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Heat impact and soil colors beneath hearths in northern Sweden

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ABSTRACT

The archaeological remains of Sami hearths in boreal and subarctic areas of northern Sweden are common finds. Greater understanding of the effects of heat on soil coloration will facilitate interpretation of the main purpose of these hearths, for example as heat sources or for cooking or other processing, and whether they were used seasonally for long or short periods of time. We therefore studied effects of heat on the coloration of natural B-horizons beneath traditional Sami hearths using three approaches: firing with dry pine wood in experimental hearths and measuring the temperature at various levels beneath the hearths; laboratory heating of B-horizon soils at different temperatures (200–900 °C) in a muffle oven and; measuring soil color changes in terms of RGB-values, and comparing the experimental results with soil profiles beneath real hearths used by nomadic Sami reindeer herders in northern Sweden. The study shows that the temperature reached beneath hearths strongly depends on the type of fuel used and the length of firing. The temperature can rise rapidly in upper layers of the soil but it takes considerable time for heat to penetrate 20 cm below the hearth surface. Our experimental firings, for 10 h on three consecutive days and for 72 consecutive hours, resulted in bowl-shaped areas of discoloration, with strong red coloration (rubification) towards the edges and dark grey/brown discoloration in the middle of the hearths in both tests. After laboratory heating, soil samples darkened during temperatures of 200–300 °C, and rubification at 250–350 °C depending on the amount of humus in the soil. The RGB analysis showed a steady increase in rubification from 300 °C, peaking at 750–800 °C. We believe that the rubification is caused mainly by transformation of iron compounds to maghemite and hematite and that the quantity of hematite is determined by temperature and not by time.

Excavations of ancient hearths also revealed examples of bowl-shaped discoloration in B-horizons deeper than 20 cm. These discolorations had a rather uniform red tone with no dark areas. This suggests that the darker areas, probably colored by reduced iron and not by charred particles, could have been altered over time. The main conclusion is that rubification in B-horizons beneath hearths can arise after a relatively short period of firing but-bowl shaped areas of deep coloration can only arise, in boreal and subarctic areas, when hearths have been fired heavily and continuously for long periods of time, indicating winter use.

1. Introduction

The use of fire is one of the most conspicuous features of human culture, so archaeological remains connected with its use are very common. Fire has been used for food preparation, heating dwellings and as a tool for agriculture and hunting. The first use of fire by prehistoric people in Europe can be dated to 300 000–400 000 years ago (Roebroeks and Villa, 2011). The importance of fire for human survival and comfort is especially evident in northern regions with long winters and cold climates. In northern boreal and subarctic regions, hearths (i.e. fire-places) are the most common archaeological remains, and they are identified through typical characteristics such as: fire-cracked stones, charred wood, soot and ash, burned bones and reddish coloration (rubification) of the soil. Several possible causes of the rubified soil below hearths have been offered, but archaeologists working in northern regions often associate red soil beneath hearths with strong heat. Thus, various authors have studied correlations between temperatures, firing durations and soil color in recent decades (Bellomo, 1990, 1993;

Abbreviations: NHB, National Heritage Board (Riksantikvarieämbetet).

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Bennett, 1999; Canti and Linford, 2000; Maki et al., 2006; Liedgren and Östlund, 2011; Östlund et al., 2013; Bentsen, 2012, 2014; Courchesne et al., 2015; Aldeias et al., 2016). Many studies have been carried out within the field of micro-archaeology (for an overview see Mentzer, 2014), mostly related to very early use of fire during the Paleolithic, further south than the subarctic region considered here.

Soil coloration is largely caused by various colored iron oxides, and transformation between forms can be induced or enhanced by fire (Ulery and Graham, 1993). The most common iron oxides are goethite ($\alpha FeOOH$) and hematite (αFe_2O_3), but smaller fractions of lepidocrite ($\gamma FeOOH$), maghemite (γFe_2O_3) and the non-crystalline ferrihydrite ($Fe_5OH_8 \times 4\ H_2O$) may also be present (Torrent et al., 1983). Hematite is a very strong coloring agent and even small amounts can cause rubification in soils (Scheffer et al., 1957; Childs et al., 1979; Torrent et al., 1983).

According to Scheffer et al. (1957), the main causes of high-temperature transformation are conversions of brownish-yellow goethite to red hematite at c. 390–400 °C and reddish-yellow lepidocrocite to yellowish-red maghemite at c. 400 °C. The maghemite formed converts to hematite at c. 500 °C. At 600 °C all iron oxihydrate has been transformed to hematite. The last stage occurs at temperatures around 800 °C, when all iron, which is connected mainly to silicates in the clay fraction, is transformed to hematite. Several subsequent studies (see Maki et al., 2006:208) have shown that maghemite (γFe_2O_3) changes to hematite (αFe_2O_3) across a substantial temperature range, 250 °C–≥ 900 °C depending on oxidation conditions, mineral grain size and the time length of exposure to high temperatures. Maki et al. (2006:209) postulate that this conversion is responsible for the rubification of soil associated with hearths.

The abundance of humus in natural soils also influences soil's color, darkening it (Fernandez et al., 1988). However, humus starts to combust at 100–200 °C, is largely eliminated at 400 °C (Sertsu and Sanchez, 1978) and fully oxidized at 550 °C (e.g. Bengtsson and Enell, 1986; Heiri et al., 2001).

Thus, usually soils become darker initially when they are heated (Boyer and Dell, 1980; Ulery and Graham, 1993), mainly due to the charring of humus particles they contain (Ulery and Graham, 1993). The color is also affected by the addition of ash, which makes soils brighter (Ulery and Graham, 1993).

Canti and Linford (2000: Fig. 1) have summarized results of numerous studies of temperature effects on soil using experimental fires. Most experiments to date have focused on effects of relatively low temperatures: just six published studies have reported soil temperatures above 400 °C and only two temperatures above 500 °C. In experiments with camp fires maintained for 1–4 days by Canti and Linford (2000) temperatures between 436–570 °C and 199–318 °C were registered at depths of 1 and 4 cm, respectively. Higher surface temperatures in hearths, nearly 600 °C, were reached in experiments reported by Bellomo (1993), who also concluded that campfires usually reach higher temperatures than wildfires.

The overall objectives of this study were to investigate effects of heating in hearths on podzol soils of boreal forest and alpine areas in northern Sweden, to facilitate elucidation of the evidence left by hearths used by the Sami in prehistoric and historic times. Podzolization affects all mineral soils in the region, causing spodic B-horizons (with Fe, Al and humus accumulations) to develop in most of the well-drained forest soils (Tamm, 1920).

We specifically addressed the following questions.

1 At what temperatures does differential coloration appear in B-horizons?
2 How does the heating duration and maximum temperature influence the development of soil coloration?
3 Can the observed experimental results be confirmed by evidence from excavated old hearths?

We addressed these questions by carrying out experiments in the field, during early winter, at sites used by native Sami people in northern Sweden during prehistoric and historic periods, and by heating soils from such sites in the laboratory.

2. Archaeological setting

Numerous ancient hearths have been registered in the northern part of Sweden. In the county of Norrbotten (c. 100 000 km^2) alone, there could be more than 100 000 (Liedgren and Hedman, 2005). These hearths can be divided into two main groups: heaps of fire-cracked stones, and hearths with stone linings. Heaps of fire-cracked stones are mostly found close to lake shore lines and date mainly to the Stone Age and Early Iron Age in northern Sweden. Most of the stone-lined hearths are connected with the Sami culture and were constructed in a period ranging from the Late Iron Age (from about 700–800 AD) to modern times (Storli, 1994; Mulk, 1994; Hedman, 2003; Liedgren et al., 2007; Hedman and Olsen, 2009; Bergman et al., 2013; Hedman et al., 2015). They are most readily visible on unexcavated ground.

Stone-lined hearths mark a change in utilization of fire during the course of the Iron Age. They are found in locations suggesting that people utilized the landscape in accordance with the needs of the reindeer and have consequently been associated with reindeer domestication (Bergman, 1991; Aronsson, 1991; Hedman, 2003). Open fires within people's living quarters became more common, with heat being generated mainly by radiation from the flames (Liedgren and Östlund, 2011). Stone-lined hearths have diverse forms of construction and size (Hedman, 2003; Edbom et al., 2001; Liedgren et al., 2007; Hedman et al., 2015). The largest are more than 2 m long and the smallest just 0.6–0.7 m long. Some are filled with one to several layers of stones of various sizes, with a maximum height of 0.3–0.4 m. In the lowland boreal forest and the mountain subalpine birch forest, an ordinary hearth is about 1.1–1.3 m long and 0.9–1 m wide (Mulk, 1994; Hedman, 2003; Liedgren et al., 2007). The most common forms are oval or rectangular (Mulk, 1994; Hedman, 2003). Some of the stone-lined hearths were used in permanent huts but most of them were used in tents.

The nomadic Sami moved around in the landscape with their herds of reindeer during the course of the year (Manker, 1953, 1968), and they mostly burnt mountain birch (*Betula pubescens* ssp. *czerepanovii*) in their hearths for cooking, light and heat when staying in the mountain birch forest because it was abundant and easy to handle (Hellberg, 2004; Liedgren et al., 2007). The collection and processing of birch fuel during winter in the mountains were described by Leem (a Norwegian priest and linguist) in the 18th century (Leem, 1975) and the difficulties in keeping huts warm and cutting fuel during the winter are vividly described by Johan Turi (born in 1854): "*… when it is so cold that the canvas of the tent hut is covered by white frost on the inside even if the fire burns in the hut all the time and can be seen above the smoke hole; then it's a big task to get fuel to the fire and to look after the children to stop them from getting frozen or frostbitten*" (Turi, 1910: 137; translation by the authors).

In the coniferous forest natural seasoned Scots pine (*Pinus sylvestris*) was mainly used for the same reasons (see Liedgren et al., 2016; Ryd, 2005). Dry pine was abundant in the northern boreal forests in the past (Andersson and Östlund, 2004; Östlund et al., 1997) and was easy to use as fuel. From the Viking Age