The use of magnetic measurements in interpreting the fire histories of lake drainage basins

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Abstract

The magnetic parameters S.I.R.M. and magnetic susceptibility have been used to try and establish the fire histories of lake drainage basins. The technique is demonstrated using sediments from three lakes: Llyn Bychan (N. Wales), a lake with a recently burnt catchment, Lake Biscarrosse (S.W. France), a lake with a well documented fire history, and Lake Laukunlampi (E. Finland), a lake with laminated sediments and a long, but unknown fire history.

Introduction

The magnetic enhancement of soils by burning was first demonstrated by Le Borgne (1955). He surmized that under the action of reducing gasses weakly magnetic forms of iron reduce to strongly ferrimagnetic magnetite on cooling. Longworth *et al.* (1979), however, have shown that the end product of the burning process is often non-stoichiometric magnetite. Rummery *et al.* (1979) demonstrated that forest fires produce magnetically enhanced secondary ferrimagnetic oxides in the soil with magnetic susceptibility (χ) and saturated isothermal remanent magnetisation (S.I.R.M.) values up to two to three orders of magnitude greater than unburnt soils.

This paper attempts to demonstrate the formation of secondary ferrimagnetic oxides in burnt soils and their persistence over time in the soil and lake sediment environment, were their presence can be used as a means of identifying past forest fires. The technique may therefore be used as a tool in examining and recreating past fire episodes and histories in lake catchments.

Methods

The sediments from three lakes were studied. Those from Llyn Bychan, Wales and Lake Biscarrosse, France were sampled using a 1 m Mackereth corer. After measurements of continuous whole-core magnetic susceptibility, the sediment was extruded in 1 or 2 cm slices. The sediments from Laukunlampi were sampled using a freezing technique (Huttunen & Merilainen, 1978), and subsampled every 0.25 cm. Replicate samples were subsampled at 0.5 cm intervals.

All samples were prepared for single sample magnetic measurements of magnetic susceptibility (χ) and saturated isothermal remanant magnetisation (S.I.R.M.) (cf. Oldfield *et al.* 1978). Sediments from lakes Biscarrosse and Laukunlampi were analyzed for pollen and charcoal (Faegri & Iversen 1964; Swain 1973). The lake Biscarrosse core BP6 was dated by the ^{137}Cs method.

Results

Llyn Bychan is a small lake in an area of magnetically favourable lithology of slates and siltstones

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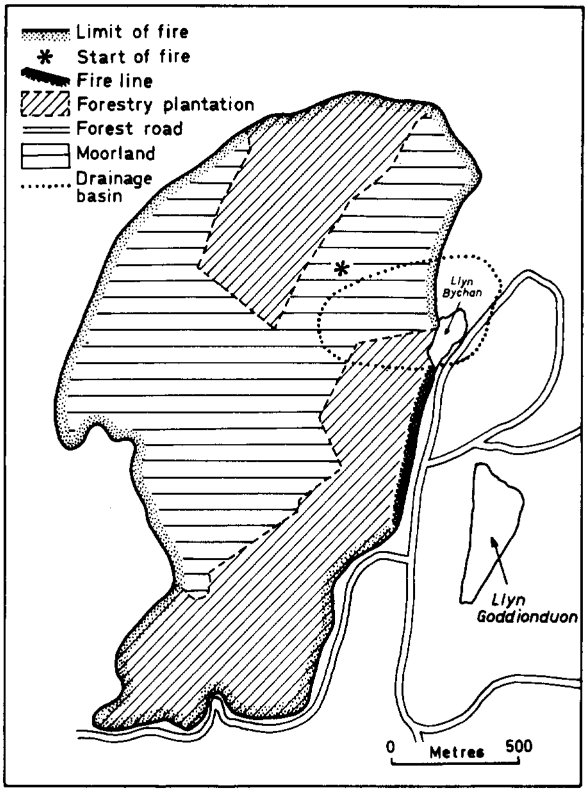

Fig. 1. The area burnt in the 1976 forest fire, N. Wales.

10 km north–west of Betws-y-Coed, Wales. In August 1976, half of the lake catchment was burnt in a forest fire (Fig. 1).

The effects on the magnetic properties of χ and S.I.R.M. in the soil by the heating in the fire is demonstrated in Table 1. Both the χ and S.I.R.M. values of the burnt soils are typically 2–3 orders of magnitude greater than the values for the unburnt soils, indicating the formation in the burnt soils of magnetically enhanced secondary ferrimagnetic oxides. Rapid erosioin of the soils followed the fire removing magnetically enhanced oxides and transporting them into the lake systems. The lake sediments were sampled 3 months after the fire and the continuous core χ traces for 5 cores are shown in Fig. 2. Cor LB1 was taken from the deepest part of the lake; the other cores are more marginal. The high values at the top of LB1 and the low values at the top of the marginal cores suggests that the magnetically enhanced material was initially concentrated in the deeper parts of the lake. If single samples are measured defined units can be used and Fig. 3 plots single sample S.I.R.M. against depth for core LB6 a paired core to LB1. LB6 has S.I.R.M. values of around 200×10^{-6} G.Oe.cm^3 g^{-1} up to 4 cm and S.I.R.M. values in the topmost sediments reaching $4\,270 \times 10^{-6}$ G.Oe.cm^3 g^{-1}. Three years after the fire event it was found that the magnetically enhanced layer was present over the whole surface of the sediment.

Table 1. Magnetic parameters for burnt and unburnt soils.

	S.I.R.M. -10^{-6} G.Oe.cm^3 g^{-1}	$\chi \times 10^{-6}$ G.Oe.cm^3 g^{-1}	S.I.R.M./χ
a. Burnt			
BY1	23051	399	57
BY5/1	16733	1168	14
BY5/2	108390	3264	33
BY9	11528	100	115
BY10/1	40024	713	56
BY10/2	175736	4516	39
TB3	7320	378	19
b. Unburnt			
BY20/2	211	2.0	106
BY20/3	156	2.0	78
BY19/2	200	3.0	67
BY19/3	47	1.0	47
BY19/4	49	1.0	49
BY17/2	100	0.7	142
BY17/3	207	0.3	69

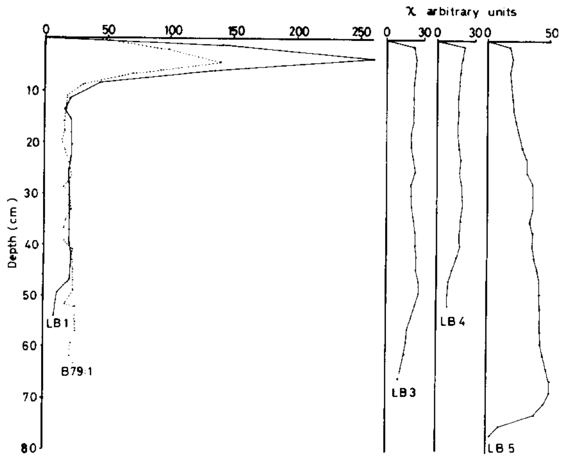

Fig. 2. Continuous core χ results for 5 cores from Llyn Bychan.

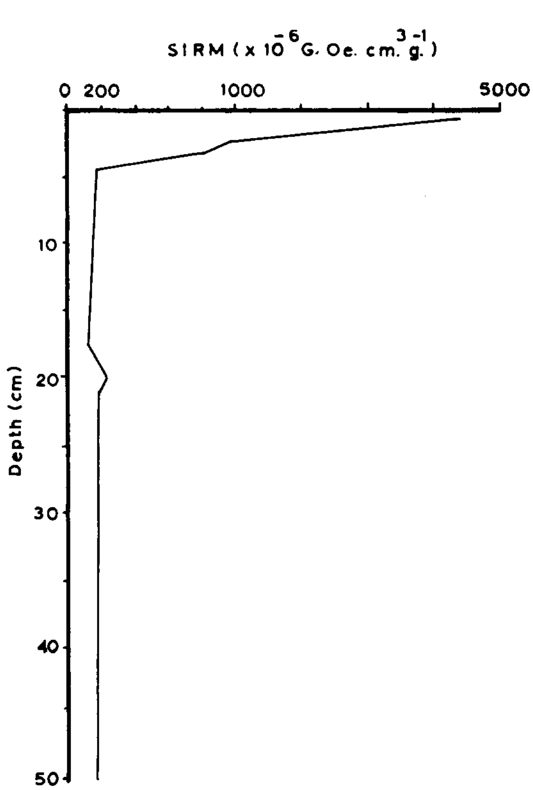

Fig. 3. Single sample S.I.R.M./depth plot for core LB6 from Llyn Bychan.

In order to evaluate the persistence of fire-induced marker layers in lake sediments, Lakes Biscarrosse and Sanguinet, in the sandy Landes region of south-west France were cored. Forests in the catchment areas of these lakes were severely damaged by extensive fires in the 1940s and especially in 1949. Details of fires and of the magnetic characteristics of the sediments are reported in Rummery (1981). Here some of the data for L. Biscarrosse are summarised (cf. Fig. 4).

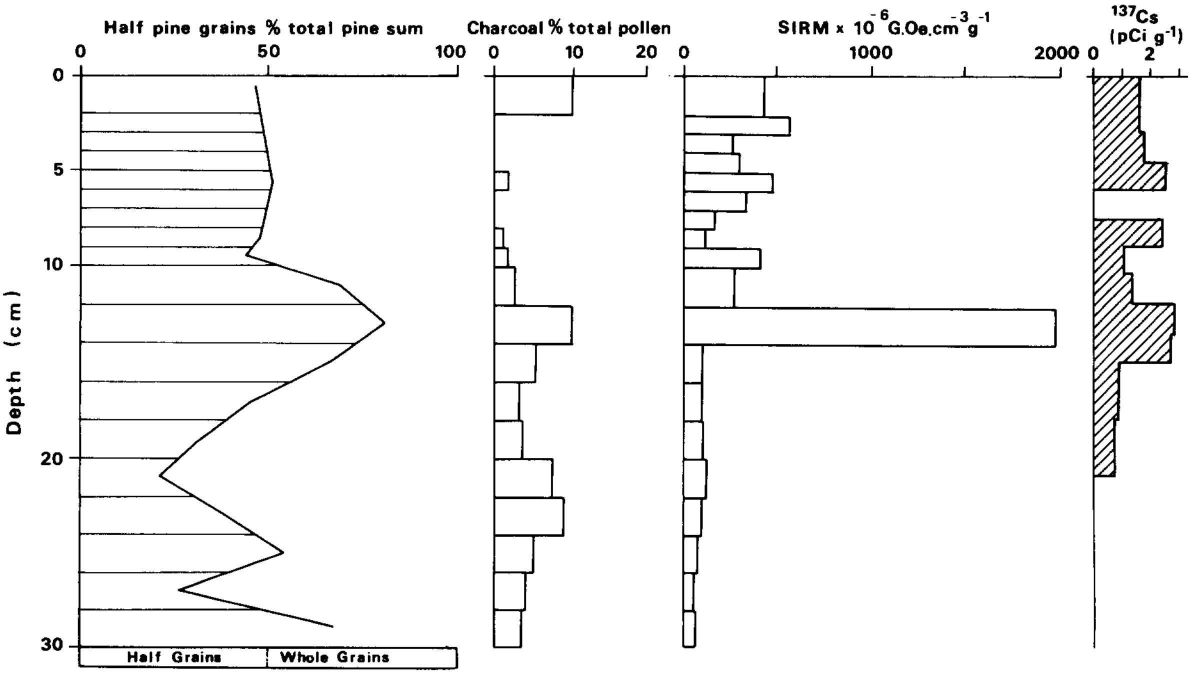

Fig. 4. Broken pine pollen ratio, charcoal, S.I.R.M., and ^{137}Cs for core PB6, Lake Biscarrosse, France.

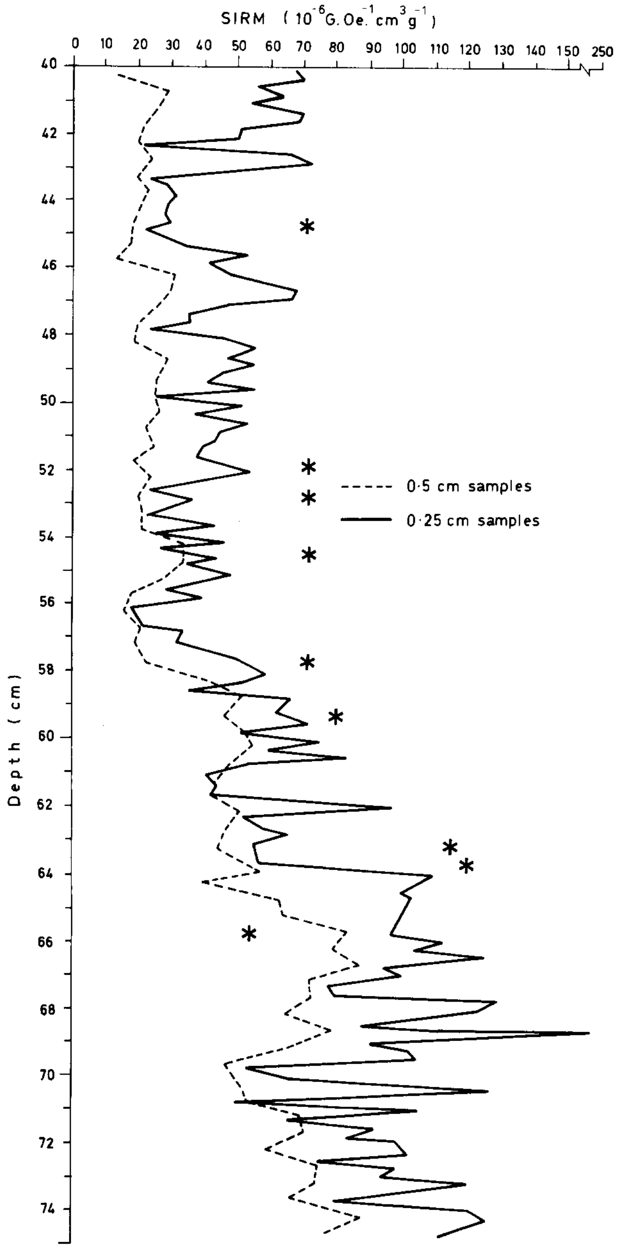

Fig. 5. Corrected S.I.R.M. 0.25 cm samples and 0.5 cm samples for a core from Laukunlampi, E. Finland. Rejected samples shown by a star.

A strong peak in S.I.R. M. was found in core BP6 (Fig. 4). In order to assess its relationship to the 1949 fire, pollen and charcoal analysis and ^{137}Cs dating was carried out. Charcoal may be considered to be the most direct evidence of fire and Oldfield (1978) demonstrated that a large broken to whole pine pollen ratio is also indicative of an ecological disturbance such as a forest fire. It can be seen (Fig. 4) that the charcoal maximum at 12–14 cm, the maximum pine pollen breakage ratio of 80% and the S.I.R.M. peak are all synchronous. In addition, the ^{137}Cs profile indicates that the peak falls slightly before the 1954 onset of ^{137}Cs fallout (Digerfeldt *et al.* 1975) and compatible therefore with a date during the previous decade of forest fires or with the extremely severe 1949 fire.

In an attempt to test the applicability of the technique on a longer time-scale the annually laminated sediments of Laukunlampi, a small kettlehole lake in North Karelia, E. Finland, were examined (Battarbee 1982). Initial measurements of S.I.R.M. showed a number of sharp peaks in the upper 1 m of sediment. Replicate measurements of 40–75 cm at 0.5 cm intervals (Fig. 5) failed to reproduce some of the peaks and these values have consequently been discarded. The S.I.R.M. data for both 0.25 and 0.5 cm samples are shown in Fig. 5

The S.I.R.M. profile can be divided into two parts, the lower part from 56–75 cm with an average time interval between S.I.R.M. peaks of 20–21 years (using varve counts), and the upper part from 40–56 cm with an average time interval between peaks of 10 years. The time interval between S.I.R.M. peaks in the lower part may be consistent with a rotational slash and burn system of agriculture and the reduced time interval between the peaks in the upper part, if caused by fire, may suggest the more intensive exploitation of the forests during the nineteenth century by this system of agriculture.

Charcoal and pollen analysis has been carried out on samples from 59–72 cm and the results are presented in Fig. 6. Although there is not a complete agreement between the magnetic and the palaeoecological data, several of the S.I.R.M. peaks are synchronous with pollen and charcoal fire indicators, suggesting that fire layers may be restricted to single samples. Further analysis is required for a definite history of this site to be constructed.

Discussion

The high level of magnetic enhancement in the soils from the formation of secondary ferrimagnetic oxides during a forest fire is shown in the Llyn Bychan catchment. Erosion of the oxides from the

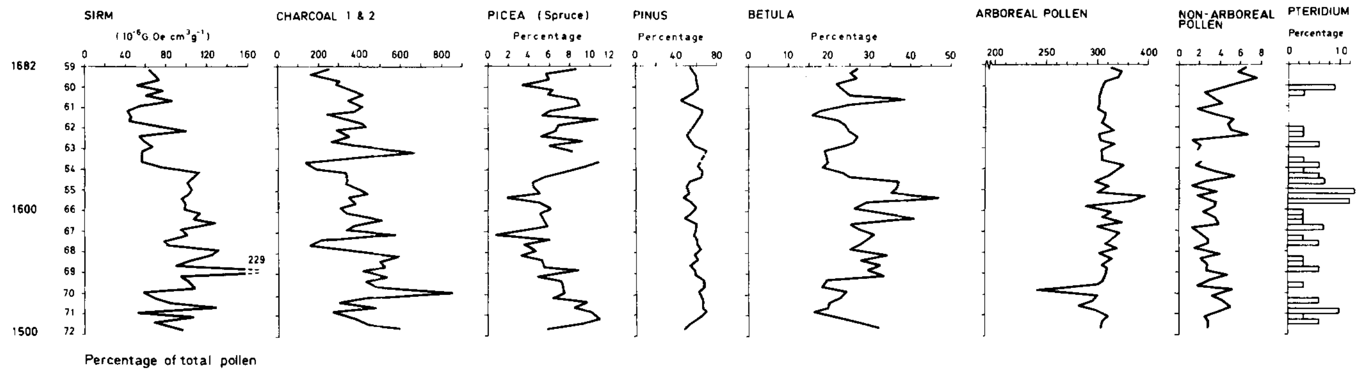

Fig. 6. S.I.R.M., charcoal, and pollen fire-indicators for Laukunlampi sediment 59–72 cm.

soil into the lake sediments leads to the formation of a magnetically distinct layer in the sediment which provides an easily identifiable fire level, a fixed datum for future studies and a feature upon which a core correlation scheme can be based. The Landes study demonstrates the persistence over time of the magnetically enhanced oxides in the lake environment and the use of the S.I.R.M. peak as a fire indicator by virtue of its synchroniety with known pollen and charcoal fire indicators. Construction of a multiple core correlation scheme using magnetic features and the rapid identification of a core suitable for the more time-consuming pollen and charcoal analysis is also demonstrated. In the case of Laukunlampi, the relationship between fires and S.I.R.M. peaks is ambiguous. This may be because the catchment area of the lake has an unfafourable magnetic lithology for this kind of study. The Laukunlampi soils were poor in convertible forms of iron but the substrate was rich in primary magnetic minerals. Correspondingly, in the lake sediments there is difficulty in differentiating between fire formed S.I.R.M. peaks and those formed by large inputs of primary magnetic minerals from the substrate.

In general the advantages of using magnetic measurements to identify past forest fires are numerous. The technique is rapid, undestructive and can differentiate between fires burning within the catchment from those outside. Movement of the oxides is primarily within the drainage basin and it is therefore likely that local fires will be preferentially recorded. The technique can also differentiate between areas in the catchment where the temperatures of the fire were high enough to form magnetically enhanced secondary ferrimagnetic oxides. A soil temperature of at least 400 °C, a rapid heating and cooling of the soil and a reducing soil atmosphere is required for the maximum formation of these oxides. A differentiation may therefore be made between canopy fires, cool ground fires (often controlled burns) and hot ground fires resulting from accidents and natural forest fires. A thorough review of the conditions needed to induce maximum magnetic enhancement in bedrock is given in Oldfield *et al.* (1981). It is suggested that the technique should be used to compliment rather than replace other more time-consuming techniques for identifying fire records.

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