SEISMOTECTONICS STUDY OF THE VALLE UMBRA AREA AT DIFFERENT SPACE AND TIME SCALES: AN INTEGRATION OF GEOMORPHOLOGICAL, GEOPHYSICAL AND REMOTE SENSING DATA

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The Valle Umbra is a NW-SE 20 km long and 10 km wide Quaternary alluvial basin located in the internal sector of the **active extensional tectonic Apennine chain**, central Italy.

This area **historically suffered major earthquakes** such as in 1832 (ME=6.3; I0=X) and 1854 (Me=5.6; I=VIII), both localized in the valley. It was marginally affected by the seismic event localized in the Colfiorito basin (M 6.0; September 1997) and more recently suffered from damages to buildings caused by the last seismic sequence of Amatrice-Visso-Norcia (main shock, Norcia, PG, Mw 6.5, 30 October 2016).

We investigate the presence of active segments that may be hidden under the unconsolidated deposits filling the basin.

We integrate **single station ambient noise** measurements with previously acquired **seismic reflection data and surface geology** in order to **reconstruct the subsurface geometry of the basin and localize buried faults**.

Preliminary results from the **ambient noise spectral ratios** show, in general, one resonance peak at around 0.8 - 1 Hz for stations installed on the lower Pleistocene deposits overlapping the Miocenic bedrock and two resonance peaks for stations installed in the alluvial infill deposits in the central portion of the valley.

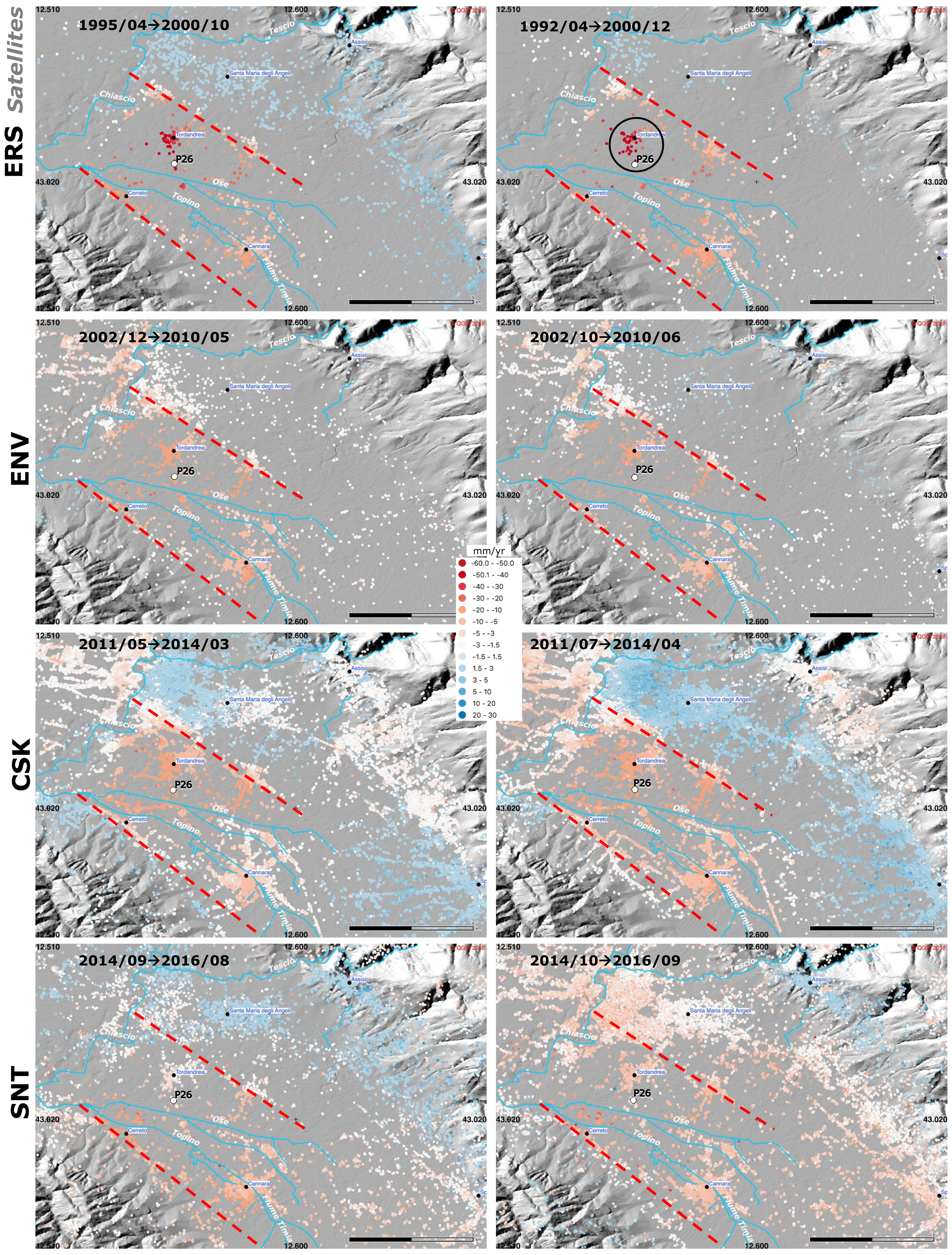
An **accelerometric station** of the national civil protection provided us additional constraints about the level of amplification of the site, (connected to the presence of impedance contrasts in the subsoil) as recovered by spectral ratio analysis of several earthquakes recorded from the 1986 up to date.

Moreover, **the availability of more than 20 years of SAR data archives** for the studied area, allowed us the observation of a **differential ground subsidence**, detected by means of the application of Differential InSAR techniques. The subsidence can be due to either **human induced aquifers withdrawal** or **to tectonic of the area**, and we interpret that these can be co-responsible for the observed subsidence pattern.

Through the correlation of the time-series of observed recent ground deformations with the buried geological structures identified using geophysical techniques, we made an attempt of detecting and characterizing the geologic heterogeneities in the subsurface, defining the geometry and kinematics of the buried faults and eventually addressing the seismogenic potential of the area.

InSAR Ground Velocity Maps

Fig 2



Ground velocities (mm/yr) measured for coherent points toward to -and away from- the four satellites during ascending or descending orbits between 1993 and 2016. In the upper left side of each map the first and last date of data acquisitions for each satellite/orbit. ***Red dashed lines*** *are the limits of ground deformations and can be referred to the upper part of buried faults (Fig). The black circle locate Tordandrea area and the water well P26.*

InSAR time series

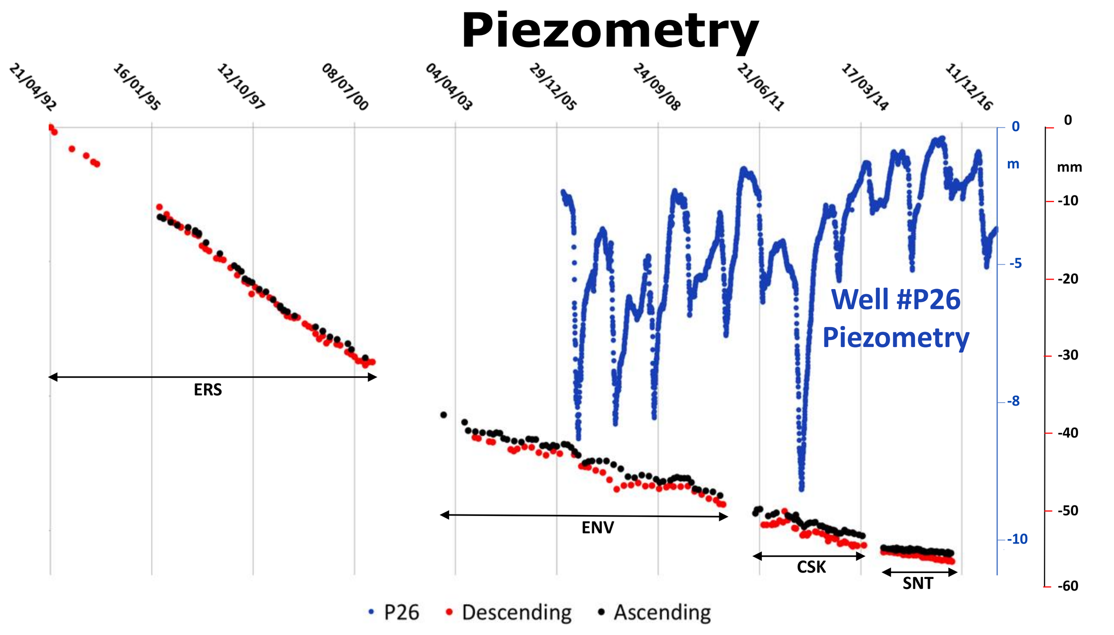
Satellites / Orbits	Ascending	Descending
ERS	199504-200010 (35)	199204-200012 (56)
ENV	200212-201005 (51)	200210-201006 (37)
CSK	201105-201403 (40)	201107-201404 (30)
SNT	201409-201608 (48)	201410-201609 (42)

Time interval *(yyyymm) and* ***number of acquisitions over the study area*** *of four satellites of the European Space Agency (ESA) and Agenzia Spaziale Italiana (ASI)*

- ***ERS****: European Remote Sensing (ESA)*
- ***ENV****: Environmental Satellite (ESA)*
- ***CSK****: COSMO-SkyMed [COnstellation of small Satellites for Mediterranean basin Observation] (ASI)*
- ***SNT****: Sentinel-1 (ESA)*

Fig 3

Ground Displacements and Piezometry



Averaged vertical ground displacements (Redmeasured between 1993 and 2016 in the Tordandrea area using SAR data acquired by the satellites ERS1-2, Envisat, COSMO-SkyMed and Sentinel-1 compared to water levels in the P26 well.

RED *and* ***BLACK*** *dots are the displacement measured in the ascending and descending orbits respectively. Displacements are in mm (black bar on the right) while piezometries are expressed in meters (blue bar).*

BLUE *dots are the well P26 piezometry south of the Tordandrea area.*

Satellites and Subsidence

- Satellite measurement shows the **gradual sinking of the valley ground surface** in a predominantly **vertical direction** in the Tordandrea wells area;
- **Subsidence** shows **inverse relationship** with **piezometric** level;
- Subsidence seams to be driven by the **morphology of the bedrock hidden by valley deposits.**

Open question: does the geometries of the subsidence highlight the shape of hidden structures?

Fig 1

Historical Earthquakes

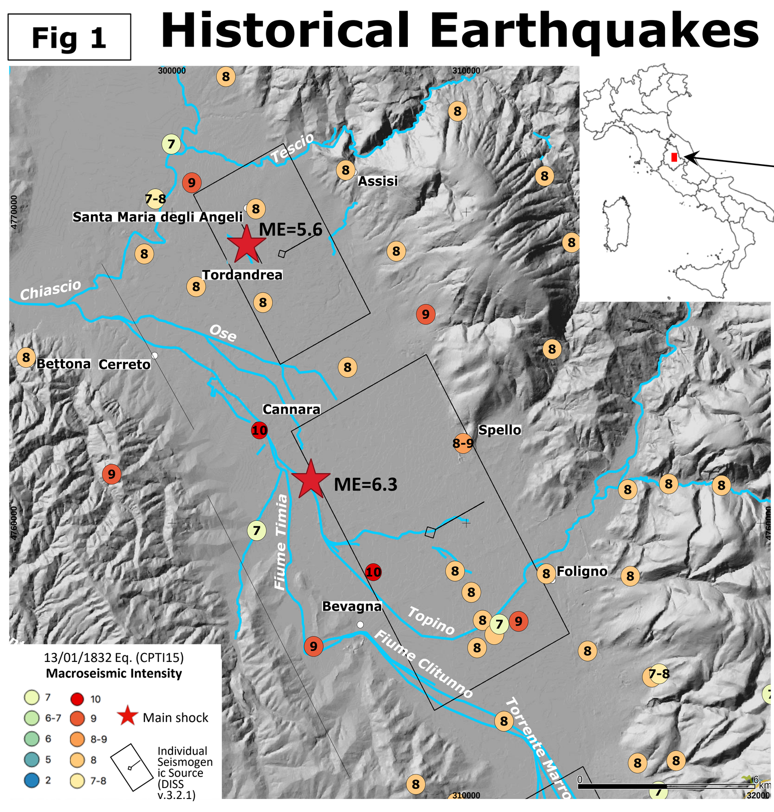
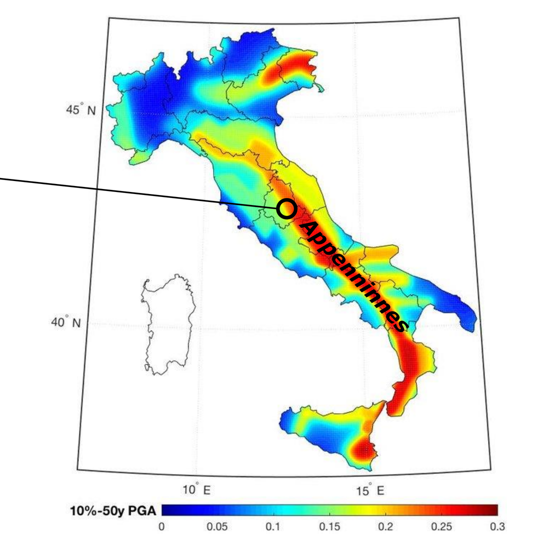
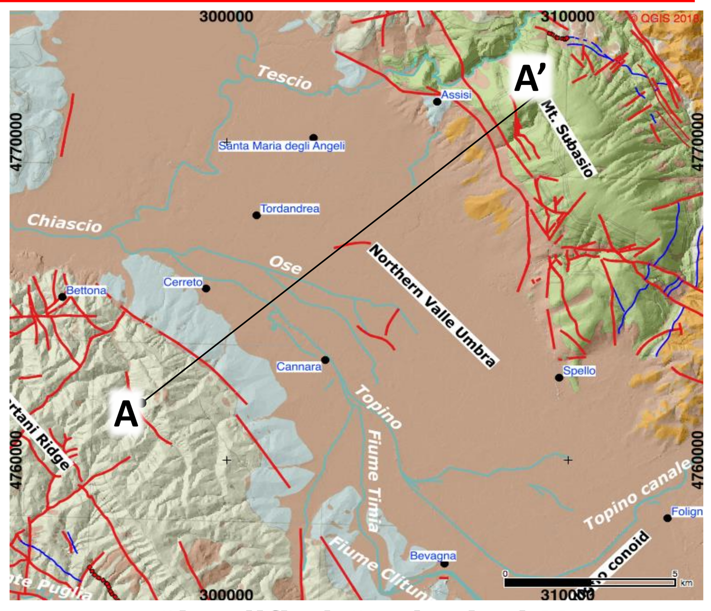


Fig. 1 *Macroseismic effects of the 13 January 1832 earthquake [CPTI15-DBMI15] and local Individual Seismogenic Sources (DISS 3.2.1)*

The *Valle Umbra* is located in Central Italy between the Foligno and Perugia towns, experienced two major earthquakes in the 19th century.
The 13 January 1832 ME=6.3; I0=X : On 27 October 1831 started a long sequence culminating with 13 January the 1832 earthquake
On **12 February 1854** another seismic sequence interested the Northern part of the Umbra Valley (**ME=5.6; I0=VII**)



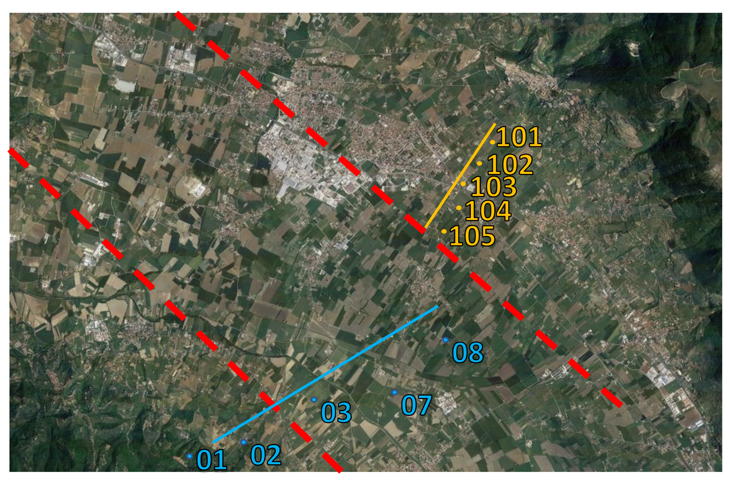
Seismic hazard map *for Italy in terms of 10%-50y PGA (http://esse1-gis.mi.ingv.it). The highest seismicity is concentrated along the Apennine ridge (coincident with the the red «band»), in Calabria and Sicily and in some northern areas, like Friuli, part of Veneto and western Liguria. The black circle indicate the Valle Umbra location.*



Simplified Geological Map of the Valle Umbra

- Normal Fault
- Thrust
- Alluvial and fluvial deposits (Upper Pleist.-Holoc.)
- Umbria-Marche stratigraphic sequence (Cret.-Oligoc.)
- Umbria Turbidites (Early-Middle Miocene)
- Umbria-Romagna Turbidites (Mid.Late Mio. to Mid.Plio)
- Bevagna Unit (Early Pleistocene)

HVNSR Transects



Red dashed lines are the limits of the subsidences (see InSAR velocity maps); blue and yellow points are the location of Seismic station sites.

Geophysical techniques

Geophysical techniques are useful tools to investigate the **trend of the main geological units hidden below the quaternary deposits** in the valley.
A campaign of single station noise measurements was performed to detect the main impedance contrasts.
Seismic stations (blue and orange dots in **Fig.4**) has been deployed mainly **perpendicularly to the elongation of the valley** to follow the trend of the hidden geometries.
Recorded seismic signals processed with the **Noise Spectral Ratios Technique**.

Noise Spectral Ratios Technique (HVNSR)

Noise spectral ratios (HVNSR) curves were computed at each site using a moving window of 40s long to select data to analyse after applying an anti trigger algorithm to remove short transients in the recordings.
For the time windows selected, the mean and the trend was removed, the Fourier spectra was calculated and smoothed using a Konno and Ohmachi filter (Konno & Ohmachi 1998). The two horizontal spectra were geometrically averaged and divided by the spectrum of the vertical component. The results for each window selected were statistically combined to obtain the mean and standard deviation of the spectral ratios curves.

Spectral ratios show a main difference between the SW and the NE sides of the transect A-A' (see the "Simplified Geological Map").
Blue transect in **Fig.4** (from SW to NE, from **#1** to **#7**): once abandoned the outcropping Umbria Turbidites formation, the HVNSR of **Fig.5**, exhibit two sharp resonance peaks ascribable to the two impedance contrasts: the top of the Bevagna Unit interface and the Umbria Turbidites formation interface. Furthermore **#8** curve has only one low frequency peak which can suggest the absence of the Bevagna Unit.

Orange transect in **Fig.4** (from NE to SW, from **#101** to **#105**): from the middle valley towards the outcropping Umbria-Marche stratigraphic sequence, shows one broad amplification at frequencies below 1 Hz (**Fig.6**). This could be due to the presence of a shallow alluvial fan as reported the Regione Umbria 1:10.000 geological map of the area.

This geological element can represent a velocity inversion in the subsoil velocity profile of the NEsternmost portion of the valley affecting the seismic response of the area smoothing the shape of resonance peaks.

Fig.5

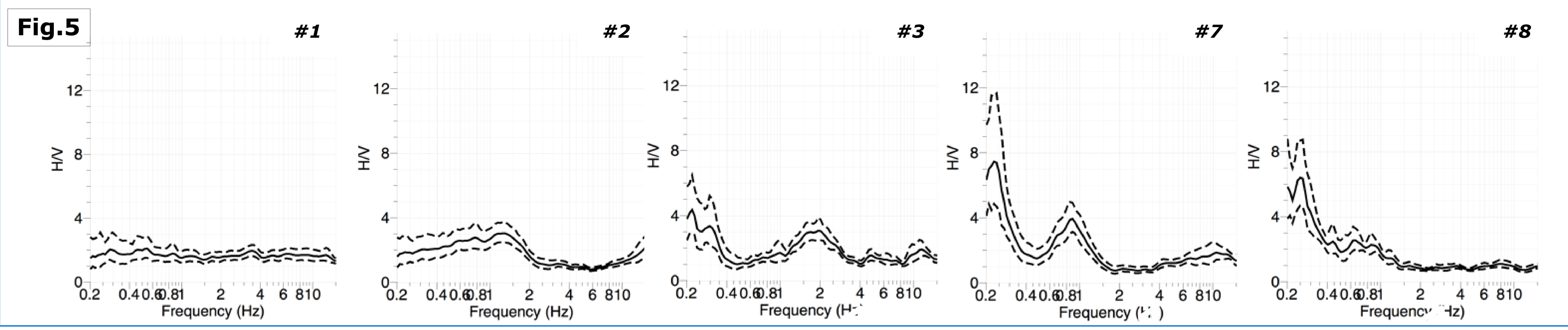
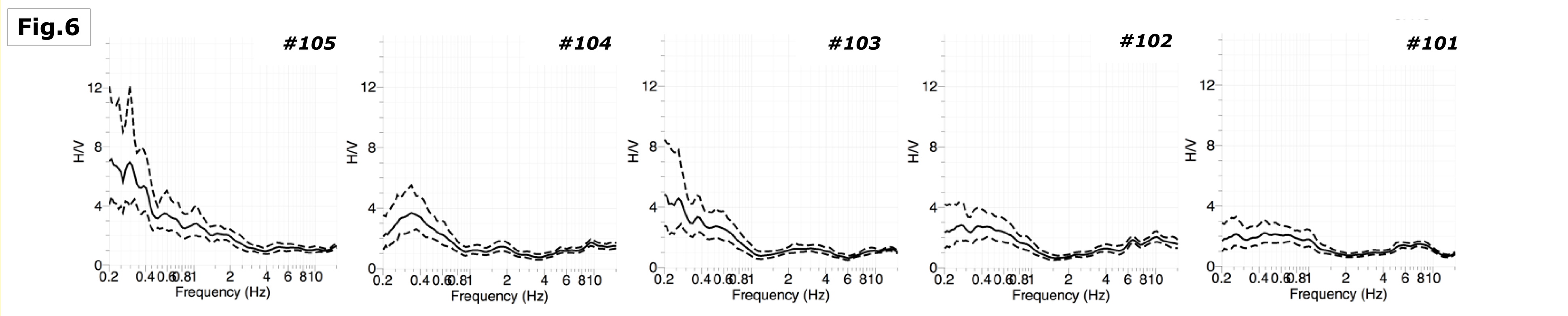


Fig.6



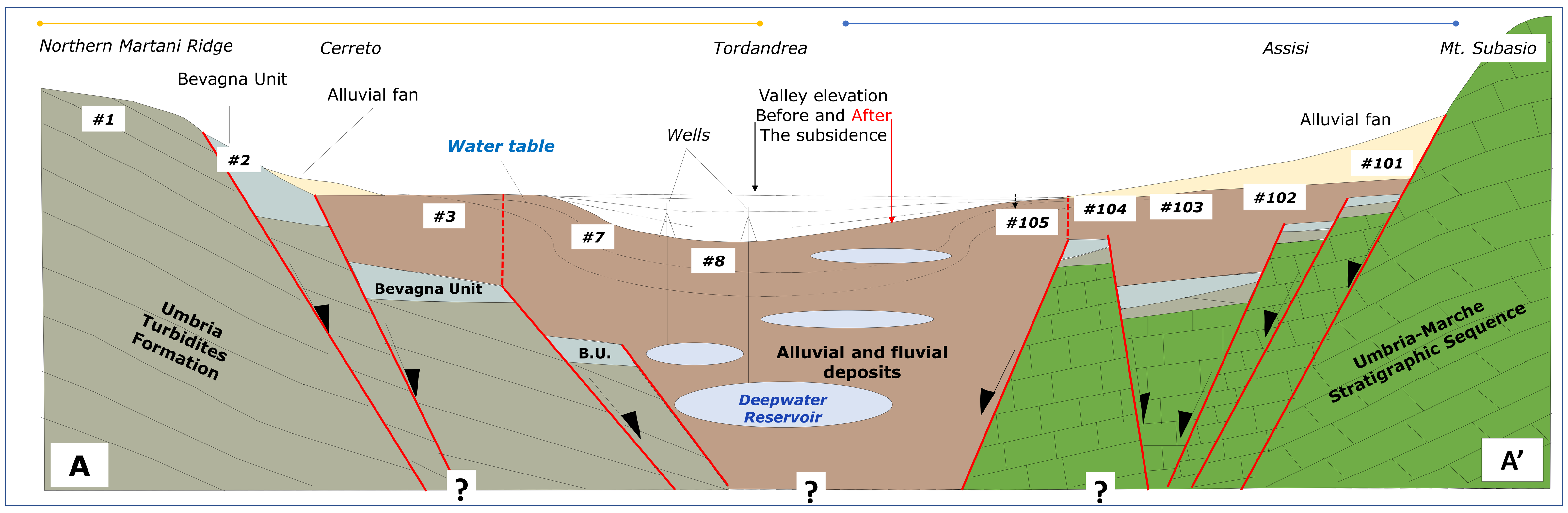


Fig.7 ***Schematic Geological profile out of scale*** *(A-A' profile on the geologic map). In the Tordandrea area the intense pumping of water from the deep reservoirs induced ground subsidence due to the compaction of recent deposits filling the valley. The geometry of the subsidence probably highlights the position of buried tectonic structures. The hidden faults can drive the shallow vertical displacements (****Yellow*** *and* ***Blue*** *lines are the profiles of Fig. 4* ***B.U. – Bevagna Unit; Red*** *dashed lines are the projection toward the surface of the buried faults)*

Data Interpretation

Preliminary considerations about the thickness of deposits in the lights of **HVNSR** results and the geological setting suggest a **high depth of the top of the geological bedrock (> 500m)** as highlighted in Barchi et al. 2015 from the interpretation of seismic reflection profiles performed in the southernmost part of the Valle Umbra.

The trend of the fundamental resonance frequency observed along the transect suggest a **graben structure with two main faults systems with an important vertical throw bordering the two edges of the valley**.

From the first interpretation of our results (**Fig 7**), we can't exclude the presence of horst structures under the valley; this kind of bedrock organization can be **responsible for the distribution of the observed subsidence detected using InSAR techniques.**

To describe more precisely the geology of the valley and in general to better constrain the lateral distribution of geological features, further geophysical measurements as seismic reflection profiles, seismic arrays and other single station noise measurements are required.