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A rapid, non-destructive scanning method for detecting distal tephra layers in peats

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Abstract: Rapid, automatic scanning of reflectance variations along peat profiles from Corlea, central Ireland, known to contain prehistoric tephra layers dated to around 2300 cal. BC, has enabled the detection of these layers by non-destructive means. By using both light reflectance and luminescence properties it is believed that very thin and often discontinuous distal tephras characteristic of the Late Quaternary in northwest Europe may be detected within peat profiles.

Key words: Tephra, reflectance, luminescence, peat, scanning method, Late Quaternary, Holocene, Corlea, Ireland.

Introduction

The identification of distal tephra layers of Icelandic origin, often very thin and discontinuous, in peats and lake sediments of Late-Quaternary, and especially Holocene, age in northwest Europe has marked an important development in geochronological research. The presence of such marker horizons of varying dating precision and provenance now allows more confident correlation and dating of sequences in a range of European contexts (e.g., Persson, 1971; Mangerud *et al*., 1986; Merkt *et al*., 1993; Dugmore *et al*., 1995; Pilcher *et al*., 1995), and has also proved of value in other areas of the globe affected by tephra fallout. Where tephra layers are not visible in profiles, identification requires preparation of contiguous samples for microscopic examination through acid digestion (Dugmore *et al*., 1992; Pilcher *et al*., 1995), or more rapidly by ashing (Pilcher and Hall, 1992), prior to removal of tephra shards for geochemical analysis. Both procedures are time-consuming relative to the new technique discussed here and destructive of the sample. X-ray analysis has also been used (Butler, 1992; Dugmore and Newton, 1992) but has not been able to detect low-density tephra layers, and analysis of magnetic properties may be of value but has so far only had limited application (van den Bogaard *et al*., 1994). Here we present a new method for identifying tephra horizons in peats which utilizes the reflectance and luminescence properties of the tephra shards, and is rapid, non-destructive and flexible in terms of laboratory manipulation of profiles to isolate tephra-rich layers or lenses.

Methods

Luminescence occurs when molecules, having been excited previously by a high-energy light source that raised the energy levels of the electrons within the molecule, release energy in the form of light. The emitted fluorescent light is at a longer wavelength than the excitation; the most common form of luminescence is emission in the long wave ultraviolet and blue wavelengths (350–500 nm) after excitation by UV light (200–400 nm). Luminescence in natural environments is predominantly generated by organic acids (humic and fulvic) and amino-acid groups within proteins, which predominantly derive from decomposed plant and animal material in the soil zone, although inorganic minerals may occasionally generate luminescence. Detection of the luminescence signal in a series of peat monoliths was made using a Perkin-Elmer LS50B spectrophotometer with a fibre optic attachment (2 mm spot size) and moving stage. Monoliths of peat were cleaned with a scalpel to provide a smooth peat surface, and scanned at 0.1 s intervals at a rate of 25 mm min^{-1} (giving an effective sampling resolution of 0.05 mm). Reflection off the peat surface was measured using excitation and emission wavelengths of 445 nm, with spectro-photometer slit widths set to minimum aperture possible (<2 nm). For all analyses a Perkin-Elmer RG5 excitation filter (100% transmission <400 nm only) was used to minimize any scatter effects.

In addition, tephra shards from a peat site at Krosshóll in Northern Iceland (Stötter, 1991; Caseldine and Hatton, 1994) deriving from the Hekla-4 eruption were analysed to investigate their

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luminescence. Excitation wavelength was varied from 400 to 500 nm and emission wavelengths from 400 to 700 nm, with 10 nm slit width. Peak luminescence for the tephra was observed in the excitation region 400–450 nm, and emission 520–570 nm, probably deriving from organic acids adsorbed onto the tephra shards, and this combination was also used in the analysis of the peat monoliths, utilizing the methods as for the reflection scans. No clear evidence of trace element luminescence was observed, using both the spectrophotometer set up as described above, as well as a nitrogen pumped dye laser (excitation = 337 nm and 430–530 nm), despite the presence of luminescent trace elements at 10^1–10^3 ppm concentrations in most tephra (Westgate *et al.*, 1984; Pearce *et al.*, 1996).

Results

Continuous scans were run on replicated profiles from peats containing microscopic tephra shards originally detected by light microscopy and dated to *c.* 2300 cal. BC from Corlea, Co. Longford, central Ireland (Caseldine *et al.*, 1998). Two profiles, West Corlea I and West Corlea II, were examined, for which detailed palaeoecological records have already been published (Caseldine *et al.*, 1998). The samples scanned were from monoliths of dimensions 30 × 10 × 5 cm, allowing a series of parallel scans down the profile to isolate the strongest luminescence signal. The scanning process clearly identified variations in this strength over small surface areas, a feature to be discussed later. Comparison with the earlier work demonstrated greater apparent variability of the tephra distribution, but the samples extracted for microscopic investigation covered 4 cm in depth, against a sampling resolution of 0.05 mm for the luminescence analyses, and included material from a greater depth into the monolith, whereas the luminescence only reflects the character of the surface layer of the peat. Scanning for West Corlea II covered a 20 cm block between 18 and 38 cm, dating to 2290–2400 cal. BC, and for West Corlea I a 30 cm block between 30 and 60 cm, dating to 2250–2400 cal. BC. Microscopic examination of these sections had revealed a single main peak for tephra with a concentration in excess of 60 000 shards g dry weight^{-1} focused on 27 cm at West Corlea II, with concentrations around 20 000 shards g dry weight^{-1} in the above 10 cm. At West Corlea I there was an early peak around 56 cm (>20 000 shards g dry weight^{-1}) and a much higher peak around 45 cm (>50 000 shards g dry weight^{-1}), before very low concentrations above this, i.e., less than 10 000 shards g dry weight^{-1} (Figures 3 and 2 in Caseldine *et al.*, 1998; data transposed onto Figures 1 and 2; note in original paper the values for tephra concentration omitted the term × 10^2). At West Corlea I the double peak was interpreted as a redeposition of tephra in a very small surface pool as indicated by the peat stratigraphy.

Figures 1 and 2 show the results of the intensity scans for both profiles for light reflection and for luminescence. West Corlea II reveals two very clear peaks for both parameters at 26 and 27.5 cm with values above background levels of <300 for reflectance and peaks above 1.5 for luminescence. A general rise in both reflectance and luminescence above very low background levels occurs after 34 cm. The actual intensities and luminesence, which are measured on a unit scale from 0 to 1000, will vary not only with the strength of the signal but also with distance of the fibre optic from the peat surface and its relative roughness. It is therefore the relative changes that are of significance. At West Corlea I there are a number of peaks above comparable background levels at 56 cm, 50.5 cm, 49.5 cm and 31 cm. The spread of peaks reflects the more dispersed nature of the tephra deposit in this profile, and also highlights the difference in sampling intervals for the microscopic and spectrophotometric procedures, with much finer resolution possible by the spectrometer. Thus, inevitably there will be a difference between the two records with the spectrometry revealing a much more detailed record across a defined peat surface rather than generalizing the average tephra content of a specified volume or mass of peat. Furthermore, the unevenness of the original peat surface adds error to any direct depth comparisons. Caseldine *et al.* (1998) pointed out the variability in tephra representation across replicated profiles and the potential problems this caused where redeposition had occurred, both of tephra and aeolian mineral matter, and the luminescence analyses underline this.

Previous microscopic analysis of the profiles had revealed the presence of enhanced mineral matter over a similar period to that of tephra deposition. At West Corlea I enhanced aeolian mineral deposition was found only in the pool peat at 45 cm and is not

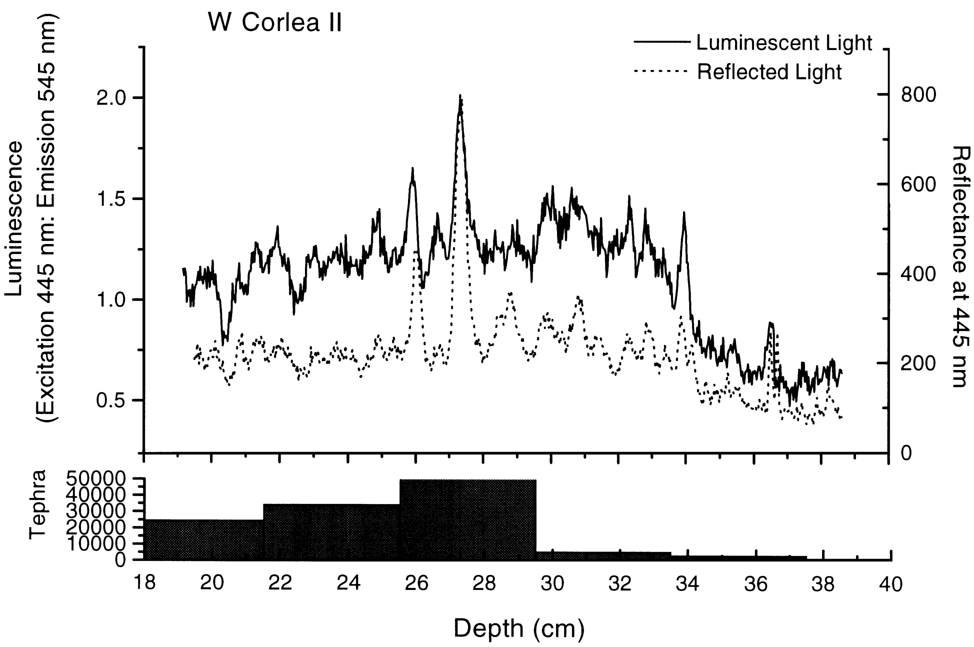

Figure 1 Reflectance and luminescence profile for West Corlea II. The peat stratigraphy covered by the profile is a uniform moderately humified *Sphagnum* peat with occasional remains of *Eriophorum*.

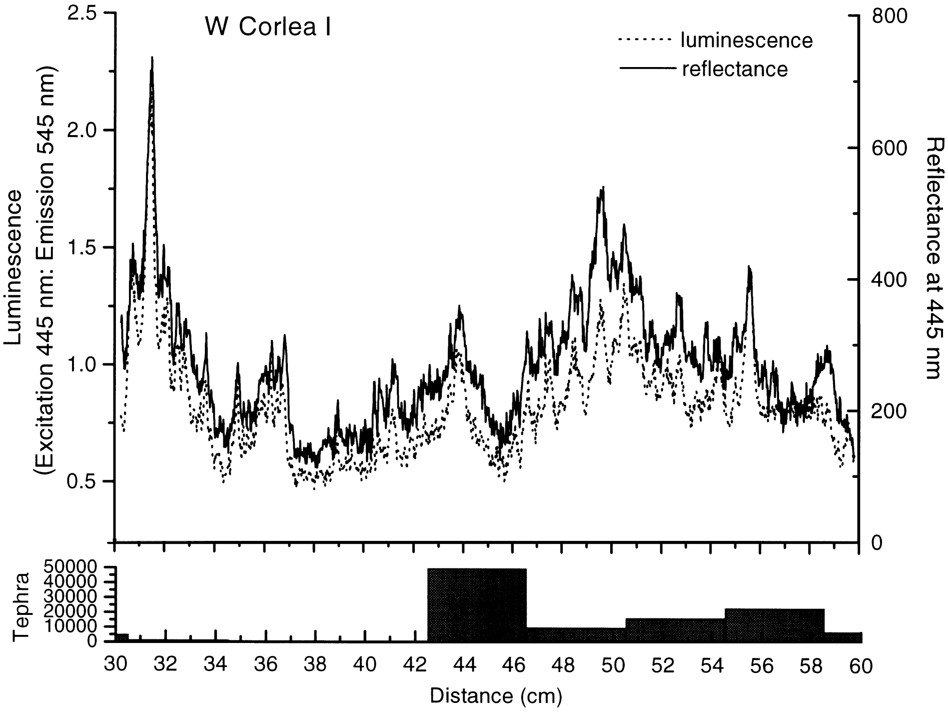

Figure 2 Reflectance and luminescence profile for West Corlea I. The peat stratigraphy is as follows. 30–41 cm: moderately to poorly humified *Sphagnum* peat. 41–46 cm: greasy olive-green pool peat. 46–59 cm: moderately humified *Sphagnum* peat with occasional *Eriophorum* remains. 59–60 cm: well-humified *Sphagnum* peat.

spread over the same depth as that indicated by the microscopic tephra or the reflectance/luminescence signal (see also Figure 2 in Caseldine *et al.*, 1998). Thus, while it may be possible that some of the reflectance is influenced by the presence of aeolian mineral material (mainly quartz), it is considered that both the reflectance and luminescence signals are predominantly determined by tephra distribution, where the luminescence is being caused by the adsorption of organic acids onto the tephra shards.

The possible tephra identified at 31 cm at West Corlea I, dated to *c.* 2300 cal. BC, was not identified in the original analysis but may well correlate with the upper tephra layer at Croaghaun East in Co. Mayo (Dwyer and Mitchell, 1997), a layer geochemically distinct from the lower of two adjacent tephras dated to within 100 years of each other. Although neither Croaughaun East tephras have been firmly provenanced, one is likely to be Hekla-4, and their radiocarbon age is extremely similar to the Corlea tephras. The lack of identification of this layer at Corlea by previous methods may not be so surprising when the distribution of such low-density tephras in peat is considered.

In order to establish the distribution of tephra over a more extensive peat surface across a known tephra layer, a second monolith was examined from West Corlea II. During the course of re-sampling the site two monoliths were taken adjacent to the original profile covering the depths from which the tephras had been identified. Wider monolith tins were inserted at 90°C to the originals, thus providing a much larger area for investigation. An area of 10 cm depth by 7 cm width was rescanned to provide a contour plot of the reflectance intensity of the peat, and hence the distribution of tephra (Figure 3). The tephra is seen as a highly discontinuous layer of high-intensity reflectance with pockets of concentration in the lower levels (one main peak at around 6 cm across in particular), very distinct from the peat overlying the layer which has much lower reflectance properties, and little if any tephra. These results demonstrate that any down-profile scanning used to detect tephra layers will need to be replicated to ensure that possible layers are not missed due to the narrowness of the scan, and the dispersed nature of peak tephra deposition. Nevertheless the presence of areas of enhanced reflectance and luminescence is still likely to be identified, and replication can be undertaken quickly to establish the location of likely peak concentrations. At this site it has not proved possible to identify the nature of the microrelief that influenced tephra deposition and redeposition, but this would be possible with a denser tephra layer in a more poorly humified peat deposit. The presence of an undulating original peat surface is indicated by the fact that the scanned profile, although immediately adjacent to the original profile, shows the tephra occurring at a lower depth.

Conclusion

Rapid scanning at intervals of 0.05 mm along peat profiles from Corlea has revealed the occurrence of tephra layers found previously by light microscopy and also revealed much greater detail concerning the distribution of tephra shards within the peat. In this context the technique also affords the possibility of examining tephra distribution both laterally and vertically within peats, providing an opportunity to understand what happens to such particles when they are deposited onto a bog surface. Scanning can be done extremely rapidly to a high degree of temporal resolution and thus provides a valuable reconnaissance method for finding those areas of peat suitable for more detailed geochemical examination. Although reflectance is quick and easy to scan, it is also influenced by the sparseness of the tephra, seen as a low signal intensity, and hence varies considerably across the uneven former peat surfaces, necessitating some replication of scans. The combination of reflectance and luminescence provides a technique of considerable geochronological potential for identifying distal tephras.

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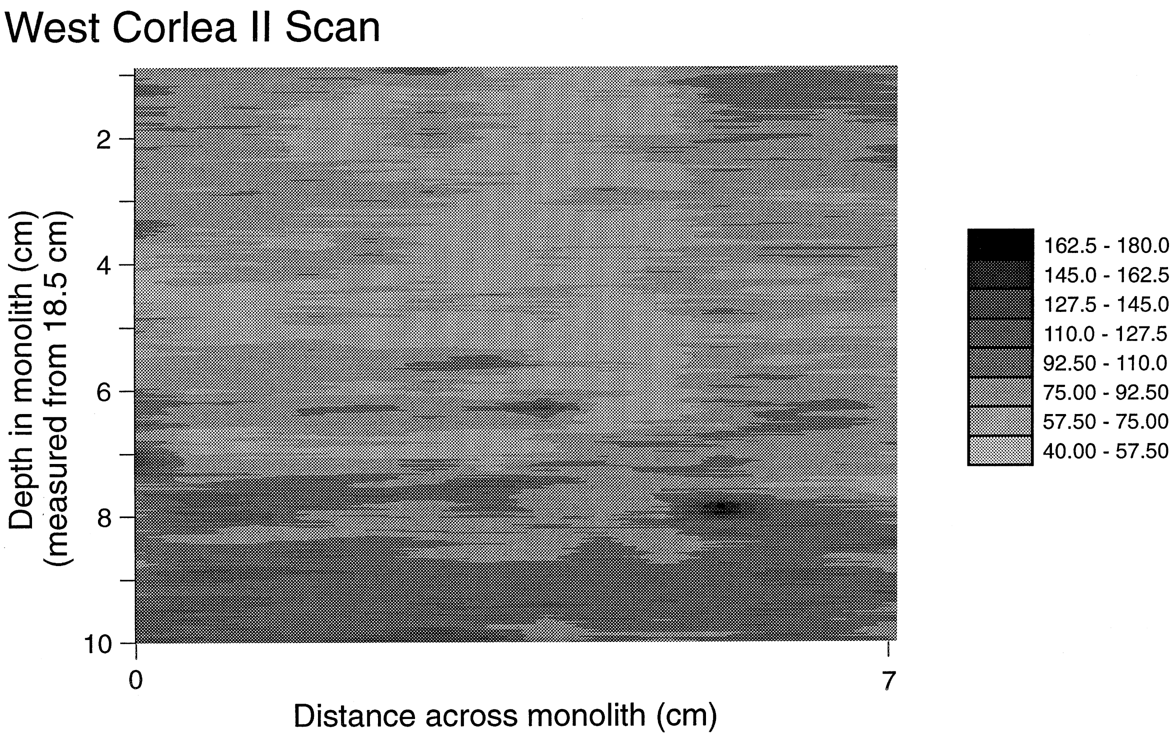

Figure 3 Scan of the peat block for West Corlea II. The darkest areas represent highest intensity of reflectance and hence concentration of tephra. The very light area above 6 cm depth is virtually devoid of tephra, whereas there is a distinct pocket at a depth of 8 cm, 6 cm across. The lowest 1 cm of the profile has generally higher tephra concentrations.

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