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Soil chemistry, vegetation history and human impact at the Late Holocene iron production site of Åskagsberg, western Sweden

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A Viking Age/Early Medieval slagheap and remains of clay from furnace walls have been found in the close vicinity of a mire at Åskagsberg, western Sweden (60°17'30"N, 5°31'42"E). About 100 m south of the mire, groundwater movements have favoured precipitation of iron oxides to form red soil. Despite the low concentrations of iron in the primary minerals, the red soil contains *c.* 60% Fe_2O_3. These concentrations allow direct iron production. The silica content (2–7% SiO_2) is probably too low for slag formation, however. To compensate for this deficiency, it is likely that till that was rich in silica was collected at the margin of the mire for mixing with the red soil. A maximum of 10 m^3 of red soil is estimated to have been mined, containing c. 10^4 kg iron. Charcoal incorporated in a piece of slag collected from the bottom of the heap was radiocarbon dated to 990–1160 cal AD. A marked decrease in tree pollen concentration, contemporary with an increase in charcoal particles, indicates that wood cut from the surrounding forest was used for charcoal production between 1000 cal AD and 1350 cal AD. Small-scale cultivation and forest grazing were dated to AD 1600, corresponding to the initiation of the Finnish colonisation.

Keywords: Early Medieval/Viking Age iron production, vegetation history, red soil, chemical composition

Introduction

During recent years, archaeologists in Sweden have shown a growing interest in the formation and quality of ores found in connection with iron production sites from the Iron Age onwards (Wedberg 1987; Joosten et al. 1998; Espelund 1999:98–112). To reconstruct the labour process, an important question is whether the ore was of local origin or transported to the site from some distance away. The iron making process also demanded large amounts of wood, so that several attempts have been made to trace forest cutting from studies of pollen stratigraphy in adjacent lake sediments and peat accumulations (Königsson & Qvarfort 1988; Solem 1991; Karlsson 2000; Karlsson & Robertsson 2001). Although it is well known that ores from bogs, lakes and red soil were used for iron production during the Iron Age and the Medieval period (G. Magnusson 1986; Björkenstam 1990:55–56), there have been few geological and geochemical studies of the available iron ores. Furthermore, opinions differ about the chemical composition of iron-rich soils, i.e. red soils, and thus their usefulness for this purpose (Espelund 1999:98–112). Björkenstam (1990:55–56) states that the first ores used in Sweden were red soil, iron ochre and bog iron. Recent studies and experiments have shown that red soil sometimes has a sufficient iron content to be used as an ore (Wedberg 1984; Augustsson 1985; Wedberg 1987; Pettersson 1998:34–36), but as there are no accepted standard extraction or analytical techniques, comparisons between reports are difficult (Buchwald 1997:225–253; 1998; Espelund 1999:98–112). The molar ratio between iron and silica is important for the formation of slag, and thus for iron production. To produce iron, a Fe/Simolar ratio between 1.2 and c. 6 was needed (Espelund 1999:98–112).

Direct iron production was introduced in Sweden during the late Bronze Age (Serning 1984; Hjärtner-Holdar 1993) or at the beginning of the Early Iron Age, c. 500 BC (G. Magnusson 1986), and the technique continued to be practised in some areas of mid-western Sweden until the mid-19th century (G. Magnusson 1986). More than 90 iron production sites and more than 1000 charcoal burning pits have been identified in the northern part of the county of Värmland (E. Svensson 1998:79–101). Radiocarbon dates for charcoal incorporated in pieces of slag indicate that the majority of the iron production sites date to the Late Iron Age and/or Early Medieval period (E. Svensson 1998:79–101; Myrdal-Runebjer 1998:4-19). One feature common to all the sites dated to these periods is that no furnace constructions are visible above the ground, and that they are situated in areas with several charcoal pits. At Åskagsberg (Fig. 1), iron was produced by the direct reducing method, i.e. only the slag was melted (cf. G. Magnusson 1992). The purposes of the present interdisciplinary pilot study at Åskagsberg were to describe the chemical characteristics of a supposed local ore, to estimate the quantity of material mined and to investigate human impact on the vegetation.

Gun Pettersson was responsible for the chemical analyses and the measurements of mineral magnetic concentrations, Sven Karlsson for the pollen analyses and Eva Myrdal-Runebjer for the archaeological data. The authors made interpretations jointly.

Site description

Åskagsberg (60°17'30"N, 5°31'42"E) is situated on a plateau about 290 m a.s.l. in a fissure valley landscape in northern Värmland (Fig. 1A–D). The bedrock is dominated by red gneiss, with varying amounts of magnetite (N.H. Magnusson et al. 1962:5–18). The site is located west of the mylonite zone, and is part of the gneiss region of south-west Scandinavian Domain. The bedrock is mostly covered by a thin, more or less uniform sandy till, rich in boulders (Lundqvist 1956; 1958:35–77). The mineralogy of the boulders indicates short-distance glacial transport (Lundqvist 1958:35–77). The valleys are often occupied by mires.

The remains surviving from iron production at this site consist of a slagheap, including scattered pieces of clay from furnace walls (RAÄ 421 in Östmark parish; Fig. 1C, D). Charcoal incorporated in a piece of slag collected from the bottom of the heap was radiocarbon dated to the transition between the Late Iron Age and Early Medieval times (975±70 BP, Ua-13412; Myrdal-Runebjer 1998:4–19). This date corresponds to 990-1160 cal AD (Stuiver et al. 1998). Nine charcoal pits have been found within 500 m of the slagheap.

The hill-slope at the iron production site is covered by a thin layer of till, and lenses of reddish soil occur sporadically along the mire margin west of the slagheap. Chemical weathering in the till close to the mire has occasionally been efficient enough to break down some of the boulders to gravel-sized particles, and a reddish precipitation of iron oxides occurs underneath these. A terrace-like feature in the minerogenic material was observed at the boundary between the mire and the till slope, east of point 5 (Fig. 1D).

Drainage from the mire is characterised by seepage of surface and groundwater from the south-western corner to enter the River Valpån c. 150 m south-east of the slagheap (Fig. 1C). Fine-grained red soil rich in iron has been formed where the ground surface shows the steepest inclination (Fig. 1C, E). A ≤45 cm thick layer of red soil covers an area of 15–20 m^2 on the eastern side of the drainage basin, while red soil occurs sporadically on the western side. These areas are separated by a depression c. 60 cm deep. The red soil consists of a fine-grained matrix. Iron nodules, 1–2 mm in diameter, were found east of the depression. This occurrence of red soil can be traced up-slope, towards the crest of an elongated till ridge (N55°E), at the south-western end of which thin layer of red soil measuring up to 5 cm was identified. Podzols were dominant at the opposite end, with transitional soils in between. Drainage from the south-western part of the till ridge is directed towards the major occurrence of red soil, east of the mire drainage basin.

The vegetation surrounding the mire is characterised by a relatively open pine forest. The ground cover is formed by cowberry plants (*Vaccinium vitis-idaea)* and reindeer lichen. Sparse stands of pine and birch (*Pinus sylvestris*, *Betula pubescens*) are growing on the mire surface, while dwarf birch (*Betula nana*) occurs sporadically. The ground vegetation consists of

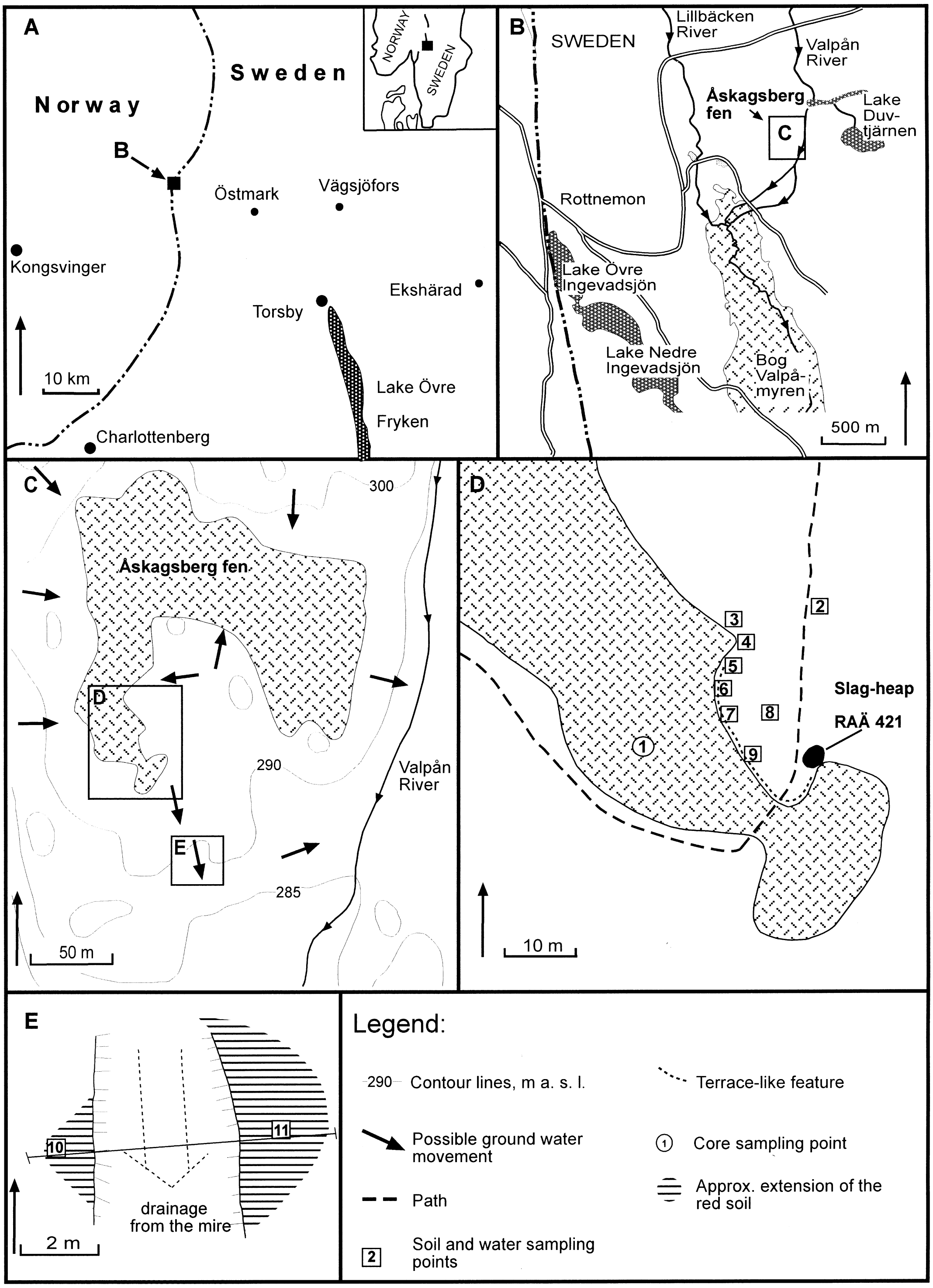

Figure 1. A, B. The Åskagsberg site is situated in northern Värmland, c. 30 km north-west of Torsby and 2 km east of the Norwegian border.

C. The mire is located on a plateau, c. 290 m a.s.l.

D. Positions of sampling points 1–9 and location of the slagheap.

E. An area with red soil was found along the diffuse drainage area. The line between sampling points 10 and 11 indicate the position of the schematic cross-section shown in Fig. 6.

Table 1. Concentrations of the major elements in the soil samples. There is only a small difference in geochemical composition between the <20 mm and <2 mm samples, but there is a large difference between the samples collected close to the mire and those from the red soil. Since the particles constituting the red soil fall within the grain size fraction <2 mm, only this fraction was analysed.

Point	Depth (cm)	Material analysed	SiO_2 (%) <20 mm	Al_2O_3 (%) <20 mm	Fe_2O_3 (%) <20 mm	MnO (%) <20 mm	P_2O_5 (%) <20 mm	Fe/Si Mole ratio	SiO_2 (%) <2 mm	Al_2O_3 (%) <2 mm	Fe_2O_3 (%) <2 mm	MnO (%) <2 mm	P_2O_5 (%) <2 mm	Fe/Si Mole ratio
2	06–11	B-horizon	66.5	13.4	3.8	0.06	0.16	0.0	62.5	12.1	3.2	0.04	0.16	0.0
3	40–45	Reddish lens	57.0	12.8	6.0	0.05	0.08	0.1	44.1	12.2	7.1	0.03	0.10	0.1
4	30–40	Reddish lens	67.1	13.4	2.1	0.05	0.06	0.0	52.3	12.4	2.2	0.03	0.12	0.0
5	20–30	Reddish lens	56.0	12.9	4.1	0.04	0.12	0.1	48.3	12.7	4.1	0.02	0.19	0.1
5	30–33	Reddish lens	56.5	10.8	6.2	0.05	0.08	0.1	42.9	8.5	8.3	0.02	0.14	0.1
5	35–45	Reddish lens	44.2	13.5	3.7	0.04	0.13	0.1	39.3	13.4	3.6	0.02	0.18	0.1
6	42–62	Reddish lens	55.2	12.0	6.1	0.04	0.11	0.1	46.3	11.0	6.4	0.02	0.14	0.1
7	19–21	Reddish lens	64.4	12.8	3.3	0.06	0.12	0.0	65.0	12.3	3.1	0.04	0.14	0.0
8	21–40	C-horizon	68.1	12.4	3.3	0.06	0.12	0.0	65.8	11.2	2.9	0.03	0.15	0.0
9	20–25	Reddish lens	67.6	12.0	2.9	0.03	0.08	0.0	64.5	11.6	3.0	0.03	0.08	0.0
9	25–40	Reddish lens	64.9	14.1	4.3	0.07	0.09	0.0	31.5	9.5	3.4	0.02	0.08	0.1
9	40–50	Reddish lens	54.0	13.4	7.1	0.05	0.13	0.1	40.1	13.0	6.9	0.02	0.13	0.1
10	10–15	Red soil							3.0	1.2	67.6	1.20	0.23	17.0
11	10–15	Red soil							3.0	2.2	65.8	4.00	0.25	16.5
11	20–25	Red soil							3.3	2.6	63.1	4.90	0.27	14.4
11	25–30	Red soil							2.5	2.4	62.3	3.40	0.27	18.8
11	30–35	Red soil							2.5	2.6	55.8	8.70	0.30	16.8
11	35–45	Red soil							7.4	3.0	53.8	4.80	0.26	5.5

heather, crowberry, wild rosemary, bog whortleberry, bilberry and cowberry (*Calluna vulgaris*, *Empetrum hermaphroditum*, *Ledum palustre*, *Vaccinium uliginosum*, *V. myrtillus* and *V. vitis-idaea*).

Materials and methods

Fieldwork

After stratigraphic explorations of the mire, a 170 cm long core was retrieved using a Russian peat sampler (Jowsey 1966) from point 1, c. 25 m west of the slagheap (Fig. 1D). The pollen content and the concentrations of mineral magnetic particles were determined. The main part of the sequence, between 170 and 30 cm, consisted of fen peat with a medium degree of humification, and the uppermost 30 cm of bog peat. The organic material was superimposed on coarse-grained minerogenic matter. Eighteen soil samples were collected from reddish lenses, the B and C soil horizons in the till and the red soil. These samples were analysed regarding their chemical composition.

Geochemical analyses

The geochemical soil analyses were performed on minerogenic particles <2 mm. If coarser particles were present, the grain size fraction <20 mm was also analysed. The material was dried at 105°C for two hours, homogenised and ground to a fine powder in an agate mill. 100 mg of this powder and 150 mg lithium methaborate ($LiBO_2$) was ignited at 1000°C for 30 minutes, dissolved in 25 ml 8% nitric acid (HNO_3) and diluted to 100 ml (Burman et al. 1977). The solutions were analysed with an ICP (Induced Coupled Plasma) spectrometer. In view of the high iron concentrations, carbon was added to the samples from points 10 and 11 to reduce Fe^{3+} to Fe^{2+}. The silica, aluminium, iron, manganese and phosphorous concentrations are expressed in terms of their oxides (SiO_2, Al_2O_3, Fe_2O_3, MnO and P_2O_5).

Radiocarbon dates

Three bulk samples of peat from the core, collected at 36, 65 and 95 cm depth covering the presumed period of human impact, were AMS dated at the Ångström Laboratory, Uppsala University, Sweden (Possnert 1990). Macroscopic roots were removed prior to dating. The sodium hydroxide (NaOH) soluble fraction (SOL) was dated using a half-life $T_{1/2}$=5568±30 years.

Pollen analysis

The core from point 1 was subsampled at 2.5, 5 and 10 cm intervals, resulting in 32 samples. The denser intervals were chosen to cover the sequence assumed to reflect human activities, while a less dense interval was accepted for the bottom part. The material was processed by the conventional acetolysis method (Erdtman 1936; Berglund & Ralska-Jasiewiczowa 1986). Tablets containing c. 12500 *Lycopodium* spores each were added to the samples at the initial stage for calculation of the pollen concentration/g dry weight (Stockmarr 1971). The basic sums varied between 300 and 500 pollen grains per sample. These sums were normally reached after counting one slide. A second slide was scanned for additional pollen grains of human indicator plants, which were added to the basic sum. Identification of the pollen and spores followed mainly Faegri & Iversen (1989) and Moore et al. (1991), and a reference slide collection was also used for comparison purposes. Trees, shrubs, dwarf shrubs and terrestrial herbs were included in the pollen sum for the percentage calculations. Spores were excluded from the pollen sum in the percentage diagram. Microscopic charcoal particles, >20 mm, were counted in parallel with the pollen because they may provide information about fires close to the sampling point (cf. Zackrisson 1977; Tolonen 1986; Patterson et al. 1987; Bradshaw & Hannon 1992; Renberg et al. 1993; Almquist-Jacobson 1994:58–62).

The pollen results were compiled using the computer programs TILIA, version 2.0. b.4, and TILIA GRAPH, version 2.0. b.5 (Grimm 1992). Trees and shrubs are presented as separate groups, while herb pollen is divided into cultivated plants, general apophytes, forest herbs, fresh meadows, wet meadows and ruderal communities (Behre 1981, Berglund & Ralska-Jasiewiczova 1986, Gaillard & Berglund 1988, Hammar 1999). Local pollen assemblage zones were established by cluster analysis implemented using the computer program CONISS (Grimm 1987).

Mineral magnetic measurements

The peat was subsampled contiguously at one cm intervals, resulting in 171 levels. The material was put into non-magnetic polystyrene containers, each representing c. 8 cm^3. The initial magnetic susceptibility of the fresh samples was measured with a Geofysica Brno KLY-2 Kappabridge at the Department of Quaternary Geology, Lund University, Sweden, the final result being corrected for the diamagnetic contribution of the sample holder. Saturation Isothermal Remanent Magnetisation (SIRM) was induced in 1 Tesla, using a Redcliffe BSM-700 pulse magnetiser and measured with a Molspin Minispin magnetometer. After the magnetic analyses, the samples were dried at 40°C and weighed to allow calculation per unit of dry weight (cf. Lagerås & Sandgren 1994). The results are expressed in mass-specific SI units.

Results and interpretation

Soil chemistry

The sample collected from the C-horizon at point 8 contained 2% Fe_2O_3, which represents an average value for Swedish tills (cf. Melkerud et al. 1992:20–21) and may be taken here to represent the local background. The samples collected from lenses in the till close to the mire show similar values (2–5%) and low Fe/Si molar ratios (Table 1), indicating that the material cannot have been used for iron production (cf. Espelund 1999:98–112). The chemical composition as determined for the grain size fractions <20 mm and <2 mm is relatively uniform, indicating low variability in mineralogical composition for these grain sizes in the soil.

The red soil is dominated by particles <2 mm, allowing analysis only of this fraction. The six samples studied show a distinct difference in chemical composition from the lenses in the till (Table 1). The iron content varies between 54 and 68% Fe_2O_3, with values decreasing downwards in the soil profile. The Fe/Si molar ratio is high, 5.5 to 18.8, making this material suitable for direct iron production (cf. Espelund 1999:98-112), although the silica concentration may be close to the lower boundary for production (2.5-7.4% SiO_2). The manganese content is high, 1.2–8.7% MnO, which may compensate for the low silica content to some extent (cf. Espelund 1999:98-112).

Radiocarbon dates

The 1 cm slices of peat from depths of 95, 65 and 36 cm were dated to 2980±70, 1680±70 and 605±50 ^{14}C years BP, respectively (Table 2), corresponding to 1320–1110 cal BC, with 61.7% probability, 250–440 cal AD, and 1300–1400 cal AD with 68.2% probability (Stuiver et al. 1998). A time-depth model was constructed on this basis (Fig. 2) allowed an age of 6300 ^{14}C years to be achieved at depth 170 cm by extrapolation from the two lower dates. This age should be considered a minimum for the level concerned, as the higher degree of humification in the bottom 0.5 m could have resulted in a higher compaction, increasing the age of the bottom layer. A line was fitted between the two upper dates and extrapolated to the boundary between the fen peat and bog peat. If affected by contamination errors, it is possible that the dates may be too young, because of downward penetrating rootlets (cf. Olsson 1986; 1991; Åkerlund et al. 1995). Conventional and calendar year ages for the zones were estimated from the time-depth model.

Pollen analysis

Four local pollen assemblage zones were identified (LPAZ ÅS 1-4), covering changes in the local vegetation history for the last c. 6300 ^{14}C years BP (5300 cal BC).

In LPAZ ÅS 1, estimated to extend from 6300 to 1600 ^{14}C years BP (5300 cal BC – 450 cal AD, 170–62.5 cm), *Pinus* and *Betula* pollen dominate the forest vegetation, with values mainly between 35 and 50% (Fig. 3). Pollen values for *Alnus* vary between 5 and 10% and the combined figure for *Corylus, Quercus, Ulmus* and *Tilia* fluctuates around 1%. Scattered pollen grains from *Picea* are found in the upper part of the zone. The fen taxa are dominated by Cyperaceae, *Menyanthes* and *cf. Potentilla palustris*. There are weak traces of human activities at depths of 150 and 95–85 cm, as indicated by single pollen grains of *Plantago lanceolata* and *Melampyrum* together with a peak in grass pollen (Poaceae). This pollen composition may be interpreted as the result of forest grazing at around 3000–2600 ^{14}C years BP (1200–800 cal BC). Two charcoal layers at 125 cm and 105 cm depth, corresponding to c. 4200 and 3700 ^{14}C years BP (2800 and 2100 cal BC), indicate that forest fires occurred in the vicinity. These were most likely of natural origin, since there is no pollen indicating human activities. The forested area around the Åskagsberg fen is interpreted as having possessed stable vegetational conditions dominated by pine and birch. A large proportion of the birch stands may have been growing on and around the fen (to-

Table 2. AMS radiocarbon dates (^{14}C yrs BP) and calibrated ages (BC/AD) according to Stuvier et al. (1998). The dated samples correspond to 1 cm slices of bulk *Carex* peat.

Depth (cm)	Lab. no	Uncorr ^{14}C yrs BP±1σ	Calibrated age BC/AD	δ^{13}C
36	Ua-19485	605±50	AD 1300–1400	–26.6
65	Ua-15096	1680±70	AD 250–440	–27.7
95	Ua-15095	2980±70	1320–1110 BC	–27.8

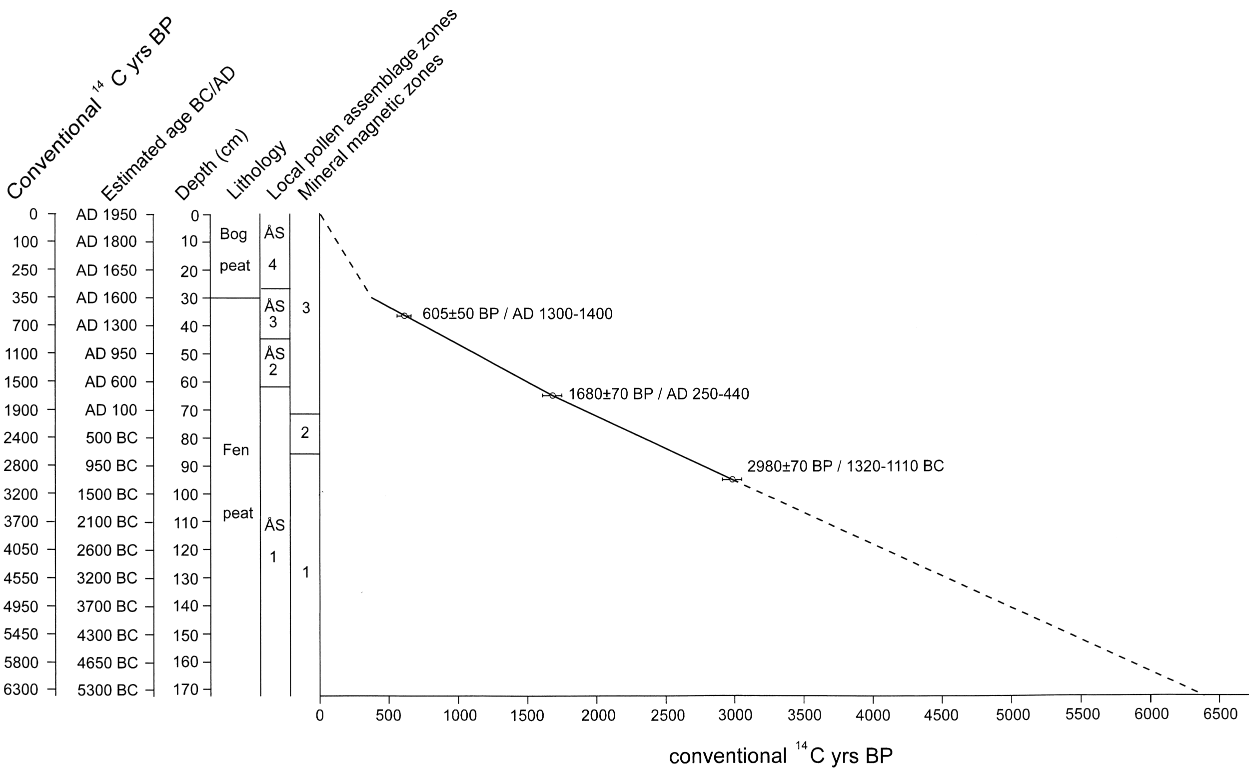

Figure 2. Time-depth model based on three radiocarbon dates. We assume that the rate of accumulation changes at the boundary between the fen peat and bog peat. The scale showing estimated cal. years BC/AD is based on Stuvier et al. (1998).

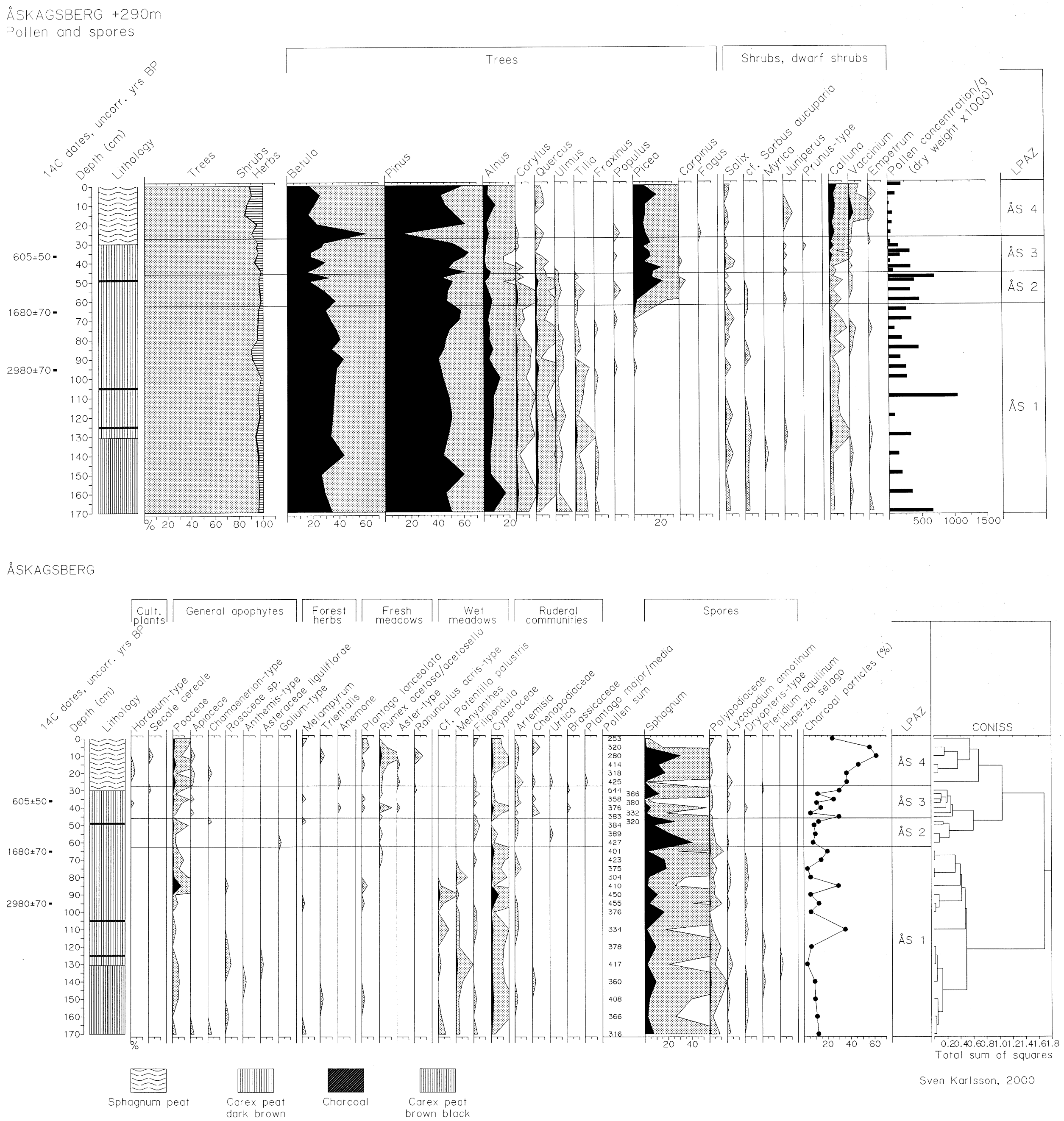

Figure 3. A, B. The percentage pollen diagram from point 1 reflects the vegetation changes since *c.* 6300 ^{14}C years BP (c. 5300 years cal BC). The increased human impact in LPAZ ÅS 3 and ÅS 4 is interpreted as a result of forest grazing and cultivation. Approximate calibrated ages corresponding to every 10 cm are shown in Fig. 2.

gether with *Alnus*). The sparse occurrence of *QM* trees (*Quercus*, *Ulmus*, *Tilia* and *Fraxinus*) is probably related to the altitude and the thin, nutrient-poor soil.

In LPAZ ÅS 2, dated to 1600–1000 ^{14}C years BP (450–1000 cal AD, 62.5–46.0 cm), pollen of *Pinus* is dominant, while the *Betula* curve decreases. *Picea* increase rapidly from single percentages to c. 20% at the lower zone boundary (Fig. 3), reflecting the general spread of spruce to the area , dated to 1680±70 BP (250–440 cal AD). This age correspond well with the results of earlier investigations (Hafsten 1985; 1991; 1992; Mattsson 2001:13–17). Pollen of the *QM* trees *Quercus*, *Ulmus* and *Tilia* occurs in low but regular amounts, as in the previous zone. There are no obvious signs of human impact in the pollen record. The forest is still dominated by pine and birch, but spruce stands

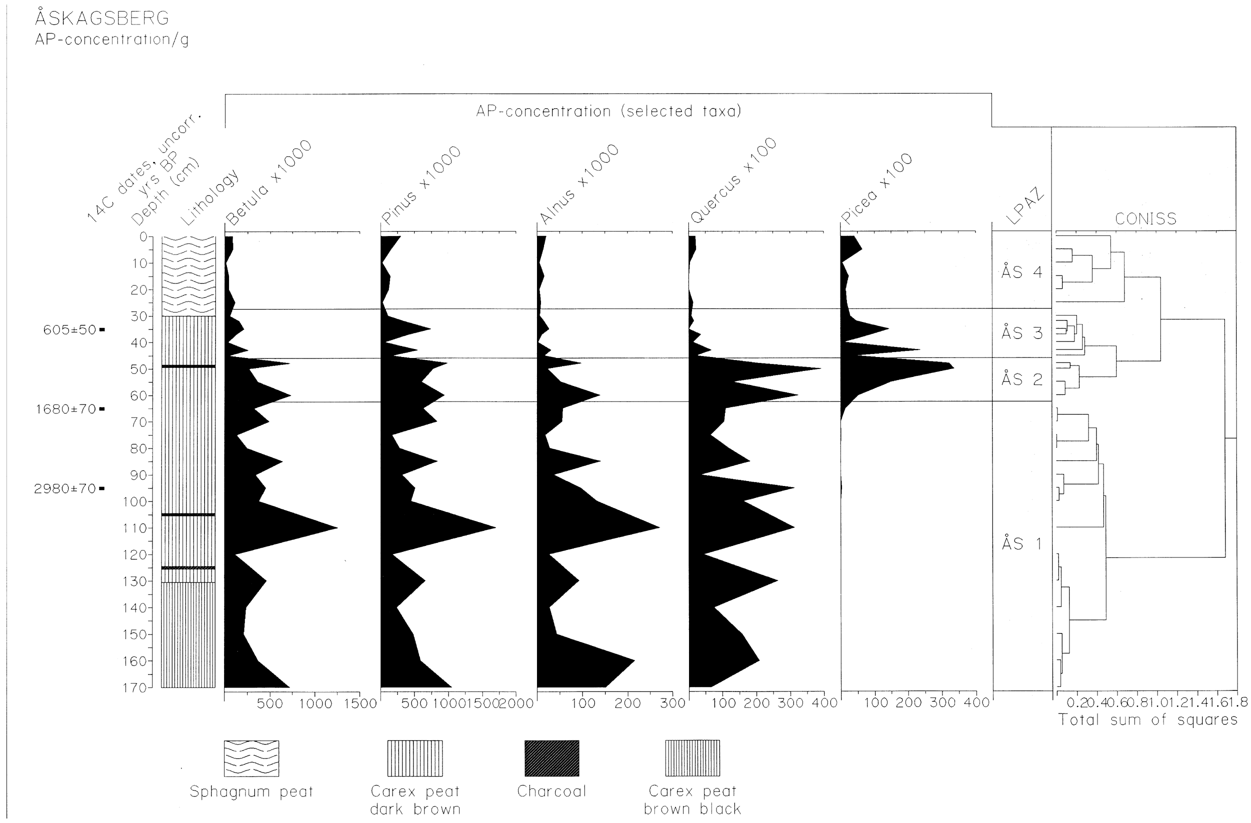

Figure 4. Pollen concentrations/g dry weight for the most common tree taxa in the peat sequence analysed for point 1. The decrease in pollen concentration at the LPAZ ÅS 2/3 transition, is a result of comprehensive forest cutting. The evidence of forest clearance in the lower part of LPAZ ÅS 3 is interpreted as having been connected with iron production during the Viking and/or Early Medieval Period.

are evidently increasing. The charcoal layer at depth 49 cm is probably the result of a forest fire.

In LPAZ ÅS 3, dated to 1000–300 ^{14}C years BP (1000–1625 cal AD, 46.0–27.5 cm), the pollen curves for *Betula* in particular, but also for *Pinus*, have a fluctuating appearance, while *Corylus* and *Quercus* decrease. Pollen of *Ulmus* and *Tilia* disappears completely at the lower zone boundary. These changes in forest composition were contemporary with the presence of several pollen taxa indicative of human impact, *e.g. Plantago lanceolata* and *Juniperus*, interpreted as reflecting grazing. *Rumex acetosa/acetosella*, probably *R. acetosa*, and Cyperaceae are characteristic of wet meadows, so that their peaks at a depth of 40 cm may be related to haymaking. The first pollen grains of cereals appear at 37.5 cm (*Hordeum* type) and 30 cm (*Secale*), corresponding to 650 and 350 ^{14}C years BP (1350 and 1600 cal AD). Human impact is also reflected by an increased proportion of charcoal particles (cf. Fig. 3), probably as a result of forest clearance.

There is a decrease in tree pollen concentrations at the lower zone boundary (Fig. 4), possibly caused by extensive cutting of the forest for charcoal making in connection with iron production. This coincides in time with the date obtained for charcoal from the bottom of the slagheap (975±70 ^{14}C years BP, corresponding to AD 990–1160). The pollen concentration values remain low throughout the zone, probably as a consequence of the combination of an artificially open forest, a decrease in compaction and a transition to a poorly humified *Sphagnum* peat.

In LPAZ ÅS 4, dated to 300–0 ^{14}C years BP (1625–1950 cal AD, 27.5–0 cm), tree pollen is dominant, as in the previous zones, in the form of *Pinus*, *Betula* and *Picea*. The increasing proportions of pollen from the light-demanding species *Juniperus* and of charcoal particles, together with pollen of *Chamaenerion*, indicate a relatively open forest. Pollen of *Hordeum* and *Secale* re-appears at 20–15 cm and 10 cm, respectively, dated to 250–200 and 100 ^{14}C years BP (1650–1700 and 1800 cal AD). The finds of *Hordeum* and *Secale* pollen and the distinct increase and maximum in charcoal particles (Fig. 3) together indicate slash-and-burn cultivation by Finnish immigrants, which started in

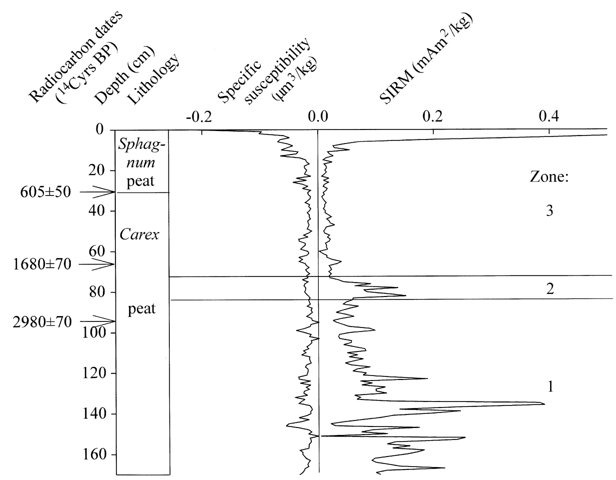

Figure 5. Specific magnetic susceptibility and SIRM in the core from point 1. The increase in SIRM in zone 2 represents a slight increase in soil erosion.

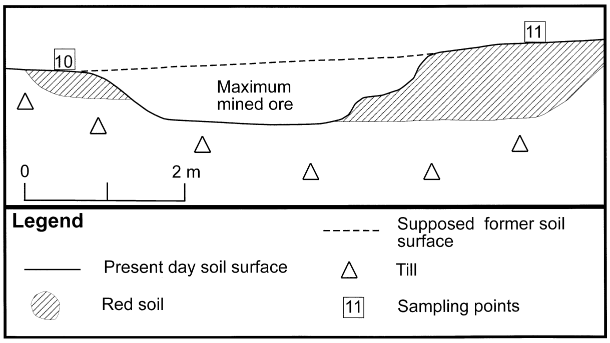

Figure 6. Patches of red soil were identified at the margins of the diffuse mire drainage area (cf. Fig. 1E). The topographic depression between these red soil areas is interpreted as a result of the excavation of ore for iron production. The volume of red soil mined is estimated to have been c. 10 m^3.

the early-middle 17th century (Broberg 1988). The increase in *Pinus* in the uppermost sample may reflect reforestation of the area during the last 200 years.

Mineral magnetic properties

The concentrations of magnetic particles in the peat display low values throughout the sequence, indicating a limited input of minerogenic particles at the sampling point (Fig. 5). In fact, magnetic susceptibility shows negative values, varying between -0.2 and 0 mm^3/kg. SIRM decreases from c. 0.2 mAm^2/kg in the lower part of zone 1 to almost zero in zone 3. The fluctuating SIRM values in zone 1 are probably the result of variations in the rates of the peat accumulation. The general decreasing trend in the input of minerogenic particles at the sampling point is a consequence of the accumulation of peat, causing a gradual rise in the ground surface. There is a minor increase in SIRM to c. 0.15 mAm^2/kg in zone 2, which is interpreted as representing the effects of intensified soil surface erosion bringing minerogenic particles to the sampling point.

Discussion

Reports differ regarding the chemical composition of ores used for iron production during the Medieval period (Wedberg 1984; Björkenstam 1990:55–56; 1991; Buchwald 1997:225–253; 1998; Joosten et al. 1998). Different extraction and analytical methods have been used and concentrations have been reported in terms of Fe, FeO or Fe_2O_3, making comparisons between investigations difficult. At Riddarhyttan, southern central Sweden, iron is produced nowadays from a fine-grained red soil containing 60–73% Fe_2O_3 (Pettersson unpubl.), the extraction method being comparable to that used in the present investigation. Many iron production sites are situated close to mires and a common assumption is that bog ore was used as the source material. As the field inventory did not reveal the presence of bog iron, we started to search for iron-rich soils in the immediate vicinity of the slagheap. Two probable areas were located. The first was located only 10–20 m west of the slagheap. The slope morphology displays a pronounced terrace towards the mire, and digging in this material revealed several lenses of a dark red soil. Initially, these lenses were thought to have been used as an ore for iron making, but the idea was rejected because of their low iron content. The second area was in the discharge area from the mire, about 100 m south of the slagheap. Here a fine-grained red soil was found in the slope (Fig. 1E) which in the light of the above references has a high enough iron content for iron making. The Fe/Si molar ratios (5.5–18.8) are extremely high by comparison with those given by Espelund (1999), and the Mn content is also high, which could compensate for the low Si concentration. The till at the border of the mire, with its low Fe/Si molar ratios, could have been explored and mixed with the red soil in order to promote slag formation, and thereby iron production. This sce-

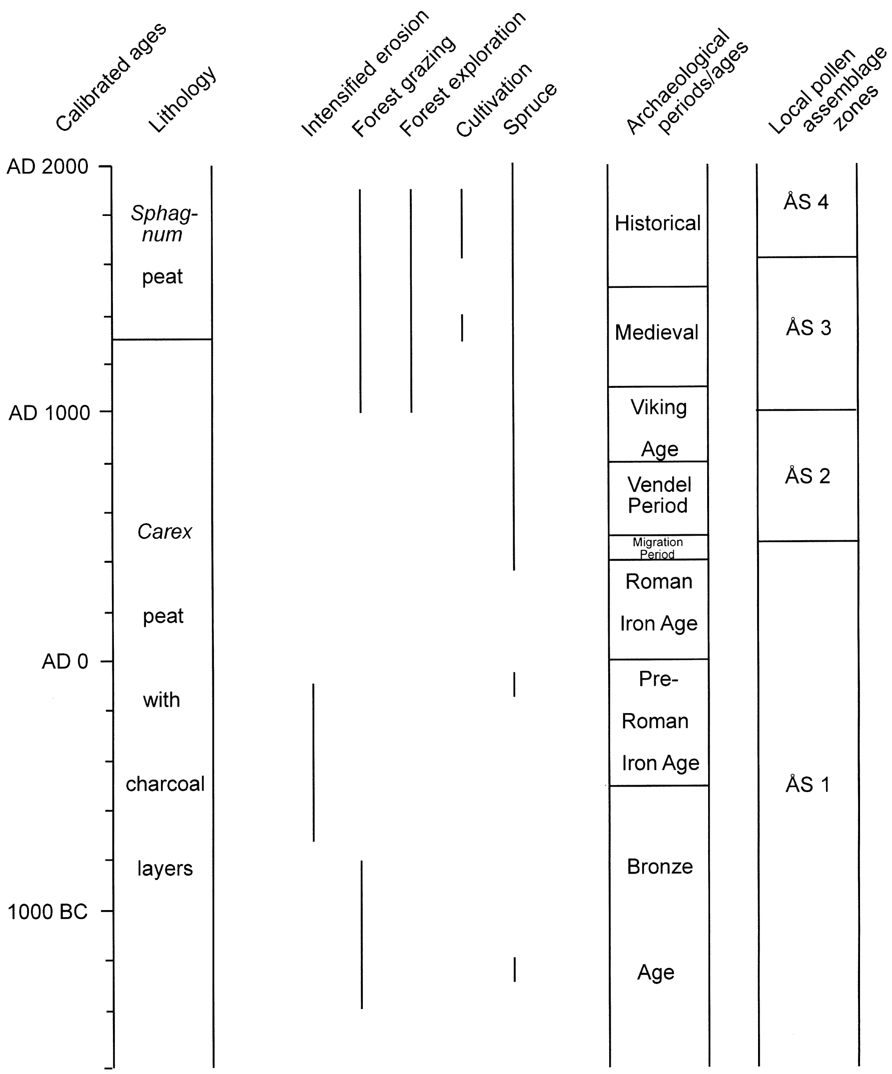

Figure 7. Human impact during the last *c.* 3600 calendar years and the immigration of spruce, as reflected in the pollen diagram (Figs 3 and 4). An erosion phase is detected in the mineral magnetic measurements (Fig. 5). It is assumed that iron production was initiated c. 1000 cal AD, as shown by a comprehensive exploitation of the forests, possibly for charcoal making.

nario could explain the formation of the terrace-like feature, although it could also have been formed when the iron makers were searching in vain for bog iron.

The red soil found today may be a remnant of the spent ore. If so, the depression between points 10 and 11 (Fig. 6) could be a result of ore mining. We assume that about 10 m^3 of soil had been excavated. With the assumption of a mean iron content of 61% Fe_2O_3 (i.e. 43% Fe) and a 50% reduction in volume due to pore space, rootlets and crystalline water, the content of solid iron could have been of the order of 10^4 kg (cf. Espelund 1999:98–112), based on the assumption that the pore space of the red soil is comparable to that of non-compacted clay (C. Svensson 1984; Ledskog & Lundgren 1989:33; Griph & Rodhe 1991:22; Knutsson & Morfeldt 1995:34–35). It has been suggested that 1 m^3 of slag corresponds to the production of 10^3 kg of iron (G. Magnusson 1986). Thus the slagheap at Åskagsberg, with a volume of 10–15 m^3, corresponds to an iron production of 10^4 kg iron. This is in agreement with the amount of iron which could have been produced from the red soil.

As reflected in the pollen stratigraphy and the presence of the slagheap, the land area surrounding the mire must have been used for different purposes at different times (Fig. 7). Pollen of *Plantago lanceolata* and *Melampyrum* was identified at two depths, 150 cm and 95–85 cm, the age of the lower one being estimated as

c. 5500 ^{14}C years BP (4350 cal BC), so that it could be contemporary with scattered finds of lithic material from the Mesolithic within the parish of Östmark (Myrdal-Runebjer 1998:4–19). The latter observation is accompanied by peaks in Poaceae, charcoal and an increase in mineral particles and is dated to 3000–2600 ^{14}C years BP (1200–800 cal BC). This composition may reflect the effect of forest grazing in causing increased erosion (Zone 2, Fig. 5) and is contemporary with records from Gammeltorpmyra, c. 20 km south-west of Åskagsberg (Mattsson 2001:13–17), which also suggest forest grazing from around 2700 ^{14}C years BP (900–800 cal BC) onwards.

The forest composition seems to have remained stable until the immigration of *Picea*, dated to c. 1700 ^{14}C years BP (350 cal AD). There are clear indications in the pollen record of extensive cutting of the forest at around 1000 cal AD. We believe that this is a result of the making of the charcoal needed for iron production. Charcoal remains included in the slag at Åskagsberg were dated to 975±70 ^{14}C years BP (990-1160 cal AD), which falls within the age interval for the majority of direct iron production sites in northern Värmland, 800–1200 cal AD (E. Svensson 1998:79–101; Myrdal-Runebjer 1998:4-19). The age of the charcoal remains corresponds well with the estimated age in the time-depth model, indicating that iron production at Åskagsberg started c.1000 cal AD. It is not possible to date the end of charcoal production from the pollen stratigraphy, however. It might be assumed that the tree pollen concentration would increase as a result of the closing of the forest after the iron production period, but this presumes that there were no other human activities to keep the forest open. Our investigation indicates that the forest continued to be open, possibly as a result of forest grazing (Fig 3b).

The first indications of cultivation in the vicinity are dated to roughly 1350 cal AD (cf. Mattsson 2001:13–17). In a pollen investigation at the low-lying bog of Önneby c. 30 km south-east of the sampling site and 1 km east of Torsby (cf. Fig. 1A), the first cultivation identified is dated to 1030±55 ^{14}C years BP (c. 950–1040 cal AD; Wallin 1996), it is c. 350 calendar years older. Furthermore, there are areas with clearance cairns dated to the Late Iron Age at the latest along the shores of Lake Fryken, south of Torsby (Myrdal-Runebjer & Nilsson 1998). The younger date for the introduction of cultivation in Åskagsberg is thus reasonable. The expansion of cultivation at the bog of Önneby started in the early 15th century, with *Hordeum* as the main cereal. The first pollen of *Hordeum* appears in the peat of Åskagsberg in the 18th century, and the expansion of cultivation there started after AD 1600, with colonisation by Finnish forest swidden cultivators, as indicated here by the finds of *Secale* pollen. It is uncertain whether or not the cereal pollen found emanated from the immediate surroundings of the site, as it could have been transported by the wind from settlements situated further away from the mire. There are remnants of eight crofters' holdings within a radius of two km of the mire which were abandoned around AD 1900, and the finds of *Secale* pollen at a depth of 10 cm might have come from these. The agrarian period with its small-scale settlements came to an end during the last 50–100 years and the forest gained a new role as a raw material producer, causing re-forestation, especially with pine.

The entire iron production process, from cutting of the forest for charcoal burning to extraction of the ore, may thus have been carried out within a radius of 500 m of the furnace site. As no contemporary settlement sites have been identified in the vicinity, we may thus consider this an example of a seasonal production site that was in use during a period when cultivation and cattle rearing was expanding in the neighbouring forest areas.

Conclusions

• An iron-rich red soil was identified c. 100 m south of the slagheap at Åskagsberg. The soil contained 54 to 68% Fe_2O_3 and had a Fe/Si molar ratio between 5.5 and 18.8. This relatively high ratio probably made it necessary to mix the material with soil that was rich in silica in order to improve the ore quality.

• Approximately 10 m^3 of soil had been mined, indicating that a maximum of c. 10^4 kg iron could have been produced.

• The pollen record indicates weak traces of human impact, possibly as early as the Mesolithic and/or Neolithic. Forest grazing is interpreted as having occurred c. 1200–800 cal BC and from c. 1000 cal AD onwards. Clear-cutting of the forest for charcoal making in connection with iron production also started around 1000 cal AD.

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