ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Site characterization report at the seismic station IV.TREG – Tregnago (VR)

Report di caratterizzazione di sito presso la stazione sismica IV.TREG – Tregnago (VR)

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

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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.TREG (Tregnago).

Location and coordinates are reported in Table 1.

Table 1

CODE	NAME	LAT [°]	LON [°]	ELEVATION [m]
IV.TREG	Tregnago	45.5229 *	11.1608 *	342 **
ADDRESS	Strada Provinciale 10, 37039 Tregnago (VR), Italy			

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

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 centre (VC)

Table 3

Geological map	**Source**	**Scale**
IV.TREG	Geological Map of Italy, sheet 49 (Verona)	1:100.000

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**	
Geological Map of Italy 1:100.000, sheet 49 (Verona) *original*		Amanti *et al.* (2008) *deduced*		(MZS) *deduced*	
code	**description**	**code**	**description**	**code**	**description**
$a^{1\text{-}2}$	Alluvial deposits	B4	Mixed grain size deposits	GCtf	Gravel-sand-clay mixture
C^1-G^1	Dolostones and dolomitic limestones	A1-A2	Dolomitic limestone, dolostone	SFALS	Fractured/weathered layered alternance of lithotypes
$C^6 - G_c^{11}$	Marly limestones	A3	Marly limestone	SFLP	Fractured/weathered rock

A2. GEOLOGICAL MAP

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

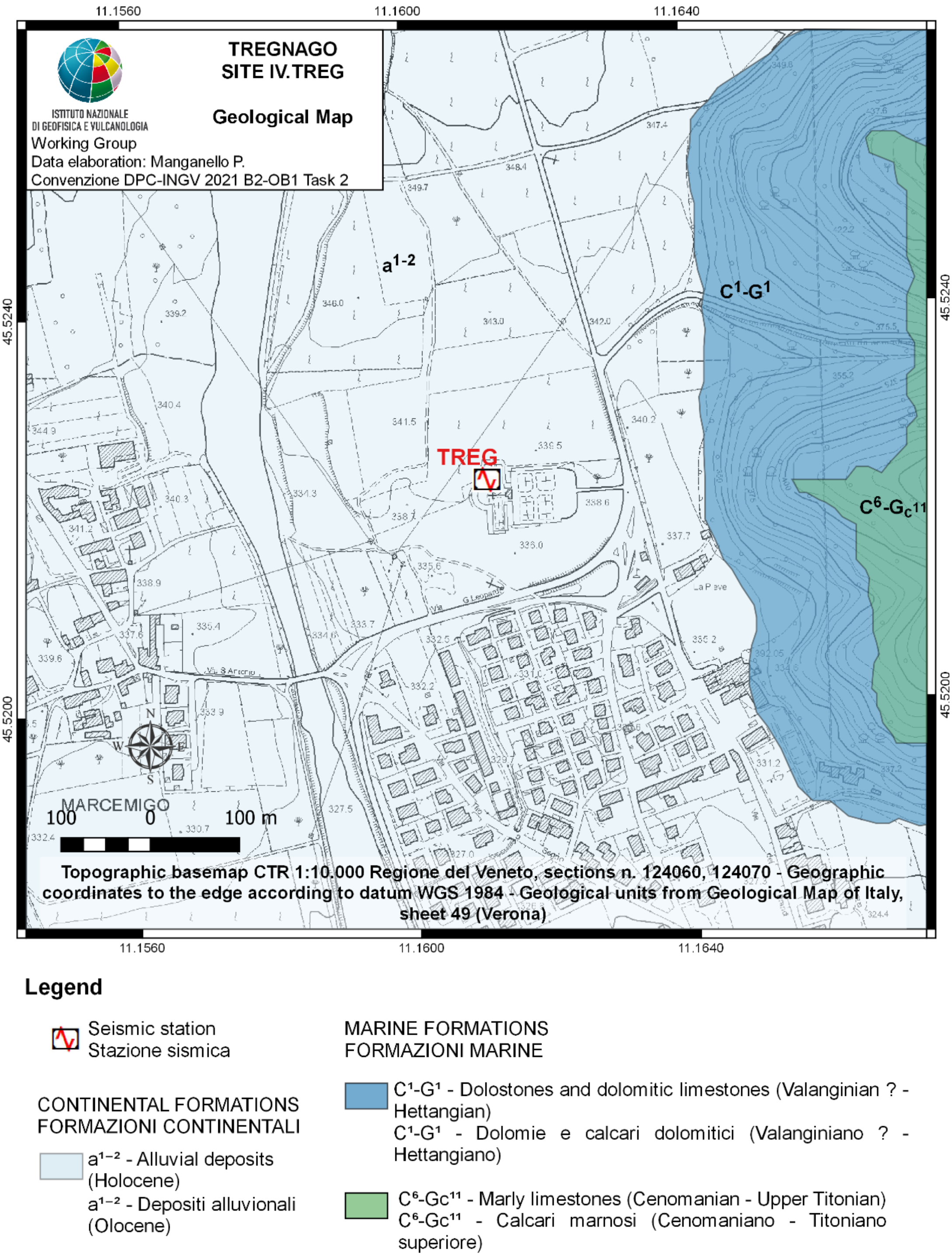

Figure 1: Geological map of seismic station IV.TREG. Scale 1:5.000. Geological units come from Geological Map of Italy 1:100.000, sheet 49 (Verona).

A3. LITHOLOGICAL MAP

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

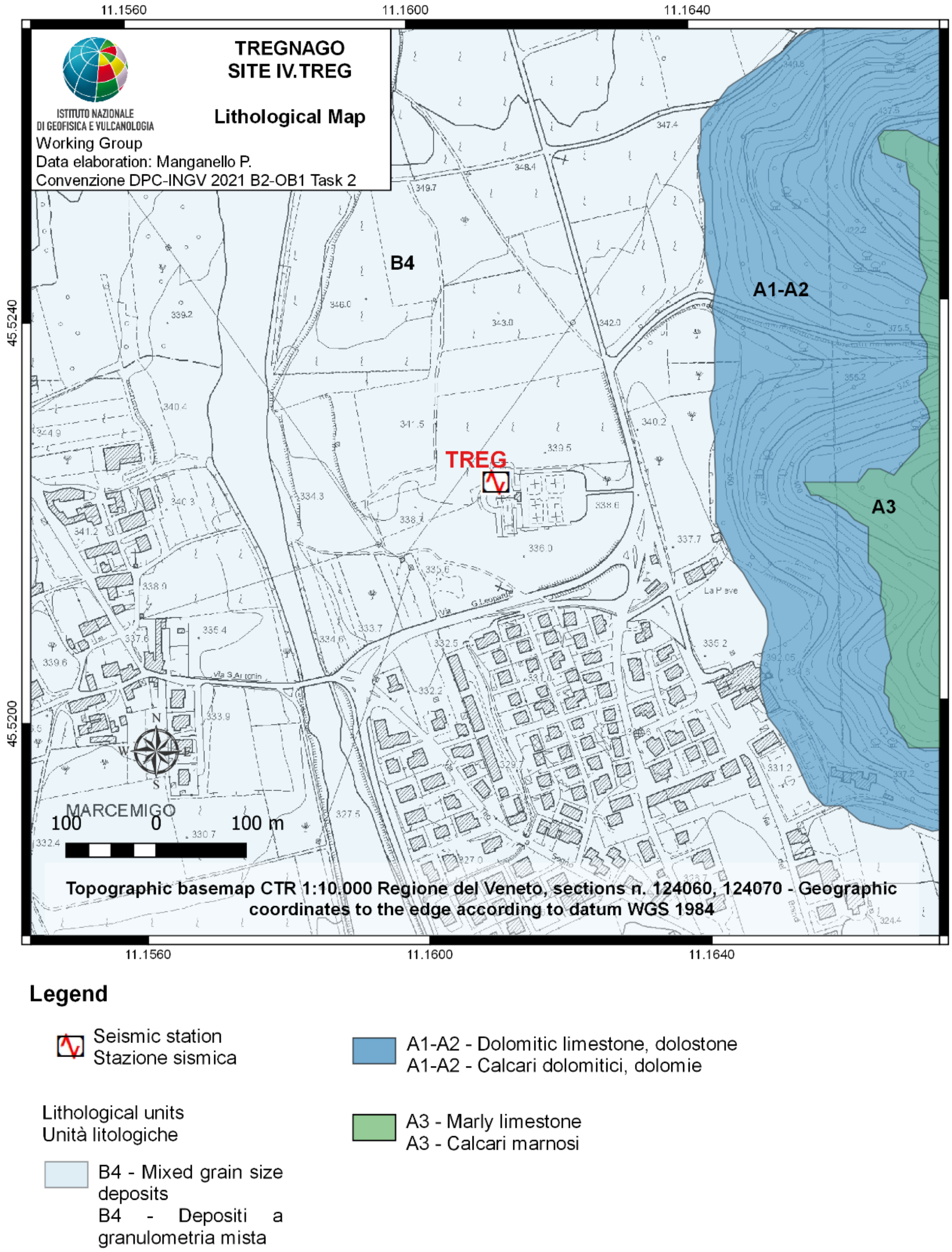

Figure 2: Lithological map of the seismic station IV.TREG. Scale 1:5.000. The codes of the lithological units are assigned according to the nomenclature of the Lithological map of Italy ISPRA 1:100.000 (Amanti *et al.*, 2008).

A4. LITHOTECHNICAL MAP

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

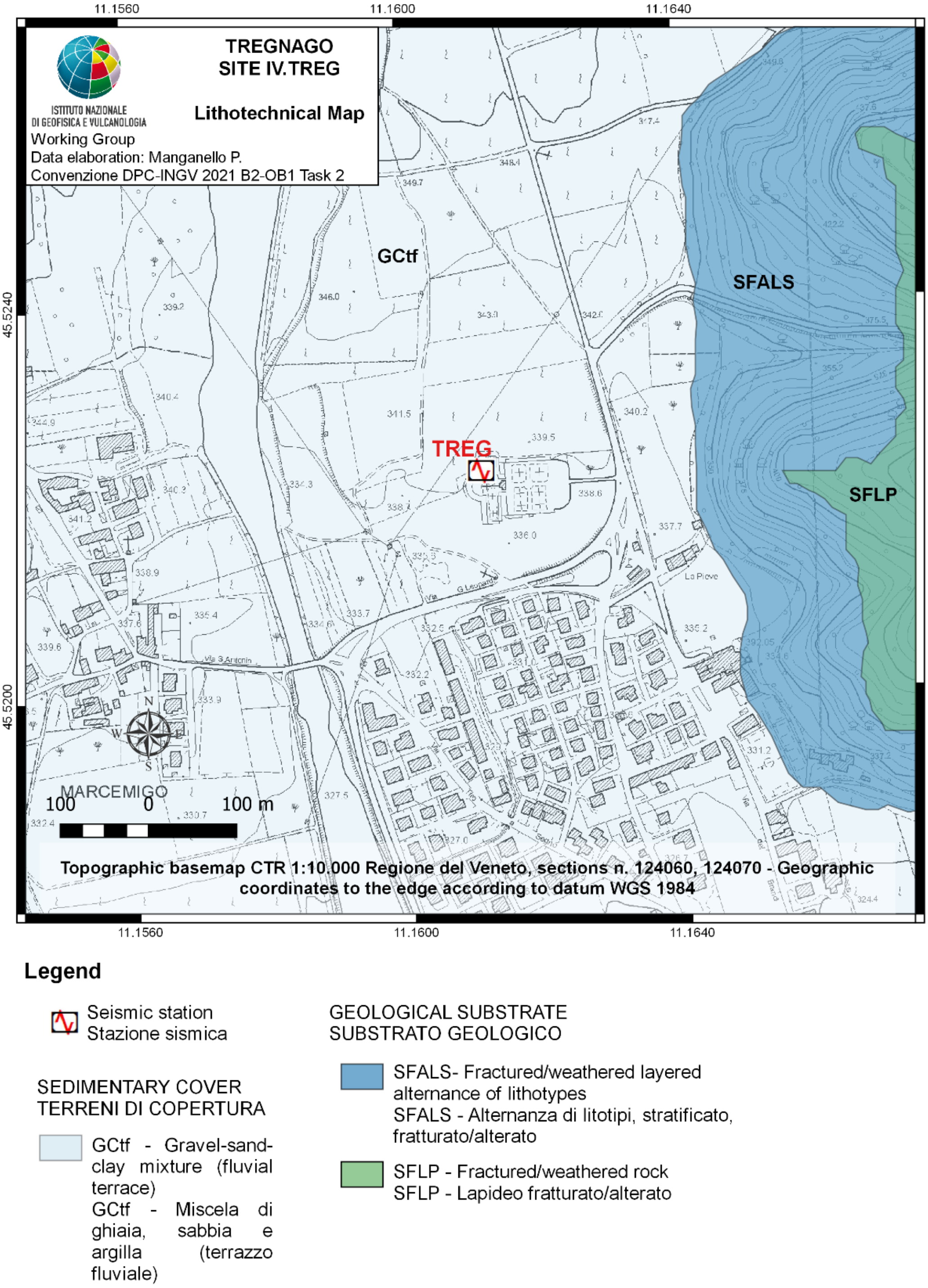

Figure 3: Lithotechnical map of the seismic station IV.TREG. Scale 1:5.000. The lithotechnical units are deduced according to the nomenclature of Seismic Microzonation (Technical Commission SM, 2015).

A5. SURVEY MAP

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

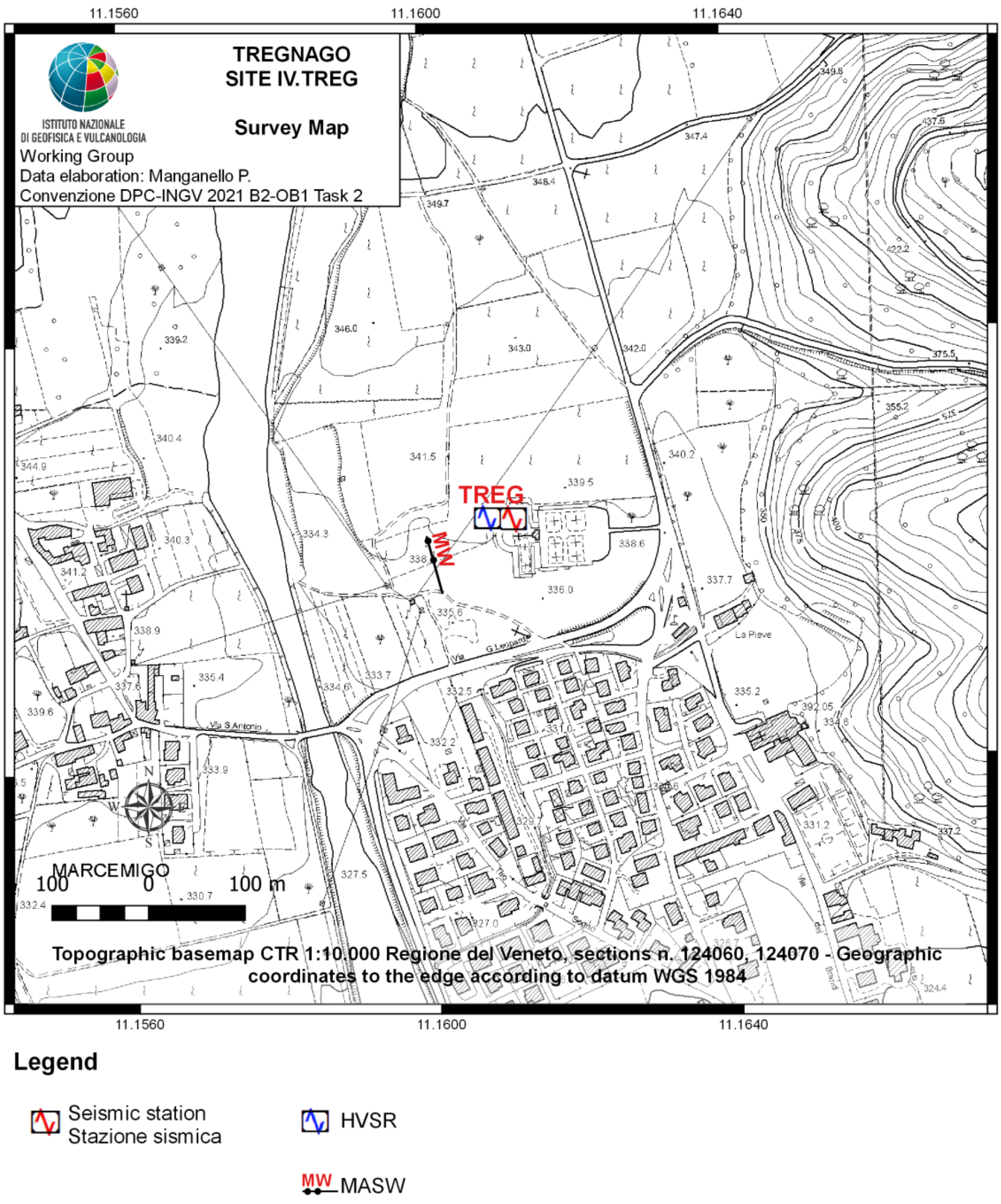

Figure 4: Map of the surveys in the surroundings of the station IV.TREG. Scale 1:5.000.

A6. GEOLOGICAL MODEL

6.1 General description

The seismic station IV.TREG is installed in the Tregnago municipality, which is situated in the northeastern sector of Verona Province.

The geological setting of the study area is related to the evolution of Lessini Mountains, which are a tableland located in the western Venetian Region, at the transition between the Fore-Alps and the Po Plain sedimentary basin. The surface geology of Lessini Mountains is mainly characterized by the presence of Mesozoic carbonate rocks. The tectonics of this area is connected to episodes of Mesozoic and early Tertiary extension, late Tertiary contraction and Pliocene-Quaternary block tilting (Zampieri, 2000).

The territory of Tregnago municipality is situated in the Illasi Valley, including part of the valley floor of Illasi torrent and the surroundings ridges with N-S direction, constituted by carbonate rocks (Comune di Tregnago, 2020).

6.2 Geological section

In the surroundings of IV.TREG seismic station there are not boreholes. The WSW-ENE oriented geological section is reported and highlights the geological and structural setting of IV.TREG 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 shows the presence of alluvial deposits (Holocene) characterized by mixed grain size.

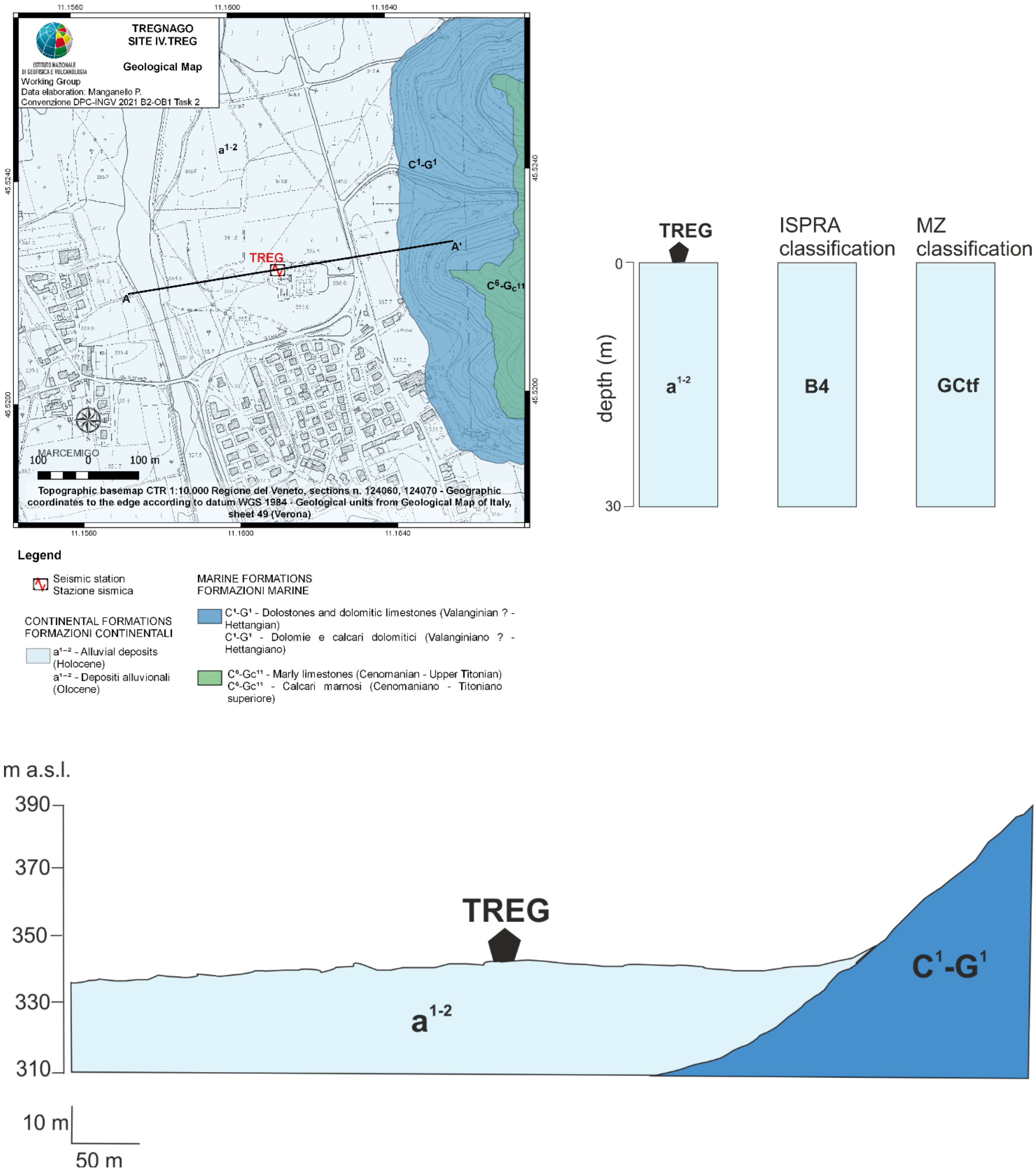

Figure 5: Upper left: Geological map of the study area where is installed IV.TREG seismic station. Upper right: Geological section. Bottom: Subsoil model for the site.

B. V_S profile

B1. GEOPHYSICAL INVESTIGATIONS

Geophysical measurements executed nearby the station TREG of the network IV (INGV, 2006) consist in a) ambient-vibration measurements in single-station configuration and b) Multi-channel Analysis of Surface Waves (MASW) survey (Figure 6), that provide results in terms of H/V curve (HVSR) and in terms of Rayleigh dispersion curve. 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.TREG (Latitude 45.5229, Longitude 11.1608 WGS84) installed in the municipality of Tregnago (VR).

Seismic microtremor is acquired using a Reftek-130 24-bits recording system equipped with short-period Lennartz LE-3D/5s sensor and GPS timing. The sampling rate is fixed to 100 *Hz*, while the gain is set as “high”.

The MASW survey is based on the simultaneous analysis of surface wave traces recorded by an equally spaced array of receivers (Foti *et al.*, 2017). The used acquisition device has been a Geometrics Geode seismograph (24 channel) and the acquisition line consisted in 24 vertical geophones (4.5 *Hz* natural frequency) with receiver spacing of 2.5 *m* (Figure 7). Two shots have been performed with offsets equal to 5 and 10 *m*. This range allows the analysis of a range of wavelengths that guarantee sufficient shallow resolution in order to estimate the $V_{S,30}$ and the site-class according to current building codes (i.e. NTC18 and EC8). The used source has been a sledgehammer striking on a metal plate. The chosen data acquisition parameters have been a time window of 2 *s* and a sampling frequency of 2 *kHz*.

The Rayleigh-wave dispersion curve (Figure 9) is estimated by picking the maximum amplitudes on the phase velocity – frequency plot obtained from recorded data. We interpret and assume that the final dispersion curve consists of the fundamental mode of Rayleigh dispersive waves.

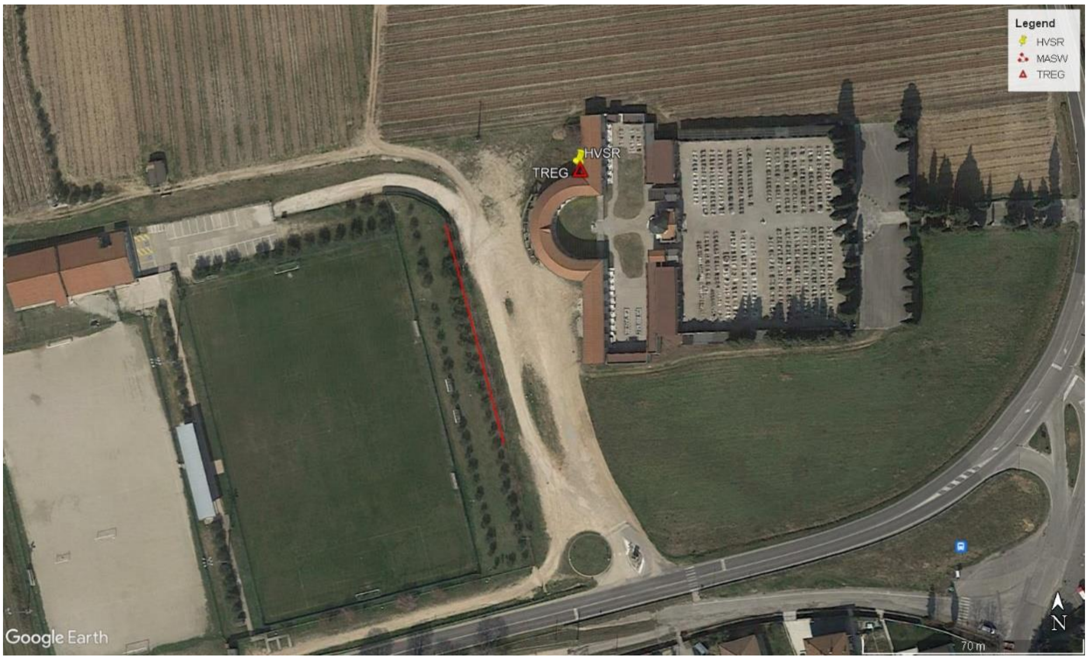

Figure 6: Map of the geophysical measurements performed at the IV.TREG site. The yellow place-marker indicates the single station ambient vibration measurement. The red line indicates the line of 24 geophones used for MASW. The red triangle indicates the IV.TREG accelerometric station (image from Google Earth http://www.earth.google.com).


Figure 7: Left: IV.TREG accelerometric station installed in the municipality of Tregnago (VR). Right: MASW acquisition line with 2.5 *m* receiver spacing.

Figure 8 shows HVSR recorded close to the station IV.TREG, while Figure 9 depict Rayleigh dispersion curve obtained from the MASW survey.

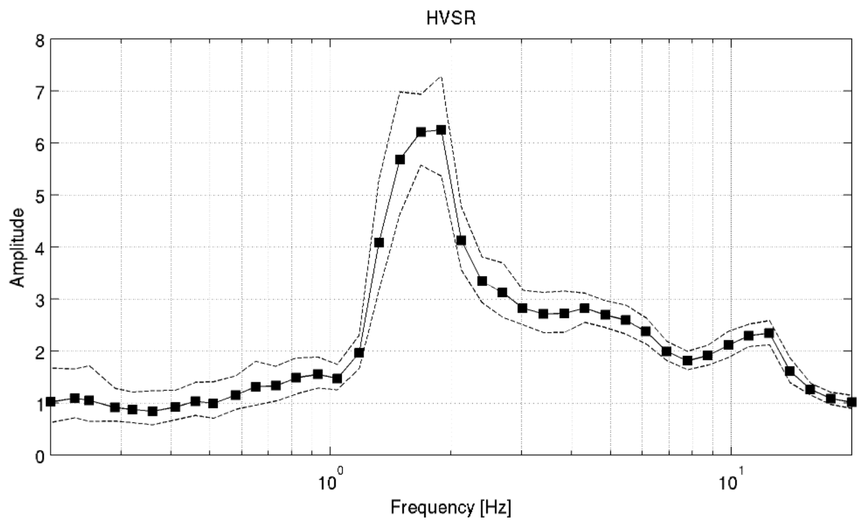

Figure 8: HVSR representative for the site. Dashed lines represent +/- one standard deviation.

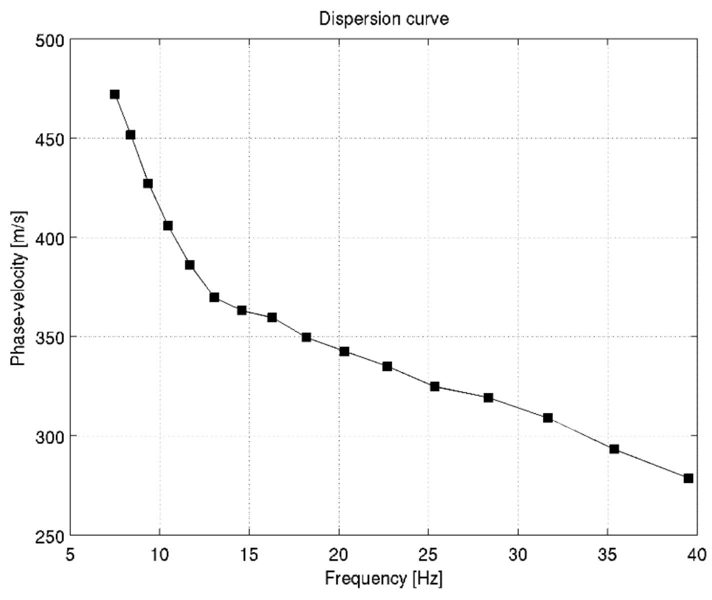

Figure 9: Rayleigh dispersion curve obtained from the MASW survey.

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 MASW analysis in the frequency interval 7 - 40 *Hz*. The experimental HVSR is used between about 1 and 8 *Hz*. In the left panel of Figure 10 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 10 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 - 70 *m* is very well constrained. Table 5 reports the minimum-cost shear-wave velocity model.

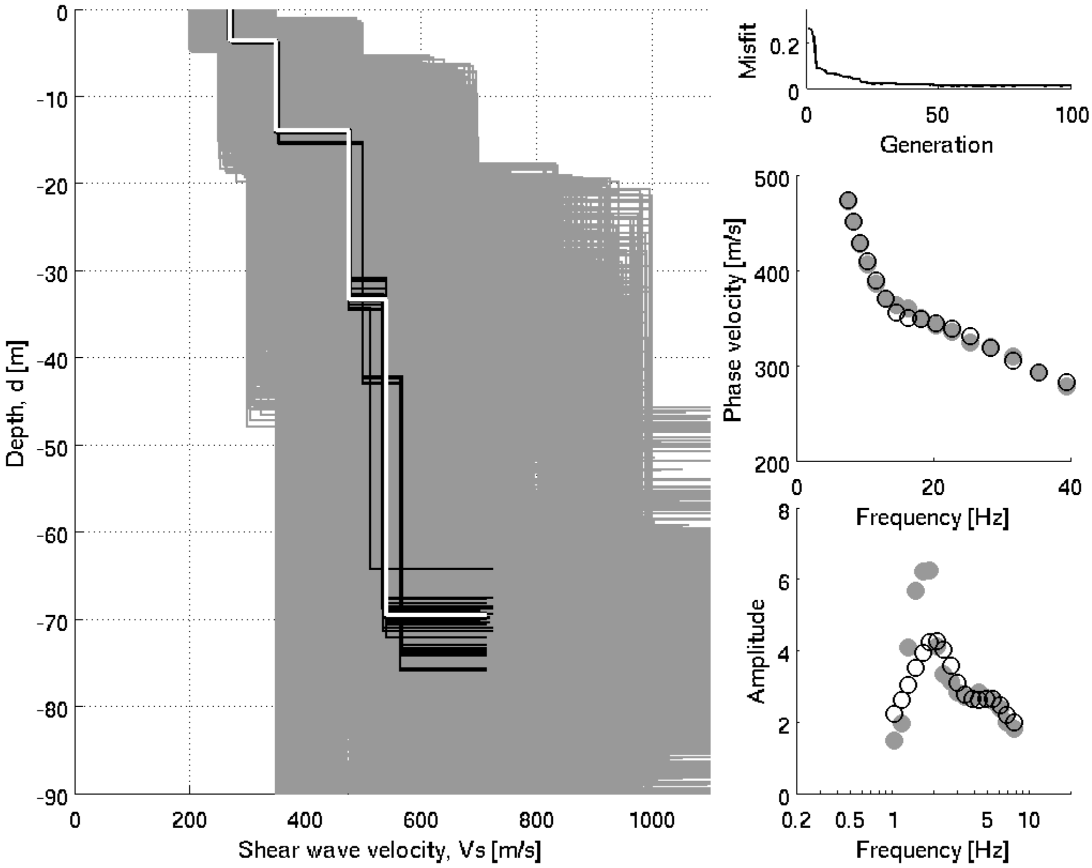

Figure 10: Shear-wave velocity models modeled during the inversion procedure (left panel): tested models (grey lines), the minimum cost model (white line) and models lying inside the minimum cost + 10% range (black lines); the generation values versus misfit (right-upper panel); the fitting of experimental 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	3.6	3.6	270
3.6	13.9	10.3	349
13.9	33.4	19.5	476
33.4	69.5	36.1	541
69.5	-	-	714

B3. CONCLUSIONS

As evinced from results of geophysical investigations carried out by INGV Working Group, we can attribute to the Holocene alluvial deposits (a^{1-2}) V_S values between 270 and 476 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 10, the velocity of 800 m/s is reached for an unknown depth, well below the depth of 30 m.

Therefore, in this case, both $V_{S,eq}$ and $V_{S,30}$ are equal to 391 m/s. Of consequence, IV.TREG 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

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

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