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Rapid communication

High-precision ultra-distal Holocene tephrochronology in North America

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A B S T R A C T

Far-travelled volcanic ashes (tephras) from Holocene eruptions in Alaska and the Pacific northwest have been traced to the easternmost extent of North America, providing the basis for a new high-precision geochronological framework throughout the continent through tephrochronology (the dating and correlation of tephra isochrons in sedimentary records). The reported isochrons are geochemically distinct, with seven correlated to documented sources in Alaska and the Cascades, including the Mazama ash from Oregon (~7600 years old) and the eastern lobe of the White River Ash from Alaska (~1150 years old). These findings mark the beginning of a tephrochronological framework of enhanced precision across North America, with applications in palaeoclimate, surface process and archaeological studies. The particle travel distances involved (up to ~7000 km) also demonstrate the potential for continent-wide or trans-Atlantic socio-economic disruption from similar future eruptions.

1. Introduction

Tephrochronology is a geochronological technique which uses volcanic ash layers (tephras) as time-parallel horizons (isochrons) with which to link sedimentary archives (Alloway et al., 2007; Lowe, 2011). Such isochrons are often geochemically distinct and are deposited virtually instantaneously in geological terms, thereby providing highly precise correlations which are largely free of many of the contextual uncertainties associated with conventional dating techniques (Telford et al., 2004; Lowe et al., 2007). In recent years the technique has been developed to exploit the ultra-distal component ('cryptotephras': <100 μm size) of ashes which are not observable in the stratigraphical record with the naked eye. The result has been a many-fold increase in detectable isochron range in a number of depositional environments (Davies et al., 2002; Mortensen et al., 2005; Lowe et al., 2008; Lowe, 2011; Davies et al., 2012). However, with the exception of a handful of studies from Alaska (e.g. Payne and Blackford, 2004, 2008; Payne et al., 2008) this technique has been an underutilised geochronological resource throughout North America. This study reports the detection on the eastern seaboard of a number of cryptotephra isochrons encompassing much of the Holocene and deriving from multiple North American sources. The findings demonstrate the potential of the technique as a high-precision geochronological tool which can be applied throughout the continent.

The study site, Nordan's Pond Bog (hereafter: NDN), is located in eastern Newfoundland (Fig. 1). It is a raised ombrotrophic bog with

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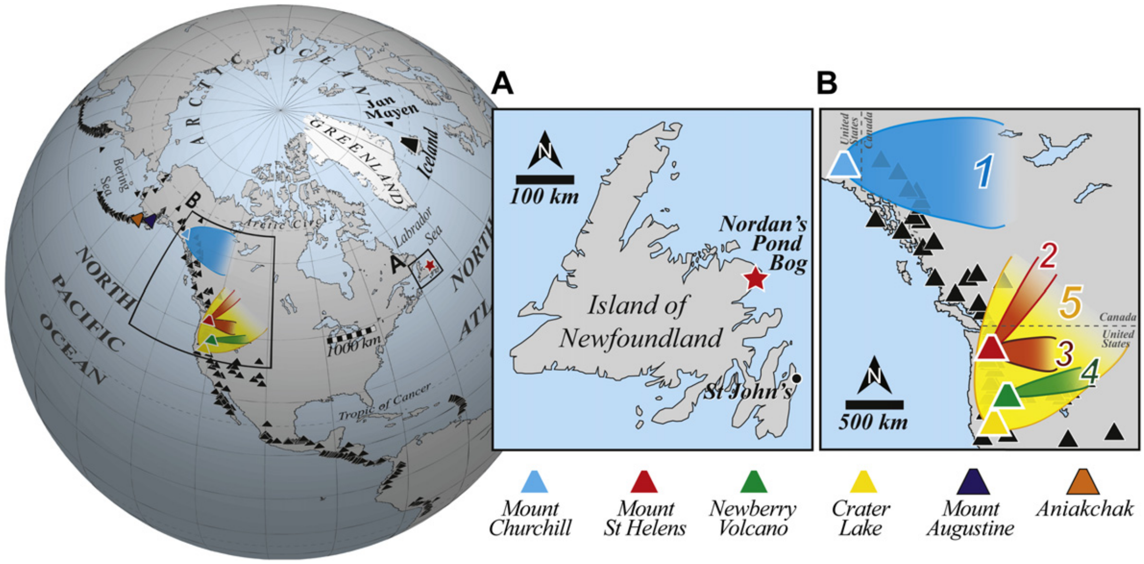

Fig. 1. (A) The location of Nordan's Pond Bog (indicated by red star: 49° 9′ 30″ N; 53° 35′ 50″ W) relative to a number of global volcanic sources (black volcano symbols) with documented Holocene eruptions, (B) proximal distributions of tephras detected at Nordan's Pond Bog: 1. White River Ash (eastern lobe) (Mount Churchill) (Lerbekmo, 2008); 2. Mount St Helens Wn (Sarna-Wojcicki et al., 1983); 3. Mount St Helens We (Sarna-Wojcicki et al., 1983); 4. Newberry Pumice (Kuehn, 2002; Kuehn and Foit, 2006); 5. Mazama ash (Crater Lake) (Sarna-Wojcicki et al., 1983).

a basal age of ~9000 cal yr BP (calibrated years before present). Field methods used in core collection and radiocarbon age model details are described in Hughes et al. (2006) and Daley et al. (2009). Isochron ages at NDN are interpolated from the age model of Daley et al. (2009). The nearest volcanic source areas are Iceland and Jan Mayen, ~2700–3400 km to the northeast, with nearest Cascade and Alaskan sources lying ~5000–6000 km to the west.

2. Methods

Cryptotephra-derived glass shards were extracted and concentrated from the core sediments by ashing the highly organic peats (Pilcher and Hall, 1992). More minerogenic basal intervals required additional stages, with sieving between 80 and 15 µm followed by heavy liquid flotation to separate rhyolitic shards from background sediments (Blockley et al., 2005).

Geochemical characterisation of NDN layers was conducted by electron probe microanalysis with wavelength dispersive spectrometry (WDS-EPMA) at the Tephra Analytical Unit, University of Edinburgh (Appendix A, Supplementary Information). Microprobe analytical details are outlined in the relevant table footnotes. Correlations with known eruptions were made by comparison with geochemical data from proximal reference analyses conducted at the Electron Microprobe Laboratory, University of Alberta (Appendix B, Supplementary Information). Some NDN layers analysed with the Edinburgh probe (NDN-95, NDN-185, NDN-300 and NDN-490) were found to be geochemically similar (e.g. Mount St Helens Wn and We, and the Newberry Volcano layers). Therefore, these were additionally analysed with the Alberta probe alongside proximal reference samples in order to negate inter-laboratory calibration issues (Kuehn et al., 2011). Both microprobe laboratories produced data sets that differed, in that P_2O_5 was measured at Edinburgh but not Alberta, and Cl at Alberta but not Edinburgh. Therefore, P_2O_5 and Cl were removed from the relevant data sets and the remaining oxide concentrations adjusted by normalisation for comparison purposes. Correlation strength between candidate and reference tephras was assessed by similarity coefficients (SC) (Borchardt et al., 1972) (Appendix C, Supplementary Information).

3. Results and discussion

Up to 12 discrete cryptotephras were detected throughout the stratigraphic sequence (Fig. 2) in an interval between ~545 cm and ~95 cm depth, with three (545 cm, 230 cm and 160 cm) being most prominent. Average shard size for all cryptotephras range from ~30 to 40 µm (Table 1). Shard morphology consists predominantly of clear glass which is often vesicular or bubble-walled with elongate flutes. Occasional platy and cuspate (Y-shaped) shards are present. Brown and blocky shards are also occasionally present. No pumice grains were observed. The predominant glass composition for each distinct cryptotephra is rhyolitic, with lesser quantities overlapping the dacitic-trachydacitic ranges. Basaltic-andesite and basaltic shards are also present, but rare. Each cryptotephra has a relatively homogeneous geochemical population with few outliers. Outliers likely represent deposition from atmospheric background since they are not consistent with other beds at the site or geochemical trends of correlated sources. Seven cryptotephra horizons are correlated with known eruptions as outlined below. Sample NDN-345 was not analysed because it had insufficient shards. Samples NDN-455, NDN-430, NDN-410 and NDN-365 were analysed but remain uncorrelated with known eruptions, and in the cases of NDN-430 and NDN-410 are also predominantly geochemically heterogeneous.

NDN-545 (~7300 cal yr BP). This deposit (Fig. 2) has the most abundant glass shards in the core and is correlated with the Mazama ash climactic event (SC: 0.98) (Bacon and Lanphere, 2006) from Crater Lake caldera (Cascade Range, Oregon) (Fig. 3). The Mazama ash has an age of ~7620–7470 cal yr BP (Hallett et al., 1997), whereas distal Mazama ash detected in the Greenland (GISP2) ice-core stratigraphy indicates an age of 7627 cal yr BP (Zdanowicz et al., 1999). Bounding radiocarbon dates (Table 2) are consistent with the Mazama age, but the NDN age model under-represents the age for the bed by ~300 years. This was one of the largest eruptions of the late Quaternary (estimated VEI 7: volcanic explosivity index), with up to ~50 km^3 of mainly rhyodacitic magma produced (Bacon and Lanphere, 2006). Deposits cover much of western North America, extending predominantly to the northeast (Fig. 1).