ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Site characterization report at the seismic station IV.CAPR – Capriolo (BS)

Report di caratterizzazione di sito presso la stazione sismica IV.CAPR – Capriolo (BS)

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

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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.CAPR (Capriolo).

Location and coordinates are reported in Table 1.

Table 1

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IV.CAPR	Capriolo	45.6372 *	9.9345 *	217 **
ADDRESS	Via Parco Rimembranza, 2, 25031 Capriolo (BS), Italy			

* Coordinates from ITACA (Nov. 2021)   ** Elevation from CTR 10k Regione Lombardia

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
	Flat surfaces, isolated slopes and reliefs with slope i ≤ 15°	T1	Valley edge (VE)

Table 3

Geological map	Source	Scale
IV.CAPR	Geological Map of Italy (CARG Project), sheet 98 (Bergamo)	1:50.000

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		LITHOLOGICAL UNITS		LITHOTECHNICAL UNITS	
Geological Map of Italy 1:50.000 (CARG Project), sheet 98 (Bergamo) *original*		Amanti *et al.* (2008) *deduced*		(MZS) *deduced*	
code	**description**	**code**	**description**	**code**	**description**
ROY	Timoline Unit – Monterotondo Supersynthem	B3	Gravel	GP fg	Poorly graded gravels
ROO	Torbiato Unit – Monterotondo Supersynthem	B3	Gravel	GP fg	Poorly graded gravels
FAT	Fantecolo Synthem	B3	Gravel	GP fg	Poorly graded gravels
SAR	Sarnico sandstone	A10	Pelite-sandstone alternance	ALS	Alternance of lithotypes, layered
FSE_2	Monte S. Onofrio Member – Sorisole Formation	A1-A7	Limestone, marl	ALS	Alternance of lithotypes, layered
SDL	Sass de la Luna	A3	Marly limestone	ALS	Alternance of lithotypes, layered

A2. GEOLOGICAL MAP

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

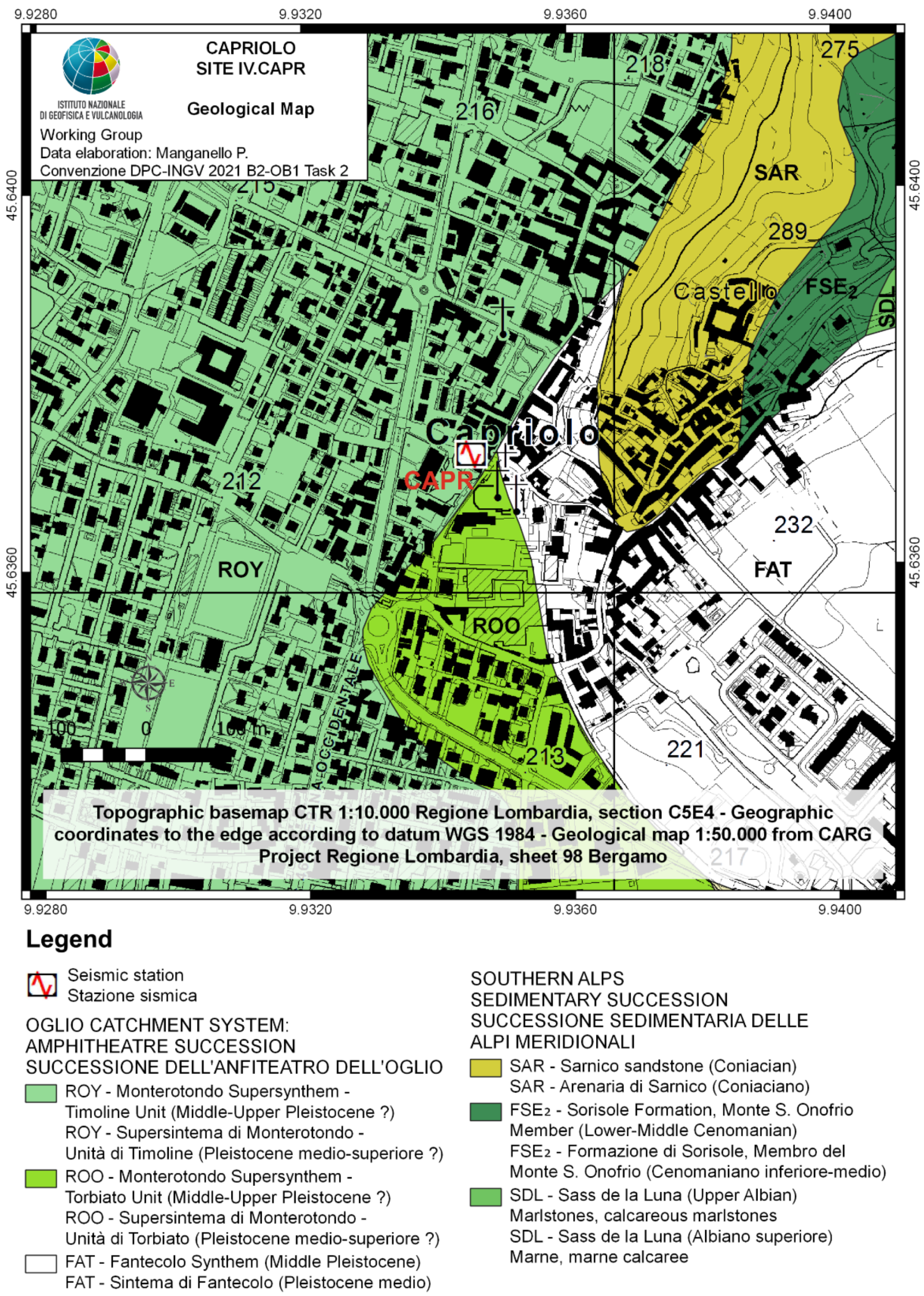

Figure 1: Geological map of seismic station IV.CAPR. Scale 1:5.000. Geological units come from the Geological Map of Italy 1:50.000, sheet 98 Bergamo**.**

A2. LITHOLOGICAL MAP

In Figure 2 Lithological Map is reported in a 1 *km* × 1 *km* square around the station.

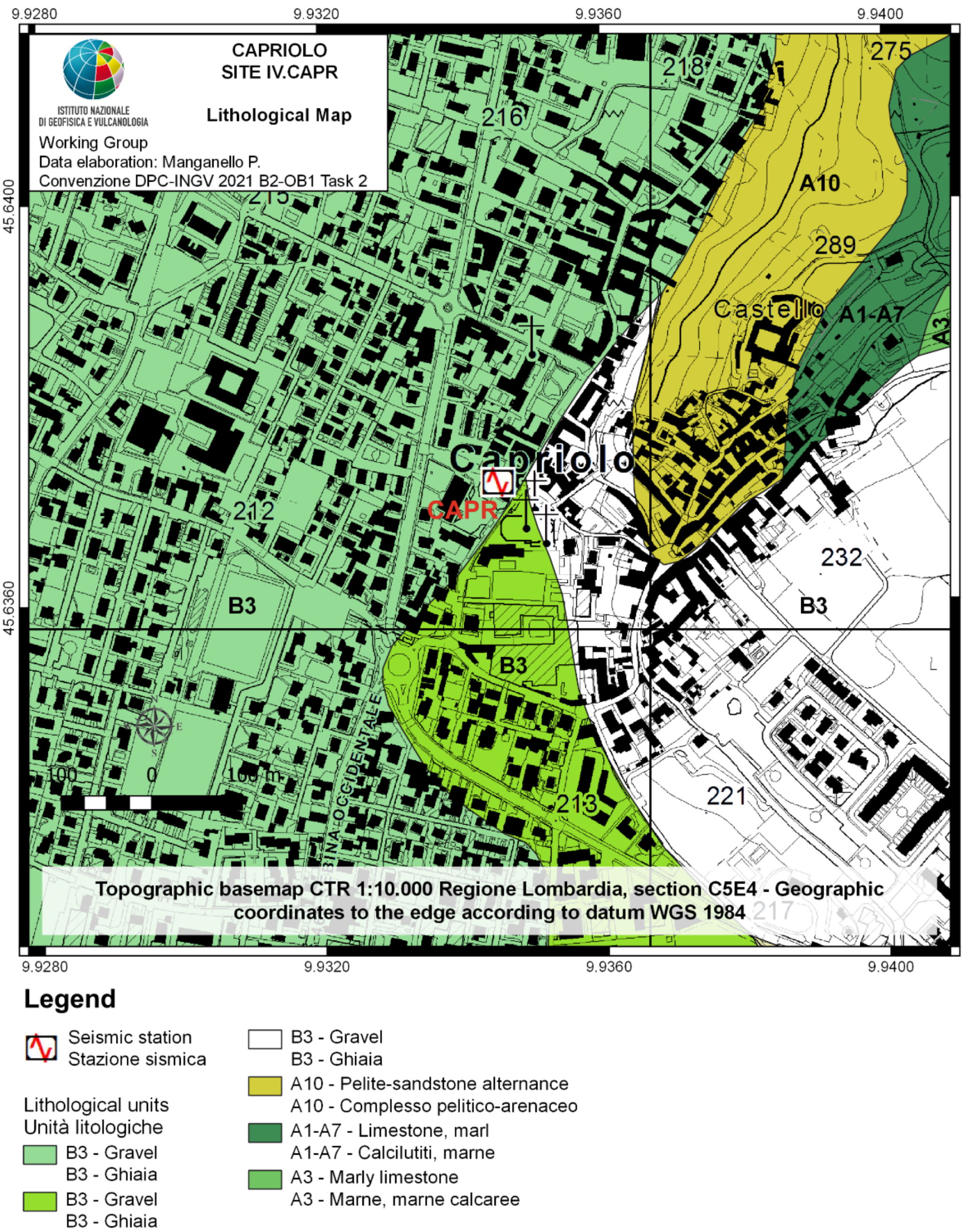

Figure 2: Lithological map of the seismic station IV.CAPR. Scale 1:5.000. The codes of the lithological units are assigned according to the nomenclature of the Lithological map of Italy ISPRA 1:100.000 (Amanti *et al.*, 2008).

A3. LITHOTECHNICAL MAP

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

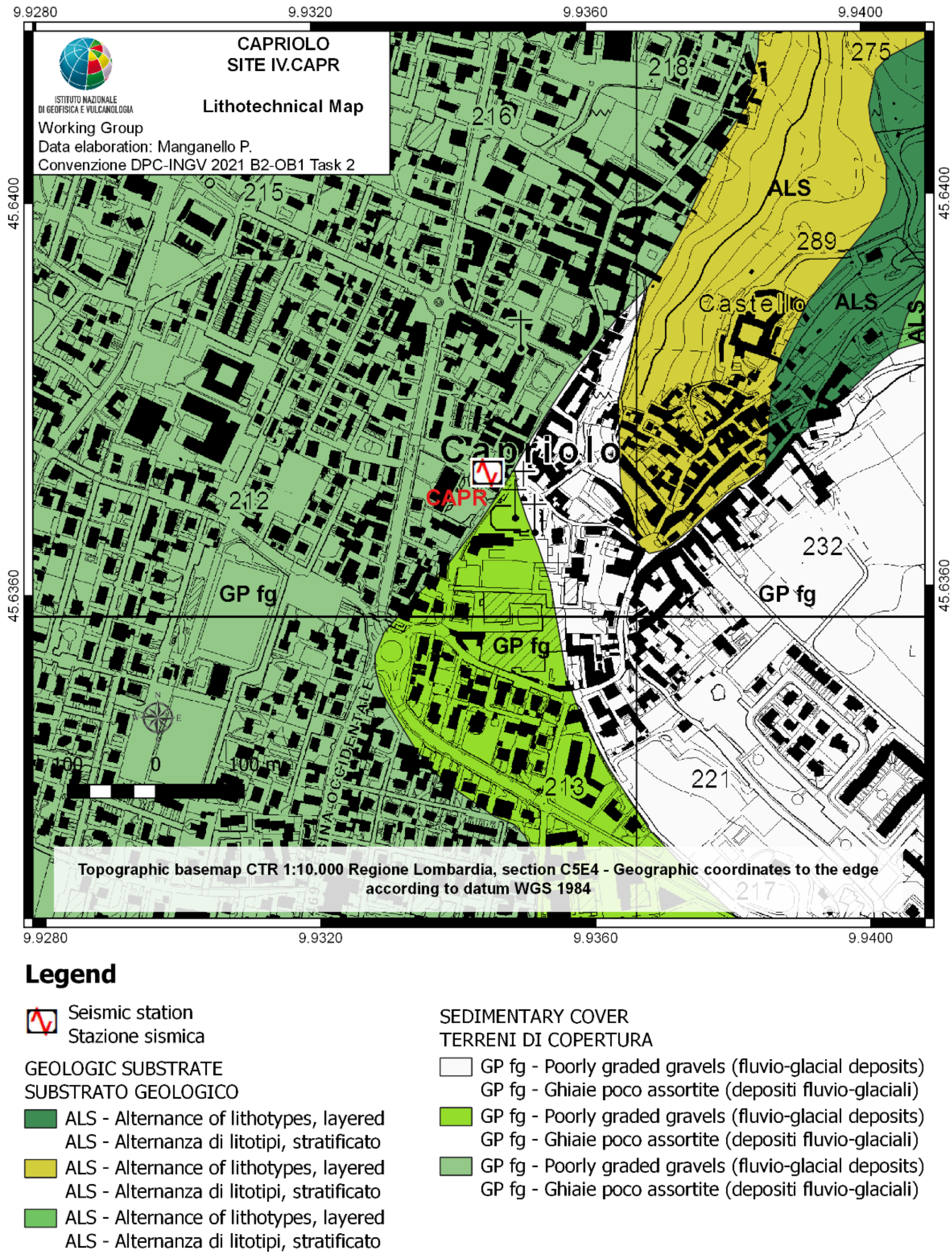

Figure 3: Lithotechnical map of the seismic station IV.CAPR. Scale 1:5.000. The lithotechnical units are deduced according to the nomenclature of Seismic Microzonation (Technical Commission SM, 2015).

A5. SURVEY MAP

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

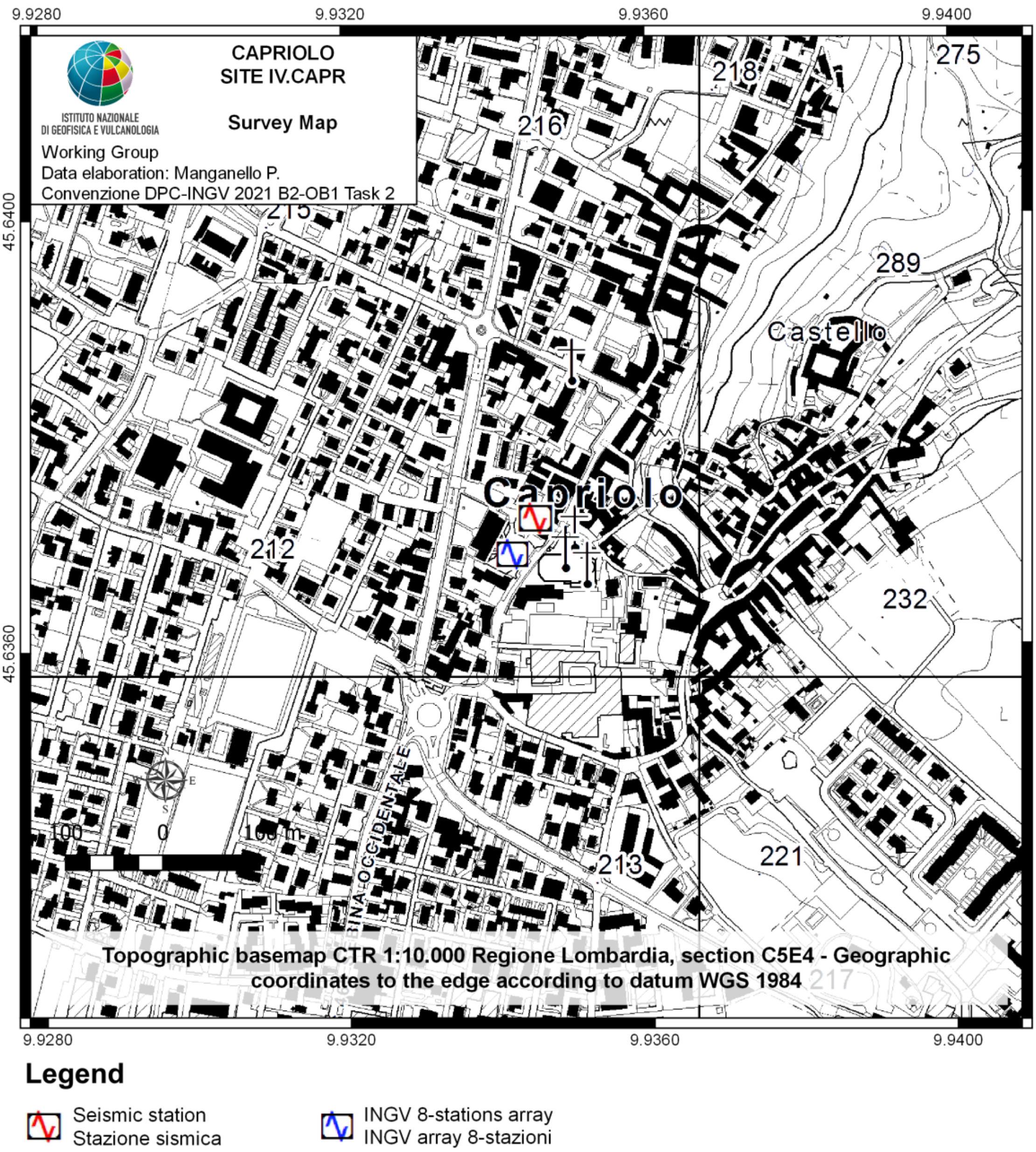

Figure 4: Map of the surveys in the surroundings of the station IV.CAPR. Scale 1:5.000.

A6. GEOLOGICAL MODEL

6.1 General description

The seismic station IV.CAPR is installed in the town center of the Capriolo municipality, which is located in the western part of Brescia Province.

The north-eastern area of the Capriolo municipality is characterized by the presence of reliefs belonging to the Brescian Prealps, which are jointed southward and westward to the plain characterized by continental Quaternary deposits (fluvioglacial origin). This plain extends to the West up to Oglio River and it shows the presence of fluvial terraces (Comune di Capriolo, 2012).

The geological setting of the study area is connected to the evolution of the Lombardian Basin, which represents a structurally complex area of the Mesozoic South-Alpine rifted margin, between the Lake Maggiore fault and the Ballino - Garda fault. After the Liassic extension the Lombardian Basin consisted of several half-grabens delimited by normal faults. When the tectonic activity ended at the beginning of the Toarcian, turbiditic deposition was replaced by thick pelagic sedimentation across the entire Lombardian basin. The Cenozoic Alpine collisional history is thus primarily responsible for the structural setting of this area (Bersezio and Mensini, 1992; Bertotti *et al.*, 1993; Bertotti, 2001; Cassinis *et al.*, 2000).

6.2 Geological section

In the surroundings of IV.CAPR site there are not boreholes. The WSW-ENE oriented geological section is reported and highlights the geological and structural setting of IV.CAPR site. The trace with the location of the section is reported as a black line in the geological map (Fig. 5 upper left).

6.3 Subsoil model

The geological description reported from the surface to the bottom is described in the following part. A subsoil model is built up to a depth of 30 *m* on the basis of geological information (Figure 5 bottom). The stratigraphic succession starts with the Timoline Unit of the Monterotondo Supersynthem (Middle - Upper Pleistocene) and below the Fantecolo Synthem (Middle Pleistocene), both characterized by gravelly fluvio-glacial deposits. At a depth of about 10-15 *m* the stratigraphic succession is characterized by the presence of the Sarnico Sandstone (Coniacian - Southern Alps sedimentary succession).

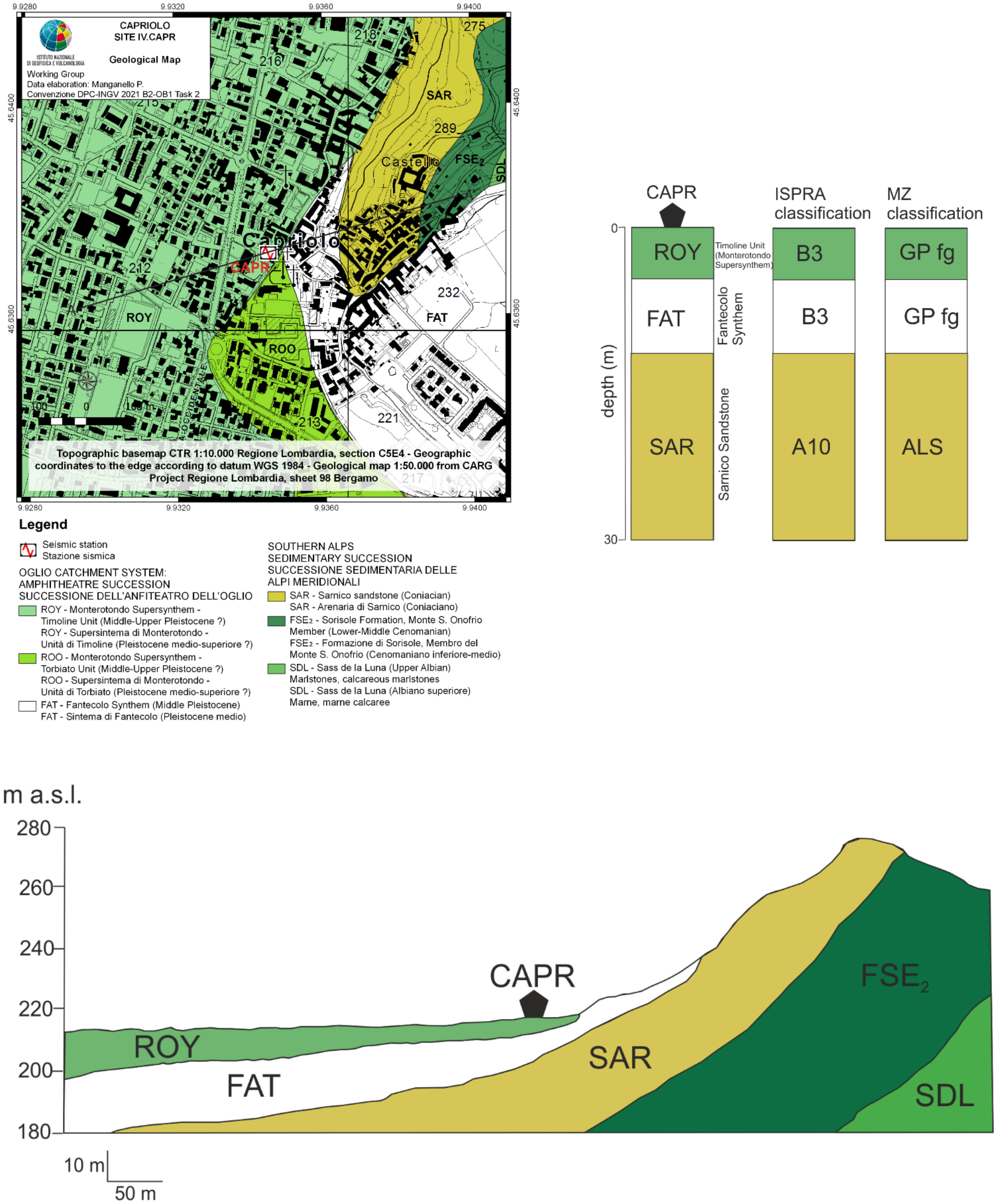

Figure 5: Upper left: Geological map of the study area where is installed IV.CAPR seismic station. Upper right: Geological section. Bottom: Subsoil model for the site.

B. V_S profile

B1. GEOPHYSICAL INVESTIGATIONS

Geophysical measurements executed nearby the station CAPR of the network IV (INGV, 2006) consist in ambient-vibration measurements in both single-station and 2D array configuration (Figure 6) 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 (V_S) profile that, together with the geological study at section A, is suitable for assigning the soil class according to the current Italian seismic code (NTC18) and Eurocode (EC8). Figure 7 shows the location of the station IV.CAPR (Latitude 45.6372, Longitude 9.9345 WGS84) installed at Capriolo (BS).

Seismic noise is acquired using 8 Reftek-130 24-bits recording systems equipped with short-period Lennartz LE-3D/5s sensors and GPS timing (Figure 7). The sampling rate is fixed to 200 *Hz*, while the gain is set as "high". Ambient noise recordings have a minimum duration of 1 hour. The array geometry (Figure 8) is chosen in order to have a good coverage of both azimuths and inter-station distances, the latter between the minimum (less than 10 *m*) and the maximum (about 30 *m*). These ranges allow the analysis of a range of wavelengths that guarantee sufficient shallow resolution (Okada, 2003) in order to estimate the $V_{S,30}$ and the site-class according to current building codes (i.e. NTC18 and EC8).

Figure 6: Map of the geophysical measurements performed at the IV.CAPR site. The yellow place-markers indicate the geometry used for 2D array in passive configuration. The red triangle indicates the IV.CAPR accelerometric station (image from Google Earth http://www.earth.google.com).

Figure 7: Upper left: library where the IV.CAPR accelerometric station is installed at Capriolo (BS). Bottom left: IV.CAPR accelerometric station. Upper right: single station ambient noise measurement. Bottom right: 2D passive ambient noise array installed close to the IV.CAPR station.

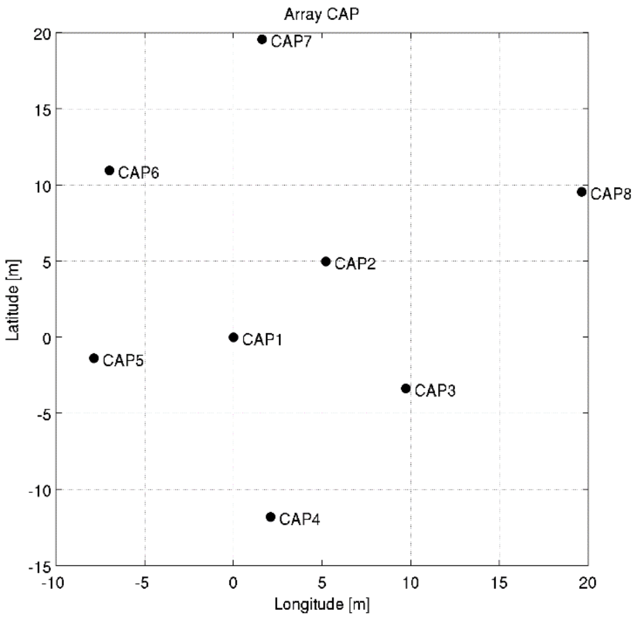

Figure 8: Array geometry.

The first step of the analysis consists in a visual inspection of the recordings at each station of the array. In particular, in order to identify malfunctioning and to select signal windows suitable for the surface wave analysis, the quality of the recording is evaluated analyzing the signal stationarity in the time domain, the relevant unfiltered Fourier spectra, and the H/V variation over time. Figures 9 and 10 provide graphical results about station CAP5.

It is common practice during surface wave investigation to verify the reliability of the one-dimensional site structure assumption (Aki, 1957; Okada, 2003). For this reason, we estimated the HVSR at each station of the array and the stability of HVSR among the array stations has been verified. Figure 11 depicts the HVSR assumed as representative for the array.

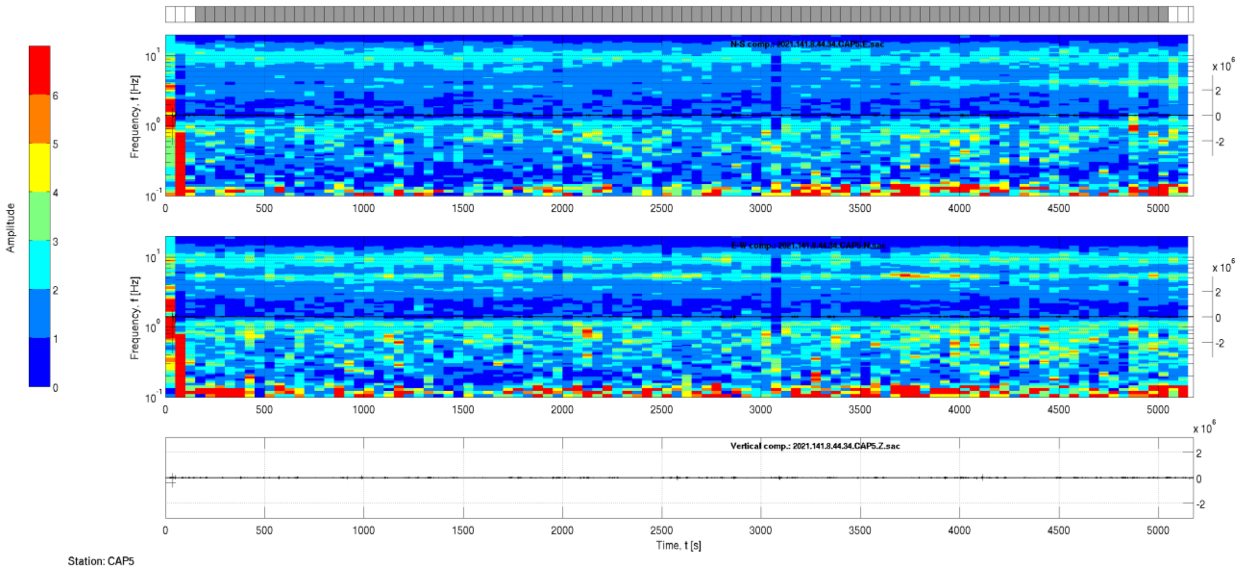

Figure 9: HVSR versus time (top and central panel for the NS and EW component, respectively) and corresponding time-histories.

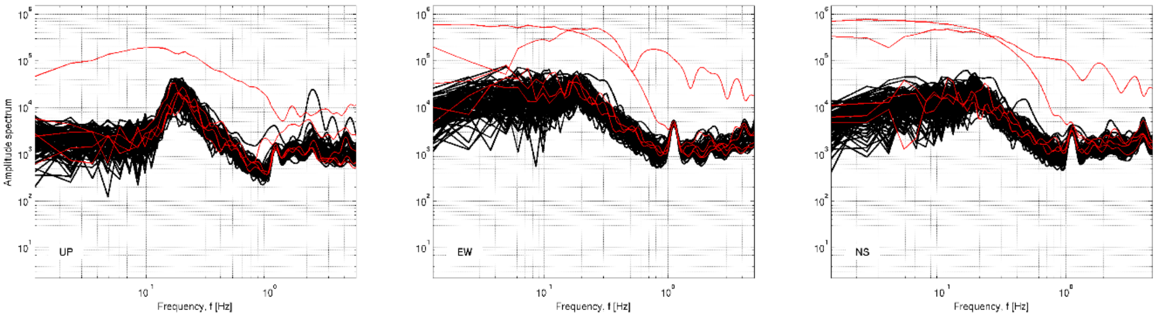

Figure 10: Fourier spectra for each noise window (left: Vertical, center: EW, right: NS). Red spectra are excluded from HVSR analysis.

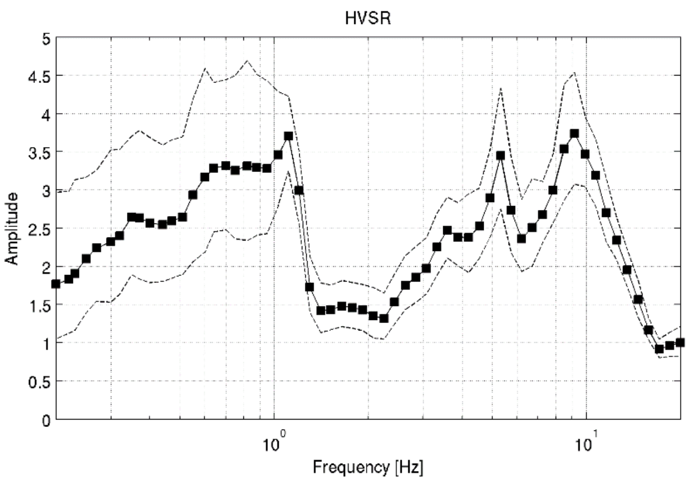

Figure 11: HVSR representative for the array. Dashed lines represent +/- one standard deviation.

The Rayleigh-wave dispersion curve is estimated by analyzing the vertical component of the recorded seismic noise. In particular, the Extended Spatial Auto-Correlation (ESAC; Ohori *et al.*, 2002; Okada, 2003) and the frequency-wavenumber (F-K; Lacoss *et al.*, 1969; Capon, 1969) methods are adopted. Further details about the combined use of ESAC and F-K approaches can be found in Parolai *et al.* (2006).

Both analyses use 35 synchronized signal windows of 60 *s* each, extracted from recordings within the UTC date-time interval 2021-05-21 09:15:00 – 2021-05-21 09:50:00, avoiding time periods affected by local disturbance.

The ESAC Rayleigh-wave dispersion curve is obtained by minimizing the root-mean-square (RMS) of the differences between experimental and theoretical Bessel functions (Figure 12). Values differing by more than two standard deviations from those estimated by the best fitting functions are automatically discarded (red circles in Figure 12) and the procedure is repeated iteratively. For this data set, data are also discarded whenever the inter-station distance is 2 times longer than the relevant wavelength. Figure 13 shows the Rayleigh-wave dispersion curve estimated using the ESAC approach.

The F-K analysis allows checking on the noise source distribution. One of the basic assumptions for the application of the ESAC method is indeed that the seismic noise wavefield is nearly isotropic. Figures 14 and 15 show results of the F-K analysis in terms of power density function for several frequencies using the Maximum Likelihood Method (MLM) and the Beam Forming (BF) respectively. Figure 16 shows the good agreement above 17 *Hz* between the Rayleigh wave dispersion curves estimated by both ESAC and F-K approaches. As expected, due to the array geometry, below this threshold the F-K analysis provides larger phase velocities.

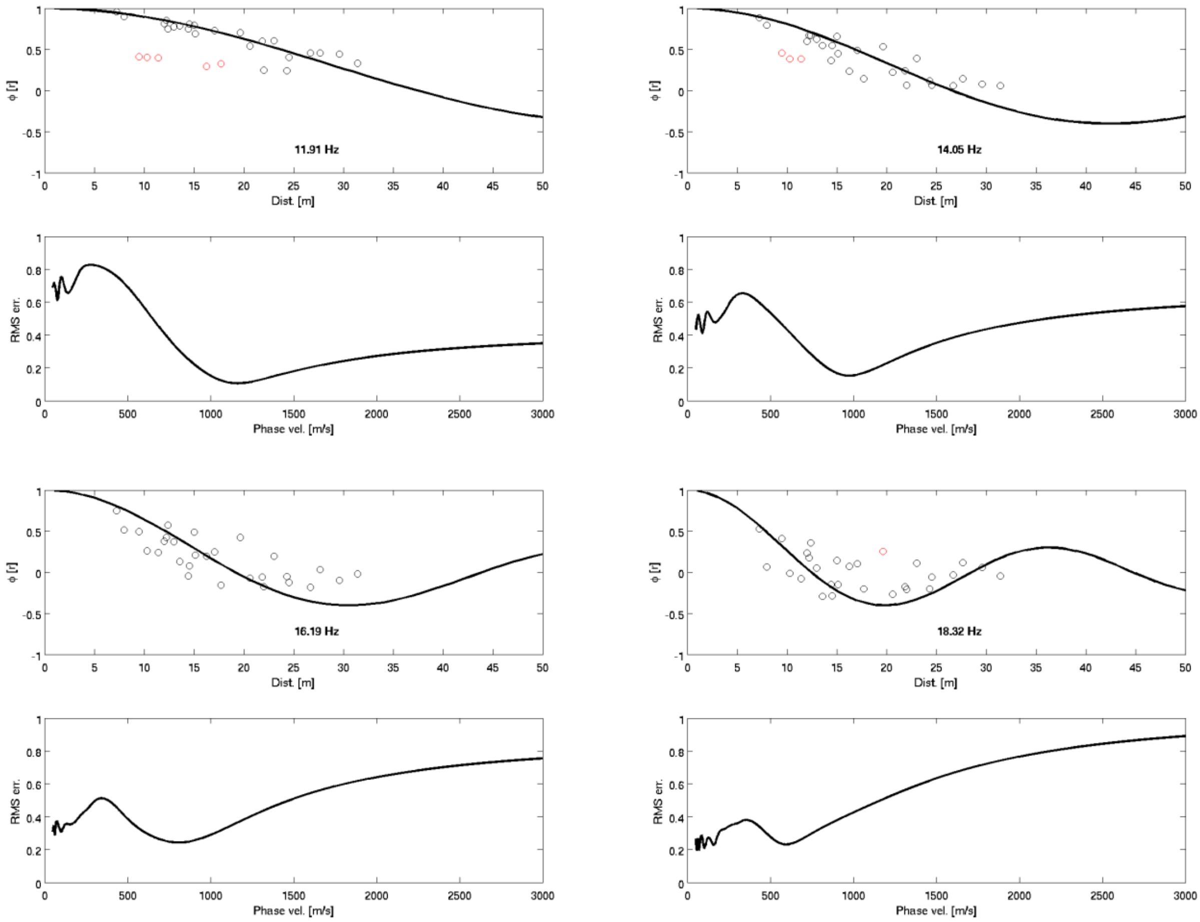

Figure 12: Experimental space-correlation function values versus distance (circles) for different frequencies. The red circles indicate values that are discarded. The black lines depict the estimated space-correlation function values for the phase velocity that furnishes the best fit to the data. The bottom panels show the relevant root-mean-square errors (RMS) versus phase velocity tested.

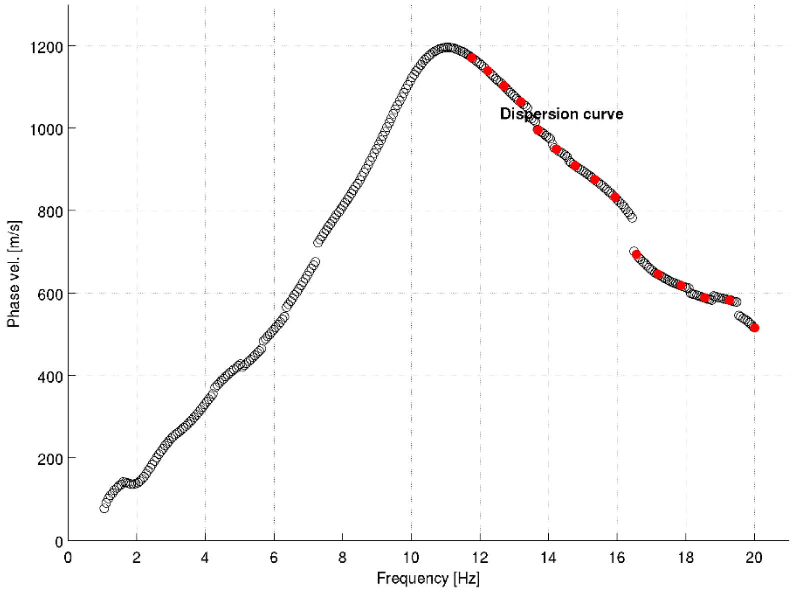

Figure 13: Rayleigh-wave dispersion curve from ESAC. Red-filled circles represent values potentially used for inversions.

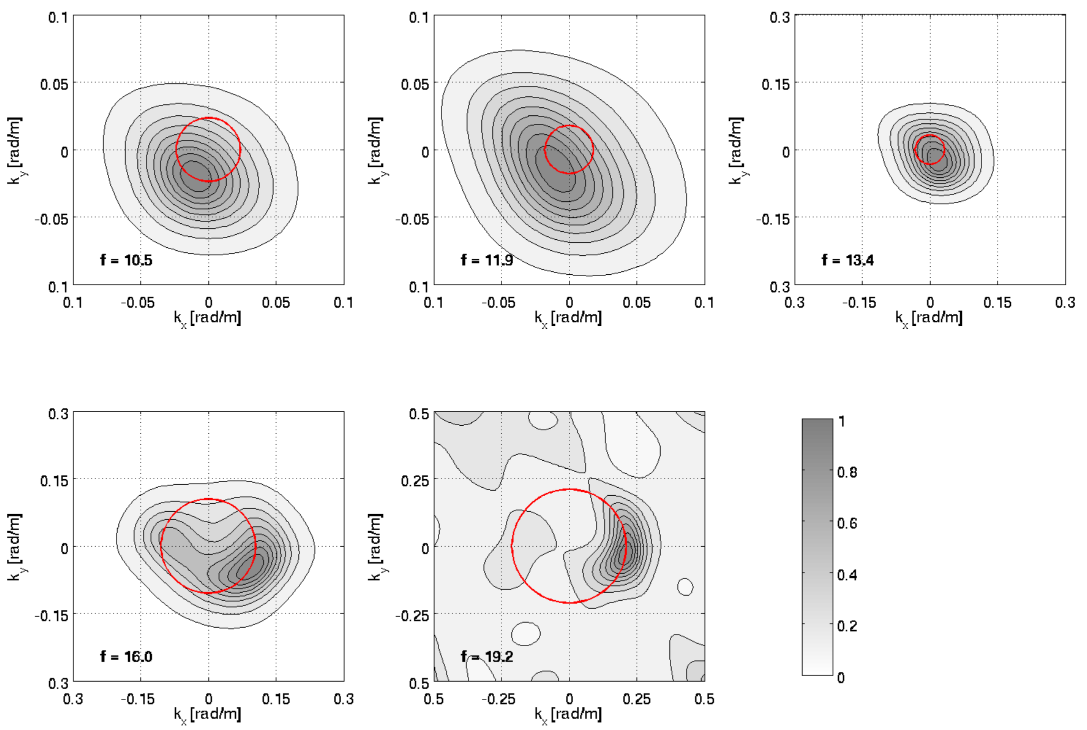

Figure 14: F-K power density function (Maximum-Likelihood Method) at selected frequencies.

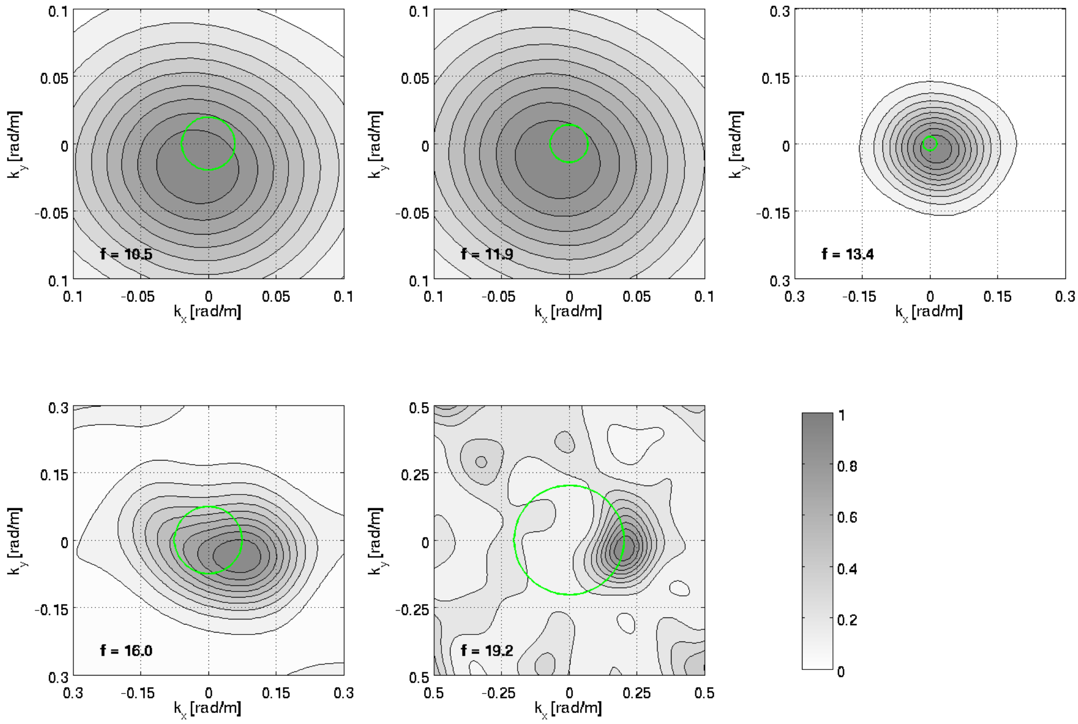

Figure 15: F-K power density function (Beam Forming) at selected frequencies.

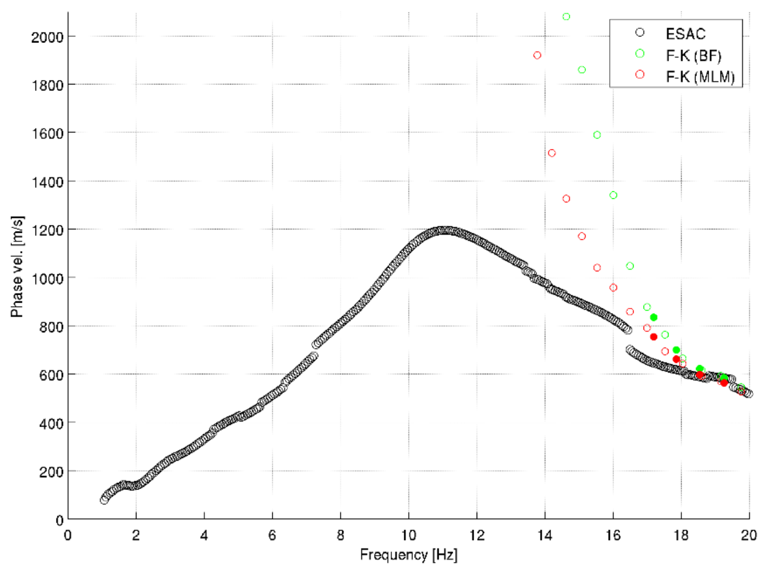

Figure 16: Comparison of experimental phase velocity estimated by the ESAC and the F-K (for both Beam-Forming and Maximum-Likelihood Method) methods; filled circles represent values potentially used for inversions.

B2. SEISMIC VELOCITY MODEL

The non-linear inversions are performed using the software *joinv6* (Parolai *et al.*, 2005; Giustiniani *et al.*, 2020), which adopt a genetic algorithm (Yamanaka and Ishida, 1996). The forward modelling of Rayleigh wave phase velocities and HVSR curves is performed under the assumption of a vertically heterogeneous 1D Earth model using the modified Thomson-Haskell method proposed by Wang (1999) and following the suggestions of Arai and Tokimatsu (2004) and Tokimatsu *et al.* (1992). The modelling is not restricted to the fundamental mode, preserving the possibility that higher modes participate in simulating the observed dispersion and HVSR curves.

The experimental dispersion curve used as input for inversions is the one estimated from the ESAC analysis in the frequency interval 11.5-20 *Hz*. The experimental HVSR is used between about 2 and 20 *Hz*. In the left panel of Figure 17 tested models are shown in different colors according to their cost value: the more reliable model (minimum cost) is in white, the models lying inside the 10% range of the minimum cost are in black and the other tested models are shown in grey. In the right-central and right-bottom panels of Figure 17, agreement between experimental and theoretical (grey and open circles, respectively) Rayleigh-wave dispersion curves and HVSR are shown. The agreement is good and, considering the wavelengths related to the dispersion curve frequency range, the V_S profile between about 5-35 *m* is well constrained. Table 5 reports the minimum-cost shear-wave velocity model.

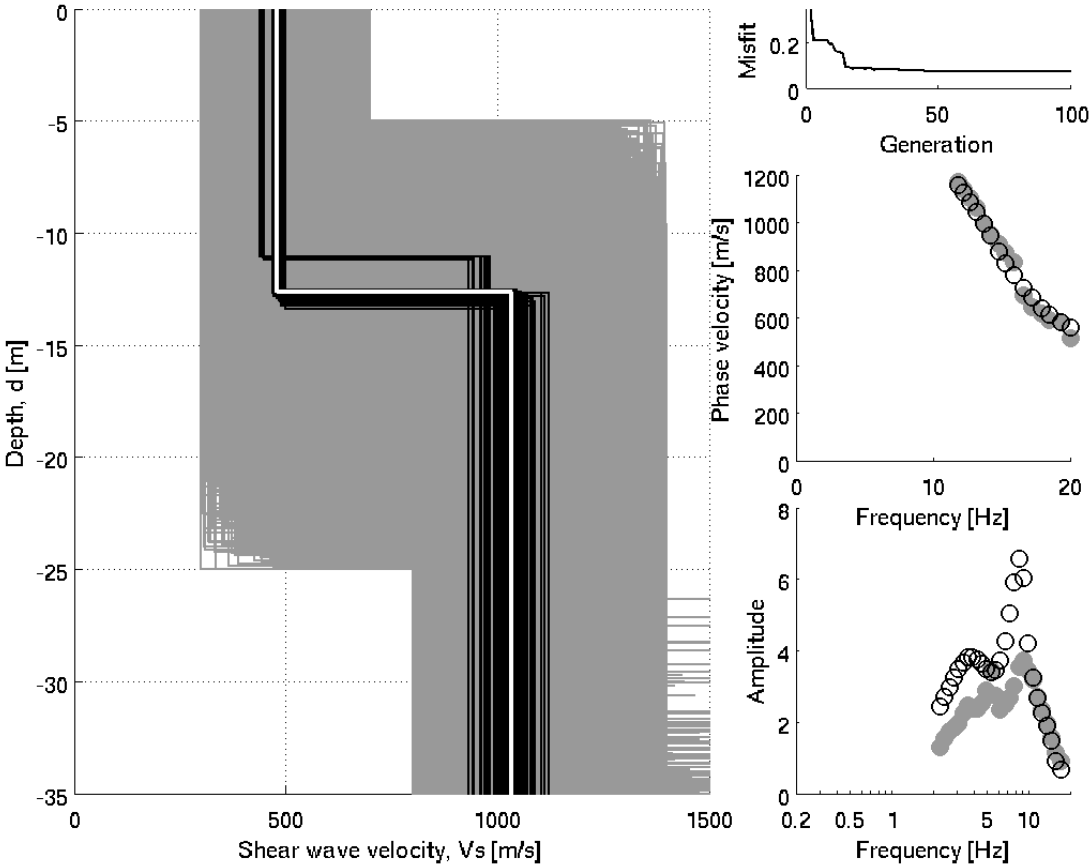

Figure 17: Shear-wave velocity models modeled during the inversion procedure (left panel): tested models (grey lines), the minimum cost model (white line) and models lying inside the minimum cost + 10% range (black lines); the generation values versus misfit (right-upper panel); the fitting of experimental data (grey circles) and empirical values relative to the minimum cost model (white circles) relevant to the dispersion curve (right-central panel) and to HVSR (right-bottom panel).

Table 5: Best-fit shear-wave velocity model

From [*m*]	To [*m*]	Thickness [*m*]	V_S [*m/s*]
0	12.6	12.6	480
12.6	-	-	1033

B3. CONCLUSIONS

As evinced from results of geophysical investigations carried out by INGV Working Group, we can attribute to the gravels of Timoline Unit (Monterotondo Supersynthem) and Fantecolo Synthem a V_S value of 480 m/s, and to the Sarnico Sandstone a V_S value of 1033 m/s, compatible with EC8 class assigned at the site according to geological evidences.

According to the current Italian seismic code (NTC18), if the bedrock (V_S > 800 m/s) is more than 30 m in depth, the equivalent velocity ($V_{S,eq}$) is equal to the $V_{S,30}$. From Figure 17, the velocity of 1033 m/s is reached at 12.6 m depth.

Therefore, in this case, $V_{S,30}$ is equal to 696 m/s and $V_{S,eq}$ to 480 m/s. Of consequence, IV.CAPR site is classified in the soil category B, for both the NTC18 and EC8 seismic codes (Table 6).

Table 6: $V_{S,eq}$,$V_{S,30}$ and soil classes

$V_{S,30}$ [m/s]	$V_{S,eq}$ [m/s]	Soil class (NTC18)	Soil class (EC8)
696	480	B	B

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L'INGV concorre, nei limiti delle proprie competenze inerenti la valutazione della Pericolosità sismica e vulcanica nel territorio nazionale e secondo le modalità concordate dall'Accordo di programma decennale stipulato tra lo stesso INGV e il DPC in data 2 febbraio 2012 (Prot. INGV 2052 del 27/2/2012), alle attività previste nell'ambito del Sistema Nazionale di Protezione Civile. In particolare, questo documento[1] ha finalità informative circa le osservazioni e i dati acquisiti dalle Reti di monitoraggio e osservative gestite dall'INGV. L'INGV fornisce informazioni scientifiche utilizzando le migliori conoscenze scientifiche disponibili al momento della stesura dei documenti prodotti; tuttavia, in conseguenza della complessità dei fenomeni naturali in oggetto, nulla può essere imputato all'INGV circa l'eventuale incompletezza ed incertezza dei dati riportati.
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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)"