Characteristics of Soil Carbon Buried for 3300 Years in a Bronze Age Burial Mound

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To elucidate the mechanisms responsible for the long-term retention of soil C, soil samples were retrieved from a paleosolic A horizon (M_{bur}) buried underneath a Bronze Age mound and from waterlogged anaerobic (M_{an}) and aerobic zones (M_{ae}) within the mound. For comparison with a modern soil, samples were taken from the surrounding arable field (Ar). The soils were characterized by cross-polarization magic angle spinning ^{13}C nuclear magnetic resonance spectroscopy, by phospholipid fatty acid (PLFA) analysis, and by CO_2 production during incubation. At sampling, the Ar, M_{an} , M_{ae} , and M_{bur} soils contained 22.6, 17.9, 6.5, and 6.2 g C kg $^{-1}$ soil, respectively. Compared with the Ar and M_{an} soils, the M_{bur} and M_{ae} soils were depleted in alkyl C, N-alkyl C, and O-alkyl C and enriched in aromatic and carboxylic groups. The content of PLFA in the mound soils was much lower than normally found for arable soils and the ability of the deprived biomass to decompose glucose was retarded and included a 2- to 3-wk lag phase. The lability of C left under aerobic conditions for more than three millennia did not differ significantly from that of C in the contemporary Ar soil. Although the chemical nature of the C in the Ar and M_{an} soils was similar, C that had resided under anaerobic conditions was less labile than C from the arable soil. We consider the persistence of C in the unwaterlogged parts of the burial mound to result from physical restrictions imposed on gas exchange and water availability, and thus restricted microbial activity, rather than from biochemical recalcitrance of the remaining C.

Abbreviations: NMR, nuclear magnetic resonance; OM, organic matter; PLFA, phospholipid fatty acid.

The turnover and long-term retention of organic matter (OM) in soil is important not only for plant growth but also for the global C cycle (Janzen, 2005). Enhanced sequestration of C in soil may be a measure to alleviate increasing atmospheric CO_2 levels, provided that the C is retained in soil OM pools with slow turnover. Radiocarbon dating has shown that OM may indeed persist in the soil for centuries (Falloon and Smith, 2000), but the quantitative significance of the mechanisms responsible for long-term retention of OM in soil remain obscured. Nevertheless, most compartment models for the simulation of OM turnover and storage in soil include a pool of refractory soil OM (RSOM). These pools are taken to include biologically inert OM or OM with extremely slow turnover rates (Christensen, 1996a; Falloon and Smith, 2000). The slow turnover time of RSOM pools excludes direct verification on the time scale of even the longest running field experiment.

More than 100,000 burial mounds have been identified in southern Scandinavia and other parts of northern Europe (Kristiansen et al., 2003). Bronze Age mounds were typically constructed entirely from sods that were cut from the area surrounding the burial site and placed upside down (Holst et al.,

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1998). Today, therefore, the mounds contain OM that has been stored for millennia under contrasting conditions with regard to temperature, gas exchange, and water availability (Breuning-Madsen and Holst, 1998).

When the Danish Bronze Age burial mound Skelhøj was excavated in 2002 to 2004 as part of an archaeological investigation, we obtained soil samples from different parts of the mound. Carbon in the mound soil was characterized in terms of chemical composition and lability during incubation, and the decomposer community was characterized by its ability to decompose added substrates and by the contents of extractable phospholipid fatty acids (PLFAs). We envisaged that analyses of C from the mound would contribute to the identification of mechanisms responsible for the chemical stabilization of C in soil.

MATERIALS AND METHODS

The Skelhøj Mound

The Skelhøj burial mound is located on a glacial outwash plain in southern Jutland (55°25' N; 8°52' E) near the present Kongeå River valley. The plain is dominated by periglacial solifluction material (unsorted loamy sand with gravels) from nearby Saale moraines overlying a stratified subsoil of Weichselian outwash sand deposits (Breuning-Madsen and Dalsgaard, 2008). The climate is temperate Atlantic, with mean annual precipitation and temperature of 850 mm and 8.3°C, respectively. Radiocarbon dating has established that the mound was erected about 3300 yr BCE (Kristiansen et al., 2003).

The mound was built of sods cut from the topsoil layers of the grassland or heath-covered area that surrounded the burial site and placed with top downward. A paleosol horizon buried beneath the mound provides evidence of arid plowing. Following completion, the mound was about seven meters high, with a diameter of about 30 m. Two grave robbing disturbances had affected the central parts of the mound, the first apparently shortly after the construction and the last of them dating to the 19th century CE. The pedological processes taking place since the mound was erected have caused systematic differences in the soil from the outside toward the bottom of the mound. The resulting profile can be divided into four major sections (Breuning-Madsen and Dalsgaard, 2008): (i) the outer 1 m of the mantle strongly influenced by root activity and bioturbation, (ii) the well-drained mantle below with distinct sods, (iii) the core with distinct hydromorphic features and encapsulated by an upper semipermeable and a lower impermeable ferruginous (Fe) pan, and (iv) the paleosolic A horizon beneath the lower Fe pan of the core (Fig. 1). The diameter of the core was 15 m and the paleosol beneath the core has been protected from percolation by the lower impermeable Fe pan. The core can be subdivided vertically into an upper predominantly aerobic part and a lower anaerobic part serving as a stagnant water basin.

Soil Sampling

Soil samples were retrieved from three positions (Fig. 1): from the aerobic part of the core (M_{ac}), from the anaerobic part of the core just above the lower Fe pan (M_{an}), and from the paleosolic A horizon situated beneath the lower Fe pan (M_{bur}). The soils were air dried and sieved (2 mm). Soil characteristics are shown in Table 1. Soil was also collected from the 0- to 20-cm depth in the surrounding arable field (Ar), where 10 subsamples were bulked to obtain a representative sample. The textural composition was similar to the mound soils but liming had raised the pH of this soil (Table 1).

Incubation

The sieved soil was compressed in stainless steel cylinders (100 cm³; diameter 61 mm, height 34 mm) by sequentially filling four portions of soil into the cylinder. Each individual portion was compressed with a manual tamper before the next portion was added. The resulting soil bulk density was 1.54, 1.53, 1.51, and 1.49 Mg m⁻³ for M_{ac} , M_{an} , M_{bur} , and Ar, respectively. The soil was incubated either unamended or amended with glucose (2 g glucose C kg⁻¹ soil), inorganic nutrients [1 g (NH₄)₂SO₄ kg⁻¹ soil plus 0.1 g KH₂PO₄ kg⁻¹ soil], or a humic acid preparation (2 g C kg⁻¹ soil) purchased from Aldrich Chemical Co. (Milwaukee, WI). The various amendments were first dissolved in water and then an appropriate volume of the solutions was applied between each of the four soil portions when these were added to the cylinders. Each soil and treatment was incubated in three replicates, providing a total of 48 cylinders. The soil water content was adjusted to -10 kPa. The actual amount of water needed to obtain this matric potential was determined in a preliminary test in which three samples of each soil packed to the same bulk

Fig. 1. Cross-section of the Skelhøj burial mound showing the different profile sections and the positions from which soil was sampled (marked with squares): buried A horizon and anaerobic and aerobic parts of the core. The disturbed area suffered an intrusion by grave robbers.

Table 1. Characteristics of the soils sampled in the mound and in the surrounding arable field.

Soil origin	Clay (<2 μm)	Silt (2–63 μm)	Sand (63–2000 μm)	Total N	Total C	C/N	pH(CaCl ₂)
	g kg ⁻¹ soil						
Arable soil (Ar)	67	100	797	1.8	22.6	12	6.4
Buried A horizon (M_{bur})†	49	119	821	0.5	6.2	12	5.1
Aerobic core (M_{ae})	56	101	831	0.5	6.5	14	4.5
Anaerobic core (M_{an})	51	99	835	1.1	17.9	17	4.9

† Texture from Breuning-Madsen and Dalsgaard (2008).

density were saturated with water and then drained to -10 kPa on sand boxes (Schjønning, 1985).

Each cylinder was placed on a supporting metal mesh (mesh size of 4 by 4 mm) in sealed 2-L jars and incubated in the dark at 20°C. A beaker with water (10 mL) was placed in each jar to minimize sample desiccation during the incubation. Evolved CO₂ was absorbed in 20 mL of 1 mol L⁻¹ NaOH, the NaOH being renewed after 2, 4, 6, 8, 13, 20, 27, 34, 41, 48, and 62 d. Any loss of water from the cylinders (checked by weighing) was corrected by a mist sprayer. The CO₂ trapped in the NaOH was determined by titration of excess NaOH with 1 mol L⁻¹ HCl after precipitation with 1 mol L⁻¹ BaCl₂ (adapted from Anderson, 1982).

Carbon-13 Nuclear Magnetic Resonance

To concentrate the OM and to remove paramagnetic material, the soil samples were treated with HF before solid-state nuclear magnetic resonance (NMR) analysis. Ten-gram samples were shaken with 50 mL of 10% (w/w) HF for 12 h in polyethylene bottles. After centrifugation, the supernatants were siphoned off and discarded. The procedure was repeated five times at room temperature. The remaining sediment was washed five times with 40 mL of deionized water and freeze-dried.

The solid-state ¹³C NMR spectra were obtained on a Bruker DSX 200 (Bruker Biospin, Billerica, MA) operating at a frequency of 50.3 MHz using zirconium rotors of 7 mm o.d. with KEL-F-caps. The cross-polarization magic angle spinning technique was applied during spinning of the rotor at 6.8 kHz. A ramped ¹H pulse was used during contact time to circumvent spin modulation of Hartmann–Hahn conditions. The ¹³C chemical shifts were calibrated to tetramethylsilane (=0 ppm) and glycine (176.04 ppm). Between 11,096 and 191,478 scans were accumulated for each sample using a pulse delay of 300 to 500 ms. Tests in which ¹H-spin-lattice relaxation times were measured confirmed that this delay was sufficient to avoid saturation. A line broadening of 50 to 100 Hz occurred before Fourier transformation was applied. The relative distribution of C was determined by integrating the signal intensity in various chemical shift regions assigned to alkyl C (0–45 ppm), N-alkyl and methoxyl C (45–60 ppm), O-alkyl C (60–110 ppm), aromatic C and alkenes (110–160 ppm), carboxyl and amide C (160–185 ppm), and ketones and aldehydes (185–245 ppm). At the spinning speed of 6.8 kHz, the chemical shift anisotropy cannot be completely averaged and corrections concerning the intensity distribution were made according to Knicker et al. (2005) by adjusting intensities to that of the parent signal.

Phospholipid Fatty Acids

Lipids were extracted from 1-g soil samples of the three mound soils (M_{ae} , M_{an} , and M_{bur}) with a 1:2:0.8 mixture of chloroform, methanol, and 50 mmol L⁻¹ phosphate buffer ($n = 3$). Phospholipid fatty acids were isolated, methylated, and analyzed as described by Nielsen and Petersen (2000).

Statistical Methods

For CO₂ evolution in the incubation study, the variance between replicates differed for the four treatments. To obtain variance homogeneity, data for accumulated CO₂ evolution after 62 d were logarithmically transformed before the statistical analyses were performed with general linear models using Version 9.1 of SAS (SAS Institute, 1988).

RESULTS AND DISCUSSION

Soil Sampling Environments

The Skelhøj mound (Fig. 1) consisted of topsoil sods that had been stored under contrasting gas, moisture, and temperature regimes since the Bronze Age. The lower impermeable Fe pan is considered to have developed relatively soon after the mound was erected, leading to an accumulation of water (Breuning-Madsen and Holst, 1998), and the M_{an} soil from the lower part of the core has probably resided under anaerobic conditions most of the time. As the lower Fe pan situated above the buried paleosol (M_{bur}) prevented downward movement of water, the M_{bur} soil must have been subject to sustained dry conditions. Also, due to the depth of soil overlying the paleosol, temperatures have been constantly low (around 8°C), and low O₂ and elevated CO₂ concentrations have prevailed. The formation of the upper Fe pan indicates that the entire core of the mound was originally water saturated and thus anaerobic. The grave-robbing trenches dug into the mound after its construction broke the pans and lowered the water level. Numerous Fe and Mn precipitation bands in the upper part of the core suggest that the M_{ae} soil has been under fluctuating anaerobic and aerobic conditions. The M_{an} soil from the lower part of the core appears to have remained water logged and anaerobic, however, and showed no sign of Fe precipitations. Since the core was encapsulated by an Fe pan, it is unlikely that the M_{ae} , M_{bur} , and M_{an} soils have received additional OM following the erection of the mound. Therefore, we consider the OM residing in the mound soils at the time of sampling to have been preserved from the time when the sods were cut.

Microbial Activity

The cumulated CO₂ evolution from unamended soil was much greater for Ar than for the mound soils, in which respiration decreased from M_{bur} to M_{ae} and M_{an} (Table 2). When expressed as a proportion of the initial content of soil C, M_{bur} lost 2.6%, which was significantly more than M_{ae} , where 1.5% of soil C was evolved. Neither of these two aerobic soils differed significantly from Ar, which lost 1.8% of its C content. The least C was lost from the M_{an} soil, with only 0.4% of the soil C being evolved as CO₂.

Usually added glucose is readily consumed by the soil microbial biomass and addition of glucose did increase the production of CO₂ from all soils (Fig. 2). While CO₂ was evolved

without delay from the glucose-amended Ar soil, however, there was a distinct lag phase of 2 to 3 wk in the CO₂ evolution from the mound soils. Occurrence of a lag phase has also been observed in sand amended with glucose and microbial inoculum (Hamer et al., 2004). The lag phase and the reduced rate of CO₂ evolution from glucose-amended mound soils gave a lower total loss of glucose C than found for the arable soil (Fig. 3). At the end of the incubation, 82% of the glucose C had been evolved as CO₂ from the Ar soil, whereas 57% was evolved from M_{an} and 44 to 46% from M_{bur} and M_{ae}.

The microbial biomass was substantially reduced in the three mound soils, as determined from the PLFA analysis. The PLFA concentrations in M_{ae}, M_{an}, and M_{bur} corresponded to 0.8, 2.5, and 1.4 $\mu\text{mol PLFA kg}^{-1}$ soil, which is 10 to 20 times less than the concentration of PLFA normally found in arable soil (25–35 $\mu\text{mol PLFA kg}^{-1}$ soil; Nielsen and Petersen, 2000). Due to the low concentrations, a reliable identification of individual fatty acids was not possible. It appears that the severely deprived biomass in the mound soils was unable to metabolize glucose initially, while the Ar soil metabolized glucose immediately following its addition. More than 20 d of incubation was required to establish an active population of glucose-metabolizing microorganisms in the mound soils. Significant reductions in soil microbial biomass have also been observed by Demkina et al. (2000) in a 1650-yr-old paleosol located beneath a burial mound. Demkin et al. (1995) and Khomutova et al. (2004) observed different proportions of total to active soil microbial biomass in two paleosols of different ages, but, in accordance with our study, soil buried for up to 4000 yr was found to retain microorganisms that could be reactivated by glucose.

The humic acid preparation represents a mixture of condensed and highly oxidized OM compounds dominated by biologically resistant materials. The turnover rate of humic acid C was consequently very low (Fig. 2). For two of the mound soils (M_{bur} and M_{ae}), the evolution of CO₂ from the humic acid amended samples was not different from that of the unamended soils (Table 2). Thus the mound soils, stored for more than three millennia without fresh OM inputs, did not seem to have selected for microorganisms adapted for decomposition of resistant OM. The Ar and M_{an} soils showed a significant net increase in respiration, with 7 to 8% of the humic acid C being evolved as CO₂, but the temporal pattern of CO₂ production differed between the two soils (Fig. 3). While the CO₂ evolution from humic acid added to the Ar soil followed a

Table 2. Cumulated evolution of CO₂ after 62 d of incubation of soil samples amended with glucose, inorganic nutrients, or humic acid or left unamended.

	Glucose	Inorganic nutrients	Humic acid	Unamended
	$\log(\text{g CO}_2\text{-C kg}^{-1} \text{ soil})$			
Arable soil (Ar)	0.723 aA†	−0.677 aBC	−0.570 aB	−0.886 aC
Buried A horizon (M _{bur})	0.068 bA	−2.590 bcC	−1.987 bB	−1.883 bB
Aerobic core (M _{ae})	−0.105 bA	−2.817 cC	−2.065 bB	−2.370 cBC
Anaerobic core (M _{an})	0.192 bA	−2.501 bC	−1.620 bB	−2.627 cC

† Values within a column followed by the same lowercase letter are not significantly different ($P > 0.05$); values within a row followed by the same uppercase letter are not significantly different ($P > 0.05$).

hyperbolic function, the production of CO₂ in the M_{an} soil increased linearly throughout the incubation and no lag phase was observed.

Application of inorganic nutrients had little effect on CO₂ evolution (Fig. 2), although inorganic nutrients apparently reduced the CO₂ production in the M_{bur} soil (Table 2). Thus a lack of N, P, K, and S was not considered to have been a limiting factor in the decomposition of the OM residing in any of the mound soils.

Carbon-13 Nuclear Magnetic Resonance

The NMR spectra of the soils are given in Fig. 4. The aliphatic C in the region between 0 and 45 ppm was distinctive in the Ar and M_{an} soils and was ascribed to alkyl C in lipids, plant waxes, fatty acids, and amino acid residues (Mahieu et al., 1999; Knicker et al., 2005). The peak occurring at 54 ppm, related to methoxyl groups and N-substituted alkyl C, dominated in the Ar soil, while the signals around 72 and 103 ppm in the O-alkyl region were tentatively assigned to carbohydrate-derived structures (Knicker et al., 2005). The intensity near 128 ppm was distinct in the M_{ae} and M_{bur} soils and was assigned to aromatic C and alkenes. Carboxyl, amides, and esters were considered responsible for the peak at 173 ppm.

Fig. 2. Evolution of CO₂ from incubated soil samples of arable soil (Ar), buried A horizon (M_{bur}), and aerobic (M_{ae}) and anaerobic (M_{an}) parts of the core. The soil was amended with glucose, inorganic nutrients, or a humic acid preparation or left unamended and incubated for 62 d at 20°C and −10 kPa. Bars denote ± 1 SE ($n = 3$).

Fig. 3. Percentage of (A) glucose C and (B) humic acid C evolved as CO₂ during incubation of arable soil (Ar), soil from the aerobic (M_{ae}) and anaerobic (M_{an}) parts of the core, and soil from the buried A horizon (M_{bur}). Only data with significant differences in CO₂ evolution between the corresponding amended and unamended soil (Table 2) are presented. Bars denote ±1 SE (*n* = 3).

Fig. 4. Cross-polarization magic angle spinning ¹³C nuclear magnetic resonance spectra taken on soil samples from the arable soil (Ar), the buried A horizon (M_{bur}), and the aerobic (M_{ae}) and anaerobic (M_{an}) parts of the core.

Fig. 5. Relative abundance of functional groups in samples of the arable soil (Ar), the buried A horizon (M_{bur}), and soil from the aerobic (M_{ae}) and anaerobic (M_{an}) parts of the core.

The relative abundance of the functional groups is shown in Fig. 5. Compared with M_{bur} and M_{ae}, C in the Ar and M_{an} soils was enriched in alkyl, N-alkyl, and O-alkyl C and depleted in aromatics and to some extent also in carboxyl groups. The C content in M_{bur} and M_{ae} corresponded to only 27 and 29% of the C in the Ar soil (Table 1), while the anaerobic soil (M_{an}) held more C than the two other mound soils (corresponding to 79% of the C in Ar). Our results for the M_{an} soil are in line with the results of Scanlon and Moore (2000), showing that anaerobic conditions slow the mineralization of added OM considerably. When the relative abundance of the functional groups was related to the actual C contents in the samples, the M_{ae} and M_{bur} soils appeared to be depleted in all C forms compared with Ar (Table 3). The aromaticity percentage, defined as [aromatic C (110–160 ppm)/(aromatic C (110–160 ppm) + aliphatic C (0–110 ppm)] 100 (Fründ et al., 1994), was higher for C in M_{bur} and M_{ae} soils (49 and 59%, respectively) than for C in the Ar and M_{an} soils (20 and 28%, respectively). The aromaticity of the C in the M_{an} soil resembled that of the C in the Ar soil, but the percentage of C held in the 110 to 160 ppm region was slightly higher for M_{an} than for Ar (Table 3).

For both peat (Preston et al., 1989) and mineral soils (Baldock et al., 1992), a high degree of decomposition increases the proportion of alkyl C while O-alkyl C decreases. In an intermediate stage of decomposition, a certain enrichment of aromatic C seems to occur (Baldock et al., 1992), but changes associated with aromatic C are generally small and more variable than found for alkyl and O-alkyl C (Preston et al., 1989; Baldock et al., 1992; Quideau et al., 2001). Based on their location of sampling and their very reduced C contents (Table 1), the M_{bur} and M_{ae} soils could be considered to contain more decomposed C than the Ar and M_{an} samples; however, M_{bur} and M_{ae} did not follow this general pattern of a higher proportion of alkyl C. In contrast, these two soils had higher aromaticity and lower alkyl C than the other two soils (Ar and M_{an}).

The sensitivity of ¹³C NMR spectroscopic analysis is often too low to reveal changes in the composition of C in soil sampled within a given location (Mahieu et al., 1999). For soil subject to more than a century of contrasting fertilization (unmanured, mineral fertilizer, or animal manure), Randall et al. (1995) found only small differences in the distribution of C functional groups as revealed by ¹³C NMR. A statistical

Table 3. Distribution of soil C across functional groups in the arable soil (Ar) and the soils from the burial mound. The C content relative to the arable soil is indicated for each chemical shift.

Functional group	Chemical shift	Arable soil	Buried A horizon		Aerobic core		Anaerobic core	
			Conc.	Relative content	Conc.	Relative content	Conc.	Relative content
	ppm	– g C kg ⁻¹ soil –		% Ar C	g C kg ⁻¹ soil	% Ar C	g C kg ⁻¹ soil	% Ar C
Alkyl-C	0–45	7.4	1.1	14	1.2	16	5.3	71
N-alkyl	45–60	1.8	0.3	14	0.2	11	1.2	67
O-alkyl	60–110	6.1	1.2	19	0.8	13	4.4	72
Aromatic	110–160	3.8	2.4	65	3.0	80	4.3	115
Carboxyl	160–185	2.7	1.0	37	1.0	38	1.9	71
Ketone/aldehyde	185–245	0.8	0.3	34	0.3	38	0.8	96
Aromaticity, %†		20	49		59		28	

† Aromatic C (110–160)/[aromatic C (110–160) + aliphatic C (0–110)]100 (Fründ et al., 1994).

analysis of 311 published NMR spectra (Mahieu et al., 1999) demonstrated a remarkable similarity among soils with respect to the distribution of functional groups across a wide range of land uses, soil origins, OM contents, and climatic conditions. For the four soils included in our study, we observed distinct differences in the NMR spectra. Although the conditions for OM turnover in the M_{an} and Ar soils would have been very different, their ¹³C NMR spectra revealed greater similarities than between the spectra from the M_{an} soil and from the M_{ae} and M_{bur} soils. The aromatic region (110–160 ppm) turned out to be most prominent in the M_{bur} and M_{ae} soils, whereas the O- and N-alkyl C region accounted for the highest proportions of C in the Ar and M_{an} soils. The differences in aromaticity between soils were substantial (from 20% in the Ar to 59% in the M_{ae} soil) and much greater than differences induced by long-term (~30–100 yr) fertilization and variations in organic inputs (Kiem et al., 2000). Macroscopic plant remains recovered from the sods were found to show signs of heath burning and the sods may have contained varying amounts of charred materials when retrieved from the field. The M_{ae} and M_{bur} spectra having a high intensity in the aromatic region were comparable to spectra typically obtained for fire-affected soils (Knicker et al., 2006) and archaeological soils (Schmid et al., 2002). The high aromaticity in the M_{bur} and M_{ae} samples may thus result from a charcoal signal combined with altered decomposition in the two soils compared with Ar and M_{an} .

CONCLUSIONS

The mechanisms for stabilization of OM in soil can be divided into three different categories (Christensen, 1996b): (i) biochemical recalcitrance due to enzymatic, or free radical or other nonenzymatic reactions or to inherent chemical characteristics of substrates, (ii) chemical stabilization of otherwise labile substrates by interactions with, e.g., clay minerals or sesquioxides, and (iii) physical protection of otherwise labile substrates by physical barriers between substrates and decomposers. The biochemical recalcitrance is considered to be important during the early phases of decomposition, while the importance of spatial inaccessibility and of chemical stabilization by organo–mineral interactions dominates in the later stages of decomposition (Lützow et al., 2006). All mound soils evolved CO₂ during the unamended incubations, where microbial activity relied exclusively on indigenous OM. Since the M_{bur} and M_{ae} soils probably had been subject to aerobic conditions while in the mound, it was envisaged that the OM left in these

soils would be dominated by recalcitrant material. In line with this, the reduced C content in the two soils (~6 g C kg⁻¹ soil) and the relatively high aromaticity suggest that the availability of the OM to decomposers might be reduced; however, the lability of the OM, expressed by the fraction of soil C that was decomposed during the 2 mo of incubation of M_{bur} and M_{ae} soils, was not significantly different from that of the Ar soil. Thus C residing in the M_{bur} and M_{ae} soils does not seem to be dominated by biochemically recalcitrant or chemically stabilized OM fractions. The OM may have been physically protected while residing in the mound and then released by the disturbance related to sampling and sample pretreatments. We therefore consider the persistence of C in the nonwaterlogged parts of the burial mound to result mainly from physical restrictions imposed on gas exchange and water availability.

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