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Average shear wave velocity of the plain of the province of Treviso (Northern Italy)

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SCIENCE

Average shear wave velocity of the plain of the province of Treviso (Northern Italy)

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The accompanying map is the result of a regional survey to present average shear wave velocity in the uppermost layers (20–40 m in depth) of a large area situated in the province of Treviso, northeastern Italy. The research was conducted using the Refraction Microtremors (ReMi) seismic technique. Data from a total of 250 recording stations, scattered over an area of 2000 km², was collected during a two months in early 2006. The final Vs map shows the tight correlation between the seismic response of the area and the structure of alluvial deposits formed during late Pleistocene and Holocene. The ReMi technique, as well as the other techniques based on the survey of the surface wave, can be valuable tools for regional mapping average values of the shear wave in near surface deposits. These data, from a seismological perspective, along with measurements of the fundamental period, represent an excellent alternative for the site modeling.

Keywords: seismic survey; ReMi technique; Vs₃₀; Venetian-Friulian plain; fluvial geomorphology

1. Introduction

The map presents the results from an extensive seismic survey using the ReMi technique to detect the distribution of the shallow shear wave velocity for part of the Venetian-Friulian plain in the Veneto Region (Northern Italy; [Figure 1](#)). The study area covers ~2000 km² of alluvial plain in the province of Treviso. The principal aims of the research were the definition of a reference velocity map, to guide geotechnical studies, and an assessment of a low cost technique to investigate the elastic properties of large areas ([Nakamura, 1989](#)). The results match the required parameter (generally indicated as Vs₃₀) given by the EN1998 Eurocode 8 ([European Committee for Standardization, 2004](#)) “Design of structures for earthquake resistance” and by Italian regulation (D. M. 14 gennaio, 2008).

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Figure 1. Location map of the study area.

Existing geomorphological, geological and pedological data were collated and, taking in to consideration the known geomorphological and textural models, a map of superficial depositional units was produced, thereby minimizing the number of measuring stations. The V_s seismic network was then designed according to the geometry of the different geological units, assuring an adequate number of stations at key locations. The V_s field was finally interpolated onto a regular grid weighting the V_{s30} itself and several other parameters (geological constrains and borehole geophysical data). The shear wave velocity field shows close correlation to the textural properties of the sediments, moving from the foothills to the coastal areas.

2. Geological setting

The study area is part of the Venetian-Friulian Plain, which corresponds to the eastern portion of the Southern Alps foreland basin, consisting of several, coalescent alluvial megafans (Carton et al., 2009; Fontana, Mozzi, & Bondesan, 2008, 2010; Figure 2). These large-size sedimentary

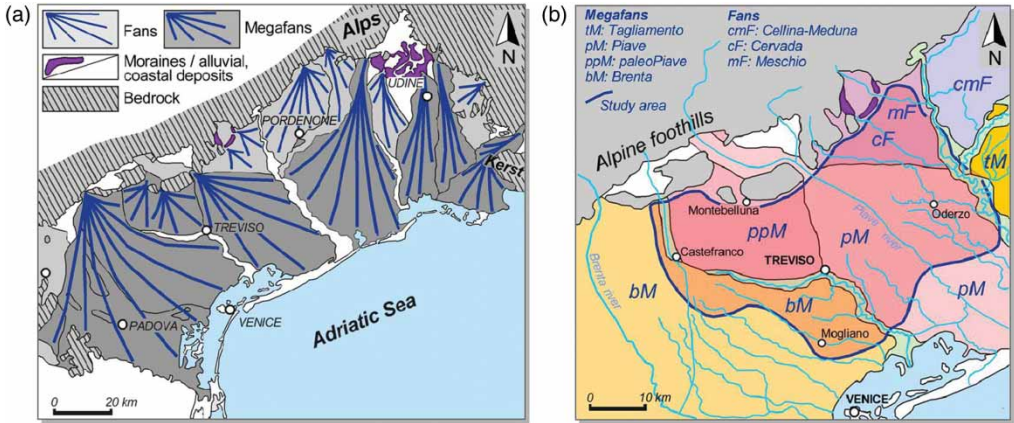


Figure 2. (a) Alluvial fans and megafans in the Venetian-Friulian Plain (modified from Fontana et al., 2008) and (b) Depositional architecture of the study area (modified from Carton et al., 2009).

systems were formed during the Upper Pleistocene and the Holocene, due, mainly, to climatic change and eustatic movement (Fontana et al., 2008).

The maximum aggradation took place during the GM (Last Glacial Maximum), between 24 and 16 ky C¹⁴ BP. The Alps were covered by an extensive glacial network known as *Eisstromnetz* (Ehlers & Gibbard, 2004) and the present-day main alpine river valleys were occupied by

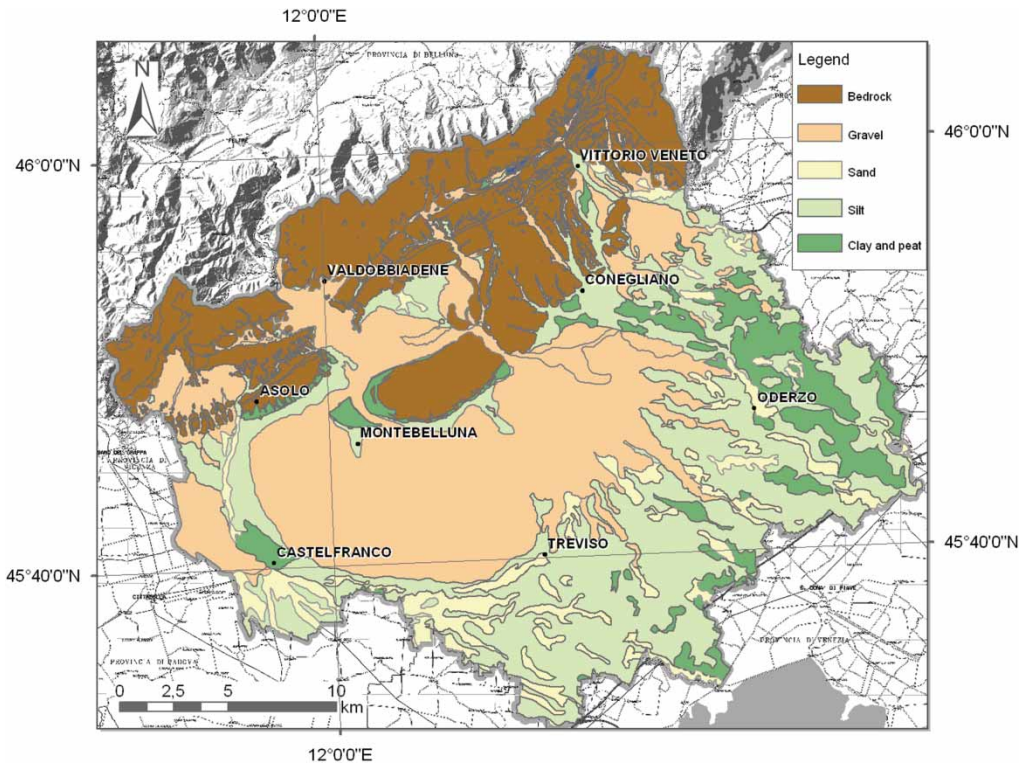


Figure 3. Simplified textural map of the study area.

meltwater streams, which washed out great amounts of fluvio-glacial sediments; some of the main glaciers reached the plain, building wide terminal morainal arcs (Antonioli, Vai, & Cantelli, 2004). After a long erosional phase following the LGM and during the Upper Holocene the last aggradation stage took place, starting from 5–6 ky C¹⁴ BP (Carton et al., 2009).

The surface deposits (Figure 3) are thick sequences of coarse sediments (mainly gravel and sandy gravel deposited by braided rivers in the so called high plain), while the distal sectors of the megafans show fine deposits intercalated by sandy channels, consisting of alternations of over-bank, crevasse, natural-levee and floodplain deposits with frequent thin and widespread peat intercalations. Ribbon-shaped tongues of coarse sediments are present in a radial pattern starting from the megafan apex; their thickness varies between one to dozens of meters and the width from dozens of meters to several hundred (Bondesan, Primon, Bassan, & Vitturi, 2008; Bondesan & Furlanetto, 2011; Bondesan & Meneghel, 2004; Fontana et al., 2008, 2010; Miola et al., 2006).

3. Methods

Geological and geomorphological maps produced in several former projects included a geomorphological map (REF), a map of landscape units (Bondesan, Meneghel, & Levorato, 2011) and a soil map (Arpav, 2008), as well as other related maps. These were reprocessed and imported in to a geographical information system (GIS). Other existing data included manual and mechanical core drillings, aerial LIDAR digital terrain models (and derived data), hyperspectral and radiometric surveys and aerial photos. These were also imported in to the same geographical database.

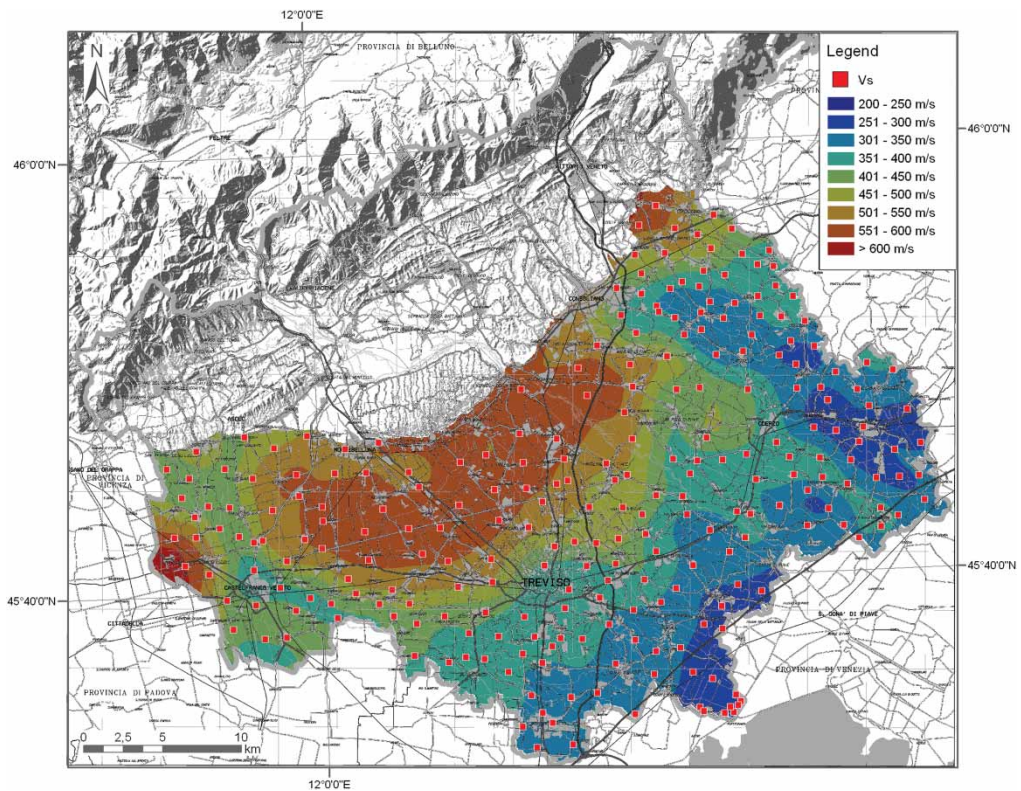


Figure 4. Shear wave velocity map of the uppermost layers (30 m) of the plain area of the Treviso Province and Vs station locations.

Table 1. V_{S30} values derived from CPTs.

Geology	V_S (m/s) 0–15 m of depth	V_S (m/s) 15–30 m of depth
Gravel	410	520
Sand	310	390
Silt	270	340
Clay and Peat	210	260

Table 2. Weight values for MCE analysis.

Weight Type	Weight source	Weight value
Geology V_S	0–15 m of depth	0.5
Geology V_S	15–30 m of depth	0.5
Surveyed V_S 30	Borehole data	2
Surveyed V_S 30	ReMi data	2

All these data were then re-processed in order to construct a map of near surface deposits. The resulting shallow depositional model is reliable down to a depth of 20–30 m below the surface. The ReMi- V_S acquisition network was designed based on the geometry of the depositional units. A total of 250 stations were unevenly distributed over an area of approximately 2000 km². The survey was completed in 40 days.

Each site was investigated using the Refraction Microtremors (ReMi) technique (Louie, 2001), capable of estimating the 1D shear velocity profile through the analysis of the dispersion of Rayleigh waves. The recording station comprised two orthogonal 24-channel lines with 3 m geophone spacing. Ten records of 30 seconds in length were collected (5 in north-south direction and 5 in east-west direction). Soil vibration was detected using 4.5 Hz geophones connected to a 24-bit Sigma-Delta seismic amplifier.

Rayleigh wave dispersion was recorded in the slowness-frequency (p-f) domain (Louie, 2001). Data processing included the standard application of a multidimensional Fourier transform, balancing amplitude among seismic traces and in time within a single trace, and averaging several p-f spectra. In this way it was possible to identify the dispersion curve reliably and to determine the fundamental mode. In some cases (less than 10% of the sites) the fundamental mode was not clearly recognizable and the measurements were discarded.

Forward modeling of the vertical V_S profile to fit the dispersion curve of the Rayleigh waves provided the main set of V_{S30} values. These V_S values were averaged, according to the definition of V_{S30} , in the uppermost 30 m. The ReMi V_{S30} field was then interpolated onto a grid of 1 km of aperture using the kriging algorithm (Figure 4). A second set of V_{S30} values was a priori assigned to the different geological units comparing deep CPT (Core Penetration Test) data and ReMi data at 38 different sites (Table 1).

The final V_{S30} values were then interpolated over a refined grid (0.5 km of aperture) using a Multicriteria Evaluation Algorithm (Eastman, Jin, & Toledano, 1995) based on three weights (Table 2). The gridding process residuals (Figure 5) were acceptable with a maximum positive value of 6.5% and a minimum value of -7.5%.

4. Discussion and Conclusions

The values of V_S in the near surface layers (30 m deep) range from 200 m/s to 550 m/s. Highest values belong to gravel deposits in the upper plain, while in the middle and lower plain, the lowest

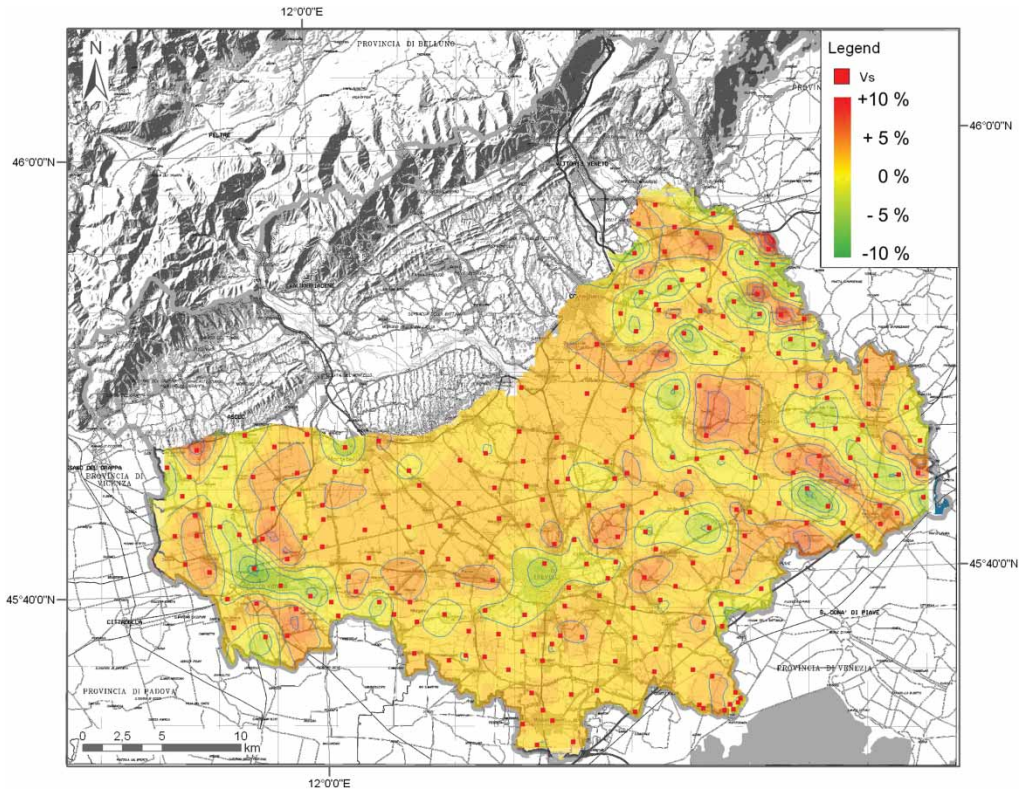


Figure 5. Map of the residuals.

values are typical of the clay and silty deposits. The granulometry of the sediments strictly controls the V_s values, especially in the upper plain, where soil and subsoil are formed by high-velocity gravel layers. The 500 m/s contour line of the V_{s30} map is well correlated with the boundary between the high-energy depositional environment, mainly consisting of gravel deposits and located in the upper plain, and the finer fluvial sediments of the middle and lower plain. In some sites shear wave velocities higher than 550 m/s were also measured; those extreme values are probably linked with partial cementation of the gravel layers.

In the lower plain, the near surface textures are mostly silt and clay, typically giving V_s values down to about 200 m/s. In the eastern segment of the middle-lower plain two distinct high velocity anomalies, characterized by V_s values ranging from 350 to 400 m/s, were observed. Although it is not clearly detectable at the surface, these sort of tongues are linked with coarse and high velocity buried deposits due to the major lines of Pleistocene river flow; this is partially confirmed by a series of aligned fluvial ridges.

In the north-eastern portion of the middle-upper plain, the V_{s30} low velocity anomaly is shown on the map. The structure is aligned in a north-west/south-east direction and terminates close to the alpine foothills margin. It corresponds with the narrow corridors located along the edge of the lateral lobes of the two primary megafans generated by the Tagliamento and Piave rivers; these elongate bands coincide with distal deposits composed by clay, silt and peat.

The seismological-geotechnical classification of soils that is currently in use for the design of building foundations follows European and Italian laws and regulations (D. M. 14 January, 2008; European Committee for Standardization, 2004; Presidenza del Consiglio dei Ministri, 2003).

The soils of the study area belong to types B and C (D. M. 14 January, 2008). The 360 m/s contour line marks the boundary between the two classes and exhibits a sinuous geometry, roughly following the elevation contours and the boundary between the coarse sand-gravelly deposits and the fine silt-clayey units. In the north-eastern and in the south-western portions of the surveyed plain, the limit appears to be undulating as it is controlled by many changes in the depositional environments that occurred during the late Pleistocene.

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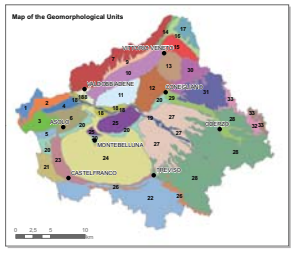
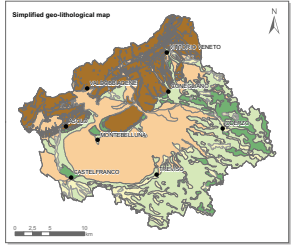
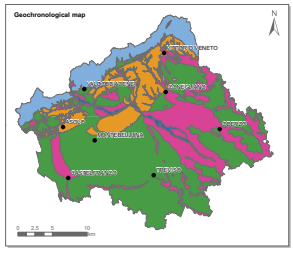
Software

Optim ReMi was used to interpret the field data; these were stored in a Microsoft Access database. Golden Software Surfer 10 was used for the kriging interpolation. The V_{S30} data were exported and the map was then edited using Esri ArcGIS 9.3.

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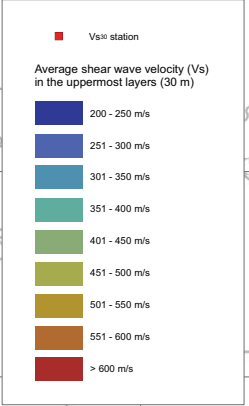
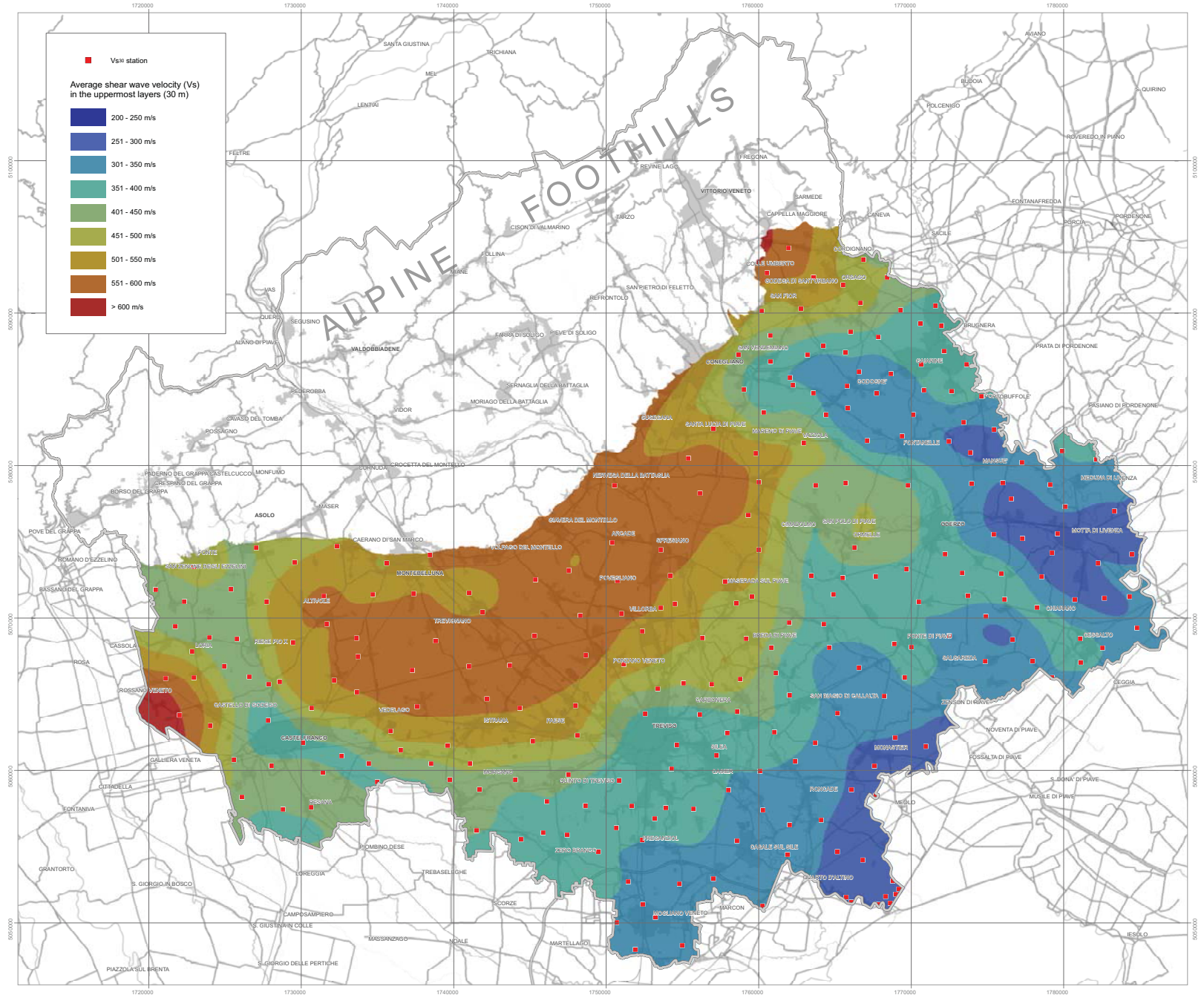
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|---|--|-----------------------------------|
| 1. Grappa Plateau | 12. Conchigera Hills | 23. Mauna |
| 2. Grappa Slopes | 13. Mottese amphitheater of Motta Veneta | 24. Piave Montebelluna |
| 3. Paderno del Grappa Clans | 14. Val Lantano | 25. Montello |
| 4. Val Cavallotti | 15. Poggio Spadine | 26. Sile |
| 5. Western Asolo Hills | 16. Campio Slopes | 27. Plain of Nepesina (low plain) |
| 6. Eastern Asolo Hills | 17. Campio Plateau | 28. Plain of Nepesina (low plain) |
| 7. Mt. Casan M. Vianin | 18. Piave Plain | 29. Montebelluna |
| 8. Valsobotta | 19. Current flow bed of the Piave River | 30. Caravita-Mantova (high plain) |
| 9. Riviera Latisca | 20. Foothill alluvial fan | 31. Caravita-Mantova (low plain) |
| 10. High plain of the Tera-Pergine-Conegliano-Mantova | 21. Sile (high plain) | 32. Liverno |
| 11. Quarter del Piave | 22. Sile (low plain) | 33. Sapperton |

AVERAGE SHEAR WAVE VELOCITY OF THE PLAIN OF THE PROVINCE OF TREVISO (NORTHERN ITALY)

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Map Editing
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PROVINCIA DI TREVISO



The base cartography was derived from the Regional Technical Map of the Veneto Region on a scale of 1:10,000, in the Universal Transverse Mercator (UTM) Projection. The plane coordinates are defined in the Gauss-Boaga Italian National System (west zone).