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1 **FIVE MILLENNIA OF HUMAN-ENVIRONMENT INTERACTIONS RECONSTRUCTED**  
2 **FROM PEDOSEDIMENTARY ARCHIVES OF THE LAC DU PUY WETLAND (CORENT, FR.)**

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18 **Abstract**

19 This paper presents a multi-proxy geoarchaeological analysis of the complex pedo-sedimentary  
20 archives of a small pond situated within the protohistoric site of Corent, in central France. A robust  
21 chrono-stratigraphic framework was developed integrating all chronological data from previous  
22 studies. Micromorphological, geochemical and sedimentological analyses were performed on a

23 radiocarbon-dated core. Results are discussed alongside palynological data from previous work on  
24 the same core, in order to reconstruct human-environmental interactions on the Corent volcanic  
25 plateau since the Neolithic. After intense soil erosion recorded during the Early and Middle Neolithic,  
26 the Late Neolithic is characterized by vegetation recovery and soil stability in the basin  
27 contemporaneous with site abandonment, perhaps due to pronounced soil degradation in the  
28 plateau. During the Early Bronze Age, agropastoral land use contributed to major environmental  
29 changes in the pond's basin, including soil profile sealing and gleyfication. Environmental impact  
30 patterns detected in the pedo-sedimentary record indicate settlement intensification during the  
31 Middle Bronze Age. After the substantial impacts of an intense anthropogenic disturbance in the  
32 Early Iron Age, the Lac du Puy becomes a vertic depression recurrently flooded while a late Iron Age  
33 Gallic *oppidum* develops on the plateau, and is finally backfilled at the end of the Iron Age. The  
34 detailed multi-proxy picture from this intra-urban wetland helps nuance our understanding of the  
35 environmental impacts of prehistoric societies in Western Europe. Indeed, our results highlight the  
36 importance of keeping a long term perspective when dealing with past human-environment  
37 interactions.

38

39 **Keywords:** Human-environment interactions; Pedo-sedimentary archives; Geoarchaeology; Soil  
40 Micromorphology; Palaeosoils; Limagne; Holocene

41

## 42 **1-Introduction**

43 Long-term human-environment interactions and the gradual 'anthropogenization' of natural systems  
44 are topics that have been widely investigated and discussed in geoarchaeological,  
45 palaeoenvironmental and environmental archaeological studies, from western Europe in recent  
46 decades (e.g. van der Leeuw et al., 2005; Dearing, 2006; Berger et al., 2007; Butzer, 2011; Notebaert

47 & Berger, 2014; Carozza et al., 2015; Arnaud et al., 2016; Cremaschi et al., 2016; Lespez et al., 2016).  
48 More recently renewed research momentum has been stimulated by the emergence of the hotly  
49 debated 'anthropocene' paradigm (Crutzen & Stoermer, 2000; Foley et al., 2013; Cremaschi, 2014;  
50 Butzer, 2015; Lewis & Maslin, 2015; Verstraeten, 2015; Ruddiman et al., 2015; Ruddiman, 2017;  
51 Bauer & Ellis, 2018).

52 Off-site palaeoenvironmental and geoarchaeological research (e.g. in lakes, peatlands, floodplains  
53 etc.) continue to provide valuable records of human impacts in environmental dynamics (e.g. Miras  
54 et al., 2004; Brown et al., 2013; Arnaud et al., 2016; Berger et al., 2016; Peña-Monné, 2018; Dubois et  
55 al., 2018). In addition, progress in site-based geoarchaeological approaches is producing large  
56 amounts of detailed archaeometric data related to human-environment interactions (Butzer, 2008).  
57 Improvements in our understanding of Holocene palaeoclimatic change are allowing the  
58 development of detailed analyses of the interaction between climate and society (Magny et al., 2009;  
59 Armit et al., 2014; Lespez et al., 2016; Roberts et al., 2019). Together, these new data contribute to  
60 feed scientific discussion and to improve our understanding of the progressive anthropogenic forcing  
61 of natural systems through the Middle to Late Holocene.

62 Despite these achievements some "grey zones" remain in human-environment interaction studies,  
63 often neglected by palaeoenvironmental and geoarchaeological works. This is typically the case for  
64 human-environment interface halfway between site-based and off-site contexts, as researchers  
65 regularly focus on areas suitable for the formation and preservation of "optimal" sedimentary  
66 records, that are able to provide unambiguous interpretations. Intermediate, or "site-proximal"  
67 contexts are often neglected due to their sometimes incomplete sedimentary records, signal  
68 complexity or poor taphonomic conditions (Ledger et al., 2015, 2017).

69 These "site-proximal" contexts are nevertheless crucial for developing an integrated understanding  
70 of the complex nature of long term human-environment interactions. They provide unique and  
71 sensitive records of processes characteristic of transitional zones, displaying a mixture of natural and

72 cultural features. This makes them useful for characterizing human-environment interaction, such as  
73 locally increased impacts related to proto-urban emergence (Kaniewski et al., 2013; Danielisova and  
74 Hajnalova, 2014; Ledger et al., 2015; Styring et al., 2017). Formation processes of pedosedimentary  
75 sequences on the periphery of archaeological sites, often marked by hiatuses and cumulated  
76 dynamics, are valuable yet complex palimpsests that present a real geoarchaeological challenge, and  
77 are fertile ground for multi-proxy approaches. Wetlands under human influence are similar case and  
78 they have been widely studied from a palaeoenvironmental and geoarchaeological perspective in  
79 rural areas (e.g. Martín-Puertas et al., 2009; Macaire et al., 2010; Bernigaud et al., 2014; Hausmann  
80 et al., 2018; Haas et al., 2019), but site-proximal or intra-site wetlands are rare and consequently less  
81 frequently studied.

#### 82 *Geographical Settings and Archaeological Background*

83 The Lac du Puy is typical of these rare contexts. The small wetland is situated within the extension of  
84 the large protohistoric archaeological site of Corent, located on a volcanic plateau dating from the  
85 Pliocene (Greffier et al., 1980; Nehlig et al., 2003; Mayoral et al., 2018). The plateau is located in a  
86 commanding position, controlling the north-south axis of the valley of the River Allier, 20 km south of  
87 Clermont-Ferrand (French Massif Central, see Fig. 1). The southern part of the plateau is a scoria  
88 cone with moderate slopes, while the Lac du Puy basin is situated in the northern area of the  
89 plateau, a basaltic lava flow with gentle topography. It is a closed circular depression (c. 2 Ha)  
90 interpreted as a pseudo-sinkhole (Mayoral et al., 2018), nowadays occupied by a dry (but seasonally  
91 wet) agricultural field with a small drained pond (20x20m) fed by runoff and subsurface flow. Aerial  
92 photography and historical maps suggest that before drainage operations in the early XIX<sup>th</sup> century  
93 (Ledger et al., 2015), the open water area in the depression was probably more extensive (c.  
94 100x80m) and could perhaps have been a valuable water source.

95 Extensive archaeological excavation at Corent since the 2000's has shown human occupations  
96 spanning from Middle Neolithic to Roman period. The Middle Neolithic, dated c. 4200-3700 BCE

97 (Before Common Era), is characterized by a large fortified settlement and ditched structures (Poux et  
98 al., 2018). Later, a collective burial was installed in the summit of the plateau (Daugas, 1972), maybe  
99 in the Late Neolithic (c. 3000-2400 BCE). The Bronze Age is characterized by several occupations. The  
100 most studied is a Late Bronze Age III (950-800 BCE) agglomerated settlement with proto urban  
101 features, which given its hilltop position and size is unique in France (Milcent et al., 2014a; Ledger et  
102 al., 2015). Centuries later in the Early Iron Age (Hallstatt D1, 625-510 BCE) a proto-urban settlement  
103 developed as is seen elsewhere in Western Europe (Milcent et al., 2014b; Fernández-Götz, 2018).  
104 The most celebrated phase of the site is undoubtedly the Late Iron Age *oppidum* (La Tène D1-2 140-  
105 30 BCE). This was an immense, monumental and wealthy urban centre including public, artisanal,  
106 religious and commercial buildings, which was probably the capital of the *Arverni* (Poux, 2012;  
107 Milcent et al., 2014b; Poux et al., 2018). After the Roman conquest, the site became a well-  
108 developed secondary agglomeration (30 BCE-300 CE, Poux et al., 2018).

109 This trajectory of successive occupations makes Corent an important site in European protohistory  
110 with rich potential for analyzing long-term socio-environmental interactions, and human impacts  
111 during proto-urban and urban episodes of the 1<sup>st</sup> millennium BCE. Surprisingly, the  
112 palaeoenvironmental and geoarchaeological potential of the wetland has long time been neglected,  
113 aside from a restricted archaeological survey in the early 1990s (Guichard, 1991).

114

115

#### 116 *Summary of recent research and Objectives*

117 In the framework of the AYPONA palaeoenvironmental program, begun in 2013, palynological  
118 research (Ledger et al., 2015) and geoarchaeological survey (Mayoral and Depreux, 2017; Mayoral et  
119 al., 2018) were undertaken within this wetland. The objectives were to investigate long-term human-  
120 environment interaction, impacts of human settlements since the Neolithic, and localized impacts  
121 during the proto-urbanization episodes of the 1<sup>st</sup> millennium BCE.

122 Palynological investigations analyzed (pollen and NPPs) half of a sedimentary core extracted in the  
123 Lac du Puy basin and developed an age-depth model based on radiocarbon dating (see Ledger et al.,  
124 2015). The results indicated more or less continuous human impact from the Neolithic until the  
125 Roman era. The Neolithic to Middle Bronze Age was characterized by a classical pattern of woodland  
126 clearance and landscape opening, coupled with the gradual intensification of agriculture, and  
127 development of pastoral activity. From the end of the Late Bronze Age, there is evidence of increased  
128 biodiversity, plants indicative of ruderal environments and limited evidence of agriculture. These  
129 patterns, together with other key features such as occurrences of non-native plant taxa, were  
130 interpreted as those of emerging proto-urban areas in the Late Bronze Age and the Late Iron Age  
131 (Ledger et al., 2015). Further geoarchaeological research involved trench-based survey, developed in  
132 2015 (Mayoral et al., 2018). The infilling of the basin, divided in 12 Stratigraphic Units (SU), is in  
133 general clayey and ranges from 30 cm to 2m in deeper central sectors of the basin, with very variable  
134 depth and often sharp lateral changes of pedo-sedimentary facies (Fig. 1F).

135 Geomorphology and stratigraphy from logs and cross-sections, geophysics, radiocarbon dating and  
136 archaeological findings were used to build a first chrono-stratigraphic framework at the scale of the  
137 basin, and ultimately to outline the main phases of its complex pedo-sedimentary and hydrological  
138 evolution (Fig. 1F&G, adapted from Mayoral et al., 2018). The first phase of the infilling of the basin  
139 starts somewhere at the end of the Early, or in the beginning of the Middle Neolithic (before 4500  
140 cal. BCE). Sparse pools in the irregular basaltic bedrock revealed by geophysics (Fig. 1D) received  
141 strong runoff bringing scoria and clays (SU6A/B), whereas a weathering profile had started to  
142 develop over basalts in higher areas (WB). By the Middle Neolithic (circa or after 4500 cal. BCE), an  
143 oscillating water table and detrital sedimentary inputs smoothed the irregular topography of the  
144 basin (SU5A-B-C, Fig. 1F&G). Fragmentary archaeological remains are indicative of human activity in  
145 the area, maybe related to contemporaneous occupations of the plateau. Following this phase, a  
146 very low deposition rate, or even a hiatus between SU5 and SU4, makes interpretation of the  
147 depositional environment difficult (Mayoral et al., 2018). A new sedimentary phase, beginning in the

148 Early to Middle Bronze Age (1900-1600 cal. BCE), was characterized by low-energy environment and  
149 high watertable level (clayey gleysol, SU4-4a1-4b; see Fig. 1F&G). At the top of this unit, is an  
150 archaeological soil containing *in-situ* structures dating to the Late Bronze Age 3 (950-800 BCE). This  
151 unit is almost certainly associated by the contemporaneous LBA3 occupation of the plateau and  
152 indicates human activity in the basin at this time. Following this period, and until the fifth century BC,  
153 sedimentation was interrupted coinciding with a soil stability phase in the plateau. However shortly  
154 after (600-425 BCE), the digging of c. one thousand storage pits, probably associated by the  
155 neighboring Hallstatt D settlement, massively disturbed pedo-sedimentary and hydrological  
156 dynamics of the basin (Fig. 1F&G). After abandonment of these pits, the disturbance period was  
157 followed by deposition of SU3, characterized by ephemeral flooding, detrital inputs and vertisol-type  
158 dynamics (seasonal shrink-swell processes). In the late Iron Age (La Tène D, 100-40 BCE) at least two  
159 phases of soil leveling and backfilling affected southern parts of the basin (SUA1-A2), followed by a  
160 generalized leveling and backfill of the Lac du Puy (50/40-30 BCE, SU2). These backfill layers, always  
161 associated with archaeological structures, are characterized by heterogeneous grain-size, very  
162 frequent basaltic and amphorae inclusions, homogeneous thickness in all their extent, and abnormal  
163 or erosive stratigraphic contacts (Fig. 1F). Indeed, they partly truncate positive reliefs on SUs 3 and 4  
164 (Fig. 1F&G). These earthworks were caused by the gradual extension of the Gallic oppidum and were  
165 certainly accompanied by drainage (Mayoral et al., 2018). After Antiquity, sedimentation slowly  
166 covered antique backfill and a topsoil with incipient vertic features developed (SU1) as wet  
167 conditions gradually returned, until the depression was drained in recent centuries.

168 In summary, previous palynological and geoarchaeological research provided the first chrono-  
169 stratigraphic framework for the basin, and revealed the human influences likely driving its  
170 development since the Neolithic. However, the precise relationship between changing pedo-  
171 sedimentary processes and human activity remains unclear. For instance, were Neolithic detrital  
172 inputs connected with woodland clearance detected by palynology and with occupation phases of  
173 the plateau? Were the gleyic conditions at the onset of the Bronze Age related to human activity?

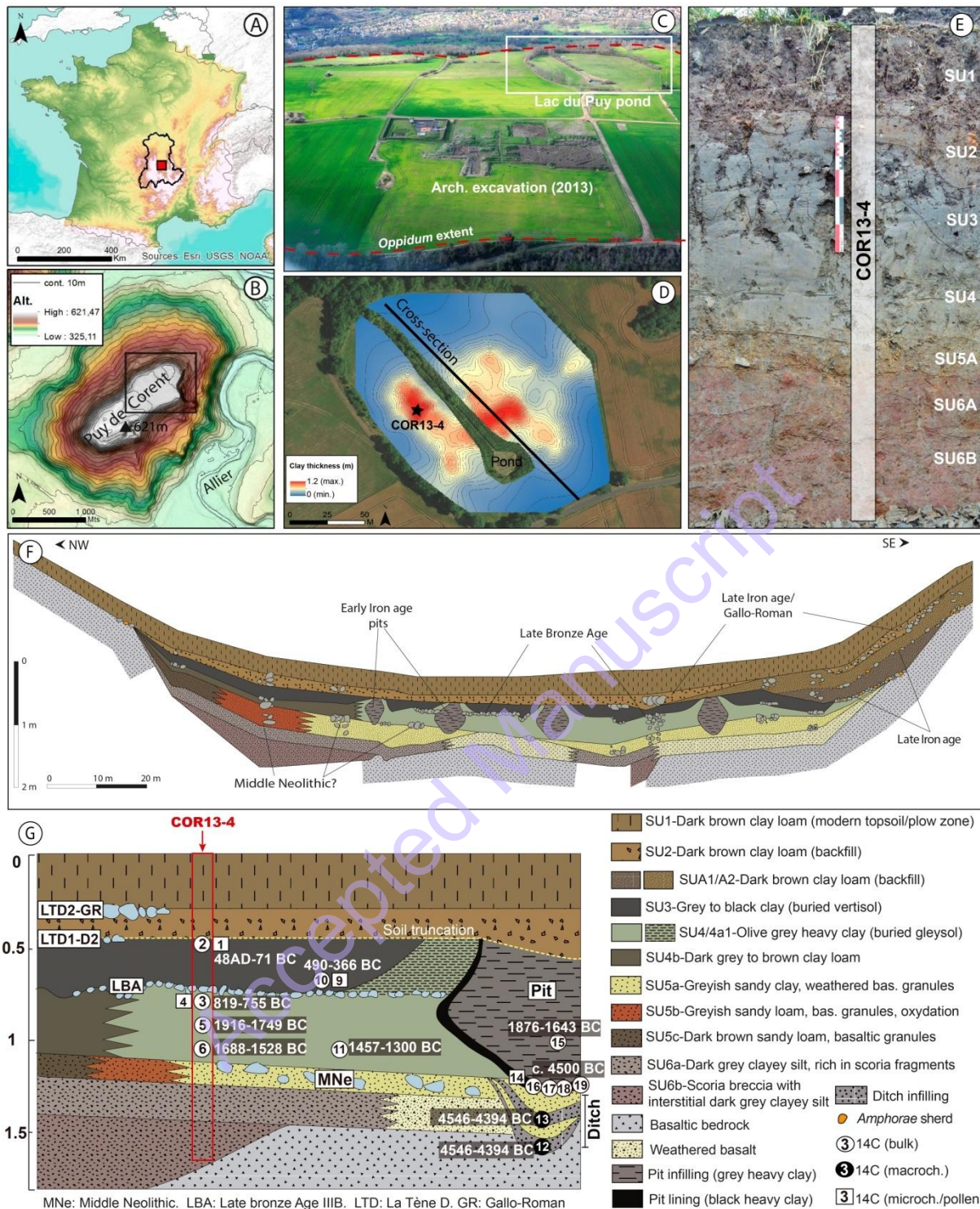


174 How did the vertisolization processes following the abandonment of storage pits in the Iron Age  
175 develop? Similarly, the *hiatus*/low-deposition phases were hindering comprehensive understanding  
176 of the sequence, and required more detailed examination.

177 This work aims to resolve these questions by applying an integrative and high-resolution  
178 geoarchaeological approach to the rich but complex pedo-sedimentary archives of the Lac du Puy. A  
179 multi-proxy geoarchaeological analysis was performed on a sedimentary core from the deepest area  
180 of the basin (Fig 1D), well-representative of the pedo-sedimentary sequence of the lower areas of the  
181 Lac du Puy (Fig. 1E&G). New micromorphological analyses, completed with high-resolution  
182 sedimentological and geochemical data, were integrated with previous palynological and  
183 archaeological information. Results were interpreted within a refined chrono-stratigraphic  
184 framework based on a compilation and integration of available radiocarbon, archaeological and  
185 stratigraphic evidence.

186

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188 Figure 1. A) Location of study site in central France. Black line delineates Auvergne region. B) Location (black frame) of  
 189 archaeological site and the Lac du Puy pond in lower part of the plateau of Corent. C) Aerial view of the Lac du Puy and the  
 190 archaeological excavation (2013), with the known *oppidum* extent (red dashed line). Image credits: B. Dousteysier. D)  
 191 Depth model of the clayey infilling of the Lac du Puy basin (Mayoral and Depreux, 2017) with location of core COR13-4 and  
 192 cross-section shown in F. Clayey infilling is thicker in red areas. No data are available on the today water body and its  
 193 drainage (central part of the basin). E) Profile section corresponding exactly to core COR13-4. F) Stratigraphic cross-section  
 194 of the Lac du Puy, modified from Mayoral et al. 2018. G) Chrono-stratigraphic synthesis of the Lac du Puy pedosedimentary

195 sequence, including stratigraphic information, radiocarbon dates, archaeological remains, and relative location of COR13-4  
196 in the sequence.

## 197 **2-Materials and Methods**

198

### 199 ***Coring and pedo-sedimentary description.***

200 Coring was performed in the basin in November 2012 following a hand auger survey, using a Geotool  
201 GTR 790 corer (diameter of 7 cm, for location see Fig. 1D). Half of the obtained 186 cm core (COR13-  
202 4) was used for palynological analysis and radiocarbon dating (see Ledger et al., 2015 for details). In  
203 the summer of 2015 geoarchaeological prospection based on geophysics and systematic trenching  
204 (Guillemoteau et al., 2016; Mayoral and Depreux, 2017; Mayoral et al., 2018) confirmed that COR13-  
205 4 was representative of the complete natural pedo-sedimentary sequence of the Lac du Puy, with  
206 limited or no truncation (Fig. 1F & G). The remaining half was used for multi-proxy geoarchaeological  
207 analyses which are described in the present study: sampling and pedosedimentary description were  
208 performed in laboratory using a Munsell color chart (see Log in Fig.2, for detailed description see  
209 Table 3 in Appendix). Detailed laboratory descriptions and macro observations were correlated with  
210 exhaustive field description of stratigraphic units and pedo-lithofacies of the basin, already  
211 established from exposures and logs (Mayoral et al., 2018).

### 212 ***Construction of chrono-stratigraphic framework***

213 Radiocarbon dates from previous studies were inform the COR13-4 core and a series of stratigraphic  
214 sections across the basin (Table 1). Dates 1-6 are in COR13-4 core and dates 7-11 in a stratigraphic  
215 log in the centre of the basin (Log 4). Dates 7 and 8, taken in SU2 base (interpreted as anthropogenic  
216 backfill, see introduction), were inconsistent with the well-established typo-chronological dating of  
217 this unit (100-40 to 50-30 BCE) and were then rejected (see Mayoral et al. 2018 for details). Dates 12  
218 and 13 were on a small ditch excavated in SU5A. Finally, dates 14-19 were at the base of storage pits

219 dug through SU5A and Weathered Basalt (WB), except date 15 which was in the infilling of a pit  
220 (SU4).

221 Dated materials include bulk sediment (11 samples), macrocharcoal (>125 $\mu$ m, 2 samples),  
222 microcharcoal (<125 $\mu$ m, 3 samples) and pollen (1 sample). Of the dated materials macrocharcoal can  
223 be considered the most accurate, whereas microcharcoal and pollen often show larger age  
224 discrepancies (relative to their stratigraphic position) owing to reworking of sediment. While bulk  
225 sediment is notoriously unreliable owing to uncontrolled ageing due to the contamination by older  
226 carbon (e.g. Grimm et al., 2009), but introduction of younger organic material can also distort  
227 radiocarbon dates. To assess potential reservoir effects or disturbance by pedological processes  
228 some of the dates were paired (dates 1-2, 3-4 and 9-10).

229 Given the scattering of dates, the possibility of sharp changes in accumulation rate and lateral  
230 variability of facies, and possible contaminations or reservoir effects, we used a broad chronological  
231 approach based on the assignment of radiocarbon dates to a SU, and when possible, to a part of this  
232 SU (base, middle or top, see Table 1). Well-dated archaeological levels or structures with a clear  
233 stratigraphic position were also used, such as archaeological layers from the Late Bronze Age 3 (950-  
234 800 BCE), La Tène D1B-D2A (100-40 BCE) and La Tène D2B to Gallo-Roman (50-30 BCE) (Mayoral et  
235 al., 2018). For a graphic summary of the relative stratigraphic positions of all available radiocarbon  
236 dates and archaeological landmarks, see Fig. 1G.

237 The seventeen AMS radiocarbon dates were calibrated with Calib 7.0 using Intcal 13 (Stuiver and  
238 Reimer, 1993; Reimer et al., 2013), and their probability distribution was plotted using CLAM  
239 (Blaauw, 2010). The obtained plot was then integrated with litho-stratigraphic and archaeological  
240 data following the assignment of dates to SUs. The resulting chrono-stratigraphic diagram proposes a  
241 maximum age-range for each SU of COR13-4, which can be used as a robust chronological framework  
242 to discuss multi-proxy data (Fig. 2).

243

| Nº | Loc. (Depth / Position)  | Position in SUs    | Lab. code          | Material             | 14C yr. BP       | Cal. BP (2σ)     | Cal. BCE/CE (2σ)     |
|----|--------------------------|--------------------|--------------------|----------------------|------------------|------------------|----------------------|
| 1  | COR13-4 (54-57 cm)       | Top of SU3         | Beta-379416        | Microcharcoal        | 2240 ± 30        | 2340-2155        | 390-205 BCE          |
| 2  | COR13-4 (54-57 cm)       | Top of SU3         | Beta-379417        | Bulk sed.            | 1990 ± 30        | 1998-1879        | 48 BCE-CE 71         |
| 3  | COR13-4 (71-72 cm)       | Top of SU4         | Beta-377232        | Bulk sed.            | 2590 ± 30        | 2769-2705        | 819-755 BCE          |
| 4  | COR13-4 (71-73 cm)       | Top of SU4         | Beta-379418        | Pollen               | 2750 ± 30        | 2894-2773        | 944-823 BCE          |
| 5  | COR13-4 (87-88 cm)       | Middle of SU4      | Beta-375785        | Bulk sed.            | 3510 ± 30        | 3866-3699        | 1916-1749 BCE        |
| 6  | COR13-4 (102-103 cm)     | Base of SU4        | Beta-379419        | Bulk sed.            | 3330 ± 30        | 3638-3478        | 1688-1528 BCE        |
| 7  | <i>Log L4 (43-47 cm)</i> | <i>Base of SU2</i> | <i>Beta-434187</i> | <i>Microcharcoal</i> | <i>5550 ± 40</i> | <i>6407-6289</i> | <i>4457-4339 BCE</i> |
| 8  | <i>Log L4 (43-47 cm)</i> | <i>Base of SU2</i> | <i>Beta-430610</i> | <i>Bulk sed.</i>     | <i>1430 ± 30</i> | <i>1375-1293</i> | <i>575-657 CE</i>    |
| 9  | Log L4 (59-63 cm)        | Base of SU3        | Beta-434188        | Microcharcoal        | 2390 ± 30        | 2492-2347        | 542-397 BCE          |
| 10 | Log L4 (59-63 cm)        | Base of SU3        | Beta-430611        | Bulk sed.            | 2340 ± 30        | 2440-2316        | 490-366 BCE          |
| 11 | Log L4 (87-91 cm)        | Base of SU4        | Beta-430612        | Bulk sed.            | 3130 ± 30        | 3407-3250        | 1457-1300 BCE        |
| 12 | Ditch (base)             | SU5A/WB (indet.)   | Beta-418695        | Macrocharcoal        | 5650 ± 30        | 6496-6344        | 4546-4394 BCE        |
| 13 | Ditch (middle)           | SU5A/WB (indet.)   | Beta-418694        | Macrocharcoal        | 5650 ± 30        | 6496-6344        | 4546-4394 BCE        |
| 14 | Pit 25604 (base)         | SU5A/WB (indet.)   | Poz-74925          | Microcharcoal        | 5520 ± 40        | 6403-6277        | 4453-4327 BCE        |
| 15 | Pit 25604 (fill)         | SU4 (indet.)       | Beta-425790        | Bulk sed.            | 3430 ± 30        | 3826-3593        | 1876-1643 BCE        |
| 16 | Pit 25677 (base)         | SU5A/WB (indet.)   | Beta-425426        | Bulk sed.            | 6130 ± 30        | 7158-6942        | 5208-4992 BCE        |
| 17 | Pit 25703 (base)         | SU5A/WB (indet.)   | Beta-425787        | Bulk sed.            | 5240 ± 30        | 6176-5921        | 4226-3971 BCE        |
| 18 | Pit 25699 (base)         | SU5A/WB (indet.)   | Beta-425788        | Bulk sed.            | 4780 ± 30        | 5591-5469        | 3641-3519 BCE        |
| 19 | Pit 25610 (base)         | SU5A/WB (indet.)   | Beta-425789        | Bulk sed.            | 5640 ± 30        | 6491-6322        | 4541-4372 BCE        |

245 **Table 1.** Radiocarbon database for the Lac du Puy used to build the chrono-stratigraphic framework (Fig.2), all dates have  
 246 been previously published in Ledger et al. 2015 and in Mayoral et al. 2018. *Dates 7 & 8 were rejected on a stratigraphic*  
 247 *basis (italic).* Dates are given in BCE/CE system (Before Common Era/Common Era). Microcharcoal: <125µm,  
 248 Macrocharcoal: >125µm. Dates have been placed in their stratigraphic context on Fig 1G.

### 250 **Micromorphological analysis**

251 The half-section of COR13-4 core between 40 and 144 cm was cut in 10 blocs (9 to 12.5 cm length, 7  
 252 cm width). Micromorphological thin sections were prepared from these blocks at Ghent University  
 253 (B). Descriptions of thin sections from macro- to microscale were performed with a Leica M80

254 binocular microscope (x2.5 to x60), a Leica DMLP polarizing microscope (x16 to x400), and a Leica DM  
255 2500M (x500). A Leica built-in camera was used to take microphotographs and measurements.  
256 Minerals and alteration were identified and described following petrography references (MacKenzie  
257 et al., 1982; Delvigne, 1998; Loaiza et al., 2015). Micromorphological features were semi-  
258 quantitatively described and recorded, according to reference works (Bullock et al., 1985; Stoops,  
259 2003; Loaiza et al., 2015; Macphail & Goldberg, 2018). Interpretation was based on international  
260 standards (Nicosia and Stoops, 2017; Stoops et al., 2010a). The reconstruction of the pedo-  
261 stratigraphic sequence and the pedo-sedimentary processes is based on a hierarchical approach of  
262 pedofeatures (Fedoroff and Courty, 2002; Fedoroff et al., 2010).

### 263 ***Geochemistry and Magnetic Susceptibility***

264 The geochemistry of the COR13-4 core was analyzed using an AVAATECH XRF core-scanner at  
265 EDYTEM laboratory (Université Savoie Mont-Blanc, F). The core was analyzed at a resolution of 10  
266 mm under 10 Kv and 30 Kv beams generated by a rhodium anode, providing results in counts per  
267 second (cps) for 24 elements. A Principal Component Analysis (PCA) was performed on selected  
268 elements using XLSTAT software, in order to bring to light relationships between elements and with  
269 sedimentary units of the infilling (Birks & Birks, 2006 ; Sabatier et al., 2010 ; Bajard et al., 2015). On  
270 this base, elements and ratios were selected as palaeoenvironmental proxies and interpreted.

271 The Magnetic Susceptibility (MS) of the core was measured (unit:  $SI \cdot 10^{-5}$ ) using a Bartington MS2E  
272 susceptibilimeter. Four measurements were taken each cm and the mean value was retained in  
273 order to integrate signal variability (Dearing, 1999). Measurements were focused on the clayey  
274 sedimentary matrix avoiding coarse basaltic particles, because their strong magnetic properties  
275 obscured the sedimentary signal.

## 276 **3-Results**

### 277 **3.1-Stratigraphic Units and chrono-stratigraphic framework**

278 Seven Stratigraphic Units (SU) were identified in COR13-4, consistent with those described in the  
279 basin infilling by previous works (see Introduction, and Fig. 1E & G; for detailed pedo-  
280 sedimentological description at the scale of the basin see also Mayoral et al., 2018). Several subunits  
281 were detected within these SU, drawing a more detailed stratigraphy for SU4, 5A, 6A and 6B (see log  
282 in Fig. 2, see also Table 3 in Appendix for detailed description of COR13-4).

283 The chronostratigraphic framework in Fig. 2 includes radiocarbon dates belonging to three SU (SU5A,  
284 SU4, SU3) and archaeological data at the contacts between SU4-SU3, SU3-SU2 and SU2-SU1. From  
285 these data, the chronology of SU1, SU6A and SU6B can only be estimated. Furthermore, caution  
286 must be exercised in interpreting the chronology of SU5A which was established from data drawn  
287 from multiple profiles. In the case of the Lac du Puy sequence, a reservoir effect due to old lithogenic  
288 carbon is unlikely for bulk radiocarbon samples: the geology of the basin includes exclusively volcanic  
289 materials such as basalt and scoria (Mayoral et al., 2018) which are not prone to release significant  
290 quantities of lithogenic carbon in the sedimentary environment. However, the pedogenic nature of  
291 this relatively short sedimentary sequence suggests that bulk could be subject to contamination from  
292 upper levels due to pedoturbation. From a macroscopic perspective, SU3, 4 and 5A seem not have  
293 been subject to major disturbance, but the action of rootlets, cracks due to posterior vertisolization  
294 processes or other pedogenic sedimentary inputs is not easily discernible (Mayoral et al., 2018).

295 A detailed analysis of the paired dates on same samples (1-2, 3-4, 9-10) shows that bulk sediment  
296 provides slightly younger ages than microcharcoal or pollen. This could be due to a limited  
297 incorporation of modern carbon from above, but microcharcoal and/or pollen could also have a small  
298 reservoir effect (Ledger et al., 2015). This is especially the case with paired dates at the top of SU3 (1-  
299 2): bulk seems slightly too young respect the corresponding archaeological landmark (100-40 BCE),  
300 whereas microcharcoal is slightly too old. When comparing other paired dates, such as at the top of

301 SU4 (3-4) with archaeological landmarks (950-800 BCE), it appears that both bulk and pollen dates  
302 can be considered reliable. A similar case is evident for paired dates 9-10 at the base of SU3. Bulk  
303 dates therefore appear more reliable in SU4 (massive gleysol) than in SU3 (especially towards its top),  
304 maybe due to vertisolization processes in the unit and posterior disturbance related to SU2 (Mayoral  
305 et al., 2018). Bulk dates 6 and 11 in SU4 are then considered as broadly correct.

306 Dates 5 and 15 are older than other SU4 dates and deserve detailed analysis: nº 5 is clearly too old  
307 considering its position at 87-88 cm in the middle of SU4 (Fig.2, Table 3). A potential cause for this  
308 would be lateral erosion of unit SU4b (see Fig 1.), bringing to the centre of the basin pedogenic  
309 materials which could include some older carbon. Date 15 corresponds to the infilling of a storage pit  
310 after its abandonment (600-425 BCE), certainly using SU4 sediment extracted when digging a new  
311 neighboring pit (Mayoral et al. 2018). In the process older or younger carbon could have been  
312 incorporated, but the date is nevertheless roughly consistent with others in SU4.

313 The situation is more complicated in SU5A. Here, a comparison of dates 12 and 13 (macrocharcoal)  
314 from two levels of a structure dug in this SU, with quasi-identical date 14 (microcharcoal) and slightly  
315 younger date 19 (bulk), both from adjacent levels, indicates that bulk dating is relatively accurate in  
316 SU5A. Therefore dates 16, 17 and 18 can also be considered as broadly correct. However, these dates  
317 are all situated in profiles where SU5A is in gradual transition with underlying WB, and both are  
318 almost always difficult to distinguish. Dates 16-18 therefore cannot be considered an "exact" age of  
319 SU5A, but rather provide an indicative *terminus post quem* (TPQ) and *terminus ante quem* (TAQ) for  
320 its long-term formation since first weathering stages of basaltic bedrock, a process probably initiated  
321 in early phases of the evolution of the basin from a pseudo-sinkhole (Mayoral et al., 2018).

322 In light of this uncertainty and the high lateral variability in stratigraphy, a direct transposition of  
323 these SU5A/WB dates to SU5A in core COR13-4 is inadvisable. Particularly given the presence of the  
324 underlying SU6A/B, which was absent in a majority of the dated profiles. Indeed, translocation of  
325 dates from elsewhere in SU5A to COR13-4 would imply ages older than 4.5-5 kyr. cal. BCE for the



326 lower part of the palynological sequence (see Fig. 1). This would be in marked disagreement with  
327 pollen data and with well-known regional vegetation history. Indeed, assemblages from the base of  
328 COR13-4 (Ledger et al., 2015) are clearly coherent with a landscape typical of the Mid/Late Holocene  
329 boundary in the Auvergne region, which is characterized by recognizable vegetation dynamics such  
330 as rarefaction of *Tilia* pollen frequencies, absence of *Ulmus* and increasing trends of *Abies* and *Fagus*  
331 values, amongst other significant taxa (Trément et al., 2007; Miras et al., 2018).

332 This apparent 2000 yr mismatch between radiocarbon dates and vegetation history is undoubtedly  
333 related to the complex chrono-stratigraphic relation between SU5A/WB and SU6A/B. These  
334 stratigraphic ensembles are at the same time in lateral transition and overlaid depending on the  
335 previous (and irregular) topography (see Fig 1). This indicates that SU5A is non-isochronous, but  
336 rather temporally- and spatially-transgressive. The development of SU5A was likely dependent on  
337 topography, in a context of differentiated micro-scale sedimentary environments in high- and low-  
338 relief areas of the basin. In this scenario, a first stage SU5A would have formed slowly on WB in  
339 higher areas, whereas SU6A/B deposited simultaneously in lower areas. In a second phase SU6A/B  
340 inputs decreased or eventually ceased, and SU5A extended to lower areas overlying them. In later  
341 stages (after SU5 deposition) the basin was leveled by sedimentary accumulation and chrono-  
342 stratigraphy becomes significantly more uniform (Fig. 1). The temporal envelope provided by  
343 radiocarbon dates in SU5/WB in high-topography areas corresponds not only to SU5A in the lower  
344 areas where COR13-4 is located, but probably also to SU6A/B.

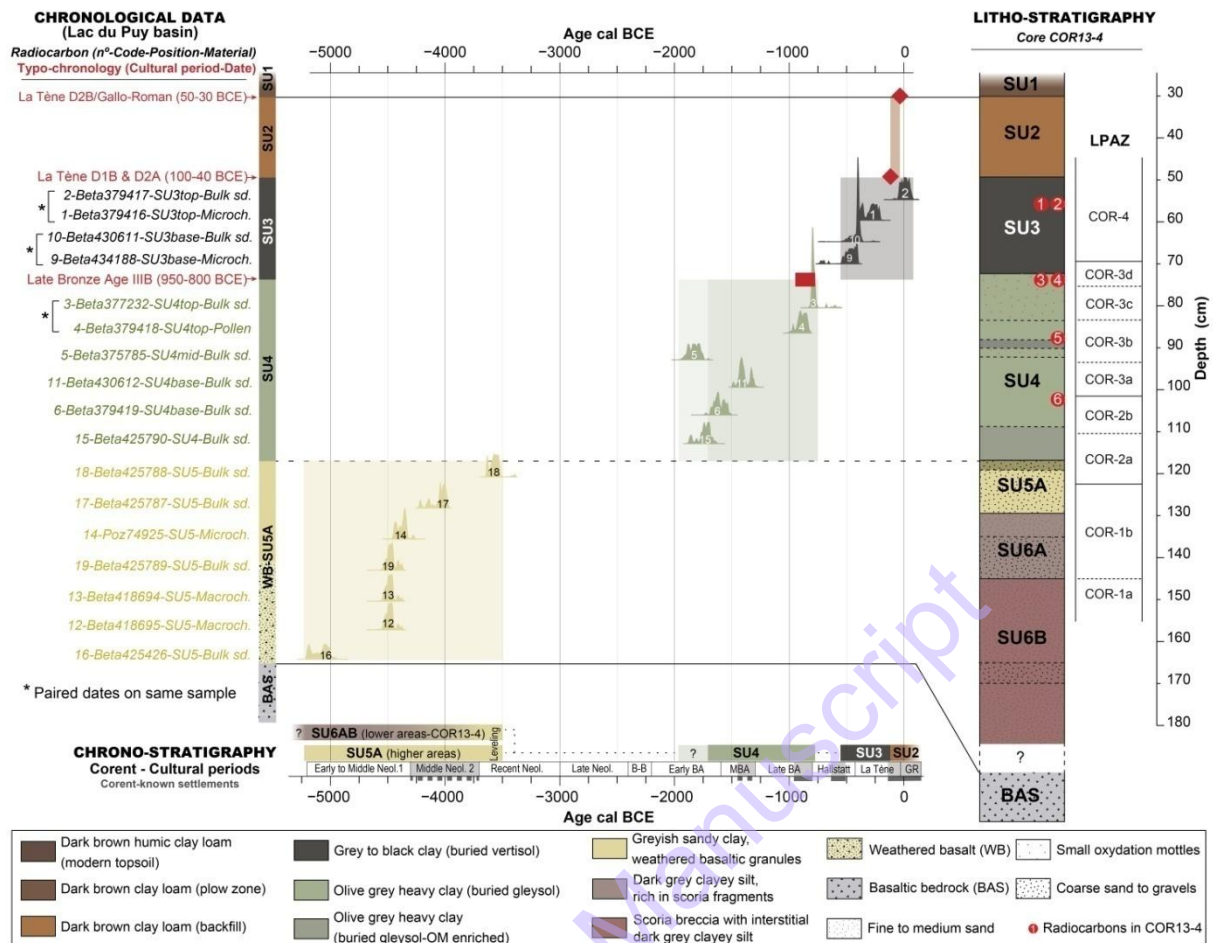
345 As a consequence, the younger date obtained in SU5A (n°18) is a reliable TAQ for its deposition in  
346 both low and high areas of the basin, and also for SU6A/B. The older date obtained in SU5A (n°16)  
347 must be contemporary with the first weathering stages of basalt in high-topography areas of the  
348 basin, and is likely close to the age of the base of SU6A/B in contact with the bedrock in low-  
349 topography areas. Despite its uncertainties and limitations, this refined chrono-stratigraphic

350 interpretation of basal units of the pedo-sedimentary sequence satisfactorily incorporates  
351 radiocarbon, stratigraphic and palynological evidence.

352 Ultimately, integration of all the radiocarbon assays with archaeological data allowed to constrain  
353 the maximum age ranges for SUs 6A/B, 5A, 4 and 3 in COR 13-4 (Fig.2, down) which will be used to  
354 discuss multi-proxy data in this core. The inception of SU6A/B is unclear, although it is likely around  
355 5200 cal. BCE. Its deposition is followed by SU5A until 3500 cal. BCE. SU4 dates range from 2000 to  
356 800 cal. BCE approx., however considering that dates 15 and 5 could be subject of reservoir effect  
357 the interval 2000-1700 to 800 cal. BCE is proposed in order to integrate this uncertainty. SU3 age  
358 ranges from 500 cal. BCE approx. to 100-40 BCE. SU2 age, exclusively from archaeological data, is  
359 dated between 100-40 and 50-30 BCE. Two major hiatus or very slow sedimentation periods are  
360 outlined between 3500 and 2000-1700 cal. BCE, and between 800 and 500 cal. BCE.

361 This chrono-stratigraphic framework highlights the non-linear nature of the sedimentary chronology  
362 in COR13-4 and nuances previous age-depth model used for palynological analysis, which included  
363 only 6 dates and was very imprecise for SU5A and 6A (Ledger et al., 2015). Only minor changes affect  
364 upper units (SU2, 3, 4), which are now better constrained, especially the base of SU3 (c.500 cal. BCE,  
365 implying a short hiatus after the top of SU4) and SU4 (c. 2000-1700 cal. BCE) which are both slightly  
366 younger than previously estimated. By contrast, SU5A and SU6A/B appear slightly older (c. 5200–  
367 3500 cal. BCE). Considering this, chronology of previous data (Ledger et al., 2015; Mayoral et al.,  
368 2018) for these SUs was revised in the discussion. The apparent hiatus between 3200 and 2000-1700  
369 cal. BCE (Fig. 2) is certainly due to a very low sedimentation phase between the top of SU5A and the  
370 base of SU4A.

371



372  
 373 **Figure 2.** Chrono-Stratigraphic framework for Stratigraphic Units in COR13-4. Chronological data (probability distribution of  
 374 radiocarbon dates and archaeological landmarks, left) from all the Lac du Puy basin are correlated to the Stratigraphic Units  
 375 present in COR13-4 (right) and Local Pollen Assemblage Zones (LPAZ) from Ledger et al. (2015). Note that radiocarbons 1-6  
 376 are in COR13-4 itself. Relative position of dates in each SU is indicated when available (left). Dated material (bulk sediment,  
 377 microcharcoal, macrocharcoal or pollen) is also noted. Red rectangle and diamonds indicate archaeological tie points.  
 378 Chrono-stratigraphy resulting from the integration of dates grouped by SU and archaeological data (centre) is represented  
 379 as maximum age ranges for each SU (down). Note that SU5 is not isochronous between higher and lower areas of the basin  
 380 before its leveling. Note also the existence of chrono-stratigraphic hiatus or very low sedimentation phases (dotted lines).  
 381 Corent chrono-cultural periods follow Poux et al., 2018 (B-B: Bell-Beaker period, MBA: Middle Bronze Age, GR: Gallo-  
 382 Roman). Grey-shaded periods and grey lines indicate known settlements (dashed line: imprecise chronology or partial  
 383 evidence). For detailed description of Stratigraphic Units and subunits, and archaeological data, see Table 3 (Appendix), and  
 384 Mayoral et al. (2018).

385

386

## 387 **3.2 Micromorphology**

388

### 389 ***General features***

390 A detailed micromorphological description is synthetized in Table 2, and a gallery of outstanding  
391 features is shown in Figs. 3 to 5. The pedosedimentary sequence of the Lac du Puy is particularly  
392 complex due to the low accretion rate and the overlapping of successive pedological processes and  
393 features (gleyfication, vertisolization, illuviation, weathering, etc.) since the Neolithic. The coarse  
394 lithogenic fraction is strictly composed of volcanic materials such as basalt and scoria, given the  
395 limited lithology of the plateau (Bouiller, 1979 ; Greffier & Restituto, 1980 ; Nehlig et al., 2003 ;  
396 Mayoral et al., 2017). Chert or quartz occur as very small rock fragments (typically coarse silt to fine  
397 sand fraction) and in very small quantities, and can be difficult to distinguish from small plagioclases.  
398 These small lithogenic fragments are not native in the volcanic geology of the plateau, and can only  
399 derive from inputs related to human activities. They are therefore considered as indicators of  
400 anthropogenic influence. Micromass is composed of abundant smectitic matrix as indicated by  
401 noticeable macroscopic swelling, but also clayey domains organization and a typical yellowish color  
402 under microscope (Bullock et al., 1985; Loaiza et al., 2015). This matrix is often dotted with dark  
403 opaque particles sometimes difficult to identify, generally magnetite and microcharcoal (<125um) or  
404 small organic debris.

405 Larger organic features are uncommon and macrofaunal activity traces are extremely rare. Clusters  
406 of small channels with regular diameter (100-200µm) and smooth walls, sometimes digitated or in  
407 fork, are present in some layers. Studies dealing with these morphologies (Retallack, 2001; Kooistra  
408 and Pulleman, 2010) allowed us to identify them as traces of rootlet mats of grasslands. Silicified  
409 microfossils as phytoliths or sponge spicules (Fig. 4G) appear in some SUs: we interpreted them as  
410 indicators of grasslands and wet environments respectively following literature (Gutiérrez-Castorena

411 and Effland, 2010; Vrydaghs, 2017). Masses of translucent filaments, similar to fungal hyphae but  
412 much smaller (0.5µm diameter, see Fig. 3I), were identified as silicified *streptomyces*-type bacteria  
413 (e.g. Néraudeau et al., 2016; Néraudeau et al., 2017). Development of these bacteria requires  
414 aerobic conditions and abundant organic matter (Mayfield et al., 1972 ; Ringrose-Voase &  
415 Humphreys, 1994 ; Gutiérrez-Castorena & Effland, 2010), their presence was therefore interpreted as  
416 an indicator of surface horizons from a palaeosoil.

417 Pseudomorphs and alterorelics usually result from a high degree of minerals *in situ*-weathering (e.g.  
418 Fig. 3) and subsequent pedoplasation processes (Delvigne, 1998; Stoops and Schaefer, 2010). We  
419 interpreted them as an indirect indicator of strong alteration processes in the soil profile due to  
420 hydrological variability, drainage conditions or mechanical constraints (Fedoroff and Courty, 2002).

421 Weathering of scoria fragments in acid conditions is known to produce neoformation of aluminium  
422 silicate clays such as allophane coatings (AC) and infillings. This neoformation is characteristic of  
423 andic soils (Baize and Girard, 2008) and has already been described in the region (Jongmans, Van  
424 Doesburgl, & Van Breement, 1990; Anthony, 1990; Jongmans et al., 1991; Ringrose-Voase &  
425 Humphreys, 1994). However, the Lac du Puy pedosedimentary sequence does not include andic  
426 horizons (Mayoral et al., 2018): therefore we interpreted these features (Fig. 5H and I) as inherited  
427 from other soil profiles with andic features outside the basin. Additionally, small and rounded  
428 fragments of clay coatings (CC) and allophane coatings (200-300µm) are present throughout the  
429 sequence. Taken together, these indicators can be interpreted as evidence of the erosion of mature  
430 surrounding soils with andic properties. Indeed, even clay-rich volcanic soils are especially prone to  
431 runoff erosion when exposed to excessively dry or wet conditions, and especially under cultivation  
432 (Legrand et al., 2007).

433 Clay translocation is quasi ubiquitous in the pedosedimentary sequence, however it is much more  
434 complex in lower SUs. Various generations of clay coatings (CC) and clay infillings (CI) with different

435 characteristics can be observed (Table 2), indicating overlapping processes likely resulting from  
436 successive illuviation phases under different environmental conditions.

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|         |         |          |            |     |    |         |        |     |    |      |      |      |      |   |    |      |    |     |     |    |    |     |    |    |      |    |    |      |      |   |
|---------|---------|----------|------------|-----|----|---------|--------|-----|----|------|------|------|------|---|----|------|----|-----|-----|----|----|-----|----|----|------|----|----|------|------|---|
| 5a      | 125-115 | 25 to 50 | OP / DS P  | GPS | GR | SB      | WA -PS | *** | ** | *    | **** | **   | *    | * | -  | **** | ** | -   | *** | ** | PY | *   | ** | -  | **** | ** | ** | **   | **   | 1-Massive whitish Cl, poorly oriented, between granules 2-Very abundant CC and Cl whitish, in crescent, well laminated and oriented, sometimes dusty 3-Dusty brown CC in residual voids                       |
| 5a - 6a | 134-125 | 50       | DS P / SSP | GPS | GR | SB to F | WA -PS | *** | ** | **** | **** | **** | -    | - | ** | **** | *  | *** | *** | PY | ** | *   | *  | *  | **   | *  | *  | *    | **** | 1-Ubiquitous and massive CC and Cl between granules, poorly oriented, dotted 2-Several thin CC and Cl, crescent-laminated, limpid and well oriented 3-Dusty brown CC in residual voids with organic particles |
| 6a      | 144-134 | 50 to 66 | DS P / SSP | GPS | GR | SB to F | WA -PS | *   | *  | **   | **** | **** | **** | * | *  | **** | *  | **  | -   | PY | ** | *** | ** | ** | **   | ** | ** | **** | *    | 1-Very abundant thin whitish CC and Cl, between granules, not laminated neither oriented 2- Abundant thin whitish CC and Cl, limpid and laminated, moderately oriented  |

**Table 2. Detailed micromorphological descriptions of COR13-4. System:** Stoops 2003; **CF:** Coarse-Fine (boundary fixed at 20  $\mu\text{m}$ ); **Related Distribution:** OP: Open Porphyric; VOP: Very Open Porphyric; DSP: Double Spaced Porphyric; SSP: Single Spaced Porphyric; **Birefringence Fabric:** GPS: Grano-Porostriated; CS: Circular Striated; ST: Striated/Strial; **Microstructure:** SB: Subangular Blocky; AB: Angular Blocky; F: Fissural; GR: Granular; PR: Prismatic; WA: Well Aggregated; WS: Well Separated; PA: Poorly Aggregated; PS: Poorly Separated; MA: Moderately Aggregated; MS: Moderately Separated; **Pedofeatures and coarse fraction:** CCoats. or CC: Clay Coatings; Cl: Clay Infillings; A. Neof. : Neoformed Allophane; Frgts.: Fragments; Pedog. Aggr.: Pedogenic Aggregates; Qtz.: Quartz; Pseud. (B): Black pseudomorph; Pseudom. (R): red pseudomorph; coats.: coatings; hypocoats. : hypocoatings; Nods. : nodules; **Colors:** PY: Pale Yellow; GY: Greyish Yellow; YG: Yellowish Grey. **Abundance symbols:** no symbol: absence; - Rare; \* Few; \*\*Several; \*\*\*Abundant; \*\*\*\*Very abundant.

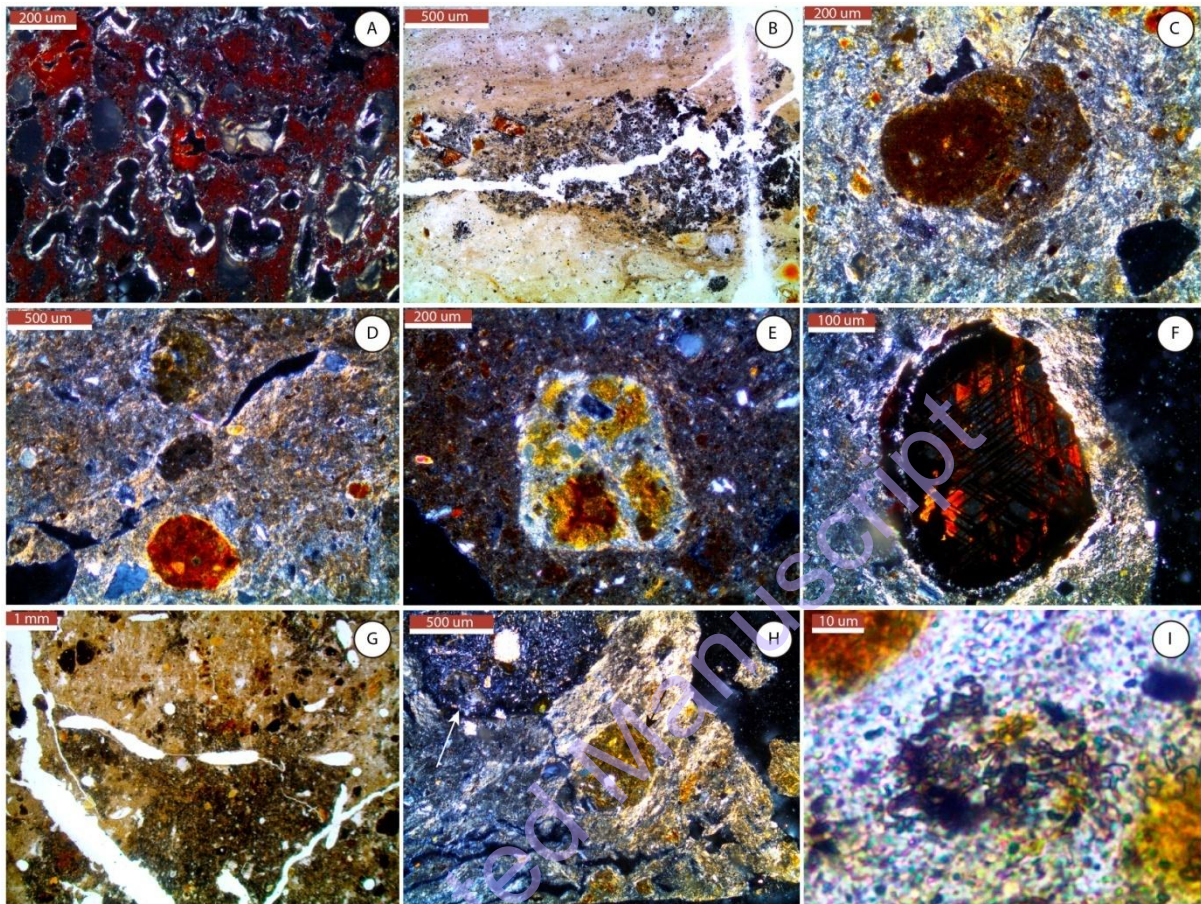


445 Iron and manganese pedofeatures are ubiquitous throughout the sequence (see Table 2, and Figs. 3  
446 to 5). Each type of these features indicate different redox conditions (Kovda & Mermut, 2010 ;  
447 Lindbo, Stolt, & Vepraskas, 2010), therefore we used their variability to infer redox changes in the  
448 sequence.

449 Pedogenic disorthic to anorthic aggregates are also abundant in all the SUs (see Figs. 3 to 5), and can  
450 be roughly grouped in five types (A,B,C,D,E) defined as following: A) Reddish nodules, impregnated  
451 with Fe oxides, seem to be the result of local redox processes and can be found in all the SUs; B)  
452 Large, irregular, brownish nodules, with abundant organic fragments, come likely from upper  
453 superficial units, i.e. SU2 or SU1 (brown humic clay, see Fig. 2) and are translocated in underlying US3  
454 and 4; C) Smectitic nodules, with abundant bright clayey domains and highly similar to SU4 matrix,  
455 come certainly from this unit (SU4); D) Greyish rounded aggregates form the matrix of lower units  
456 (SU5a and 6a). Their micromass, rich in microcharcoal, organic fragments and feldspar (Fig. 5)  
457 suggests that they result from erosion of former organo-mineral horizons, belonging to the soils of  
458 the plateau surrounding the pond. Amongst these, some (E) are particularly rich in organic micro-  
459 debris and charcoal, giving them a dark brown color and a relatively humic aspect.

460 All these anorthic or disorthic pedogenic aggregates in the profile, except those from SU5A and 6A,  
461 are reworked downwards due to vertisolization processes. In general terms vertisolization affects  
462 SU2 to 4 as indicated by prismatic macro-structure, grano-porostriation of the fine clay matrix, mixed  
463 and phytolith-rich matrix and ferromanganic nodules (Kovda and Mermut, 2010), however several  
464 phases could be superimposed due to these layer-crossing processes. To disentangle this complexity  
465 the established nodule types were used, as several are original from one specific layer. When  
466 appearing downwards in older layers, they served as *Terminus Post Quem* for a given vertisolization  
467 phase. Their vertical distribution in the profile allowed then to distinguish in relative chronological  
468 order several vertisolization phases. However, when nodules appeared in levels younger than their

469 original layer, they were rather interpreted as indicators of lateral erosion from nearby areas  
470 (Fedoroff et al., 2010).



471  
472 Figure 3. Micromorphological features common in all the pedosedimentary sequence of the Lac du Puy. A: scoria with  
473 allophane hyaline coatings in rock vesicles. The coatings, neoformed as a weathering product, are microlaminated and  
474 well oriented (SU6a, XPL). B: Black-colored scoria fragment with its left part strongly weathered, in process of  
475 pedoplasmation (alterorelic). Note several pseudomorphs and an abundant clay matrix, probably in part neoformed (SU5a,  
476 PPL). C: Polyphased pedogenic aggregate, made of A-type reddish nodule embedded in a B-type greyish-brown nodule,  
477 both anorthic in a grano-porostriated clayey matrix (SU4, XPL). D: Variety of A- and B-type pedogenic aggregates, all  
478 anorthic in a grano-porostriated clayey matrix (SU4, XPL). E: C-type smectitic aggregate from SU4, anorthic in the clayey  
479 matrix of SU2 (XPL). F: Pseudomorph in *boxwork*, probably from hornblende, with strong peripheral grano-porostriation  
480 (SU3, XPL). G: abundant small channels (rootlets) and dark mass composed by *streptomyces*, marking an aerobic palaeosoil  
481 level (SU4, PPL). H: Basalt fragment (white arrow) and moderately iron impregnated A-type nodule (black arrow), disorthic to  
482 anorthic, in a grano-porostriated matrix (SU3, XPL). I: zoom into a *streptomyces* cluster, in the micromass. Note the small  
483 diameter (0.5 to 1µm) of filaments (SU4, PPL).

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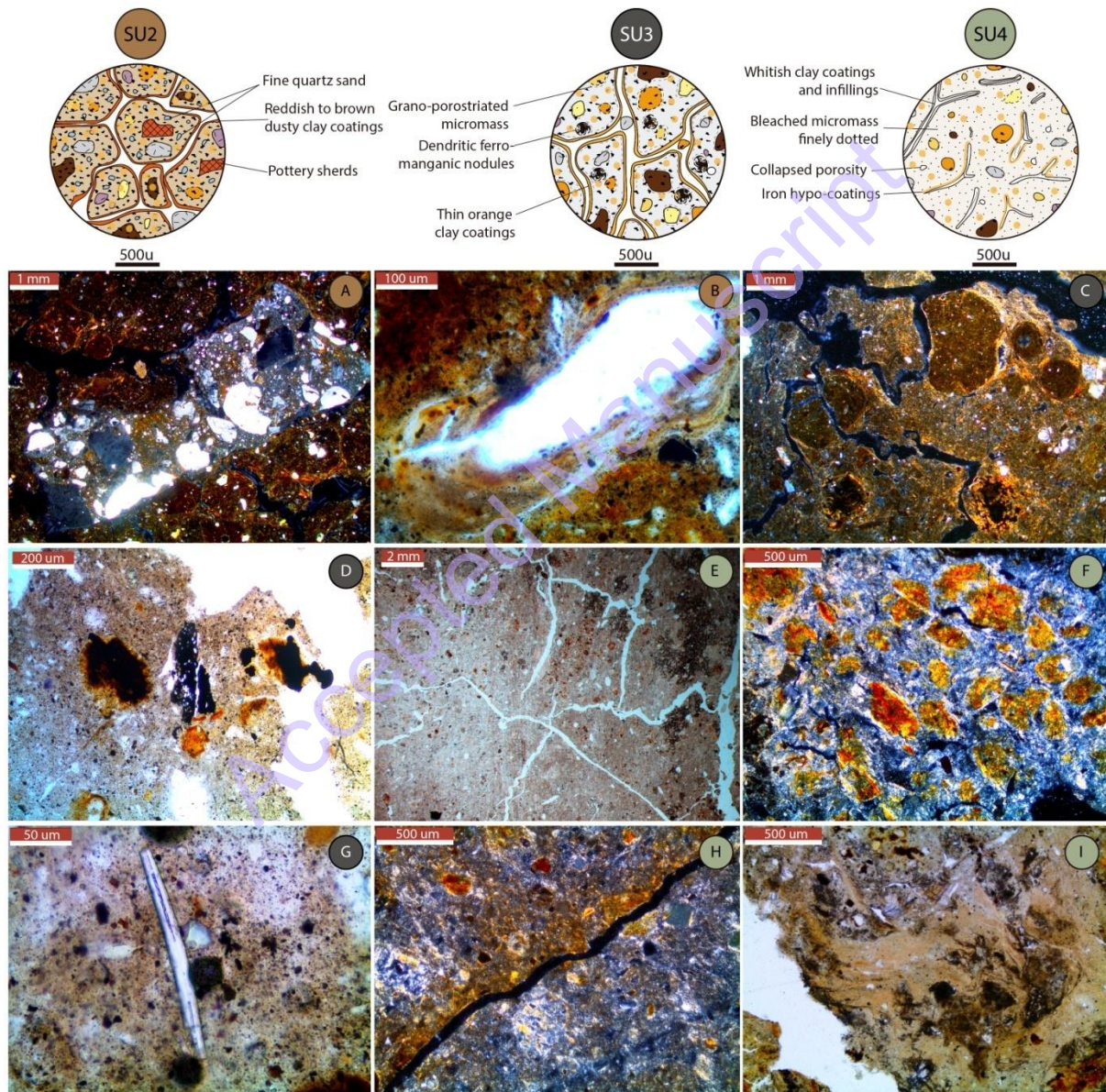
486 **Processes and hierarchy**

487

488 After identification, micromorphological features have been grouped and interpreted as processes

489 affecting one or more SUs, and finally organized in a relative chronology based on hierarchy concept

490 (Fedoroff et al., 2010), presented on Fig. 6.



491

492 Figure 4. Micromorphological features of SU2 (brown labels), SU3 (black labels) and SU4 (green labels). A: pottery fragment,

493 note pedogenic nodules around the fragment, the reddish thin CCs and the abundance of small feldspar or quartz crystals

494 (SU2, XPL). B: Laminated and very dusty CC in a channel void (SU2, PPL). C: Anorthic B-type pedogenic nodules (central and

495 upper parts of the picture) and two orthic ferromanganese nodules (lower part of the picture), with peripheral grano-

496 porostriation (SU3, XPL). D: Macrocharcoal and ferromanganese nodules impregnated in the groundmass (SU3, PPL). E:

497 Blocky Angular to subangular microstructure, with poorly developed intrapedal porosity. The micromass is clayey, yellowish  
498 to grayish, dotted with organic microdebris, microcharcoal, and opaque volcanic minerals. Note also reddish Fe mottles and  
499 dark *streptomyces*-impregnated areas. (SU4, OIL). F: Iron impregnated nodules (A-type, *in situ*) in a very clayey, smectitic  
500 matrix with low first-order birefringence (SU4, XPL). G: Sponge spicule in a yellowish-grayish and densely dotted  
501 (microcharcoal, organic debris, volcanic minerals) clayey micromass (SU3, PPL). H: Diffuse iron hypocoating of a planar void.  
502 Note the clay-rich micromass with Fe mottles, bright oriented clay domains, and dotted with organic microdebris and  
503 microcharcoal. (SU4, XPL). I: massive illuviation (infillings) of the structural (inter-aggregate) porosity by fine clay (beige  
504 areas). Dark areas are *Streptomyces* masses developed on preexisting aggregates (SU4, PPL).

505

#### 506 ***SU6A and SU5A***

507 Micromorphological results show that SU5A and 6A have highly similar composition and  
508 microstructure, and are mainly differentiated by post-depositional processes. Blocky subangular  
509 microstructure, overlaid to a granular microstructure exclusively composed by stacked greyish  
510 aggregates (D- and E-type) and coarse mineral fraction (Table 2, Fig. 5) suggests soil re-aggregation  
511 after deposition of granules and coarse fraction by intense and concentrated hydrosedimentary  
512 fluxes (Fedoroff et al., 2010; Stoops et al., 2010b).

513 Volcanic minerals in these granules are strongly degraded (presence of pseudomorphs and hyaline  
514 allophanes), causing a differential enrichment in plagioclase probably due to long-term weathering  
515 (Delvigne, 1998 ; Stoops & Schaefer, 2010), which can be interpreted as a result of prolonged  
516 pedogenic evolution. Some of these pedogenic aggregates (E-type) have dark brown micromass, very  
517 rich in small organic fragments and microcharcoal, suggesting an origin in organo-mineral or in humic  
518 soil horizons.

519 With these evidences, SU6A and 5A can be interpreted as pedosediment, *i.e.* the resulting deposit of  
520 erosion of upper and middle horizons of mature andic soils from the lower and upper parts of the  
521 plateau, transported to the basin by concentrated hydro-sedimentary fluxes as small and rounded  
522 pedogenic aggregates. Erosion of these upper horizons was probably followed by dismantling of

523 deeper horizons (presence of anorthic papules in SU5A), indicating progressive erosion and land  
524 degradation on the plateau.

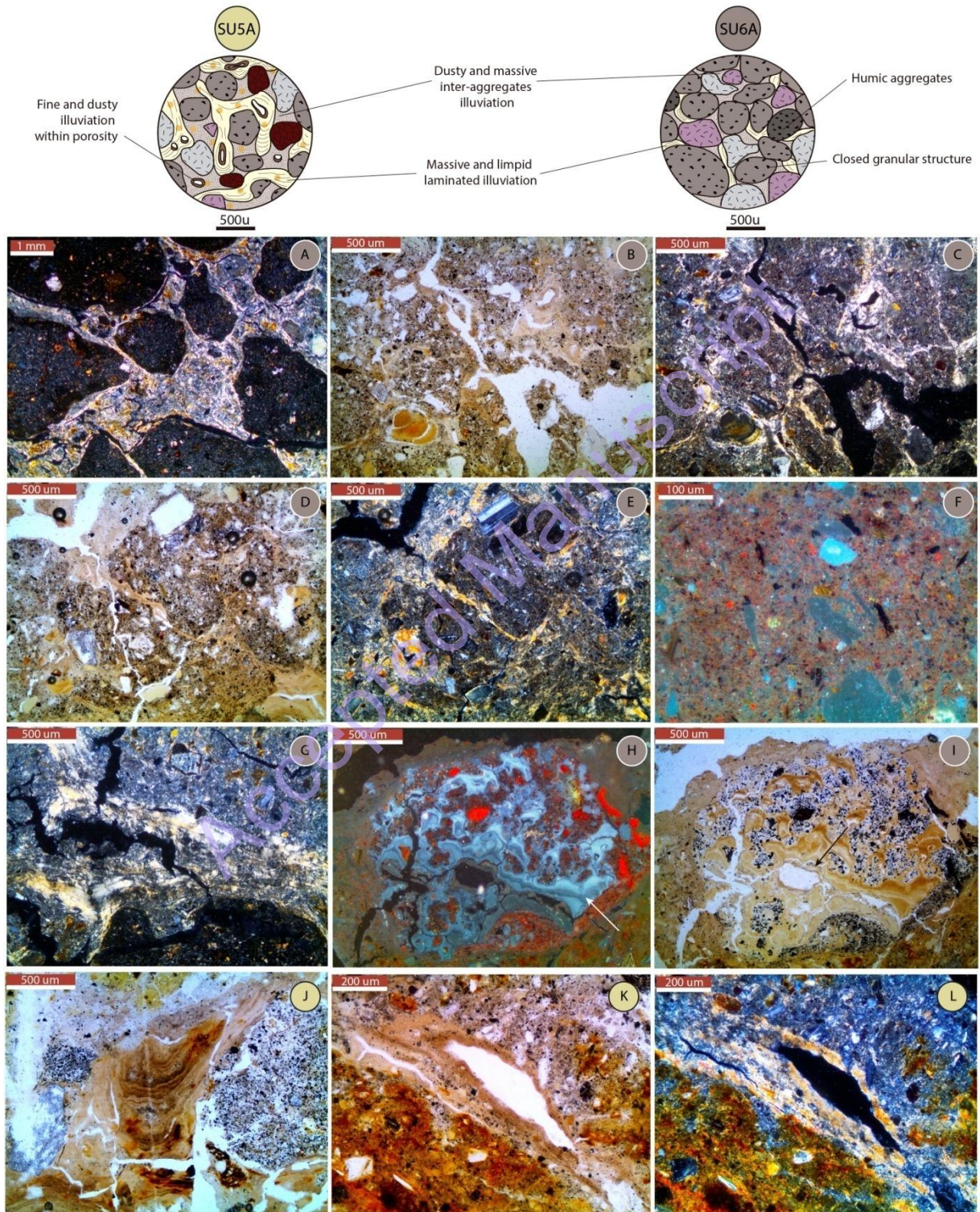
525 Organic microparticles (mainly microcharcoal, <125 $\mu$ m) are especially abundant in granules at the base  
526 of SU6A, and are associated to macrocharcoal (>125 $\mu$ m) which are indicative of local fires (Deák et  
527 al., 2017). This, together with the presence of chert and quartz subangular microfragments at the  
528 base of SU6A, indicate anthropogenic activity in these eroded soils around the basin.

529 Furthermore, the coarse fraction in SU6A and 5A shows a marked weathering gradient towards the  
530 top of SU5A. Indeed, the abundant weathered scoria fragments (alterorelics) are much more  
531 disaggregated and their pedoplasation is generally more advanced upwards. This indicates that  
532 deposition of pedosediment and soil re-aggregation (see above) was followed by post-depositional *in*  
533 *situ*-weathering and pedoplasation processes affecting especially SU5A and the base of SU4 (Fig. 8).  
534 This evidence supports the development of a well-drained and stable palaeosoil level when  
535 sedimentary inputs ceased (see also SU4 analysis below).

536 Illuviation is abundant and complex in SU6A and 5A, with three main phases (see Table 2, Fig. 6 and  
537 Fig. 5B-E, G, and J-L) affecting both units. A first illuviation concerns the base of SU5A and SU6A.  
538 Massive and poorly oriented CC and CI partially clogging the stacking voids of the pedosediment can  
539 be interpreted as syn-sedimentary "flood coatings". They are likely formed by a relatively fast  
540 downwards translocation of the fine fraction of the hydrosedimentary fluxes which deposited the  
541 granules (Brammer, 1971 ; Buurman, Jongmans, & PiPujol, 1998 ; Fedoroff & Courty, 2002 ; Kühn,  
542 Aguilar, & Miedema, 2010 ; Van Vliet-Lanoë, 2010).

543 The second generation of illuvial features, with abundant thin, well-oriented and microlaminated CC  
544 clog quasi completely remaining structural porosity in SU6A and especially in SU5A. Thin  
545 microlaminations of CC suggest stable, well-drained soil as it occurs for example under arboreal  
546 vegetation which controls illuviation (Fedoroff & Courty, 2002 ; Kühn, Aguilar, & Miedema, 2010 ;  
547 Sedov, Stoops, & Shoba, 2010 ; Van Vliet-Lanoë, 2010). Therefore it can be interpreted as a palaeo-Bt

548 horizon developed mainly in SU5A. This Bt horizon could be related with overlying palaeosurface  
 549 horizons, as found at the base of SU4 (see  
 550 below).



551

552 Figure 5. Micromorphological features of SU5A (yellow labels) and SU6A (purple labels). A : Basaltic coarse sand to gravel,  
553 subangular to rounded, in a clayey granoporostriated matrix (SU6A, XPL). B and D: Closed granular structure, formed by D-  
554 type pedogenic aggregates, and poorly separated due to posterior illuviation. Note the abundance of dark organic particles  
555 in pedogenic aggregates (SU6A, PPL). C and E: same areas in XPL, note high birefringence of clay coatings and infillings, and  
556 the relatively dark color of the D-type pedogenic aggregates rich in plagioclase. F: Micromass of a D-type pedogenic  
557 aggregate, rich in charcoal and in small reddish particles resulting from quasi-total weathering and pedoplasation of  
558 volcanic materials (SU6A, OIL). G: Massive clayey infilling, moderately laminated, limpid and well oriented, between a basalt  
559 fragment and a dark pedogenic aggregate (SU6A, XPL). H: Strongly weathered scoria granule, with reddish pseudomorphs  
560 and abundant bluish-grey neoformed hyaline allophanes (white arrow) in the vacuoles (SU6A, OIL). I: same granule in PPL,  
561 note opaque volcanic minerals, and fine and dusty layered illuviation in the center of the scoria fragment (black arrow) vs.  
562 limpidity of surrounding hyaline allophanes. J: microlaminated coating in crescent, between several basaltic fragments.  
563 Each lamination has sharper and darker base. Over imposed Fe-Mn impregnation occurs posteriorly (SU5A, PPL). K: Dark  
564 and dusty clay coating in residual interstitial porosity, formed within illuvial clays between two pedogenic nodules (SU5A,  
565 PPL). L: same area in XPL, note high birefringence of smectitic clays despite a poor orientation.

566 A third phase of illuviation consists in abundant thin, roughly laminated, brownish and very dusty CC  
567 deposited above the textural features of the precedent phases, but also in biogenic voids developed  
568 within them. These « dusty coatings » (rich in dark opaque microparticles, including microcharcoal  
569 and small organic debris, e.g. Fig. 5K and L) indicate soil disturbance, even disappearance of  
570 vegetation cover previously developed. They are often linked to agricultural activity (Jongerius, 1970  
571 ; Macphail, Courty, & Gebhardt, 1990 ; Adderley et al., 2010 ; Kühn, Aguilar, & Miedema, 2010 ; Deák  
572 et al., 2017), even if their interpretation remains complex and subject to controversy (Carter and  
573 Davidson, 1998; Davidson and Carter, 1998; Macphail, 1998; Usai, 2001; Fedoroff and Courty, 2002).  
574 Redox pedofeatures, mainly superimposed to illuvial features or developed in residual porosity,  
575 indicate relatively important phases of water saturation (Lindbo et al., 2010) and changing  
576 hydrological conditions after the last illuviation phase. This suggests a progressive drainage  
577 deterioration gradually leading to typical reductic conditions.

#### 578 **SU4**

579 Despite apparently homogeneous conditions at macroscopic level, micromorphological  
580 analysis revealed sharp vertical changes in microstructure and voids pattern throughout SU4. These  
581 changes are also noticeable in groundmass, coarse fraction and pedofeatures (see Table 2). Redox

582 pedofeatures show, in general terms, absence of ferric iron and persistence of saturated reducing  
583 conditions in all the SU4 (Lindbo et al., 2010), which can be interpreted as permanently high  
584 groundwater level. Superimposition of textural pedofeatures shows different phases of illuviation,  
585 whose characteristics (e.g. thin and limpid clay coatings) indicate that clay translocation process is  
586 generally weak and slow probably under dense vegetal cover (Fedoroff and Courty, 2002; Kühn et al.,  
587 2010). Based on micromorphological descriptions (Table 2), SU4 has clearly different characteristics  
588 in its lower (102-115 cm), central (80-102 cm) and upper (73-80 cm) sections.

589 Microstructure and redox pedofeatures of the lower section of the SU4 (102-115 cm, see Table 2)  
590 suggest weak and relatively short saturations (Fedoroff & Courty, 2002 ; Lindbo, Stolt, & Vepraskas,  
591 2010 ; Stoops, Marcelino, & Mees, 2010b). This indicates a relative degradation of porosity and  
592 drainage following SU5 well-drained conditions. Composition of coarse fraction (basalt and scoria)  
593 suggests sedimentary inputs resulting of relatively low-intensity soil erosion affecting extensively the  
594 plateau.

595 Weathering is moderate to strong in all the SU4, but is especially intense at its base (105-115 cm),  
596 with abundant and very disaggregated alterorelics of scoria fragments coming from the upper slopes  
597 of the plateau. This indicates very strong *in situ* chemical and/or mechanical weathering (Delvigne,  
598 1998), which appears to be a layer-crossing process affecting also underlying SU5A. The advanced  
599 state of pedoplasmation of these alterorelics suggests prolonged exposition to surface bio-climatic  
600 agents (Fedoroff and Courty, 2002). A dense *streptomyces* mass indicates well-drained, aerobic  
601 conditions. These elements support the interpretation of the base of SU4 (105-115 cm) as the upper  
602 horizon of a well-drained palaeosol level developing downwards into SU5A and 6A, which was  
603 certainly allowed by less detrital and wetter conditions in the basin.

604 Massive, limpid and poorly oriented CI indicate very strong illuviation under a stable surface with  
605 vegetation cover. These characteristics suggest that clay translocation may have occurred here faster  
606 than in the underlying SU5A. This is probably due to runoff inputs into the basin with abundant clayey



607 suspended load, as previously described for soils subject to seasonal flooding (Brammer, 1971 ;  
608 Buurman, Jongmans, & PiPujol, 1998 ; Fedoroff & Courty, 2002 ; Fedoroff, Courty, & Guo, 2010 ;  
609 Kühn, Aguilar, & Miedema, 2010). This thick illuviation phase quickly causes the clogging of the  
610 porosity at the base of the SU, sealing the soil profile and strongly degrading the drainage conditions.  
611 This subsequently resulted in the rising of the watertable and the gleyfication of the profile: this  
612 process can be understood as secondary hydromorphy (Begon and Jamagne, 1973; Jamagne, 1978).

613 Microstructure and voids in the central section of the SU4 (80 to 102 cm, Table 2) show a collapsed  
614 porosity, very weak detrital inputs, and redox pedofeatures (Fe nodules, hypocoatings and coatings,  
615 Mn nodules), indicating a strong and quasi-permanent saturation (Lindbo et al., 2010). This is  
616 interpreted as a result of an intensification of previously started drainage degradation. The beginning  
617 of wetter conditions is clearly marked by formation of several ferromanganic nodules c. 102 cm,  
618 superimposed to CC of SU5A. Clay illuviation features (CC and CI) are gradually whiter, thinner and  
619 less abundant upwards. These evidences support the interpretation of a microstructure closure and a  
620 weakening of illuviation processes due to the installation of gleyic conditions (Fig. 8).

621 Indicators of soil erosion inputs by runoff (coarse mineral grains) also become gradually weaker in  
622 central and upper parts of the SU4. An increase in the content of microcharcoal could be interpreted  
623 as erosion of soils in the catchment or as local fires on grasses, however the presence of some  
624 macrocharcoal (>125 $\mu$ m) between 93 and 102 cm, which are usually considered as local (Deák et al.,  
625 2017), supports the latter hypothesis.

626 The upper section of the SU4 (72-80 cm, see Table 2) has a better developed microstructure and  
627 porosity, and redox pedofeatures point to weaker and shorter periods of saturation. These features  
628 indicate slightly improved drainage conditions. A slight increase in the coarse fraction suggests  
629 increased runoff energy and erosion and microcharcoal is still relatively abundant. Abundant, limpid  
630 but thin and poorly oriented CC are indicative of weak clay illuviation processes. A dense

631 *streptomyces* mass at the top of SU4 indicates the development of a well-drained, aerobic palaeosoil  
632 level at this depth (73-85 cm) , in a similar way as in the lower section of SU4 (see above).

633

### 634 **SU3**

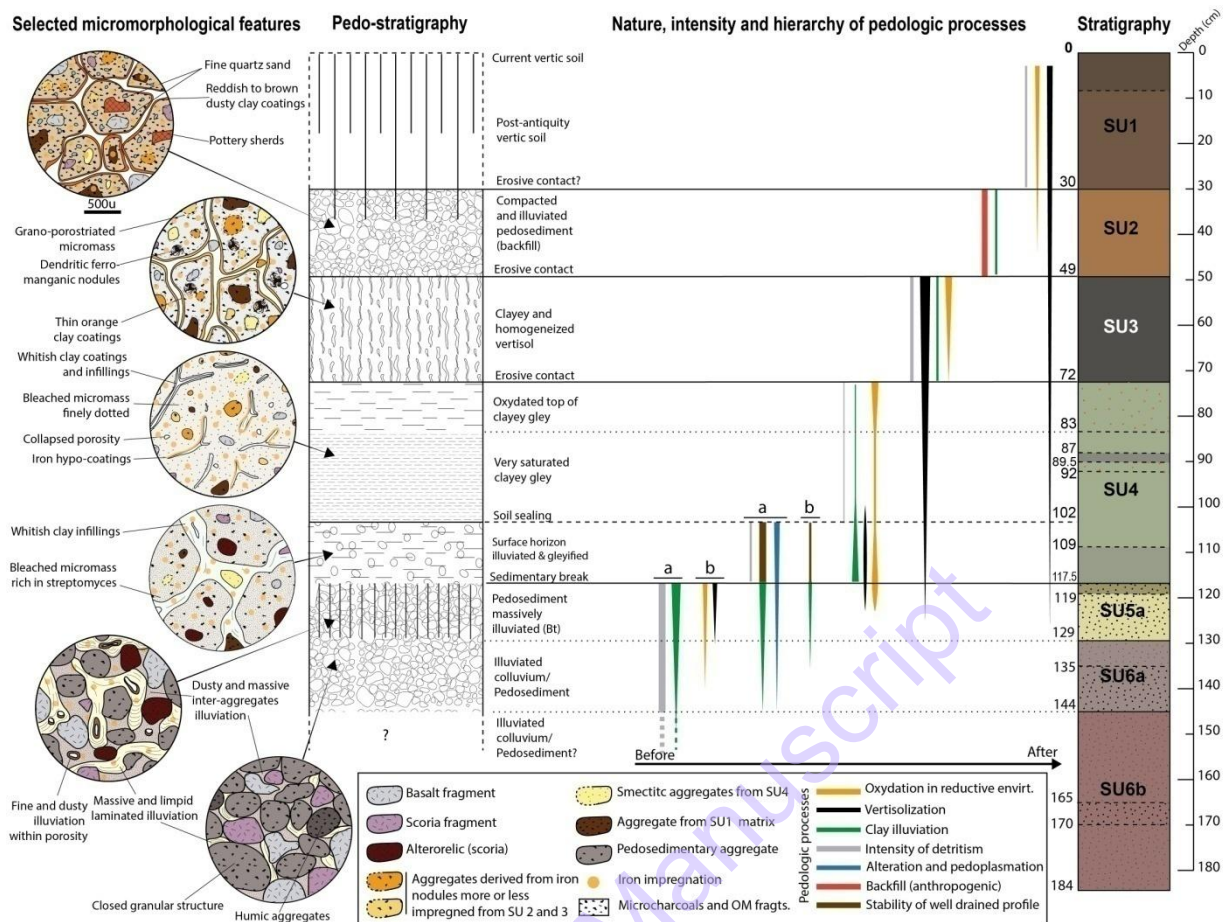
635 The microstructure of SU3 (prismatic with grano-porostriation, see Table 2), the marked  
636 weathering of an otherwise heterogeneous coarse fraction, and the presence of phytoliths  
637 accompanied by sponge spicules are all indicators of highly variable hydrological inputs and intense  
638 shrink-swell processes (Kovda and Mermut, 2010), which clearly denote vertisolization. Redox  
639 pedofeatures such as developed dendritic Fe-Mn nodules are indicative of strong redox oscillations in  
640 this SU (Kovda & Mermut, 2010 ; Lindbo, Stolt, & Vepraskas, 2010), and their distribution suggests  
641 weaker saturation but more erratic hydrology towards the top of the unit. Textural features indicate  
642 that illuviation is weak to moderate, and occurs probably under incomplete vegetal cover. Presence  
643 of fragments of well-developed and laminated CC, abundant fragments of hyaline allophanes, some  
644 smectitic C-type nodules (from SU4) and a general increase in coarse fraction towards the top of the  
645 unit are all indicators of surrounding soil erosion and increasing detrital inputs. Sustained micro- and  
646 macrocharcoal concentration together with a bone fragment could be indicative of human activities.  
647 These data suggest a frame of generalized erosion of evolved andic soils in all the plateau including  
648 the Lac du Puy itself and highly variable hydro-sedimentary conditions under human influence.

### 649 **SU2**

650 This unit has an abundant and heterogeneous volcanic coarse fraction rich in feldspar,  
651 including chert, pottery fragments (Fig. 4), allochthonous quartz grains and a micromass rich in  
652 charcoal, which point to detrital origin under strong human influence. Abundant dusty CC and CI are  
653 indicators of rapid illuviation from a bare or disturbed surface (Fedoroff & Courty, 2002 ; Fedoroff,  
654 Courty, & Guo, 2010 ; Deák et al., 2017). A marked lack of biogenic voids could be indicator of surface

655 compaction and an absence of vegetation (Adderley et al., 2010 ; Deák et al., 2017). Grano-  
656 porostriation of the unit and presence of sponge spicules indicate that SU2 is at some point affected  
657 by temporary flooding (Kovda and Mermut, 2010; Lindbo et al., 2010), and suggests vertisolization  
658 processes. Some redox features superimposed to the granular structure (Fig. 4A) indicate subsequent  
659 moderate saturation phases. This unit had already been interpreted as backfill in precedent studies,  
660 based on its litho-stratigraphic characteristics (see introduction, and Mayoral et al., 2018).  
661 Micromorphological features indicating detrital sediment including abundant human activity  
662 markers, and a bare, compacted and disturbed surface at the top of the unit, are largely consistent  
663 with this previous interpretation. Moreover, they indicate a local origin of sediment from densely  
664 occupied soils of the surrounding plateau, and they also outline hypothetic posterior phases of  
665 flooding and saturation.

666 Despite the lack of thin sections in SU1, some of its characteristics could be inferred from available  
667 data. Presence of B-type nodules (likely from SU1 and/or SU2) in SU2-3-4, and shrink-swell cracks  
668 observed on the surface of the Lac du Puy basin during fieldwork, suggest that vertic processes  
669 affected a part of the sequence posteriorly to SU2 deposition and until recent times (Fig 6).



670

671 Figure 6. Pedo-stratigraphy and hierarchized interpretation of micromorphological observations of COR13-4, summarizing  
 672 successive pedo-sedimentary processes distinguished in the Lac du Puy sequence.

### 673 3.3 Geochemical endmembers and selected elementary proxies

674 In general, the results of geochemical analysis of COR13-4 were well correlated to the different SU of  
 675 the core. Nevertheless, the signal is relatively noisy due to complex pedo-sedimentary evolution of  
 676 the sequence and the relatively homogeneous lithology of the plateau, making its interpretation far  
 677 from straightforward. PCA shows a relatively good separation of the variables, with 70% of the  
 678 variability explained by the two first components (represented by dimensions 1 and 2, Fig. 7A). Two  
 679 endmembers of chemical elements can be identified, positively correlated respectively with first and  
 680 second components of the PCA. The first endmember includes several lithogenic and detrital  
 681 elements such as Ti, Zr, Fe, K, Si, Al, Rb and Pb, which show generally good correlation between each  
 682 others in most sections of the core. The second endmember groups other elements such as Cu, Mn,  
 683 Sr and Ca (Fig. 7A).

684 The distribution plot shows a relatively clear separation of the dataset by SUs (Fig. 7B). SU pedo-  
685 sedimentary and micromorphological information (see previous sections) provide some clues for  
686 components and related endmembers interpretation. Taking into account characteristics of SUs, the  
687 primary dimension of the PCA seems to represent a gradient between lithogenic sedimentary influx  
688 (positive loadings, SU3 and 4) versus pedo-sedimentary influx (negative loadings, SU6B and SU1). The  
689 second dimension likely reflects finer grain-size deposits in saturated conditions (negative loadings,  
690 mainly SU4), versus better drained conditions or irregular saturations with coarser grain-size of  
691 deposits (positive loadings, mainly SU6B). Therefore the two endmembers represent very different  
692 sedimentary inputs: elements of the first endmember are likely related to relatively fine lithogenic  
693 detrital inputs, whereas elements of second endmember to coarser inputs richer in pedo-sediment.

694 Elements such as Ti, Zr, Si or Fe are lithogenic and representative of the dynamics of the first  
695 endmember along the core (Fig. 7C). Zr and Ti display a very noisy signal with relatively high values at  
696 the base of the core (SU6B, 6A, 5A), followed by a very sharp drop at the base of SU4. Their values  
697 then exhibit less variability and are lower in this SU, but tend to increase gradually to the top of the  
698 unit, and reach maximum values in SU3 before dropping again in SU2 and SU1. Zr, Ti and Fe are  
699 abundant in most volcanic rocks and derived detrital materials, however Zr tends to be more  
700 abundant in coarser sediment (and is often used to describe grain-size of flood layers, e.g. Corella et  
701 al., 2014), whereas Ti and Fe are usually more related to fine detrital fraction (Mielke, 1979; Salminen  
702 et al., 2005; Davies et al., 2015). Considering the basaltic and scoriaceous geology of the catchment  
703 of the Lac du Puy, we interpret Zr, Ti and Fe as indicative of lithogenic detrital inputs, and propose to  
704 use the Zr/Fe ratio as a proxy of an increase in their grain-size. This interpretation of the ratio  
705 appears consistent with the grain-size observed in litho-stratigraphy (Fig. 2, Table 3).

706 Fe and Si signals are very similar to Zr and Ti (Fig. 7C), which indicates a similar relation with detrital  
707 inputs. However, both show much higher relative values than Ti and Zr in units such as SU4 or SU6A,  
708 suggesting sensibility to other factors. In the Lac du Puy catchment, Si results certainly from

709 weathering of basaltic rock. Colloidal Si is known to be mobile in wet, organic rich and acid  
710 environments (Anthony, 1990 ; Kabata-Pendias & Pendias, 2001 ; Salminen et al., 2005). Anoxic  
711 degradation of organic matter can also lead to a low pH (Osman, 2013; Blume et al., 2016), making  
712 concentrations of biogenic silica more stable (e.g. phytoliths, or sponge spicules observed in thin  
713 section). These considerations suggest that exceptionally high values of Si in the sequence can be  
714 interpreted as a proxy of reducing conditions.

715 Fe is also a particular case, as it is an element very sensitive to redox conditions, especially mobile in  
716 very wet environments (Salminen et al., 2005). This suggests that although a part of Fe in the Lac du  
717 Puy is detrital, Fe concentrations are also increased in units with reducing conditions (e.g. SU4, Fig.  
718 7C). Mn is also sensitive to changes in soil moisture, but is more readily mobilized in less saturated  
719 conditions than Fe, and is then a good marker of oxic conditions (Lindbo et al., 2010; Kylander et al.,  
720 2011). The very sharp peaks in SU3 (Fig. 7C), a unit characterized by vertic processes, suggest that  
721 high Mn values can be due to ephemeral flood and drying cycles. However, as Mn can also be of  
722 lithogenic origin, we propose to use Mn/Ti ratio to discriminate this hydrological signal.

723 Furthermore, given the opposite sensitivity to redox conditions in the Lac du Puy of Fe and Mn, their  
724 ratio could therefore be a proxy very sensitive to redox variability and especially the intensity of  
725 reducing conditions (e.g. Haberzettl et al., 2007; Cuven et al., 2011; Corella et al., 2012), which  
726 appears consistent with previous litho-stratigraphic and micromorphological observations.

727 Ca variability provides information of the dynamics of the second endmember: its values are  
728 especially high at the base of SU6B, and then gradually decrease upwards in SU6A and 5A (Fig. 7C). A  
729 drop is also clearly visible at the base of SU4, followed by slowly and regularly increasing values from  
730 SU4 to SU1. In volcanic contexts, Ca often derives from the chemical weathering of plagioclases  
731 (Wedepohl, 1978 ; Mielke, 1979 ; Salminen et al., 2005). This process can result in relative Ca-  
732 enrichment of volcanic soils (Kabata-Pendias & Pendias, 2001 ; Salminen et al., 2005). At the scale of  
733 the basaltic plateau of Corent, we propose to interpret high Ca values of soils as the result of their

734 long-term evolution under relatively moist conditions facilitating weathering, *versus* raw detrital  
735 products richer in Fe or Ti. In the Lac du Puy basin, we can therefore interpret that high Ca/Fe ratio  
736 values indicate predominantly pedogenic instead of lithogenic sedimentary inputs. This  
737 interpretation is clearly supported by higher values of Ca and Ca/Fe in SU5A and 6A-B (Fig. 7C),  
738 where micromorphological analysis revealed abundant pedosediment (see 3.2.). Ca/Fe can hence be  
739 seen as an indicator of soil erosion in the plateau (especially if it covariates with other proxies of  
740 detrital inputs), however it could also indicate *in situ* pedogenetic processes.

741 Finally MS (see Fig. 7C), a measurement sensitive to magnetization, can be sensitive to different  
742 natural processes including soil genesis, fires, detrital influx or volcanic fallouts (Dearing, 1999; Dalan,  
743 2017). In the basaltic context of the Lac du Puy, MS signal is likely sensitive to fine detrital influx  
744 (partly obscured by coarse fraction rich in magnetite grains). However, given high values in SU5A and  
745 base of SU4A, it could also be indicating pedogenic sediment influx and/or local soil genesis. MS can  
746 hence be combined with Zr/Fe and Ca/Fe to interpret complex processes where detrital lithogenic  
747 inputs of variable grain-size, pedosediment influx and local soil genesis are entangled.

748 Following the interpretations and proposed elementary ratios developed above, a clear  
749 differentiation between SUs can be detected, indicating broadly different environmental dynamics  
750 between lower (SU5A and 6A/B), middle (SU4 and 3) and upper (SU2 and 1) sections of the sequence  
751 (Fig. 7C).

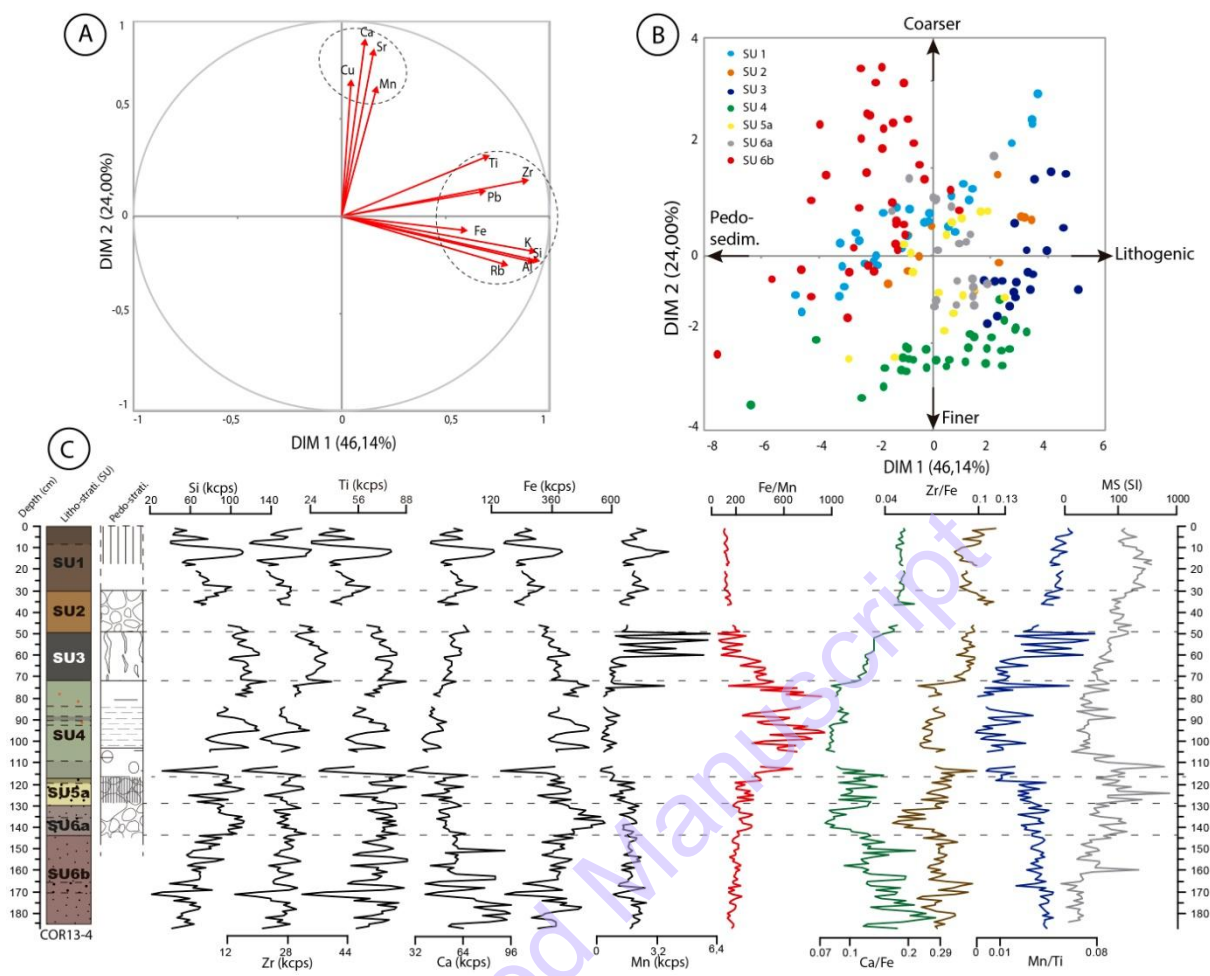
752 Pedogenic inputs are high (Ca/Fe) but diminishing upwards in SU6A and 6B, as shown by  
753 micromorphological analysis. Relatively dry conditions seem permanent through the SU (Fe/Mn,  
754 Mn/Ti). MS increase and lower values of Zr/Fe and Ca/Fe in SU6A suggest less pedosedimentary and  
755 more lithogenic inputs in the basin, in slightly wetter conditions (higher Fe/Mn and Si). However, the  
756 highly detrital nature of the unit demands caution in data interpretation. SU5A and the base of SU4  
757 show stronger lithogenic detrital inputs and pedogenic influx signal (high MS, Zr/Fe, Ca/Fe). This is  
758 roughly consistent with detrital inputs followed by pedogenesis and Bt horizon formation shown by

759 micromorphological analysis (see 3.2). Changing redox conditions suggest a relatively dry phase  
760 followed by wetter conditions from the top of SU5A (sharp increase of Fe/Mn and fall of Mn/Ti c. 120  
761 cm), also consistent with litho-stratigraphic and micromorphological data.

762 In the middle and upper part of SU4, geochemical proxies show a clear break: ratios indicating  
763 lithogenic and pedogenic detrital inputs fall dramatically and remain quasi-stable, with only a faint  
764 increase towards the top of the SU, and the fine fraction becomes dominant (low Ca/Fe, Zr/Fe, and  
765 MS). Hydrological conditions become highly and quasi-permanently saturated (Fe/Mn, Mn/Ti), and  
766 reductic (gleyic) processes broadly dominate save for two short slightly drier phases, one intercalated  
767 in the middle-upper section of the SU (92-86 cm approx.) and the other at its top (75-72 cm),  
768 associated with minor detrital pulses. Lithogenic and pedogenic detrital inputs increase sharply at the  
769 transition to SU3 (Zr, Ti, Ca/Fe, Zr/Fe, MS), and continue to rise gradually upwards. The general trend  
770 towards less reducing (drier) conditions is punctuated by very sharp drying episodes recorded in the  
771 upper part of the unit (peaks of Mn/Ti), consistent with recurrent seasonal flooding and  
772 vertisolization observed in thin section (see 3.2). Geochemical data are lacking for SU2, and SU1  
773 represents subactual to actual pedo-sedimentary dynamics.



774



775

776 Figure 7. Selected geochemical results of COR13-4. A) PCA correlation circle according to dimensions 1 and 2 and identified  
777 endmembers. B) Plot with SU distribution C) detailed geochemical diagram of COR13-4 with selected elements and  
778 elementary ratios selected as environmental proxies. MS values are in SI ( $10^{-5}$ ) and XRF values in counts per second (CPS).  
779 Ratios are dimensionless.

780

781

782

783

## 784 4-Discussion

785

### 786 4.1 The Early and Middle Neolithic (Mid-Holocene period)

787

788 SU6A/B and SU5A likely date to the late Early and Middle Neolithic period (c. 5200-3500 cal. BCE, Fig.  
789 8). The period from the base of SU6B is characterized by marked detrital influx including abundant  
790 scoria and pedological aggregates, suggesting significant erosion across the plateau. The lack of  
791 palynological and micromorphological data, as well as chronological data limits interpretation for this  
792 period, which is based on geochemical and sedimentological proxies. Detrital influx increases  
793 toward the top of SU6B accompanied by slightly moister conditions. However, the pedogenic fraction  
794 is less abundant suggesting that mature andic soils of the plateau were gradually eroded and  
795 replaced by younger, more lithogenic materials.

796 Numerous proxies (Ca/Fe and Zr/Fe ratios, MS in Fig. 8) suggest a second phase characterized by a  
797 slight reduction in soil erosion and detrital inputs (SU6A) accompanied by a minor increase in  
798 moisture (Fe/Mn, Mn/Ti). Micromorphology indicates recurrent flooding of the basin due to intense  
799 hydro-sedimentary fluxes from the plateau. These inputs, rich in detritic and pedogenic elements  
800 embedded in fine clayey matrix, imply that despite a relative lull the erosion of soils of the plateau  
801 remains intense. The presence of allochthonous microfragments of chert and quartz, accompanied by  
802 micro and macrocharcoal indicate anthropogenic activity close to the basin. Palynological data (Fig.  
803 8) indicate the possibility of local cereal cultivation associated with an opening of the local pine  
804 woodlands, which were developed around the depositional basin, from the beginning of SU6A as  
805 shown by lower half of LPAZ (Local Pollen Assemblage Zone) COR-1b (Ledger et al., 2015).

806 The end of the period (SU5A) is characterized by renewed soil erosion (higher values of Ca/Fe, Zr/Fe,  
807 MS and *Glomus*), also evidenced by micromorphological analyses (abundant pedo-sedimentary

808 aggregates). This suggests an increase of the anthropogenic impact on soils. Palynological data  
809 indicate an intensification of woodland clearance (decrease of arboreal pollen, increase of Poaceae)  
810 perhaps associated with pastoralism (presence of coprophilous fungi), corresponding to the upper  
811 half of LPAZ COR-1b and start of COR-2a (Ledger et al., 2015, see Fig. 8).

812 These geoarchaeological and palaeoenvironmental data reflect a more or less continuous impact on  
813 soils and maintained erosion during the Late Early and Middle Neolithic. The opening of its first phase  
814 (SU6B) c. 5200 cal. BCE fits well with the earliest evidences of Neolithic activity at Coirent (5200 to  
815 4300 BCE, Poux et al., 2018), and suggests soils of the plateau were affected by human activities from  
816 their beginning. During later phases (SU6A, 5A), micromorphological and palynological data indicate  
817 that soil erosion and detrital inputs are more certainly linked with human activities such as forest  
818 clearance and agropastoralism. The two separated episodes of impact on vegetation detected by  
819 previous palynological study (Ledger et al., 2015) become here more clearly differentiated as they  
820 roughly correspond to SU6A and SU5A. Due to chronological uncertainties, it is difficult to say if the  
821 first is associated with Early or Middle Neolithic impacts. However, the second and more intense  
822 impact episode affecting vegetation and soils (SU5A) seems more clearly related to the Middle  
823 Neolithic fortified camp dated 4200-3700 BCE approx. (Poux et al., 2016, 2018). This latter phase can  
824 be seen as the culmination of long-term environmental impact history started in the Early Neolithic.

825

#### 826 4.2 Recent to Late Neolithic and transition to Early Bronze Age (Middle to Late 827 Holocene shift)

828

829 The period covering Recent to Late Neolithic and the transition to the Early Bronze Age corresponds  
830 to the base of SU4 in the COR13-4 sequence, between 117,5 and 102 cm approx. (c. 3500 to 2000-  
831 1700 cal. BCE, see Fig. 8). Two different phases can be distinguished within this relatively short core

832 section. In its lower half, micromorphological and litho-stratigraphic data show increased landscape  
833 stability, however geochemical data temper this interpretation, suggesting continued mineral and  
834 pedogenic detrital inputs (MS, Ca/Fe, Zr/Fe, *Glomus*) while soil hydrological conditions become more  
835 saturated (Fe/Mn, Mn/Ti, Fig. 8). Palynological data point to continued opening of the landscape and  
836 general disturbance (peak of Poaceae and presence of apophytes; end of COR-2a in Fig. 8, see also  
837 Ledger et al., 2015). Relatively mild climatic conditions prevailed during the Recent and Late Neolithic  
838 in Western Europe, although bounded by two Rapid Climate Change periods of 5.6-5.3 and 4.2-3.9  
839 kyr. cal. BP (Mayewski et al., 2004; Magny et al., 2006; Wang et al., 2013; Carozza et al., 2015). Thus,  
840 increased saturation of the basins soils was unlikely to have been climatically driven, but rather a  
841 result of gradual soil profile sealing and slight drainage deterioration due to sedimentary  
842 accumulation.

843 The upper half of the 117.5-102 section shows clearly different dynamics. Despite a data hiatus,  
844 geochemical and sedimentological proxies (MS, Zr/Fe, Ca/Fe, Fig. 8) indicate reduced lithogenic and  
845 pedogenic detrital inputs. This decrease is also supported by a reduction in the content of *Glomus*  
846 fungal spores, which are indicative of soil erosion (Ledger et al. 2015). Soil saturation remains  
847 moderate and comparable to the previous period. Micromorphological analysis revealed that this  
848 phase corresponds to the development of a well-drained palaeosoil (top of surface horizon c. 102  
849 cm, Fig. 6 and Fig. 8) certainly under vegetal cover, consistent with palynological data which indicate  
850 local pine and oak woodlands recovery and decline of human activity suggested by the fall of  
851 Poaceae and apophytes (LPAZ COR-2b in Fig.8, see also Ledger et al., 2015). The high degree of  
852 weathering of coarse fraction in the profile of this palaeosoil, and the well-developed clay illuviation  
853 features below its upper horizon (see Fig. 6) are traits usually needing several centuries or even  
854 millennia to develop (Courty & Fedoroff, 2002 ; Fedoroff & Courty, 2002 ; Kühn, Aguilar, & Miedema,  
855 2010). This strongly suggests that this palaeosoil remained stable (and so the surrounding  
856 environmental conditions) over a long period, implying a marked demise of anthropogenic impact in  
857 the Lac du Puy and in the surrounding plateau. This palaeosoil is also crucial to understand the basin

858 chrono-stratigraphy, as it explains the almost negligible sedimentary accretion between the top of  
859 SU5A and the base of SU4 (3500-2000/1700 cal. BCE). Hence, the Recent and Late Neolithic are  
860 represented in the sequence by only a few centimeters, and SU4 truly starts at 102 cm, c. 2000/1700  
861 cal. BCE (see Fig. 8).

862 Geoarchaeological and palaeoenvironmental data show a clear trend towards a decreased human  
863 activity and reduced impact on palaeoenvironments between 3500 and 2000/1700 cal. BCE. A first  
864 phase of apparent stabilization and incipient slowdown is followed by a second and prolonged phase  
865 of more marked demise with vegetation recovery, reduced sedimentary accretion and soil  
866 stabilization in the Lac du Puy, indicating a long period of very limited soil erosion of the plateau. This  
867 two-phased pattern of decreasing human influence on environments appears consistent with the  
868 archaeological record. During the Recent Neolithic (3700-3000 BCE) signs of occupation at Coirent are  
869 limited. However significant environmental impacts are recorded in COR13-4, suggesting  
870 archaeological data may be underestimating human activity from this period. Our knowledge of  
871 human activities at Coirent during the Late Neolithic comprises a collective burial in the summit of the  
872 plateau (Daugas, 1972; Milcent et al., 2014b; Poux et al., 2018), roughly dated c. 3000-2400 BCE.  
873 After this, archaeological data become scarcer as the site is all but abandoned from the end of the  
874 Bell-Beaker period (c. 2400-2200 BCE), until the first centuries of the Bronze Age (Poux et al., 2018).  
875 The rather warm and dry climate of the Middle Holocene period prior to the 4.2 kyr BP climatic event  
876 (Wanner et al., 2008; Carozza et al., 2015; Bini et al., 2019; Cartier et al., 2019), suggests that the  
877 primary cause of this marked abandonment has to be found in social dynamics (e.g. local changes in  
878 settlement pattern ), perhaps combined with pronounced andic soils deterioration after centuries of  
879 strong soil erosion due to anthropogenic activities.

### 880 4.3 The Bronze Age

881 Central and upper sections of SU4 (102-83 and 83-72 cm respectively in COR13-4) broadly  
882 correspond to the Bronze Age (BA), perhaps excepting its first centuries (2000/1700 to 800 cal. BCE

883 approx.). The distribution of radiocarbon dates on COR13-4 (Fig.2 and Table 1) indicates that central  
884 section of SU4 represents likely end of Early and Middle Bronze Age, whereas upper section of the  
885 unit records roughly the Late Bronze Age.

886 From the opening of central section of SU4 (102-83 cm in COR13-4, Early to Middle Bronze Age)  
887 major hydro-sedimentary changes occur: sedimentary inputs become dominated by the clayey  
888 fraction, and water saturation of the soils of the basin becomes permanent (high Fe/Mn, low Mn/Ti  
889 in Fig. 8). Despite the apparently low activity of sediment transport indicators (MS, Zr/Fe, *Glomus*),  
890 micromorphological analysis indicates sedimentary sources extended through the plateau. This  
891 suggests generalized erosion requiring, paradoxically, increased energy to ensure sedimentary  
892 connectivity and sedimentary transfer from upper to lower areas of the plateau. Micromorphological  
893 features also indicate sudden changes affecting soils of the basin (dusty coatings, macrocharcoal),  
894 likely anthropogenic disturbance of soils, land clearing and local fires (Deák et al., 2017). Towards the  
895 top of the central section of SU4, micromorphology and geochemistry suggest that reductive  
896 conditions decrease with more irregular and oscillating water saturation (Fe/Mn, Mn/Ti, Fig. 8), and  
897 a slight increase of detrital inputs intensity (MS, Zr/Fe, Ca/Fe).

898 Palynological data from previous studies indicate here a second significant episode of woodland  
899 clearance (Arboreal Pollen (AP) falls to minimum values, Fig. 8) probably fire-induced (substantial rise  
900 of microcharcoal concentrations throughout the SU) and evidences of an arable and pastoral  
901 agriculture (maximum values of *Cerealia* pollen-types, pollen evidences from weeds, significant rise  
902 of coprophilous fungi, see LPAZ COR-3a in Fig. 8, and also Ledger et al., 2015). Towards the end of the  
903 phase, pronounced landscape opening after a minor woodland recovery and sustained agricultural  
904 activity (continuous presence of cereal pollen type) are accompanied by a minor microcharcoal peak  
905 (LPAZ COR-3b in Ledger et al., 2015).

906 Geoarchaeological and palaeoenvironmental indicators co-variation suggests that human activity  
907 increased at Corent during the end of Early and Middle BA: this situation runs contrary to the

908 regional pattern for this period, where climatic deterioration (Burga et al., 2001; Siklosy et al., 2007;  
909 Gauthier et al., 2008; Magny et al., 2009) seems contemporaneous to a marked cultural decline and  
910 re-location of sites in peripheral areas respect to the previous settlements (e.g. Berger et al., 2007;  
911 Pétrequin and Weller, 2007; Milcent et al., 2014b). Understanding the reasons for these particular  
912 dynamics at Corent, perhaps related to its hilltop situation, would require more robust archaeological  
913 and palaeoenvironmental data at the scale of the southern Limagne region.

914 The discrepancy between probable important impacts on soils across the plateau and extremely low-  
915 energy hydrosedimentary signal in the Lac du Puy, which persists in all the SU4, is another major  
916 issue raised by our results. It can only be explained by a constrained sedimentary connectivity, i.e.  
917 restricted to finer particles. A hedge-type structure bordering the basin, linked to specific pastoral  
918 land use of this wet area is therefore plausible, perhaps similar to the current situation. It is  
919 worthwhile noting that it is also during the BA when the first traces of agricultural plots demarcations  
920 are noted in France (Carozza et al., 2007). Even a simple vegetal structure can have efficiently  
921 filtered hydrosedimentary inputs into the basin (Rey, 2005). It likely caused that exclusively fine  
922 suspended load supplied the basin, despite probable intensive impacts on surrounding soils and  
923 enhanced erosion and runoff. However contribution of other factors to this buffering, such as  
924 improved agropastoral management (e.g. reduced splash erosion on grasslands) since the Late  
925 Neolithic (Barker, 1985 ; Rösch, 1998, 2013) cannot be excluded.

926 These hydrosedimentary inputs rich in fine fraction are also presumably the cause of soil porosity  
927 clogging shown by micromorphological analysis. Clays deposited in the basin were probably also  
928 illuviated into underlying soil porosity, already partly obstructed by previous illuviation phases (see  
929 4.1 and 4.2). The consistent rise of microscopic charcoal from the base of SU4 (Fig. 8) and  
930 micromorphological evidence of local fires (macrocharcoal) indicate that burning was probably used  
931 to maintain open grasslands for agro-pastoral activity in the basin, a practice whose efficiency is  
932 attested by experimental archaeology (Pavelka et al., 2017). This kind of management could have

933 favored clay illuviation (Slager & van de Wetering, 1977 ; Huisman et al., 2012 ; Deák et al., 2017).  
934 This certainly resulted in complete obstruction and collapse of soil porosity, drainage deterioration,  
935 and subsequent development of vertic conditions, quickly followed by true reductic, permanently  
936 saturated conditions. Hence, our data suggest that agropastoral management practices since the end  
937 of Early BA have indirectly but strongly contributed to the sealing of the soil profile and provoked a  
938 marked change in environmental conditions in the basin. Increasingly wetter conditions could have  
939 encouraged this kind of pastoral management, then generating a feedback effect.

940 In the upper section of SU4 (83-72 cm in COR13-4, Late Bronze Age, Fig. 2 & 8) micromorphology and  
941 geochemistry indicate similar dynamics to previous phase. It is first characterized by very weak  
942 detrital inputs and marked reductic conditions. Palynological data continues to depict a very open  
943 and cultivated landscape as suggested by lowest values for woodland pollen and maximal values of  
944 cereal and Poaceae pollen types (LPAZ COR-3c in Ledger et al., 2015). However, at the end of this  
945 phase (Late BA3, 9<sup>th</sup> century BCE) indicators are again similar to the top of central section of SU4,  
946 with suddenly drier conditions and slightly higher detrital inputs, but also biological activity on stable  
947 and aerobic soils revealed by micromorphology (see 3.2). Palynology notes a slight woodland  
948 increase, agricultural practices are less intensive or are more distant from the Lac du Puy basin, and  
949 pastoralism markers such as coprophilous fungi slightly increase, suggesting the local presence of  
950 livestock in the basin (LPAZ COR-3d in Ledger et al., 2015).

951 Therefore, two similar cycles of palaeoenvironmental impact can be distinguished during the BA,  
952 despite a relatively imprecise chronology. The first one (central section of SU4, 102-83 cm in COR13-  
953 4) covers likely the end of Early and Middle Bronze Age, and the second one the Late Bronze Age.  
954 Both start with impacts linked to pastoral and arable agriculture, while archaeological traces of  
955 human activity remain weak for these periods (Milcent et al., 2014b ; Poux et al., 2018). Then,  
956 impacts on the basin increase with a roughly similar signature (drier conditions, increased detrital  
957 inputs), during the end of the Middle Bronze Age (c. 1450-1300 BCE), and more clearly in the Late



958 Bronze Age 3 (950-800 BCE). Situation of the end of LBA has been connected with extensive and  
959 dense settlement developed in the plateau, including an extended archaeological layer in the centre  
960 of the Lac du Puy (Milcent et al., 2014a; Ledger et al., 2015; Mayoral et al., 2018). Considering that  
961 environmental conditions of the basin appear dependent on human activity, these parallel impact  
962 signatures allow proposing that relatively large settlement on the plateau perhaps developed during  
963 the end of the Middle BA. This hypothesis suggested by our results is also supported by recent  
964 archaeological finds suggesting a hitherto underestimated scale of settlement in the middle BA at  
965 Corent, even if the period remains poorly known (Poux et al., 2018). This highlights how  
966 palaeoenvironmental studies in “site-proximal” contexts can efficiently complement more classical  
967 archaeological approaches.

968

#### 969 4.4 The Iron Age and the Romanization

970

971 The Iron Age approximately corresponds to SU3 in COR13-4 (Fig. 8). However, radiocarbon  
972 probability distribution associated with results from previous works (Fig. 2) are indicative of a hiatus  
973 in the pedo-sedimentary sequence. This encompasses most of the Hallstatt period, and is associated  
974 with the construction of a battery of storage pits (c. 1000 structures estimated) in the VI<sup>th</sup> or V<sup>th</sup>  
975 century cal. BCE (Mayoral et al., 2018). Sedimentary accumulation restarted only after this  
976 disturbance of the basin. Therefore SU3 records only the end of the Hallstatt and La Tène periods  
977 (500 to 100-40 cal. BCE aprox.). Additionally, the low chronological resolution, poor quality and  
978 homogenization of the sedimentary signal (see 3.2), together with anthropogenic destabilization of  
979 hydrosedimentary functioning of the basin associated with the pits excavation (Mayoral et al., 2018)  
980 imposes caution on interpretation. In general terms, sedimentological and micromorphological data  
981 (see 3.2) suggest a strong increase in discontinuous hydrosedimentary detrital inputs arriving into the

982 basin. Considering the maturity of observed vertic pedofeatures of SU3 (Kovda and Mermut, 2010),  
983 active vertisolization due to these discontinuous inputs occurred for at least four to five centuries.

984 Two phases with different trends can nevertheless be distinguished in SU3. The first one starts from  
985 the base of the SU: the geochemical signal becomes much more detrital than in SU4, and richer in  
986 the pedogenic fraction (higher values of MS, Zr/Fe, Ca/Fe, Fig. 8). Chemical proxies indicative of  
987 redox (Fe/Mn, Mn/Ti) suggest generally drier and less saturated conditions than in previous phases.  
988 Palynological data point to a slight vegetation recovery despite continued evidence of anthropogenic  
989 activity such as microcharcoal or pollen of disturbance-related plants. However, strong post-  
990 depositional disturbances such as marked erosion or seasonal flooding indicated by increased  
991 records of algal spores of *Zygnema*-type (and also supported by presence of sponge spicules, see 3.2)  
992 make interpretation complex (LPAZ COR-4 in Ledger et al., 2015). Suddenly increased  
993 hydrosedimentary activity, soil erosion and intermittent hydrology from our results can be  
994 considered as specific environmental consequences of strong disturbance induced by Hallstatt  
995 settlement and battery of storage pits excavation, followed by their rapid abandonment (Mayoral et  
996 al., 2018). In addition, the abundance of microcharcoal at the base of SU3 noted both by palynology  
997 and micromorphology (Fig. 8, Table 2) can be interpreted as traces of dismantling of first Iron Age  
998 soils from the archaeological site, likely destroyed by fire (Milcent et al., 2014b). Anthropogenic  
999 pressure weakens during this period, consistent with partial site abandonment during late Hallstatt  
1000 and early La Tène periods (Poux et al., 2018). However, the persistence of these hydrosedimentary  
1001 dynamics over several centuries suggests a relative continuity of human impacts on soils.

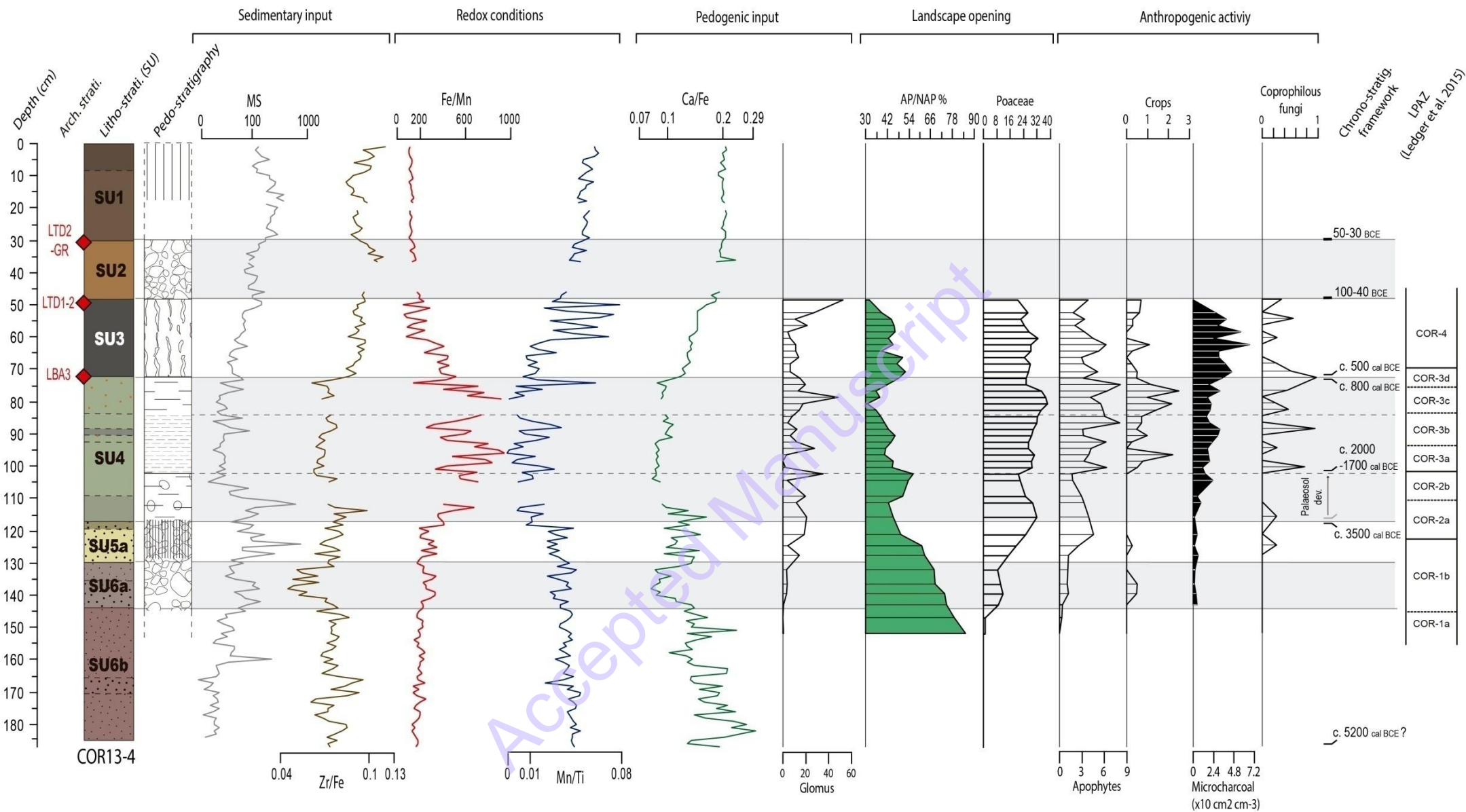
1002 In a second phase, detrital fluxes intensify towards the top of SU3 including coarser particles and  
1003 pedogenic fractions coming from distant areas of the plateau, indicating intense and widespread soil  
1004 erosion (high values of MS, Zr/Fe, Ca/Fe, *Glomus* fungal spores, microcharcoal, fragments of textural  
1005 pedofeatures and scoria fragments). Some markers of human activity such as bone or pottery  
1006 fragments (see Fig. 4) appear for the first time in the sequence. Micromorphology and geochemical

1007 proxies suggest short and violent cycles of saturation (flooding) and drying of soils. Intensified and  
1008 extended erosion processes and irregular hydro-sedimentary activity are indicative of renewed  
1009 anthropogenic disturbance and intensified impacts on soils and hydrology. This signal is consistent  
1010 with the gradual emergence of the huge Gallic *oppidum* covering the entirety of the plateau towards  
1011 the end of the Iron Age (Poux, 2012). Surprisingly, only the margins of the Lac du Puy are occupied  
1012 during this period (Mayoral et al., 2018). Geoarchaeological results from this study suggest that the  
1013 basin probably formed part of the sanitation/drainage system of the *oppidum*. At this time, the Lac  
1014 du Puy was a marginal occupation zone, affected by repeated concentration of hydro-sedimentary  
1015 fluxes caused by increased runoff and erosion, likely related to increased sedimentary connectivity  
1016 and massive soil disturbance and artificialization in the plateau.

1017 Interpretation of environmental dynamics in SU2 (dated 100-40 to 50-30 cal. BCE) is hindered by a  
1018 gap in geochemical data, which only permits us to speculate on generally drier conditions and  
1019 increased pedogenic inputs than in the preceding phase (Fig. 8). Micromorphology depicts a rather  
1020 dry, compacted and bare surface, where dusty and quick illuviation occurred following deposition of  
1021 sediment made of pedogenic aggregates, coarse lithogenic fraction and including abundant markers  
1022 of anthropization (ceramic, bones). These features are typical of both massive deposits of  
1023 pedosedimentary materials and anthropogenic deposits (Fedoroff, Courty, & Guo, 2010 ; Deák et al.,  
1024 2017). Thus, geochemical and micromorphological data strongly support the previous hypothesis  
1025 derived from field evidence, *i.e.* artificial and massive backfill of the basin probably accompanied by  
1026 drainage works in the Late Iron Age or early Roman period (Mayoral et al., 2018), certainly to  
1027 remediate the degraded situation of the wetland and extend the urban space. The post-Antiquity  
1028 evolution of the basin is probably represented by SU1, however a lack of analytical and chronological  
1029 data, and the interaction with present pedological activity prevent any detailed interpretation.

1030

1031



**Figure 8.** Synthetic multi-proxy diagram of COR13-4. Palynological, microcharcoal data and palynozones (LPAZ) are extracted from Ledger et al. (2015). Chronological landmarks are taken from chrono-stratigraphic framework, see Fig. 2. MS: Magnetic Susceptibility (SI.10<sup>-5</sup>). AP: Arboreal Pollen. NAP: Non-Arboreal-Pollen. Pollen data are given as % of TLP (Total Land Pollen) - Lactuceae.

## 1036 **5-Conclusions**

1037

1038 The general objective of this paper was to analyze long-term human-environment interactions at the  
1039 Lac du Puy of Corent, a small wetland with a unique intra-urban setting within the protohistoric site  
1040 of Corent. Building on previous studies, this paper employed a multi-proxy geoarchaeological  
1041 approach of pedo-sedimentary archives of the Lac du Puy to address unresolved research questions,  
1042 mainly concerning changing pedo-sedimentary processes and environmental conditions under  
1043 human influence. New micromorphological, geochemical and sedimentological results were  
1044 combined with existing palynological data within a refined chrono-stratigraphic framework.  
1045 Micromorphological data in particular were used to disentangle the pedo-sedimentary processes,  
1046 whose traces were superimposed in the complex pedo-sedimentary record. Geochemical proxies  
1047 provided valuable and complementary data where micromorphology was equivocal, and pollen  
1048 evidence was especially useful when discussing the impact of human activities on vegetation and  
1049 soils. Data obtained in this, and previous studies were combined to provide a comprehensive  
1050 understanding of complex human-environment interaction around the Lac du Puy since the  
1051 Neolithic.

1052 Here we have significantly refined previous interpretations, revealing anthropogenic impacts on  
1053 vegetation, soil erosion and geomorphological processes probably began in the Early Neolithic,  
1054 contemporary with the first traces of human activity on the plateau. These impacts gradually  
1055 intensify until a shift at the end of the Middle Neolithic, associated with the development of a  
1056 fortified settlement in the plateau.

1057 In the Recent and Late Neolithic, anthropogenic impacts on soils tend to decrease and ultimately  
1058 cease as human traces in the site become rare. Results of this study suggest that this abandonment is  
1059 perhaps due to centuries of cumulated soils degradation. Our findings revealed a “hidden” phase of

1060 pedogenesis in the Lac du Puy basin between Recent Neolithic and the first centuries of the Early  
1061 Bronze Age, with very low sedimentation rate. This phase of soil stability and vegetation recovery in  
1062 the basin, and reduced erosion in the plateau, coincides with long-term abandonment of the  
1063 occupation at Corent.

1064 During the Early Bronze Age, human agropastoral reappraisal of the plateau brings specific land use  
1065 and management of the Lac du Puy. Micromorphology revealed that these new practices are  
1066 certainly the anthropogenic catalyst of soil profile sealing and drainage degradation of the basin,  
1067 which probably becomes a very stable wet grassland maintained by a feedback effect between  
1068 agropastoral management, hydrosedimentary fluxes and pedogenic processes. From our results, two  
1069 cycles of environmental impact can be distinguished in the later evolution of the basin during the  
1070 Bronze Age. The first covers Early and Middle Bronze Age, and second the Late Bronze Age. Both start  
1071 with reduced anthropogenic impacts characterized by pastoral and arable agriculture, and finish with  
1072 drier and more detrital conditions. The clear association of the end of the later cycle with settlement  
1073 expansion during Late Bronze Age 3 suggests that similar signal at the end of the Middle Bronze Age  
1074 could have analogous causes. This implies an extended settlement during this period, which is not  
1075 evident in existing archaeological data.

1076 The Iron Age is harder to interpret in the pedo-sedimentary record of the Lac du Puy. A major and  
1077 permanent hydro-sedimentary change is noticeable in the basin, lasting despite the apparent demise  
1078 of occupation during several centuries after abandonment of the Hallstatt site and associated storage  
1079 pit battery. Geoarchaeological analysis shown that these “inherited” impacts are exacerbated by  
1080 development of the *oppidum* in the late La Tène period, which presumably increased soil  
1081 disturbance, erosion and runoff nourishing hydro-sedimentary inputs of the basin. Our study  
1082 suggests that the Lac du Puy then becomes part of the sanitation/drainage system of the urban  
1083 environment of the plateau and is recurrently flooded by hydro-sedimentary fluxes.  
1084 Micromorphology confirmed that circa 50-30 BCE the area is backfilled probably in order to reclaim

1085 this wasted space for urban area extension, however the function of this new space could not be  
1086 determined. Later evolution of the basin after the Antiquity remains uncertain due to the lack of  
1087 analytical and chronological data.

1088 Results of this study draw a detailed multi-proxy picture of the complex evolution of socio-  
1089 environmental interaction and human impacts on natural systems at Corent since the Early Neolithic.  
1090 It contributes to refining our perceptions of the environmental impacts of prehistoric societies in  
1091 Western Europe and highlights the crucial importance of keeping a long term perspective when  
1092 dealing with past human-environment interactions.

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1094

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1109 **7-Conflicts of interest**

1110 The authors declare no conflict of interest. The funding sponsors had no role in the design of the  
 1111 study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in  
 1112 the decision to publish the results.

1113

1114

1115 **8-Appendix**

1116

| SU | Depth (cm) | Munsell color              | Description  |
|----|------------|----------------------------|--|
| 1  | 0-30       | 10 YR 3/2                  | Dark brown clay loam, visible blocky to granular aggregation, basaltic granules, vegetal remains (topsoil)   |
| 2  | 30-49      | 10 YR 3/2                  | Dark brown clayey-silty loam, several basaltic granules, one amphorae sherd, some oxidation mottles.   |
| 3  | 49-72      | 10 YR 2,5/1                | Very dark grey to black silty clay, rare oxidation mottles, basaltic sands and granules.   |
|    | 72-87      | 5 Y 4/2                    | Olive grey massive heavy clay, with abundant oxidation mottles in the top (above 83 cm), very rare sands and basaltic granules, one quartz gravel.   |
| 4  | 87-89,5    | 5 Y 4/2 to 5 Y 3,5/2       | Dark olive grey massive heavy clay, with some oxidation mottles, very rare sands and basaltic granules.  |
|    | 89,5-92    | 5 Y 4/2                    | Olive grey massive heavy clay, with several oxidation mottles, very rare sands and basaltic granules.  |
|    | 92-109     | 5 Y 4/2                    | Olive grey massive heavy clay, with some oxidation mottles, very rare sands and basaltic granules.   |
|    | 109-117,5  | 5 Y 4/2 to 5 Y 3,5/2       | Dark olive grey silty clay. Some oxidation mottles, rare sands and granules.   |
| 5A | 117,5-119  | 10 YR 2,5/1 to 2,5 Y 3,5/2 | Dark grey massive clayey silt, mottled aspect with fine sands and well-sorted small granules of scoria and basalt, weathered. Abundant dark grey and small clayey-silty granules, rounded. |
|    | 119-129    | 10 YR 3/1 to 2,5 Y 3,5/2   | Dark grey massive clayey silt, mottled aspect with fine sands and well-sorted small granules of scoria and basalt, weathered. Dark grey or brown small clayey-silty granules, rounded.     |
| 6A | 129-135    | 10 YR 4,5/1                | Dark grey clayey silt, slightly mottled aspect with rare fine sands and small granules of scoria and basalt, weathered. Dark grey or brown small clayey-silty granules, rounded.           |
|    | 135-144    | 10 YR 4,5/1                | Dark grey clayey silt, mottled aspect with fine sands and small granules of scoria and basalt, weathered. Dark grey or brown small clayey-silty granules, rounded.                         |



|           |         |           |  |
|-----------|---------|-----------|--|
|           | 144-165 |           | Dark grey clayey silt, breccia-like mottled aspect with rare sands and dark reddish scoria and basaltic granules, weathered. Dark grey or brown small clayey-silty granules, rounded.      |
| <b>6B</b> | 165-170 | 10 YR 4/1 | Dark grey sandy silt, breccia-like mottled aspect with abundant fine to coarse sands and dark reddish scoria and basaltic granules, several fine to medium gravels, weathered.             |
|           | 170-184 |           | Dark grey clayey silt, breccia-like mottled aspect with some sands and dark reddish scoria, basaltic granules to fine/medium gravels, weathered. Dark grey small clayey granules, rounded. |

1117 **Table 3.** Litho-stratigraphic description of COR13-4

1118

1119

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