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Article

The Pyrogenic Archives of Anthropogenically Transformed Soils in Central Russia

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Abstract: Charred materials (anthracomass) stored within a soil constitute a major part of its pyrogenic archive and could provide evidence of past fire events, both natural and anthropogenic. However, the dynamics of man-made contributions to the total anthracomass of soil at different time scales are insufficiently understood. In this study, we determined the anthracomass concentrations, stocks, and particle-size distribution in anthropogenically transformed soils of different genesis and ages. Materials were collected from the following archaeological sites within Central Russia—3 Upper Paleolithic sites (Avdeevo, Khotylevo-2 and Yudinovo-1), 2 Early Iron Age settlements (Khotylevo-2 and Yaroslavl), and 1 Medieval site (Yaroslavl). Samples from different cultural layers (CLs), plough layers, and native soils (control) were studied. We identified anthracomass accumulation over a wide chronological scale starting from the Upper Paleolithic Period. The high degree of preservation of anthracomass in ancient anthropogenically transformed soils was explained by the presence of large fragments of charred bones, which are more durable in comparison to wood charcoal. The anthracomass concentrations and stocks in the Early Iron Age plough layer were lower than those in the Medieval plough layer. CLs were generally more enriched in the anthracomass than plough layers, due to their sedimentational genesis, which is more favorable for anthracomass preservation than the turbational genesis of plough layers. However, the differences between charred particle sizes in synlithogenic CLs and turbational plough layers were less clear than expected, due to the specific conditions of formation of each particular layer, e.g., burial rate, duration of ploughing, and type of agricultural land use.

Keywords: charcoal; anthracomass; anthropogenic impact; Paleolithic; Iron Age; Medieval period

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1. Introduction

Soils preserve large amounts of information related to past environmental conditions and anthropogenic pressures. One aspect of the great diversity of such information is represented by the charred materials (anthracomass) of different genesis (wood and bone) that form the pyrogenic archive of soil. For example, recent studies on the species composition and the particle-size distribution of charcoal assemblages allowed for determinations of wildfire frequency and tree species composition and dynamics [1–14]. Of particular interest, there were several literature reviews showing that any territory colonized by people is inevitably subjected to fires, which results in the formation of pyrogenic archives of specific archaeological epochs [15–19]. The majority of studies to date focused on macro fragments of charcoal that are used in the identification of tree species burned by ancient people for various industrial or domestic purposes ([20–24] and others). There are few studies on the micro particles of charcoal [25] and even fewer assessments of the total reservoir of anthracomass produced by people [25,26]. Relationships between the content, genesis, and chronological dynamics of anthracomass were not yet investigated, until the present time.

The aim of this study was to determine the anthracomass concentration, stocks, and particle-size distribution in anthropogenically transformed soils of different genesis and ages within Central Russia.

2. Materials and Methods

The study materials were collected from archaeological sites of different ages within Central Russia, i.e., the central part of the East European Plain (Figure 1). Brief descriptions of the sites are given below; summarized in Table 1.

Figure 1. Locations of the study sites on the East European Plain. Indices are explained in Section 2.1 below and Table 1.

Table 1. Brief characteristics of the study sites and anthropogenically transformed soil horizons—cultural layers (CLs) and plough layers (Ap).

Index [1]	Site/GPS	Sample	Age	Topographic Position	Archaeological Culture	References
A	Avdeevo N51.6903° E35.8019°	CL, pit fill	Upper Paleolithic, 23–21 ky BP	Promontory of allegedly the 1st terrace of the Ragozna river	Eastern Gravettian (Kostenkovo-Avdeevo)	[27–30]
B	Khotylevo-2 N53.3469° E34.1081°	Hearth	Upper Paleolithic, 24–21 ky BP	Promontory of a flat interfluve between two U-shaped gullies that join the Desna river valley	Eastern Gravettian (Khotylevo)	[31,32]
C		CL, house fill	Early Iron Age, 3rd–5th centuries AD		Early Slavic (Kiev)	[33]
D	Yudinovo-1 N52.6708° E33.2828°	CL1 CL2	Upper Paleolithic, 14–12 ky BP	Promontory of the 1st terrace of the Sudost river (the tributary of Desna)	East-European Epigravettian (Timinovka-Yudinovo)	[34–36]
E	Yaroslavl N57.6264° E39.8933°	CL1	1220–1238 AD	The 2nd terrace at the confluence of Kotorosl and Volga rivers	Slavic	[16]
		CL2	Early 13th century AD			
		CL3	Middle of the 12th century AD			
F		Ap1	The 8th–10th centuries AD			
		Ap2	Early Iron Age		Dyakovo	

[1] Indices correspond to those in Figure 1.

2.1. Study Sites

2.1.1. The Upper Paleolithic Site of Avdeevo (A)

The Avdeevo site was located on the left bank of the Ragozna river (the right tributary of the Seim river), near the Avdeevo village, at a distance of 35 km from the city of Kursk, in the Oktyabrsky District of the Kursk Region. The cultural layer (CL) was formed on sandy loams and contained bones of the mammoth fauna (indicating that the ancient settlement was located within the periglacial zone) and numerous artifacts made of stone (large arrowheads, knives of Kostenkovo type, etc.) and bone (e.g., female figurines). The archaeological findings from this CL were subdivided into two assemblages located at different depths that were separated by a fill of different composition. Both assemblages originated from typical earthen houses of the Kostenkovo-Avdeevo archaeological culture. Such houses were characterized by the presence of various pits and large hearths. The Kostenkovo-Avdeevo culture is generally regarded as a variety of the East-European Gravettian culture. Detailed archaeological descriptions of this site were published by [27–30].

2.1.2. The Upper Paleolithic Site of Khotylevo-2 (B)

The Khotylevo-2 site was located on the right bank of the Desna River, at the north-western margin of the Khotylevo village in the Bryansky District of the Bryansk Region. This site is mostly known for the Upper Paleolithic CL containing vestiges of the Khotylevo version of the Eastern Gravettian culture. The CL, which was concealed under loess-like sandy loams 3–8 m thick, was excavated at five points within the study site. The archaeological finds originated from a dark brown organic-rich sandy loam layer that was 2–4 cm thick and included the following—flint microliths, bones of the mammoth fauna (the periglacial zone indicator), items made of bone and tusk (e.g., ornate arrowheads and female figurines), hearths, pits, charred bone, ocher, stone tools, etc. This site was described in detail by [31,32].

2.1.3. The Early Iron Age Site of Khotylevo-2 (C)

At the same location of Khotylevo-2, there was a CL of an Early Iron Age settlement of the Kiev (Early Slavic) culture, dated between the 3rd–5th centuries AD. Archaeological excavations exposed numerous utility pits and traces of earthen houses, with finds of rare metal items (e.g., metal knives and fishing hooks), fragmented pottery, clay spindle whorls, and a sharpening stone. The archaeological report on this site was published recently [33].

2.1.4. The Upper Paleolithic Site of Yudinovo-1 (D)

The Yudinovo-1 site was located on the right bank of the Sudost river (the right tributary of the Desna river), within the Yudinovo village in the Pogarsky District of the Bryansk Region. Archaeological excavations exposed two CLs of the Upper Paleolithic Age in loess-like sandy loams. The findings included vestiges of five bone-earthen constructions (so-called "mammoth bone houses") of the Anosovo-Mezino type, pits, bones of the mammoth fauna, charred bone fragments, ocher stains, and numerous items made of stone, bone, and tusk (e.g., ornate spearheads). This site was identified as a monument of the Timinovka-Yudinovo variety of the East-European Epigravettian culture. Detailed descriptions of this site were published in [34–36].

2.1.5. The Early Iron Age and Medieval Sites of Yaroslavl (E, F)

The Yaroslavl Kremlin on the highly raised interfluve between Volga and Kotorosl rivers was the most ancient part of the city of Yaroslavl, which was located approximately 280 km to the north-east of Moscow. In the Early Iron Age (Dyakovo culture) and during the Early Middle Ages (Slavic culture between the 8th–10th centuries AD), this site was used as a ploughland. A small settlement was founded there in the early 11th century AD. By the middle of the 12th century, Yaroslavl became a fortified settlement, which resulted in the accumulation of the deepest CL studied by us. The early 13th century CL was associated with constructions of the first stone church and the "Prince's Court". The uppermost CL of

1220–1238 coincided with the fire of 1221, followed by town expansion and the building of new fortifications that sealed the native soils. The chronicles mention Yaroslavl as being among the towns that suffered from the 1237–1238 Mongol Tatar invasion. Recently, we published a detailed description of the Yaroslavl site [16].

2.1.6. Control Samples

At each study site, we collected subsoil samples from native soils to use as controls, which allowed us to assess and compare the pyrogenic archives created by the different archaeological cultures. The native soils were represented by Retisols and Podzols (according to the WRB).

2.2. Methods

2.2.1. Grouping of Sites

In order to reveal the most significant changes in the composition, concentration, and stocks of the anthracomass accumulated due to human activities, we subdivided the study sites into two chronological groups that included charred materials of different genesis.

Group 1—the Upper Paleolithic (12–24 ky BP), which comprised charred materials from localized ash pockets (corresponding to ancient hearths), as well as continuous CLs.

Group 2—the last millennia including the Early Iron Age and the Middle Ages (the 3rd—the 13th centuries AD), which comprised charred materials from the Ap layers and CLs that were considered to be anthropogenically transformed soils of "turbational" (regularly disturbed, mixed) and the "sedimentational" (accumulative) genesis, respectively.

2.2.2. The Extraction of Anthracomass from Soil Samples

Charred materials were extracted using our modifications of standard techniques [1,5,25]. Soil samples 500–1100 cm^3 taken from each unit (see Table 1) were dispersed to extract charred particles, which were then separated by wet sieving into the following fractions: >5, 5–2, 2–1, and 1–0.5 mm. The obtained fractions were then dried, weighed, and inspected, using soft tweezers and a Leica MZ6 binocular.

2.2.3. Determination of Anthracomass Concentration, Stocks, and Particle-Size Distribution

The anthracomass (g) was determined within a layer of certain thickness. The values of anthracomass concentration (ppm) were determined as a proportion of anthracomass of the total mass of soil, according to [1,2]. The actual anthracomass stocks (kg/m^2) were calculated per unit area, based on the bulk density and thickness of the studied layer. The normalized anthracomass stocks per unit area within a 10-cm-thick layer were used for a comparative analysis of the data obtained in terms of the spatial distribution of pyrogenic archives.

The determinations of anthracomass concentration (ppm) and its stocks (kg/m^2) are the main methods of quantitative analyses used in modern anthracology. In this work, we used both methods to compare their informative potentials and limitations.

We also determined the particle-size distribution of anthracomass from the weights of anthracomass fractions in the studied samples of anthropogenically-transformed soils.

2.2.4. Charcoal Identification

Selected fractions of anthracomass were studied under a Nikon Eclipse E200 (Nikon Corporation, Minato, Tokyo, Japan) optical microscope and a JEOL 6610LV (JEOL, Akishima, Tokyo, Japan) scanning electron microscope (SEM) with an INCAx-act microanalyzer (Oxford Instruments, Abingdon, UK). We separated charred wood from charred bone. In well-preserved charcoal fragments of coarse fractions (>5 and 5–2 mm), original tree species were identified using the handbook by Barefoot and Hankins [37], together with our charcoal reference collection and the anatomy atlas [38].

In the Khotylevo-2 hearth sample, we additionally analyzed the fraction of less than 0.5 mm, under the SEM with the microanalyzer.

3. Results and Discussion

3.1. Anthracomass

The majority of samples taken from the anthropogenically transformed soils, independent of their genesis (turbational or sedimentational), dramatically differed from the control samples in terms of their anthracomass concentration and stocks (Figure 2 and Table S1).

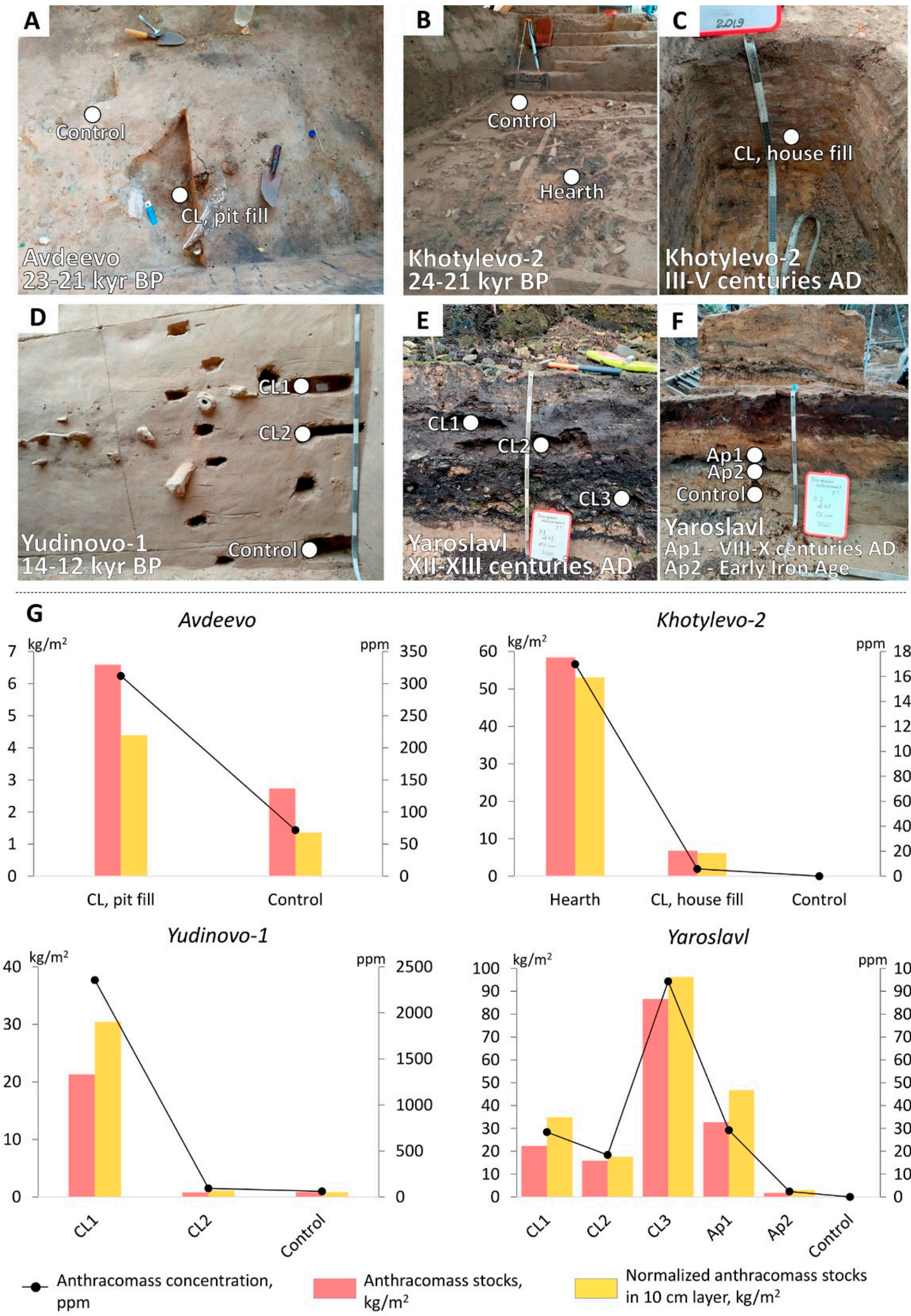

Figure 2. Anthracomass sampling locations (**A**–**F**) and anthracomass concentration and stocks (**G**) in the anthropogenically transformed soil horizons.

The sites of Group 1 included an ash pocket corresponding to the ancient hearth (Khotylevo-2) that was characterized by the highest anthracomass concentration. The Upper Paleolithic CL1 of Yudinovo-1, despite its greater age, had nearly the same anthracomass concentration and stocks as the Medieval CL1 of Yaroslavl. In some cases, normalization of anthracomass stocks was particularly useful. For example, the actual anthracomass stocks of the CL2 of Yudinovo-1 appeared to be slightly lower than the control, because the latter had a greater thickness, but the normalized stocks were slightly higher.

All samples from Group 2 sites were, to varying degrees, enriched in charred materials. The anthracomass concentration and stocks in the Medieval Ap1 and CLs from Yaroslavl were not related to the genesis of those layers, with the maximal values found within the lowest CL3, which is associated with the first fortified settlement at this site. A comparison of Early Iron Age samples showed that the plough layer (Ap2) from Yaroslavl contained less anthracomass than the house filled from Khotylevo-2. However, the Medieval plough layer (Ap1) had significantly higher anthracomass concentration and stocks than either of the Early Iron Age samples.

The data obtained clearly demonstrated a significant human contribution to the formation of pyrogenic archives in soils. Due to the anthropogenic activity, the soil anthracomass stocks increased in most cases by at least several times or occasionally by an order of magnitude and even more (the anthracomass stocks increment could be as high as $n \times 10^3$, in comparison to the background level in soil). Even horizons with low anthracomass concentrations (CL2 in Yudinovo-1, Ap2 in Yaroslavl) were enriched in pyrogenic material, as compared to the control (as for the stocks—after data normalization).

At the same time, we found no direct relationship between the level of society development, the density of settlements, and the amount of pyrogenic material stored in CLs. For example, in the Paleolithic CLs, the anthracomass stocks could be higher than those in more recent anthropogenically transformed soil horizons. The anthracomass stocks of closely related CLs could differ by an order of magnitude, even within the context of one historic-cultural group.

3.2. Particle-Size Distribution of Anthracomass

Results of the particle-size distribution analysis of the samples are presented in Figure 3.

The Upper Paleolithic sites were characterized by the predominance of either the 1–0.5 mm fraction (Khotylevo-2 Hearth and Yudinovo-1 CL2) or the coarsest fraction (Avdeevo CL and Yudinovo-1 CL1). An irregular particle-size distribution was also observed in the medieval sites. The medieval plough layer (Yaroslavl Ap1) was characterized by a predominance of the coarsest fraction (>5 mm). The underlying Early Iron Age plough layer (Yaroslavl Ap2) was dominated by the 5–2 mm fraction, with no particles >5 mm. Apparently, such particle-size distribution is predetermined by the past processes involved in the formation of these layers.

The studied CLs were generally more enriched in anthracomass. This could be explained by genetic differences, i.e., the sedimentational genesis of CLs is favorable for anthracomass preservation and the turbational genesis of plough layers leads to the fragmentation of large charcoal particles due to regular mixing. However, the observed differences between charred particle sizes in synlithogenic CLs and turbational plough layers were less clear than expected in most samples, except for the Early Iron Age plough layer (Yaroslavl Ap2), probably due to the specific conditions of formation of each particular layer, e.g., rate of burial, duration of ploughing, etc. Anthracomass parameters of plough layers could also dramatically vary due to differences in agricultural land use, for example, arable lands or kitchen gardens.

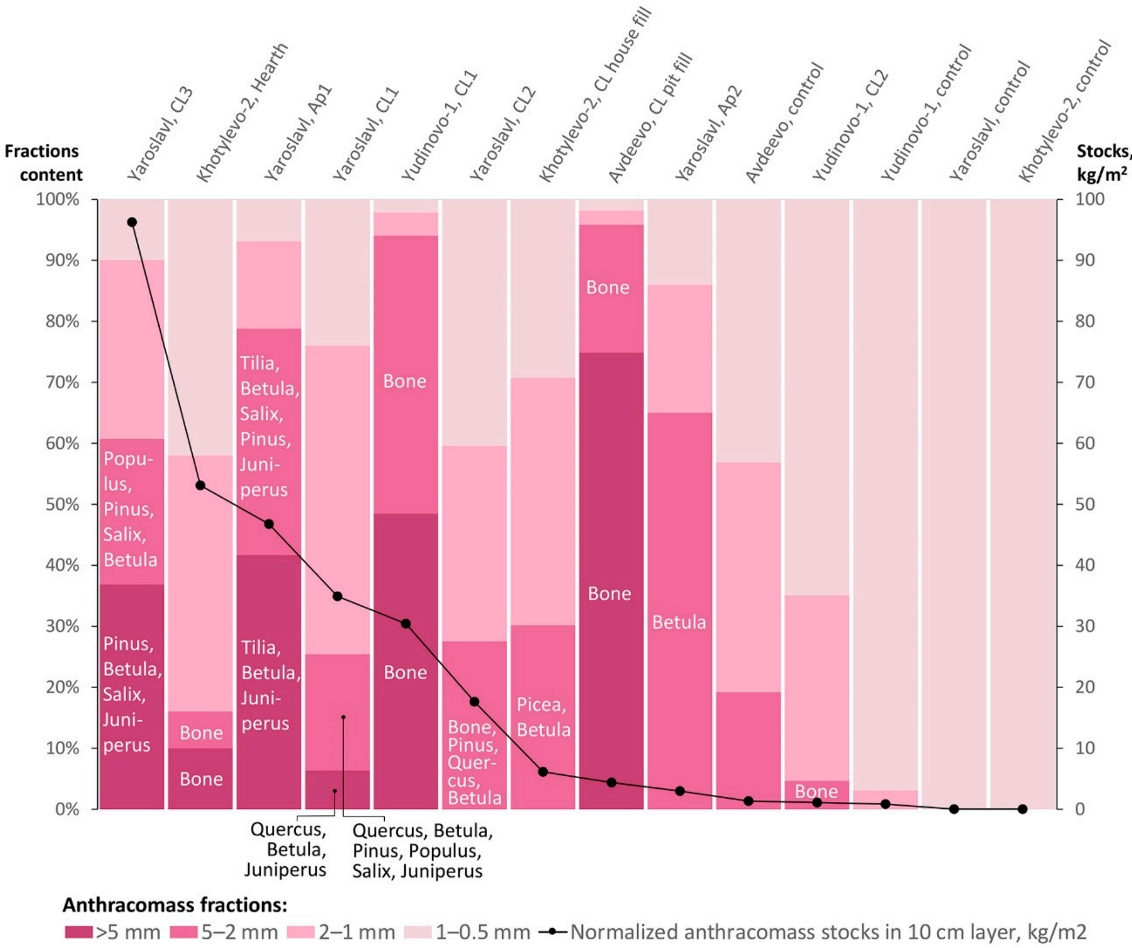

Figure 3. The particle-size distribution and identification of charcoal.

3.3. Identification of Charred Materials

The data of charcoal identification are presented in Figures 3 and 4 and Table S2. In all samples of Group 1 (Upper Paleolithic), coarse fractions were represented by charred bone (Figure 4A,B), which could be explained by its high durability in the ancient CLs. Our observations did not agree with the data from the south of France, where the presence of large fragments of wood charcoal was reported in even more ancient layers [39]. However, the French researchers collected samples from a cave, i.e., a closed system, whereas we studied CLs that represent an open system and, therefore, were not protected from natural climatic fluctuations over the past 12–24 thousand years.

In the Khotylevo-2 hearth sample, the fraction of less than 0.5 mm contained plant cells consisting of biogenic silica (i.e., phytoliths), as well as debris of plants that do not form phytoliths (Figure 4C,D). Therefore, the fraction of <0.5 mm from the hearth consisted of strongly fragmented charcoal that originated from trees and herbs.

Regarding the samples from Group 2 (Middle Ages and Early Iron Age), charred bone was found only in the 5–2 mm fraction of the Yaroslavl CL2, despite the fact that the presence of bone fragments was generally typical of CLs. The other samples of Group 2 consisted entirely of charcoal, which originated from the tree species (Figure 4E,F) that is common for the natural zones of the study sites. As an exception, there were specimens of oak charcoal in CLs from Yaroslavl, which was located within the middle taiga subzone dominated by coniferous forests, therefore, it was not ruled out that oak could have been imported to this site.

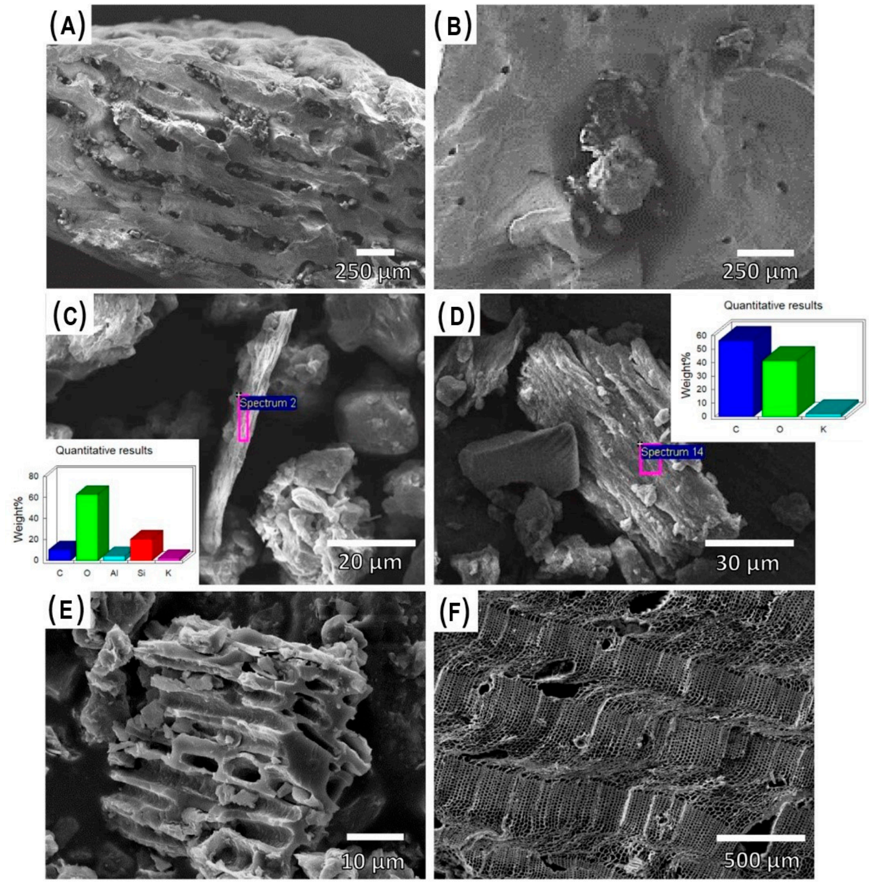

Figure 4. Anthracomass composition—charred bones >5 mm in (**A**) Yudinovo-1 CL1 and (**B**) Khotelevo-2, hearth; plant debris <0.5 mm in Khotelevo-2, hearth—(**C**) plant debris consisting of biogenic silica (phytoliths) and (**D**) plant debris that do not form phytoliths; charred wood particles in (**E**) Khotylevo-2 CL, house fill, and (**F**) Yaroslavl CL3.

The largest charred fragments in the studied samples occurred in the most ancient CLs and originated from bones. Due to the high preservation capacity of the charred bones, the contribution of ancient communities (Upper Paleolithic) to pyrogenic soil archives could be significantly higher than that of more recent cultures (Early Iron Age, Khotylevo-2).

4. Conclusions

The data obtained confirmed the thesis that human activities result in the enrichment of nearby soils by charred materials. We identified anthracomass accumulation over a wide chronological scale starting from the Upper Paleolithic Period. The high degree of preservation of anthracomass in ancient anthropogenically transformed soils could be explained, most probably, by the presence of large fragments of charred bone, which is durable in comparison to wood charcoal. Nevertheless, large quantities of wood charcoal occurred in the fine fractions of the anthracomass from ancient hearths.

The content of anthracomass in the Early Iron Age plough layer was lower than that in the Medieval plough layer. This could be explained by the use of wood ash as a fertilizer in the Middle Ages, as well as the low degree of preservation of charcoal in layers where charcoal is subjected to disintegration, due to the growth of plant roots and the activity of soil fauna.

The studied CLs were generally more enriched in anthracomass than plough layers. This could be explained by genetic differences, i.e., the sedimentational genesis of CLs is favorable for anthracomass preservation and the turbational genesis of plough layers leads to the fragmentation of large charcoal particles, due to regular mixing. However, the difference between the charred particle sizes in synlithogenic CLs and turbational plough layers was not so clear, which was due to the specific conditions of formation of each particular layer, e.g., burial rates, duration of ploughing, and different types of agricultural land use (e.g., arable lands or kitchen gardens).

The anthracomass concentration calculated as a proportion of the total mass of soil was more informative than the actual or normalized anthracomass stocks calculated per unit of soil area in those cases where the analyzed layers were thinner than the control samples. In other cases, both methods were equally efficient for quantitative evaluations of man-made contributions to the pyrogenic archives of soils.

The results presented in this paper are the initial findings from a large series of planned studies on the nature of pyrogenic components in anthropogenically transformed soils of different ages and genesis in Russia. Our data unequivocally demonstrated a major increment of soil anthracomass as a result of human activity in the past. While this ancient reservoir of pyrogenic carbon is significant, it is poorly understood and suggests further detailed research on the relationship between the combustion and the charring processes, ash-to-char ratios, identification of wood, straw and bone char, as well as its degradation processes with the use of a full set of micromorphological, phytolith, palynological, and chemical analyses.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/geosciences11040165/s1. Table S1: Anthracomass (AM) properties in anthropogenically transformed soil horizons. Table S2: The particle-size distribution and identification of charred materials.

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Data Availability Statement: The data presented in this study are available within this article.

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Conflicts of Interest: The authors declare no conflict of interest.

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