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A high-resolution tephrostratigraphy from Quoyloo Meadow, Orkney, Scotland: Implications for the tephrostratigraphy of NW Europe during the Last Glacial-Interglacial Transition

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ABSTRACT

Macro- and crypto-tephra layers deposited in European climate archives during the Last Glacial-Interglacial Transition (LGIT ca. 16–8 ka) have become increasingly important as a means to robustly correlate palaeoclimate records, and to test the spatial and temporal synchronicity of climatic transitions. However, correlations between climate archives are currently limited by the number of tephra-linkages that can be made. This disparity in the observed distributions of tephras may lie with methodological limitations relating to the resolution of cryptotephra refinement within palaeoclimate records. Here we present new data from Quoyloo Meadow, Orkney Mainland, Scotland, where nine tephra horizons and ten chemically distinct tephra populations have been identified and correlated to known eruptions during the LGIT. Three of the tephras; the Hässeldalen, Hovsdalur and the Fosen are characterised and placed into a reliable tephrostratigraphy for the first time in the British Isles. The detection of new tephra layers in this case is thought to reflect modifications to the sampling approach applied here. The resulting tephrostratigraphy is used to produce an age model with centennial-scale precision, providing new age estimates for three poorly dated tephras. The chronology rivals the output of more traditionally dated radiocarbon chronologies, and illustrates the potential for tephra to develop robust age-depth models for carbonate sequences.

1. Introduction

The development of methods leading to the detection, separation, and reliable chemical characterisation of cryptotephra layers in minerogenic sediments (Turney, 1998a; Blockley et al., 2005; Pearce et al., 2007; Tomlinson et al., 2010; Hayward, 2011) has significantly enhanced the potential to make robust correlations between palaeoenvironmental records of the Last Glacial-Interglacial Transition (LGIT, ca. 16 to 8 ka BP) (Davies, 2015). In Europe at least 56 discrete macro- and crypto-tephra layers of varying provenance and LGIT age have now been identified within terrestrial sediment archives. Over the past decade these records, along with tephras preserved in marine and ice-core archives, have been at the forefront of several key research initiatives, including; the 'Integrating Ice core, Marine, and Terrestrial records' (INTIMATE) group, and the 'Response of Humans to Abrupt Environmental Transitions' (RESET) project. Both ventures have prioritised the definition of regional European tephrostratigraphies, and furthered the development of pan-European tephra frameworks or 'lattices' (Lowe et al., 2008a; Davies et al., 2012; Blockley et al., 2014; Lowe et al., 2015). The development of these lattices, and their application, have revealed the importance of tephra research by emphasising: i) the dynamic spatial variability of climatic transitions (Lane et al., 2013); ii) the phasing of environmental response to abrupt climate change (Lane et al., 2012a); and iii) the complex interplay between climate and human dispersal; details that would have otherwise remained obscured by the broader uncertainties of traditional radiometric dating techniques (Lowe et al., 2012; Barton et al., 2015). These studies illustrate that a successful tephra lattice must contain: i) sequences of tephras ubiquitous or frequent across a study region; ii) horizons which can be reliably correlated based on distinctive chemical characteristics; iii) tephras which are positioned at key stratigraphic/climato-stratigraphic intervals and

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boundaries; and iv) tephras which have quantifiable ages associated with them (Lowe et al., 2015). If these criteria are met, tephra lattices offer an opportunity to test the asynchronous nature of abrupt climate change with a greater degree of chronological control than has previously been achievable (Bronk Ramsey et al., 2015; Lowe et al., 2015).

The number and quality of tephra-linkages that can be made across regions, however, currently limits the effectiveness of tephrochronology. In NW Europe there are significant disparities in the quantity, and identity of cryptotephra layers represented in key areas, with many tephras restricted to single sites, countries, or regions based on current data. For example, the early Holocene Hässeldalen tephra is an important marker horizon for constraining the Pre-Boreal Oscillation (PBO) in Europe. The tephra has been identified at 13 sites on the European mainland (e.g. Davies et al., 2003; Wohlfarth et al., 2006), and as yet there are no reliably confirmed cases of this tephra within records from the British Isles. This apparent spatial inconsistency of records may be attributable to physical factors such as ash plume circulation, and shard concentration/preservation following deposition (e.g. Pollard et al., 2003; Pyne-O'Donnell, 2011; Stevenson et al., 2013). However, this disparity may have also arisen from methodological limitations and incomplete refinement of stratigraphic profiles. MacLeod et al. (2015) have demonstrated that the number of cryptotephras identified and characterised in sites that were the focus of early tephra work may be under-estimated particularly where detection, extraction, and analytical techniques were still in their infancy (e.g. Turney et al., 1997; Lowe et al., 2008b). Further refinement and expansion of the tephrostratigraphic framework in Britain and Europe is now required (Lowe et al., 2015); priority should be focused on sites that improve the superposition and absolute dating of tephras across Europe, augment and link local tephrostratigraphies to neighbouring regions, and relate to quantifiable palaeoclimatic or archaeological information that can be resolved to a high resolution.

Northern Britain is one such region with the potential to develop and refine a pan-European tephra lattice. The proximity of the Icelandic volcanic province (Fig. 1A), and the dominance of westerly air movements allows for the 'capture' of all but the most localised eruptions (e.g. Lacasse, 2001; Davies et al., 2010; Swindles et al., 2011; Stevenson et al., 2012, 2013). Yet the locale remains distal enough to permit a clear stratigraphic discrimination of closely spaced events (e.g. MacLeod, 2008; Matthews et al., 2011). Hitherto, the most northerly cryptotephra studies of LGIT age are limited to mainland Scotland (e.g. Turney et al., 1997; Ranner et al., 2005). These studies identify tephra layers that are frequently found across Scotland but are missing crucial tephra markers detected in Scandinavia and the Faroe Islands. The outlying Orcadian and Shetland archipelagos (Fig. 1A) thus offer great potential in augmenting the northern sector of the British tephrostratigraphic lattice by providing new links between the Nordic and European tephrostratigraphies and are, furthermore, well placed to record rapid palaeoclimatic oscillations of LGIT age (e.g. Whittington et al., 2015). This study forms part of a wider investigation designed to: i) assess the potential for tephra in developing precise chronological frameworks exclusive of other dating methods; ii) evaluate the potential of tephra in constraining abrupt climatic events; and iii) understand the spatial disparity between the tephrostratigraphic records of Britain and neighbouring parts of NW Europe.

2. Regional setting

2.1. Quoyloo Meadow (59° 03′ 56.42″ N/3° 18′ 35.10″ W)

The Orkney Isles consist of approximately 70 islands located between the northern coast of mainland Scotland and the Shetland Isles (Fig. 1A). Previous palaeoclimatic studies on the archipelago have identified two basins, Quoyloo Meadow and Crudale Meadow (Fig. 1B), which exhibit lithostratigraphic and pollen-stratigraphic successions indicative of the LGIT (Moar, 1969; Bunting, 1994; Whittington et al., 2015). Lithologies at both sites are dominated by calcium carbonate rich sediments deposited during warmer

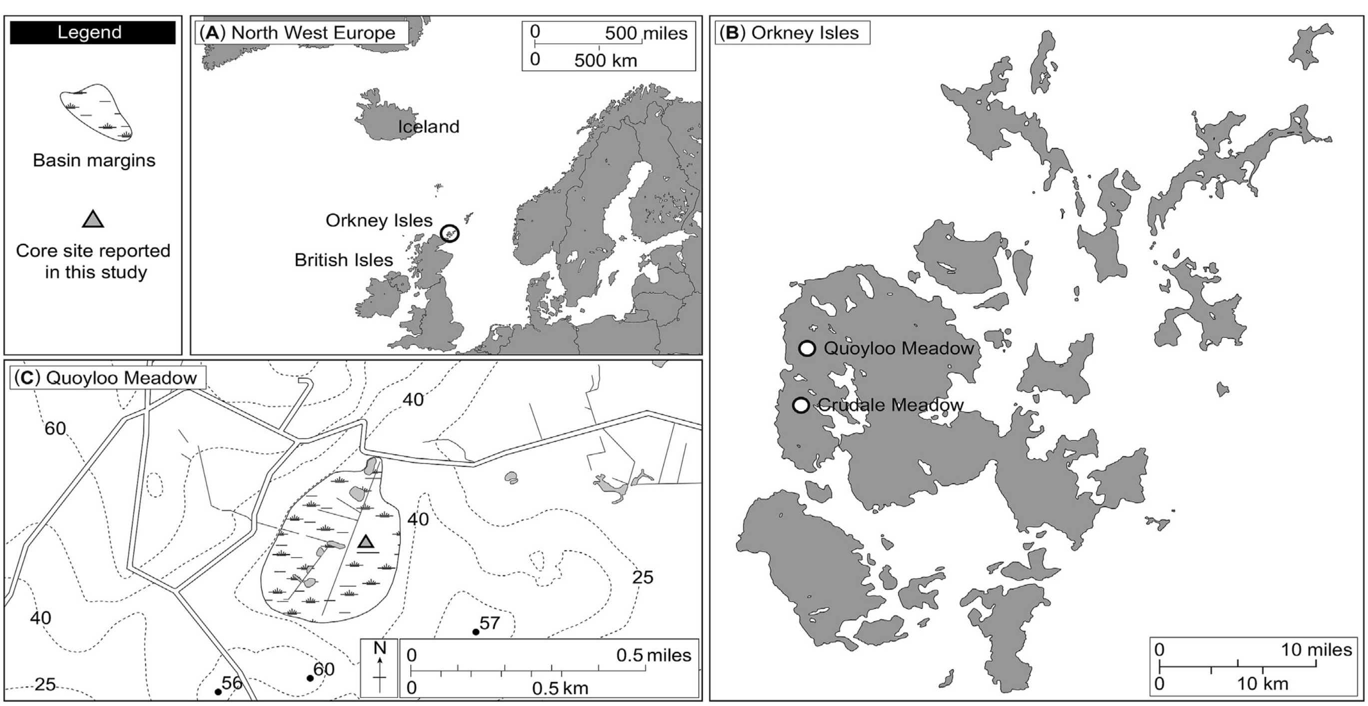

Fig. 1. A) Regional context of the Orkney Isles. B) Study site location, other sites noted in text also shown. C) Local site map of Quoyloo Meadow.