Moshyttan: Sweden’s oldest known blast furnace?

A multiproxy study based on geochemical and pollen analyses

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Abstract

Radiocarbon datings in a previous study suggested that Moshyttan in Nora bergslag is the oldest blast furnace in Sweden and Europe. The aim of this study was specifically to study the origin of the Moshyttan blast furnace to answer the question: when was the blast furnace at Moshyttan established? To this end, a 2.5 m sediment record was collected from Fickeln, a lake 600 m downstream of Moshyttan, in March 2012. The geochemical properties of the sediment record were analyzed for major and trace elements using XRF. The organic content was calculated from the ash residue following the mercury analyses as a proxy for organic matter. Pollen and charcoal were analyzed using a standardized method. A age-depth model was created based on four radiocarbon datings of the sediment profile. The pollen data suggest that early land use consisted of forest grazing from about AD 220, and agriculture from about AD 880. An increase in Pb and charcoal particles about AD 880 indicates early metallurgy in the area. The first significant evidence of the establishment of a blastfurnace was between AD 1020 and AD 1090 marked by a decrease in organic content combined with a strong increase of ore related metals such as Pb, Zn, Cu and a strong increase of charcoal particles. Within the uncertainty of the age-depth modeling, the results from this study offers support to Wetterholms radiocarbon datings, thus making Moshyttan the oldest known blast furnace in Sweden and Europe.

Keywords: Metallurgy, Lake Sediment, Geochemistry, Pollen, Blast furnace
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1 Introduction

The Nora mining district, one of 23 mining districts, is located in the Bergslagen region in central Sweden. The region is well known for its long history of mining and metallurgy, which have been driving the landscape development for hundreds of years. The landscape is littered with mine pits, mine shafts, smelters and blast furnaces with historical records back to at least the 14th century (Landeholm and Eriksson 2001). A blast furnace uses a high temperature process to produce considerable amounts of high quality iron known as cast iron, and was the single most important innovation in the history of European metallurgy (Anderson 2010). The oldest known blast furnace in Europe is Lapphyttan in Norbergs mining district, dated to the 12th century (Magnusson 1984). Bindler et al. (2011a) analyzed two sedimentary records and one peat record in close proximity to Lapphyttan and recorded a decline in $^{206}\text{Pb}/^{207}\text{Pb}$ ratios and an increase in charcoal particles about AD 1180.

During the 1990’s Wetterholm studied the development of blast furnaces and smelters in the Nora mining district. By using radiocarbon dating on carbon trapped in slag from known blast furnaces Wetterholm (1999) was able to date the establishment of some of the blast furnaces in the Bergslagen mining district. Wetterholm was able to date the entire profile of one of the slag heaps on the site of Moshyttan. The geochemical composition of the iron slag was characteristic of a high-temperature process. Based on these results he speculated that a blast furnace was established on the site in the late 10th century, predating Lapphyttan in Norberg, making this the oldest known blast furnace in Sweden and Europe. Moshyttan was first mentioned in historical texts AD 1539 and was abandoned AD 1721 (Landeholm and Eriksson 2001).

This project builds on Wetterholm’s original study analyzing and dating slag from the Moshyttan site. The aim of this study was specifically to study the origin of the Moshyttan blast furnace to answer the question: when was the blast furnace at Moshyttan established?

1.2 Background

Metal pollution is something most of us associate with recent developments of human society and especially the start of the Industrial Revolution in the 19th century. The human impact from deforestation, agriculture, mining and metallurgy before the Industrial Revolution are often neglected and not considered to be on a scale large enough to matter. Policy makers even refer to the time before the 19th century as an example of a pristine environment and use this as a background reference for environmental management (European Parliament, Council 2000). Another common misconception is the belief that remote areas such as northern Sweden reflect a pristine environment from which background values can be derived. However, this is a problematic illusion that is simply not true. The first clues surfaced when Patterson et al. (1955) dated the earth by analyzing the isotopic composition of lead in minerals. During this study he encountered a problem with widespread contamination of lead. After further research on this new found phenomena he concluded that the industrial use of lead introduced to the environment 100 times more lead than the natural lead leached to lakes and rivers, and that the atmosphere of the northern hemisphere contains 1000 times more lead than natural amounts (Patterson 1965). After studying mining and metallurgy from ancient and medieval times he also recognized the prehistoric pollution as a significant factor to the global extent of lead pollution (Patterson 1971, 1972; Settle and Patterson 1980). A new branch of science sprouted from the groundbreaking work.
Patterson and his colleagues started with the goal to understand the influence of anthropogenic lead on biogeochemistry (Bindler 2011b).

The first evidence supporting this global scale of preindustrial pollution came in 1994. Renberg et al. (1994) analyzed sediment cores from 19 lakes in Sweden and concluded that atmospheric lead deposition increased above background levels as early as 2600 BP with a peak around 2000 BP. These results were later supported by several sediment and peat records in Sweden (Brännvall et al. 1997, 1999) and from the Greenland ice (Hong et al. 1994). Brännvall et al. (1997) examined lead concentrations and isotopes in peat and sediment cores in Sweden and found that the lead isotope ratio declined while the lead concentration increased. The declining isotope ratio indicates deposition of long-range transported Pb. Brännvall et al. (1999) conducted a similar study in northern Sweden using high resolution varved lake sediment cores. Their results show clear atmospheric transported lead 2000 years ago, followed by a relatively clean period, at least in the north of Sweden, between AD 400 and AD 900. It was not until after AD 900 that the atmospheric deposition showed a general increasing trend. The peak 2000 BP corresponds to the Greek and Roman Empires and is widely known as the “Roman lead peak”. The same general pattern with the Roman lead peak and the clean period thereafter has been found in lake sediment and peat cores all over Europe (UK; Cloy et al. 2008, France; Monna et al. 1997; Switzerland; Shotyk et al. 1998; Spain: Martínez Cortizas et al. 2000; Novák et al. 2003; Germany; Le Roux et al. 2005; Belgien; De Vleeschouwer et al. 2010).

Studies about previous atmospheric pollution in peat and lake records do not reveal much about the environmental impact of mining on regional and local scales. This is where the multiproxy research based on pollen and geochemical analyses in peat and lake sediments offer a more detailed description of the past (Segerström et al. 2010, Bindler et al. 2011b). These methods have been successful in describing the history of mining in areas where limited historical records exist (Monna et al. 2004; Breitenlechner et al. 2010). Historically, large-scale pollution reflects trends in economies in mainland Europe and the British Isles. For example, the Harz region in Germany was a historically important mining district starting in pre-medieval times and stretching for a thousand years (Matschullat et al. 1997, Kempter et al. 1997, Kempter and Frenzel 1999; Monna et al. 1999; Le Roux et al. 2005). Monna et al. (2004) used a combination of geochemical and pollen data and found indications of local mining and metallurgical activities in the Morvan region (France) starting from the late Bronze Age (1300 BC). The same methods with the addition of macrofossils and fossil insects were used by Mighall et al. (2002) in the Coppa hill area of Wales (United Kingdom). Based on this multiproxy study Mighall and his colleagues were able to reconstruct the local prehistoric mining in great detail. Martínez Cortizas et al. (2005) managed to find a significant variation in pollen following an increased flux in lithogenic elements in a high-resolution peat record from Spain. They were also able to distinguish between local and regional variations.
2 Method

2.1 Site description and sampling
Moshyttan is located in the Nora Municipality, 25 km from Nora itself. The remains of the blast furnace consist of remnants from the shaft and chimney, some rubble and two slag heaps (Figure 1). The sediment sample was taken from Fickeln, a small lake 600 m downstream from the blast furnace site. Fickeln has an area of 2.5 hectares and a depth of 10.5 m.

Figure 1: The blast furnace is located beside the small stream Mosjöböcken, which flows from Mosjökälla to Fickeln. The right map is drawn by hand using a compass (Wetterholm 1999). The sampling site is located in the central deep part of Fickeln. The bottom map is a three dimensional landscape, created by draping an aerial photo over elevation data (Appendix 2).

The fieldwork was conducted in the middle of March 2012 from Fickeln’s ice surface. A Russian peat corer with a length of 1 meter and diameter of 8 cm was used to sample the
sediment profile. Three overlapping cores were collected from the central and deepest part (10.5 m) of Fickeln. The cores were sampled with a 20 cm overlap hence the complete cored sediment profile had a depth of 230 cm, which does not include the complete sedimentary profile of Fickeln. Additionally the top 20 cm were sampled using a HTH gravity corer with a diameter of 8.5 cm (Renberg and Hansson 2008). The sediment cores were wrapped in plastic film, placed on wooden boards, and covered with aluminum foil to avoid contamination during the transport to the laboratory.

Before subsampling in the lab, the surfaces of the Russian cores were cleaned by scraping off the surface to avoid potential contamination. The cores were sampled at 2 cm resolution to 124 cm depth and 4 cm from 128 to 230 cm depth. All subsamples were freeze dried and homogenized prior to analysis.

### 2.2 Geochemical analyses

0.5 g of the sample was analyzed for major and trace elements using a wavelength dispersive X-ray fluorescence spectrometer (XRF) modified from the methods of De Vlesschouser et al. (2011) specifically for lake sediments. The XRF can analyze total 26 elements but not Hg, which is an important element that's strongly related to mining (Bindler et al. 2011). Instead a PerkinElmer SMS 100 mercury analyzer was used for this purpose. A mercury analyzer heats up the sediment to vaporize the Hg which then can be measured. The PerkinElmer SMS 100 has a detection limit of 0.05 ng/ Hg. The calibration curve was based on analyses of standard reference materials (NCS DC 73002 and NCS DC 73323) and the accuracy was verified based on analyses of two additional standard reference materials (MESS-3 and NCS DC 73309). Replicate analyses of the samples were within 10% and the standard reference materials were within their certified range. The content of organic matter was estimated by loss on ignition and was calculated as a byproduct of the Hg analysis. The samples were reweighed after being analyzed for Hg at 800°C.

### 2.3 Pollen analyses and radiocarbon dating

A series of 18 samples between the depth 88 cm – 54 cm, one sample every 2 cm, was selected for pollen analyses. Preparation of the samples was carried out using the standardized method described by Moore et al. (1991). The samples were treated with 5% KOH and acetolysis and then mounted on slides with safranin-stained glycerine. 500 pollen grains were counted per slide. The charcoal particles were classified as 50-150 µm and >150 µm. Particles larger then >150 µm are not transported very far, hence they are assumed to be a result of local fires.

Four bulk sediment samples and one macrofossil were sent Ångström laboratory in Uppsala for radiocarbon dating. The program R with the CLAM module (Blaauw 2010) was used to calibrate the age and produce an age-depth model using a linear interpolation between the dated levels.
3 Results

3.1 Age-depth model

The results of the radiocarbon dating from Fickeln and the calibrated ages are presented in Table 1. The age-depth model was calculated based on the bulk sediment samples and is extrapolated down to 150 cm (Figure 2). The calibrated age for the macrofossil (75 cm depth) had an unrealistically old age, probably due to resuspension, and was not included in the age-depth model (shown in figure 2). The age-depth model uses a linear interpolation between the dated samples.

Table 1: Results from radiocarbon dating for the sedimentary profile from Fickeln. The calibration was done using the Clam model in R (Blaauw 2010). The probability explains the relative probability that the true age falls within the calibrated range.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Material</th>
<th>Sediment depth</th>
<th>C14 age</th>
<th>Calibrated range</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core 1:32 cm</td>
<td>Bulk sediment</td>
<td>50</td>
<td>500 ±30</td>
<td>AD 1448-1398</td>
<td>95 %</td>
</tr>
<tr>
<td>Core 1:44 cm</td>
<td>Bulk sediment</td>
<td>62</td>
<td>956 ±30</td>
<td>AD 1154-1023</td>
<td>100 %</td>
</tr>
<tr>
<td>Core 1:57 cm</td>
<td>Macrofossil</td>
<td>75</td>
<td>1744 ±75</td>
<td>AD 433-85</td>
<td>94,8 %</td>
</tr>
<tr>
<td>Core 1:64 cm</td>
<td>Bulk sediment</td>
<td>82</td>
<td>1652 ±30</td>
<td>AD 441-326</td>
<td>83,9 %</td>
</tr>
<tr>
<td>Core 1:92 cm</td>
<td>Bulk sediment</td>
<td>110</td>
<td>2361 ±30</td>
<td>384-520 BC</td>
<td>100 %</td>
</tr>
</tbody>
</table>

Figure 2: Age-depth model based on radiocarbon dating based on four bulk sediment samples. The model uses a linear interpolation between the datings. The gray shading indicates the uncertainty of the model. The macrofossil was not included in the model but is displayed in red in the figure.
The most important results from the geochemical analyses are presented in (figure 3).

Figure 3: The most important geochemistry results from Fickeln. The lines mark the periods for which the results will be discussed. The y-axis is calibrated depth where 0 is the sediment surface.

3.2 Geochemical analyses below 88 cm depth (< AD 220)

The section of the sediment record is characterized by generally stable conditions in the sediment profile (figure 3). For example, LOI and elements related to mineral matter are relative constant. LOI is about 62±5% and Zr 25±7 ppm. Although there is no specific trend for LOI and the lithogenic elements, there is slightly more variation towards the end of this section (<120 cm depth). The same pattern is found in the trace metals. Zn, for example remains at stable background concentrations at an average 36 ppm. However, Pb increases at 116 cm from concentrations near the detection limit (6 ppm), and peaks at 106 cm (320 BC) with 18 ppm. Pb declines down to the detection limit at 92 cm. Cu has a general decreasing trend from 65 ppm to 24 ppm. Hg remains stable between 230 to 136 cm at an average 144 ppb, after which a more fluctuating pattern emerges towards 88 cm.
3.3 Geochemical analyses 88 - 54 cm (AD 220 – AD 1300)

LOI increases from 60% to 66% between 88 and 82 cm, after which it starts a steady declining trend and reaches 61% at 54 cm. The lithogenic elements Rb, Zr, and Ti are significantly correlated with the LOI or more precisely, the organic content, (α=0.05, R² = 0.64, 0.54, and 0.47 respectively. When the lithogenic elements increase, the organic content declines. The lithogenic elements are steadily increasing from 88 cm to 54 cm with the exception of Zr, which remains stable until 60 cm before any noticeable increase occurs. For instance, Ti almost doubles from 566 ppm to 971 ppm between 88 cm and 54 cm. The same pattern can be seen in Rb with concentrations doubling from 6 ppm to 11 ppm. However, Zr remains stable until 60 cm, at which point the concentration doubles from 13 ppm to 24 ppm in the short interval between 60 cm (AD 1150) and 54 cm (AD 1300). Pb increases above the background concentration to 10 ppm at 72 cm (AD 750) and show a small peak at 68 cm, (AD 880) with 37 ppm, which is roughly double the previous peak seen at 106 cm (260-390 BC). Pb then continues to increase and peaks again at 58 cm (AD 1200) with 119 ppm, concentrations four times higher than the previous peak at 68 cm. Zn concentrations increase from 66 cm (950) and climb above the background levels (36 ppm) at 62 cm (AD 1090) and show a peak at 58 cm (AD 1200) with 92 ppm, which is more than double the background concentration. Hg increases from a background average of 144 ppb to 209 ppb at 88 cm (AD 220) and remains stable at average 185 ppb until 54 cm (AD 1310). Cu have a peak from 88 to 78 (AD 218 - 536) with average concentrations of 41 ppm, followed by a decreasing trend to 26 ppm at 64 cm (AD 1020). The Cu concentration increases from 64 cm and continues to do so until 50 cm (AD 1420), were it peaks at 51 ppm, double the concentration at 64 cm.

3.4 Pollen and charcoal 88 - 54 cm (AD 220 – AD 1300)

Small and large charcoal particles show three small but simultaneous peaks at 82 cm, 78 cm and 74 cm (Figure 4). Small charcoal particles occur again at 70 cm and continue to be present in small amounts until 64 cm (AD 1020). However, small charcoal particles increase tenfold from 64 cm (AD 1020) to 62 cm (AD 1090). Large charcoal particles are once again present in small quantities at 66 cm but start to double each cm between 60 cm and 54 cm.

Apart from a single Plantago pollen grain at 78 cm, there are no signs of agriculture until 68 cm (AD 880), where two Cerealia pollen and one Secale pollen are found. Plantago is not a crop that is intentionally cultivated, although it is considered to be an indicator of agricultural land (Behre 1980). However, no anthropochores (cultivated plants) are present between 66 cm (AD 950) and 60 cm (AD 1150) but after 60 cm anthropochores are present continuously until 56 cm. Apophytes are indicators of disturbance in the area and are present continuously throughout the analyzed section. There is also peak in apophytes at 68 cm (AD 880). Juniperus, Ericaceae and Rumex, that are regarded as indicators for forest grazing are present throughout the period from 88 cm (AD 220) to 54 cm (AD 1300), but Juniperus shows an increasing trend from 66 cm (AD 950) towards 54 cm (Appendix 1).

The sum of all tree pollen is stable and suggests that the forest was closed from 88 cm to 68 cm (AD 220 – AD 880) with a minor increase between 68 cm and 54 cm. There are some changes in the tree composition. Betula increases between 64 and 54 cm, and Picea decreases at 66 cm but increases again towards 54 cm. Pinus and broadleaf trees show a decreasing trend between 66 and 54 cm. Isoetes, an aquatic plant, and Polypodiaceae species start a
decreasing trend from 66 cm and 68 cm, respectively, with a synchronous decrease starting after 62 cm, possibly indicating changes in the erosion pattern surrounding the lake.

3.5 Geochemical analysis 54 - 0 cm (AD 1300 – present)
LOI decreases from 61% at 54 cm to 39% at 20 cm, the lowest share of organic material in the sediment profile. The LOI increases to 65% at 10 cm followed by a dip to 53% at 8 cm, before it finally resumes the increasing trend towards the surface. The lithogenic elements continue the increasing trend and Zr peak between 50 cm (AD 1420) and 38 cm (AD 1450) with more than three times the background concentrations. The next peak occurs at 26 cm, simultaneously with the dramatic decrease in the trace metals. K has a concentration at 7150 PPM at this point, more than seven times higher than the background concentration. This peak is followed by a sharp decrease in all lithogenic elements towards 24 cm (AD 1730). All lithogenic elements (except K) show the highest peak in the sediment profile at 20 cm, three to six times higher than the background concentrations. Pb peaks at 30 cm (AD 1660) with a concentration of 188 ppm, which is 36% higher than the previous peak at 58 cm (AD 1200). Pb decreases dramatically towards 26 cm (AD 1700) and reaches 58 ppm, the lowest concentration since 64 cm (AD 1020). Pb quickly increases and peaks again at 12 cm (AD 1870) at 204 ppm, which is the highest concentrations in the entire sediment profile, after which Pb decreases towards the surface. Other trace metals such as Zn, Cu and As follow the same pattern with little or no deviance from this trend. However, Hg has a fluctuating pattern with a general increase towards the surface.

4 Discussion

4.1 230 - 88 cm (1040 BC – AD 220)
The sediment profile does not cover the whole history of the lake since the deglaciation, but the period before 88 cm or AD 220 can be generally considered as background geochemical conditions except for Pb. The peak in Pb between 620 BC and AD 99 (116 cm – 92 cm) was the only change in the geochemistry at this point, thus indicating a long-range atmospheric transport and deposition. This peak has been found in many other lakes in Sweden (Renberg et al. 2001), and Europe (Cloy et al. 2008) and is known as the “Roman lead peak”. Bindler et al. (2011) analyzed two sediment records and one peat record close to Lapphyttan, only 80 km northeast of Moshyttan and found this peak in lead accompanied by a decline in the $^{206}\text{Pb}/^{207}\text{Pb}$ ratio, centered about AD 80. Because of the higher LOI in Fickeln's sediment and thus long influence of natural Pb derived from soil mineral matter, the early atmospheric signal is quite clear in this lake (Bränvall et al. 2001).
4.2 88 - 54 cm (AD 220 – AD 1300)
A Summary of geochemistry, pollen and charcoal particles for AD 220 – AD 1300 are presented in (Figure 4), combined with Wetterholms radiocarbon datings on slag.

Figure 4: Summary of geochemistry, pollen and charcoal particles for AD 220 – AD 1300 (88 cm -54 cm). The range of Wetterholms radiocarbon datings on slag produced by Moshyttan are presented on the top of the diagram (Wetterholm 1999).
The increase in lithogenic elements combined with the decrease in organic matter from AD 218 (88 cm) indicates changes in land use in the area. This is supported by a presence of Juniperus, Ericaceae, Rumex and minor peaks in charcoal particles, and a Plantago pollen at AD 540. The trace elements are represented by stable concentrations. Natural forest fires can also explain the occurrence of charcoal, which makes it difficult to draw a firm conclusion regarding the causes based on these data (Ohlson and Tryterud 2000).

The first undisputable agricultural activities in the area are detected at AD 880 (68 cm). Two Cereiala pollen, one Secale pollen and a small increase in apophytes were recorded at the same time that Pb reaches higher levels. According to Vuorela (1973), rye pollen (S. Cereale) does not travel very far, hence suggesting that the agricultural activities were located in the nearby area. Small shares of small charcoal particles are recorded since AD 810 (70 cm). The results suggest that human settlement with small-scale agriculture and possibly metallurgy established in the area about AD 880. Because the signals are small, it is not possible to state with confidence where this initial increase in Pb derived from. Similar studies tracing the early origins of ore mining and metallurgy from Norberg (Bindler et al. 2011) and also Gladhammar (Karlssson and Berg 2011) found this combination of weak pollution Pb signal together with a weak signal of local land use during the 10th century, prior to the more significant changes in geochemistry and pollen during the 12th–14th centuries that could be clearly linked to activities close to their respective study lakes. Inclusion of stable Pb isotop analyses in those studies suggested that some of this weak Pb pollution signal in the 10th century was derived from Bergslagen ores.

Wetterholm’s analyses of ore chemistry and his radiocarbon datings suggest that a high temperature method was being used during the late 10th century at Moshyttan. Within the uncertainty of the age-depth model from Fickeln, the changes in geochemistry, pollen, and charcoal particles in the sediment record provides support for Wetterholm’s hypothesis that a blast furnace was established at Moshyttan ca. AD 1000–1100. The main evidence in the sediment record is the increase from AD 1020 in Pb (twofold), Zn and Cu together with the increasing number (tenfold) of charcoal particles. This combination would suggest a local source as has been shown in Norberg and Gladhammar (Bindler et al. 2011, Karlsson and Berg 2011). In addition to these pollution indicators, although the total percentage of tree pollen does not decline, the forest composition changes from AD 950 towards AD 1300. The proportion of broadleaf trees and Pinus decreased from AD 950 towards AD 1300 while Betula increased during the same period. These changes in the tree composition are consistent with results from Lapphyttan (Bindler et al. 2011) and the Gladhammar mining area (Karlsson and Berg 2011).

These changes in pollution indicators and tree pollen are also connected to changes in aquatic pollen types, where decreasing amounts of Isoetes from AD 1090 occur in combination with an increase in lithogenic elements (e.g., Ti, Zr and Rb). These changes suggest increased transport of eroded material to the lake (indicated by the lithogenic elements), which alters the conditions that would affect the distribution of this shallow water plant types. Isoetes is an indicator species for oligotrophic lakes and the increased nutrient input from the lithogenic elements increased the production of algae and thus reducing the light input.
These data would suggest that Moshyttan was possibly established one or even two centuries earlier than Lapphyttan.

4.3 54-0 cm (AD 1300 – present)

Significant changes occur in the sediment after the establishment of the blast furnace in the 11th century. The increase of minerogenic material and decrease in organic matter indicates human settlement in the area. The first time Moshyttan was mentioned in historical texts was not until 1539 (Landeholm and Eriksson 2001). The pollution from metallurgy continues to increase from the establishment of Moshyttan and peaks about AD 1600. The activities at the blast furnace at Moshyttan continued until AD 1721 when it finally was abandoned, ~700 years after it was first established.

Jacobson and Bradshaw (1981) presented a model that describes the relationship between basin size and pollen source area and predicted the proportions of local and regional pollen sampled by lake basins of different size. In short, smaller area reflects local changes while larger areas result in a regional signal. Fickeln is not a large lake and should record changes on the local scale; however, the distance between Fickeln and Moshyttan is over 600 m, and thus the forest in the closest proximity to the lake might be overrepresented compared to the changes closer to Moshyttan (Jacobson and Bradshaw 1981, Bradshaw 1988).

The pollen and charcoal analyses alone would not suggest the establishment of a blast furnace in the area. The decline in trees, increase in shrubs, anthropochores and apophytes could be a result of forest burning in preparation of agricultural activities, so called slash and burn (Mighall et al. 2006). The same point can be made in regard of the geochemical analyses. For example, the increase in Pb can be explained by atmospheric deposition due to the low concentrations and similarity with patterns of atmospheric deposition in Sweden (Renberg et al. 1994). However, when the ecological changes are combined with the dramatic increase in both small and large charcoal particles and the independent geochemical data the results offers substantial support for Wetterholms radiocarbon datings, thus making Moshyttan the oldest known blast furnace in Sweden and Europe. The combination of geochemical and ecological data is the main strength of this multiproxy study and the results are consistent with multiproxy studies from France (Monna et al. 2004), The United Kingdom, (Mighall et al. 2002), Spain (Martínez Cortizas et al. 2005), and Sweden (Bindler et al. 2011a).

5 Acknowledgements

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Appendix 1

Complete pollen diagram.
Appendix 2

Three dimensional model over the landscape around Fickeln and Moshyttan.