MOORS FOR THE FUTURE PARTNERSHIP: SMALL RESEARCH PROJECT GRANT (2005) REPORT

ASSESSING THE POTENTIAL OF ENVIRONMENTAL MAGNETISM AS A FIRE MARKER IN MOORLAND SOILS

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Acknowledgements

Assistance in the field was generously provided by Catherine Flitcroft (MFF), Wineke Straatsma and Majolein Pardoen (University of Wageningen, NL).

Sample characterisation in the laboratory was undertaken by Claire Blet-Charaudeau as a part of an undergraduate dissertation. Additional mineral magnetic measurements were made through access to facilities at the University of Manchester courtesy of James Rothwell. The chemical analyses were made at QMC, University of London by Laura Shotbolt.

The acquisition of relevant, historical spatial data such as aerial photography and other items was assisted by Sheffield City Council, the Peak District National Park, MFF and The Star newspaper.

This project was funded by the Moors for the Future Partnership Small Research Grant spg_Salford_Hutchinson_2005.

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Summary

This project has investigated the potential of mineral magnetic measurements as a means of assessing the impact of fire on moorland soils. Burning is an important and widespread activity in upland environments and is a key theme in the minds of those concerned with the management of moorland.

On Burbage Moor which lies to the west of Sheffield on the Eastern Edges of the National Park a volume susceptibility-based survey of an area with a relatively well known history of burning (eg. major accidental fires in 1959 and 1976) has been undertaken. Susceptibility measures magnetic concentration of, in this case, the soil surfaces of the moor. This parameter can indicate whether an area has been burnt in the past without damaging the environment that is being investigated. A long core (approx. 4.3m in length) was also taken from a small basin of peat deposits. This core may provide an environmental history of the landscape of the area; as peat builds up it can act as an 'environmental tape recorder' that extends far beyond the time period for which we have monitoring, or other records of human impacts on the landscape.

A detailed survey (i.e. at 50m intervals) of a part of the moor demonstrated that moorland burning can lead to surface magnetic enhancement detectable via in-field mineral magnetic measurements. The pattern of volume susceptibility (K) values determined was, however, complex. A clear relationship between elevated surface magnetic susceptibility and the spatial extent of the accidental moor fire in 1976 was not found. In order to account for the pattern of surface magnetism a number of factors that can also influence a soil's magnetism, and may have affected the area since the accidental fire, need to be taken into consideration. These include erosion of the damaged area (removing any magnetically enhanced materials), dissolution of the magnetic signal under waterlogged conditions, revegetation (masking the burnt surface) and subsequent managed burns, which can also increase the magnetisability of the soil surface.

The long core taken from an area of basin mire provided a potential long-term record of the environmental history of the moor. The impacts of land use change including the consequences of burning were apparent, but interpretation of the profile is limited by the lack of independent dating. (This is an item of further work for which additional funding is being sought). The long core from Burbage Moor provides an interesting and well resolved insight into, not only moorland management practices such as drainage and burning, but also a record of environmental pollution in the region. According to work by English Nature many upland SSSIs are in poor condition as a result of overgrazing, drainage and damaging burning. In providing a longer-term time perspective on key management practices associated with heather moorland this study contributes to the debate over the future environmental management options for upland areas.

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Assessing the potential of environmental magnetism as a fire marker in moorland soils

1. Introduction

Burning is an important and widespread activity in upland environments and is a key theme in the minds of those concerned with the management of moorland. The impacts of fire on moorland soils in particular are, however, not fully understood. The impact of fire as a natural component of upland ecosystems has recently been reviewed by (Tucker 2003). Both natural and deliberate burning may have occurred in many upland areas throughout the Holocene (or post glacial period) (MacDonald 1999), however, fire-based management of moorland in the northern parts of the UK dates from *c.*1800 reflecting increased sheep grazing and the development of grouse shooting (Rackham 1986).

The technique of environmental magnetism has been widely applied in environmental studies. The various applications of this relatively rapid and non destructive technique are described in Thompson and Oldfield (1986) and Walden *et al.* (1999). As burning is known to enhance the natural magnetic properties of soils, the technique provides a potential opportunity of assessing the impacts of fire on moorland soils. The particular magnetic 'marker' resulting from fire may therefore allow both a possible retrospective view of the spatial extent of burning and thereby a longer-term time perspective on the significance of burning in the moorland landscape.

2. Objectives

This study has three main, interrelated objectives. These are set out below:

1. To test the hypothesis that moorland burning leads to surface magnetic enhancement detectable via in-field mineral magnetic measurements (*e.g.*, magnetic susceptibility).

2. To assess the variability of such magnetic enhancement (*e.g.*, with age / severity of the burn and site characteristics) and the importance of other factors affecting the soil magnetism at a previously identified burn site.

3. To investigate the off-site topsoil tracing properties of any magnetic enhancement exploring the potential of the technique to determine post fire ('marked') topsoil erosion (and associated contaminants).

On the basis of this pilot study consideration can then be given to the potential for the wider application of this approach such as the landscape scale mapping of the mineral magnetic 'fingerprint' of burning and the longer-term time perspective that the magnetic marking of peat core profiles may provide.

3. Methodology

3.1 Site selection

Burbage Moor (SK 272825) on the Eastern Edges of the Peak District National Park and to the west of Sheffield was selected as the study site for this project. This area was significantly impacted by accidental moorland fires in 1959 and 1976 which were mapped by Ardron (1999). The moor therefore provides a 'known baseline' of historical fires against which the approach of mineral magnetic-based mapping could be tested (i.e. hypotheses 1 and 2).

Burbage Moor was also selected as it not only has a relatively well known fire history, but also because, adjacent and downslope from the area most significantly affected by the historical burns, there is an area of relatively deep basin mire. This area of deeper peat accumulation has also been investigated as a potential 'sink' of the post fire erosion of surface materials from the burnt areas (i.e. hypothesis 3).

The site is also relatively accessible and an area of open access. It is therefore suitable for repeat surveying.

3.2 Field survey

An initial, trial field survey in the form of a linear transect across the burnt areas was undertaken using a volume magnetic susceptibility (K) search loop sensor (MS2D) and a Bartington Instruments MS2 meter. Magnetic susceptibility measures the 'magnetisability' of a material (Dearing 1994). Measurement locations were logged using a Garmin GPS (Global Positioning System) (see figure 1).

Following this initial investigation a 50m-interval grid of K measurements was made (see figure 2). These measurements were made using a K probe sensor (MS2F), rather than the search loop sensor in order to improve contact with soil surfaces under heather cover. The grid was positioned over the area most significantly impacted by the 1976 fire as indicted by Ardron's mapping of the moor. The grid of measurements consisted of over a thousand individual point measurements of K at 106 locations and covered an area of approximately 700 by 800m. The grid of sample points was effectively built up through a number of field visits using a GPS to locate predetermined points. At each sample point an average of 10 individual measurements were made and detailed notes were also made of the site's characteristics (*e.g.* vegetation cover, depth of peat, exposure of the substrate, evidence of burning).

At six locations on the sample grid peat samples were removed for further, lab-based analyses. At four of these sites samples from the entire peat profile were easily removed by digging a shallow pit (<0.3m). At remaining sites the peat was deeper and samples were removed from the side of exposed peat haggs in a continuous series of down-profile blocks (>1m). These samples were carefully bagged and labelled in the field. The basin mire was also sampled using a Russian, or d-section, peat corer. Incremental and overlapping sections (0.5m in length) were taken at a central location to a depth of 4.3m from two adjacent boreholes (see figure 3). These long core samples were carefully wrapped, bagged and labelled in the field to prevent contamination and dessication. The depth of peat deposits across the basin was also determined at this time by probing. The peat has accumulated in a relatively flat-bottomed, and apparently, steep-sided depression (approximately 2.5 to 4.3m in depth) with a surface area of approximately 250m^2.

3.3 Laboratory analyses

The peat samples taken from selected sites on the grid survey were dried at <40^{o}C in the lab and packed into pre weighed sample holders for mass specific mineral magnetic measurements. These measurements included magnetic susceptibility (X), frequency dependent magnetic susceptibility (Xfd), Anhysteretic Remanent Magnetisation (ARM) and Saturation Isothermal Remanent Magnetisation (SIRM). These measurements (including inter parametric ratios) aim to characterise the samples in terms of their magnetic concentration and dominant magnetic grain size, thereby allowing inferences to be made concerning their nature and possible sources.

Mass specific (X) and frequency dependent (Xfd) magnetic susceptibility measurements were made using Bartington MS2 Susceptibility System (*e.g.* MS2 meter and MS2B single sample sensor). Samples were then subjected to a range of magnetising fields. ARM measurements must be made first and employ a modified Molspin AF demagnetiser to generate the appropriate magnetic fields. The sample's magnetic remanence was then measured using a Molspin fluxgate magnetometer. A further mineral magnetic parameter (and inter parametric ratios) was derived by the magnetic 'saturation' of the samples. The required magnetic field was generated via a Molspin pulse discharge magnetiser. The induced magnetic remanence was measured in a Molspin fluxgate magnetometer.

The long core samples from the basin mire were described according to the Troels-Smith (1955) scheme for the characterisation of unconsolidated sediments. This scheme characterises sediments by their components and physical properties (see Aaby and Berglund 1986). The long core samples were sectioned at 2cm intervals, dried at <40^{o}C in the lab and weighed to allow the calculation of dry density. Selected samples were subjected to the suite of mineral magnetic measurements described above. At 10 or 20cm intervals samples were chemically digested via nitric acid and analysed to determine the concentration of 18 elements (of which only a selection are presented) using an ICP-AES. The quality control of this analysis was assured by the measurement of sample replicates and appropriate reference materials.

It is planned to attempt to date the long core samples from the basin mire, however, this will require additional funding which is currently being sought from a variety of sources. It is planned to use a novel approach to dating though the determination and counting of SCPs (*e.g.* Rose and Appleby 2005). This approach will also provide an insight into the sources of the heavy metal content of the long core profile and thereby the environmental history of the site.

3.4 Spatial data

The K survey information, site characteristics and other spatial data, for example from aerial photography of the area, has been stored in and manipulated through the use of a Geographical Information System (GIS) (*e.g.* ESRI ARCVIEW v8.3).

4. Results and discussion

4.1 Mineral magnetic mapping of moorland burning

Figure 4 shows a transect of magnetic concentration measurements (*K*) across Burbage Moor as a trial to test the applicability of the technique. At first glance it is apparent that the volume susceptibility (*K*) of the moor's surface is highest in the area affected by the 1976 fire. The *K* values are lower across that part of the moor thought to have been affected by the older (1959) accidental fire and lowest outside the limits of these burns. There are numerous examples in the literature that have demonstrated that burning can lead to the magnetic enhancement (including an increase in magnetic susceptibility), particularly in archaeology (e.g. Bellomo 1993, Peters and Thompson 1999). The transect seemed to indicate a relationship between the known accidental burns (mapped by Ardron 1999) and surface soil magnetic concentration.

The grid-based magnetic survey was undertaken across a selected section of the area mapped by Ardron (1999) where considerable variability in the impact of the 1976 fire was apparent. In making the measurements at predetermined locations the aim was to remove any subjectivity in sample site location in order to produce a detailed map of *K* values. The survey has shown that magnetic concentration (measured as volume susceptibility (*K*)) can vary considerably both at and between sample sites. Table 1 shows that the maximum *K* value found at each site ranges from 1 to 79 (highest at site D2). The standard deviation of the mean *K* at many of the sites is relatively high. Therefore it has been most informative to plot the modal and median *K* values (see figures 5 and 6).

Figure 5 shows the modal volume susceptibility (*K*) concentrations (shown as proportional circles) superimposed on a simplified version of Ardron's (1999) fire map. It is immediately clear that the highest *K* values in the survey are not associated with the area apparently most affected by the 1976 accidental burn i.e. the areas shown as bare mineral soil or partially revegetated. Indeed the largest modal values lie mainly to the north and south of this burn. Some of the lowest values sit within the central area of the survey. The median *K* concentrations, superimposed on a 2005 aerial photograph that has been draped over a digital terrain model (DTM), are shown in figure 6 and the spatial pattern is similar. It is interesting to note, however, that some of the highest values are associated with recent, managed burns (identifiable on the aerial photograph), especially to the north of the accidental burn and towards the road.

4.2 Assessing the variability of mineral magnetic enhancement

The results of the grid survey indicate that there is no simple and unequivocal relationship between soil surface magnetic susceptibility and the major, accidental moor fire in 1976 (as mapped by Ardron 1999). Thus it might be suggested that, at this site, this event might not have lead to an enhancement in surface soil magnetic concentration. In order to account for the pattern of surface magnetism that has been detected, a number of other factors that can also influence a soil's magnetism must also be taken into consideration.

Modal volume susceptibility (*K*) concentrations, superimposed on a simplified version of Ardron's (1999) fire map, are shown in figure 7. The columns have been colour coded according to dominant characteristics of each site. It is significant that the highest values are associated with signs of either recent (managed) burning (B) or burning at some time in the past (OB). The latter category may have subsequently been affected by erosion (OB/E). Furthermore, the lowest values correlate with sites at which there was standing water (W). These relationships are also clearly indicated in figure 8 where the median *K* concentrations have been superimposed on a 2005 aerial photograph that has been draped over a digital terrain model (DTM). The image shows the extent of managed burns (and heather brash cutting) in the northern part of the survey where the median values are highest. There is also a strong peak in median *K* value on the southern edge, which sits at the edge of a large managed burn (at site O13). There is also a cluster of relatively high median values (characterised in the field as burnt) around a bright, white area on the underlying aerial photo (i.e. an area of high reflectance). This indicates a major erosion scar and therefore bare, mineral soil that has developed following the 1976 fire (see figure 9).

Interpretation of the pattern of magnetic concentration revealed by this survey is complex. The elevated susceptibility values associated with those sites more recently affected by managed burns suggest that fire can lead to magnetic enhancement. Therefore the areas affected by the 1976 burn may also have become an area of elevated magnetic concentration, however, this appears to have subsequently been widely dissipated by post fire events such as erosion. Thus surface materials (which may or may not have become magnetically enhanced) may have been removed from the site during the extensive erosion that has taken place. Furthermore, it is highly likely that at the waterlogged sites any magnetic enhancement to have occurred may have been lost due to diagenetic change of mineral magnetic properties associated with saturated, acidic conditions.

A further factor which must also be taken into account is the relative importance of the magnetic signal associated with fire and that attributable to the atmospheric fallout of fossil fuel combustion products. A number of studies have demonstrated that the upper part of peat cores taken from a range of sites, including the south Pennines, tends to have a relatively high magnetic concentration. This is often associated with elevated heavy metal levels and is derived from pollution since the Industrial Revolution (e.g. Lee and Tallis 1973, Livett et al. 1979, Markert and Thornton 1990, Jones and Hao 1993, Hutchinson 1995 and Rothwell *et al.* 2005). Figure 10 illustrates a more detailed level of mineral magnetic characterisation of one of the selected sites within the grid survey. Magnetic enhancement associated with particulate pollution tends to be magnetically coarse grained (Thompson and Oldfield 1986). The surface peaks in *X*fd (frequency dependent susceptibility) suggest that the surface magnetism of a recently burnt site (e.g. J12) is relatively fine grained as this parameter is sensitive to the finer (super paramagnetic) grain size fractions indicative of naturally enhanced (including burning) surfaces (Walden *et al.* 1999). Therefore burning appears to have played an important part in the magnetic properties of these sites, especially where there is a marked surface concentration peak. However, magnetic enhancement related to particulate pollution must remain a significant factor (as indicated by the elevated SIRM/ARM values in the upper part of the profile). Indeed at some sites burning, followed by surface erosion, may have lead to an elevated level of surface magnetism by exposing an atmospheric pollution-derived layer of magnetic (and other) contamination, rather then being caused by fire related magnetic enhancement processes.

4.3 Recording the impact of burning in the peat profile

A 4.3m long core was extracted from an area of basin mire downslope from the area of moorland affected by the 1976 accidental fire and the grid survey (see figure 2). The physical characteristics and selected mineral magnetic properties of this core are shown in figure 11. In the upper part of the peat profile there are two clear zones of elevated density. The upper peak at around 0.8m is associated with small mineral clasts, broken stems of *Calluna* and particles of carbonised peat fragments. It appears to reflect an inwash of eroded materials. No such allochthonous deposits are found at the depth interval of the lower of these peaks (*c.*1.08 and 1.16m). The elevated densities toward the base of the core reflect a transition to an increasingly minerogenic deposit. ARM and SIRM are magnetic concentration parameters that peak at 0.4m in depth. The interparametric ratio SIRM/ARM suggests that the magnetic material in this core has become increasingly coarse grained from a depth of approximately 1.4m. This depth profile reflects the deposition of atmospherically derived particulate pollution during the last two centuries (Oldfield *et al.* 1978, Livett *et al.* 1979, Richardson 1986, Tolonen and Oldfield 1986, Hutchinson 1995 and Rothwell 2005). SIRM/ARM closely reflects the lead (Pb) concentration profile of the core (see figure 12) and thereby provides two, crude dating horizons.

The first significant increase in the Pb level of peat profiles in this part of the country is usually attributed to approximately 1800 (Livett *et al.* 1979 and Richardson 1986). The Pb peak at 0.4m probably also reflects around 1970. The core can therefore be divided into three zones: A: minerogenic (below *c.*3.2m), B: pre industrial (*c.*1.4-3.2m) and C: post industrial (*c.*0-1.4m). The increase at the base of the core in aluminium (Al) levels suggests an early, more lithospheric input to the site before ombrotrophic conditions were established as the basin infilled (see figure 12). Table 2 provides a summary of the levels of selected heavy metals in the core. With the exception of the Al, the profile of all the heavy metals is very similar to the Pb profile suggesting a common source of contamination; atmospheric, particulate pollution. Indeed the depth profile is similar to that found in many studies (cited above). The notable exception in the case of the core from Burbage Moor is that the metal profile extends over some 1.4m, rather than the more usual 0.3m (e.g. Rothwell *et al.* 2005). Thus this site provides a potentially much greater level of resolution and therefore a rather clearer picture of the details of the environmental history of the area.

Interpretation of the environmental history held in the peat core is hampered by the lack of independent dating evidence. Nevertheless, some approximate dates for the density change in the upper part of the profile, and the possible impact of the accidental moor fires, at least can be calculated.

Hicks (1971) has examined the pollen record of peat deposits on the Eastern Edges of the Peak District National Park and suggested that the initiation of peat growth occurred at the time of the Boreal-Atlantic Transition (approximately 8000 years BP). This would have particularly occurred in poorly drained depressions such as the Burbage Moor site. A forest cover of mixed-oak was not extensively cleared until the Iron Age and following the Roman period forest clearance and soil erosion lead to the development of an extensive shallow peat cover and the generally treeless heather moorland seen today (Hicks 1971). The higher density values and the presence of fine particles of the local bedrock in the lower part of the peat core (i.e. zone A) suggest a period when the basin was infilling. This may date to the Boreal-Atlantic Transition (see Conway 1947, 1954). The other major changes in the density profile are much more recent and appear to have occurred within the last two centuries (i.e. zone C).

Based on the Pb profile they may be very roughly dated to the period 1830-1850 (lower peaks) and 1890-1910 (upper peak). Although these dates are very crudely calculated it is interesting to note that the date of the lower peaks in particularly coincide with the time period when this area of moorland was enclosed. The mire is bounded to the east by a linear drainage ditch (over 1km in length) (see figure 2). Drainage of upland areas at this time was often associated with their so-called improvement following enclosure (Turner 1980). Archive evidence shows that enclosure of Burbage Moor (following an Act of Parliament) occurred around 1810-1830. The drainage ditch may have initially led to a drying of the bog's surface leading to a change in density in the peat profile.

The upper peak in density is associated with other characteristics that suggest that the bog surface has been affected by an inwash of eroded material following burning. The basin mire lies immediately down slope from an extensive area of peat erosion that has developed since the 1976 fire. It is significant, however, that this change in density appears to have occurred much earlier in the twentieth century than either the 1976 or the 1959 fires mapped by Ardron (1999). Therefore, despite the evidence of significant peat loss on the gentle slopes above the basin, post fire peat erosion following the 1976 burn does not correspond to this feature as it predates the main peak in Pb, which is widely attributed to the 1970s. Fire-related erosion events have been recorded in peat profiles elsewhere (e.g. Tallis 1987). On Burbage Moor, however, materials eroded following the 1976 fire may effectively be stored at the base of the slope and have not yet reached the bog in any significant quantity. It is interesting to note, however, that the peaks in density in the profile correspond to decreases in the SIRM/ARM ratio (see figure 11). This suggests a fining in magnetic grain size and, in the upper peak in density (e.g. at 0.8m), may reflect the input of burnt and magnetically enhanced sediments. One of the largest inversions in SIRM/ARM occurs at 0.4m. There is also a small peak in density that occurs at approximately the time interval of the 1976 fire.

5. Conclusions and further work

A detailed survey (i.e. at 50m intervals) of a part of Burbage Moor has demonstrated that moorland burning can lead to surface magnetic enhancement detectable via in-field mineral magnetic measurements. The pattern of volume susceptibility (K) values determined was, however, complex. A clear relationship between elevated surface magnetic susceptibility and the spatial extent of the accidental moor fire in 1976 was not found. In order to account for the pattern of surface magnetism a number of 'post fire' factors (e.g. erosion, dissolution, revegetation and managed burns) that can also influence a soil's magnetism, appear to have been important.

The long core taken from an area of basin mire provides a potential long-term record of the environmental history of the moor. Land use change including the impact of burning was apparent, but interpretation of the profile is limited by the lack of independent dating. This is an important area of further work as the long core from Burbage Moor provides an interesting and well resolved insight into, not only moorland management practices such a drainage and burning, but also a record of environmental pollution. Many upland SSSIs are in poor condition as a result of overgrazing, drainage and damaging burning (English Nature 2003). In providing a longer-term time perspective on key management practices associated with heather moorland (English Nature 2001) the study contributes to the debate over the future environmental management options for upland areas.

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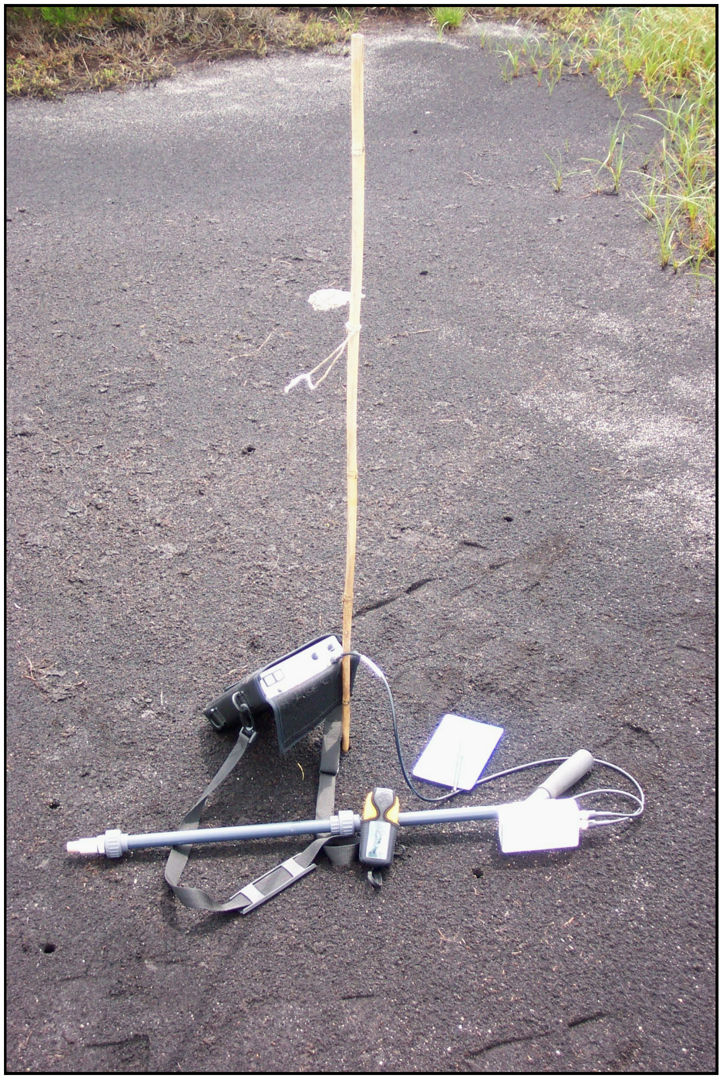

Figure 1. Field equipment used in the volume susceptibility (K) field survey comprising a Bartington Instruments MS2 susceptibility meter, MS2F Probe sensor and Garmin GPS.

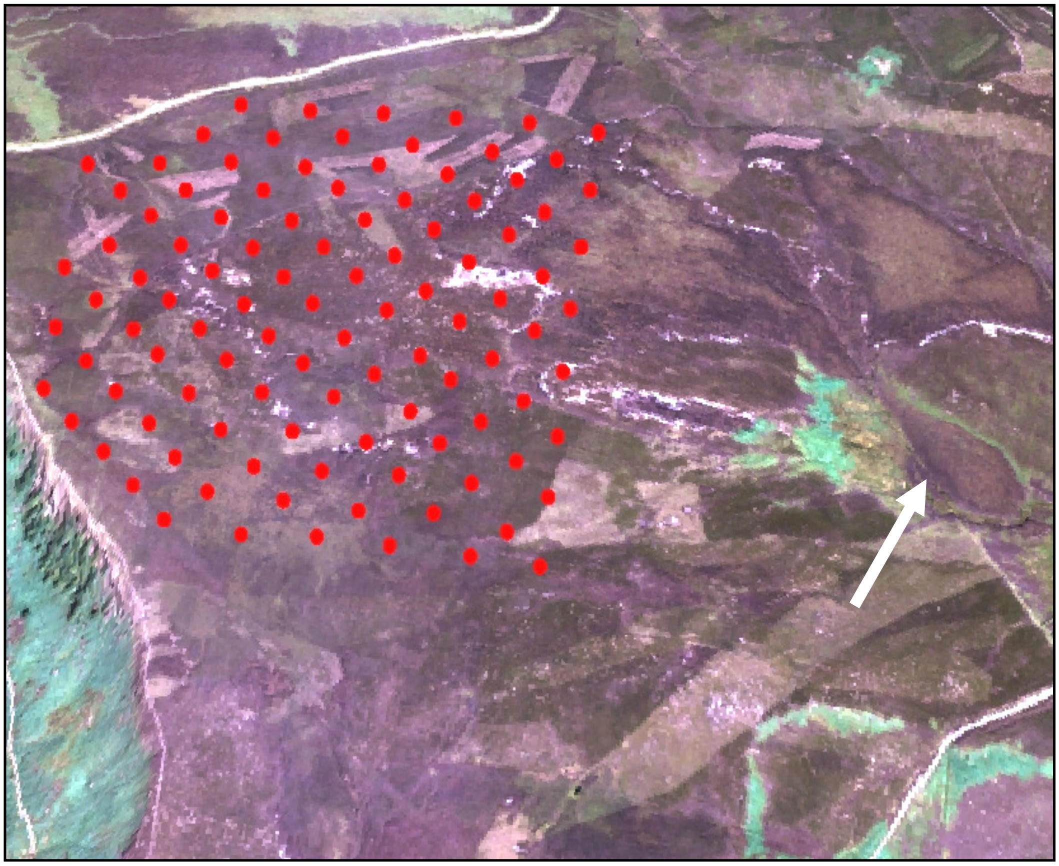

Figure 2. Sample grid of the volume susceptibility (*K*) survey overlying a 2005 aerial photograph which has been draped over a digital terrain model (DTM) to provide an impression of the relief of the area. (The sample points are labelled A to O from left to right and 1 to 15 from top to bottom.) The arrow indicates the location of the basin mire from which a long core was extracted.

Figure 3. Peat core samples (0.5m in lengths) extracted using a Russian corer to a depth of 4.3m from the basin mire area (the core sections increase in depth from left to right).

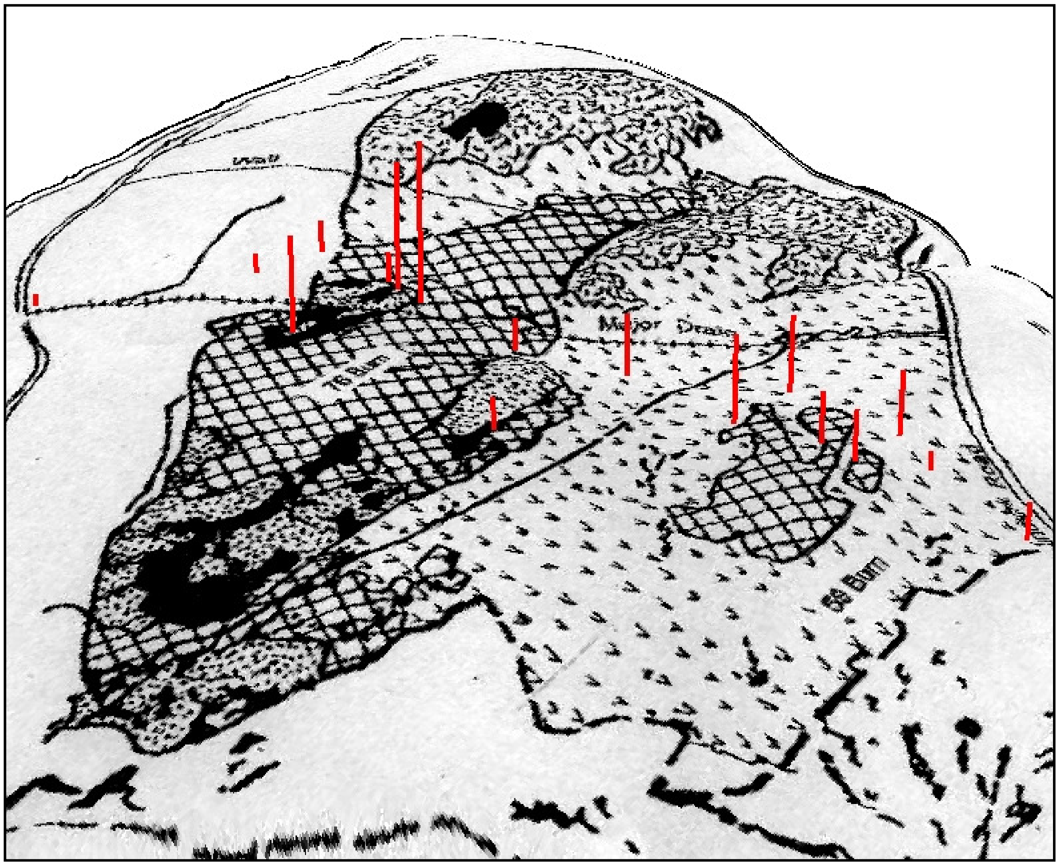

Figure 4. Transect of volume susceptibility (*K*) measurements across Burbage Moor. (The height of the columns is proportional to the *K* value (or magnetic concentration) of the surface soil at each site). The transect data overlay the map of burnt areas produced by Ardron (1999) which has been geo-corrected and draped over a digital terrain model (DTM).

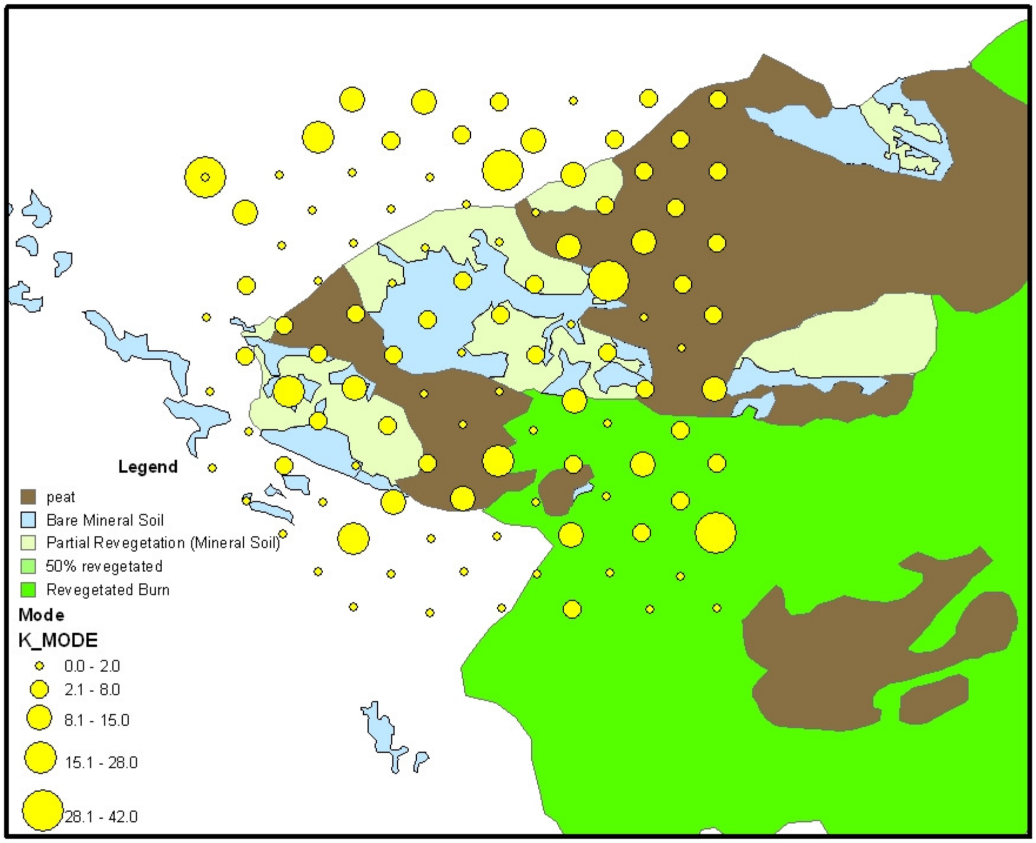

Figure 5. Modal volume susceptibility (*K*) concentrations (shown as proportional circles) superimposed on a simplified version of Ardron's (1999) fire map.

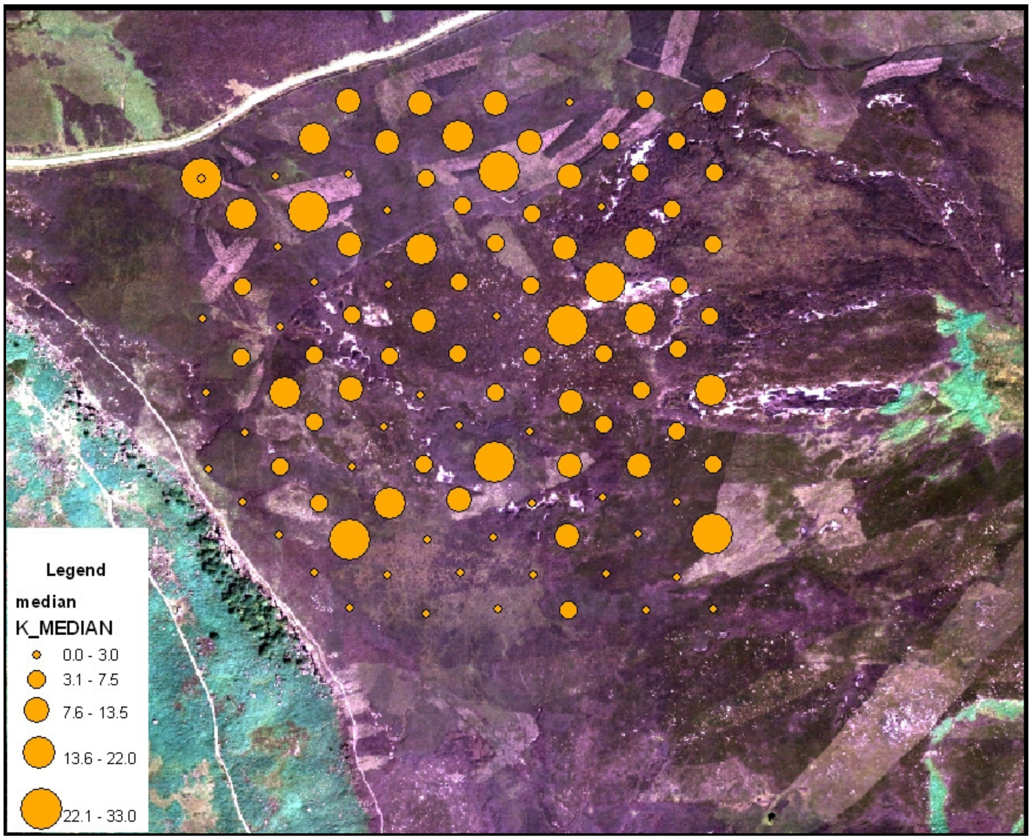

Figure 6. Median volume susceptibility (*K*) concentrations (shown as proportional circles) superimposed on a 2005 aerial photograph that has been draped over a digital terrain model (DTM).

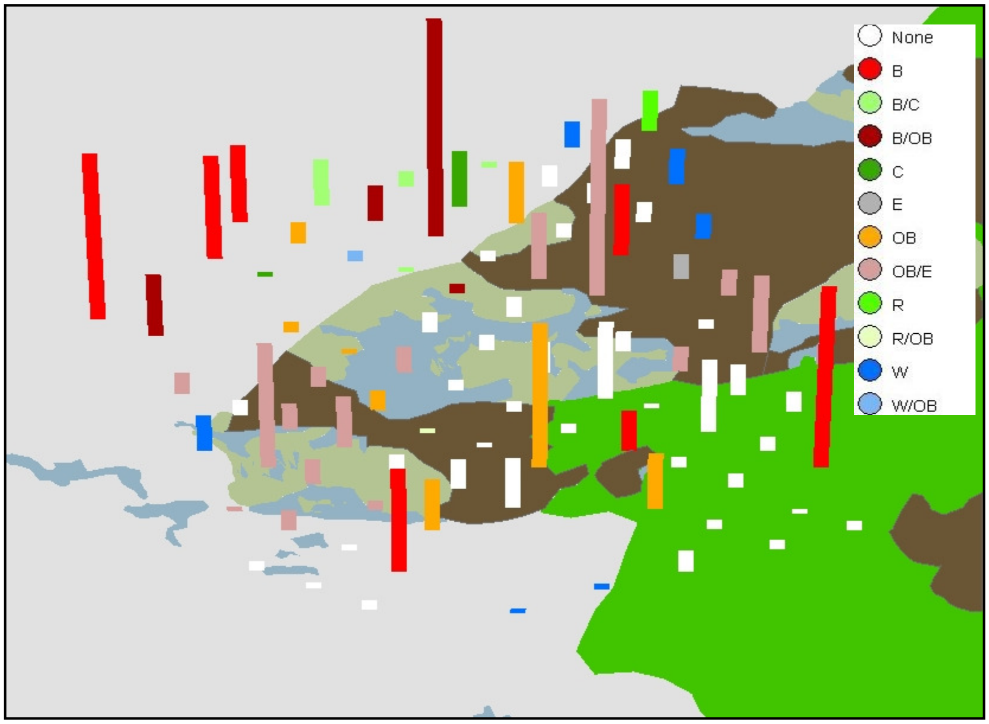

Figure 7. Modal volume susceptibility (*K*) concentrations (where the height of the column is proportional to the *K* level) superimposed on a simplified version of Ardron's (1999) fire map (see Figure 5 for key). The columns have been colour coded according to dominant characteristics of each site (e.g. B = recently burnt, B/C = burnt and/or heather cut, B/OB = evidence of both older burning and recent burn, C = heather cut, E = eroded, OB = older burn, OB/E = older burn and erosion, R = regeneration of surface vegetation, R/OB = regeneration and older burning, W = surface standing water, W/OB = surface standing water and older burn).

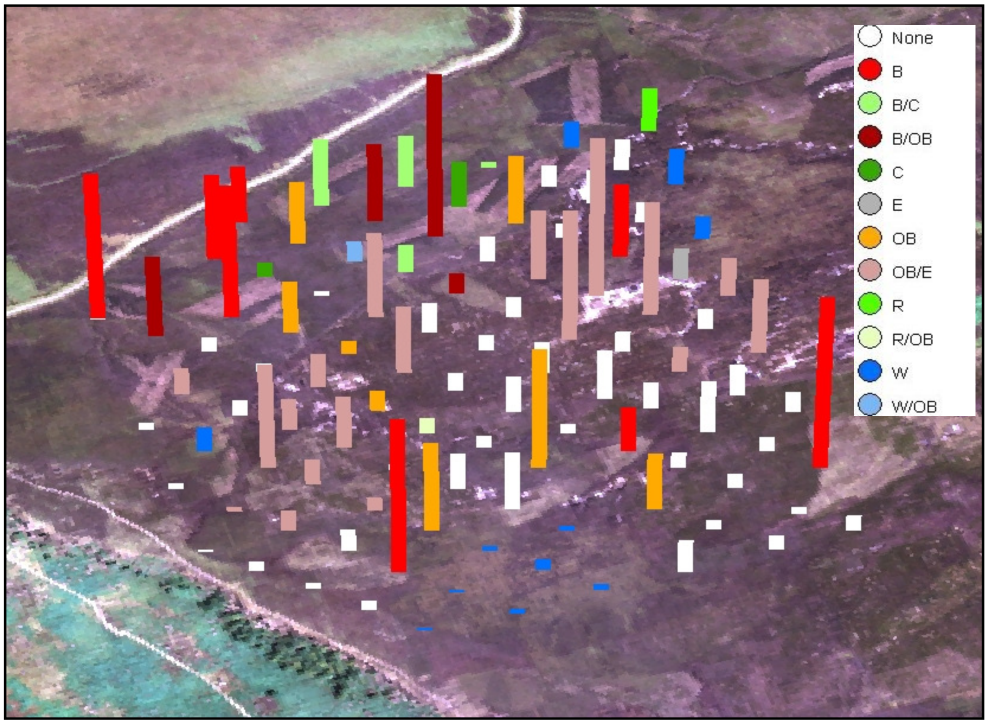

Figure 8. Median volume susceptibility (*K*) concentrations (where the height of the column is proportional to the *K* level) superimposed on a 2005 aerial photograph that has been draped over a digital terrain model (DTM). The columns have been colour coded according to dominant characteristics of each site (e.g. B = recently burnt, B/C = burnt and/or heather cut, B/OB = evidence of both older burning and recent burn, C = heather cut, E = eroded, OB = older burn, OB/E = older burn and erosion, R = regeneration of surface vegetation, R/OB = regeneration and older burning, W = surface standing water, W/OB = surface standing water and older burn).

Figure 9. Extensive area of peat erosion following accidental burning in 1976.

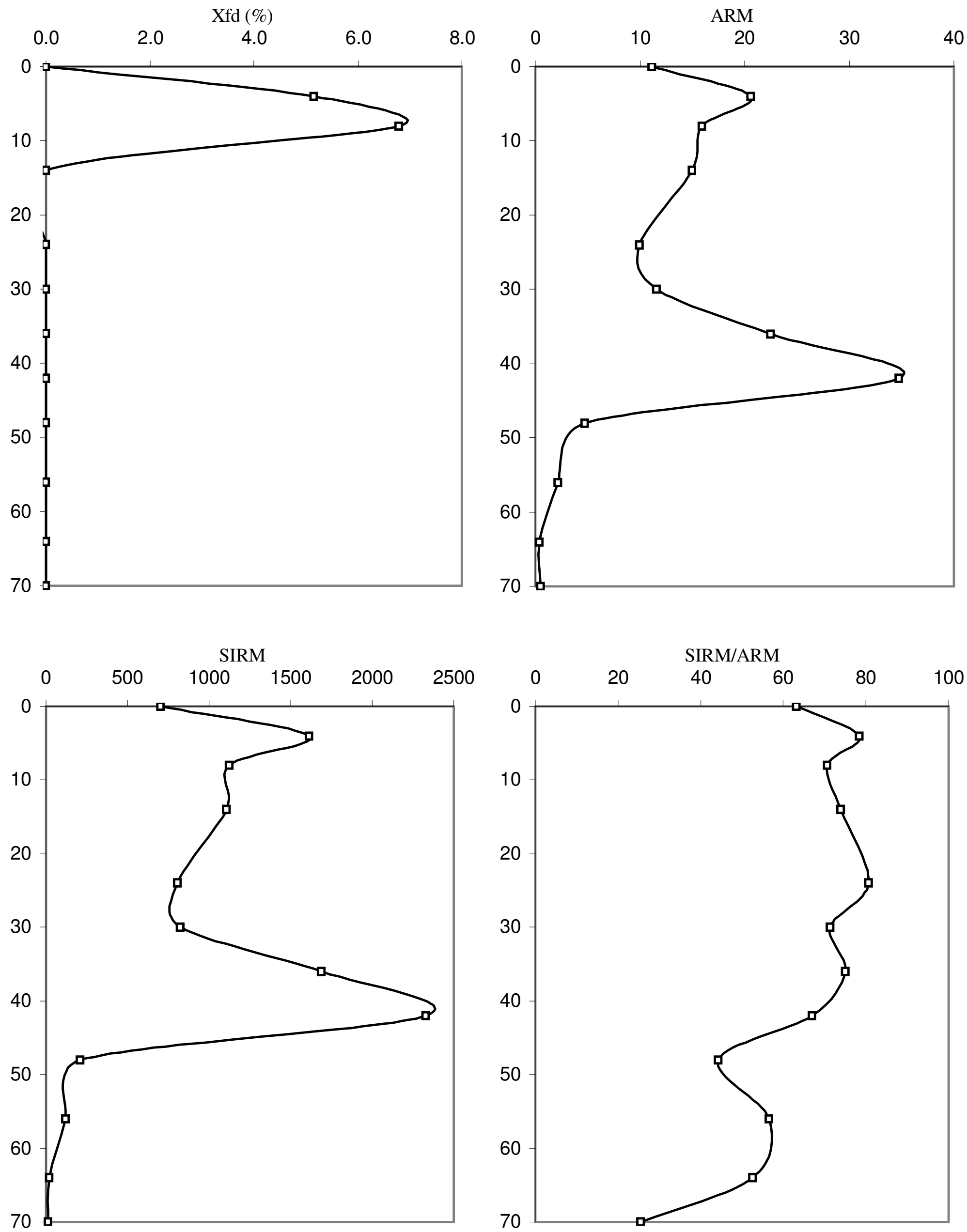

Figure 10. The mineral magnetic properties (Xfd (%), ARM and SIRM) of a peat monolith samples at site J12 selected from the grid survey.

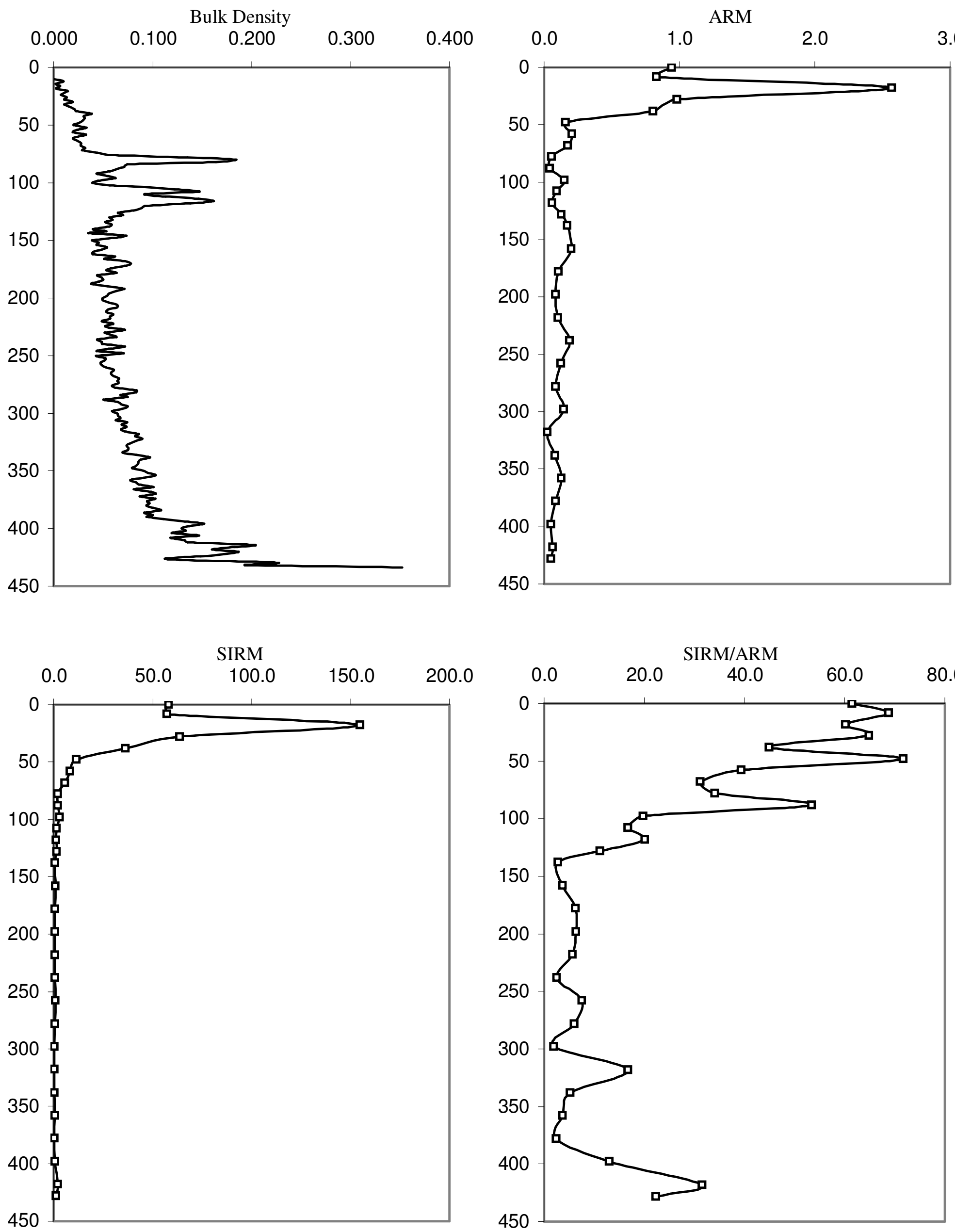

Figure 11. The physical characteristics (bulk density) and mineral magnetic properties (ARM. SIRM and SIRM/ARM) of the long peat core from the basin mire.

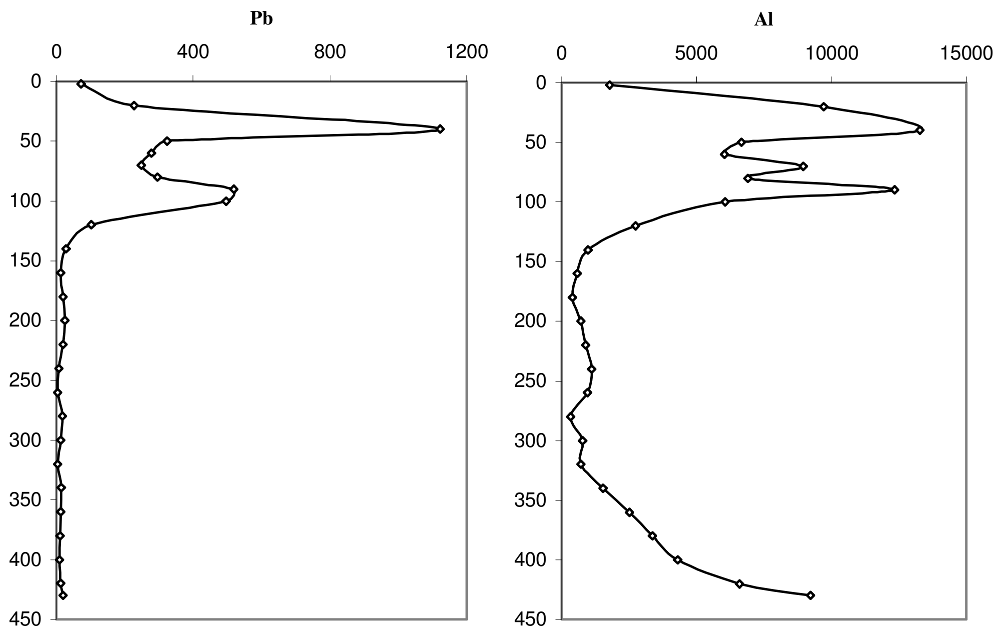

Figure 12. Selected heavy metal concentration depth profiles of the long core from the basin mire (units: mg/kg).

Table 1. Summary of the volume susceptibility (*K*) grid survey.

Site code	Grid ref. (SK)		Mean	Std. Dev.n	Mode	Median	Max.
A3	26694	82894	28.5	12.6	32	28.0	54
A5	26694	82894	2.3	2.0	0	2.5	5
A7	26696	82701	1.9	1.8	0	1.5	5
A9	26701	82600	1.7	1.7	0	1.0	5
A11	26704	82494	0.7	0.9	0	0.5	3
B4	26749	82846	22.7	15.8	12	15.5	54
B6	26751	82745	6.7	5.9	4	5.0	21
B8	26749	82648	5.1	3.0	7	4.5	10
B10	26753	82544	1.4	1.1	1	1.0	3
B12	26750	82448	2.1	1.0	2	2.0	4
C3	26796	82898	0.6	1.3	0	0.0	4
C5	26800	82801	7.9	10.1	0	3.0	29
C7	26803	82690	4.7	5.9	3	3.0	22
C9	26809	82600	18.7	6.9	24	20.0	26
C11	26802	82497	4.5	4.2	4	4.0	15
C13	26801	82403	1.4	0.8	1	1.0	3
D2	26850	82949	23.7	22.8	20	16.5	79
D4	26841	82849	29.2	20.9	N/A	25.5	74
D6	26850	82751	1.7	1.6	0	1.5	4
D8	26850	82651	7.1	3.4	5	6.0	14
D10	26849	82559	4.6	2.3	5	5.0	9
D12	26856	82447	4.0	2.4	1	4.0	8
D14	26850	82351	2.0	0.9	2	2.0	4
E1	26896	83001	10.5	6.8	15	11.0	27
E3	26897	82901	3.3	3.3	1	3.0	12
E5	26898	82803	12.2	8.5	2	10.0	32
E7	26901	82706	6.7	3.8	4	6.5	16
E9	26900	82604	14.1	10.2	10	10.0	41
E11	26902	82497	5.3	6.0	2	2.5	18
E13	26899	82397	35.4	20.1	20	29.5	73
E15	26899	82303	0.7	0.9	0	0.5	3
F2	26950	82945	12.2	7.7	4	12.0	27
F4	26950	82851	1.2	1.3	0	1.0	3
F6	26951	82748	3.7	3.6	1	2.5	12
F8	26954	82649	5.5	3.1	4	4.0	13
F10	26945	82552	1.9	1.8	3	1.0	6
F12	26953	82447	20.1	15.4	10	17.0	59
F14	26950	82348	0.9	1.1	0	0.5	3
G1	26995	82998	15.2	7.8	9	13.0	36
G3	27003	82894	4.1	2.4	2	4.0	10
G5	26998	82797	18.1	6.7	N/A	16.5	29
G7	27001	82699	15.1	7.9	5	13.0	36
G9	26996	82596	3.4	1.8	1	3.0	6
G11	27001	82500	7.1	2.6	6	7.0	13
G13	27005	82397	0.8	0.8	0	1.0	2
G15	27003	82294	1.2	0.8	1	1.0	2
H2	27047	82953	16.7	12.1	7	15.0	42

H4	27054	82858	6.3	5.1	1	5.5	16
H6	27049	82752	5.7	2.7	4	6.0	10
H8	27048	82653	3.4	1.2	2	3.5	5
H10	27049	82554	2.2	1.4	1	2.5	4
H12	27049	82452	13.8	9.7	10	11.0	37
H14	27051	82351	1.5	1.4	0	2.0	4
I1	27099	82998	10.4	6.7	3	10.0	24
I3	27105	82905	29.7	17.2	42	31.5	62
I5	27099	82805	8.0	7.6	2	4.0	23
I7	27101	82704	4.3	3.2	3	3.0	10
I9	27099	82599	7.7	7.2	2	7.0	26
I11	27098	82504	21.3	6.9	28	23.0	28
I13	27096	82400	1.2	1.0	0	1.0	3
I15	27103	82301	1.4	1.6	1	1.0	5
J2	27147	82945	8.7	6.1	11	9.0	23
J4	27149	82846	4.9	3.6	2	5.0	13
J6	27148	82747	6.0	3.4	4	4.0	13
J8	27150	82650	7.5	3.7	6	6.0	16
J10	27147	82546	3.2	2.5	2	2.0	9
J12	27149	82447	0.3	0.5	0	0.0	1
J14	27152	82347	0.4	0.5	0	0.0	1
K1	27201	83000	2.2	2.1	1	1.0	6
K3	27202	82898	13.1	2.6	12	13.0	17
K5	27196	82799	14.2	2.5	13	13.5	19
K7	27198	82692	28.3	12.3	N/A	25.0	42
K9	27204	82587	10.5	5.0	15	9.5	20
K11	27202	82498	8.8	2.7	8	8.5	13
K13	27199	82401	19.4	16.1	11	11.0	54
K15	27200	82299	5.6	2.3	4	6.0	9
L2	27259	82946	3.2	2.6	4	4.0	7
L4	27245	82856	2.6	1.6	3	3.0	5
L6	27250	82751	32.0	6.1	38	30.5	40
L8	27249	82653	3.9	2.0	4	4.0	9
L10	27249	82556	5.9	4.0	1	5.0	11
L12	27247	82455	2.7	1.5	2	3.0	6
L14	27252	82350	2.6	1.5	2	2.0	7
M1	27305	83003	5.9	2.0	5	5.0	9
M3	27299	82902	7.2	3.2	4	6.5	13
M5	27299	82806	14.3	7.1	14	14.0	26
M7	27299	82701	24.0	10.5	N/A	22.0	40
M9	27300	82602	6.7	4.8	5	5.0	16
M11	27297	82499	10.2	3.4	14	10.0	14
M13	276304	82401	3.7	2.5	3	3.0	10
M15	27307	82299	3.2	2.1	2	3.0	7
N2	27349	82947	6.6	2.5	6	6.0	13
N4	27343	82853	5.9	5.1	4	4.0	22
N6	27352	82747	10.3	8.3	5	6.0	31
N8	27351	82659	4.1	2.3	2	4.0	10
N10	27349	82545	6.3	3.1	6	6.0	12
N12	27350	82449	3.9	2.6	3	3.0	9
N14	27350	82344	2.1	1.4	1	1.5	5
O1	27402	83002	9.5	4.4	8	8.5	17

O3	27401	82903	7.6	3.9	7	7.0	16
O5	27399	82804	4.3	2.0	5	4.5	8
O7	27395	82704	8.1	4.5	5	7.5	15
O9	27396	82603	13.4	4.8	15	14.5	21
O11	27400	82500	3.3	2.6	4	4.0	7
O13	27398	82405	32.6	16.6	35	33.0	55
O15	27399	82300	3.6	2.0	2	3.0	8

Table 2. Summary of the heavy metal concentrations of the long core from the basin mire (units: mg/kg).

Metal	Mean	Std. Dev.n	Maximum
Al	4214	3957	13273
Cd	1.1	1.1	3.6
Co	2.3	2.6	8.9
Cr	2.3	3.4	17.4
Cu	10.3	20.3	100.4
Fe	1302	507.3	2615
Mn	19.0	19.5	63.2
Pb	150.3	252.2	1122
Zn	29.9	47.7	195.0