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Tracing marine cryptotephras in the North Atlantic during the last glacial period: Protocols for identification, characterisation and evaluating depositional controls

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ABSTRACT

Tephrochronology is increasingly being utilised as a key tool for improving chronological models and correlating disparate palaeoclimatic sequences. For many sedimentary environments, however, there is an increased recognition that a range of processes may impart a delay in deposition and/or rework tephra. These processes can affect the integrity of tephra deposits as time-synchronous markers, therefore, it is crucial to assess their isochronous nature, especially when cryptotephras are investigated in a dynamic marine environment. A methodology for the identification and characterisation of marine cryptotephras alongside a protocol for assessing their integrity is outlined. This methodology was applied to a wide network of North Atlantic marine sequences covering the last glacial period. A diverse range of cryptotephra deposits were identified and, based on similarities in physical characteristics (e.g. glass shard concentration profiles and geochemical homogeneity/heterogeneity), indicative of common modes of tephra delivery and post-depositional reworking, a deposit type classification scheme was defined. The presence and dominance of different deposit types within each core allowed an assessment of spatial and temporal controls on tephra deposition and preservation. Overall, isochronous horizons can be identified across a large portion of the North Atlantic due to preferential atmospheric dispersal patterns. However, the variable influence of ice-rafting processes and an interplay between the high eruptive frequency of Iceland and relatively lower sedimentation rates can also create complex tephrostratigraphies in this sector. Sites within a wide sector to the south and east of Iceland have the greatest potential to be repositories for isochronous horizons that can facilitate the synchronisation of palaeoclimatic records.

1. Introduction

Deposits of volcanic ash, tephra, can act as time-synchronous marker horizons linking palaeoclimatic sequences to help improve chronological models and assess the relative timing of climatic changes (Lowe, 2011). Two fundamental principles that underpin the application of tephrochronology are the rapid deposition of ash at all sites, i.e. instantaneous in geological terms, and that the stratigraphic position of the ash in a sequence directly relates to the timing of the volcanic eruption. Processes that either delay the transportation of ash particles to a site or rework the material following initial deposition can have major impacts on the integrity of deposits as well-resolved isochronous markers. The operation of such processes has been investigated in many sedimentary environments (e.g. Ruddiman and Glover, 1972; Austin et al., 2004; Davies et al., 2007; Brendryen et al., 2010; Payne and Gehrels, 2010; Pouget et al., 2014; Todd et al., 2014; Hopkins et al., 2015; Watson et al., 2015; Zawalna-Geer et al., 2016) and are particularly crucial for cryptotephras, due to the absence of any visible stratigraphic features that would identify the position of the isochron, and hence the timing of deposition, and draw attention to any post-depositional reworking (Davies, 2015). For the marine environment it is critical to consider these processes due to its dynamic nature and the wide range of potential influences, especially when investigating sediments from glacial periods and high-latitude settings where ice-rafting processes could be a significant complicating factor.

Isochronous tephra deposits are formed in the marine environment if primary tephra fallout is deposited on the ocean surface, rapidly transported through the water column, deposited on the seabed and

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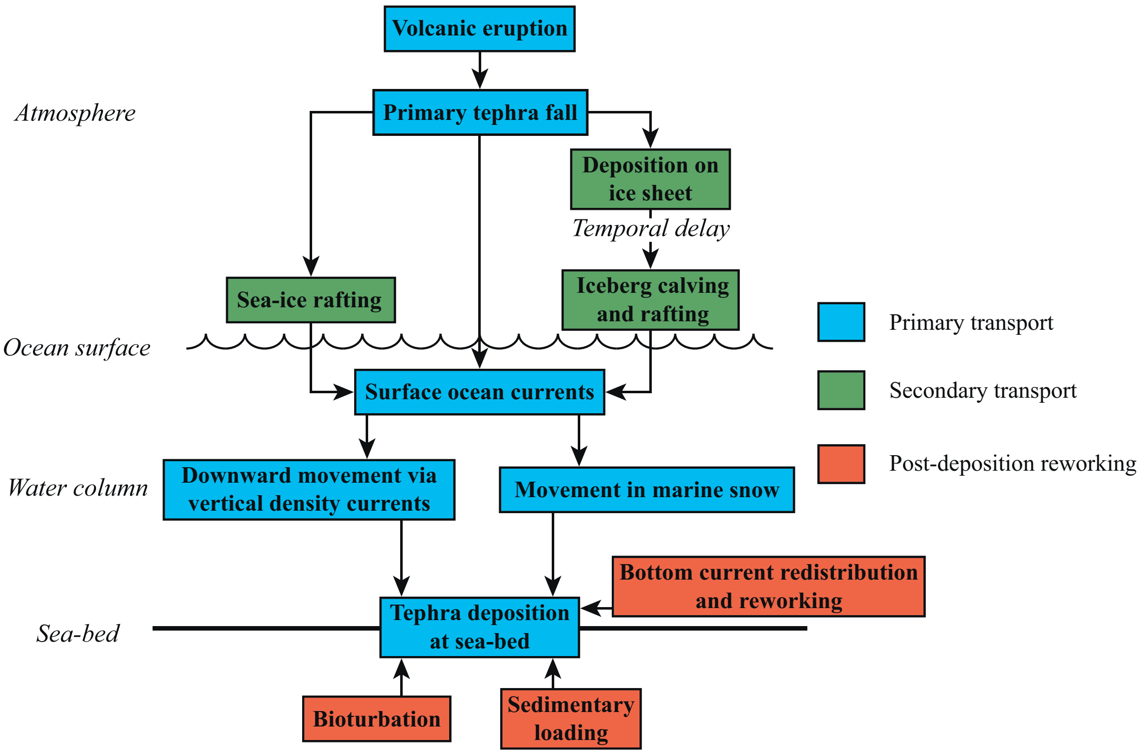

Fig. 1. Flow chart of the transportation and depositional processes that could have affected tephra within the glacial North Atlantic prior to preservation in marine sediments. Adapted from Griggs et al. (2014).

then preserved in the sediment by subsequent marine sedimentation (Fig. 1). However, deposition onto other surfaces, e.g. ice sheets and sea-ice, subsequent rafting, and post-depositional reworking and redistribution processes, such as bioturbation and sedimentary loading, can have a major impact on the integrity of tephra deposits in this environment (Fig. 1). For instance, these processes can affect the stratigraphic position of a tephra, a pertinent issue for marine sequences due to their lower resolution relative to other records, and potentially compromise the use of the deposit as an isochron. Therefore, it is essential that a full assessment of the sedimentation and depositional processes influencing the preservation, form and isochronous nature of marine cryptotephra deposits is undertaken. This is especially important if tephra or cryptotephra horizons are to be used as tie lines to assess the relative timing of climatic changes between depositional environments.

Here we present an optimised protocol for marine cryptotephra studies that builds on previous studies, such as, Austin et al. (2004), Brendryen et al. (2010), Abbott et al. (2011, 2013, 2014, 2016), Davies et al. (2014) and Griggs et al. (2014), which all used similar methods and indicators to assess visible or cryptotephra deposits within single core sequences. Our examples are derived from a range of depositional settings in the North Atlantic region (Fig. 2), but the methodological approach could be applicable to many other marine settings. Within our approach, cryptotephras are identified and characterised using density separation, magnetic separation and electron probe micro-analysis (EPMA) techniques. We then employ a series of indicators to assess the isochronous nature of tephra deposits in the North Atlantic. These include (i) high-resolution shard concentration profiles, (ii) glass shard size variations, (iii) comprehensive single-shard geochemical analysis, and (iv), when available, co-variance with ice-rafted debris (IRD). With a focus on the time-period between 60 and 25 cal ka BP in the North Atlantic we define several key types of cryptotephra deposit. These are manifested as variations in glass shard concentrations, that share characteristics, such as shard concentrations profiles and geochemical compositions, which are interpreted as being indicative of common transport, depositional and post-depositional processes. The cryptotephra deposit types provide a basis for assessing the dominant controls on tephra deposition in different areas and time periods. Given the widespread core network employed in this study we pinpoint sectors of the North Atlantic Ocean that preferentially preserve isochronous deposits and these underpin a marine tephra framework presented in Abbott et al. (in press). These horizons are the most valuable for establishing independent high-precision correlations to the Greenland ice-core records to assess the relative timing of abrupt climate changes.

2. Methodology

2.1. Core network

Thirteen marine sequences are included in our core network and each record was investigated using the same methodological approach (Figs. 2 and 3; Table 1). Cores with well-developed proxy records were prioritised due to the overarching goal of assessing the relative timing of abrupt climate changes during the last glacial period. In addition, cores from areas with high sedimentation rates and sufficient material for contiguous tephra sampling were selected. Overall the network has a wide geographical spread. However, in some instances paired cores from nearby locations were investigated to assess the stratigraphic integrity of individual tephra deposits. It was not always possible to fulfil all of these requirements. For instance, contiguous samples were not available from MD95-2024 and two sites, M23485-1 and GIK23415-9, do not have well-resolved records of abrupt climate changes. However, these sites were included to increase the geographical extent and capture a wide range of depositional settings.

2.2. Identification of cryptotephra deposits

Cryptotephras were identified and characterised according to the methodological protocol outlined in Fig. 3. Although most aspects of this marine-focussed methodological approach have been described