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LEVEL II SEISMIC MICROZONING IN THE SAN GIMIGNANO AREA (CENTRAL ITALY)

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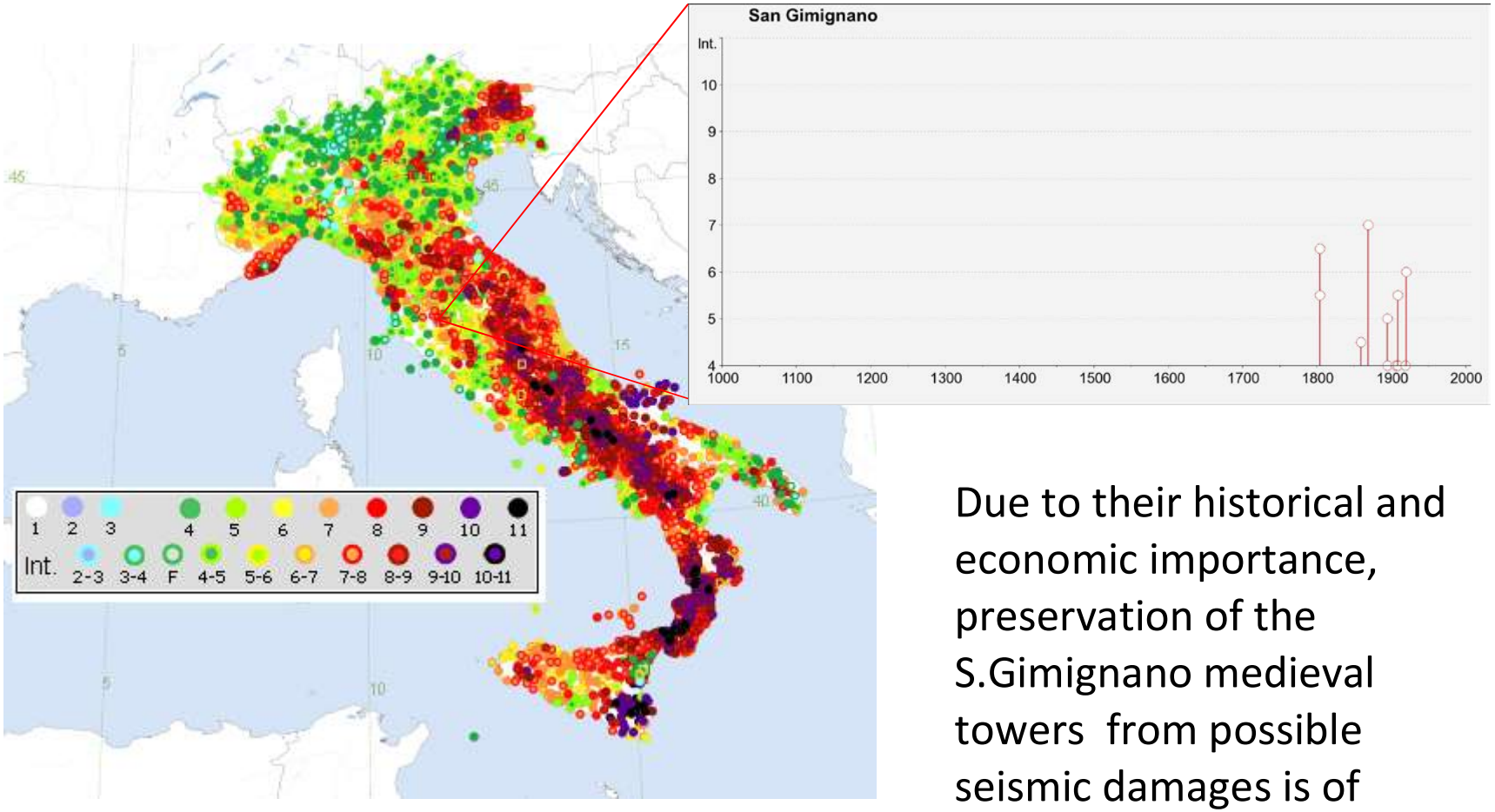
The small town of S.Gimignano in Central Tuscany (Italy) was declared by UNESCO to be part of the World's Architectural Heritage

Middle-age towers represent the most distinctive trait of the town and the most important touristic attraction

Despite of the fact that seismic hazard in central Tuscany cannot be considered as high, several events occurred in the recent past that struck S.Gimignano with intensity up to VII MCS (i.e., of the order of that of the recent May-June 2012 earthquake in Northern Italy)



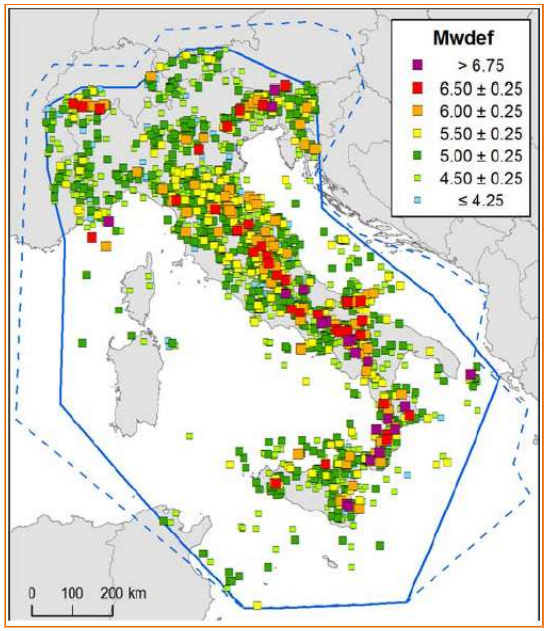
Due to their historical and economic importance, preservation of the S.Gimignano medieval towers from possible seismic damages is of major importance

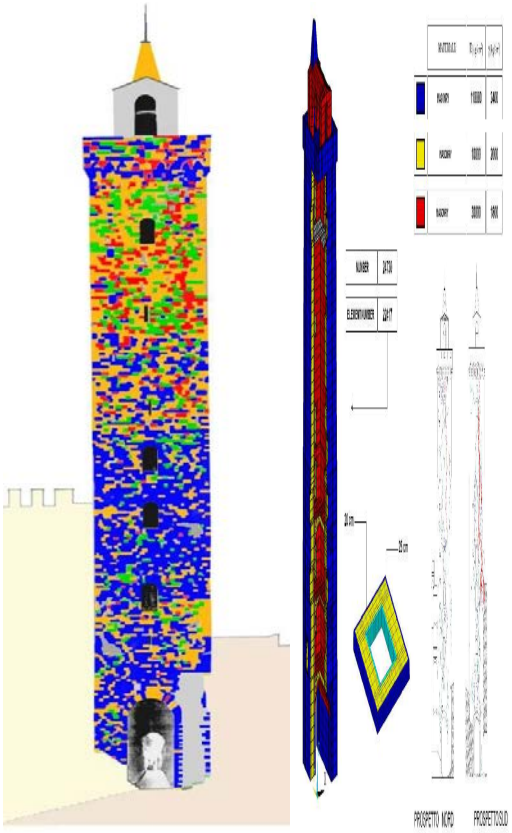
Thus, the pilot research program RiSEM (i.e., Seismic Risk of Monumental Buildings) was established by the Tuscany Regional Administration to evaluate seismic risk of the S.Gimignano Towers

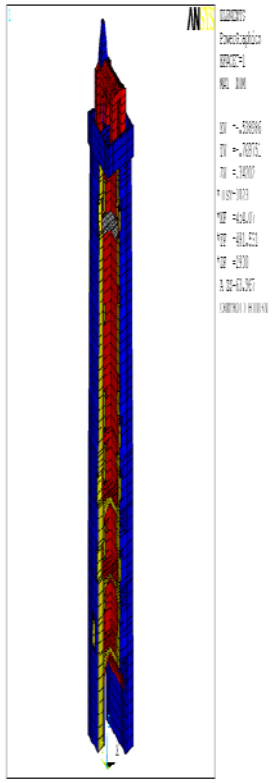
In this research program the two Tuscany Universities (Florence, and Siena) were involved aiming at the development and field application of low cost and not invasive techniques for seismic risk assessment of historical buildings

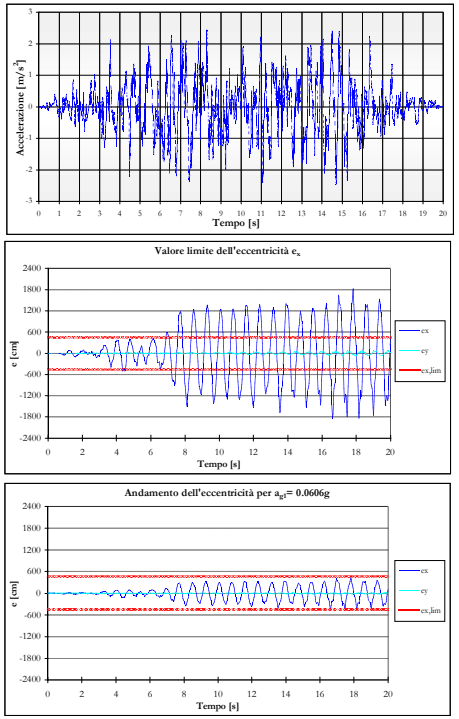
Potentially, the procedures here tested could be applied extensively in the Tuscany area, where similar structures and a number of historical settlements exist and are widely distributed over the regional territory

The project includes four work packages









Local Seismic hazard assessment

Description and characterization of the towers

Numerical modelling

Seismic risk assessment

RiSEM

Rischio Sismico negli Edifici Monumentali

Local Seismic hazard assessment aims at defining variations of expected seismic ground motion at scale ranging from few Km down to few hundreds of meters (Seismic Microzoning)

This analysis is a basic premise for the identification of the input ground motion to be considered as representative for the local hazard and used to evaluate dynamic response of buildings (the towers) and eventual expected damages

Few years ago, general Guidelines for Seismic Microzoning (ICMS) have been developed on behalf of the Conference of Regional Administrations with the contribution of Academic institutions, Local administrations and Technical Organizations under the coordination of the National Department of Civil Protection of Italy

ICMS identify three level of studies for the seismic microzoning

Level I

It is propaedeutic to the following analyses and is not a true microzoning study. The basic aim is the reconstruction of the **reference geological model**. Fundamental is the use of low cost extensive prospecting tools and of data locally available (drillings, geologic maps from city plans or single building design, etc.).

Most problematic situations are outlined by defining geometries of zones characterized by similar criticalities (**stable zones with expected amplification** of the seismic ground motion and **seismically unstable** zones) and where more detailed analysed are needed, and those (**Stable zones** with no amplification) where no further analyses are requested
No quantification of the expected ground motion and soil instabilities is provided at this level

To this purpose, of major importance is the identification of geological contacts between formations characterized by different mechanical rigidity

Level II and Level III

Represents a very rough preliminary microzoning where a **quantitative** evaluation is provided of effects identified in the first level of analysis

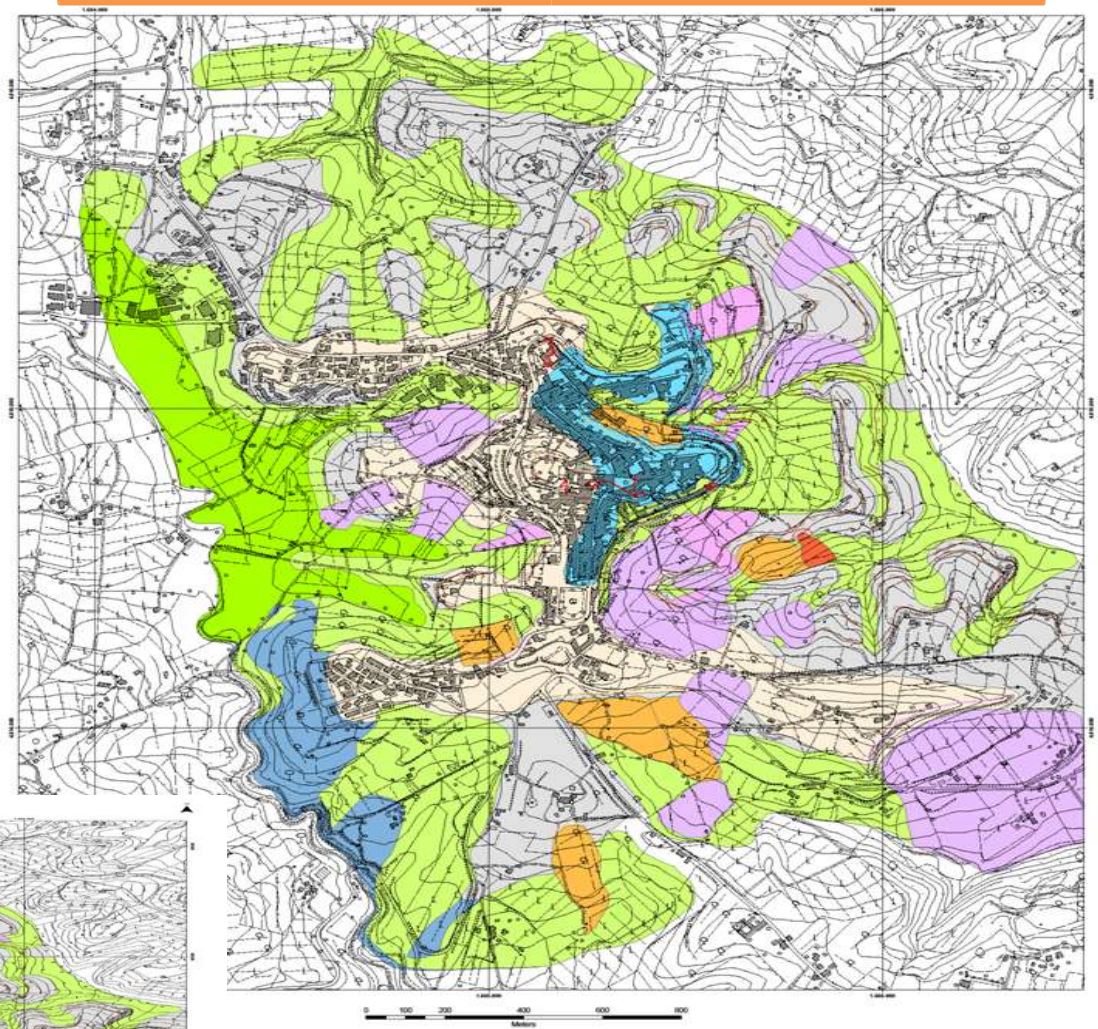
In this analysis new data are acquired by performing on purpose surveys to retrieve information necessary to quantify expected amplification in the different areas or the dimension and probability of ground instabilities induced by eventual earthquakes

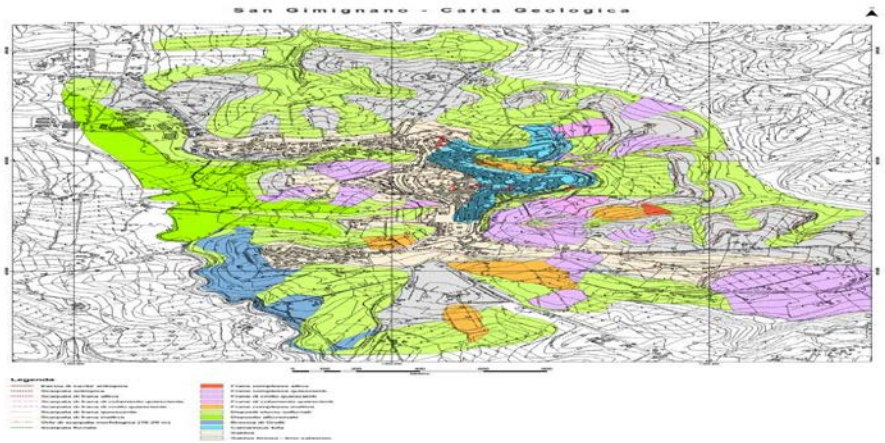
In particular, as concerns ground motion amplification, 1D resonance phenomena are quantified (via **an Amplification Factor - FA**) to identify areas where these effects are potentially more dangerous or areas where more detailed analyses (e.g. 2D or 3D) are requested due to the complexity of the local geomorphological and stratigraphical situation.

These analyses will represent the bulk of the **Level III** analysis, where more complex situations are modelled by acquiring new and more detailed information about the local subsoil (laboratory testing, deep drillings, etc.)

Geological map

A detailed geological survey of the S.Gimignano area was carried on at first





Four main Geological outcrops were identified

Campiglia dell'Elsa Sinthem of (Calcareus Tufa, Pleistocene) => it is a formation characterized by different continental lithofacies. It consists of: white calcareous silt or fine-grained sand intercalated with up to 1 meter thick micritic limestone. Such formation frequently show internal parallel stratifiation and lamination.

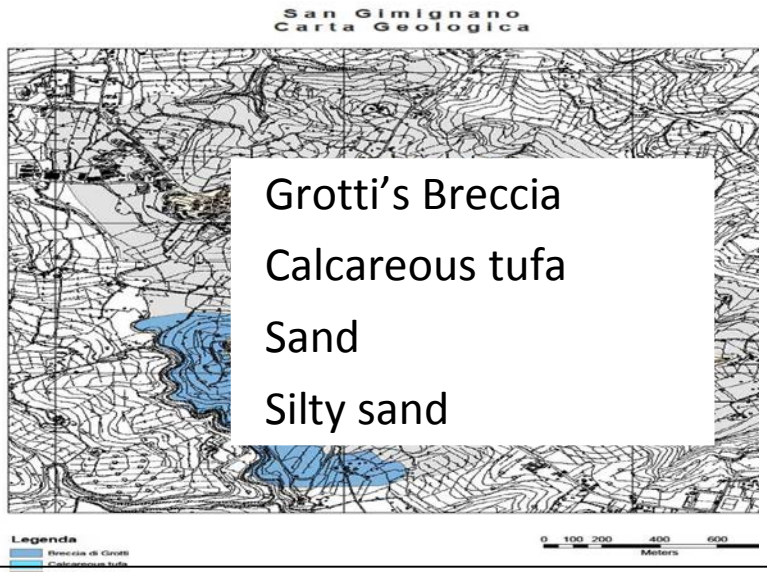
Sabbie di San Vivaldo (San Vivaldo sandstone, Pliocene) => this marine formation is dominantly composed of yellow sandstone (medium – coarse grained) that are often lightly lithified; stratification is lacking due to the pervasive bioturbation.

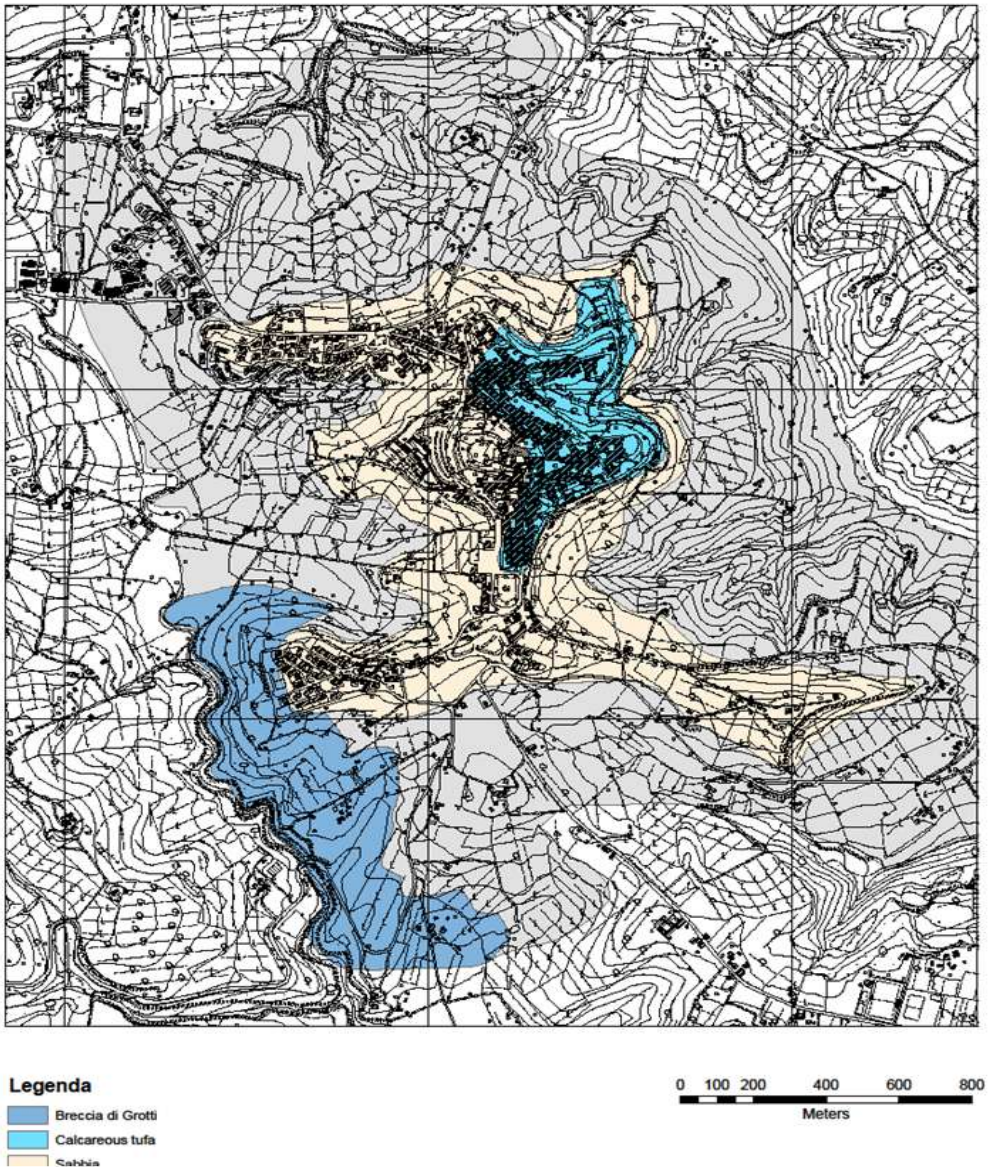
Argille azzurre (silty- and muddy-sand, Pliocene) => this marine formation consists of grey very fine-grained sand and silt. Stratification is lacking and marine molluscs are common within these deposits.

Breccia di Grotti (calcareous breccia, Miocene) => continental formation of clast-supported gravels and debris of carbonate rocks (mainly composed of Calcare Cavernoso Fm.). The clasts range in size between few cm to some dm and are sometimes weathered. Sandy matrix is uncommon and consists of medium-coarse-grained sand.

Lithological map

From the geological map, the outcrops were characterized in terms of lithological properties of the outcrops





A geophysical survey was thus planned to

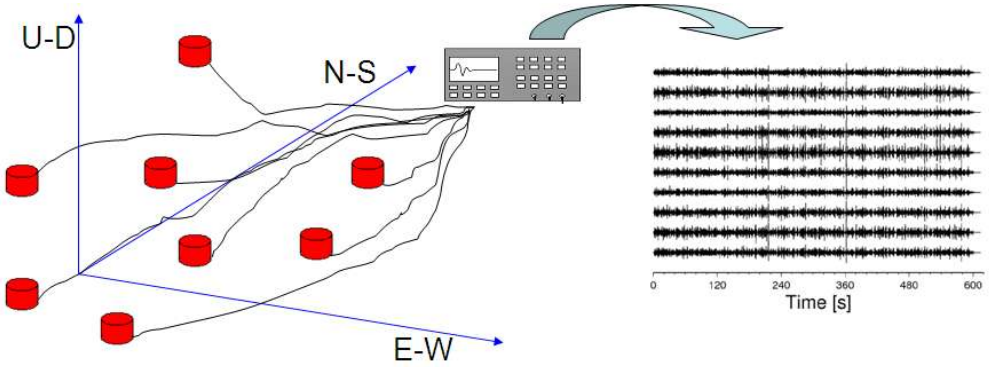
1. *Identify the possible presence of seismic resonance phenomena responsible for amplification of the ground motion in the frequency range of engineering interest*
2. *identify geological contacts corresponding to significant variations of the seismic impedance (Vs contrasts)*
3. *define the buried topography of these contrasts*
4. *identify the seismic bedrock where the reference seismic ground motion has to be applied to estimate the local seismic response via1D numerical modelling*
5. *Indentify areas where 2D/3D modelling of the seismic response in mandatory due to the peculiar subsoil configuration*

To this purpose, the considered methodology had to be characterized by relatively low costs (per unit volume of the subsoil explored), large penetration (up to hundreds of meters), low occupancy and invasivity

The monitoring of ambient vibrations (in single and multi station configurations) was considered on purpose

Single station ambient vibration measurements (**HVSR technique**) allows detection of **resonance phenomena** of potential engineering interest and constrain (very roughly) the **depth of velocity contrasts** responsible for this phenomenon

Array ambient vibration measurements (**ESAC technique**) allows the retrieval of the Rayleigh wave dispersion curves that, jointly with HVSR data can be inverted to retrieve the local **Vs profile** up to several hundreds of meters of depth



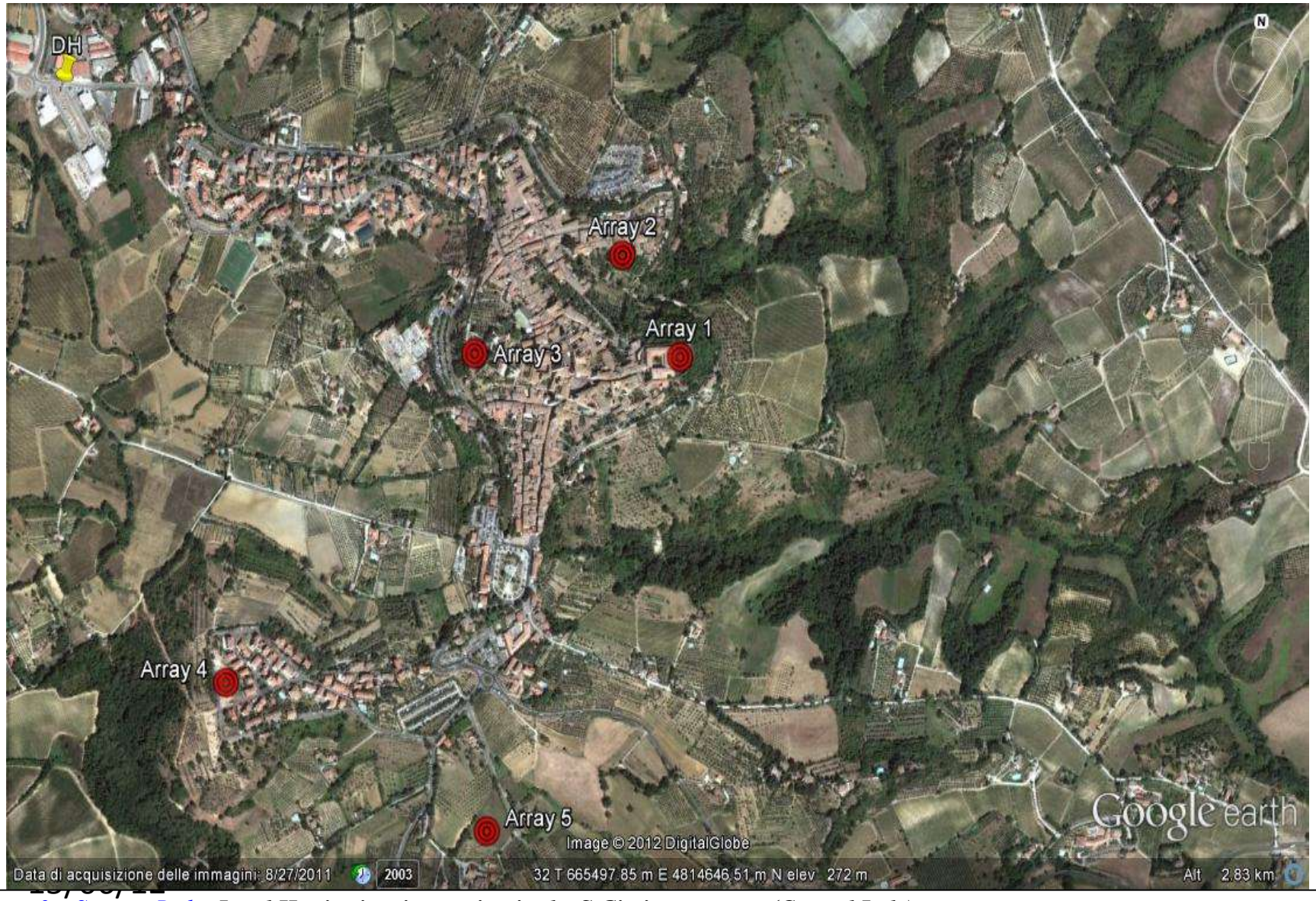
HVSR measurements

Legenda

- <1 Hz
- 1 - 2 Hz
- 2 - 4 Hz
- 4 - 8 Hz
- >8 Hz
- no peak

f_0 (Hz)	h (m)
< 1	> 100
$1 - 2$	$50 - 100$
$2 - 3$	$30 - 50$
$3 - 5$	$20 - 30$
$5 - 8$	$10 - 20$
$8 - 20$	$5 - 10$
> 20	< 5

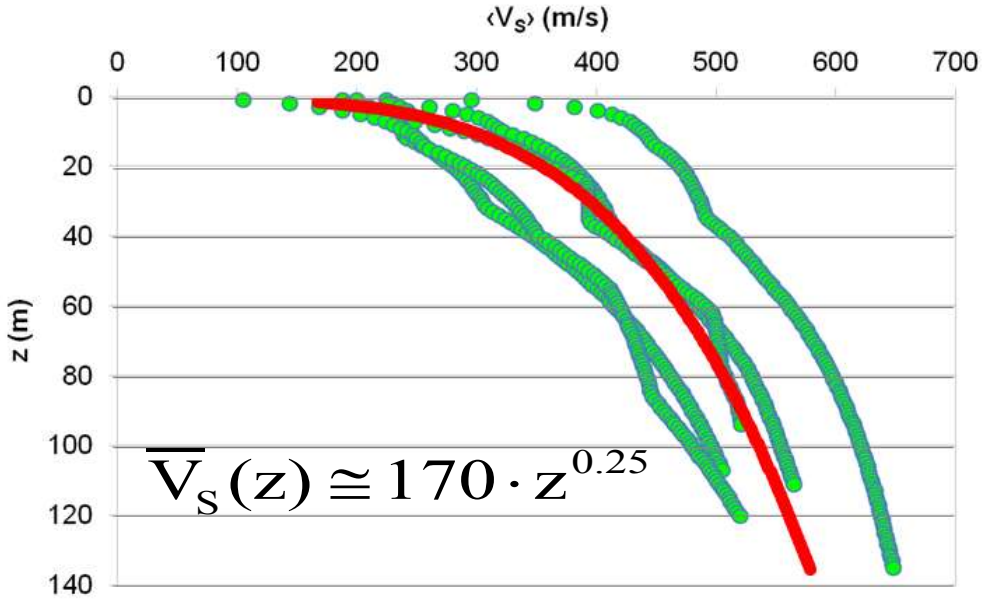
Array measurements



By jointly inverting HVSR and ASAC results, Vs profiles were determined form each array

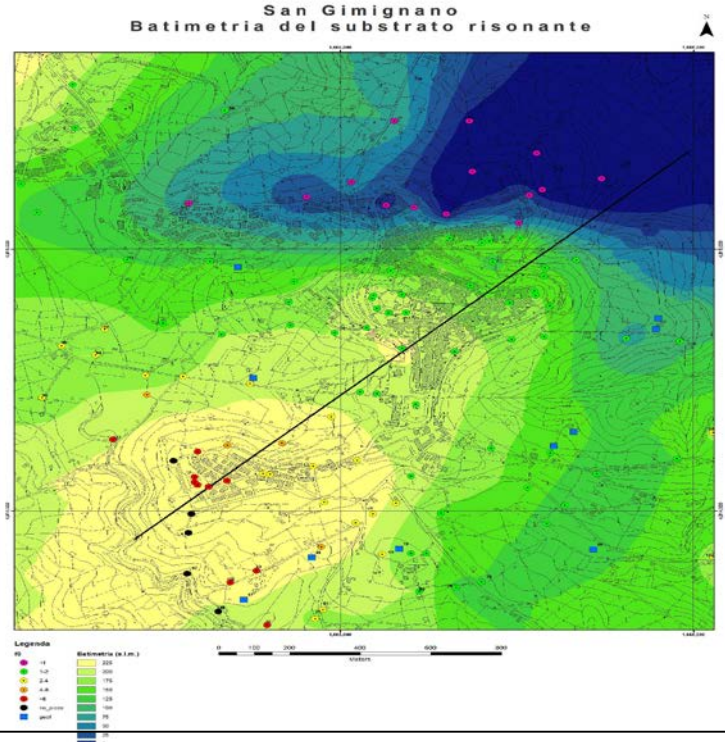
These velocity profiles can be used to infer the depth of the resonant layer under each HVSR measurement point

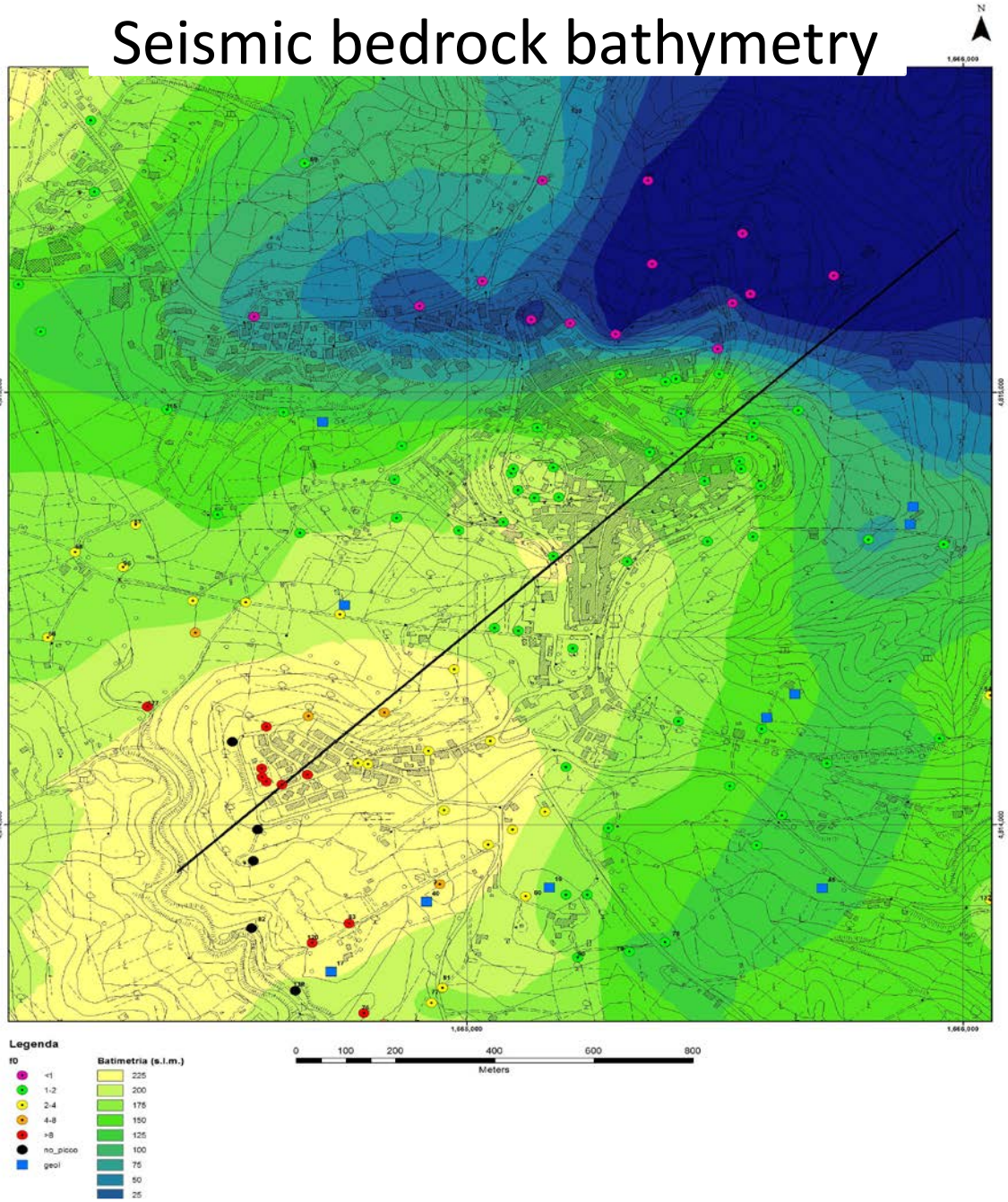
To this purpose, and the pattern of average VH values as a function of the depth H has to be determined in the form of a power law. This can be used to establish a simple relationship between the resonance frequency and the depth of the resonant layer



$$H \approx A\, v^{B}$$

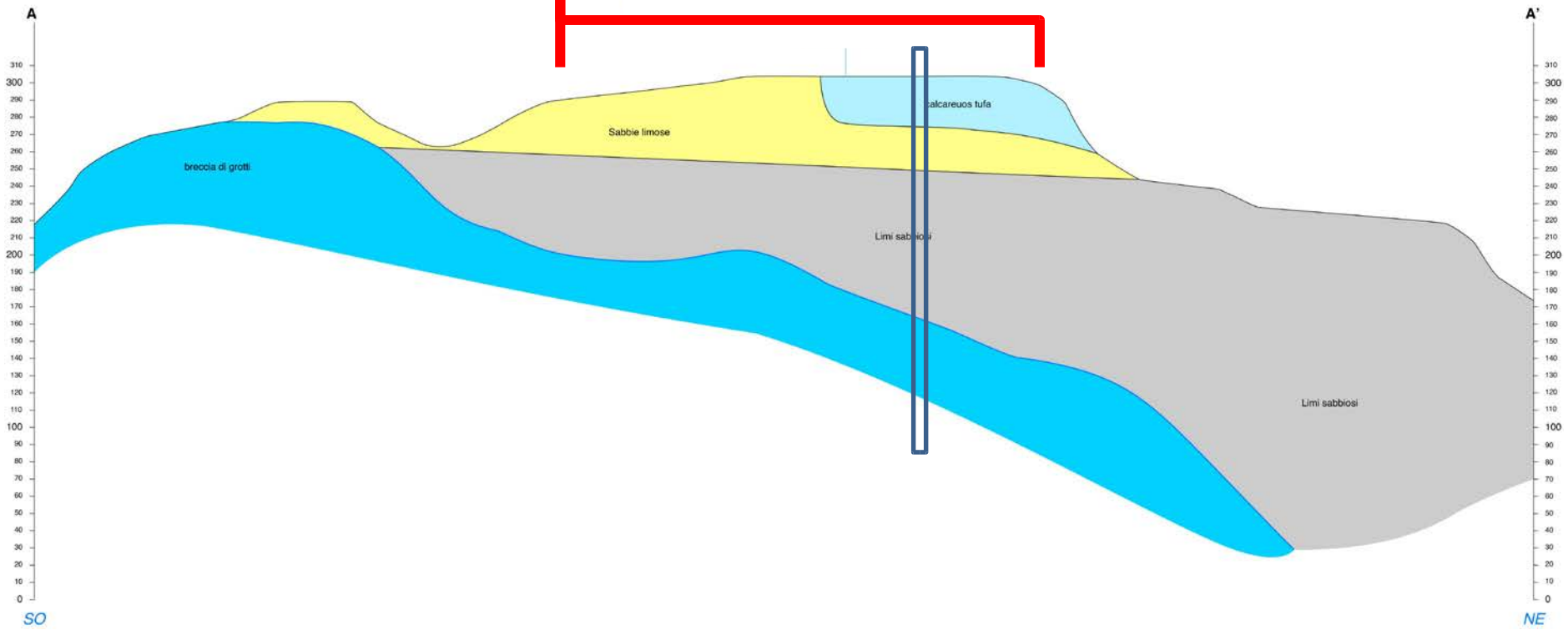
Seismic bedrock bathymetry





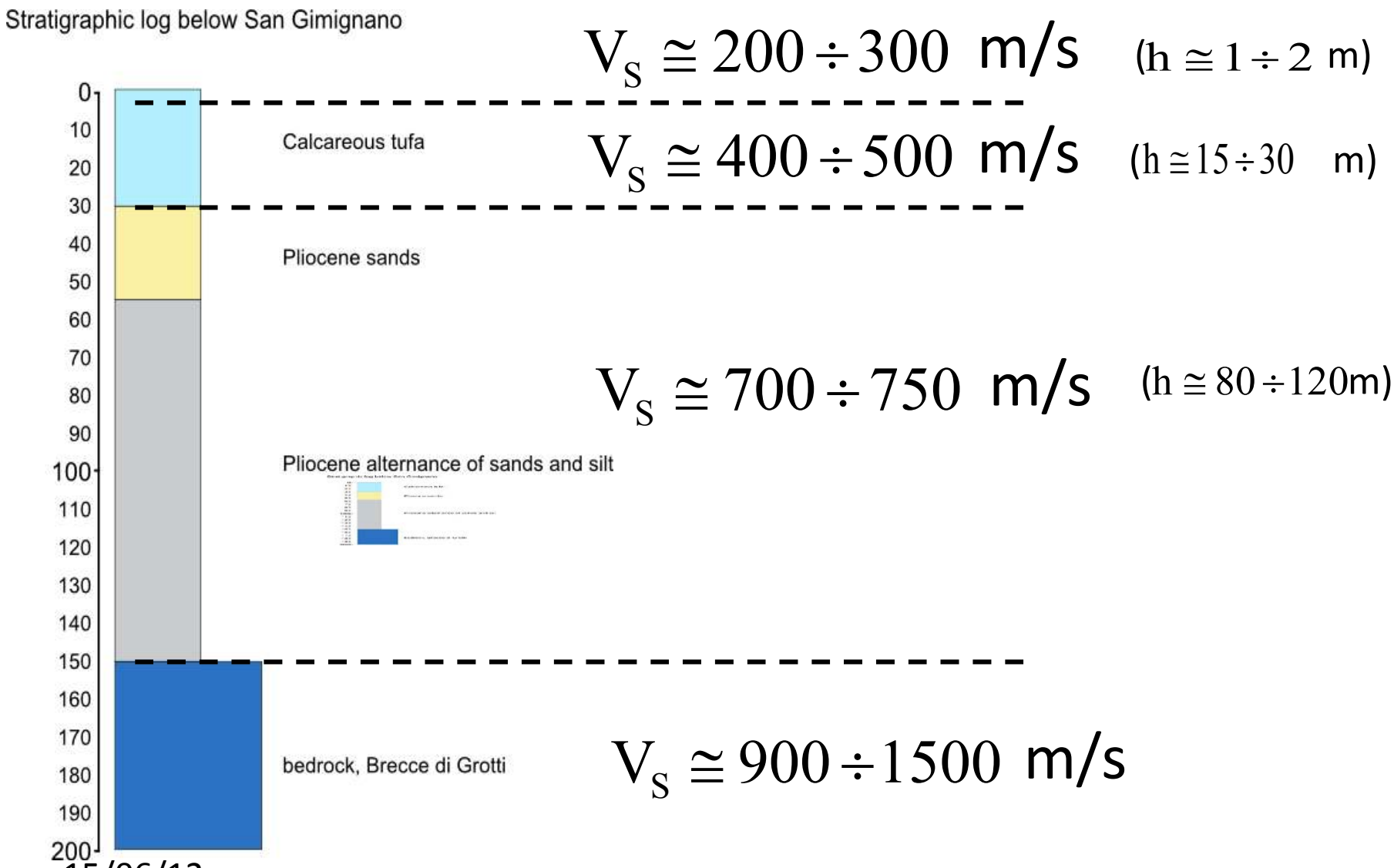
Geological cross section

San Gimignano hamlet

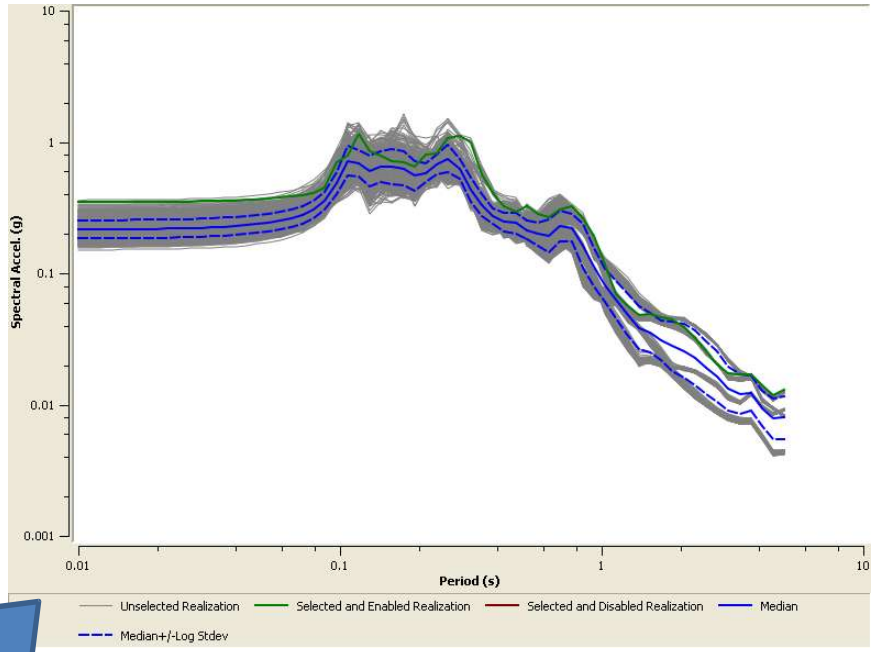


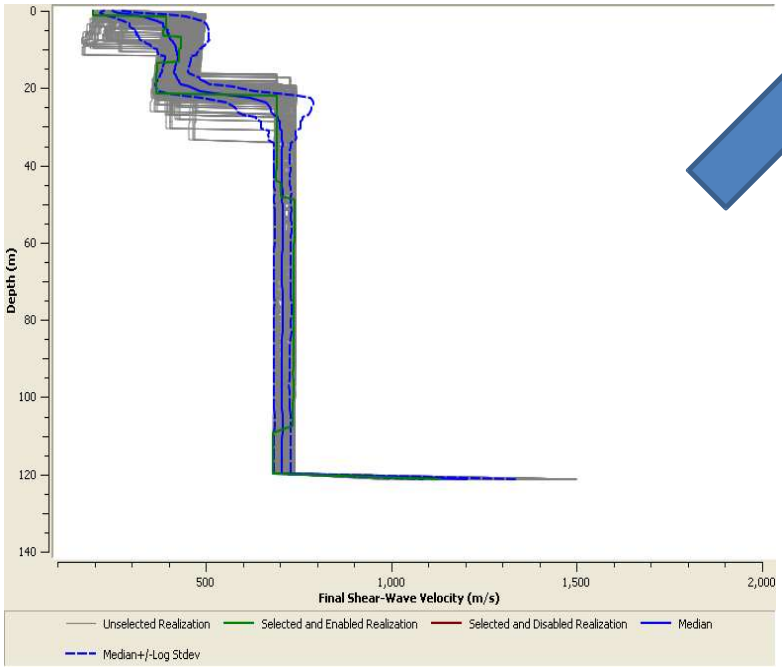
SW NE

Representative Vs profile under the hamlet



Rough estimate of the amplification factor (FA) at S.Gimignano





FA50% = 1.6

FA75% = 1.8

Conclusion

Recent Italian guidelines for seismic microzoning have been applied to the area of S.Gimignano (Central Italy)

Results obtained show that interesting ad useful indications can be obtained with relatively low costs by a full exploitation of available information, a careful geological survey of the area and by the use of low-cost exploratory geophysical prospecting tools

This allowed to elaborate a geological model of the study area in the perspective of a characterization of the local seismic hazard assessment