SEISMIC SOIL CLASS MAP ACCORDING TO EUROPEAN AND ITALIAN CODES

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Introduction

Soil conditions affect groundmotion amplification. Thus, seismic site classification is a critical issue to predict ground motion parameters in the context of both probabilistic seismic hazard analysis and real-time generation of shaking maps. Especially on large areas, simplified procedures for estimating the seismic soil amplification can be advantageous. In order to account for these local effects, some proxies which account for the soil behaviour can be identified; e.g., the average shear-wave velocity of the upper 30 m (VS,30), or the equivalent shear-wave velocity from the depth of the seismic bedrock (VS,eq). In this study, two maps of seismic shallow soil classification for Italy according to Eurocode 8 (EC08) and the new Italian Building Code (ItBC2018) are presented. The methodology from which the maps are derived is described in Forte et al. (2019) and accounts for two sources of information: site-specific measurements and large-scale geological maps. The soil maps are obtained via a four-step procedure: (1) a database of about four-thousand shear-waves velocity (Vs) measurements coming from inhole tests, surface geophysical tests and microtremors is built, covering (unevenly) the whole national territory; (2) twenty geo-lithological complexes are identified from the available geological maps; (3) the investigations are grouped as a function of the geo-lithological complex and the distribution of measured VS,30, VS,eq are derived; (4) medians and standard deviations of such distributions are assumed to be representative of the corresponding complexes that are consequently associated to soil classes.The EC08 soil class map and the available database of Vs measurements were compared with the seismic soil map provided by the USGS based on a topographic slope-proxy (Allen and Wald, 2007). The latter is obtained by the correlation between topographic slope and VS,30, assuming morphometrical characteristics of the terrain as representative of the lithology. The slope-based method appears less reliable than the proposed approach, because its predictions resulted in a slight but systematic overestimation of the measured soil classes. Therefore, the proposed map can be more suitable for large-scale seismic risk studies, despite it is not a substitute of seismic microzonation and local site response analyses.

Data

Vs data comes from In-Hole Tests, Surface Geophysical Tests and Microtremors, they were collected from a wide range of sources, resulting in a strongly uneven distribution in both quantity and quality of the information.

All data were stored in a GIS database and, for each investigation, the values of $V_{S,30}$ and $V_{S,eq}$ were calculated (Figure 1). The complete database features **3842** VS measurements. **1570** In-Hole Tests (DH, CH, SCPT), **319** Surface Geophysical Tests (MASW, SASW, seismic refraction surveys) and **1937** Microtremors (ESAC, Re.Mi., HVSR, Passive Array, FTAN) designed to measure shear-wave velocity profiles. The figure 1 shows that the overall data distribution clearly follows the Apennine mountain chain, where there is the largest seismic hazard , or identifies the areas affected by the most recent earthquakes.

Starting from the original geological formations as classified by Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), a simplified geo-lithological classification was set up. The new classification accounts for 20 geological complexes. They were identified on similar lithology, geomorphologic setting, genetic processes (facies), age and seismic behaviour of the original categories. The geo-lithological classification polygons were digitized and implemented in the GIS database (See Figure 2 and Table 1).

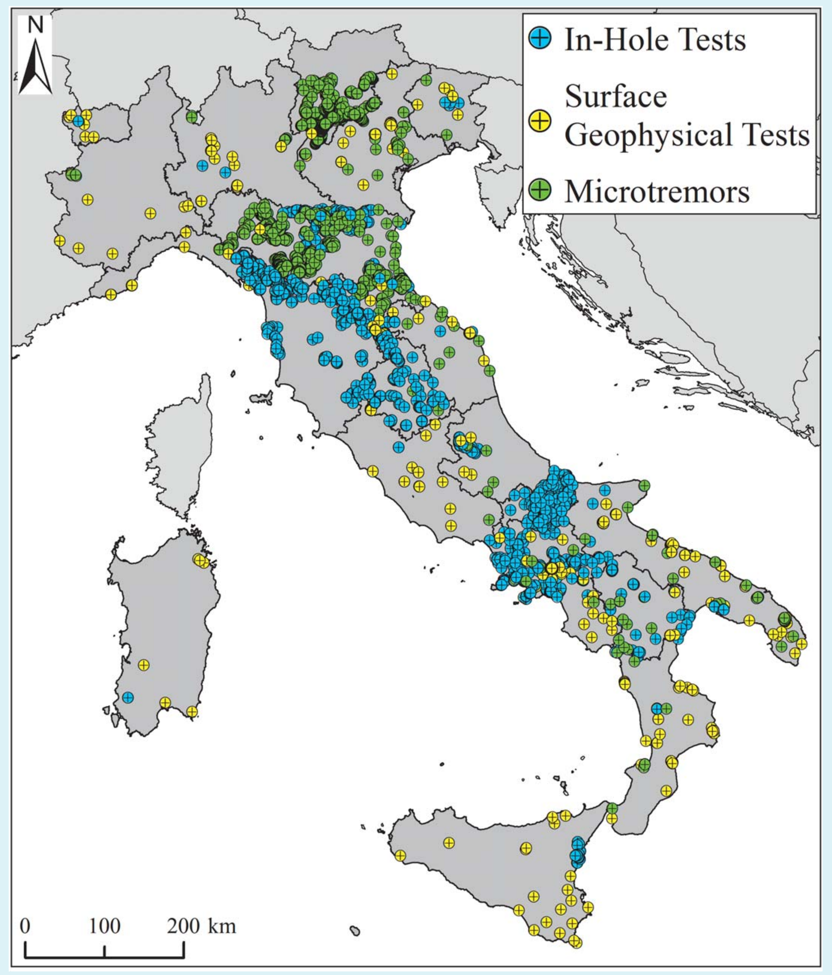

Fig. 1 Distribution and type of collected data

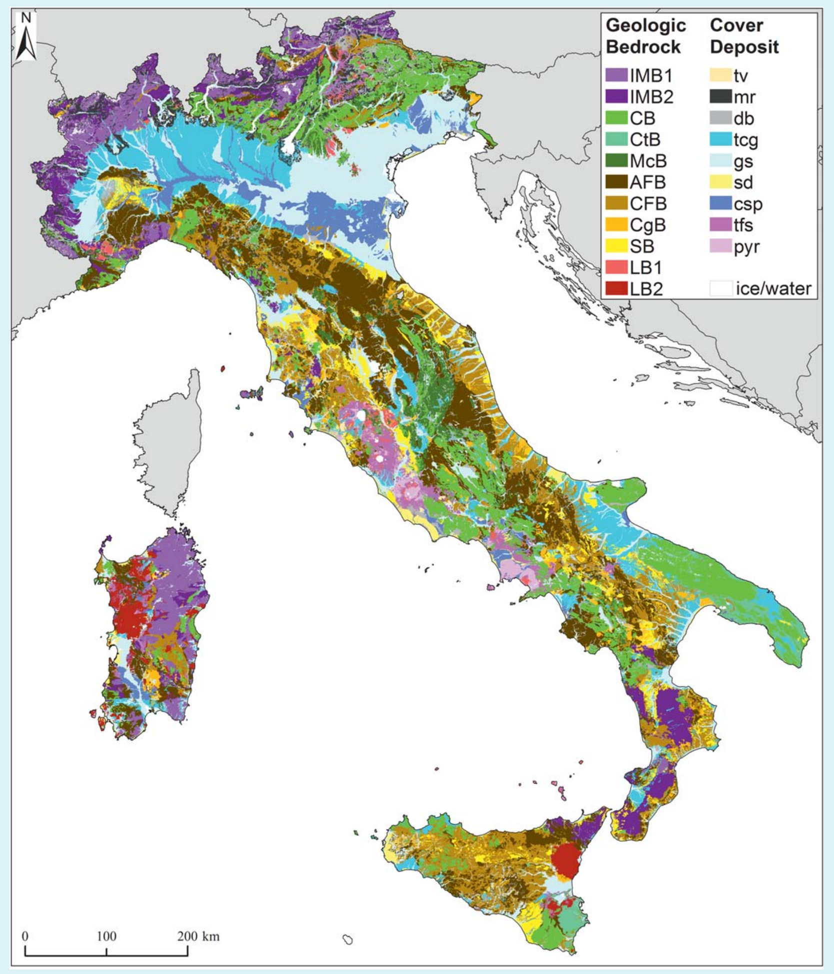

Fig. 2 Map of Italy showing the identified geo-lithological complexes (keys in Tab. 1). Ice or water are reported in white.

Name of the Complex	ID	Description	Geologic Age
Cover deposits			
Pyroclastic soil	**pyr**	Successions of ashes, pumices and scoriae	Pleistocene-Holocene
Tuff and scoriae	**tfs**	Tuffs and ignimbrites	Oligocene-Pleistocene
Clay silt and peat	**csp**	Clays, silts, peat from palustrine environment	Pleistocene-Holocene
Sand	**sd**	Sands and gravels from dunes and beaches	Pleistocene-Holocene
Gravel and sand	**gs**	Conglomerates, gravels and sands from alluvial deposits.	Pleistocene-Holocene
Terraced conglomerate	**tcg**	Conglomerates, sands and shale from terraced successions.	Pleistocene
Shallow debris	**db**	Infill, alluvial fan, debris, colluvium, breccia, debris talus and sandy-silt talus on igneous and metamorphic bedrock.	Pleistocene-Holocene
Moraine	**mr**	Moraines deposits and large landslide bodies	Pleistocene-Holocene
Travertine	**tv**	Travertines and soft limestones	Pleistocene-Holocene
Geologic Bedrock			
Lava	**LB1** **LB2**	Porphyries and lava Lava (Sardinia and Sicily)	Paleozoic-Holocene Cenozoic-Holocene
Sand	**SB**	Sands and sandstone bedrock	Pliocene-Pleistocene
Conglomerate	**CgB**	Gravels and conglomerates bedrock	Pliocene-Pleistocene
Clay and Clay flysch	**CFB**	Clay, clayey flysch, phyllites, clayey schists	Cenozoic-Pleistocene
Arenaceous flysch	**AFB**	Arenaceous and marly flysch, marly limestones, gypsums clayey metamorphic rocks	Cenozoic
Marly calcareous	**McB**	Marly, calcareous and siliceous successions deposited in pelagic environment	Meso-Cenozoic
Calcareous tuff	**CtB**	Calcarenites	Pliocene-Pleistocene
Carbonate	**CB**	Limestones, dolostones, marbles	Meso-Cenozoic
Igneous metamorphic	**IMB1** **IMB2**	Igneous and metamorphic rocks (Sardegna, Lombardia, Valle d'Aosta, Toscana) Igneous and metamorphic rocks (Calabria, Sicilia, Liguria)	Paleozoic-Cenozoic Meso-Cenozoic

Tab. 1 Geo-lithological complexes.

Statistics of Vs and soil class for geolithological complexes

The $V_{S,30}$ and $V_{S,eq}$ measurements are grouped in the geolithological complexes and the statistics of data for each complex are computed through the box-plots for EC8 (Eurocode 8) in Figure 3 and ItBC2018 (New Italian Building Code) in Figure 4. Some of geolithological bedrocks also represent seismic bedrock (V_S > 800 m/s).

The complexes representative of geologic bedrock characterized by median $V_{S,30}$ between 360 and 800 m/s, with the exception of CB and SB, which have median value equal to 847 and 326 m/s, respectively. Quaternary deposits (Figure 3) are characterized by shear-waves velocity clearly decreasing as function of the grain-sizes, sorting and textures.

With respect to $V_{S,eq}$, as reported in Figure 4, results are in good accordance with those shown in Figure 3. The only differences are: (i) LB2 does not belong to the 360–800 m/s interval, having median value of 315 m/s; (ii) IMB2 has median value lower than 800 m/s and equal to 476 m/s. The latter are due to the definition of $V_{S,eq}$, which does not take in account the increase of stiffness provided by the seismic bedrock contribution.

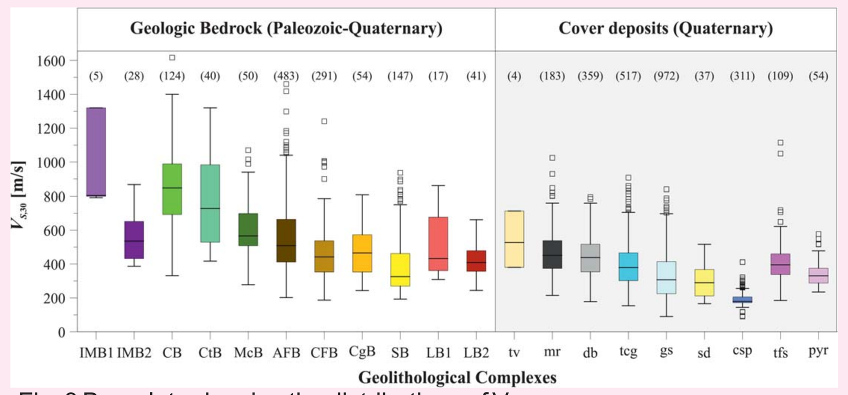

Fig. 3 Box-plots showing the distributions of $V_{S,30}$.

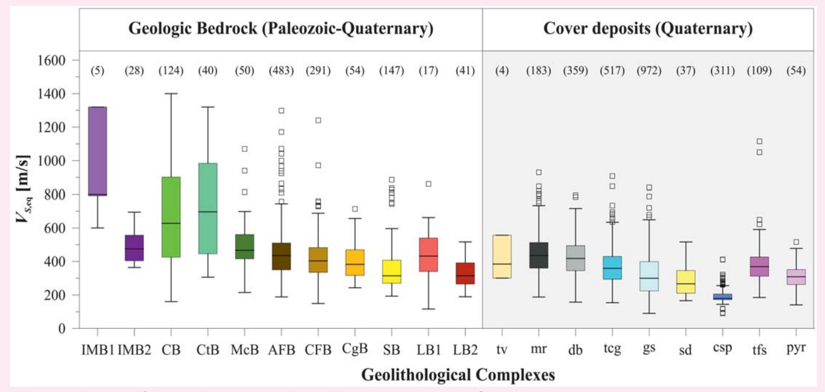

Fig. 4 Box-plots showing the distributions of $V_{S,eq}$.

In Figures 5 and 6 histograms show the distributions of soil classes according to EC8 and ItBC2018. In most cases, one soil class is predominant with respect to the others, but for *CB* and *CtB* the frequencies of A and B class occurrences are comparable as well as the frequencies of B and C classes for *tcg* and the frequencies of C and D classes for *csp*. Comparing Figures 3 and 5, it can be seen that site classification of the latter is in perfect accordance with the median $V_{S,30}$ values shown in the former. This is partially described by the fact that the number of investigations that assigned class E (the soil class not defined only on $V_{S,30}$ parameter) is negligible. Soil class frequencies in accordance with ItBC2018 classification are reported in Fig. 6.

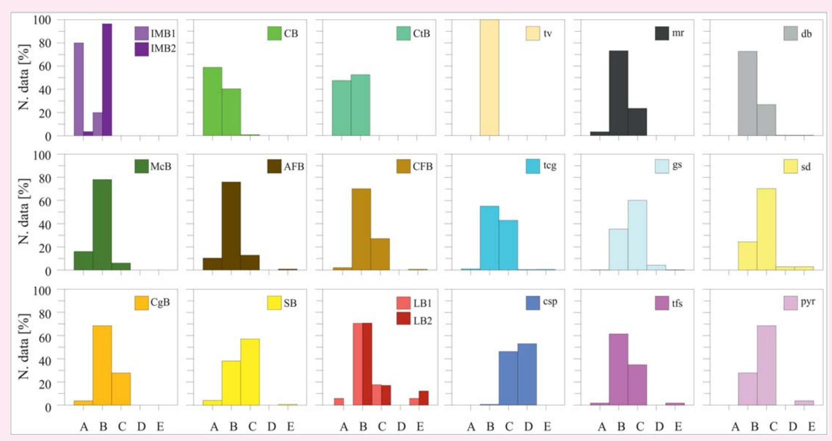

Fig. 5 Histograms showing the distributions of soil classes according to EC8

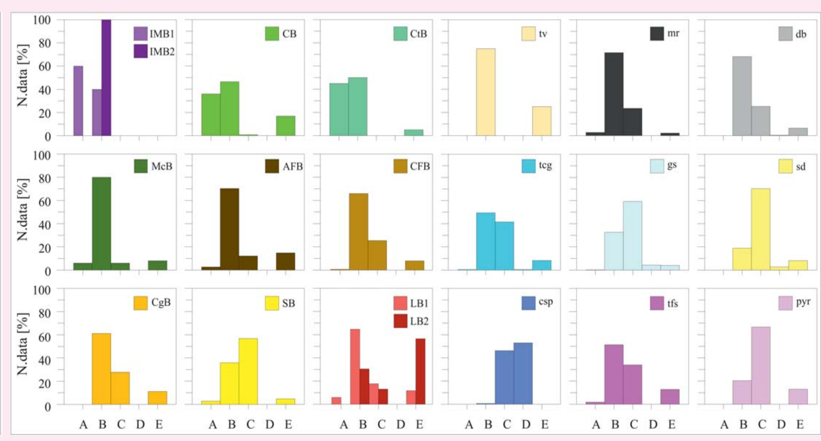

Fig. 6 Histograms showing the distributions of soil classes according to ItBC2018

Seismic soil classification

Statistics of V_S measurements were associated to each geo-lithological class. Site classification following EC8 was based on the attribution of the VS median to the geolitological complex (Figure 3). Conversely, for ItBC2018, the frequency of soil class occurrence is assumed as the representative class of the whole complex (Figure 6).

EC8 and ItBC2018 classifications account for some soil classes that are not defined exclusively on the basis of VS measurements (E, S1 and S2 for EC8 and class E for ItBC2018).

LB2 and CB display a significant presence of E site-class and topographic slope was assumed as a proxy for the identification of sub-areas. Hence, LB2 was classified as B and E, the former with slopes higher than 20° and the latter less than 20°.

The code-conforming soil classes are attributed to the geo-lithological complexes as shown in Figure 7 for EC8 and ItBC2018 soil classes, respectively.

The EC8 map of Italy highlights a widespread B class distribution (57.4% of the area of Italy), followed by C (19.2%). The soil class A is 18.4% of Italian sites, D is the smallest area (4.2%), E class is not represented. On the ItBC2018 map, B is again the most represented (55.8%), A is lower (13.2%), C and D respectively remain 19.2% and 4.2%, while E class is characterized by 6.8% (Fig.8).

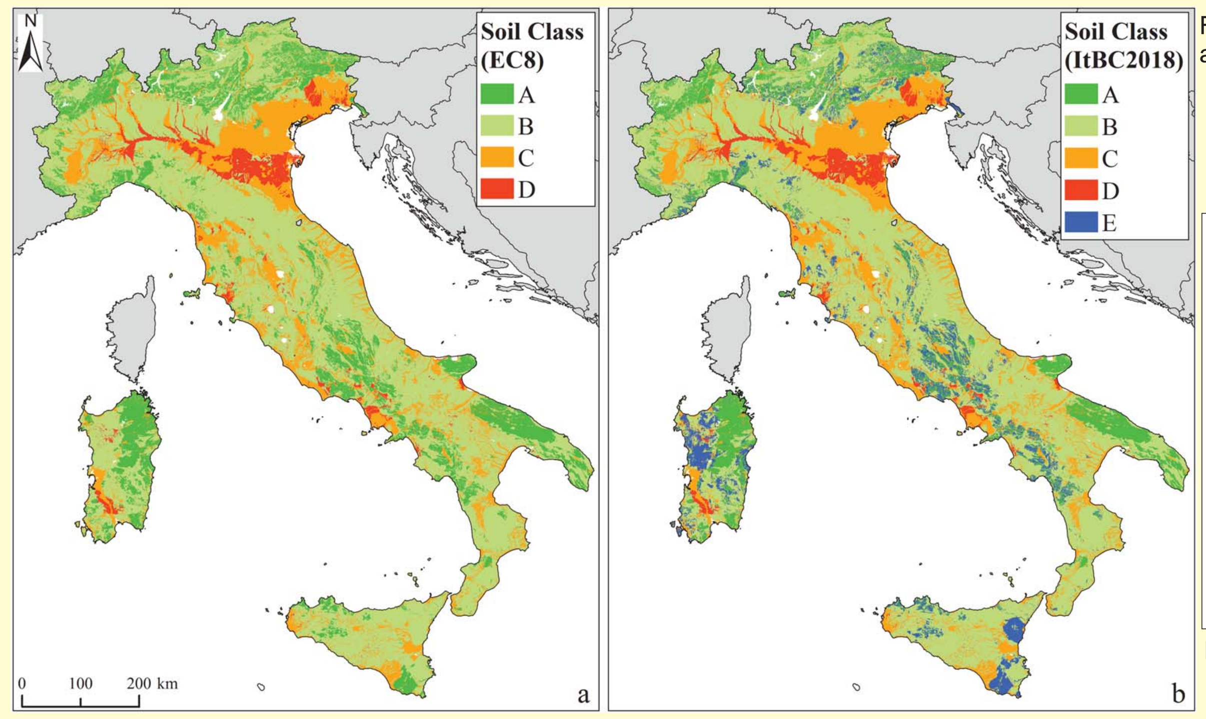

Fig. 7 Soil Class maps obtained in accordance with (a) EC8 and (b) ItBC2018.

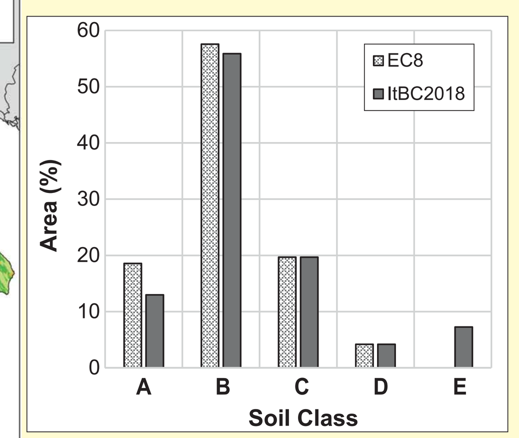

Fig. 8 Distribution of soil classes for Italy

To make soil classification available to scientific community, a stand-alone software for database interrogation was developed. It is named Seismic Soil Class-Italy (SSC-Italy) and provides the results of soil classification for any set of sites within the Italian country. The tool is coded in MATHWORKS-Matlab® and benefits from the graphical user interface (GUI) shown in Figure 9. The output can be exported as a text file with the median(s) and the standard deviation(s) of $V_{S,30}$ (or $V_{S,eq}$) of the sites together with the geo-lithological complexes.

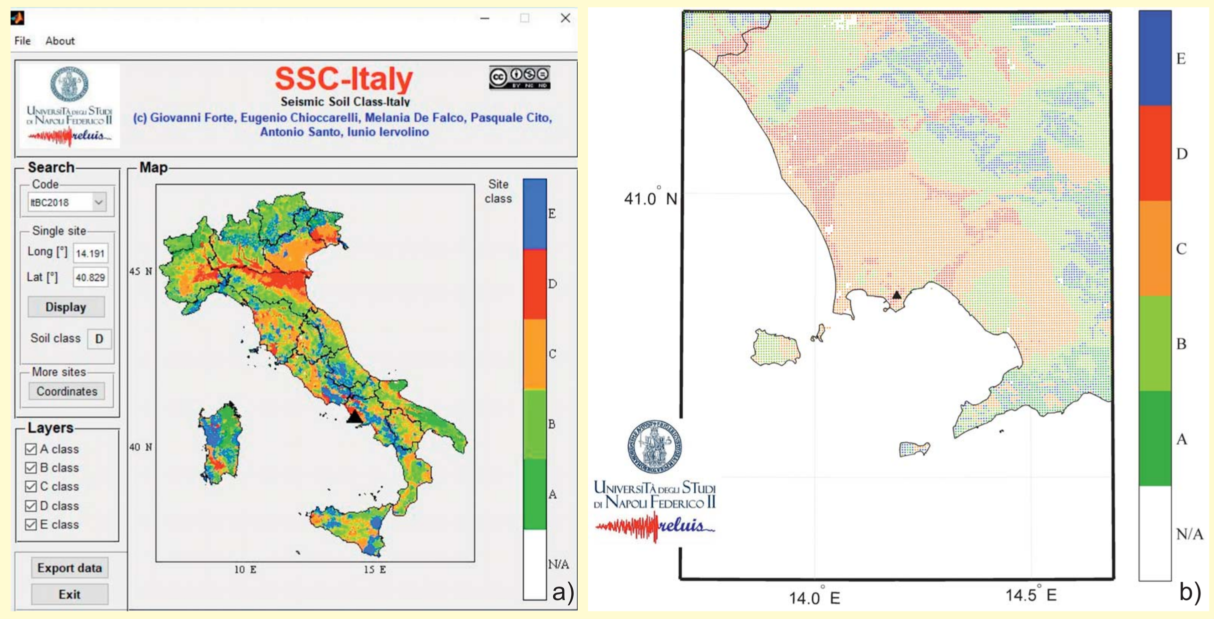

Fig. 9 Main GUI of SSC-Italy software (a) and the output (b)

	USGS				
EC8	A	B	C	D	E
A	85.2	14.0	0.8	0.0	0.0
B	57.3	37.7	4.8	0.1	0.0
C	12.0	44.9	41.6	1.5	0.0
D	3.3	20.8	71.4	4.5	0.0

	USGS				
ItCB18	A	B	C	D	E
A	87.0	12.4	0.6	0.0	0.0
B	56.3	38.6	5.0	0.1	0.0
C	12.0	44.9	41.6	1.5	0.0
D	3.3	20.8	71.4	4.5	0.0
E	83.7	15.3	1.0	0.0	0.0

Tab. 2 Comparison between the soil classes estimated with EC8, ItCB18 maps and USGS approach.

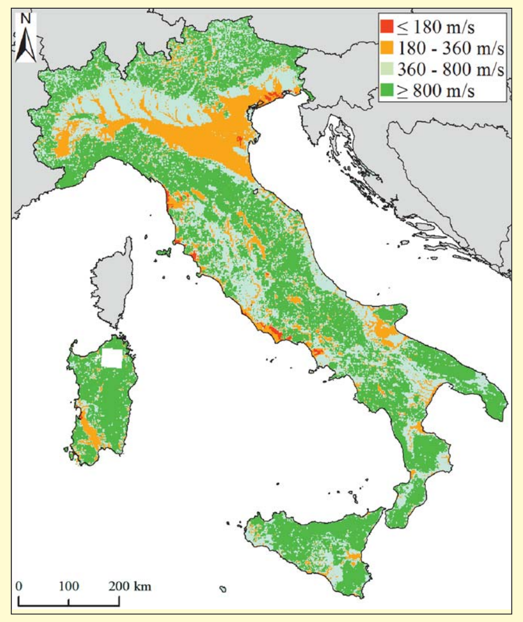

Fig. 10 USGS Map of Vs

The resulting map was compared with the seismic soil map provided by the USGS (Allen and Wald, 2007) in Figure 10 based on a topographic slope-proxy. The latter is obtained from the correlation between topographic slope and $V_{S,30}$, by assuming morphometrical characteristics of the terrain as representative of the lithology. More in detail, steep slopes generally reflect rock formations, nearly-flat basins indicate soft soils, and intermediate slopes correspond to stiff soils. As shown in Table 2, the slope-based method appears less reliable than the proposed approach, because its predictions resulted in a slight but systematic overestimation of the measured soil classes (Forte et al. 2017). Therefore, the proposed map **IT IS NOT A SUBSTITUTE OF SEISMIC MICROZONATION** and can be more suitable for large-scale seismic risk studies.

References

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