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The Effect of Microtopography and Vegetation on the Catchment of Airborne Particles Measured by Remanent Magnetism

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Measurements of saturation isothermal remanent magnetization (SIRM) for recent ombrotrophic peats show that the rate of deposition of magnetic particulates from the atmosphere varies strongly in response to the persistent, small-scale, spatial changes in vegetation and microtopography characteristic of many raised bogs. Hummock environments may trap over an order of magnitude more magnetic particulates than do *Sphagnum* lawns and pools. These results, thought to reflect the interception of subhorizontally moving particles by the hummock forming plants, have potentially important implications for studies of pollen deposition ("influx") rates in peat.

INTRODUCTION

Provided chronological control is sufficiently detailed to allow confident reconstruction of peat accumulation rates as they have varied in response to changes in climate, bog hydrology, and vegetation cover, the calculation of pollen deposition ("influx") rates for ombrotrophic peat profiles appears to be a useful and attractive exercise. Pollen supply is from atmospheric sources only (Oldfield, 1970) and the many complications associated with pollen accumulation in lakes (e.g. Peck; Pennington, 1973; Bonny, 1976) can be avoided. Several recent studies seek to interpret variations in pollen deposition rates or absolute concentration in terms of variations in pollen production within the source area of the site (e.g., Nichols, 1975; Beckett and Hibbert, 1976; Brown, 1977). The present paper uses magnetic measurements to draw attention to the possible effect on deposition rates of spatial variations in the distribution of major peat-forming plant species.

The surface vegetation pattern on many ombrotrophic mire crowns forms a small-scale mosaic that gives rise to spatial microtopographic variations such as the "pool and hummock" complex characteristic of many growing peat bogs in northwest Europe (Osvald, 1923). Small-scale relief of 0.5 to 1 m is common within an area of 10 m^2. The relief can be emphasized by the form of the vegetation growing in the different habitats—*Sphagnum* "lawns" and open pools interspersed with hummocks topped by tussocky sedges such as *Eriophorum vaginatum*. This pattern creates variations in surface roughness that make effective measurement or modeling of air flow close to the boundary layer exceptionally complex. This in turn makes it difficult to deduce spatial variations in particulate deposition densities, the more so since variations in the relative contributions of particles trapped from dry eddy diffusion or direct overhead wet fallout introduce an additional source of uncertainty (e.g., Tauber, 1965).

The present results summarize an attempt to evaluate small-scale spatial variations in particulate input to several ombrotrophic mire surfaces in northwest England by means of magnetic measurements.

MAGNETIC PARTICULATES

Several authors have shown that industrial and domestic processes involving fossil fuel combustion can generate large atmospheric concentrations of magnetic spherules. Oldfield *et al.* (1978) analyzed the concentration of these in the upper layers of ombrotrophic peat profiles from three sites at varying distances from major

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urban sources of atmospheric pollution. Their results confirm an increase in concentration of the magnetic particles of two to three orders of magnitude since ~1800 AD. The method used to estimate magnetic concentrations and deposition rates involves measurement of the magnetic remanence induced in a peat sample at room temperature in a saturating field of Tesla (10 k Oersteds) generated by an electromagnet. Placing a sample in a saturating field and measuring the induced remanence in a computerized slow-speed flux-gate magnetometer can be carried out at the rate of over 100 samples an hour. Variations in the resulting property, saturation isothermal remanent magnetization (IRM_{sat} or SIRM) are likely to be roughly proportional to variations in the volume of ferrimagnetic minerals from sample to sample where the magnetic minerals are spherical and where the magnetic forms of iron are either uniform or in constant proportion from sample to sample (Thompson *et al.*, 1975). In the present case, as with the material studied by many previous authors, the spherical form of the magnetic minerals can be confirmed visually by inspection of magnetic extracts under the microscope.

The lack of significant variation in coercivity of IRM (B_{CR}) profiles between samples (Fig. 1) and the approximately constant ratios between magnetic susceptibility (χ) and SIRM in the samples studied confirm the relative uniformity of the ferrimagnetic mineral assemblages from sample to sample. In view of the B_{CR} and χ/SIRM ratio values obtained and the results of thermomagnetic and Mössbauer effect studies on ferrimagnetic minerals produced by combustion of soil during forest fires (Longworth *et al.*, in press) the dominant mineral is likely to be magnetite, although further studies on particulates are required in order to confirm this. Table 1 defines the magnetic parameters used in the present paper and outlines their significance in simplified terms.

Oldfield *et al.* (1978) found that preindustrial SIRM values ranged from 10 to 80 $\times 10^{-6}$ A·m² kg⁻¹ in sites as diverse as L. Fea Bog in a remote upland area of Co. Tyrone, N. Ireland and Holland Moss near Liverpool. Peak postindustrial values reach 1200 at the former site and 20,000 at the latter. Similar consistency in preindustrial values and subsequent domestic and industrial source-related variations are pres-

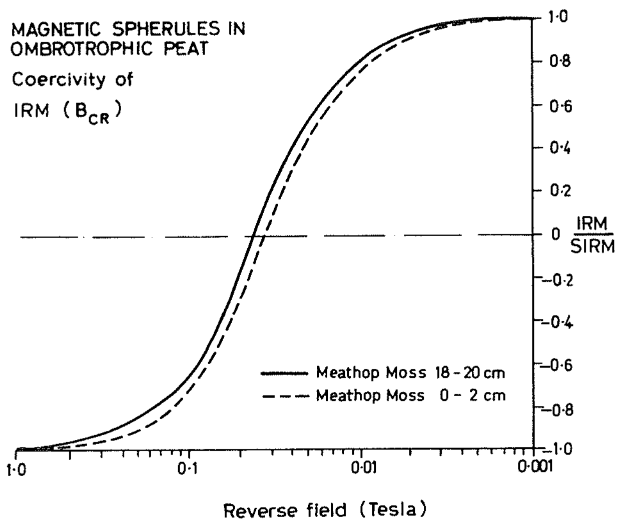

FIG. 1. Extreme examples of coercivity of saturation isothermal remanent magnetization curves for the peat samples used in the present study.

TABLE 1

MAGNETIC PARAMETERS AND DEFINITIONS

Specific magnetic susceptibility (χ)

This is the ratio of the magnetization produced in a substance to the intensity of the magnetic field to which it is subject. This measure of "magnetizability" is often approximately proportional to the volume of ferrimagnetic oxides in a sample. Specific (mass) susceptibility is defined and discussed more fully in Thompson *et al.* (1975).

Saturation isothermal remanent magnetization (SIRM)

Isothermal remanent magnetization (IRM) is the magnetization which remains after a sample has been subjected to a magnetic field at room temperature. IRM increases nonlinearly with increasing field strength, and saturates in a high field. This maximum remanent magnetization is known as the saturation isothermal remanent magnetization. In this study a fluxgate magnetometer was used to measure the SIRM which was grown in a field of IT (10 kOe), produced by a conventional electromagnet. The SIRM/χ ratios obtained for the recent peats studied lie within the range characteristic of fine-grained magnetite, and therefore support the use of SIRM as well as χ as a rough index of the volume fraction of ferrimagnetic material present in the sample.

Coercivity of saturation isothermal remanent magnetization (B_{CR})

This is the magnetic field strength required to reduce to IRM to zero after saturation. In this study the field has been determined from a series of IRM measurements. The procedure followed involved growing and measuring the SIRM of a sample and then growing and measuring IRMs in a sequence of increasing reverse fields, so that initially the net IRM decreased at each step and then subsequently increased until saturation in a reverse field took place. A curve of normalized IRM versus field strength, as shown in Figure 1, can then be drawn. The coercivity of remanence is the field at which the descending curve intersects the horizontal zero line. B_{CR} may be regarded as a measure of the stability of magnetization and is effected by mineral type and size rather than mineral concentration. Similar coercivity of remanence profiles are indicative of similar magnetic mineral assemblages and *vice versa*.

ent in Finnish peats dated by the moss increment method (Pakarinen and Tolonen, 1977; Oldfield *et al.*, in prep). These dated profiles, coupled with minimum age determinations for the onset of increased SIRM values at L. Fea Bog and Bolton Fell Moss by ^{210}Pb analysis (Oldfield *et al.*, in press) show that as for atmospheric CO_2 (Mitchell, 1970) and total lead concentrations (Rühling and Tyler, 1969; Appleby and Oldfield, in press) values begin to rise from the mid-19th century onward and increase at an accelerating rate to a mid-20th century peak.

It follows from the above that since (1) the preindustrial values of SIRM are negligible compared with late 19th and 20th century values, and (2) the age of onset of increase is synchronous regionally, cumulative SIRM values for a column of recent ombrotrophic peat of constant surface area are proportional to the mean rate of atmospheric input of magnetic spherules to any given site of accumulation over approximately the last 120 yr.

RESULTS

The lowland area of Cumbria round the head of Morecambe Bay, Northwest England, includes several open valleys flooded by the mid-Flandrian marine transgression characterized by Gresswell (1958), Oldfield (1960), and Tooley (1974). The plain of tidal alluvium laid down by this transgression together with sediments associated with contemporary brackish and fresh-water lagoon development, form the substrate for extensive development of lowland raised bogs. In many cases ombrotrophic peat accumulation has persisted into the last few decades, the raised bog crowns have not been subject to peat cutting, and they remain intact. Where this is so, they preserve a record of the sum of airborne particulates deposited during the last 120 yr despite any variations in peat type and accumulation rate which may have occurred at any given sample site. This sum may be compared from site to site and used as a measure of the total volume of mag-

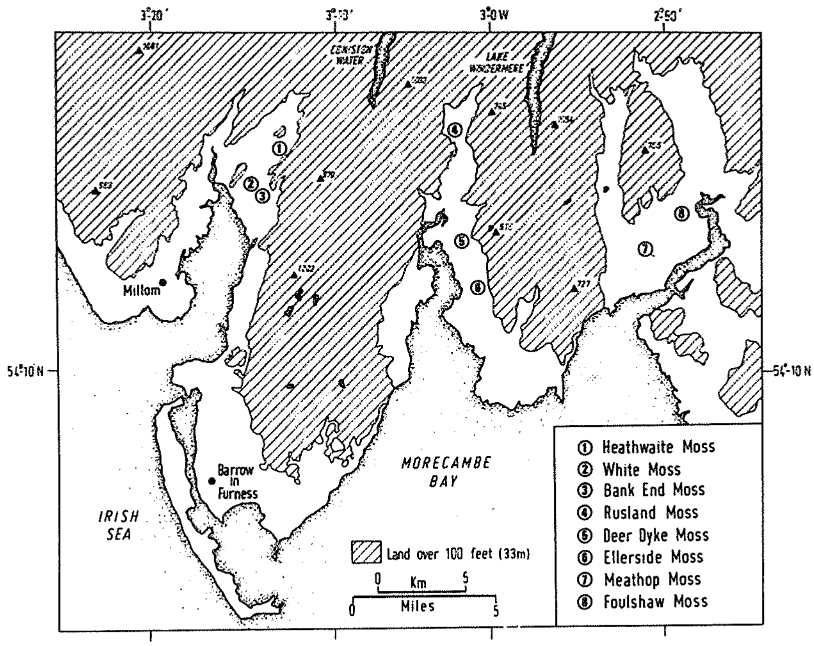

FIG. 2. Location map of the sites studied.

netic spherules trapped at each locality. Figure 2 plots the distribution of sample sites used in the present study.

Although the depth of ombrotrophic peat accumulated since 1800 A.D. may be expected to vary from place to place, Smith (1959), Oldfield (1969), and Dickinson (1973) have shown from pollen-analytical evidence that this seldom if ever exceeds the uppermost 20 cm at each of the sites studied. Samples for the present analyses were taken in 30-cm-long drainpipe sections each with an internal diameter of 13 cm. Each profiles was sliced into 2-cm sections and the sections were dried and pulverized. SIRM measurements were made on subsamples varying between 1 and 6.5 g. This procedure permits calculation of specific and volume SIRM at each depth, as well as cumulative SIRM at each stage above the level of initial 19th century increase. Total cumulative SIRM for the whole profile is roughly proportional to the total volume of magnetic particulates deposited over an area of 0.0133 m^2 at each site since the initial impact of fossil fuel combustion. Figures 3 and 4 plot changing concentrations and cumulative SIRM for each profile. A sample strategy was designed to determine the extent to which variations in the cumulative atmospheric input of magnetic particulates was dominated by major sources outside the region (e.g., the heavily industrialized areas of South Lancashire), by sources within the region such as Millom or Barrow-in-Furness, or by the different trapping efficiencies of the various types of plant cover. The results show little evidence for major transregional or within-region variations, but where, as at Heathwaite and Rusland Mosses, for example, persistent neighboring *Eriophorum* hummocks and open or *Sphagnum*-infilled pools have been sampled on the same undisturved bog crown, the hummocks have trapped at least an order of magnitude more magnetic spherules than the adjacent pools. Although modal sizes and densities of the magnetic spherules responsible will give them terminal velocities that differ from those characteristic of pollen grains, the local variation is so striking as to suggest

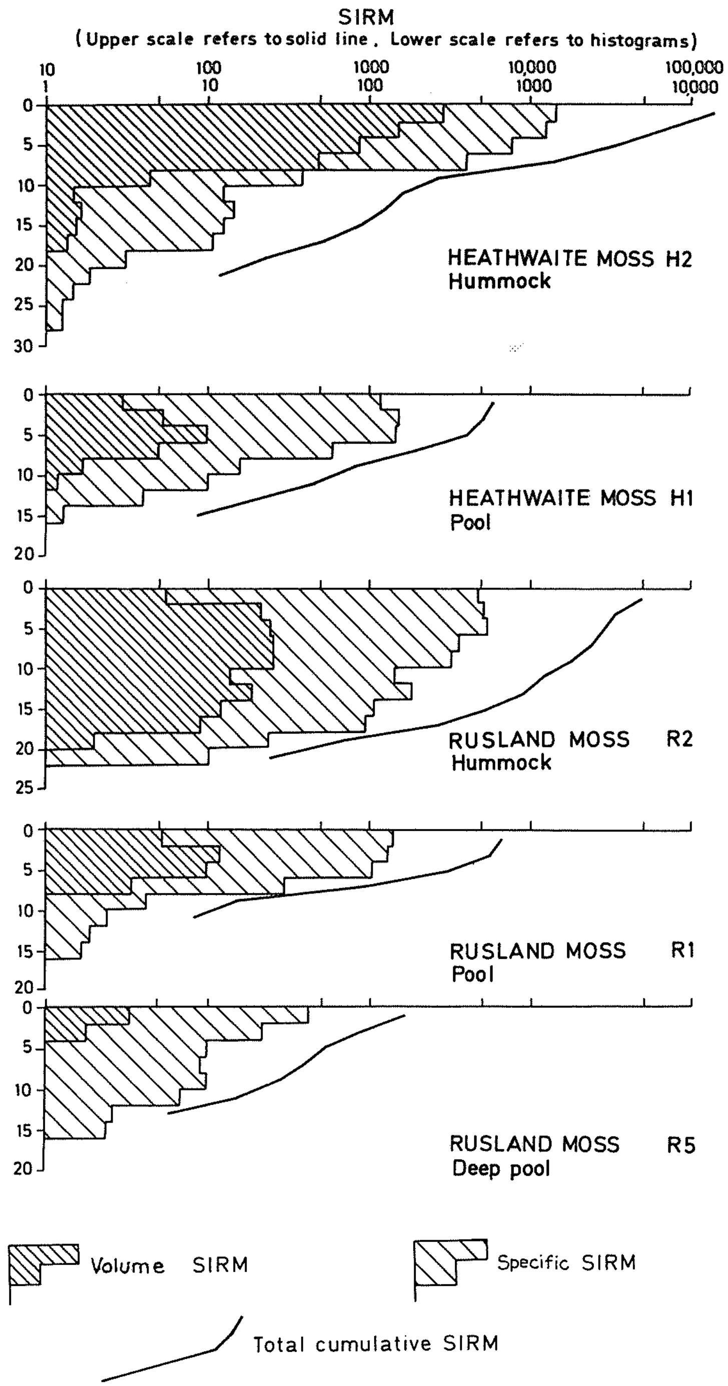

FIG. 3. Saturation isothermal remanent magnetization (SIRM) values in recent peats at Heathwaite and Rusland Mosses. The histograns plot changes in concentration with depth, the solid line plots the cumulative SIRM as a magnetic moment in $\mu A \cdot m^2$ from the beginning of increased concentrations up the the present day surface. Both horizontal scales are logarithmic. Volume SIRM is plotted as $\mu A \cdot m^{-1}$, specific SIRM as $\mu A \cdot m^2\ kg^{-1}$.

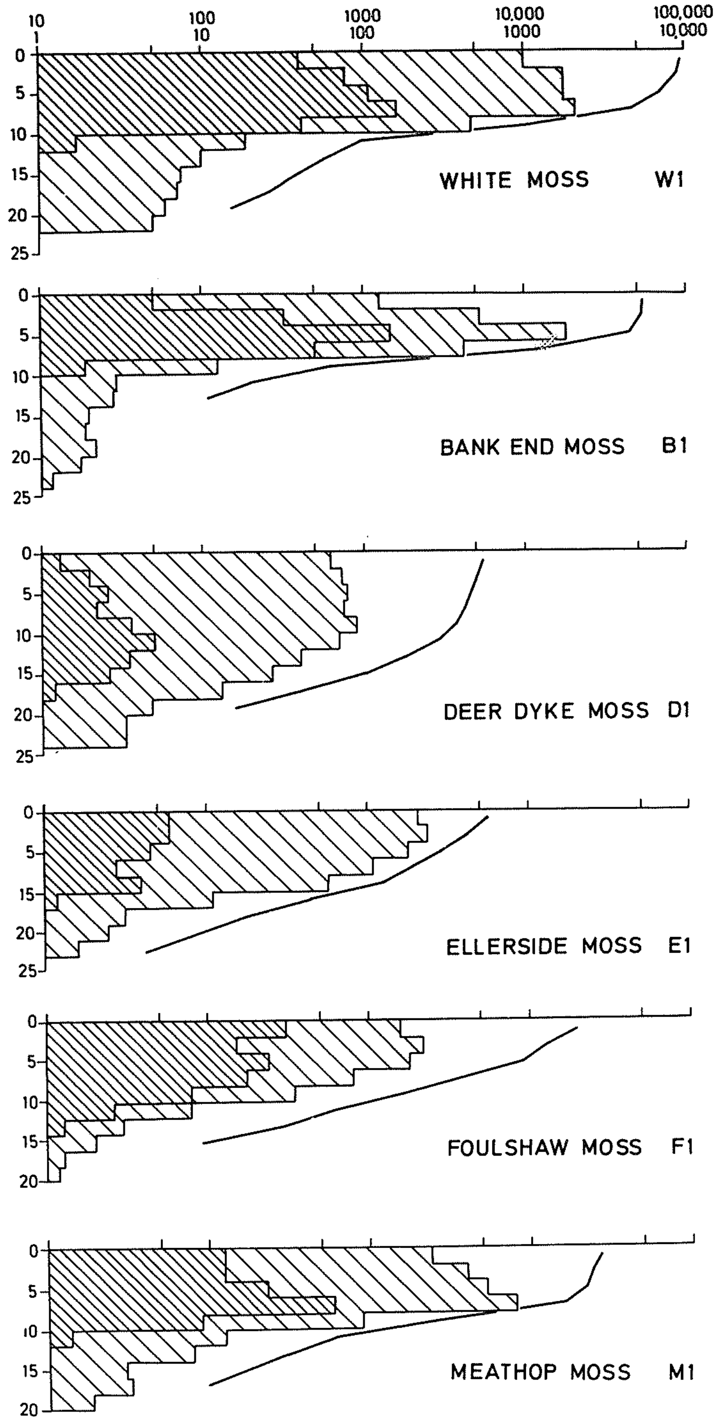

FIG. 4. Saturation isothermal remanent magnetization values in recent peats at Bank End, White, Deer Dyke, Ellerside, Foulshaw, and Meathop Mosses. Legend as for Figure 3.

the importance of evaluating this potential source of variation in pollen concentrations and deposition rates.

CONCLUSIONS

The rate of atmospheric input of magnetic spherules to the crowns of raised bogs can be shown to vary by at least an order of magnitude at adjacent locations on the same mire surface depending on whether samples are collected from the sites of persistent pools or hummocks. The hummock localities appear to filter out much higher numbers of the magnetic spherules which are responsible for the magnetic properties recorded. The variation is thought to result from the interception by hummock-forming vegetation, of small particles borne along subhorizontally close to the ground surface by dry eddy diffusion. The possible implications of these results for peat-based studies of pollen concentrations and deposition (influx) rates are noted and would appear to merit further study.

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