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1 Revised map of European aeolian deposits derived from soil texture data

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22

23 **Abstract**

24 European aeolian deposits have been mapped using the LUCAS topsoil texture database and the
25 location, thickness and grain size mode of loess sections described in the literature have been
26 compiled. The map, in fairly good agreement with those based on a classical geological approach, has
27 the advantage of being of equal precision for the whole study area and makes it possible to highlight
28 grain size gradients. It shows three main types of aeolian systems, i.e. systems associated with ice
29 sheets (FIS, BIIS, AIS) and the rivers they feed, continental systems related to the erosion of
30 **sedimentary** rocks, and coastal systems. Each **aeolian** system **is comprised of** a band of coversands of
31 varying extent close to the sources and **bands of** sandy loess and loess away from the sources. The
32 thickness of loess is highly variable throughout Europe. The areas of greatest accumulation are
33 associated with the rivers draining the AIS (Rhine, Danube, Rhône). The Middle Danube, which
34 combines sources of glacial origin (AIS) and local sources, constitutes the main accumulation area in
35 Europe. Conversely, continental and coastal systems generated only limited loess cover. The

36 latitudinal gradient of vegetation probably played an important role in loess sedimentation during
37 the LGM. Weak interference between particle transport and vegetation (periglacial desert in the sand
38 belt, cryptogamic crusts and steppe in the north European loess belt) allowed for particle sorting
39 through aeolian transport to develop. The loess band is extensive in low-relief areas and is typified by
40 a low sand content. In southern Europe, on the other hand, the capture of saltating and suspended
41 particles by the shrubby steppe vegetation led to the dominant accumulation of sandy loess near
42 sources.

43 **Keywords:** loess, coversand, cartography, Europe, LUCAS topsoil database

44

45 1. Introduction

46 Along with the development of databases and GIS software, the cartography of aeolian deposits in
47 Europe has given rise to a great deal of work over the **past** decade due to **a rising interest** in various
48 fields, particularly **agriculture** and **the** reconstruction of Quaternary glacial environments. The
49 cartography **has been** achieved using two main types of methods: (1) the **compilation** of regional
50 maps based on a conventional geological or pedological approach, **and** (2) the use of databases on
51 soil texture interpolated from a dense mesh of measurement points, sometimes coupled with other
52 variables. Among the first type of maps, the most notable are those produced by **Wagner et al.**
53 **(2011)** and **Lehmkuhl et al. (2018a)** for Germany, **Prognon et al. (2011)** for France, **Lindner et al.**
54 **(2017)** and **Lehmkuhl et al. (2018b)** for the Pannonian Basin (Croatia, Hungary, Serbia), and **Jipa**
55 **(2014)** for the **Lower Danube Basin** (Romania and Bulgaria). These maps were then **compiled** in order
56 to produce a homogeneous document at **a continental** scale (**Haase et al., 2007; Lehmkuhl et al.,**
57 **2021**). The second type of method has been developed more recently using the topsoil texture
58 database provided by the European project Land Use and Cover Area Frame Statistical Survey
59 (LUCAS, **Tóth et al., 2013; Ballabio et al., 2016**) and the French Donesol project of the Institut
60 National de Recherche Agronomique (INRA). The resulting maps cover French regions (**Sitzia et al.,**
61 **2017; Bosq et al., 2018**) and the European Union (**Bertran et al., 2016**). A similar approach, coupled
62 with airborne gamma-ray radiometric data, was proposed by **Chen et al. (2020)** for a small region
63 (Beauce) in the Paris Basin, France.

64 Both methods have their own advantages and limitations. The main drawbacks of the conventional
65 cartographic approach lie in the heterogeneity of the data used depending on the country (geological
66 or pedological maps), in the heterogeneity of the thickness criteria for the mapped deposits and,
67 finally, in the difficulties inherent to the mapping of discontinuous Quaternary formations because of
68 the contrasting interest shown by the authors in surface deposits at the expense of bedrock. This
69 factor is clearly perceptible by looking at adjacent sheets of the **French 1:50,000 geological map,**
70 **where loess areas can stop abruptly when crossing sheet boundaries.** Therefore, the accuracy and
71 reliability of the maps remain variable from one region to another.

72 In comparison, the second type of cartography has the advantage of being established **with**
73 homogeneous data over the whole territory under consideration. It also **has the advantages of** (1)
74 proposing a map of equal precision for all regions, and (2) showing particle size gradients, which
75 provide important information on the origin of particle sources. The limits are mainly those inherent
76 to the interpolation of particle size data from a limited number of observation points. However, the
77 evaluation made by **Ballabio et al (2016)** for the LUCAS database indicates that the difference

78 between predicted and measured texture does not exceed 10% for low-altitude areas. Another
 79 uncertainty lies in the delimitation of the textures corresponding to aeolian deposits. For the map
 80 proposed by [Bertran et al \(2016\)](#), the range of textures measured by the pipette method on loess
 81 samples from northern France by [Lautridou \(1985\)](#), similar to the method used in the LUCAS project,
 82 was chosen as representative of all European loess. Comparison with the geological maps and the
 83 distribution of known loess sections subsequently showed that the extent of loess was largely
 84 underestimated in some European regions, particularly in the Rhône valley ([Bosq et al., 2018](#)) and
 85 southern Germany ([Lehmkuhl et al., 2018a](#)). Similar observations can also be made for a large part of
 86 **southeastern Europe. Finally, another uncertainty exists with the similar textures of non-aeolian**
 87 **deposits (e.g., silt-rich lacustrine or fluvial deposits) with that of loess and the potential erroneous**
 88 **consideration of these deposits. Nevertheless, first evaluations in France through a comparison**
 89 **between field data and the map generated using the LUCAS database** have shown that this
 90 uncertainty is minimal, due to the particular texture of aeolian deposits ([Bertran et al., 2016](#); [Bosq et](#)
 91 [al., 2018](#)). **Aeolian deposits show both a specific texture and a great continuity in the landscape,**
 92 **covering usually many square kilometres without significant textural changes. In contrast, only**
 93 **isolated pixels in areas of sedimentary formations or weathering mantles satisfy the textures used for**
 94 **aeolian deposits. These pixels have been removed through data treatment (see below).**

95 This paper proposes a new cartography of European aeolian deposits based on topsoil texture
 96 (LUCAS), using an improved envelope for loess texture and a modified treatment. In parallel, a
 97 compilation of data on the thickness of the loess cover has been carried out using sections available
 98 in the literature and borehole databases. Information on the particle size distribution of Marine
 99 Isotope Stage (MIS) 2 loess obtained by laser granulometry has also been gathered from databases
 100 and information provided by various scientists. **Goal here is to** shed new light on the distribution of
 101 Pleistocene aeolian deposits and contribute to a better understanding of the factors that controlled
 102 their emplacement.

103 2. Methods

104 Raster maps of the topsoil (**0-20 cm depth**) content in clay (< 2 µm), silt (2-50 µm), sand (50-
 105 2000 µm) and coarse fragments (> 2 mm) interpolated over the entire territory of the European
 106 Union by [Ballabio et al. \(2016\)](#) from the LUCAS database (available on the European Soil Data Centre
 107 website, eusoils.jrc.ec.europa.eu/data.html) were used as starting data for the analysis. **In this**
 108 **database, the texture was measured using the pipette and sieving method.** The target texture for
 109 three categories of aeolian deposits (coversands, sandy loess and loess) was determined using the
 110 following method. The texture of 500 randomly distributed points in the areas mapped by [Lehmkuhl](#)
 111 [et al. \(2018a\)](#) in middle and southern Germany as loess with a thickness greater than 2 m was
 112 extracted from the LUCAS rasters. The area corresponding to the textures obtained ([Fig. 1A](#)), minus
 113 the most sandy part (the boundary between loess and sandy loess was set at 37% sand), provides the
 114 target texture for the 'Central European loess' category ([Fig. 2, Table 1](#)). The choice of a 37% sand
 115 limit, slightly higher than that used by [Haase et al. \(2007\)](#), i.e. 30%, is motivated by the difference
 116 between the minimum sand size for LUCAS (50 µm) and for [Haase et al.](#) (63 µm). It also enables **us** to
 117 obtain categories whose areas are roughly equivalent in a sand-silt-clay diagram. The coarse
 118 fragment content was limited to 13% as for [Bertran et al. \(2016\)](#).

119 The texture of loess from northern France from [Lautridou \(1985\)](#), used by [Bertran et al. \(2016\)](#) to
 120 define the target texture of loess, is characterised by a higher percentage of silt **on** average and a

121 very low percentage of sand, i.e., less than 20% for the majority of the sites analysed (Fig. 1B).
 122 Comparison between the composition of Lautridou's samples and the LUCAS texture of 500 points
 123 randomly distributed in the area mapped as loess with a thickness greater than 4 m by the same
 124 author shows **good agreement** between the texture ranges and indicates that loess in that region is
 125 **fairly** homogeneous and **contains little sand**. Therefore, the target texture of the **Northern European**
 126 **Loess Belt (NELB)** has been extended towards the silt pole compared to that of central Europe (Fig.
 127 2). For Brittany, where loess can be mixed with **sand derived from** granite weathering, the envelope
 128 of Lautridou's samples has been retained for the loess target texture.

129 The 'Central European loess' texture was then slightly modified for southern European regions, so as
 130 to include as many of the **LUCAS textural data points as possible** corresponding to the loess outcrops
 131 listed in the literature, while **also** keeping the window as narrow as possible. Comparison with the
 132 distribution of known loess outcrops in the Rhône valley in France (Bosq et al., 2018) and the
 133 available maps for Italy (Cremaschi et al., 2015; 'Pleistocene silts' from the 1:1,000,000 geological
 134 map, onegeology, <http://www.europe-geology.eu/onshore-geology/>) shows that the target texture
 135 of the 'Central European loess' significantly underestimates the **extent** of loess. In both areas, the
 136 main issue is related to the high percentage of coarse fragments in the topsoil, which exceeds 13% in
 137 the majority of cases (Fig. 3A). The abundant coarse fraction can have two main origins: (1) the
 138 presence of anthropogenic remains (shards, various debris) left by the dense occupation of these
 139 areas during the Holocene, (2) the presence of carbonate concretions favoured by the
 140 Mediterranean climate **and mixed with the topsoil because of ploughing, erosion or colluviation**.
 141 Observations in the Rhône Valley by Bosq et al (2018, 2020a) have shown that the second factor
 142 plays an important role. The upper limit of coarse fragments was therefore raised to 18% for Italy
 143 and 20% for the Rhone valley following Bosq et al. (2018). However, such an adjustment increases
 144 the risk of improperly classifying as loess **other deposits or mixtures of** loess and coarser material
 145 **such as colluvium**.

146 Although loess accumulations forming part of the NELB were mapped by Catt (1977, 1985) in the UK
 147 over large areas, few pixels were found to meet the target loess texture, primarily because of a
 148 percentage of coarse fragments greater than 13%. Observations by Murton et al (2003) in Kent
 149 suggest that the loess cover, generally less than 2 m thick, has been strongly affected by periglacial
 150 processes. In this area, **loess forms pockets surrounded by involutions of chalk diamicton (brecciated**
 151 **chalk substratum)**. The involutions reach the surface and probably explain the abundance of coarse
 152 debris in the topsoil. Consequently, the maximum content of coarse fragments was set at 18%.

153 Finally, an adjustment was made for the maximum **allowable** percentage of clay in loess from
 154 southern Europe, since the typical soils of these regions, respectively Mediterranean **Cambisols**
 155 **(Rhône valley, Italy) and Chernozems (Bulgaria, Romania)**, are richer in clay than the Luvisols and
 156 Cambisols of the rest of Europe, **where weaker weathering and stronger clay eluviation take place in**
 157 **the topsoil** (Fig. 3B). **An additional factor that may have accounted for higher clay content in**
 158 **southern Europe is the contribution of clay-rich dust from the Sahara, although this contribution is**
 159 **still debated (e.g., Varga et al., 2016; Bosq et al., 2020b)**. The threshold has been set at 33% instead
 160 of 30%.

161 The LUCAS **texture points** corresponding to the sections of aeolian sand described in Aquitaine (Sitzia
 162 et al., 2017; Bertran et al., 2020) made it possible to define a target texture for coversands (Fig. 1A).
 163 The upper limit **of** coarse fragments was set at 12%. This target texture was considered

164 representative of all European coversands. The compositions between coversands and loess define
165 the category of 'sandy loess'. As with loess, adjustments were made regionally according to the
166 percentage of clay and coarse fragments (Fig. 2, Table 1).

167 The extraction of pixels (500 m x 500 m) satisfying the target textures by combining the LUCAS
168 rasters for sand, silt, clay and coarse fragments was carried out region by region using the software
169 QGIS version 3.10. In order to generate more continuous map units and to reduce the noise related
170 to local texture variations, the value of each pixel (1: satisfies the target texture, 0: does not satisfy
171 this texture) was recalculated from the average of the closest pixels and values below a threshold of
172 0.5 were eliminated. The areas corresponding to Holocene formations in the 1:1,000,000 European
173 geological map, modified from the data provided by Lehmkuhl et al. (2018b) for several countries
174 and the Carte du Régolite (Prognon et al., 2011) for France, were then subtracted. The areas of
175 northern Europe covered by the Fennoscandian (FIS) and British-Irish (BIIS) ice sheet at 15 ka (Clark
176 et al., 2012; Stroeven et al., 2016) were also subtracted. The resulting rasters were converted into
177 polygons and then assembled into a single file for the European Union. Polygons with an area of less
178 than four pixels were finally eliminated.

179 The location of the loess sections mentioned in the literature was gathered into a point file, either
180 from the coordinates provided by the authors or, in few cases, by georeferencing the published
181 maps. Depending on the sources, these locations have a varying precision. For France, the boreholes
182 listed in the Banque du Sous-Sol (BSS) of the Bureau des Recherches Géologiques et Minières (BRGM)
183 and located in areas with a loess cover were exploited, although not exhaustively. Data from rescue
184 archaeology (Bertran et al., 2011, 2016; Font et al., 2016; Borderie et al., 2017; Sitzia et al., 2017;
185 Gardère and Djemmali, 2018; Coutard et al., unpublished) and various academic works were also
186 taken into account. Overall, the network of observation points is relatively dense in France (N=1707),
187 much looser for the rest of Europe (N=138). For each point, the fields completed are (1) the total
188 thickness of the loess cover, (2) the thickness of the Last Glacial loess cover, i.e. all the loess located
189 above the Interglacial - Early Glacial palaeosol complex, and (3) the main mode of the grain size
190 distribution of loess from Marine Isotopic Stage (MIS) 2. When several samples were available for
191 MIS 2, only one representative sample (i.e. with an intermediate particle size distribution between
192 the extremes) was chosen.

193 3. Results

194 3.1. Comparison between the new map and previous maps

195 Overall, the visual concordance between the new map (Fig. 4) and the map by Lehmkuhl et al. (2021)
196 is good (Fig. 5). There is a 55% overlap between the loess and sandy loess areas mapped by the latter
197 authors and those of the new map. An important part of the discrepancies comes from the
198 peripheral areas of the main aeolian accumulations. Significant differences also appear for some
199 regions, e.g., Aquitaine, where the map by Lehmkuhl et al. (2021) does not show any loess, as well as
200 the French side of the English Channel (Brittany-Normandy) and the Po basin where loess is much
201 more extensive in the new map. Similarly, the sandy loess category forms a more continuous band
202 south of the North European coversands. Another noteworthy point is the small extent of sand on
203 the map by Lehmkuhl et al (2021). Large areas of Hungary mapped as coversands by both Sebe et al.
204 (2011) and the present study appear as sandy loess in Lehmkuhl et al. (2021), especially around the

205 towns of Kecskemet and Debrecen. In total, loess, sandy loess and coversands cover an area of about
 206 382419 km², 107111 km² and 372119 km² respectively **on the new map presented here**.

207 The Cotentin peninsula on the French side of the English Channel was the subject of numerous field
 208 observations **using trenches and augering** by Coutard (2003) and enables a precise comparison to be
 209 made between available maps and the location of the points where the presence or absence of loess
 210 has been proved (Fig. 6). Compared to the other maps, the new one scores better (ca. 86%) in
 211 classifying as loess those points where the presence of loess is actually **confirmed by field studies**
 212 (Fig. 7), largely because this category is more widely represented. The average loess thickness in this
 213 map unit determined from all the observation points is 0.54 m, while it is only 0.20 m in areas not
 214 mapped as loess. When only the points where loess has been observed are taken into account, the
 215 average thickness reaches 1.55 m in the areas mapped as loess, while it reaches only 1.16 m outside.
 216 **Unexpectedly**, the latter values are reversed for the other maps (BRGM geological map 1:50,000,
 217 Lehmkuhl et al., 2021), *i.e.* the thickest loess sections are located outside the **mapped** loess areas.

218 The resulting map shows relatively independent aeolian systems, each characterised by the
 219 juxtaposition of sand, sandy loess and loess areas. These systems are detailed separately in the
 220 following paragraphs.

221 **3.2. Northern European Sand Belt (NESB) and Loess Belt (NELB)**

222 Northern Europe is covered by a wide band with a dominant texture of aeolian sand approximately
 223 bounded by the parallel N50° in Poland and N52° in the Netherlands and Belgium. This band matches
 224 well with the coversands and continental dunes mapped by Koster (1988) and Zeeberg (1998),
 225 referred to as the 'European Sand Belt'. It suggests a much greater extension and continuity of the
 226 aeolian sand cover than is indicated by the geological maps (Lehmkuhl et al., 2016, 2021) probably
 227 **because it is thin**, often less than 1 m (Kasse, 1997, 2002). Comparison with the 1:1,000,000
 228 geological map of Europe shows that the southern limit of sand coincides with the **extent** of Upper
 229 and Middle Pleistocene tills and fluvioglacial deposits from Poland to the Netherlands, as already
 230 noted by Koster (2005) (Fig. 8), and suggests a genetic relationship between glacial outwash and
 231 coversands (Kasse, 1997; Koster, 2005). This low-altitude zone (< 100 m asl) is also typified by very
 232 little contrast in relief, which is favourable to the progression of sand by saltation over large areas
 233 (Pye, 1995; Mason et al., 1999). The extensive low-lying plains in the southern Netherlands and
 234 Belgium probably accounts for the spread of coversands there well beyond the limit reached by the
 235 Quaternary glaciers, from sources located in today's North Sea (Vandenberghe and Krook, 1981;
 236 Kasse, 1997). The **sand belt** continues westwards to East Anglia in the UK (Catt, 1977; Bateman,
 237 1995), where the map shows only discontinuous patches due to the thin cover and disturbance by
 238 periglacial processes favoured by the frost-susceptible chalk substratum (Murton et al., 1995).

239 The **sand belt** is bordered along its entire southern length by a band of sandy loess of varying width,
 240 from less than 10 km (Germany, Poland) to more than 50 km (Belgium), which gives way **still farther**
 241 **south** to loess forming a blanket 20 to 40 km wide in the east to more than 100 km **wide** in the west
 242 (Belgium and northern France). It can be noted that **rivers flowing from south to north in Germany**
 243 **and Poland, e.g. the Leine, the Saale, the Lausitzer Neisse and the San, cross the aeolian bands**
 244 **without significant disturbance of the latter**. The juxtaposition of these belts reflects the size sorting
 245 of the particles transported in suspension and **suggests** the same sources as for the coversands. This
 246 is consistent with the potassium-rich and relatively calcium-poor geochemical composition of loess

247 from Poland and northern Germany, which is similar to that of the felsic rocks of the Scandinavian
 248 Shield (Bosq et al., 2020b; Skurzynski et al., 2020). The same holds true further east for loess in the
 249 Dnieper basin in Ukraine (Buggle et al., 2008), not shown on the map. The composition becomes
 250 richer in carbonates and resistant minerals westwards (Belgium, France) following the contribution of
 251 alluvial deposits from the Rhine and Seine.

252 The **spatial extent** of the loess belt is controlled **primarily** by relief, particularly to the south by
 253 **mountain ranges such as** the Carpathians, the Sudeten Mountains, the Rhenish Schist Massif and the
 254 Ardennes. As already pointed out by Bertran et al (2016), loess spreads westwards to the tip of
 255 Brittany and indicates that the Manche River (i.e. the river that occupied the English Channel, e.g.
 256 Toucanne et al., 2009) fed both by meltwater from the ice sheets and by the rivers Rhine, Seine and
 257 Thames, was an important source of particles (Lautridou, 1985). Due to its thinness and
 258 discontinuous nature, the loess cover located west of the Seine is **underrepresented** on available
 259 geological maps (e.g., Prognon et al., 2011; Lehmkuhl et al., 2021). Along the English Channel, whose
 260 coasts are dominantly bordered by cliffs that formed an obstacle to the progression of saltating sand,
 261 coversand and sandy loess are lacking on the currently emerged part of the continent. The small sand
 262 patches at the periphery of the Mont-Saint-Michel Bay described by Lautridou (1985), which are
 263 associated with ventifacts and sand wedge casts, are an exception. They are not visible on the map,
 264 probably due to their discontinuous nature. Some loess sections studied by Coutard (2003) located
 265 along the Normandy coast also have a significant sandy fraction (40-60%).

266 In detail, there are also areas with sandy loess texture, more rarely loess, within the ESB, which form
 267 narrow bands that are increasingly developed eastwards **into** Poland. These bands run along ice
 268 marginal valleys (IMV), in particular the Elbe-Glogow-Baruth IMV (Marks, 2002; Badura et al., 2013)
 269 and probably reflect phases of stagnation of the ice front during deglaciation, associated with the
 270 northward shift of the aeolian system **that followed the retreat of the ice**. Loess **accumulations**,
 271 however, remain **limited due to the short** duration of these phases.

272 **3.3. Perialpine systems**

273 Rivers fed by the Alpine Ice Sheet (AIS) were the source of **thick** aeolian **deposits** along the **adjacent**
 274 valleys. In spite of the specific properties of each catchment area, the geochemical composition of all
 275 perialpine loess is similar and characterised by a high **Ca** content due to abundant calcareous rocks in
 276 the AIS bedrock (Bosq et al., 2020b). Four major rivers have created aeolian systems of significant
 277 **extent**, the Rhine, the Danube, the Rhône and the Po, each of which has a sandy area of limited
 278 width near the river and finer deposits away from the river on either side, often with a marked
 279 asymmetry. For the Rhine, accumulations develop mainly in the graben upstream of the Rhine-Main
 280 confluence (**Upper Rhine Graben, URG**) as well as further north (**Lower Rhine Embayment, LRE**) in the
 281 congruence zone with the NELB as already shown by Lehmkuhl et al. (2018a). In the **URG**, the
 282 accumulations remain primarily confined to the graben where they cover alluvial terraces. They
 283 spread more widely over the **plateaus** in areas where relief does not exceed 250 m asl, particularly
 284 on the right bank between Karlsruhe and Heidelberg. Geochemistry supports a predominantly Alpine
 285 origin (Rhine alluvium) for Nussloch loess (Schatz et al., 2015; Bosq et al., 2020b).

286 A north-south asymmetry appears **clearly** in the distribution of aeolian deposits along the Rhône
 287 valley, with predominant loess accumulation over fluvio-glacial fans to the north of Valence and
 288 sandy loess to the south, associated with dunes and deflation features (yardangs, pans, ventifacts)

289 close to the river (Gabert, 1965; Ambert, 2013; Bosq et al., 2018). The transition takes place
 290 downstream of valley narrowings between the Massif Central and the Alps, which **channeled** and
 291 accelerated the prevailing winds.

292 The Po catchment area is largely covered by loess, with a strong asymmetry between the northern
 293 and southern banks. **Overall, the map presented here suggests that aeolian deposits are more**
 294 **widespread than shown by Cremaschi et al. (2015) and Lehmkuhl et al. (2021). Sandy silt mantles the**
 295 **northern banks of the Po and forms strips along alpine tributaries. These deposits were interpreted**
 296 **as Late Pleistocene fluvial sediments by Italian authors instead of aeolian deposits. Close association**
 297 **of loess and sediments with a sandy loess texture questions, however, such an interpretation.**
 298 **Additional field work would be necessary to solve this issue.**

299 The Danube system is more complex and **overlaps** with other river systems and with the system of
 300 the Pannonian Basin (Hungary, Serbia). The main areas of **loess** accumulation are located in the
 301 upper basin (**Upper Danube Basin, UDB**: Southern Germany, Austria), the middle course (**Middle**
 302 **Danube Basin, MDB**) as it crosses the Pannonian Basin (**Lehmkuhl et al., 2018b**) where the Danube
 303 joins the Morava coming from the Bohemian Massif, then the Drava, another Alpine river, and the
 304 lower course (**Lower Danube Basin, LDB**) **downstream** of the Carpathians (Romania, Bulgaria; **Jipa,**
 305 **2014**). In the **LDB**, sandy loess expands and is mainly distributed at the exit of the Carpathians, along
 306 the tributaries, as well as in the downstream course where the Danube flows northwards before its
 307 confluence with the Prut. In this sector, the pattern in bands of decreasing grain size away from the
 308 river becomes confused and sandy loess extends over more than 80 km northwest of the Danube.

309 **3.4. 'Continental' systems**

310 These systems correspond to outcrops of (often Cenozoic) **sedimentary rocks** (sand, sandstone,
 311 molasse) at the outlet of corridors that channelled the wind. One of the best examples is the
 312 Pannonian Basin (Hungary) described by **Sebe et al (2011, 2015)**. It comprises successively from
 313 upwind to downwind (1) a zone dominated by deflation, where **sedimentary rocks** are carved by the
 314 wind (yardangs, pans, ventifact pavements), (2) coversands and (3) a loess belt. In this basin crossed
 315 by the Danube, Alpine (Danube alluvium) and local inputs are closely intertwined and their respective
 316 contributions remain difficult to assess (**Smalley and Leach, 1978; Wright, 2001**). Geochemical data
 317 clearly indicate the mixture of different sources, in particular Danube alluvium, alluvial **fan deposits**
 318 from the Carpathians, and dolomite-rich rocks **cropping out** in the basin (**Ujvari et al., 2012**).

319 Similar but smaller systems, combining yardangs, playas and coversands, have been described in
 320 Spain in the Ebro basin (**Gutiérrez-Elorza et al., 2002**), the Duero basin (**Bateman and Diéz-Herrero,**
 321 **2001; Bernat Rebollal and Pérez-Gonzalez, 2008**) and the Manchega plain (**Bernat Rebollal and Pérez-**
 322 **Gonzalez, 2008**). The sandy areas as mapped by these authors are poorly captured by the map
 323 **presented** here, although **aeolian** sand patches are present in the Duero Basin. Loess patches also
 324 occur in the map downwind of the deflation areas in the Ebro Basin, in agreement with **Boixadera et**
 325 **al. (2015)** and along the Tagus (**Wolf et al., 2018, 2019**).

326 Small continental systems also exist in France in the Loire basin between Tours and Orléans where
 327 the **formations that were the sources of aeolian particles** are Eocene to Middle Pleistocene in age
 328 (**Macaire, 1986; Liard et al., 2017**), as well as **possibly** in Germany around Nuremberg (Triassic).
 329 Aeolian accumulations are limited in extent and dominated by coversands and sandy loess. Deflation-
 330 related features are restricted to ventifact pavements. In the Nuremberg area, **aeolian sand patches**

331 are indicated by Lehmkuhl et al. (2021), demonstrating that the Triassic substrate has been affected
 332 by deflation during the Pleistocene. The map presented here suggest that the deposits have a sandy
 333 loess texture instead of a typical coversand texture (at least in the topsoil) and forms larger patches
 334 than shown by Lehmkuhl et al. (2021). This may be an effect of the method used for mapping.
 335 Conventional geological approach only takes into account units thicker than one or two metres,
 336 whereas much thinner aeolian covers are captured by the approach based on topsoil texture.

337 **3.5. Atlantic coastal systems**

338 Several aeolian systems have developed along the Atlantic coast, particularly in southwestern France
 339 (Aquitaine, Sitzia et al., 2015, 2017; Bertran et al., 2020) and in the Iberian Peninsula (Gulf of Cadiz,
 340 Spain, Zazo et al., 2005, 2008; Aveiro area, Portugal, Granja et al., 2008; Thomas et al., 2008). The
 341 progression of sands far inland was made possible during the glacial periods by the absence of
 342 coastal relief. The loess belt remains modest in Aquitaine and almost non-existent in the Iberian
 343 systems. According to Sitzia et al (2017), the grain size gradients and the geochemical composition
 344 argue for a loess origin essentially related to aeolian abrasion of the sands in the south and a mixed
 345 origin (aeolian abrasion together with the contribution of alluvium from the Garonne) for the loess
 346 located on the right bank of the river.

347 **3.6. Other systems**

348 Other minor systems have developed in connection with rivers draining areas of high relief that were
 349 not or only slightly glaciated during the LGM. This is the case of the Saône valley, the Doubs valley
 350 and the upper Garonne basin in France, the upper Elbe basin in the Czech Republic and the Moravia
 351 River on the border between the Czech Republic and Slovakia. For the Moravian system, zircon
 352 morphology indicates a source from the Bohemian Massif (Morava alluvium) and Tertiary
 353 sedimentary rocks in the lower river (Lisá and Uher, 2006), while the geochemistry of the fine
 354 fraction also suggests a contribution from the NELB (Bosq et al., 2020b). Loess patches also occur in
 355 small intramontane basins in Italy and along the Adriatic coast (Slovenia to Albania). It should be
 356 noted that in Italy, the patches located at the foot of volcanoes around Rome and Naples likely
 357 correspond to weathered tephra and not to loess.

358 **3.7. Loess thickness**

359 The available loess thickness data are not evenly distributed across Europe and are much denser in
 360 France than elsewhere. Therefore, thickness variations are better represented in this country than in
 361 the rest of Europe. As the sections described in the literature are primarily used for
 362 chronostratigraphic studies and are among the thickest in a given region, the thicknesses indicated in
 363 most countries should be considered close to maxima. Keeping in mind this limitation, the map of
 364 total loess thickness shows the following points at the European scale (Fig. 9A):

365 (1) Extensive accumulations are associated with the perialpine systems, especially along the Rhine
 366 valley and the Danube valley, with thicknesses locally exceeding 30 m. Many loess-palaeosol
 367 sequences (LPS) in the MDB (Hungary, Serbia) cover 800 ka to almost 1.1 Ma (e.g., Varga et al., 2011;
 368 Ujvari et al., 2014; Sümegei et al., 2018). The congruence of multiple aeolian systems in the MDB
 369 makes it a region of preferential loess deposition.

370 (2) The NELB is typified by comparatively thinner accumulations, ranging from 5 to 10 m except to
 371 the East (eastern Poland, up to 20 m) and in the congruence area LRE-NELB. A westward decreasing

372 trend is also clearly visible (3 to 4 m maximum in Brittany; [Bigot and Monnier, 1987](#); [Coutard et al.,](#)
 373 [2005](#)). Only the last two to three glacial-interglacial cycles are usually preserved in the LPS in France
 374 and Germany (e.g., [Coutard et al., 2018](#); [Kels and Schirmer, 2010](#); [Meijs, 2002](#)), exceptionally the
 375 whole Middle and Upper Pleistocene ([Antoine et al., 2020](#)).

376 (3) In France, thin accumulations occur on the periphery of coastal (Aquitaine, [Hernandez et al.,](#)
 377 [2012](#); [Sitzia et al., 2017](#)) and continental (Tours-Orléans region, [Macaire, 1986](#); [Gardère and](#)
 378 [Djemali, 2018](#)) systems. In Aquitaine, only the Weichselian and sometimes the Upper Saalian have
 379 given rise to substantial loess accumulations overlying a complex Middle Pleistocene palaeosol.

380 For France, the large network of observation points reveals a great variability in thickness within the
 381 NELB. The main factor involved is relief, with a preferential accumulation of loess in depressions on
 382 plateaus, on leeward slopes and at the foot of hills ([Lautridou, 1985](#); [Antoine, 2002](#)). The loess cover
 383 is truly continuous only in northern France. In other regions, although large areas are characterised
 384 by a topsoil with a typical loess texture, the boreholes stored in the BSS indicate that the thickness is
 385 at best one metre and often unreported. Nevertheless, accumulations of several metres in thickness
 386 have been described in favourable locations.

387 In the Mediterranean areas, the extension of loess is reduced mainly due to relief and the lack of
 388 glacier-fed rivers, with the exception of the Rhône, Po and Durance. However, loess thickness can be
 389 substantial and exceed 10 m (Ebro valley, [Boixadera et al., 2015](#); Tagus valley, [Wolf et al., 2018](#)). It
 390 can exceed 20 m in the Po valley ([Washa et al., 2011](#)) and along the Durance ([Bonifay, 1962, 1965](#)).
 391 Possible contribution from Saharan dust has been suggested by some authors (e.g., [Mahowald et al.,](#)
 392 [2006](#)), but remained minor compared to local inputs. In the Rhône valley, such Saharan contribution
 393 has not been detected by [Bosq et al. \(2020b\)](#) using geochemistry.

394 The map of loess thickness for the Last Glacial provides a less contrasting picture, with average
 395 accumulation of 3-6 m in many European regions ([Fig. 9B](#)). This pattern implies that the variation in
 396 total loess thickness is largely due to erosion processes and, to some extent, to differences in the age
 397 of the surfaces on which the loess accumulated (alluvial terraces, areas glaciated before the
 398 Weichselian). Areas of high deposition are located close to the coversands, (1) in the NELB with
 399 typically 8 to 14 m of loess in northern France, Belgium, Germany and Poland, with a clear decrease
 400 in France away from the sands, (2) in the URG, with peak deposition of up to 19 m at the edge of the
 401 graben (Nussloch; [Antoine et al., 2009](#)) where loess forms ridges ("gredas", [Leger, 1990](#)), and (3) in
 402 the MDB, with thicknesses reaching 15-20 m in Croatia and Serbia (Erdut, [Galovic et al., 2009](#);
 403 Sarengrad, [Galovic et al., 2011](#); Mosorin, Titel, [Bockhorst et al., 2011](#), [Markovic et al., 2015](#)).
 404 Comparatively, the LDB is characterised by relatively weak accumulation (4 to 5 m) whereas the total
 405 loess thickness can be considerable (> 30 m; [Jipa, 2014](#)).

406 **3.8. Grain size and gradients**

407 The various aeolian systems are characterised by an almost regular change in grain size as a function
 408 of the distance from the coversands. The evolution of sand percentages from the LUCAS data is
 409 illustrated in [Figure 10](#) for two profiles oriented perpendicular to the boundaries between coversand,
 410 sandy loess, and loess in Aquitaine and Belgium. Both profiles show a similar trend. The sand
 411 percentage adjusts on average to a negatively sloping line for the first 40 km. The main divergence
 412 between regions is the decrease to a low asymptotic value, around 10-15% in the NELB, whereas it
 413 remains above 20-30% in other systems.

414 The few data available on the main mode of loess measured by laser granulometry show a high
 415 degree of homogeneity in the NELB, with values ranging from 30 to 42 μm (Fig. 11), down to 24 μm
 416 at greater distances from the coversands (e.g., Courville section in the Paris Basin, Coussot et al.,
 417 2019). The section at Maastricht-Belvedere (Netherlands), located close to the sandy loess band,
 418 yields a mode around 47 μm (J. Vandenberghe, written communication, 2021). A few samples from
 419 the Val de Saire along the French coast of the English Channel, also yield a mode at around 49 μm
 420 (Coutard, 2003). Comparatively, as noted by Bosq et al. (2018), the main mode of loess taken from
 421 sections described elsewhere in Europe, in particular in southern and southeastern Europe, is far
 422 more variable and fluctuates between 30 and 75 μm .

423 In most regions, loess and sandy loess have a dominant grain size mode, which decreases with the
 424 distance from the coversands (Fig. 12). Depending on that value, the part of the distribution located
 425 beyond 63 μm is of varying proportion and the decrease in sand percentage reflects the decrease in
 426 modal particle size. A few exceptions can be mentioned, such as Grafenberg 2, Germany (Fischer et
 427 al., 2019), where some samples are bimodal (one mode at 41 μm distinct from the mode in the sands
 428 at 120 μm) (Fig. 12). The Aquitaine loess contrasts with other loess deposits due to a fine mode (14-
 429 20 μm), which decreases slightly away from the coversands. This results from the bimodal (or even
 430 plurimodal) nature of the grain size distribution, with a sand mode distinct from the silt mode (Sitzia
 431 et al., 2017). The trend as a function of distance is marked by the progressive increase in the amount
 432 of silt at the expense of sand, without a substantial change in the dominant silt mode. The loess of
 433 the Rhone valley has an intermediate grain size distribution between those of the NELB and
 434 Aquitaine, with a secondary silt mode of $\sim 15 \mu\text{m}$ (Bosq et al., 2020a).

435 4. Discussion

436 The new map highlights distinct aeolian systems in Europe, the most extensive of which are related
 437 to particle sources of glacial origin transported by sandurs, particularly along the FIS, or by larger
 438 rivers (Manche, Rhine, Danube). Such observations have been made by previous investigators (e.g.,
 439 Smalley, 1966; Tsoar and Pye, 1987; Muhs, 2013), although these have sometimes been questioned
 440 even by the same authors (Smalley et al., 2009). Nevertheless, these observations are in line with
 441 those made in current proglacial environments, which act as major dust sources (Bullard, 2013;
 442 Bullard and Austin, 2011). Overall, the measurements show that sediment production in current ice-
 443 covered catchments (due to abrasion, quarrying and the remobilisation of previous sediments) is
 444 much higher, sometimes by an order of magnitude, than in unglaciated catchments (Hallet et al.,
 445 1996). Therefore, the extent of the loess belt primarily reflects the abundant production of silts by
 446 glacial action (Tsoar and Pye, 1987). Other mechanisms must have contributed to a lesser degree,
 447 particularly river transport (Osborne et al., 1993; Wright et al., 1998; Smith et al., 2002). However,
 448 the downstream decreasing trend of the thickness of Last Glacial loess along the Manche River and in
 449 the MDB-LDB clearly demonstrates that neither silt production during fluvial transport, nor inputs by
 450 tributaries from unglaciated regions were able to compensate for the decrease, by sedimentation
 451 and dilution, of the river's load of particles of glacial origin. It is likely that the large glacial lakes that
 452 occupied the North Sea (Patton et al., 2017) contributed to trapping suspended particles from
 453 meltwater, thus limiting the load carried downstream by the Manche River. The MDB, where inputs
 454 from glacial and local particle sources combined, is the largest area of loess accumulation in Europe
 455 (Markovic et al., 2015).

456 The thickest loess deposits are related to the rivers draining the AIS and, therefore, suggest that the
 457 AIS contributed more to dust production than the FIS. Glacial abrasion occurs under temperate-
 458 based glaciers when ice slides over the bedrock. The abrasion rate depends primarily on ice velocity
 459 and, thus, on the slope of the bed, on ice thickness that modulates the stress applied to the bed, and
 460 **on the nature of the** rock substrate, **particularly** its hardness (e.g., [de Winter et al., 2012](#)). These
 461 factors may have acted together to explain the high **silt** production by the AIS, particularly the steep
 462 slope of valley glaciers and the relatively soft bedrock (predominantly sedimentary rocks), **in contrast**
 463 **to** the plutonic and metamorphic basement of the Scandinavian Shield.

464 In the NESB-NELB system, the zoning **of** coversand-sandy loess-loess is well marked and mainly
 465 controlled by relief. In the loess belt, the texture of the sand-silt fraction is approximately unimodal
 466 and the mode decreases gradually with the distance **from the boundary of the** coversands. Some
 467 samples from the Grafenberg section (**Germany**), located in the sandy loess band, are exceptions and
 468 are bimodal. Given the context, they can be interpreted as the result of a mixture (by bioturbation or
 469 cryoturbation) of silty and sandy beds, linked to variations in wind strength or soil moisture. These
 470 deposits may be a finer equivalent of the facies composed of alternating sand and silt beds described
 471 by [Schwan \(1986\)](#) and [Kasse \(2002\)](#) in the coversands of Belgium and the Netherlands.

472 This pattern is in striking contrast to the coastal (southwest France, Iberian Peninsula) and
 473 continental (Ebro, Duero and Loire basins, Nuremberg region) aeolian systems, where the loess belt
 474 is **much less extensive** or even almost absent. **Total deposition was minimal** (1 to 2 m) during the Last
 475 Glacial **period** in Aquitaine and in the Loire basin ([Hernandez et al., 2012](#); [Gardère and Djemmali, 2018](#)).
 476 The silty fraction comes both from the reworking of older **sediments** and from the abrasion of
 477 sand grains during aeolian transport, especially in coastal systems.

478 According to experiments ([Kuenen, 1960](#); [Wright et al., 1998](#); [Bullard et al., 2007](#)), aeolian abrasion is
 479 a process capable of producing silt-sized particles in significant quantities, although comparatively
 480 small compared to fluvial and particularly glacial abrasion, with often a fine mode (< 20 μ m) ([Wright et al., 1998](#);
 481 [Smith et al., 2002](#); [Bullard et al., 2007](#)). [Swet et al. \(2020\)](#) suggest, however, that
 482 fragmentation of quartz sand produces little dust, **most of the particles released during collisions**
 483 **coming from the erosion of clay coatings**. The emission of dust caused by the blasting of fine-grained
 484 soils by saltating grains ([Shao, 2001](#)) may also have contributed greatly to the genesis of loess,
 485 especially during the phases of coversand extension. The bimodal particle size distribution of
 486 Aquitaine loess and sandy loess ([Sitzia et al., 2017](#)) is **unusual** compared to their equivalents derived
 487 from glacial sources. This is likely the result of silt production by aeolian abrasion, as grain size
 488 gradients and geochemistry indicate a single source, the coversands. It can be **noted here** that Negev
 489 loess, which **is derived in part** from the Sinai dune sands by abrasion (**together with a contribution of**
 490 **African clay-rich dust, e.g.,** [Wieder et al., 2008](#)), also has a bimodal distribution with a mode shifted
 491 towards fine silt (4-10 μ m) ([Crouvi et al., 2008](#)).

492 The amount of fines produced by this process is a function of the duration of grain transport in
 493 saltation and the distance travelled. This factor may explain why loess is relatively well developed in
 494 Aquitaine, but is almost absent in Iberian systems. In Aquitaine, the -120 m isobath (i.e. the level
 495 reached during the LGM lowstand) is located 100 to 160 km to the west of the limit of the maximal
 496 coversand extension, or even significantly more (> 200 km) considering that the dominant winds
 497 came from the northwest ([Sitzia et al., 2017](#)). Conversely, it is located less than 50 km away in the

498 Iberian Peninsula, both because of the narrowness of the continental shelf and the small **extent** of
499 the aeolian sands due to relief.

500 One of the most intriguing points that emerges from the grain size of the samples listed in the
501 database is the very homogeneous nature of the NELB loess compared to other regions. The particle
502 size distribution shows a mode falling within a narrow window, ranging from 47 to 30 μm , while it
503 ranges from 30 to 75 μm elsewhere. In addition, coversands, sandy loess and loess form well-defined
504 bands in the NELB, whereas this pattern is more **complex** in the other systems, with the exception of
505 the Aquitaine. In particular, the coversands are poorly developed compared to the other categories
506 of aeolian deposits in the **LDB**, the Po and the Rhône valleys, whereas the sandy loess **deposits** cover
507 large areas. Two factors can be considered to account for this pattern, (1) the grain size gradient
508 from the sources to the distal zones, (2) the influence of vegetation on particle trapping.

509 The distance of the sections **from** the sources and the gradient due to particle sorting during
510 transport, modulated by the effects of relief, is often the main factor invoked to explain the grain size
511 variations. This effect is real and accounts for the formation of bands of increasingly fine texture
512 away from the sources. Fluctuations are also observed within each LPS and are thought to reflect
513 variations in wind speed and precipitation regime in relation to climatic fluctuations (e.g., [Rousseau
514 et al., 2002, 2011](#); see [Ujvari et al., 2016](#), for a critical assessment of this proxy). However, the
515 distance-**from**-source factor does not provide an adequate explanation for why the sections
516 described in the NELB have similar grain sizes in contrast to other regions, **unless one assumes that
517 geomorphologists have only documented one particular type of loess in the NELB.**

518 The influence of vegetation has been proposed as a co-factor behind the variability of grain size by
519 [Bosq et al. \(2018\)](#) based on observations made in the Rhône valley. The effectiveness of trapping
520 windblown particles by vegetation has long been recognised (e.g., [Tsoar and Pye, 1987](#); [Pye, 1995](#))
521 and has been the subject of numerous field experiments and measurements (e.g., [Raupach et al.,
522 2001](#); [Leenders et al., 2007](#); [Field et al., 2012](#); [Hugenholtz and Wolfe, 2010](#); [Youssef et al., 2012](#);
523 [Suter-Burri et al., 2013](#)). This work shows that vegetation favours the deposition of particles by
524 reducing wind speed and by intercepting particles on leaves and stems. Its influence largely depends
525 on plant size, arrangement and density, which determine the quantity of particles retained relative to
526 the flow. Overall, bush, shrub **or tree** vegetation acts as a much more effective particle trap than
527 grass and a fortiori cryptogamic vegetation, and favours sedimentation at its base. Simultaneous
528 capture of sand in saltation or in modified saltation and of silt in suspension by tall vegetation, as
529 well as wind speed reduction at ground level, which limits the erosion by the impact of saltating
530 grains of the particles already deposited, help to explain the formation of sandy loess near the
531 sources. In the Rhône valley, the thickest accumulations, which are most likely to provide a detailed
532 chronostratigraphic record, are all characterised by a coarse texture (sandy loess), whereas the distal
533 fine loess forms only poorly developed accumulations ([Bosq et al., 2018, 2020a](#)).

534 Various arguments suggest that the scheme proposed for the Rhône valley can be **extended** to other
535 regions and that the vegetation factor can account for some particularities of loess at the European
536 scale. As in today's cold and temperate environments, a latitudinal gradient of vegetation must have
537 existed in Europe during the glacial periods. The NESB was associated with a periglacial desert
538 landscape ([Kasse, 2002](#)), while denser vegetation developed towards the south. Simulations
539 ([Strandberg et al., 2011](#); [Janská et al., 2017](#)) as well as reconstructions based on pollen records
540 ([Cheddadi and Bar-Hen, 2009](#); [Magyari et al., 2014](#)) agree on the predominance of steppe or tundra

541 steppe over large parts of Europe, while shrubby steppe existed in the south (Iberian and Italic
 542 peninsulas, Balkans, southern France). Low CO₂ concentration in the atmosphere and the increase in
 543 wind speed hampered the development of trees (Woillez et al., 2011), which persisted locally as
 544 open stands in favourable sites, especially in mountainous areas and valleys (Magyari et al., 2014).
 545 Genetic data (Petit et al., 2002; Cheddadi et al., 2006; Magri et al., 2006) and simulations (Svenning
 546 et al., 2008) also indicate the persistence of LGM refugia in large parts of Europe for boreal forest
 547 species and in southern Europe for mesophilic trees. Therefore, it seems likely that the vegetation
 548 gradient had a significant impact on loess sedimentation.

549 The depositional models proposed by Bosq et al. (2018) modified from Pye (1995), which involve
 550 vegetation, accurately capture some specific features of the different aeolian systems in Europe. In
 551 northern Europe, typified by a virtual absence of vegetation (NESB) or cryptogams (Smalley et al.,
 552 2011; Svirčev et al., 2019) and open steppe (NELB), **vegetation interfered little with particle**
 553 **transport**. The progression of sand by saltation was limited by relief (Mason et al., 1999) and the
 554 sorting of suspended dust led to the formation of well-defined bands of sandy loess and loess. In
 555 these bands, the accumulation rate decreased progressively with the distance to the sources. The
 556 sections described in the loess band are thus characterised by a homogeneous texture with a
 557 reduced sand component. In southern Europe, on the other hand, tall vegetation (shrubby steppe)
 558 interfered strongly with the transport of particles. Sand spreading was limited by vegetation and **the**
 559 **extent of** the coversand band was reduced. The simultaneous capture of sand and dust favoured the
 560 formation of thick sandy loess deposits near the sources. The sedimentation rate was, therefore, very
 561 high in this band and then rapidly decreased at greater distance. In the other regions of Europe (**URG,**
 562 **UDB, MDB, Moravia**), intermediate situations existed in relation to steppe-tundra vegetation.

563 **5. Conclusions**

564 The main conclusions that can be drawn from this study are the following:

565 (1) The improvement of the extraction procedure of aeolian deposits from the LUCAS topsoil texture
 566 database compared to Bertran et al. (2016) allowed **generation of a map that agrees reasonably well**
 567 with those based on a classical geological approach. This method has the advantage of providing a
 568 map of equal precision for all the regions and of clearly showing grain size gradients.

569 (2) The map shows three main types of aeolian systems, i.e. systems associated with ice sheets (FIS,
 570 BUIS, AIS) and the rivers they feed, continental systems related to the erosion of **sedimentary** rocks,
 571 and coastal systems. Some have a mixed character (e.g., Middle Danube). All systems are relatively
 572 **independent of each other**.

573 (3) Each system combines a band of coversands of varying extent close to the sources with bands of
 574 sandy loess and loess away from the sources. This pattern is well developed in northern Europe
 575 (North European Sand Belt and Loess Belt). In southern Europe, on the other hand, coversands are
 576 poorly developed along the rivers, whereas sandy loess **was deposited over large areas**. Loess is
 577 mainly present in systems derived from glacial sources and suggests that glacial abrasion was the
 578 main factor that provided fine particles to aeolian **entrainment and transport**.

579 (4) The **total** thickness of loess is highly variable throughout Europe, for reasons related to the
 580 sedimentation rate, the age of the surfaces on which the loess was deposited, and erosion processes.
 581 The areas of greatest accumulation are associated with the rivers draining the AIS (Rhine, Danube,

582 Rhône). The Middle Danube, which combines sources of glacial origin (AIS) and local sources (erosion
 583 of sedimentary rocks outcropping in the Pannonian Basin due to wind **channeling** by the relief),
 584 constitutes the main accumulation area in Europe. Conversely, continental and coastal systems
 585 generated only limited loess cover.

586 (5) The thickness of loess from only the Last Glacial period is more homogeneous. The main factor
 587 involved in thickness variations is the proximity to the sources. The downstream decrease in
 588 thickness along rivers draining the ice sheets (Manche River, Danube) shows that local inputs along
 589 their course do not compensate for the decrease in glacial particles due to sedimentation and
 590 dilution.

591 (6) The latitudinal gradient of vegetation probably played an important role in loess sedimentation
 592 during the LGM. Weak interference between particle transport and vegetation (periglacial desert in
 593 the NESB, cryptogamic crusts and steppe in the NELB) allowed for particle sorting through aeolian
 594 transport to develop. The loess band is extensive in low relief areas and is typified by low sand
 595 content. In southern Europe, on the other hand, the capture of saltating and suspended particles by
 596 the shrubby steppe vegetation led to the dominant accumulation of sandy loess near sources.

597 These findings open up new perspectives in the study of aeolian dynamics during glacial periods. The
 598 close connection between glacial sources and loess suggests that:

599 (1) The chronology of deposition may not be perfectly synchronous at the European scale, insofar as
 600 the growth and retreat of the ice sheets did not take place strictly synchronously and the
 601 palaeogeographic changes caused by the retreat necessarily led to the displacement of sources,
 602 particularly in the case of the FIS. In addition, non-glacially-fed systems (coastal and continental
 603 systems) probably behaved differently, since the factors controlling the susceptibility of soils to
 604 deflation are not identical to those controlling glacial dynamics.

605 (2) Simulations of LGM dust emission, which only take into account the susceptibility of soils to
 606 deflation as a function of moisture, vegetation cover and wind speed ([Sima et al., 2013](#); [Hopcroft et
 607 al., 2015](#); [Schaeffernicht et al., 2020](#)), are probably not suitable for reproducing the production of
 608 dust, most of which came from the alluvium of glacier-fed rivers.

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617 **Supplementary Information**

618 Map of European eolian deposits (shapefiles)

619 Table of loess observation points (Excel file)

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985

986 **Table and figure captions**

987 Table 1: Target textures of the aeolian deposits.

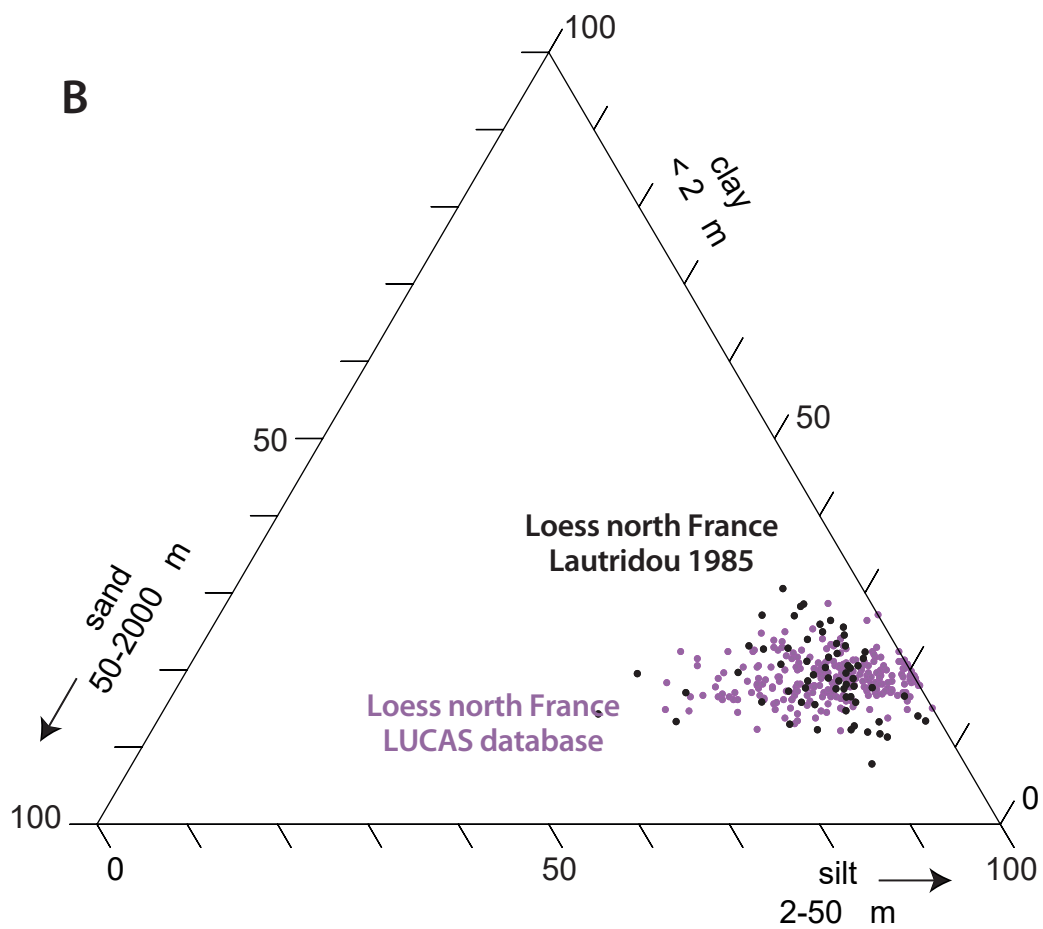
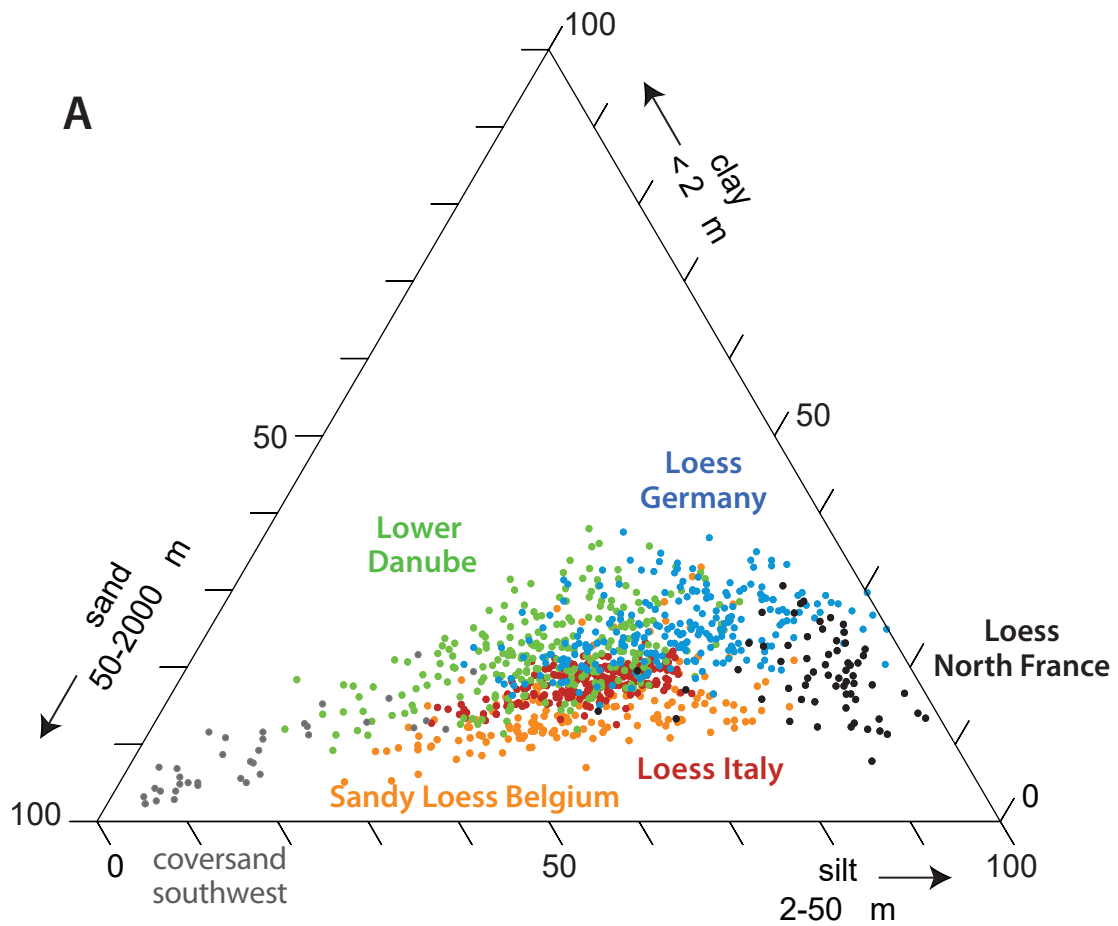
988 Figure 1: Texture of European aeolian deposits. A - Points extracted from topsoil texture rasters in
 989 different areas of aeolian deposits; B - Samples of loess from northern France analysed by [Lautridou](#)
 990 [\(1985\)](#), compared to 500 points extracted from topsoil texture rasters ([Ballabio et al., 2016](#)) in the
 991 zone of loess with a thickness greater than 4 m.

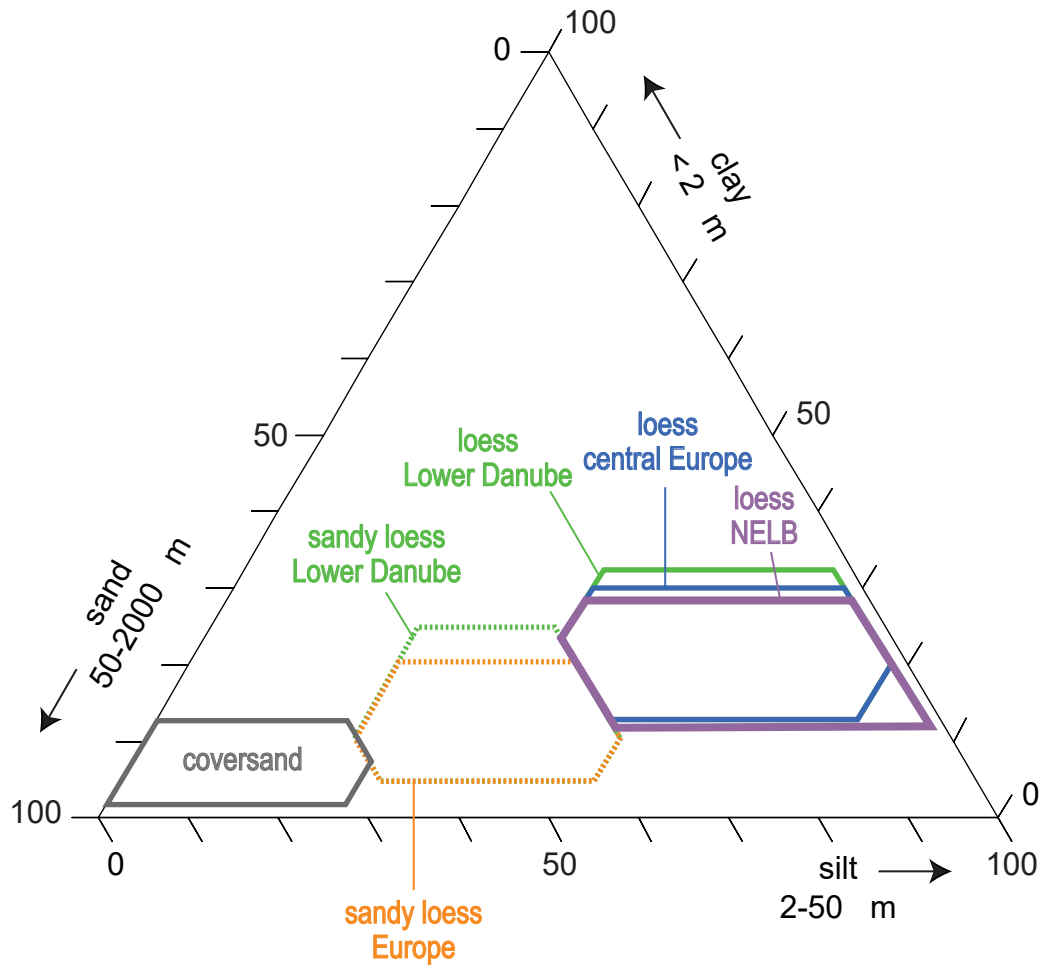
992 Figure 2: Target textures of aeolian deposits according to regions.

993 Figure 3: Random points extracted from topsoil texture rasters ([Ballabio et al., 2016](#)) in loess from
 994 northern France, Germany, Italy, the Lower Danube Basin and the Rhône Valley. A - Percentage of
 995 coarse fragments; B - Percentage of clay.

996 Figure 4: Map of European aeolian deposits. The 21 ka ice sheets are taken from [Hughes et al. \(2016\)](#)
 997 for FIS and BIIS and from [Ehlers and Gibbard \(2004\)](#) for the rest of Europe. The 15 ka ice sheets are
 998 from [Clarke et al. \(2012\)](#) for BIIS and [Stroeven et al. \(2016\)](#) for FIS. AL – Albania, AU – Austria, BE-
 999 Belgium, BO – Bosnia Herzegovina, BU – Bulgaria, CR – Croatia, CZ – Czech Republic, DE – Denmark,

- 1000 FR – France, GE – Germany, GR – Greece, HU – Hungary, IT – Italy, NE – the Netherlands, PO –
 1001 Portugal, RO – Romania, SE – Serbia, SL – Slovakia, SP – Spain, UK – United Kingdom.
- 1002 Figure 5: Comparison of the distribution of loess and sandy loess in this study and [Lehmkuhl et al.](#)
 1003 [\(2021\)](#). Common areas are in red.
- 1004 Figure 6: Distribution of loess in the Cotentin (NW France) according to this study, the 1:50,000
 1005 geological map (BRGM) and [Lehmkuhl et al. \(2021\)](#), compared with the observed loess sections
 1006 ([Coutard et al., 2005](#)).
- 1007 Figure 7: Comparison between maps and observation points in the Cotentin region. A - Percentage of
 1008 points with loess or without loess well classified according to maps; the thickness indicated
 1009 corresponds to the average thickness of the observed loess (points without loess excluded); B -
 1010 Average loess thickness all points combined.
- 1011 Figure 8: Distribution of coversands (this study), till and fluvio-glacial alluvium ([http://www.europe-
 1012 geology.eu/onshore-geology/](http://www.europe-geology.eu/onshore-geology/)) in northern Europe.
- 1013 Figure 9: Map of loess thickness. A - Total loess thickness; B - Last Glacial loess.
- 1014 Figure 10: Evolution of the percentage of sand in loess as a function of the distance to the coversands
 1015 for 2 profiles extracted from the rasters of topsoil texture ([Ballabio et al., 2016](#)).
- 1016 Figure 11: Map of the main mode of MIS 2 loess, according to different authors.
- 1017 Figure 12: Grain size distribution of coversands, sandy loess and loess from different European
 1018 regions. Aur: Auriac, Bou: Bourg-sur-Gironde, Mar: Marsas, SGe: Saint-Gein, after [Sitzia et al. \(2017\)](#);
 1019 Cug: Cuges-les-Pins, Fey: Feyzin, Lau: Lautagne, Mau: Mauves-sud, after [Bosq et al. \(2018\)](#); Ach:
 1020 Achenheim, after M. Bosq (unpublished); BK: Bialy Kościół, Tys: Tyszowze, after Z. Jary (unpublished);
 1021 Buh: Bůhzdař, after K. Flasarova (unpublished), Gra: Grafenberg 2, after [Fischer et al. \(2019\)](#).
- 1022





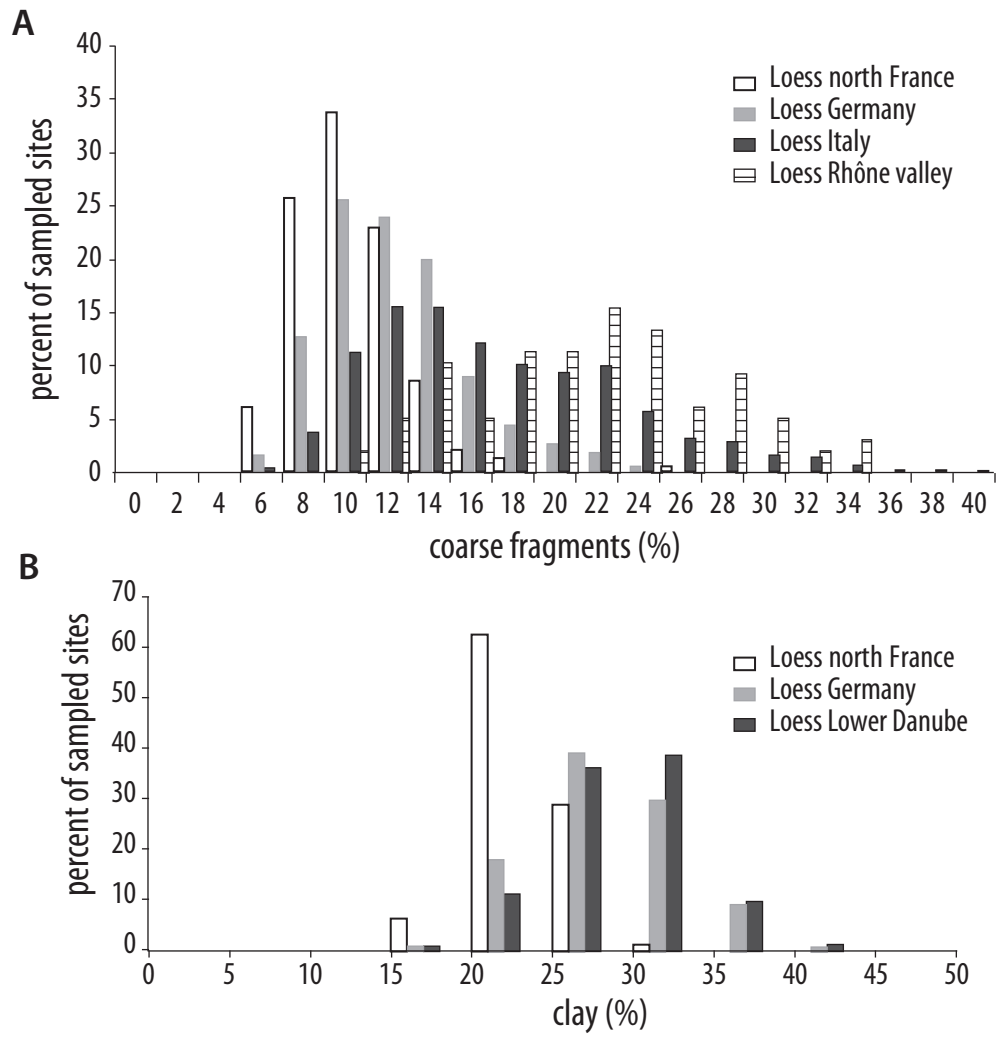


Figure 4

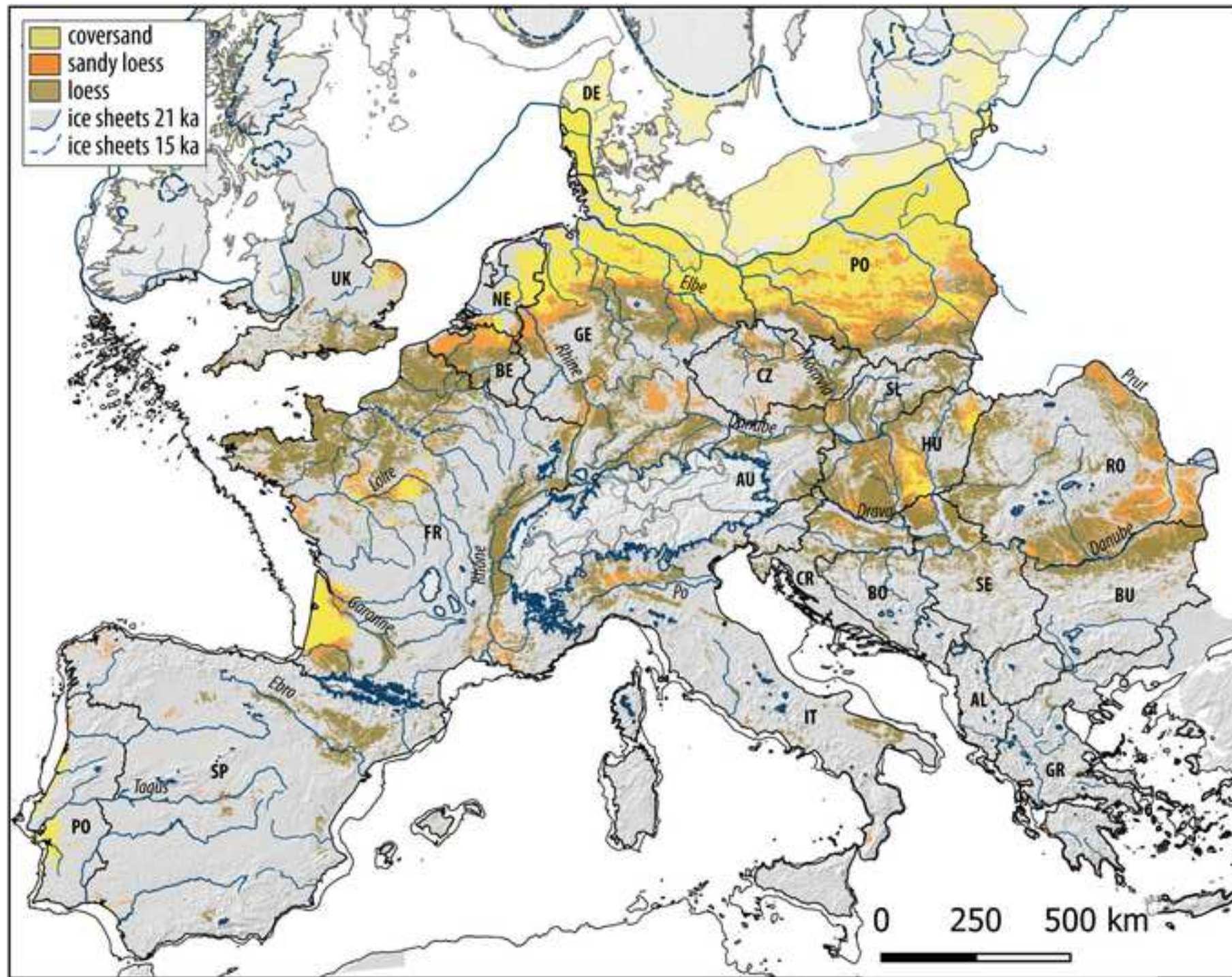
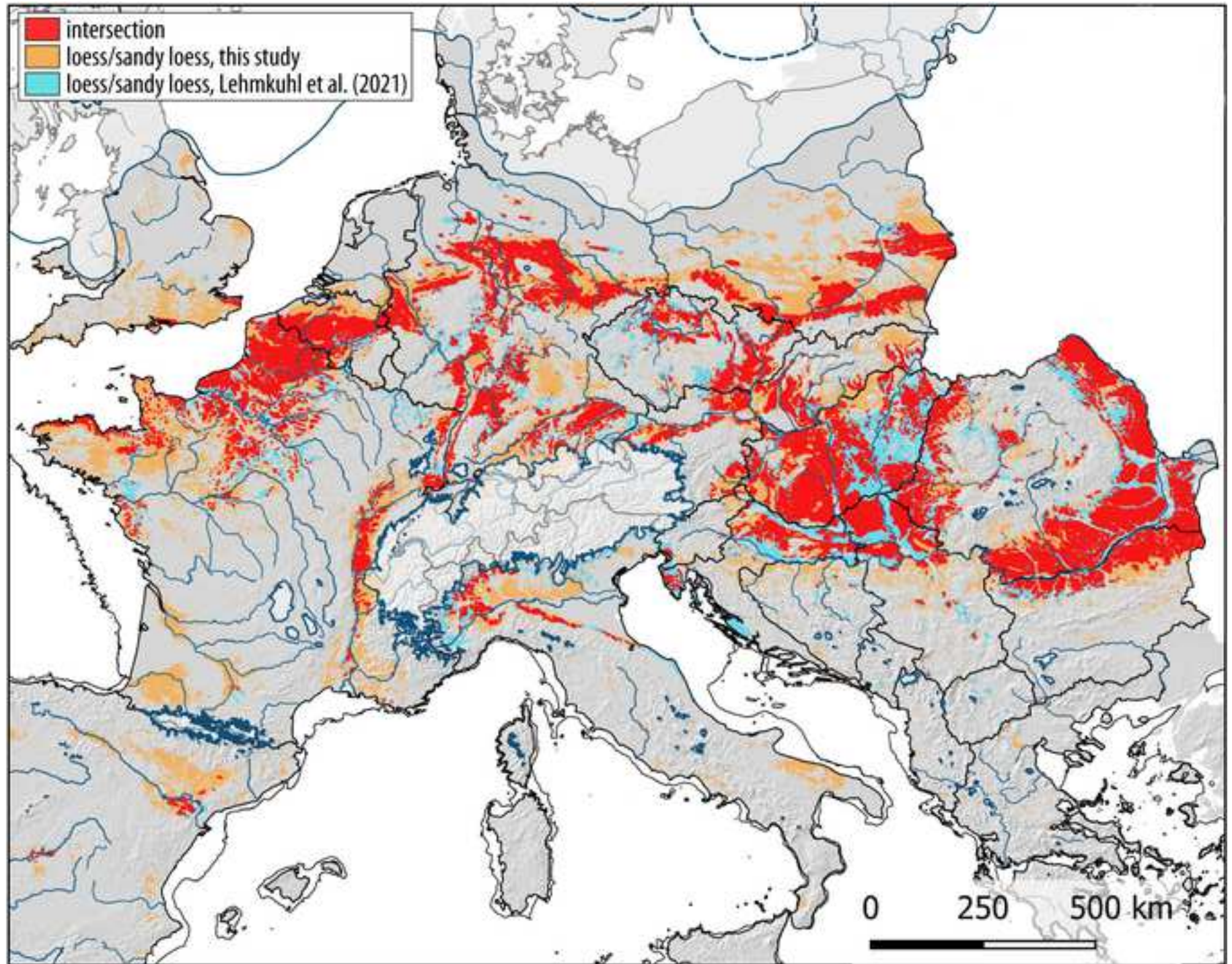
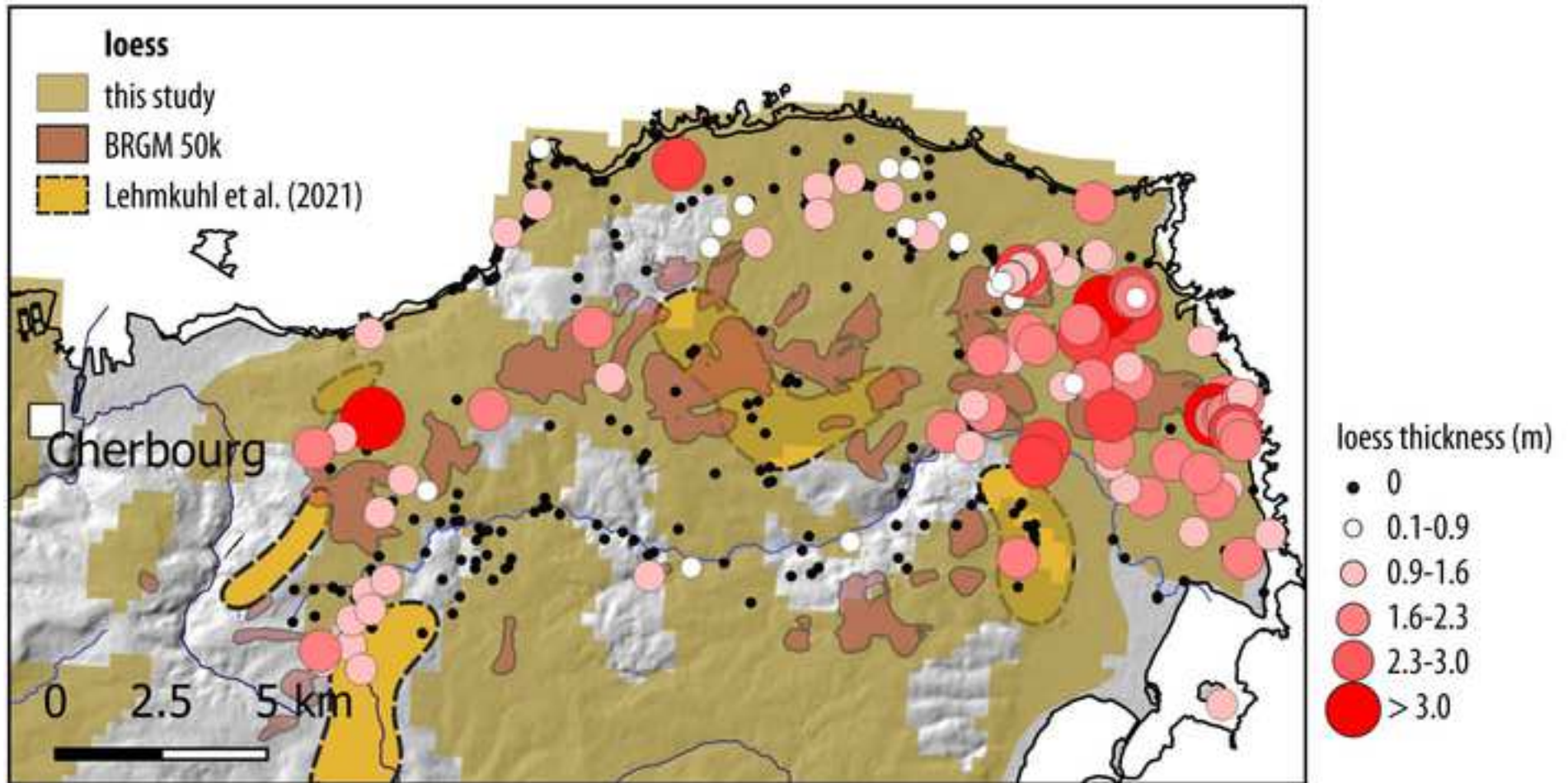


Figure 5

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Carte_intersection_LUCAS_Lehmkuhl2.jpg





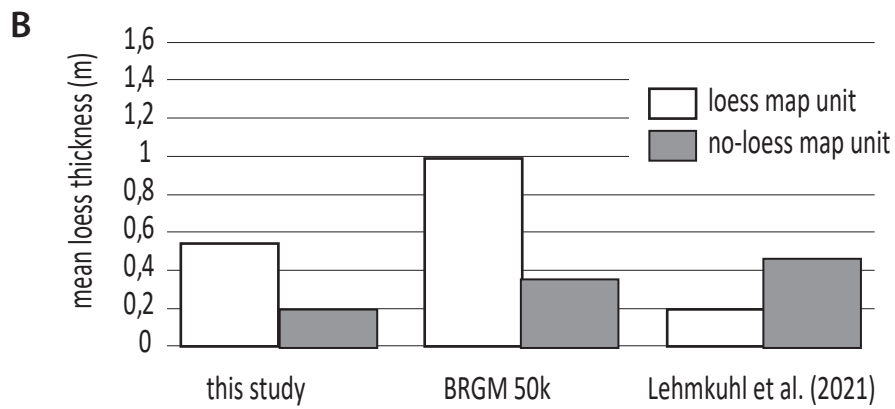
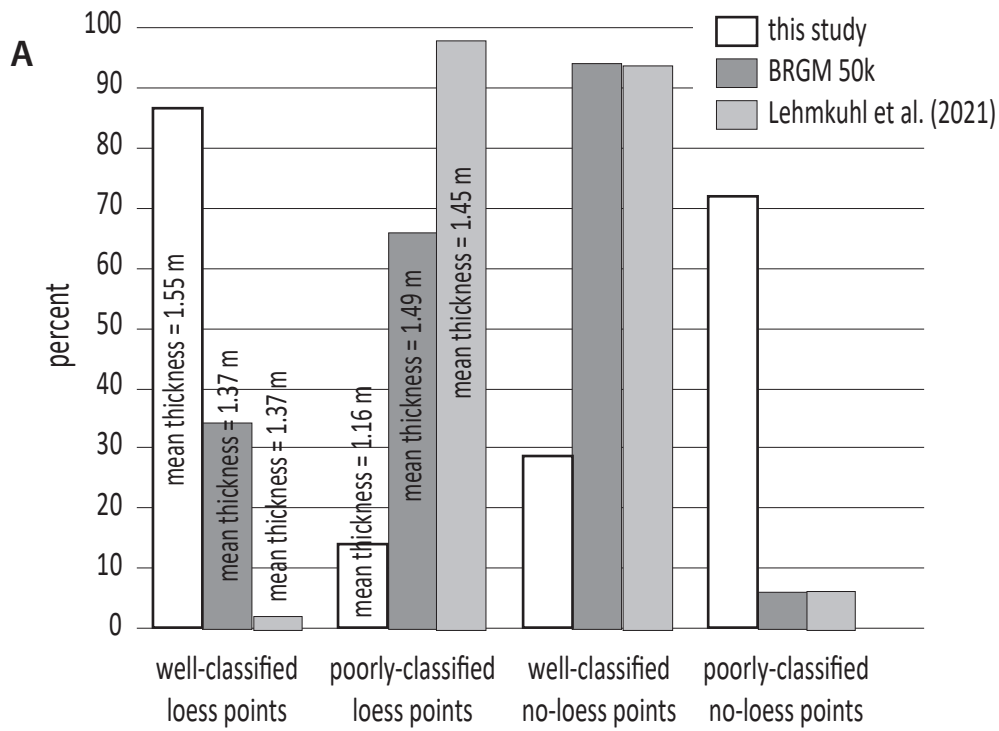
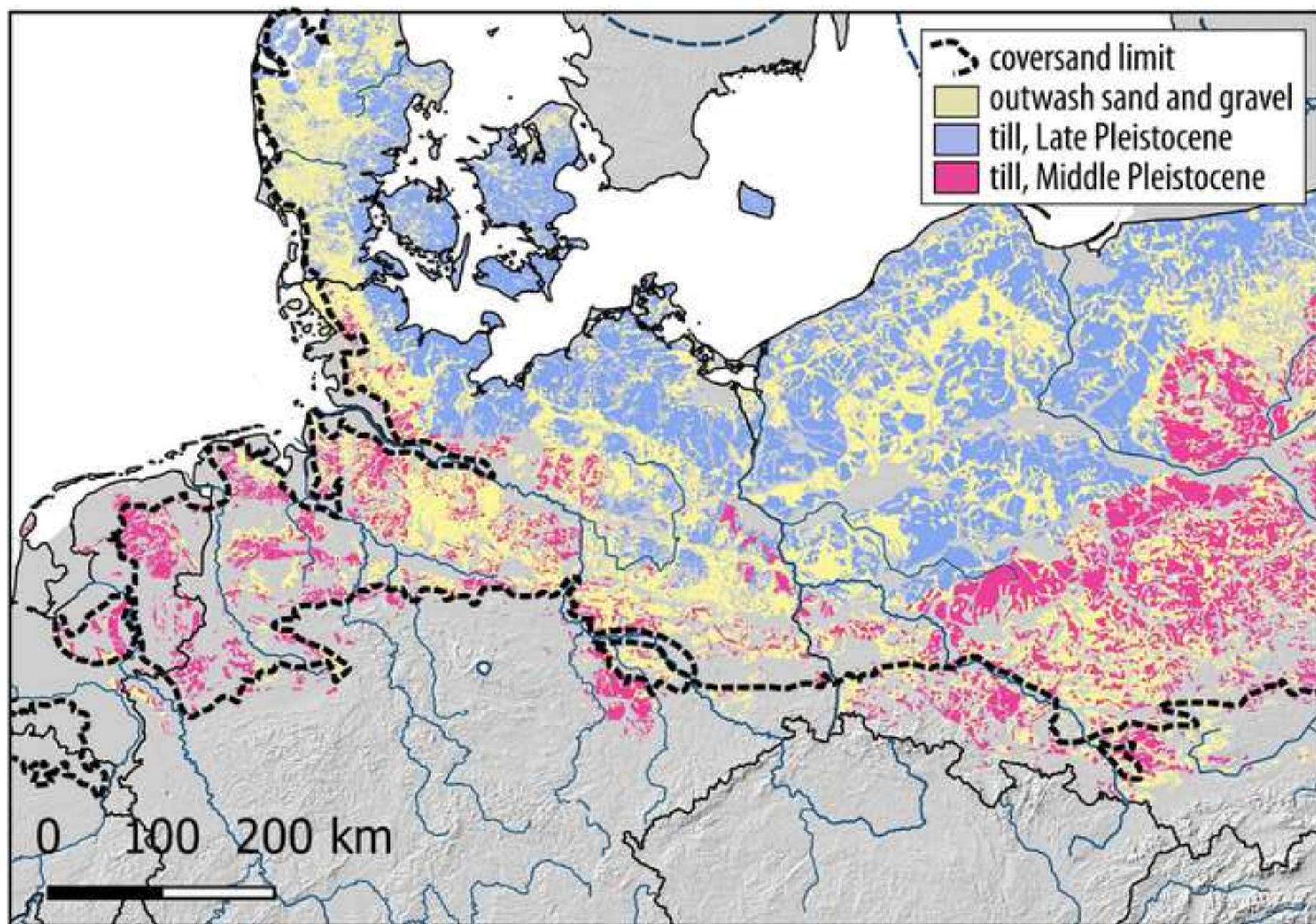
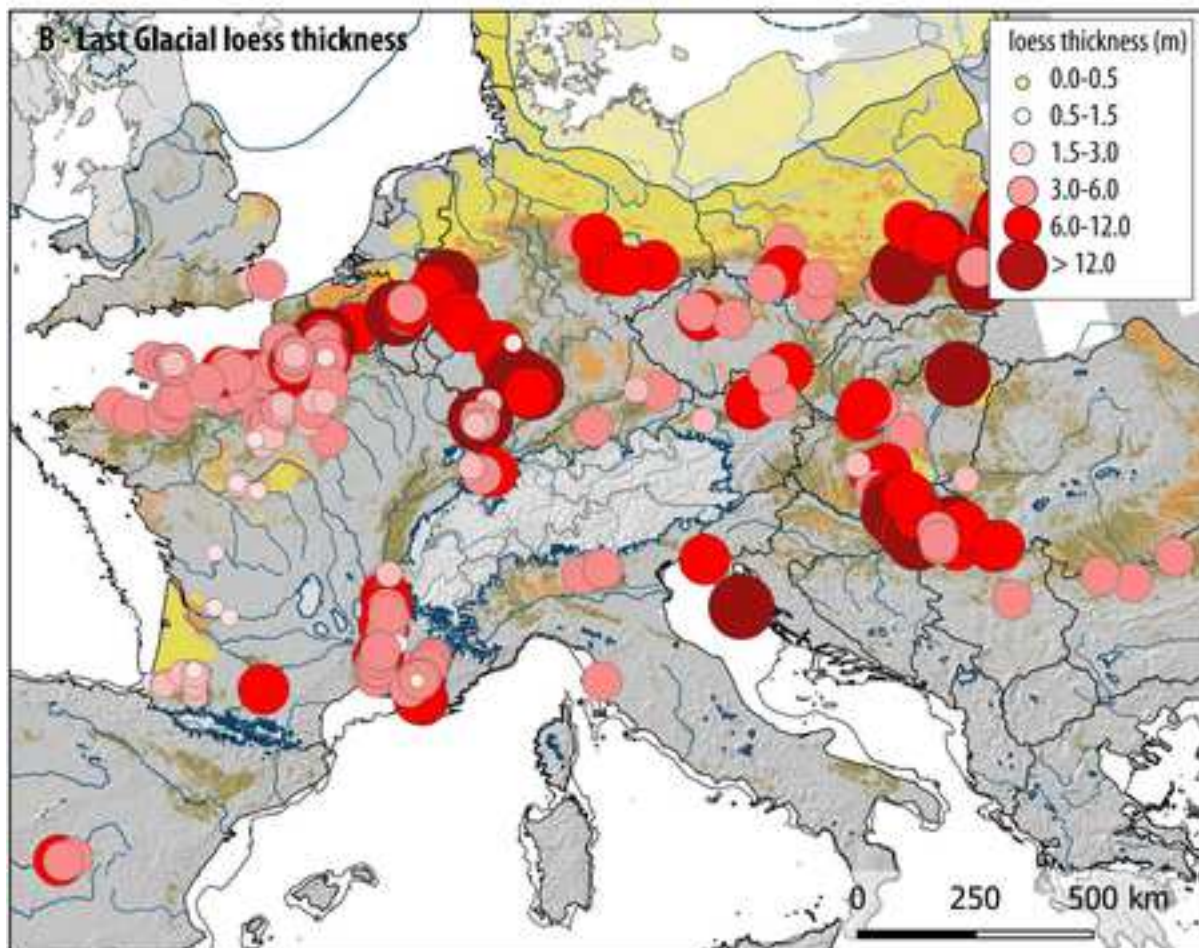
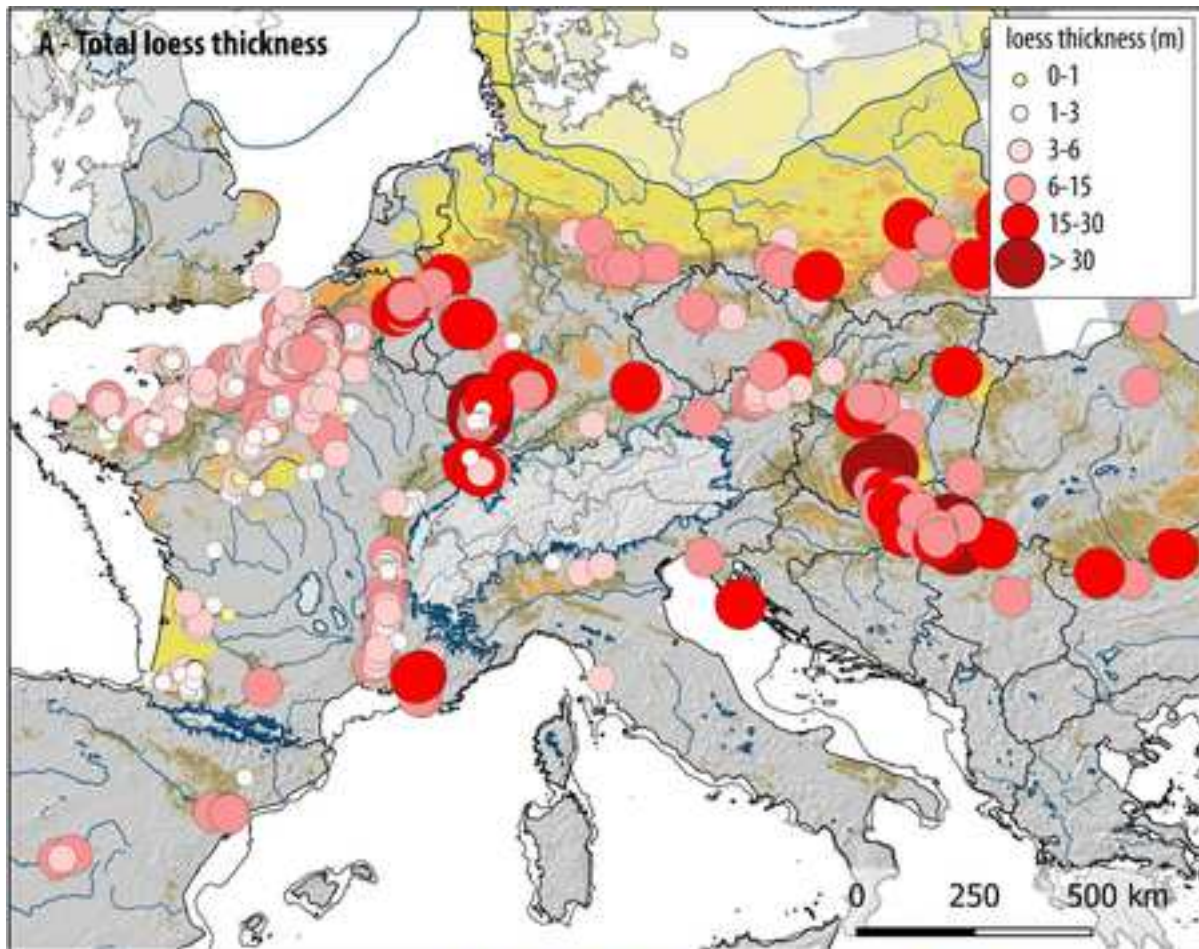


Figure 8





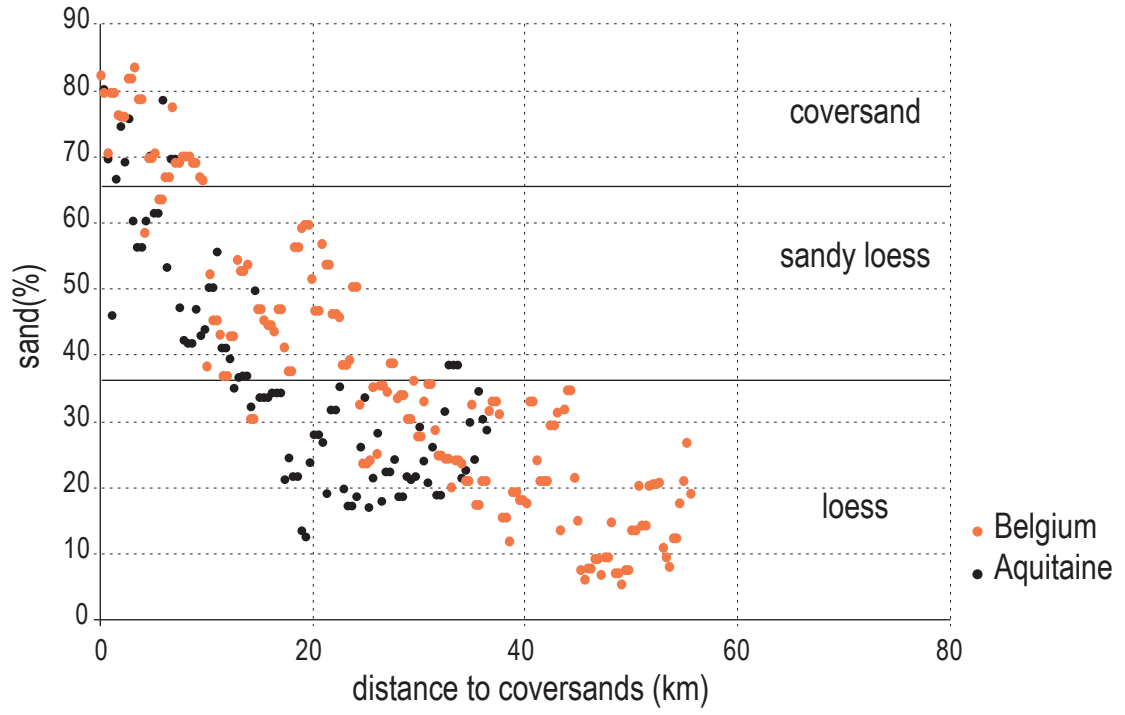
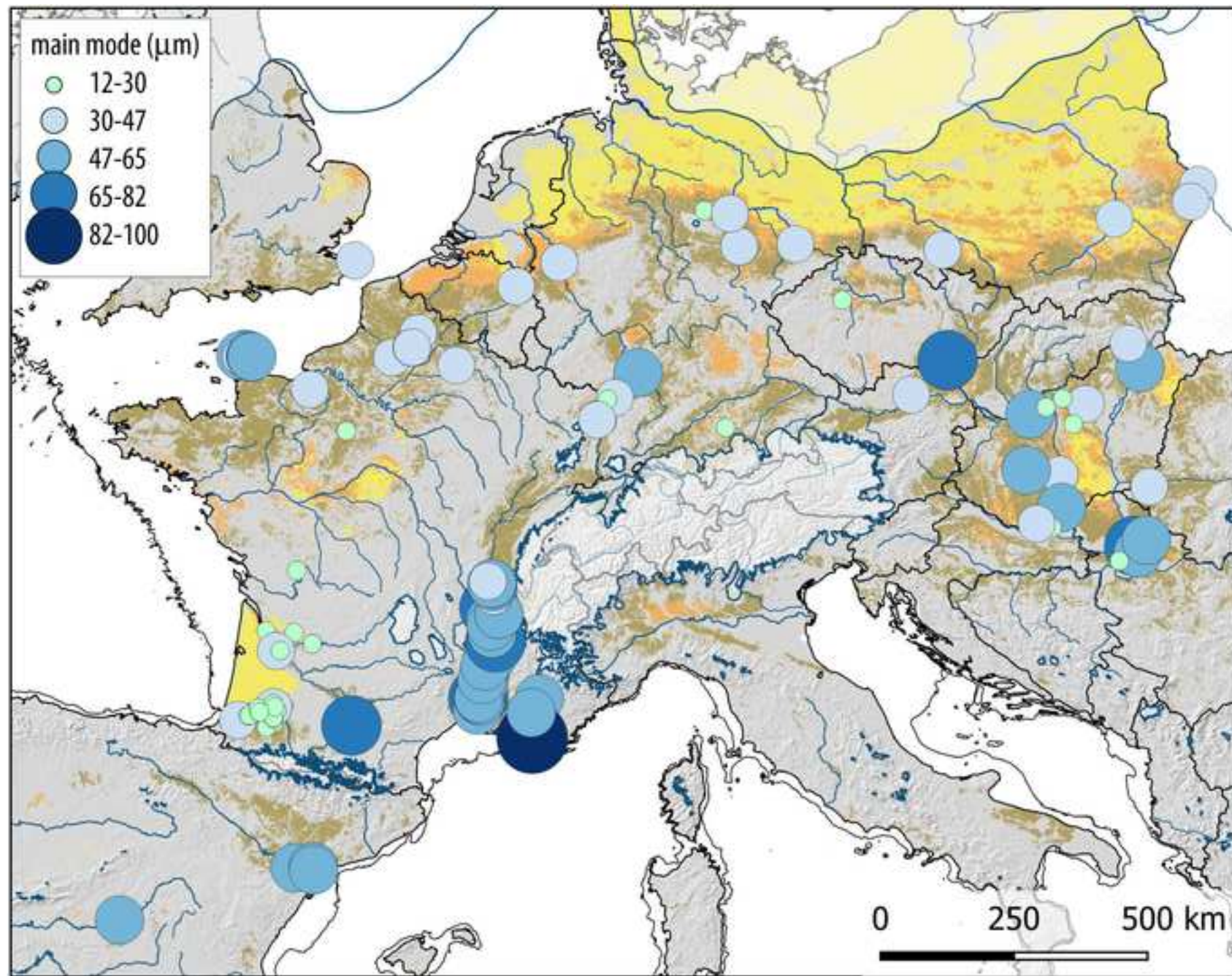
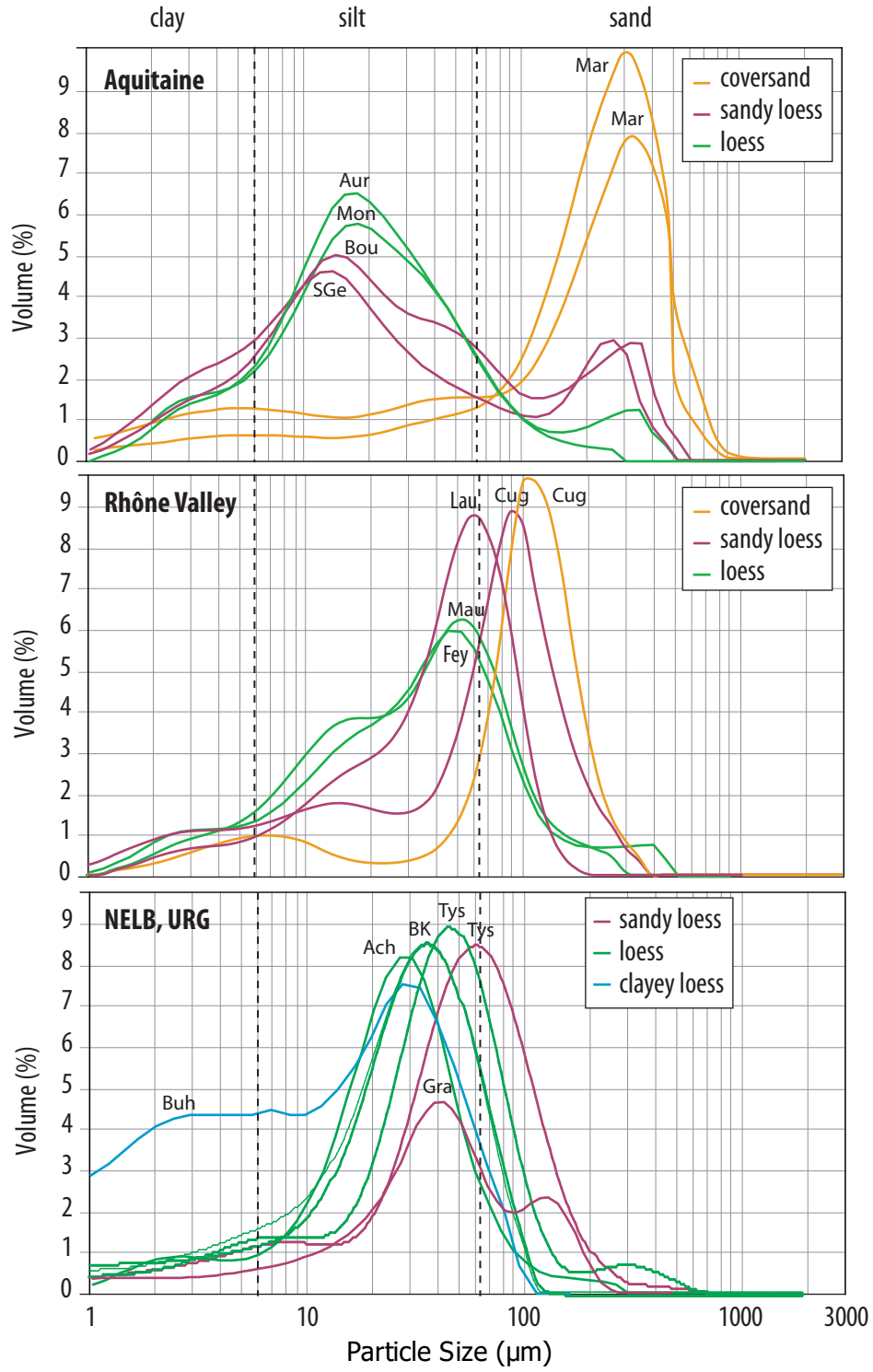


Figure 11





	clay (%)	silt (%)	sand (%)	coarse (%)
Loess NELB	12-28	40-78	3-37	<13
Loess UK	12-28	40-78	3-37	<18
Loess central Europe	12-30	40-78	3-37	<13
loess Lower Danube Basin	12-33	40-78	3-37	<13
Loess Po Plain	12-33	40-78	3-37	<18
Loess Rhône Valley	12-33	40-78	3-37	<20
Sandy loess NELB-central Europe	5-20	23-53	37-67	<12
Sandy loess Lower Danube Basin	5-26	23-53	37-67	<12
Sandy loess Rhône Valley	5-26	23-53	37-67	<20
Coversand	2-13	0-27	66-100	<12



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