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Palaeolimnology and Palaeomagnetism

MAGNETIC studies of freshwater sediments from northwest England and Northern Ireland have revealed a wide range of applications of magnetic measurements to palaeolimnological studies. They have also shown that lacustrine sediments give a unique record of past changes in the geomagnetic field. This letter is chiefly concerned with the uses of magnetic measurements in helping to interpret lacustrine successions; Creer *et al.*[1] have already discussed the implications of the secular changes of the Earth's magnetic field as recorded in the sediments of Lake Windermere.

The magnetic parameters which have contributed in helping to decipher the information locked in lake deposits are declination, inclination and intensity of the natural (NRM) and cleaned magnetic remanence; initial susceptibility; and response of NRM intensity to a variety of thermoremanent and thermomagnetic tests. Variations in declination with depth can be used to date the sediments. Initial susceptibility and intensity measurements are useful for fine correlations between cores from the same lake, and also provide information about processes which have been operating in the lake's drainage basin. Other magnetic studies have provided information principally about the origin of the material holding the NRM. Instruments have recently been developed at Newcastle to measure the important properties of magnetic declination and its intensity[2,3] and initial susceptibility[10] on whole lengths of core. All samples were collected by Mackereth pneumatically operated piston corers of either 1, 3 or 6 m length[4,5].

The record of secular variation for Lake Windermere is accurately known for the past 11,000 yr (Fig. 1) with a time scale provided by a suite of radiocarbon dates. Fourier and spectral analyses of the results revealed a single significant periodicity of about 2,800 yr in the declination variations, but

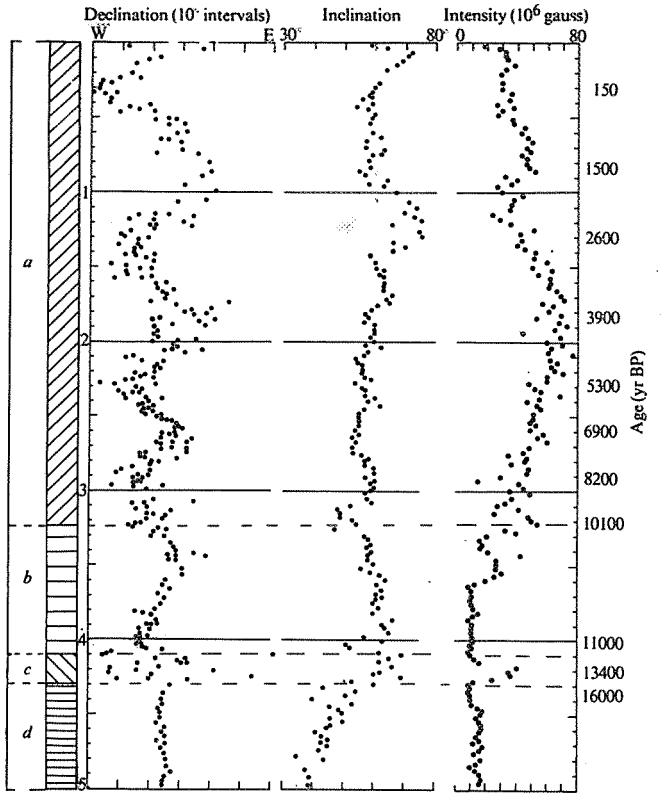

Fig. 1 Composite plot of stratigraphy: declination, inclination and intensity of the NRM versus depth in metres from four 6-m cores of sediment from Lake Windermere. Ages and declinations from Mackereth[6]. Relative, rather than absolute, values of declination are plotted. *a*, Post-Glacial organic; *b*, Late-Glacial laminated clays; *c*, amelioration period; *d*, Glacial varved clay.

none in the inclination changes (Fig. 2), confirming Mackereth's conclusion[6] that the oscillations in declination were of constant frequency. Comparison of detailed measurements from the top metre of sediment in Windermere with observatory and archaeomagnetic results for the past 500 yr showed that the NRM became stabilized soon after the time of deposition of the sediment, and alternating field cleaning showed that the NRM was of high stability[1]. Thus the Windermere record of declination changes (Fig. 1) provides a reference curve which can be used to date other lacustrine successions simply on their variations in declination of magnetic remanence.

agreement with the magnetic age. Other cores gave similar swings in declination (Fig. 3*b*, *c*) indicating comparable rates of deposition to those in core AB9, but one core (AB11) held more swings in declination than the other cores (Fig. 3*d*).

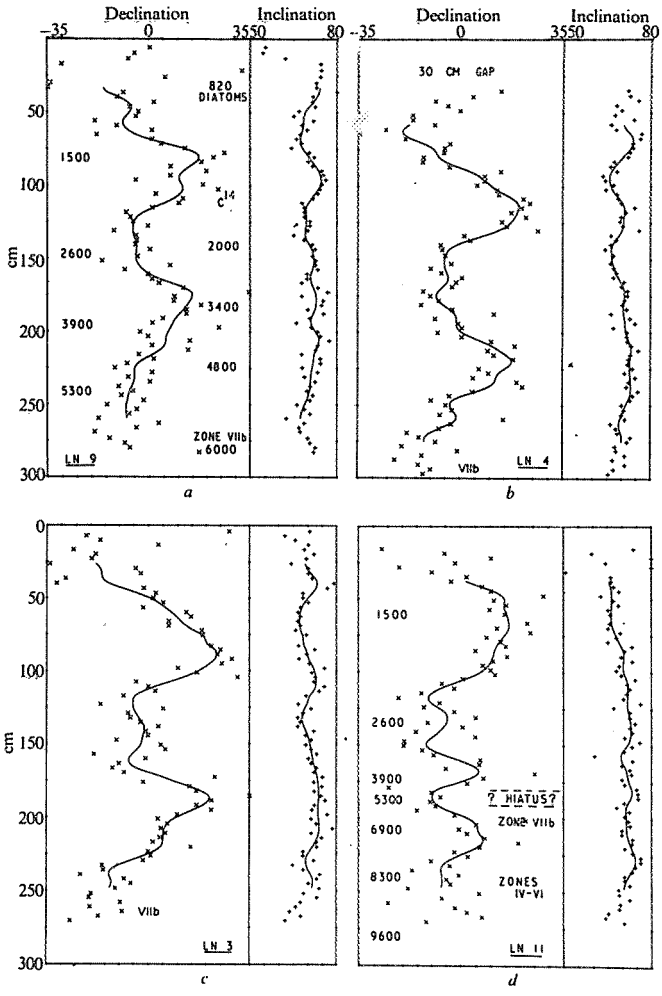

Fig. 3 Declination and inclination changes for four 3-m cores from Lough Neagh. In diagram *a* the left hand dates are derived by comparison with the Lake Windermere magnetic record, the right hand dates are from Lough Neagh. In diagram *d* the dates are derived from the Lake Windermere magnetic record.

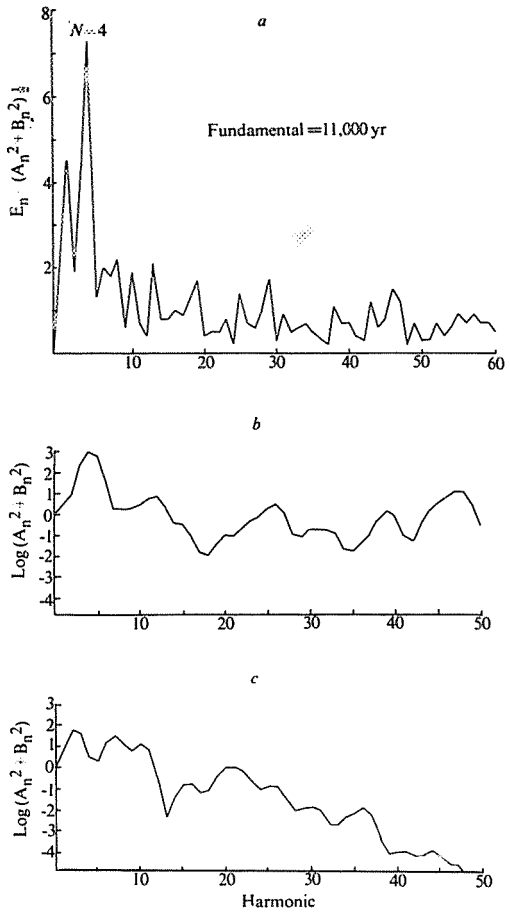

Fig. 2 Lake Windermere. *a*, Fourier analysis of the declination record; *b*, spectral analysis of the declination record; *c*, spectral analysis of the inclination record.

One 6-m and eight 3-m cores from Lough Neagh were provided by F. Oldfield for magnetic measurements from a larger collection intended for palaeobotanical studies. Carbon 14 ages[7] have been assigned to core AB9 by correlating its pollen assemblages with those of another Lough Neagh core which had been isotopically dated. Only the carbon 14 ages of 4,800 and 3,400 BP are now thought to be reliable estimates of the sediment age. These ages compare well with the palaeomagnetic dates (Fig. 3*a*). Further, pollen analyses yield an age of about 6,000 BP for the basal material in core AB9, in good

Comparison with the Windermere reference curve suggests an age of about 9,000 yr BP for the oldest sediment in this core, and shows that the rate of deposition has been markedly slower in the lower half of the core compared with the upper part. Pollen analyses conform remarkably well to this pattern and time scale of deposition[8].

Mackereth (personal communication) showed that the horizontal intensity of the NRM in Windermere was related to the carbon content of the sediments. Measurement of the total intensity of NRM of both Lough Neagh and Lake Windermere sediments again produced the same relationship of direct proportionality between carbon content and intensity. This is a clear indication that the intensity of the remanence was controlled by biological activity in the lake and in particular in the soils of the surrounding areas, rather than by changes in intensity of the geomagnetic field. There is an inverse correlation between the mineral content of the lake sediments and the intensity of their magnetization. For example, in both Lake Windermere (Fig. 1) and Lough Neagh the intensity of NRM reached a maximum in mid-Post-Glacial times, when erosion was at a minimum, but leaching of soils and lake productivity were at a maximum[9]. Thus the remanence is of a chemical, as opposed to a depositional, origin. Low temperature transition studies have shown that the NRM is largely carried by haematite[1].

Initial (low field) susceptibility measurements were made on all the subsamples from the Lough Neagh cores. Sediments from deeper water areas had lower values and smaller fluctuations of susceptibility than the cores from the shallower water nearer the edge of the Lough. The changes in susceptibility of the deep water cores (Fig. 4) were similar from core to core and give a method of accurate correlation between cores in the Post-Glacial organic material, which without detailed analysis seems homogeneous. Correlation with the shallow water cores is also possible but it is not as precise. Oldfield (personal communication) has demonstrated that the course of susceptibility change (Fig. 4) closely parallels the sequence of forest clearance in the Lough Neagh drainage basin, as reflected in the grass, bracken and rib-wort plantain pollen content of the cores. This aspect of the palaeolimnological work is being pursued in greater detail by magnetic, chemical and botanical investigations of the most recent sediments in Lough Neagh.

The detailed information about the past changes of the geomagnetic field obtained from Lake Windermere sediments can thus be used to help in the investigation of other Post-Glacial lacustrine deposits. Measurements of changes in declination, particularly using the whole core method, form an

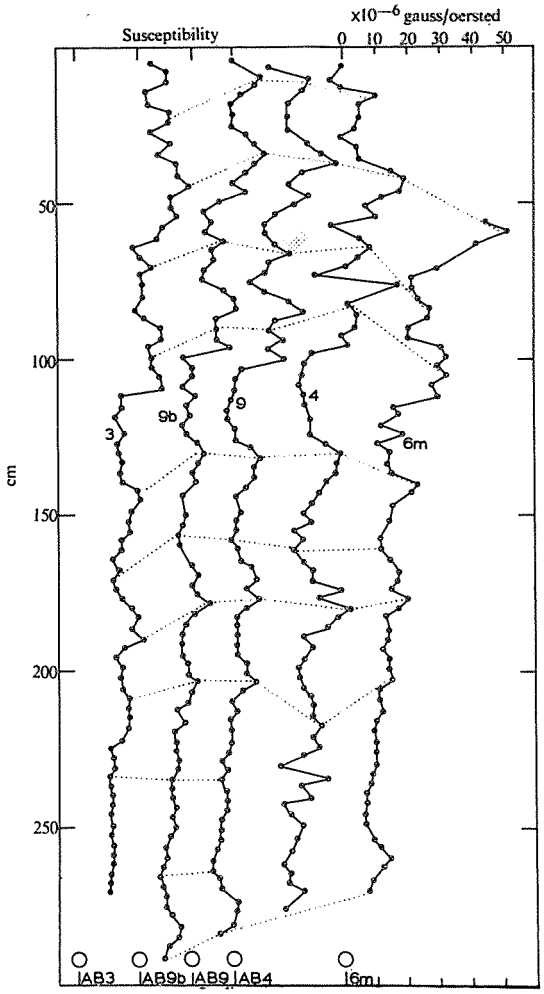

Fig. 4 Susceptibility against depth for the deep water Lough Neagh cores. Susceptibility is plotted on a linear scale: the origin of the susceptibility scale for each core is indicated along the bottom axis. Correlations between cores are shown by the dotted lines. (For comparison with Fig. 3 add 40 cm to depths in core AB4.)

extremely rapid dating technique. Declination and intensity variations are useful as reconnaissance tools for providing, nondestructively, stratigraphical information about cores before more detailed and time consuming investigations are

carried out. Susceptibility and declination changes give a means of correlating accurately between cores from the same lake. Information about the sediment type, and the biochemical conditions in which it was formed and deposited, are provided by the magnitude of initial susceptibility and intensity of NRM. Present studies on lacustrine sediments from a previous (Hoxnian) interglacial period indicate that the work can be extended further back into the Pleistocene. I thank A. Green for assistance with the spectral analyses.

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