ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Site characterization report at the seismic station IT.SSU – Sassuolo (MO)

Report di caratterizzazione di sito presso la stazione sismica IT.SSU – Sassuolo (MO)

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

Convenzione DPC-INGV 2019-21, All. B2- WP1, Task 2: "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 IT.SSU (Sassuolo).

Location and coordinates are reported in Table 1.

Table 1

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IT.SSU	Sassuolo	44.507027 *	10.784814 *	407 **
ADDRESS	Via per il Castello, 1, 41049 Sassuolo (MO), Italy			

* Coordinates from ITACA (Nov. 2020) ** Elevation from CTR 5k Regione Emilia-Romagna

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.

Topography	Description	Topography Class	Morphology Class	EC8 Class
	Slope with average slope angle i>15°	T2	SL	B

Table 2

* Reference table from ITACA (Nov. 2020)

Table 3

Geological map	Source	Scale
IT.SSU	Geological map of Italy sheet 086 (Modena)	1:100.000
IT.SSU	Geological map of Italy sheet 219 (Sassuolo)	1:50.000
IT.SSU	Geological map from Emilia-Romagna Region database	1:10.000

In Table 4 Geological, Lithological 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		**LITHOLOGICAL UNITS**		**LITHOTECHNICAL UNITS**	
(10k Regione Emilia-Romagna) *original*		(Amanti *et al.*, 2008) *deduced*		(MZS) *deduced*	
code	**description**	**code**	**description**	**code**	**description**
TER2	Sandstone, marl	A10	Pelite-sandstone alternance	ALS	Stratified bedrock

A2. GEOLOGICAL MAP

In Figure 1 Geological Map is reported in a 1 $km \times 1$ km square around the station.

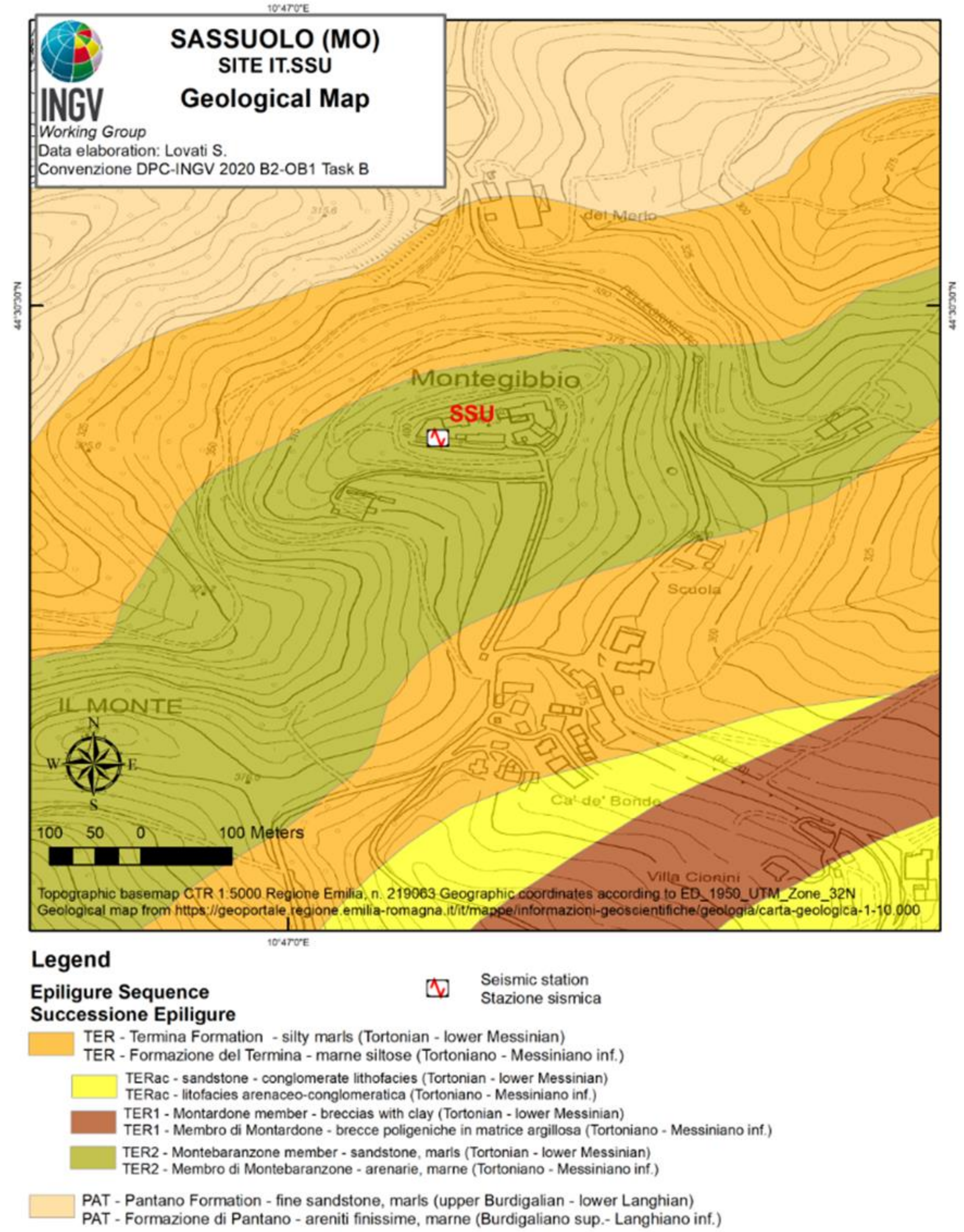

Figure 1: Geological map of seismic station IT.SSU. Scale 1:5.000. Geological units are established according to the nomenclature of geological map 1:10.000 of Emilia-Romagna Region.

A3. LITHOLOGICAL MAP

In Figure 2 Lithological Map is reported in a 1 $km \times 1$ km square around the station.

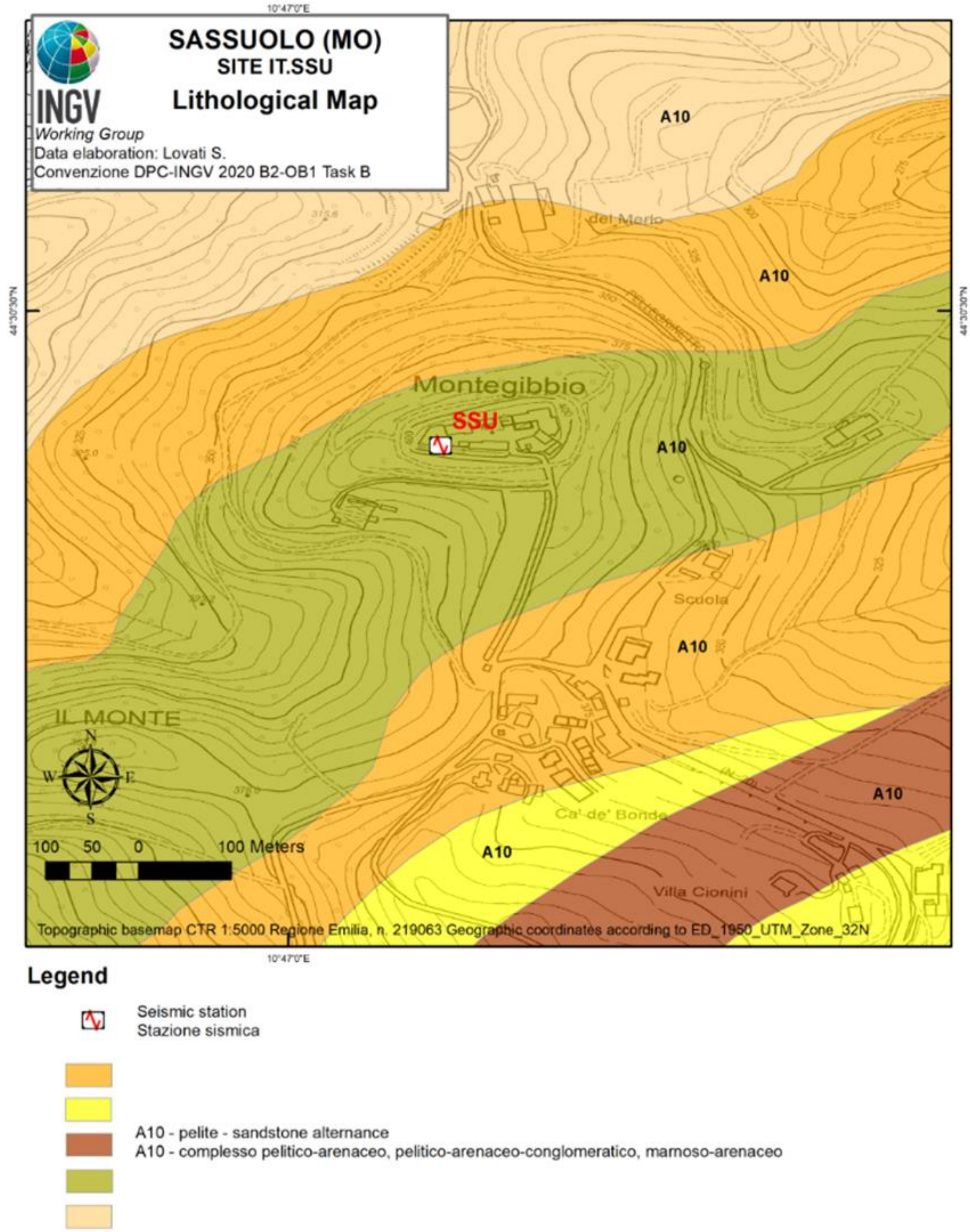

Figure 2: Lithological map of seismic station IT.SSU. Scale 1:5.000. The codes of the lithological units are assigned according to the nomenclature of the Lithological map ISPRA 1:100.000 (Amanti *et al.*, 2008).

A4. LITHOTECHNICAL MAP

In Figure 3 Lithotechnical Map is reported in a 1 $km \times 1$ km square around the station.

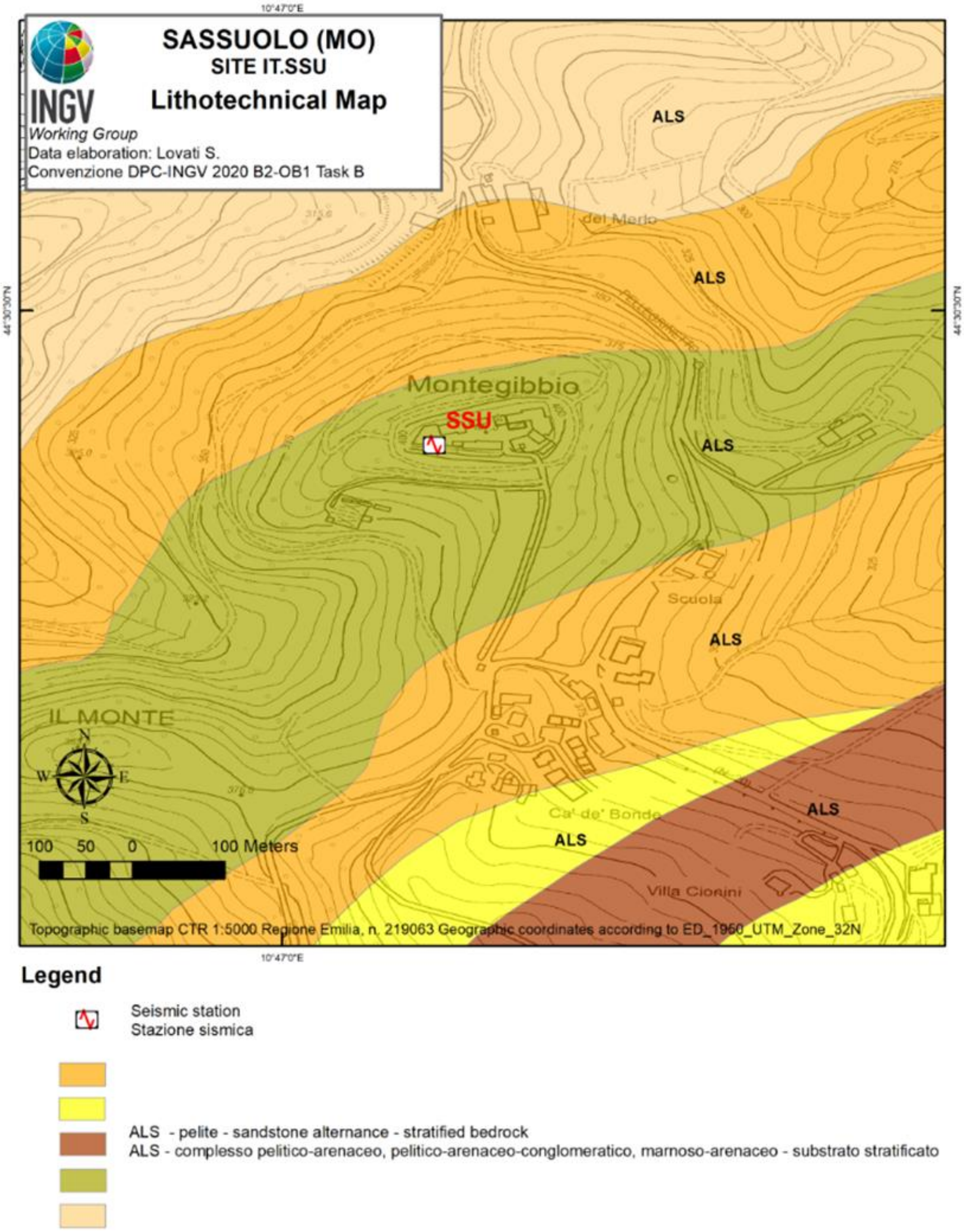

Figure 3: Lithotechnical map of the seismic station IT.SSU. Scale 1:5.000. The lithotechnical units are deduced according to the nomenclature of Seismic Microzonation (Technical Commission SM, 2015).

A5. SURVEY MAP

Figure 4 shows the Survey Map reporting both previous investigations and geophysical surveys conducted by INGV Working Group.

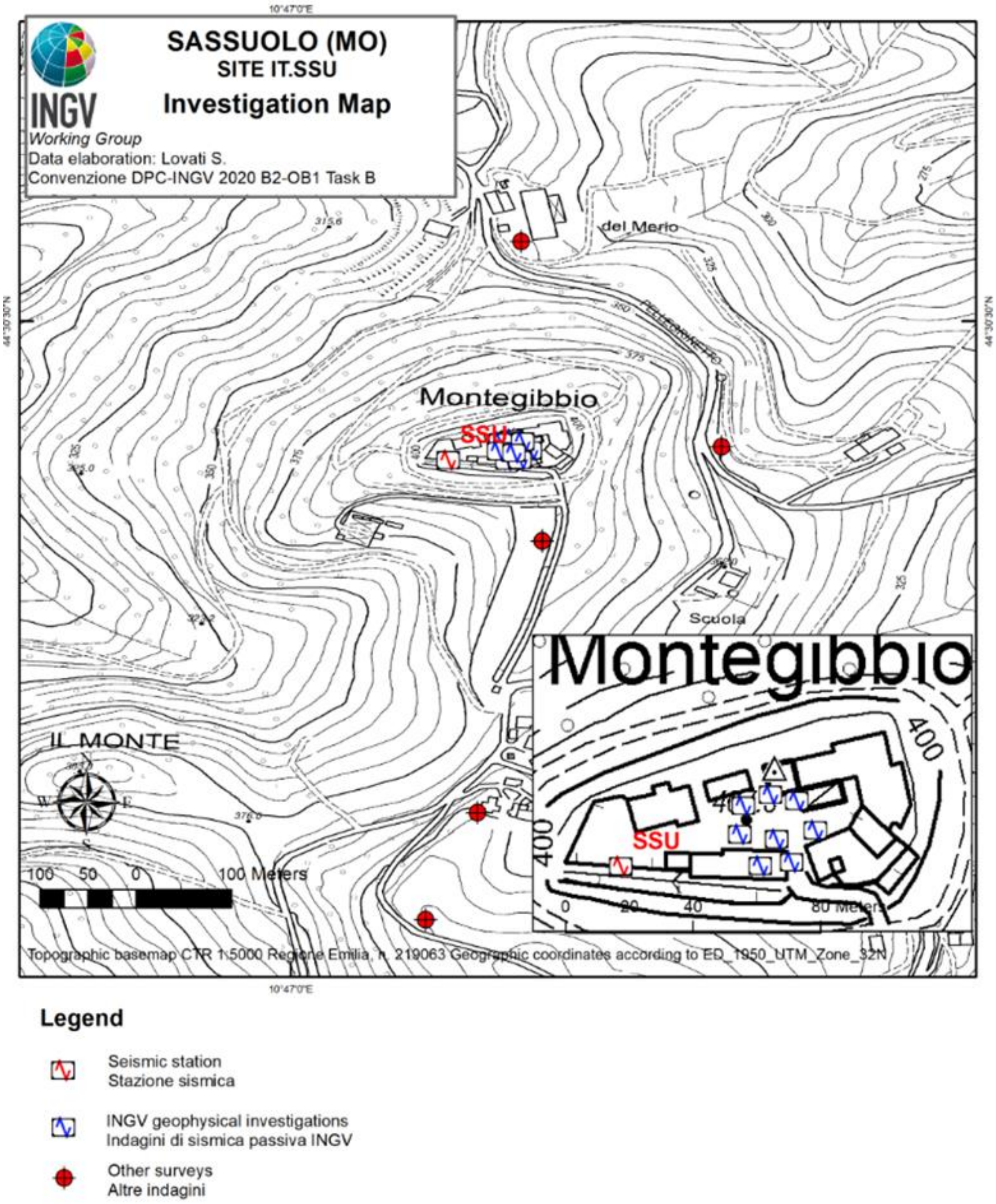

Figure 4: Map of the surveys in the surroundings of the station IT.SSU. Scale 1:5.000. The box at the bottom right contains a zoom of the area with the detail of the geophysical 8-stations array conducted by INGV Working Group for the seismic characterization of the site (Agreement DPC-INGV 2019-21, All. B2, WP1 - TASK 2, Velocity profile report IT.SSU).

A6. GEOLOGICAL MODEL

6.1 General description

The studied area belongs to Sassuolo Municipality and is a 400 m a.s.l. hill at the top of which the ancient Montegibbio Castle (X century) is located. The hill presents a slope with a degree higher than 30°. In the court of the castle the RAN IT.SSU station is installed. The castle is southern and 5 Km far from Sassuolo Municipality.

Sassuolo is part of the high Modenese Plain that develops on the edge of the Northern Apennines, characterized by Plio-Pleistocene clayey successions that are, together with the others marine formations, the substrate the river deposits of Secchia River and others streams. The deep geology of the area is mostly known through data provided by surveys carried out in the context of hydrocarbon exploration. The front of the Apennine chain does not coincide with the chain-plain morphological limit but is identifiable in the deep structures (Emilian and Ferraresi folds) buried by the Quaternary sediments of the Po Valley: the northern Apennines is a chain of thrusts belonging to the Alpine system, formed for the interaction between the African and Eurasian plate.

It is from the upper Oligocene that the formation of the northern Apennine chain begins through a deformation process in which two phases can be distinguished: during the first, which develops from the upper Oligocene to the lower Pliocene, the arc structure of Northern Apennines is defined, while in the second phase, starting from the Middle Pliocene, the external sector of the chain is involved, with a jumping of the overall front which is also accompanied by a change in the lithology of the sediments that characterize the foredeeps. The subsequent withdrawal of the waters from the Po plain Gulf took place with intense tectonic movements that led to the lifting of the Apennine chain and subsidence of the plain and gave rise to the geological structure that is found in the foothills and in the Po Valley.

The territory of the Municipality of Sassuolo can be divided from the lithological and morphological point of view in two distinct parts: the north part and the south ones towards the hilly area of our studies.

From the comparison of the stratigraphies of the water wells in the south-west area, close to the hill, the thickness of alluvial sediments is normally less than 10 meters, while in the north area the thickness of alluvial deposits is of the order of many tens of meters.

The I and II level microzonation of the municipal territory show two geological models of reference: the first coincides with the conoid area of the Secchia River in which Quaternary sediments of continental origin (Upper and Lower Emiliano Romagnolo Synthem) characterized by gravels in silt-sandy matrix, emerge; the second one is morphologically coincident with the hilly area characterized by the outcrop of the marine substrate (Argille Azzurre Formation, Termina Formation and Clay Breccias of Baiso).

In detail, Montegibbio Castle is built on the Termina Formation (TER, Tortonian-lower Messinian) in particular on Montebaranzone Member (TER2, Tortonian-lower Messinian). It is a marine formation formed by alternations between medium-coarse arenaceous layers alternating with marls (turbidites). Strata dip almost vertically towards SE. Laterally, Montebaranzone Member passes to the Termina Formation (TER), that is mainly constituted of clayey-silty gray marls with little stratification.

6.2 Geological Section

Closing at IT.SSU station a schematic geological section A-A' crossing the RAN seismic station IT.SSU from NNW to SSE (Figure 5 bottom) following the dipping of layer towards SE.

Starting from NNW the section crosses the Pantano Formation (PAT, upper Burdigalian-lower Langhian), the Termina Formation (TER, Tortonian-lower Messinian) composed by clayey-silty gray marls and Montebaranzone Member (TER2, Tortonian-lower Messinian) that are marine formations formed by alternations between medium-coarse arenaceous layers alternating with marls (turbidites). In the area around the IT.SSU station, strata dip almost vertically towards SE.

6.3 Subsoil model

A subsoil model is built up to a depth of 50 m in the area around the IT.SSU station on the basis of geological information from literature, from public databases and in particular from a recent geological-geophysical survey performed at Montegibbio castle in occasion of its restoration.

The comparison between the data obtained from 5 core surveys and from passive geophysical investigation (8 station array), highlighted the presence of three layers as seismic prospection showed.

The most superficial part, apart some bricks within the first 40-60 cm in depth, is characterized by fine silty / clayey sandstones alternating with macro-fissured marls (with frequent levels of calcification due to the solution and resedimentation of the carbonates and / or ferrous minerals). The sequence described is up to 4-5 m in depth.

The second level shows the same sequence of lithotypes but the sandstones become slightly coarser and have calcarenitic intercalations while the alteration of the marls is less pronounced. This level is up to 10-15 m in depth.

The third layer is rich in silty, sandy and marly part and have a high degree of compactness.

The fifth survey differs from the other ones, since after 4-5 m of alternations between altered marls and fine sandstones, it shows a predominantly marly subsoil.

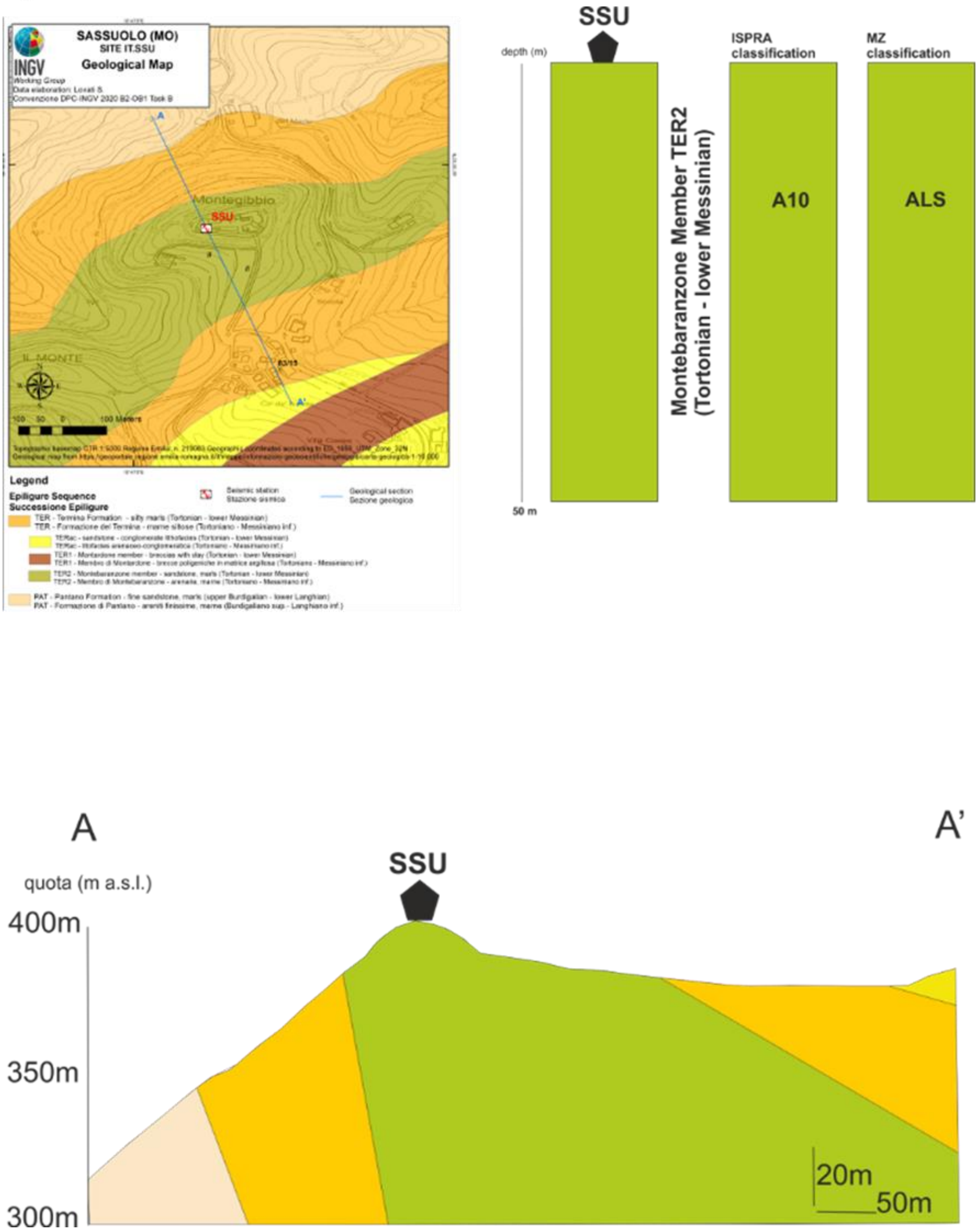

Figure 5: Bottom: Geological section A-A' crossing seismic station IT.SSU. Top right: Subsoil model under the IT.SSU seismic station and classification according to ISPRA: A10: pelite-sandstone alternance; according to MZ (deduced): ALS: stratified bedrock.

B. Vs profile

B1. GEOPHYSICAL INVESTIGATIONS

Geophysical measurements executed next to the station IT.SSU (Italian Accelerometric Network, RAN-DPC) consist in ambient-vibration measurements in both single-station and 2D array configuration that provide results in terms of resonance frequency of the soil deposits and in terms of dispersion curves of surface waves. These curves are inverted to obtain a shear-wave velocity (Vs) profile that is suitable for assigning the soil class according to the current Italian seismic code (NTC 2018) and the current Eurocode (EC8).

Figure 6 shows the location of the station IT.SSU (Latitude 44.507027, Longitude 10.784814 WGS84) installed inside an ENEL transformation cabin. The seismic sensors were positioned in a circular geometry with a radius of 15 m, in order to have a homogeneous azimuthal coverage that allows a better performance of the array techniques.

Figure 6: Map of the geophysical measurements performed at the IT.SSU site. The white placemarkers in circular geometry are the 8 stations of the 2D array in passive configuration. The red triangle indicates the IT.SSU accelerometric station (image from Google Earth http://www.earth.google.com).

Figure 7: Left: IT.SSU accelerometric station installed on a concrete insulated pillar inside an ENEL transformation cabin (Montegibbio Castle, Sassuolo). Upper right: single station ambient noise measurement performed at IT.SSU station. Bottom right: 2D passive ambient noise array installed close to the SSU station.

Both for single and 2D array passive measurements, the ambient noise vibrations have been acquired with Lennartz-5s velocimetric sensor coupled to the Reftek-130 (24 bits) digitizer. For 2D passive array the measurement has duration of about two hours. The sampling rate was set to 200 sps.

To assess the resonant frequency at IT.SSU station, the horizontal-to-vertical spectral ratio (H/V) has been calculated, using the *Geopsy* software (http://www.geopsy.org). The H/V analyses show a first broad peak around 2.75 Hz (f_0), with amplitude lower than 3 and secondary peaks with amplitude around 2 in the frequency range 10 to 25 Hz. The directional H/V shows for the f_0 a slight polarization around 140°N.

The results are summarized in figure 8.

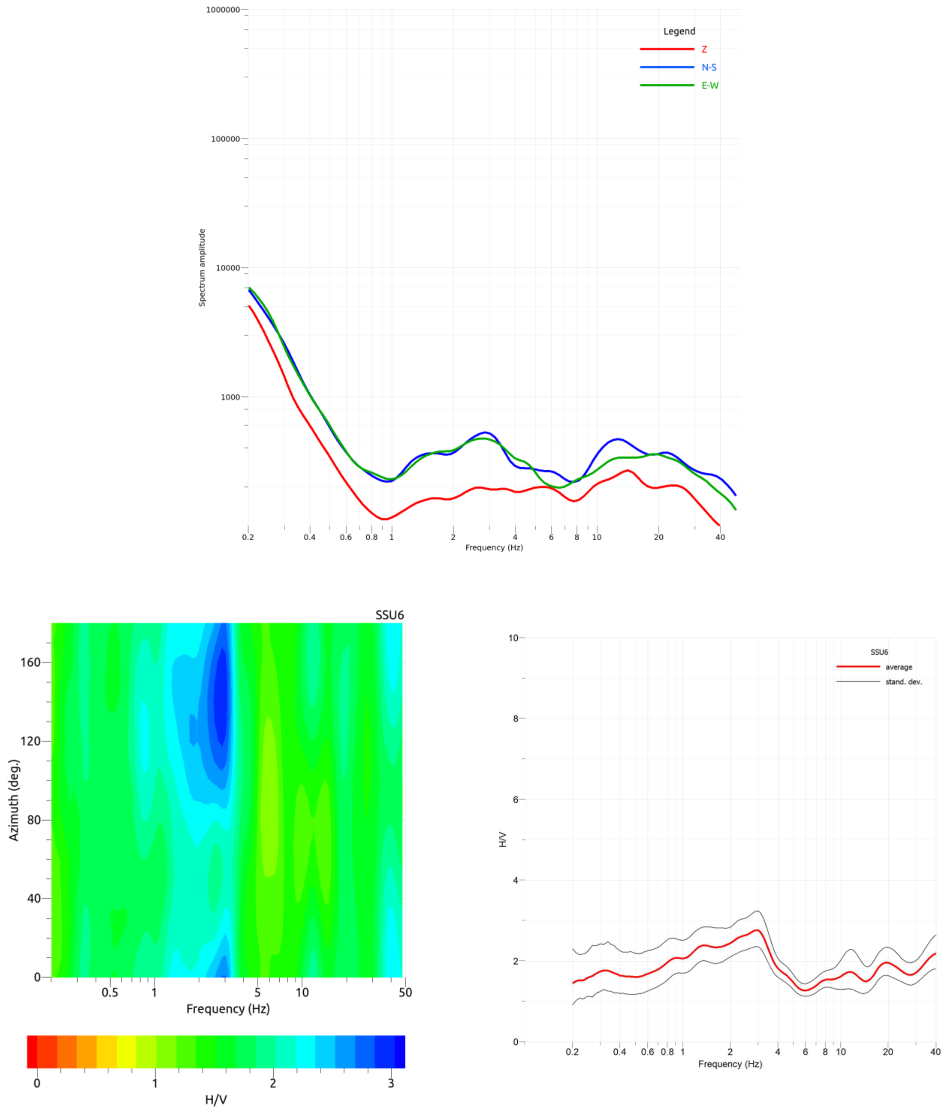

Figure 8: H/V results at IT.SSU station. Top: Fourier spectra of the three components. Bottom left: directional H/V. Bottom right: H/V curve (with mean and standard deviation in red and grey respectively).

Data from the 2D array have been analyzed with the GEOPSY code (http://www.geopsy.org) in terms of high-resolution FK analysis. In this case other methods (e.g MSPAC or ESAC) do not provide reliable results. The FK dispersion curve (in this case not clear), obtained from the vertical components, is shown in Figure 9. We interpret and assume that the dispersion curve is relative to the fundamental mode of the Rayleigh dispersive waves. The aliasing conditions (black lines) constrain the validity range of the picked dispersion curves in a narrow frequency range, included in the interval 10-15 Hz.

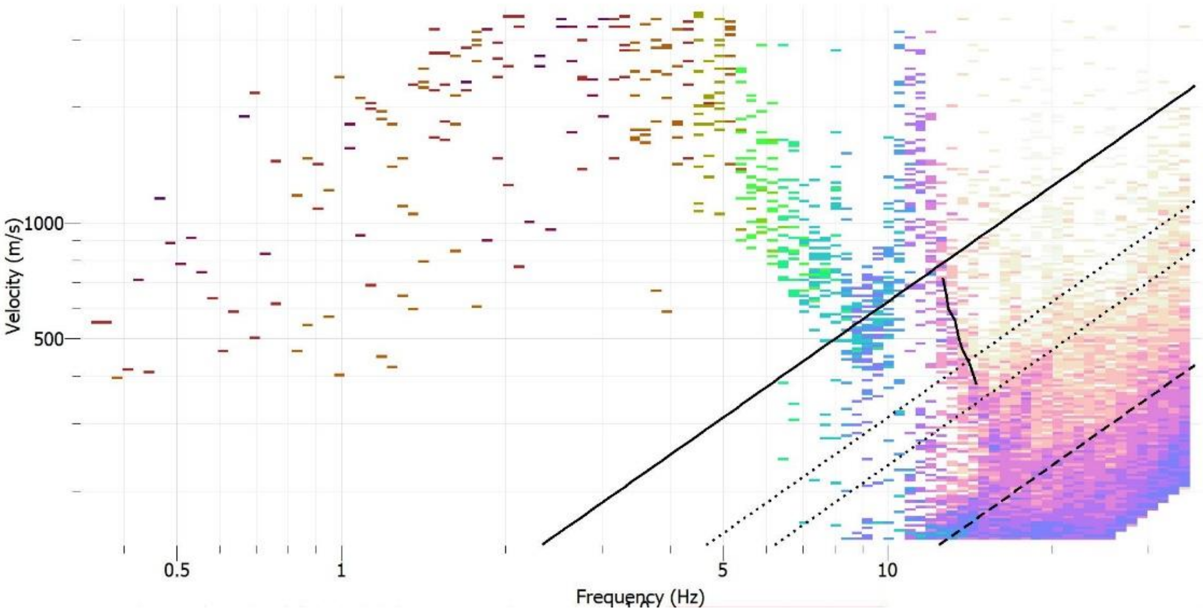

Figure 9: FK analysis and picked dispersion curve for the 2D ambient noise passive array.

Considering the broad H/V peak and its low amplitude value (lower than 3), to obtain the shear wave velocity profile for the area the FK dispersion curve has been only considered.

B2 SEISMIC VELOCITY MODEL

The subsoil model is divided in three parts: the most superficial part is characterized by fine silty/clayey sandstones (alternating with macro-fissured marls with frequent levels of calcification due to the solution and resedimentation of the carbonates and/or ferrous minerals) with depth up to about 5 m.

The second level shows the same sequence of lithotypes, but the sandstones become slightly coarser and have calcarenitic intercalations while the alteration of the marls is less pronounced. This level is up to 10-15 m in depth.

The third layer (in this case the half space) is rich in silty, sandy and marly part and have a high degree of compactness.

The resulting models after the inversion step are shown in Figure 10. We obtained a fairly good fit between experimental and theoretical curves using a model parameterization composed of two main layers over half space.

The final result of the inversion is shown in Figure 10 where we can observe two discontinuities at about 4 and 12 m, as the subsoil model highlights. The velocity values are reported in table 5. The best -fit model of V_s is represented in Figure 11 and Table 5.

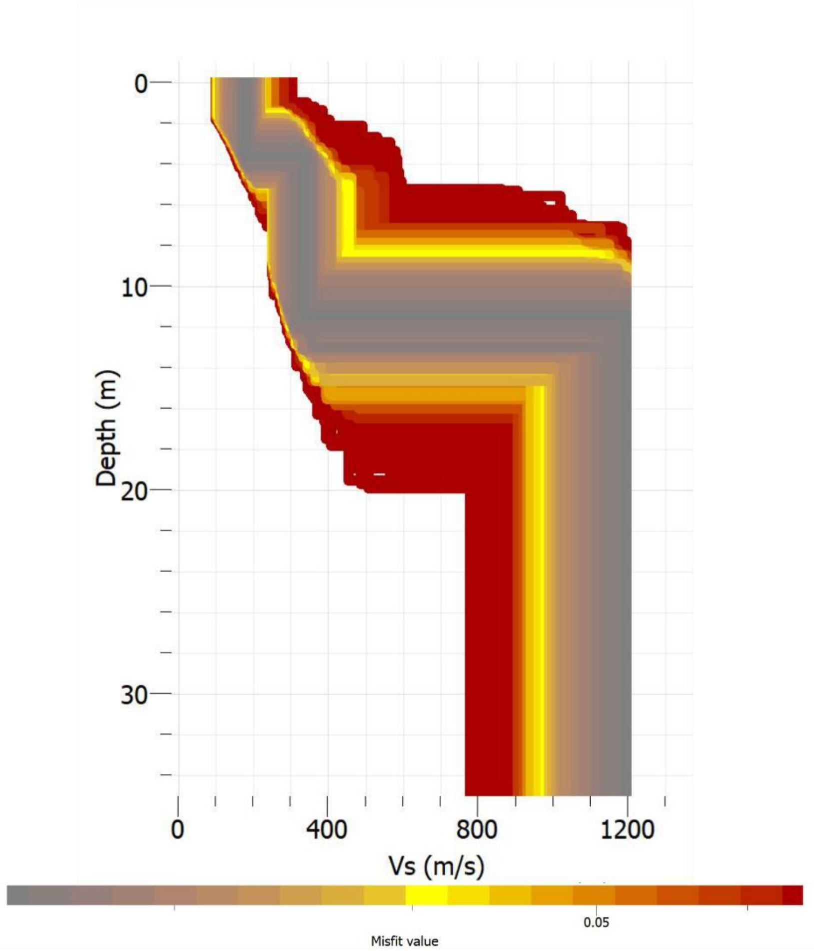

Figure 10: V_s profile obtained through the inversion of the FK dispersion curve of Figure 9.

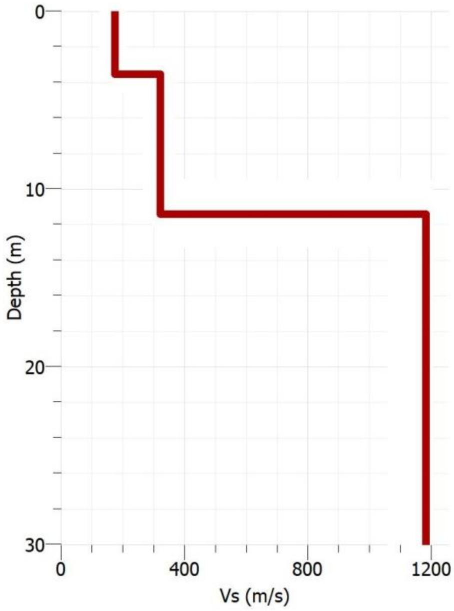

Figure 11: Best-fit model of V_s values

From	*To*	*Thickness (m)*	*V_s (m/s)*
0	3.56	3.56	170.94
3.56	11.34	7.78	314.69
11.34	30	18.66	1181.05

Table 5: Best-fit model

B3. CONCLUSIONS

According to the current Italian seismic code (NTC, 2018), if the bedrock (Vs > 800 m/s) is more than 30 m in depth, the equivalent velocity ($Vs_{,eq}$) is equal to the $VS_{,30}$. In this case , the velocity of 800m/s is reached around 12 m of depth so that $Vs_{,eq}$ is different from $VS_{,30}$.

The $V_{S,eq}$ retrieved from the best inverted model is 249 m/s (Table 6), therefore IT.SSU is classified in the soil category E following the NTC18 seismic classification. On the other hand, the $V_{S,30}$ retrieved from the best inverted model is 489 m/s (Table 6), therefore IT.SSU is classified in the soil category B following the EC8 seismic classification.

$V_{s,eq}$ = [m/s]	V_{s30} [m/s]	Soil class (NTC 2018)	Soil class (EC8)
249	489	E	B

Table 6: Soil Class

REFERENCES

Amanti M., Battaglini L., Campo V., Cipolloni C., Congi M.P., Conte G., Delogu D., Ventura R., Zonetti C. (2008). The Lithological map of Italy at 1:100.000 scale: An example of re-use of an existing paper geological map. 33rd International Geological Conference, IEI02310L – 6-14th August, Oslo (Norway).

Commissione tecnica per la microzonazione sismica (2015). Microzonazione sismica. Standard di rappresentazione e archiviazione informatica, Versione 4.0b (Commissione tecnica inter-istituzionale per la MS nominata con DPCM 21 aprile 2011).

Comune di Sassuolo (2020). Riduzione del rischio sismico-riduzione della vulnerabilità e restauro del Castello di Montegibbio.

EC8: European Committee for Standardization (2004). Eurocode 8: design of structures for earthquake resistance. P1: General rules, seismic actions and rules for buildings. Draft 6, Doc CEN/TC250/SC8/N335.

ISPRA - Geological Survey of Italy - Lithological map of Italy 1:100.000 - Geological Survey Portal http://sgi.isprambiente.it/geoportal/ Sheets *086* (Modena).

ISPRA - Geological Survey of Italy - Geological Map of Italy 1: 50.000. Sheet *219* (Sassuolo).

NTC 2018: Ministero delle Infrastrutture e dei Trasporti (2018). Aggiornamento delle Norme Tecniche per le Costruzioni. Part 3.2.2: Categorie di sottosuolo e condizioni topografiche, Gazzetta Ufficiale n. 42 del 20 febbraio 2018 (in Italian).

Regione Emilia Romagna – Geoportale - https://geoportale.regione.emilia-romagna.it/it.

[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)"