Architecture of Relict Charcoal Hearths in Northwestern Connecticut, USA

Raab, Thomas; Brandenburg University of Technology Cottbus-Senftenberg - Geopedology and Landscape Development, Cottbus, Brandenburg, Germany

Hirsch, Florian; Brandenburg University of Technology Cottbus-Senftenberg - Geopedology and Landscape Development, Cottbus, Brandenburg, Germany

Ouimet, Will; University of Connecticut, Department of Geography and Center for Integrative Geosciences, Storrs, Connecticut, USA

Johnson, Katharine; University of Connecticut, Department of Geography and Center for Integrative Geosciences, Storrs, Connecticut, USA

Dethier, David; Williams College, Department of Geosciences, Williamstown, Massachusetts, USA

Raab, Alexandra; Brandenburg University of Technology Cottbus-Senftenberg - Research Centre Landscape Development and Mining Landscapes, Cottbus, Brandenburg, Germany

Scientific editing by Rolfe Mandel

ABSTRACT

Relict charcoal hearths are round or elliptical earthen platforms up to 11 m in diameter and a widespread feature of historical industry that supplied charcoal used in the production of iron in furnaces or smelters. The iron industry dominated Litchfield County, Connecticut and surrounding areas in the northeast United States throughout the 19th century, peaking in ~1850. The large number of charcoal hearths in this region is a relic of > 150 years of widespread iron production. In this study, we describe the architecture and soil stratigraphy of 26 charcoal hearths in Litchfield County. This contribution aims to 1) compare soils that comprise the charcoal hearths with “natural” adjacent soils; 2) measure the thickness of topsoil developed upon the hearths; and 3) characterize the stratigraphy associated with

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these features. Results indicate that the black topsoils overlying the charcoal hearths contain residual charcoal and are on average 2.6 times thicker than adjacent Cambisols. Charcoal hearths display two or more black, charcoal-rich strata separated by layers of reddish-brown soil low in charcoal content indicating multiple episodes of use. We also find that many charcoal hearths have been stabilized with boulders on the downslope side during construction and repeated use. Overall, the results presented here provide significant information regarding the construction, use, and associated impacts of earthen platforms for charcoal production in the northeast United States, with further relevance to other areas where historical charcoal production occurred.

1. INTRODUCTION

Large relict charcoal hearths, herein termed charcoal hearths, are anthropogenic features often found in historical mining areas that document the pyrolytic production of charcoal as an energy resource from wood. Besides the archaeological aspects of charcoal hearths, the potential impacts of charcoal burning on ecosystems and particularly the pedosphere must be considered. These include increased accumulation and storage of soil organic carbon (Borchard et al., 2014) and their disadvantageous effects on plant growth (Mikan and Abrams, 1995, 1996). The interrelationships of archaeological remains with geomorphological and pedological processes make charcoal hearths a perfect subject for geoarchaeological research.

Charcoal hearths have been documented in Germany (Raab et al. 2014), Great Britain (Bond, 2007; Crutchley, 2010), the Netherlands (Groenewoudt, 2005), France (Fruchart, et al., 2011), Belgium (Deforce et al., 2013) and Norway (Risbøl et al., 2013) as well as the northeast United States (Johnson, Ouimet & Raslan 2015; Potter, Brubaker & Delano 2013; Rolando, 1992). Discovery of several thousand charcoal hearths in the North German Lowland has increased awareness that historical charcoal production may have significantly contributed to late Holocene landscape changes (Raab et al., 2014; Schirren, 2008). In recent years, newly available and highly accurate Digital Elevation Models (DEMs), based on high-resolution Light Detection and Ranging (LIDAR) data have been used to identify these archaeological remains (Schneider et al., 2014). Other regions in Germany with a high density of charcoal hearths are reported from several low mountain ranges in Germany such as the Black Forest (Hesse, 2013) and the Harz Mountains (Knapp, Nelle & Kirleis 2015). Especially in the Harz Mountains, smaller charcoal hearths are often found constructed on slopes with evidence of multiple use.

Charcoal production also occurred at regional scales in the US from the Mid-Atlantic to New England, though its effects on the landscape have not been thoroughly studied. Charcoal hearths have been surveyed at local scales in Vermont (Rolando, 1992), and deforestation associated with charcoal production has been linked to increased sediment mobilization during the 19th century in the Mid-Atlantic (Merritts et al., 2011). Recently, an evaluation of topographic LIDAR data revealed over 3000 charcoal hearths in a 40 km^2 area of Pennsylvania (Potter, Brubaker & Delano 2013) and >20,000 charcoal hearths in a 1170 km^2 area of Litchfield County in northwest Connecticut (Johnson et al., 2015). These results depict a new and emerging picture of the human impacts on soil landscape evolution in the northeast US.

Preliminary field surveys in Litchfield County suggested differences between soils located inside and outside the perimeter of charcoal hearths. Soils developed within the perimeter seem to have comparatively thick, humus-rich and charcoal-rich topsoils whereas topsoils located outside the perimeter are typically thinner and less rich in humus. We conducted a more thorough investigation to test the hypothesis that the remains of historical charcoal burning strongly influence the properties, distribution and development of local soils. Our study 1) compares soils that comprise the charcoal hearths with adjacent "natural" soils, 2) measures the thickness of topsoil overlying the charcoal hearths, and 3) characterizes their stratigraphy. This short contribution presents the first results from our field studies focusing on the architecture and soil stratigraphy of 26 charcoal hearths in Litchfield County.

2. MATERIALS AND METHODS

The study area is located ~60 km west of Hartford, Connecticut and ~140 km north-northeast of New York City (Fig. 1) within the Appalachian Highlands, an area characterized by rolling uplands dissected by valleys (Stone et al., 2005). The south-flowing Housatonic River is the main fluvial component in the study area. However, floodplains are narrow and thus the main geomorphological elements are hillslopes. Glacial sediments, mainly tills, assigned to the Wisconsin glaciation (Late Glacial Maximum), are widespread (Stone et al., 2005). Lithology and texture of glacial deposits are diverse although clasts of local metamorphic bedrock and loamy gravels are quite abundant. Glacial sediments almost entirely cover the bedrock geology: marble and schist to the west and east of the Housatonic River, respectively. Soils that are developed in glacial tills are mainly Cambisols (IUSS Working Group WRB, 2014), mesic Lithic Dystrudepts or mesic Typic Dystrudepts in the US Soil taxonomy, with diagnostic cambic horizons indicating brunification (Web Soil Survey USDA 2016). The climate is temperate (mean annual temperature 7.2–8.3 °C; average annual precipitation 1200–1350 mm), and most parts of the landscape are covered with deciduous forests (e.g., maple, oak, birch, aspen).

Historically, Litchfield County was the location of the Salisbury Iron District, known nationally for production of high-quality pig iron and derivative iron products manufactured at nearby foundries and blacksmith shops (Knowles, 2013; Knowles & Healey, 2006; U.S. Census Bureau, 1850a, 1850b). During property surveys for town settlement in the early 1730s, iron ore was discovered and small-scale extraction began (Gordon, 2001a; Gordon & Raber, 2000; Kirby, 1998). By the mid-18th century, bloomeries, forges, and iron works opened along the major rivers in the area, and the first furnace was operating by 1762 (Gordon, 2001a). At least 24 known blast furnaces were built between 1762 and 1872, with ~80 % operating simultaneously in 1856 (Gordon, 2001a; Gordon & Raber, 2000; Harte, 1944; Kirby, 1998; Lesley, 1859). By the turn of the 20th century, only three furnaces were still in operation; the last, owned by the Barnum & Richardson Corporation, went out of blast in 1923.

Historical census records at the height of iron production for Litchfield County in 1850 show that blast furnaces in the towns of Cornwall, Sharon, and Kent used approximately 5300 m^3 to 10,500 m^3 (150,000 to 300,000 bushels[1]) of charcoal each year (U.S. Census Bureau, 1850a). Local production of charcoal in nearby forests by colliers was the dominant source of charcoal for cold and hot blast furnaces, foundries, and small blacksmiths in the region until the last half of the 19th century, when local sources were supplemented with

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[1] Metric conversions of bushels and cords according to Straka (2014).

charcoal from elsewhere in New England and anthracite from Pennsylvania (Gordon, 2001a; Gordon & Raber, 2000). One charcoal hearth required 90–127 m^3 of wood (25–35 cords), associated with 4050–8100 m^2 (1–2 acres) of cleared forest, and produced 32–42 m^3 (900–1200 bushels) of charcoal. Colliers used both hard and softwoods in charcoal production, though output varied depending on wood type such that hardwood such as red maple, oak and chestnut were often preferred over hemlock (Gordon, 2001b, Straka, 2014). Demand for wood resulted in the clearing of extensive tracts of land in Litchfield County for charcoal production, and as early as 1812 there were reports of wood scarcity in Litchfield County towns such as Kent as a result of iron production (Slosson, 2003). Individual farmers in the area and throughout the region likely also produced charcoal on their farms for extra income (Barger & Rogerson, 2013). By the late 19th century, many companies found that charcoal production in brick or metal kilns produced more predictable results than charcoal hearths, and also allowed for extraction of by-products such as acetate of lime and alcohol which could be sold (Gordon, 2001a).

In the Litchfield Hills there is a relatively high density of charcoal hearths that are especially well preserved on slopes of the tributary valleys of the Housatonic River, forming circular ramparts or platforms with diameters typically between 8 and 14 m. Three study sites (Fig. 1) were selected due to the high charcoal hearth densities visible on slope and shaded relief maps (SRM). Maps were created using DEMs with a 1 m pixel resolution derived from ground-classified LIDAR points which are part of a dataset collected in Spring 2011 for the USDA-NRCS that has a point spacing of ~1 point per 0.7 m (CT ECO, 2016).

The Sharon Audubon site (Fig. 1) is about 3 km west of West Cornwall on the northeast-facing slope of Carse Brook. The Beaver Wetland site is located on the western flank of the Housatonic River valley about 4 km north of West Cornwall. The Hollenbeck site is ~7 km northeast of West Cornwall in the mountains between the Housatonic River and the White Hollow Brook. These sites represent only a small, but representative, sample of charcoal hearths available for study over the 1170 km^2 area where they have been mapped.

We studied 10 charcoal hearths at the Beaver Wetland site and eight charcoal hearths each at the Sharon Audubon and Hollenbeck sites. Charcoal hearth locations were determined with a handheld GPS and are listed in Table 1. Analyses included 12 hand auger borings (45 mm core diameter) at each charcoal hearth (six over the charcoal hearth, six outside the perimeter) to identify soil stratigraphy and to collect a bulk sample of the humus-rich topsoils (Auh horizon on the charcoal hearth and Ah horizon outside, respectively). The outside borings were placed in a perimeter around the charcoal hearth at a minimum distance of 10 m, and the thicknesses of the topsoils were recorded. In order to account for the increasing thickness of the charcoal hearth substrate caused by slope inclination, three borings were placed upslope and three borings downslope of the platform. Borings on the charcoal hearth extended to the depth of the undisturbed subsoil.

In addition to the borings, at each study site one charcoal hearth was selected and two soil profiles were dug and described with one soil profile on the charcoal hearth and one (control) outside the perimeter of the feature. At the Sharon Audubon and Hollenbeck sites, these selected charcoal hearths were trenched to obtain a complete cross-section through the platform. Cross-sections were surveyed with a clinometer. Soils were described according to the FAO (2006) and classified according to the WRB (IUSS Working Group WRB, 2014).

3. RESULTS AND DISCUSSION

The natural soil at all three study sites is a Cambisol developed into glacial till. Following glacial retreat, the soil was likely affected by periglacial processes (e.g., Raab, Leopold & Völkel 2007). Cambisols have characteristic Ah/BA/Bw/C profiles (Fig. 3d, 3h). Bw horizons are distinguished from unweathered till by a more reddish yellow to brown color (6.25 YR 4/6 to 7.5YR 4/3.5) and blocky soil structure. Ah and BA horizons have dark grayish brown colors (10 YR 4/2) and abundant roots. The texture of the Cambisols is coarse-loamy (Web Soil Survey USDA 2016) and loamy according to the FAO (2006) with decreasing sand content with depth. In contrast, soils associated with the charcoal hearths (Fig. 2b, 2c, 2f, 2g) are classified as Spolic Technosols (Pretic) overlying buried Cambisols and have either a two-layered (Auh/2Bwb/2C) or four-layered (Auh/2Cu/3Auh/4Bwb/4C) stratigraphy. Soils comprising the charcoal hearths contain comparatively thick topsoil with a black to very dark gray color (10 YR 2.5/1) resulting from high content of charcoal fragments (up to 3 cm in diameter) and abundant humus. The quantification of the humus and pyrogenic material for sand-sized and smaller residues was not possible in the field, but dark black smearing between the fingertips indicated the presence of silt and clay-sized pyrogenic material.

Borings and trenches into the charcoal hearths failed to reveal native Cambisol topsoil suggesting that the natural soil was truncated during the their preparation and operation. Humus and pyrogenic material associated with the charcoal hearth subsequently accumulated, thereby fossilizing the truncated Cambisols. The texture of the charcoal hearth substrate is sandier than in the weathering horizons of the Cambisols. Higher sand content in the charcoal hearth compared to the natural subsoil could be caused by the amendment of topsoil substrate with surrounding soil materials or by the *in situ* breakdown of gravels due to thermal alteration during burning. Given that soil texture was assessed only in the field by touch, i.e., ribbon test, the apparent sandy texture could also be caused by sand-sized charcoal fragments.

Topsoils on the charcoal hearths are densely rooted by shrubs. Near the surface, the soil has a granular structure, but a single grain soil structure dominates as depth increases. At the transition zone between the charcoal hearths and the underlying and truncated Cambisols, and also within the multi-layered substrate of the charcoal hearths (Fig. 2b, 2f), reddish mottles indicate the thermal alteration of iron oxides. Whereas the black uppermost deposit of the two-layered profiles (Auh) and the first and third layers of the four-layered profiles (Auh and 3Auh) are dominated by charcoal fragments, the upper Auh at the surface contains humified organic matter deposited at the surface and formed in place by decomposition of roots. Differentiating between organic matter and pyrogenic material for the black 3Auh horizon in the field was not possible. It remains uncertain to what degree this horizon is pedogenic formed by humification vs. depositon of reworked topsoil material on the hillslope; an alternate classification of the 3Auh as a transitional horizon (A/C) is also possible. The second layer (2Cu), which consists of reworked and brunified substrate composed of glacial sediments, is further intermixed with charcoal fragments and challenges pedogenic classification. Because the amount of *in situ* soil formation is uncertain, we classified it as unweathered parent material.

Borings into the charcoal hearths show that locally the charcoal-rich substrate is thicker than 50 cm and thus we consider it a pretic horizon according to the WRB (IUSS Working Group WRB, 2014). Thus these soils can alternatively be classified as Pretic Anthrosols, as such soils need not be restricted to tropical environments in the Amazon Basin where they are more commonly known. Because charcoal-rich organic residues comprising the charcoal hearths are related to industrial-scale production rather than agriculture, the diagnostic feature for 'Terra Preta de Indio' (Glaser et al., 2000), we prefer the classification of a Technosol.

Slopes were convenient sites for the operation of these charcoal hearths, because wood for their construction could be delivered from upslope and the haul from the charcoal harvest transported downslope (Kemper, 1941). At all three sites the charcoal hearths were built on slopes ranging 7° to 17° with a mean of 10.5°. Our trenches revealed that the volume of the charcoal hearths could be roughly calculated as a cylindrical segment by using the averaged depth of the six borings from the charcoal hearth. Ah horizons on the charcoal hearths are on average 2.6 times thicker than in the surrounding Cambisols (means of 34 vs. 13 cm) (Table 1). Borings and trenching of Charcoal Hearth 14 (Fig. 2a) and 25 (Fig. 2e) indicate that the hearths exhibit increasing thickness and layer complexity in the downslope direction. Therefore, using a cylindrical segment form, the average volume of the 26 charcoal hearths' deposits/soils based on our sampling is ~ 25.4 m^3 per charcoal hearth (Table 1).

The diameters of the 26 charcoal hearths range 8 –11 m (Tab.1), which is similar to other charcoal hearths in the northeast U.S. but slightly smaller than those from Northern Germany (Table 2), possibly due to the latter being constructed on more level surfaces where larger construction is more easily accommodated. Similar to Northern Germany (Rösler et al. 2012, Raab et al. 2016), the charcoal hearths presented here are often surrounded by a ditch that is partly filled with reworked deposits from the charcoal hearth due to the harvesting process. At some the charcoal hearths in our study sites, boulders up to 1 m in diameter were placed partly at one or both sides of the ditch likely to stabilize the construction, or to prevent fire from spreading. Stabilization of charcoal hearth platforms on slopes with boulders has also been reported in the Harz Mountains in Germany (von Kortzfleisch, 2008). In the current study, we trenched only two charcoal hearths and therefore at other sites boulders may have been present in the subsurface, buried under ash and charcoal fragments, and overlooked during our field survey.

Stratigraphy suggests two episodes of use (Fig. 3). For initial use, the colliers trenched a ditch around the platform for the wood stack; the platform was not horizontal but slightly inclined. The residual layer containing ash and charcoal fragments mixed with sediment from the first charcoal production process was displaced in the downslope direction and 'fresh' substrate from the upslope position was used to build a second platform. Charcoal remains extending stratigraphically below the boulders on the upslope side of the ditch suggest that these boulders were placed to stabilize the platform during subsequent use. The second charcoal hearth was constructed on the remains of the first one. The modern surface of the charcoal hearths is almost horizontal in contrast to the adjacent hillslope (Fig 3h). This is a result of the second charcoal harvest and resulting materials placed downslope where they abut against the emplaced boulders, resulting in a localized terrace with < 1° slope.

Although stratigraphy suggests that the charcoal hearths were used at least twice, the time span between use remains unknown. It is feasible that the initial and subsequent usage occurred within 30-60 years of one another, because historical photographs of our study area indicate that large areas of forest were clear-cut in order to obtain wood for charcoal production (Gordon & Raber, 2000; Pawloski, 2006), and most areas of forest needed at least 30 years to regenerate to sufficient forest yield (Kemper, 1941, Straka, 2014). On the other hand, the multi-layered charcoal hearths might be developed from quick reuse if large amounts of wood were procured, i.e., several runs would have been necessary to consume all the cleared wood to charcoal. Multiple hearths may also have operated simultaneously as indicated by reports about charcoal production from Pennsylvania, where colliers operated up to five charcoal hearths at a time (Heite, 1992). In our three study sites the charcoal hearths are only separated about 100 m or less from each other and therefore could facilitate a simultaneous operation.

Whereas some companies in Michigan sold the deforested land after the first clear cut as farmland (Birkinbine, 1883), in Connecticut some large companies purchased tracts of forest that were harvested and charcoaled in a rotation and therefore practiced a type of forest management (Gordon, 2001a, 2001b). Iron production sites within 5-10 km of the three study areas in Litchfield were in operation as early as the 1760s (Lakeville Furnace) with production as late as 1900 (Lime Rock). Despite this wide range of use, most blast furnaces in the immediate area were only in operation for 12–70 years, with an average of only 34.6 years. The short operation period of the nearby blast furnaces indicates that a second clear-cut might not have been necessary due to the closure of the blast furnaces, technical improvements in the furnaces, or changes in the methods of charcoal production (Gordon, 2001b). During the middle of the 19th century, the production of charcoal switched from ephemeral charcoal hearth sites to more permanent stone or brick kilns. Furthermore, until the end of the 19th century, the labor-intensive and therefore more expensive charcoal was still preferred over coke because of the former's lower sulfur content. However, technical improvements in furnace combustion soon led to rapid replacement of charcoal by coal..

5. CONCLUSIONS

Forest soils in Litchfield County, Connecticut are strongly influenced by archaeological remains associated with historical charcoal production. The charcoal hearths presented here are similar to those of mountainous regions in Europe with respect to soil stratigraphy, size (e.g., average inner diameters of 9.5 m) and the construction of platforms on hillslopes. Although architecture and soil stratigraphy may be comparable, completely different time frames and land use histories for European and New England sites must be considered. In the case of Europe, intensification of mining in the High Middle Ages accompanied by deforestation for charcoal production caused over 1000 years of widespread landscape changes. Some areas were affected by extensive mining even earlier, and many regions experienced subsequent farming or forestry. In contrast, the landscape of the northeast US was subject to very different types of land use by Native American groups who had inhabited the region for thousands of years (Jones & Forrest, 2003). The colonization of the region by Europeans in the 17th century brought drastically different types of land use, including charcoal production, European agricultural practices, and different forms of resource extraction (Cronon, 1983). It is remarkable that present landscapes are densely forested and remains of former charcoal production, although only 125 years old, are barely visible at the surface, yet they have left a distinct pedogenic imprint. Geoarchaeological research on charcoal hearths is an emerging field that can significantly enhance our understanding of the environmental impact of historical charcoal production on our soil landscapes. Because European colonists brought knowledge of iron-working and charcoal production to New England, comparative studies between Europe and North America may allow us to quantify the “legacy effect” of this past land use on our modern ecosystems.

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Captions

Fig. 1: a) Map of the study area and b), c), d) shaded relief maps of the three study sites with charcoal hearths (CH), e) one meter high Charcoal Hearth 21 at the Sharon Audubon site.

Fig. 2: a) Cross-section through Charcoal Hearth 14 (Hollenbeck site); b) multi-layered downslope soil profile;, c) upslope profile with only one layer of the charcoal hearth overlying

a truncated Cambisol; and d) an undisturbed Cambisol approximately 50 m outside of the charcoal hearth. e) Cross-section through Charcoal Hearth 25 (Sharon Audubon site); f) downslope multi-layered soil profile; g) upslope profile with only one layer of the charcoal hearth overlying a Cambisol; and h) an undisturbed Cambisol approximately 50 m outside of the charcoal hearth.

Fig. 3: Sketch of the life history of a charcoal hearth: a) site before construction; b) preparation of the platform by removing topsoil and excavation of a ditch on the downslope side; note that platform is inclined; c) accumulation of wood fuel for the first charcoal hearth; d) harvest of the charcoal in downslope directions and resulting wedge of charcoal-rich sediments;, e) charcoal-rich sediments (lower charcoal hearth substrate) are covered with sediments taken from the Bw horizons of Cambisols around the charcoal hearth; boulders of up to 1 m in diameter are placed around the platform to stabilize construction; f) accumulation of wood fuel the second charcoal hearth; g) harvest of the charcoal, with downslope redistribution of upper charcoal hearth sediments; h) relict charcoal hearth on modern hillslope.

Table I. Location and characteristics of the investigated charcoal hearths. Charcoal hearth and topsoil thickness, and the volume of the charcoal hearths are based on median values determined from coring.

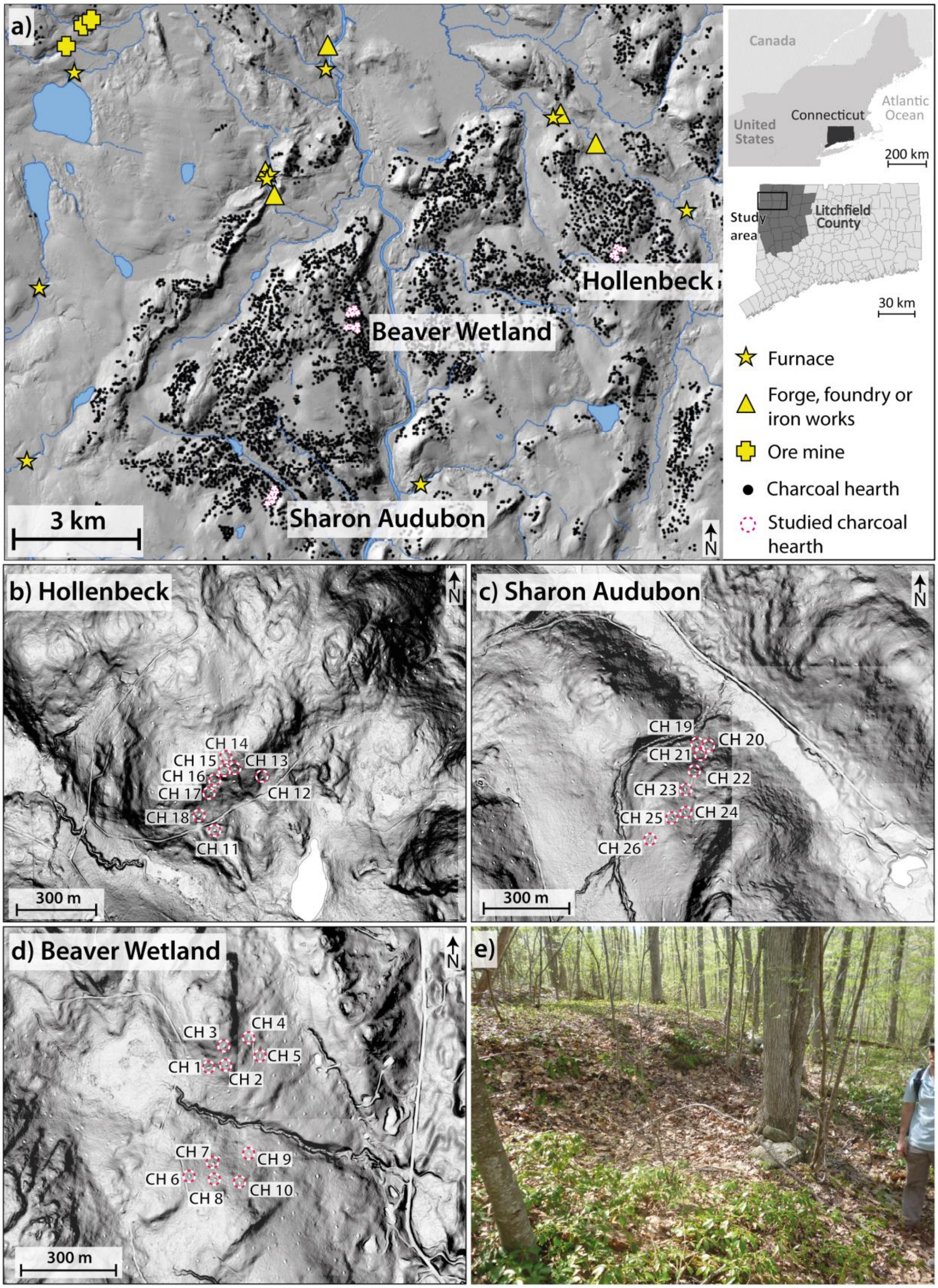
Charcoal hearth	Location (UTM)	Site	Diameter of the charcoal hearth (m)	Thickness of the charcoal hearth (m)	Volume of the charcoal hearth (m
CH 1	18 T 634963 4640987	Beaver Wetland	9	0.375	23.9
CH 2	18 T 635023 4640995	Beaver Wetland	9	0.36	22.6
CH 3	18 T 635006 4641065	Beaver Wetland	10	0.32	24.7
CH 4	18 T 635092 4641105	Beaver Wetland	10	0.44	34.2

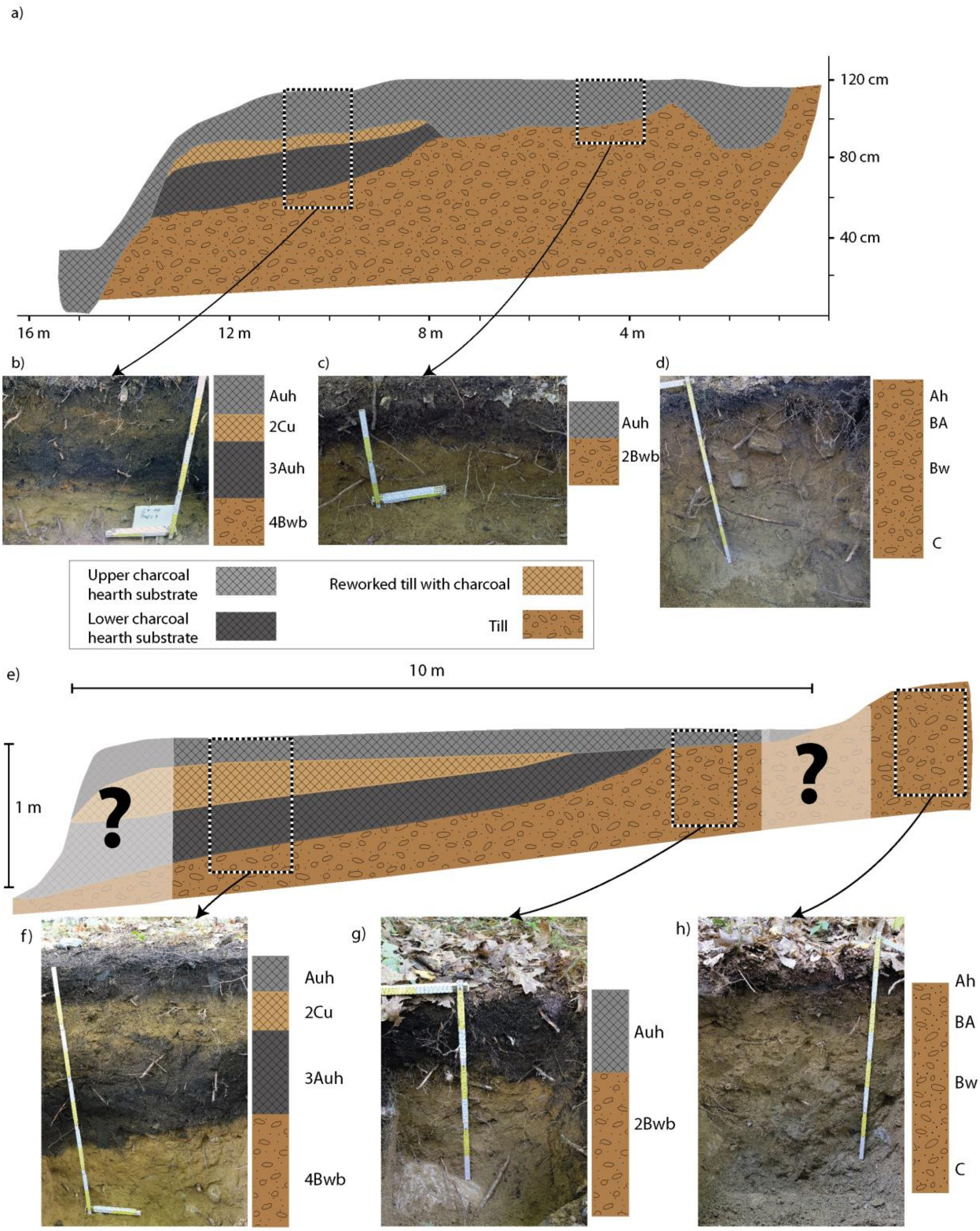
CH 5	18 T 635120 4641041	Beaver Wetland	9	0.31	19.7
CH 6	18 T 634908 4640656	Beaver Wetland	10	0.24	18.5
CH 7	18 T 634977 4640701	Beaver Wetland	9	0.36	22.6
CH 8	18 T 635097 4640604	Beaver Wetland	-	0.28	-
CH 9	18 T 635064 4640639	Beaver Wetland	9	0.47	29.9
CH 10	18 T 635064 4640635	Beaver Wetland	8	0.27	13.3
CH 11	18 T 641115 4641819	Hollenbeck	11	0.42	39.9
CH 12	18 T 641287 4642003	Hollenbeck	9	0.32	20.0
CH 13	18 T 641183 4642034	Hollenbeck	11	0.28	26.1
CH 14	18 T 641164 4642084	Hollenbeck	10	0.40	31.4
CH 15	18 T 641150 4642042	Hollenbeck	10	0.36	27.9
CH 16	18 T 641103 4641991	Hollenbeck	9	0.32	20.0
CH 17	18 T 641098 4641960	Hollenbeck	10	0.45	35.3
CH 18	18 T 641056 4641874	Hollenbeck	11	0.35	32.8
CH 19	18 T 633008 4637106	Sharon Audubon	8	0.34	17.1
CH 20	18 T 633010 4637088	Sharon Audubon	8	0.33	16.3
CH 21	18 T 632982 4637086	Sharon Audubon	10	0.39	30.6
CH 22	18 T 632961 4637036	Sharon Audubon	8	0.55	27.4
CH 23	18 T 632927 4636971	Sharon Audubon	10	0.29	22.4
CH 24	18 T 632924 4636888	Sharon Audubon	10	0.32	24.7
CH 25	18 T 632884 4636871	Sharon Audubon	10	0.46	35.7

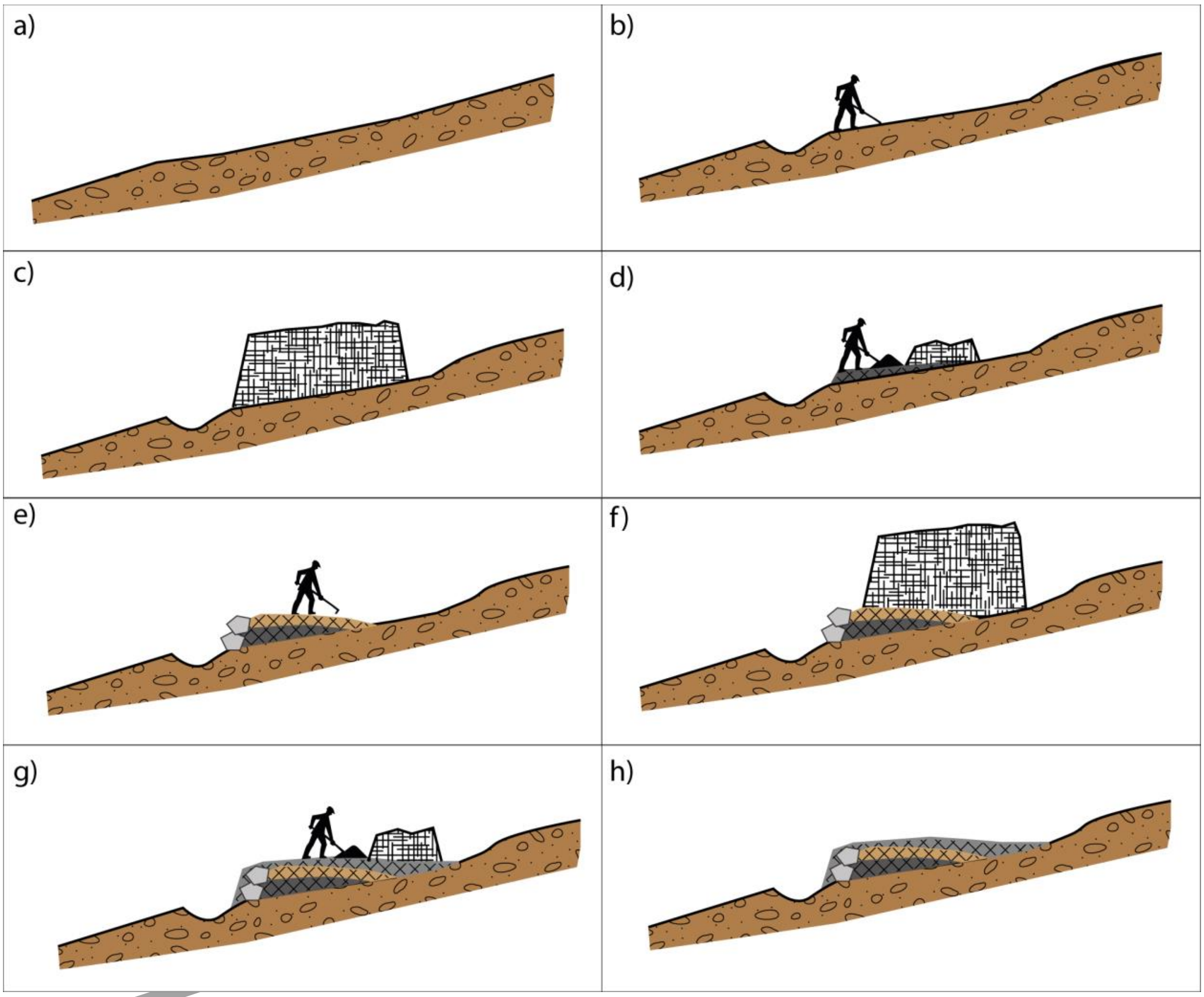
CH 26	18 T 632747 4636876	Sharon Audubon	10	0.24	18.8
		median	**10.0**	**0.34**	**24.7**
		average	**9.5**	**0.35**	**25.4**

Table II. Location, diameter, and timeframe of charcoal hearths.

Location	**Charcoal hearth diameter**	**Geomorphology**	**Timeframe**	
Connecticut, USA	8 to 11 m	slope	1760 to 1900	this stud
Pennsylvania, USA,	about 15 m	slope	1716 to 1840	Potter,
Brandenburg, northern Germany	13 to 29 m	flat land	17th to 19th century	Raab et
Northern Pyrenees, southern France	9 to 11 m	slope	Middle Ages	Pèlachs
Palatinate Forest, southwestern Germany	about 6 m	slope	18th to 19th century	Stolz &
Black Forest, southwestern Germany	7 to 11 m	slope	unknown	Hesse 2
Harz Mountains, central Germany	4 to 12 m	slope	16th to 19th century	Knapp,
Bavaria, southern Germany	10 to 15 m	slope and flat land	18th to 19th century	Zenger 1
Hampshire, Great Britain	8 to 16 m	slope and flat land	16th to 19th century	Passmor
Southern Norway	about 20 m	slope and flat land	unknown	Risbøl et
Styria, Austria	6 to 11 m	slope	Modern Ages	Klemm 2


a)
Canada
Atlantic Ocean
United States
Connecticut
200 km
Study area
Litchfield County
30 km
Hollenbeck
Beaver Wetland
Sharon Audubon
3 km
N
Furnace
Forge, foundry or iron works
Ore mine
Charcoal hearth
Studied charcoal hearth
b) Hollenbeck
N
CH 14
CH 15
CH 13
CH 16
CH 17
CH 12
CH 18
CH 11
300 m
c) Sharon Audubon
N
CH 19
CH 20
CH 21
CH 22
CH 23
CH 24
CH 25
CH 26
300 m
d) Beaver Wetland
N
CH 3
CH 4
CH 5
CH 1
CH 2
CH 7
CH 9
CH 6
CH 8
CH 10
300 m
e)


a)
120 cm
80 cm
40 cm
16 m
12 m
8 m
4 m
b)
Auh
2Cu
3Auh
4Bwb
c)
Auh
2Bwb
d)
Ah
BA
Bw
C
Upper charcoal hearth substrate
Lower charcoal hearth substrate
Reworked till with charcoal
Till
e)
10 m
1 m
?
?
f)
Auh
2Cu
3Auh
4Bwb
g)
Auh
2Bwb
h)
Ah
BA
Bw
C



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Southern Norway	about 20 m	slope and flat land	unknown	Risbøl et
Styria, Austria	6 to 11 m	slope	Modern Ages	Klemm 2