

1 Seismic soil classification of Italy based on surface geology and shear- 2 wave velocity measurements

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12 Abstract

13
14 During an earthquake the seismic wave amplification related to local site conditions can have a
15 significant impact on the ground motion characteristics. In order to account for these local effects
16 some proxies for the soil characteristics exist; e.g., the average shear-wave velocity of the upper 30
17 meters ($V_{S,30}$), or the equivalent shear-wave velocity from the ground to the depth of the seismic
18 bedrock when this is less than 30 meters ($V_{S,eq}$).

19 The aim of this paper is to provide maps of seismic shallow soil classification for Italy accounting for
20 two sources of information: site-specific measurements and large-scale geological maps. The soil
21 maps are obtained via a four-step procedure: (1) a database of available site-specific investigations is
22 built, covering (unevenly) the whole national territory; (2) twenty geo-lithological complexes are
23 identified from the available geological maps; (3) the investigations are grouped as a function of the
24 geo-lithological complex and the distribution of measured $V_{S,30}$ and $V_{S,eq}$ are estimated; (4) medians
25 and standard deviations of such distributions are assumed to be representative of the corresponding
26 complexes. The statistics of investigations are used to derive the large-scale soil maps. To make the
27 results of the study available, a stand-alone software has been developed. Despite not being adequate
28 substitutes of site-specific studies such as microzonation and local site response analyses, the
29 provided results can be useful for large-scale seismic risk studies.

30 **Keywords:** probabilistic seismic hazard assessment, regional seismic risk, site classification, soil
31 classes, seismic soil response

32 **1. Introduction**

33 Seismic fault ruptures generate waves that propagate in all directions through the rigid bedrock for
34 kilometres. Before reaching the ground surface, seismic waves go through the shallower materials
35 covering the bedrock. It is known that this last part of propagation may have significant effects on a
36 number of ground motion parameters (e.g., peak ground acceleration, spectral ordinates, etc.). Indeed,
37 the so-called local site effects are deeply discussed in the literature (e.g., [1]) and must be taken into
38 account for the estimation of seismic effects on engineering structures. This is pointed out by the
39 landmark papers of Dobry and Vucetic [2] and Seed et al. [3] and is systematically confirmed by the
40 distribution of observed damages after significant earthquakes (e.g., [4–6]). In the hypothesis of a
41 uniform layer of isotropic, linear elastic soil overlying rigid bedrock, the soil amplification of a
42 harmonic horizontal motion of the bedrock is a function of (i) the thickness of the soil layer and (ii)
43 the propagation velocity of shear-waves. In real cases, seismic waves propagation is more
44 complicated and *site response analysis* is required to characterize the peculiar soil dynamics (e.g.,
45 [7,8]). However, for the cases in which such analyses cannot be performed, a simplified parameter to
46 account for the site response, the average shear-wave velocity of the upper 30 m, $V_{s,30}$, was proposed
47 at the end of the last century ([9,10]). $V_{s,30}$ is defined as per Equation (1) where N is the number of
48 homogeneous soil layers up to thirty meters depth whereas h_i and $V_{s,i}$ are the thickness and the shear-
49 wave velocity (V_s) in the soil layer i , respectively.

$$50 \quad V_{s,30} = \frac{30}{\sum_{i=1}^N \frac{h_i}{V_{s,i}}} \quad (1)$$

51 The depth of 30 m was conventionally assumed as relevant (it is, typically, a depth that can be attained
52 in one working day of boring). The value of $V_{s,30}$ has the advantage of being easily obtainable, at
53 relatively low cost, by performing in-hole (*Down-Hole* or DH, *Cross-Hole* or CH), or surface (SASW,
54 MASW, Microtremors) geophysical tests (e.g., [11]). Furthermore, several scientific studies (e.g.
55 [12–14]) provided strategies to infer $V_{s,30}$ values from the most common in-field tests, such as
56 standard penetration test (SPT) or cone penetration test (CPT).

57 Today, $V_{s,30}$ is the main single-value parameter that summarizes seismic soil behaviour. The majority
58 of the ground motion prediction equations (GMPEs) refer to $V_{s,30}$ either by (i) directly considering
59 the $V_{s,30}$ value in the functional form (e.g., [15–18]); (ii) categorizing the soil behaviour (e.g., stiff or
60 soft soil) depending on $V_{s,30}$ intervals and defining dummy variables associated to each soil category
61 (e.g., [19,20]) or (iii) allowing both of these strategies (e.g., [21,22]). $V_{s,30}$ is also adopted by several
62 seismic codes to identify the appropriate site-dependent design spectrum for structures; some
63 examples are NEHRP Provisions [23] and the Eurocode 8, or EC8 [24].

64 On the other hand, several authors highlighted that knowledge of $V_{s,30}$ may not be enough to properly
65 quantify the variation of seismic motion from bedrock to ground surface (see for example [25–28]).
66 Indeed, it is known that the overall tendency of V_s is to increase with depth; nevertheless, actual soil
67 profiles may exhibit a shallow velocity inversion, due to the soil depositional variability along the
68 profiles, which is reflected in peculiar characteristics of the seismic signal propagated through them.

69 This case, in fact, cannot be detected if only the $V_{s,30}$ parameter is considered. Similarly, $V_{s,30}$ is not
70 able to account for non-linear soil behaviour, for the actual depth of seismic bedrock, for deep soft
71 deposits lying on much stiffer rock, for velocity profiles that do not exhibit a strong impedance
72 contrast in the first meters or in basin-type geological settings. Thus, in the last years, scientific efforts

73 have been made to develop and update classification criteria based on $V_{s,30}$ together with other
74 relevant parameters, such as the bedrock depth (e.g., [29]), or site period/frequency (e.g., [30]).
75 In accordance with this trend, the recent Italian building code, or ItBC2018 [31], tries to overcome
76 some of the $V_{s,30}$ limitations (those related to bedrock depth), by referring to the so-called $V_{s,eq}$, which
77 derives from a slight modification of the $V_{s,30}$ parameter. This is defined in Equation (2), in which H
78 is the depth of the bedrock if it is less than 30 meters. When the bedrock is deeper, H is equal to 30
79 (and $V_{s,eq}$ degenerates into $V_{s,30}$).

$$80 \quad V_{s,eq} = \frac{H}{\sum_{i=1}^N \frac{h_i}{V_{s,i}}} \quad (2)$$

81 It should be noted that, although $V_{s,30}$ or $V_{s,eq}$ can be useful for a preliminary soil site classification,
82 they cannot be considered as sufficient information for structural seismic risk assessment at a specific
83 site. In this case, a number of additional parameters, such as the soil resonance frequency or the whole
84 shear-waves profile to the bedrock would be required. On the other hand, in the case of a large area
85 of interest (i.e., large-scale/regional seismic risk analyses), because more refined soil information is
86 often impossible to acquire, $V_{s,30}$ (or $V_{s,eq}$) values are commonly considered as viable parameters.
87 Moreover, in these cases, since actual measurements are usually available at a limited number of sites,
88 strategies to extend the single-site evaluations to a broader area are often required. Several approaches
89 have been proposed in both technical and scientific literature (see for instance [32,33]) based on
90 geological, geomorphological or geotechnical units [34–39]. Thompson et al. [40] proposed a $V_{s,30}$
91 map for the California using a hybrid geostatistical approach able to account for geology, topography,
92 and site-specific shear-wave velocity measurements. Although there is extensive literature on the
93 topic, the most widespread method, due to its user-friendliness, is the United States Geological Survey
94 (USGS) approach developed in [41]. The method is based on the use of a correlation between
95 topographic slope and $V_{s,30}$; according to that method, steep slopes generally reflect rock formations,

96 nearly-flat areas indicate soft soils and intermediate slopes correspond to stiff soils (the accuracy of
97 results often depends on the resolution of the digital elevation model). Lemoine et al. and Forte et al.
98 [42,43] compared the $V_{s,30}$ map predicted by USGS method for Mediterranean Europe and a case
99 study in Italy with a fair collection of V_s measurements. Both studies found that the USGS approach
100 tends to overestimate the actual $V_{s,30}$ measurements.

101 In Italy, site classifications on a national scale have been made by the Italian *Istituto Nazionale di*
102 *Geofisica e Vulcanologia* (INGV), which is responsible for providing the seismic hazard map for
103 structural design in Italy. More specifically, Luzi and Meroni [44] proposed a national 1:500.000 map
104 for site classification, based on a broad geological criterion considering lithology and age, and related
105 to three ground types. Later, Michellini et al. [45] upgraded this map by classifying the geological
106 units derived from the 1:100.000 geology map of Italy into five ground categories (from A to E).
107 They correlated these categories to those specified by EC8 (see the next section), being characterized
108 by the following reference $V_{s,30}$ values: (A) 1000 m/s; (B) 600 m/s; (C) 300 m/s; (D) 150 m/s; (E)
109 250 m/s, with soil thickness < 20 m. The most recent map was provided by Di Capua et al. [46] based
110 on 1:100.000 geological maps. It represents an attempt to merge geological formations in lithoseismic
111 classes following their lithological description, in order to identify areas characterized by a
112 homogeneous seismic response.

113 In the remaining part of the paper, a four-step procedure for correlating the surface geological maps
114 with site-specific investigations is presented. Then, referring to the Italian case, each step is
115 quantitatively described. An intermediate result of the procedure is the assessment of medians and
116 standard deviations of $V_{s,30}$ and $V_{s,eq}$ parameters for all the Italian sites. The final result is the soil
117 classification, according to EC8 and ItBC2018, of the country. All results are provided by means of
118 a software (available at <http://wpage.unina.it/iuniervo/SSC-Italy.zip>) that can be a useful tool for large
119 scale seismic studies or post-earthquake shakemap generation (e.g., [47,48]). Finally, an illustrative

120 application is carried out to quantify the effect of soil classification in the case of probabilistic seismic
 121 hazard analysis at a national scale.

122 2. Methodology

123 From 2008 until the beginning of 2018, the [49] was the national seismic code for structural design
 124 and assessment. Criteria for soil classification were in good accordance with the current version of
 125 EC8. The latter associates a soil class on the basis of $V_{s,30}$ assessment or, alternatively, on the values
 126 of SPT blow-count or the undrained shear strength of soil. The description of each soil class together
 127 with the $V_{s,30}$ intervals are reported in Table 1 for the sake of completeness. The $V_{s,30}$ parameter could
 128 be computed from the V_s profiles that are characterized by a gradual increase of mechanical properties
 129 with depth. In the table, four main soil categories (from A to D) are identified for decreasing $V_{s,30}$
 130 value. Then, three other classes (E, S1, S2) can be defined considering additional information.

131 **Table 1.** Ground type/Soil classification according to EC8.

Ground type/Soil class	Description of stratigraphic profile	$V_{s,30}$ [m/s]
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth.	800 – 360
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters.	360 – 180
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180
E	A soil profile consisting of a surface alluvium layer with V_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $V_s > 800$ m/s.	-
S1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index ($PI > 40$) and high-water content.	< 100 (indicative)
S2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S1.	-

132

133 In the new version of the Italian building code, ItBC2018, some differences in the criteria for soil site
 134 classification have been introduced. Site classification now refers to $V_{S,eq}$, the number of soil classes
 135 has been reduced to five and the definition of class E has been changed as reported in Table 2.

136 **Table 2.** Ground type/Soil classification according to ItBC2018.

Ground type/Soil class	Description of stratigraphic profile	$V_{S,eq}$ [m/s]
A	Rock or other rock-like geological formation, including at most 3 m of weaker material at the surface.	> 800
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth.	800 – 360
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness higher than 30 meters and characterized by a gradual increase of mechanical properties with depth.	360 – 180
D	Deposits of loose-to-medium cohesion soil with thickness higher than 30 meters and characterized by a gradual increase of mechanical properties with depth.	180 – 100
E	Soils with characteristics and equivalent shear velocity analogous to those defined for classes C and D but with a deposits thickness not higher than 30 meters.	-

137
 138 This paper provides statistics of $V_{S,30}$ and $V_{S,eq}$ values for the Italian sites that are used to derive a
 139 seismic soil classification on a national scale according to both EC8 and ItBC2018. Here the general
 140 procedure adopted in the study is summarized. The approach aims to account for two types of
 141 information that are (i) the site-specific investigations and V_S measurements, and (ii) the existing
 142 geological maps that identify geographic area, or polygons, with homogeneous features. The
 143 procedure is summarized in four steps.

- 144 1. The first effort was the search and collection of the available data about investigations
 145 performed for any inland site of Italy. Retrieved information was analysed by the authors in
 146 order to obtain a dataset of geographical locations and soil classes. All data were stored in a
 147 geographical information system (GIS) database and, for each investigation, the values of
 148 $V_{S,30}$ and $V_{S,eq}$ were calculated.
- 149 2. Starting from the original geological formations as classified by *Istituto Superiore per la*
 150 *Protezione e la Ricerca Ambientale (ISPRA)*, a simplified geo-lithological classification was

151 set up. The new classification accounts for similar lithology, geomorphologic setting, genetic
152 processes (*facies*), age and seismic behavior of the original categories. The geo-lithological
153 classification polygons were digitized and implemented in the GIS database.

154 3. Data from step one and step two were combined: values of $V_{S,30}$ and $V_{S,eq}$ were grouped as
155 function of the geo-lithological class in which they were measured and the statistics were
156 computed for each class.

157 4. Finally, V_s measurements were associated to each geo-lithological class, together with the
158 first, second (median value) and third quartiles of the considered distributions. This allowed
159 to provide $V_{S,30}$ and $V_{S,eq}$ median values and standard deviations for each geo-lithological
160 complex. Additionally, as described in Section 6, combining the V_s measurements with the
161 other available information, each investigated site was classified according to soil classes
162 proposed by EC8 and ItBC2018. This allowed to identify a more probable soil class for each
163 geo-lithological complex which has been assumed as representative of the complex.

164 It should be noted that two new contributions can be identified in the procedure. First, this is, to
165 authors' knowledge, the first attempt to collect the available measurements of soil shear-wave
166 velocities on a national scale in Italy, combined with geo-lithological characteristics. This requires a
167 significant effort in the search and homogenization of information and allows continuous enrichment
168 of the database with new available investigations. Second, the identification of geo-lithological
169 complexes and the association of V_s statistics, as well as soil classes, to each complex have not been
170 proposed before for Italy. Nevertheless, similar procedures were described in [37] and [43], which
171 developed the maps for single Italian regions (Campania and Molise, respectively), using a smaller
172 sample of V_s measurements.

173 **3. Available data (step one)**

174 The authors collected data from a wide range of sources resulting in a strongly uneven distribution in
175 both quantity and quality of the information. This is mainly because only some Italian administrative
176 regions operate geological services that collect and distribute data; consequently there are no common
177 standards about the data and format. More specifically, data used in this paper were retrieved from
178 the following sources (see the Data sources section for further details): available scientific and
179 technical reports for the seismic characterization of the strong-motion stations of the Italian
180 Accelerometric Archive (ITACA); reports from microzonation projects for the Abruzzo, Molise and
181 Basilicata regions; regional databases of the seismic service of Emilia Romagna; Civil Protection
182 studies for Sicilia and Trentino Alto-Adige regions; local site effects valuation Project for Toscana
183 (VEL); local civil engineering practitioners; scientific reports; civil engineering projects and
184 unpublished technical reports.

185 The collected data are considered reliable if the location is clearly defined and V_s is measured through
186 standard geophysical tests. This implies, for example, that $V_{s,30}$ values inferred through the most
187 common or recent empirical correlations with penetration resistance (e.g., [12,14,30]) were excluded.
188 Moreover, in some cases, available data are characterized by shear-wave velocity profiles that do not
189 reach 30 m; these data were not used to compute $V_{s,30}$ even if several methods allow to infer it from
190 shallow velocity profiles (e.g., [50–52]). These same data were adopted only to compute $V_{s,eq}$ when
191 the depth of the bedrock is known. Apart from shear-wave velocity measurements, a number of sites
192 have other relevant information as geological description of the study area, stratigraphic logs, and
193 results of laboratory and field geotechnical tests.

194 The available in situ tests were uploaded as a database (DB) in a GIS environment. The DB consists
195 of an identifier code for the different regions of Italy, UTM geodetic coordinates, type of
196 investigation, data source, the shear-wave velocity at each depth (when available), that is $V_{s,z}$, and

197 $V_{S,30}$ or $V_{S,eq}$ measurements. A detailed description of the database is reported in the following but,
198 before proceeding any further it is important to recall that the assessment of $V_{S,30}$ and $V_{S,eq}$ requires
199 slightly different information, hence data were differently selected depending on the considered
200 parameter.

201 The complete database features 3842 V_S measurements. In 16 cases, the $V_{S,z}$ profiles are extended to
202 the bedrock depth, which is shorter than 30 m; thus, they cannot be used for the $V_{S,30}$ assessment.
203 Therefore, two subsets of data of 3826 and 3842 measurements are used for $V_{S,30}$ and $V_{S,eq}$,
204 respectively. As pertaining to $V_{S,30}$, Table 3 describes the DB in detail: the measurements come from
205 different types of investigations: 1570 In-Hole Tests (DH, CH, SCPT), 319 Surface Geophysical
206 Tests (MASW, SASW, seismic refraction surveys) and 1937 Microtremors (ESAC, Re.Mi., HVSR,
207 Passive Array, FTAN) designed to measure shear-wave velocity profiles (ASTM D7400-08 [53]).
208 For each type of investigation, the table shows the available information. For 1433 sites, only the
209 $V_{S,30}$ value is available, whereas for 2393 sites the $V_{S,z}$ profile to 30 m depth is available; among these,
210 for 815 sites, the seismic bedrock is less than 30 m deep while in the remaining 1578 it is deeper than
211 30 m.

212 The location of the collected data in terms of type of investigation is reported in Figure 1. The figure
213 shows that the overall data distribution clearly follows the Apennine mountain chain, where there is
214 the largest seismic hazard [54], or identifies the areas affected by the most recent earthquakes (the
215 magnitude, or M, equal to 6, Umbria-Marche earthquake, 1997; the M5.7 Molise earthquake, 2002;
216 the M6.3 L'Aquila earthquake, 2009; the M6 Emilia sequence, 2012), where post-event studies
217 provided a relevant number of investigations. It should also be noted that Microtremors provide a less
218 accurate estimation of shear-wave velocity with respect to In-Hole Tests and Surface Geophysical
219 Tests. Although Microtremors provide the highest percentage of data (about 45%), these kinds of test
220 were concentrated in two regions: Emilia Romagna and Trentino Alto Adige. On the other hand, In-

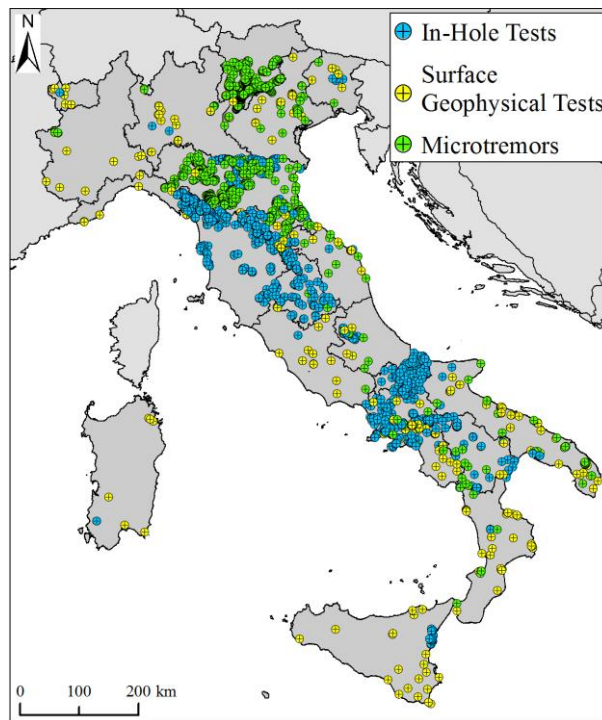
221 Hole Tests, which provide the most accurate information, are distributed over a large area covering
 222 the whole Apennine chain.

223

224 **Table 3.** Subset of data adopted for $V_{S,30}$.

Investigation type	Seismic bedrock deeper than 30 m	Seismic bedrock less deep than 30 m	Only $V_{S,30}$ available	Total number of data
In-Hole tests	607	903	60	1570
Surface Geophysical Tests	82	101	136	319
Microtremors	126	574	1237	1937
Total number of data	815	1578	1433	3826

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226

227 **Figure 1.** Distribution and type of collected data. .

228

229 The preliminary screening of data provides slightly different results when the $V_{S,eq}$ is considered. In
 230 this case, investigations in which $V_{S,z}$ profiles reach the seismic bedrock can be used even if they do
 231 not reach the depth of 30 meters (Table 4). Thus, a total of 3842 investigations are considered eligible
 232 for $V_{S,eq}$ identification. Among them, 2409 are those in which the entire $V_{S,z}$ profile to the bedrock is
 233 available (seismic bedrock is deeper than 30 m in 1578 sites whereas is less than 30 m deep in 831);

234 for the remaining 1433 sites only the $V_{s,30}$ is available. In these cases, to avoid rejecting a large amount
 235 of data, it is assumed that the seismic bedrock is deeper than 30 m and consequently $V_{s,30}$ is equal to
 236 $V_{s,eq}$.

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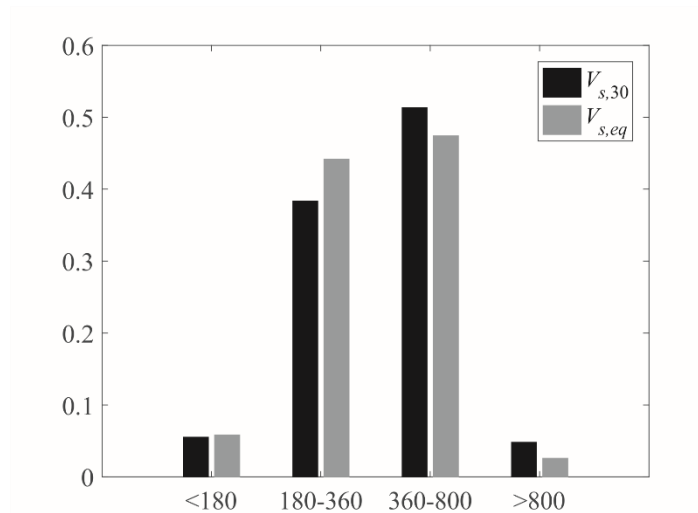
238 **Table 4.** Subset of data adopted for $V_{s,eq}$.

Investigation type	Seismic bedrock deeper than 30 m	Seismic bedrock less deep than 30 m	Only $V_{s,30}$ available	Total number of data
In-Hole tests	622	903	60	1585
Surface Geophysical Tests	83	101	136	320
Microtremors	126	574	1237	1937
Total number of data	831	1578	1433	3842

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240 A preliminary classification is performed as a function of velocity intervals for both considered
 241 parameters. Considered intervals are those used by EC8 and ItBC2018 for soil class identification,
 242 that is, >800 m/s, 800-360 m/s, 360-180 m/s and <180 m/s. Classification results are reported inFigure
 243 2. According to the figure, most of the sites (51%) are in the 800-360 m/s interval of $V_{s,30}$, while the
 244 38% are within 360-180 m/s. Fewer sites (5%) have $V_{s,30}$ higher than 800 m/s and 6% of sites are
 245 lower than 180 m/s. Similar are the results in terms of $V_{s,eq}$: 3% of sites are higher than 800 m/s, the
 246 majority (47%) are within 800-360 m/s, 44% are within 360-180 m/s and 6% are lower than 180 m/s.
 247 Site class A represents the seismic bedrock and is characterized by fewer investigations with respect
 248 to the others. This is due to the common practice of not performing geophysical investigations on
 249 rock outcrops (usually in mountainous settings). On the other hand, more efforts are usually addressed
 250 to the characterization of areas of towns or engineering works that, in Italy, mainly correspond to B
 251 and C soil classes.

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Figure 2. Distribution of data with respect to $V_{s,30}$ and $V_{s,eq}$.

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4. Geo-lithological map (step two)

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ISPRA is currently building the geological map of Italy at a 1:50.000 scale. It will cover the national territory with a total of 652 sheets but only 254 of them are available so far. Two hundred seventy-seven geological maps covering Italian territory produced by ISPRA at the 1:100.000 scale [55] are adopted for this study. They were completed in 1976 from field surveys performed on a 1:25.000 scale. Each geologic formation is characterized by lithological characteristics and age. However, similarly to other geological classifications on a national scale (see for example [56], for the case of Greece), it is easy to identify a lack of consistency at the boundaries of each sheet in which the territory is divided. This is due to the different interpretations and classifications made by geologists who carried out the survey in different years and adopting different classification criteria. In order to combine these national geological maps with the data described in the previous section, a simplified classification harmonizing the original categories was set up, involving expert judgement. With this aim, broader categories were introduced as function of similar lithology and geomorphologic setting, genetic processes (*facies*), age, and seismic behavior. To give an example, all the original geological formations described as "gravel and sand coming from river and alluvial environment" were grouped, because these types of soil have, in general, very similar lithological

271 features independently of the geographic location. Other examples are some geologic bedrocks such
 272 as "limestones" or "crystalline rocks".

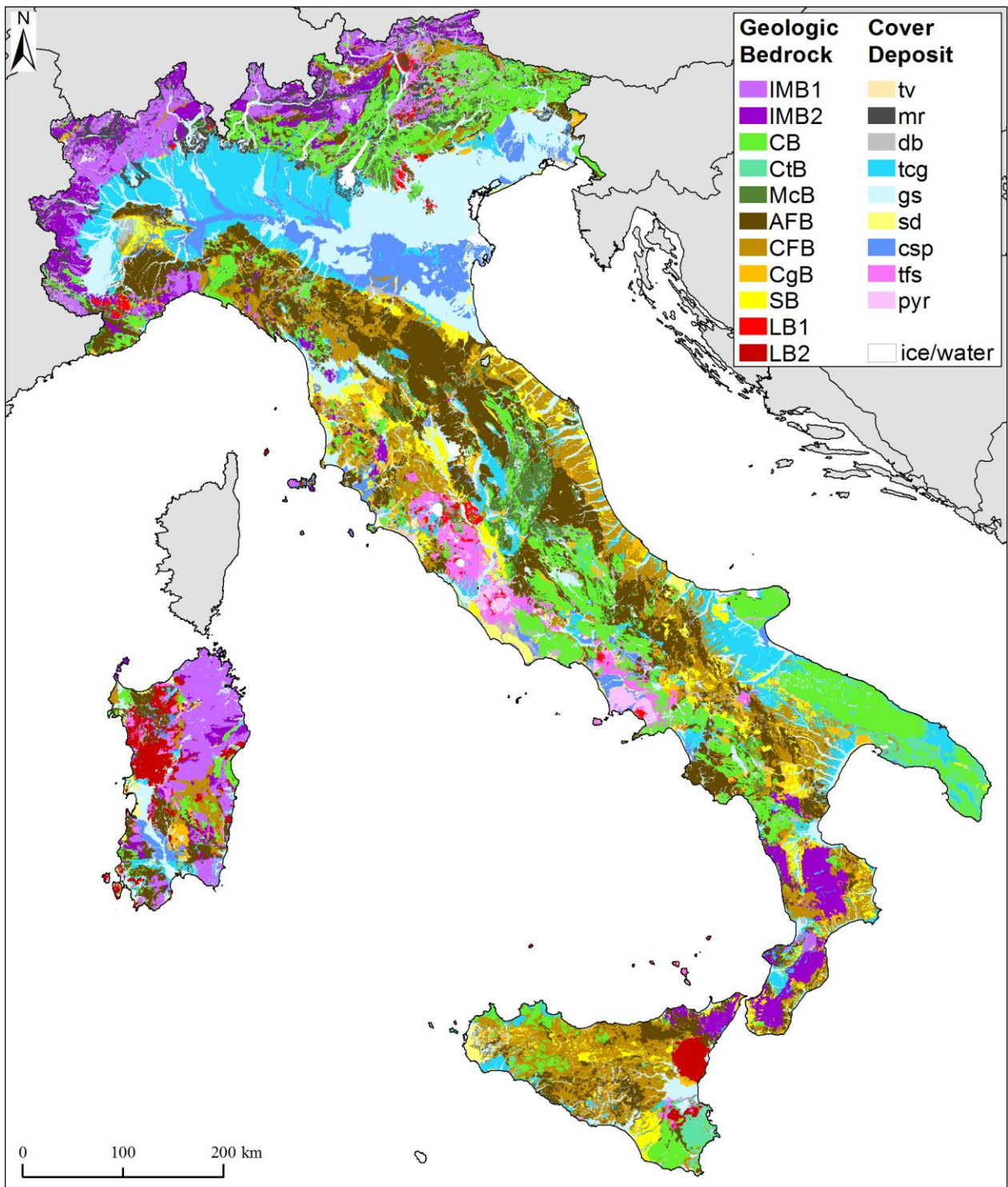
273 In fact, a relevant distinction was based on the identification of geo-lithological complexes as
 274 *geologic bedrock* (Paleozoic to Pleistocene) versus those representative of *cover deposits*
 275 (Quaternary). Geologic bedrock formations were mainly grouped from a lithological and age point
 276 of view (note that geologic bedrock category is not directly related to defined values of V_s), while
 277 cover deposits were distinguished by depositional environment, also accounting for soil grain
 278 categories, as it is a general understanding that V_s values increase passing from fine-grained soils to
 279 coarser ones. The followed approach permitted to summarize the Italian geological setting in eighteen
 280 geo-lithological complexes. Furthermore, an effort to better characterize some local Italian geological
 281 features can be found in the distinction in two different sub-complexes for Igneous metamorphic
 282 bedrock (IMB) and Lava bedrock (LB). Indeed, some Italian geographic areas experienced a different
 283 tectonic history, which strongly modified the fracturing states and resulted in the IMB1 and IMB2
 284 sub-complexes. Meanwhile, LB1 and LB2 are characterized by a different magmatic composition,
 285 which strongly controlled the eruptive style and the consequent deposits [57]. These issues could
 286 affect the soil properties and the geo-lithological complexes considered hereafter are twenty. Each of
 287 them is described in Table 5, while the map representing the twenty identified complexes is reported
 288 in Figure 3.

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290 **Table 5.** Geo-lithological complexes

Name of the Complex	ID	Description	Geologic Age
Cover deposits			
Pyroclastic soil deposits	pyr	Successions of Ashes, Pumices and Scoriae	Pleistocene-Holocene
Tuff and scoriae deposits	tfs	Tuffs and Ignimbrites	Oligocene - Pleistocene
Clay silt and peat deposits	csp	Clays, Silts, Peat from palustrine environment	Pleistocene-Holocene
Sand deposits	sd	Sands and Gravels from Dunes and Beaches	Pleistocene-Holocene
Gravel and sand deposits	gs	Conglomerates, Gravels and Sands from alluvial deposits.	Pleistocene-Holocene
Terraced conglomerate deposits	tcg	Conglomerates, Sands and Shale from terraced successions.	Pleistocene

Shallow debris deposits	db	Infill, Alluvial fan, Debris, Colluvium, Breccia, Debris talus and Sandy-silt talus on igneous and metamorphic bedrock.	Pleistocene-Holocene
Moraine deposits	mr	Moraines deposits and large landslide bodies	Pleistocene
Travertine deposits	tv	Travertines and soft limestones	Pleistocene-Holocene
Geologic Bedrock			
Lava bedrock	LB1	Porphyries and Lava	Paleozoic - Holocene
	LB2	Lava (Sardinia and Sicily)	Pleistocene - Holocene
Sand bedrock	SB	Sands and sandstone bedrock	Pliocene - Pleistocene
Conglomerate bedrock	CgB	Gravels and conglomerates bedrock	Pliocene -Pleistocene
Clay flysch bedrock	CFB	Clayey Flysch, phyllites, clayey schists	Cenozoic - Pleistocene
Arenaceous flysch bedrock	AFB	Arenaceous and marly flysch, marly limestones, gypsums, clayey metamorphic rocks	Cenozoic
Marly calcareous bedrock	McB	Calcareous successions deposited in basin environment	Meso-Cenozoic
Calcareous tuff bedrock	CtB	Calcareous sandstones	Pliocene - Pleistocene
Carbonate bedrock	CB	Limestones, Dolostones, Marbles	Meso - Cenozoic
Igneous metamorphic bedrock	IMB1	Igneous and metamorphic rocks (Sardegna, Lombardia; Valle d'Aosta, Toscana)	Paleozoic - Cenozoic
	IMB2	Igneous and metamorphic rocks (Calabria, Sicilia, Liguria)	Meso- Cenozoic



292

293 **Figure 3.** Map of Italy showing the identified geo-lithological complexes (keys in Table 5). Ice or
 294 water are reported in white.

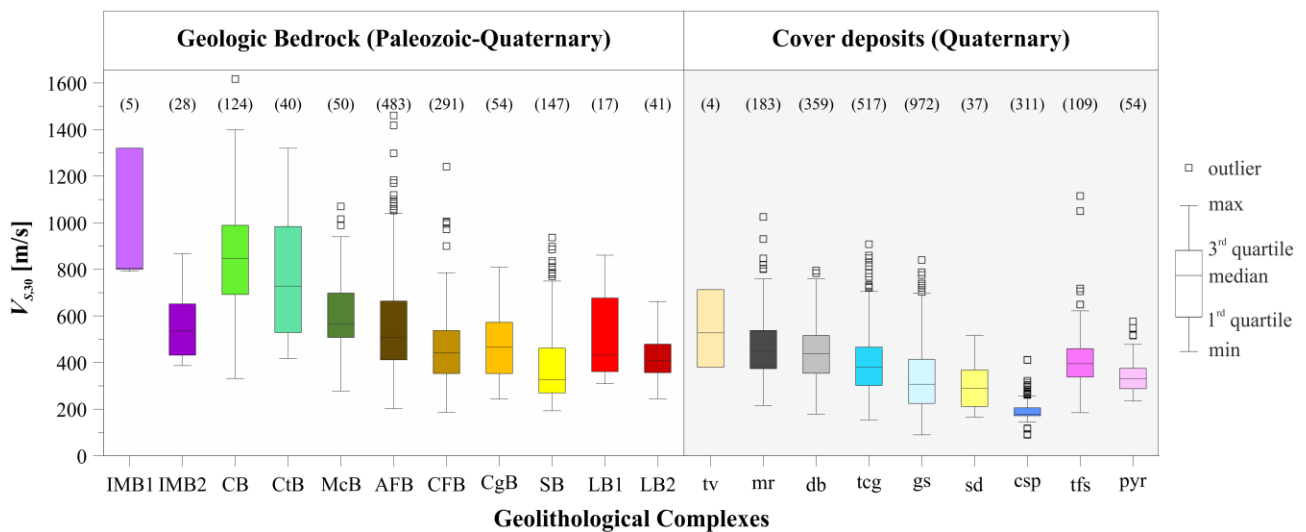
295

296 The identified complexes account for the overall geological formations existing in Italy; however, an
 297 analogous classification could be adopted in other countries, as all geological materials and
 298 environments identified in this classification can also be found worldwide.

299 5. Statistics of Vs values per geo-lithological complex (step three)

300 The $V_{s,30}$ and $V_{s,eq}$ measurements are grouped into the twenty geo-lithological complexes shown in
 301 Table 5. The statistics of $V_{s,30}$ data associated to each complex are computed and represented through
 302 the box-plots of Figure 4 (numerical values of mean, median and standard deviations of data are
 303 reported in Appendix). In the same figure, the number of data for each geo-lithological complex are
 304 also shown (data in IMB1 are few and first and second quartiles cannot be graphically distinguished).

305



306

307 **Figure 4.** Box-plots showing the distributions of $V_{s,30}$ for the geo-lithological complexes listed in
 308 Table 5.

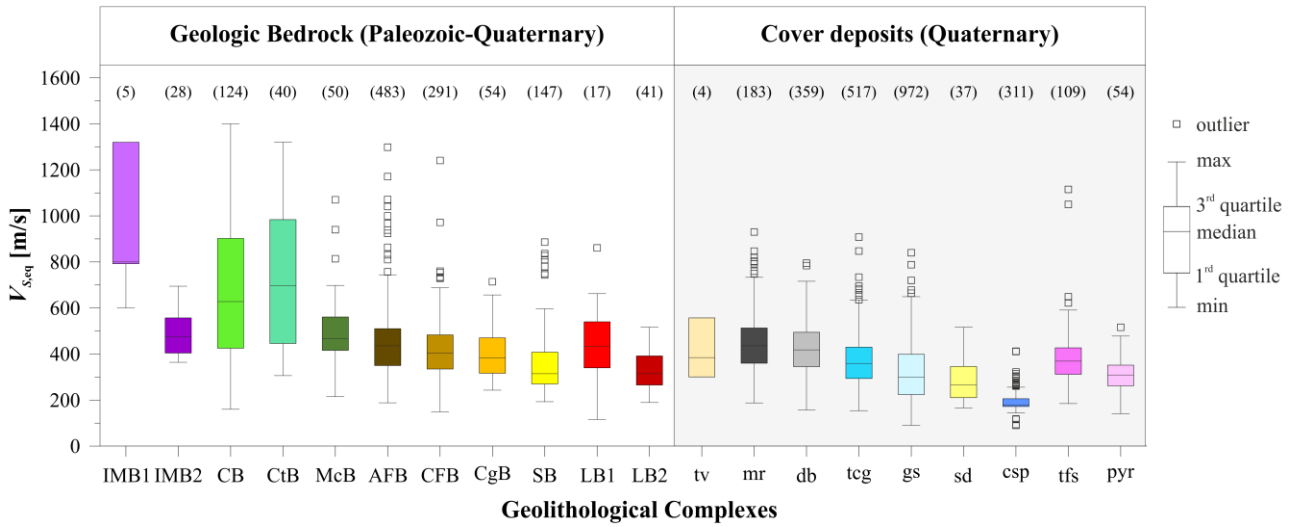
309

310 The first, second (median value), and third quartiles are reported together with the minimum and
 311 maximum values of the empirical distribution. The outliers are defined as the values that lie outside
 312 the range defined by 1.5 times the interquartile range (IQR) minus the first quartile and 1.5 times the
 313 IQR plus the third quartile (e.g., [58]).

314 For the geologic bedrock formations, Figure 4 shows that the distinction between the two sub-
315 complex IMB1 and IMB2 resulted in differences of soil characteristics: median $V_{S,30}$ values are 805
316 m/s and 536 m/s, respectively. On the other hand, median values associated to LB1 and LB2 are
317 almost equal (some differences between LB1 and LB2 appear when $V_{S,eq}$ is of concern, as shown in
318 Figure 5). All the other geologic bedrock complexes resulted in median $V_{S,30}$ between 360 and 800
319 m/s, with the exception of CB and SB, which have median value equal to 847 and 326 m/s,
320 respectively. For Quaternary deposits, Figure 4 shows that they are characterized by shear-waves
321 velocity clearly decreasing as function of the grain-sizes, sorting and textures. Coarse gravel-grained
322 and massive deposits, such as tv, mr, db and tcg, resulted in median $V_{S,30}$ between 360 and 800 m/s,
323 finer deposits made of gravels and sands resulted within 180 and 360 m/s (gs, sd), while $V_{S,30}$ lower
324 than 180 m/s was attributed to silts, clays and peats grouped in the csp complex. Finally, the
325 distinction between ignimbrites (tfs) and pyroclastic soils (pyr), with the former being more lithic and
326 the latter loose, resulted in two different intervals of $V_{S,30}$: between 360 and 800 m/s and 180 and 360
327 m/s, respectively.

328 An analogous classification is performed with respect to $V_{S,eq}$, as reported in Figure 5. Results are in
329 good accordance with those shown in the previous figure. The only differences are: (i) LB2 does not
330 belong to the 360 – 800 m/s interval, having median value of 315 m/s; (ii) IMB2 has median value
331 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
332 take in account the increase of stiffness provided by the seismic bedrock contribution.

333



334

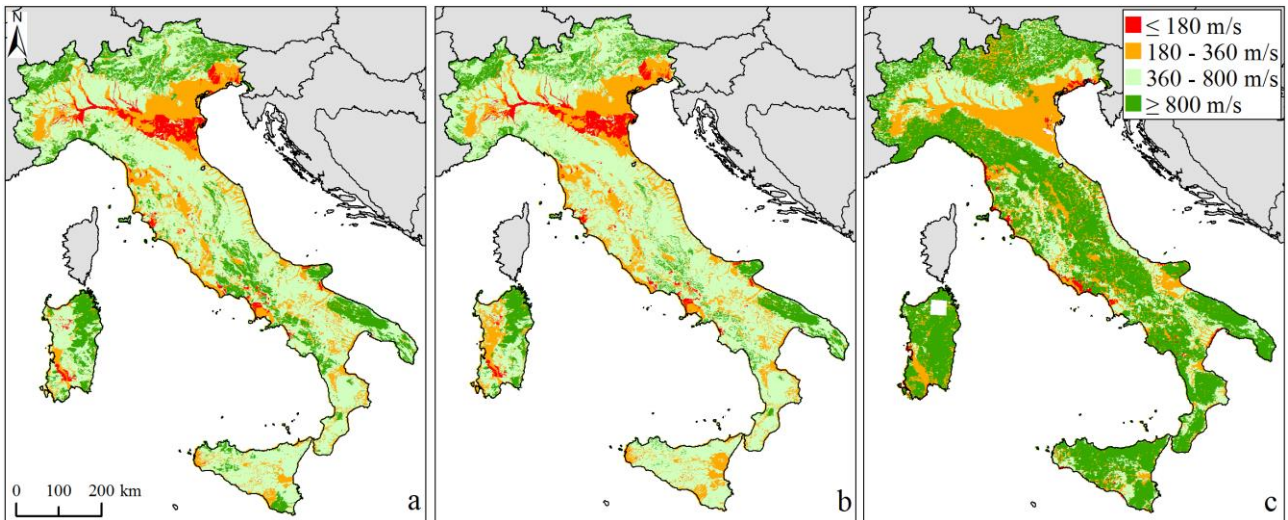
335 **Figure 5.** Box-plots showing the distributions of $V_{s,eq}$ values measured by geophysical tests, in the
 336 geo-lithological complexes listed in Table 5.

337 **6. Seismic soil classification of Italian sites (step four)**

338 In the framework of this study, median and standard deviation values of $V_{s,30}$ and $V_{s,eq}$ of each geo-
 339 lithological complex are associated to all locations within a complex. This allows providing a soil
 340 characterization for the whole national territory that can be used in the case of large-scale seismic
 341 hazard/risk analysis.

342 Figure 6 shows the maps of (a) $V_{s,30}$ and (b) $V_{s,eq}$ distribution for Italy coming from the median values
 343 identified from the box-plots of Figure 4 and Figure 5, respectively. The two maps display a similar
 344 shear-waves velocity distribution, with some differences for the values higher than 800 m/s, which
 345 are more present in Figure 6a and the 180 – 360 m/s range, which in Figure 6b replaces some sites
 346 identified in the range 360 – 800 m/s in Figure 6a.

347 Figure 6c reports the corresponding $V_{s,30}$ map of [45] for comparison. It shows a widespread
 348 distribution of sites characterized by values higher than 800 m/s, with fewer areas in the range 360 –
 349 800 m/s. The sites having 180 – 360 m/s values are mainly concentrated in the North, while values
 350 less than 180 m/s are poorly represented.



351

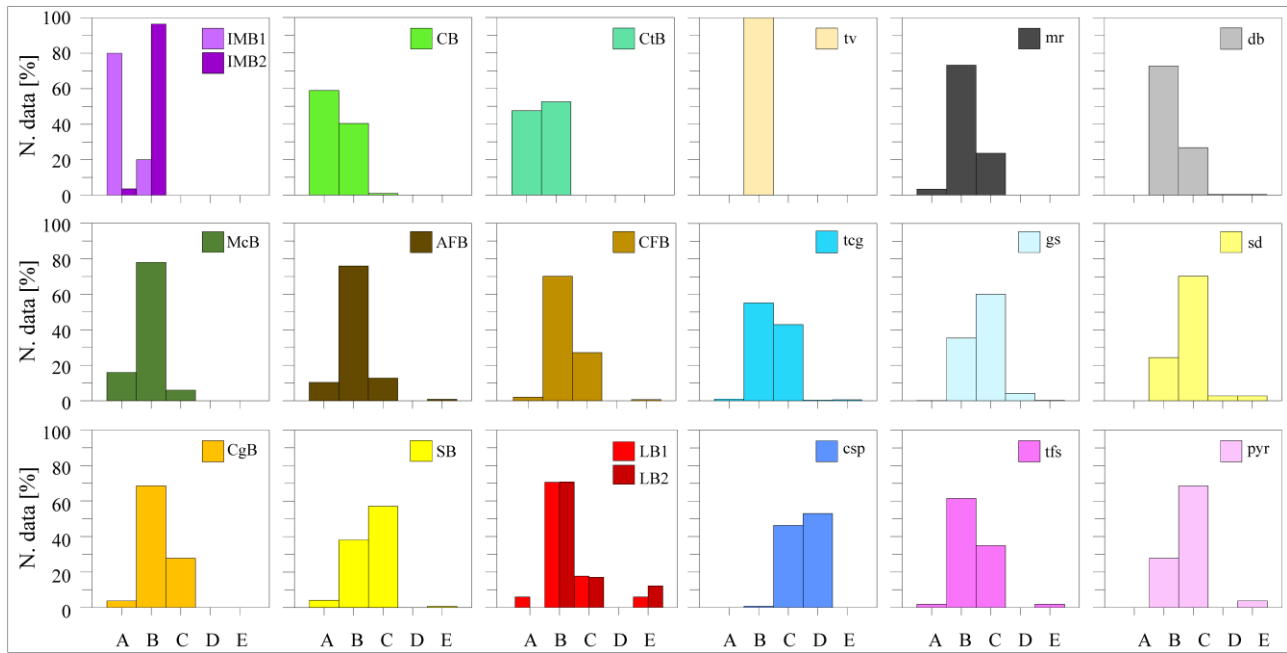
352 **Figure 6.** Maps of shear-wave velocity for Italy: (a) and (b) median values of $V_{S,30}$ and $V_{S,eq}$,
 353 respectively, according to this study; (c) map of $V_{S,30}$ provided by [45].

354

355 Recall (Table 1 and Table 2) that both EC8 and ItBC2018 classifications account for some soil classes
 356 that are not defined exclusively on the basis of V_s measurements: these are class E, S1 and S2 for
 357 EC8 and class E for ItBC2018. Hence, some additional analyses of data are required to extend soil
 358 classification to code-conforming classes. More specifically, after having grouped data per geo-
 359 lithological complex, each site is classified in accordance with EC8 and ItBC2018. Thus, the
 360 frequency of soil class occurrence for each complex is computed and the most frequent (modal) soil
 361 class is assumed as the representative class of the whole complex.

362 According to this procedure, Figure 7 shows the soil class frequencies in accordance with EC8
 363 classification. In most cases, one soil class is predominant with respect to the others, but for CB and
 364 CtB the frequencies of A and B class occurrences are comparable, and for t_{cg} and c_{sp} frequencies of
 365 B and C class occurrences are comparable.

366 Comparing Figure 4 and Figure 7, it can be seen that site classification of the latter is in perfect
 367 accordance with the median $V_{S,30}$ values shown in the former. This is partially described by the fact
 368 that the number of investigations that assigned class E (the soil class not defined only on $V_{S,30}$
 369 parameter) is negligible.

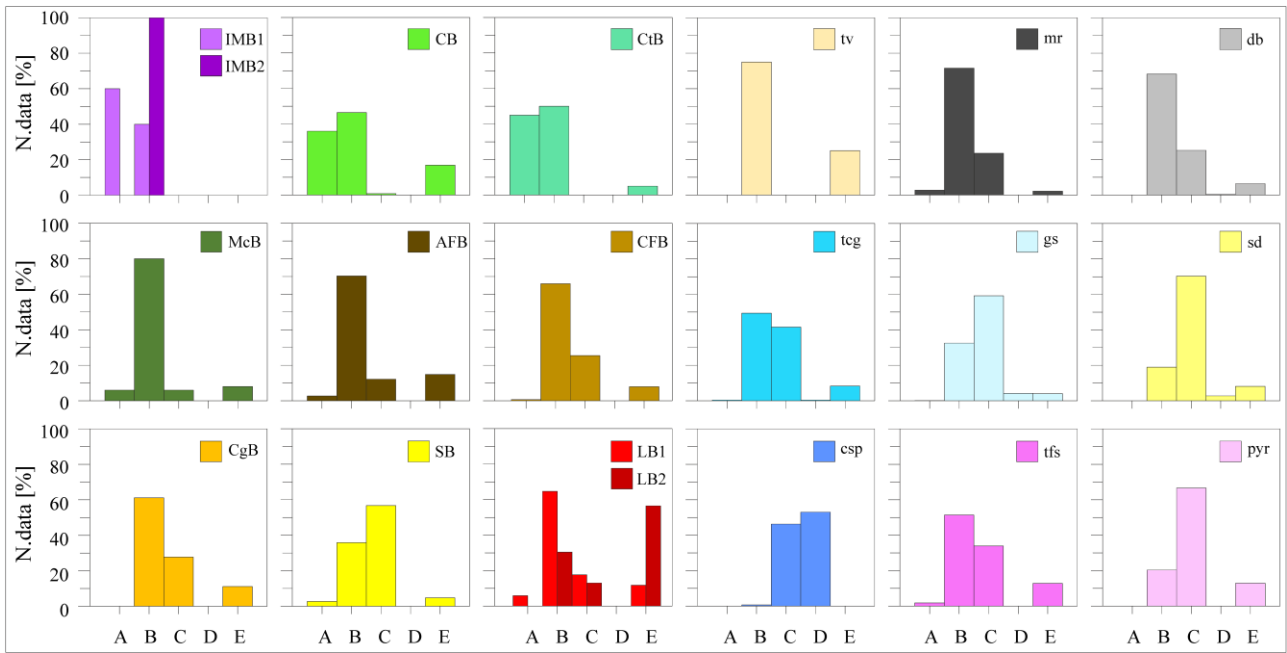


370

371 **Figure 7.** Histograms showing the distributions of soil classes according to EC8 for each geo-
 372 lithological complex listed in Table 5.

373

374 Soil class frequencies in accordance with ItBC2018 classification are reported in Figure 8. For each
 375 complex, soil class attribution is the same as for EC8, except for LB2 and CB. Both these complexes
 376 display a significant presence of E site-class. Thus, an attempt to distinguish different local settings
 377 within the same complex is carried out. Topographic slope was assumed as a proxy for the
 378 identification of sub-areas. In particular, a value of 20° was considered representative of the critical
 379 slope value, above which only thin soils can bury a shallow bedrock, while areas characterized by
 380 slope less than 20° can accumulate thicker soils (e.g., [59]). Following this assumption, LB2 was
 381 classified as B and E, the former with slopes higher than 20° and the latter less than 20°. For complex
 382 CB, B class is the most frequent, although the analysis of data clearly shows that this complex is
 383 characterized by rigid materials, as the sum of A and E classes is greater than class B. These data are
 384 also biased by the fact that few investigations are performed on outcrops that are clearly bedrock,
 385 hence this complex was also split into sub-areas following the slope proxy, assuming E class where
 386 slope is lower than 20°, but assigning A to the slopes higher than 20°.



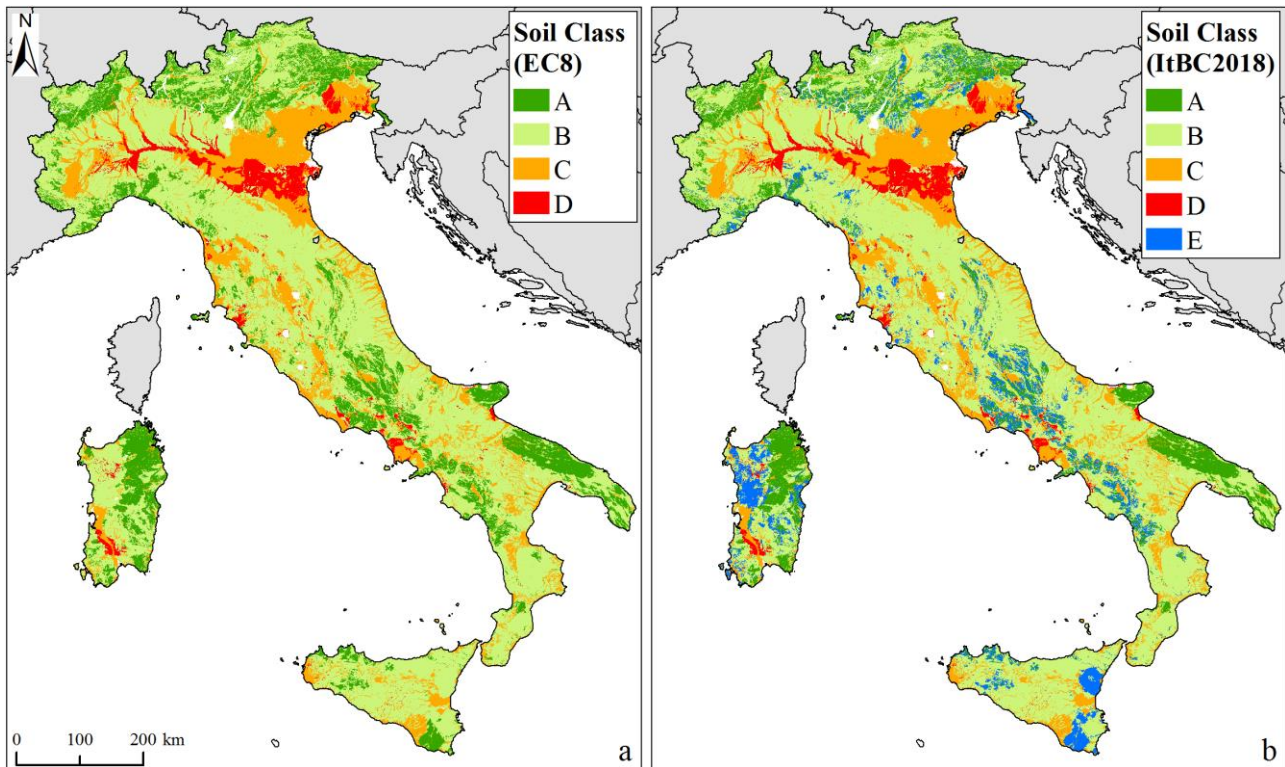
387

388 **Figure 8.** Histograms showing the distributions of soil classes according to ItBC2018 for each geo-
 389 lithological complex listed in Table 5.

390

391 **7. Discussion**

392 The code-conforming soil classes are attributed to the polygons of the geo-lithological map as shown
 393 in Figure 9a and Figure 9b for EC8 and ItBC2018 soil classes, respectively.



394

395 **Figure 9.** Soil Class maps obtained in accordance with (a) EC8 and (b) ItBC2018. Ice or water are
 396 reported in white.

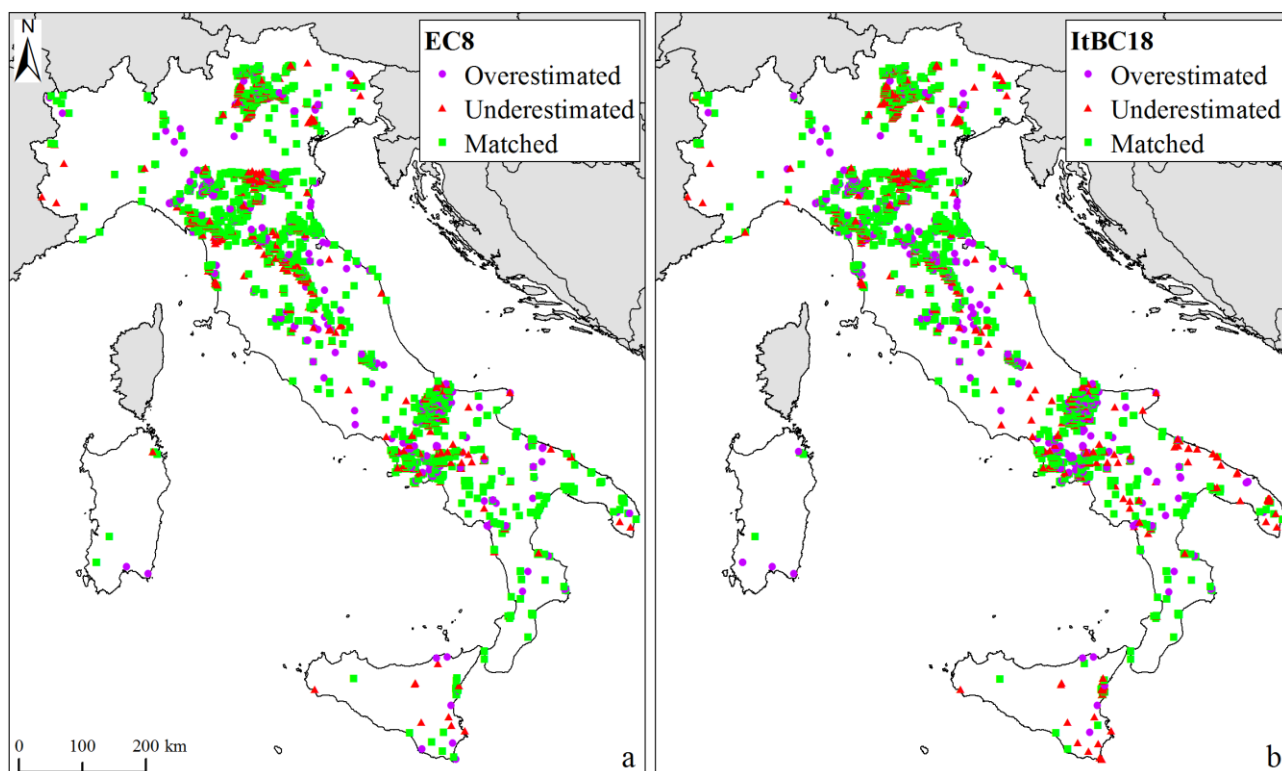
397

398 Both maps provide, based on a 1:100.000 geologic scale, the seismic soil classifications suitable for
 399 large scale studies for which ground motion modifications due to stratigraphic amplification need to
 400 be accounted for. At this scale, a reasonable agreement can be observed between both maps, with an
 401 enhancement in the ItBC2018 maps, where the area characterized by E class is identified.

402 The EC8 map highlights a widespread B class distribution (57.4% of the area of Italy), followed by
 403 C (19.2%). The soil class A is 18.4% of Italian sites, D is the smallest area (4.2%), E class is not
 404 represented. On the ItBC2018 map, B is again the most represented (55.8%), A is lower (13.2%), C
 405 and D respectively remain 19.2% and 4.2%, while E class is characterized by 6.8%. In both the EC8
 406 and ItBC2018 maps there are small areas (0.8%) which are not included in any of the soil classes,
 407 being representative of ice or water.

408 In order to discuss the global accuracy of classification, each measured soil class is compared with
 409 the inferred soil class of the polygon in which the measurement is enclosed. When the measured class

410 is less stiff than the soil class inferred from the polygon, the site is considered as “overestimated”
411 whereas it is considered as “underestimated” and “matched” when the measured one is stiffer than or
412 equal to the inferred class, respectively (Figure 10). It can be observed that mismatched values are
413 evenly distributed and local spatially coherent anomalies cannot be identified. Matched sites are the
414 63% and 60% of the total available measurements for EC8 and ItBC2018, respectively. The
415 overestimation is for 19% and 23% of the sites, whereas an underestimation is for 18% and 17% of
416 the sites with respect to EC8 and ItBC2018 classification, respectively.



417
418 **Figure 10.** Geographic distribution of comparison between measured and inferred site classes
419 according to (a) EC8 and (b) ItBC2018.

420
421 A more quantitative discussion of EC8 results is provided through Table 6. Each line of the table
422 shows, for each measured soil class, the percentage of sites that are associated to each soil class in
423 the framework of this paper. For example, of the measured soil class A, 39.7% of sites are enclosed
424 into polygons corresponding to site class A in Figure 9a, 53.2% are enclosed into site class B and
425 7.1% are in site class C. Thus, 60.3% of the investigated sites from soil class A are underestimated

426 according to the polygons in Figure 9a. The second line of the table shows that the 71.3% of the total
 427 sites classified as soil class B by measurements are equivalently classified by the proposed procedure,
 428 while 3.9% and 24.7% are overestimated and underestimated, respectively. Indeed, B and D sites are
 429 the best predicted, with 78.6% correctly matched D class. As pertains to C class, half of the cases are
 430 correctly predicted (50.0%), while 40.0% are overestimated against 10% of underestimated. Finally,
 431 E class is never identified in the proposed procedure and most of investigations sites are attributed to
 432 B class (see Figure 7).

433 **Table 6.** Comparison between the inferred and the measured classes according to EC8

		Inferred Classes according to EC8 [%]				
		A	B	C	D	E
Measured classes	A	39.7	53.2	7.1	0.0	0.0
	B	3.9	71.3	24.7	0.1	0.0
	C	0.4	39.6	50.0	10.0	0.0
	D	0.0	1.4	20.0	78.6	0.0
	E	0.0	75.0	25.0	0.0	0.0

434

435 Similarly, Table 7 compares investigations with the soil class map according to ItBC2018. The results
 436 are quite similar for B, C, and D classes. E class is also represented; it results correctly matched for
 437 13.8% of cases and it is mainly predicted as B. The A class still results in a poor-quality prediction
 438 with only 33.3% of sites correctly matched and 13.1% of cases falling in the E class.

439

440 **Table 7.** Comparison between the inferred and the measured classes according to ItBC2018

		Inferred Classes according to ItBC2018 [%]				
		A	B	C	D	E
Measured classes	A	33.3	46.5	7.1	0.0	13.1
	B	2.4	70.2	24.4	0.2	2.8
	C	0.3	38.4	50.6	10.1	0.6
	D	0.0	1.4	20.0	78.6	0.0
	E	3.0	61.6	21.5	0.0	13.9

441

442 Finally, results are also discussed in terms of V_s statistics per soil class. To this aim, the measured
 443 data are grouped as a function of the EC8 soil class resulting from the discussed procedure (Figure

444 9a): the number of observations (N. of data), median, standard deviation and coefficient of variation
 445 (CV), that is the ratio of the standard deviation to the mean, of each group of data are reported in
 446 Table 8. The table shows a good accordance of median values with the interval identified by EC8 for
 447 each soil class (see Table 1). Dispersions of data are not negligible: site class B and C are those with
 448 the highest CV and are the classes in which the highest number of observations are located (2176 and
 449 1210, respectively). The lowest number of observations (129) are within site class A and the CV is
 450 0.26 while observations that are comprised in site class D are 311 and the corresponding dispersion
 451 of measurements is the lowest, i.e., 0.21; this is because only csp complex is associated to class D.

452 **Table 8.** Statistics of $V_{S,30}$ measurements for each soil EC8 soil class

	$V_{S,30}$ [m/s]			
	N. of data	Median	Standard deviation	CV
A	129	841	222	0.26
B	2176	444	170	0.36
C	1210	310	133	0.39
D	311	179	40	0.21

453
 454 The equivalent analysis of results is reported in Table 9 referring to $V_{S,eq}$ and the ItBC2018
 455 classification. Median values of measurements located in site classes from A to D are in good
 456 accordance with the reference code (see Table 2) whereas measurements pertaining to site class E are
 457 higher than what is expected, that is higher than the 100 - 360 m/s interval. Indeed, as discussed in
 458 Section 6, soil class E is identified in the LB2 and CB complexes by introducing the topographic
 459 slope as a proxy of the soil characteristics; Table 9 suggested that this strategy can be improved in
 460 future development of this work. The CV of B, C and D class are comparable with those of Table 8
 461 while the CV of site class A is higher than the one associated to EC8 soil class.

462
 463 **Table 9.** Statistics of $V_{S,eq}$ measurements for each soil ItBC2018 soil class

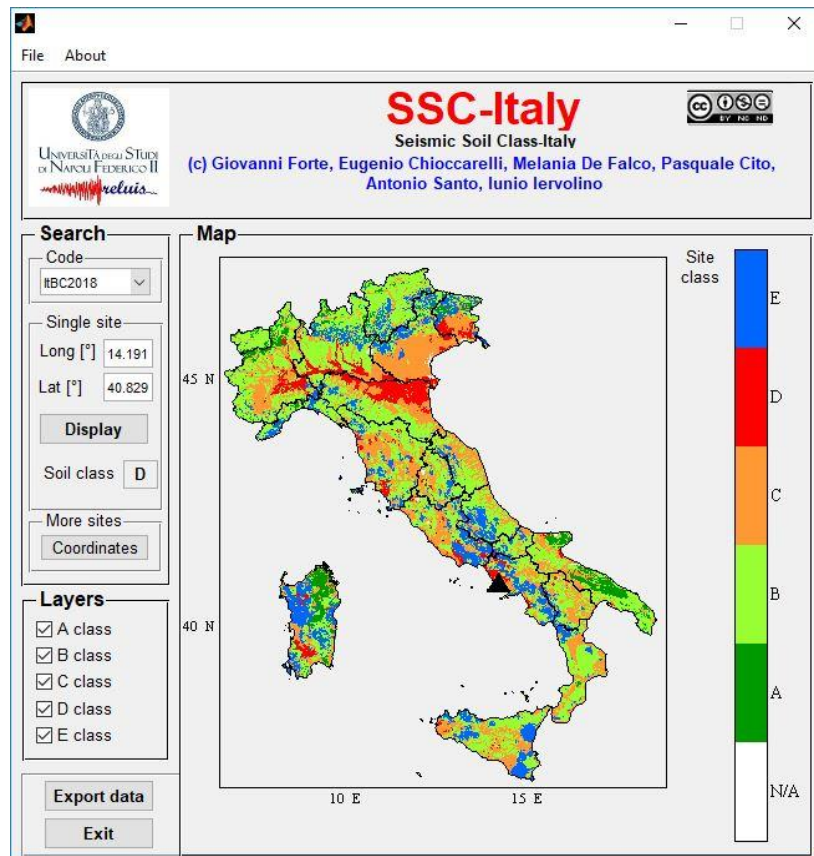
	$V_{S,eq}$ [m/s]			
	N. of data	Median	Standard deviation	CV
A	60	831	292	0.36

B	2141	405	145	0.34
C	1214	302	114	0.35
D	311	179	40	0.21
E	116	403	239	0.51

464

465 **8. Software for data retrieval and illustrative application**

466 To make soil classification available to practitioners, a stand-alone software for database interrogation
467 was developed. It is named Seismic Soil Class-Italy (SSC-Italy) and provides the results of soil
468 classification for any set of sites within the inland Italian country. The tool is coded in
469 MATHWORKS-Matlab® and benefits from the graphical user interface (GUI) shown in Figure 11.
470 As first step, the user is required to select the reference code; i.e. EC8 or ItBC2018 (the selected code
471 can be modified at any step of the analysis). In the second step, the user defines the coordinates of
472 the site(s). For each selected site, SSC-Italy provides the corresponding soil class according to the
473 selected code. In addition, various forms of output can be exported: these are the map with the location
474 of the site(s) and a text file with the median(s) and the standard deviation(s) of $V_{S,30}$ (or $V_{S,eq}$) of the
475 polygon(s) containing the site(s), together with the geo-lithological complex(es) the point(s) belongs
476 to.



477

478 **Figure 11.** Main GUI of SSC-Italy software

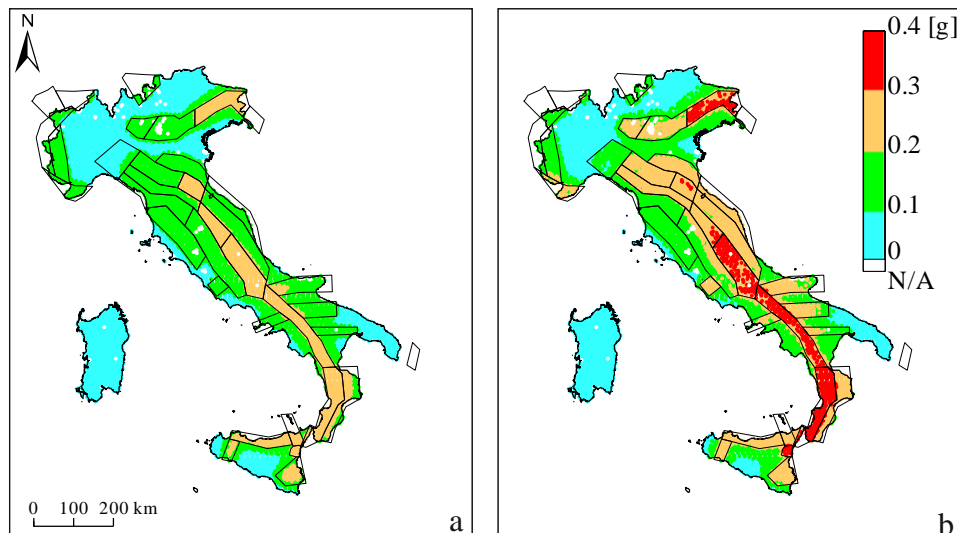
479 **8.1 Rock vs soil probabilistic seismic hazard in Italy**

480 In this section, the importance of soil classification in regional analyses is highlighted via a large-
 481 scale application. To this aim, the peak ground acceleration (PGA) resulting from probabilistic
 482 seismic hazard analysis (PSHA, e.g. [60]) on a national scale and characterized by an exceedance
 483 return period (T_R) equal to 475 years, is computed accounting for the $V_{S,30}$ polygons derived in this
 484 paper. PSHA is performed adopting the same models as the official seismic hazard map used for
 485 design (which is provided for rock site conditions only), as described in [54]. The latter features a
 486 logic tree made of several branches and, among them, the branch named 921, in which the Ambraseys
 487 et al. [61] GMPE is considered. This branch produces the results that are considered to be the closest
 488 to those provided by the full logic tree. The seismic source model is the one of [62] which features
 489 36 seismic source zones. For each zone, the annual rates of earthquakes belonging to discrete bins of

490 magnitude, that is *activity rates*, are adopted (see [63] for further details). A grid of about ten-thousand
491 points covering the whole territory has been created and, at each site of the grid, the soil class from
492 SSC-Italy is associated. Calculations are carried out with the REASSESS software [64]. Each site is
493 classified in four classes of seismicity as a function of the resulting PGA values, between 0 and 0.1g,
494 0.1g and 0.2g, 0.2g and 0.3g, 0.3g and 0.4g.

495 The described analysis is then repeated assuming rock conditions for all the sites in order to compare
496 the resulting seismicity classes. The maps for comparison are given in Figure 12 together with the
497 seismic sources of [62]. For rock site conditions (Figure 12a), the first class includes the 33.2% of the
498 sites, while 48.7% and 18.1% of the sites are obtained for the second and third hazard classes,
499 respectively. Since the maximum PGA value on rock across Italy is equal to 0.27g, no sites can be
500 found in the fourth seismicity class. Due to the soil effects (Figure 12b), the percentage of sites within
501 the first and second class reduces to 23.2% and 37.4%, respectively. The sites with PGA in the range
502 between 0.2g and 0.3g cover the 31.8% of the territory and, in the remaining 7.6% of sites,
503 accelerations are between 0.3g and 0.4g. For each site, the soil effect on the seismic hazard assessment
504 has also been computed as the *relative difference*, i.e., difference between the PGA considering the
505 soil class and the PGA computed on rock divided by the PGA on rock. Then, for each class of
506 seismicity on rock, the mean of relative difference has been evaluated. Such a mean difference does
507 not vary significantly from one class to another, being equal to 24.8%, 27.5% and 25.6% for the first,
508 second and third, respectively. This is expected because soil and seismic classes are independent and
509 thus the soil effect on the hazard is uniformly spread on the seismic classes.

510



511

512 **Figure 12.** Seismic classification for Italy on (a) rock and (b) soil site condition; the sites in which
 513 the PGA is not assigned (N/A) are those belonging to the ice/water category of Figure 3

514 **9. Conclusions**

515 The study discussed in this paper addresses the issue of soil classification in Italy, which may be
 516 required, for example, for large scale seismic risk analyses or post-earthquake shakemap generation.
 517 In these cases, although site-specific seismic propagation analyses are not feasible, an approximate
 518 characterization of soil dynamic behaviour is required. The latter, which may be represented by the
 519 knowledge of $V_{S,30}$ or $V_{S,eq}$ is usually not available. On the other hand, large-scale geological maps
 520 are often available, but they do not include appropriate information for soil characterization in seismic
 521 conditions.

522 In the study, a four-step procedure to correlate the surface geological maps with site-specific
 523 investigations was presented and discussed. It was implemented for Italy, where geological maps at
 524 1:100.000 scale are available, together with a large database of site specific investigations that were
 525 collected. The results, which can be upgraded as new site specific investigations become available,
 526 are maps of soil characteristics in terms of median and standard deviation $V_{S,30}$ and $V_{S,eq}$ values as

527 well as soil classification according to EC8 and ItBC2018. They have been made available through a
528 simple stand-alone software (SSC-Italy) available at <http://wpage.unina.it/iuniervo/SSC-Italy.zip>.
529 The soil classes measured via site-specific investigations have been compared to the soil classes
530 inferred from the maps. For EC8, in the 63% of sites the soil class is correctly matched whereas in
531 19% and 18% of cases soil classes are underestimated and overestimated, respectively. Similar
532 percentages are obtained for ItBC2018 classification: 60% of sites are correctly matched, 23% are
533 underestimated and 17% are overestimated.

534 To assess the effect of soil classification on a national scale, an illustrative application has been
535 developed. It is the seismic hazard map of Italy in terms of PGA with 475-years return period on soil
536 compared to the corresponding seismic hazard map computed for rock. Due to models adopted for
537 computation, the latter is a good approximation of the national official seismic hazard.

538 It is important to finally remark that the derived results are not appropriate at all for site-specific
539 studies as they do not replace microzonation and local site response studies, which require more
540 detailed investigations for the soil site characterization and the structural design.

541 **Appendix**

542 Figure 4 and Figure 5 summarize data distribution for each geo-lithological complex. The numerical
543 value of mean, median and standard deviation of data for each complex are reported in the following
544 table in term of $V_{S,30}$ and $V_{S,eq}$.

545 **Table A.**

Acronym	$V_{S,30}$ [m/s]			$V_{S,eq}$ [m/s]		
	Mean	Median	Standard deviation	Mean	Median	Standard deviation
IMB1	981	805	254	863	800	269
IMB2	556	536	132	490	476	92
CB	855	847	221	670	628	302
CtB	777	728	253	741	697	287
McB	612	566	178	494	467	156
AFB	550	509	195	451	436	155

CFB	458	442	150	416	403	124
CgB	474	466	148	401	383	100
SB	384	326	168	355	315	133
LB1	511	432	172	439	432	177
LB2	419	409	84	329	315	80
tv	537	528	138	407	384	108
mr	465	451	141	455	436	138
db	441	439	120	424	418	117
tcg	396	379	132	367	360	108
gs	333	308	129	320	300	112
sd	296	290	96	284	267	89
csp	195	179	40	195	179	40
tfs	418	395	138	385	369	131
pyr	346	331	83	317	309	77

546

547

Data sources

548

- In addition to the cited references, data used in this study were readily accessible from the following sources (last accessed 18/09/2018):

549

550

- Italian accelerometric archive ITACA (<http://itaca.mi.ingv.it>);

551

- Seismic microzonation of Abruzzo Region

552

(<https://protezionecivile.regione.abruzzo.it/index.php/microzonazione>);

553

- Seismic microzonation of Basilicata Region

554

(<http://www.crisbasilicata.it/microzonazione/index.html>);

555

- Regional Seismological and Geological Service of Emilia Romagna Region

556

(<http://geo.regione.emilia-romagna.it/geocatalogo/>);

557

- Regional Seismological and Geological Service of Molise Region

558

(<http://www3.regione.molise.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/381>);

559

- Civil Protection of Catania for Sicilia Region

560

(<http://sit.protezionecivilesicilia.it/opcm3278/>);

561

- VEL project for Toscana Region (<http://www.regione.toscana.it/-/banca-dati-vel>);

- 562 • Civil Protection of Trento for Trentino Alto-Adige (<http://www.protezionecivile.tn.it/>);
- 563 • Regional Seismological and Geological Service of Umbria Region
- 564 ([http://storicizzati.territorio.regione.umbria.it/Static/IndaginiGeologicheKmz/Index_kmz.ht](http://storicizzati.territorio.regione.umbria.it/Static/IndaginiGeologicheKmz/Index_kmz.htm)
- 565 m);

566

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577

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582 Prop. Seism. response soft clay Depos., 1987, p. 51–87.
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