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Site characterization report at the seismic station IV.LNSS – Leonessa (RI)

Report di caratterizzazione di sito presso la stazione sismica IV.LNSS – Leonessa (RI)

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Subject: **Final report illustrating the site characterization for seismic station IV.LNSS**	

Convenzione DPC-INGV 2019-21, All.B2- OB1, Task B: "Caratterizzazione siti accelerometrici" (Coord.: G.Cultrera, F. Pacor)
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INTRODUCTION

In this report we present the geological setting and the geophysical measurements and results obtained in the framework of the 2019-2021 agreement between INGV and DPC, called *Allegato B2: Obiettivo 1 - TASK 2: Caratterizzazione siti accelerometrici (Responsabili: G. Cultrera, F. Pacor)* for the site characterization of station IV.LNSS (Leonessa).

Location and coordinates are reported in Table 1.

Table 1.

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IV.LNSS	Leonessa (RI)	42.60286*	13.04032*	1102**
ADDRESS	Località Pianezza, 15, 02016 Pianezza RI, Italy			

* Coordinates from ITACA (Nov. 2019) **Elevation from CTR 5k Regione Lazio

A. Geological setting

A1. TOPOGRAPHIC AND GEOLOGICAL INFORMATION

Topographic information related to the site are reported in Table 2. Table 3 summarizes all available geological maps from literature for geological analyses.

Table 2.

Topography	Description	Topography Class	Morphology Class	EC8 Class
	Flat top of isolated relief with slope i<=15°	T1	R*	A

*Reference table from ITACA (Nov. 2019)

Table 3.

Geological map	Source	Scale
IV.LNSS	Geological map of Italy sheets 139 (L'Aquila)	1:100.000
IV.LNSS	Geological-technical map Seismic Microzonation	1:5.000

In Table 4 Geological and Lithotechnical Units (according to Seismic Microzonation classification; Technical Commission SM, 2015) are described and are concerned to maps of following chapters. The term “original” means the result comes from a preexisting cartography (Table 3); the term “deduced” means the result comes from an interpretation of a preexisting cartography according to the nomenclature of corresponding cartography.

Table 4.

GEOLOGICAL UNITS		**LITHOTECHNICAL UNITS**	
Geological map of Italy 1:50.000		(MZS) *deduced*	
code	**description**	**code**	**description**
b2	Eluvial-colluvial cover	CLec	Clay, sandy or gravelly clay, silty clay (eluvial-colluvial)
e	Lake and marsh deposits	CLfI	Clay, sandy or gravelly clay, silty clay (lake fluvio deposit)
SAA	Scaglia Bianca Formation (fine grain, white micritic limestone with black and white and reddish flint layers)	LPS	Geologic substratum layered stone rocks
FUC	Marne a Fucoidi Formation (Gray, light green and reddish layered marl, carbonate marl and clayey marl)	SFALS	Geologic substratum rock-type alternations, layered, fractured rocks
MAI	Maiolica Formation (fine grain, white micritic limestone with grayish flint layers	LPS	Geologic substratum layered stone rocks
		SFLPS	Geologic substratum layered stone rocks fractured

A2. GEOLOGICAL MAP

In Figure 1 Geological Map is reported in a 1kmx1Km square around the station.

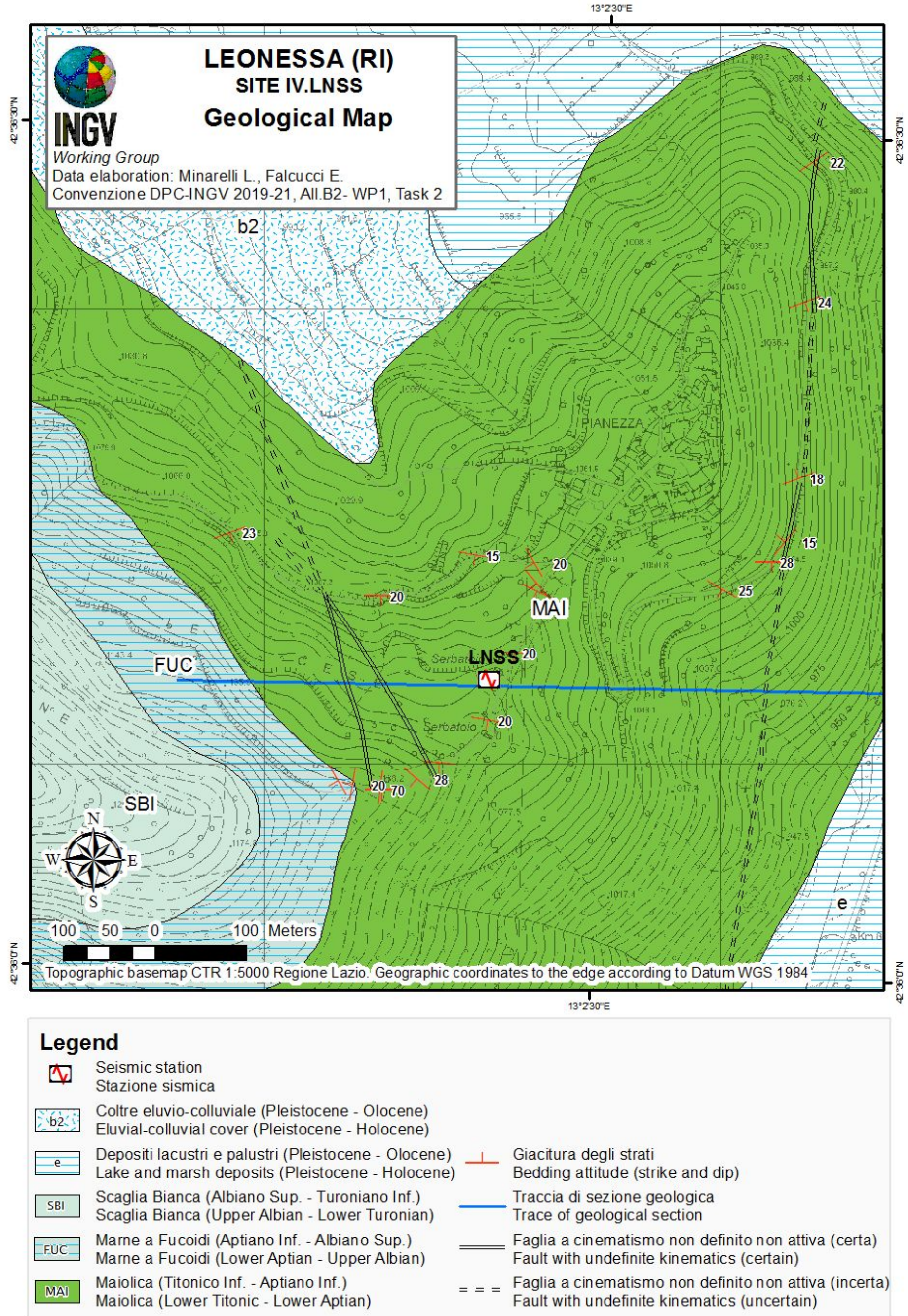

Figure 1. Geological map of seismic station site IV.LNSS. Scale 1:5.000. Geological units are mapped according to the nomenclature of geological map of geological map of Italy 1:50.000

A3. LITHOTECHNICAL MAP

In Figure 2 Lithotechnical Map is reported in a 1kmx1Km square around the station.

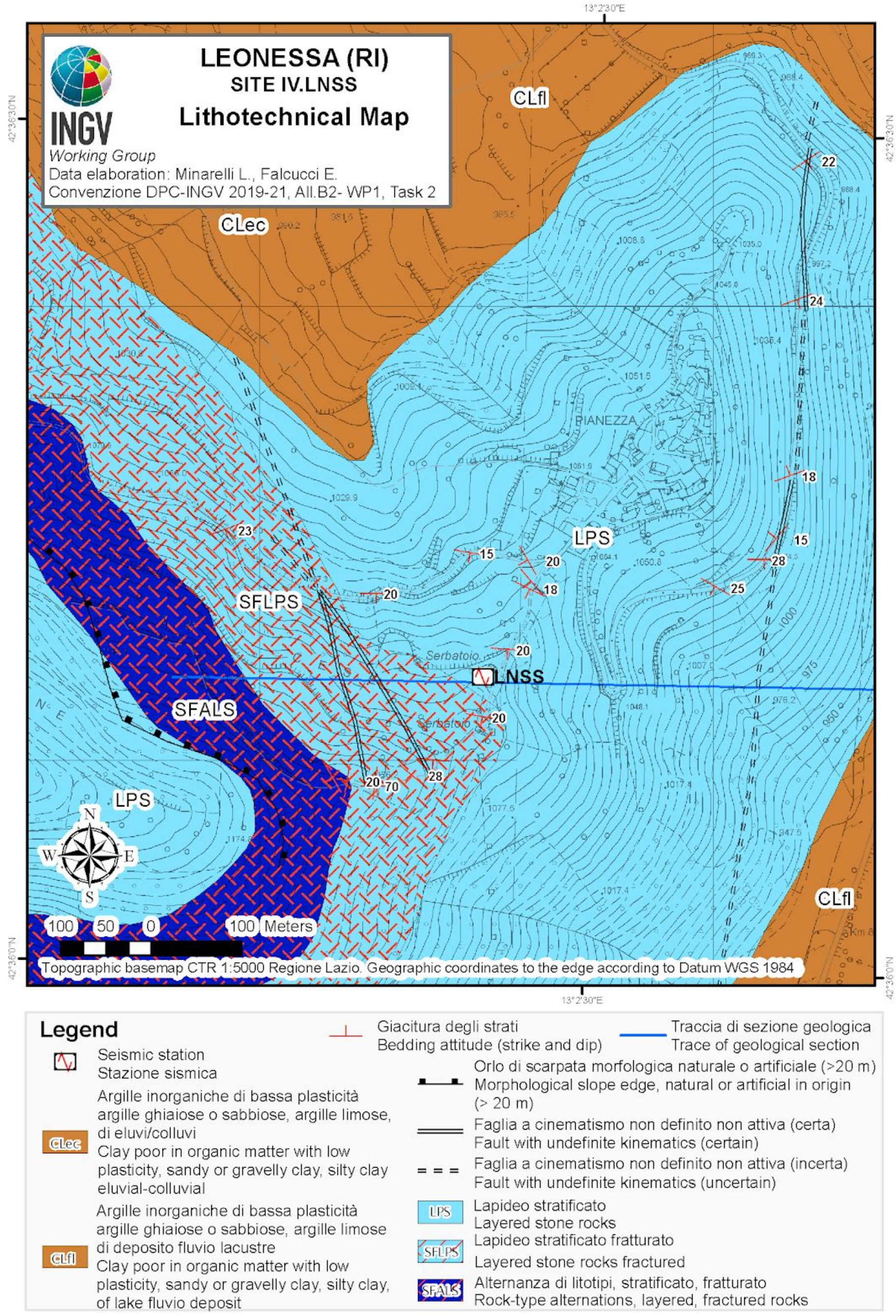

Figure 2. Lithotechnical map of the seismic station site IV.LNSS. Scale 1:5.000. The lithotechnical units are attributed according to the nomenclature of Seismic Microzonation study (Technical Commission MS, 2015).

A4. SURVEY MAP

Figure 3 shows the Survey Map reporting both previous investigations and geophysical surveys conducted by INGV Working Group.

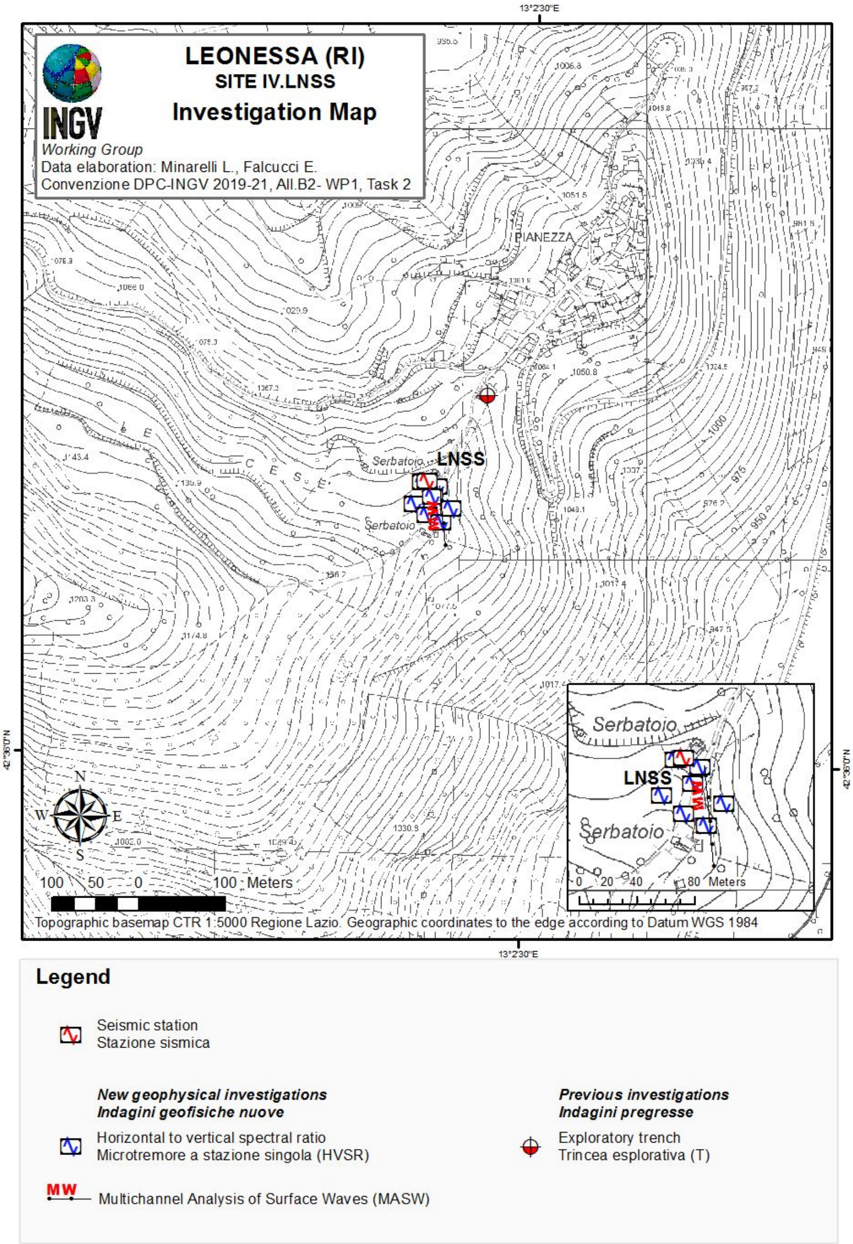

Figure 3. Map of the geophysical surveys made in the sectors around the seismic station IV LNSS. Scale 1: 5.000. The box at the bottom right contains a zoom of the area with the detail of the geophysical investigation conducted by INGV Working Group for the seismic characterization of the site (Convenzione DPC-INGV 2019-21, Allegato B2-WP1, Task B, Velocity profile at the seismic station report IV.LNSS).

A5. GEOLOGICAL MODEL

5.1 General description

The seismic station is located within the Leonessa basin, an intermontane depression located about 20 km NNE of the town of Rieti, in northern Latium. The basin is surrounded by central Apennine reliefs, namely by the Terminillo Massif to the south, Mt. Tolentino to the north, and Mt. Boragine to the east.

The SW margin of the Leonessa depression is affected by a WNW-ESE striking and NNE dipping normal fault (e.g. Cello et al., 1997; Michetti and Serva, 1990), whose recent activity is still a matter of debate (e.g. Fubelli et al., 2009).

The mountain reliefs surrounding the basin are made of the Meso-Cenozoic marine carbonate sequences of the Umbria–Marche succession (Lotti and Crema,1927); the depression is filled by Plio-Quaternary continental depositional sequence (e.g. Fubelli et al., 2008) here briefly described (Figure.4). The sedimentary sequence comprises some synthems. The oldest one, detected only by drilling, is made of clayey-sandy-gravelly sediments related to a lacustrine/braided-plain continental environment, referred to the Early Pleistocene. The overlying synthem, related to the upper part of the Early Pleistocene-lower part of the Middle Pleistocene, is exposed in the basins and is made of *i*) alluvial fan deposits (gravel and sand), mostly outcropping in the central-western sector of the basin, and of *ii*) lacustrine deposits (clay and silt) exposed in the eastern sector of the basin. The latest synthem unconformably overlays the older ones; it is represented by reddish sand and clayey-sand with abundant reworked volcanic material. The central part of the basin shows a deep fluvial incision related to the Tascino Creek fluvial system, the presently rules the hydrographic network of the basin. Two orders of fluvial terraces are found along the flanks of the Tascino Creek incision (Fubelli et al., 2008).

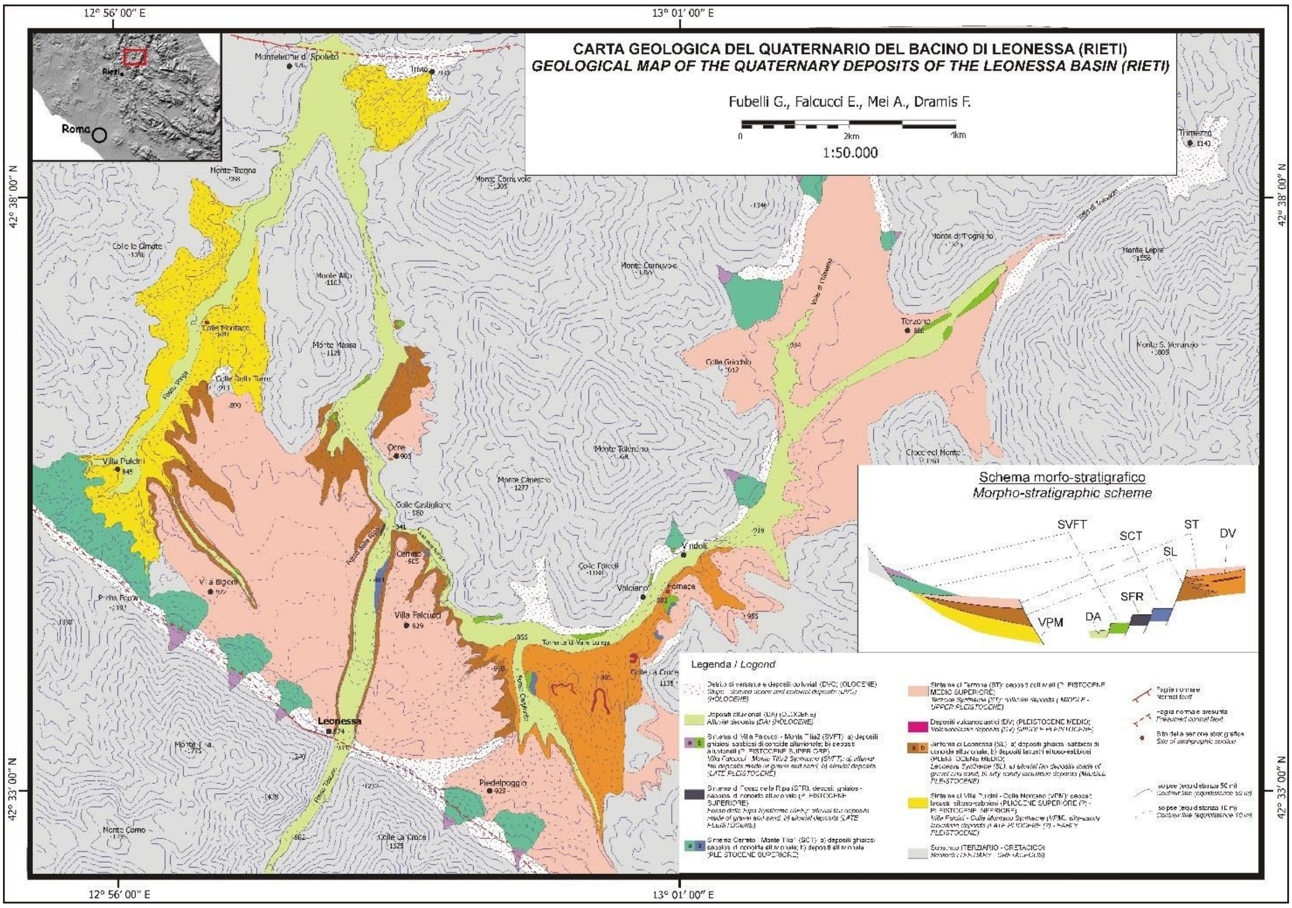

Figure 4. Geological map of the Quaternary deposits of the Leonessa basin with the morpho-stratigraphic scheme (Fubelli et al., 2008).

5.2 Geological Section

The seismic station is located in the vicinity of the Pianezza Village, on top of a small relief roughly N-S oriented, in the NE sector of the Leonessa basin. The geological cross-section (indicated as A-A' in Figure. 5) shows the deep geological and structural setting of the study area. The section, traced across the seismic station site, roughly E-W trending, is based on the information derived from the Geological map of Italy sheet N139 L'Aquila (scale 1:100.000), the Geological and Technical map made for Seismic Microzonation studies and on new data acquired by means of geological field surveys and geotechnical and geophysical investigations. The seismic station is localized on a monoclinal structure made of above mentioned marine Meso-Cenozoic carbonate Umbria-Marche succession constituted by

Scaglia Bianca Formation (fine grain, white micritic limestone with black and white and reddish flint layers), Marne a Fucoidi Formation (Gray, light green and reddish layered marl, carbonate marl and clayey marl) and Maiolica Formation (fine grain, white micritic limestone with grayish flint layers).

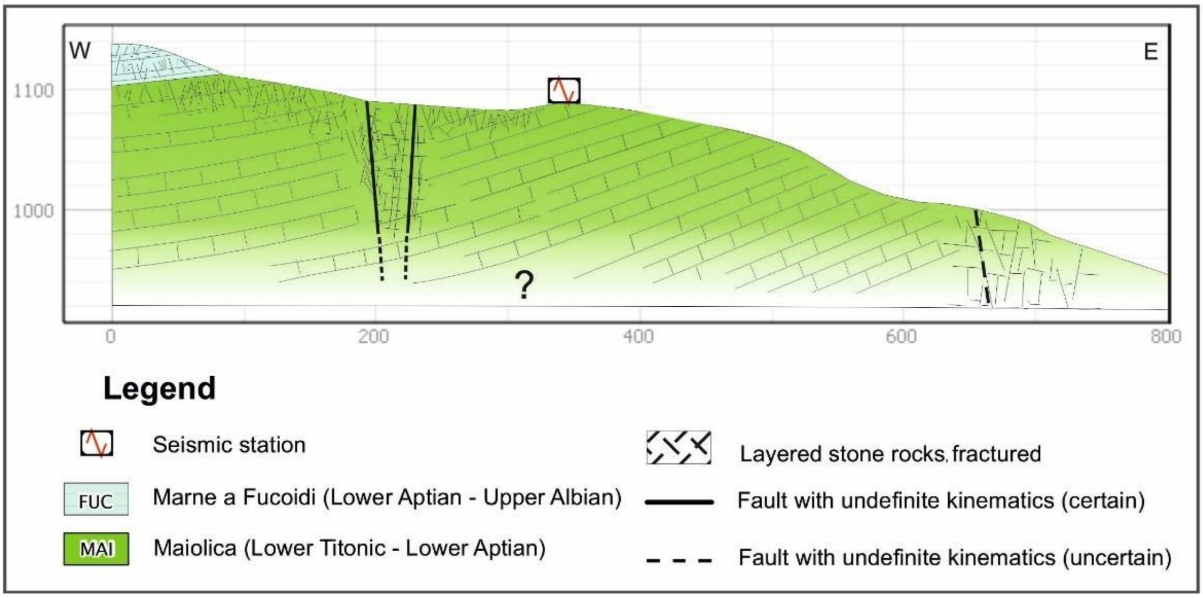

Figure 5. Geological cross section of the seismic station site IV.LNSS area.

In particular, the seismic station is located on the "Maiolica" limestone Formation (Figure.6A), here extensively outcropping (Figure.5). Very close to the seismic station site, a fractured zone affecting the "Maiolica" Formation has been identified (shown in the geological cross-section of figure 5), characterized by shear planes with undefined kinematics, mostly N-S and NW-SE oriented (Fig.6B).

Figure 6. A) Layers of the "Maiolica" Formation outcropping near the seismic station site IV LNSS. B) Shear planes (black dashed line) with undefined kinematics, here NW-SE striking.

This small relief onto which the seismic station site locates is mostly surrounded by lake, alluvial and slope deposits of the aforementioned Quaternary continental succession infilling the Leonessa basin.

5.3 Subsoil model

Field observations coupled with information derived from the available geological maps allowed to derive a 2D geological model (down to about 100 m depth), underneath the IV.LNSS seismic station site (Figure 7). The geological model obtained has been also compared to the new geophysical investigations, performed by the INGV Working Group, for the seismic characterization of the site and for the definition of body waves velocity profiles. The first 8-10 m depth consists in the layered limestone bedrock of the "Maiolica" Formation characterized by rather diffuse fracturing. Downward, the layered limestone of the "Maiolica"

Formation continues but maintaining its primary mechanical characteristics, that is, being not fractured.

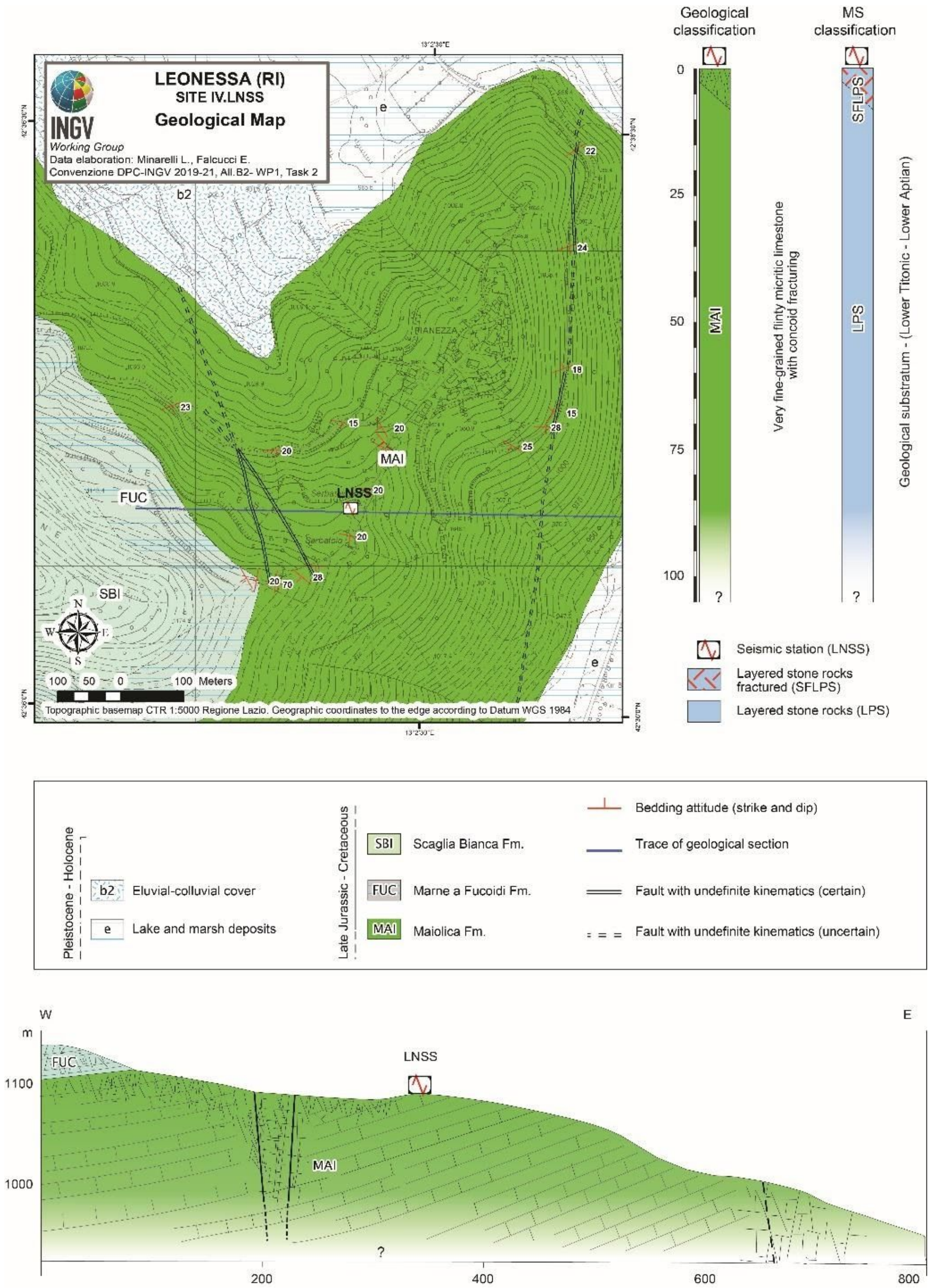

Figure 7. Bottom - Geological section crossing seismic station IV.LNSS. Right - Subsoil modelunder the IV.LNSS seismic station and classification according to nomenclature of geological map of Italy 1:50.000 and according to Seismic Microzonation (MS).

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B. Vs profile

B1. PREFACE

In this section, the geophysical surveys carried out to characterize IV.LNSS station are presented. We performed a MASW experiment with an active source by using 72 vertical geophones installed in linear configuration. In combination with the MASW survey, we installed 7 seismic stations near IV.LNSS for ambient seismic noise recordings that were used for computing the H/V curve (horizontal-to-vertical noise spectral ratio). Data records of IV.LNSS were also extracted and analyzed in terms of H/V curve. Using surface-wave frequency-wavenumber analysis, we provide results in terms of resonant peaks of the H/V curves, and dispersion curves that were inverted to obtain shear-wave velocity (V_s) profiles for the studied area. The inverted models are suitable for determination of the average Vs velocity in the uppermost 30 m (V_{s30}) and assigning then the soil class category as prescribed by building codes (EC8, NC8 or NC18). The software of analysis was Geopsy (www.geopsy.org; Wathelet et al. 2020). The date of the geophysical survey was 20 June 2020.

B2. GEOPHYSICAL INVESTIGATION

The map of Figure 1 shows the position of: IV.LNSS station (black marker), the MASW line of geophones (black line in Fig. 1) and of the temporary seismic stations deployed in the target area (yellow and red markers in Fig. 1). The linear MASW array was composed of 72 vertical geophones equipped with vertical sensors (4.5 Hz natural frequency) equally spaced of 1 m. Noise measurements were performed by 5 stations equipped with triaxial geophones (4.5 Hz natural frequency, Terrabot stations by Sara Electronics; the TB stations in Fig. 1 in red colour) and 2 stations composed of a Reftek130 digitizer with Lennartz-5s sensor (LE stations in Fig. 1 in yellow color). The time-length of each noise measurement was about 3 hours. Due to the rock soil properties in the area, the geophones were placed through ad hoc plastic bases and the sensors were not buried.

Figure 2 shows some pictures of the investigated area; note that not far from IV.LNSS a telecommunication area antennas and a water cabinet are installed and could potentially act as a noise source (in particular the water cabinet is at about 10 m far from position of the IV.LNSS station).

The position of the noise measurements and of geophones was taken by a GPS RTK Leica antenna, with a precision of the order of a few centimeters.

All the geophysical measurements were recorded the 20th June of 2020 (it was a sunny day, no wind).

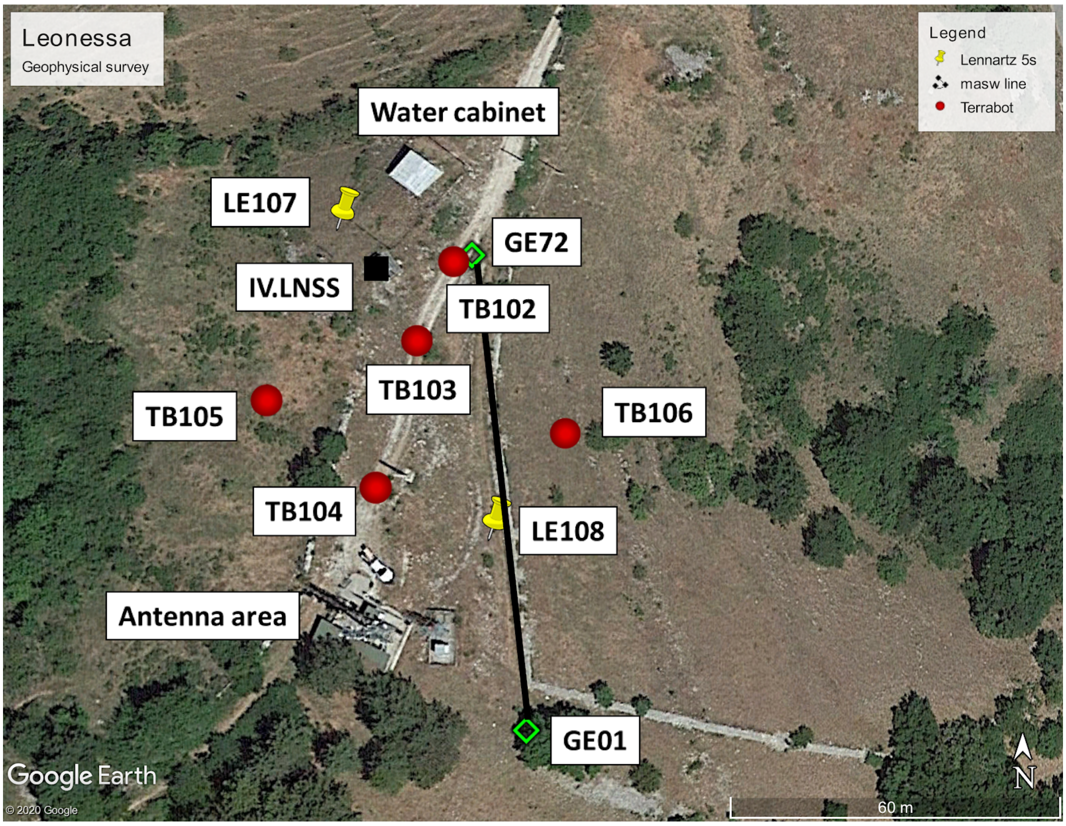

Figure 1. Google map of the geophysical surveys for the IV.LNSS station (black square). The black line shows the linear MASW array of 72 vertical geophones (GE01 and GE072 indicate the first and last geophone of the line). The yellow and red marks show the positions of the 7 temporary seismic stations deployed for seismic noise acquisition (TB and red flag for Terrabot seismometer; LE and yellow flag for Lennartz 5s velocimeter).

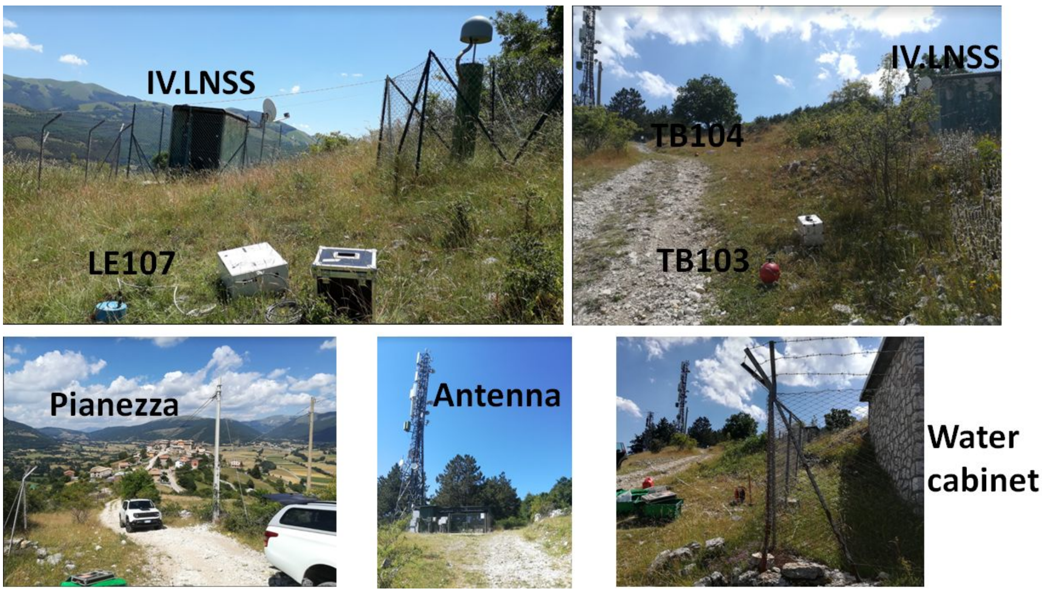

Figure 2. Pictures showing the investigated area.

2.1 H/V noise spectral ratio of temporary stations

Figure 3 shows the H/V curves obtained from the 7 temporary seismic stations. Details of computations are reported in the summary reports. The results of Fig. 3 indicate a not good agreement in terms of H/V shapes for all the stations, especially for frequencies below 2 Hz where some sites (TB102, TB103 and TB105) show pronounced peaks with an unreliable trend. Stations working better in the low-frequency band are LE107 and L108 equipped with Lennartz 5s (eigen-frequency 0.2 Hz), and both stations show a weak peak at about 0.8 Hz (which is also suggested by TB104). TB106 is the only site without amplified H/V curves below 1 Hz. However, the most reliable peak of the area seems the one at about 3 Hz (range 2.8-3.2 Hz with average amplitude level of about 3), which is present at all stations (except at TB102 and TB103 where it is masked by the abrupt rise in the low frequency part).

Figure 4 shows still the H/V curves (mean and mean +/- a standard deviation) of selected stations (i.e. without TB102, TB103 and TB105); the power spectral density of the three-components of the motion and the directional H/V curves are also reported.

The directional H/V curves evidence a polarization of the amplified H/V peak in a direction approximately NS (for stations LE107 and TB104) and N+40° (for TB106 and LE08). These polarizations are not of easy interpretation because could be related to the presence of some anthropic sources in Pianezza (see Fig. 2) or to complex resonance phenomena (such as fracturing or topographic effects). In particular the topographic relief where the station is located, as described in the geological section, is roughly oriented in a NS elongation.

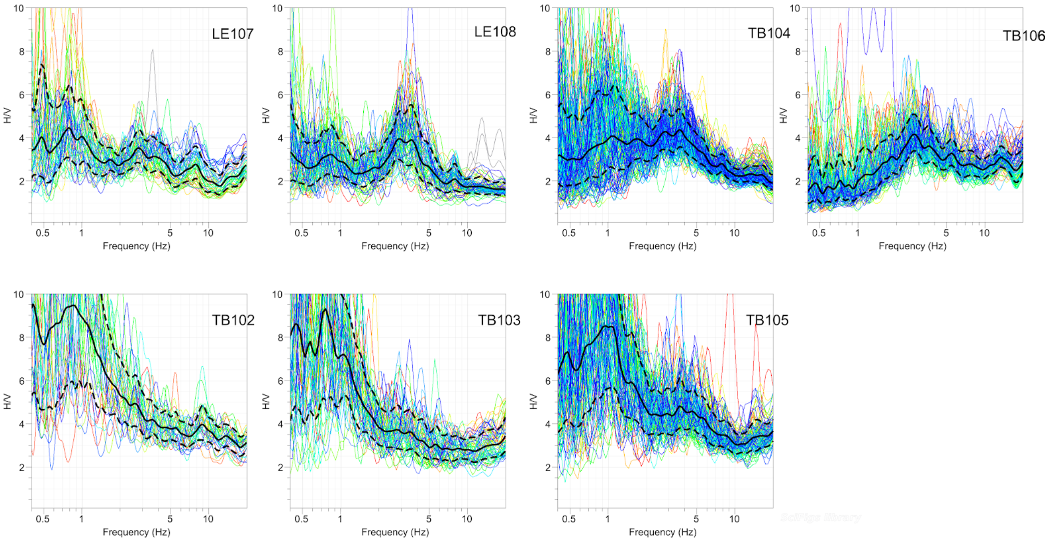

Figure 3. H/V noise spectral ratios. The seismic stations recorded ambient vibrations for about three hours (TB indicates the Terrabot instruments, LE the Lennartz 5s velocimeter).

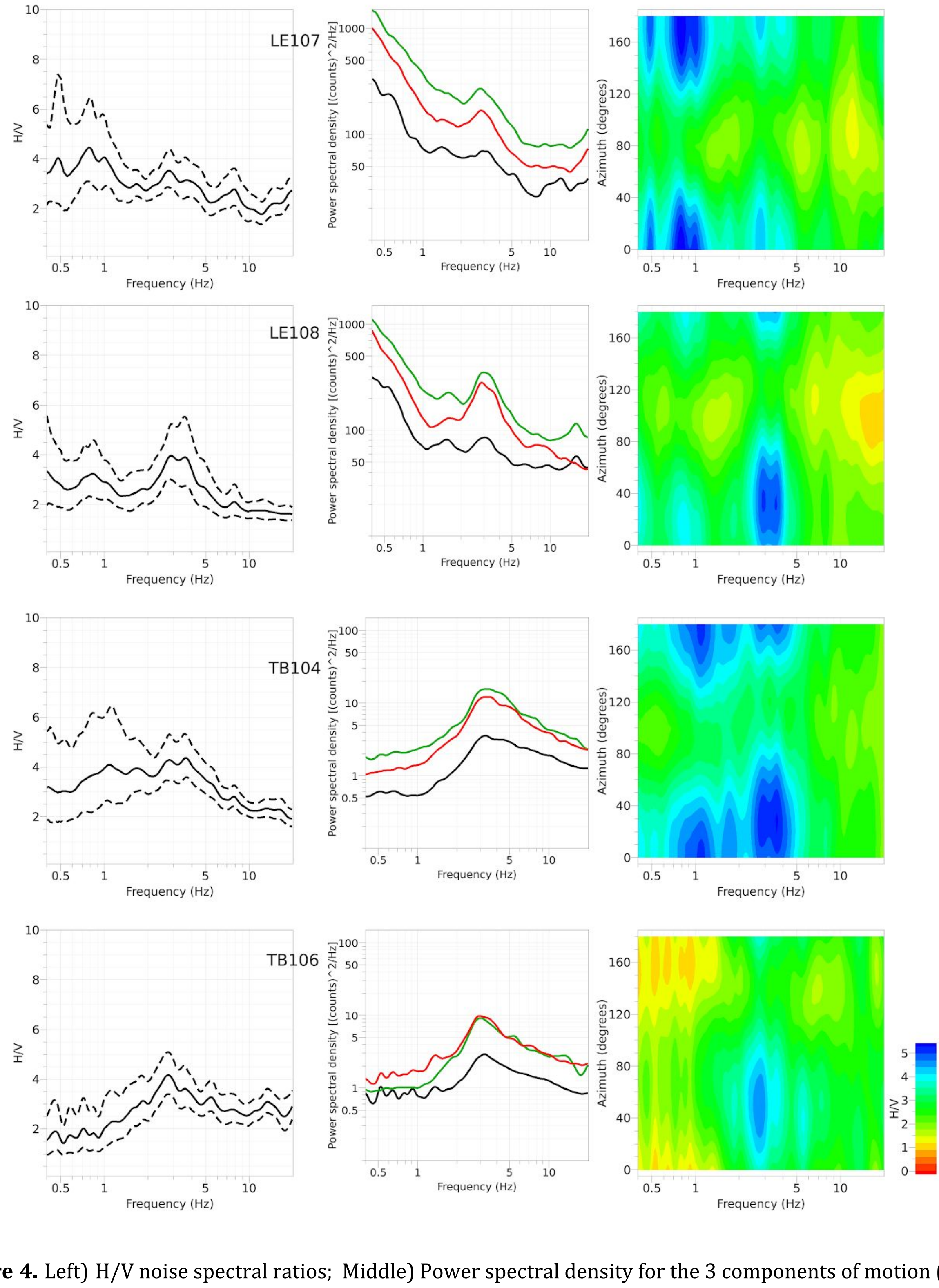

Figure 4. Left) H/V noise spectral ratios; Middle) Power spectral density for the 3 components of motion (black, green and red for vertical, NS and EW components); and Right) directional H/V ratios computed for LE107, LE108, TB104 and TB106 stations.

2.2 H/V noise spectral ratio using data of IV.LNSS

To further investigate the resonance frequency of the station IV.LNSS, we extracted continuous two-months data recorded by this station (on channel HH; data extracted from 1 march 2019 to 30 april 2019). We performed the H/V computation averaging the H/V curve day by day. The results of Figure 5 confirm the presence of a consistent peak at about 3 Hz (average amplitude value around 4), with additional peaks at 8 Hz and also at higher frequencies not found by our temporary measurements. Note that on the ISMD site (http://ismd.mi.ingv.it/ ; Massa et al. 2016) it is available the H/V curve of IV.LNSS station (Fig. 6), which confirms the results found by our time analysis.

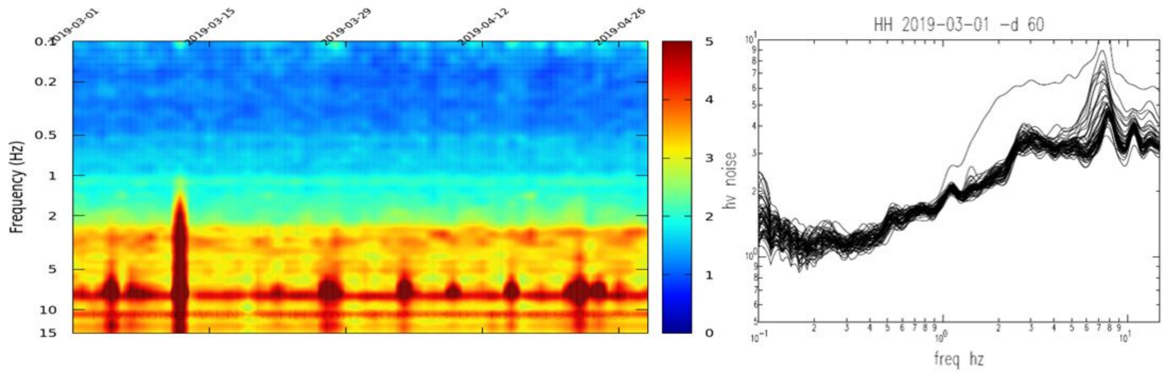

Figure 5. H/V spectral ratios using two months of continuous data extracted from IV.LNSS station starting from 2019/03/01. On the left panel the continuous H/V curve is reported as contouring as a function of time, with the color scale proportional to the amplitude of the H/V ratio. On the right panel the daily average H/V curves are overlaid.

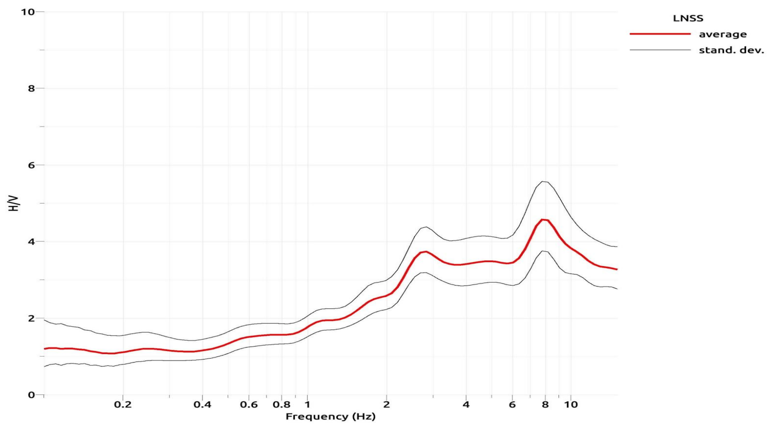

Figure 6. H/V noise spectral ratios as reported by the ISMD site (http://ismd.mi.ingv.it/; Massa et al. 2016).

2.3 Linear Array of geophones (masw)

The 72 vertical geophones were aligned in a straight line (the last geophone was at a distance of about 10 m from IV.LNSS; see Fig. 1) and were equally spaced of 1 m. For the MASW analysis, we acquired the seismic signals produced by the impact of a 5 kg hammer on the ground. The shots were made along the line at distances (offset) of -10 m, -1m, 36.5m, 72m and 81 m from the position of the first geophone (GE01 in Fig. 1 considered at 0m). In each shot point, the measurements were repeated three times in order to increase the signal-to-noise ratio. The seismic data were acquired using three multichannels systems (Geode manufactured by Geometrics) with a sampling rate of 0.125 ms for a duration of 2 s. Figure 7 illustrates the deployment of the MASW survey.

Figure 7. Photos showing the linear array of geophones (on the left and middle panel, the picture is taken in proximity of the last geophone Geo72). The Antenna area is also visible.

The acquired data were processed using the *GEOPSY* software tools (www.geopsy.org) in order to extract the surface-wave dispersion properties of subsoil by applying frequency-wavenumber (FK) transform to the seismic signals. Figure 8 shows the results obtained with the linear active survey (MASW). A no dispersion curve was obtained for shots with offset -5 m and -1 m from the first geophone GE01, whereas a picking of the dispersion curve was possible for the reaming offsets (middle, +1 m and +5 m from the last GE072 geophone) Using the shots at the beginning of the acquisition line (offset at -5 m and -1 m), FK analysis do not highlight a clear dispersion curve in contrast to offset at the end of acquisition line; we can tentatively explain this observation in connection to the presence of fractured layer with different elastic properties as reported in the geological part.

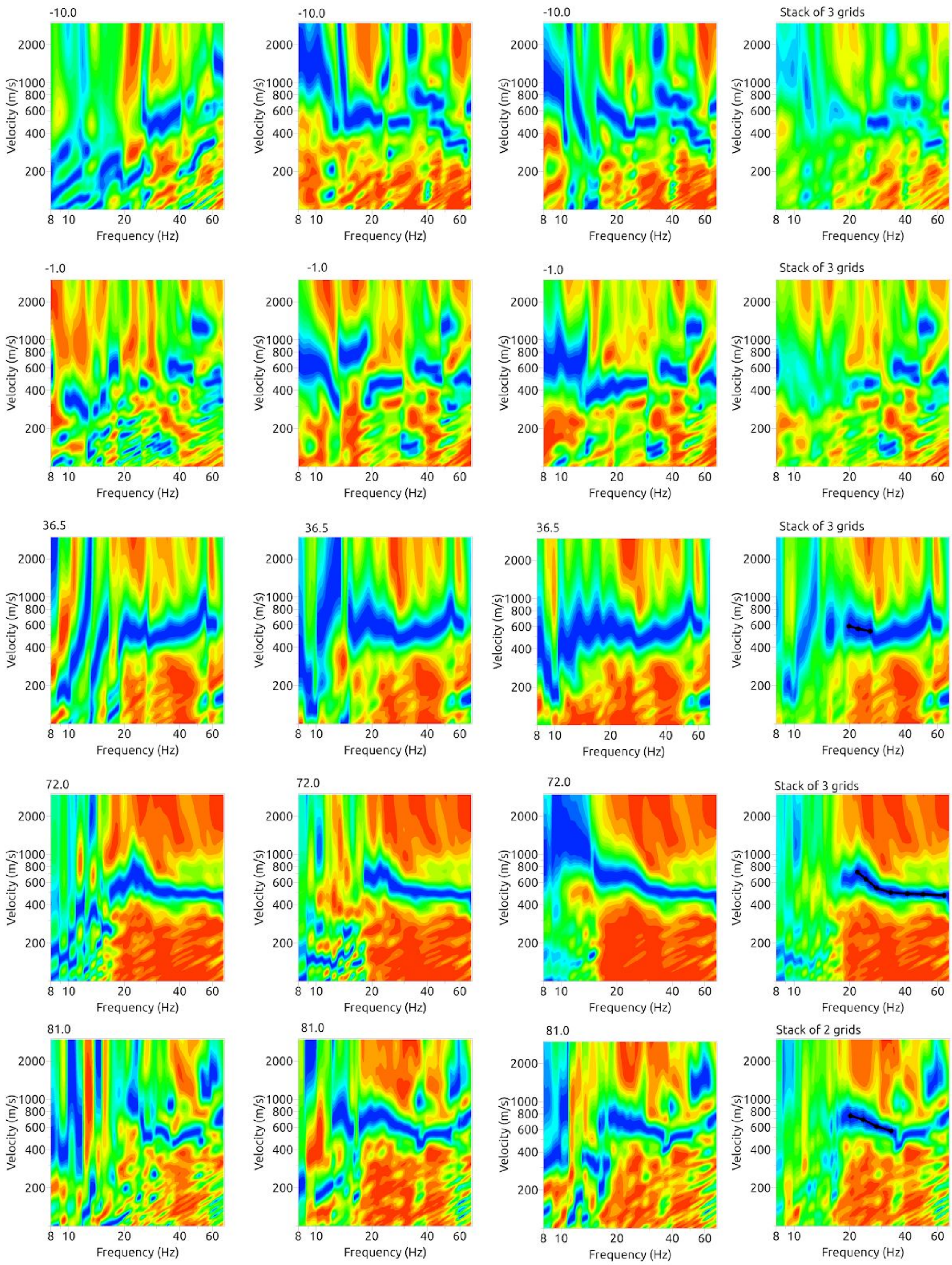

Figure 8. FK analysis. The results obtained by MASW linear array shot are shown for each shot; from top to down the offset is -10 m, -1 m, 36.5 m, 72m and 82m. Plots in the same horizontal panel refer to the same shot offset location. The plot of the last column shows the stack image obtained for the same offset (the black curve is the picked dispersion curve).

To compute the final dispersion curve, we combine the experimental curves obtained with the offset +1m and +10 m with respect to the position of GEO72. The selected dispersion curves are reported in Fig.s 9; an average dispersion curve was computed (the red one) using the two experimental curves. The final mean dispersion curve is in the frequency range 20-65 Hz using a resampling of 20 points, and the apparent velocity values are ranging from 470 m/s (at 65 Hz) up to 750 m/s at 20 Hz. The maximum wavelength of our dispersion curve is 37 m , and as an experimental rule the depth of investigation is between ½ or ⅓ of the maximum

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wavelength (i.e. between 12-18 m of depth).

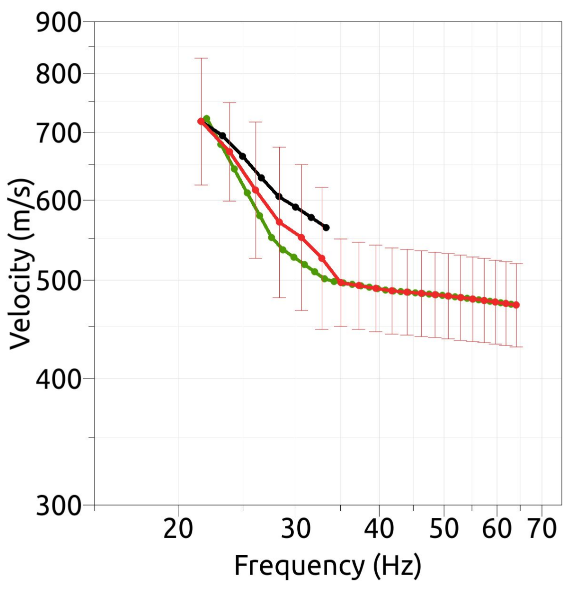

Figure 9. The final dispersion curve selected for the inversion step was provided as the average (red curve) of the two experimental curves (black and green curves) at offset +1 and +10m.

B3. 1D SEISMIC VELOCITY MODEL

We extract a dispersion curve from the linear 1D array of geophones, aimed at reconstructing the1D velocity model. We combined the dispersion curves obtained at offset +1 m and at +10 m of the MASW survey; at these offsets we have a more clear dispersion feature than the others offsets (Figure 9) . The final dispersion curve used as target in the inversion procedure is the red one of Fig. 9.

To proceed with the inversion step, the dispersion curve derived from the vertical component of motion has been associated with the fundamental mode of surface Rayleigh-wave. Then, we inverted through the geospy tool the apparent surface-wave dispersion curve for recovering the shear-wave velocity (Vs) model. Because the HV curves were with unclear and polarized peaks (see Fig.s 3 and 4), they were not considered during the inversion step.

The resulting velocity models after the inversion of the dispersion curve are shown in Fig. 10. We tested several simple starting model-parameterization composed of one or two main uniform layers over halfspace, keeping in mind the limited depth of maximum investigation associated with our dispersion curve (12-18 m). Our best results show (Fig.s 10) a first uniform layer at shear-wave velocity of 522 m/s, with a reference layer found by the inversion at 9.3 m deep. The best Vp and Vs models (i.e. lowest misfit) resulting from the inversion are shown in Fig. 11 and Table 1.

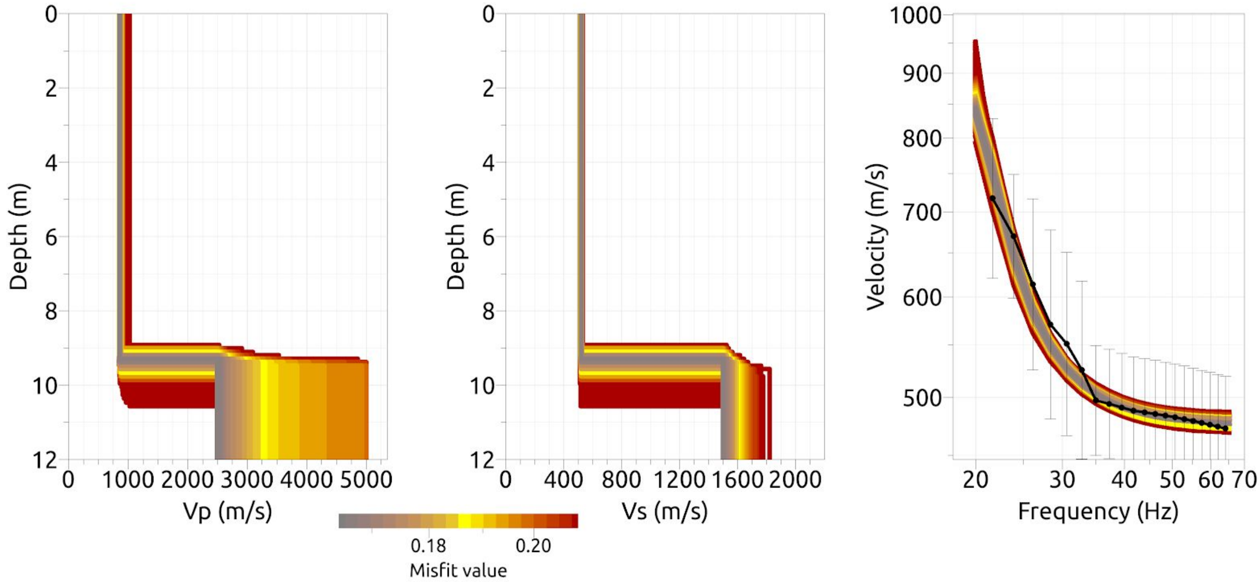

Figure 10. Resulting models after the inversion of the dispersion curves (the field dispersion is shown in black colour; the color scale is proportional to the misfit between experimental curve and theoretical models). The best Vp and Vs model (i.e. lowest misfit) are presented in Fig. 11.

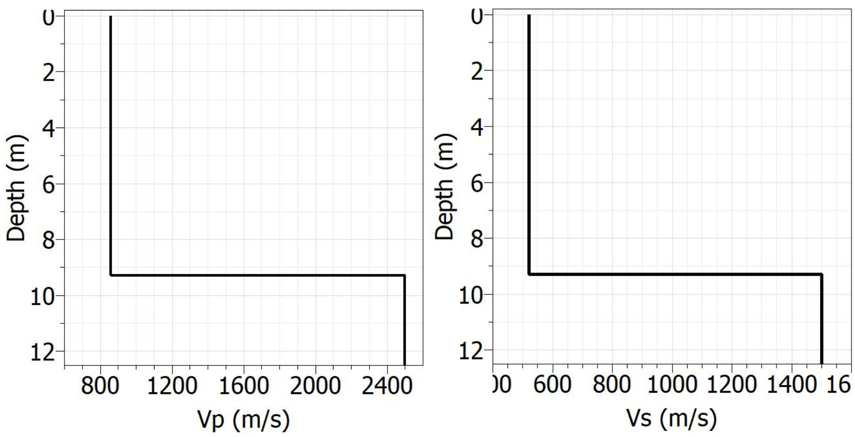

Figure 11. Best Vp and Vs models (extracted from the models of fig. 10) after the inversion of the apparent surface-wave Rayleigh dispersion curve.

Table 1. Best-fit model.

From (m)	To (m)	Thickness (m)	Vs (m/s)	Vp (m/s)
0	9.3	9.3	521.5	858.5
9.3	12	12	1500	2500

B4. CONCLUSION

Surface-wave analysis at IV.LNSS station indicates a site of soil class A ??? (Table 2). The best Vp and Vs models (i.e. lowest misfit) resulting from the inversion are proposed in Fig. 11 and Table 1. HV noise spectral ratios of the temporary stations are of not easy interpretation, although we found the most convincing peak at about 3 Hz. This peak is confirmed by the analysis of the continuous two/months data records extracted at the station IV.LNSS. From this continuous time-data analysis, additional narrow peaks at higher frequencies occur but these peaks are not found by the temporary measurements around IV.LNSS, suggesting that are very localized or likely related to the presence of the schelder or of the close water cabinet. Because the 3 Hz peak is also polarized, we cannot exclude complex resonance phenomena in connection to the topography relief or as effects of fractured near-surface layers characterized by different elastic properties.

The 1D active linear array of geophones provides a final dispersion curve from 20 to 65 Hz (Fig. 9), and the inversion procedure gives the Vs models of Fig.s 10 and 11 where the bottom bedrock layer is found at a depth of 9.3 m (Table 1). The first layer with Vs of 522 m/s, following the geological section, is interpreted as fractured layered limestone of the “Maiolica” Formation. Downward, the layered limestone of the “Maiolica” Formation continues and it is no more fractured.

The V_{S30} retrieved from the best inverted model is 949 m/s (Table 2), therefore IV.LNSS is classified following EC8 or NTC08 as soil class A also taking into account the geological observation described in the first part of the report. Following the definition of $V_{S,eq}$ within NTC18 and because the value of 800 m/s is reached at a depth larger than 3 m, $V_{S,eq}$ is equal to 521.5 m/s (velocity of the first layer) and the soil class should be B (with the substratum considered at 9.3 m of depth).

Table 2. f0 value, and soil class following NTC08 and NTC18.

f_0 (Hz)	Note
2.8 Hz	Not easy to interpret; the H/V peak seems polarized

V_{S30} (NTC08 or EC8)	Soil Class
949 m/s	A

$V_{S,eq}$ (NTC18)	Soil Class
521.5 m/s	B

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[1]This document is level 3 as defined in the "Principi della politica dei dati dell'INGV (D.P. n. 200 del 26.04.2016)"

RESONANCE FREQUENCY

fo +/- STD [Hz]	3
Quality index 1	0.67

Source	Earthquake	✔	Ambient noise	✔

Ambient noise

Method	H/V	✔	Ellipticity	☐	Other	☐
fo +/- std [Hz]						

Experiment date [DD/MM/YY]	Distance from station [m]	Lat. [WGS84]	Lat. [WGS84]
20/06/2020	10	42.602887	13.040238

Environment

Weather conditions	Sunny	Windy	Rain
	✔		
Soil-sensor coupling	Earth	Asphalt	Artificial
	✔		
Urbanization	None	Dense	Scattered
	✔		

Equipment

Sensor	Type [acc/vel]	manufacturer	cut-off frequency [Hz]
	vel	Lennartz (+S	0.2 (4.5)
Digitizer	Type	Manufacturer	Sampling frequency [Hz]
	Reftek130(+	Reftek+ (Sar	250
Measurement	Number	Duration [min]	
	7 (plus con	180 (two mo	

Analysis

Software	geopsy (www.geopsy.org
Smoothing type (e.g. triangular, Konno-Ohmachi, ...)	Window length [s]
konno-ohmachi	60

Fo uncertainty estimate from

Fo from individual windows	H/V curve width	Manual picking
?	?	

Earthquake

Method	HVSR	✔	SSR	☐	GIT	☐	Other	☐
fo +/- std [Hz]								

Recording period [DD/MM/YY]		Number of earthquakes
from	to	
?	?	7 (f0=2.8 Puglia t

Epicentral distance [km]		Magnitude range	
from	to	from	to
13.	205.2	3.3	4.3

HVSR

Seismic phase	P	S	Coda	S + coda	All
		✔	✔		

window duration [s]	Min	Max
	?	?

SSR

Seismic phase	P	S	Coda	S + coda	All
Reference station	Lat. (WGS84)	Lon. (WGS84)			

window duration [s]	Min	Max

GIT

Parameters	Free (to be inverted)	Imposed
Reference paper		
Reference station	Lat. (WGS84)	Lon (WGS84)

Vs30

Vs30 +/- STD [m/s]	949
Quality index 1	1

Source	Geophysical measurements	✔	Geotechnical measurements	☐	Digital Elevation Model (DEM)	☐	Geology	✔	DEM & Geology	☐

Geophysical measurements

Method	Surface waves methods (active, passive methods)		Borehole methods (DH, CH, PS-Logging)	
Vs30 +/- STD [m/s]	From Vs(z)	✔	From Down-Hole	☐
	From Vr40	☐	From Cross-Hole	☐
	From Vsz-Vs30 correlation	☐	From PS Logging	☐
Reference relationship Vsz - Vs30				

Geotechnical measurements

Method	N-SPT	☐	CPT	☐	Shear strength	☐	OTHER	☐
Vs30 +/- STD [m/s]								

Experiment date [DD/MM/YY]	Distance from station [m]	Lat. [WGS84]	Lon. [WGS84]

Reference relationship Vs30-geotechnical parameter		
	N-SPT	
	CPT	
	Shear strength	
	Other	

Geology

Method	Geological map	✔	Stratigraphic log	☐
Vs30 +/- STD [m/s]				
Geological map scale				
Geological unit name				

Stratigraphic log	Experiment date [DD/MM/YY]	Lat. [WGS84]	Lon. [WGS84]
Reference relationship Vs30-geology	stiff formation outcropping (bedrock relief)		
Reference relationship Vs30-Stratigraphic log			

Digital Elevation Model

Vs30 +/- STD [m/s]	808			
DEM resolution	?	Slope range	from	
			to	15
Reference relationship Slope - Vs30	ESM-ITACA working group Wald DJ, Allen TI (			

DEM & GEOLOGY

Vs30 +/- STD [m/s]	
Reference relationship Slope - Vs30 - geology	

Vs profile

Quality index 1	1

Source

Non-invasive methods (active and/or passive seismics)			
Active surface waves	✔	Refraction	
Passive surface waves		Refection	
HV / ellipticity			

Invasive methods (measurement in borehole)	
Cross-hole / Down-hole	
Geotechnical methods (CPT, SPT, ...)	
PS-Logging	

Non-invasive : surface waves methods

Experiment date [DD/MM/YY]	Distance from station [m] Min	Distance from station [m] Max	Lat. [WGS84] center location	Lon. [WGS84] center location
20/6/2020	12 (geophd	70 (geophd	42.602530	13.040547

Active surface waves acquisition layout

Minimum receiver spacing (m)	1
Profile length (m)*	71
Geophones number	72
Number of profiles	1

* Provide the length for the various profiles (e.g. 46 m, 94 m)

Geophone cut-off frequency (Hz)	4.5 Hz
Geophone type (vertical / horizontal)	vertical
Geophone manufacturer	Geospace GS11D
Source (hammer, vibrator, ...)	hammer
Digitizer type	3 Geodes
Digitizer manufacturer	Geometrics

Weather conditions	Sunny	Windy	Rain	Soil-sensor coupling	Earth	Asphalt	Artificial	Urbanization	None	Dense	Scattered
	✔						✔		✔		

Passive surface waves acquisition layout

Number of sensors	
Minimum array aperture	
Maximum array aperture	
Number of arrays	
Minimum duration [min]	

Sensor cut-off frequency (Hz)	
Sensor type (vertical / horizontal)	
Sensor manufacturer	
Digitizer type	
Digitizer manufacturer	

Weather conditions	Sunny	Windy	Rain	Soil-sensor coupling	Earth	Asphalt	Artificial	Urbanization	None	Dense	Scattered

Type of dispersion and/or H/V estimates

		Reference paper (Name, Journal, DOI)
Rayleigh DC	✔	FK on active data (geopsy code)
Love DC		
Ellipticity		
H/V (DFA, EHVR)		
H/V (SH)		

Dispersion curves

	Rayleigh	Love
Min wavelength (m)	7	
Max. wavelength (m)	37	
Min. phase vel. (m/s)	470	
Max. phase vel. (m/s)	750	
Modes (R0, L0, ...)	R0	

H/V or Ellipticity curves

Min. frequency (Hz)	Max. frequency (Hz)

Inversion

Rayleigh waves	✔	Love waves		Ellipticity curves		H/V (DFA, EHVR)		H/V (SH)		resonance frequency	

A priori information used in inversion	seismic refraction		stratigraphic log		geotechnical information		water table depth	

Inversion algorithm/code	dinver
Reference	Wathelet M (2008) An improved neighborhood algorithm: parai

Non-invasive : body waves methods

Experiment date [DD/MM/YY]	Distance from station [m]		Lat. [WGS84] center location	Lon. [WGS84] center location
	Min	Max		

Acquisition layout

Receiver spacing (m)	
Profile length (m)*	
Geophones number	
Number of profiles	
Shot spacing (m) - reflection meas.	

Geophone cut-off frequency (Hz)	
Geophone type (vertical / horizontal)	
Geophone manufacturer	
Source (hammer, vibrator, ...)	
Digitizer type	
Digitizer manufacturer	

** Provide the length for the various profiles (e.g. 46 m, 94 m)*

Weather conditions	Sunny	Windy	Rain	Soil-sensor coupling	Earth	Asphalt	Artificial	Urbanization	None	Dense	Scattered

Processing methods

		Reference paper (Name, Journal, DOI)
classical refraction		
refraction tomography		
classical reflection		
advanced method		

Invasive methods

	Down-Hole	Cross-Hole	PS-Logging	SPT	CPT	OTHER
Borehole depth (m)						
Geophone type						
Source type						
Distance between wells						
Depth resolution (m)						
Latitude (WGS84)						
Longitude (WGS84)						
Distance from station (m)						
P-wave velocity						
S-wave velocity						

Processing methods

		Reference paper (Name, Journal, DOI) or ASTM norm
Down-Hole		
Cross-Hole		
PS-Logging		
SPT		
CPT		
OTHER		

Authoritative velocity profile

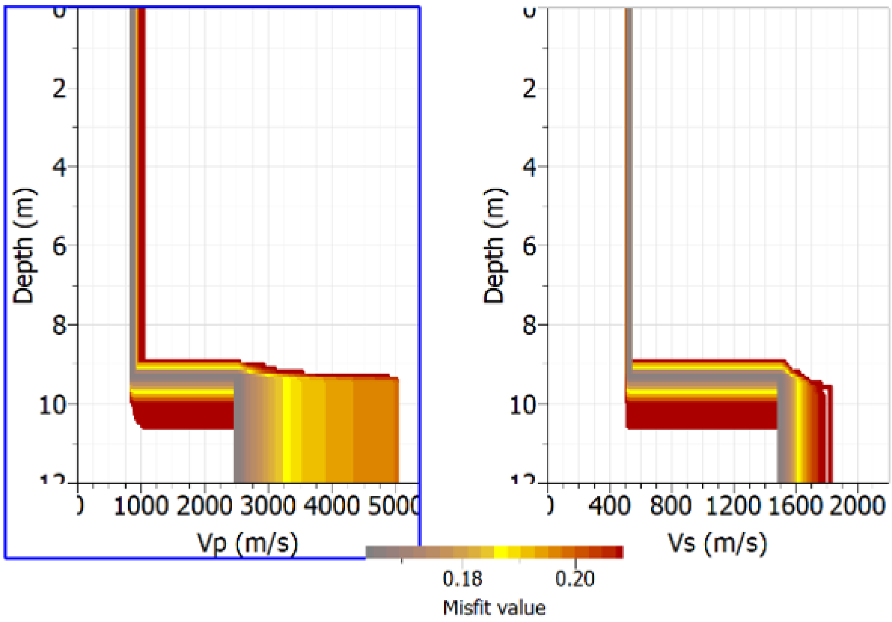
Note: You do not have to fill in all the columns. You can provide either single values for Vp or Vs (e.g. profiles derived from borehole measurements) or either a range for Vp and Vs (e.g. profiles derived from stochastic surface waves inversion)

Is Vs derived from Vp ?	**Yes**	☐	**No**	☑

Top depth (m)	Bottom depth (m)	Vp (m/s)	STD Vp (m/s)	Vs (m/s)	STD Vs (m/s)
0	9.3	858.5		521.5	
9,3	12	2500		1500	

Vs range		Vp range	
Vs min (m/s)	Vs max (m/s)	Vp min (m/s)	Vp max (m/s)
490	550	800	1100
1400	1900	2400	5000

Figure with authoritative velocity profiles



Surface geology

Quality index 1	1

Source	Cartography (geological, lithological, ...)	✔	Field survey	✔	Stratigraphic log	

Geological map

Map reference	Geological map according to the geological map c	
Map scale	1:5000	
Map sheet	348-Antrodoco	
Predominent geologic/lithologic unit	Name :	
	Description :	Maiolica limestone formation
	Age :	Lower Titonic, lower Aptian
	Thickness :	undefined
	Rock mass structure :	it could be fractured in the uppermost
Fault presence	✔	
Weathering		
Cross-section	✔	

Field survey

Map reference	Working group INGV "Agreement DPC-INGV 2019-	
Map scale	1:5000	
Predominent geologic/lithologic unit	Name :	
	Description :	Maiolica limestone formation
	Age :	Lower Titonic, lower Aptian
	Thickness :	undefined
	Rock mass structure :	it could be fractured in the uppermost
Fault presence	✔	
Weathering		
Cross-section	✔	

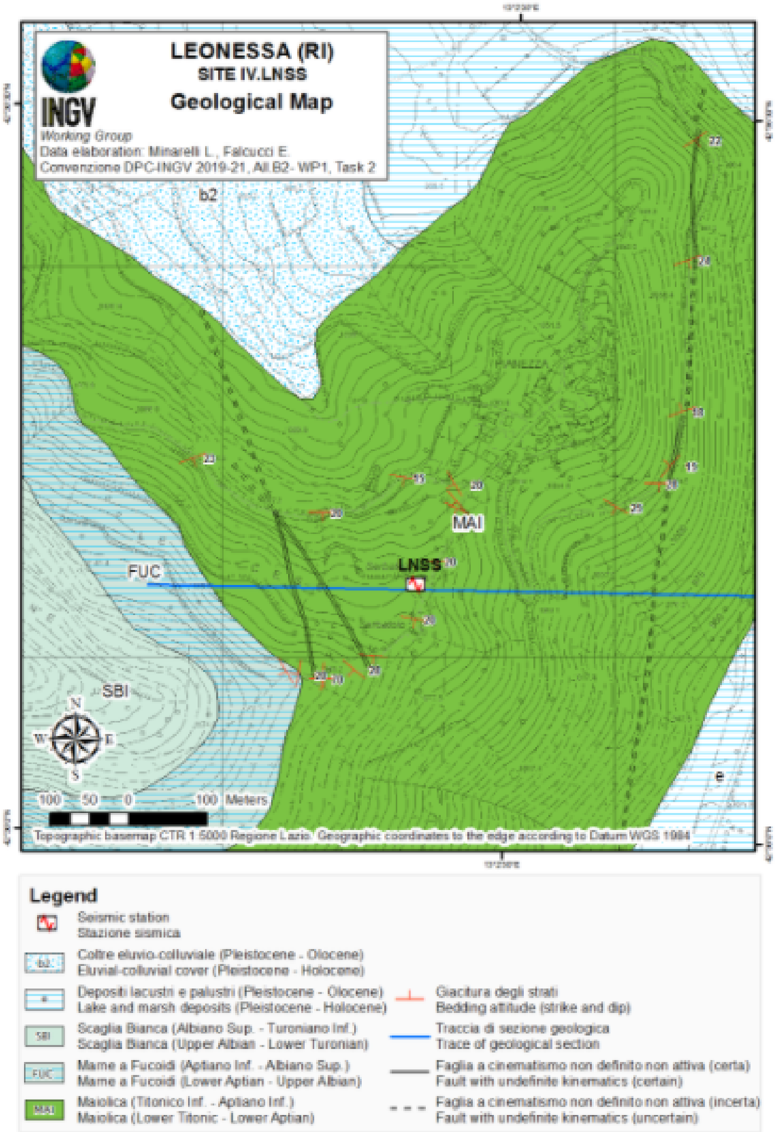
Stratigraphic log

log depth (m)	

Top depth (m)	Bottom depth (m)	Stratigraphic description

Surface geology

Map



Site class

Site class	A
Quality index 1	1

Reference building code for site classification (EC8-1, EC8-2, NEHRP, national code, ...)	

Source	Geophysical measurements	✔	Geotechnical measurements		Digital Elevation Model (DEM)		Geology		DEM & Geology	

Reference relationship geology - soil class	NTC18: Ministero delle Infrastrutture e dei Trasporti (2018). Agg
Reference relationship slope from DEM - soil class	
Reference relationship slope from DEM - geology - soil class	

Parameters for deriving soil class as prescribed in building code	Vs30, bedrock depth and its mean Vs (Vs equivalent)

Seismological bedrock depth

Depth +/- STD [m]	9.3
Quality index 1	1

Source	Vs profiles	✔	Geology		Other (gravity, seismic refraction, TDEM, ...)	
	Resonance frequency		Stratigraphic log			

Vs profile

	Non-invasive methods	Invasive seismic methods	Geotechnical methods
Bedrock depth +/- STD(m)	9.3 +/- 2		
Bedrock Vs +/- STD(m)	9.3 +/- 2		
Bedrock Vp +/- STD(m)	9.3 +/- 2		
Is Vs derived from Vp ?	Yes ☐	No ✔	

Resonance frequency

Bedrock depth +/- STD(m)	
Reference relationship Fo - bedrock depth	

Geology

Bedrock depth +/- STD(m)	
Bedrock geological unit	
Reference	

Stratigraphic log

Bedrock depth +/- STD(m)	
Bedrock geological unit	
Reference	

Other methods

	Bedrock depth +/- STD(m)	Reference
Gravity		
Seismic refraction		
Seismic reflection		
TDEM		

Engineering bedrock depth

Depth +/- STD [m]	9.3
Quality index 1	1

Reference Vs related to engineering bedrock in m/s	>=800	Reference building code for site classification (EC8-1, EC8-2, NEHRP, national code, ...)	NTC18 (Itali

Source	Vs profile	✔	Geology		Stratigraphic log	

Vs profile

	Non-invasive methods	Invasive seismic methods	Geotechnical methods
Bedrock depth +/- STD(m)	9.3		

Is Vs derived from Vp ?	Yes		No	✔

Geology

Bedrock depth +/- STD(m)	
Bedrock geological unit	
Reference	

Stratigraphic log

Bedrock depth +/- STD(m)	
Bedrock geological unit	
Reference	