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# Techno-moder: A proposal for a new morpho-functional humus form developing on Technosols revealed by micromorphology

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## ► To cite this version:

Gabin Colombini, Apolline Auclerc, Françoise Watteau. Techno-moder: A proposal for a new morpho-functional humus form developing on Technosols revealed by micromorphology. *Geoderma*, 2020, 375, pp.114526. 10.1016/j.geoderma.2020.114526 . hal-02972163

**HAL Id: hal-02972163**

<https://hal.univ-lorraine.fr/hal-02972163v1>

Submitted on 21 Jun 2022

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1 **Title: Techno-moder: a proposal for a new morpho-**  
2 **functional humus form developing on Technosols revealed**  
3 **by micromorphology**

4  
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12  
13 **Abstract:**

14 Human impact on soil systems is now widely acknowledged. “Technosols” appeared in soil  
15 classification only a decade ago and the notion of “techno humus system” has emerged even more  
16 recently. Yet the variety of humus forms that could develop on Technosol remains largely unknown.  
17 To contribute to filling this knowledge gap, we studied the humus form developing on two Technosols  
18 resulting from the activity of a former coking plant and compared it with one developed on a Cambisol  
19 as a reference for the area. We used field description and micromorphology on thin sections coupled  
20 with a point-and-count method to precisely describe the surface of the humipedons of the area studied.  
21 A total of 13,841 counts and identifications were performed on 11 thin sections and spread into 17  
22 fabric units. Micromorphology on thin soil sections revealed that epi-saprophagous organisms

23 transformed most of the neo-formed organic matter on the Technosols studied, leading to an  
24 accumulation of feces on the surface of the humipedon. Our results suggested that the humus form  
25 developing on the Technosols was similar to a moder and exhibited the same ectorganic horizons (OL,  
26 OF, zOH), whilst overlaying a technogenic one composed mostly of coal fragments. We would like to  
27 propose the term “techno-moder” for this new humus form, developing in the absence of an A horizon.  
28 On the other hand, micromorphology allowed us to classify the humus form developed on the  
29 Cambisol as a eumull containing anthropic coal by-products. Specification of the humus form  
30 developing on such soils could represent a promising way to specify pedological processes such as  
31 organic matter decomposition, soil aggregation and also to enrich the humus form classification on  
32 Technosols.

### 33 **Keywords:**

34 Microstratification, Litter transformation, Faunal activity, Humipedon aggregation, Anthropized soil,  
35 Coal

## 36 **1. Introduction**

37 Human activity is profoundly modifying soil systems worldwide. Industry and urbanization lead to a  
38 degradation of soil, with either physical, chemical or biological damage (Cundy et al., 2016; Mudrak  
39 et al., 2010; Sheoran et al., 2010; ourkova et al., 2005a; Wong and Bradshaw, 2003). Disruption of  
40 the soil structure, organic and metallic pollution and a reduction of faunal and microbial biodiversity  
41 have been widely reported on post-industrial sites (Frouz, 2013; Gillet and Ponge, 2002). In a time  
42 where pressures on soils are rapidly increasing, the rehabilitation of post-industrial sites has become a  
43 major concern. In fact, soils are important carriers of ecological functions and ecosystem services,  
44 such as carbon storage, water retention and filtration, organic matter recycling and support  
45 biodiversity (Adhikari and Hartemink, 2016; Millennium Ecosystem Assessment, 2005) and therefore  
46 contribute to human well-being, even in anthropized soil systems (Morel et al., 2015). Technosols are  
47 a new group of soil that was added to the classification by the WRB in 2006. They result from human  
48 activities and are defined by incorporating at least 20% technogenic elements or being sealed within

49 the first 100 centimeters of a soil (Rossiter, 2006). Technosols are known to present both a wide  
50 vertical and horizontal heterogeneity. They might exert extreme physico-chemical properties resulting  
51 from their composition such as having high pH, low nutrient content, high carbon content, or high  
52 coarse element proportions (Joimel et al., 2016; Morel et al., 2005). Technosols undergo pedogenesis  
53 processes, that might be faster than one of natural soils such as a formation of macro- and meso-  
54 aggregates, an evolution of water retention or decalcification reactions (Séré et al., 2010). Technosols  
55 are often found in post-industrial areas and might be left as derelict brownfield or on sites to be  
56 reclaimed (Frouz et al., 2006a; Vincent et al., 2018).

57 Revegetation of soil is widely used to reclaim post-industrial areas. Besides helping in soil  
58 stabilization, it allows the incorporation of neo-formed organic matter, resulting from roots, barks,  
59 twigs or senescent leaves of the plants, which is involved in soil fertility and support faunal and  
60 microbial diversity (Bradshaw, 1997; Tiessen et al., 1994). In some cases, authors have suggested the  
61 natural succession of spontaneous vegetation to be an equally efficient way to reclaim ecological  
62 functioning of degraded soil (Frouz et al., 2006b). Whatever the strategy used, it is important to assess  
63 the recovery of pedological processes such as the dynamics of organic matter or the formation of soil  
64 structure on degraded areas. One way to assess this recovery is to study the evolution of the neo-  
65 formed organic matter and its interactions with the initial soil components (Gillet and Ponge, 2002;  
66 Rabot et al., 2018).

67 These interactions between biotic and abiotic components occur in a part of the soil system named the  
68 humipedon, corresponding to the OL, OF, OH and A horizons (Zanella et al., 2017a). This  
69 compartment houses complex interactions between microorganisms, soil fauna, roots, decaying  
70 organic matter or mineral constituents. Depending on the biotic and abiotic components of the  
71 humipedon, different layers or horizons will develop over time and space, depending on the varying  
72 nutrient and energy cycling dynamics (Ponge, 2013). The ability of soil fauna, such as earthworms to  
73 colonize or thrive in a given environment has been reported as one of the main drivers in the  
74 morphological organization of the humipedon, in slightly (Bernier and Ponge, 1994) to highly-  
75 anthropized soils (Gillet and Ponge, 2002). Plant litter may accumulate on the soil surface, be

76 consumed and transformed into feces by soil saprophagous organisms, or mixed with mineral material  
77 when consumed by anecic earthworms. This morphological organization of the humipedon thus  
78 depends on the chemistry of the organic matter, the climate, the bedrock properties and the community  
79 of soil fauna and microorganisms (Barratt, 1969). Such interactions drive physical parameters such as  
80 organo-mineral aggregation, the size and shape of the porosity, as well as participating in the functions  
81 provided by the soil profile. Thus, the spatial organization and morphology of the constituents in the  
82 humipedon can provide useful information on the functioning of the ecosystem (Ponge, 2013). This  
83 morpho-functional organization is called “humus form” and is defined as a “reference for a group of  
84 humus profiles displaying the same series of diagnostic horizons”, according to Zanella et al. (2017b).  
85 It has been described in little anthropized ecosystems for decades (Barratt, 1969) and its classification  
86 is still evolving. Forms such as “Para” and “Anthropogenic” have recently been added (Zanella et al.,  
87 2017c). Para-humus systems are driven by specific ecological determinants such as bryophytes, roots  
88 or even biological crusts (Zanella et al., 2018a), while Anthropogenic, or “techno” humus system  
89 result from human activities (Zanella et al., 2018b).

90 One way to characterize the humus form developing on the soil surface is the use of thin-section  
91 micromorphology. This is based on a morphological classification of the organic material and minerals  
92 developing in a natural ecosystem that forms humus layers (Bal, 1973, 1970) and fits the identification  
93 of humus form resulting from natural pedogenetic processes, as shown by Zaiets and Poch (2018) on  
94 Mediterranean soils. Furthermore, it allows a discrimination between neo-formed and anthropogenic  
95 soil components (Stoops, 2003) and this method is well-adapted to Technosols, even when the  
96 heterogeneity and diversity of components can render the task arduous (Stoops et al., 2010). In fact,  
97 micromorphology has already been used to identify Technosol constituents (Monserie et al., 2009) and  
98 to study pedogenetic processes, such as organic matter dynamics, soil porosity evolution, the impact of  
99 faunal activity or physical properties, such as hydric conditions (Watteau et al., 2018, 2019).

100 So far, Technosol studies using humus form identification are scarce, probably because Technosols  
101 resulting from industrial activities are a young entity of study, while humus form investigation  
102 requires a time scale sufficient for neo-formed organic matter to evolve (Zanella et al., 2017b).

103 Because of their high carbon content, some studies have already focused their interest on the  
104 morphological assessment of soil organic matter on anthropized soils (Abakumov et al., 2014; Frouz et  
105 al., 2001; Frouz and Nováková, 2005; Huot et al., 2018). However, only two studies have proposed the  
106 notion of « techno humus », although with two different definitions (Markiewicz et al., 2018; Zanella  
107 et al., 2018b). While these two papers have open a door for an integrated view of both Technosols and  
108 humus systems, the relationships between technogenic elements and humus form development on  
109 Technosols still require much more attention.

110 In this vein, the aim of this paper is to identify and classify the humus form developing on Technosols  
111 of a former coking plant area, using micromorphology to assess the recovery of pedogenetic processes  
112 on the site. We hypothesized that (i) the succession of diagnostic horizons of Technosol humipedons  
113 would not follow the one described in the already existing humus form classification and (ii) that soil  
114 fauna footprints would be limited or absent since technogenic elements constitute most of the soil  
115 matrix and would not suit their requirements. By coupling a Technosol profile study and  
116 micromorphological analysis of thin sections, the vertical organization and interaction of  
117 anthropogenic and neo-formed organic constituents of the humipedon will be described. The  
118 identification and classification of humus form developing on Technosols as a promising way to assess  
119 the recovery of soil processes such as organic matter decomposition and soil aggregation after  
120 rehabilitation on post-industrial areas is discussed.

121

## 122 2. Materials and methods

### 123 2.1. Localization and properties of the study sites

124 The study area is located on the former coking plant of Homécourt, in north-eastern France, on the  
125 group of scientific interest for soil study (GISFI) experimental station at Homécourt ([www.gisfi.univ-](http://www.gisfi.univ-lorraine.fr)  
126 [lorraine.fr](http://www.gisfi.univ-lorraine.fr)). The ceasing of the plant's activity in 1985 was followed by an embankment of a 3 ha site,  
127 composed of a mix of coking plant by-products, building residues, and industrial ground and left

128 derelict since, resulting in derelict spolic Technosols. This area is mainly covered by *Populus tremula*  
129 (L.), *Robinia pseudoacacia* (L.) and *Betula pendula* (L.) that developed spontaneously. Two forest  
130 stations (20 m x 20 m) were selected for morphological study of the humipedon at the surface of the  
131 Technosols (stations T1 and T2, Fig. 1). In order to compare the surface of the humipedon of the  
132 Technosols with a reference, we added a woodland station located near the former coking plant  
133 (Station A, Fig. 1). This station is dominated by *Acer campestre* (L.) and *Fraxinus excelsior* (L.) and is  
134 developing on a Cambisol. This station was chosen as the local reference of humus form developing in  
135 the area because it resulted from (i) the action of the soil fauna community (ii) in a soil resulting from  
136 pedogenetic processes occurring on the natural bedrock and (iii) under a spontaneously developed  
137 vegetation. Thus this forest station might represent a potential sink for soil fauna colonization toward  
138 the Technosols. The samples for chemical analyses across all stations were collected between the 25<sup>th</sup>  
139 and the 30<sup>th</sup> of April, 2018. For each station, five soil samples were taken to a depth of 20 cm for  
140 abiotic characterization corresponding to soil chemical and physical analyses. At each sampling point,  
141 four 500 g soil samples, taken from the first 0-20 cm soil layer, were pooled into one composite  
142 sample. Prior to analyses, soils were air-dried for 72 h then sieved at 2 mm. The size of each sample  
143 were reduce homogeneously to 500 g using an open-bin riffle splitter (Schumacher et al., 1990), then  
144 divided into two homogenous samples using a rotary splitter coupled with a vibratory feeder with a V-  
145 shaped channel (Laborette 24, Fritsch). One sample was kept in the laboratory for chemical analyses  
146 and the other was sent for particle size distribution. Table 1 shows the physico-chemical properties of  
147 the soils from each studied stations.

## 148 2.2. Description of the humipedons

149 In September 2018, one soil pit was opened to a depth of 1 m wherever possible on each station and a  
150 description (*i.e.* depth of each horizon, nature and origin of the organic and mineral constituents) of  
151 each humipedons' horizons was made.

152 In order to describe the humus form developing on the humipedon of each station of the former coking  
153 plant area, eleven undisturbed soil samples were taken vertically using Kubiena boxes (9 × 6 cm) at  
154 the soil surface and distributed as follow: 4 boxes on Station A (Aa, Ab, Ac, Ad), 3 on Station T1

155 (T1a, T1b, T1c) and 4 on Station T2 (T2a, T2b, T2c, T2d). From each Kubiena box, one thin soil  
156 section (20  $\mu\text{m}$  thick) was prepared according to the protocol developed by Guilloré (1983) and  
157 Murphy (1986).

158 Two types of analyses were carried out on these thin sections: (i) a general description of the  
159 micromorphological features such as microstructures, voids, organic materials and minerals, or  
160 technogenic elements for at least one thin soil section of each station, following Stoops, (2003) to  
161 reveal 4 contrasting situations (1 from Station A, 1 from Station T1 and 2 from Station T2); (ii) point-  
162 counting observations to quantify the proportion of the micromorphological features, conducted on the  
163 11 thin sections. In total, 17 fabric units, as explained below, were used to describe the 11 thin  
164 sections.

165 Based on the works of Babel (1975), Stoops (2003) and Zaiets and Poch (2016), 9 fabric units were  
166 used: pore, leaf fragment, other plant tissue, root, fungi, macro-arthropod dropping ( $> 200 \mu\text{m}$ ), meso-  
167 faunal dropping ( $< 200 \mu\text{m}$ ), earthworm cast and fine organic material (FOM). We followed the  
168 definition of “organic fine material” given by Zaiets and Poch (2016) adapted from Stoops (2003)  
169 which is in short: “organic material with no recognizable origin, including groups of five or less  
170 interconnected cells, amorphous organic fine material, punctuations and organic pigment in the  
171 inorganic micromass.” We also added a “particulate organic matter” (POM) fabric for groups of 5 or  
172 more interconnected cells, without organic o-plasma *sensu* Bal (1973) and with no recognizable  
173 origin. We added a “animal tissue” fabric for the few animal parts that can be encountered on thin  
174 section, such as external skeletons (Stoops, 2003).

175 As additional fabric units, we distinguished fine minerals ( $< 2 \text{ mm}$ ) from coarse minerals ( $> 2 \text{ mm}$ )  
176 and we added 4 fabric units in order to highlight Technosol specificities. The two first were organic,  
177 namely fine ( $< 2 \text{ mm}$ ) and coarse ( $> 2\text{mm}$ ) coal fabric units that referred to coal, charcoal by-products  
178 and coal fly ashes, likely to be found in the humipedon of a former coking plant area. Examples of  
179 these micromorphological features can be found in Stoops et al. (2010). The 2 remaining fabric units  
180 that we added to our study were fine ( $< 2 \text{ mm}$ ) and coarse ( $> 2\text{mm}$ ) mostly mineral, technogenic



181 artefacts and refer to all other features resulting from or added by human activity such as brick or glass  
182 fragments, cement blocks or individualized cement constituents.

183 The point and count method is usually carried out for each horizon in natural soils (Zaiets and Poch,  
184 2016) or each centimeter in anthropized soils (Frouz et al., 2007) where pedogenetic processes may  
185 not have yet separated proper horizons. As we studied Technosols, the second method was chosen.  
186 Because the number of counts per thin section varied in the literature and at least 300 were performed  
187 (Zaiets and Poch, 2016), we counted 1200 points for each thin section, divided into about 200 points  
188 (mean = 210, SD = 13, n = 66) for each of the 6 cm of the 11 thin sections.

189 The point and count method was conducted under a stereomicroscope (MZ FLIII, Leica), using a x16  
190 to x200 magnification. A transparent plastic sheet pierced with 1200 holes along the parallel lines of  
191 the thin sections was placed on top of the thin sections. We used an eyepiece reticle to classify the  
192 component under the crosshairs inside one of the 17 fabric units described above. In order to avoid a  
193 misinterpretation of a feature on the sides of the thin sections, where the thickness of the sample could  
194 slightly decrease (edge effect), we moved the grid and counted again until the adequate number of  
195 observations was reached.

196 For a given thin section, the result was expressed as a proportion of each fabric unit within each  
197 centimeter, using the following formula:

$$198 \textit{Proportion } X = \frac{\textit{Count } X \textit{ category}}{\textit{Total count}} \times 100$$

199 With « count X category » being the number of counts of the category X within a given depth of a  
200 given thin section and « total count » the total number of points counted within the same depth of the  
201 thin section.

### 202 2.3. Multivariate and statistical analyses

203 To compare the morphological composition of the 11 studied humipedons, a principal component  
204 analysis (PCA) was performed using the `dudi.pca` function of the `ade4` package in R software (version  
205 1.1.383, 2017). This was performed using the proportion of each fabric within each centimeter of the

206 thin sections. Correlations between variables and dimensions of the PCA were obtained using the  
207 `dimdesc()` function of the `FactoMineR` package using one way analysis of variance (ANOVA) to test  
208 for statistically significant correlations ( $p\text{-value} \leq 0.05$ ).

## 209 3. Results

### 210 3.1. Humipedon description on the macroscale

211 The three soil profiles are shown in Fig. 1. The vertical organization of the stations were highly  
212 heterogeneous.

213 At the Station A, the OLn layer was composed of *Acer campestre* and *Fraxinus excelsior* leaves and  
214 represented less than 1 cm. The soil profile was composed of a 20 cm thick A organo-mineral horizon  
215 on top of a 10 cm B horizon, laying on a calcareous bedrock.

216 At the T1 station, the profile was composed of 0.5 cm thick OLn and OLv layers, mostly of *Robinia*  
217 *pseudoacacia* and *Salix caprea*, a 2 to 5 cm thick OF layer including fragmented leaves of *R.*  
218 *pseudoacacia*, herbaceous leaf sheaths and a few wood fragments. The 2 cm thick OH layer was  
219 composed of a mix of fecal pellets and fine black coal particles. Underneath these organic layers laid a  
220 50 cm thick technic (carbonic) soil material, composed of fine and blocky coal elements.

221 At the T2 station, the profile was composed of a 1 cm thick OLn and OLv layer, with *Populus tremula*  
222 leaves and a few *Betula pendula* and *Salix caprea* leaves. The 1 cm thick OF layer was composed of  
223 leaves of the previously-cited tree species, as well as wood and bark fragments. The 3 to 5 cm thick  
224 OH layer was mainly composed of dark colored fecal materials. The underlying horizon was  
225 heterogeneous at the profile scale (Fig. 1). A 20 cm thick AB organo-mineral brown horizon (Munsell  
226 code 7.5YR 4/4) varied laterally toward a black technogenic horizon (Munsel code 10YR 2/1) and  
227 with 50 to 70% blocky elements. This horizon laid upon a 10 cm thick concrete slab underneath which  
228 was found 1 m of technogenic embankments, composed of coal by-products, gravels and bricks.

### 229 3.2. Humipedons' description at the microscale

230 The general description of the microstructures of 4 thin sections (1 from Station A, 1 from Station T1  
231 and 2 from Station T2) are shown in Table 2. The depth, continuity and boundary of the layers were  
232 measured and described according to the evolution of the main morphological features: microstructure  
233 and porosity, organic components, soil fauna excrements, mineral material and technogenic material.  
234 Scans of soil thin sections of the three stations and examples of morphological features such as macro  
235 and mesofaunal droppings, roots, fine and coarse coal particles or fine and coarse technogenic  
236 artefacts are shown in Figures 2 to 4.

237 Following the point and count method, a total of 13.841 identifications were made on the 11 thin  
238 sections according to the 17 chosen fabric units. Barplots were drawn following the proportion of each  
239 unit (Fig. 5, S1 and S2). Figure 5 showed the proportion of each of the 17 fabric units within the 11  
240 thin sections. For the second barplot (Fig. S1), we pooled the fabric units into one of the following  
241 four categories: organic component, mineral component, Fine Organic Matter (FOM) and  
242 anthropogenic component. We separated FOM from organic components, because FOM usually  
243 describes organic material aggregated with the inorganic micromass. At the magnification of the  
244 study, minerals < 20  $\mu\text{m}$  are hardly recognizable, so pooling FOM and organic component would have  
245 led to an imbalance between organic and mineral components. Anthropogenic components might be  
246 either organic (coal and coal by-products) or mineral (building block residues, cements), but the  
247 addition of this category might be useful in order to highlight the relationships between anthropogenic  
248 components and neo-formed organic material. The four categories combined together represent 100%  
249 of the solid volume of a given thin section. The third barplot (Fig. S2) represents the proportion of  
250 each fabric of neo-formed organic matter as a proportion of the total organic component as described  
251 above.

### 252 3.2.1 Description of humipedon of each station

#### 253 Humipedon of the Cambisol on Station A

254 The 4 thin sections of Station A were composed of a total of 24 layers of 1 cm (Fig. 5). The main  
255 constituents of the solid fraction of Station A were FOM, fine mineral, fine coal, and earthworm casts.

256 They constitute 50 to 75% of the overall volume. These constituents were aggregated and formed a  
257 crumb microstructure (Table 2).

258 The most abundant morphological feature in this station was FOM. This represented more than 30% of  
259 the solid volume in 21 out of the 24 layers and more than 55% of the organic matter in 19 out of 24  
260 layers of the 4 thin sections and reached 83% in Ac thin section. Earthworm casts varied from 0 to  
261 11.8% of the overall volume of the surface of the humipedon and welding of ageing earthworms' casts  
262 was visible. Casts were mostly composed of FOM and fine minerals, as well as fine coal fragments  
263 embedded in the inorganic micromass. Coarse minerals never exceeded 0.9% of the overall volume,  
264 while fine minerals could reach 16.7%. Roots were present in each layer of the 4 thin sections studied  
265 and their morphology attest that they were living. Mesofaunal features such as biogenic aggregates  
266 were visible, as indicated by the presence of mesofaunal droppings smaller than 200  $\mu\text{m}$  within  
267 macroaggregates, leading to small dropping infillings. Only a few animal parts were found on the thin  
268 sections, and reached a maximum of 1.0% of the overall volume of the 2-3 cm layer of the Ab thin  
269 section with the presence of snail exoskeletons. Visible fine minerals were mostly composed of fine  
270 quartz grain. No coarse coal was found in any layer of the 4 thin sections of this station. Yet, the fine  
271 coal microfeatures were present in every one of the 24 layers. Their proportion reached 22.8% of 5-6  
272 cm layer of the Aa thin section and was greater than 10.0% in 19 out of the 24 layers.

273 Humipedon of the Technosols on stations T1 and T2

274 Fragments of leaves represented 14.1 to 21.1% of the overall volume of the first layer of the  
275 humipedon sampled in station T1 and 10.3 to 16.3% for the one of the T2 stations. On neither of the  
276 stations did the leaf fragments show much decomposition and presented a laminated microstructure  
277 (Fig. 3-b and 4c-d). Other plant tissues were mostly woody, such as barks and twigs and represented  
278 12.2 to 18.9% of the overall volume of the first layer of the humipedon from the station T1 and 7.5 to  
279 14.9% for the one of the T2 stations. Such observations confirmed the diagnosis of the OLn and OLv  
280 layers.

281 Below this first layer, a crumb microstructure was observed with compound packing voids between  
282 mesofaunal feces and fine coal particles. Mesofaunal feces could represent up to 17% and 24% of the  
283 volume of the humipedon at depths between 1 cm and 3 cm while, at the same depth, the macrofaunal  
284 feces could represent 24% and 8% of the overall volume of stations T1 and T2, respectively. The fine  
285 coal particles represented up to 42% of the overall volume of the fractions on both stations. Multiple  
286 morphological features of organic matter occurred within the same layer in Technosol humipedons  
287 including neo-formed organic matter such as macro- and mesofaunal feces and fragmented shoot  
288 materials or technogenic organic matter such as coal particles. Yet little to no aggregation was found  
289 between the two categories of components (Fig. 3c, 4e-f). The only aggregation of these two  
290 component categories occurred in feces of invertebrate macroarthropods such as diplopods, in which  
291 neo-formed OM and coal particles were packed.

292 A morphological feature that differed between the two stations was the mycelium. The presence of  
293 mycelium was observed in 24 out of 24 layers of the T2 station, while only occurring in 5 out of 24  
294 layers in station T1. Quantitatively, mycelium represented up to 8.1% of the overall volume in the 2-3  
295 cm layer of the T2b thin section, while never exceeding 1.5% of the humipedon at the T1 station, all  
296 thin sections considered. The high proportion of meso- and macrofaunal feces on top of the  
297 humipedon, together with fungi mycelium and a rapid decrease in the proportion of leaf fragments  
298 were all morphological criteria of a OF and a zOH layers. The evidence of the zoological nature and  
299 genesis of the OH horizon, namely the epi-saprophagous feces, allowed it to be specified as a “zOH”.

300 The porosity tended to decrease with depth in the thin sections, falling by 2.7 fold on average between  
301 the first and the deepest layers of the T1 station and by 1.7 fold on average on the T2 station (Fig. 5).

302 The proportion of technogenic elements showed an inverted trend to that of porosity and reached 75%  
303 of the solid volume at a depth of 6 cm (Fig. S1). Most of the technogenic elements were either fine or  
304 coarse coal fragments. A peculiar situation was found in the T2b thin section, in which the only  
305 technogenic elements were coarse and centimetric embankments, probably residuals of building  
306 blocks, while no coal particles were visible. T2b thin sections exhibited the thickest layers of neo-  
307 formed organic-matter, most of which was composed by both macro- and mesofaunal feces. In fact,

308 within the 4 first cm of this soil thin section, 28 to 35% of the overall volume consisted of faunal  
309 excrement, representing more than 50% of neo-formed organic matter (Fig. 5 and S2). The proportion  
310 of minerals in the solid volume of Technosol humipedons were below 10% in 38 out of the 42 layers  
311 studied for both stations T1 and T2, (Fig. 5), without considering the minerals linked to organic matter  
312 in the FOM fabric unit. According the presence of roots in the deeper layers of the thin sections  
313 composed mostly of anthropic material (Fig. 3e-f), roots seemed to be able to grow within this  
314 technogenic horizon and might be decomposed by soil fauna as revealed by the accumulation of  
315 excrement within some decaying roots (Fig. 4f).

### 316 3.2.2 Multivariate analysis

317 The PCA performed with the proportion of every fabric unit in the 66 layers is shown on Figure 6. The  
318 first 2 axes of the PCA explained 47.1% of the total inertia. The statistically significant correlations  
319 between each variable and the first two dimensions of the PCA are shown in Table S1.

320 On the right of the first axis, variables such as percentage of particulate organic matter, meso- and  
321 macrofaunal feces, leaves and plant tissues, as well as mycelium percentage in a given humipedon, co-  
322 varied and were negatively correlated to the percentage of earthworm casts, fine organic matter and  
323 fine minerals in the humipedon. Soil surface components such as earthworm casts, leaves and plant  
324 tissues and the high porosity percentage in a given humipedon were positively correlated with the  
325 second dimension of the PCA. The variables that were negatively correlated to this second dimension  
326 are the 4 technogenic components found in the humipedon of the coking plant area, such as coal and  
327 technogenic artefacts.

328 The humipedon of Station A showed little evolution in the morphology of its components with depth,  
329 except a decrease in the porosity and earthworm cast quantity. In contrast, the T1 and T2 stations  
330 shared a similar trend in the evolution of the morphological features and were characterized by  
331 specific sets of variables at each depth (Fig. 6b). The first centimeters were characterized by porous  
332 layers, mostly composed of organic matter originating from the shoot part of the vegetation  
333 developing on the Technosol, such as leaf fragments or plant tissue. Then, from 1 to 4 cm, a layer was

334 composed of neo-formed organic matter, transformed by soil fauna as indicated by the positive  
335 correlation of meso- and macrofaunal feces, together with fungi mycelium and particulate organic  
336 matter. The deepest layers were mostly composed of technogenic elements such as artefacts, fine and  
337 coarse coal.

## 338 4. Discussion

### 339 4.1. Classification of the humipedon humus forms on the former coking plant

340 At the time of the study, the morphological organization of the organic matter of the humipedons  
341 clearly indicated two different humus forms between the forest stations developed on the two  
342 Technosols studied in comparison with that on Cambisol. Indeed, the first dimension of the PCA  
343 allowed discrimination between the morphology and the size of the neo-formed organic matter that  
344 composed the humipedon of Station A and from that of the two Technosol stations (T1 and T2) of the  
345 coking plant area.

#### 346 4.1.1 Humus form of the Cambisol from station A

347 The morphological features of the humipedon developed on Station A, observed in the 4 thin sections  
348 are typical of an eumull according to the classification of Zanella et al. (2011). The macroaggregates  
349 composed of a mix of fine organic matter and fine minerals is a key feature of the mull and can be  
350 diagnostic as a macroA horizon, formed by macroaggregates greater than 4 mm (Zanella et al.,  
351 2017d). The soil pH above the threshold of 5 confirm the diagnostic horizon proposed by Zanella et al.  
352 (2017d). The slight changes in the morphological features type with increasing depth, revealed by the  
353 second axis of the PCA, may result from the mixing activity of burrowing earthworms in this forest  
354 (Lavelle et al., 1997). The welding of casts with ageing has been described by Bal (1970) and is  
355 coherent with the observation of welded structures on the thin sections studied. Furthermore, the  
356 observation of numerous mesofauna excrement in the casts have also been reported in the mull humus  
357 form in natural forests, as earthworm casts and macroaggregates are sources of carbon and nutrients  
358 for enchytraeids or collembola (Bal, 1970; Salmon, 2004).

359 Thanks to the precision of micromorphology, our results showed that fine coal particles are present in  
360 anecic earthworms casts from Station A, while they were not visible to the naked eye during field  
361 description. Thus, according to the classification proposed by Jabiol et al. (2013), this humus form is  
362 an Haplic eumull (technic) on Cambisol. The prefix “Haplic” indicates that no other prefix proposed in  
363 the classification fits the humus form, while the suffix “technic” indicates that the diagnostic horizon  
364 A contained at least 10% of anthropic artefacts. Even though the microprofiles of Station A seemed  
365 homogeneous, micromorphological analysis of humipedon thin sections allowed precise classification  
366 and anthropization traces to be revealed. The consumption of fine coal particles by earthworms have  
367 been described in other ecosystems, notably in cultivated land in Amazonian rain forest, where  
368 *Pontoscolex corethrurus* mixed separated charcoal with organo-mineral aggregates (Ponge et al.,  
369 2010; Topoliantz and Ponge, 2003, 2005). In our sites, these particles are probably coal fly ashes,  
370 known to be generated by coking plants (González et al., 2009). Deposits of fly coal ashes would be  
371 carried by the dominant west-wind of the region, while Station A is located east of the former coking  
372 plant (Fig. 1). The coal particles observed in the thin sections were smaller than 200 µm (Figs. 2 and  
373 5) which correspond to the range of sizes described by Ghosal and Self (1995) for ashes resulting from  
374 the burning of different coals. The mull humus form and the soil fauna footprints in the Cambisol  
375 developed on Station A, indicate that the coking plant activity has not impacted nearby ecosystems  
376 sufficiently to prevent an earthworm community from developing.

377

#### 378 4.1.2 Humus form of the T1 and T2 station Technosols

379 Considering the humipedons of the 2 Technosols studied, the evolution of soil organic matter’s  
380 morphological features with depth appears to be analogous to a moder form of humus according to the  
381 classification of Zanella et al. (2011). The moder humus form is composed of poorly decomposed  
382 plant material resulting from the activity of diplopods, isopods, collembola, enchytreids or oribatid  
383 mites and from the absence of anecic earthworms (Bal, 1970). In temperate regions, an absence of  
384 anecic earthworms is caused by low soil pH or sandy texture causing a poor water regime. In the case  
385 of the studied Technosols, the high sand content together with the low water holding capacity might



386 explain the absence of earthworm's footprints. While the moder *stricto sensu* is composed of the same  
387 ectorganic horizons OL, OF and zOH that we found in this study, it is also characterized by its  
388 underlying horizon, which is an organo-mineral A horizon, that is generally meso- or micro-structured  
389 (Zanella et al., 2017e). Mixes of neo-formed organic matter with underlying horizons have been  
390 widely reported in moder on natural soil systems, attributing a significant role to enchytraeids (Ponge,  
391 2003; Zanella et al., 2017b). On the T1 and T2 stations, the underlying horizons differed from this  
392 definition, being mainly composed of fine coal embankments or coarser technogenic artefacts that  
393 represented 55 to 89% of the solid volume at a 5 to 6 cm depth. In contrast to the station A  
394 humipedon, fine coal particles had not been incorporated into organo-mineral aggregates, but  
395 constituted most of the groundmass, resulting in a technogenic horizon with a granular structure. The  
396 high TOC concentration and the high C to N ratio measured in the Technosols result directly from the  
397 nature of the substrate used as embankments. The high pH values found for the Technosol are not  
398 surprising as a slight alkalinity is often described in Technosols literature (Joimel et al., 2016),  
399 although the development of ectorganic horizons occurs generally on acidic soils (Andreetta et al.,  
400 2012; Bernier, 2018; Bernier and Ponge, 1994; Toutain, 1987). A neutral to slightly alkaline horizon  
401 underlying an ectorganic one does not fit the actual classification, yet could occur frequently on  
402 Technosols. Finally, saprophagous activity had induced the mixing of feces and fine coal particles  
403 within the same depth, leading to a transitory boundary between neo-formed and technogenic horizons  
404 as revealed by the second axis of the PCA. The reason for the low proportion of mycelium found in  
405 the thin sections of the T2 station is still unclear, but could result from a higher grazing activity of the  
406 mesofauna, as may be inferred from the higher proportion of mesofaunal feces in the T2 station than in  
407 T1.

408 On the basis of the diagnostic horizons that we observed in the Technosols humipedons, we would like  
409 to propose the term "techno-moder" to characterize this new humus form within the "techno humus  
410 system" of the European morpho-functional classification proposed by Zanella et al. (2018b).  
411 According to the above-mentioned classification, the humus form present in the thin sections of the  
412 Technosols humipedons are techno-dismoder, as zOH horizons were > 1 cm, except in T1c thin-

413 section. We think that keeping the term “moder” is important because it comes from « vermoderung »  
414 as proposed by Kubiěna (1953) to describe the consumption of plant litter by soil fauna without  
415 mixing this organic matter with minerals. This is the case for the Technosols studied here and it is  
416 highlighted by the composition of the meso- and macrofaunal feces, which are either holoorganic or  
417 are, to some extent, mixed with fine technogenic material. The prefix “techno” would be used to  
418 indicate that the evolution of neo-formed organic-matter occurred on a diagnostic technogenic layer, in  
419 the absence of an A horizon. We think that the addition of subsystems within the “techno humus  
420 system” could allow specific soil-plant-fauna interactions to be highlighted in the same manner it has  
421 been done in natural ecosystems (Zanella et al., 2011). When looking at the classification proposed by  
422 Jabiol et al. (2013) within the World Reference Base for soil resources, the humus form described in  
423 this study would be a Hyperspolitic techno-moder on Technosol for the 3 profiles from Station T1 and 3  
424 out of 4 profiles from Station T2. The Hyperspolitic prefix indicates that the diagnostic horizons, here  
425 the organic and technogenic horizons, contain at least 75% artefacts, with 35% or more of industrial  
426 waste. The only exception found on the T2b thin section would be described as a techno-moder (urbic)  
427 on Technosol. The suffix “urbic” indicates that the diagnostic horizons, contain at least 25% artefacts,  
428 with 35% of them being rubble and refuse from human settlements. The addition of “techno” to the  
429 qualifier “moder” would be necessary in this case for two reasons. Firstly, the prerequisite for the  
430 moder humus form is not met, *i.e.* the absence of an organo-mineral horizon underlying the ectorganic  
431 ones and the presence of a slightly alkaline technogenic horizon. Secondly, the parahumus system  
432 could fit the morphological diagnostic, but this would reduce the amount of information regarding the  
433 vertical organization of the organic matter and mask the animal activity, revealed by  
434 micromorphology.

435

436 4.2. Consideration of the humus form on Technosols as a tool to assess the recovery of ecological  
437 processes on the coking plant area

438 In 2002, Ponge et al. proposed the humus index as an integrated tool to assess the properties of the  
439 topsoils in a little anthropized forest ecosystem and in 2018, Korkina and Vorobeichik showed the

440 humus index to be an effective indicator of the impact of metal pollution on topsoil fauna communities  
441 (Korkina and Vorobeichik, 2018; Ponge et al., 2002). In post mining sites, Šourková et al. (2005b)  
442 proposed the formation of the organic layers to be an indicator of the recovery of ecological functions.  
443 Such previous studies have already suggested interesting responses of the humus form to human  
444 activities that can be assessed from the soil profile to the microprofile scale, using microstratification.  
445 The PCA allowed us to discriminate the constituents of the humipedons of the Cambisol and  
446 Technosols according to the morphology of the organic matter and consequently to reveal its evolution  
447 within a given humipedon with depth. From a functional point of view, the vertical and gradual  
448 stratification of the Technosol humipedons indicates that pedogenesis is currently occurring and is  
449 driven jointly by soil animal activity, although without the participation of anecic earthworms, and  
450 also by roots and shoots that appeared to be an important source of neo-formed organic matter. The  
451 morphology of the organic matter in these Technosols suggests a limitation of the bioturbation process  
452 when compared with the Cambisol, as highlighted by the accumulation of arthropods feces on the soil  
453 surface of the techno-moder and the negative correlation of fine organic matter with arthropods feces.  
454 While the observed humus form developed on Technosols differed micromorphologically from the  
455 reference used in our study, our results suggest that neo-formed organic matter allowed an epigeic soil  
456 fauna community to colonize the Technosols stations. The techno-moder form developing on  
457 Technosols could highlight an ecological strategy allowing plants, soil fauna and microorganisms to  
458 cope with extreme environments, as suggested by Ponge (2003), but this hypothesis is still to be  
459 tested. Following the evolution of the humus form of the studied Technosols could represent a  
460 promising way to understand humus form resilience on highly anthropized soils.

461

#### 462 4.3 Usefulness of micromorphology for humus form classification on Technosols

463 Micromorphological analysis of soil thin sections appears to be particularly well adapted to the study  
464 of the vertical organization of the Technosol humipedon constituents, following the microstratification  
465 developed by Ponge (1984), who described a moder humus under a *Pinus sylvestris* forest station. The

466 use of thin sections, coupled with a point and count method allows a semi-quantitative evaluation of  
467 the proportion of each fabric unit composing Technosol humipedons. In addition to field  
468 measurements, the two-scale approach of the humipedon allows complementary information to be  
469 gathered, which is useful for humus form classification. Precise localization and identification of soil  
470 fauna fecal material can be made using thin sections and thereby provide relevant information as to the  
471 interactions between specific taxa and their environment (Bal, 1970). The nature and origin of the  
472 morphological features can be determined precisely using the classification developed by previous  
473 authors for natural soils (Stoops, 2003; Zaiets and Poch, 2018). However, in the case of humipedon  
474 developed on Technosol, additional fabric units are required in order to cover the whole spectrum of  
475 the constituents that can be encountered. In our case, the “fine and coarse coal” fabric unit appeared to  
476 be a required fabric unit on a former coking plant and allow discrimination between those site-specific  
477 features from other anthropogenic artefacts (Howard and Orlicki, 2016). In the case of Technosols  
478 high spatial heterogeneity, micromorphology on thin sections can highlight peculiar situations and  
479 specific links between neo-formed organic matter and parent technogenic material, such as the lack of  
480 aggregation between technogenic coal by-products and neo-formed organic matter.

481

## 482 5. Conclusion

483 Micromorphology have been shown to be a relevant tool for describing humus forms developing on  
484 Technosols. Our study has allowed the description of a new humus form that had developed on the  
485 humipedons of a former coking plant and led us to propose the name “techno-moder”. Footprints of  
486 specific soil fauna taxa revealed by micromorphology, as well as the identification and composition of  
487 diagnostic horizons are key elements required for the classification of humus form and help the  
488 description of current ecological processes occurring on Technosols. We think that an addition of  
489 details to the current “techno humus system” label is the next step toward an integrative understanding  
490 of anthropic activities and soil ecological processes such as organic matter transformation and  
491 bioturbation. Moreover, in a context of increasing anthropic pressure on soil systems, the capacity to

492 specify the exact humus form developing on such soils, could represent a promising way to understand  
493 (i) their pedogenesis and (ii) their ability to support ecological functions and biodiversity.

494

## 495 Acknowledgments

496 The authors would like to thank the GISFI ([gisfi.univ-lorraine.fr](http://gisfi.univ-lorraine.fr)) members, especially the technical  
497 staff, namely Adeline Combat and Yannick Cazes for the access to the study sites, as well as Jean-  
498 Claude Begin for the preparation of the soil thin sections.

## 499 Funding

500 This work was financially supported by the “Ministère de l’Enseignement Supérieur, de la Recherche  
501 et de l’Innovation” with a three-year doctoral scholarship.

## 502 Declarations of interest

503 None

## 504 References

505 Abakumov, E.V., Cajthaml, T., Brus, J., Frouz, J., 2013. Humus accumulation, humification, and  
506 humic acid composition in soils of two post-mining chronosequences after coal mining. *J. Soils*  
507 *Sediments* 13, 491–500. <https://doi.org/10.1007/s11368-012-0579-9>

508 Adhikari, K., Hartemink, A.E., 2016. Linking soils to ecosystem services — A global review.  
509 *Geoderma* 262, 101–111. <https://doi.org/10.1016/J.GEODERMA.2015.08.009>

510 Adriano, D.C., Page, A.L., Elseewi, A.A., Chang, A.C., Straughan, I., 1980. Utilization and Disposal  
511 of Fly Ash and Other Coal Residues in Terrestrial Ecosystems: A Review<sup>1</sup>. *J. Environ. Qual.* 9,  
512 333. <https://doi.org/10.2134/jeq1980.00472425000900030001x>

513 Andreetta, A., Macci, C., Ceccherini, M.T., Cecchini, G., Masciandaro, G., Pietramellara, G.,

514 Carnicelli, S., 2012. Microbial dynamics in Mediterranean Moder humus. *Biol. Fertil. Soils* 48,  
515 259–270. <https://doi.org/10.1007/s00374-011-0622-9>

516 Babel, U., 1975. Micromorphology of Soil Organic Matter, in: *Soil Components*. Springer Berlin  
517 Heidelberg, Berlin, Heidelberg, pp. 369–473. [https://doi.org/10.1007/978-3-642-65915-7\\_7](https://doi.org/10.1007/978-3-642-65915-7_7)

518 Bal, L., 1973. Micromorphological analysis of soils. Lower levels in the organization of organic soil  
519 materials. *Soil Surv. Institute, Wageningen Soil Surv. Pap. No. 6*.

520 Bal, L., 1970. Morphological investigation in two moder-humus profiles and the role of the soil fauna  
521 in their genesis. *Geoderma* 4, 5–36.

522 Barratt, B.C., 1969. A revised classification and nomenclature of microscopic soil materials with  
523 particular reference to organic components. *Geoderma* 2, 257–271.

524 Bernier, N., 2018. Hotspots of biodiversity in the underground: A matter of humus form? *Appl. Soil*  
525 *Ecol.* 123, 305–312. <https://doi.org/10.1016/j.apsoil.2017.09.002>

526 Bernier, N., Ponge, J.-F., 1994. Humus form dynamics during the sylvogenetic cycle in a mountain  
527 spruce forest 26, 183–220.

528 Biache, C., Faure, P., Mansuy-Huault, L., Cébron, A., Beguiristain, T., Leyval, C., 2013.  
529 Biodegradation of the organic matter in a coking plant soil and its main constituents. *Org.*  
530 *Geochem.* 56, 10–18. <https://doi.org/10.1016/j.orggeochem.2012.12.002>

531 Bradshaw, A., 1997. Restoration of mined lands—using natural processes. *Ecol. Eng.* 8, 255–269.  
532 [https://doi.org/10.1016/S0925-8574\(97\)00022-0](https://doi.org/10.1016/S0925-8574(97)00022-0)

533 Cundy, A.B., Bardos, R.P., Puschenreiter, M., Mench, M., Bert, V., Friesl-Hanl, W., Müller, I., Li,  
534 X.N., Weyens, N., Witters, N., Vangronsveld, J., 2016. Brownfields to green fields: Realising  
535 wider benefits from practical contaminant phytomanagement strategies. *J. Environ. Manage.* 184,  
536 67–77. <https://doi.org/10.1016/j.jenvman.2016.03.028>

537 Eijsackers, H., 2010. Earthworms as colonisers: Primary colonisation of contaminated land, and  
538 sediment and soil waste deposits. *Sci. Total Environ.* 408, 1759–1769.

539 <https://doi.org/10.1016/j.scitotenv.2009.12.046>

540 Frouz, J., 2013. Soil biota and ecosystem development in post mining sites. CRC Press, Boca Raton,  
541 FL.

542 Frouz, J., Elhottová, D., Kuráž, V., Šourková, M., 2006a. Effects of soil macrofauna on other soil  
543 biota and soil formation in reclaimed and unreclaimed post mining sites: Results of a field  
544 microcosm experiment. *Appl. Soil Ecol.* 33, 308–320.  
545 <https://doi.org/10.1016/j.apsoil.2005.11.001>

546 Frouz, J., Keplin, B., Pizl, V., Tajovsky, K., Sary, J., Luksesova, A., Novakowa, A., Balik, V., Hanel,  
547 L., Materna, J., Duker, C., Chalupski, J., Rusek, J., Heinkele, T., 2001. Soil biota and upper soil  
548 layer development in two contrasting post-mining chronosequences. *Ecol. Eng.* 17, 275-284 ST-  
549 Soil biota and upper soil layer deve. [https://doi.org/10.1016/S0925-8574\(00\)00144-0](https://doi.org/10.1016/S0925-8574(00)00144-0)

550 Frouz, J., Nováková, A., 2005. Development of soil microbial properties in topsoil layer during  
551 spontaneous succession in heaps after brown coal mining in relation to humus microstructure  
552 development. *Geoderma* 129, 54–64. <https://doi.org/10.1016/j.geoderma.2004.12.033>

553 Frouz, J., Pižl, V., Elhottová, D., 2006b. Soil and Soil Biota in Reclaimed and Non-Reclaimed Post  
554 Mining Sites. *J. Am. Soc. Min. Reclam.* 215–220. <https://doi.org/10.21000/JASMR06010215>

555 Frouz, J., Pižl, V., Tajovský, K., 2007. The effect of earthworms and other saprophagous macrofauna  
556 on soil microstructure in reclaimed and un-reclaimed post-mining sites in Central Europe. *Eur. J.*  
557 *Soil Biol.* 43, 184–189. <https://doi.org/10.1016/j.ejsobi.2007.08.033>

558 Ghosal, S., Self, S.A., 1995. Particle size-density relation and cenosphere content of coal fly ash. *Fuel*  
559 74, 522–529. [https://doi.org/10.1016/0016-2361\(95\)98354-H](https://doi.org/10.1016/0016-2361(95)98354-H)

560 Gillet, S., Ponge, J.F., 2002. Humus forms and metal pollution in soil. *Eur. J. Soil Sci.* 53, 529–539.  
561 <https://doi.org/10.1046/j.1365-2389.2002.00479.x>

562 González, A., Navia, R., Moreno, N., 2009. Fly ashes from coal and petroleum coke combustion:  
563 Current and innovative potential applications. *Waste Manag. Res.* 27, 976–987.

564 <https://doi.org/10.1177/0734242X09103190>

565 Guilloré, P., 1983. Méthode de fabrication mécanique et en série des lames minces, 2nd ed, Institut  
566 National Agronomique, Paris-Grignon, France. Institut National Agronomique Paris Grignon,  
567 Département des sols, Thiverval-Grignon.

568 Howard, J.L., Orlicki, K.M., 2016. Composition, micromorphology and distribution of microartifacts  
569 in anthropogenic soils, Detroit, Michigan, USA. *Catena* 138, 103–116.  
570 <https://doi.org/10.1016/j.catena.2015.11.016>

571 Huot, H., Morel, J.L., Schwartz, C., Nahmani, J., Sirguy, C., Watteau, F., Milano, V., Cortet, J.,  
572 2018. Diversity and activity of soil fauna in an industrial settling pond managed by natural  
573 attenuation. *Appl. Soil Ecol.* 132, 34–44. <https://doi.org/10.1016/j.apsoil.2018.08.020>

574 Jabiol, B., Zanella, A., Ponge, J.-F., Sartori, G., Englisch, M., Van Delft, B., De Waal, R., Le Bayon,  
575 R.-C., 2013. A proposal for including humus forms in the World Reference Base for Soil  
576 Resources (WRB-FAO). *Geoderma* 192, 286–294.  
577 <https://doi.org/10.1016/j.geoderma.2012.08.002>

578 Joimel, S., Cortet, J., Jolivet, C.C., Saby, N.P.A., Chenot, E.D., Branchu, P., Consalès, J.N., Lefort, C.,  
579 Morel, J.L., Schwartz, C., 2016. Physico-chemical characteristics of topsoil for contrasted forest ,  
580 agricultural , urban and industrial land uses in France. *Sci. Total Environ.* 546, 40–47.  
581 <https://doi.org/10.1016/j.scitotenv.2015.12.035>

582 Korkina, I.N., Vorobeichik, E.L., 2018. Humus Index as an indicator of the topsoil response to the  
583 impacts of industrial pollution. *Appl. Soil Ecol.* 123, 455–463.  
584 <https://doi.org/10.1016/j.apsoil.2017.09.025>

585 Koukouzas, N., Ketikidis, C., Itskos, G., 2011. Heavy metal characterization of CFB-derived coal fly  
586 ash. *Fuel Process. Technol.* 92, 441–446. <https://doi.org/10.1016/j.fuproc.2010.10.007>

587 Kubiëna, W., 1953. *Bestimmungsbuch und Systematik der Böden Europas*. Enke, Stuttgart 392.

588 Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., Heal, O.W., Dhillion, S., 1997.



589 Soil function in a changing world: The role of invertebrate ecosystem engineers. *Eur. J. Soil*  
590 *Biol.* 33, 159–193.

591 Ma, W., Eijsackers, H., 1989. The influence of substrate toxicity on soil fauna return in reclaimed  
592 land., in: *Animals in Primary Succession: The Role of Fauna in Reclaimed Land*. Cambridge: pp.  
593 233–43.

594 Markiewicz, M., Hulisz, P., Charzyński, P., Piernik, A., 2018. Characteristics of soil organic matter of  
595 edifisols – An example of techno humus system. *Appl. Soil Ecol.* 123, 509–512.  
596 <https://doi.org/10.1016/j.apsoil.2017.04.022>

597 Millennium Ecosystem Assessment, 2005. *Living Beyond Our Means: Natural Assets and Human*  
598 *Well-being*. Annu. Rep. 28. <https://doi.org/10.2111/RANGELANDS-D-13-00013.1>

599 Monserie, M.F., Watteau, F., Villemin, G., Ouvrard, S., Morel, J.L., 2009. Technosol genesis:  
600 Identification of organo-mineral associations in a young technosol derived from coking plant  
601 waste materials. *J. Soils Sediments* 9, 537–546. <https://doi.org/10.1007/s11368-009-0084-y>

602 Morel, J., Chenu, C., Lorenz, K., 2015. Ecosystem services provided by soils of urban, industrial,  
603 traffic, mining and military areas (SUITMAs). *J. Soils Sediments* 561–565.

604 Morel, J.L., Schwartz, C., Florentin, L., De Kimpe, C., 2005. Soil management and conservation:  
605 Urban soils, in: Hillel, D. (Ed.), *Encyclopaedia of Soils in the Environment*. pp. 202–208.

606 Mudrák, O., Frouz, J., Velichová, V., 2010. Understory vegetation in reclaimed and unreclaimed post-  
607 mining forest stands. *Ecol. Eng.* 36, 783–790. <https://doi.org/10.1016/j.ecoleng.2010.02.003>

608 Murphy, C.P., 1986. *Thin section preparation of soils and sediments.*, Berkhamsted (UK) A B  
609 Academic Publishers. <https://doi.org/10.1097/00010694-198710000-00013>

610 Owojori, O.J., Reinecke, A.J., 2009. Avoidance behaviour of two eco-physiologically different  
611 earthworms (*Eisenia fetida* and *Aporrectodea caliginosa*) in natural and artificial saline soils.  
612 *Chemosphere* 75, 279–283. <https://doi.org/10.1016/j.chemosphere.2008.12.051>

613 Ponge, J., Topoliantz, S., Ballof, S., Rossi, J., Lavelle, P., Betsch, J., Gaucher, P., Ponge, J.,

614 Topoliantz, S., Ballof, S., Rossi, J., Lavelle, P., 2010. Ingestion of charcoal by the Amazonian  
615 earthworm *Pontoscolex corethrurus* : a potential for tropical soil fertility. *Soil Biol. Biochem.* 38,  
616 2008–2009. <https://doi.org/10.1016/j.soilbio.2005.12.024>

617 Ponge, J.F., 2013. Plant-soil feedbacks mediated by humus forms: A review. *Soil Biol. Biochem.* 57,  
618 1048–1060. <https://doi.org/10.1016/j.soilbio.2012.07.019>

619 Ponge, J.F., 2003. Humus forms in terrestrial ecosystems: A framework to biodiversity. *Soil Biol.*  
620 *Biochem.* 35, 935–945. [https://doi.org/10.1016/S0038-0717\(03\)00149-4](https://doi.org/10.1016/S0038-0717(03)00149-4)

621 Ponge, J.F., 1984. Etude écologique d'un humus forestier par l'observation d'un petit volume,  
622 premiers résultats. I. La couche L1 d'un moder sous pin sylvestre. *Rev. d'Ecologie Biol. du Sol*  
623 21, 161–187.

624 Ponge, J.F., Chevalier, R., Loussot, P., 2002. Humus index: An integrated tool for the assessment of  
625 forest floor and topsoil properties. *Soil Sci. Soc. Am. J.* 66, 1996–2001.  
626 <https://doi.org/10.2136/sssaj2002.1996>

627 Rabot, E., Wiesmeier, M., Schlüter, S., Vogel, H.J., 2018. Soil structure as an indicator of soil  
628 functions: A review. *Geoderma* 314, 122–137. <https://doi.org/10.1016/j.geoderma.2017.11.009>

629 Rachwał, M., Magiera, T., Wawer, M., 2015. Coke industry and steel metallurgy as the source of soil  
630 contamination by technogenic magnetic particles, heavy metals and polycyclic aromatic  
631 hydrocarbons. *Chemosphere* 138, 863–873. <https://doi.org/10.1016/j.chemosphere.2014.11.077>

632 Rossiter, D.G., 2006. Proposal for a new reference group for the World Reference Base for Soil  
633 Resources ( WRB ) 2006 : the Technosols 2 nd revised draft. *Work. Gr. Technosols WRB* 16.

634 Salmon, S., 2004. The impact of earthworms on the abundance of Collembola: improvement of food  
635 resources or of habitat? *Biol. Fertil. Soils* 40, 323–333. [https://doi.org/10.1007/s00374-004-](https://doi.org/10.1007/s00374-004-0782-y)  
636 [0782-y](https://doi.org/10.1007/s00374-004-0782-y)

637 Schumacher, B.A., Shines, K.C., Burton, J. V., Papp, M.L., 1990. Comparison of Three Methods for  
638 Soil Homogenization. *Soil Sci. Soc. Am. J.* 54, 1187.

639 <https://doi.org/10.2136/sssaj1990.03615995005400040046x>

640 Séré, G., Schwartz, C., Ouvrard, S., Renat, J.C., Watteau, F., Villemin, G., Morel, J.L., 2010. Early  
641 pedogenic evolution of constructed Technosols. *J. Soils Sediments* 10, 1246–1254.  
642 <https://doi.org/10.1007/s11368-010-0206-6>

643 Sheoran, V., Sheoran, A., Poonia, P., 2010. Soil Reclamation of Abandoned Mine Land by  
644 Revegetation: A Review. *Int. J. Soil, Sediment Water* 3, 13.

645 Šourková, M., Frouz, J., Fettweis, U., Bens, O., Hüttl, R.F., Šantrůčková, H., 2005. Soil development  
646 and properties of microbial biomass succession in reclaimed post mining sites near Sokolov  
647 (Czech Republic) and near Cottbus (Germany). *Geoderma* 129, 73–80.  
648 <https://doi.org/10.1016/j.geoderma.2004.12.032>

649 Šourková, M., Frouz, J., Šantrůčková, H., 2005. Accumulation of carbon, nitrogen and phosphorus  
650 during soil formation on alder spoil heaps after brown-coal mining, near Sokolov (Czech  
651 Republic). *Geoderma* 124, 203–214. <https://doi.org/10.1016/j.geoderma.2004.05.001>

652 Stoops, G., 2003. Guidelines for Analysis and Description of Soil and Regolith Thin Sections. *Soil*  
653 *Sci. Soc. Am. J* 1. <https://doi.org/10.2134/jeq2004.1585>

654 Stoops, G., Marcelino, V., Mees, F., 2010. Interpretation of micromorphological features of soils and  
655 regoliths, Amsterdam: Elsevier.

656 Tiessen, H., Cuevas, E., Chacon, P., 1994. The role of soil organic matter in sustaining soil fertility.  
657 *Nature* 371, 783–785. <https://doi.org/10.1038/371783a0>

658 Topoliantz, S., Ponge, J.-F., 2003. Burrowing activity of the geophagous earthworm *Pontoscolex*  
659 *corethrurus* (Oligochaeta : Glossoscolecidae) in the presence of charcoal. *Appl. Soil Ecol.* 23,  
660 267–271. [https://doi.org/10.1016/S0929-1393\(03\)00063-5](https://doi.org/10.1016/S0929-1393(03)00063-5)

661 Topoliantz, S., Ponge, J.F., 2005. Charcoal consumption and casting activity by *Pontoscolex*  
662 *corethrurus* (Glossoscolecidae). *Appl. Soil Ecol.* 28, 217–224.  
663 <https://doi.org/10.1016/j.apsoil.2004.08.003>

664 Toutain, F., 1987. Activité biologique des sols, modalités et lithodépendance. *Biol. Fertil. Soils* 3, 31–  
665 38.

666 Vincent, Q., Auclerc, A., Beguiristain, T., Leyval, C., 2018. Assessment of derelict soil quality:  
667 Abiotic, biotic and functional approaches. *Sci. Total Environ.* 613–614, 990–1002.  
668 <https://doi.org/10.1016/j.scitotenv.2017.09.118>

669 Watteau, F., Huot, H., Séré, G., Begin, J.C., Rees, F., Schwartz, C., Morel, J.L., 2018. Micropedology  
670 to reveal pedogenetic processes in Technosols. *Spanish J. Soil Sci.* 8, 148–163.  
671 <https://doi.org/10.3232/sjss.2018.v8.n2.02>

672 Watteau, F., Jangorzo, N.S., Schwartz, C., 2019. A micromorphological analysis for quantifying  
673 structure descriptors in a young constructed Technosol. *Boletín la Soc. Geológica Mex.* 71, 11–  
674 20.

675 Wong, M.H., Bradshaw, A.D., 2003. The Restoration and Management of Derelict Land, The  
676 Restoration and Management of Derelict Land. <https://doi.org/10.1142/5179>

677 Xiang, W., Han, B., Zhou, D., Nzihou, A., 2012. Physicochemical properties and heavy metals  
678 leachability of fly ash from coal-fired power plant. *Int. J. Min. Sci. Technol.* 22, 405–409.  
679 <https://doi.org/10.1016/j.ijmst.2011.12.002>

680 Zaiets, O., Poch, R.M., 2018. Use of micromorphology for humus characterization and classification  
681 in some mediterranean calcareous soils. *Appl. Soil Ecol.* 123, 672–681.  
682 <https://doi.org/10.1016/j.apsoil.2017.09.016>

683 Zaiets, O., Poch, R.M., 2016. Micromorphology of organic matter and humus in Mediterranean  
684 mountain soils. *Geoderma* 272, 83–92. <https://doi.org/10.1016/j.geoderma.2016.03.006>

685 Zanella, A., Berg, B., Ponge, J.F., Kemmers, R.H., 2017a. Humusica 1, article 2: Essential bases-  
686 Functional considerations. *Appl. Soil Ecol.* 0–1. <https://doi.org/10.1016/j.apsoil.2017.07.010>

687 Zanella, A., Jabiol, B., Ponge, J.F., Sartori, G., De Waal, R., Van Delft, B., Graefe, U., Cools, N.,  
688 Katzensteiner, K., Hager, H., Englisch, M., 2011. A European morpho-functional classification

689 of humus forms. *Geoderma* 164, 138–145. <https://doi.org/10.1016/j.geoderma.2011.05.016>

690 Zanella, A., Ponge, J.-F., Briones, M.J.I., 2017b. *Humusica* 1, article 8: Terrestrial humus systems and  
691 forms – Biological activity and soil aggregates, space-time dynamics. *Appl. Soil Ecol.* 0–1.  
692 <https://doi.org/10.1016/j.apsoil.2017.07.020>

693 Zanella, A., Ponge, J.-F., Fritz, I., Pietrasiak, N., Matteodo, M., Nadporozhskaya, M., Juilleret, J.,  
694 Tatti, D., Le Bayon, R.-C., Rothschild, L., Mancinelli, R., 2018a. *Humusica* 2, article 13: Para  
695 humus systems and forms. *Appl. Soil Ecol.* 122, 181–199.  
696 <https://doi.org/10.1016/j.apsoil.2017.09.043>

697 Zanella, A., Ponge, J.-F., Gobat, J.-M., Juilleret, J., Blouin, M., Aubert, M., Chertov, O., Rubio, J.L.,  
698 2017c. *Humusica* 1, article 1: Essential bases – Vocabulary. *Appl. Soil Ecol.*  
699 <https://doi.org/https://doi.org/10.1016/j.apsoil.2017.07.004>

700 Zanella, A., Ponge, J.F., Jabiol, B., Sartori, G., Kolb, E., Gobat, J.M., Bayon, R.C. Le, Aubert, M.,  
701 Waal, R. De, Delft, B. Van, Vacca, A., Serra, G., Chersich, S., Andreetta, A., Cools, N.,  
702 Englisch, M., Hager, H., Katzensteiner, K., Brethes, A., Nicola, C. De, Testi, A., Bernier, N.,  
703 Graefe, U., Juilleret, J., Banas, D., Garlato, A., Obber, S., Galvan, P., Zampedri, R., Frizzera, L.,  
704 Tomasi, M., Menardi, R., Fontanella, F., Filoso, C., Dibona, R., Bolzonella, C., Pizzeghello, D.,  
705 Carletti, P., Langhor, R., Cattaneo, D., Nardi, S., Nicolini, G., Viola, F., 2017d. *Humusica* 1,  
706 article 4: Terrestrial humus systems and forms-Specific terms and diagnostic horizons. *Appl. Soil*  
707 *Ecol.* <https://doi.org/10.1016/j.apsoil.2017.07.005>

708 Zanella, A., Ponge, J.F., Jabiol, B., Sartori, G., Kolb, E., Le Bayon, R.C., Gobat, J.M., Aubert, M., De  
709 Waal, R., Van Delft, B., Vacca, A., Serra, G., Chersich, S., Andreetta, A., Kölli, R., Brun, J.J.,  
710 Cools, N., Englisch, M., Hager, H., Katzensteiner, K., Brêthes, A., De Nicola, C., Testi, A.,  
711 Bernier, N., Graefe, U., Wolf, U., Juilleret, J., Garlato, A., Obber, S., Galvan, P., Zampedri, R.,  
712 Frizzera, L., Tomasi, M., Banas, D., Bureau, F., Tatti, D., Salmon, S., Menardi, R., Fontanella,  
713 F., Carraro, V., Pizzeghello, D., Concheri, G., Squartini, A., Cattaneo, D., Scattolin, L., Nardi, S.,  
714 Nicolini, G., Viola, F., 2017e. *Humusica* 1, article 5: Terrestrial humus systems and forms - Keys

715 of classification of humus systems and forms. *Appl. Soil Ecol.* 1–12.

716 <https://doi.org/10.1016/j.apsoil.2017.06.012>

717 Zanella, A., Schad, P., Galbraith, J., Ponge, J.-F., 2018b. *Humusica* 2, Article 14: Anthropogenic soils

718 and humus systems, comparing classification systems. *Appl. Soil Ecol.* 122, 200–203.

719 <https://doi.org/10.1016/J.APSOIL.2017.07.006>

720

## 721 Table titles

722 Table 1: Main physico-chemical parameters of the Cambisol and the two Technosols from 0 to 20 cm. Values are mean  $\pm$  SD (n=5).

Soil classification	Cambisol	Technosol	
Soil parameters <sup>a</sup>	Station A	Station T1	Station T2
pH	7.9 $\pm$ 0.1	7.5 $\pm$ 0.3	7.6 $\pm$ 1.4
TOC (g kg <sup>-1</sup> )	186 $\pm$ 36	507 $\pm$ 62	410 $\pm$ 140
N (g kg <sup>-1</sup> )	6 $\pm$ 1	6 $\pm$ 1	8 $\pm$ 2
C/N	31 $\pm$ 9	84 $\pm$ 26	49 $\pm$ 9
CEC (cmolc kg <sup>-1</sup> )	47 $\pm$ 2	18 $\pm$ 5	28 $\pm$ 18
Clay (g kg <sup>-1</sup> )	507 $\pm$ 19	78 $\pm$ 21	112 $\pm$ 41
Silt (g kg <sup>-1</sup> )	336 $\pm$ 4	276 $\pm$ 43	248 $\pm$ 59
Sand (g kg <sup>-1</sup> )	157 $\pm$ 17	646 $\pm$ 65	640 $\pm$ 97
Water Holding Capacity (%)	26 $\pm$ 0.9	19.8 $\pm$ 3.5	21.2 $\pm$ 2.1
Bulk density (g cm <sup>-3</sup> )	0.97 $\pm$ 0.14	0.69 $\pm$ 0.07	0.98 $\pm$ 0.20

723

724 <sup>a</sup> Soil pH was measured according to the standard ISO 10390. Total organic carbon (TOC) and total nitrogen (N) were measured according to the standards NF

725 ISO 10694 and NF ISO 13878 respectively. Total cation exchange capacity (CEC) were measured using the cobalthyhexamine method (NF ISO 23470).

726 Particle size distribution analysis was performed according to the standard NF X 31-107. Bulk density (Bd) was calculated according to the norm NF EN ISO

727 11272. Water holding capacity (WHC) was assessed according to the standard NF EN ISO 274.

728 Table 2: Micromorphological description of thin sections

Plot	Depth (cm)	Continuity and boundary	Microstructure and porosity	Organic components	Excrements	Mineral material	Technogenic material
Aa	1-6.5	Continuous	Crumb microstructure, mostly composed of 4 mm subrounded blocky peds moderately separated and partially accommodated with channels as main voids and some compound packing voids within macroaggregates. Chambers are present as well	Organic components on the thin section are mostly composed of fine organic material within the inorganic micromass. Frequent living roots are present at all depth. Few plants residues containing phlobaphene-like substances within aggregates	Earthworms casts frequent within the first centimeters. They are similar to the s-matrix and composed of fine organic matter in the inorganic micromass and contain particulate coal grains. Some casts are welded. Lot of mesofaunal droppings within aggregates, mostly composed of FOM and inorganic micromass. Some of them contain small coal grains	Frequent quartz 20 - 200 µm, minerals < 20 µm are not visible at this scale and are supposed to be linked to fine organic matter	Fine coal 10-20% volume total embedded within the ground mass
T1b	0 - 1	Discontinuous with a sharp transition	Laminated microstructure	Leaf fragments, partly comminuted ; woody tissues with recognizable cell structures	Some mesofaunal feces between leaf fragments. Very few macro-arthropods comminuted feces	None	Few free particulate fine coal
	1 - 2.5	Discontinuous with a progressive transition	Crumb microstructure with compound packing void between arthropods feces and simple grains of coal fragments	Few leaf fragments residues, woody tissues filled with o-plasma and less cell structures. Undecomposed seeds	Very frequent mesofaunal feces filling most of the solid volume. Few macroarthropods feces containing humified plant tissues and few fine coal. Most are coalescent	Very few free sandy quartz	Particulate fine coal are frequent between mesofaunal feces
	2.5 - 6.5	Continuous	Complex granular and single grain microstructure with simple packing voids	Few living roots and decomposing roots with heterogeneous degrees of decomposition	Mites feces within decomposing roots fragments. Few arthropods coalescing feces composed of a mix of humified plant tissue and fine coal	Frequent sandy sized quartz and few undetermined minerals > 200 µm. Very few mineral < 200 µm	Fine and coarse coal fragments compose more than 50% of the solid volume.
T2b	0-2	Continuous with a progressive transition	Crumb microstructure composed by arthropods feces with compound packing voids	Leaves and woody tissues showing decomposition traces such as pigmentation of the cell walls and o-plasma within the tissues. Some cell structures are well preserved. Mycelium within and between plant tissues and excrements	Feces composing most of the solid volume. Macroarthropods and mesofaunal feces composed of plant tissue with heterogeneous decomposition stages. Some feces > 200 µm are coalescent but they are never welded	None	None
	2-6	Discontinuous	Complex massive and crumb microstructure with compound packing voids	Living and decomposing roots with different stages of decomposition. Dark brown roots and woody plant tissues showed evolve organic matter. Few leaves fragments remains with low cell structure and containing mycelium	25 to 50% of the solid volume. Proportion decrease with increased depth. Macroarthropods and mesofaunal feces composed of plant tissue with heterogeneous decomposition stages. Very few are welded, coalescence of macroarthropods feces is frequent. Composed of decomposing plant tissues with low cell structure and high o-plasma content	None	More than 50% of the solid volume is occupied by coarse anthropogenic fragments. Composed of a close porphyric distribution of sand-sized particles within an inorganic micromass
T2d	0-1	Discontinuous with a sharp transition	Laminated microstructure	Leaf fragments, partly comminuted ; woody tissue with preserved cell structure	Some mesofaunal feces between leaf fragments. Mites dropping in woody tissue. Very few macroarthropods comminuted feces	None	< 1% of fine particulate coal
	1-6	Discontinuous	Crumb microstructure with compound packing void : between arthropods feces and simple grains of coal fragments	Few humified woody tissue containing phlobaphene-like substances. Very frequent shapeless organic matter with (FOM) or without (POM) o-plasma indicating heterogeneous degree of decomposition. Few mycelium in the porosity	Very frequent, mostly holo-organic enchytreids feces within the fine coal fragments groundmass. Plant cell structure within feces is not preserved. Darkbrown feces indicating humified organic matter. Rare macroarthropods dropping (> 200 µm) containing humified organic matter, fine coal and few fine minerals. Comminuting feces liberating individualized components such as organic matter and fine coal forming the groundmass	< 5% sandy sized quartz. Very few undetermined coarse > 2 mm mineral	Fine coal composing most of the groundmass with up to 20% of the overall volume. The coarse fraction is mostly composed of cement with a close porphyric distribution of sand-sized particles within an inorganic micromass representing up to 40% of the overall volume. < 5% of coarse coal with alteration traces

729



## 730 Figure captions

731 Figure 1: Aerial view of the former coking plant area of Homécourt with the localization of the 3 study  
732 stations and photographs of the 3 soil profiles.

733 Figure 2: Main microstructure and pedofeatures of the humipedon of the station A. (a) and (d)  
734 respectively scan of the Ab and Ad thin sections. (b) General microstructure of the Ab thin sections  
735 with roots (Ro) and channels (Ch). (c) Welding of ageing earthworm casts with chambers (Cm) on the  
736 Ab thin section. (e) Earthworm cast composed of Fine Organic Material (FOM), fine mineral (fm) and  
737 fine coal (fc) within a pore (P) on the Ad thin section. (f) Droppings (Dr) of soil mesofauna within a  
738 macroaggregate on the Ad thin section.

739 Figure 3: Main microstructure and pedofeatures of the humipedon of the station T1. (a) and (d)  
740 respectively scan of the T1b and T1c thin sections (b) Laminated microstructure in the 1st centimeter  
741 of the thin section formed by undecomposed leaves (Lv). (c) Crumb microstructure composed by  
742 enchytraeids droppings (ed) and macrofaunal droppings (Dr) and various morphology of neoformed  
743 organic materials such as plant tissue (ti), particulate organic material (POM) or remains of leave  
744 fragments (Lv) and few fine particulate coal (fc) fragments on the T1c. (e) Root (Ro) within a  
745 groundmass composed of technogenic fine coal (fc) and coarse coal elements (cc) on the T1b thin  
746 section. (f) Bottom of the T1c thin section with a living and decomposing roots (Ro) in the fine coal  
747 groundmass (fc). (cT: coarse technogenic element).

748 Figure 4: Main microstructure and pedofeatures of the humipedon of the station T2. (a) and (d)  
749 respectively scan of the T2b and T2d thin sections. (b) Crumb microstructure of the T2b thin section,  
750 composed of arthropods droppings (Dr), fungi mycelium (My), roots (Ro) within a compound packing  
751 voids (P) near centimetric coarse technogenic artefact (cT). (c) Laminated microstructure on top of the  
752 T2d thin section formed by undecomposed leaves (Lv). (e) Random to crumb microstructure  
753 composed by mesofaunal droppings (Dr) and fine coal particles (fc) on the T2d thin section. (fT): fine  
754 technogenic elements; here a cement residu. (f) Cluster of mites dropping in a decomposing root  
755 fragment in the middle of the T2e thin section (scan not shown). (cm: coarse mineral).

756 Figure 5: Percentage distribution of each morphological features within the first 6 cm of each thin  
757 section. c\_anthro\_artef: coarse anthropogenic artefact (> 2 mm); c\_coal: coarse coal fragments (> 2  
758 mm); c\_mineral: coarse mineral; f\_anthro\_artef: fine anthropogenic artefact (< 2 mm); f\_coal: fine  
759 coal fragments (< 2 mm); f\_mineral: fine mineral (< 2 mm); FOM: Fine Organic Material;  
760 macro\_feces: macroarthropods feces (> 200 µm); meso\_feces: mesofaunal feces (< 200 µm); plant\_t:  
761 plant tissue; POM: Particulate Organic Material.

762 Figure 6: PCA of the proportion of every fabric unit at the 6 depth of the 11 thin sections.  
763 c\_anthro\_artef: coarse anthropogenic artefact (> 2 mm); c\_coal: coarse coal fragments (> 2 mm);  
764 c\_mineral: coarse mineral; f\_anthro\_artef: fine anthropogenic artefact (< 2 mm); f\_coal: fine coal  
765 fragments (< 2 mm); f\_mineral: fine mineral (< 2 mm); FOM: Fine Organic Material; macro\_feces:  
766 macroarthropods feces (> 200 µm); meso\_feces: mesofaunal feces (< 200 µm); plant\_t: plant tissue;  
767 POM: Particulate Organic Material.

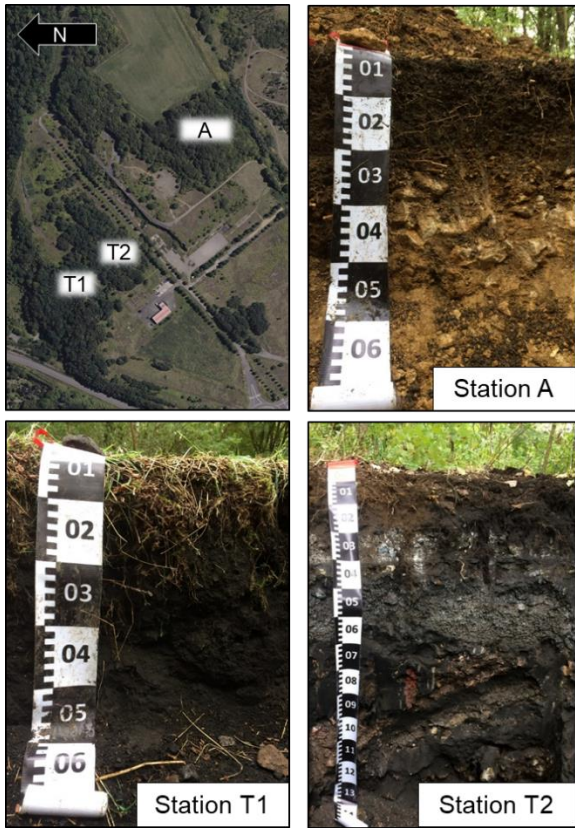


Figure 1

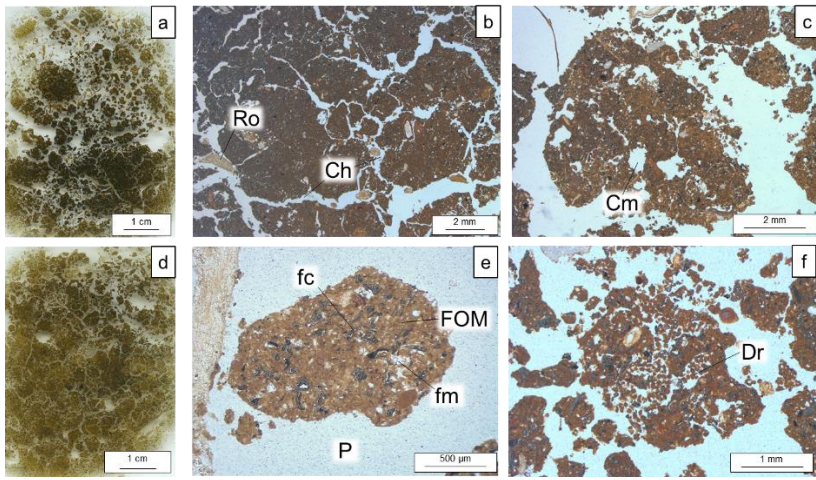


Figure 2

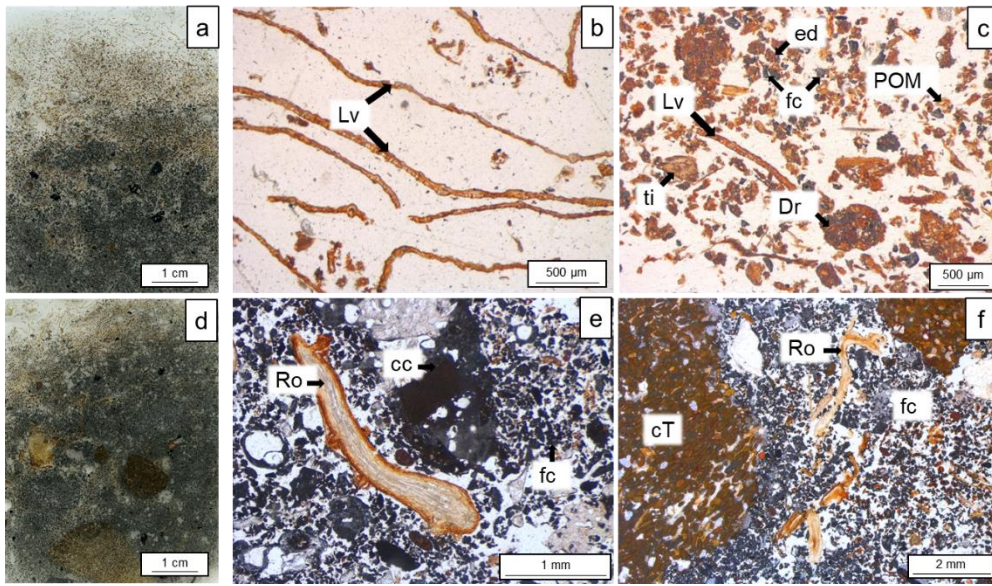


Figure 3

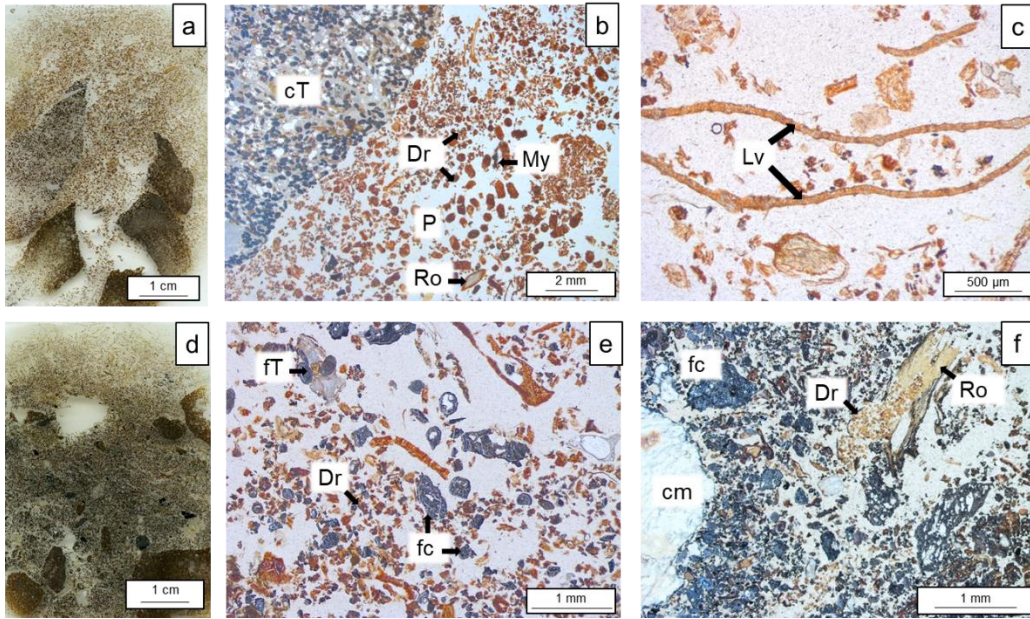


Figure 4

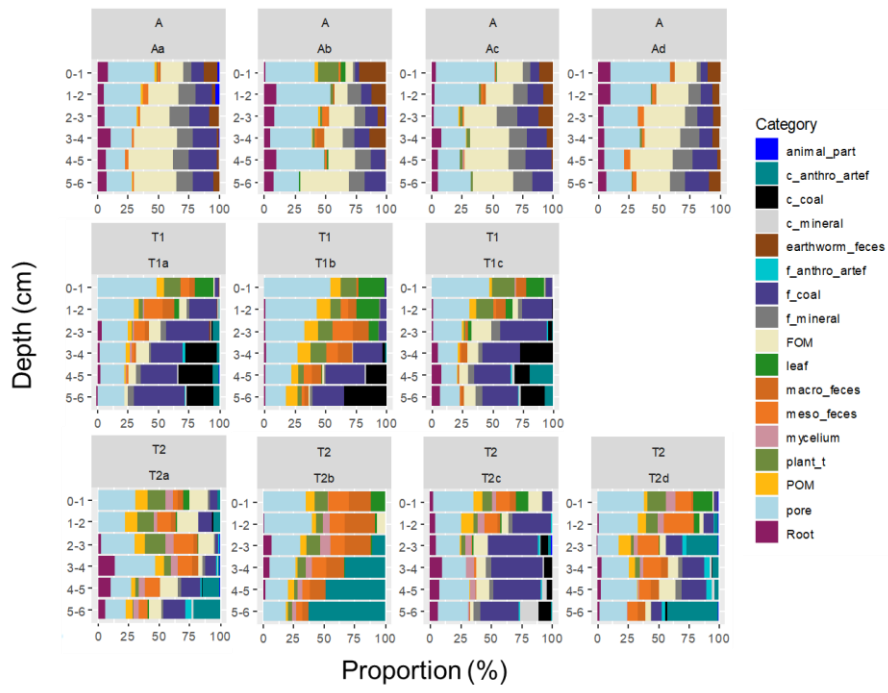


Figure 5

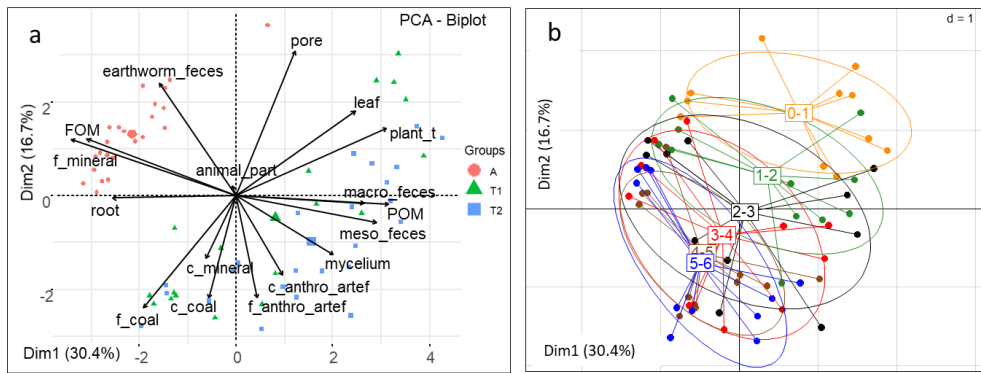
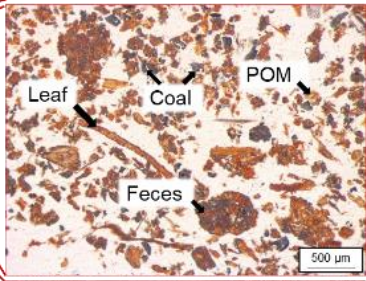
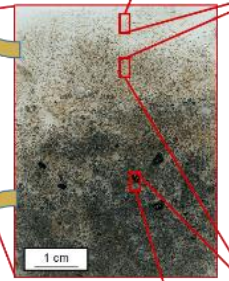
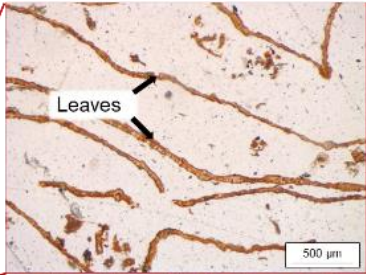


Figure 6

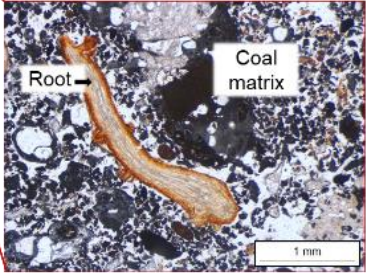


«Techno-moder» humus form on brownfield site

Litter derived organic matter:  
Soil fauna feces



Anthropogenic organic matter:  
Coal / charcoal



Humipedon as footprints of anthropic activity