity vs. depth

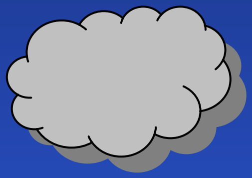


Using Ambient Vibration Array Techniques for Site Characterisation

- Short historical review on noise ambient vibration studies
- Origin and nature of ambient noise
- The links between subsurface structure and wave field propagation properties

Short historical review on the use of noise ambient vibration studies

(Bonnefoy-Claudet et al., Earth Science Review,2006)



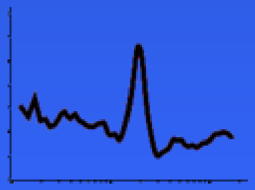
Before 1950

⇒ Correlation between meteorological perturbations and microseisms

50-70's

=> Noise array analysis thanks to Capon and Aki studies

=> Nature of noise wavefield



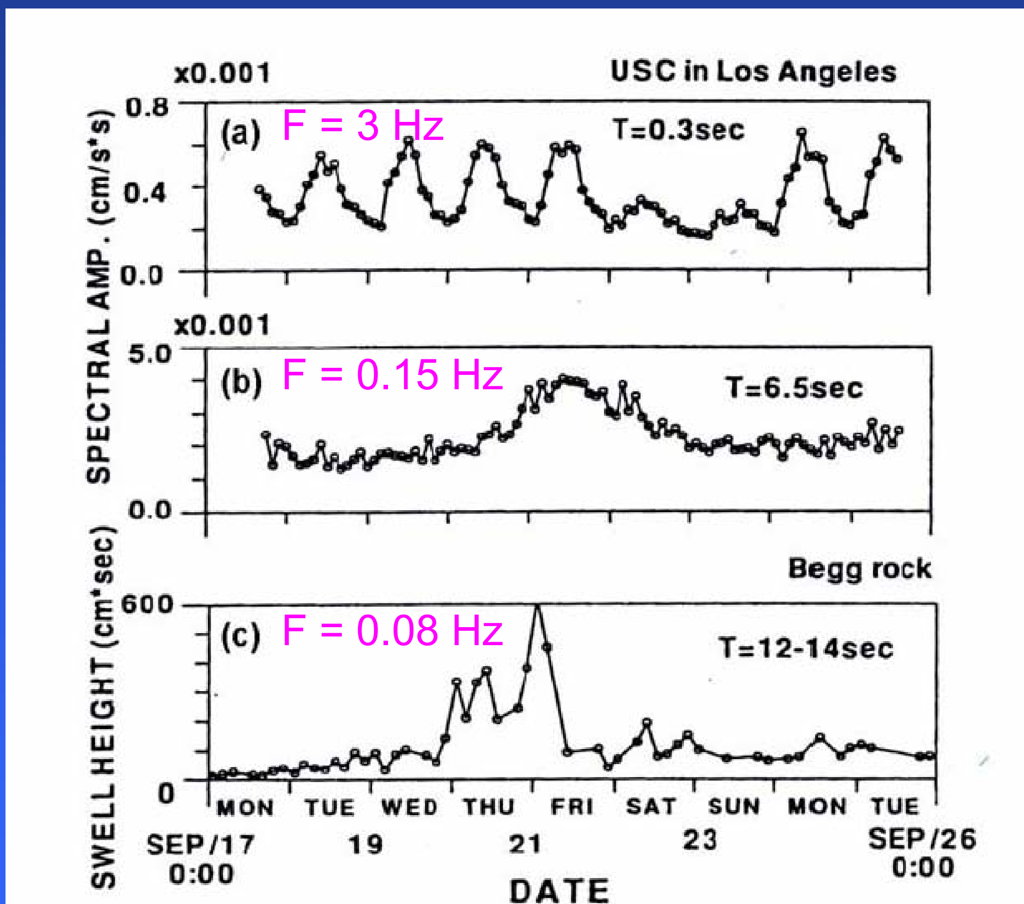
Since 70's

=> H/V

⇒ Array analysis for deriving shear-wave velocity structure

⇒ Nature of noise wave field

Origin of noise: Time amplitude variation



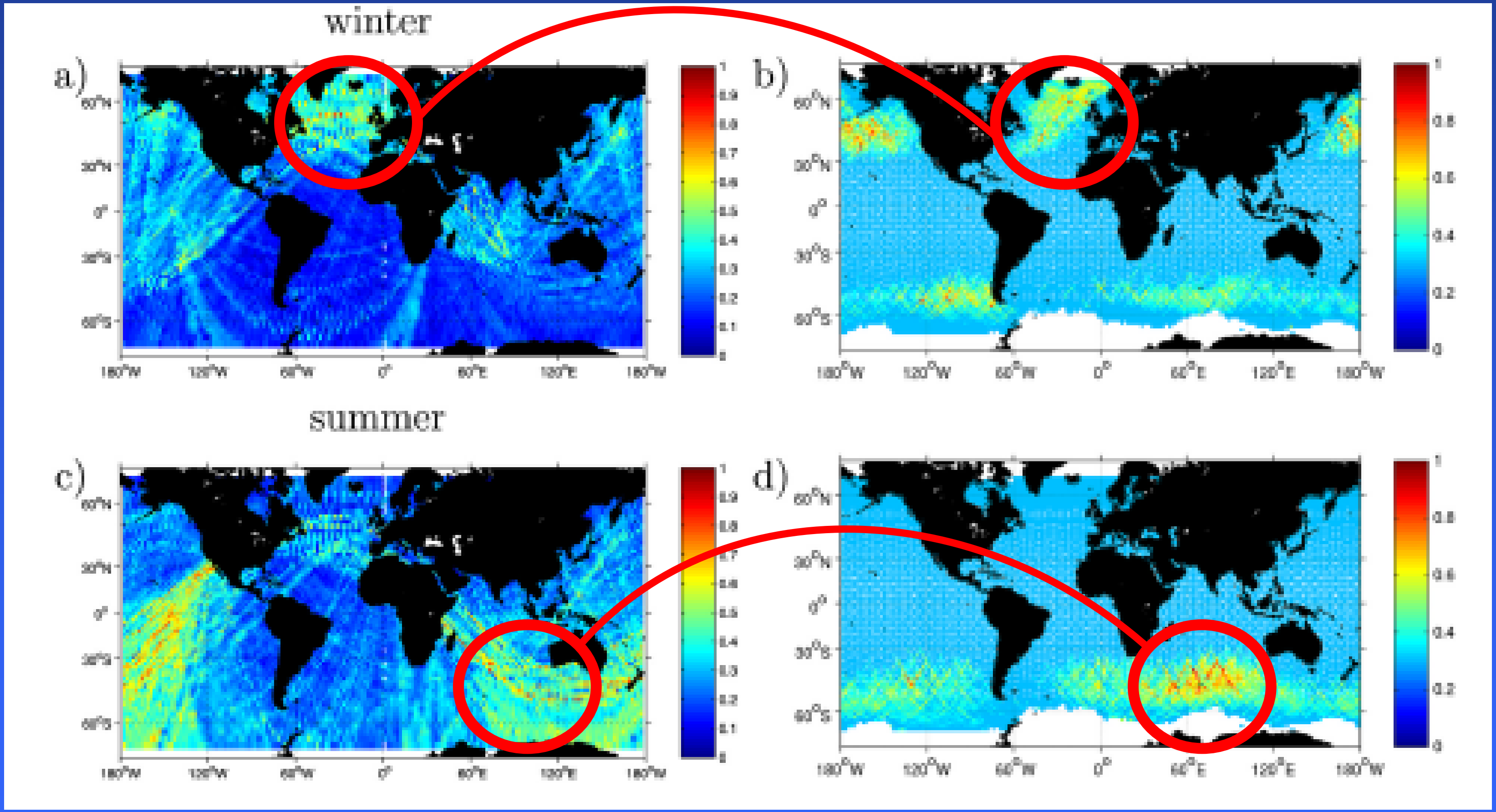
After Yamanaka et al., 1993

→ Correlation with human activities (weekly and daily activities)

→ Correlation with ocean activities

Origin of noise

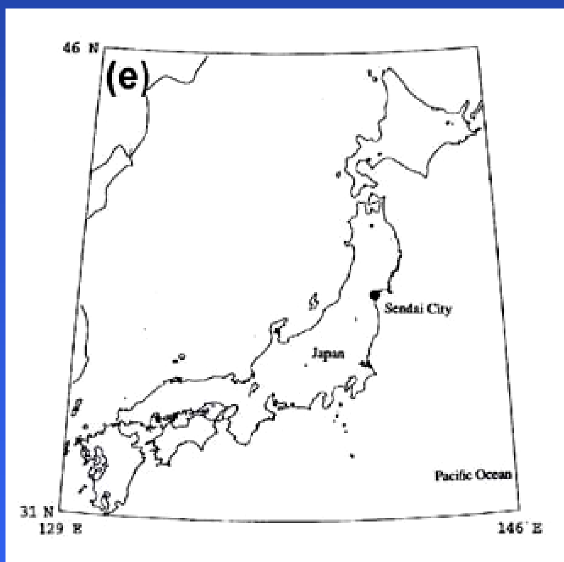
10-20 s noise | Wave height

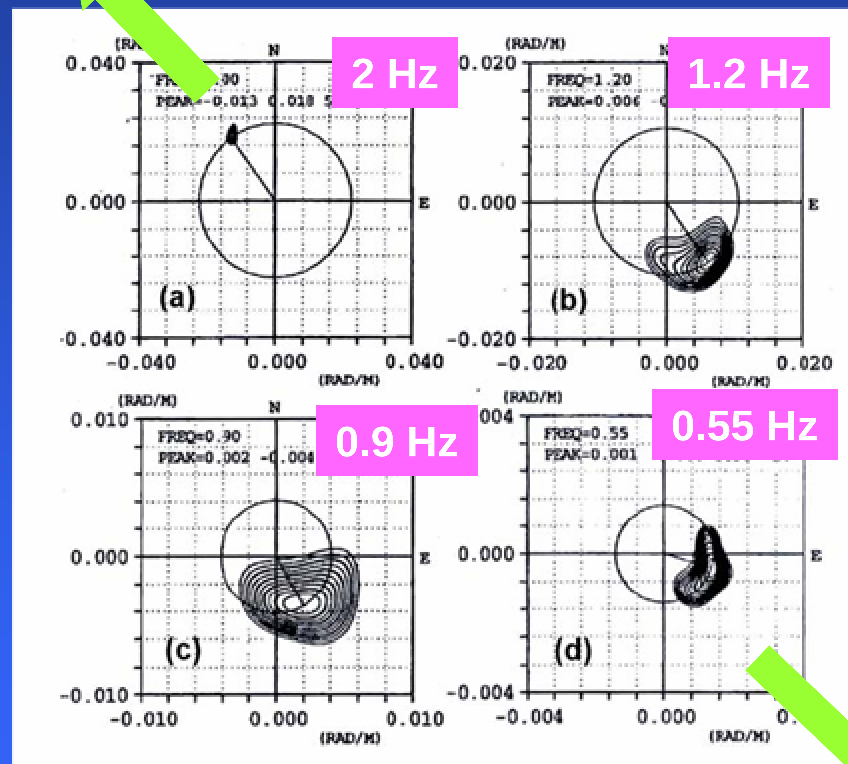


Stehly et al. (2006)

Origin of noise

Sendai city





Satoh et al. (2001)

Japan sea

Origin of noise

Below 1 Hz → oceanic and large scale meteorological conditions

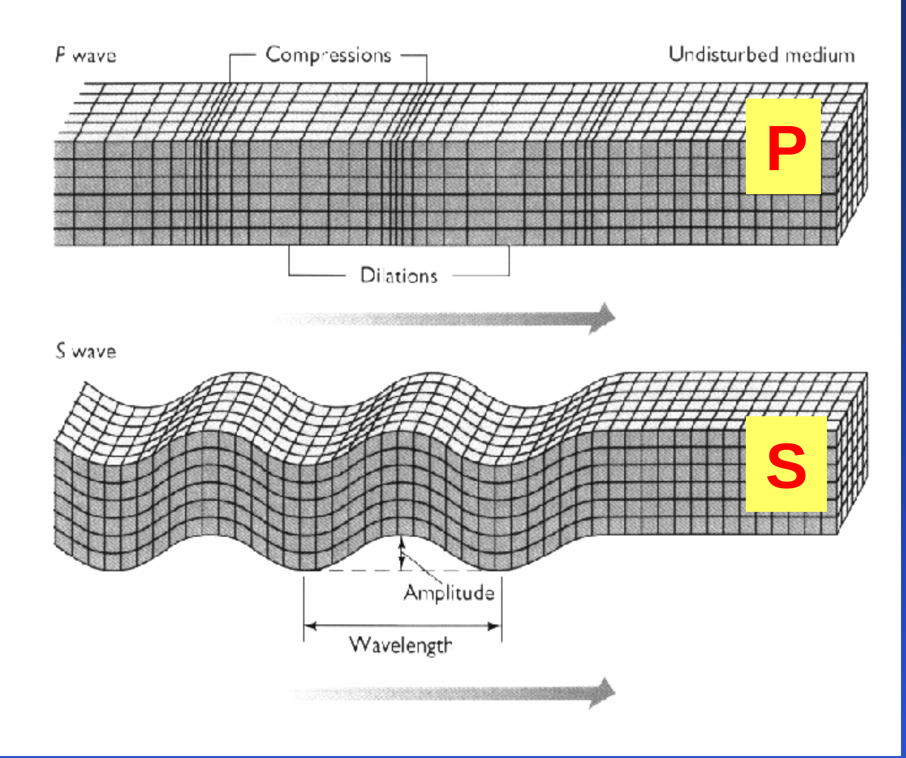
Close to 1 Hz → wind effects and local meteorological conditions

Above 1 Hz → human activies

Microseisms

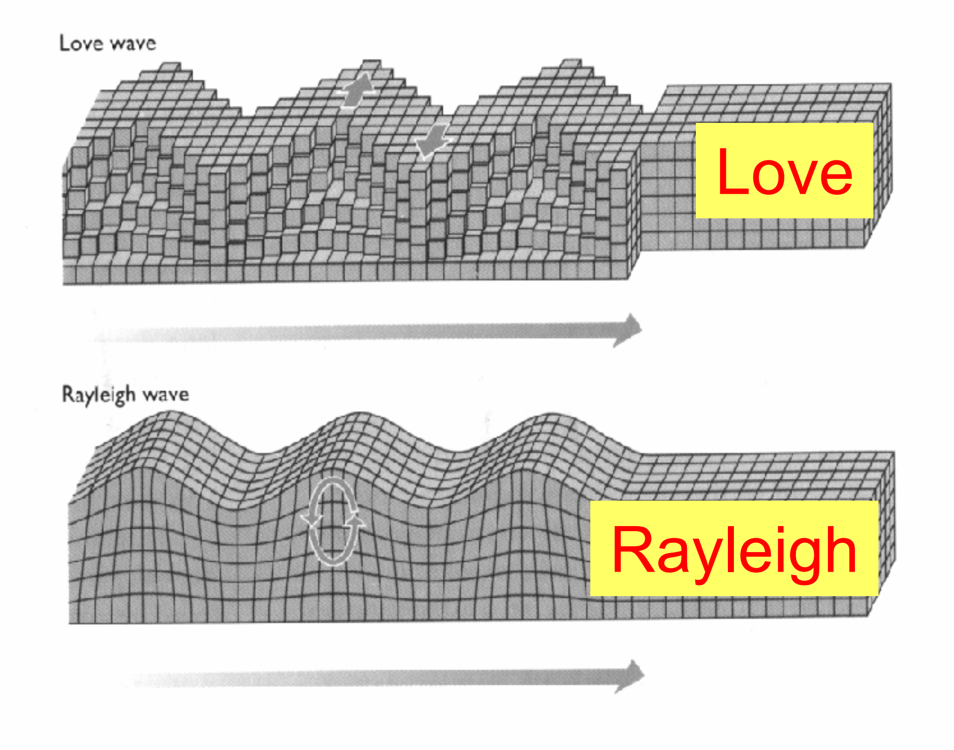
Microtremors

Nature of noise



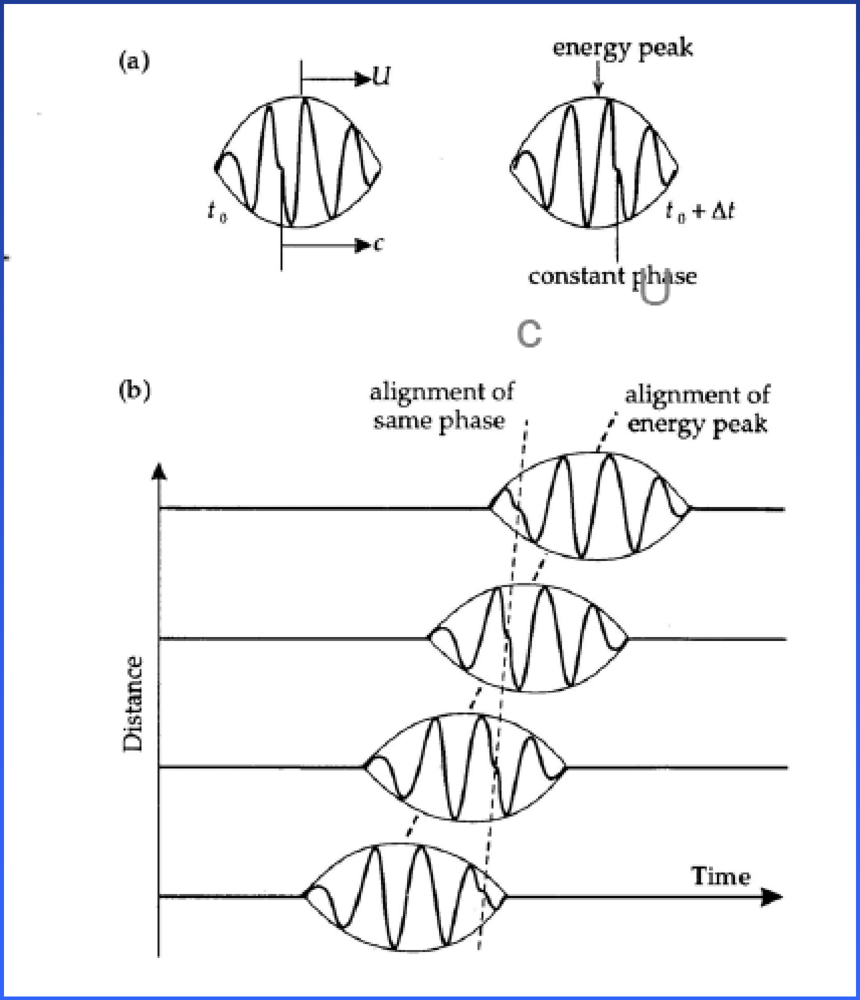
Body waves

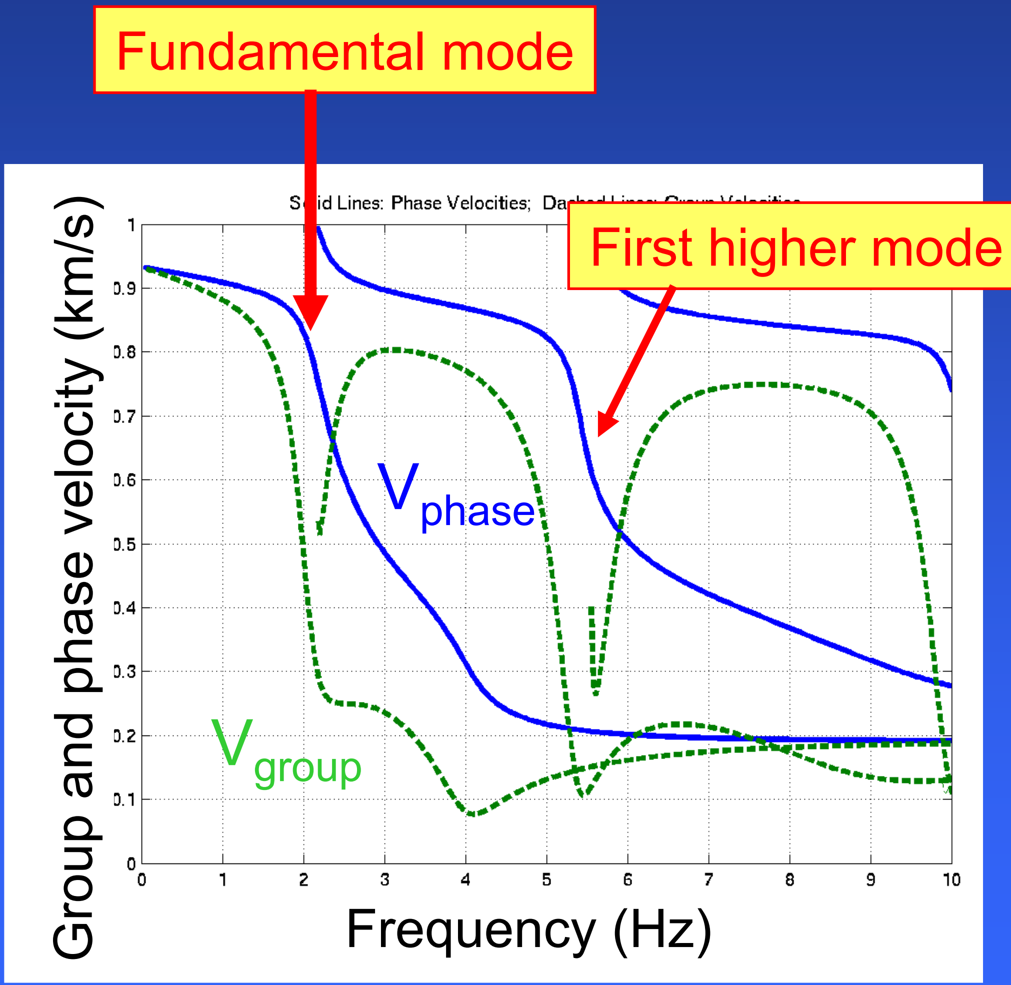
Surface waves



Source : Bolt, 1976

Characteristics of surface waves: velocity varies with frequency





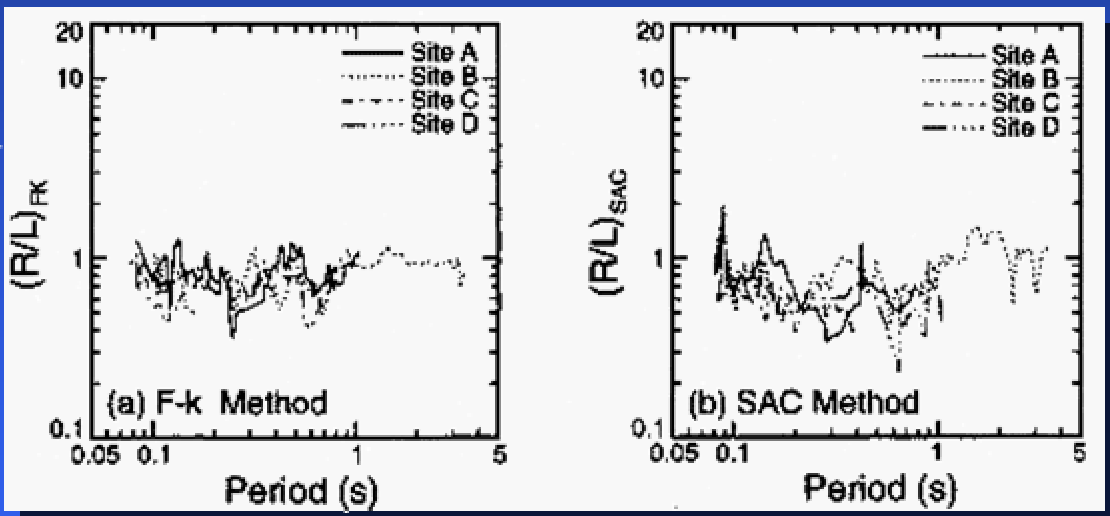
Nature of noise

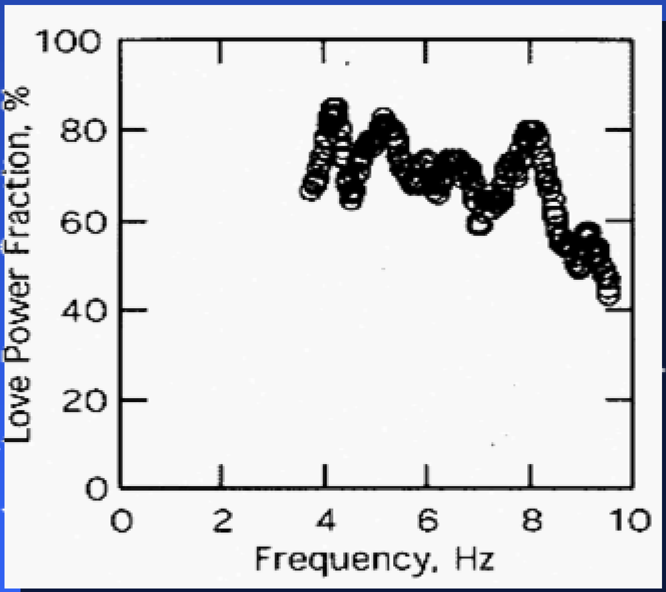
Microseisms	**Microtremors**
• Far sources	• Local sources
• Surface waves	• Surface + body waves
• Rayleigh waves	• Rayleigh + Love waves
• Fundamental mode	• Fundamental + higher modes

Composition of microtremors: proportion Rayleigh / Love

Array noise measurements (F-K, SPAC)
Tokyo, Kobe, Kushiro (Japan)

50% to 85% of Love waves in the frequency range [3-10 Hz]

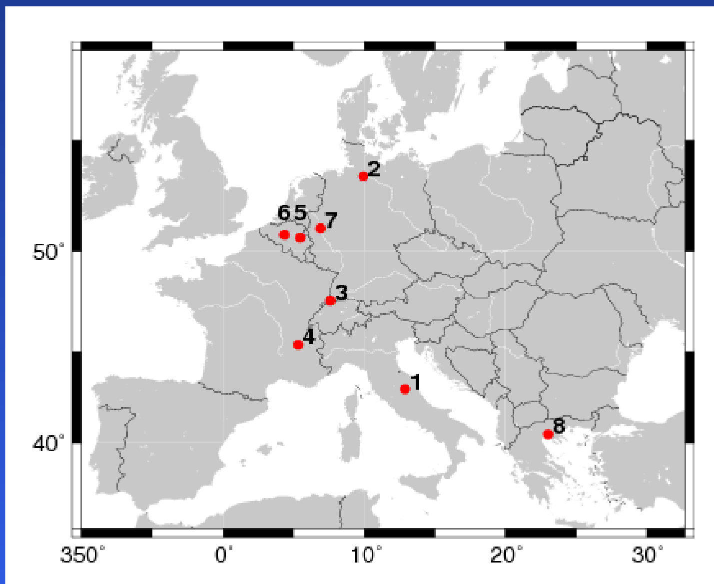




70% of Love waves in the frequency range [1-12 Hz]
(Arai and Tokimatsu, 1998)

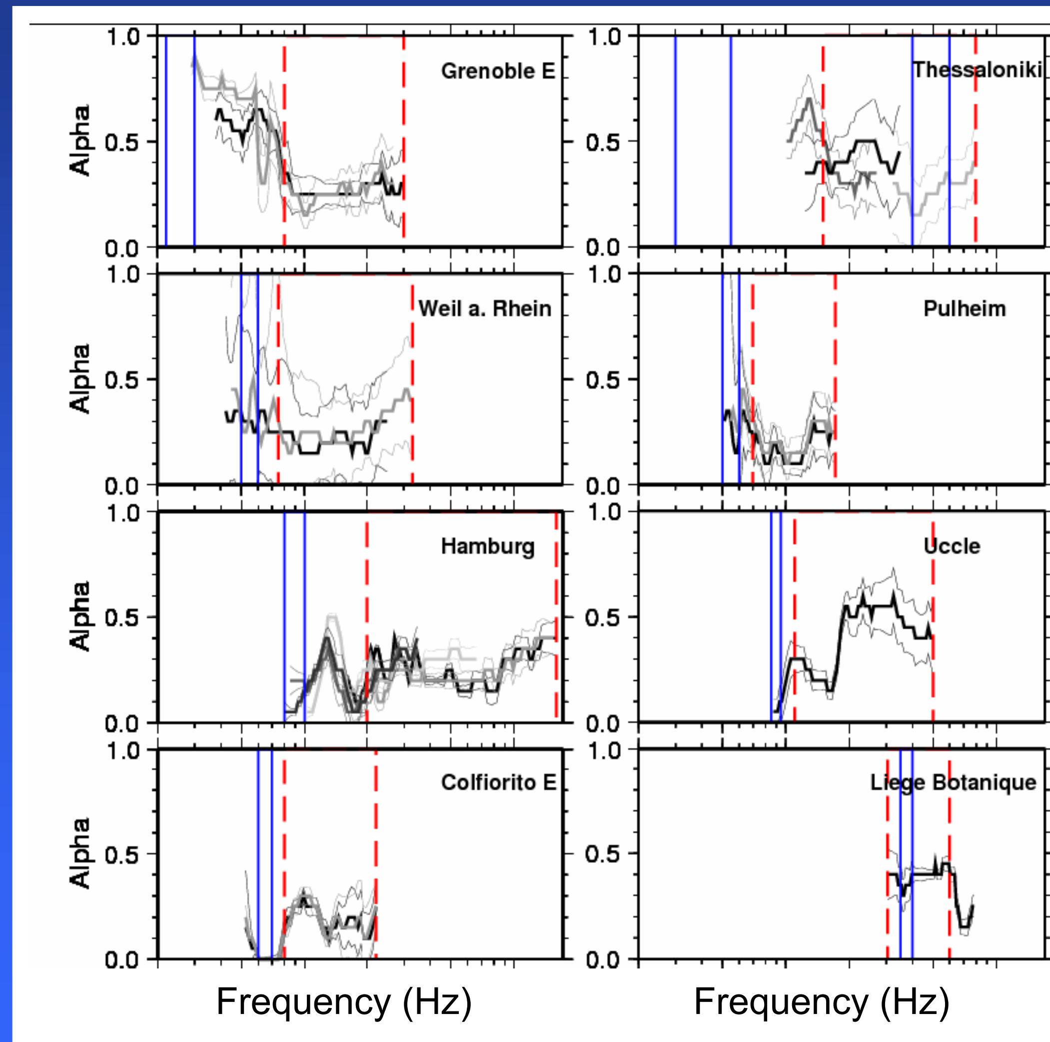
Array noise measurements (SPAC)
Morioka (Japan) (Yamamoto, 2000)

Composition of noise: proportion Rayleigh / Love



Koehler et al., 2006

Alpha = Proportion R/L
(for horizontal motion)



Composition of microtremors: proportion Rayleigh / Love

	Frequency	Rayleigh	Love
Chouet et al. 1998 *(volcanoes)*	> 2Hz	30%	70%
Yamamoto 2000	3-10 Hz	< 50%	> 50%
Arai et al. 1998	1-12 Hz	30%	70%
Cornou, 2002	0.2 – 1 Hz	50%	50%
Koehler et al. 2006	0.5 – 5 Hz	< 30%	> 70%

For a given site, proportion of R/L varies with frequency

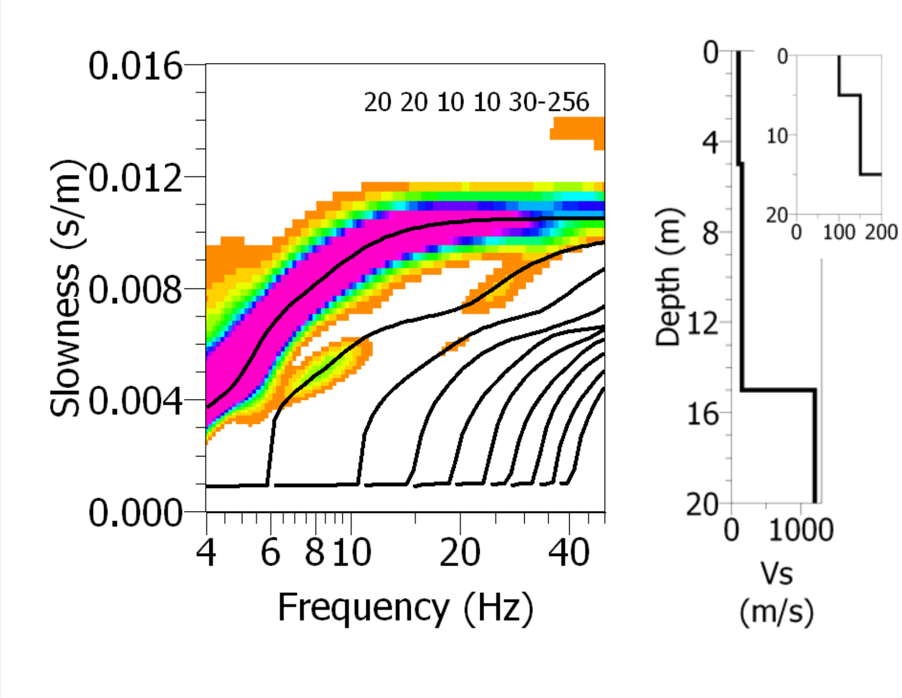
Composition of noise: fundamental / higher modes of Rayleigh waves

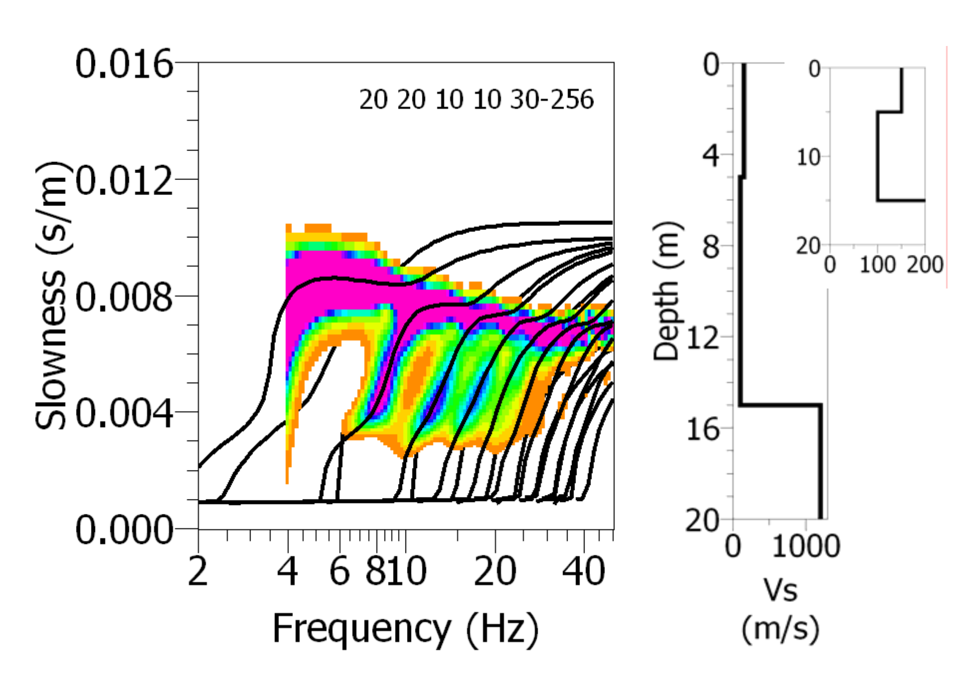
- Mainly fundamental modes especially at low frequency
- Higher modes are in most cases observed at high frequencies
- No (few?) studies regarding proportion between fundamental/higher modes
- Characteristics of stratified soil profiles that permit existence of higher modes:

  - low velocity zone
  - high attenuation (low Qs value) together with close/far sources

Composition of noise: fundamental / higher modes of Rayleigh waves (effects of Vs)

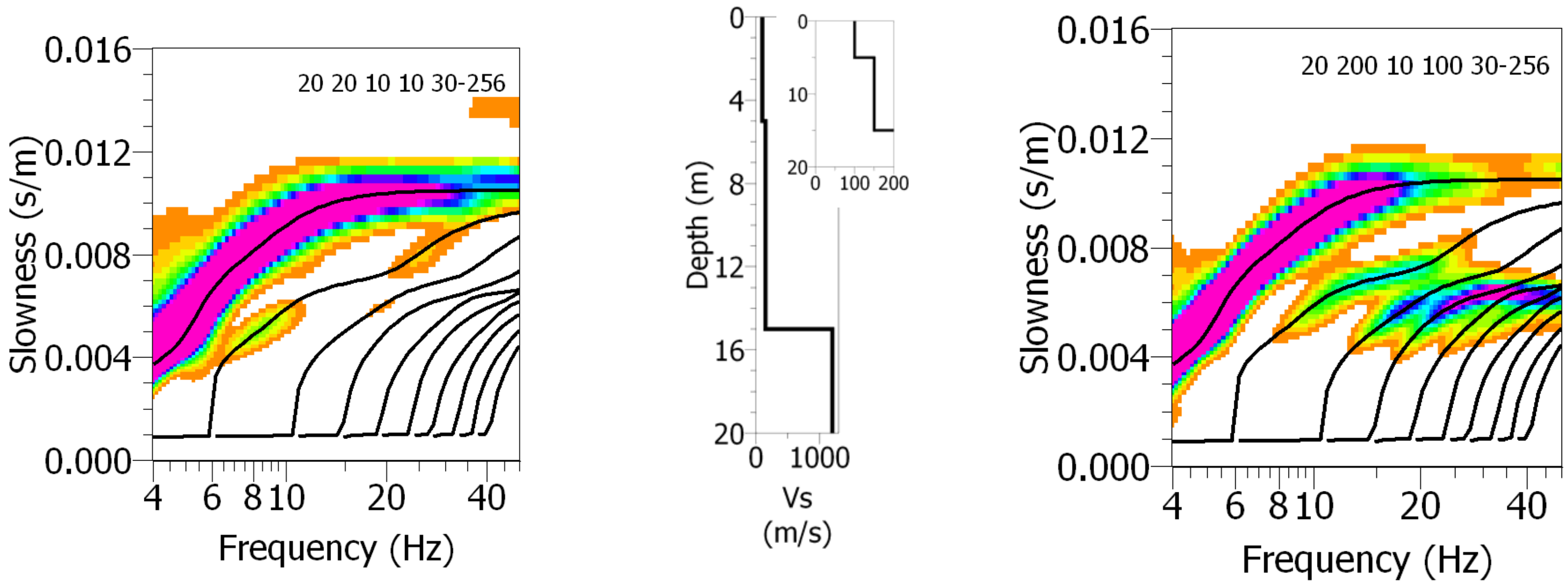
Characteristics of stratified Vs profile (especially LVZ) permit existence of higher modes





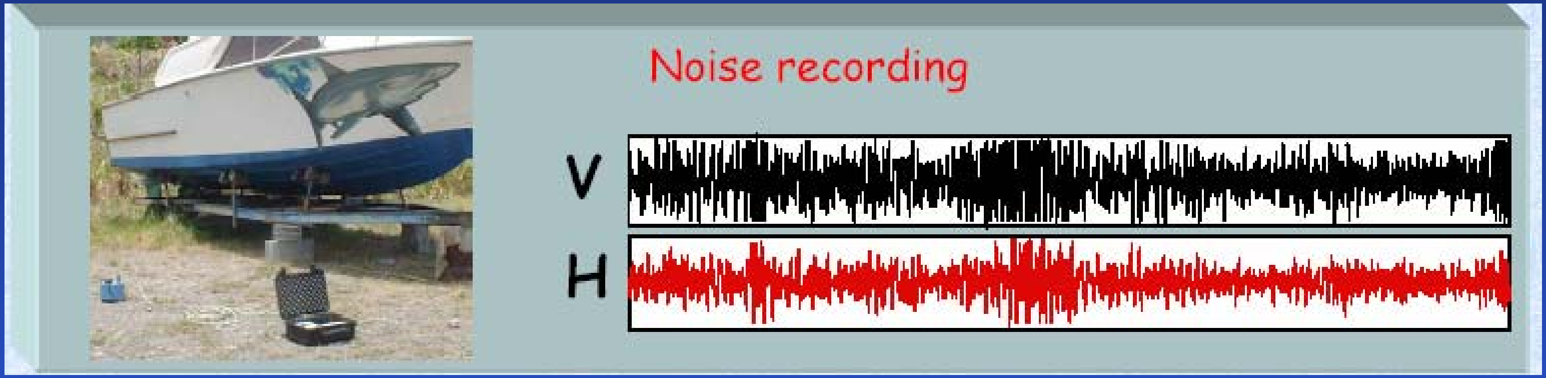
Composition of noise: fundamental / higher modes of Rayleigh waves (effects of Qs)

Geological characteristics of stratified soil (low Qs value) permit existence of higher modes



Qp	Qs
20	10
200	100
200	100

Qp	Qs
20	10
20	10
200	100



- natural + anthropogenic

- mainly surface waves (Rayleigh and Love waves)
- body waves

⇒How ambient noise can help us in deriving information on site conditions ????

H/V decomposition

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

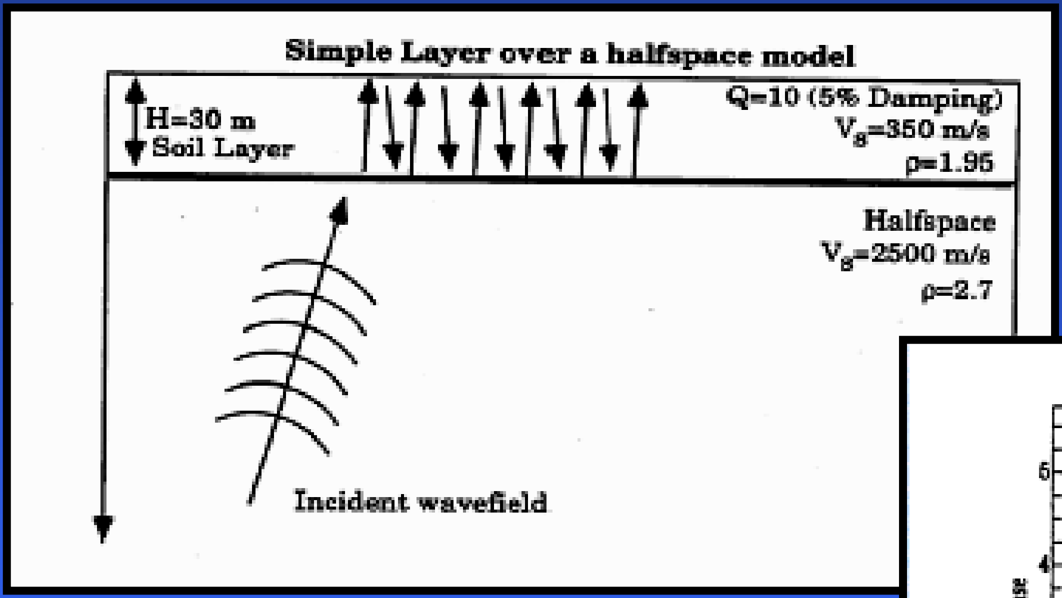
Body waves

Surface waves

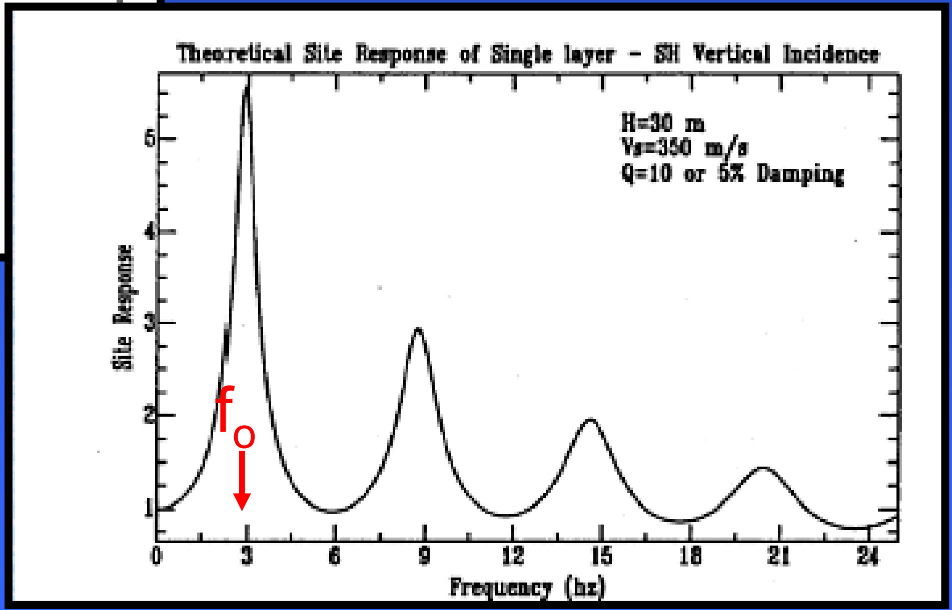
Impedance contrast	Composition
Strong ([4,∞[)	Rayleigh+Love
Moderate([3, 4])	Love+a bit of Rayleigh
Low (]∞,3])	Body waves+Love

After Bonnefoy-Claudet et al. (2008)

Links between subsurface structure and waves type: Body S-waves

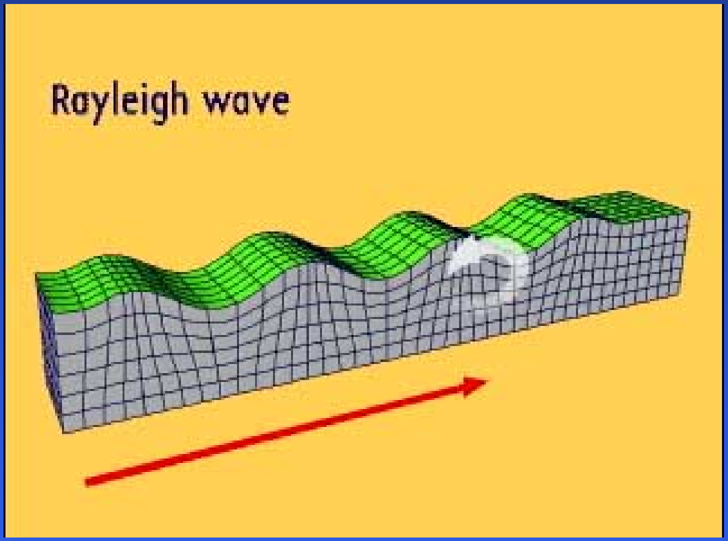


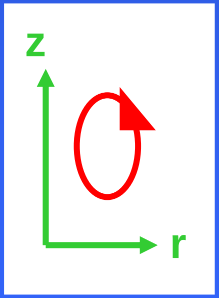
SH transfer function



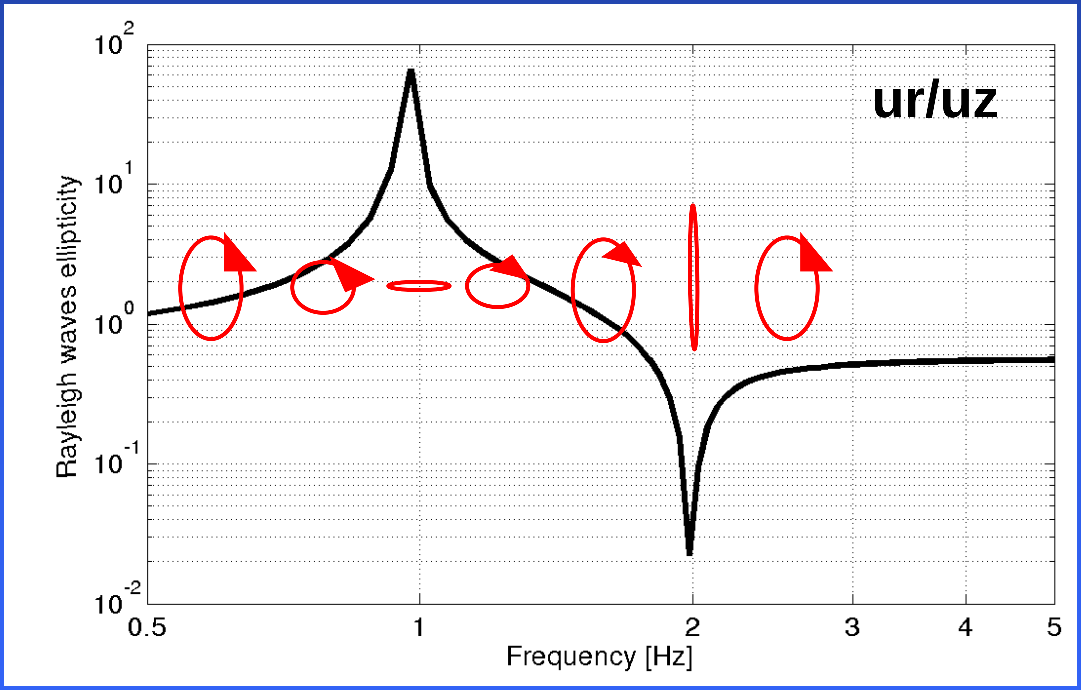
Resonance frequencies:
$f_n = (2n+1)Vs/4h$

Links between subsurface structure and ellipticiy peak of Rayleigh waves

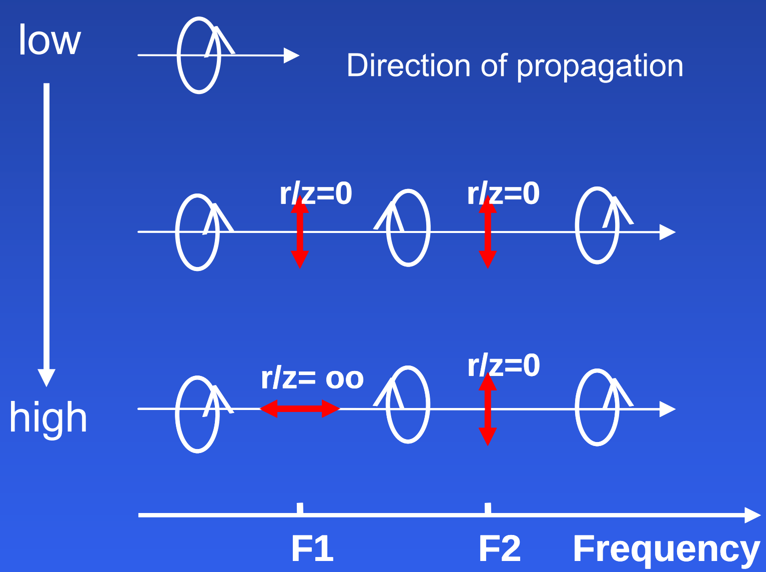


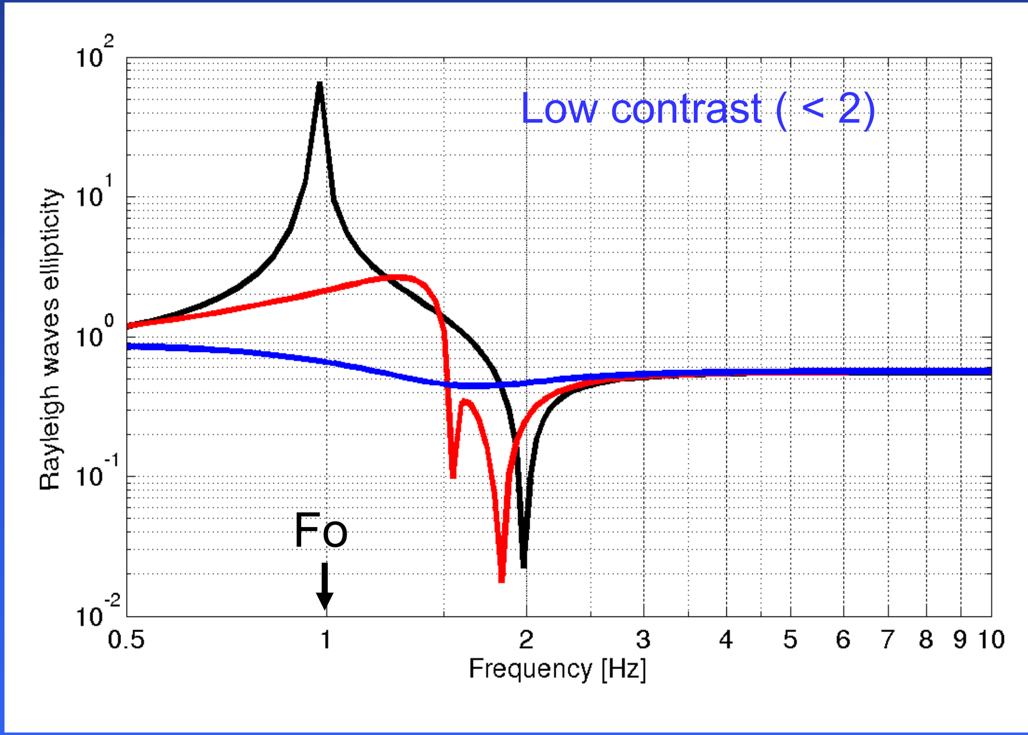


Case of a high-contrast layered model



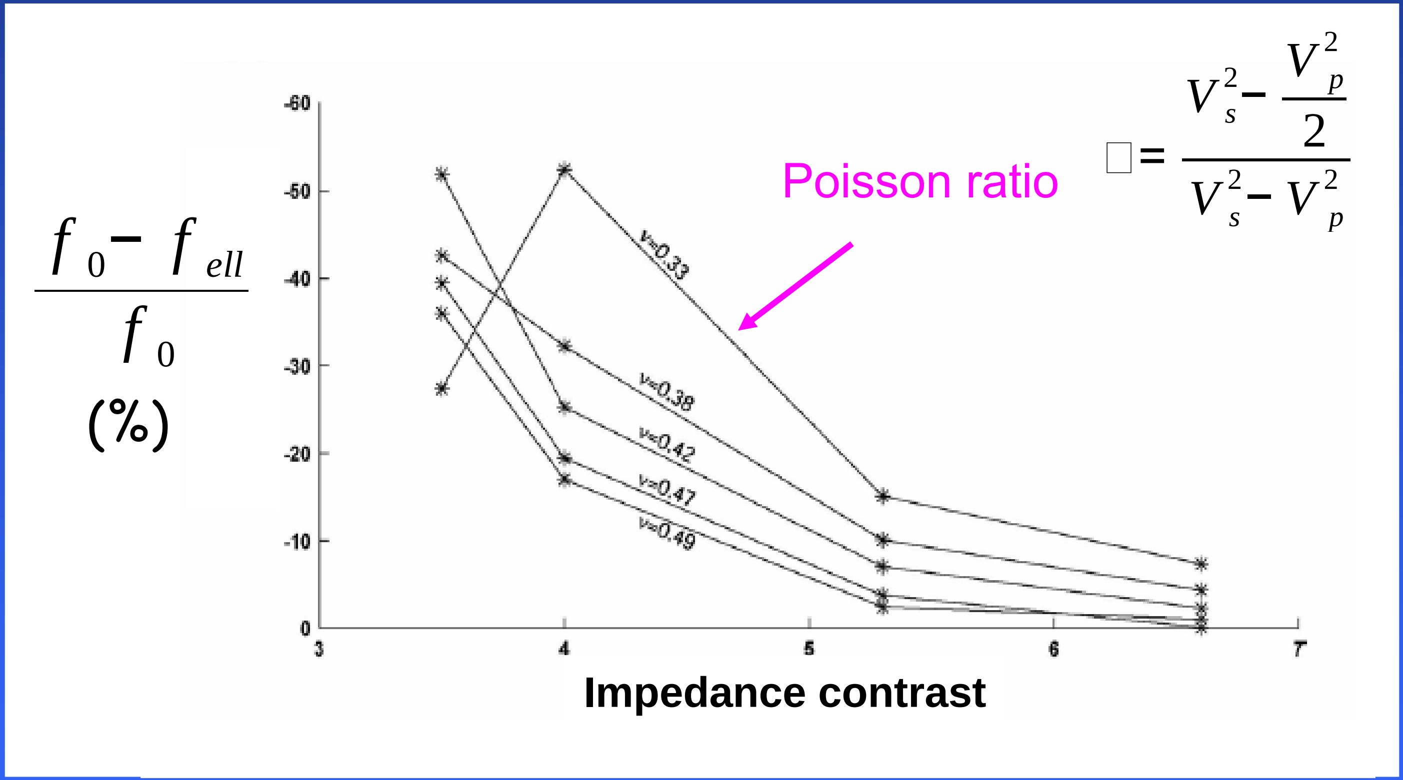
Links between subsurface structure and ellipticiy peak of Rayleigh waves





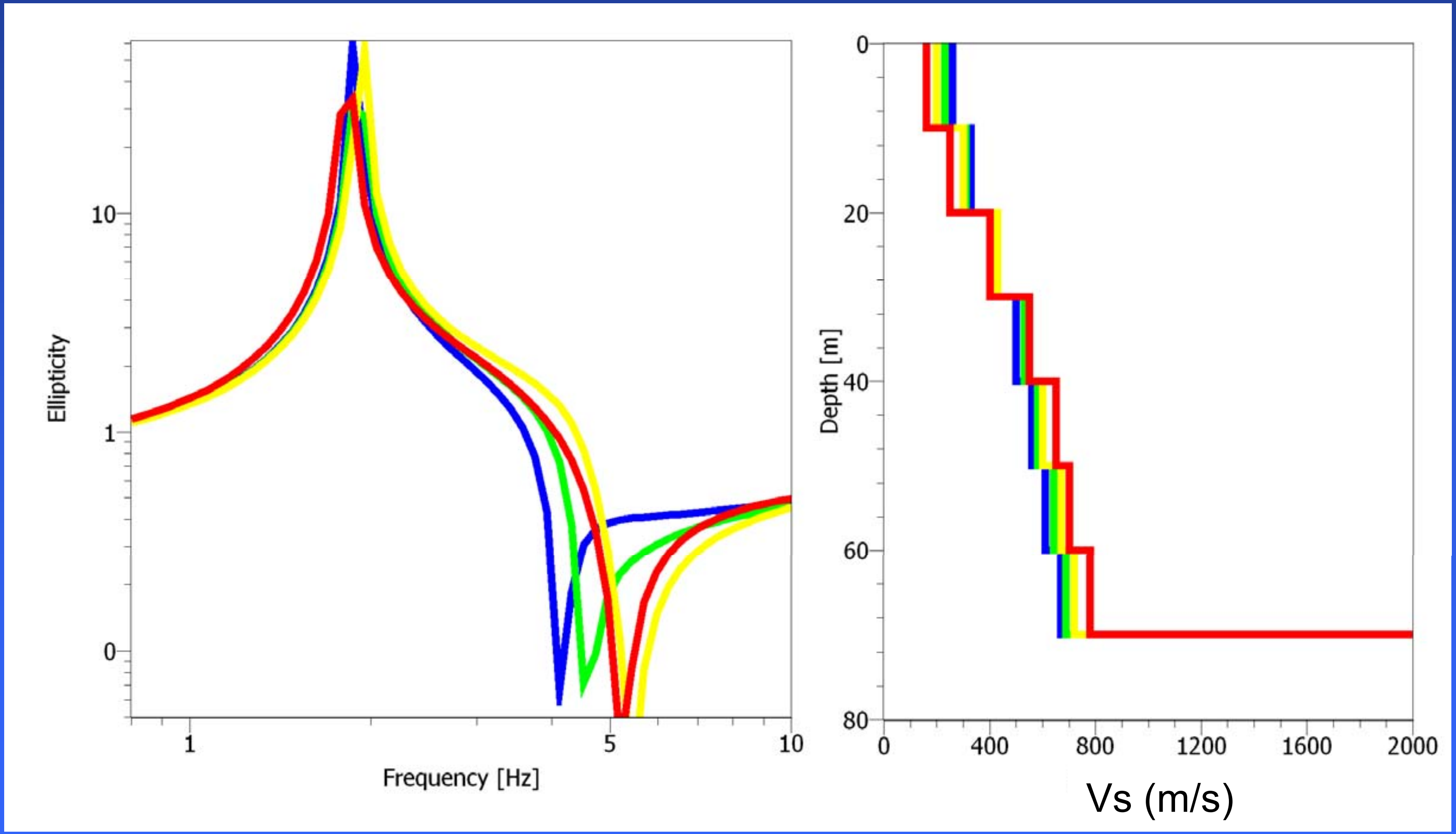
For large contrast, $f_{ellipticity}$ is very close to the resonance frequency of the site (f_o)

Links between subsurface structure and ellipticiy peak of Rayleigh waves



After Bonnefoy-Claudet (2004)

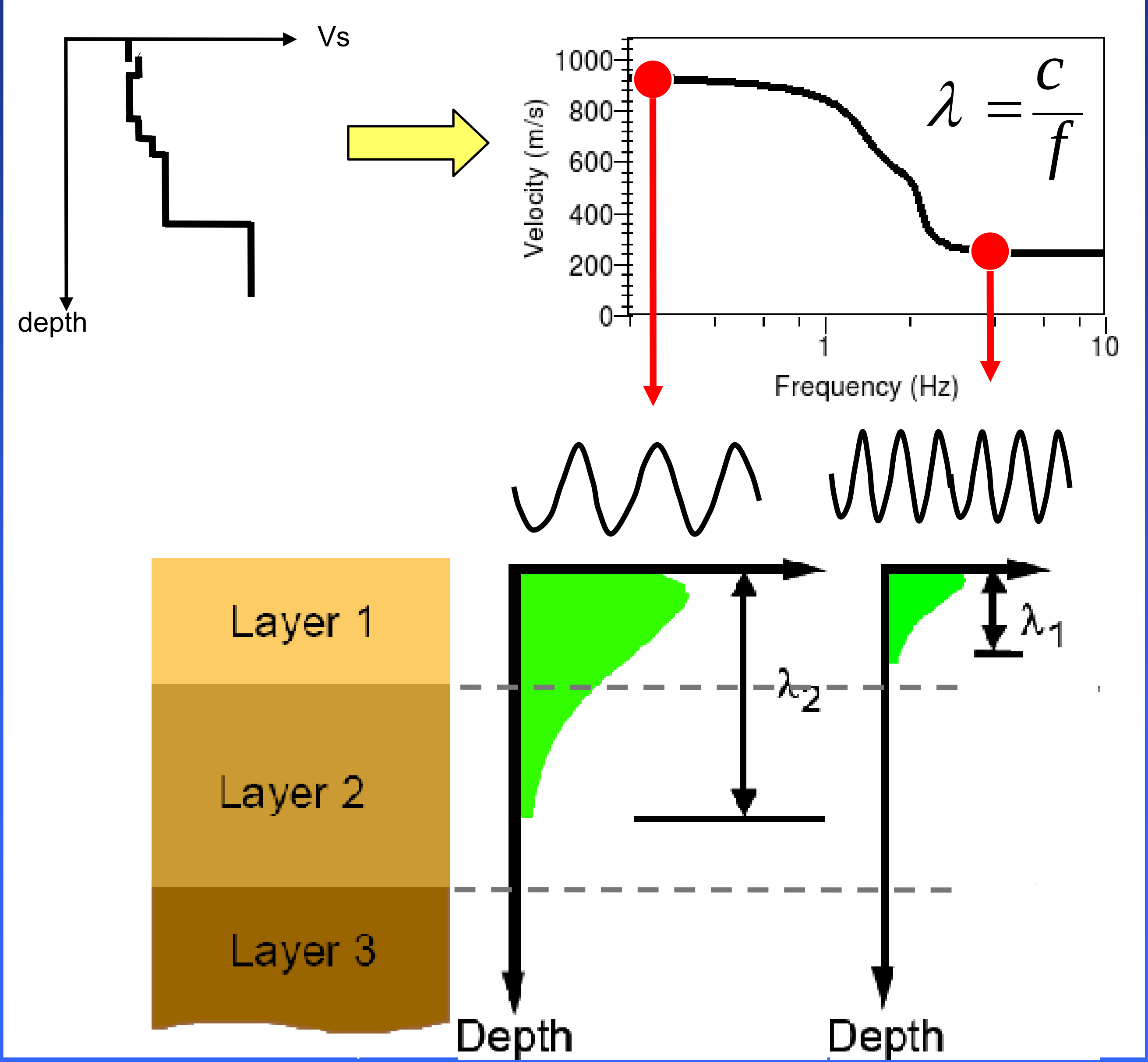
Links between subsurface structure and ellipticiy shape of Rayleigh waves



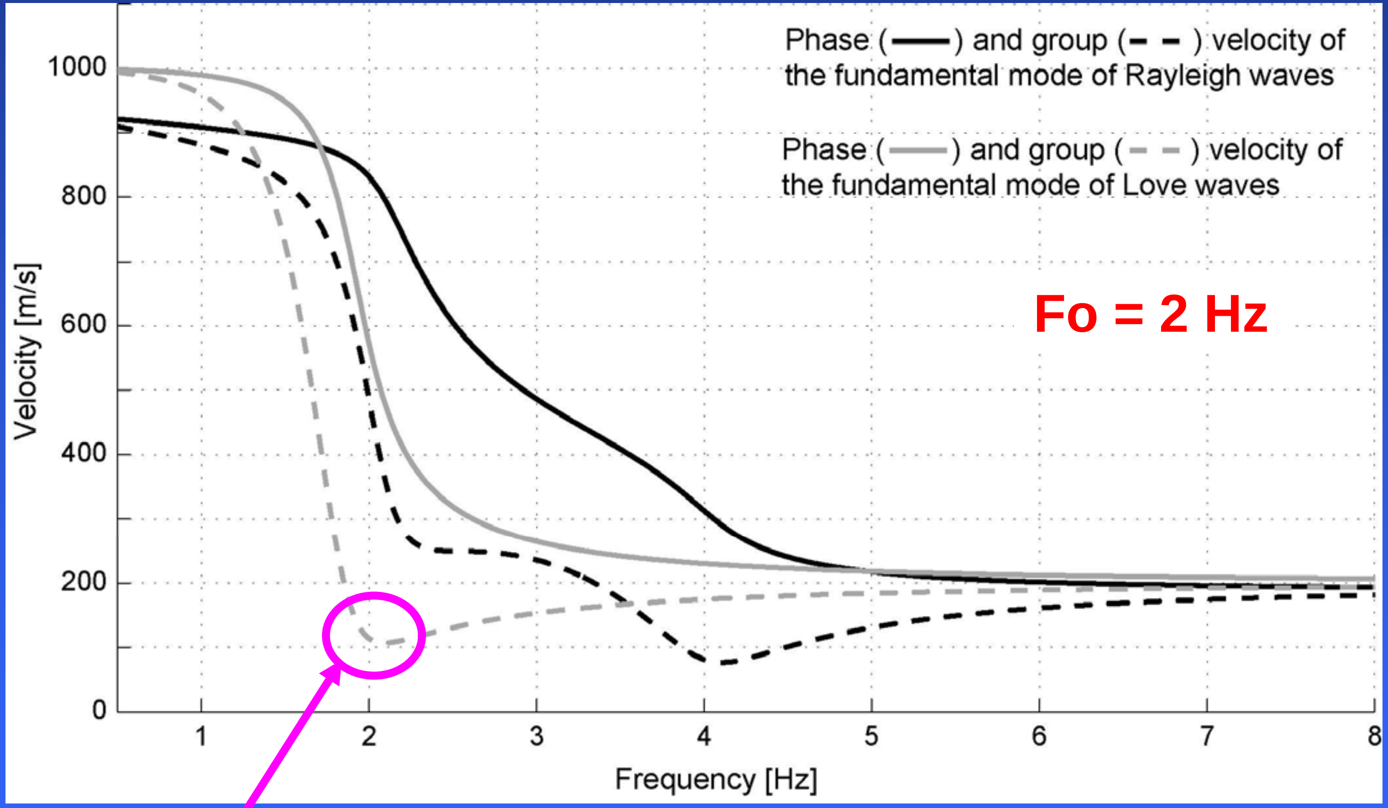
Links between subsurface structure and phase velocity of surface waves

Surface Waves
=
Dispersive Waves

velocity varies with frequency

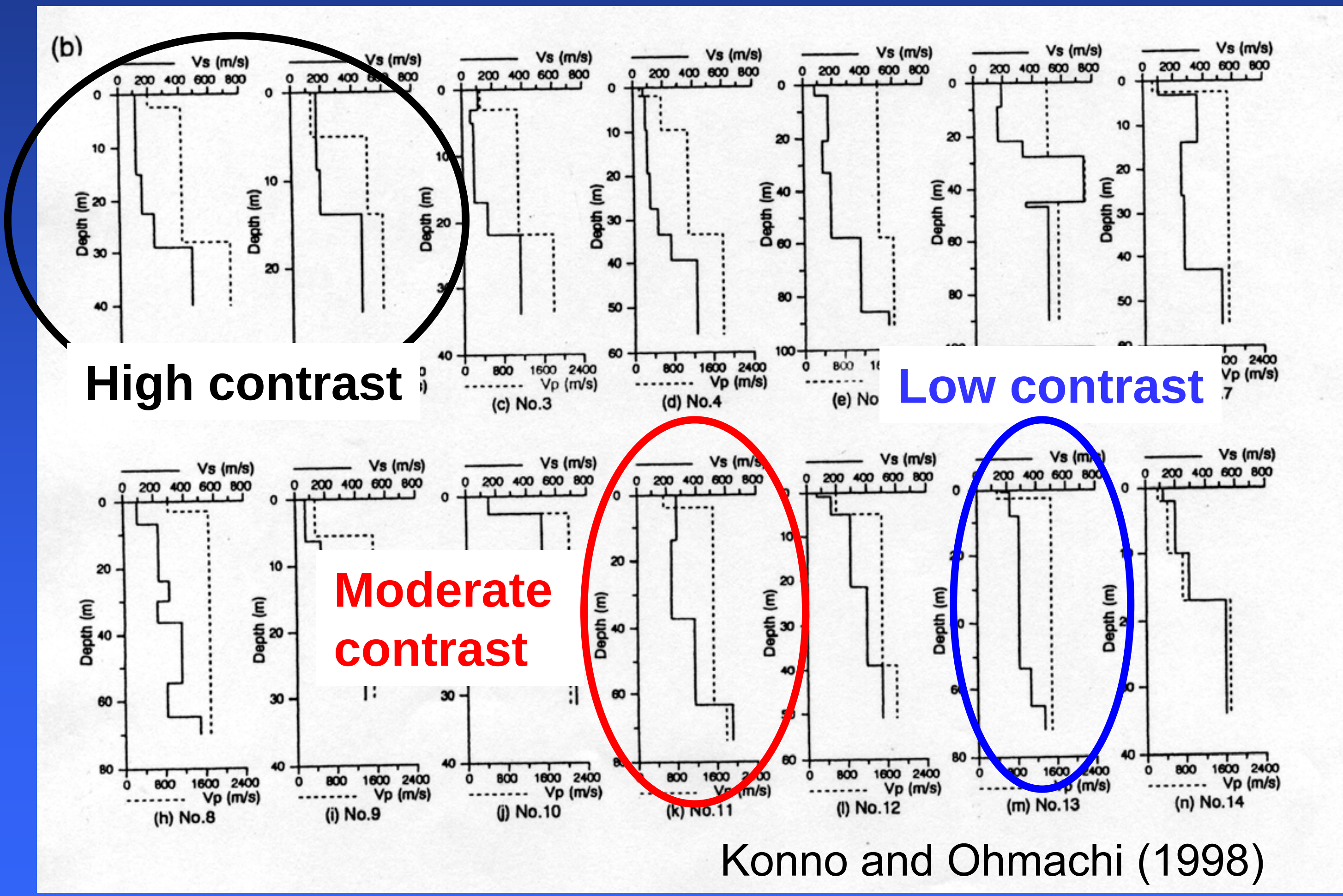


Links between subsurface structure and Airy phase of Love waves



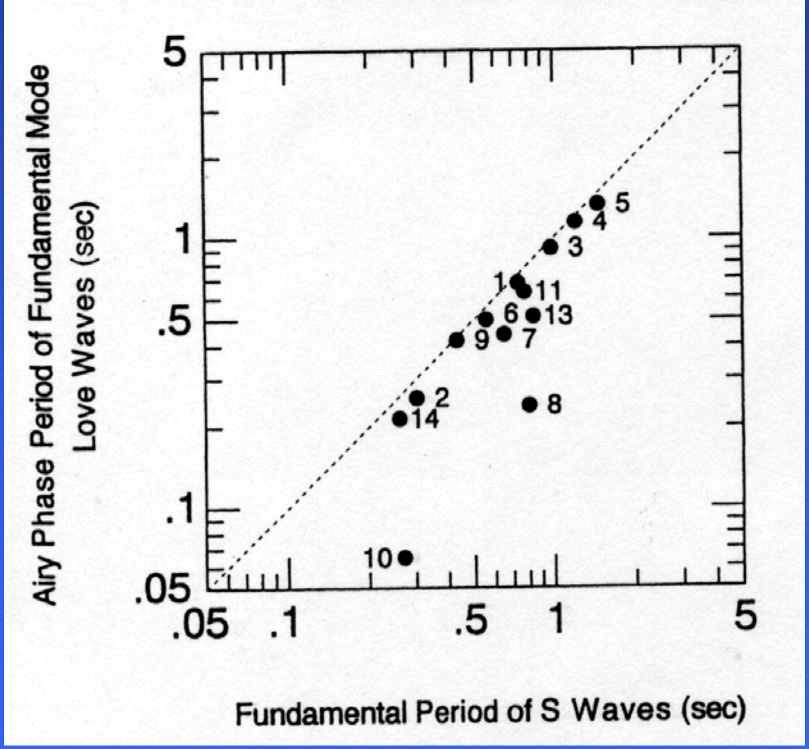
Airy phase of Love waves

Links between subsurface structure and Airy phase of Love waves

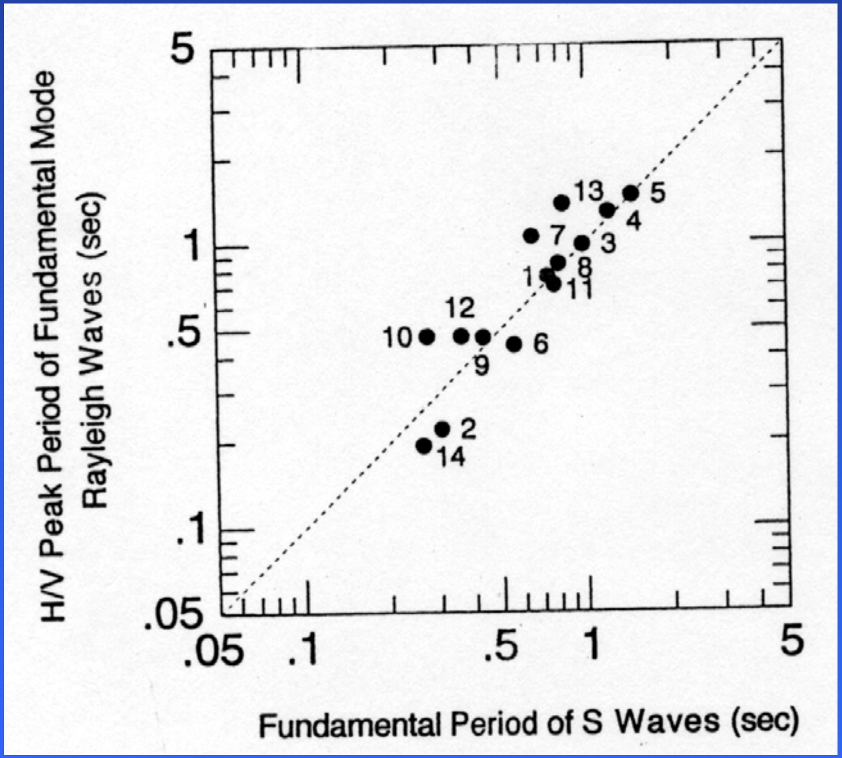


Links between subsurface structure and Airy phase of Love waves

Love waves



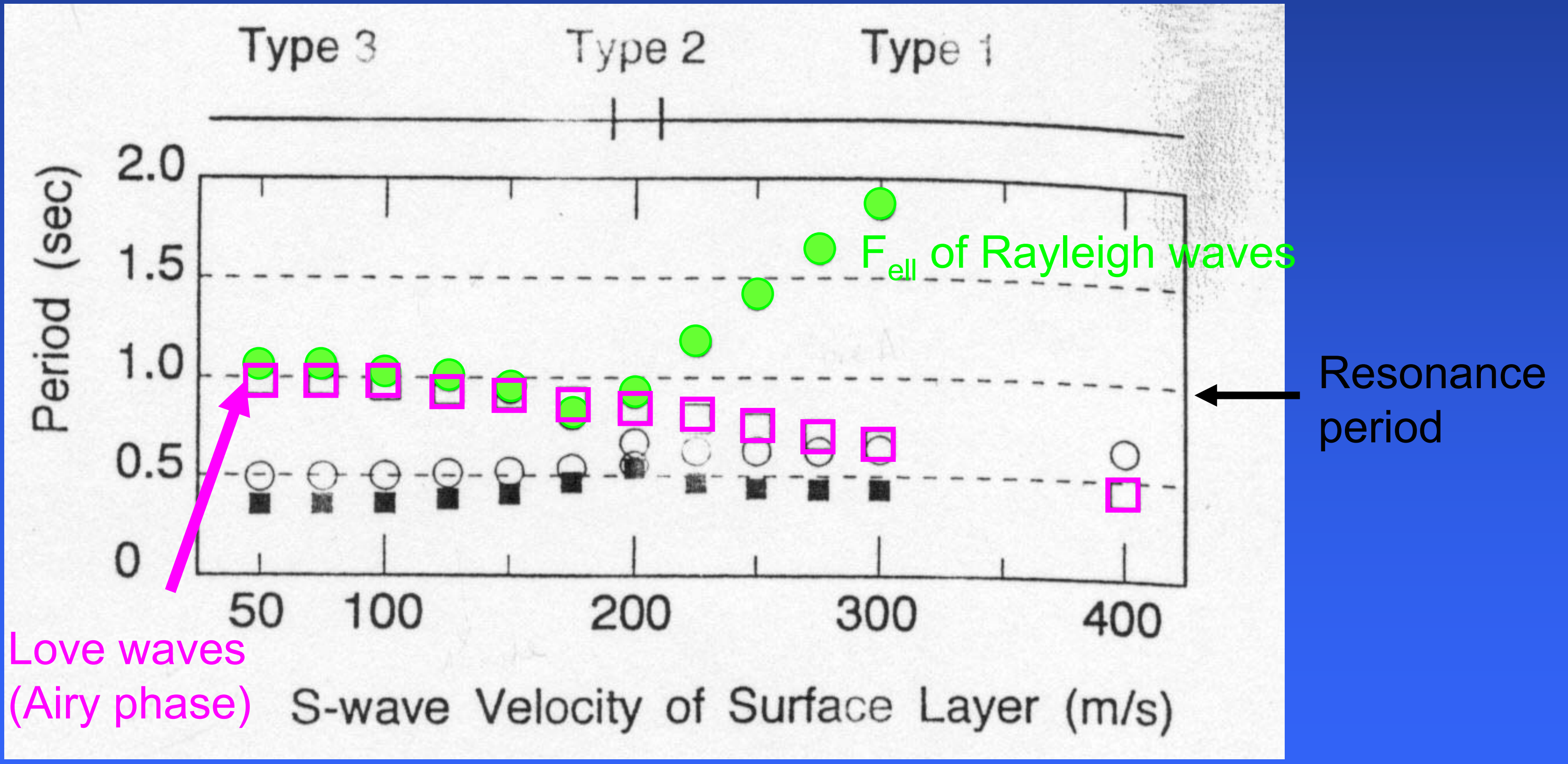
Rayleigh waves



Konno and Ohmachi (1998)

Links between subsurface structure and surface waves

High contrast ← Low contrast



Konno and Ohmachi (1998)

Summary

S waves	❑ resonance frequency ($f_o=V_s/4h$)
Rayleigh waves	❑ F_{ell} is close to fo (especially for large impedance contrasts) ❑ Frequency dependent ellipticity is related to Vs structure ❑ Frequency dependent phase velocity is related to Vs structure
Love waves	❑ F_{airy} is close to fo (especially for moderate to large impedance contrasts) ❑ Frequency dependent phase velocity is related to Vs structure