Quaternary Science Reviews 195 (2018) 195–214

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Towards a Holocene tephrochronology for the Faroe Islands, North Atlantic

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ARTICLE INFO

Article history:
Received 14 February 2018
Received in revised form
12 July 2018
Accepted 16 July 2018

Keywords:
Quaternary
Paleoclimatology
North Atlantic
Holocene
Faroe Islands

ABSTRACT

The Faroe Islands hold a key position in the North Atlantic region for tephra studies due to their relative proximity to Iceland. Several tephras have been described over the last 50 years in peat and lake sediment sequences, including the type sites for the Saksunarvatn and Mjáuvøtn tephras. Here we present a comprehensive overview of Holocene tephras found on the Faroe Island. In total 23 tephra layers are described including visible macrotephras such as the Saksunarvatn and Hekla 4 tephras and several cryptotephras. The importance of tephras originally described from the Faroe Islands is highlighted and previously unpublished results are included. In addition, full datasets for several sites are published here for the first time. The Saksunarvatn Ash, now considered to be the result of several eruptions rather than one major eruption, can be separated into two phases on the Faroe Islands; one early phase with two precursor eruptions with lower MgO concentrations (4.5–5.0 wt%) than the main eruption and a later phase with higher MgO concentrations (5.5–6.0 wt%), including the visible Saksunarvatn Ash. The Tjørnuvík Tephra, previously considered to be a primary deposit, is now interpreted as a reworked tephra with material from at least two middle Holocene eruptions of Hekla. Several of the tephras identified on the Faroe Islands provide useful isochrons for climate events during the Holocene.

1. Introduction

Tephra layers are known to be present in a wide range of climate archives in the North Atlantic region, including ice-cores, marine cores, peat and lake sediment. Tephrochronology, which is an age-equivalent dating method, exploits these often exceptionally well-dated time-synchronous markers and offers a unique possibility to test hypotheses regarding synchronous or lagged responses to climate forcing. Few, if any geochronological methods can match the precision it offers both temporally and spatially (Lowe, 2011).

A majority of tephras found in NW Europe derives from explosive volcanic eruptions in Iceland and the chronological control is often excellent for the historic part (back to the 10th Century CE) but many widely dispersed prehistoric tephras are relatively poorly dated. For example, ages for two of the largest eruptions of Hekla (Hekla 3 and Hekla 4, c. 3000 cal yr BP and 4200 cal yr BP, respectively) differ by tens to hundreds years when different dating methods (radiocarbon, dendrochronology, varves etc.) have been utilized (Baillie and Munro, 1988; Pilcher et al., 1995; van den Bogaard et al., 2002; Zillén et al., 2002; Dörfler et al., 2012). If improved numerical ages for these and other tephra layers can be obtained, tephrochronology will evolve as an even more important complement to radiocarbon dating and other geochronological methods. This will have wider implications for palaeoclimatic investigations, sea-level studies and archaeological studies as these frequently suffer from poor chronological control.

Since the first records of distal Icelandic tephra were reported in the 1960s (Persson, 1966, 1968; Waagstein and Jóhansen, 1968), an

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https://doi.org/10.1016/j.quascirev.2018.07.024
0277-3791/

increasing number of papers have been published describing findings of Icelandic tephra in Scandinavia (Boygle, 1998; Bergman et al., 2004; Borgmark and Wastegård, 2008), the Faroe Islands (Mangerud et al., 1986; Wastegård et al., 2001; Olsen et al., 2010a), Germany (van den Bogaard and Schmincke, 2002; Lane et al., 2012a), the British Isles (Dugmore, 1989; Pyne-O'Donnell et al., 2008; Hall and Pilcher, 2002), Poland (e.g. Housley et al., 2013; Ott et al., 2016), Baltic states and western Russia (e.g. Wastegård et al., 2000; Stivrins et al., 2016) and even as far south as in the Mediterranean region (Lane et al., 2011a) and Romania (Kearney et al., 2018). More recently tephra from other volcanic regions has been identified in NW Europe, which indicates the possibility of distribution of tephra over even larger areas than previously thought (Coulter et al., 2012; Jensen et al., 2014). Several middle to late Holocene tephras are widespread over NW Europe but the distribution of some of the tephras from the Lateglacial and early Holocene, e.g. the Vedde Ash and Askja-S suggests that these tephras are even more widespread than those derived from the voluminous middle Holocene eruptions of Hekla (e.g. Davies et al., 2010). This may, however, be biased since more studies have focused on erecting distal tephrochronology networks for the Last Glacial-Interglacial transition (LGIT; c. 15–8 ka BP) than for the middle and late Holocene. Several reviews of the LGIT tephras in NW Europe have been published by members of the INTIMATE group (Davies et al., 2012; Blockley et al., 2014) but more comprehensive reviews of tephras from the middle to late Holocene are less numerous with notable examples by Swindles et al. (2011) and Lawson et al. (2012) who focused on the distribution and temporal occurrence of tephras rather than the geochemical composition and correlations with events on Iceland. Despite this wealth of research that has been conducted during the last c. 20 years, several recent studies have shown that our knowledge of tephra dispersal in the North Atlantic region is far from complete (e.g. Lane et al., 2012a; Lind et al., 2013; Timms et al., 2017; Plunkett and Pilcher, 2018).

The Faroe Islands hold a key position in the North Atlantic for tephra studies due to their relative proximity to Iceland. Several sources, both from historic and sedimentary archives, show that tephra fallout has been observed during historical eruptions, including Katla 1625 and 1755, Hekla 1845 and most recently, the eruption of Eyjafjallajökull 2010 (Thorarinsson, 1981; Dugmore and Newton, 1998; Stevenson et al., 2012). The tephrostratigraphy of the Faroe Islands has been described in several papers since the first studies in the 1960s, but a more comprehensive review is lacking. The aim of this paper, therefore, is to describe the terrestrial tephrostratigraphy of the Faroe Islands for the last ca 11,000 years. The importance of some tephras originally described from the Faroe Islands is highlighted and previously unpublished results are included. In addition, full datasets for several sites are published here for the first time (App. A). The tephras are described in chronological order, from oldest to youngest in the text (Table 1).

2. Material and methods

2.1. Study area

The Faroe Islands are part of the North Atlantic Igneous Province (NAIP), which stretches from Ireland to Greenland and is centered on Iceland (e.g. Saunders et al., 1997; Horni et al., 2017) (Fig. 1A). The plateau broke up during the opening of the North Atlantic Ocean and remnants exist in e.g. Northern Ireland, Scotland, the Faroe Islands and eastern Iceland. The Faroe Islands were repeatedly glaciated during the Quaternary but the Pre-Weichelian development of the Faroe Islands is poorly known, except for an Eemian section in Klaksvík that also has been investigated for tephrostratigraphy (Wastegård et al., 2005). A local ice cap or perhaps ice caps covered the islands during the Weichselian, but it is not clear when they were finally deglaciated (Humlum et al., 1996; Humlum, 1998). Moraine systems, thought to be of Younger Dryas age, occur in some areas, and a final deglaciation shortly after the Younger Dryas-Preboreal transition (c. 11.700 ka cal BP) is supported by several ^{14}C dates from the first organic lake sedimentation c. 11.5-11-3 ka cal BP (e.g. Jessen et al., 2008; Hannon et al., 2010; Lind and Wastegård, 2011).

2.2. Methods

Both visible macrotephras and cryptotephras, invisible to the naked eye, have been found on the Faroe Islands. Cryptotephras in lake sediment sequences have been concentrated using the density separation technique outlined by Turney (1998) while peat cores were treated accordning to Pilcher and Hall (1992). Tephra glass shard identification and counting were carried out optically with a polarising light microscope. Many lake sediment records on the Faroe Islands have a background of glass shards and shard concentration peaks are not always distinct. In the Høvdarhagi site, peaks in tephra shard concentration can be deciphered but there is also evidence for bioturbation and/or secondary inwash (cf. Fig. 3B in Davies, 2015). Here, and in other sites, peaks in tephra shard concentration were chosen for geochemical fingerprinting.

3. Results

3.1. The early Holocene (c. 11,500–8200 cal yr BP)

The Faroe Islands are a key area for the early Holocene tephrochronology of the North Atlantic region, and provide a detailed insight into Icelandic volcanism during this interval. Lateglacial and early Holocene tephras from Iceland are often poorly preserved in proximal localities due to the fact that much of the Icelandic landscape was covered by ice, and remained so until c. 11,000 cal yr BP (Norddahl and Pétursson, 2005; Larsen and Eiríksson, 2008). On the Faroe Islands, subarctic conditions prevailed from the deglaciation until c. 10,300 cal yr BP during which time shallow lake systems developed, and vegetation colonised lake catchments (e.g. Jóhansen, 1985). Preserved within these lake systems are the remnants of this early Holocene vegetation i.e. abundant leaves of, for example *Betula nana* and *Salix herbacea* which is a type of material which facilitates radiocarbon dating, and can be used to develop robust ages for tephra layers. Examples of this are the Hoydalar site in Tórshavn, investigated by Waagstein and Jóhansen (1968), and the Lykkjuvøtn and Høvdarhagi sites on Sandoy (Jessen et al., 2007, 2008; Lind and Wastegård, 2011) (Fig. 1B). Several of these shallow lakes were terrestrialised in the early Holocene but other larger and deeper lakes exist today on most of the 18 islands. However, only a few of these have been investigated for tephra, and usually only for visible macrotephras. Two examples are the type site for the Saksunarvatn Ash, Lake Saksunarvatn on Streymoy (Mangerud et al., 1986) and Lake Mjáuvøtn on Streymoy (Wastegård et al., 2001; Olsen et al., 2010a) (Fig. 1B).

The most complete tephra record from the early Holocene is the palaeo-lake core from Høvdarhagi bog on Sandoy, in which seven tephra layers have been found (Fig. 1B; Lind and Wastegård, 2011). Only the basaltic Saksunarvatn Ash is visible; the remaining tephras are cryptotephras extracted through heavy liquid separation (Turney, 1998). An early Holocene tephra, L3574, was also described in the Lake Saksunarvatn sequence, below the Saksunarvatn Ash (Dugmore and Newton, 1998). Two other palaeo-lake sites, Hovsdalur on Suduroy (Wastegård, 2002) and Havnardalsmyren on Streymoy (Kylander et al., 2012) have also been investigated, but