Distal micro-tephra deposits in southeast Alaskan peatlands

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ABSTRACT

Volcanic ash (tephra) provides a valuable tool in palaeoenvironmental research. Traditionally, the main emphasis in tephra studies has been on layers which are visible to the naked eye. Recently a large body of work in Europe has been established investigating microscopic tephra layers. Microscopic methods have allowed a massive expansion of the known limits of tephra deposition; however, they have rarely been used elsewhere in the world. This report summarizes the first use of these methods in northwestern North America. Five peatland sites in southeastern Alaska were cored and analysed for tephra. A total of 14 significant layers were recovered, representing a minimum of 4 different tephras. While it is not yet possible to identify the source of these layers, these results are significant as they show that microscopic methods may prove a valuable tool enabling an expanded tephrochronology and a better understanding of volcanic impacts in the region.

RÉSUMÉ

Les cendres volcaniques (téphra) constituent un outil très utile pour la recherche paléo-environnementale. Jusqu'à ce jour, les études portant sur le téphra étaient surtout axées sur les couches visibles à l'œil nu. De nombreux travaux récents ont toutefois été réalisés en Europe sur les couches microscopiques de téphra. Ils ont permis de repousser les limites connues du dépôt des téphras, mais ces méthodes microscopiques ont été peu utilisées ailleurs dans le monde. Le présent rapport résume la première utilisation de ces méthodes dans le nord-ouest de l'Amérique du Nord. On a prélevé des carottes dans cinq tourbières du sud-est de l'Alaska que l'on a analysées pour leur teneur en téphra. On a ainsi récupéré 14 couches significatives, représentant 4 téphras différents. Même s'il n'est pas encore possible d'identifier la source de ces couches, les résultats sont importants dans la mesure où ils montrent que les méthodes microscopiques peuvent s'avérer un outil valable pour perfectionner la téphrochronologie et mieux comprendre les impacts volcaniques sur la région.

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INTRODUCTION

Volcanic eruptions produce large amounts of pyroclastic material; the finest fraction of this tephra may remain airborne for some time and be deposited over a large area. Tephra has been widely used in palaeo-environmental studies as it provides a time-specific marker horizon (isochrone). This allows age comparison between sites and, where the age of the tephra is known, a means of dating sediments. Tephrochronology has been used for over a century, particularly in areas close to volcanic source regions such as Iceland and New Zealand. In these areas, tephra layers are significant and readily identifiable by eye. More recently, methods have been developed which allow the use of tephrochronology in areas considerably more distant from the source regions. A large amount of recent research in this field has been devoted to investigating the distal deposition of tephra from Iceland in northern Europe. Since microscopic tephra layers were first found in Scotland by Dugmore (1989), similar methods have been employed to find Icelandic tephra in locations as distant as northern England, Ireland, Germany and western Scandinavia (Pilcher and Hall, 1992, 1996; Van den Bogaard et al., 1994, Wastegård et al., 2000, 2001). The methods employed here allow for the potential to expand tephra study in other areas of the world where only visible layers have been recognized. This could increase both the geographic range of known tephra deposition and the temporal extent, increasing the number of isochrones at any one site. This would allow an expanded potential for tephrochronology, as well as a better understanding of the spatial impacts of these eruptions.

Alaska contains over 100 volcanoes which have been active within the Quaternary, perhaps 8% of all active above-water volcanoes on earth (www.avo.alaska.edu, Alaska Volcano Observatory, October, 2003). The majority of these volcanoes are located in the Aleutian arc although other volcanic systems occur in the Wrangell Mountains, southeastern and interior Alaska. The visible tephra deposits of these eruptions have been studied throughout much of Alaska and Western Canada (e.g., Riehle, 1985; Begét et al.; 1992; Robinson, 2001). To date, no studies have investigated micro-tephra deposits from these volcanoes. There is therefore great potential to expand the study of tephrochronology in the region.

TEPHROCHRONOLOGY OF PEATLANDS

Peatlands make particularly good media for studying tephrochronology at a high resolution. The wet and well vegetated surfaces of bogs are efficient at trapping atmospheric particles, and tephra particles undergo minimal alteration in the low energy and acidic environment of peat (Zoltai, 1988; Dugmore et al., 1992). In addition, the continuous accumulation of peat in bogs allows long-term tephra histories to be established, the high organic content of peat makes extraction straightforward, and peat provides a good medium for radiocarbon dating.

The aim of this study is to use microscopic methods to establish the presence of micro-tephra deposits in an area which does not have a well-established tephrochronological record. The area chosen is southeastern Alaska; this region has the dual advantages of numerous suitable peatlands and a sufficient proximity to volcanic systems to make the presence of micro-tephras probable.

SITES

Five suitable peatland sites were identified in the Juneau and Haines areas (Fig. 1). All sites are Sphagnum-dominated and largely ombrotrophic (all nutrients

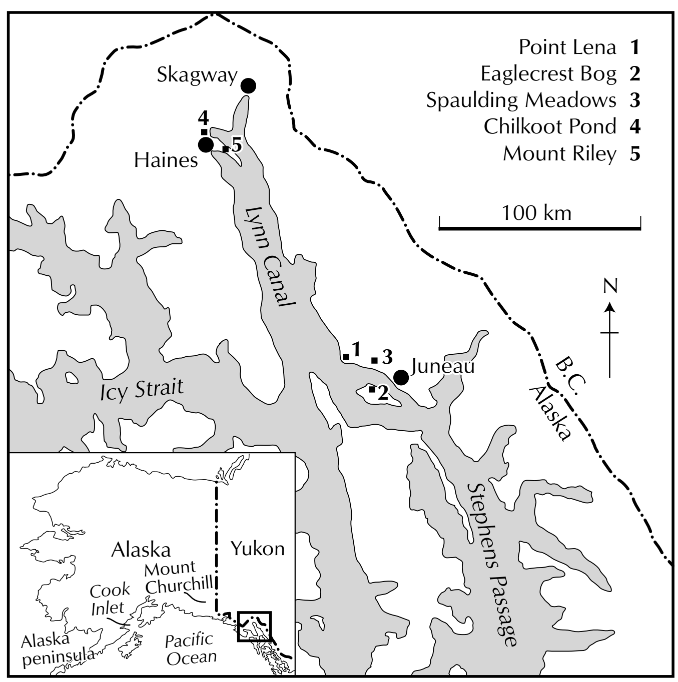

Figure 1. *Tephra sample sites (small, solid squares) in southeastern Alaska, and possible source regions (inset).*

supplied by precipitation). The sites include a range of peatland types including raised bog (Point Lena), upland blanket bog (Mount Riley, Spaulding Meadows), an intermediate site (Eaglecrest Bog), and a lake infill peatland (Chilkoot Pond). Further details of the structure and vegetation of the sites can be found in Payne (2003) and the references therein.

TEPHRA METHODS

The sites were repeatedly sampled (over five times) with a 4-cm-diameter auger to find the maximum depth of peat. A core was extracted from this deepest location using a Russian corer with a 5-cm-diameter, 50-cm-long chamber (Barber, 1984; Aaby and Digerfeldt, 1986). Extracted cores were placed in plastic gutter tubing and wrapped in plastic, the corer was cleaned after every core taken. Twin adjacent cores were taken and cores were overlapped by 5 cm using two separate boreholes for each core. A monolith was extracted from the surface where the peat was not solid enough to allow coring. The cores were packaged and returned to the United Kingdom for analysis in the laboratory.

A slightly modified version of the ashing method of Pilcher and Hall (1992) was used for tephra extraction. This method is quick and effective, however it is known to change the geochemical composition of tephra shards and is not suitable for sample preparation for geochemical analyses. Initially, contiguous 5-cm-diameter samples were sampled, oven dried and weighed. The dried peat was burned at 550°C and reweighed; the difference between these weights was used to calculate loss-on-ignition, used as an aid to rapidly locate the largest tephra layers. The residue remaining after burning was centrifuged for 5 minutes in 5 cm^3 of HCl at 3000 RPM. Following Caseldine et al. (1998), a Lycopodium inoculum was added in this stage to allow a quantitative count of tephra shards. The supernatant was then decanted off, 5 cm^3 of distilled water was added and the sample was centrifuged again. Finally, the supernatant was again decanted, 5 cm^3 of methanol added and centrifuged. The sample was transferred to a glass vial and the methanol left to evaporate. Slides were made up by mixing a drop of the final solution with glycerol. Tephra shards could then be located, described and counted under a microscope at 400x magnification. Where tephra was found to be present, the 5-cm sample was subdivided at 1-cm intervals to locate the zone of peak tephra concentration. The maximum tephra concentration in this 1-cm sample is shown in Table 1. This 1-cm sub-sampling stage was not carried out for one layer from the Spaulding Meadows site due to damage to the core in the intervening period.

RESULTS

A total of 14 significant tephra layers have been found in the 5 sites (Table 1, Fig. 2). All the tephra layers consist of small shards of volcanic glass, reaching a maximum of about 100 μm in length. Varying proportions of vesicular, columnar and platy shards are present; however this variation is insufficient to allow correlations to be made on the basis of appearance. For the rest of this paper the individual tephra layers are referred to by a code for their site followed by the depth of peak concentration. For instance, LNA39 refers to the layer at 39-cm depth in the Point Lena site.

DATING THE SEQUENCES

Preliminary radiocarbon dating has been performed on the cores. Bulk samples of approximately 1 cm^3 were submitted to the Natural Environment Research Council Radiocarbon Laboratory, East Kilbride, for AMS (accelerator mass spectrometry) radiocarbon dating. Dates were obtained from near the base of all the cores, with additional dates from near the middle of the longer Eaglecrest Bog and Point Lena cores. The raw radiocarbon dates were calibrated using the OXCAL program (Ramsey, 2002). The most probable 2σ calibrated age ranges and their mid-points are presented in Table 2.

The ages of the tephras have been inferred (Table 1) using the calibrated ages in Table 2. A constant, linear accumulation rate has been assumed and ages estimated based on the nearest available radiocarbon date. Studies have shown that while over a long period, peat bog accumulation rate may approximate to linear, there is considerable variation (Aaby and Tauber, 1975). It therefore seems likely that the real ages of these layers may differ from those estimated here by a substantial degree, and these estimates should be treated with considerable caution. It is likely that the errors will be greatest for the youngest tephra deposits, nearer to the top. This may be particularly the case for the tephras in the uppermost 50 cm due to accumulation rate differences between the acrotelm and catotelm (surface peat and relict peat). Age estimates for those tephras which are located adjacent to the dating points are likely to be more accurate, such as tephras MTR190 and

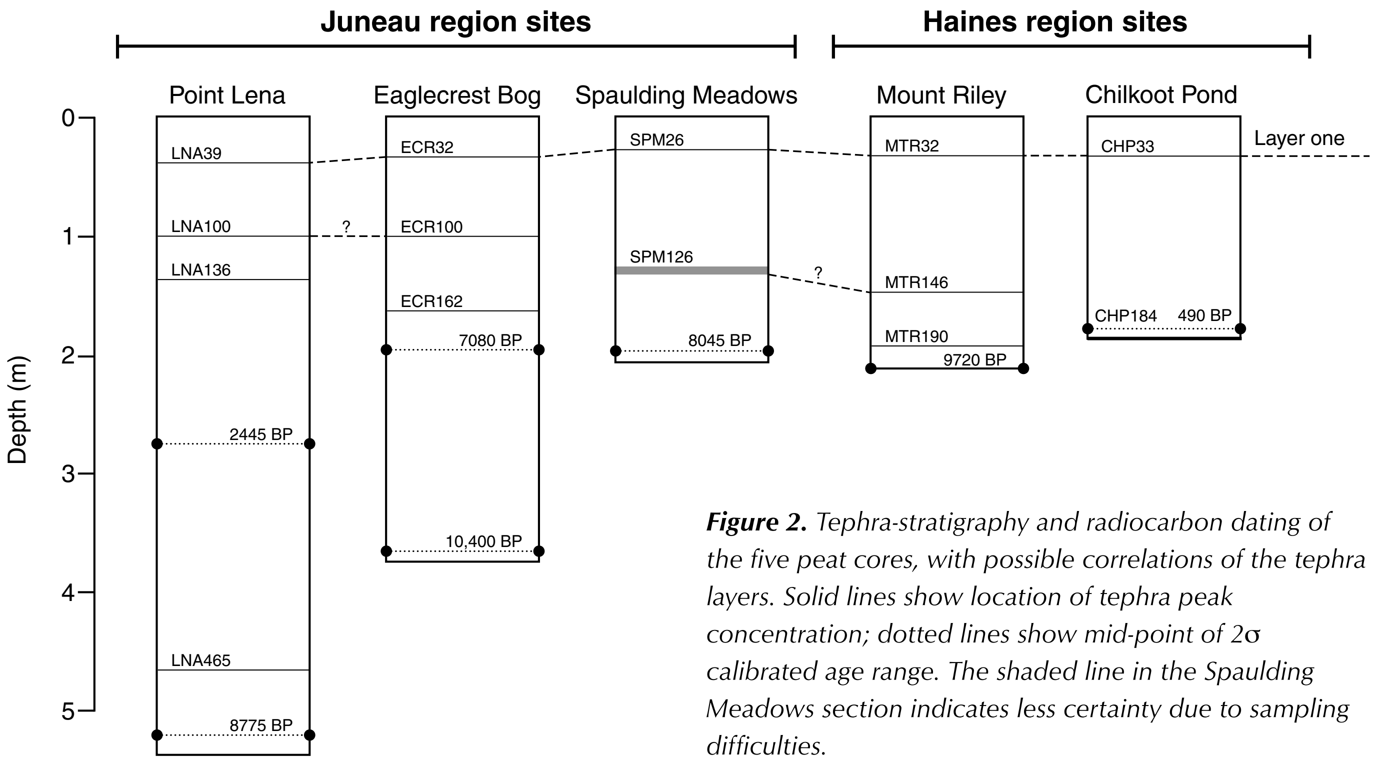

Figure 2. *Tephra-stratigraphy and radiocarbon dating of the five peat cores, with possible correlations of the tephra layers. Solid lines show location of tephra peak concentration; dotted lines show mid-point of 2σ calibrated age range. The shaded line in the Spaulding Meadows section indicates less certainty due to sampling difficulties.*

Table 1. *Tephra layer characteristics and inferred age estimate (see notes in text).*

Site name	Depth (cm)	Approximate maximum concentration (shards/gram)	Description	Age estimate (BP)
Mount Riley	32-33	2.7 x 10^4	Sparse layer. Small vesicular + columnar shards, 80% between 25-50 µm	1504
	146-147	1.6 x 10^4	Sparse layer. Shards vesicular mostly 50-75 µm	6780
	190-191	2.8 x 10^4	Sparse layer. Small highly vesicular shards, 80% below 50 µm	8816
Spaulding Meadows	26-27	1.7 x 10^6	Vesicular + columnar shards, mostly (60%) 50-75 µm	1067
	126-131	Unknown	A minor layer. More detailed description and accurate location not possible due to damage to core	5216-5376
Point Lena	39-40	2.9 x 10^6	Vesicular shards, 70% between 25-50 µm	351
	100-101	6.7 x 10^6	Shards mostly vesicular, 60% between 25-50 µm	893
	136-137	2.7 x 10^4	Small vesicular shards, most under 50 µm	1213
	465-466	8.9 x 10^3	Very sparse layer, much non-tephra mineral material. Shards vesicular generally less than 50 µm	7855
Eaglecrest Bog	32-33	1.9 x 10^6	Mostly vesicular shards with some columnar. Many (40%) above 50 µm	1179
	100-101	5.2 x 10^4	Sparse layer, much non-tephra mineral material. Vesicular shards with some platy and columnar. 80% between 25-50 µm	3648
	162-163	2.3 x 10^4	Small platy/vesicular shards, mostly <50 µm. Much non-tephra	5900
Chilkoot Pond	33-34	6.7 x 10^5	Mostly vesicular shards, 50% between 25-50 µm	N/A
	184-185	2.2 x 10^6	Numerous large vesicular/columnar shards, over 70% above 50 µm	N/A

Table 2. *Radiocarbon dates and calibrations.*

Laboratory code	Site	Depth (cm)	^{14}C date BP	2σ calibrated age range (BP)	Mid-point of calibrated age range (BP)
SUERC-564	Mount Riley	210	8688 +/- 65	9910–9530	9720
SUERC-565	Chilkoot Pond	175	468 +/- 55	560–420	490
SUERC-566	Spaulding Meadows	196	7207 +/- 53	8160–7930	8045
SUERC-567	Eaglecrest Bog	195	6183 +/- 56	7250– 6910	7080
SUERC-568	Eaglecrest Bog	365	9244 +/- 49	10,560–10,240	10,400
SUERC-569	Point Lena	275	2423 +/- 51	2550–2340	2445
SUERC-570	Point Lena	520	7919 +/- 83	9010–8540	8775

ECR162 (Fig. 2). The basal radiocarbon date from the Chilkoot Pond site is considerably younger than expected. This may be because the site represents lake infill. If the peat deposit developed as a schwingmoor (floating mire), accumulation would not be expected to be linear. It is therefore not possible to use this date to estimate the age of the CHP33 and CHP184 tephras.

TEPHRA CORRELATION

The only reliable method to compare tephra records between sites and to determine their source eruption is through examination of tephra geochemical composition by electron microprobe analysis. This is not yet complete for these tephras. However, in the absence of this data it is still possible to make some inferences based on the stratigraphic position and radiocarbon-based age estimates presented here. The very similar depths of the LNA39, ECR32, SPM26, MTR32 and CHP33 tephra layers would seem to strongly indicate that these are the same tephra (Fig. 2). There are significant differences between the inferred age estimates for these layers, ranging between 351 and 1504 BP. However, as noted previously, the irregularity of peat bog accumulation rates, combined with differences in accumulation rate between acrotelm and catotelm, imply that there would inevitably be particularly high errors in these estimates. Given the highly probable correlation of these five tephra layers, they are collectively denoted as 'Layer one' on Figure 2. It is interesting to note that this layer has a significantly greater shard concentration in the Juneau sites than the Haines sites; this could indicate a southern source.

Other layers which show some degree of similarity in stratigraphic context are SPM126 and MTR146 (both around 6000 BP) and ECR100 and LNA100 which differ markedly in dating but occur at an identical depth in nearby sites. It seems probable that the majority of these tephras occur in several of the sites; however the data here are inadequate to determine the exact correlations.

POSSIBLE SOURCES OF THE TEPHRA

At this stage it is not possible to reach any definite conclusions about the origins of these tephras. Given the relatively large (albeit microscopic) size of some of the layers, it seems most probable that the majority of the layers originate from relatively nearby volcanoes, probably in the Wrangell volcanic field or possibly Mount Edgecumbe near Sitka. It would seem likely that the products of large proximal eruptions, such as those forming the White River Ash, could have traveled as far as these sites. However, it also seems feasible that tephra could be transported to the site from distant sources such as the volcanoes around the Cook Inlet and Alaska Peninsula, possibly even the Cascade Range, British Columbia, Washington and Oregon. The recent micro-tephrochronology research conducted in Europe shows that tephra can be transported long distances (1200 km and more), and the prevailing winds are in the correct direction for tephra from the Alaska peninsula to be transported to these sites.

The most significant tephra layer found is that designated 'Layer one', found in all of the sites. The youngest inferred age estimate for this tephra is 351 BP for the LNA39 layer; it is possible that the layer may actually be younger. Richter et al. (1995) discussed a 1784 AD eruption of Mount Wrangell; this eruption is from a source relatively near the sites and within the right age range. However, given both the uncertainties in dating the layer and the poorly known volcanic history of the region, it is impossible to have sufficient confidence to attribute any single source. If the LNA100 and ECR100 layers do correlate, they could be assumed to be in the order of 1000 years old. This might put them in the right age range to be from the ca. 1147 BP eruption of Mount Churchill, the source of the White River Ash (eastern lobe; Clague, et al. 1995). The size and proximity of this eruption would strongly suggest that it could be found in these sites. The uncertainty in dating other tephra layers means that it is futile even to speculate on their possible sources.

IMPLICATIONS

This work is not yet complete and these preliminary results can tell us little about the actual distribution of products from specific eruptions, in the absence of electron microprobe data. However, the results are highly relevant to the study of tephrochronology in Alaska and Western Canada. This study has shown that microscopic analysis can reveal the presence of tephra layers in areas where none were previously recorded. This, therefore, allows the potential to greatly expand the distribution of many Holocene tephra layers, increasing the spatial and temporal utility of tephra for dating and correlating sediments. It seems probable that the same methods applied in other areas of Alaska, the Yukon and British Columbia would similarly reveal the presence of previously unrecorded micro-tephra layers. This is additionally relevant as some palaeoecological work has suggested that even micro-tephra layers as small as these may be associated with ecological impacts (Blackford et al., 1992; Dwyer and Mitchell, 1997). Expanding the limits of tephra distribution, therefore contributes to a more complete understanding of the impacts of eruptions in the past and the potential impacts of those in the future.

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