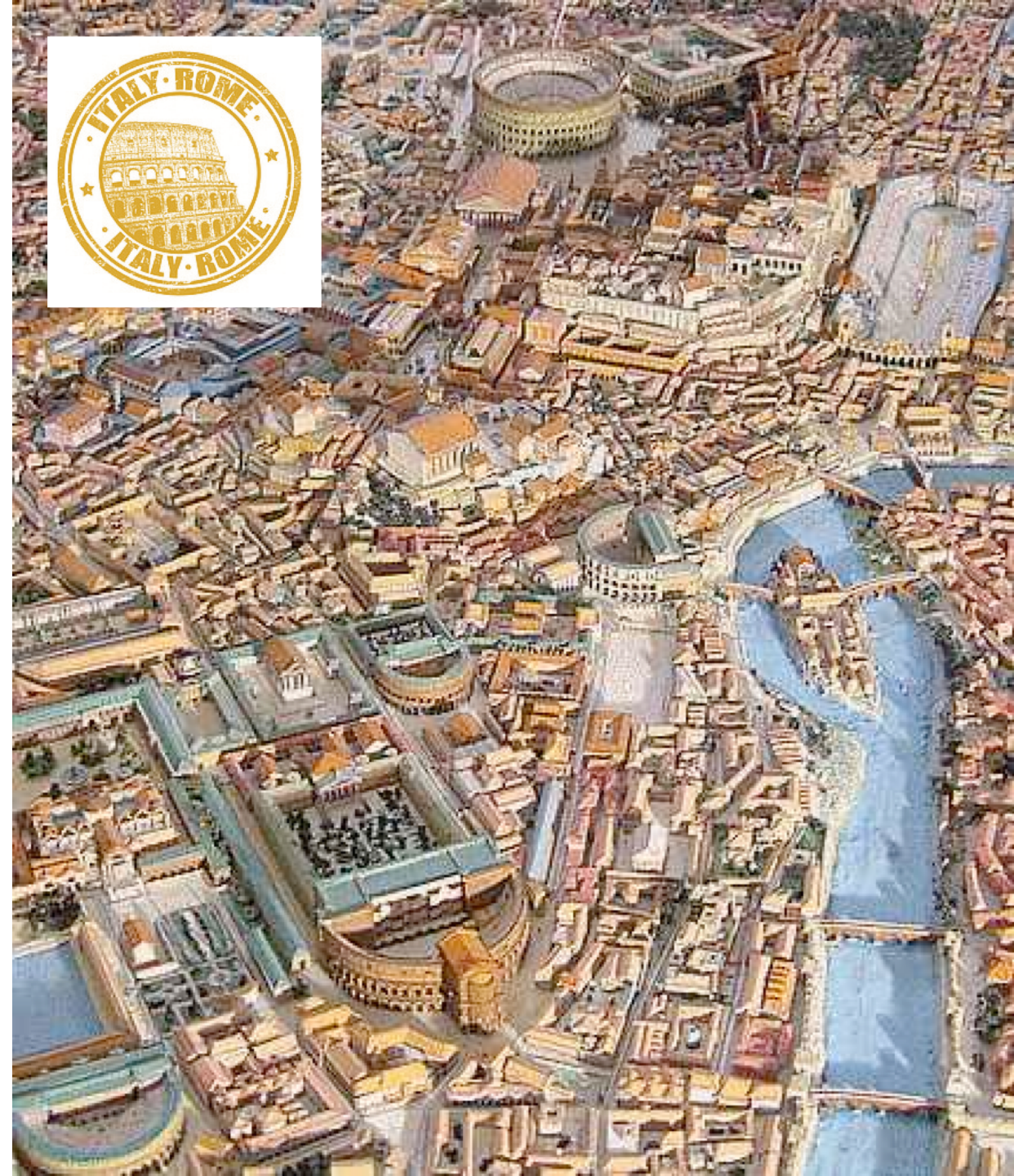


## Observation of Roman archaeological monuments & seismic site effect in the city of Rome

by Jean-Luc Berenguer

Geoazur Education & Outreach - University Côte d'Azur

The "eternal city", capital of an empire to which it gave its name, Rome has preserved treasures from its past, such as the Colosseum, which have earned it the title of the world's first museum city.





## *Let me quickly introduce myself*



Teacher Biology-Geoscience (retired), middle and high school

Lead seismology schools network in France since 25 years

Member of Education Team at Geoazur lab. (University Côte d'Azur)

Involved today in :

EDUMED Observatory > <http://edumed.unice.fr>

INSIGHT Education > <https://insight.oca.eu>

EGU Committee of Education > Deputy Chair





## Let us practice ... as we can with 'Zoom'!

- Step 1: some slides to explain the case study
- Step 2: data mining online in real time
- Step 3: experiment and conclusions

This hands-on workshop is about the seismic site effect.

I will illustrate this geophysic topic with the old Roman treasures.

We will focus on two monuments, the columns of Marcus Aurelius and Trajan built in the 2nd century.



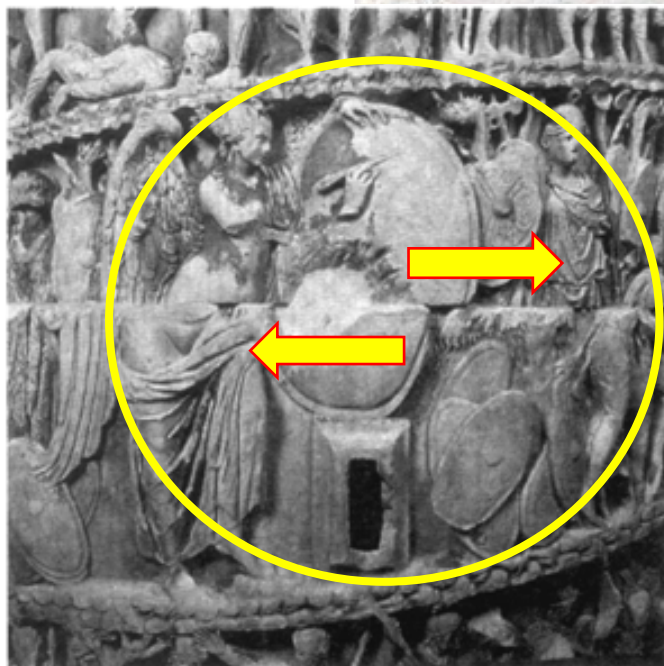


The columns of Marcus Aurelius and Trajan were built in the 2nd century.

Located at two separate points in the city, these columns, some 30 meters high, are decorated with a continuous frieze of 'bas-reliefs' showing battle scenes and groups of enemies defeated during the wars fought by the Romans.



Marcus Aurelius



A close examination of the bas-reliefs of these columns shows an anomaly in one of them.  
Could you find it? ... Let's try to explain it.



Trajan column

detail of bas relief of the columns



Two columns of similar age (2nd Century) in the city!



## Hypothesis:

History : Strong earthquakes (after the 2<sup>nd</sup> Century).

They would have affected the stability of the columns, in particular that of Marcus Aurelius...

If this fact is verified, it will be necessary to explain why the Trajan column was much less affected.

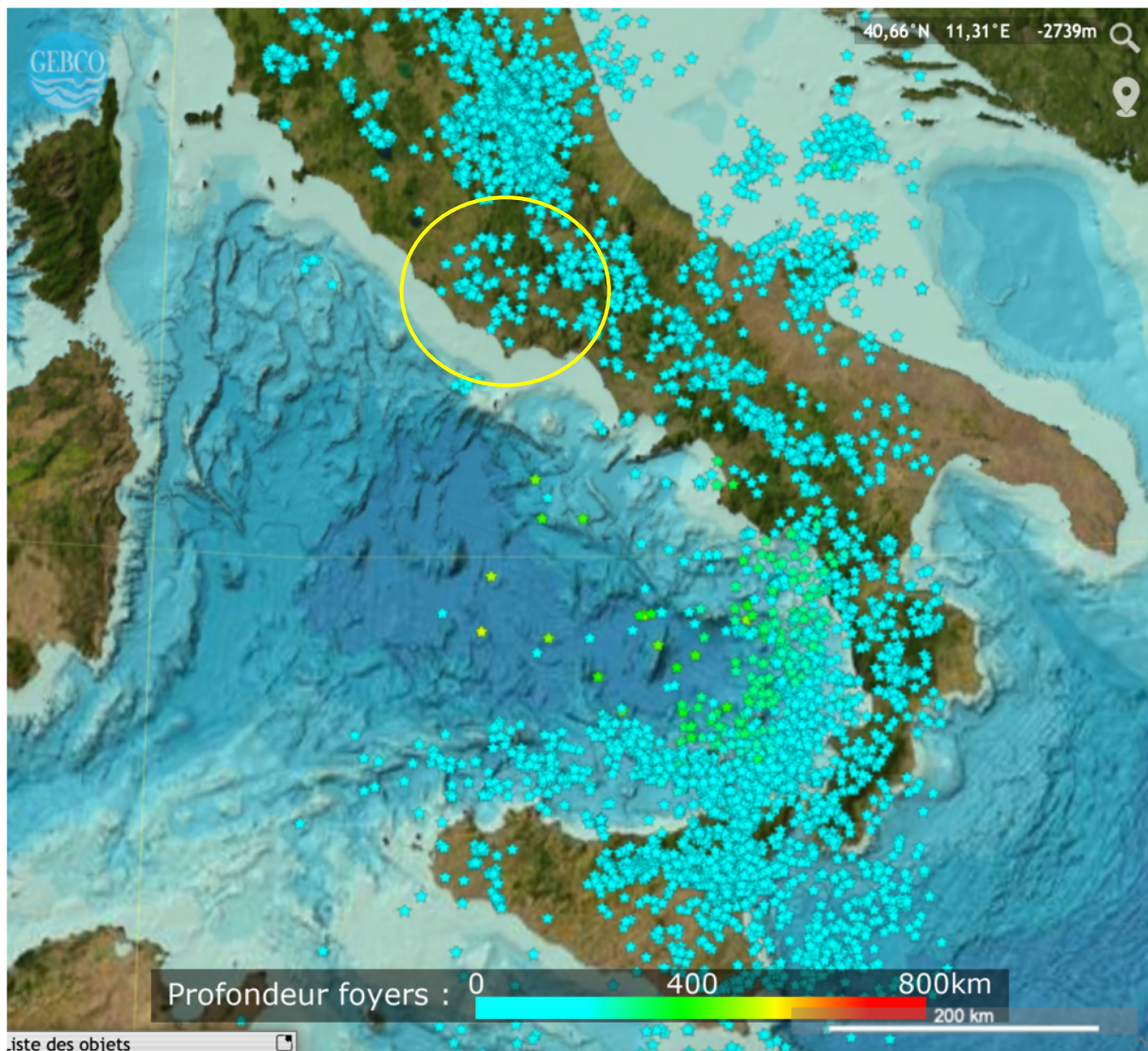
600 m

Rome City : Marc Aurelius & Trajan Columns location in the city



## What about the seismicity in Italy ?

Today, Rome could be affected by local and regional earthquakes



Seismicity Italy (2017-2022) - (source: INGV - EMSC)

 **INGVterremoti**  
@INGVterremoti

[STIMA #PROVVISORIA] #terremoto Mag tra 3.2 e 3.7 ore 05:03 IT del 11-05-2020, prov/zona Roma #INGV\_24397691

**1 LOCALIZZAZIONE AUTOMATICA**  
I PARAMETRI SONO PROVVISORI

{STIMA PROVVISORIA} #terremoto Mag tra 3.1 e 3.7 ore 17:54 IT del 25-08-2018, prov/zona Campobasso #INGV\_20497831

5:57 PM 25 Aug 2018  
E' INDICATA LA ZONA O LA PROVINCIA COLPITA PER ESPRIERE L'INCERTEZZA SULLA POSIZIONE DELL'EPICENTRO

**2 LOCALIZZAZIONE RIVISTA**  
I DATI SONO STATI ANALIZZATI DA UN SISMOLOGO

**Terremoto 4 km SE Montecilfone (CB), Magnitudo ...**  
Terremoto di magnitudo ML 3.3 del 25 agosto 2018 ore 17:54:54 (Fuso Orario Italia) in zona: 4 km SE Montecilfone (CB)  
cnt.rm.ingv.it

6:08 PM 25 Aug 2018 from Montecilfone, Molise

36 Retweets 43 Likes

I TWEET CON LOCALIZZAZIONE AUTOMATICA E RIVISTA FANNO PARTE DELLA STESSA CONVERSAZIONE

ED HANNO LO STESSO CODICE NUMERICO

ingvterremoti.com

Terremoti, il tweet con la stima rapida di epicentro e magnitudo  
Dal 4 settembre 2018, l'Istituto Nazionale di Geofisica e Vulcanologia (INGV) pubblica in tempo reale sul canale Twitte...

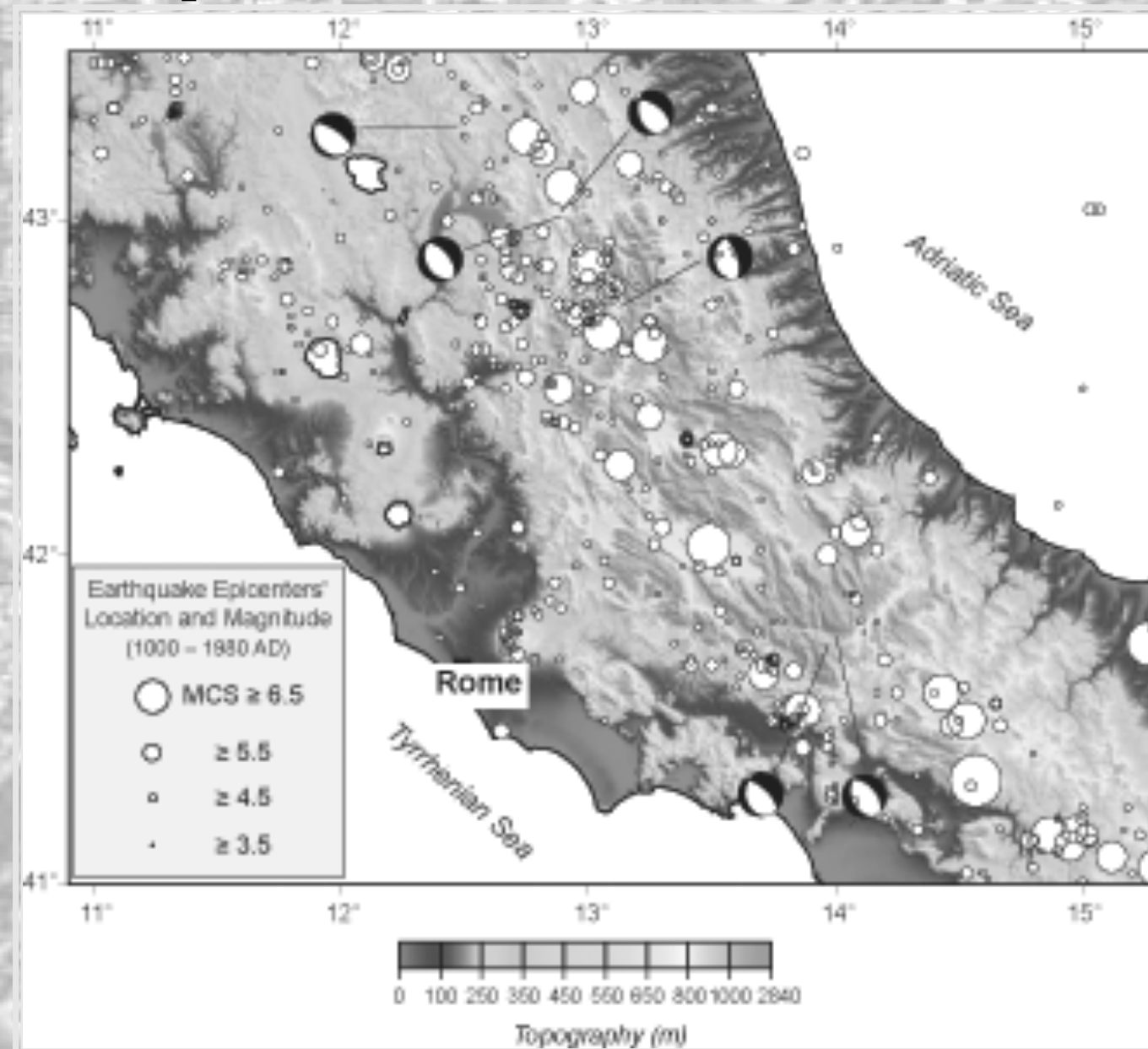
5:05 AM · 11 mai 2020



# The Link Between Rome's Geologic Setting to its Past, Present, and Future

By Grant Heiken

## Earthquakes

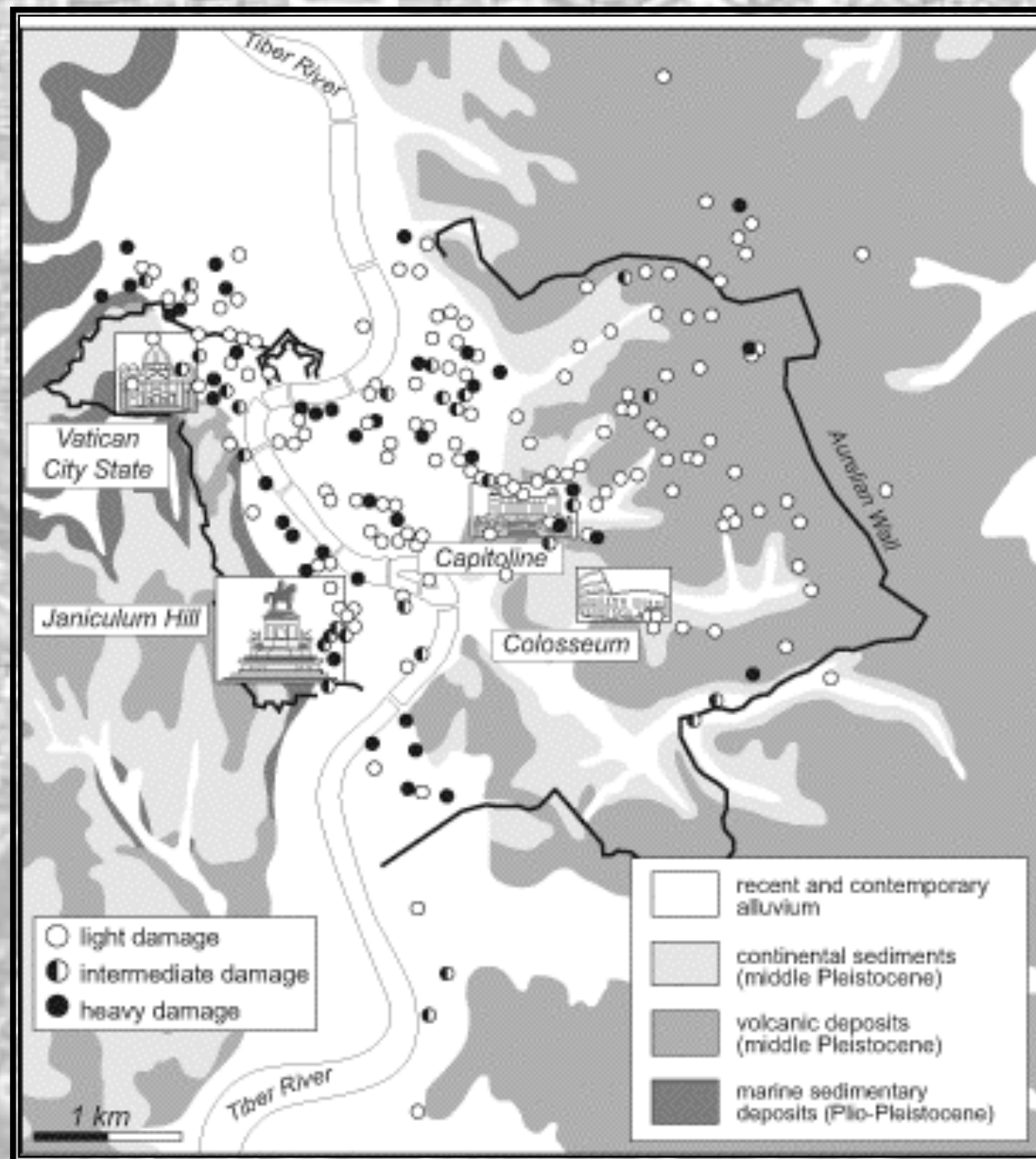




# The Link Between Rome's Geologic Setting to its Past, Present, and Future

By Grant Heiken

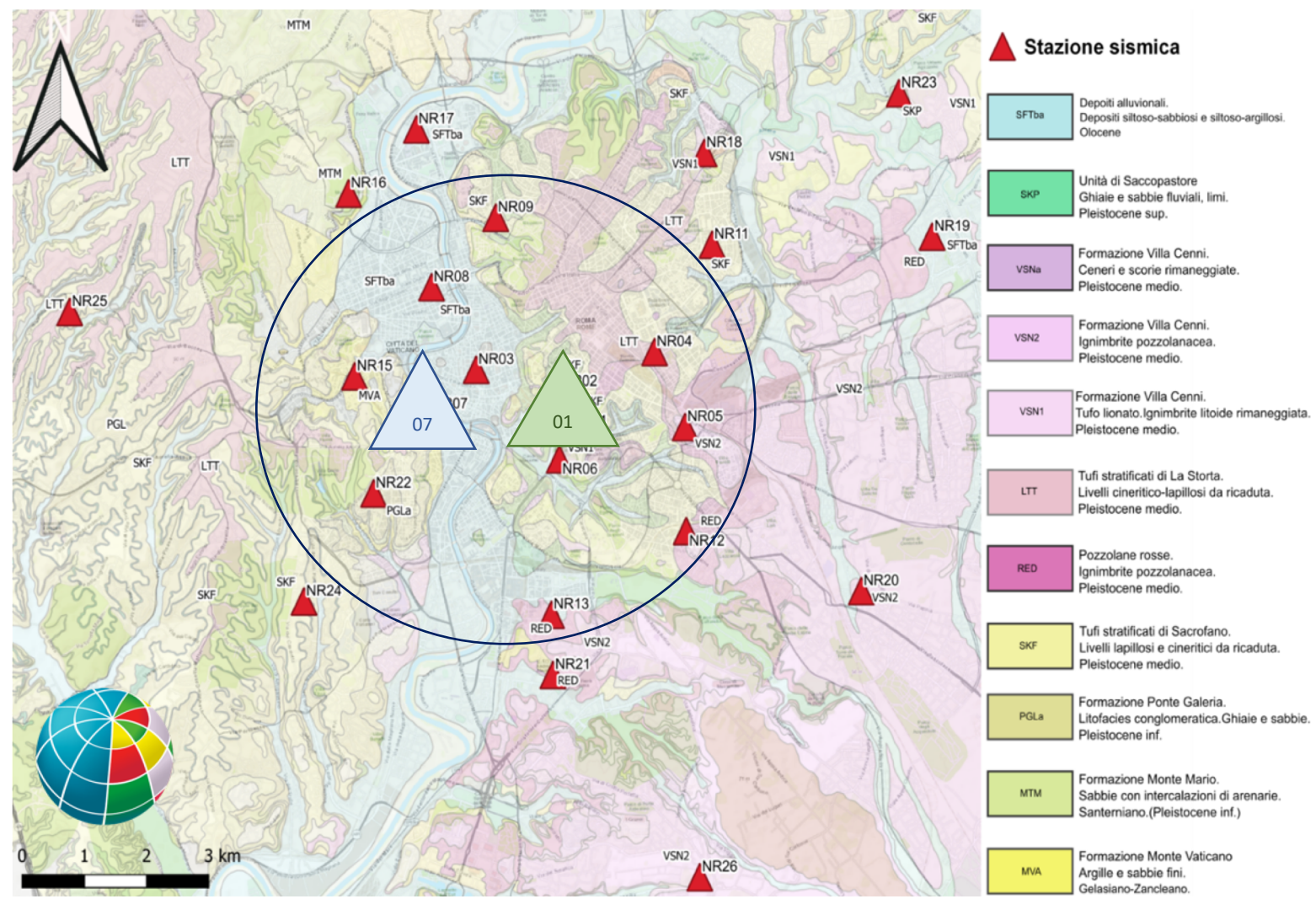
Damage to  
historical  
structures  
caused by  
earthquakes



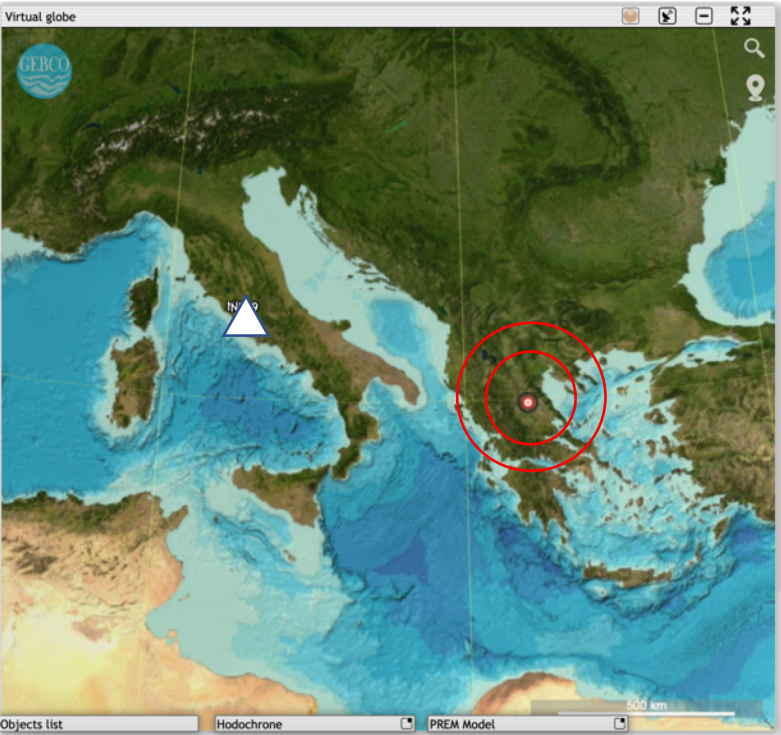


# What about the seismic network in Rome City ?

The seismological monitoring network allows the comparison of seismograms during recent seismic events.



Seismic event :  
GREECE, 2021.03.03, M=6.3



<http://edumed.unice.fr/data-center/seismo/>

2021.03.03 / Earthquake occurred in Greece, recorded in Roma  
Example of amplitudes values versus geological nature of soils.

Download ZIP file

Display with Tectoglob3D

seismological monitoring network : INGV Roma (Thanks to Giovanna Cultrera)



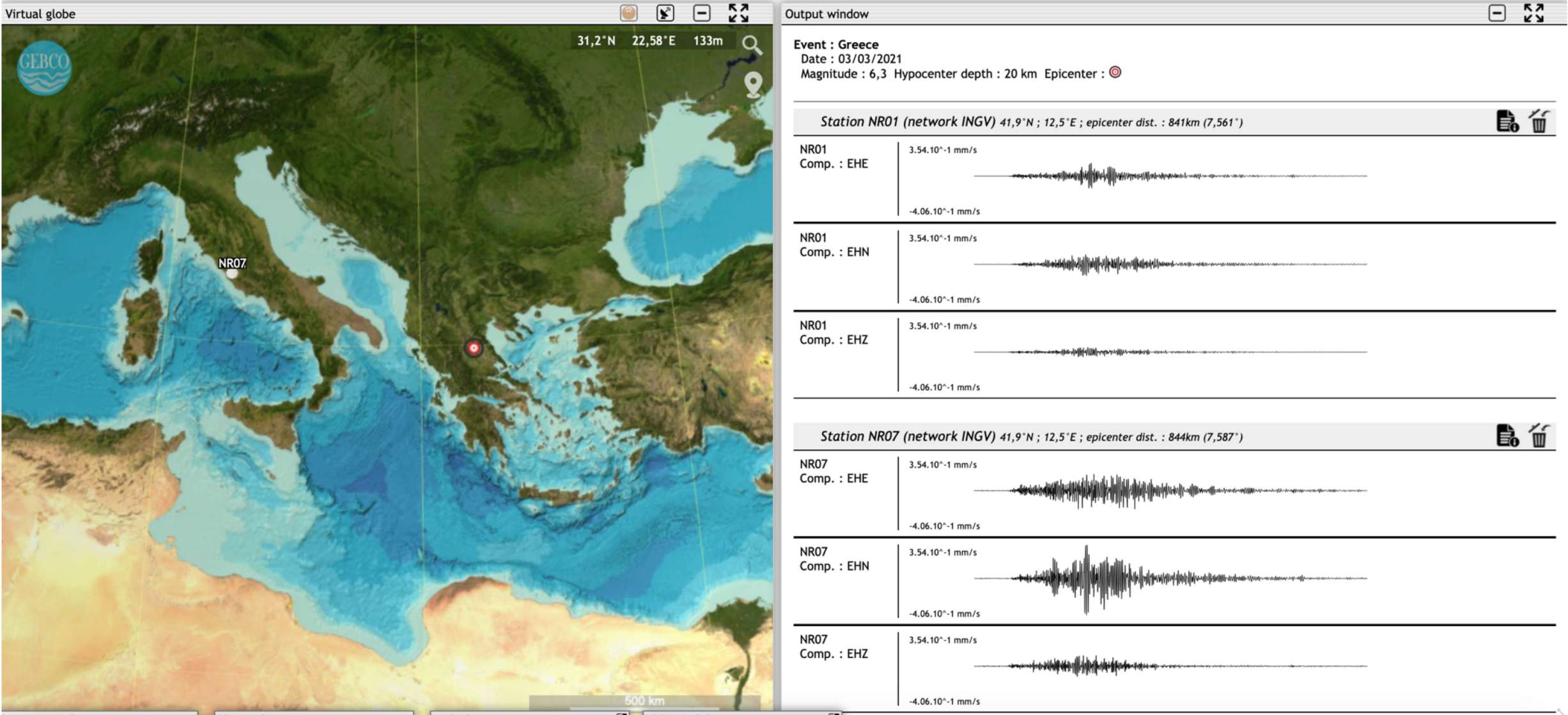
2021.03.03 / Earthquake occurred in Greece, recorded in Roma

Example of amplitudes values versus geological nature of soils.

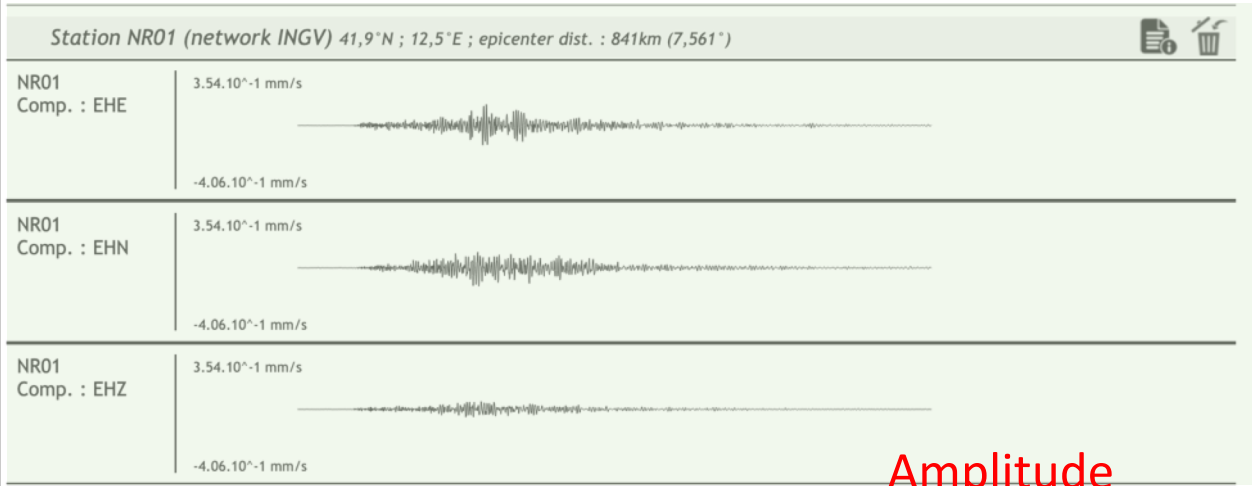
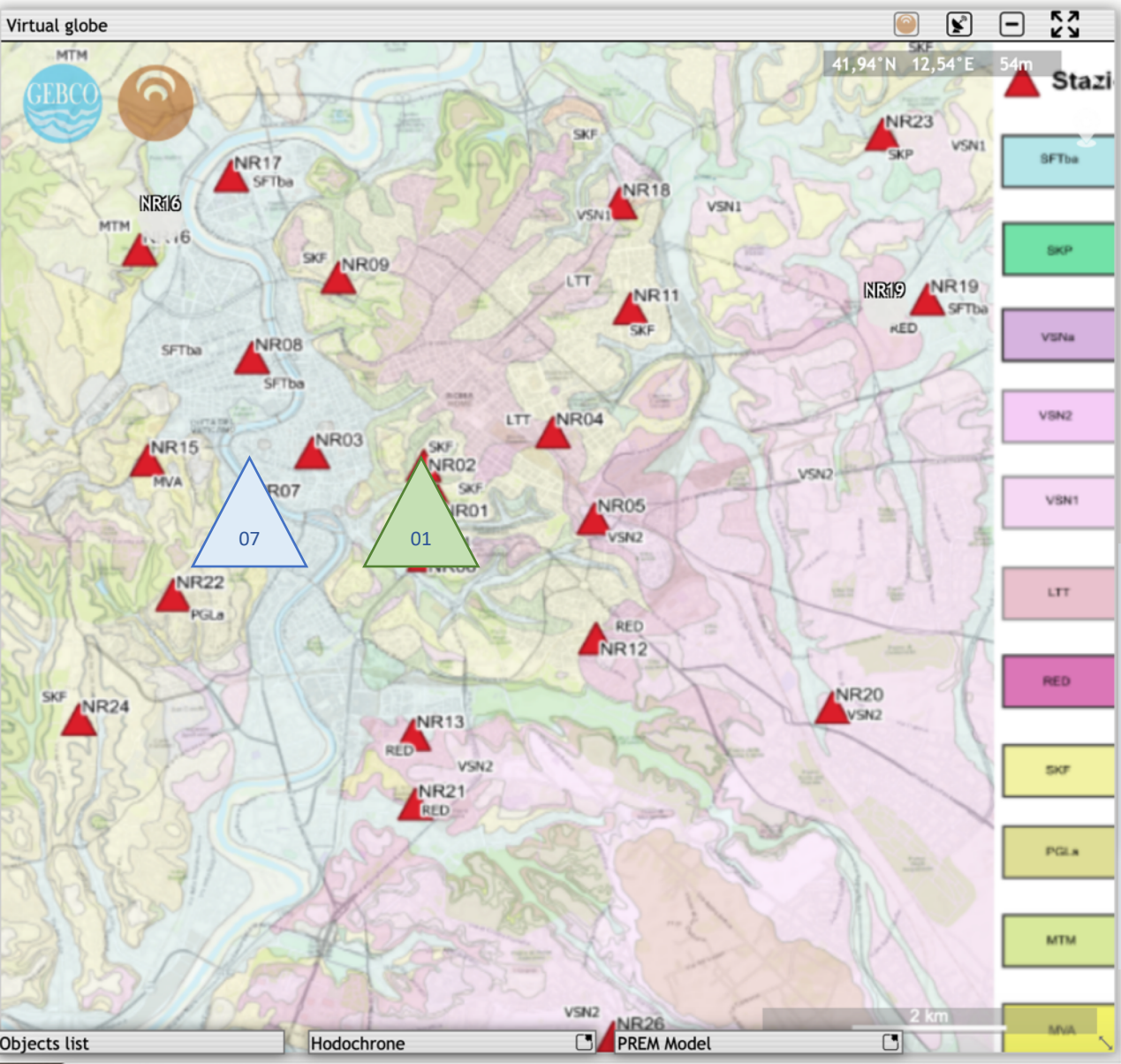
Download ZIP file

Display with Tectoglob3D

Source : EDUMED seismo center data base

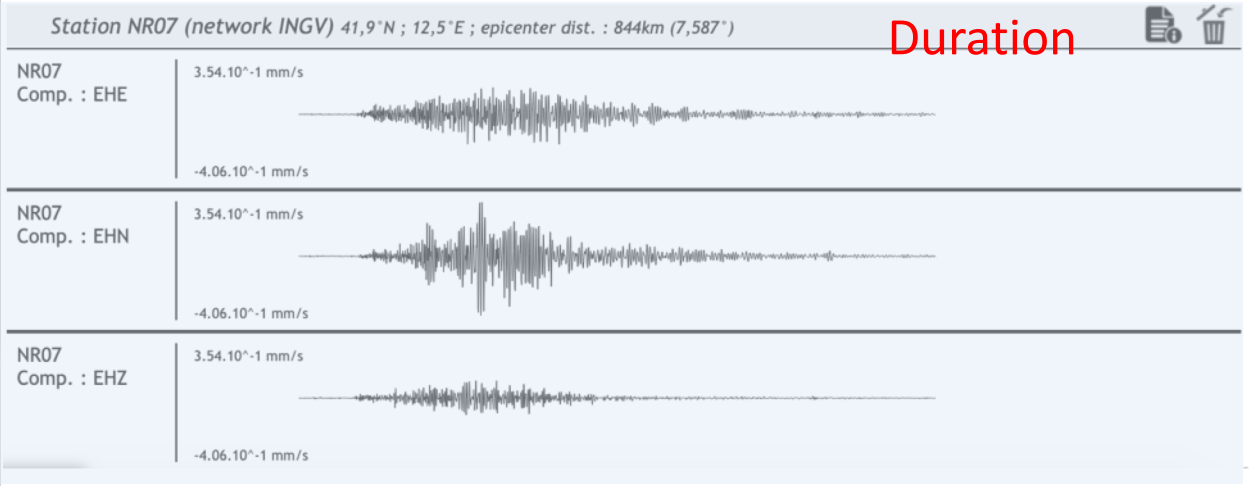






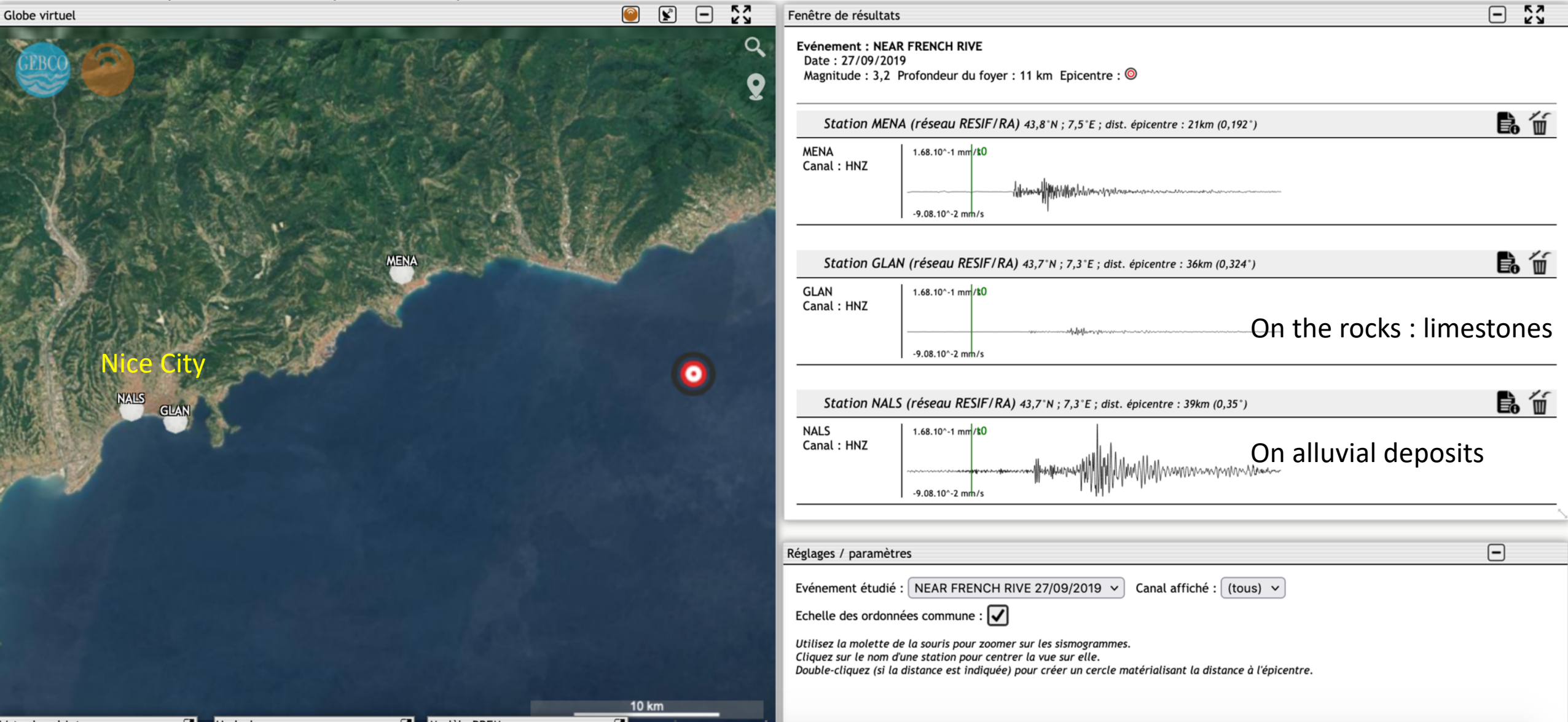
Let us compare the seismograms

Amplitude  
Frequency  
Duration





2019.09.27 / 10h13m48s / Mw=3.2 / LIGURIE

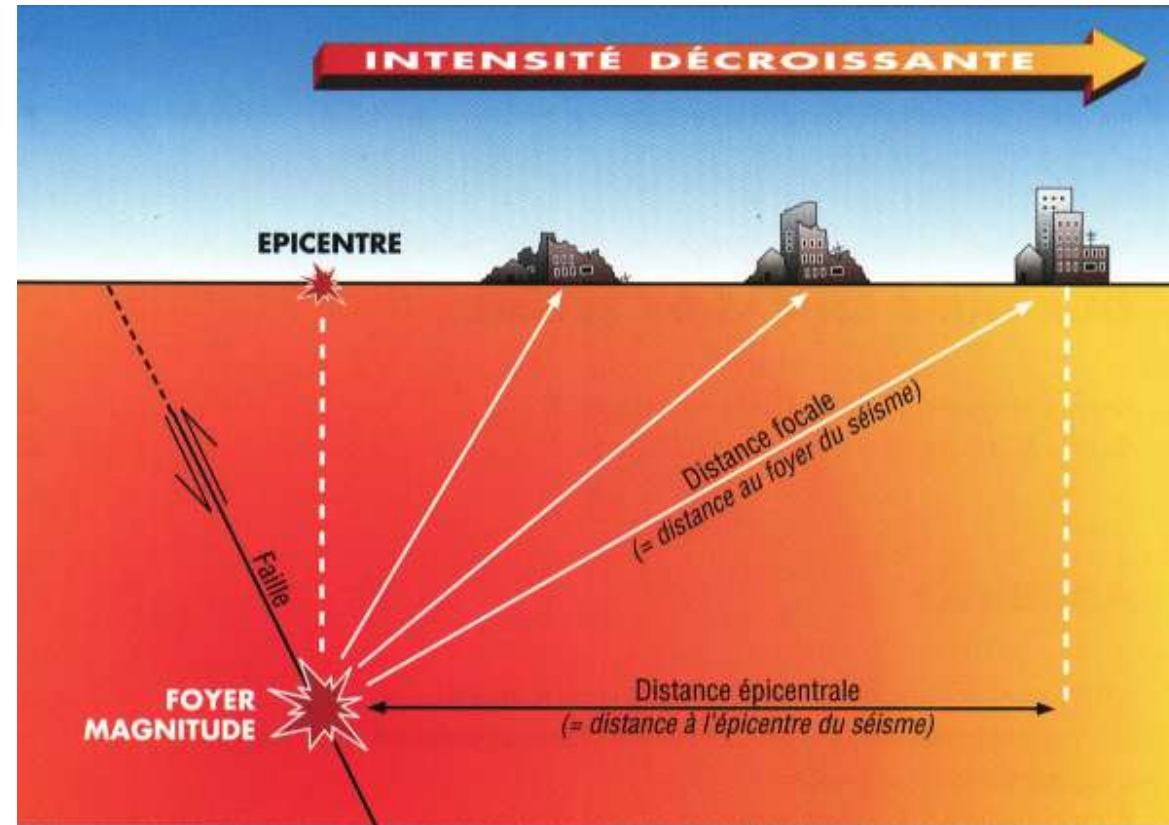




## Seismic waves arrival ... the earth shakes ... and us too

### Intensity scale (MSK / EMS98)

- Effects evaluation  
(population / buildings)
- In relation with the seismic  
focus (distance & site)
- Evaluation by testimonies &  
field observation:



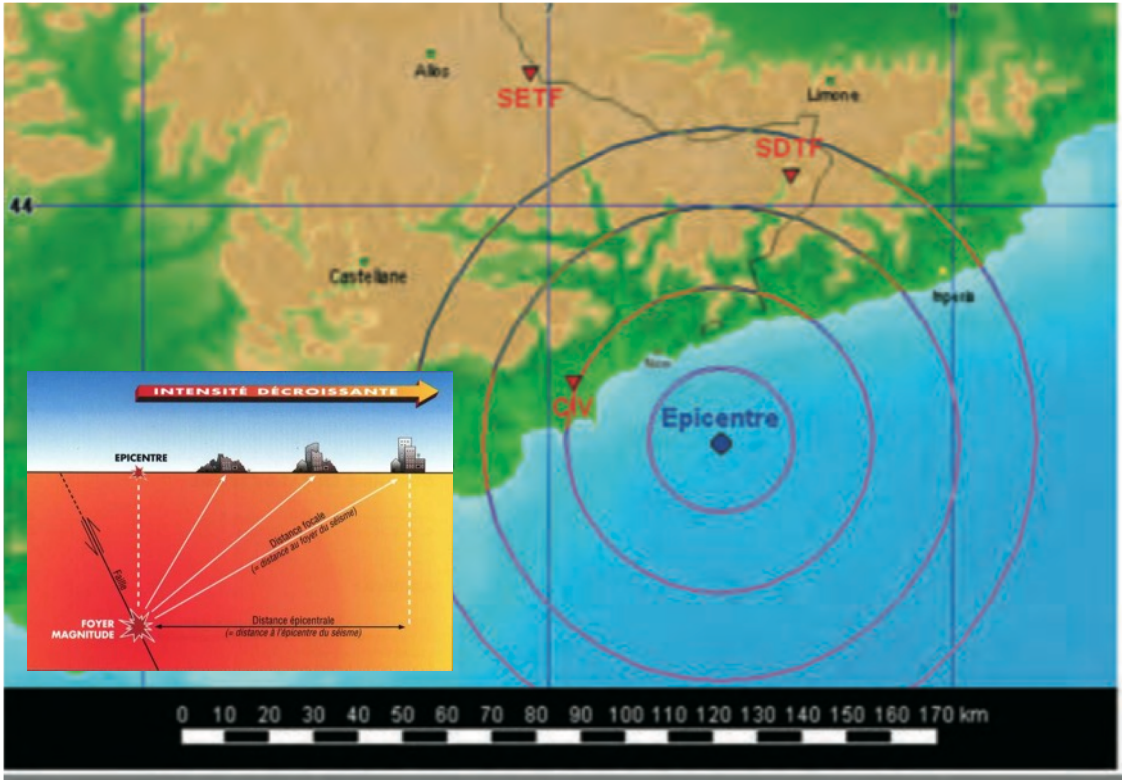
Perception Humaine	non ressenti	très faible	faible	légère	modérée	forte	très forte	sévère	violente	extrême
Dégâts Probables	aucun	aucun	aucun	aucun	très légers	légers	modérés	moyens	importants	généralisés
Accélérations (mg)	< 2	2 – 5	5 – 10	10 – 20	20 – 50	50 – 100	100 – 200	200 – 500	500 – 1000	> 1000
Intensités MSK	I	II	III	IV	V	VI	VII	VIII	IX	X+

(\*) **mg** = "milli g" est une unité d'accélération correspondant au millième de la pesanteur terrestre



Macroseismic map > evaluation of the intensity

Macroseismic map > what we can expect ...





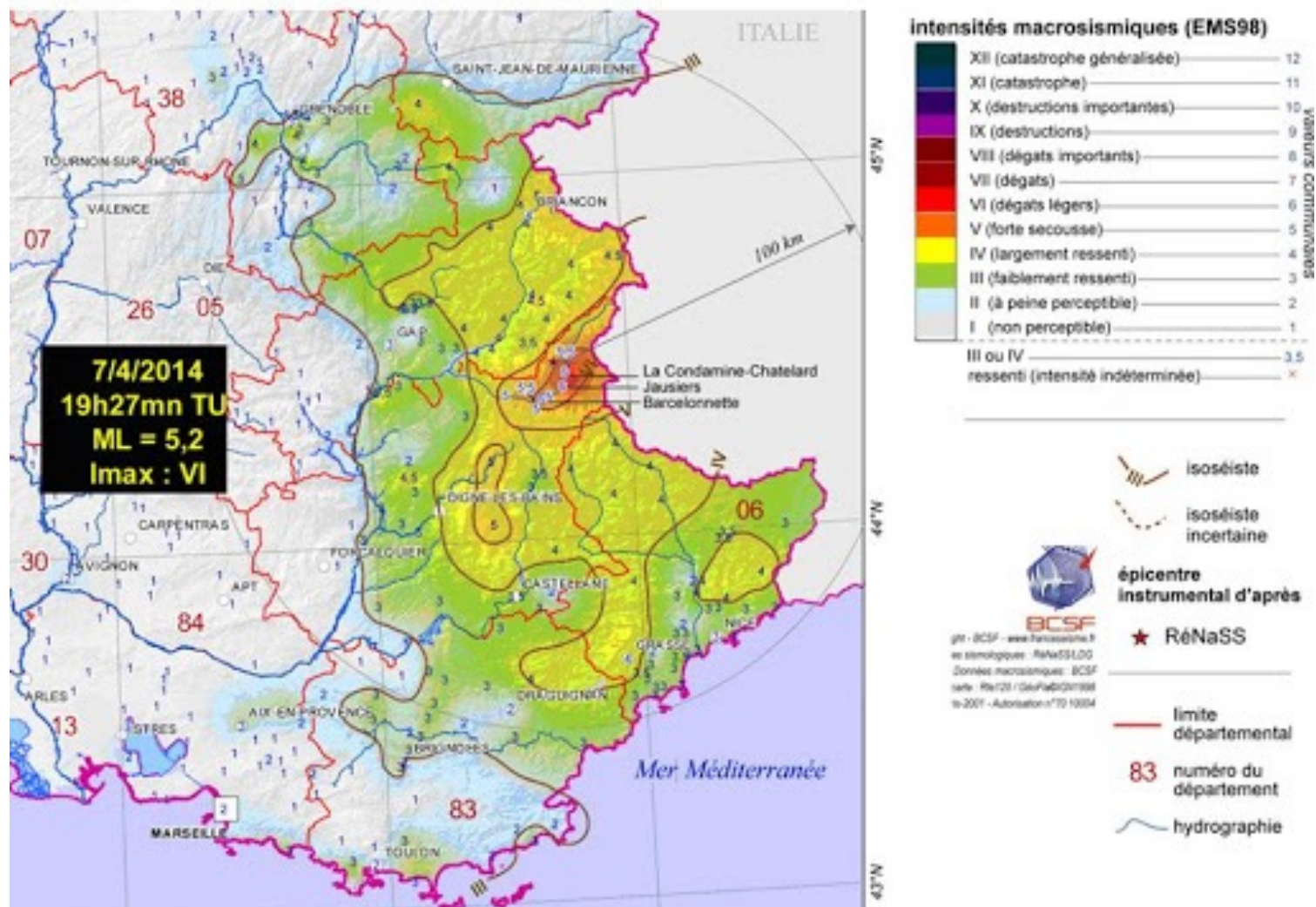


BCSF

Le Bureau Central Sismologique Français

[www.franceseisme.fr](http://www.franceseisme.fr)

LE BCSF COORDONNE, DIFFUSE, ARCHIVE LES OBSERVATIONS SISMOLOGIQUES



Formulaire de témoignage et enquête macrosismique





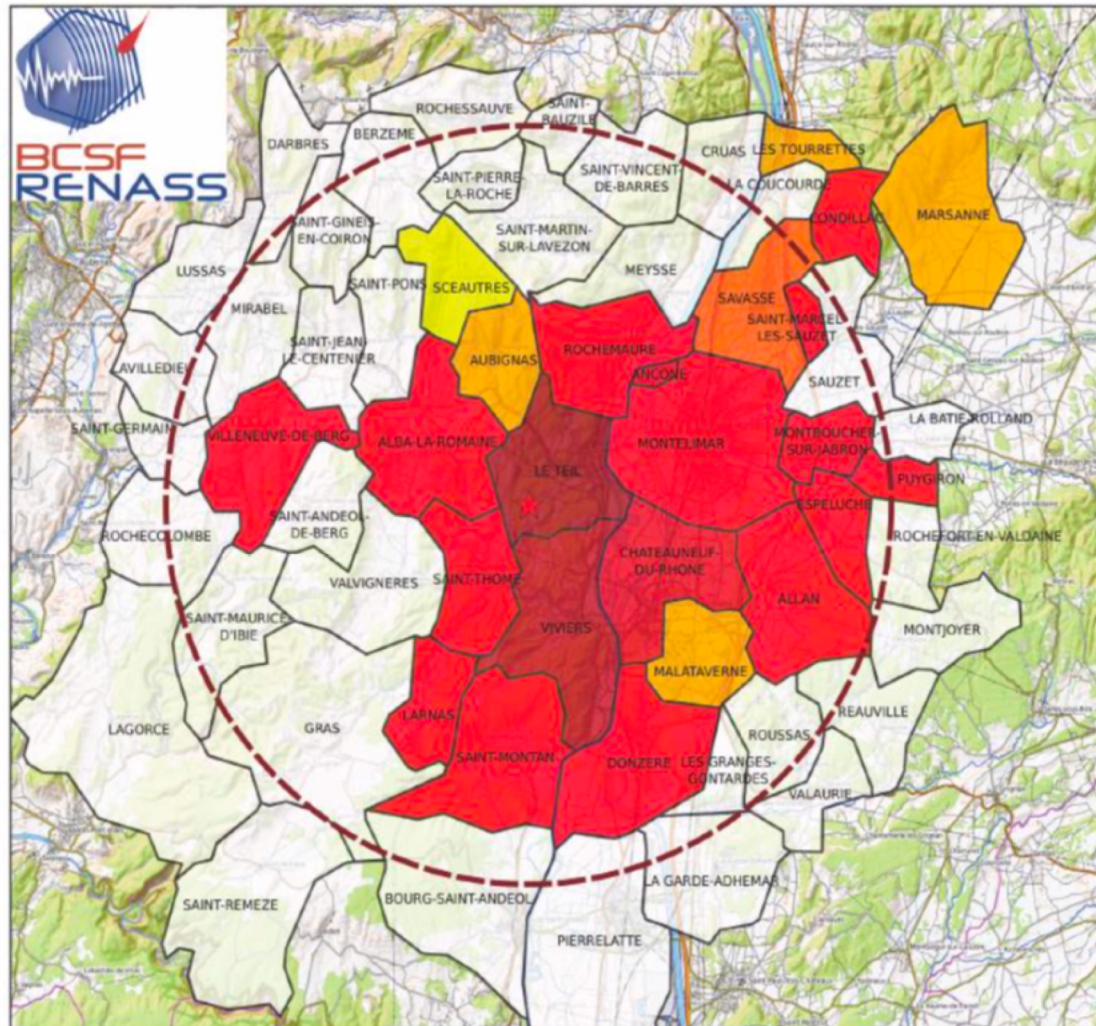
BCSF

Le Bureau Central Sismologique Français

[www.franceseisme.fr](http://www.franceseisme.fr)

LE BCSF COORDONNE, DIFFUSE, ARCHIVE LES OBSERVATIONS SISMOLOGIQUES

## Carte des intensités EMS98 estimées par le GIM - Groupe d'intervention macrosismique



Séisme du Teuil (07)

11 novembre 2019

Carte des communes enquêtées  
par le GIM

Etat des lieux au 3/12/19

16km autour de l'épicentre

★ Epicentre

Limites départementales

Intensité

IV

V

V et VI

VI

VI et VII

VII

VII et VIII

Estimation non réalisée au 3/12/19

Fond Open Street Map

RESIF RAP

IRSN Cerema

Pacte

Laboratoire de sciences sociales

0 5 10 15 km

Cartographie: Elise Beck, Pacte-Grenoble



## Seismic waves propagation (local scale)

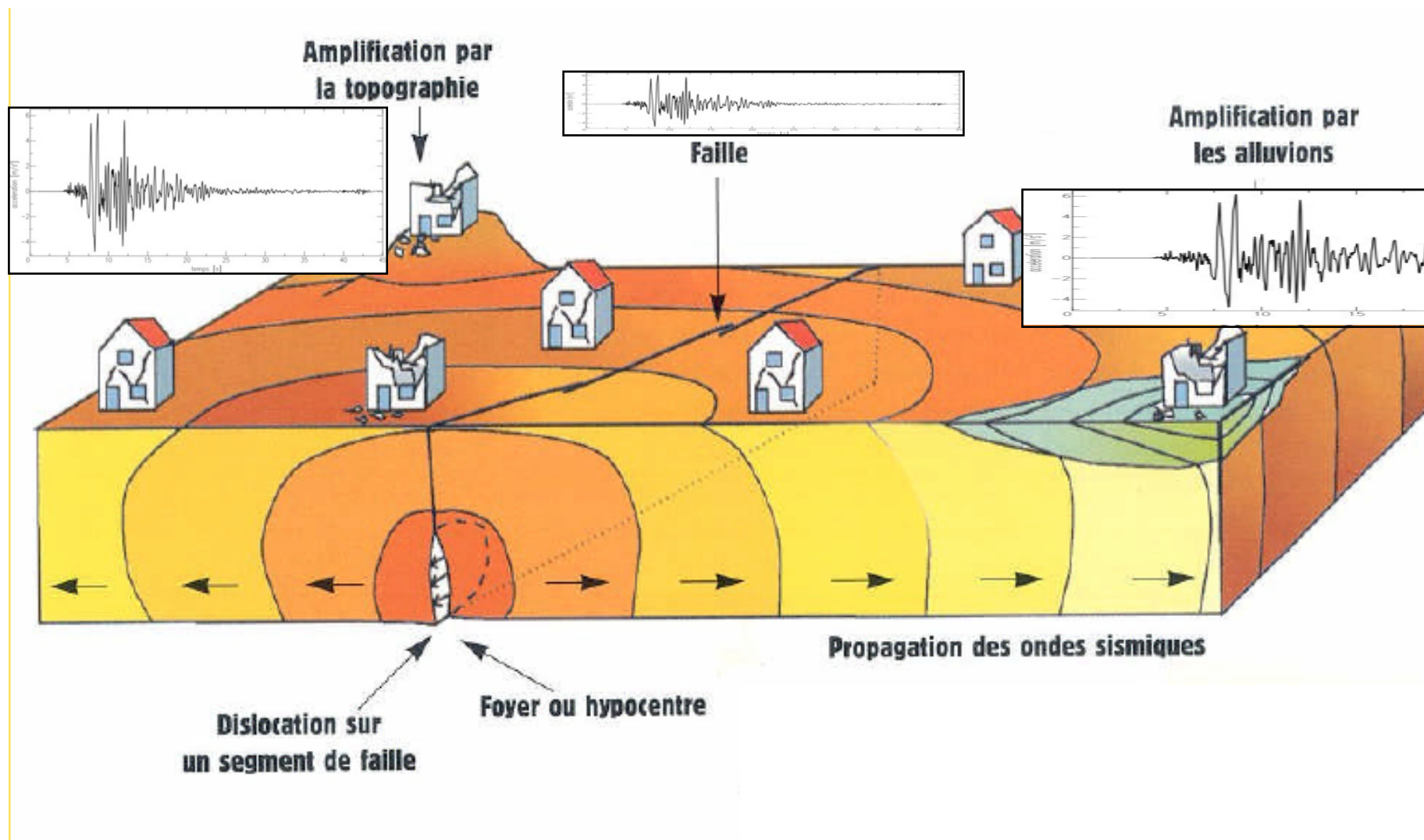


Illustration by P. Bernard (IPGP)



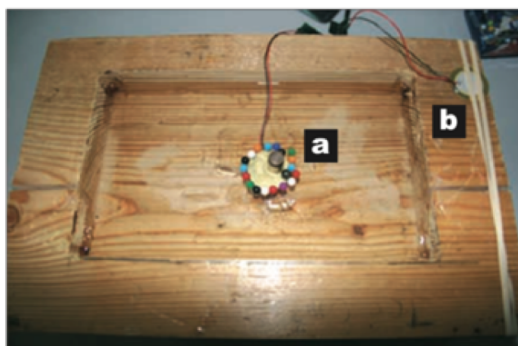
## Modeling the site effect!

The precise analysis of the seismograms shows a site effect on the city of Rome ...

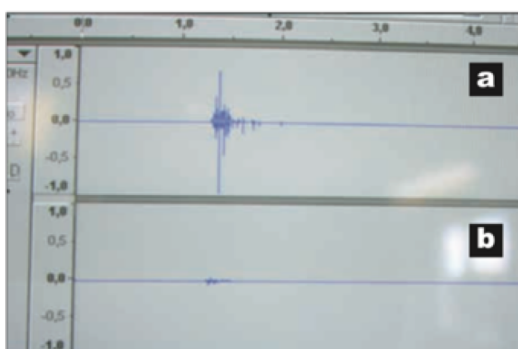
Site effect in seismology can be model at school. The result of a modelling exercise carried out by students can be shown.

Modelling of a site effect. The device consists of a wooden beam hollowed out and then filled with several layers of sand. Two piezoelectric cells (microphones) placed respectively on the wood and on the sand record the shocks created by an impact, opposite the box.

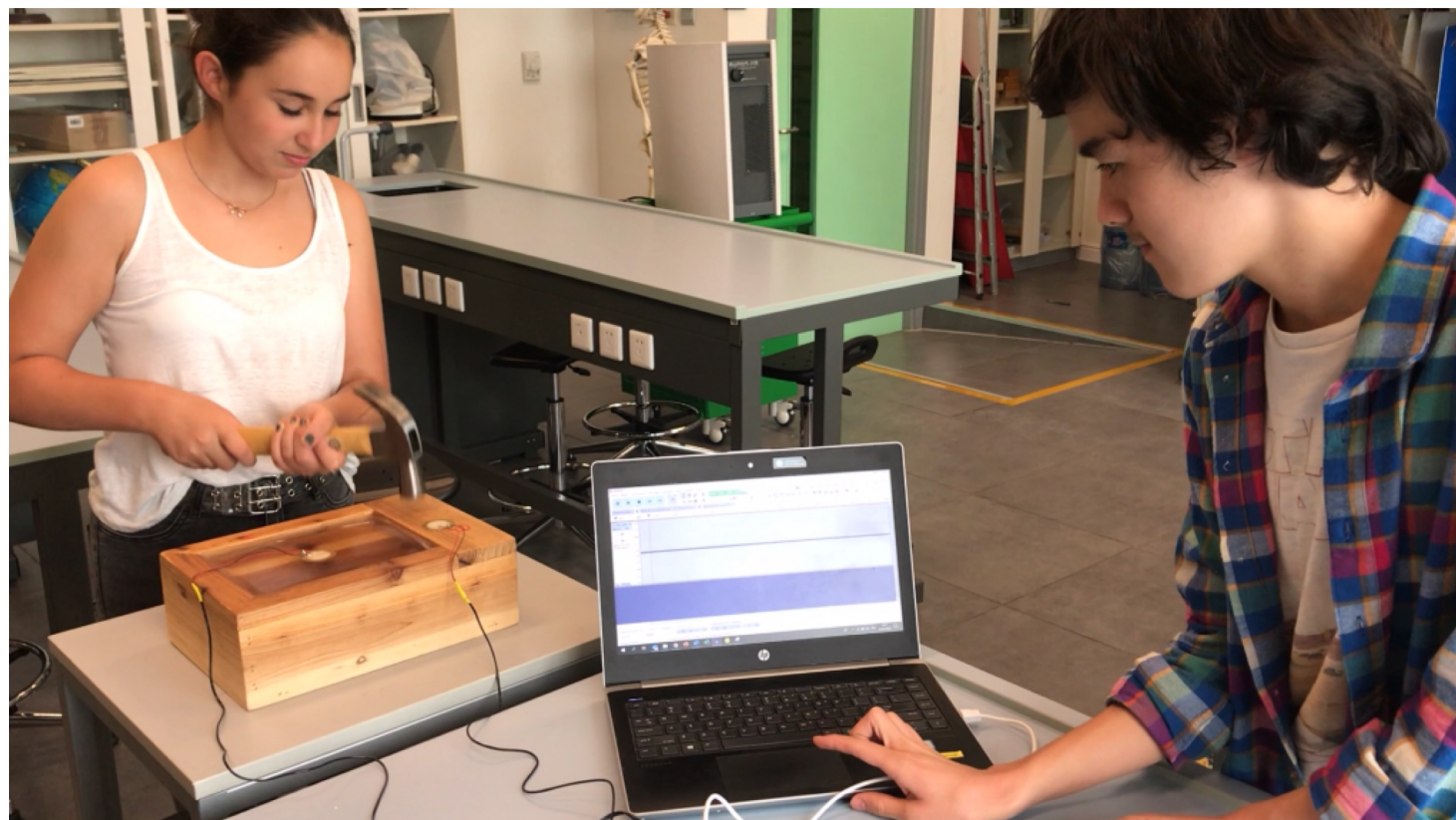
Sand or  
candlewax  
or jello



sand



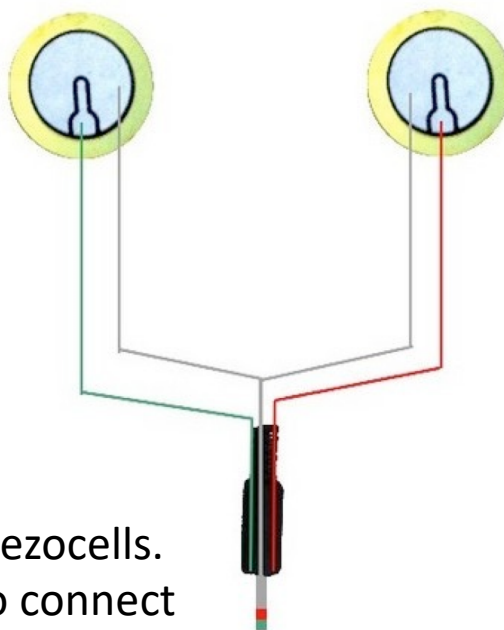
wood







piezocells

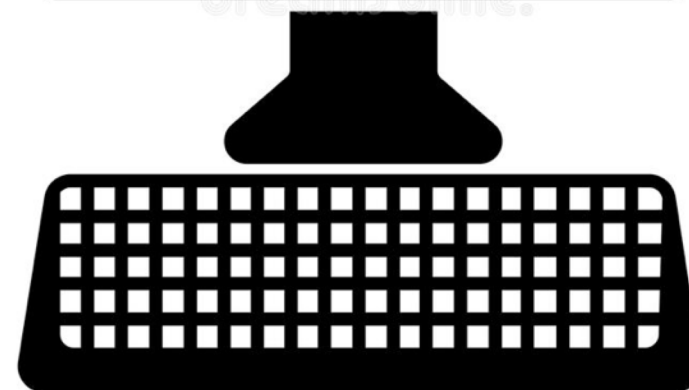
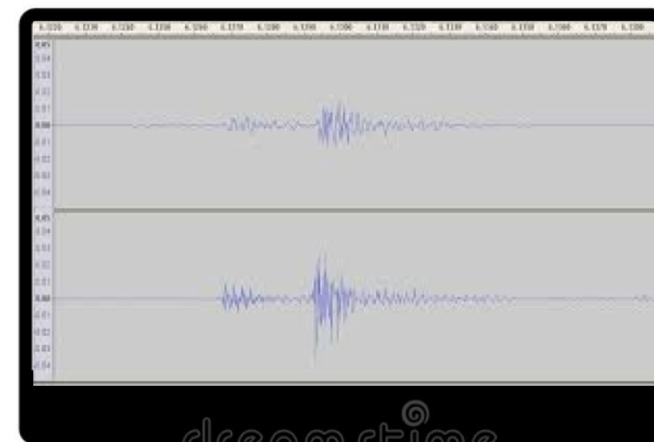


Piezocells.  
To connect  
to the computer



"line in"  
(couleur bleue sur carte récente,  
sinon noire avec repère écrit).

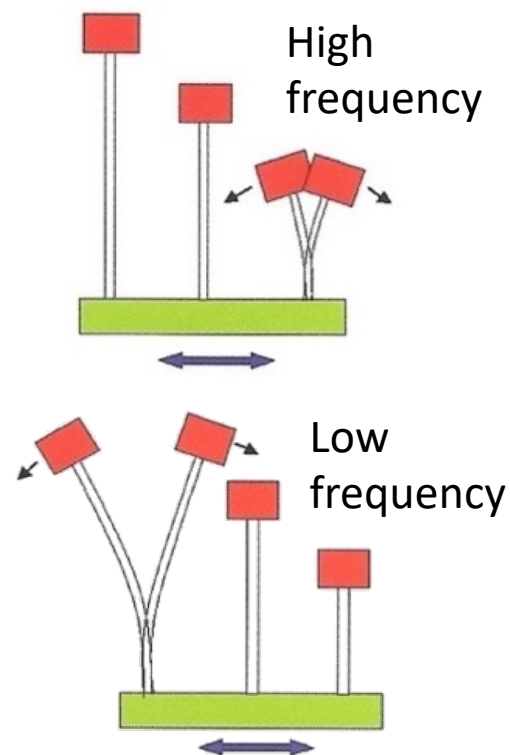
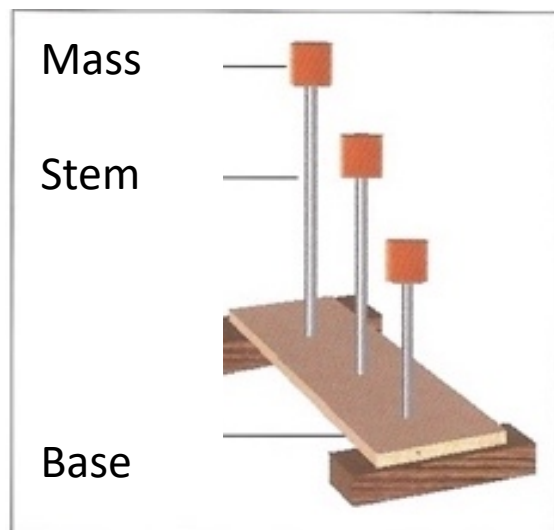
Free software 'Audacity'  
to record data





## Modeling the site effect!

The modification of the amplitude, of the frequency, of the duration can impact houses, buildings ... archeological monuments !



For example, these methods can be based on the number of floors: a flexible building has, roughly speaking, a resonance frequency equal to 10 divided by the number of floors ( $f = 10/N$ ) whereas a rigid structure has a frequency given by 20 divided by the number of floors ( $f = 20/N$ ).

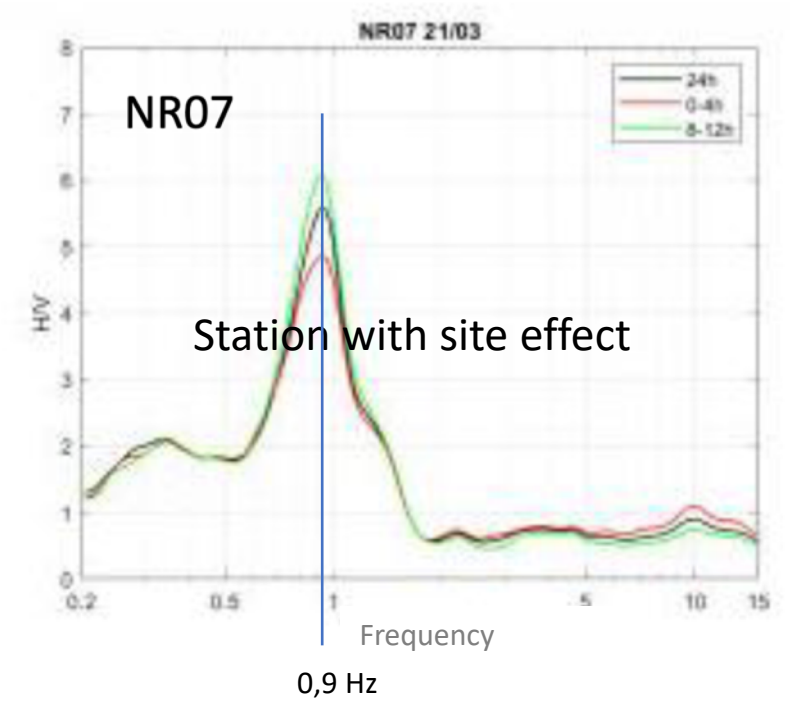
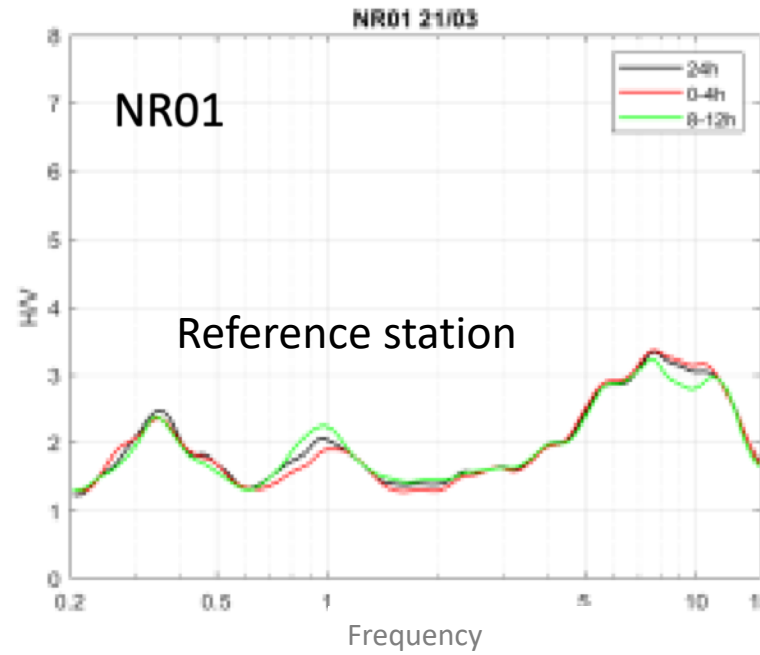


## Back to our seismic stations .... and our columns

Comparison NR07-NR01

Diagram :  
Amplitude H/V = f(frequency)`

Data from INGV Rome



Marc Aurelius



Trajan



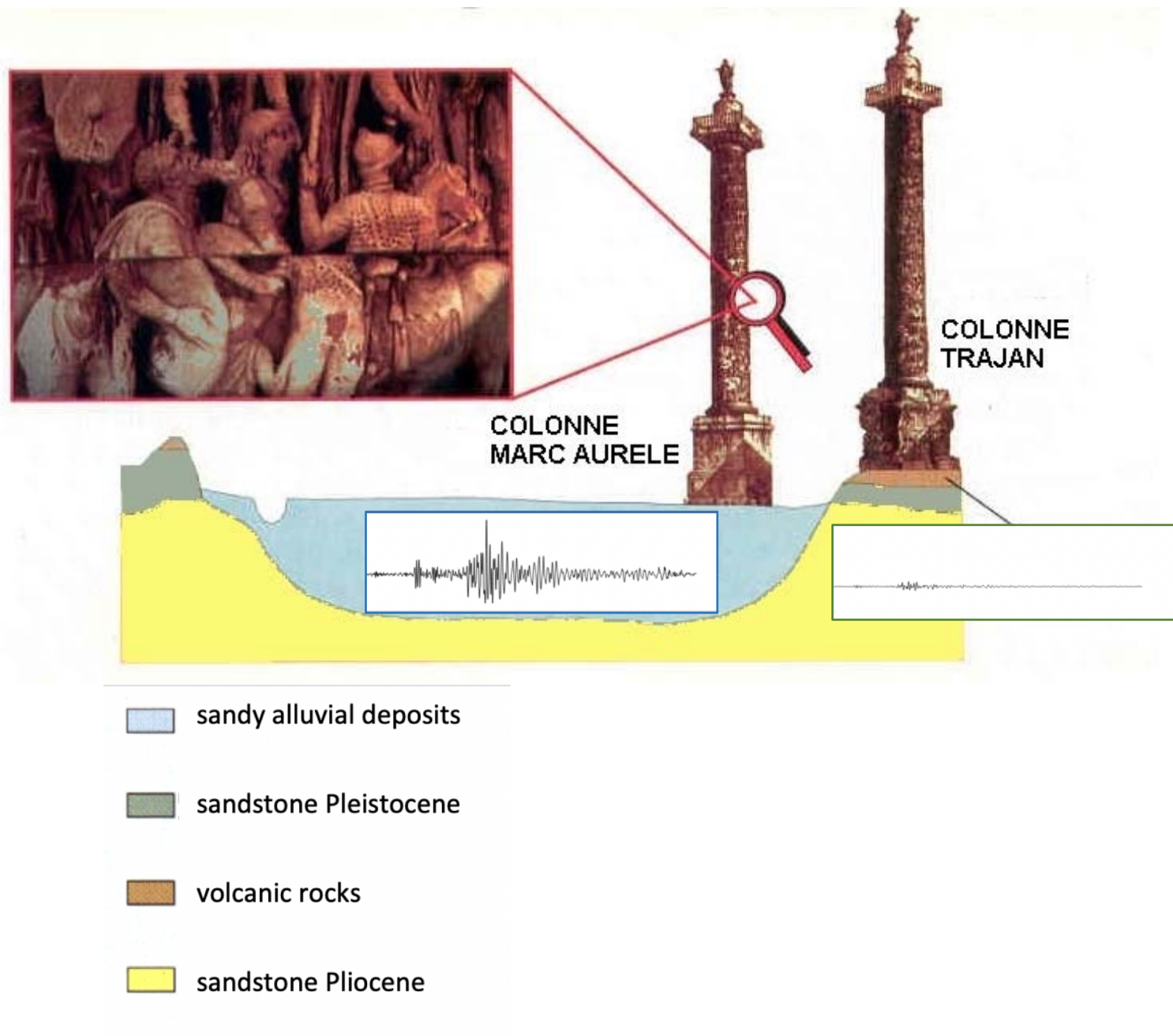
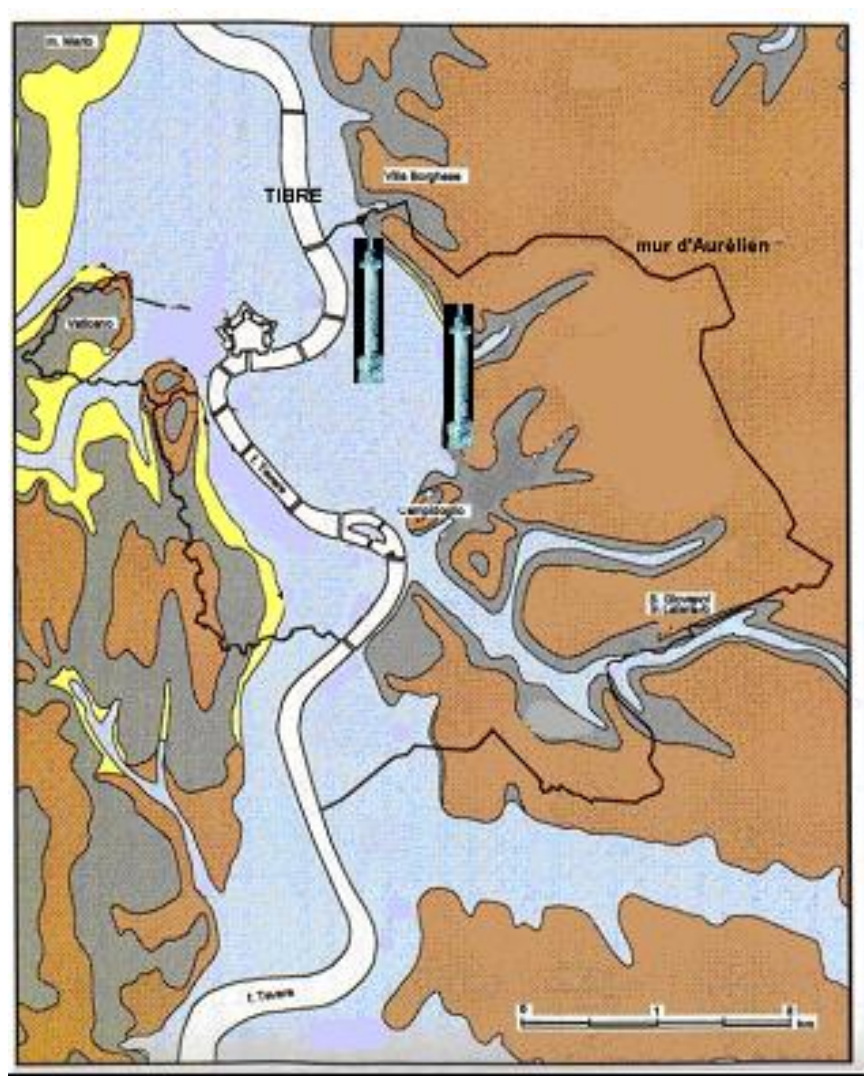
Resonance frequency =  $10/N > N = 10/0,9 = 11$  stairs = 27,5 m  
N = number of floors of a building

The Italian archaeologist Filippo Coarelli gives the following measurements  
> height of the column : 30 m



Back to our Roman columns !

The site effect in the city of Rome  
has impacted the stability of the columns ...



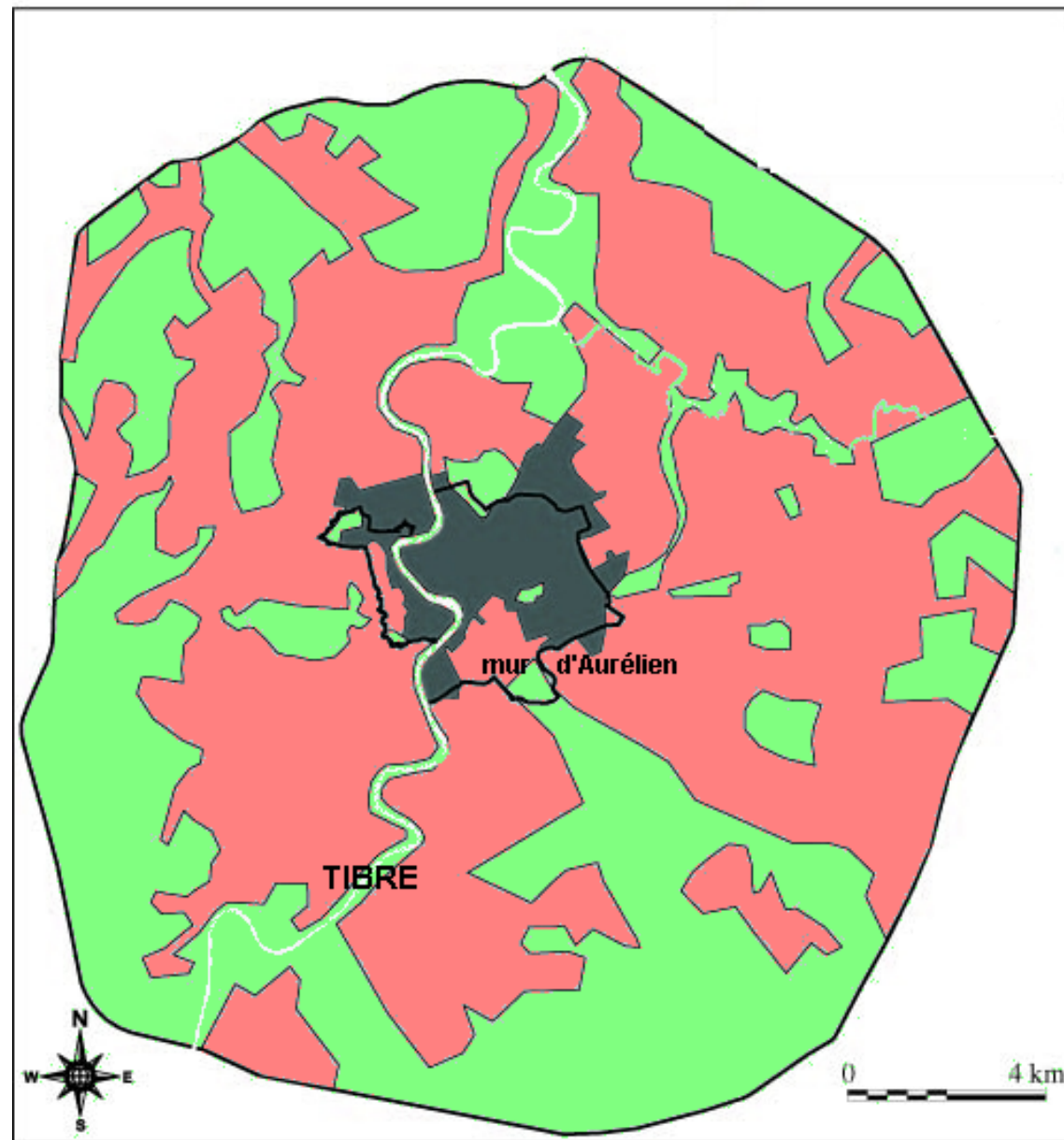
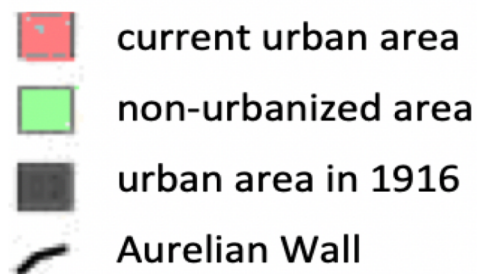


4 millions people are living in Roma !

Today, Rome is no longer just the marble city left by the Roman emperors, it has become the capital of Italy and is experiencing an unusual and huge urban expansion.

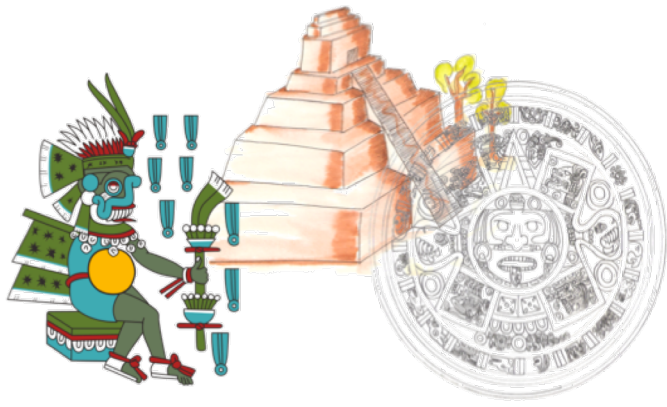
During all these centuries, the city of Rome and its region have experienced and are still experiencing many seismic events.

A seismic hazard that needs to be better understood at a time when the urban agglomeration is populated by nearly four million people.



Current urbanization of the Rome agglomeration (Department of Geological Sciences - University of Roma III, Italy)



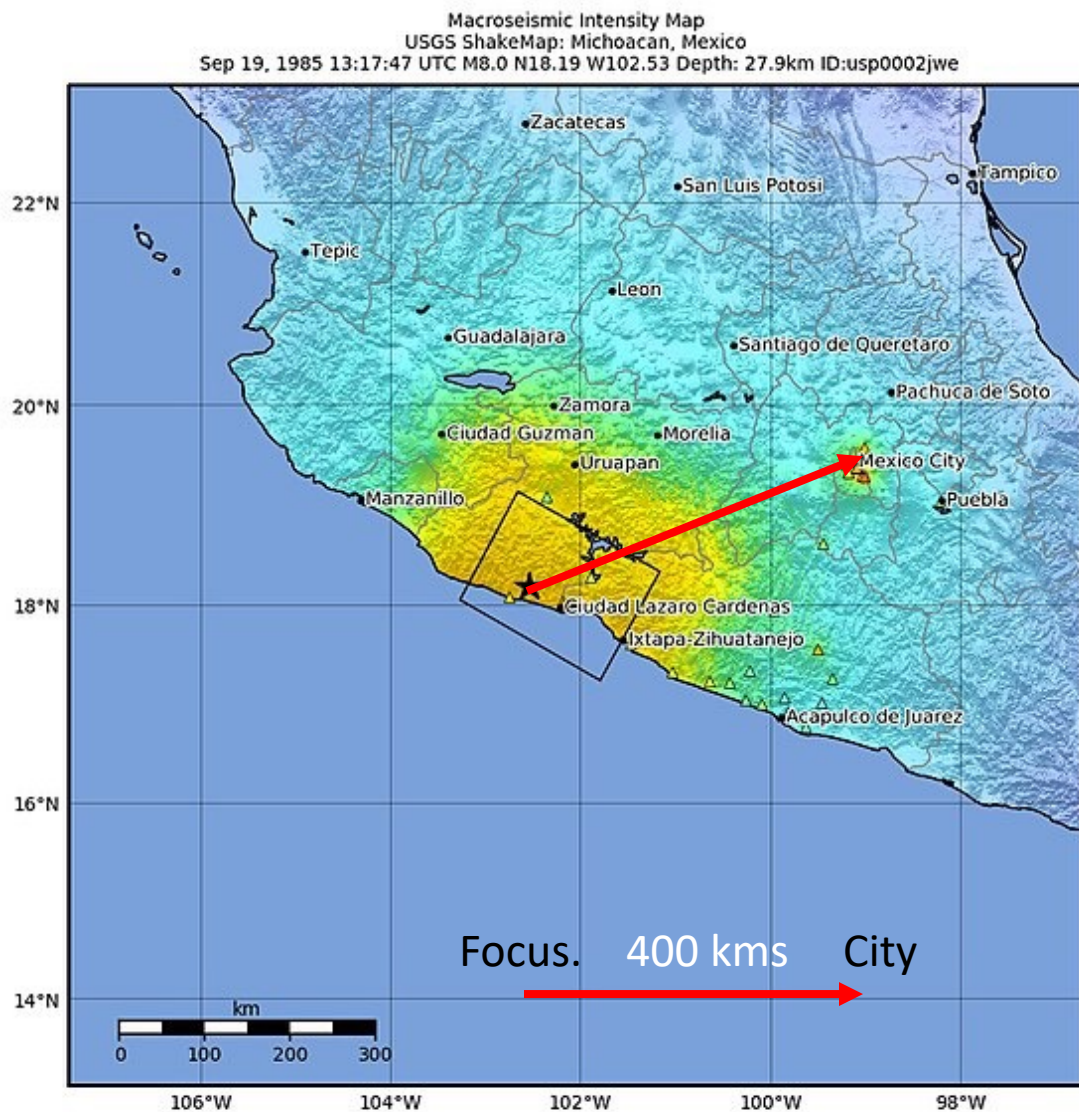


**Mexico City, a megacity in South America, is highly vulnerable to earthquakes.**

In 1985, a strong earthquake of magnitude 8.2 destroyed the capital city.



The event caused serious damage to the Greater Mexico City area and the deaths of at least 5,000 people.



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.05	0.3	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.02	0.13	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

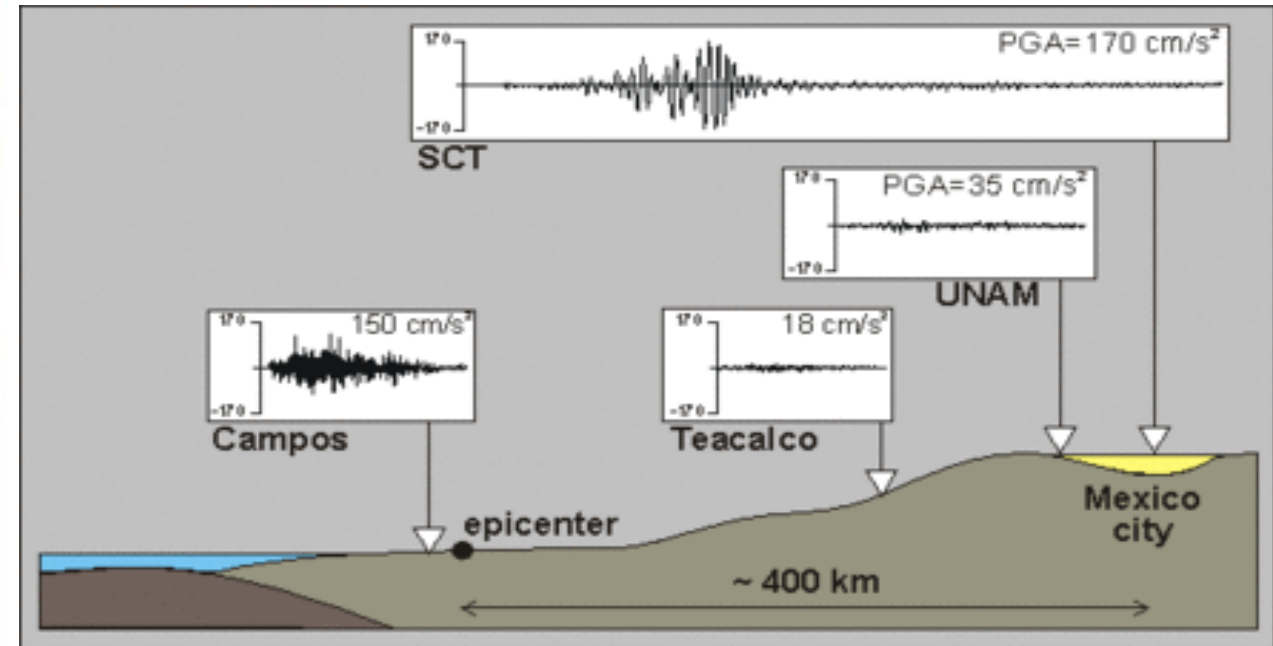
Scale based on Worden et al. (2012)

△ Seismic Instrument ○ Reported Intensity

★ Epicenter □ Rupture

Version 1: Processed 2019-09-26T07:57:58Z

Mexico city was very far from the earthquake focus ... and yet !

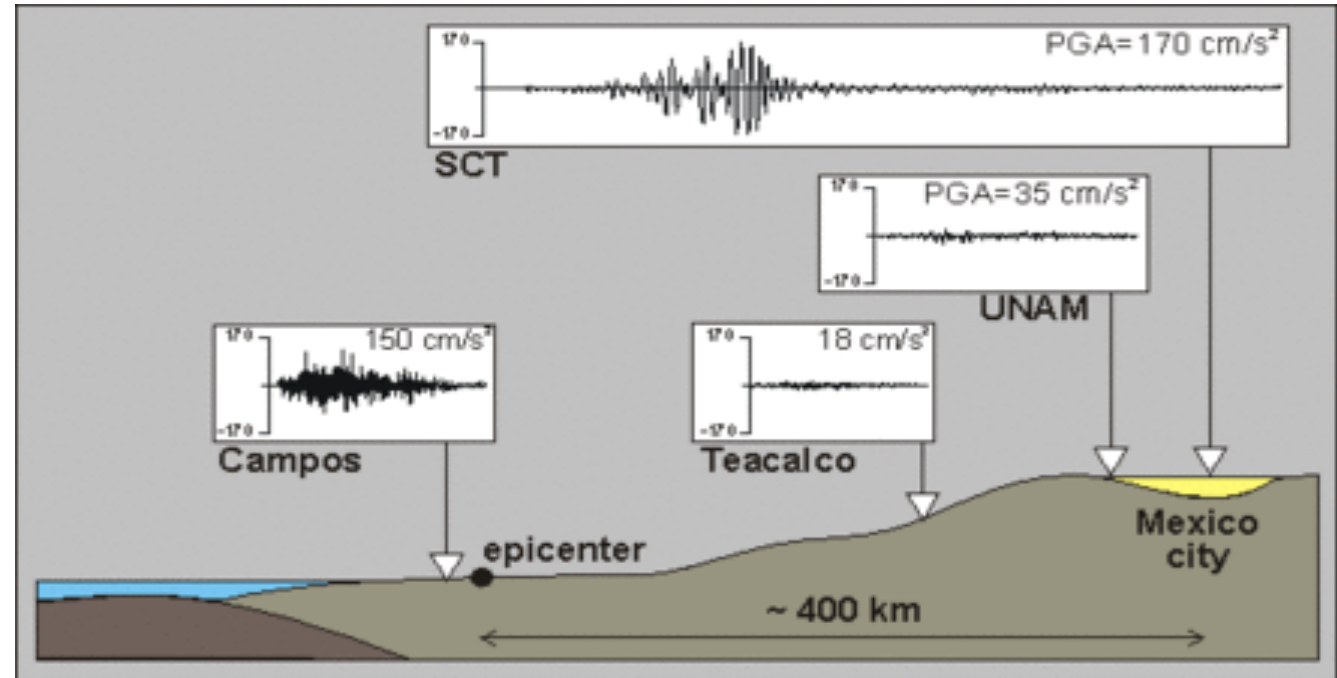
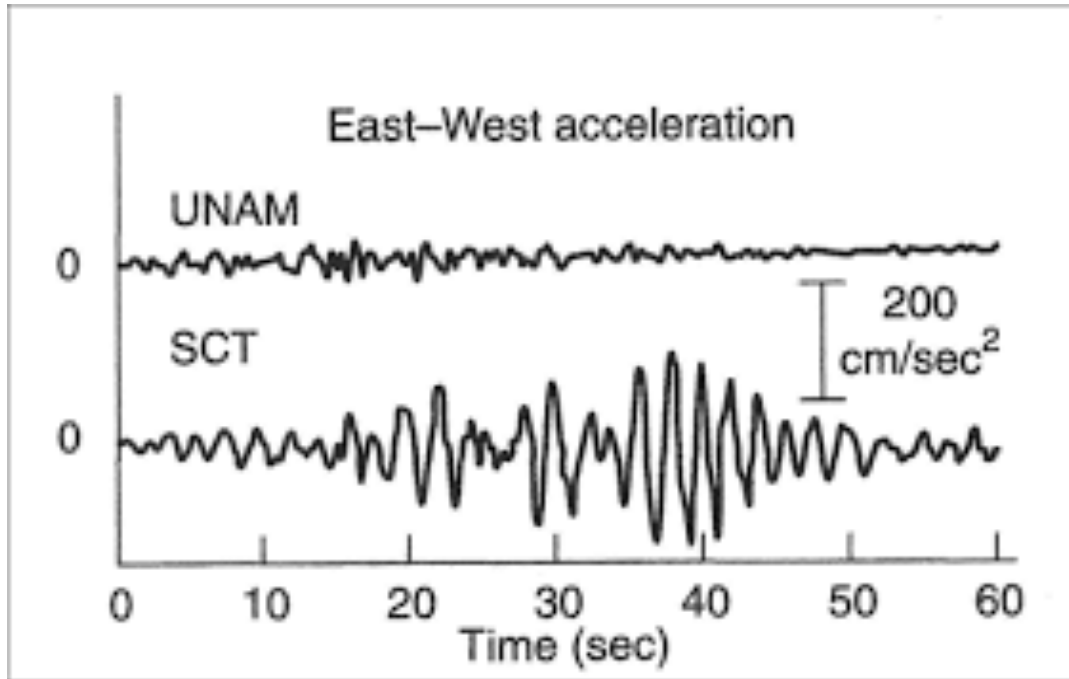


PGA: Peak Ground Acceleration

The amplitude of the waves is given in acceleration values (cm/s<sup>2</sup>)



Mexico city was very far from the earthquake focus ... and yet !



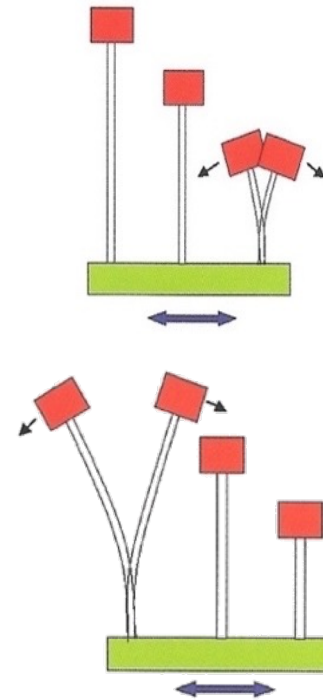
PGA: Peak Ground Acceleration

The amplitude of the waves is given in acceleration values ( $\text{cm/s}^2$ )



**Mexico City, a megacity in South America, is highly vulnerable to earthquakes.**

In 1985, a strong earthquake of magnitude 8.2 destroyed the capital city.



The collapse of buildings is related to their height.

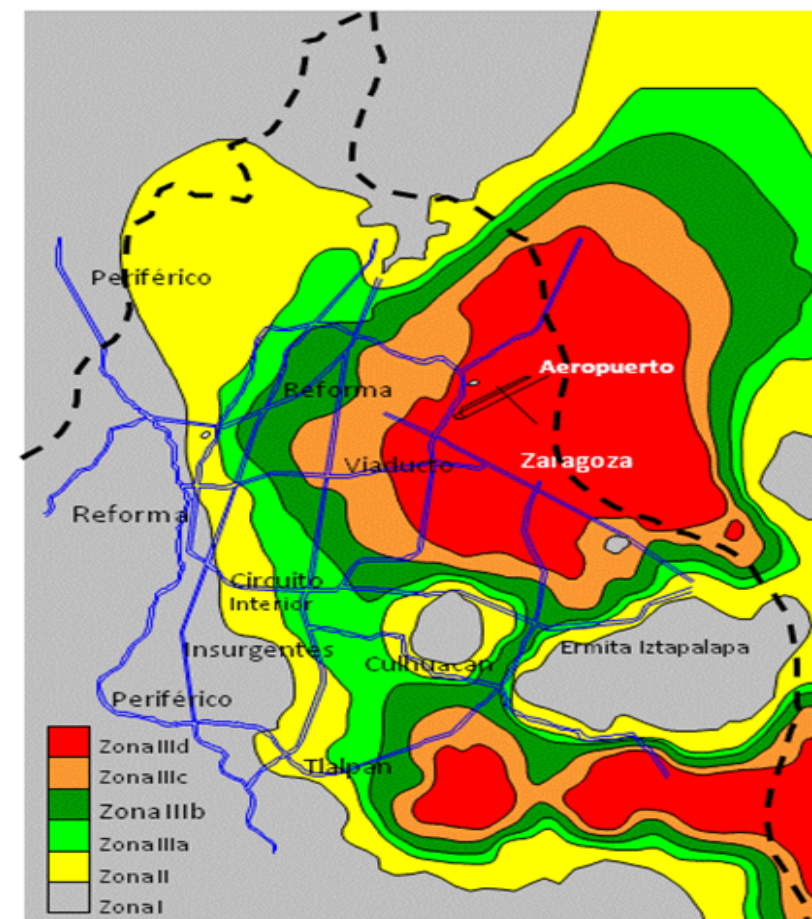


Today, the capital Mexico City is a megalopolis ...

... but just 700 years ago it was an island of two square kilometers in the middle of a lake. Like Venice in Italy, the Aztec city was built on islands and land taken from the marshes. What was once a lake was first filled in by the Aztecs, who built dykes and canals, and then by the Spanish, who conquered the city.



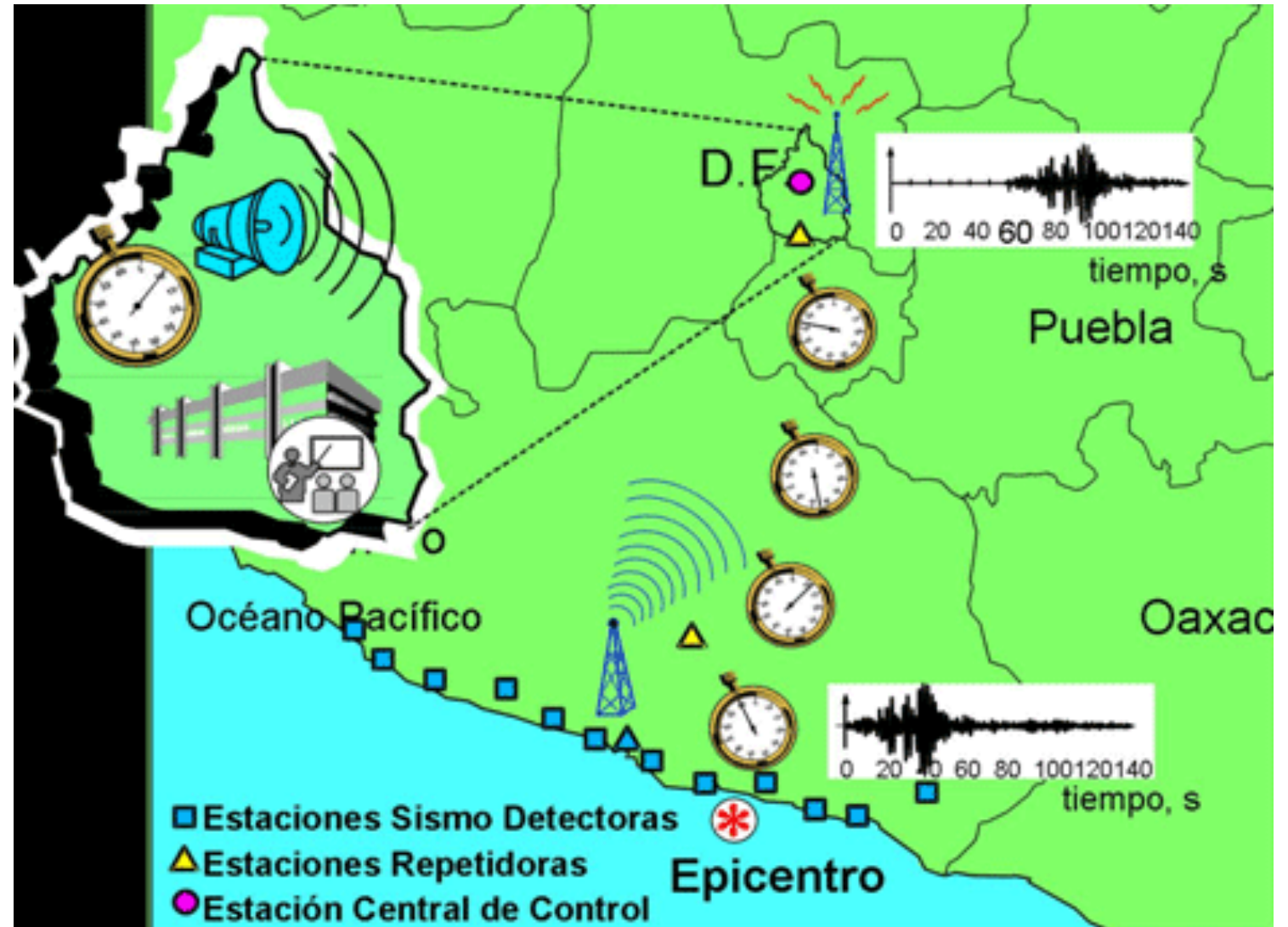
Mexico... 700 years ago



current seismic zoning (in red, maximum risk)

## Site effect in the big cities ... Focusing on prevention !

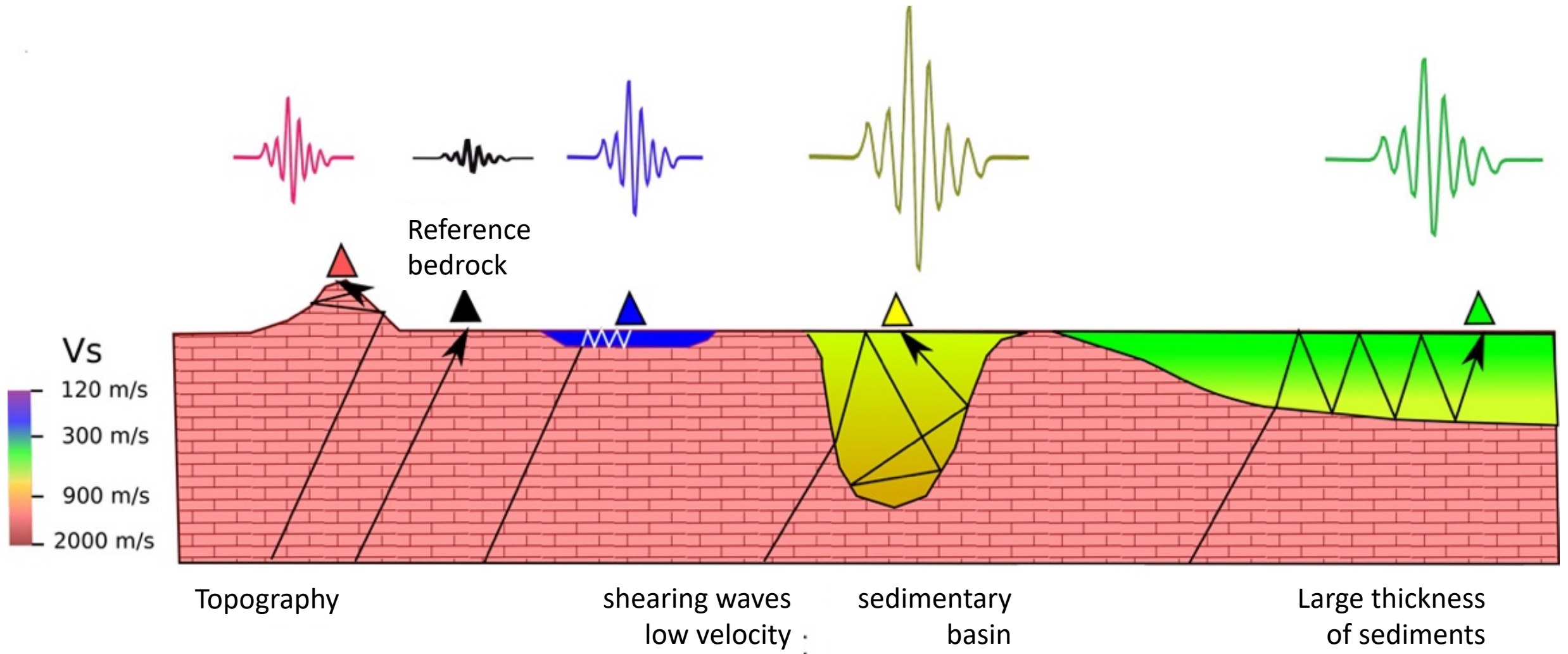
The SAS (Sistema de Alerta Sísmica), makes Mexico City a pioneer in seismic prevention



*Crédito Imagen: Dr. Carlos Valdez Gonzáles,  
Director Instituto de Geofísica UNAM*



To resume the seismic site effect



## Observation of Roman archaeological monuments & seismic site effect in the city of Rome

by Jean-Luc Berenguer  
Geoazur Education & Outreach - University Côte d'Azur

*Thanks for your attention*

