ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Site characterization report at the seismic station IT.SULA – Sulmona (AQ)

Report di caratterizzazione di sito presso la stazione sismica IT.SULA – Sulmona (AQ)

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Subject: **Final report illustrating the site characterization for seismic station** IT.SULA	

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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 IT.SULA (Sulmona).

Location and coordinates are reported in Table 1.

Table 1.

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IT.SULA	Sulmona Autoparco (AQ)	42.07340*	13.91660*	412*
ADDRESS	Via Provinciale Morronese, 13, 67039 Sulmona AQ, Italy			

* Reference table from ITACA (December 2020)

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	VC*	C

* According to nomenclature of ITACA (December 2020)

Table 3.

Geological map	Source	Scale
IT.SULP	Geological map of Italy sheet *N.146* (Sulmona)	1:100.000
IT.SULP	Geological map of Italy sheet *N.369* (Sulmona)	1:50.000
IT.SULP	Geological and 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. Seismic Microzonation (5k) - Municipality of Sulmona. *Original.*		Lithotechnical Map. According to the nomenclature of Seismic Microzonation (Technical Commission SM, 2015). *Deduced.*	
code	**description**	**code**	**description**
ant	Anthropic deposit	RIzz	Soils containing residues of anthropic activity
col	Eluvial-colluvial cover	Mlec	Inorganic silt, silty or clayey fine sand, low-plasticity clayey silt of eluvial-colluvial cover
at1	Alluvial terrace- first order	GWfd	mixed graved and sand of fluvial terrace

A2. GEOLOGICAL MAP

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

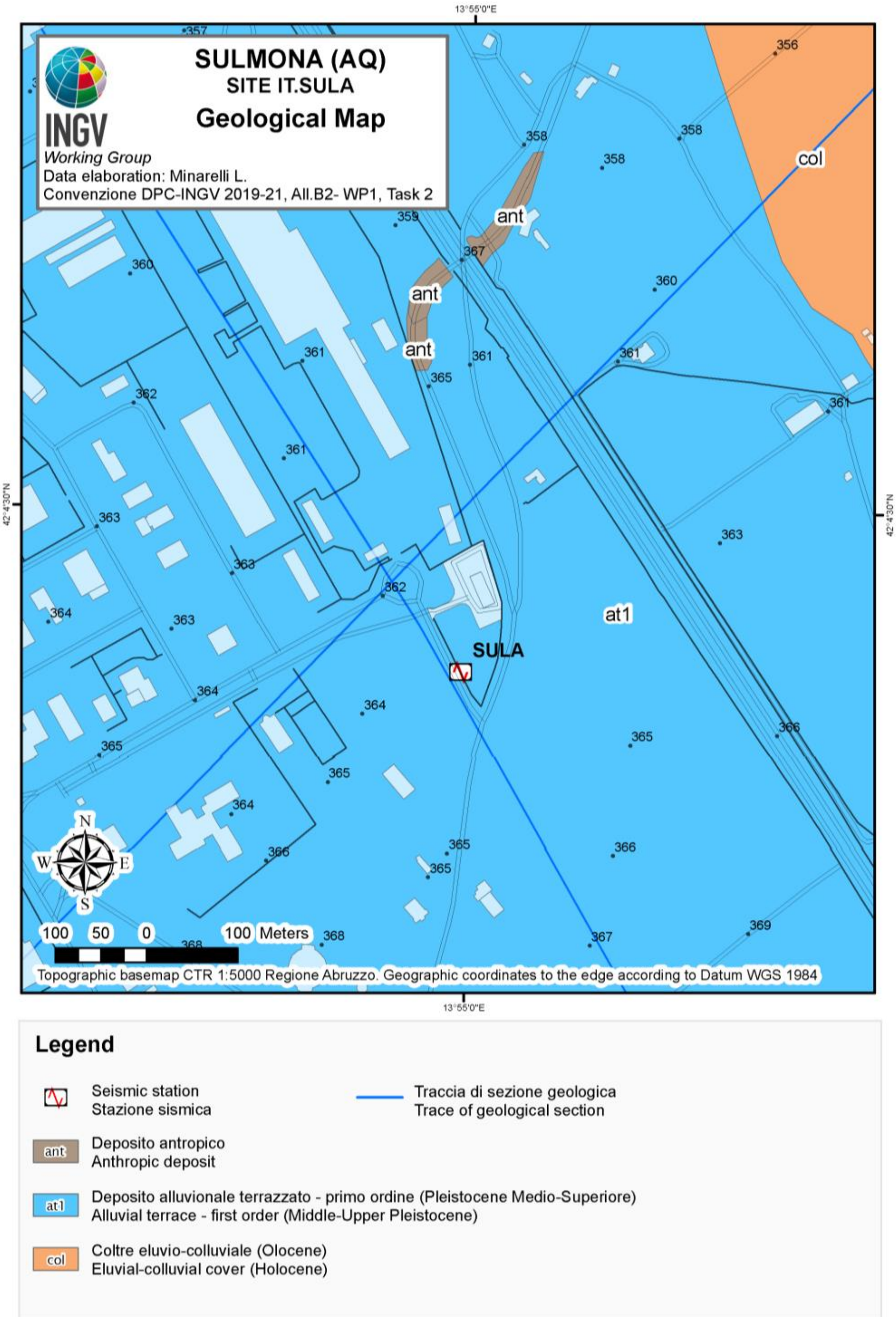

Figure 1. Geological map of seismic station site IT.SULA. Scale 1:5.000. Geological units are mapped according to the nomenclature of geological map of geological map of Italy 1:50.000

A3. LITHOTECHNICAL MAP

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

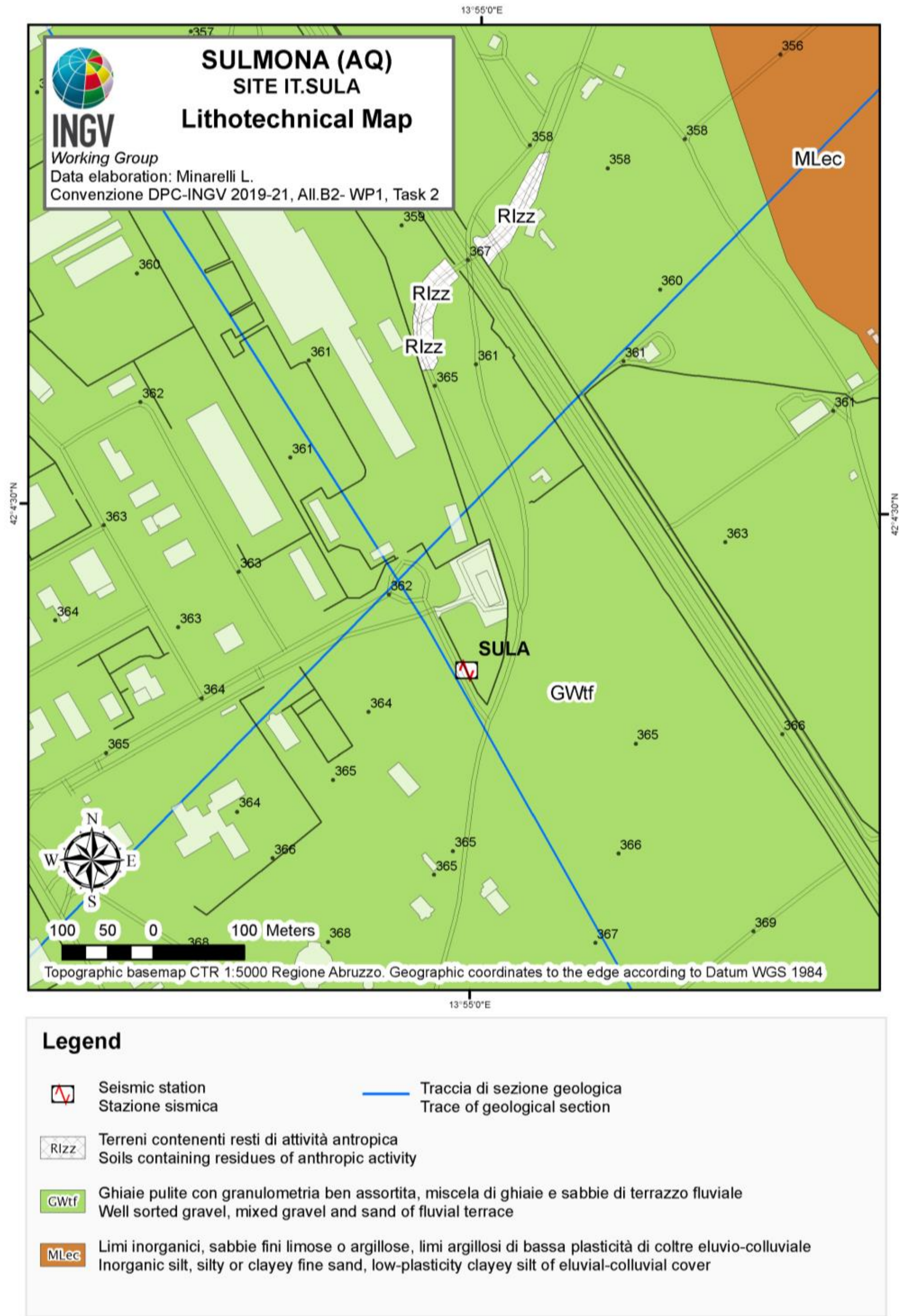

Figure 2: Lithotechnical map of the seismic station site IT.SULA. Scale 1:5.000. The lithotechnical units are attributed according to the nomenclature of Seismic Microzonation study (Technical Commission SM, 2015).

A4. SURVEY MAP

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

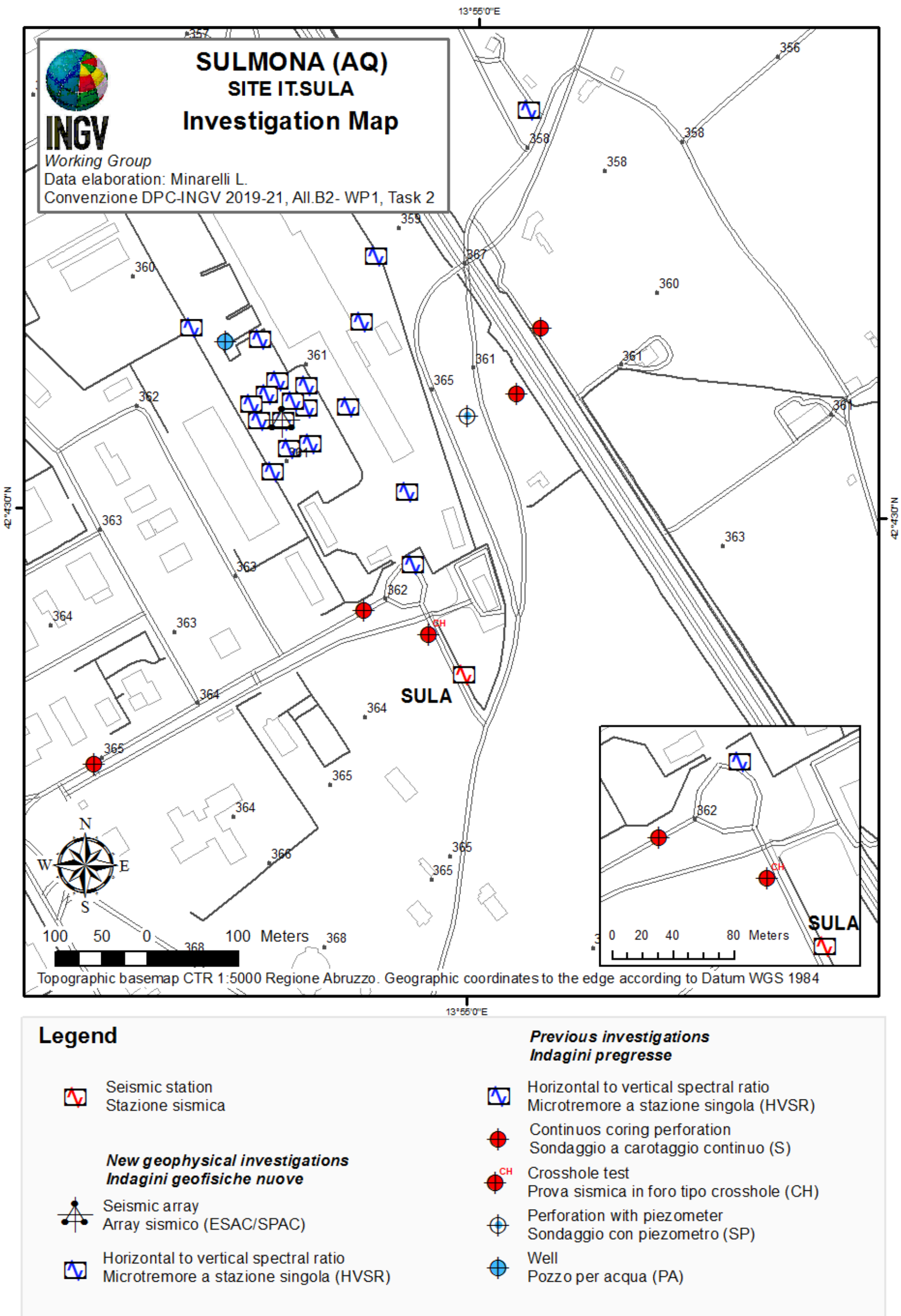

Figure 3: Map of the geophysical surveys made in the sectors around the seismic station IT.SULA. Scale 1: 5.000. The box at the bottom right contains a zoom of the area. To the northwest of the station have been performed the geophysical investigation conducted by INGV Working Group for the seismic characterization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

A5. GEOLOGICAL MODEL

5.1 General description

The seismic station is located in the Sulmona Basin, an intramontane basin extended in a NW-SE direction, in the outer portion of the Central Apennines, in the Abruzzo Region. The compressive tectonic stress that led to the formation of the Apennine Chain generated a overthrusts and folds system, with north-eastern vergence. The tectonic structures here essentially involve the Triassic-Miocene carbonate cover, belonging to the Lazio-Abruzzo domain. In the examined area, the platform and basin carbonates outcrop in the large anticline structure of the Monte Morrone. The carbonate successions constitute the oldest outcropping units of the geological substratum, here thrusting toward the north-east, over the more recent Tertiary terrigenous units of the Apennine Foredeep (Figure 4). The Sulmona Basin was generated by Plio-Pleistocene distensive deformation, on the inner side of the Morrone fold, affected by a system of normal NO-SE striking faults. The normal faults are linked to the extentional phase that has affected the area since the beginning of the Pleistocene. These faults, associated with the individual seismogenic source ITIS040 "Sulmona Basin" (DISS Working Group, 2018), are responsible for the frequent seismicity affecting this axial sector of the Apennine chain (e.g., Calamita et al., 1994; Galadini e Galli, 2000; Pizzi e Galadini, 2009). The tectonic activity of these faults induced the development of a halfgraben asymmetric basin, with the depocentre placed in the eastern sector, near the Morrone border-fault system.
The Sulmona halfgraben is filled by a thick Pleistocene-Holocene succession, consisting of continental clastic deposits, several hundred meters thick, deposited into lake, river and apron-fan environments. The seismic station is placed on the top of the continental succession.

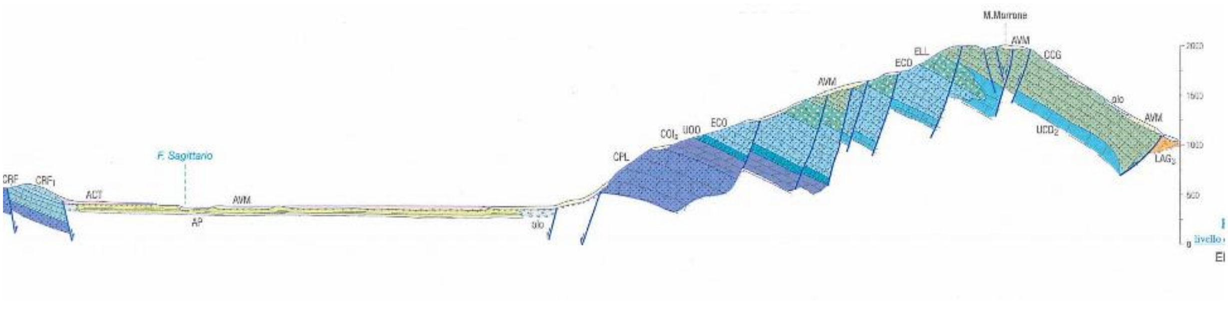

Figure 4: Geological profile crossing the Monte Morrone and the Sulmona basin plain. The folded Mesozoic carbonate units overthrusted Tertiary tubidites and were then dissected by a system of Plio-Pleistocene normal faults (Geological Sheet 369 - 1:50.000 "Sulmona").

5.2 Geological Section

The seismic station is located in the industrial area of Sulmona, in the central-northern part of the homonymous tectonic basin.

The geological sections M-M' and C-C' (Figures 5 and 6), attached to the seismic microzonation of the Municipality of Sulmona, describe the geological structure of the study area.

The geological sections intersect each other near the seismic station and were obtained through the stratigraphic correlation, based on both the information deriving from the geological field surveys and geotechnical and geophysical tests of the subsurface.

The Mesozoic Carbonate successions of the geological substratum outcrops on the walls of Monte Morrone, at the eastern edge of the Sulmona basin. Similar units, strongly lowered by direct fault movements, provide the base for the thick Quaternary deposits accumulated into the subsiding tectonic depression.

The Quaternary units accumulated at the base of the Morrone slope consist of slope debris breccias and conglomerates. At the basin margin, the slope deposits interfinger with fluvial sand-gravel deposits, with a total thickness of several tens of meters, forming morphological terraces and alluvial fans.

The river units rest on peaty clay deposits, deposited into a lake environment. The fluvial deposit are of variable thickness, which decreases towards the center of the basin. The lake successions show a maximum thickness of several hundred meters, in the depocentre areas of the eastern sectors of the basin, whereas the thicknesses decrease sharply proceeding towards the southern and western edges of the Sulmona depression.

The lake deposits interfinger with fluvio-deltaic gravelly-sand bodies, which become more frequent and thicker near the edges of the basin.

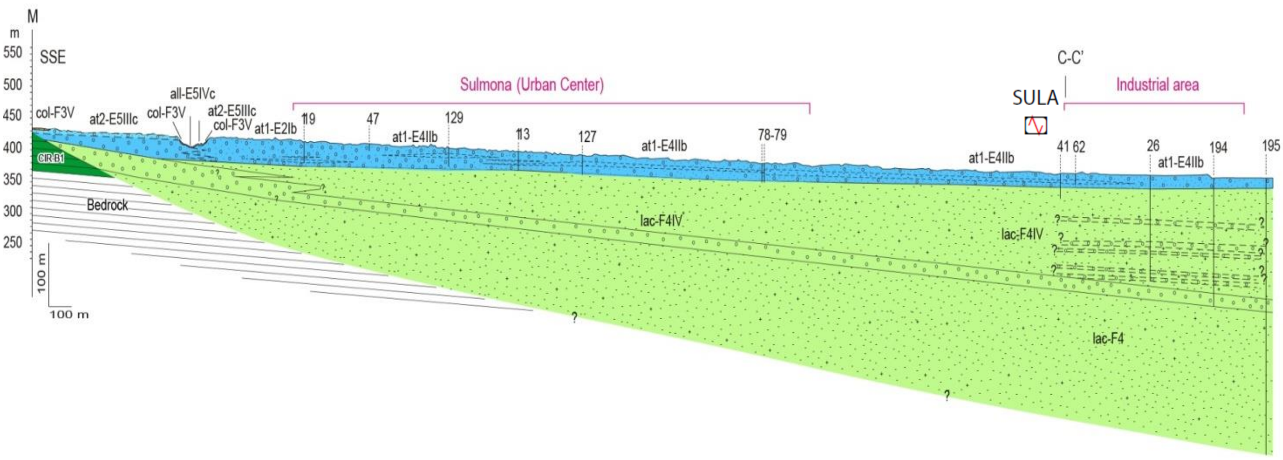

Figure 5: Schematic geological cross section, oriented SSE-NNW, showing the relationships between the Mesozoic carbonate bedrocks and the Quaternary sedimentary infilling of the active graben basin (Sulmona Seismic Microzonation - geological cross section M-M').

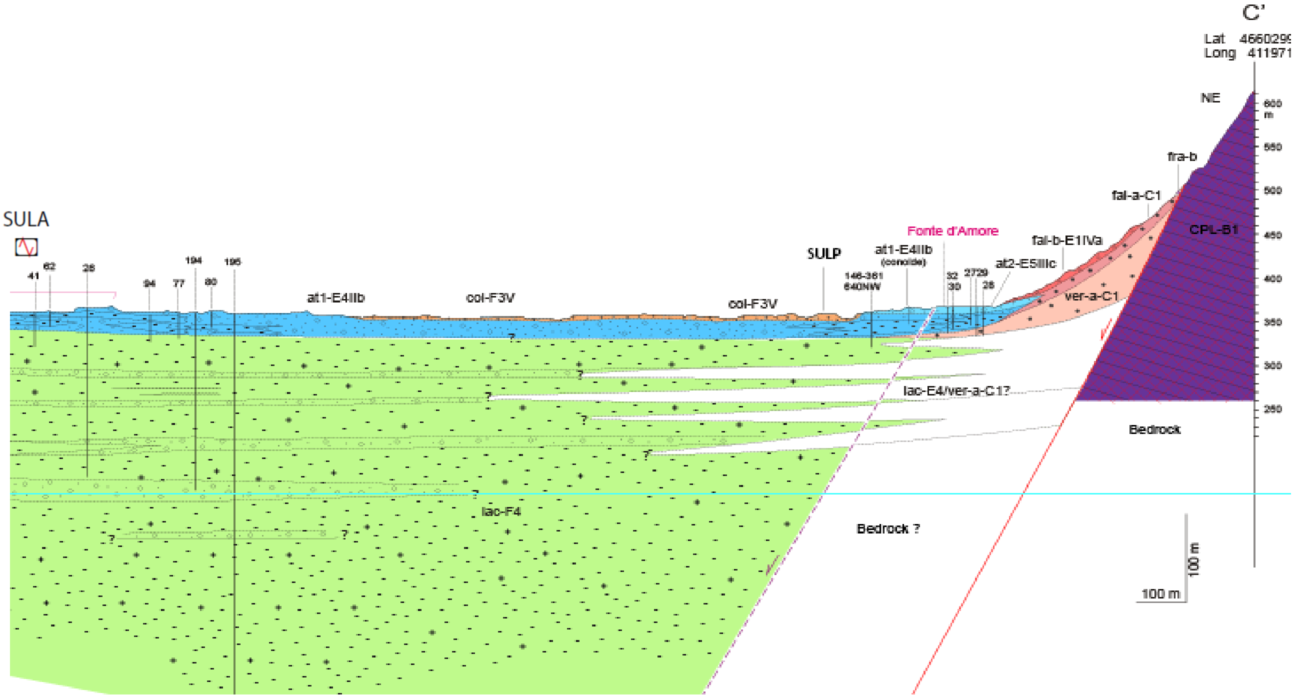

Figure 6: Schematic geological cross section, oriented NE-SW, showing the relationships between the Mesozoic carbonate bedrocks and the Quaternary sedimentary infilling of the active graben basin (Sulmona Seismic Microzonation - geological cross section C-C').

5.3 Subsoil model

A geological model to the depth of 400 m for the area surrounding the IT.SULA station was developed (Figure 7). The model is based on the extrapolation of surface data, existing geotechnical and geophysical surveys, and new geophysical investigations, performed by the INGV Working Group, for the seismic characterization of the site and the definition of the velocities profiles of the body waves.
The subsurface model is well constrained for the first 30 - 40 m of subsurface, thanks to the correlation of several continuous coring probes, available near the seismic station. The deeper part of the model is reasonably well constrained, since a few deep cores (200 to 430 m in depth) are available in the study area.
The first twenty meters of subsoil consist of terraced alluvial deposits (blue in Figure 1 and 5 and 6) consisting mainly of dense to very dense gravels, and subordinate levels of consistent sandy and clayey silts.
Beneath the terraced alluvial deposits (see the geological sections C-C' and M-M') there is a thick succession of silty-peaty clays, deposited into lake environments. These cohesive deposits increase their stiffness with depth.
Local sharp increases of stiffness are associated with gravel and sand layers. The alluvial and deltaic granular deposits can be at places well cemented (e.g. between 190 and 210 m depth).
No borehole in the central sectors of the Sulmona tectonic basin reaches the carbonate units forming the geological substratum.

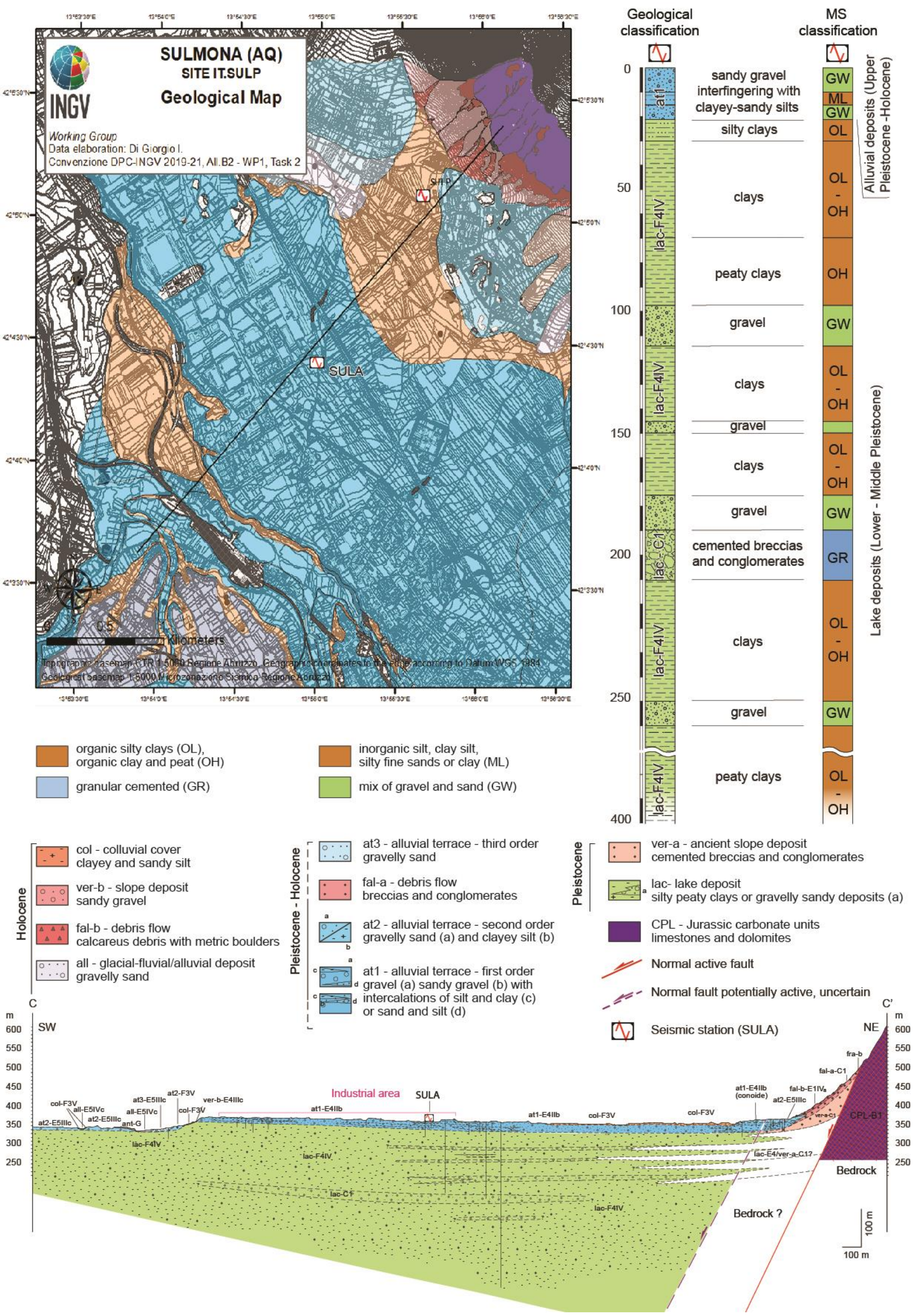

Figure 7: Bottom - Geological section crossing seismic station IT.SULA. Right - Subsoil model under the IT.SULA seismic station and classification according nomenclature of geological map of Italy 1:50.000 and according to Seismic Microzonation (SM).

B. Vs profile

B1. GEOPHYSICAL INVESTIGATIONS

IT.SULA strong motion station is located on a new developed industrial area about 3 km north of the Sulmona historical city center. The station is deployed on a small building in a flat area surrounded by cultivated fields and logistic sheds. For logistic reasons the geophysical data used to characterize the station site were collected on a field located about 300 meters apart from the strong motion station assuming a homogeneous geological setting for the two areas. To check for this hypothesis a preliminary single station ambient noise H/V measurement (HVSR) was collected in the area of geophysical investigation to be compared with the same data available at the station site. The obtained results, shown in Figure 8, are quite similar indicating a homogeneous geological condition in the area surrounding SULA station confirming the selection of the area used for the geophysical investigations.

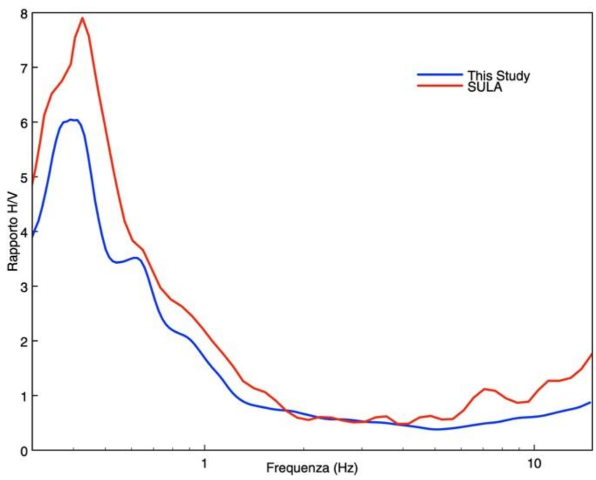

Figure 8: Comparison between HVSR available at the SULA site (red curve), and obtained at the geophysical investigations area (blue curve).

The geophysical investigations made to characterize the velocity profile at SULA site where based on:

- A 2D array composed by 12 Reftek 130 data logger equipped with triaxial velocity sensors Lennartz LE3D-5S (0.2 Hz natural frequency) in order to record the low frequency contribution to the wavefield related to the deepest part of the Sulmona alluvial basin, Figure 9. The array data were also used for single station ambient vibration analysis. The array maximum aperture was of about 300 meters.

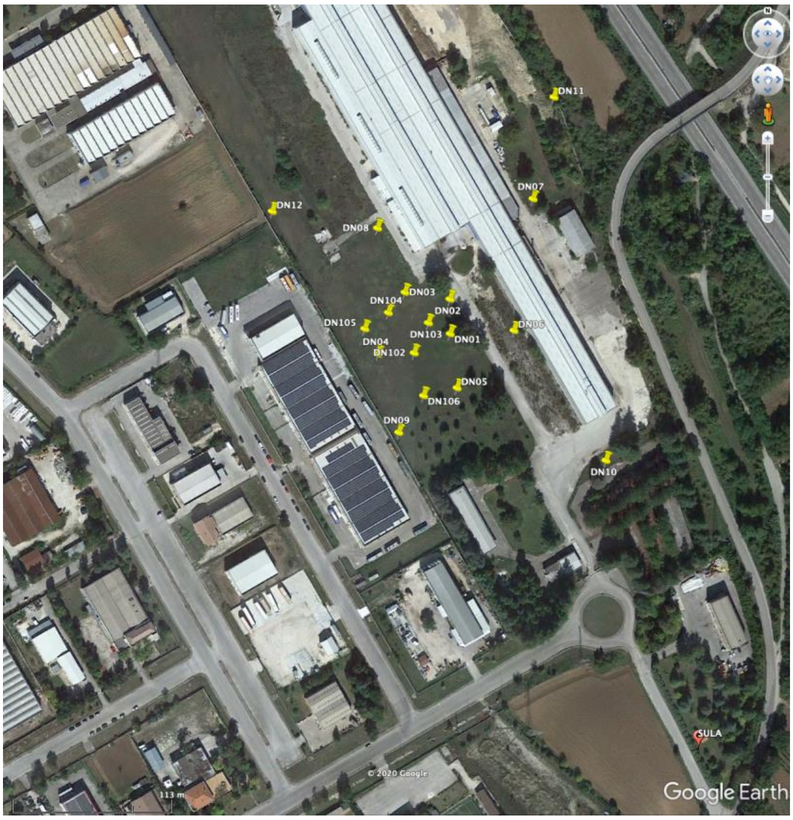

Figure 9: Plan view of the 2D array based on Reftek 130 instruments.

- A 2D array composed by 24 vertical component geophones (4.5 Hz natural frequency) deployed in two concentric circles and connected by cables to a 24 bits Geometrics Geode digital recorder, Figure 10. The radius of the two concentric circles was of 13 and 24 meters.

The data were collected on July 16,2020.

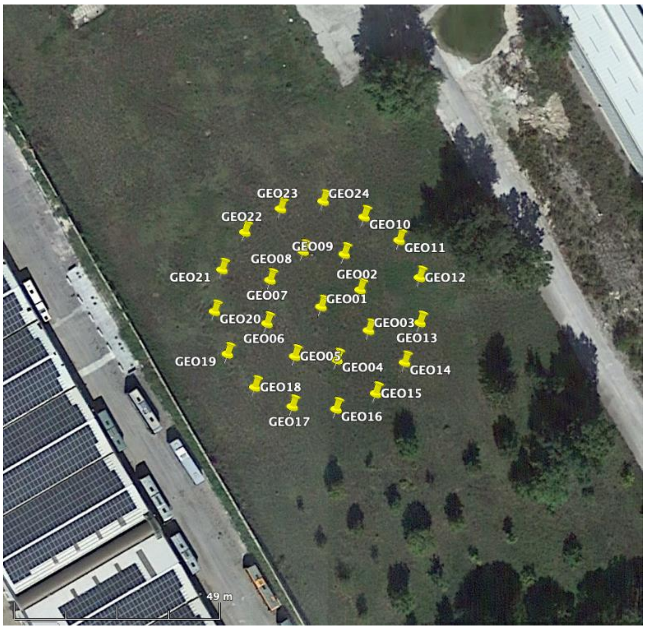

Figure 10: Plan view of the 2D array based on vertical geophones connected to Geometrics-Geode data recorder.

B2. H/V spectral ratio from temporary seismic noise measurements

The Reftek array stations were employed to evaluate HVSR at all the 12 recording sites, Figure 11 shows the obtained H/V curves. All the H/V curves are quite stable in the 0.3–15 Hz frequency band suggesting that the velocity model can be considered common to all the measuring points. A clear peak centered at around 0.4 Hz is present at all the array stations with amplitude ranging between 5.5 and 7.5. This peak can be related with a deep impedance contrast at the base of the basin. Another minor peak, with amplitude between 3.5 and 4 is also clear at a frequency of about 0.6 Hz. No peaks are visible at higher frequencies with a trend showing H/V amplitudes lower than 1 in a frequency band centered at 5 Hz. This feature suggests the absence of clear impedance contrasts in the shallow part of the basin where a velocity inversion cannot be excluded.

The rotational H/V spectral ratio, reported in Figure 12 for three of the array stations as an example, does not show any particular directional effect in the recorded data suggesting the hypothesis of an omni-directional wavefield.

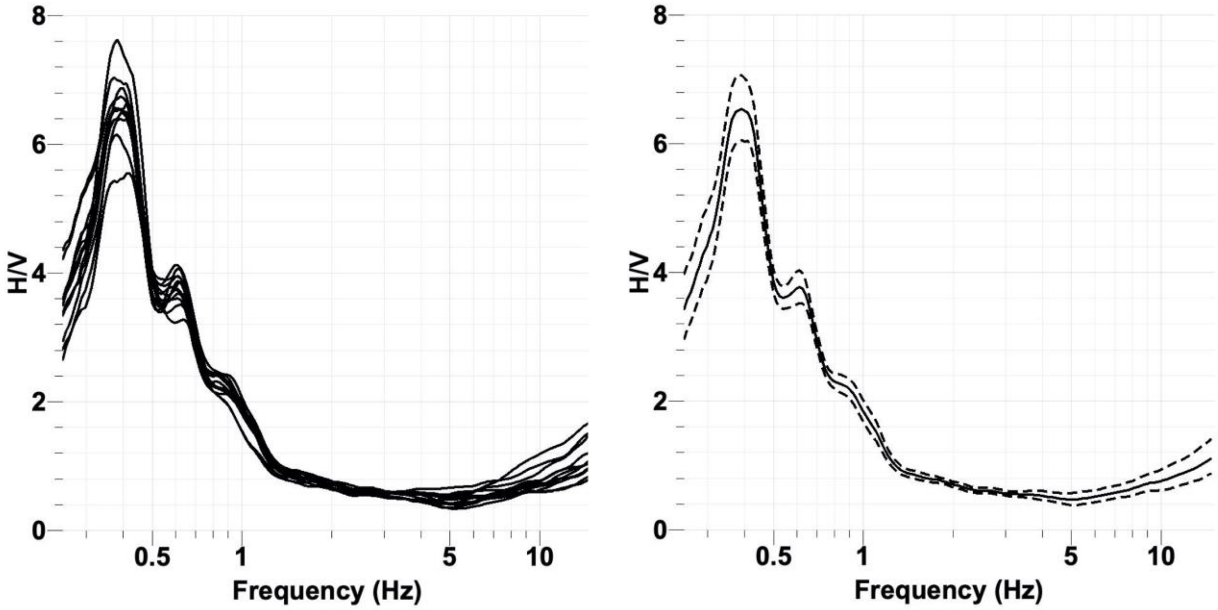

Figure 11: H/V ambient noise spectral ratio for the 12 Reftek instruments (left); average H/V curve, along with its standard deviation, (right).

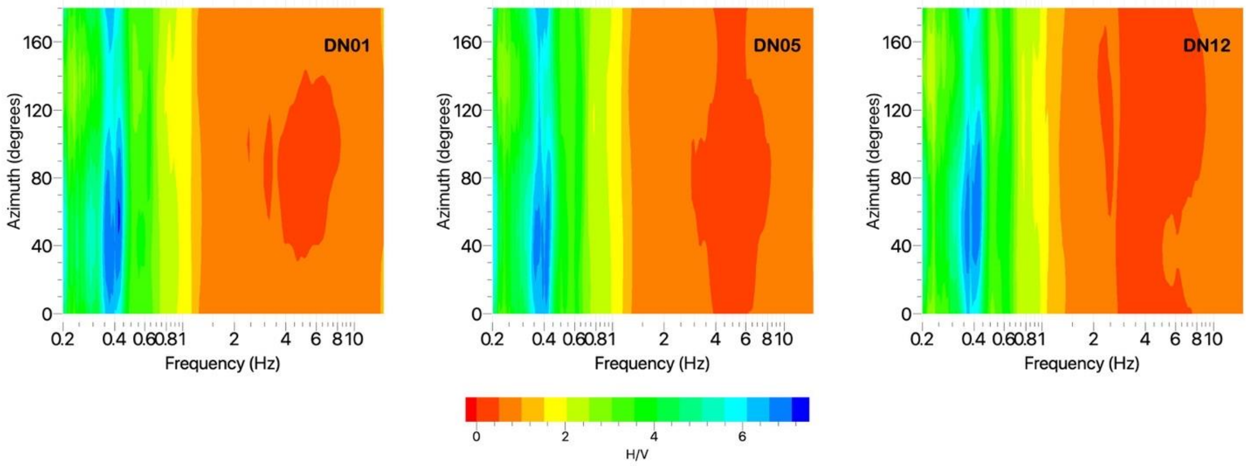

Figure 12: Rotational H/V ambient noise spectral ratio for three of the Reftek stations.

B3. Results from 2D Reftek Array

The Reftek instruments were running in continuous mode recording during a several hours time window. It was possible to cut a synchronized common time window of two and a half hours to be analyzed in terms of: high resolution frequency-wavenumber (HRFK) analysis on the vertical component of ambient vibration (Capon, 1969); three components frequency-wavenumber analysis (FK3C), (Neidell et al., 1971); Extended Spatial Autocorrelation analysis (ESAC), (Aki, 1957; Bettig et al., 2001). The results were interpreted in terms of both Rayleigh and Love surface-waves using the software Geopsy (http://www.geopsy.org).

The results, presented in Figure 13, show for Rayleigh waves, a clear dispersion curve in the 1.5 – 9.0 Hz for the FK analysis and in the 1.5 – 4.5 Hz for The ESAC approach. All the techniques produce similar results confirming the good quality of the recorded data. The velocity decrease from about 600 m/s to less than 300 m/s moving towards high frequencies.

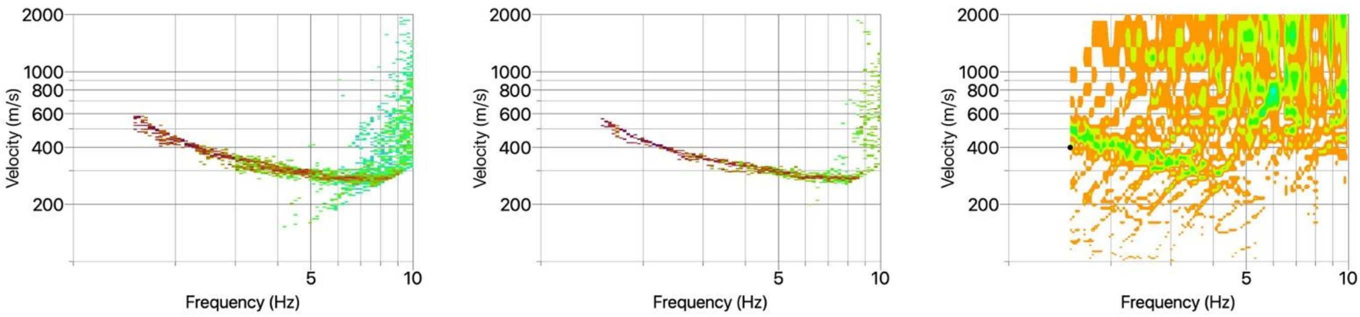

Figure 13: Rayleigh waves dispersion curve for Rektek array using different techniques: trhee components FK analysis (left); High resolution FK (center); ESAC (right).

The dispersion curve obtained for Love waves is less evident but still visible in the 1.5 – 4.0 Hz frequency band (Figure 14). In this case the velocity decreases from about 450 m/s to 350 m/s moving towards high frequencies.

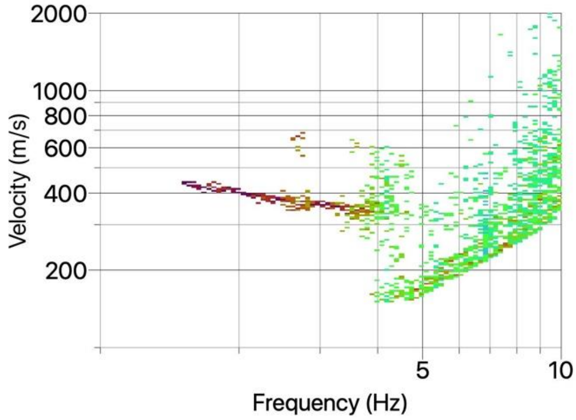

Figure 14: Love waves dispersion curve for Rektek by three components FK analysis.

B4. Results from 2D Geophones Array

The geophones array data were recorded, at a sample rate of 250 sample/s during 39 four minutes long recording windows, for a total recording length of 156 minutes. Data were then merged in a unique Sac (Seismic Analysis Code), (Goldstein et al., 2003), format data file and analyzed in terms of conventional high resolution and conventional frequency-wavenumber analysis to the vertical component of ambient vibration. Also the ESAC technique was applied. The results were interpreted in terms of Rayleigh surface-waves (http://www.geopsy.org). Figure 15 shows the dispersion results. For FK technique a dispersion curve is visible in the 4 - 20 Hz frequency interval with velocity values slowly decreasing from about 300 m/s to 250 m/s. ESAC results also show a dispersion curve in the range 3 – 15 Hz with velocity varying in the 300 – 250 m/s interval. Also in this case all applied techniques give similar results.

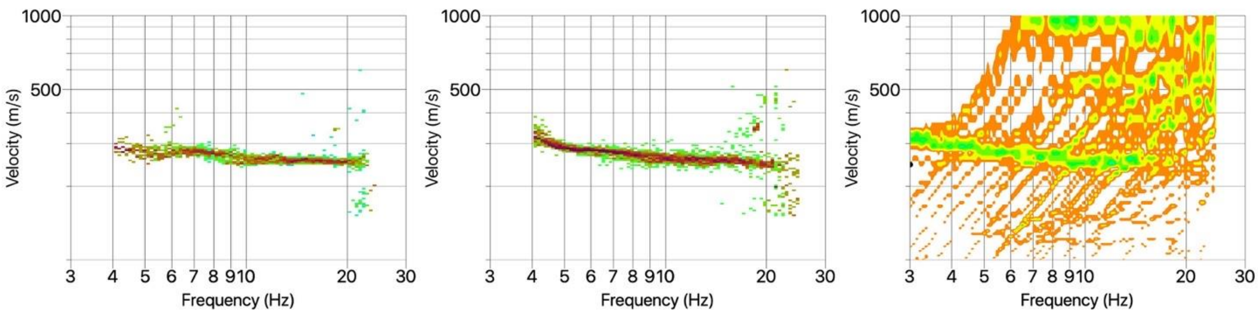

Figure 15: Rayleigh waves dispersion curve for Geophones array using different techniques: FK analysis (left); High resolution FK (center); ESAC (right).

B5. Dispersion curve selection

The good quality of the recorded data and the similarity between the results obtained using different approaches allows to put together 2D and geophones array data to obtain a unique dispersion curve for Rayleigh waves. This curve is well defined in a wide frequency range (1.5 – 20 Hz) with velocity decreasing from 500 to about 250 m/s moving towards high frequencies (Figure 16). At low frequencies ESAC dispersion curve is slightly slower than FK curves, as often observed in experimental data. For this reason, the final dispersion curve to be inverted was picked following the ESAC data at low frequencies. For Love waves we selected the only curve available (Figure 14).

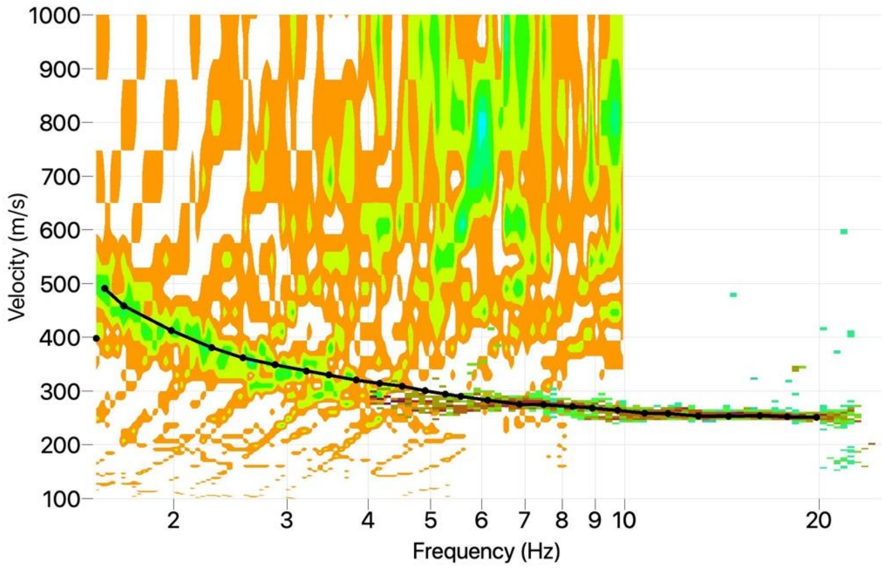

Figure 16: Rayleigh dispersion curve obtained by the combination of all the applied techniques analysis.

B6. 1D seismic velocity model

The selected dispersion curve has been associated with the fundamental mode of Rayleigh and Love surface-waves. In order to enlarge the frequency band to be used in the inversion procedure and, as a direct consequence the investigation depth, we performed a joined inversion of both Rayleigh and Love waves dispersion curve and H/V spectral ratio curve interpreted as Rayleigh waves ellipticity curve and peak. The parametrization was chosen in order to describe the sedimentary layers described in the geological section. The initial model is based on an outcropping soft soil surface low velocity overlying a sandy gravel layers with maximum thickness of 30 meters. A constraint was put to the gravel thickness tacking into account the data obtained in a cross-hole test performed between the array area and the SULA station site. Below the gravel layer the lacustrine clay unit was parameterized with three over imposed layers with increasing velocity. A velocity inversion is allowed at the gravel – clay interface. The model bedrock is constituted by limestone at a depth that can reach the value of some hundred meters. The results of the inversion are shown in Figure 17 in terms of fit between measured and inverted dispersion and ellipticity curves. The quality of fit is quite good for all the three used target curves.

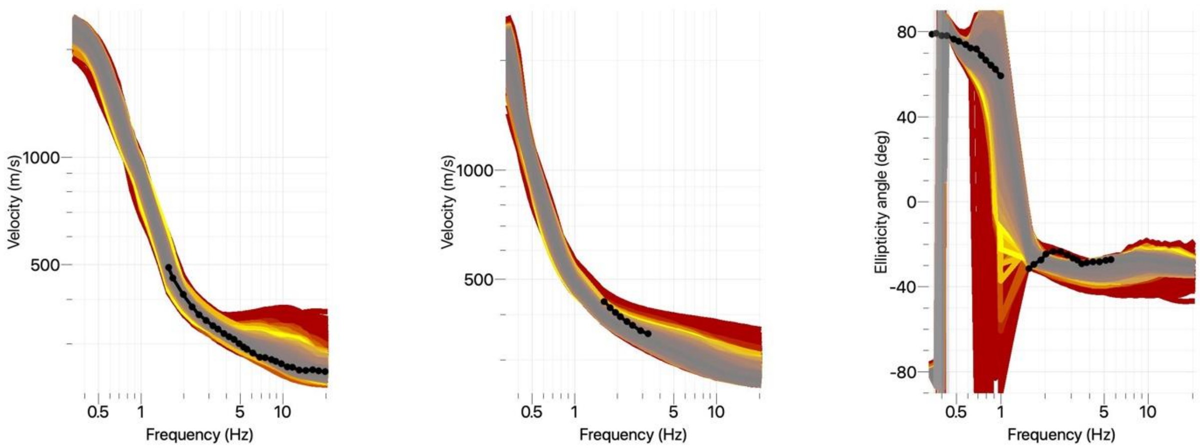

Figure 17: Fit between observed and modelled: fundamental mode Rayleigh waves dispersion curve (left); fundamental mode Love waves dispersion curve (center); ellipticity curve associated to Rayleigh waves dispersion fundamental mode (right).

The inverted velocity models are shown in Figure 18 in terms of both Vp and Vs values. The best inverted model shows a surface 10-15 meters thick layer characterized by a velocity of about 250 m/s. The underlying gravel layer is characterized by velocity in the 450 – 600 m/s range and a few meters thickness. The clay layers show a velocity value starting from about 320 m/s and increasing to about 600 m/s at a depth of 160 – 200 meters where a discontinuity is found with a step in velocity that raises up to more than 1000 m/s. The bedrock interface is found at depth between 600 and 700 meters, with an uncertainty due to the lowering of resolution typical of surface waves approach. The obtained results are in agreement with available data, in particular the cross hole results show a velocity inversion at the gravel – clay interface with gravel velocity higher than 500 m/s and clay initial value slightly higher than 300 m/s. A 400 meters deep borehole located in the vicinity of the investigation area cannot reach the bedrock confirming the high thickness of the alluvial filling of the valley in the investigation area.

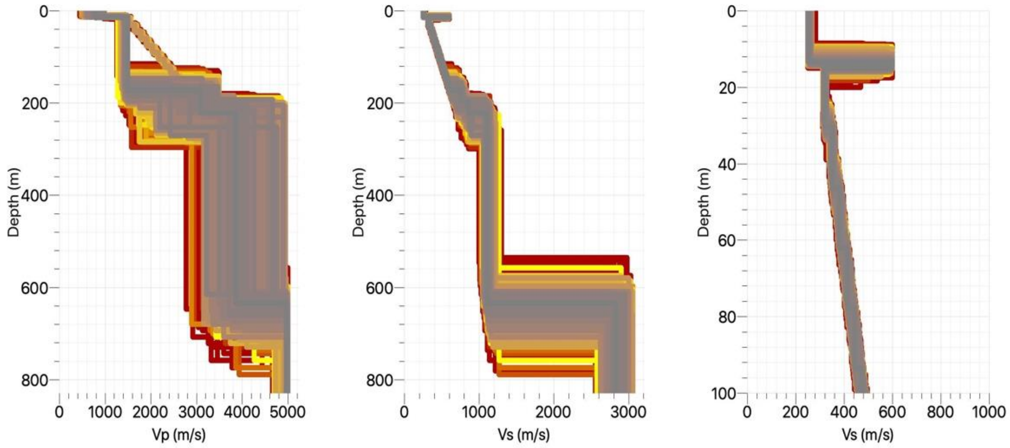

Figure 18: Inverted velocity models for Vp (left) and Vs (center). The right panel refers to the Vs profile in the first 100 meters.

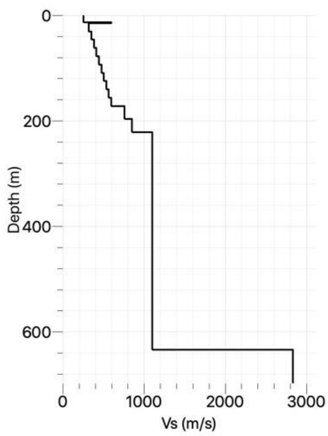

Figure 19: Best Vs model derived from the inversion procedure.

The best Vs model derived from the inversion is presented in Figure 19 and in Table 1, these data can be used for evaluating the soil class for SULA station.

From (m)	To (m)	Thickness (m)	Vs (m/s)	Vp(m/s)
0	13	13	256	780
13	15	2	595	1491
15	30	15	321	1500
30	45	15	352	1500
45	60	15	382	1500
60	75	15	413	1500
75	90	15	444	1500
90	105	15	474	1500
105	120	15	505	1500
120	135	15	536	1500
135	150	15	566	1500
150	165	15	597	1500
165	190	25	758	3082
190	215	25	854	3082
215	627	412	1102	3860
627			2831	4965

Table 1: Parameters of the best model derived from the inversion procedure.

B7. CONCLUSIONS

Surface-wave analysis at IT.SULA station indicates a site of soil class C (Table 2).

Ambient vibration H/V spectral ratio shows a clear and stable peak at low frequency (0.4Hz) and not secondary peaks at higher frequencies. The joint inversion of dispersion and ellipticity curves provides the best Vs models of Figure 19 with the bedrock layer at a depth of about 627 meters and a impedance contrast at a depth of about 160 - 200 meters indicating some possible variation in the characteristics of the clay layer characterizing the major unit in the basin.

A particular attention must be addressed to the shallow gravel layer responsible for a velocity inversion in the first meters of the stratigraphic column. Its presence is clear in the cross-hole site located close to the array area but it is not so evident analyzing the dispersion curves obtained in this study. In the best model proposed by the inversion the gravel thickness is quite small, about 2 meters, but, considering the errors associated to the inversion process, a higher value of gravel thickness can also be considered possible. In any case the thickness of about 20 meters for the outcropping gravel layer proposed by the cross-hole results is not compatible with the array results. The presence of a low velocity outcropping layer is strongly suggested by surface waves data indicating an inhomogeneity on the characteristics of the gravel layer reported as outcropping in the cross – hole data.

The VS_{30} retrieved from the best inverted model is 297 m/s (Table 2), then IT.SULA station can be classified following EC8 or NTC08 as soil class C.

V_{S30} (NTC08 or EC8)	Soil Class
297 m/s	C

Table 2: Soil class following NTC08 and NTC18.

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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]	0.4
Quality index 1	1

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]
16/07/2020	200 (minimum di	42.075793	13.914439

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 (+	0.2 (4.5)
Digitizer	Type	Manufacturer	Sampling frequency [Hz]
	Reftek130(+	Reftek(+ Ge	250
Measurement	Number	Duration [min]	
	12	180	

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	Epicentral distance [km]		Magnitude range	
from	to		from	to	from	to

HVSR

Seismic phase	P	S	Coda	S + coda	All

window duration [s]	Min	Max

SSR

Seismic phase	P	S	Coda	S + coda	All

window duration [s]	Min	Max

Reference station	Lat. (WGS84)	Lon. (WGS84)

GIT

Parameters	Free (to be inverted)	Imposed
Reference paper		

Reference station	Lat. (WGS84)	Lon (WGS84)

Vs30

Vs30 +/- STD [m/s]	297
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			
Reference relationship Vs30-Stratigraphic log			

Digital Elevation Model

Vs30 +/- STD [m/s]				
DEM resolution		Slope range	from	
			to	
Reference relationship Slope - Vs30				

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
16/07/2020	200	300	42.075793	13.914439

Active surface waves acquisition layout

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

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

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

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

Passive surface waves acquisition layout

Number of sensors	12 (24)
Minimum array aperture	10
Maximum array aperture	200
Number of arrays	2
Minimum duration [min]	90

Sensor cut-off frequency (Hz)	0.2 (4.5)
Sensor type (vertical / horizontal)	3C velocimeter
Sensor manufacturer	Lennartz (+ Geo
Digitizer type	Reftek130 (+Geo
Digitizer manufacturer	Reftek (+Geome

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	✔	3C-FK on passive data (geopsy code)
Love DC	✔	3C-FK on passive data
Ellipticity	✔	3C FK (RTBF)
H/V (DFA, EHVR)	☐	
H/V (SH)	☐	

Dispersion curves

	Rayleigh	*Love*
Min wavelength (m)	15	
Max. wavelength (m)	350	
Min. phase vel. (m/s)	280	
Max. phase vel. (m/s)	500	
Modes (R0, L0, ...)	R0, L0	

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: para

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.	

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

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

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

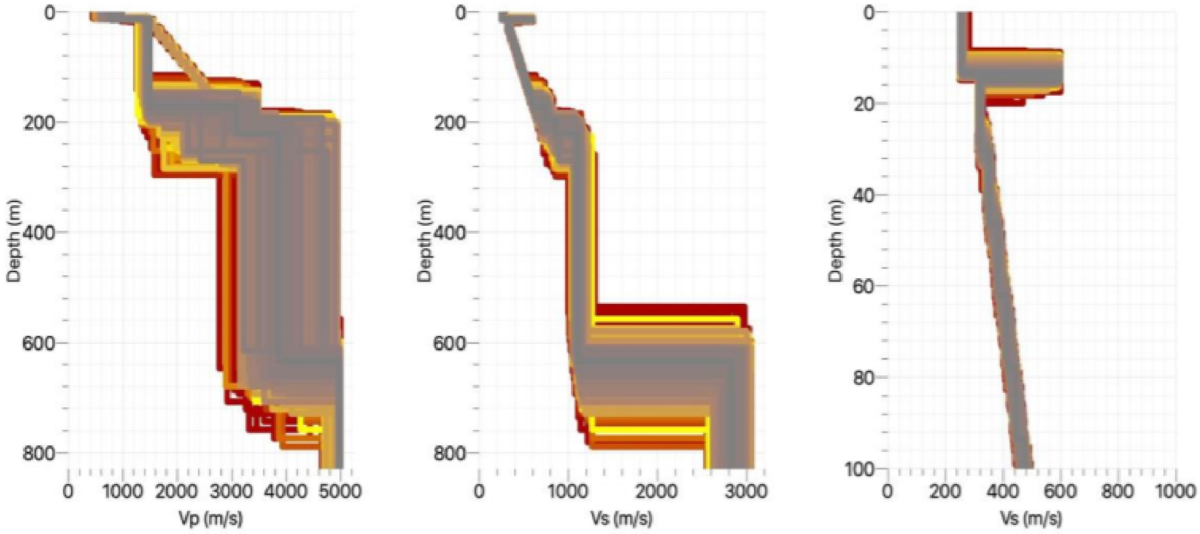
Note: You do not have to fill in all the columns. You can provide either single values for Vp or Vs (e.g. profiles derived from borehole measurements) or either a range for Vp and Vs (e.g. profiles derived from stochastic surface waves inversion)

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	13	780		256	
13	15	1491		595	
15	30	1500		321	
30	45	1500		352	
45	60	1500		382	
60	75	1500		413	
75	90	1500		444	
90	105	1500		474	
105	120	1500		505	
120	135	1500		536	
135	150	1500		566	
150	165	1500		597	
165	190	3082		758	
190	215	3082		854	
215	627	3860		1102	
627		4965		2831	

Vs range		Vp range	
Vs min (m/s)	Vs max (m/s)	Vp min (m/s)	Vp max (m/s)

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 geological map of Ita
Map scale		1.5000
Map sheet		n. 369 (Sulmona)
Predominent geologic/lithologic unit	Name :	terraced alluvial deposits (at1)
	Description :	dense to very dense gravels, and subord
	Age :	Middle-Upper Pleistocene
	Thickness :	about 20 m
	Rock mass structure :	-
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 :	terraced alluvial deposits (at1)
	Description :	dense to very dense gravels, and subord
	Age :	Middle-Upper Pleistocene
	Thickness :	about 20 m
	Rock mass structure :	-
Fault presence		
Weathering		
Cross-section		✔

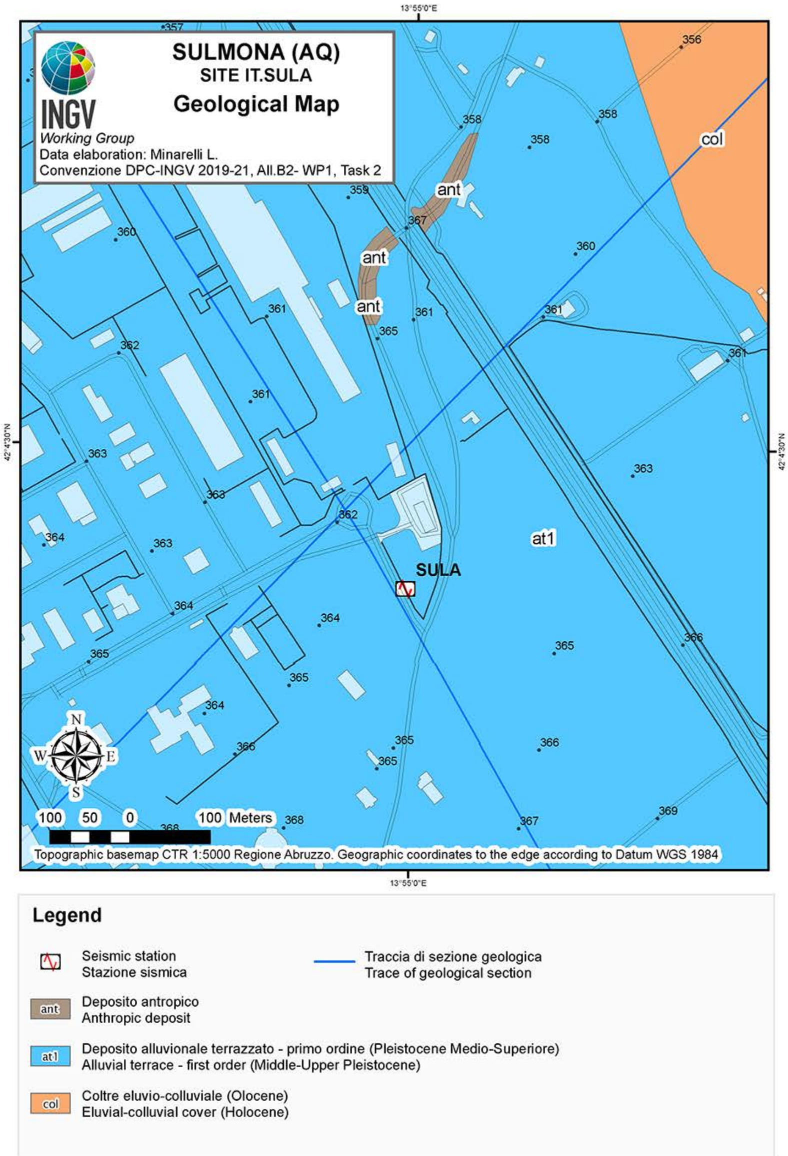
Stratigraphic log

log depth (m)	

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

Surface geology

Map



Site class

Site class	C
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]	627
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)	627 +/- 100		
Bedrock Vs +/- STD(m)	627 +/- 100		
Bedrock Vp +/- STD(m)	627 +/- 100		
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]	190
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)	190		

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	