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Spatial variability of tephra and carbon accumulation in a Holocene peatland

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ABSTRACT

Microscopic tephra layers ('cryptotephras') represent important age-equivalent stratigraphic markers utilised in many palaeoenvironmental reconstructions. When used in conjunction with proximal records of volcanic activity they can also provide information about volcanic ash cloud fallout and frequency. However, the spatial distributions of tephra layers can be discontinuous even within the same region. Understanding the deposition and post-depositional redistribution of tephra is vital if we are to use cryptotephras as records of ash cloud occurrence and chronostratigraphic markers. The discrete nature of tephra layers also allows for detailed study into processes of deposition and reworking which affect many palaeoenvironmental proxy records.

We undertook a multi-core study in order to examine the historical tephrostratigraphy of a raised peatland in Northern Ireland. Three tephra layers originating from Iceland (Hekla 1947, Hekla 1845 and Hekla 1510) are present in 14 of the 15 cores analysed. This suggests that in areas not influenced by snowfall or anthropogenic disturbance at the time of tephra delivery, the presence or absence of a tephra layer is generally consistent across a peatland of this type. However, tephra shard counts (per unit area) vary by an order of magnitude between cores. These intra-site differences may confound the interpretation of shard counts from single cores as records of regional ash cloud mass/density. Bootstrap resampling analysis suggests that total shard counts from multiple cores are required in order to make a reliable estimate of median shard counts for a site. The presence of three historical tephras in 14 cores enables a spatio-temporal analysis of the long-term apparent rate of carbon accumulation (LARCA) in the peatland. Substantial spatial and temporal variations in LARCA are identified over the last ~450 years. This high variability needs to be taken into account when designing studies of peatland carbon accumulation.

1. Introduction

Tephra layers preserved in European peatlands provide both a valuable geochronological tool (e.g. Davies, 2015; Dugmore et al., 1995; Lane et al., 2013) and a record of past volcanic activity and ash dispersal events (Swindles et al., 2011b). Tephra deposited onto a peat surface far from the volcanic source is typically fine-grained (<125 μm in size) and accordingly called 'cryptotephra'. It is mostly considered to be primary air fall material (Davies et al., 2007; *contra* Swindles et al., 2013a) and is not thought to be subject to the vigorous reworking processes in the water column and/or the soft sediment which may distort tephra records in lacustrine and marine sediments (Davies et al., 2007; Griggs et al., 2014; Pyne-O'Donnell, 2011). Although tephra layers in peatlands can occasionally span a depth of a few centimetres, the peak is most often confined to a narrow horizon in thickness (Swindles and Plunkett, 2011). These factors suggest that peatlands should act as an excellent archive of past volcanic ash fallout, and that peat records can be used to map the spatial distribution of past fallout events on a continental scale (Swindles et al., 2011; Lawson et al., 2012).

One major issue with this approach is that cryptotephra layers in peatlands can be discontinuous even over small distances

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Abbreviations: TSC, total shard count per unit area the total number of tephra shards relating to a given eruption per unit area; LARCA, long-term apparent rate of carbon accumulation; ATCA, apparent total carbon accumulation.

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(hundreds of metres to kilometres: (Bergman et al., 2004; Langdon and Barber, 2004)), which requires an explanation. At a regional scale some spatial variation in tephra horizons can be attributed to fluctuation of the volcanic plume height during the eruption, wind speed and direction variability, atmospheric processes (e.g. clouds and ice) and precipitation (Fig. 1), which can influence ash cloud density (Schumann et al., 2011), alter ash cloud trajectory and in the case of rainfall, increase the fallout of particles (Mattsson and Vesanen, 1988). At a local scale, the interaction of wind and vegetation may produce localised airflow patterns which result in the uneven delivery of tephra to the ground surface (Boygle, 1999; Pouget et al., 2014).

Even once the tephra has been deposited on the peat surface, the peat is unlikely to act as a straightforward, passive archive. Peatlands are complex ecosystems with dynamic topography, hydrological regimes, accumulation rate and vegetation composition (Swindles et al., 2012). Therefore peatland processes are likely to exert some control over the redistribution of tephra (and other paleoenvironmental proxies) both vertically and laterally, across the peatland surface (Fig. 1) – albeit probably to a lesser extent than in lacustrine or marine environments.

Previous studies of regional tephra occurrence have focused predominantly on single cores from different sites (Langdon and Barber, 2004). Inconsistent tephra records in two cores from Klocka bog, Sweden, suggest that tephra occurrence may vary at much smaller scales. In this instance tephra fell onto a prolonged snowpack (ca. 7 months) and was subsequently re-dispersed by wind and meltwater, leading to intra-site variation (Bergman et al., 2004). The majority of Holocene European tephra studies have been carried out in mid-latitude peatlands (Lawson et al., 2012), which are less likely to have been affected by prolonged snow cover. A study of two cores from Fallahogy bog in Northern Ireland comparable to the study by Bergman et al. (2004) found much less within-site dissimilarity, raising the possibility that, where prolonged snow cover is rare, tephra stratigraphies may be more consistent (Rea et al., 2012).

Tephra shards are commonly counted in order to determine the depth of peak shard concentration in the vertical profile. Recently, these counts have been used to infer ash cloud fallout over a region (Rea et al., 2012). Understanding the spatial variation in tephra shard concentrations in peatlands is important if it is to be assumed that they represent a record of ash density during an eruption event (Davies et al., 2010). The assumption that reworking has a negligible impact on total tephra shard counts within a given layer, and therefore that tephra shard counts represent a record of ash cloud density, is fundamental when attempting to use counts from one core per site to compare ash cloud fallout across many sites in a region (e.g. Langdon and Barber, 2004; Rea et al., 2012).

The main aim of this study is to assess the spatial variability in the total number of tephra shards relating to a given eruption and carbon accumulation across multiple cores from one site and to consider the implications for the interpretation of results from single core studies.

1.1. Tephra preservation in peatlands

Much of our current understanding of tephra preservation in peatlands is based on experimental evidence rather than detailed study of naturally-deposited tephra. Laboratory and artificial field experiments indicate that although the majority of tephra shards remain at the palaeo-surface during incorporation into the peat matrix, some migrate vertically (both upward and downward) (Payne and Gehrels, 2010; Payne et al., 2005). This would support the common assumption that the peak in tephra shard concentrations, rather than the first occurrence of shards, coincides with the timing of the ash fall event.

Shards are also likely to move laterally across a peatland on a variety of scales. Tephra shards may be deposited differently and/or moved to such an extent that the number of shards in some areas of the peatland becomes too low to be detected and analysed using current methods (Payne and Gehrels, 2010). Our understanding of cryptotephra redistribution on peatlands extends only to the lateral movement of tephra by wind at microtopographical scales. Experiments suggest that only a small proportion of tephra is transported over the short distance (<3 m) from hummock to hollow (Payne and Gehrels, 2010). There is evidence that tephra may move at even smaller scales (a few centimetres or less). Simulated rainfall onto thin (1 mm) tephra layers has been shown to generate patches of high and low tephra concentration across a peat surface (Payne and Gehrels, 2010). These experiments suggest that reworking does occur at small scales, but they do not address the possibility of tephra shard movement at larger scales (metres, to hundreds of metres).

Although these studies offer valuable information on the reworking on tephra in peatlands, they are experimental and represent both a simplification of reality and a compression of time. Evidence from naturally-deposited tephras which have been subject to peatland processes over a period of hundreds of years is needed to understand the interaction and overall impact of these processes on tephra redistribution in 'real world' scenarios.

Research into the spatial variation of other palaeoenvironmental proxies found in peatlands, specifically pollen and charcoal, suggests that two or more cores taken in close proximity usually display the same general trends in reconstructions but show minor differences which might affect detailed interpretation (cf. Edwards, 1983; Innes et al., 2004; Lawson et al., 2005; Turner et al., 1989). The resolution of these studies is restricted by the dating methods available. In a more recent study, Blaauw and Mauquoy (2012) used wiggle-match radiocarbon dating, which offers a more precise chronological framework, and identified variation in arboreal pollen records from four cores across the same peatland over centennial timescales, although trends were more consistent over millennial timescales. Within-site variation in peatland proxy records over centennial timescales may limit the temporal resolution of palaeoenvironmental studies.

Unlike palaeoecological proxies, historical tephra layers are unique in representing a discrete depositional event rather than a continuous influx, allowing for easier identification of reworking processes (Housley et al., 2013). By improving our understanding of the deposition and redistribution of tephra layers, we will also gain insights into how other palaeoenvironmental proxies may be reworked as they enter the stratigraphic record (cf. Irwin, 1989; Turner et al., 1989).

1.2. Carbon storage in European peatlands

Peatlands represent an important global carbon store and as such the accumulation of carbon in peat has been the focus of large-scale studies (e.g. Charman et al., 2013; Turunen et al., 2004; van der Linden et al., 2014). Although regional climate is often the major control on carbon accumulation rates (Magnan and Garneau, 2014), internal peatland processes can also exert an influence. Spatial differences in carbon accumulation within a peatland could lead to unrepresentative estimates based on one core being extrapolated over a large area.

There has been only limited investigation into variation in long-term apparent rate of carbon accumulation (LARCA) within one peatland site, the majority of studies focussing on high-latitude peatlands (e.g. Belyea and Clymo, 2001; Ohlson and Økland, 1998; Turunen et al., 2004). For example, Turunen et al. (2004)