



Congresso Nazionale Parma 2019

**Il tempo del pianeta Terra e il tempo dell'uomo:  
le geoscienze tra passato e futuro**

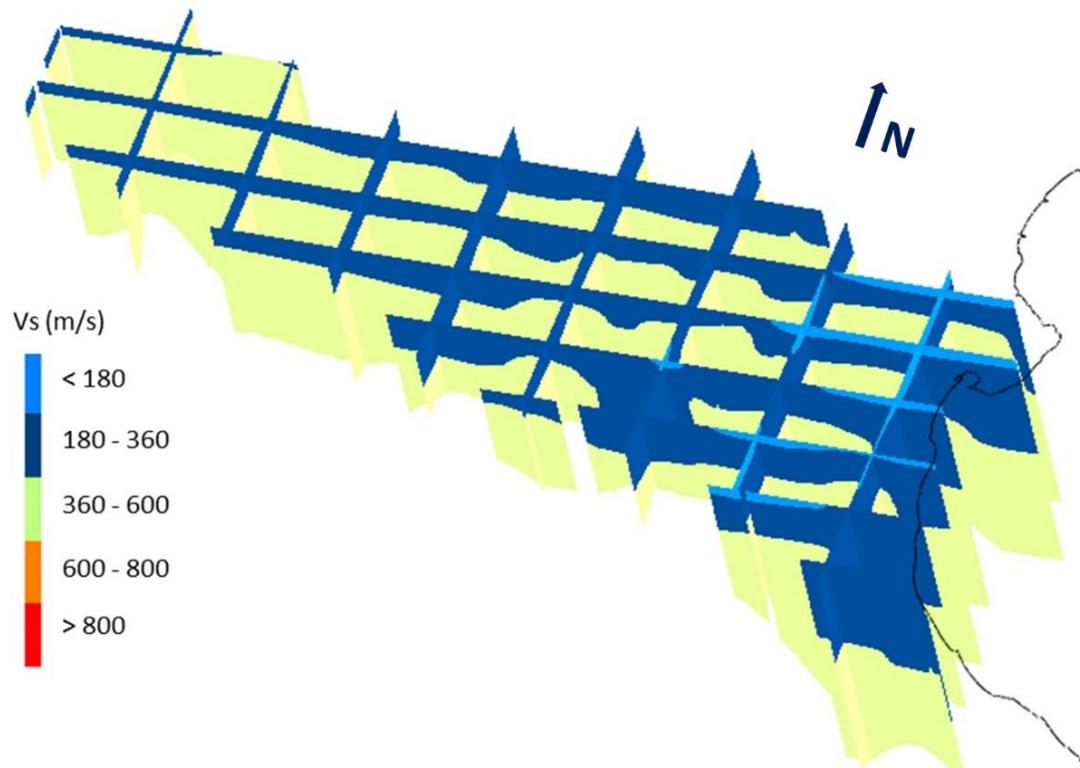
SIMP Società Italiana di Mineralogia e Petrologia

SGI Società Geologica Italiana

SOGEI Società Geochimica Italiana



# Seismo-stratigraphic model of the Po Plain (Italy)



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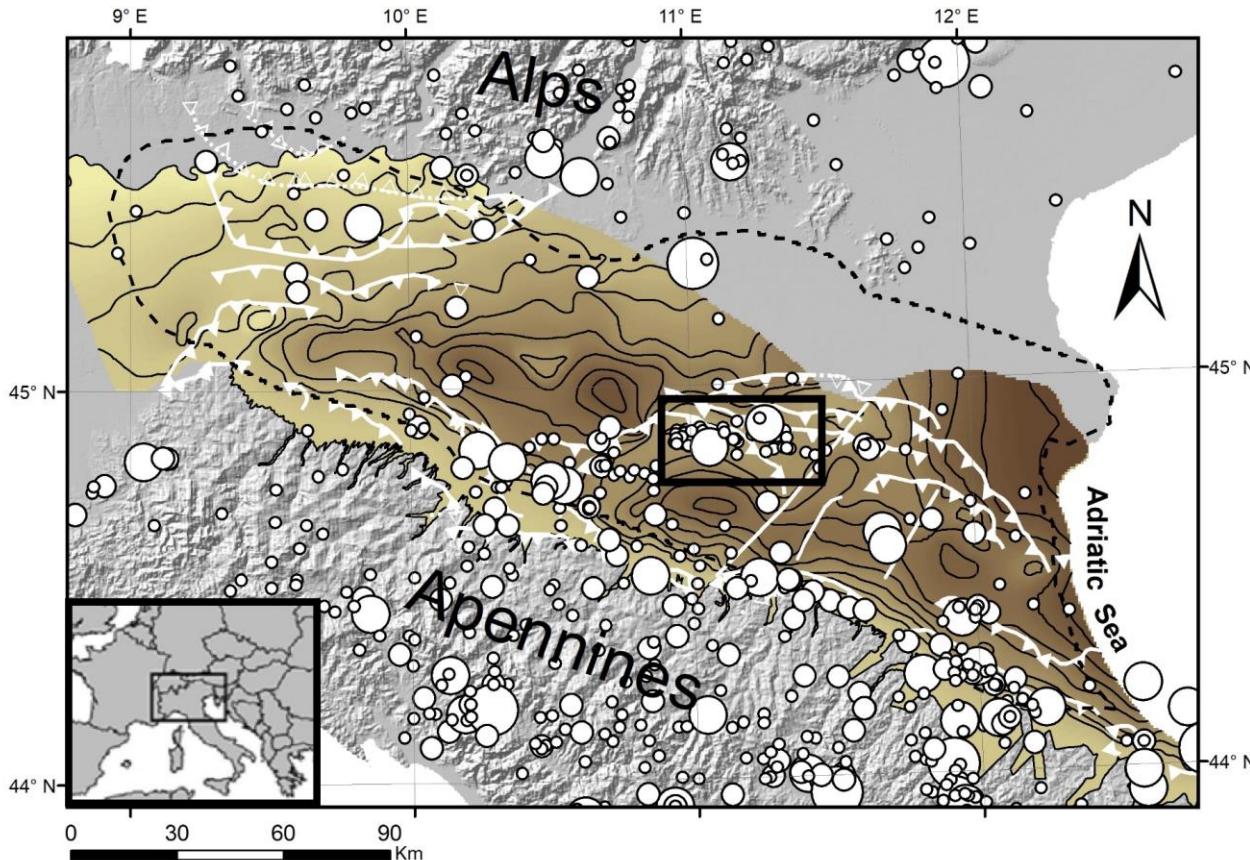
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## Outline

- 1. Study area & general stratigraphy**
- 2. Mapping the seismic bedrock depth**
- 3. Shear-wave velocity model**
- 4. Soil amplification model**
- 5. Influence on seismic hazard**

# 1. Study area & general stratigraphy



Active Tectonic Structures

- active buried thrust
- presumed active buried thrust
- inferred discontinuity

Seismic catalog  
(1000 - 2017)

Mw

- |           |           |
|-----------|-----------|
| ○ 4 - 5   | ○ 5.5 - 6 |
| ○ 5 - 5.5 | ○ > 6     |

Y-Surface 0.45 Ma

Depth (m a.s.l.)

- contour lines
- + 400
- 100

STRATIGRAPHIC UNITS	MAIN UNCONFORMITY	Facies	Geologic Time scale
Upper Synthem <b>(0.45 Ma)</b>	Subsynthem 1 (0.126 Ma) Subsynthem 2 (0.23-0.25 Ma) Lower subsynthems (0.45 Ma)		Upper Pleistocene – Holocene (0.126 Ma)
Lower Synthem <b>(0.8 Ma)</b>	Y-Surface (0.45 Ma) R-Surface (0.8 Ma)	Continental	Middle Pleistocene (0.781 Ma)
Marine Quaternary Synthems			QUATERNARY
Marine Pliocene Muds	Base of Plio-Quaternary sediments (5.3 Ma)	Transitional - Marine	Lower Pleistocene (2.588 Ma)
Miocene Marls	Rock Formation	Marine	Pliocene (5.3 Ma)
			TERtiary
			Miocene (23 Ma)

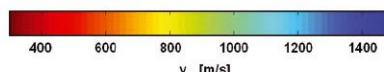
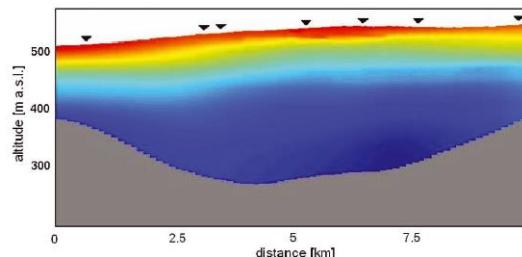
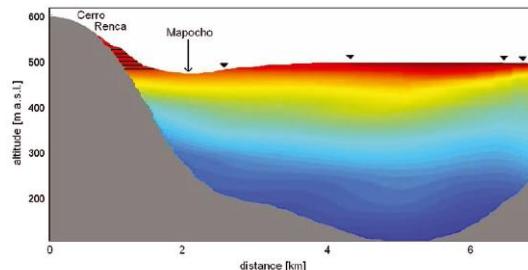
(Regione Emilia-Romagna, ENI-AGIP, 1998; Regione Lombardia, Eni Divisione Agip, 2002)

## 2. Mapping the seismic bedrock depth

### Two Main Features:

Seismic bedrock depth

Shear wave velocity model



Santiago del Cile; Pilz et al (2010)

### What is 'Seismic Bedrock'?



#### Some Definitions of 'Bedrock'

**Geological Bedrock:** defined in correspondence of rock formations underneath soil deposits

**Engineering Bedrock:** defined in correspondence of  $V_s > 800 \text{ m/s}$  (soil category A, NTC 2018, EC8)

**Seismic Bedrock:** defined in correspondence of a marked seismic impedance contrast at the base of the soil thickness responsible for seismic amplifications at the surface

In the Po Plain, it corresponds to a marked increase of  $V_s$  that approaches, or exceeds, 800 m/s (Mascandola et al., 2019)

## 2. Mapping the seismic bedrock depth

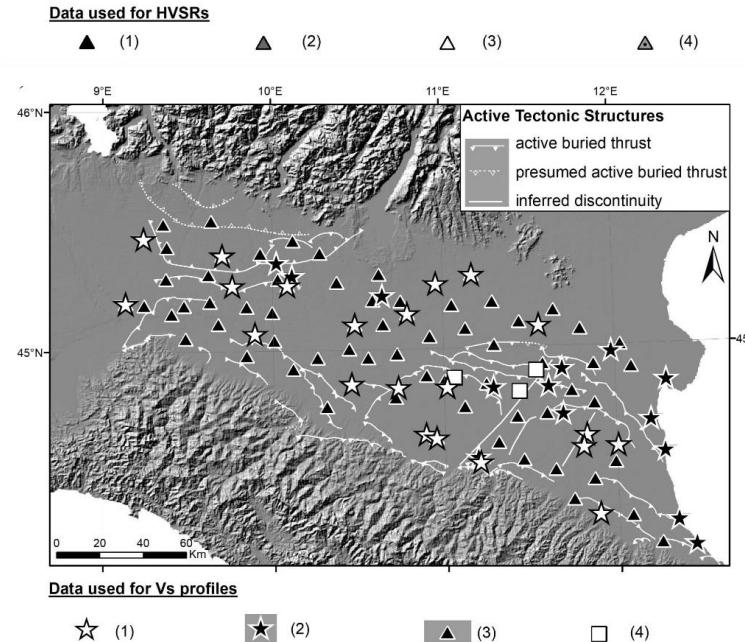
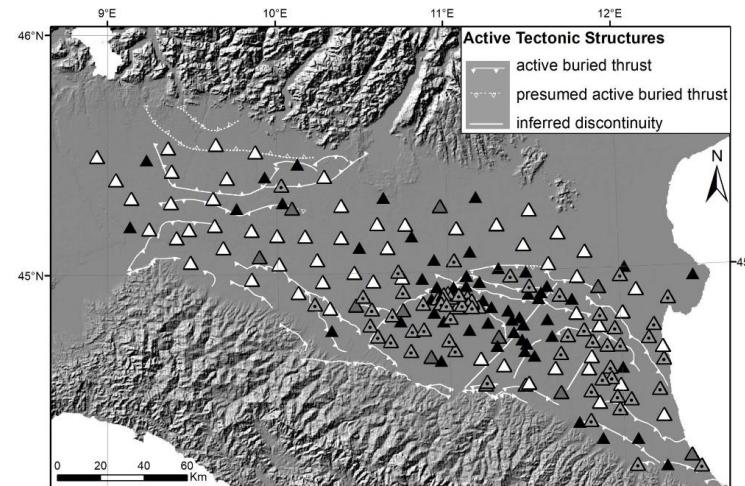
### How to map it?

**PROBLEM:** the common geophysical prospecting techniques (MASW, seismic refraction, ecc.) do not allow to reach the seismic bedrock depth in the Po Plain

**Max depth of investigation:**  
30-50 m

**SOLUTION:** ambient-vibrations allow to reach great depth at low cost

**Depth of investigation:**  
hundreds meters



### Ambient-Vibration dataset

#### **H/V functions**

- 57 24h-long measures from seismic network sites (1);
- 14 1h-long provided by DPC (2);
- 59 1h-long measures from new data acquired (3);
- 66 pre-analyzed data supplied by Regione Emilia-Romagna and Tarabusi and Caputo (2017) (4).

**Total H/V functions: 196**

#### **Vs profiles**

- 21 from Ambient-Vibration Array (1);
- 14 from Regione Emilia-Romagna (2);
- 74 from H/V inversion (3);
- 3 from Borehole test (CH, DH) (4).

**Total Vs profiles: 112**

## 2. Mapping the seismic bedrock depth

### H/V Macroareas

Macroareas based on H/V similarities:

- Shape of H/V curves
- H/V peaks

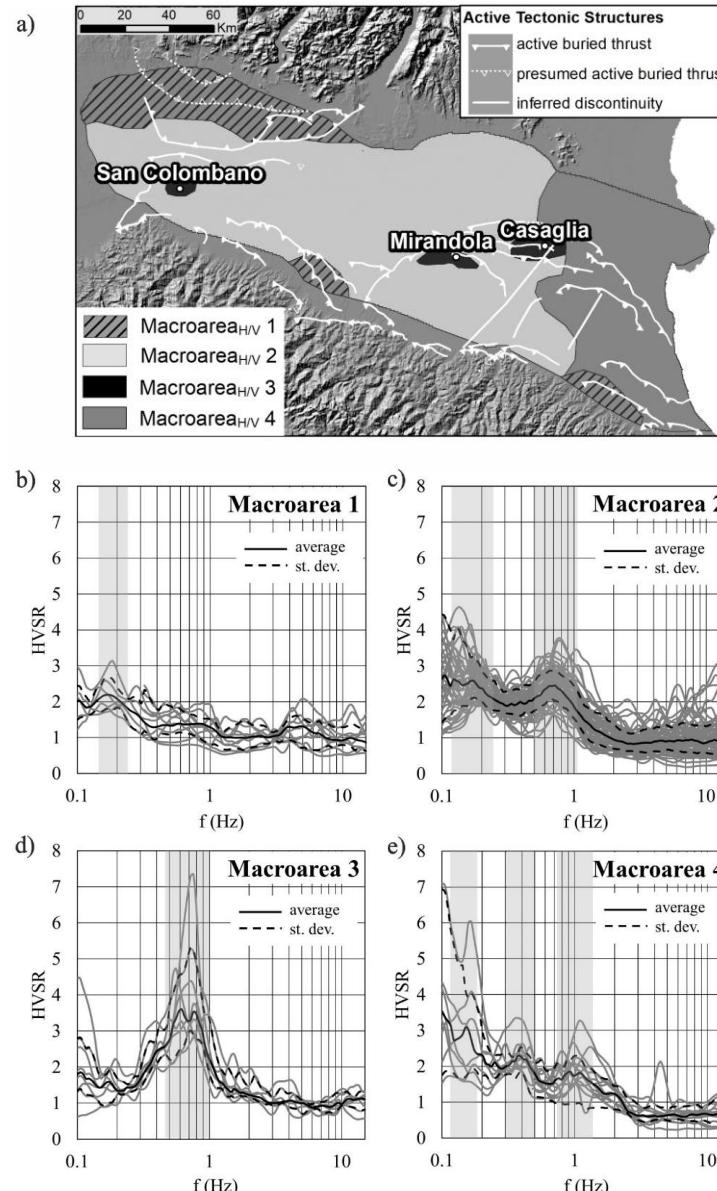
#### PROBLEM

Identification of the resonance frequency corresponding to the Seismic Bedrock depth

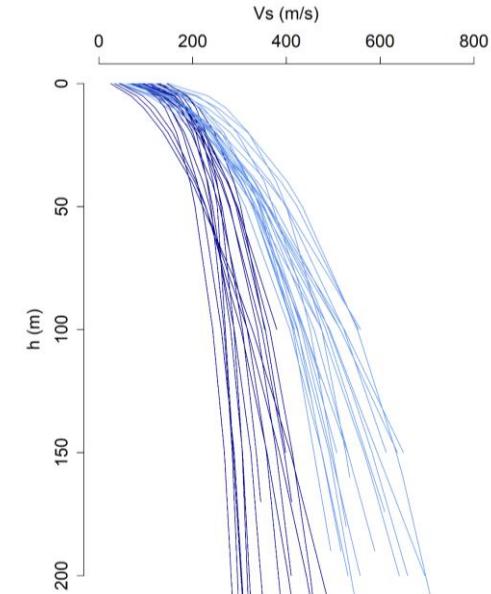
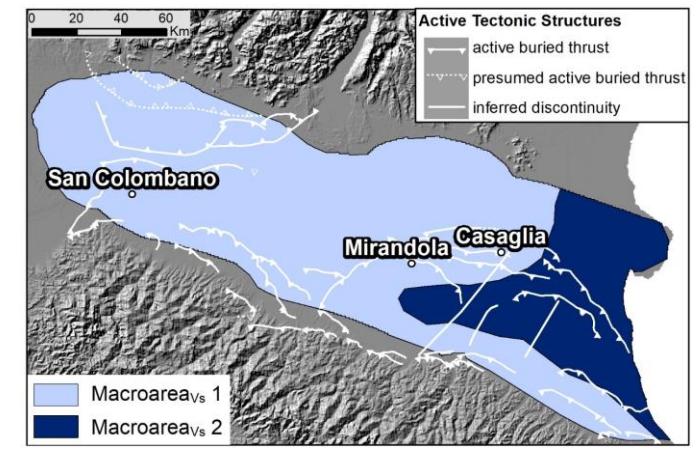
These macroareas are a simplification.

For example, moving from Macroarea 3 to Macroarea 2, there are several H/V peaks that are due to the complex underlying geological structure (anticlines).

Moving from Macroarea 4 to Macroarea 2, the specific 0.8 to 1.5 Hz peak of Macroarea 4 partially merges with the peak around 0.7 Hz of Macroarea 2.



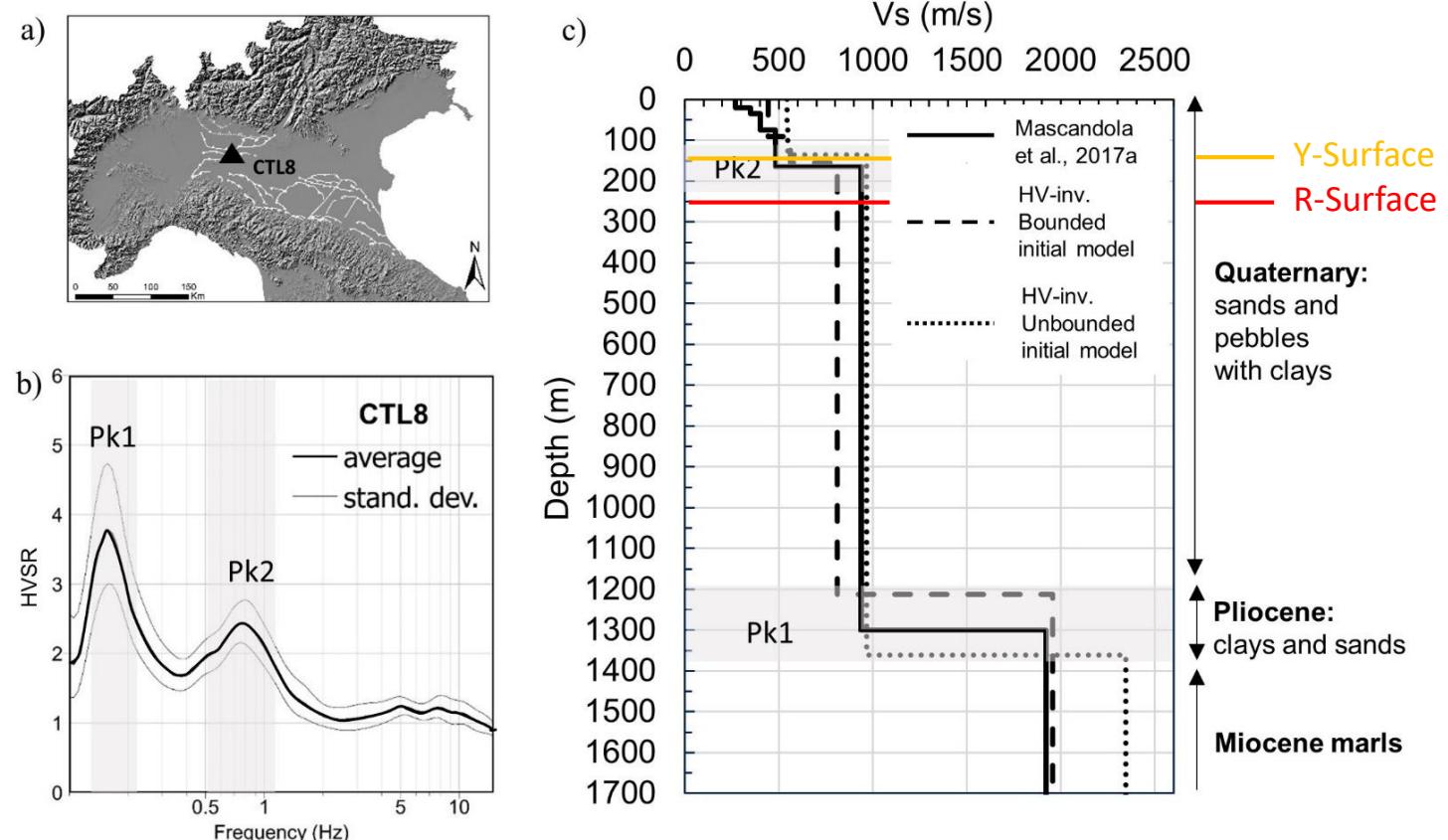
### Vs Macroareas



## 2. Mapping the seismic bedrock depth

### Example for f-h selection

- Many of the H/V curves shows resonance phenomena at multiple frequencies.
- We need to select the resonance frequency of seismic waves within soils above seismic bedrock and computing their corresponding depths.
- Given the definition of seismic bedrock used here, the H/V peak needed to be selected as that associated with the mechanical discontinuity, in which the  $V_s$  approached or exceeded the target of 800 m/s.
- An example is shown here, for the target site of Castelleone, for the CTL8 seismic station of the Italian National Seismic Network (Mascandola et al 2017).



Selected H/V peak: Pk2       $\rightarrow f = 0.75 \text{ Hz}$

Corresponding Depth: 175 m  $\rightarrow h = 175\text{m}$

## 2. Mapping the seismic bedrock depth

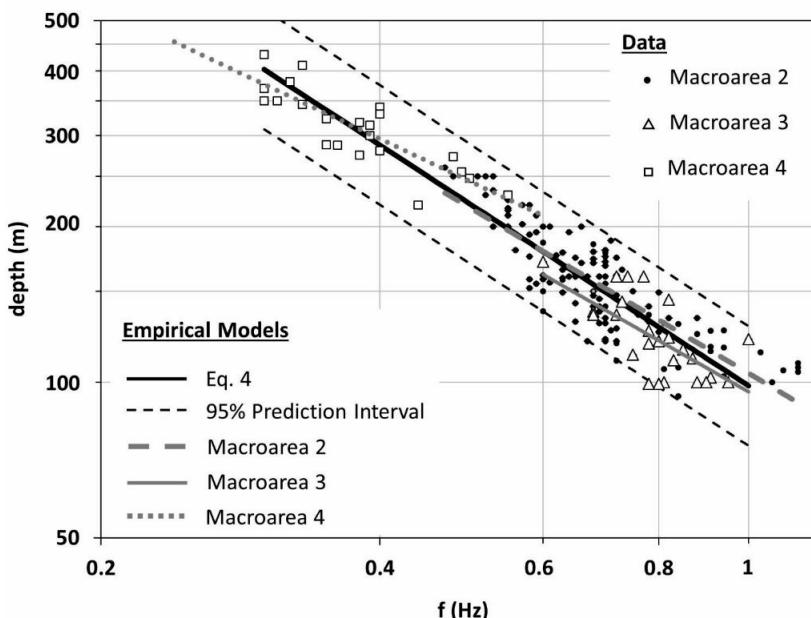
### Regression Model

$$h = \left[ \frac{V_{s0}}{4f_r} \cdot \frac{1-x}{1+x} + 1 \right]^{\frac{1}{1-x}} - 1 \cong A f_r^B$$

(Ibs-von Seht and Wohlenberg, 1999)

#### Po Plain Model

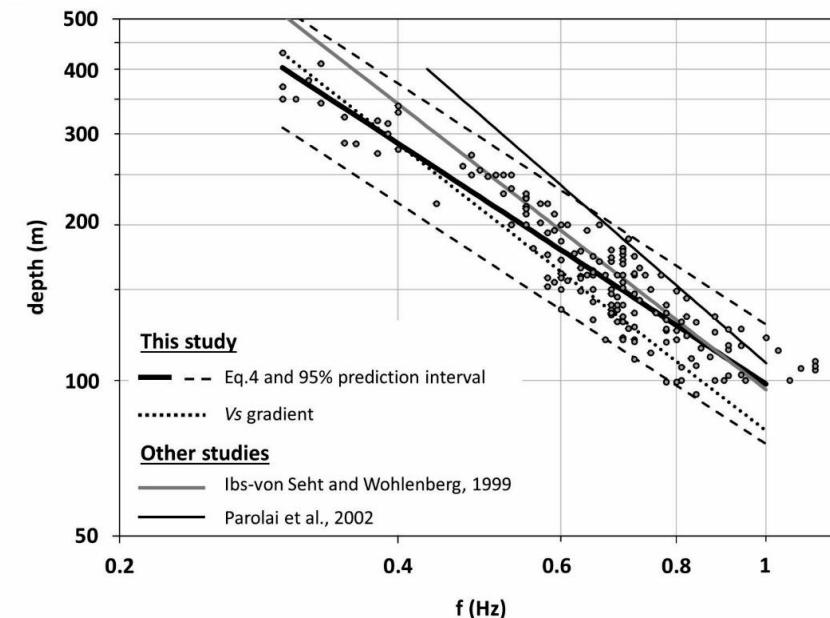
$$h = 98 f_r^{-1.17}$$



### Comparison with some other sedimentary basins..

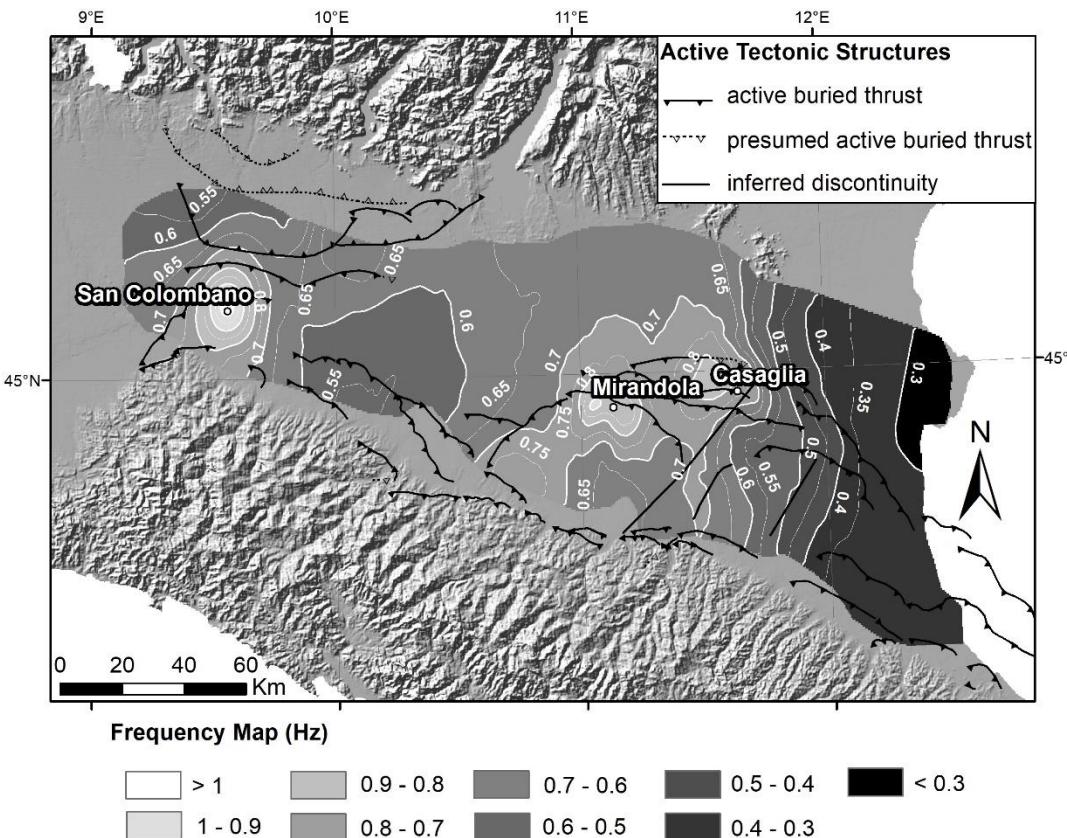
Ibs-von Seht and Wohlenberg (1999) – Western Lower Rhine embayment

Parolai et al. (2002) - Cologne area

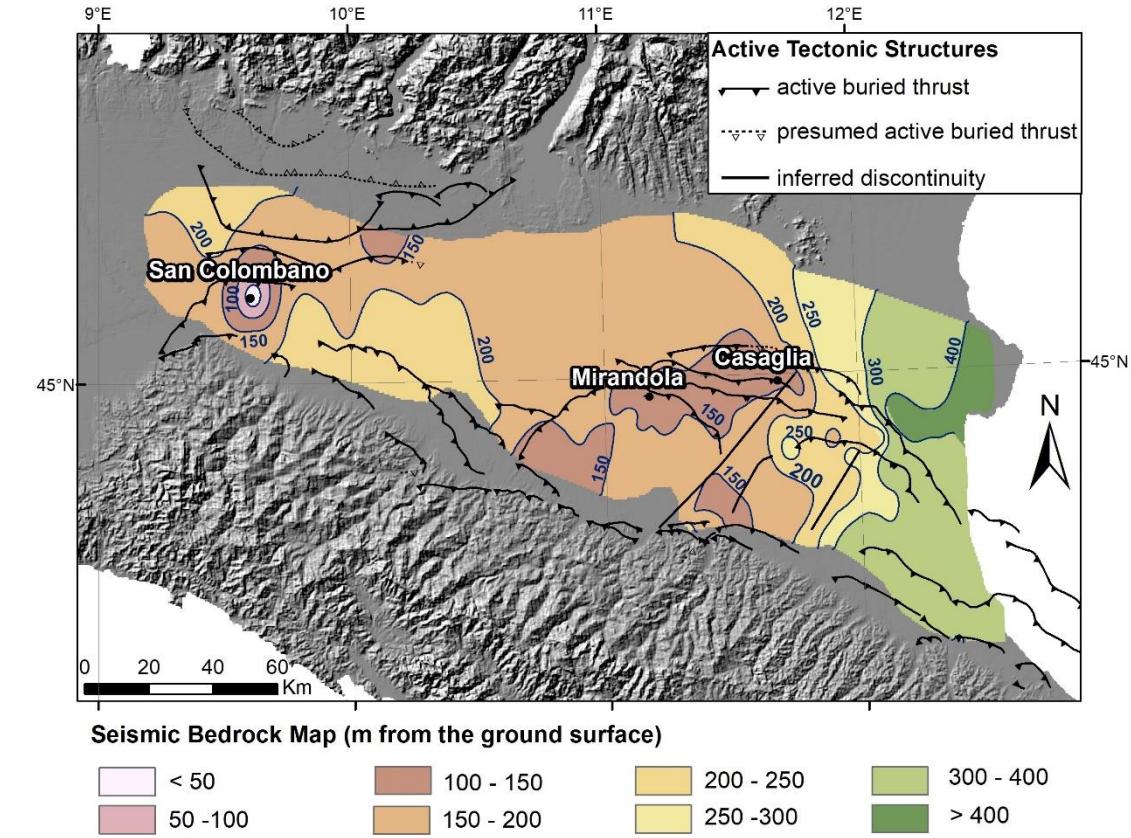


## 2. Mapping the seismic bedrock depth

Resonance frequency map of Seismic Bedrock



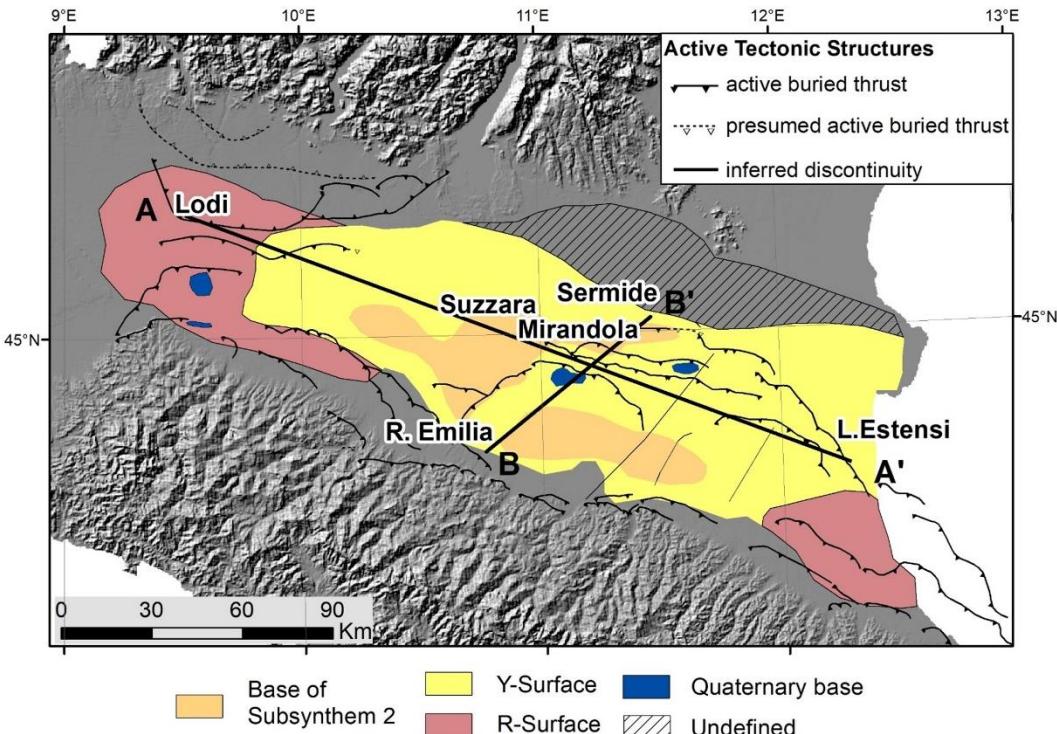
Map of Seismic Bedrock depth



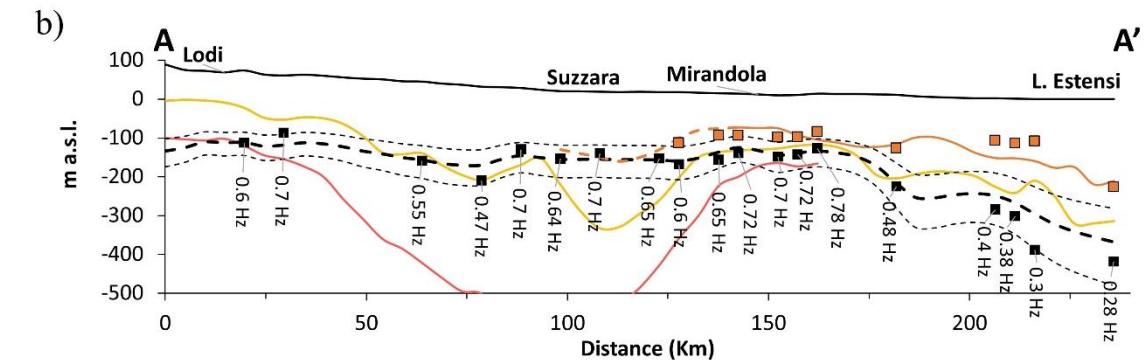
## 2. Mapping the seismic bedrock depth

### Stratigraphic correlations

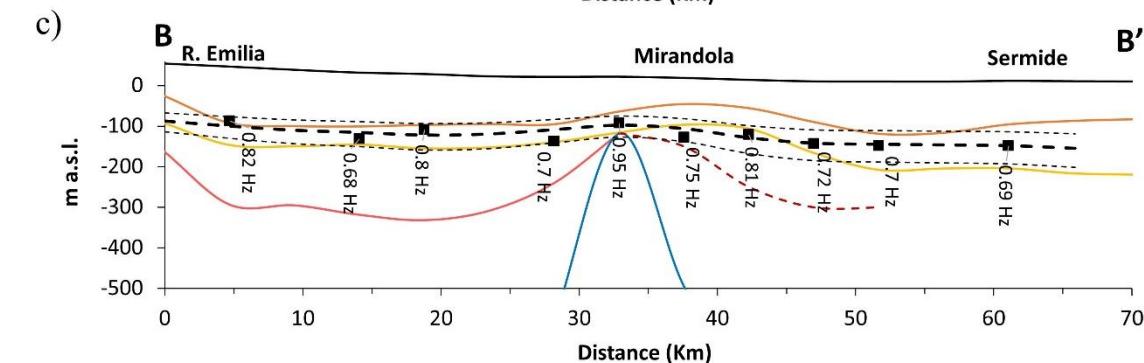
a)



b)



c)



Seismic Bedrock

mean  
95% predic. int.

Base of Subsynthem 2

Y-Surface  
R-Surface

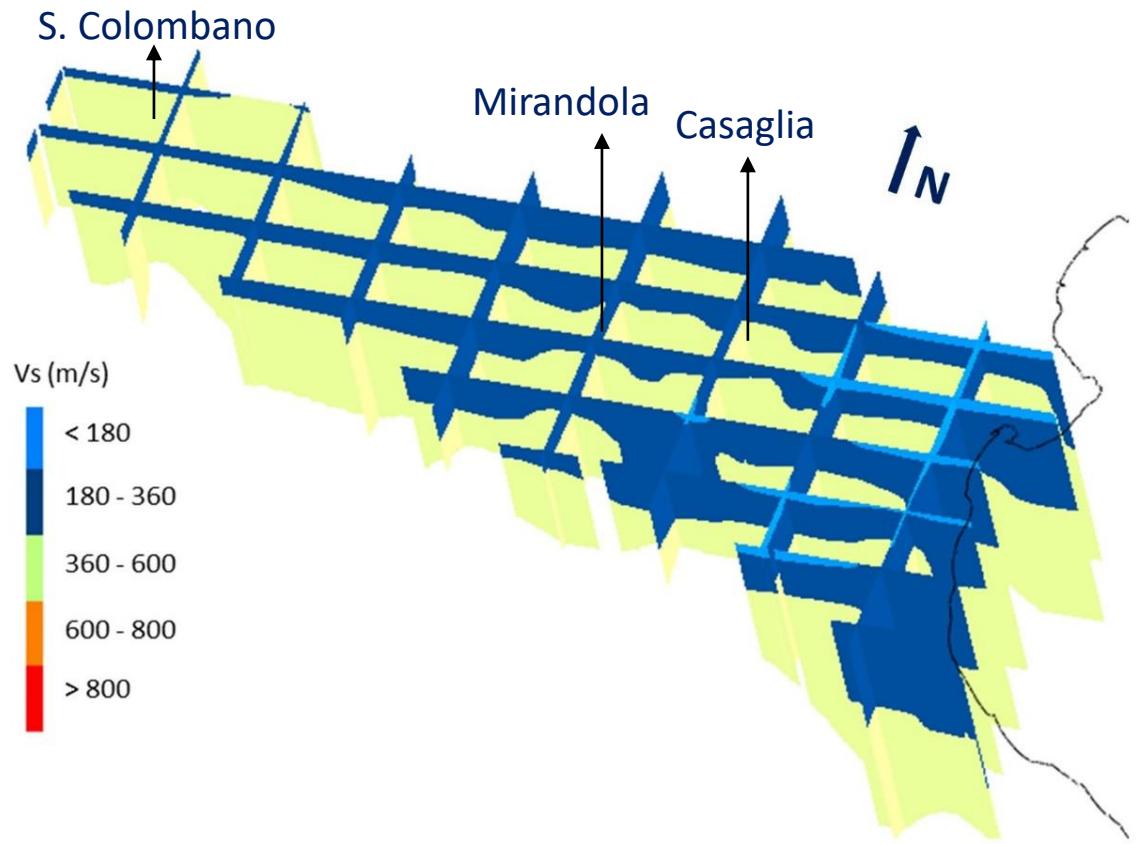
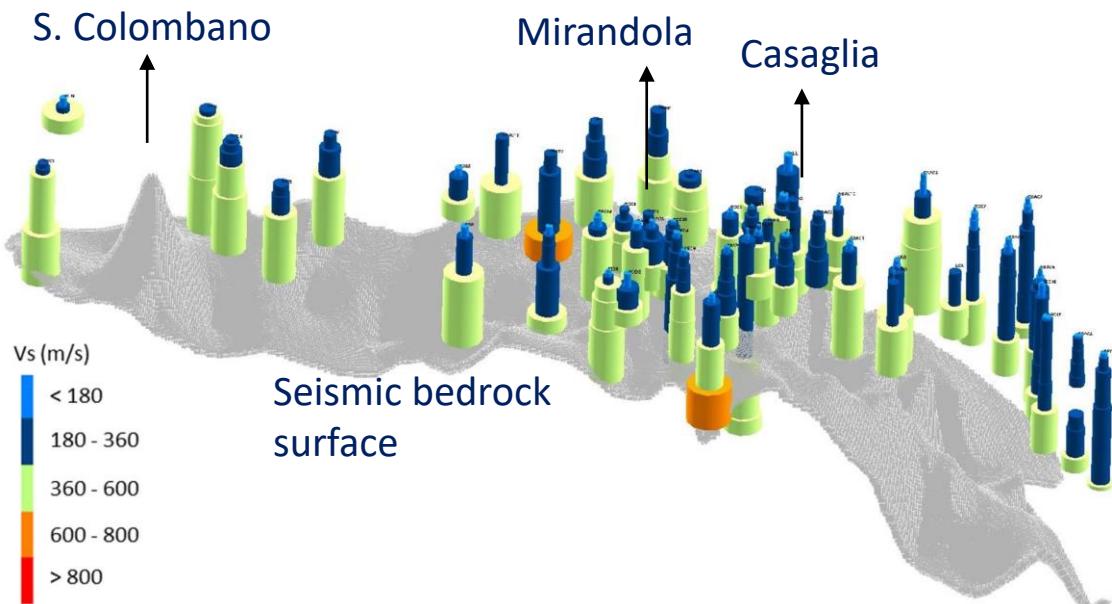
Quaternary Base

Plio-Quaternary Base  
HVSR peaks

### 3. Shear-wave velocity model

#### Input:

- 51 1D Vs profiles from Ambient-Vibration Array measurements
- Map of the Seismic Bedrock depth



# 4. Soil amplification model

## Input

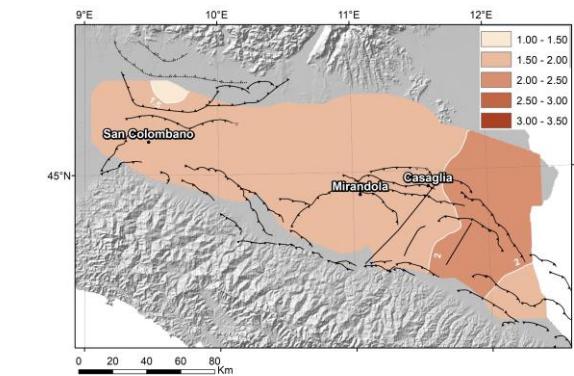
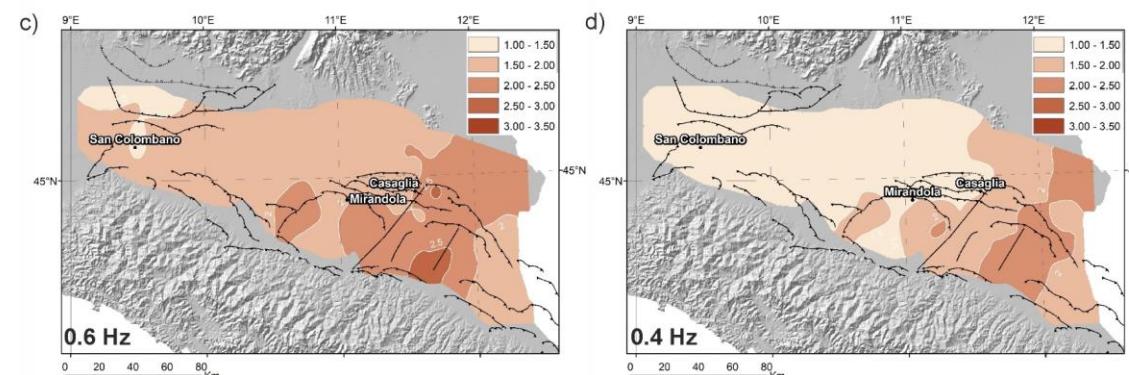
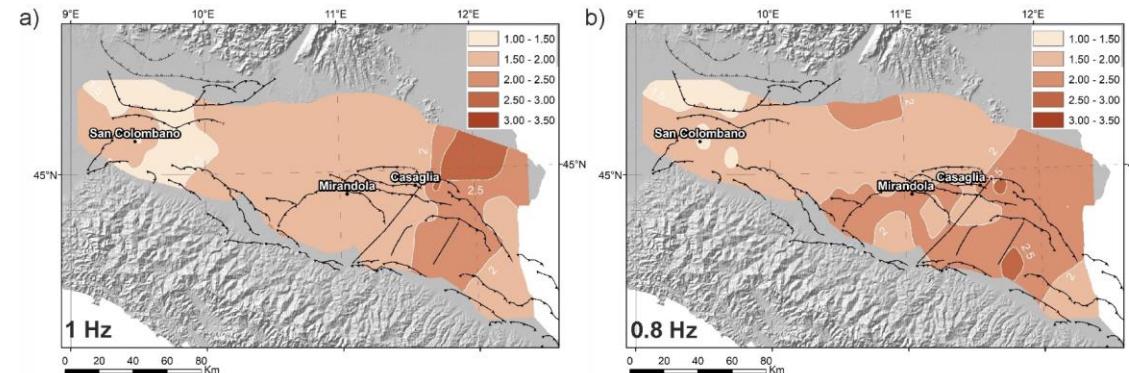
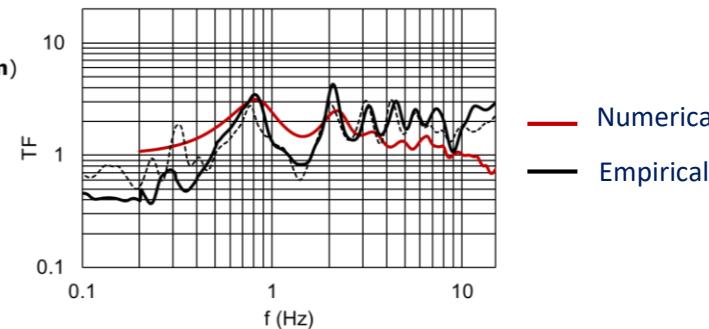
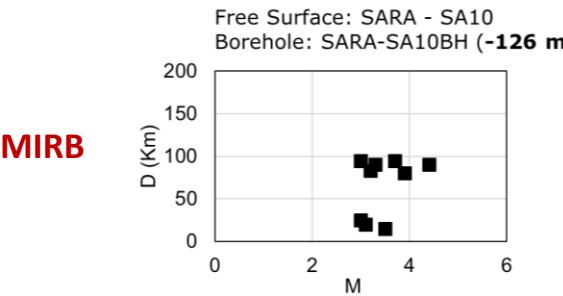
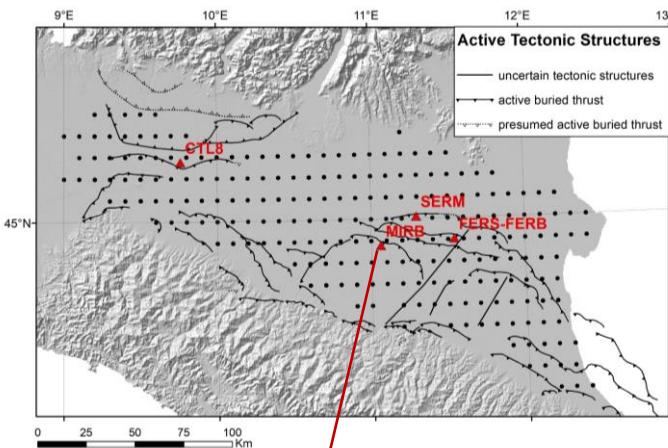
$V_s$  profiles:  $0.1^\circ \times 0.1^\circ$  grid, extracted from the regional  $V_s$  model

$V_s$  bedrock: 800 m/s; Unit Weight: Mayne (2001);  $D_0$ : 5% soil, 1% rock

G/G<sub>max</sub> and Damping curves: EPRI 1993 (soil), Schnabel et al. 1972 (rock)

Input Motion: 10 accelerograms for each zone with homogeneous seismic hazard;

Code: Shake91; Analysis: Equivalent-Linear Method



## Output – AF(f)

$AF(f)$ : ratio of the surface-level to the rock-level damped spectral accelerations for a specific value of  $f$ .

## Seismic Code - Ss

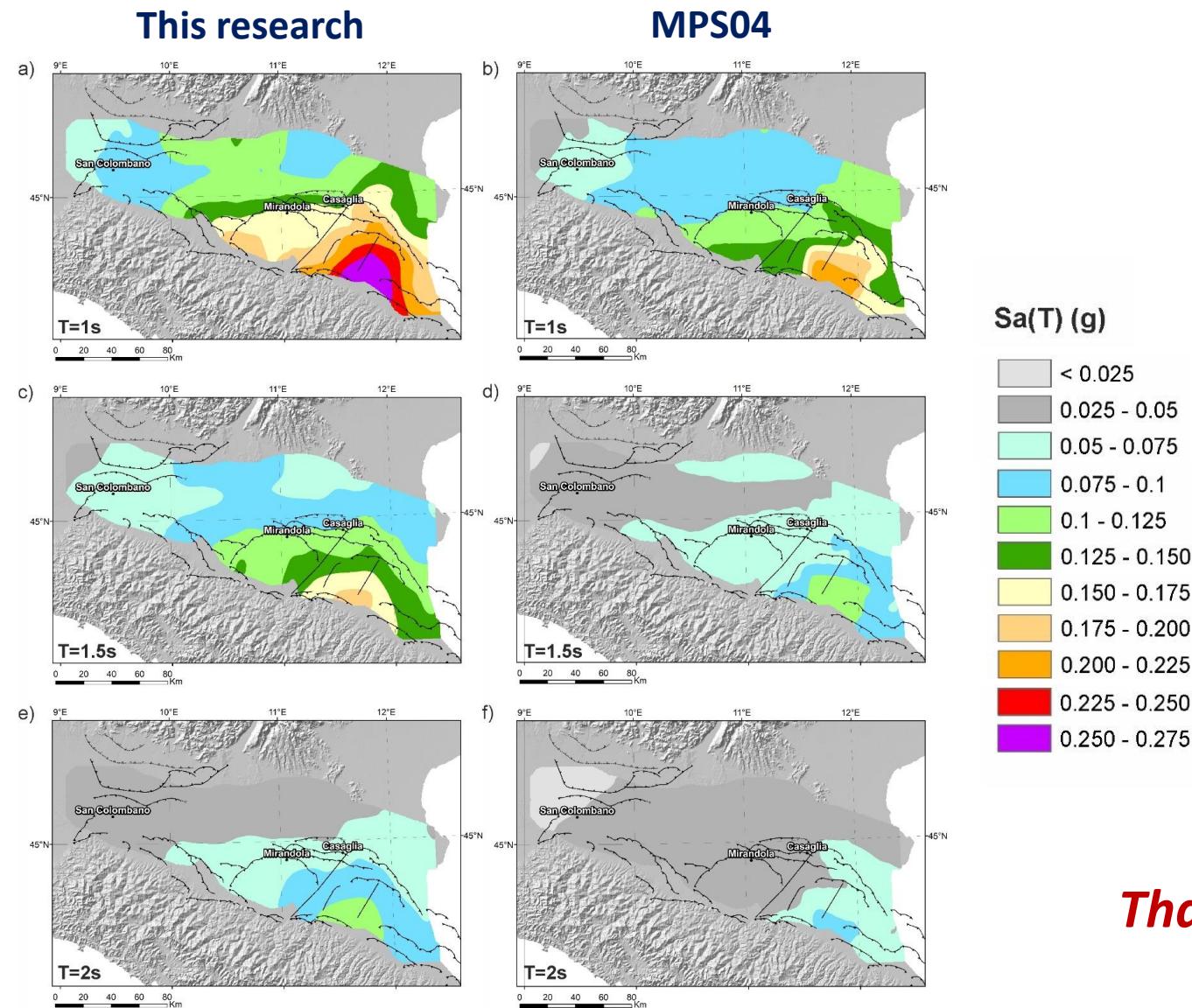
$Ss$ : frequency independent coefficient based on soil category C and D (NTC 2018)

# 4. Influence on seismic hazard

Probabilistic seismic  
hazard assessment (MRP)  
**475 yr.) of the Po Plain:  
influence of LONG PERIOD  
site effects**

New PSHA:  
Seismogenetic Zonation  
(Santulin et al. 2017);  
GMPE for Europe (Bindi et al.  
2014 );  
Logic tree on site term only  
(Part. Non Ergodic approach)

Preliminary results..



**Thank you for your  
attention!**