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Tracing marine cryptotephras in the North Atlantic during the last glacial period: Improving the North Atlantic marine tephrostratigraphic framework

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ABSTRACT

Tephrochronology is increasingly being recognised as a key tool for the correlation of disparate palaeoclimatic archives, underpinning chronological models and facilitating climatically independent comparisons of climate proxies. Tephra frameworks integrating both distal and proximal tephra occurrences are essential to these investigations providing key details on their spatial distributions, geochemical signatures, eruptive sources as well as any available chronological and/or stratigraphic information. Frameworks also help to avoid mis-correlation of horizons and provide important information on volcanic history. Here we present a comprehensive chronostratigraphic framework of 14 tephra horizons from North Atlantic marine sequences spanning 60-25 cal ka BP. Horizons previously discovered as visible or coarse-grained deposits have been combined with 11 newly recognised volcanic deposits, identified through the application of cryptotephra identification and characterisation methods to a wide network of marine sequences. Their isochronous integrity has been assessed using their physical characteristics. All horizons originated from Iceland with the vast majority having a basaltic composition sourced from the Grímsvötn, Kverkfjöll, Hekla/Vatnafjöll and Katla volcanic systems. New occurrences, improved stratigraphic placements and a refinement of the geochemical signature of the NAAZ II are reported and the range of the FMAZ IV has been extended. In addition, several significant geochemical populations that further investigations could show to be isochronous are reported. This tephra framework provides the foundation for the correlation and synchronisation of these marine records to the Greenland ice-cores and European terrestrial records to investigate the phasing, rate, timing and mechanisms controlling rapid climate changes that characterised the last glacial period.

1. Introduction

Tephrochronology, the use of volcanic ash deposits as isochronous tie-lines between disparate palaeoclimatic records, is increasingly being utilised as a key geochronological tool for reconstructing the timing and phasing of past climatic events (e.g. Lowe, 2011; Lowe et al., 2012; Lane et al., 2013; Davies, 2015). This upsurge is directly linked to advances in cryptotephra analysis, which has dramatically increased the number of potential tie-lines and led to the compilation of regional tephra frameworks (e.g. Lowe et al., 2008a,b; Tryon et al., 2009; Zanchetta et al., 2011; Davies et al., 2012; Abbott and Davies, 2012; Lowe et al., 2015). Tephrostratigraphical frameworks typically include a compilation of key information relating to the tephra horizons within them, including their spatial extent, based on preservation within palaeoclimate records, glass shard concentrations, glass shard composition and eruptive source alongside chronological and stratigraphic information (e.g. Lowe et al., 2008a,b; Davies et al., 2014; Bourne et al.,

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2015; Matthews et al., 2015). The most comprehensive frameworks include both distal and proximal tephra findings, visible and cryptotephra occurrences and combine newly discovered data with previously published deposits. Integrating all this information can provide valuable frameworks for the volcanic history of a region and key reference tools for future studies. In addition, developing the most comprehensive tephra frameworks will help to reduce instances of mis-correlation which can occur if volcanic regions produce multiple, closely-timed eruptions with similar geochemical compositions (e.g. Lowe, 2011; Bourne et al., 2013). Distal archives are often more complete than proximal records, which are prone to removal or burial of deposits, although proximal archives can often record more information regarding eruptions, such as their full geochemical evolution.

For the North Atlantic region, various detailed frameworks spanning a range of time-intervals are currently available. For example, Gudmundsdóttir et al. (2016) provides a proximal framework of Icelandic eruptions during the Holocene, Blockley et al. (2014) summarises the European tephra stratigraphy over the last glacial cycle and Davies et al. (2014) provides an integrated framework of MIS 5 tephras in Greenland ice-cores and North Atlantic marine records. The tephra framework for the Greenland ice-cores has significantly expanded in recent years (e.g. Mortensen et al., 2005; Abbott and Davies, 2012; Davies et al., 2014), in particular over the MIS 2-3 period (Bourne et al., 2015), highlighting the value of exploring these distal archives. In comparison, however, only a limited number of tephra horizons have been identified in North Atlantic marine records spanning MIS 2-3 (Haflidason et al., 2000; Wastegård et al., 2006, see Section 2). This relative paucity is despite considerable advances in distal tephrochronology and the high potential for a tephra framework from these sequences to be used to establish correlations to the Greenland ice-cores and European terrestrial records. Such correlations could help answer key questions regarding the relative timing of atmospheric and oceanic changes associated with the rapid climatic events, that punctuated the region during the last glacial period (e.g. NGRIP Members, 2004; Bond et al., 1993; Martrat et al., 2007; Hall et al., 2011; Zumaque et al., 2012; Henry et al., 2016).

Here we present a tephra framework for North Atlantic marine records spanning MIS 2-3, which is underpinned by our investigations of an extensive core network (Fig. 1) using recently developed cryptotephra identification methods (Abbott et al., in press). Prior studies are also reviewed (Section 2) and previously identified isochronous horizons are integrated with our new cryptotephra discoveries. This integration represents the most concerted attempt to improve the tephra framework for the North Atlantic, and overall a framework of 14 marine tephra or cryptotephra horizons from between 60 and 25 cal ka BP has been defined (Fig. 2).

2. Prior North Atlantic tephra investigations between 60 and 25 ka BP

It was highlighted earlier that tephra frameworks should integrate all isochronous tephra deposits from a region, so the framework presented in this work integrates our new discoveries alongside previously published data from multiple cores sites from the North Atlantic (green sites on Fig. 1). Within these prior tephrochronological studies of the MIS 2-3 period, several isochronous tephra horizons have been identified, i.e. North Atlantic Ash Zone II (NAAZ II), Faroe Marine Ash Zone (FMAZ) II and FMAZ IV. Reviewing the literature does, however, highlight some of the challenges associated with determining the isochronous nature of deposits and the limitations of earlier studies that only focused on the coarse fraction (>150 μm) of the marine sediments. These were the major factors driving the development of a procedure for isolating fine-grained cryptotephras (down to 25 μm diameter) and interpreting transportation and depositional processes (e.g. Abbott et al., 2011, 2013, 2014, in press; Davies et al., 2014; Griggs et al., 2014). This is essential to determine the isochronous nature of fine-grained, cryptotephra deposits for which macro-sedimentary evidence cannot be utilised to determine the relative influence of primary and secondary processes. These methods were utilised by Abbott et al. (2016) to identify three previously undocumented MIS 2-3 volcanic events within a core retrieved from the Goban Spur (see Section 4 for details) and are more widely applied in this study.

The first MIS 3 tephra deposit to be recognised in the North Atlantic was NAAZ II, initially identified by Bramlette and Bradley (1941) and later described by Ruddiman and Glover (1972). NAAZ II is a complex ash zone composed of the products of several Icelandic eruptions (see Section 4.1.1) with rhyolitic material from one eruption (II-RHY-1) the most widespread, being traced into multiple marine cores and the Greenland ice-cores (e.g. Kvamme et al., 1989; Grönvold et al., 1995; Lacasse et al., 1996; Zielinski et al., 1997; Haflidason et al., 2000; Austin et al., 2004; Svensson et al., 2008). The widespread nature of II-RHY-1 gives rise to a key tie-line between North Atlantic marine records and the Greenland ice-cores within the North Atlantic tephra framework (Austin and Abbott, 2010).

The FMAZs comprise a series of ash zones identified in cores around the Faroe Islands region, and three, II, III and IV, were deposited during MIS 2-3. Two of these, FMAZ II and IV, have isochronous characteristics and are integrated within the framework (Figs. 1 and 2; Rasmussen et al., 2003; Wastegård et al., 2006; Wastegård and Rasmussen, 2014; Griggs et al., 2014). FMAZ II was described by Wastegård et al. (2006) as a visible horizon and was suggested to be a widespread primary fall deposit. The FMAZ II was subsequently traced into the NGRIP ice-core by Davies et al. (2008) (NGRIP 1848 m; 26 740 ± 390 yr b2k), providing a clear demonstration of the high potential for ice-marine correlations between the Greenland ice-cores and North Atlantic marine sequences during the 60-25 cal ka BP period. FMAZ IV was first described by Wastegård and Rasmussen (2014) as a layer up to 20 cm thick deposited shortly after warming related to Dansgaard-Oeschger (DO) event 12. Due to its homogeneous composition and micro-sedimentary features (Griggs et al., 2014, 2015) it has been interpreted as a primary ashfall deposit.

FMAZ III, identified as a thick relatively dispersed zone of tephra spread over ~20 cm depth in the Faroes cores, was also thought to have a correlative in the NGRIP core (NGRIP 2066.95 m; 38 122 ± 723 yr b2k; Davies et al., 2010). However, Bourne et al. (2013) subsequently identified a series of closely-spaced tephra horizons in the NGRIP and NEEM ice-cores around NGRIP 2066.95 m, many with geochemical compositions that fall within the wide geochemical envelope of FMAZ III. This highlighted the complexity of the period and demonstrated that the suggested correlation was inappropriate and did not represent an ice-marine tie-line (Bourne et al., 2013). Bourne et al. (2013) and Griggs et al. (2014) both suggested that FMAZ III formed through the amalgamation of several separate tephra-fall events and low sedimentation rates at the core sites so the diachronous deposits are not incorporated in the marine tephra framework.

Early studies of North Atlantic tephra mainly focused on investigating visible tephra horizons or glass shards present within the coarse fraction of the sediment (i.e. >150 μm diameter). This may have created a bias towards the identification of horizons from large scale eruptions and/or horizons not deposited via primary ash-fallout (Brendryen et al., 2010; Abbott et al., 2011). The study of Lackschewitz and Wallrabe-Adams (1997) highlights the limitation