Tephra-linked studies and environmental archaeology, with special reference to Ireland

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Summary

Recent advances in tephra studies on deposits from sites widespread throughout Ireland are described. Suggested improvements in tephra preparation techniques for optical microscopy, electron microscopy and electron microprobe analysis are given.

Introduction

The purpose of this short paper is to inform the increasing numbers of environmental archaeologists interested in this new field of research about recent advances in tephra-linked palaeoenvironmental studies in the Ireland (for an introduction to the subject, see Sheets and Grayson 1979).

Tephra is volcanic ash. It is the product of a volcanic event and marks an isochrone or plane of equal age in any deposit in which it is found. Tephrastratigraphies and tephrochronologies are used by Quaternary scientists, including archaeologists, but mostly in areas where tephra layers are visible to the naked eye. It is only relatively recently that consideration has been given to using layers of micro-tephra as isochrone markers (Persson 1971; Buckland *et al.* 1981). There has been aversion to committing time and effort to this necessarily detailed study. Indeed Hammer (1984) states the following: 'How much fine grained tephra is actually produced in eruptions? Very little is known about it, as this fine tephra is almost by definition so fine, that it cannot be traced in peat bogs etc. (at least not without laborious work and much difficulty)'.

It is only within the last five years that the value of studying deposits in the British Isles where micro-tephra layers are present has been demonstrated. Refinements in electron microprobe analytical techniques which can establish the geochemistry of single shards of volcanic glass open the way for past environmental studies using micro-tephra to be carried out in areas such as the British Isles where tephra layers are composed of low concentrations of small shards.

The first finds of Icelandic volcanic ash in the British Isles were in peats from Caithness in northern Scotland (Dugmore 1989). The geochemistry of the ash proved it to be from an eruption of the volcano Hekla known as Hekla 4. This evidence that Icelandic volcanic glasses could be found in organic deposits prompted similar investigations throughout the northern British Isles. We now know that tephra is present in Holocene peats and lake deposits in Scotland, Shetland, the north of England and Ireland (Blackford *et al.* 1992; Bennett *et al.* 1992; Pilcher and Hall 1992; McVicker 1993; Hanna 1993; Hall *et al.* 1993; 1994). This paper is based on Holocene tephra studies in Ireland; sites where tephra layers have been found are shown in Figure 1.

There is a growing interest in finding tephra in deposits throughout the British Isles, including areas well to the south of those where tephra layers have been found to date. We would encourage such investigations and hope that our experience in handling a range of deposits containing various tephra types will reduce the pit-falls and frustrations of which we have extensive experience!

Tephra preparation techniques for optical and electron microscopy

The basic technique for preparing tephra samples for optical and electron microscopy is given by Pilcher and Hall (1992) with the

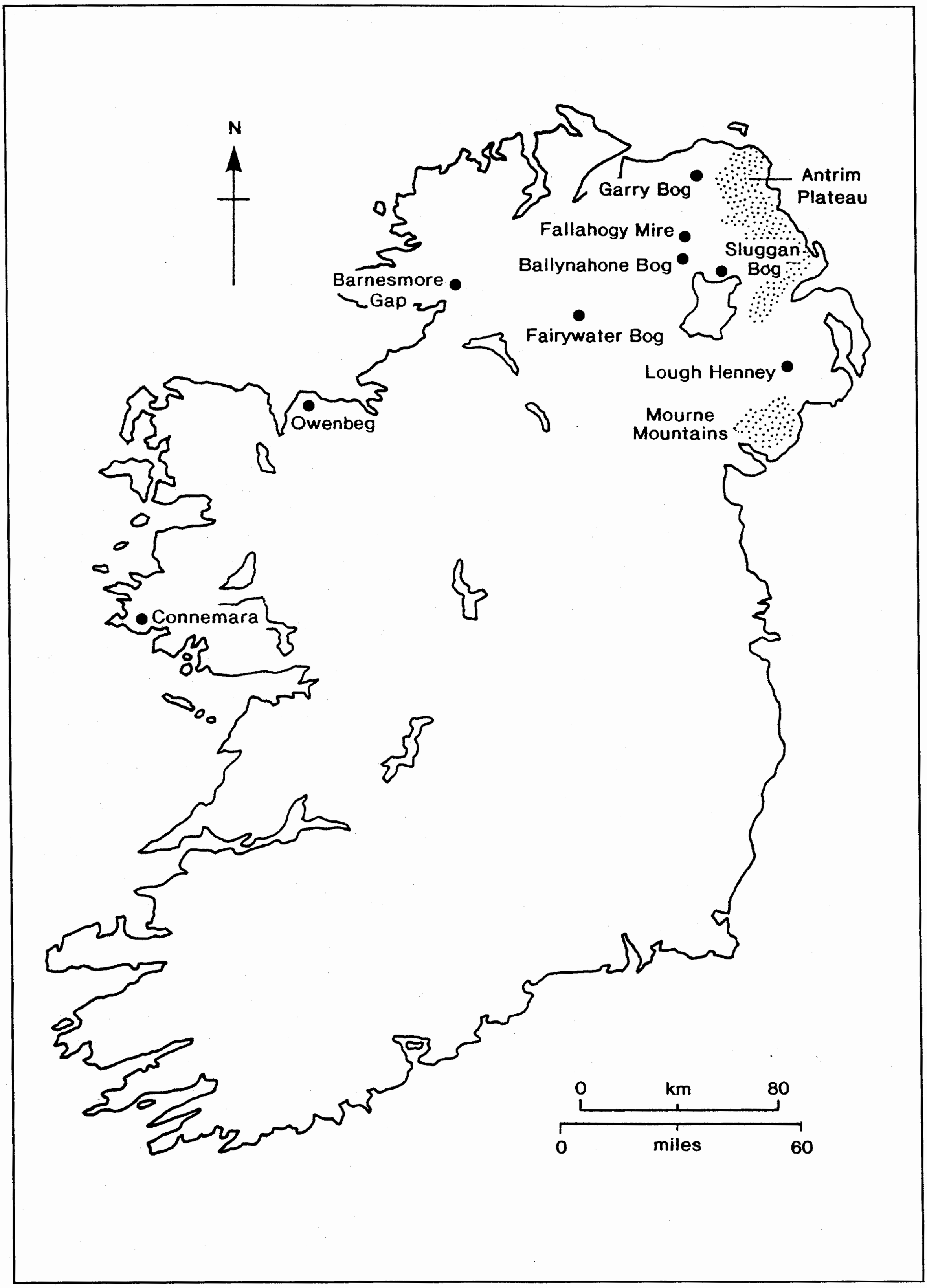

Figure 1. Sites in Ireland at which tephra layers have been found

following refinements recommended when assessing upland peats or lake muds.

Lake muds (such as those we have examined from the interdrumlin lake Lough Henney) include small amounts of tephra but considerable amounts of clay and diatoms. Upland peats (for example those from the Mourne Mountains) contain particles of quartzose granite and biogenic silica in addition to tephra shards. The presence of these inclusions makes finding tephra more difficult. For both types of sediment, careful sample preparation is vital if layers which are represented by relatively few tephra shards are to be found.

Samples prepared by combustion and removal of the soluble fraction of the ash will still contain varying amounts of inorganic debris but we suggest that this simple approach is tried first as it allows tephra size ranges and any contamination to be assessed. In general, one wash in cold 10% hydrochloric acid (HCl) is sufficient to dissolve the soluble ash fraction of lowland peat samples, but the upland material may require repeated washing in hot 10% HCl. The upland peats contain much insoluble material, both fine and large, the amount of which may be reduced by washing on precision woven polyester mesh of an appropriate aperture. Choice of mesh size depends both on the size range of the tephra shards and the size range of debris to be removed. Material which is easily recognised as tephra usually ranged from 20-80 micrometers. We use 75 micrometre mesh to discard the large fraction of the matrix and 10 micrometre mesh is ideal for removing fine particles, especially from recent lowland raised bog peats contaminated by inblown soils and from ancient peats containing small inwashed particles.

Upland peats are treated more drastically. The large amounts of debris in these samples makes optical microscopy tedious, so more of the fine fraction of the matrix is removed by washing on 24 micrometre polyester mesh. Doubtless some loss of tephra occurs, but this is more than compensated for by the relative ease with which analyses can be performed.

Lake deposits require further preparation, especially where the inorganic matrix contains clays and diatoms. If lake sediments with a high clay content are burnt, all that is left is a small piece of baked clay. Lake mud samples should thus first be suspended in distilled water and the clay fraction removed by washing on 10 micrometre polyester mesh before combustion. Two or three treatments with HCl and possibly a further wash on 10 micrometre mesh produce a cleaner sample. Sample clarity is improved by removing as much of the fine fraction as possible but, as yet, there is no way of getting rid of the large numbers of diatoms which are of similar size to the tephra. Several slides from each sample may require examination if tephra is to be found.

For optical microscopy, the inorganic residue is dried on a warm slide before the addition of the mounting medium. At this stage the residue may also be mounted for electron microscopy. Placing an adhesive tab on to the surface of a metal stub or disc and then pressing this on to the inorganic residue on the warm slide is a most effective method of preparing samples for electron microscopy.

We find that the correct optical mounting medium makes all the difference between success and failure. Throughout our studies we have used Histomount synthetic mounting medium and viewed samples by plane-polarised light. A good mounting medium emphasises the tephra while polarised light distinguishes all of the crystalline components of the mineral residue. A word of encouragement to the aspiring tephra hunter at this point: do not be disheartened if first attempts appear to fail. It takes a little time to become adept at identification.

It may be necessary to determine the colour of some tephras under normal bright field illumination rather than plane-polarised light. Not all tephras are colourless and vesicular: some are flaky or coloured. For example, there is a layer of flaky, light brown volcanic glass above the Hekla 4 layer in the peats from Sluggan bog, Fallahogy bog and Ballynahone bog (Pilcher and Hall 1992). Peats from Garry Bog on the north Irish coast also contain this layer as well as a number of well-defined layers, the glass from which is tinged yellowish or pinkish brown. Preliminary investigations of peats recently collected from Counties Galway and Mayo show that in these samples, too, some of the glass is coloured. It should be noted that some layers contain more than one type of glass, differentiated by optical properties. We have observed one layer in recent peats from a number of lowland raised bog sites, for example, which contains both colourless and light brown bubbly tephra.

We emphasise that geochemical analysis is the most reliable method of establishing the 'finger-print' of a tephra layer. Ideally, tephra should not be identified with type material or other similar tephra layers solely on optical qualities. Many of the colourless, bubbly tephra layers in north-east Irish lowland raised bog and upland blanket peats look much the same, but electron microprobe analysis has shown them to vary chemically. The only really reliable method of linking layers within or between sites or linking layers to parent eruptions is through the specific chemistry of the glass. However, there will be occasions when chemical characterisation may not be possible, usually where the tephra shards are too sparse for electron microprobe identification. In such cases, the determination of the stratigraphical position of the tephra layer will be vital (Hall *et al.* 1994).

Tephra preparation techniques for wavelength dispersive electron microprobe analysis

It must be emphasised that samples prepared by combustion are not suitable for electron microprobe analysis. Our early investigations showed that, in tephra samples prepared from peats, potassium is adsorbed or annealed on to the shard surfaces during combustion (Hall *et al.* 1993). Samples for microprobe analysis must prepared by chemical degradation of the organic matrix (Dugmore *et al.* 1992).

We prepare samples for microprobe analysis from larger peat samples than those used for optical preparations. Choice of sample size comes with experience, but there is little point in using a large sample in an attempt to increase tephra concentration if the other inorganic components present are likely to obscure the material to be analysed.

Peats may be made into a slurry in distilled water, which is then washed onto polyester meshes to remove both the large and fine fractions of the peat. The washed fraction is transferred to a large conical flask in a fume cupboard to which is added first approximately 25 cm^3 of concentrated sulphuric acid (H_2SO_4) and then a few cubic centimetres of concentrated nitric acid (HNO_3). Nitrogen dioxide (NO_2) is produced and after this has subsided, the contents of the flask are heated until they become pale yellow. During heating a little more HNO_3 may be added from time to time. On cooling, this liquid is diluted in approximately 1000 cm^3 of distilled water and the mineral residue again washed thoroughly on a 24 micrometre polyester mesh. Some deposits require the acid degradation to be repeated. Others may be contaminated by oily spherules which can be dispelled by using xylene. The now clean mineral residue is dried on to a warm slide and then mounted in a bead of epoxy resin.

Wavelength dispersive analysis requires very well polished samples where the film of resin containing the tephra is only about as thick as the tephra shards, i.e. 15-20 micrometres. The sample is first ground using 600 carborundum grit, and then polished on laps using 14, 8, 3 and 1 micron diamond pastes. During grinding some of the shard surfaces will be exposed and these may provide samples suitable for electron microprobe analysis. Only a proportion of any sample of shards will be exposed, so it is essential that as high a concentration of shards as possible is mounted in the resin.

Tephrastratigraphies and tephrochronologies

The recently published replicated studies of tephrastratigraphy in lowland raised bogs in the north of Ireland (Pilcher and Hall 1992) show that tephra events occur throughout the Holocene but their frequency increases over the last 4000 years. Tephrastratigraphies (Thorarinsson 1981) are now giving birth to the powerful tool of tephrochronology. Where the date of the tephra event can be established it is now possible to refine greatly the dating of any deposit in which it is found. A tephrochronology for deposits which accumulated over this period will be of great use to the environmental archaeologist, especially when they are working on deposits unsuitable for isotopic dating techniques (McVicker 1993).

At the Palaeoecology Centre and Institute of Irish Studies at Queen's University, Belfast, a tephrochronology for the British Isles is being constructed by combining geochemical linkage to Icelandic volcanic ash type material of known historic date and high-precision multi-sample radiocarbon dating. The rapidly accumulating Irish lowland raised bog deposits are well suited to radiocarbon dating, more so than many Icelandic peats where tephra layers are very well represented.

Ash from the eruptions of Hekla in AD 1104 and of Oraefajokull in AD 1362 are now known to be present in lowland peats from Sluggan bog through geochemical linkage to historically dated Icelandic type material. The written record for volcanic activity on Iceland spans about the last one thousand years. The dates of eruptions occurring before that time are best established by high precision radiocarbon techniques. For example, a layer of tephra in peats from Sluggan bog which has been characterised geochemically, but not linked to any known Icelandic eruption, has been dated to AD 866 ± 20 by high-precision multi-sample radiocarbon dating. Details of the geochemistry and dating techniques employed are given by Pilcher *et al.* (1994). These layers form the basis for a tephrochronology of the last millennium and offer an alternative dating technique to radiocarbon dating where calibrated dates are virtually useless (Pearson *et al.* 1986).

One of the most geographically widespread tephra layers in Scottish and Irish deposits is that from the eruption of the Icelandic volcano Hekla, known as Hekla 4. This tephra forms an isochrone over a wide geographical area (Buckland *et al.* 1981) and has now been identified from sites as far apart as the Shetland Islands (Bennett *et al.* 1992) and Slieve Meelbeg in the Mourne Mountains (McVicker 1993; Hall *et al.* in press), as well as from peats from the Faroe Islands and Scandinavia (Persson 1971). High-precision multi-sample radiocarbon dating of Irish lowland raised bog peats containing Hekla 4 tephra has provided the tight calendar date range of 2310 ± 20 BC for this event (Pilcher *et al.* 1994). Hekla 4 tephra now forms a well-dated marker in Holocene deposits throughout the north-east Atlantic seaboard.

The occurrence of geochemically characterised and dated tephra layers has been of great value in recent palynological studies of a range of deposits throughout the northern British Isles. For example, recently published papers on the palynology of deposits in which Hekla 4 tephra has been detected have examined the possible impact of the eruption products on local vegetation (Bennett *et al.* 1992; Blackford *et al.* 1992; Hall *et al.* 1994; McVicker 1993; Hanna 1993; Hall *et al.* in press). This is an area of research of growing interest as palynologists investigate the influence of distant past volcanic activity on vegetation.

The calibrated radiocarbon date of 2310 ± 20 BC for Hekla 4 allowed the vegetation history of two of the north Irish lowland raised bog sites to be compared with the climatic signal in the sub-fossil oak tree-ring chronology (Hall *et al.* 1994). A similar approach was used to compare the palynology of more recent evidence for woodland clearance and the development of regional agriculture with the dendrochronological record (Hall *et al.* 1993). This is a most exciting advance in interdisciplinary palaeoenvironmental studies which have been bedeviled by the problem of the lack of comparative dating strategies.

The microtephra layers present in the Mourne Mountain upland peats have proved to be valuable isochrones (Buckland *et al.* 1981, McVicker 1993). In addition, comparative tephra-linked palynological investigations of a lowland raised bog peat (Sluggan bog), an upland blanket peat (Slieve Meelbeg) and a lowland lake deposit (Lough Henney) have been carried out as Hekla 4 tephra occurs in all three deposits (Hall *et al.* in press).

Micro-tephra layers are present in a number of terrestrial, lacustrine and marine deposits and are now being detected in the annual laminations of the Greenland ice-cores (Palais *et al.* 1992). Palaeoenvironmental studies will continue to benefit from refined chronological constraints as further correlations are established between ice-cores, organic deposits and proxy records for climatic change, such as tree-ring studies. The work of the archaeologist is vital in these investigations. In his 1992 paper, Keith Bennett emphasises the difficulties of separating any climatic response to volcanic activity from local human impact.

There is an increasingly large and well-illustrated literature on Holocene tephra studies in the British Isles. Papers include recent investigations on the stability and geochemistry of tephra (Dugmore and Newton 1992; Dugmore *et al.* 1992) and its environmental impact (Edwards *et al.* in press). Tephra-linked palaeoenvironmental studies are published in such journals as *The Holocene, Nature* and *Journal of Quaternary Science.*

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