

Manuscript Details

Manuscript number JQSR_2018_116
Title Towards a Holocene tephrochronology for the Faroe Islands

Abstract

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Data for: Towards a Holocene tephrochronology for the Faroe Islands

Major element geochemistry of tephras from seven sites on the Faroe Islands, previously not published in full: A1: Hovsdalur, Suduroy; A2: Tjørnuvík, Streymoy; A3: Eidi bog, Eysturoy; A4: Mjáuvøtn, Streymoy; A5: Starvatn, Eysturoy; A6: Gróthusvatn, Sandoy; A7: Havnardalsmyren, Streymoy

Towards a Holocene tephrochronology for the Faroe Islands, North Atlantic

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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 Islands. In total 21 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 The importance of tephras originally described from the Faroe Islands is highlighted and previously unpublished results are included.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 Tephra, 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 tephra. 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.

Keywords: Quaternary; Paleoclimatology; North Atlantic; Holocene; Faroe Islands

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 tephtras found in NW Europe derives from explosive volcanic eruptions on Iceland and the chronological control is often excellent for the historic part (back to the 10th Century AD) but many widely dispersed prehistoric tephtras 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; Zillén et al., 2002; Dörfler et al., 2012). If improved numerical ages for these and other tephtra 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 tephtra were reported in the 1960s (Persson, 1966, 1968; Waagstein and Jóhansen, 1968), an increasing number of papers have been published describing findings of Icelandic tephtra in Scandinavia (Boyle, 1998; Bergman et al., 2004; Borgmark and Wastegård, 2008), the Faroe Islands (Mangerud et al., 1986; Wastegård et al., 2001; Olsen et al., 2010b), Germany (van den Bogaard and Schmincke, 2002; Lane et al., 2012b), 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., 2000b; Stivrins et al., 2016) and even as far south as in the Mediterranean region (Lane et al., 2011a). More recently tephtras from other volcanic regions have been identified in NW Europe, which indicates the possibility of distribution of tephtras over even larger areas than previously thought (Coulter et al., 2012; Jensen et al., 2014). Several middle to late Holocene tephtras 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., 2012b; Lind et al., 2013; Timms et al., 2017).

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 ash fallout has been observed during historical eruptions, including Katla 1625 and 1755, Hekla 1845 and most recently, 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 tephra originally described from the Faroe Islands is highlighted and previously unpublished results are also 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 (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)

(Figure 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-Weichselian 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 cal yr BP) is supported by several ¹⁴C dates from the first organic lake sedimentation c. 11.5-11-3 ka cal yr BP (e.g. Jessen et al., 2008; Hannon et al., 2010; Lind and Wastegård, 2011).

3. Results

3.1. *The early Holocene (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 Petursson, 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 remanence 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) (Figure 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) (Figure 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 (Figure 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 Suðuroy (Wastegård, 2002) and Havnardalsmyren on Streymoy (Kylander et al., 2012) have also been investigated, but not in such detail as Høvdarhagi bog. The previous age model from Høvdarhagi bog was constructed using the OxCal 4.1.6. software (Lind and Wastegård, 2011) and has been remodelled with OxCal 4.3.2. since it has been shown that earlier attempts to use OxCal often resulted in over constraining of age depth models (Bronk Ramsey and Lee, 2013). It has also been updated to the IntCal13 calibration curve (Reimer et al., 2013).

3.1.1. Sandoy A Tephra and Sandoy B Tephra (c. 11.4-11.2 ka BP)

The oldest tephra at Høvdarhagi bog is a basaltic layer with two peaks, the Sandoy A and Sandoy B Tephras, dated to c. 11,400-11,200 cal yr BP (Table 2). The peaks are separated by c. 8 cm which corresponds to c. 100 years and both have a tholeiitic geochemistry that suggests an origin in the Bárðarbunga-Veiðivötn volcanic system in south Iceland (Figure 2). There is, however, also an overlap with the Grímsvötn volcanic system in some plots. Bárðarbunga-Veiðivötn is one of the most productive systems in Iceland with c. 350 eruptions since 7600 cal yr BP (Óladóttir et al., 2011) and at least 24 eruptions in historical time (Thordarson and Larsen, 2007), including the recent Holuhraun event in 2015. There are, however, to our knowledge no other records of distal early Holocene tephras from Bárðarbunga-Veiðivötn, neither in marine, terrestrial or ice-core records and thus, the Sandoy A and B Tephras are not possible to correlate with any known tephra deposit elsewhere.

3.1.2. Hässeldalen Tephra (c. 11.3 ka BP)

The Hässeldalen Tephra has emerged as one of the most important tephras from the LGIT since its first discovery in SE Sweden (Davies et al., 2003, 2012). It has recently been found in several sites in the southern Baltic region (Lilja et al., 2013; Larsen and Noe-Nygaard, 2014;

Wulf et al., 2016) and most recently in Quoyloo Meadow on Orkney (Timms et al., 2017). It holds a key stratigraphic position in relation to climate development during the early Holocene being thought to mark the onset of the Preboreal Oscillation (PBO) (Davies et al., 2003; Larsen and Noe-Nygaard, 2014). The Hässeldalen Tephra has a rhyolitic composition with high concentration of alkalis (Figs. 3 and 4; K₂O 3.8-4.5 wt%; Na₂O 3.7-4.2 wt%). Snæfellsjökull in W Iceland has been suggested as a source volcano (Wastegård, 2002; Housley et al., 2013). The oldest silicic tephra identified from Snæfellsjökull, however, has an estimated age of 9000-7000 ¹⁴C yr BP (c. 10-8 ka cal BP) (Steinthórsson, 1967). A more probable correlation is to the Thórdarhyrna central volcano as shown in Figures 3B and 4. There are no geochemistry data available on tephra-derived glass from this volcano, situated beneath the Vatnajökull ice-cap, so the correlation is based solely on whole rock analyses (Jónasson, 2007). Furthermore, tephtras from Snæfellsjökull have a distinctive high Al₂O₃ content of 15-16 wt% (e.g. Larsen and Eiríksson, 2008; Wastegård et al., 2009; Holmes et al., 2015), which separates them from the Hässeldalen Tephra, that usually ranges between 11-12 wt%. The findings of the Hässeldalen Tephra in Høvdarhagi bog and in the southern Baltic Sea region, but not in Norway and so far only in one site in Orkney in the British Isles, suggest a rather narrow ash plume directed towards the south-east. The Hässeldalen Tephra may, however, have been overlooked, especially where high concentrations of reworked Vedde Ash shards often prevail into the early Holocene and may obscure minor tephra peaks (e.g. Lind et al., 2013; Timms et al., 2017). The Hässeldalen Tephra is dated to c. 11,596-11,194 cal yr BP at Hässeldala port by (Wohlfarth et al., 2006), and to c. 11,378-11,254 cal yr BP in the Høvdarhagi bog sequence, using the remodelled age-depth model (Figure 5; Table 2).

3.1.3. L3574 Tephra (c. 11.0 ka BP)

This layer was described by Dugmore and Newton (1998) from the Lake Saksunarvatn sequence, as a cm-scale layer “below the Saksunarvatn Ash”. The core was taken by the Geological Survey of Denmark in 1972 and the label most probably refers to the depth where this tephra was found, 35.74 m below the sediment surface of the 36.75 m long core. The Saksunarvatn Ash (c. 10.2 ka BP) at c. 29.9-30.3 m (Mangerud et al., 1986) and the lowermost radiocarbon date at 31.99-32.10 m (9390 ± 150 BP; c. 10.7 ka cal BP; Jóhansen, 1978) indicates that the L3574 Tephra has an age of c. 11,000 cal BP. Most shards have a dacitic composition and show some similarities with silicic tephtras from the Katla volcanic system, “SILK layers”,

(Larsen et al., 1999) but is lower in e.g. TiO_2 and K_2O (Figure 3). The L3574 Tephra has so far only been found in the Lake Saksunarvatn sequence.

3.1.4. Askja-S Tephra (c. 10.8 ka BP)

This early Holocene tephra from the Dyngjufjöll volcanic centre on Central Iceland has also emerged as one of the most useful and widespread tephtras from the early Holocene. The eruption occurred within the Askja caldera and the tephtra is usually referred to as the 10-ka Askja Tephtra or the Askja-S Tephtra. The distribution on Iceland has been mapped and shows that the assumed dispersal axis was towards NNE (Sigvaldason, 2002). The volume of the Askja-S Tephtra has been estimated to 1.5 million km^3 (DRE) which makes it one of the ten most voluminous Holocene silicic eruptions on Iceland (Hafliðason et al., 2000). Askja-S has been found in several distal locations since its first distal discovery in SE Sweden (Davies et al., 2003), including Northern Norway, Northern Ireland, Scotland, Wales, Germany, Poland and as far south as Soppensee in Switzerland (Pilcher et al., 2005; Turney et al., 2006; Lane et al., 2011b; Wulf et al., 2016; Kelly et al., 2017; Jones et al., 2017). Askja-S has one of the largest reconstructed distribution envelopes of all Icelandic Late Quaternary tephtras (Wulf et al., 2016; Jones et al., 2017), but seems to have a patchy distribution as many sites within the distribution envelope do not report the tephtra. Jones et al., (2017) compiled positive and negative findings of the Askja-S Tephtra and proposed a three plume trajectory, one towards northern Norway, one towards southern Scandinavia and Central Europe and the southernmost reaching the Faroe Islands and the British Isles. The Askja-S has a characteristic geochemistry with low contents of Al_2O_3 and K_2O and higher values for CaO compared with most other rhyolitic tephtras from Iceland (Figure 3). The Askja-S has been found in two sites on the Faroe Islands, Høvdarhagi bog on Sandoy (Lind and Wastegård, 2011) and Havnardalsmyren on Streymoy (Kylander et al., 2012) (Figure 1B). The geochemical analyses from the latter site are presented here for the first time in App. A. Askja-S has been identified in three cores from Havnardalsmyren c. 50-70 cm below the Saksunarvatn Ash.

The age of the Askja-S Tephtra has been vividly discussed. It has been considered to be a result of one single eruption but different dating efforts have yielded conflicting ages, spanning over almost 1000 years. The position of Askja-S in relation to early Holocene climate events such as the PBO has also been discussed (e.g. Ott et al., 2016; Kelly et al., 2017). The age estimate from Iceland is c. 10,000 ^{14}C years (Sigvaldason, 2002) which places the tephtra in the early

Holocene but is not precise enough to provide an exact calendar year age. Wohlfarth et al. (2006) used Bayesian modelling of radiocarbon dates at Hässeldala port, and the most robust model gave a 95% range of 11,050-10,570 cal yr BP. Bronk Ramsey et al. (2015) incorporated age constraints from Lake Soppensee which gave a calibrated range of 10,956-10,716 cal yr BP. A slightly older age was reported from the varved sediment record of Lake Czechowskie, Poland where varve counting provided an age of $11,228 \pm 226$ cal yr BP (Ott et al., 2016) which overlaps with the larger uncertainty range of Wohlfarth et al. (2006) but not with the more narrow uncertainty band of Bronk Ramsey et al. (2015). The remodelled chronology of the Høvdarhagi bog sequence (Figure 5) gives an age estimate for the Askja-S Tephra of 10,526-10,322 cal yrs BP (Table 2). This is still younger than the ages reported by Wohlfarth et al. (2006) and Bronk Ramsey et al. (2015) and the varve date from the Polish lake. Further radiocarbon dating of Askja-S in the Faroe sites could potentially solve this dating problem.

3.1.5. Hovsdalur Tephra (c. 10.5 ka BP?)

A rhyolitic tephra found in a core from the valley of Hovsdalur on Suduroy, c. 40 cm below the Saksunarvatn Ash was named the Hovsdalur Tephra (Wastegård, 2002). The Hovsdalur Tephra has a similar composition as the Hässeldalen Tephra, but is slightly lower in alkalis (Figure 3B; K_2O 3.7-4.1 wt%; Na_2O 3.3-3.8 wt%) which, however, could be due to less refined analytical conditions when the analyses were made in the early 2000s. It is indistinguishable, however, from the Hässeldalen Tephra when analysed with the same probe conditions (e.g. Davies et al., 2003). The suggested age of c. 10,500 cal yr BP was based on interpolation between the Saksunarvatn Ash and two radiocarbon dates immediately above the tephra which may underestimate the true age of the Hovsdalur Tephra. Davies et al. (2003) noted the geochemical similarity between the Hovsdalur and Hässeldalen tephras but did not suggest a correlation due to uncertain age estimates for both tephras at the time. Lind and Wastegård (2011), however, suggested that they might derive from the same eruption and that the age estimate of the Hovsdalur Tephra was several hundred years too young. Also the fact that only one tephra with this composition was found in the Høvdarhagi sediments (Lind and Wastegård, 2011), indicates a single event. Recently, however, evidence have been presented from Quoyloo Meadow in Orkney, Scotland suggesting that the Hässeldalen and Hovsdalur tephras indeed may represent two separate events in the early Holocene (Timms et al., 2017). The tephras are here separated by 5 cm with the Askja-S Tephra in-between. Some caution,

however, should be taken with the results from Quoyloo Meadow; both tephras are mixed with other components, probably due to a low sedimentation rate and an exacerbated mixing of tephra layers in the early Holocene. Furthermore, the number of analysed shards are few, and do not allow a fully secure correlation with the Häseldalen and Hovsdalur tephras. More work is clearly needed to resolve the issue of one or two tephras with this chemical affinity in the early Holocene. The complete dataset of the Hovsdalur Tephra is here presented for the first time (App. A1).

3.1.6. Saksunarvatn Ash (c. 10.2 ka BP)

This is the most well-known of the tephras originally described from the Faroe Islands. It was originally reported by Waagstein and Jóhansen (1968) from the Hoydalar site close to Tórshavn and Lake Skælingsvatn on Streymoy (Figure 1B) but it did not get its name until the publication of the paper by Mangerud et al. (1986), describing it in the eponymous type site on Streymoy, Lake Saksunarvatn (Figure 1B). The Saksunarvatn Ash is a visible cm-scale black layer in many sites on the Faroe Islands and a valuable isochron for the early Holocene, especially for marking the 10.3 ka event (Björck et al., 2001). The Saksunarvatn Ash is the most voluminous Icelandic basaltic tephra deposit in the Holocene, and since its discovery it has been described from numerous sites on Iceland, the British Isles, Norway, Germany, Greenland and the North Atlantic (e.g. Merkt et al., 1993; Birks et al., 1996; Grönvold et al., 1995; Timms et al., 2017). The distribution envelope indicates a main transport direction towards NW and SE (e.g. Davies et al., 2012). The source of the Saksunarvatn Ash is the Grímsvötn volcanic system in the Eastern Volcanic Zone on Iceland which is shown by plots of e.g. TiO_2 vs. MgO (Figure 2). The Saksunarvatn Ash is dated to $10,347 \pm 45$ yrs b2k in the NorthGRIP ice core (Rasmussen et al., 2006) and to $10,210 \pm 35$ cal yr BP in Kråkenes, Norway (Lohne et al., 2013). Several recent studies have, however, questioned the Saksunarvatn Ash as a result of one eruptive event and indeed, several closely separated layers with Grímsvötn geochemistry have been reported from Iceland, the Faroe Islands and the North Atlantic (Kylander et al., 2012, Jennings et al., 2014). A pilot study was performed at Havnardalsmyren, Streymoy, aiming at evaluating whether XRF core-scanning can be used to identify cryptotephra deposits. In this study five separate layers with Grímsvötn geochemistry were identified, a 3-5 cm thick visible layer and four cryptotephra layers, one above the visible

Saksunarvatn Ash and three layers below (Kylander et al., 2012). The full dataset from Havnardalsmyren is here presented for the first time (App. A1) and is discussed in detail below.

3.1.7. L-274 Tephra/Fosen Tephra (c. 10.1 ka BP)

This tephra was found c. 13 cm above the Saksunarvatn Ash in Høvdarhagi bog on Sandoy. It has a mixed geochemical signature with at least three different components, represented by three to five analyses each (Lind and Wastegård, 2011) (Figure 3). One component has a “Borrobol-type” geochemistry similar to the Borrobol and Penifiler tephras from the Lateglacial Interstadial or GI-1 (Matthews et al., 2011; Lind et al., 2016). Another component is more similar to the An Druim tephra but is lower in K_2O (Figure 3B). After this finding was made, two sites with early Holocene Borrobol-type tephras were described from Scandinavia, dated to c. 10,200 cal yr BP (Lind et al., 2013, Larsen, 2014). The tephra, called the Fosen Tephra, overlies the Saksunarvatn Ash in the Grønliia site on the Fosen Peninsula, W. Norway. The similar stratigraphic position and age of the L-274 Tephra on the Faroe Islands indicate that it could be a result of the same eruption from the yet unknown Icelandic volcano that produced the Borrobol-type tephras (Lind et al., 2016). The Fosen Tephra has recently also been described from eastern Iceland (Gudmundsdóttir et al., 2016) and Scotland (Timms et al., 2017) which makes it one of the most important isochrones for the Early Holocene. More analyses from Høvdarhagi bog and other sites are needed to confirm the correlation between the L-274 Tephra and the Fosen Tephra.

3.1.8. Skopun Tephra (c. 9.7 ka BP)

The Skopun Tephra is named after the village Skopun on Sandoy, c. 2 km east of the Høvdarhagi bog. It was found c. 2 cm below the An Druim/Høvdarhagi Tephra in the Høvdarhagi bog and the revised age model suggests similar ages for both tephras around c. 9700-9750 cal yr BP (Figure 5; Table 2). The age model is uncertain in this part of the sequence due to a scarcity of dateable material, and a better chronology would be needed to determine the ages for both these potentially important early Holocene tephras. The Skopun Tephra has a dacitic composition and correlates with the SILK tephras layers from Katla on south Iceland (Figs. 3 and 6). The SILK tephras were erupted from vents under the ice-cap and almost 20 layers have been found in Iceland, dated between c. 8100 and c. 1675 cal yr BP (Larsen et al., 2001; Óladóttir et al., 2008; Thorsteinsdóttir et al., 2016). The Skopun tephra is thus the oldest SILK layer that has been found and once again points out the fact that preservation of early

Holocene tephra on Iceland can be poor. It also sheds new light on the Holocene evolution of the Katla volcano.

3.1.9. An Druim Tephra/Høvðarhagi Tephra (c. 9.7 ka BP)

A tephra with a bimodal alkaline rhyolite composition of Torfajökull affinity was found at 217 cm in the Høvðarhagi bog sequence (Lind and Wastegård, 2011). The layer was first called the Høvðarhagi Tephra but subsequent studies suggest that it probably can be correlated with the An Druim tephra found at three sites in north Scotland (Ranner et al., 2005, Kelly et al., 2017; Timms et al., 2017). Most of the shards of the Høvðarhagi Tephra show higher concentrations of MgO and CaO than the An Druim Tephra (Figure 3A), but this could possibly reflect that tephra from different phases of the eruption have been deposited in Scotland and the Faroe Islands, or that the absence of a bi-modal trend in the Scottish sites may be an artefact of a smaller sample size (Kelly et al., 2017). The age of the tephra in Høvðarhagi bog has been modelled to 9836-9596 cal yr BP (Table 2) which overlaps with the age of the An Druim Tephra in Scotland (9776-9565 cal yr BP; Timms et al., 2017). The An Druim Tephra is a potentially widespread tephra that can be important for the correlation of early Holocene sequences.

3.2. *The middle and late Holocene (8200 cal yr BP-present)*

Several small lakes that existed in the early Holocene were infilled and overgrown by peat in the early to middle Holocene. An example of this is the Hovsdalur site on Suduroy (Figure 1B) where peat started to accumulate around 9000 cal yr BP (Wastegård, 2002) or even as early as before the deposition of the Saksunarvatn Ash (Edwards and Craigie, 1998). Expansion of peat has continued throughout the last 9000 years but cannot be tied to any climatic events (Lawson et al., 2007). Only a few peat records have been sampled contiguously for tephra since the pioneering work by Persson (1968) who investigated four sites, Saksunmyren, Havnardalsmyren and Myrarnar on Streymoy and the Klovin mire on Vágur, and identified around five tephra layers (Persson, 1968) (Figure 1B). Geochemical analyses were not available when Persson conducted his study and all correlations with Icelandic eruptions were based on radiocarbon dating, grain size distributions, refractive indices, and in one case pollen stratigraphy. One important effect of this is that only silicic and intermediate shards were found, despite the fact that ash fall-out from basaltic eruptions have been noted on several occasions, e.g. during the eruptions of Katla in AD 1625, 1660 and 1755 (Thorarinsson, 1981).

It is possible that this reflects post-depositional processes in acidic environments, which particularly affects basaltic glass (e.g. Wolff-Boenisch et al., 2004). The lowermost two tephras in Klovinmyren were dated to 3800 ± 80 ^{14}C yr BP (c. 4200 cal yr BP) and 3450 ± 70 ^{14}C yr BP (c. 3725 cal yr BP) and can most probably be correlated with Hekla-4 (c. 4260 cal yr BP) and Hekla-S (c. 3720 cal yr BP), although the latter was not known when Persson carried out his study. A further tephra higher up in the stratigraphy at Klovinmyren, was dispersed over 13 cm. A radiocarbon date of 2650 ± 75 ^{14}C yr BP (c. 2750 cal yr BP) at the bottom of the tephra indicates that it might be the Hekla-3 tephra (c. 2950 cal yr BP). Other tephras from the last millennium BC found in Northern Ireland and Germany are also possible candidates (e.g. Plunkett et al., 2004). The youngest peat in the sequences investigated by Persson were partly affected by peat cutting and only two tephras younger than 2000 cal yr BP were found; one at Saksunmyren dated to 1585 ± 70 ^{14}C yrs BP (c. 1480 cal BP) and one at Myrarnar dated to 900 ± 120 ^{14}C yrs BP (c. 830 cal BP). Without geochemical identification one can only speculate which events that produced these tephras.

3.2.1 Suduroy Tephra (c. 8.0 ka BP)

The Suduroy Tephra was discovered in a core from the Hovsdalur blanket peat on Suduroy (Wastegård, 2002). The concentration was low (c. 15 shards/cm³; Wastegård, unpublished) and later attempts to localise the tephra in other cores from Hovsdalur have failed. The geochemistry is almost identical with the rhyolitic component of the Vedde Ash (12.1 ka BP) and other Vedde-type tephras (Lane et al., 2012a), except that TiO₂ is slightly lower. It is uncertain, however, if this small difference is significant. The Faroe Islands are believed to have been completely covered by an ice-cap during the Younger Dryas (Humlum, 1998) and sediment sequences with the Vedde Ash have not been found. Since its first discovery, tephras correlated with the Suduroy tephra have been reported from North Atlantic marine records (Kristjansdóttir et al., 2007, Gudmundsdóttir et al., 2012), Scotland (MacLeod, 2008; Mithen et al., 2015), North Norway (Pilcher et al., 2005) and possibly North Germany (Housley et al., 2012) but it cannot be excluded that some of these records represent reworked Vedde Ash shards. The Suduroy Tephra is dated to c. 8.0 ka BP and is therefore a potentially important isochron for the 8.2 ka BP event.

3.2.2. SILK-A7/RF-2? Tephra and SILK A1 Tephra (c. 7.1 ka BP and 5.9 ka BP)

Two further layers with Katla affinity were found in the Hovsdalur peat record at 63-64 cm and 42-43 cm, dated to c. 7.1 and 5.9 ka yr BP, respectively (Wastegård, 2002). Both layers display geochemical characteristics typical of SILK volcanism, i.e. TiO_2 contents between 1.0 and 1.1 wt%, MgO between 0.9 and 1.3 wt% and FeO_{tot} between 5.0 and 5.6 wt% (Figure 6; App. A1). Almost 20 SILK layers from Katla have been reported from Iceland in the time period between c. 8100 and 1600 cal yr BP (Larsen et al., 2001; Óladóttir et al., 2008; Thorsteinsdóttir et al., 2016) but not all layers have been geochemically fingerprinted. Ages are often derived from soil accumulation rates between tephtras dated by radiocarbon, which makes their ages somewhat uncertain. An unambiguous correlation between the SILK layers found in Hovsdalur and the Icelandic layers cannot be made at present. It is possible, however, to speculate that the SILK-A7 Tephra is the correlative of the older tephra and SILK-A1 for the younger tephra. The SILK-A7 corresponds to SILK RF-2, dated to c. 7180 cal yr BP that was later analysed by Óladóttir et al. (2008) and the SILK-A1 Tephra dates to c. 6000 cal yr BP (Thorsteinsdóttir et al., 2016). However, further work is needed to confirm or reject these correlations.

3.2.3. Mjáuvøtn Tephra (6.6 ka BP)

A mid Holocene, visible and mm-thick basaltic tephra occurs in many lake sediment sequences on the Faroe Islands and was named the Mjáuvøtn Tephra after the lake on central Streymoy, where it was first identified (Figure 1B) (Wastegård et al., 2001). The main component, called the Mjáuvøtn Tephra A has a typical composition for basaltic tephra from the Katla volcanic system with TiO_2 contents between 3.9 and 4.4 wt% and K_2O between 0.6 and 0.9 wt% (Figs. 2 and 7). A minor component, called Mjáuvøtn Tephra B has been found at three sites and has an andesitic/trachydacitic composition with SiO_2 contents between 53.5 and 56.5 wt%, TiO_2 between 2.1 and 2.5 wt% and MgO at 2.4-3.0 wt% (Figure 2). The Mjáuvøtn Tephra B component shares some similarities with intermediate products from the Katla volcanic system, e.g. the Solheimar ignimbrite (Tomlinson et al., 2012) and intermediate Vedde Ash shards found in Norway (Lane et al., 2012a) and we suggest that the Mjáuvøtn Tephra has a bimodal Katla composition with a main basaltic and a minor andesitic/trachydacitic composition caused by bimodal mixing of basaltic magma with silicic melts (cf. Óladóttir et al., 2008). Mixing with silicic magma is also confirmed by $\text{K}_2\text{O}/\text{P}_2\text{O}_5$ ratios >1.8 (cf. Óladóttir et al.,

2008). The Mjávøtn Tephra was first given a tentative age of c. 5700-5300 cal yr BP (Wastegård et al., 2001), but age modelling of ^{14}C dates from two sites gave a significantly older and better constrained age of 6668-6533 cal yr BP (Olsen et al., 2010b).

Katla is one of the most active volcanic systems on Iceland with up to six basaltic eruptions per century in prehistoric times (Óladóttir et al., 2008). In particular, the period between c. 7500 and 6500 cal yr BP had several large basaltic eruptions falling mainly into period VI (7000-6300 cal yr BP; Óladóttir et al. (2008). This period is characterized by increasing K_2O and Na_2O and decreasing CaO and MgO with time.

Some basaltic Katla layers are potentially more widespread, and Wastegård et al. (2001) suggested a correlation between the Mjávøtn Tephra and the Tv-5 Tephra found in the Lake Torfadalsvatn sequence in north Iceland (Björck et al., 1992). The Tv-5 Tephra is dated to 6000 ^{14}C yrs BP (c. 6850 cal yr BP) and is the only visible middle Holocene tephra in Torfadalsvatn. The Tv-5 Tephra has also been reported from a marine core from the north Icelandic shelf (Kristjansdóttir et al., 2007), suggesting a main dispersal towards the north. Several basaltic Katla layers dated between c. 7100 and 6500 cal yr BP also occur in lake cores from western Iceland and in marine cores off SE Greenland (Jóhannsdóttir, 2007; Jennings et al., 2014). The K-6750/Katla EG 6.73 Tephra (c. 6750 cal yr BP) has the highest abundance of all basaltic layers younger than the Saksunarvatn in the marine records. Jennings et al. (2014) suggested that this layer also can be correlated with Tv-5, making this one of the most widespread Icelandic Holocene basaltic tephra layers. Based on minor differences in major element geochemistry between the Mjávøtn, Tv-5 and K-6750 tephras), Jennings et al. (2014), however, concluded that the Mjávøtn Tephra is an unlikely correlative with the K-6750 Tephra, also given the different dispersal directions. Geochemical plots of normalized values, however, show that the differences are small (Figure 7) and that the Mjávøtn Tephra is almost indistinguishable from the K-6750/Katla EG 6.73 Tephra as well as from the slightly younger K-6630 Tephra, also found in lake sediments in western Iceland, but distinct from the older K-7060 Tephra (Jóhannsdóttir, 2007). The best characteristics for the Mjávøtn Tephra is that it is slightly more evolved compared with most other mid Holocene basaltic tephras from Katla (e.g. $\text{K}_2\text{O}/\text{P}_2\text{O}_5$ ratio >1.8). The minor andesitic/trachyandesitic component may only be present in low numbers, and has only been found in three sites on the Faroe Islands. The Mjávøtn Tephra has so far only been found in lake sediments on the Faroes and not in peat.

3.2.4. Hov Tephra (5.9 ka BP)

The Hov Tephra is one of few basaltic tephtras found in peat on the Faroe Islands. It was found at the same depth as the SILK-A1 Tephra in Hovsdalur, and radiocarbon dating suggests an age around 5900 cal yr BP (Wastegård, 2002). It should be noted however, that ages in Hovdalur are uncertain due to a low and variable peat accumulation rate. Grímsvötn has been suggested as the source volcanic system (Wastegård, 2002) but the Hov Tephtras also has affinities of the Kverkfjöll volcanic system, north of Vatnajökull (cf. Óladóttir et al., 2011), e.g. MgO contents below 5 wt% for several analyses (Figure 2). Kverkfjöll has not erupted in historical times and is less active than most other basaltic systems on Iceland. Its highest eruption frequency was in the middle part of the Holocene, between 6000 and 5000 cal yr BP (Óladóttir et al., 2011), and especially between 5500-5200 cal yr BP (Gudmundsdóttir et al., 2016).

3.2.5. Hekla-4 Tephra (4.3 ka BP)

Hekla-4 is one of the two largest eruptions of Hekla together with Hekla-3. The erupted material has been estimated to 9 km³ and cryptotephra records are widely dispersed across mainland Europe (e.g. Davies et al., 2010; Lawson et al., 2012). Records of it have been made both in peat and in lake sediment on the Faroe Islands (e.g. Persson, 1968; Dugmore and Newton, 1998; Wastegård et al., 2001) and Hekla-4 is a visible horizon in lake sediment sequences and in peat and cuttings together with the c. 600 year younger Hekla-S Tephra (Figure 8). Hekla has a zoned magma and rhyolitic products dominate the Plinian phase, followed by more intermediate and even basaltic products. All analyses of the Hekla-4, Hekla-S and Hekla-3, Hekla-1/Hekla-1158 and Hekla-1845 from the Faroe Islands are plotted in Figure 9, including previously unpublished results from Havnardalsmyren, Gróthusvatn and Starvatn (Figure 1B; App. A). Intermediate and rhyolitic tephra dominate in all sites.

3.2.6. Hekla-S Tephra (3.7 ka BP)

Hekla-S was originally described as Hekla-2 on Iceland (Thorarinsson, 1951), but was later found to be older than Hekla-3 and the name was changed to Hekla-Selsund or simply Hekla-S, after the site Selsund on Iceland c. 15 km SW of Hekla (Thorarinsson and Larsen, 1977). Hekla-S has also been referred to as the Kebister Tephra on Shetland (Dugmore et al., 1995). Hekla-S is one of the largest eruptions of Hekla in prehistoric time, and the tephra was dispersed mainly towards the east. Several records have been made on the Faroe Islands, Shetland and Scandinavia (e.g. Wastegård et al., 2008). The Faroe Island records cover almost

the whole geochemical envelope for Hekla, from the rhyolitic shards erupted during the initial phase, to the basaltic andesite shards from later phases (Figure 9; App. A).

3.2.7. Hekla-3 Tephra (3.0 ka BP)

Although regarded as the most voluminous eruption of Hekla, and possibly the largest Late Quaternary eruption on Iceland, the Hekla-3 Tephra is less widely dispersed than many other Icelandic tephtras. Only one record has been made on the British Isles (Swindles et al., 2011) and the only Faroe record is from Brúnavatn on Streymoy (Olsen et al., 2010a). The main dispersal was to the north and northeast (Larsen and Thorarinsson, 1977) and it appears that sites south and southeast of Iceland were relatively unaffected by the ash cloud. It is also worth to mention that none of the mid Holocene tephtras from Hekla, Hekla-4, Hekla-S and Hekla-3 have been found in the Greenland ice cores so far (Coulter et al., 2012).

3.2.8. Tjørnuvík Tephra, 800s AD

An intermediate to silicic tephra of Hekla affinity has been found in three lake and peat sequences on the Faroe Islands, close in time to the first palaeobotanical evidence of human settlement on the Faroe Islands (e.g. Hannon and Bradshaw, 2000; Wastegård et al., 2001, 2003). Furthermore, it occurs together with shards correlated with the basaltic phase of the Landnám Tephra in two sites, Tjørnuvík on Stremoy and Hovsdalur on Suduroy (Figure 1B), suggesting an age in the second half of the 9th Century AD (Wastegård et al., 2001; Wastegård, 2002). The geochemistry, ranging from trachytic/andesitic to rhyolitic compositions suggests the Tjørnuvík Tephra is the product of a relatively large eruption from Hekla (Figure 10). A large, late pre-Landnám rhyolitic eruption of Hekla has, however, not been identified in Iceland and the period between Hekla 3 and Landnám (c. 3000 cal yr BP-870s AD) is characterized by relatively small-scale eruptions of Hekla, dominated by tephra of andesitic-dacitic compositions (Meara, 2011). A closer look at the geochemistry of the Tjørnuvík Tephra reveals that shards similar to both Hekla-4 and Hekla-S dominate at all three sites (Figure 10), and an alternative explanation is that the Tjørnuvík Tephra consists of reworked shards from the large Hekla-4 and Hekla-S eruptions. Reworking and redistribution of tephra during the Landnám phase due to soil erosion and increased mobilization of wind-blown sediment (cf. Edwards et al., 2005) is a possible explanation for the occurrence of the “Tjørnuvík Tephra” in sediments dated to the 9th Century AD on the Faroe Islands.

There are, however, some indications that the Tjørnuvík Tephra, or at least some parts of it, may be a primary deposit. Chambers et al. (2004) described a tephra, MOR-T6 from an eruption of Hekla found in a lake sediment sequence in western Ireland, with an estimated age of c. AD 840. The geochemistry partly matches the Tjørnuvík Tephra (Figure 10), but most analyses of the MOR-T6 tephra are tightly clustered and do not cover the whole range from andesitic to highly rhyolitic shards. Until more evidence for a large eruption of Hekla in the 9th Century AD comes forward, the identification of the Tjørnuvík tephra as a primary deposit remains inconclusive.

3.2.9. Landnám Tephra, 870s AD

The basaltic phase of the Landnám Tephra has been reported from Tjørnuvík, Eidi bog and Hovsdalur, with highest concentration at the latter site. As mentioned above, it occurs together with the Tjørnuvík Tephra in sediments dated to the first settlement phase (e.g. Wastegård et al., 2001). The Landnám Tephra or the Settlement Tephra is a product of a simultaneous silicic and basaltic eruption of the Torfajökull and Bárðarbunga-Veiðivötn volcanic systems, dated to the 870s AD in the Greenland ice-cores (e.g. Grönvold et al., 1995). The basaltic eruption is one of the largest in Iceland during the Holocene, with a tephra volume of >3.3 km³ (Larsen, 1984). The basaltic component has also been found in Scottish fjord sediments (Cage et al., 2011), which indicates that one axis of dispersal was directed to the south. Reworking from older deposits in the Faroe Islands cannot be excluded, as in the case with the Tjørnuvík Tephra. However, no older tephras with a geochemistry matching the Landnám Tephra have been found on the Faroe Islands, and the only tephra with Bárðarbunga-Veiðivötn affinity, the Sandoy A & B tephras (see above), are higher in e.g. MgO and lower in FeO_{tot} (Figure 2). We therefore consider the Landnám Tephra to be a primary deposit on the Faroe Islands.

3.2.10. Hekla-1 Tephra (AD 1104)/Hekla-1158 Tephra

The AD 1104 event was the largest Hekla eruption in historical times (Thorarinsson, 1967), and the tephra layer is one of the most important late Holocene isochrons in Icelandic terrestrial and marine records in Europe (e.g. Larsen and Thorarinsson, 1977; Boyle, 1999; Larsen et al., 1999, 2002). It is widely dispersed and found at distal sites in Europe (e.g. Pilcher et al., 2005; Chambers et al., 2004; Watson et al., 2016). Hekla-1 can be separated from other historical Hekla tephras in plots of K₂O/TiO₂ and is more evolved than any other historical tephra from

Hekla (Larsen et al., 1999). Hitherto, the only Faroe record of Hekla-1 is from Lake Brúnavatn on Streymoy (Olsen et al., 2010a). A closer look at the geochemistry, however, reveals that some shards have a more andesitic composition with CaO contents of c. 3.7-3.8 wt% and FeO_{tot} of 5.7-5.9 wt% and probably derive from the slightly younger eruption of Hekla in AD 1158. Thus, the horizon in Brúnavatn has a mixed composition with shards from the Hekla-1 and Hekla-1158 eruptions.

3.2.11. Hekla-1845 Tephra (?)

The youngest tephra in the Hovsdalur peat record has a predominantly andesitic composition and follows the Hekla evolution trend (Figure 8). The explosive opening phase of the eruption lasted one hour and produced ca 0.13 km³ tephra (0.03 km³ DRE) (Gudnason et al., 2018) and contemporary records describe ash fallout on Faroe Islands, Shetland and Orkney (Wastegård and Davies, 2009; Gudnason et al., 2018). Tephra from this eruption has also been reported from the Fallahogy peatland in Northern Ireland (Watson et al., 2015). Hekla has erupted at least 17 times since the large eruption in AD 1104 (Hekla-1) and most of the eruptives are dominated by andesitic glass with similar compositions. Tephra from the eruptions in 1158, 1510, 1845 and 1947 have so far been found in distal areas (e.g. Dugmore et al., 1995; Swindles et al., 2010; Watson et al., 2015 and 2017), but it cannot be excluded that tephra from other historical eruptions, e.g. the relatively large eruptions in 1693 and 1766 also reached the European mainland. The correlation of the tephra in Hovsdalur with Hekla-1845 is corroborated by the fact that ash fallout was recorded on Suduroy, 3 September 1845 (Wastegård and Davies, 2009).

4. Discussion

4.1. Tephras in the Faroe Islands as potential isochrones

Several tephras found on the Faroe Islands have a potential for constraining leads and lags in the climate system during the Holocene. The early Preboreal climate evolution of northwestern Europe was complex, and accurate dating and comparison of palaeoclimate data is often problematic, due in part to the two radiocarbon plateaux occurring at this time (e.g. Björck et al., 1997; van der Plicht et al., 2004). Consequently the Hässeldalen, Askja-S and Saksunarvatn tephras are particularly important markers for synchronising climate records

from the early Holocene, and for assessing whether climate re-organisations were synchronous/asynchronous at continental and hemispheric scales. The Håsseldalen Tephra is often reported to occur in conjunction with the PBO, c. 11.40-11.25 ka yrs BP, although the timing and impact of this oscillation may differ between areas (e.g. Björck et al., 1997; Bos et al., 2007). The Håsseldalen Tephra has been reported from lake sediments from Denmark and Sweden (e.g. Davies et al., 2003; Lilja et al., 2013; Larsen and Noe-Nygaard, 2014), at most sites a few cm above the onset of the rapid warming at the Younger Dryas-Preboreal boundary, but clearly below the PBO. In the Faroe Islands it occurs near the bottom of the sequence in the Høvdarhagi bog, but a clear indication of the PBO has not been seen at this site or in Lykkjuvøtn where sedimentation began at c. 11.28 ka, i.e. during the PBO (Jessen et al., 2008). At Endiger Bruch, NE Germany, the Håsseldalen Tephra occurs after the organic matter curve has reached its Holocene levels (Lane et al., 2012b), which indicates that organic sedimentation started slightly earlier in Germany than in Scandinavia. At Lake Czechowskie, Poland, the Håsseldalen Tephra has been found in varved sediments, along with the Askja-S Tephra (Ott et al., 2016), although the time span between the tephras is in disagreement with other records (Wohlfarth et al., 2006; Lind and Wastegård, 2011). Here, the PBO is indicated by a minor increase in Ti counts, possibly indicating a response to a drier climate. In south-east Sweden PBO is bracketed by the Håsseldalen and Askja-S tephras (Davies et al., 2003; Wohlfarth et al., 2006).

The climate oscillation at c. 10.3 ka BP is less pronounced than the PBO in the Greenland ice-cores (Rasmussen et al., 2007), but the lake sediment record from Lake Starvatn on Eysturoy (Figure 1B) shows a clear climate perturbation, starting c. 50-100 years before the deposition of the Saksunarvatn Ash (Björck et al., 2001), and lasting for at least another 100 years. Evidence for a climate deterioration in connection with the Saksunarvatn Ash has also been suggested from lakes in northern Germany (Merkt et al., 1993), but elsewhere, e.g. in lake sediment records from western Norway, there is no clear evidence for a climate event close to the ash fallout (cf. Aarnes et al., 2012; Lind et al., 2013). Glacial re-advances at the Preboreal-Boreal transition in Norway, the so-called Erdalen events (10.10-10.05 ka BP and 9.7 ka BP; Dahl et al., 2002) apparently postdates the Saksunarvatn Ash and the 10.3 ka event, although the dating is uncertain. However, exact correlations using the Saksunarvatn Ash are hampered by the fact that it might be a result of several eruptions close in time (e.g. Davies et

al., 2012; Bramham-Law et al., 2013). It may be that the Fosen, An Druim and Skopun tephras in the future could be useful markers for the Preboreal-Boreal climate events in the North Atlantic region.

The Suduroy tephra is a potential marker horizon for the 8.2 ka BP event (e.g. Alley et al., 1997) as well as for the Storegga tsunami event in Norway (Bugge et al. 1987; Bondevik et al. 1997), which also affected the Faroe Islands (Grauert et al. 2001). It seems to have had a widespread distribution in the North Atlantic region (e.g. Wastegård, 2002; Kristjansdóttir et al., 2007; Jennings et al., 2014), although some records may consist of reworked shards from older deposits with rhyolitic Vedde-type tephra. The Suduroy Tephra has only been traced in one site on the Faroe Islands and more work is needed to confirm that it is a primary deposit and that it can be discriminated from the 4000 year older Vedde Ash.

There are comparably few widespread Icelandic tephras in the middle Holocene, i.e. between c. 8000 and 4500 cal yr BP and a reduction in Icelandic volcanism around 5.5-4.5 ka yr BP has been suggested (Swindles et al., 2017). The Mjáuvøtn Tephra dated to c. 6600 cal yr BP has a potential to become an important marker for the middle Holocene although its relation with other middle Holocene tephras from Katla needs to be better resolved. It is, however, possible that several findings of basaltic tephra from Katla indeed can be correlated with the Mjáuvøtn Tephra, including the Tv-5 Tephra in northern Iceland and the K-6750 Tephra in western Iceland. However, more geochemical data is needed to confirm these links, also including analyses of minor and trace elements.

The three middle to late Holocene tephras from Hekla: Hekla-4, Hekla-S and Hekla-3 are important isochrones in north-western Europe, although relatively few studies have fully exploited these tie-points to assess regional differences/time lags in the responses of the climate system (e.g. van den Bogaard et al., 2002; Langdon and Barber, 2004; Plunkett, 2006; Wastegård et al., 2008). Hekla-4 and Hekla-S occur within a time period when several palaeoclimate archives around the North Atlantic show increasing wetness and a general cooling trend (e.g. Anderson et al., 1998; Lauritzen and Lundberg, 1999; Hammarlund et al., 2003; Mayewski et al., 2004). Hekla-4 is dated to c. 4260 ± 20 cal BP (Pilcher et al., 1995) which immediately predates the 4.2 ka event and the proposed mid- to late Holocene boundary at 4200 cal yr BP (Walker et al., 2012). The exact age of the Hekla-4 eruption is, however, not

known, and some varve records indicate an age closer to 4400 cal yr BP for this eruption (Zillén et al., 2002; Dörfler et al., 2012). The Faroe Islands experienced a cooling trend in climate at c. 4200 cal yr BP when lake ice occurrence and wind activity increased (Andresen et al., 2006). Hence Hekla-4 has the potential to enable detailed correlations between peat and lake sediment records around this oscillation.

The youngest tephra that has a potential to serve as a regional isochron on the Faroe Islands is the basaltic Landnám Tephra. The earliest archaeological evidence for human colonization of the Faroe Islands has been dated to the 4th-6th centuries AD, some hundreds of years earlier than originally proposed by archaeologists (Hannon and Bradshaw, 2000; Church et al., 2013) and the Landnám Tephra may serve as a dating horizon for the early settlement phase on the Faroe Islands. We advise against using the Tjørnuvík Tephra as a marker horizon, since it may consist of reworked shards from the Hekla-4 and Hekla-5 eruptions.

4.2. *Apparent absent tephras*

Some tephras of Icelandic origin are widespread in north-western European bogs but have not been described from the Faroe Islands. These include the Lairg A & B layers, Øræfajökull-1362 and Askja-1875 (e.g. Dugmore et al., 1995; Hall and Pilcher, 2002; van den Bogaard & Schmincke, 2002; Bergman et al., 2003). Only a few peat records from the Faroe Islands have been investigated in detail and there are several possible explanations for this apparent absence of these widespread tephras. One is that ash fallout never occurred on the Faroe Islands which might explain the absence of Askja-1875 that has a relatively narrow eastern dispersal from its vent (Carey et al., 2011). Another reason for tephra absence is that peat-cutting has removed younger peat, especially in areas close to human settlements (e.g. Lawson et al., 2007).

The almost total absence of basaltic tephra in peat is striking. This has been discussed elsewhere by e.g. Wastegård and Davies (2009) who suggested that post-depositional processes due to extremely acid conditions may have affected the basaltic glass in peat (Wolff-Boenish et al., 2004; Pollard and Heron, 2008). The ombrotrophic peat sequences that have been investigated (Persson, 1968; *this paper*) have only recorded a few basaltic shards, despite the fact that historic sources have documented ash fallout during several basaltic eruptions. Basaltic tephra seems to have better preservation in lake sediment sequences in the Faroe

Islands and elsewhere (e.g. Chambers et al., 2004; Davies et al., 2007). This could also explain the absence of the basaltic Mjáuvøtn tephra in peat sequences on the Faroe Islands.

4.3. *Saksunarvatn Ash: a product of several eruptions?*

The Saksunarvatn Ash is a remarkably widespread basaltic tephra and was initially regarded to represent a single continuous volcanic event in the early Holocene (e.g. Mangerud et al., 1986; Björck et al., 1992; Birks et al., 1996). The volume has been estimated at >450 km³, which would make it by far the largest explosive eruption of an Icelandic volcano, about 40 times bigger than the Hekla-3 and Hekla-4 eruptions (Thordarson, 2014). The Saksunarvatn Ash as a product of a single eruption has therefore been questioned, and recent studies of lake sediment cores from western Iceland have shown that three tephra layers of Saksunarvatn composition occur in close succession (Jóhannsdóttir, 2007). In marine cores west of Iceland, three layers with a geochemical composition consistent with the Saksunarvatn Ash were found in sediments dated between c. 10.4 and 9.9 ka BP (Jennings et al., 2014). However, most terrestrial sites in NW Europe only report one single layer (e.g. Mangerud et al., 1986; Grönvold et al., 1995; Birks et al., 1996; Björck et al., 2001; Wastegård et al., 2001; Jessen et al., 2007; Bramham-Law et al., 2013; Lind et al., 2013). Trace element compositions, however, indicate that tephras in the south-east (i.e. Faroe Islands, Scotland Scandinavia and Germany) and north-west (i.e. Greenland ice-cores and Greenland shelf cores) probably represent separate eruption events (Davies et al., 2012; Bramham-Law et al., 2013). Furthermore, a slight offset between major element geochemistry has been observed between datasets from Greenland and a North Atlantic marine core (Davies et al., 2012).

The full dataset from Havnardalsmyren is presented here for the first time (Figure 9, App. A and B). A pilot study aiming at identifying cryptotephra layers using XRF core-scanning revealed at last four basaltic cryptotephras (Havn-0, Havn-2, Havn-3 and Havn.4 from top to bottom)* and a visible 2-3 cm thick, black macrotephra layer (Havn-1)* over a core interval of c. 30 cm. We assume that the visible layer can be correlated with other Saksunarvatn Ash deposits in the Faroe Islands, Norway and Germany. High Ti, Ca, K, Fe, Mn and Sr counts were interpreted as tephra signals concordant with peaks in tephra concentration documented by Kylander et al. (2012). The main focus of the investigation was, however, not to separate the layers geochemically, but we conclude that there are clear differences between the two

lowest cryptotephra layers (Havn-3 and Havn-4) and the other layers, including the visible macrotephra. The lower cryptotephra Havn-3 and Havn-4 have lower MgO values (c. 4.5-5.0 wt%) compared with the visible layer (Havn-1) and the upper cryptotephra layers (Havn-0 and Havn-2) (Figure 11; Table 3; App. A). The lower cryptotephra, Havn-3 and Havn-4, also have slightly elevated SiO₂ concentrations compared with the other layers, but this is discernible only if the results are normalised (App. A). The peaks in tephra concentration are situated at c. 2-3 cm (Havn-2), 11 cm (Havn-3) and 18 cm (Havn-4) below the visible Saksunarvatn Ash (Havn-1). Linear interpolation between the visible Saksunarvatn Ash (Havn-1) and Askja-S Tephra suggests that the Havn-2 layer has an age of c. 10.25 ka yr BP, Havn-3 c. 10.3-10.4 ka yr and Havn-4 c. 10.35-10.45 ka yr BP. The ages are approximate, and higher ages would be inferred if we use the age for the Askja-S Tephra suggested by Ott et al. (2016), 11,228 ± 226 cal BP. The uppermost layer, Havn-0, has a higher number of shards from other volcanic systems (Katla and Veidivötn) than the cryptotephra below the macrotephra (Havn-1) (Figure 11; App. 1), and it suggests that this layer mainly consists of reworked tephra from the visible Saksunarvatn horizon and other tephra deposits.

**The Grímsvötn tephra at Havnardalsmyren were originally labelled H-1, H-2 etc. by Kylander et al., (2012) but we have avoided this terminology to avoid confusion with tephra from the Hekla volcano.*

An extensive review of published proximal and distal Saksunarvatn Ash data shows that MgO values typically exceed 5.3 wt% (Table 3) and we have only found one record with comparable low MgO values and slightly elevated SiO₂ values as in the H3 and H4 cryptotephra. This record is from Loch Ashik on Isle of Skye in western Scotland and was first reported by Pyne-O'Donnell (2007), although the geochemical data did not conclusively support a correlation with the Saksunarvatn Ash. A new analysis of material from the layer correlated with the Saksunarvatn Ash was presented by Kelly et al. (2017) and these data cluster more closely with other reported occurrences of the tephra. The MgO values are, however, almost 1% lower than in any other reported record of the Saksunarvatn Ash, except the H3 and H4 cryptotephra in Havnardalsmyren. The Saksunarvatn Ash has a vertical spread of c. 10 cm at Loch Ashik (Pyne-O'Donnell, 2007, Figure 2) and it is possible that it consists of material from several eruptions of Grímsvötn, including material from the Saksunarvatn precursors, H3 and H4. Other sites in Scotland (Bennett et al., 1992; Bunting, 1994; Timms et al., 2017) report MgO values >5 wt% in accordance with most other records of the Saksunarvatn Ash. Our

results confirm that the Saksunarvatn Ash is a product of several eruptions in the Grímsvötn volcanic system during 300-400 years but the Saksunarvatn Ash complex continues to be problematic. The identification of the low-Mg Saksunarvatn precursors Havn-3 and Havn-4 is significant. It is the first time that major element geochemistry clearly can separate between different components of the Saksunarvatn Ash-complex, and we suggest that future investigations of sequences with the Saksunarvatn Ash aims at finding basaltic cryptotephra below and above the visible horizon. The apparent lack of low-Mg Grímsvötn tephra west and north of Iceland (Jóhannsdóttir, 2007; Jennings et al., 2014) suggests that this component only was dispersed towards the east and south.

5. Conclusions

A tephra framework is of great value for palaeoclimatic studies in distal areas. The interest in distal tephra studies has been growing over the last 20 years due to new techniques for extracting cryptotephra from minerogenic deposits (e.g. Turney, 1998) and the number of identified tephra deposits has grown as well as the number of mapped distributions of several important marker layers. The Faroe Islands hold a key position for linking the proximal tephrochronology in Iceland with distal tephra networks on the European continent and the British Isles.

Some of the key Holocene tephra are well represented on the Faroe Islands and may therefore provide more precise ages than elsewhere with further study. Examples of this are the early Holocene Hässeldalen and Askja-S tephra. Another is the Mjáuvötn Tephra which has a potential to become an important marker for the middle Holocene although its relation with other middle Holocene tephra from Katla needs to be better resolved (cf. Jennings et al., 2014). Tephra found in close connection with some of the most pronounced climatic events during the Holocene can provide opportunities to find time lags in the climate system and thereby increase the understanding of climate dynamics. The Hässeldalen and Askja-S tephra provide useful isochrons for the PBO, the Suduroy Tephra for the 8.2 ka BP event and Hekla-4 for the 4.2 ka BP event. The Faroe Islands is probably also the best area outside Iceland for unravelling the complex nature of the Saksunarvatn Ash complex. Results from Havnardalsmyren suggest that up to five tephra from Grímsvötn were deposited within a sediment interval of 25 cm equivalent of c. 300-400 years, and major element geochemistry

shows that the two oldest cryptotephra have a geochemical signature which separates them from most other Saksunarvatn Ash deposits in the North Atlantic region.

5.1.1. Acknowledgements

We thank Anders Borgmark, Marianne Grauert and Liselott Wilin for assistance during fieldwork. Anthony Newton and Chris Hayward are acknowledged for their help with microprobe analyses at the Tephra Analytical Unit, University of Edinburgh, UK. Ian Snowball, Uppsala University, Sweden provided the photo. Funding to SW for salaries, fieldwork and analyses was provided by the Swedish Research Council (grant 2006-5868).

References

- Aarnes, I., Kuhl, N., Birks, H.H., 2012. Quantitative climate reconstruction from late-glacial and early Holocene plant macrofossils in western Norway using the probability density function approach. *Review of Palaeobotany and Palynology* 170, 27-39.
- Alley, R., Mayewski, P., Sowers, T., Stuiver, M., Taylor, K., Clark, P., 1997. Holocene climatic instability: a prominent, widespread event 8200 yr ago. *Geology* 25, 483-486.
- Anderson, D.E., Binney, H.A., Smith, M., 1998. Evidence for abrupt climatic change in northern Scotland between 3900 and 3500 calendar years BP. *The Holocene* 8, 97-103.
- Andresen, C.S., Björck, S., Rundgren, M., Conley, D.J., Jessen, C., 2006. Rapid Holocene climate changes in the North Atlantic: evidence from lake sediments from the Faroe Islands. *Boreas* 35, 23-34.
- Baillie, M.G.L., Munro, M.A.R., 1988. Irish tree rings, Santorini and volcanic dust veils. *Nature* 332, 344-346.
- Bennett, K.D., Boreham, S., Sharp, M.J., Switsur, V.R., 1992. Holocene History of Environment, Vegetation and Human Settlement on Catta Ness, Lunnasting, Shetland. *Journal of Ecology* 80, 241-273.
- Bergman, J., Wastegård, S., Hammarlund, D., Wohlfarth, B., Roberts, S.J., 2004. Holocene tephra horizons at Klocka Bog, west-central Sweden: aspects of reproducibility in subarctic peat deposits. *Journal of Quaternary Science* 19, 241-249.
- Birks, H.H., Gullksen, S., Hafliðason, H., Mangerud, J., 1996. New Radiocarbon Dates for the Vedde Ash and the Saksunarvatn Ash from Western Norway. *Quaternary Research* 45, 119-127.
- Björck, S., Ingólfsson, Ó., Hafliðason, H., Hallsdóttir, M., Anderson, N.J., 1992. Lake Torfadalsvatn; a high resolution record of the North Atlantic ash zone I and the last glacial-interglacial environmental changes in Iceland. *Boreas* 21, 15-22.
- Björck, S., Muscheler, R., Kromer, B., Andresen, C.S., Heinemeier, J., Johnsen, S.J., Conley, D., Koç, N., Spurk, M., Veski, S., 2001. High-resolution analyses of an early Holocene climate event may imply decreased solar forcing as an important climate trigger. *Geology* 29, 1107-1110.
- Björck, S., Rundgren, M., Ingólfsson, Ó., Funder, S., 1997. The Preboreal oscillation around the Nordic Seas: terrestrial and lacustrine responses. *Journal of Quaternary Science* 12, 455-465.
- Blockley, S.P.E., Bourne, A.J., Brauer, A., Davies, S.M., Hardiman, M., Harding, P.R., Lane, C.S., MacLeod, A., Matthews, I.P., Pyne-O'Donnell, S.D.F., Rasmussen, S.O., Wulf, S., Zanchetta, G., 2014. Tephrochronology and the extended intimate (integration of ice-core, marine and terrestrial records) event stratigraphy 8-128 ka b2k. *Quaternary Science Reviews* 106, 88-100.
- Bondevik, S., Svendsen, J.I., Mangerud, J., 1997. Tsunami sedimentary facies deposited by the Storegga tsunami in shallow marine basins and coastal lakes, western Norway. *Sedimentology* 44, 1115-1131.

- Borgmark, A., Wastegård, S., 2008. Regional and local patterns of peat humification in three raised peat bogs in Värmland, south-central Sweden. *GFF* 130, 161-176.
- Bos, J.A.A., van Geel, B., van der Plicht, J., Bohncke, S.J.P., 2007. Preboreal climate oscillations in Europe: Wiggle-match dating and synthesis of Dutch high-resolution multi-proxy records. *Quaternary Science Reviews* 26, 1927-1950.
- Boygles, J.E., 1994. Tephra in lake sediments: An unambiguous geochronological marker? PhD Thesis, University of Edinburgh, Edinburgh.
- Boygles, J., 1998. A little goes a long way: discovery of a new mid-Holocene tephra in Sweden. *Boreas* 27, 195-199.
- Boygles, J., 1999. Variability of tephra in lake and catchment sediments, Svínavatn, Iceland. *Global and Planetary Change* 21, 129-149.
- Bunting, J., 1994. Vegetation history of Orkney, Scotland: pollen records from two small basins in west Mainland. *New Phytologist* 128, 771-792.
- Bramham-Law, C.W.F., Theuerkauf, M., Lane, C.S., Mangerud, J., 2013. New findings regarding the Saksunarvatn Ash in Germany. *Journal of Quaternary Science* 28, 248-257.
- Bronk Ramsey, C., Albert, P.G., Blockley, S.P.E., Hardiman, M., Housley, R.A., Lane, C.S., Lee, S., Matthews, I.P., Smith, V.C., Lowe, J.J., 2015. Improved age estimates for key Late Quaternary European tephra horizons in the RESET lattice. *Quaternary Science Reviews* 118, 18-32.
- Bronk Ramsey, C., Lee, S., 2013. Recent and planned developments of the program OxCal. *Radiocarbon* 55, 720-730.
- Bugge, T., Befring, S., Belderson, R.H., Eidvin, T., Jansen, E., Kenyon, N.H., Holtedahl, H., Sejrup, H.P., 1987. A giant three-stage submarine slide off Norway. *Geo-Marine Letters* 4, 191-198.
- Cage, A.G., Davies, S.M., Wastegård, S., Austin, W.E.N., 2011. Identification of the Icelandic Landnám tephra ($AD\ 871 \pm 2$) in Scottish fjordic sediment. *Quaternary International* 246, 168-176.
- Carey, R.J., Houghton, B.F., Thordarson, T., 2010. Tephra dispersal and eruption dynamics of wet and dry phases of the 1875 eruption of Askja Volcano, Iceland. *Bulletin of Volcanology* 72, 259-278.
- Chambers, F.M., Daniell, J.R.G., Hunt, J.B., Molloy, K., O'Connell, M., 2004. Tephrostratigraphy of An Loch Mór, Inis Oírr, western Ireland: implications for Holocene tephrochronology in the northeastern Atlantic region. *The Holocene* 14, 703-720.
- Church, M.J., Arge, S.V., Edwards, K.J., Ascough, P.L., Bond, J.M., Cook, G.T., Dockrill, S.J., Dugmore, A.J., McGovern, T.H., Nesbitt, C., Simpson, I.A., 2013. The Vikings were not the first colonizers of the Faroe Islands. *Quaternary Science Reviews* 77, 228-232.
- Coulter, S.E., Pilcher, J.R., Plunkett, G., Baillie, M., Hall, V.A., Steffensen, J.P., Vinther, B.M., Clausen, H.B., Johnsen, S.J., 2012. Holocene tephras highlight complexity of volcanic signals in

Greenland ice cores. *Journal of Geophysical Research-Atmospheres* 117-D21. DOI: 10.1029/2012JD017698

Dahl, S., Nesje, A., Lie, Ø., Fjordheim, K., Matthews, J., 2002. Timing, equilibrium-line altitudes and climate implications of two early-Holocene glacier advances during the Erdalen event at Jostedalsbreen, western Norway. *The Holocene* 12, 17-25.

Davies, S.M., Abbott, P.M., Pearce, N.J.G., Wastegård, S., Blockley, S.P.E., 2012. Integrating the INTIMATE records using tephrochronology: rising to the challenge. *Quaternary Science Reviews* 36, 11-27.

Davies, S.M., Elmquist, M., Bergman, J., Wohlfarth, B., Hammarlund, D., 2007. Cryptotephra sedimentation processes within two lacustrine sequences from west central Sweden. *The Holocene* 17, 319-330.

Davies, S.M., Larsen, G., Wastegård, S., Turney, C.S.M., Hall, V.A., Coyle, L., Thordarson, T., 2010. Widespread dispersal of Icelandic tephra: how does the Eyjafjöll eruption of 2010 compare to past Icelandic events? *Journal of Quaternary Science* 25, 605-611.

Davies, S.M., Wastegård, S., Wohlfarth, B., 2003. Extending the limits of the Borrobol Tephra to Scandinavia and detection of new early Holocene tephtras. *Quaternary Research* 59, 345-352.

Dugmore, A., 1989. Icelandic volcanic ash in Scotland. *Scottish Geographical Magazine* 105, 168-172.

Dugmore, A.J., Larsen, G., Newton, A.J., 1995. Seven tephra isochrones in Scotland. *The Holocene* 5, 257-266.

Dugmore, A.J., Newton, A.J., 1998. Holocene Tephra Layers in the Faroe Islands. *Fróðskaparrit* 46, 191-204.

Dörfler, W., Feeser, I., van den Bogaard, C., Dreibrodt, S., Erlenkeuser, H., Kleinmann, A., Merkt, J., Wiethold, J., 2012. A high-quality annually laminated sequence from Lake Belau, Northern Germany: Revised chronology and its implications for palynological and tephrochronological studies. *The Holocene* 22, 1413-1426.

Edwards, K., Craigie, R., 1998. Palynological and vegetational changes associated with the deposition of the Saksunarvatn Ash in the Faroe Islands. *Fróðskaparrit* 46, 245-258.

Edwards, K.J., Borthwick, D., Cook, G., Dugmore, A.J., Mairs, K.A., Church, M.J., Simpson, I.A., Adderley, W.P., 2005. A hypothesis-based approach to landscape change in Suðuroy, Faroe Islands. *Human Ecology* 33, 621-650.

Eiríksson, J., Larsen, G., Knudsen, K.L., Heinemeier, J., Símonarson, L.A., 2004. Marine reservoir age variability and water mass distribution in the Iceland Sea. *Quaternary Science Reviews* 23, 2247-2268.

Grauert, M., Björck, S., Bondevik, S., 2001. Storegga tsunami deposits in a coastal lake on Suðuroy, the Faroe Islands. *Boreas* 30, 263-271.

- Grönvold, K., Óskarsson, K., Johnsen, S.J., Clausen, H.B., Hammer, C.U., Bond, G., Bard, E., 1995. Ash layers from Iceland in the Greenland GRIP ice core correlated with oceanic and land sediments. *Earth and Planetary Science Letters* 135, 149-155.
- Gudmundsdóttir, E.R., Larsen, G., Björck, S., Ingólfsson, Ó., Striberger, J., 2016. A new high-resolution Holocene tephra stratigraphy in eastern Iceland: Improving the Icelandic and North Atlantic tephrochronology. *Quaternary Science Reviews* 150, 234-239.
- Gudmundsdóttir, E.R., Larsen, G., Eiríksson, J., 2012. Tephra stratigraphy on the North Icelandic shelf: extending tephrochronology into marine sediments off North Iceland. *Boreas* 41, 718-734.
- Gudmundsson, M.T., Thordarson, T., Höskuldsson, A., Larsen, G., Björnsson, H., Prata, F.J., Oddsson, B., Magnusson, E., Högnadttir, T., Petersen, G.N., Hayward, C.L., Stevenson, J.A., Jonsdóttir, I., 2012. Ash generation and distribution from the April-May 2010 eruption of Eyjafjallajökull, Iceland. *Scientific Reports* 2. DOI: 10.1038/srep00572
- Gudnason, J., Thordarson, T., Houghton, B.F., Larsen, G., 2018. The 1845 Hekla eruption: Grain-size characteristics of a tephra layer. *Journal of Volcanology and Geothermal Research* 350, 33-46.
- Haflidason, H., Eiríksson, J., van Kreveland, S., 2000. The tephrochronology of Iceland and the North Atlantic region during the Middle and Late Quaternary: a review. *Journal of Quaternary Science* 15, 3-22.
- Hall, V.A., Pilcher, J.R., 2002. Late Quaternary Icelandic tephras in Ireland and Great Britain: detection, characterisation and usefulness. *The Holocene* 12, 223-230.
- Hammarlund, D., Björck, S., Buchardt, B., Israelson, C., Thomsen, C., 2003. Rapid hydrological changes during the Holocene revealed by stable isotope records of lacustrine carbonates from Lake Igelsjön, southern Sweden. *Quaternary Science Reviews* 22, 353-370.
- Hannon, G.E., Bradshaw, R.H.W., 2000. Impacts and timing of the first human settlement on vegetation of the Faroe Islands. *Quaternary Research* 54, 404-413.
- Hannon, G.E., Wastegård, S., Bradshaw, E., Bradshaw, R.H.W., 2001. Human impact and landscape degradation on the Faroe islands. *Proceedings of the Royal Irish Academy* 101B, 129-139.
- Hannon, G.E., Rundgren, M., Jessen, C.A., 2010. Dynamic early Holocene vegetation development on the Faroe Islands inferred from high-resolution plant macrofossil and pollen data. *Quaternary Research* 73, 163-172.
- Hayward, C., 2011. High spatial resolution electron probe microanalysis of tephras and melt inclusions without beam induced chemical modification. *The Holocene* 22, 119-125.
- Holmes, N., Langdon, P.G., Caseldine, C.J., Wastegård, S., Leng, M.J., Croudace, I.W., Davies, S.M., 2016. Climatic variability during the last millennium in Western Iceland from lake sediment records. *The Holocene* 26, 756-771.

- Horni, J.Á., Hopper, J.R., Blischke, A., Geisler, W.H., Stewart, M., McDermott, K., Judge, M., Erlendson, Ö., Árting, U., 2017. Regional distribution of volcanism within the North Atlantic Igneous Province. In: Péron-Pinvidic, G., Hopper, J.R., Stoker, M.S., Gaina, C., Doornenbal, J.C., Funck, T., Árting, U.E. (eds.): *The NE Atlantic Region: A Reappraisal of Crustal Structure, Tectonostratigraphy and Magmatic Evolution*. Geological Society of London, Special Publications 447. DOI: 10.1144/SP447.18
- Housley, R.A., Lane, C.S., Cullen, V.L., Weber, M.J., Riede, F., Gamble, C.S., Brock, F., 2012. Icelandic volcanic ash from the Late-glacial open-air archaeological site of Ahrenshoft LA 58 D, North Germany. *Journal of Archaeological Science* 39, 708-716.
- Housley, R.A., MacLeod, A., Nalepka, D., Jurochnik, A., Masojc, M., Davies, L., Lincoln, P.C., Ramsey, C.B., Gamble, C.S., Lowe, J.J., 2013. Tephrostratigraphy of a Lateglacial lake sediment sequence at Wegliny, southwest Poland. *Quaternary Science Reviews* 77, 4-18.
- Humlum, O., 1998. Rock glaciers on the Faeroe Islands, the North Atlantic. *Journal of Quaternary Science* 13, 293-307.
- Humlum, O., Christiansen, H.H., Svensson, H., Mortensen, L.E., 1996. Moraine Systems in the Faroe Islands: Glaciological and Climatological Implications. *Danish Journal of Geography* 96, 21-31.
- Jennings, A.E., Grönvold, K., Hilberman, R., Smith, M., Hald, M. 2002. High-resolution study of Icelandic tephras in the Kangerlussuaq Trough, southeast Greenland, during the last deglaciation. *Journal of Quaternary Science* 17, 747-757.
- Jennings, A., Thordarson, T., Zalzal, K., Stoner, J., Hayward, C., Geirsdóttir, Á., Miller, G., 2014. SE Greenland Shelf Archive of Icelandic and Alaskan Volcanic Eruptions during the Holocene. In: Austin, W., Abbott, P., Davies, S., Pearce, N., Wastegård, S. (eds.), *Marine Tephrochronology*. Geological Society, London. Special Publications., London, pp. 157-193.
- Jensen, B.J.L., Pyne-O'Donnell, S., Plunkett, G., Froese, D.G., Hughes, P.D.M., Sigl, M., McConnell, J.R., Amesbury, M.J., Blackwell, P.G., van den Bogaard, C., Buck, C.E., Charman, D.J., Clague, J.J., Hall, V.A., Koch, J., Mackay, H., Mallon, G., McColl, L., Pilcher, J.R., 2014. Transatlantic distribution of the Alaskan White River Ash. *Geology* 42, 875-878.
- Jessen, C.A., Rundgren, M., Björck, S., Muscheler, R., 2007. Climate forced atmospheric CO₂ variability in the early Holocene: A stomatal frequency reconstruction. *Global and Planetary Change* 57, 247-260.
- Jessen, C.A., Rundgren, M., Björck, S., Andresen, C.S., Conley, D., 2008. Variability and seasonality of North Atlantic climate during the early Holocene. *The Holocene* 18, 851-860.
- Jóhannsdóttir, G., 2007. Mid Holocene to late glacial tephrochronology in West Iceland as revealed in three lacustrine environments. MSc Thesis. Department of Geology and Geography. University of Iceland, Reykjavík.
- Jóhansen, J., 1985. Studies in the vegetational history of the Faeroe and Shetland Islands. PhD Thesis. University of Copenhagen, 117 pp.

- Johansson, H., Lind, E., Wastegård, S., 2017. Compositions of glass in proximal tephras from eruptions in the Azores archipelago and their links with distal sites in Ireland. *Quaternary Geochronology*, 40, 120-128.
- Jónasson, K., 2007. Silicic volcanism in Iceland: Composition and distribution within the active volcanic zones. *Journal of Geodynamics* 43, 101-117.
- Jones, G., Davies, S.M., Farr, G.J., Bevan, J., 2017. Identification of the Askja-S Tephra in a rare turlough record from Pant-y-Llyn, south Wales. *Proceedings of the Geologists' Association* 128, 523-530.
- Kelly, T., Hardiman, M., Lovelady, M., Lowe, J., Matthews, I.P., Blockley, S.P.E., 2017. Scottish early Holocene vegetation dynamics based on pollen and tephra records from Inverlair and Loch Etteridge, Inverness-shire. *Proceedings of the Geologists' Association* 128, 125-131.
- Kristjansdóttir, G.B., Stoner, J.S., Jennings, A.E., Andrews, J.T., Grönvold, K., 2007. Geochemistry of Holocene cryptotephras from the north Iceland shelf (MD99-2269): intercalibration with radiocarbon and palaeomagnetic chronostratigraphies. *The Holocene* 17, 155-176.
- Kylander, M., Lind, E.M., Wastegård, S., Löwemark, L., 2012. Recommendations for using XRF core scanning as a tool in tephrochronology. *The Holocene* 22, 371-375.
- Lane, C.S., Andrič, M., Cullen, V.L., Blockley, S.P.E., 2011a. The occurrence of distal Icelandic and Italian tephra in the Lateglacial of Lake Bled, Slovenia. *Quaternary Science Reviews* 30, 1013-1018.
- Lane, C.S., Blockley, S.P.E., Bronk Ramsey, C., Lotter, A.F., 2011b. Tephrochronology and absolute centennial scale synchronisation of European and Greenland records for the last glacial to interglacial transition: A case study of Soppensee and NGRIP. *Quaternary International* 246, 145-156.
- Lane, C.S., Blockley, S.P.E., Mangerud, J., Smith, V.C., Lohne, Ø.S., Tomlinson, E.L., Matthews, I.P., Lotter, A.F., 2012a. Was the 12.1 ka Icelandic Vedde Ash one of a kind? *Quaternary Science Reviews* 33, 87-99.
- Lane, C.S., De Klerk, P., Cullen, V.L., 2012b. A tephrochronology for the Lateglacial palynological record of the Endinger Bruch (Vorpommern, north-east Germany). *Journal of Quaternary Science* 27, 141-149.
- Langdon, P.G., Barber, K.E., 2004. Snapshots in time: precise correlations of peat-based proxy climate records in Scotland using mid-Holocene tephras. *The Holocene* 14, 21-33.
- Larsen, G., 1984. Recent volcanic history of the Veidivötn fissure swarm, southern Iceland - an approach to volcanic risk assessment. *Journal of Volcanology and Geothermal Research* 22, 33-58.
- Larsen, G., Dugmore, A., Newton, A., 1999. Geochemistry of historical-age silicic tephras in Iceland. *The Holocene* 9, 463-471.

- Larsen, G., Eiríksson, J., 2008. Late Quaternary terrestrial tephrochronology of Iceland - frequency of explosive eruptions, type and volume of tephra deposits. *Journal of Quaternary Science* 23, 109-120.
- Larsen, G., Eiríksson, J., Knudsen, K.L., Heinemeier, J., 2002. Correlation of Late Holocene terrestrial and marine tephra markers, north Iceland: implications for reservoir age changes. *Polar Research* 21, 283-290.
- Larsen, G., Newton, A., Dugmore, A., Vilmundardóttir, E., 2001. Geochemistry, dispersal, volumes and chronology of Holocene silicic tephra layers from the Katla volcanic system, Iceland. *Journal of Quaternary Science* 16, 119-132.
- Larsen, G., Thorarínsson, S., 1977. H4 and other acid Hekla tephra layers. *Jökull* 27, 28-46.
- Larsen, J.J., 2014. Lateglacial and Holocene tephrostratigraphy in Denmark - Volcanic ash in a palaeoenvironmental context. PhD Thesis. Faculty of Science. University of Copenhagen.
- Larsen, J.J., Noe-Nygaard, N., 2014. Lateglacial and early Holocene tephrostratigraphy and sedimentology of the Store Slotseng basin, SW Denmark: a multi-proxy study. *Boreas* 43, 349-361.
- Lauritzen, S.E., Lundberg, J., 1999. Calibration of the speleothem delta function: an absolute temperature record for the Holocene in northern Norway. *The Holocene* 9, 659-669.
- Lawson, I.T., Church, M.J., Edwards, K.J., Cook, G.T., Dugmore, A.J., 2007. Peat initiation in the Faroe Islands: climate change, pedogenesis or human impact? *Earth and Environmental Science Transactions of the Royal Society of Edinburgh* 98, 15-28.
- Lawson, I.T., Swindles, G.T., Plunkett, G., Greenberg, D., 2012. The spatial distribution of Holocene cryptotephra in north-west Europe since 7 ka: implications for understanding ash fall events from Icelandic eruptions. *Quaternary Science Reviews* 41, 57-66.
- Lilja, C., Lind, E.M., Morén, B., Wastegård, S., 2013. A Lateglacial-early Holocene tephrochronology for SW Sweden. *Boreas* 42, 544-554.
- Lind, E., Lilja, C., Wastegård, S., Pearce, N., 2016. Revisiting the Borrobol Tephra. *Boreas* 45, 629-643.
- Lind, E.M., Wastegård, S., 2011. Tephra horizons contemporary with short early Holocene climate fluctuations: New results from the Faroe Islands. *Quaternary International* 246, 157-167.
- Lind, E.M., Wastegård, S., Larsen, J.J., 2013. A Late Younger Dryas-Early Holocene tephrostratigraphy for Fosen, Central Norway. *Journal of Quaternary Science* 28, 803-811.
- Lloyd, J.M., Norddahl, H., Bentley, M.J., Newton, A.J., Tucker, O., Zong, Y., 2009. Lateglacial to Holocene relative sea-level changes in the Bjarkarlundur area near Reykhólar, North West Iceland. *Journal of Quaternary Science* 24, 816-831.
- Lohne, Ø, Mangerud, J., Birks, H.H., 2013. Precise ¹⁴C ages of the Vedde and Saksunarvatn ashes and the Younger Dryas boundaries from western Norway and their comparison with the Greenland Ice Core (GICC05) chronology. *Journal of Quaternary Science* 28, 490-500.

- Lowe, D.J., 2011. Tephrochronology and its application: A review. *Quaternary Geochronology* 6, 107-153.
- MacLeod, A (2008) Tephrostratigraphy of the Loch Laggan East lake sequence. In: Palmer, A.P., Lowe, J.J., Rose J. (eds.): *The Quaternary of Glen Roy and Vicinity, Field Guide*. Quaternary Research Association; 83-91.
- Mangerud, J., Furnes, H., Jóhansen, J., 1986. A 9000-year-old ash bed on the Faroe Islands. *Quaternary Research* 26, 262-265.
- Matthews, I.P., Birks, H.H., Bourne, A.J., Brooks, S.J., Lowe, J.J., MacLeod, A., Pyne-O'Donnell, S.D.F., 2011. New age estimates and climatostratigraphic correlations for the Borrobol and Penifiler Tephra: evidence from Abernethy Forest, Scotland. *Journal of Quaternary Science* 26, 247-252.
- Mayewski, P.A., Rohling, E.E., Stager, J.C., Karlén, W., Maasch, K.A., Meeker, L.D., Meyerson, E.A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R., Steig, E.J., 2004. Holocene climate variability. *Quaternary Research* 62, 243-255.
- Meara, R., 2011. Geochemical fingerprinting of Icelandic silicic Holocene tephra layers, College of Science and Engineering. PhD thesis. University of Edinburgh, Edinburgh.
- Merkt, J., Müller, H., Knabe, W., Müller, P., Weiser, T., 1993. The early Holocene Saksunarvatn Ash found in lake sediments in NW Germany. *Boreas* 22, 93-100.
- Mithen, S., Wicks, K., Pirie, A., Riede, F., Lane, C., Banerjea, R., Cullen, V., Gittins, M., Pankhurst, N., 2015. A Lateglacial archaeological site in the far north-west of Europe at Rubha Port an t-Seilich, Isle of Islay, western Scotland: Ahrensburgian-style artefacts, absolute dating and geoarchaeology. *Journal of Quaternary Science* 30, 396-416.
- Mortensen, A.K., Bigler, M., Grönvold, K., Steffensen, J.P., Johnsen, S.J., 2005. Volcanic ash layers from the Last Glacial Termination in the NGRIP ice core. *Journal of Quaternary Science* 20, 209-219.
- Norddahl, H., Pétursson, H.G., 2005. Relative sea-level changes in Iceland: new aspects of the Weichselian deglaciation of Iceland. In: Caseldine, C., Russell, A., Hardardóttir, J., Knudsen, Ó (eds). *Iceland - Modern processes and past environments, Developments in Quaternary Science* 5. Elsevier: Amsterdam; 25-78.
- Óladóttir, B., Larsen, G., Thordarson, T., Sigmarsson, O., 2005. The Katla volcano S-Iceland: Holocene tephra stratigraphy and eruption frequency. *Jökull* 55, 53-74.
- Óladóttir, B.A., Sigmarsson, O., Larsen, G., Devidal, J.L., 2011. Provenance of basaltic tephra from Vatnajökull subglacial volcanoes, Iceland, as determined by major- and trace-element analyses. *The Holocene* 21, 1037-1048.
- Óladóttir, B.A., Sigmarsson, O., Larsen, G., Thordarson, T., 2008. Katla volcano, Iceland: magma composition, dynamics and eruption frequency as recorded by Holocene tephra layers. *Bulletin of Volcanology* 70, 475-493.

- Olsen, J., Björck, S., Leng, M.J., Gudmundsdóttir, E.R., Odgaard, B.V., Lutz, C.M., Kendrick, C.P., Andersen, T.J., Seidenkrantz, M.-S., 2010a. Lacustrine evidence of Holocene environmental change from three Faroese lakes: a multiproxy XRF and stable isotope study. *Quaternary Science Reviews* 29, 2764-2780.
- Olsen, J., Gudmundsdóttir, E.R., Björck, S., Odgaard, B.V., Heinemeier, J., 2010b. Revised age estimate of the Mjáuvøtn tephra A on the Faroe Islands based on Bayesian modelling of C-14 dates from two lake sequences. *Journal of Quaternary Science* 25, 612-616.
- Ott, F., Wulf, S., Serb, J., Slowinski, M., Obremaska, M., Tjallingii, R., Blaszkiwicz, M., Brauer, A., 2016. Constraining the time span between the Early Holocene Håsseldalen and Askja-S Tephra through varve counting in the Lake Czechowskie sediment record, Poland. *Journal of Quaternary Science* 31, 103-113.
- Persson, C., 1966. Försök till tefrokronologisk datering av några svenska torvmossar. *Geologiska Föreningens i Stockholm Förhandlingar* 88, 361-395.
- Persson, C., 1968. Försök till tefrokronologisk datering i fyra färöiska myrar. *Geologiska Föreningens i Stockholm Förhandlingar* 90, 241-266.
- Pilcher, J., Bradley, R.S., Francus, P., Anderson, L., 2005. A Holocene tephra record from the Lofoten Islands, Arctic Norway. *Boreas* 34, 136-156.
- Pilcher, J.R., Hall, V.A., McCormac, F.G., 1995. Dates of Holocene Icelandic volcanic eruptions from tephra layers in Irish peats. *The Holocene* 5, 103-110.
- Plunkett, G., 2006. Tephra-linked peat humification records from Irish ombrotrophic bogs question nature of solar forcing at 850 cal. yr BC. *Journal of Quaternary Science* 21, 9-16.
- Plunkett, G.M., Pilcher, J.R., McCormac, F.G., Hall, V.A., 2004. New dates for first millennium BC tephra isochrones in Ireland. *The Holocene* 14, 780-786.
- Pollard, A., Heron, C., 2008. *Archaeological Chemistry*. RSC Publishing, Cambridge, UK.
- Pyne-O'Donnell, S., 2007. Three new distal tephra in sediments spanning the Last Glacial-Interglacial Transition in Scotland. *Journal of Quaternary Science* 22, 559-570.
- Pyne-O'Donnell, S.D.F., Blockley, S.P.E., Turney, C.S.M., Lowe, J.J., 2008. Distal volcanic ash layers in the Lateglacial Interstadial (GI-1): problems of stratigraphic discrimination. *Quaternary Science Reviews* 27, 72-84.
- Ranner, P.H., Allen, J.R.M., Huntley, B., 2005. A new early Holocene cryptotephra from northwest Scotland. *Journal of Quaternary Science* 20, 201-208.
- Rasmussen, S.O., Andersen, K.K., Svensson, A., Steffensen, J.P., Vinther, B.M., Clausen, H.B., Siggaard-Andersen, M.-L. Johnsen, S.J., Larsen, L.B., Dahl-Jensen, D., Bigler, M., Röthlisberger, R., Fischer, H., Goto-Azuma, K., Hansson, M.E., Ruth, U., 2006. A new Greenland ice core chronology for the last glacial termination. *Journal of Geophysical Research* 111, D06102. DOI: 10.1029/2005JD006079

- Rasmussen, S.O., Vinther, B.M., Clausen, H.B., Andersen, K.K., 2007. Early Holocene climate oscillations recorded in three Greenland ice cores. *Quaternary Science Reviews* 26, 1907-1914.
- Rasmussen, T.L., Thomsen, E., Nielsen, T., Wastegård, S., 2011. Atlantic surface water inflow to the Nordic seas during the Pleistocene-Holocene transition (mid-late Younger Dryas and Preboreal periods, 12 450-10 000 a BP). *Journal of Quaternary Science* 26, 723-733.
- Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP. *Radiocarbon* 55, 1869-1887.
- Saunders, A.D., Fitton, J.G., Kerr, A.C., Norry, M.J., Kent, R.W., 1997. The North Atlantic Igneous Province. In: Mahoney, J.J., Coffin, M.F. (eds.): *Large Igneous Provinces: Continental, Oceanic and Planetary Flood Volcanism*. Geophysical Monograph 100, 45-93.
- Sigvaldason, G., 2002. Volcanic and tectonic processes coinciding with glaciation and crustal rebound: an early Holocene rhyolitic eruption in the Dyngjufjöll volcanic centre and the formation of the Askja caldera, north Iceland. *Bulletin of Volcanology* 64, 192-205.
- Steinthorsson, S., 1967. Tvær nýjar C14-aldursákvarðanir á öskulögum úr Snæfellsjökli. *Náttúrufræðingurinn* 37, 236-238.
- Stevenson, J.A., Loughlin, S., Rae, C., Thordarson, T., Milodowski, A.E., Gilbert, J.S., Harangi, S., Lukacs, R., Højgaard, B., Ártíng, U., Pyne-O'Donnell, S., MacLeod, A., Whitney, B., Cassidy, M., 2012. Distal deposition of tephra from the Eyjafjallajökull 2010 summit eruption. *Journal of Geophysical Research-Solid Earth* 117. DOI:10.1029/2011JB008904
- Stivrins, N., Wulf, S., Wastegård, S., Lind, E.M., Alliksaar, T., Galka, M., Andersen, T.J., Heinsalu, A., Seppä, H., Veski, S., 2016. Detection of the Askja AD 1875 cryptotephra in Latvia, Eastern Europe. *Journal of Quaternary Science* 31, 437-441.
- Streeter, R., Dugmore, A., 2014. Late-Holocene land surface change in a coupled social ecological system, southern Iceland: a cross-scale tephrochronology approach. *Quaternary Science Reviews* 86, 99-114.
- Swindles, G.T., Lawson, I.T., Savov, I.P., Connor, C.B., Plunkett, G., 2011. A 7000 yr perspective on volcanic ash clouds affecting northern Europe. *Geology* 39, 887-890.
- Swindles, G.T., Watson, E.J., Savov, I.P., Lawson, I.T., Schmidt, A., Hooper, A., Cooper, C.L., Connor, C.B., Gloor, M., Carrivick, L., 2017. Climatic control on Icelandic volcanic activity during the mid-Holocene. *Geology* 46, 47-50.
- Thorarinsson, S., 1951. Laxárgljúfur and Laxárhraun. A tephrochronological study. *Geografiska Annaler* 1-2, 1-89.
- Thorarinsson, S., 1967. The eruptions of Hekla in historical times, The eruption of Hekla 1947-48 I, 1-183.

- Thorarinsson, S., 1981. Greetings from Iceland - ash-falls and volcanic aerosols in Scandinavia. *Geografiska Annaler* 63A, 109-118.
- Thordarson, T., 2014. The widespread ~10ka Saksunarvatn tephra is not a product of a single eruption. American Geophysical Union. Fall Meeting 2014. Abstract id V24B-04.
- Thordarson, T., Larsen, G., 2007. Volcanism in Iceland in historical time: Volcano types, eruption styles and eruptive history. *Journal of Geodynamics* 43, 118-152.
- Thornalley, D.J.R., McCave, I.N., Elderfield, H., 2011. Tephra in deglacial ocean sediments south of Iceland: Stratigraphy, geochemistry and oceanic reservoir ages. *Journal of Quaternary Science* 26, 190-198.
- Thorsteinsdóttir, E., Larsen, G., Gudmundsdóttir, E.R., 2016. Grain characteristics of silicic Katla tephra layers indicate a fairly stable eruption environment between 2800 and 8100 years ago. *Jökull* 62, 69-81.
- Timms, R., 2016. Developing a refined tephrostratigraphy for Scotland, and constraining abrupt climatic oscillations of the Last Glacial-Interglacial Transition (ca 16-8 ka BP) using high resolution tephrochronologies. PhD Thesis. Centre for Quaternary Research, Department of Geography. Royal Holloway, University of London.
- Timms, R.G.O., Matthews, I.P., Palmer, A.P., Candy, I., Abel, L., 2017. A high-resolution tephrostratigraphy from Quoyloo Meadow, Orkney, Scotland: Implications for the tephrostratigraphy of NW Europe during the Last Glacial-Interglacial Transition. *Quaternary Geochronology*, 40, 67-81.
- Tomlinson, E.L., Thordarson, T., Lane, C.S., Smith, V.C., Manning, C.J., Muller, W., Menzies, M.A., 2012. Petrogenesis of the Solheimar ignimbrite (Katla, Iceland): Implications for tephrostratigraphy. *Geochimica et Cosmochimica Acta* 86, 318-337.
- Turney, C.S.M., 1998. Extraction of rhyolitic component of Vedde microtephra from minerogenic lake sediments. *Journal of Paleolimnology* 19, 199-206.
- Turney, C.S.M., van den Burg, K., Wastegård, S., Davies, S.M., Whitehouse, N.J., Pilcher, J.R., Callaghan, C., 2006. North European last glacial-interglacial transition (LGIT; 15-9 ka) tephrochronology: extended limits and new events. *Journal of Quaternary Science* 21, 335-345.
- Waagstein, R., Jóhansen, J., 1968. Tre vulkaniske askelag fra Faeroerne. *Meddelelser fra Dansk Geologisk Forening* 18, 257-264.
- Walker, M.J.C., Berkelhammer, M., Björck, S., Cwynar, L.C., Fisher, D.A., Long, A.J., Lowe, J.J., Newnham, R.M., Rasmussen, S.O., Weiss, H., 2012. Formal subdivision of the Holocene Series/Epoch: a Discussion Paper by a Working Group of INTIMATE (Integration of ice-core, marine and terrestrial records) and the Subcommittee on Quaternary Stratigraphy (International Commission on Stratigraphy). *Journal of Quaternary Science* 27, 649-659.
- van den Bogaard, C., Dörfler, W., Glos, R., Nadeau, M., Grootes, P., Erlenkeuser, H., 2002. Two tephra layers bracketing Late Holocene palaeoecological changes in northern Germany. *Quaternary Research* 57, 314-324.

- van den Bogaard, C., Schmincke, H.-U., 2002. Linking the North Atlantic to central Europe: a high resolution Holocene tephrochronological record from northern Germany. *Journal of Quaternary Science* 17, 3-20.
- van der Bilt, W.G., Lane, C.S., Bakke, J., 2017. Ultra-distal Kamchatkan ash on Arctic Svalbard: Towards hemispheric cryptotephra correlation. *Quaternary Science Reviews* 164, 230-235.
- van der Plicht, J., van Geel, B., Bohncke, S.J.P., Bos, J.A.A., Blaauw, M., Speranza, A.O.M., Muscheler, R., Björck, S., 2004. The Preboreal climate reversal and a subsequent solar-forced climate shift. *Journal of Quaternary Science* 19, 263-269.
- Wastegård, S., 2002. Early to middle Holocene silicic tephra horizons from the Katla volcanic system, Iceland: new results from the Faroe Islands. *Journal of Quaternary Science* 17, 723-730.
- Wastegård, S., Andersson, S., Hohl Perkins, V., 2009. A new mid-Holocene tephra in central Sweden. *GFF* 131, 293-297.
- Wastegård, S., Björck, S., Grauert, M., Hannon, G.E., 2001. The Mjauvotn tephra and other Holocene tephra horizons from the Faroe Islands: a link between the Icelandic source region, the Nordic Seas, and the European continent. *Holocene* 11, 101-109.
- Wastegård, S., Björck, S., Greve, C., Rasmussen, T.L., 2005. A tephra-based correlation between the Faroe Islands and the Norwegian Sea raises questions about chronological relationships during the last interglacial. *Terra Nova* 17, 7-12.
- Wastegård, S., Davies, S.M., 2009. An overview of distal tephrochronology in northern Europe during the last 1000 years. *Journal of Quaternary Science* 24, 500-512.
- Wastegård, S., Hall, V.A., Hannon, G.E., van den Bogaard, C., Pilcher, J.R., Sigurgeirsson, M.A., Hermanns-Auðardóttir, M., 2003. Rhyolitic tephra horizons in northwestern Europe and Iceland from the AD 700s-800s: a potential alternative for dating first human impact. *Holocene* 13, 277-283.
- Wastegård, S., Rundgren, M., Schoning, K., Andersson, S., Björck, S., Borgmark, A., Possnert, G., 2008. Age, geochemistry and distribution of the mid-Holocene Hekla-S/Kebister tephra. *The Holocene* 18, 539-549.
- Wastegård, S., Wohlfarth, B., Subetto, D.A., Sapelko, T., 2000: Extending the known distribution of the Younger Dryas Vedde Ash into northwestern Russia. *Journal of Quaternary Science* 15, 581-586.
- Watson, E., Swindles, G., Lawson, I., Savov, I., Wastegård, S., 2017. The presence of Holocene cryptotephra in Wales and southern England. *Journal of Quaternary Science* 32, 493-500.
- Watson, E.J., Swindles, G.T., Lawson, I.T., Savov, I.P., 2015. Spatial variability of tephra and carbon accumulation in a Holocene peatland. *Quaternary Science Reviews* 124, 248-264.
- Watson, E.J., Swindles, G.T., Lawson, I.T., Savov, I.P., 2016. Do peatlands or lakes provide the most comprehensive distal tephra records? *Quaternary Science Reviews* 139, 110-128.

Wohlfarth, B., Blaauw, M., Davies, S.M., Andersson, M., Wastegård, S., Hormes, A., Possnert, G., 2006. Constraining the age of Lateglacial and early Holocene pollen zones and tephra horizons in southern Sweden with Bayesian probability methods. *Journal of Quaternary Science* 21, 321-334.

Wolff-Boenisch, D., Gislason, S.R., Oelkers, E.H., Putnis, C.V., 2004. The dissolution rates of natural glasses as a function of their composition at pH 4 and 10.6, and temperatures from 25 to 74 degrees C. *Geochimica et Cosmochimica Acta* 68, 4843-4858.

Wulf, S., Drager, N., Ott, F., Serb, J., Appelt, O., Gudmundsdóttir, E., van den Bogaard, C., Slowinski, M., Blaszkiewicz, M., Brauer, A., 2016. Holocene tephrostratigraphy of varved sediment records from Lakes Tiefer See (NE Germany) and Czechowskie (N Poland). *Quaternary Science Reviews* 132, 1-14.

Zillén, L., Wastegård, S., Snowball, I., 2002. Calendar year ages of three mid-Holocene tephra layers identified in varved lake sediments in west central Sweden. *Quaternary Science Reviews* 21, 1583-1591.

List of Figures, Tables and Appendices

Figures

- Fig. 1 A: Regional map of the North Atlantic Region. The North Atlantic Igneous province (NAIP) is marked in grey (after Horni et al., 2017)
B: Map of the Faroe Islands with sites mentioned in the text and in Appendix 1 (L. = lake):
1. Eidi bog (Wastegård et al., 2001, 2003, this paper)
 2. Tjørnuvík (Wastegård et al., 2001, 2003, this paper)
 3. L. Saksunarvatn (Mangerud et al., 1986; Dugmore and Newton, 1998)
 4. Saksunmyren (Persson, 1968)
 5. Myrarnar (Persson, 1968)
 6. L. Mjáuvøtn (Wastegård et al., 2001, this paper; Olsen et al., 2010a & b)
 7. Klovinmren (Persson, 1968)
 8. L. Starvatn (Wastegård et al., 2008, this paper)
 9. L. Stórvatn (Olsen et al., 2010a)
 10. L. Brúnavatn (Olsen et al., 2010a & b)
 11. L. Skælingsvatn (Waagstein and Jóhansen, 1968; Dugmore and Newton, 1998)
 12. Hoydalar (Waagstein and Jóhansen, 1968)
 13. Havnardalsmyren (Persson, 1968; Kylander et al., 2012; Wastegård et al., this paper)
 14. Høvdarhagi bog (Lind and Wastegård, 2011; Wastegård et al., this paper)
 15. L. Lykkjuvøtn (Jessen et al., 2007, 2008)
 16. L. Gróthúsvatn (Hannon et al., 2001; Wastegård et al., this paper)
 17. Hovsdalur (Wastegård, 2002)
- Fig. 2 Geochemical characterisation of the main basaltic tephras found on the Faroe Islands. “Saksunarvatn precursors” from Havnardalsmyren are excluded. (A) TiO_2 vs. MgO (wt%); (B) K_2O vs. TiO_2 (wt%). Geochemical field for Iceland source volcanoes are based on Óladóttir et al. (2008; 2011). The field for Katla also includes data from Boyle (1994), Larsen et al. (2001), Lane et al., (2012a), Tomlinson et al. (2012), Streeter and Dugmore (2014), Gudmundsdóttir et al (2016) and Holmes et al. (2016) and also covers intermediate and silicic products (e.g. “SILK tephras” and the Vedde Ash).
- Fig. 3 Geochemical characterisation of early Holocene silicic tephras found on the Faroe Islands. (A) FeO vs. CaO (wt%); (B) SiO_2 vs. K_2O (wt%). Geochemical fields for the Hässeldalen Tephra (HDT) from Housley et al. (2013), Lilja et al. (2013) and Larsen and Noe-Nygaard (2014); Askja-S Tephra from Turney et al. (2006), Jones et al. (2017) and Kelly et al. (2017); Fosen Tephra from Lind et al. (2013) and Larsen (2014); SILK Tephras from Larsen et al. (2001); Óladóttir et al. (2008) and

Thorsteinsdóttir et al. (2016); An Druim Tephra from Ranner et al. (2005); Kelly et al. (2017) and Timms et al. (2017). Major element composition of volcanic rocks from Thórdarhyrna from Jónasson (2007).

- Fig. 4 Biplot of the Häseldalen and Hovsdalur tephras from the Faroe Islands (SiO_2 vs. K_2O) compared with published data of the Häseldalen Tephra from Sweden, Denmark, Germany and Poland (Lane et al., 2012b; Housley et al., 2013; Lilja et al., 2013; Larsen and Noe-Nygaard, 2014) and with rhyolitic tephras from Snæfellsjökull (Sn-1: Larsen et al., 2002; Holmes et al., 2015; Watson et al., 2016); (Sn-2/LBA-2: Wastegård et al., 2009). Major element composition of volcanic rocks from Thórdarhyrna from Jónasson (2007).
- Fig. 5 Output of Bayesian age-depth modelling of the Høvdarhagi core (Lind and Wastegård, 2011), using OxCal 4.3.2. and the IntCal13 calibration curve. The age for the Saksunarvatn Tephra ($10,210 \pm 35$ cal yr BP) is from Lohne et al. (2013). The previous age model from Høvdarhagi bog was constructed using the OxCal 4.1.6. software (Lind and Wastegård, 2011).
- Fig. 6 Biplots of SILK tephras found on the Faroe Islands (A: MgO vs. TiO_2 ; B: FeO_{tot} vs. CaO) compared with published data of SILK tephras from Iceland (Larsen et al., 2001; Óladóttir et al., 2008; Thorsteinsdóttir et al., 2016); Icelandic records of SILK-A1 and SILK-A7/RF-2 are shown with 1 s.d. (Larsen et al., 2001).
- Fig. 7 Biplots of the Mjáuvøtn Tephra A (A: TiO_2 vs. K_2O ; B: FeO_{tot} vs. MgO) compared with the K-6630, K-6750 and K-7060 tephras from western Iceland (means with 1 s.d.; Jóhannsdóttir, 2007), Tv-5 from Lake Torfadalsvatn, N Iceland (Björck et al., 1992) and the Katla EG-6.73 ka Tephra (= K-6750 Tephra) from the SE Greenland shelf (Jennings et al., 2014).
- Fig. 8 Peat cutting from Streymoy with two visible tephras, Hekla-4 and Hekla-S. Photo: Ian Snowball.
- Fig. 9 Biplots of all tephras from Hekla included in this study with exception of the Tjørnuvík Tephra (Wastegård et al., 2001, 2008 and unpublished; Olsen et al., 2010a); (A: SiO_2 vs. $\text{Na}_2 + \text{K}_2\text{O}$; B: FeO_{tot} vs. CaO) compared with data from Tephabase (www.tephrabase.org), including analyses of Hekla-5, Hekla-4, Hekla-3, Hekla-S and several historical eruptions of Hekla. All analyses have been normalized to 100 wt%.
- Fig. 10 Biplot of the Tjørnuvík Tephra from Eidi bog, Hovsdalur and Tjørnuvík (A: SiO_2 vs. $\text{Na}_2 + \text{K}_2\text{O}$) compared with analyses of Hekla-4 and Hekla-S/Kebister tephras from Tephabase (www.tephrabase.org) and the MOR-T6 tephra from western Ireland (Chambers et al., 2004). All analyses have been normalized to 100 wt%.

Fig. 11 Biplot of CaO vs. MgO in early Holocene Grímsvötn tephras from the Havnardalsmyren peat section compared with data from Tephabase (www.tephrabase.org). Four basaltic cryptotephras (Havn-0, Havn-2, Havn-3 and Havn-4 from top to bottom) and a visible 2-3 cm thick, black macrotephra layer (Havn-1) was found over a core interval of c. 25 cm. The dashed line separates between “Low Mg Saksunarvatn”, Havn-3 & 4 and “High Mg Saksunarvatn” (Havn-0, 1 & 2). The Saksunarvatn Ash reported from Loch Ashik, Isle of Skye, NW Scotland is also shown (Kelly et al., 2017). Low MgO values indicate that this tephra can be correlated with the Havn-3 or 4 layers rather than with the main Saksunarvatn eruption. All analyses have been normalized to 100 wt%.

Tables

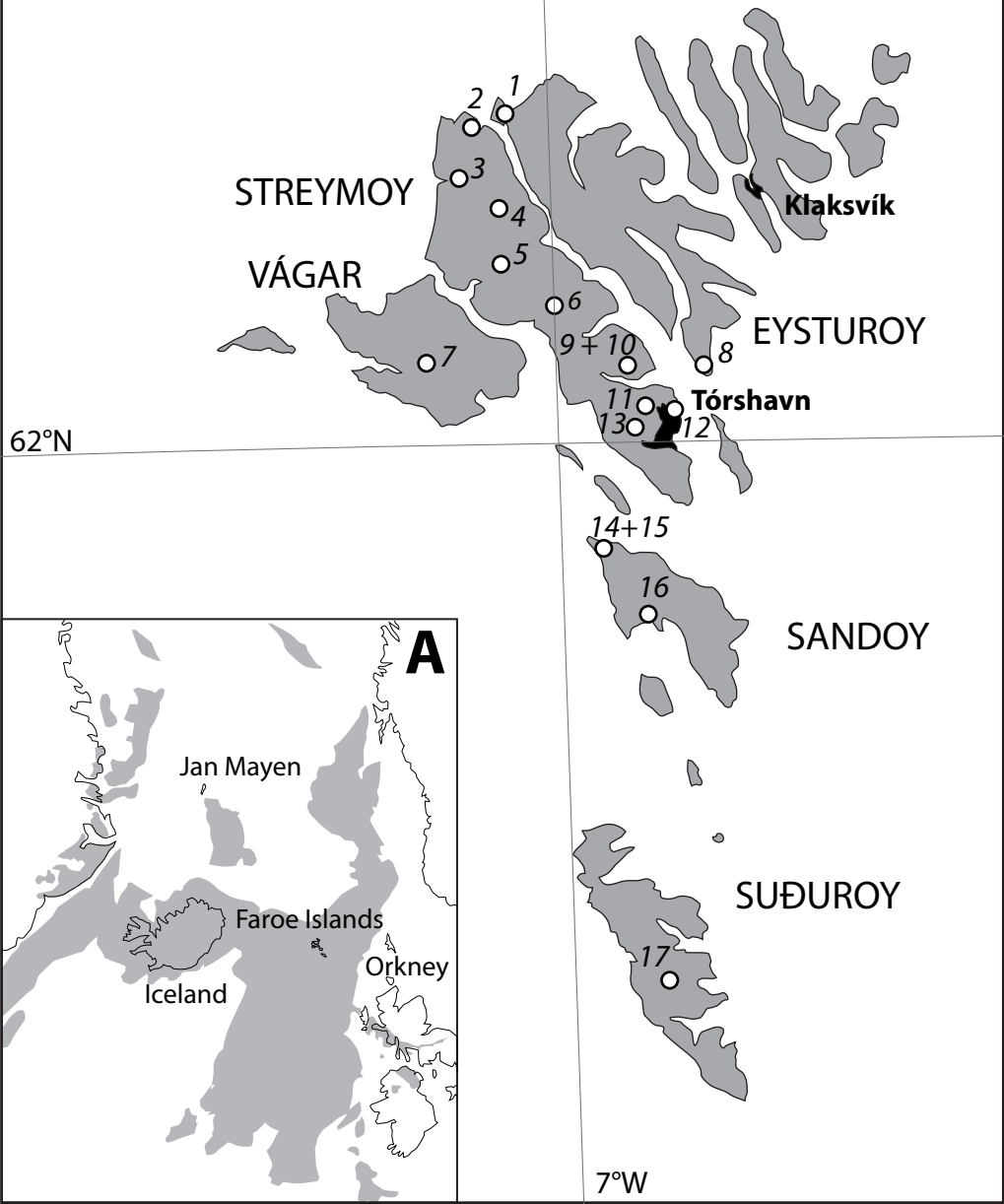
Table 1. Holocene tephras identified on the Faroe Islands, from youngest to oldest. For full description, see text. *At least four, possible five layers on the Faroe Islands; **Age in cal yr BP from Lohne et al. (2013); ***Possibly same as Hässeldalen Tephra; ***Age in cal yr BP from Bronk Ramsey et al. (2015).

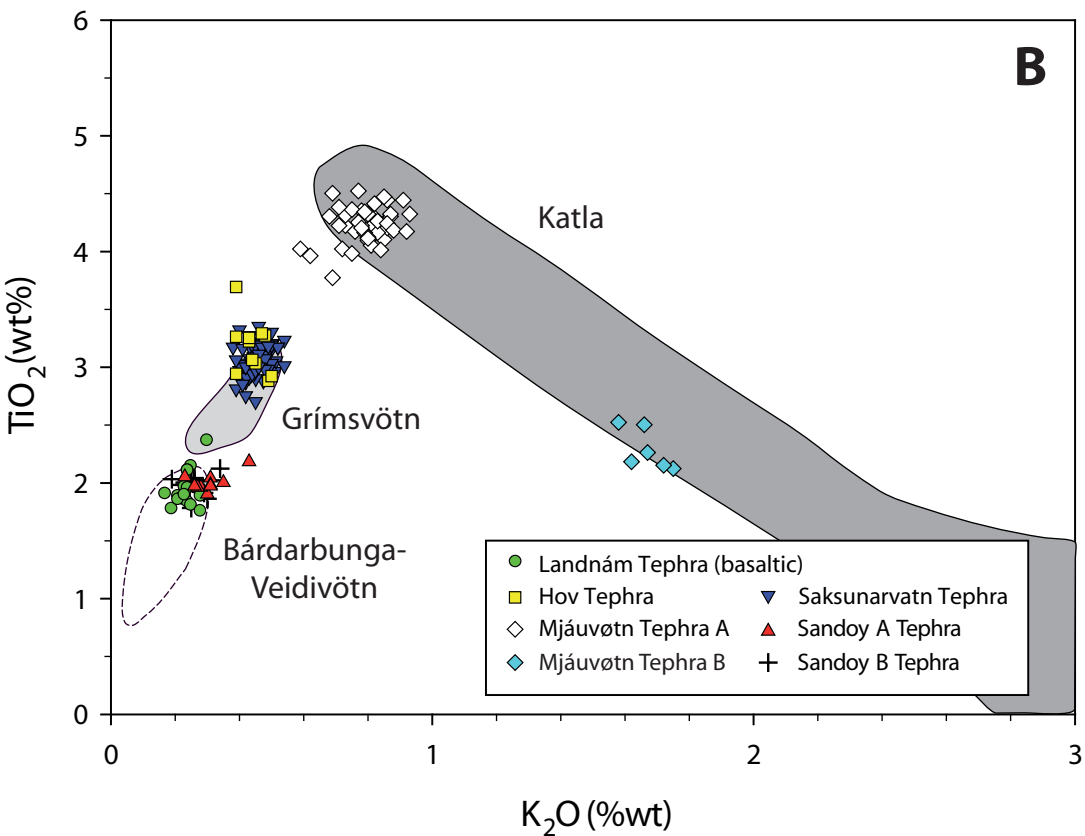
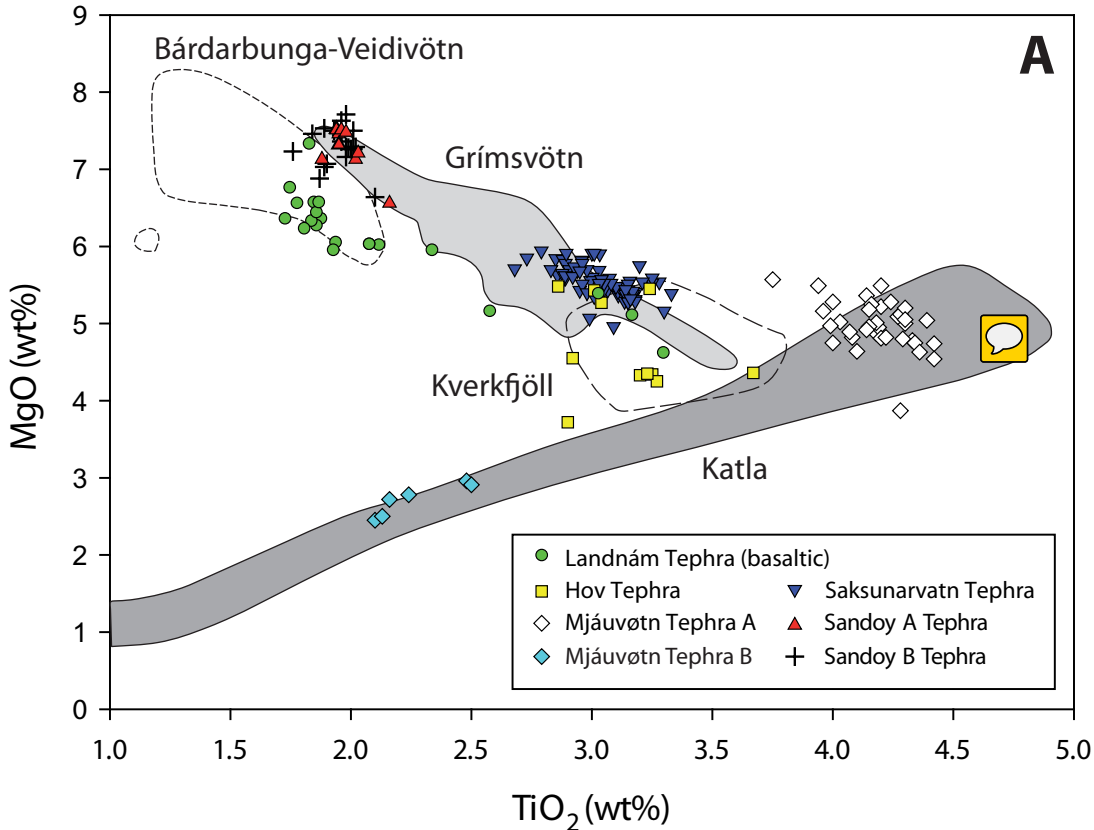
Table 2 Ages for tephras from the Høvdarhagi bog sequence derived from the age-depth model in Fig. 5. *age for the Saksunarvatn Tephra from Lohne et al. (2013)

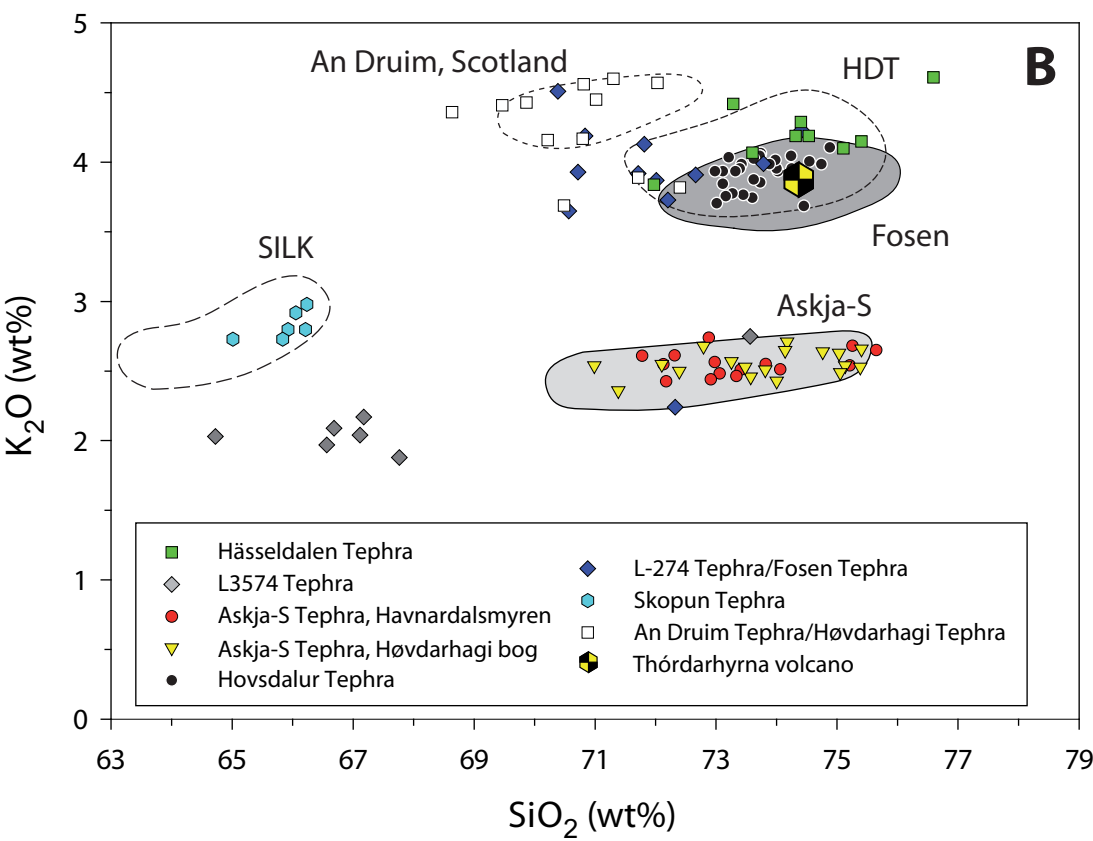
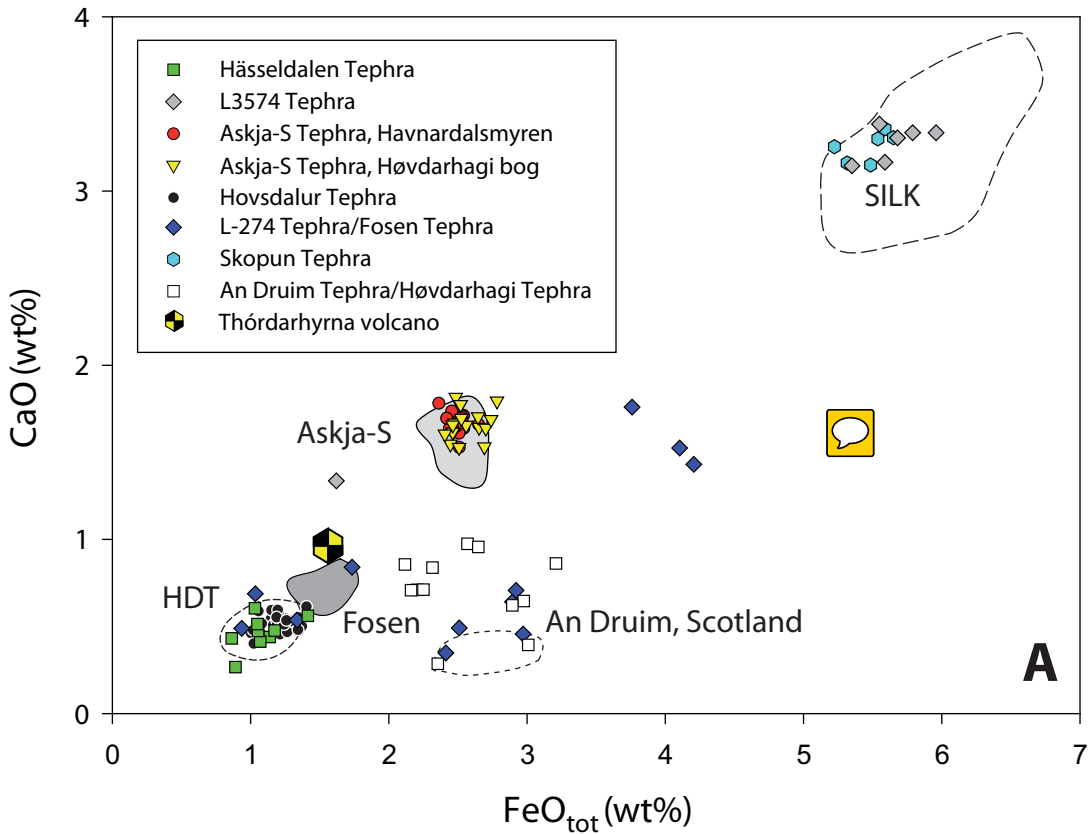
Table 3 Geochemical composition of Grímsvötn tephras from Havnardalsmyren including the visible Saksunarvatn Tephra (Havn-1) and four cryptotephras, Havn-0, 2, 3 and 4. Ages for the cryptotephras are estimated using linear interpolation between the Saksunarvatn macrotephra horizon and the Askja-S Tephra at 385-387 cm (Kylander et al., 2012); ** age from Lohne et al., (2013). All tephras were analysed in October 2010 using microprobe settings recommended by Hayward (2011) in order to avoid beam-induced chemical modification. *May be placed as supplementary material.*

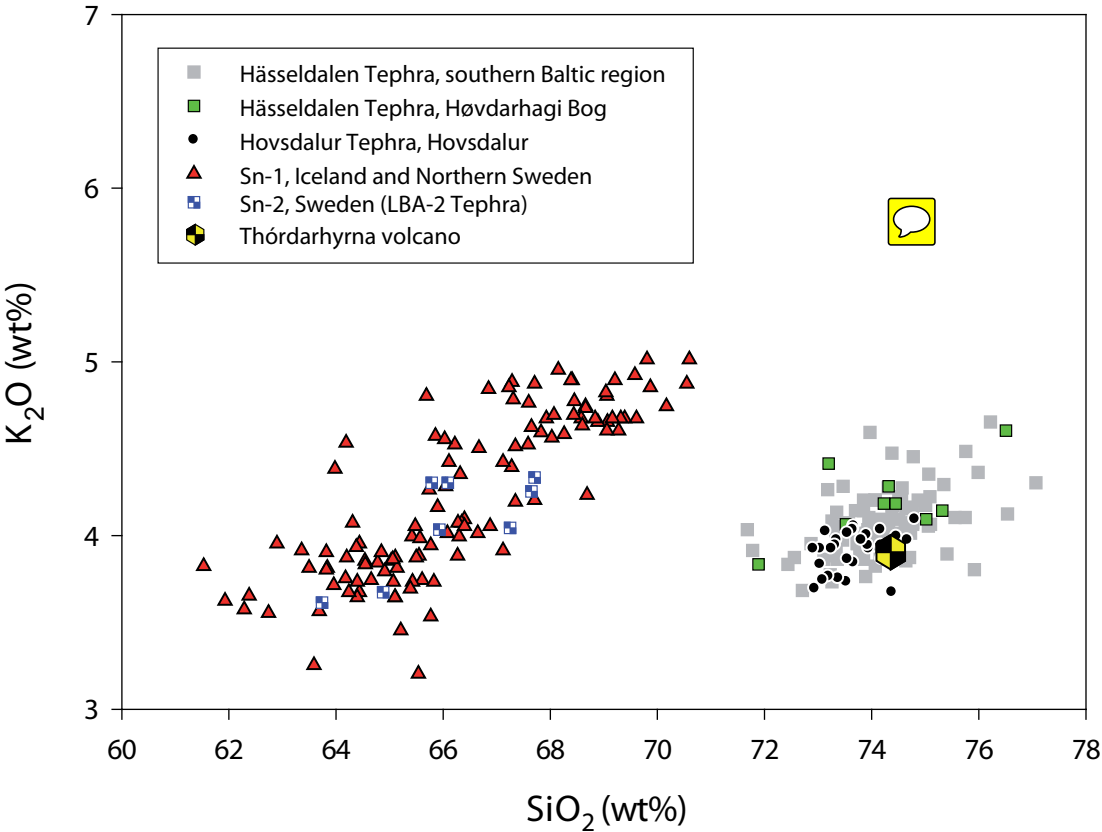
Appendices

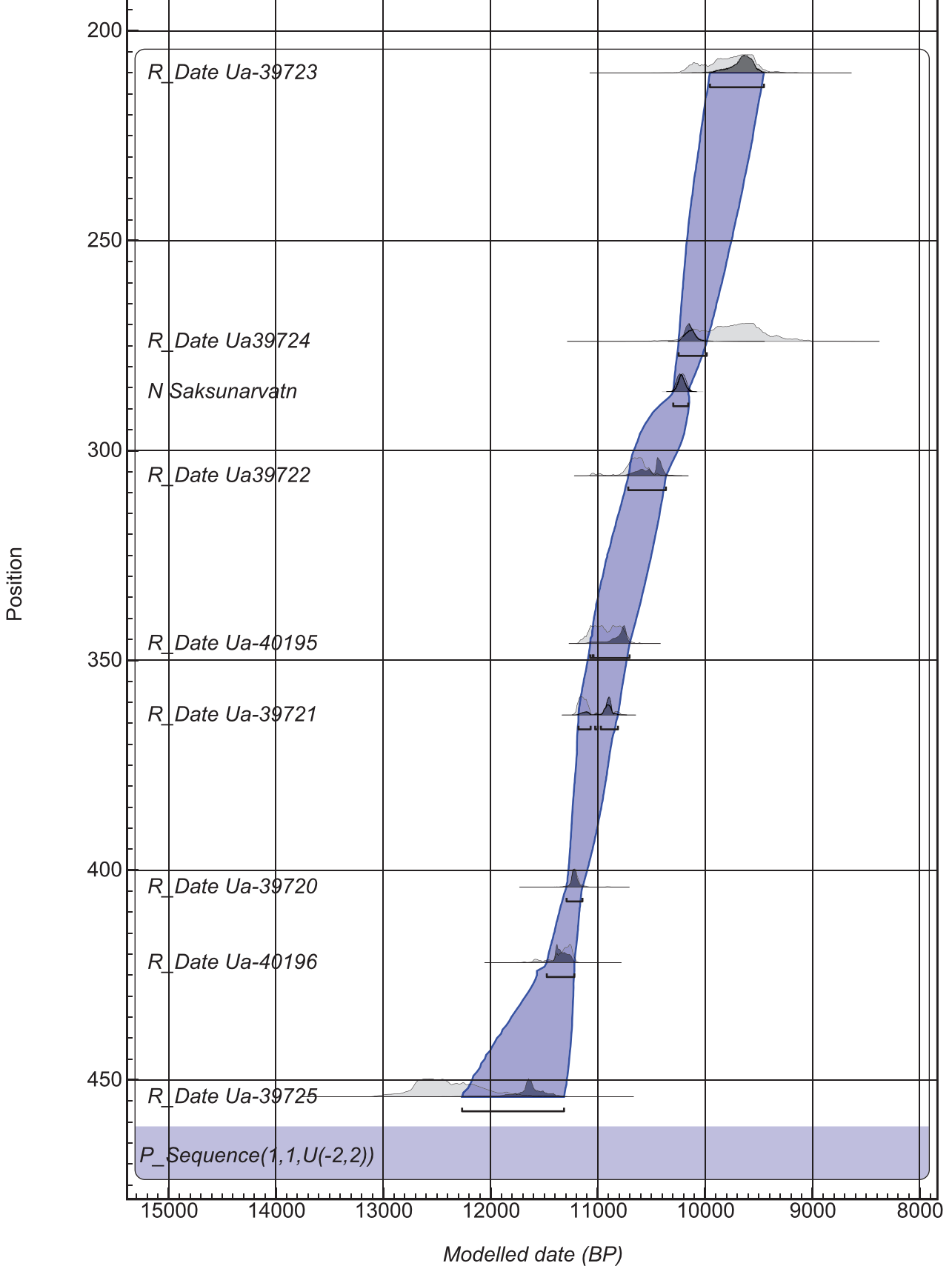
A Major element geochemistry of tephras from seven sites on the Faroe Islands, previously not published in full: A1: Hovsdalur, Suduroy; A2: Tjørnuvík, Streymoy; A3: Eidi bog, Eysturoy; A4: Mjáuvøtn, Streymoy; A5: Starvatn, Eysturoy; A6: Gróthusvatn, Sandoy; A7: Havnardalsmyren, Streymoy. *Uploaded to Mendeley.*

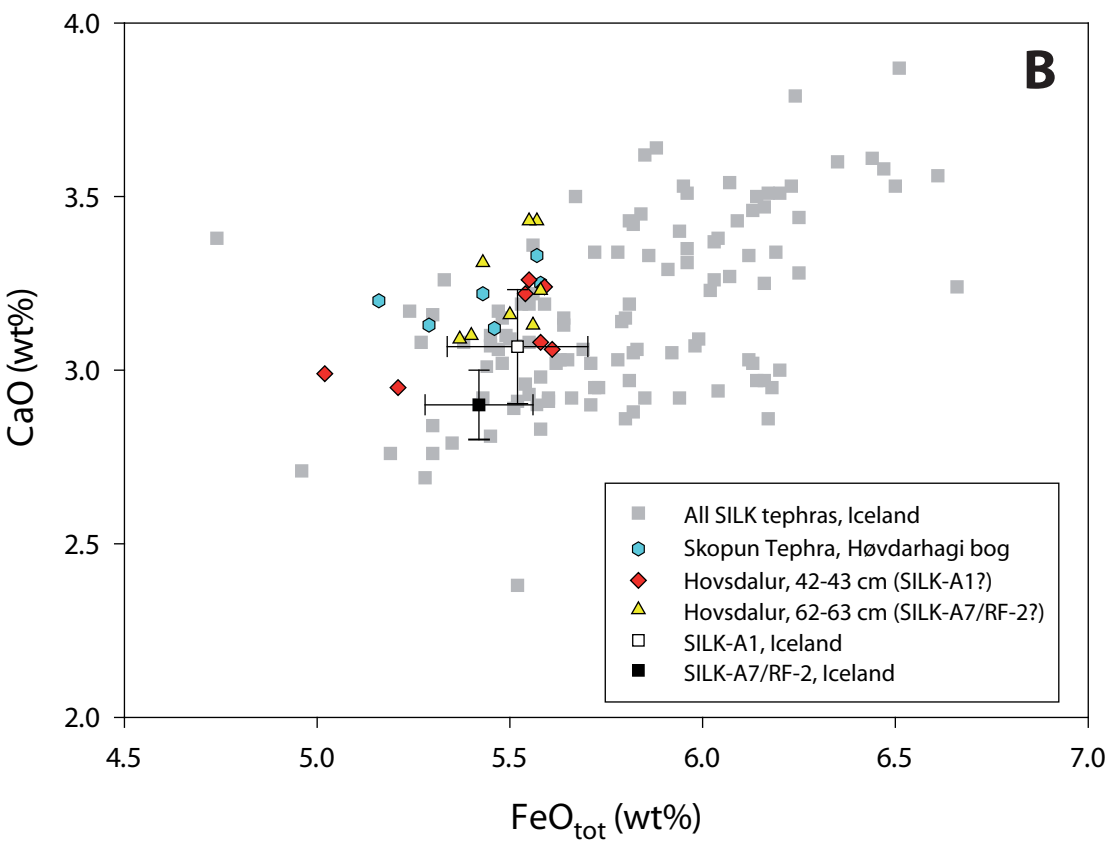
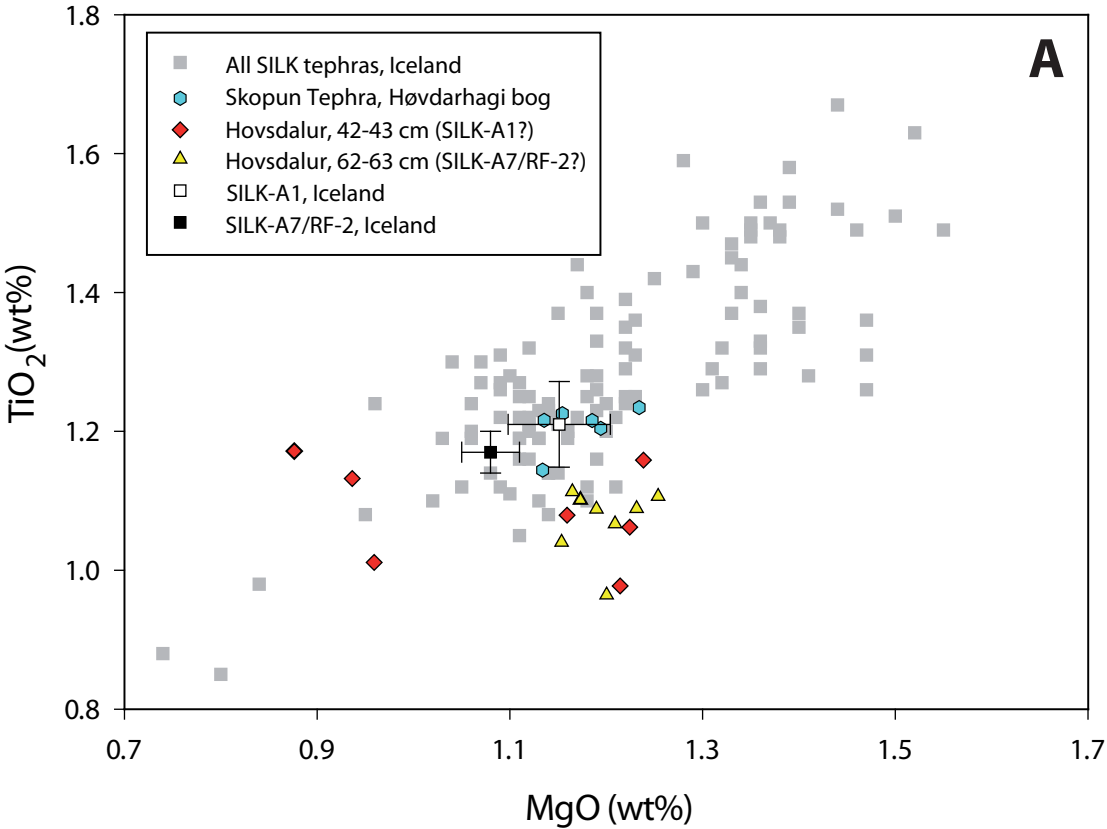
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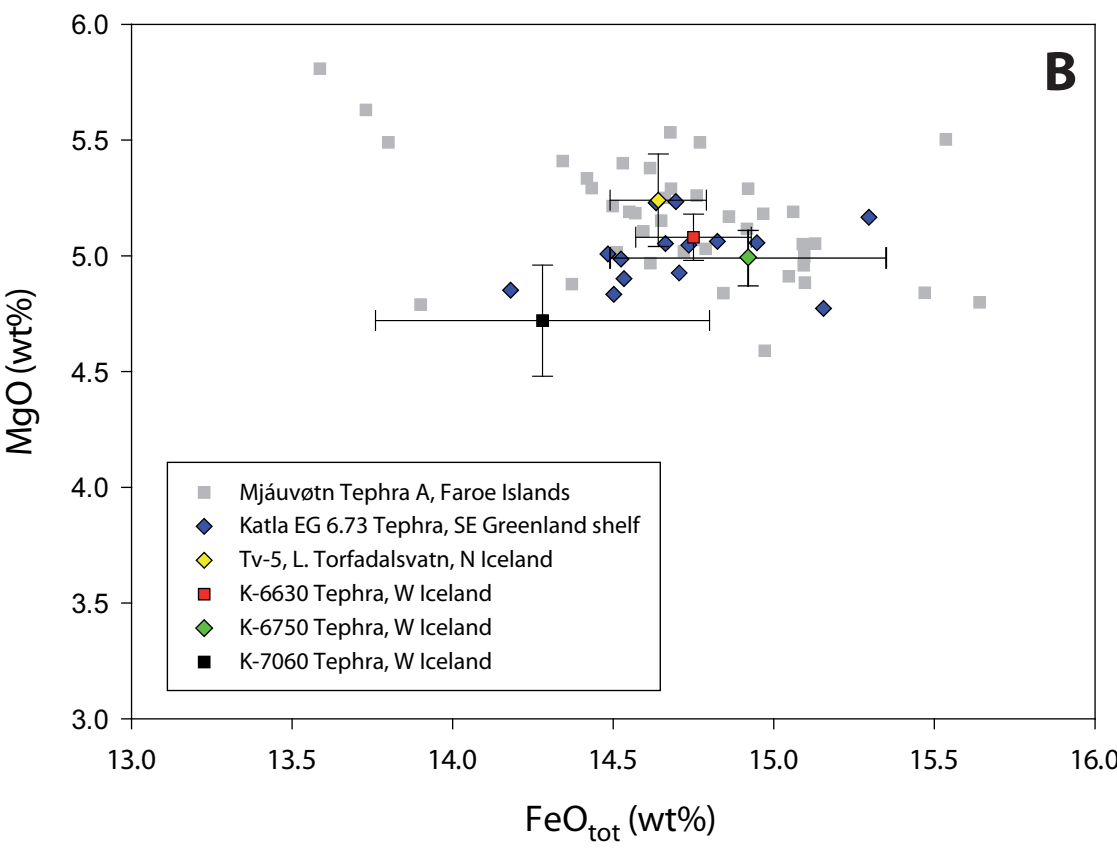
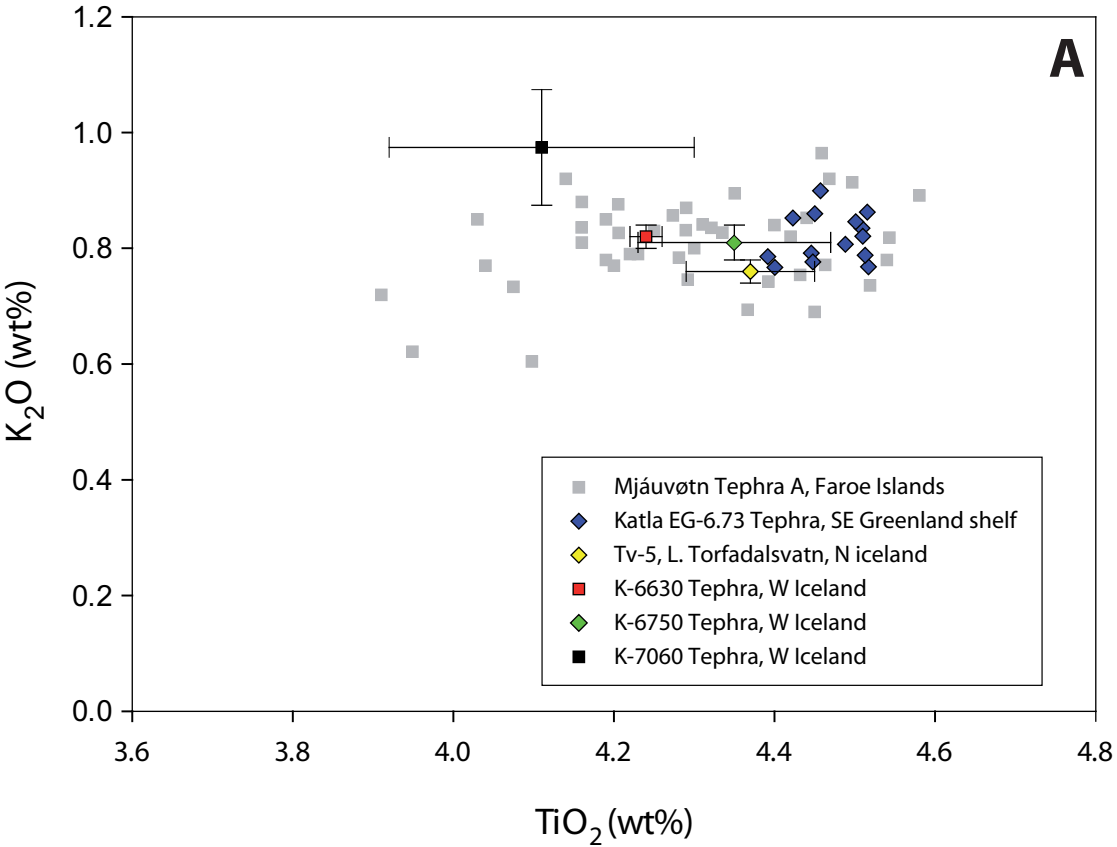


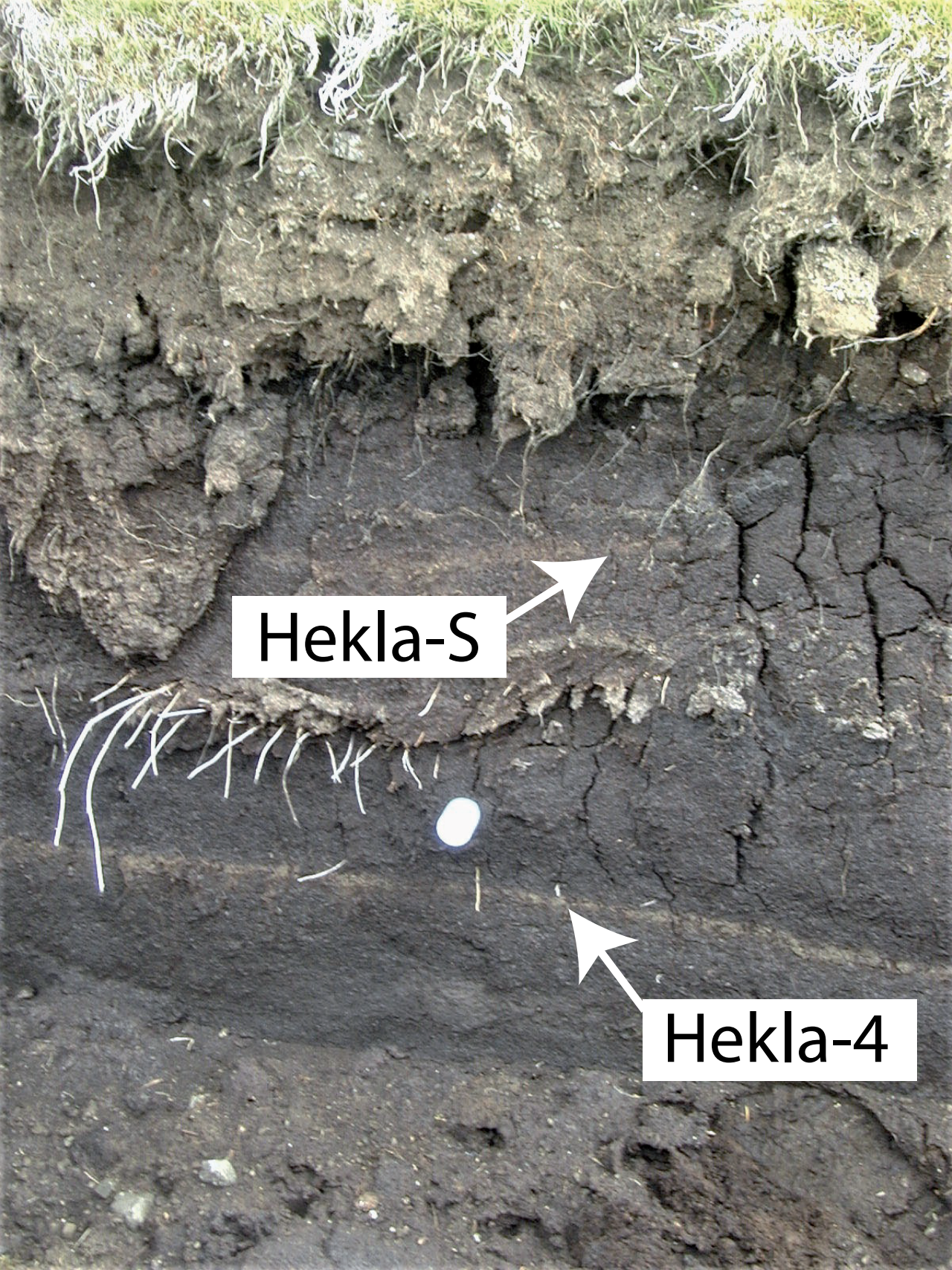






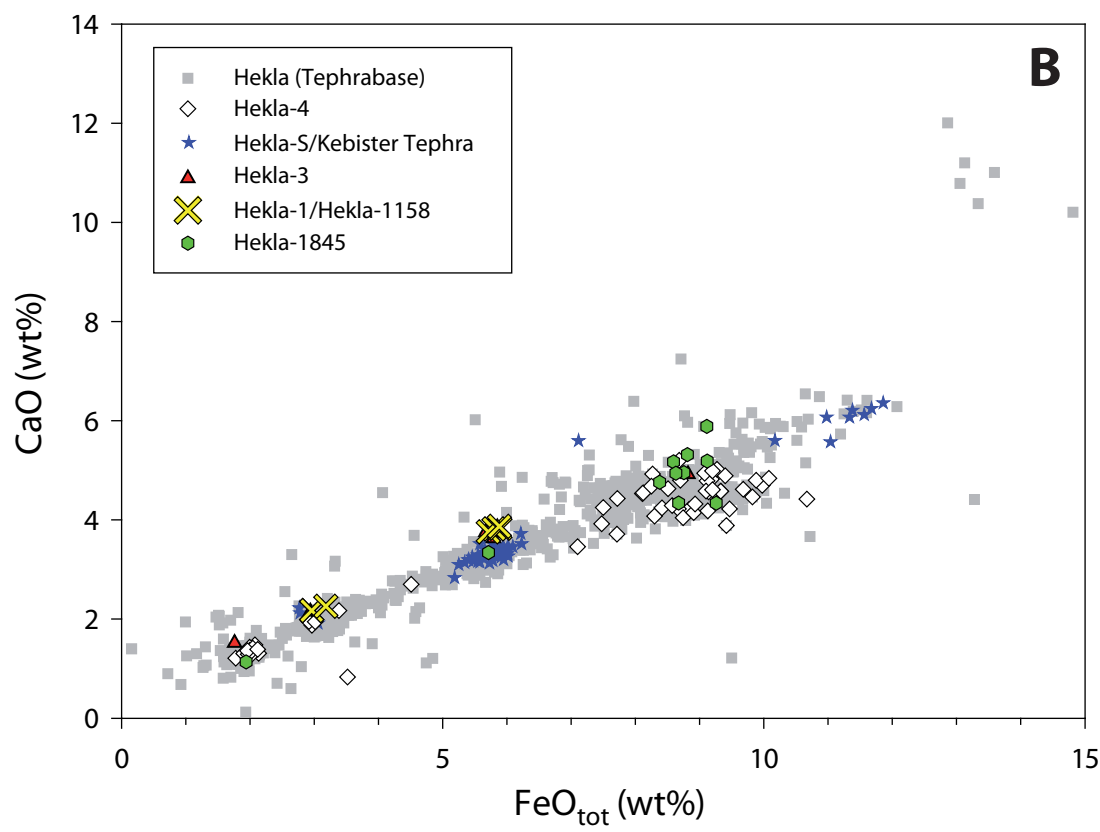
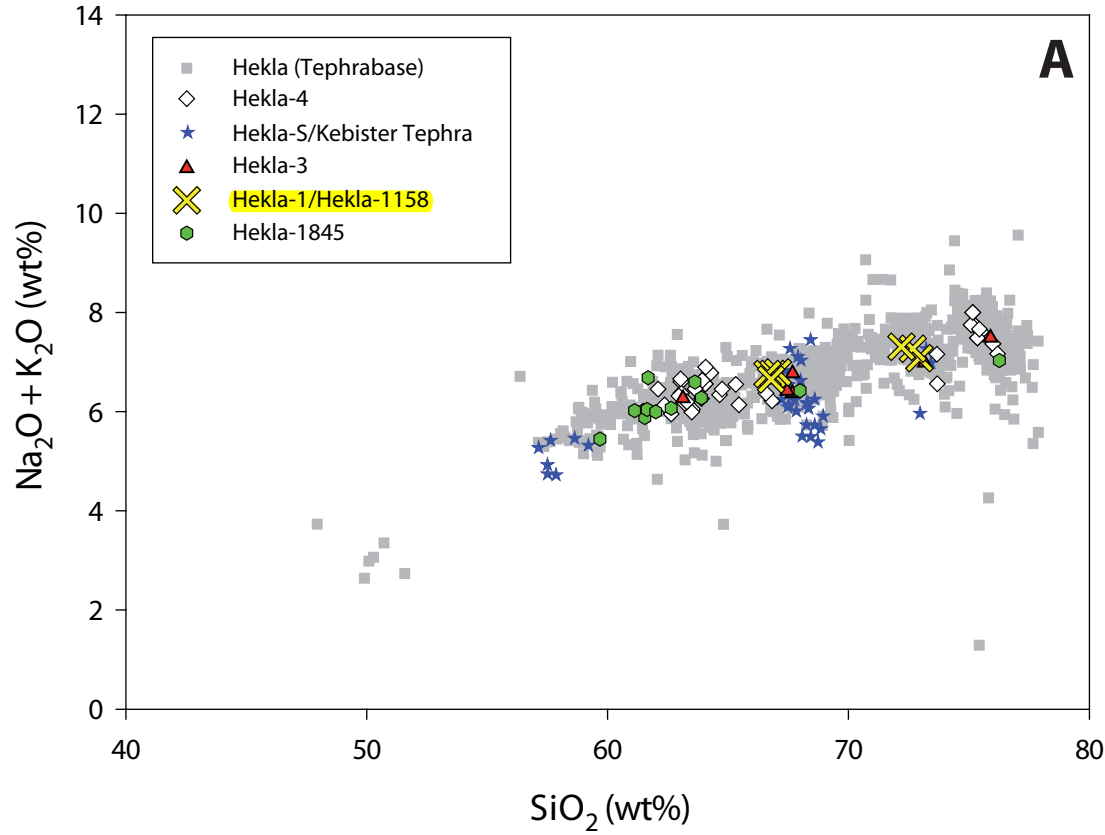


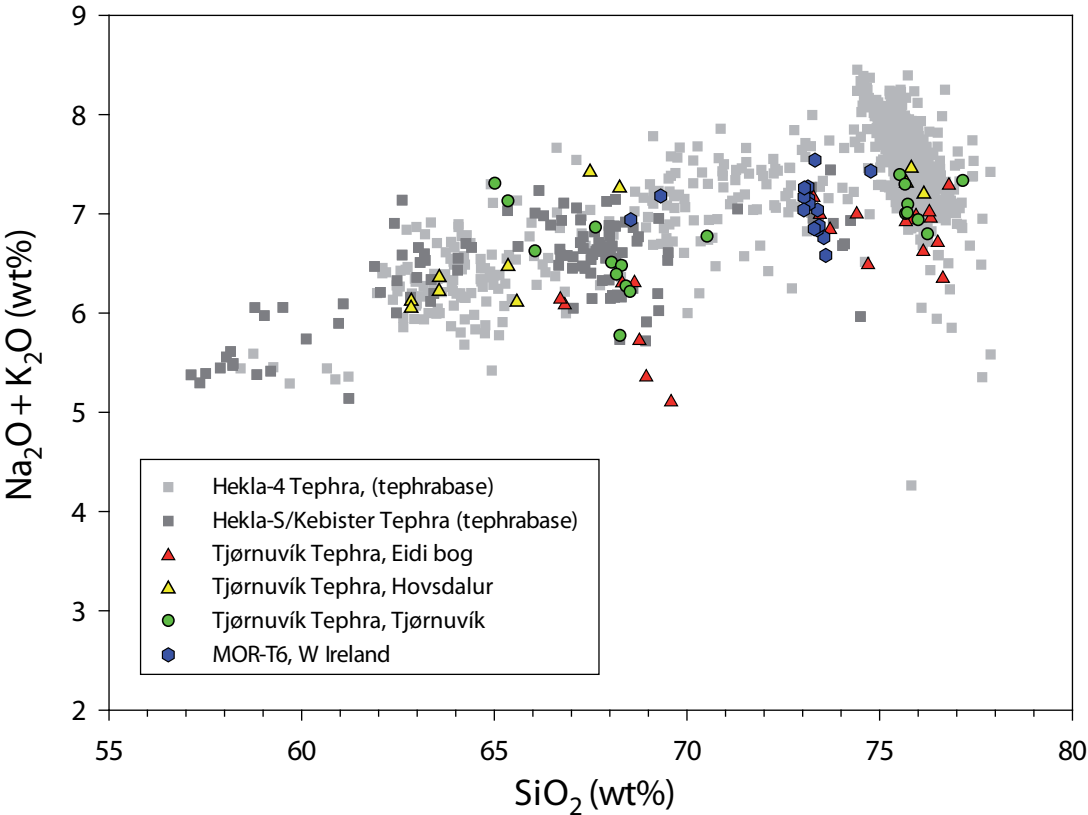




Hekla-S

Hekla-4





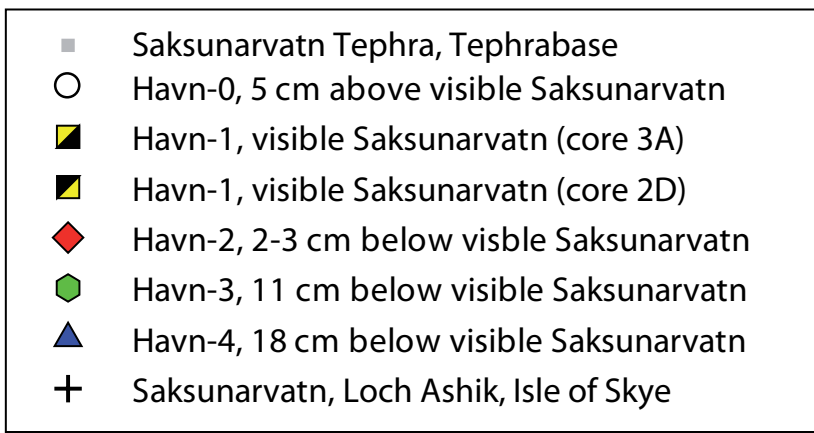
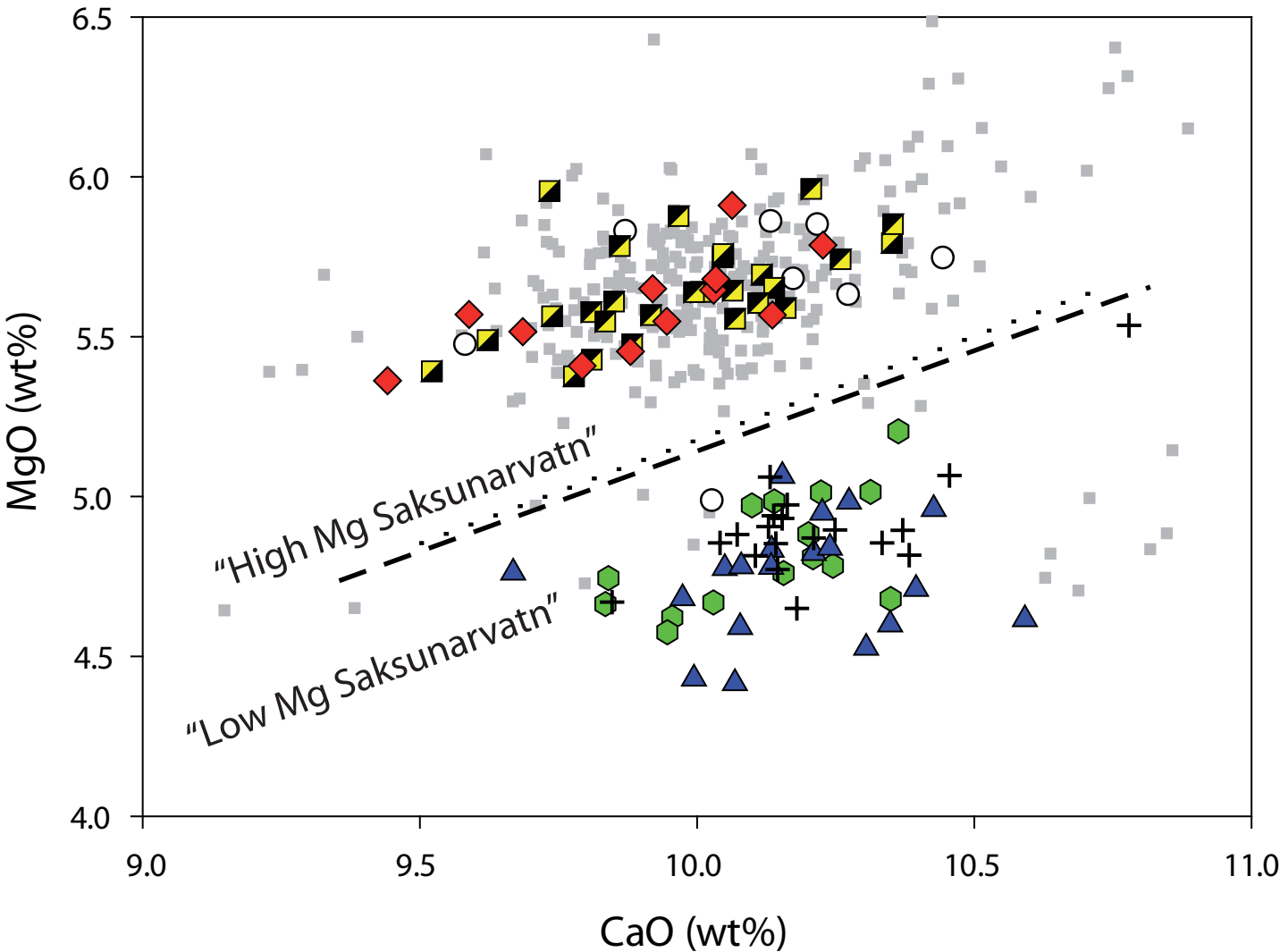


Table 1. Holocene tephtras identified on the Faroe Islands, from youngest to oldest. For full description, see text. *At least four, possible five layers on the Faroe Islands; ** Age in cal yr BP from Lohne et al. (2013); *** Possibly same as Häseldalen Tephra; **** Age in cal yr BP from Bronk Ramsey et al. (2015)

Tephra	Age ka yr (AD/BP)	Composition	Source volcano
Hekla-1845	AD 1845	Andesite/Dacite	Hekla
Hekla-1/Hekla-1158	AD 1104	Dacite/Rhyolite	Hekla
Landnám (BAS)	AD 872±2	Basaltic	Bárdarbunga-Veidivötn
Tjörnuvík	AD 800s		Hekla (reworked)
Hekla-3	~3.0	Dacite/Rhyolite	Hekla
Hekla-S	~3.7	Andesite/Dacite/Rhyolite	Hekla
Hekla-4	~4.3	Andesite/Dacite/Rhyolite	Hekla
Hov	~5.9	Basaltic	Kverkfjöll?
SILK-A1?	~5.9	Dacitic	Katla (SILK composition)
Mjáuvötn	~6.6	Basaltic	Katla
SILK-A7/RF-2?	~7.1	Dacitic	Katla (SILK composition)
Suduroy	~8.0	Rhyolitic	Katla (rhyolitic)
Skopun	~9.7	Dacitic	Katla (SILK composition)
An Druim/ Høvdarhagi	~9.7	Rhyolitic	Torfajökull
L-274/Fosen	~10.1	Rhyolitic	?
Saksunarvatn*	10,210 ± 35**	Basaltic	Grímsvötn
Hovsdalur***	~10.2	Rhyolitic	Þórðarhyrna?
Askja-S	10,836 ± 120****	Rhyolitic	Askja
L3574	~11.0?	Dacitic	?
Häseldalen	~11.3	Rhyolitic	Þórðarhyrna?
Sandoy A & B	~11.2-11.4	Basaltic	Bárdarbunga-Veidivötn



Table 2. Ages for tephras from the Høvdarhagi bog sequence derived from the age-depth model in Fig. 5. * age for the Saksunarvatn Tephra from Lohne et al. (2013)

Tephra	Peak depth (cm)	Age, cal yr BP (mean + 1 σ)
An Druim/Høvdarhagi	217	9716 ± 120
Skopun	219	9730 ± 130
L-274	274	10,130 ± 68
Saksunarvatn*	286	10,210 ± 35
Askja-S	300	10,424 ± 102
Sandoy B	410	11,260 ± 47
Sandoy A	418	11,316 ± 62
Hälshalen	418	11,316 ± 62

Table 3. Geochemical composition of Grimsvötn tephra from Havnardalsmyren including the visible Saksunarvatn Tephra (Havn-1) and four cryptotephra, Havn-0, 2, 3 and 4. Ages for the cryptotephra are estimated using linear interpolation between the Saksunarvatn macrotephra horizon and the Askja-S Tephra at 385-387 cm (Kylander et al., 2012); ** age from Lohne et al., (2013). All tephras were analysed in October 2010 using microprobe setting recommended by Hayward (2011) in order to avoid beam-induced chemical modification.

Core	3A	3A	2D	2D	2D	2D
Age	10.100-10.200	10 210 ± 35**	10 210 ± 35**	ca 10.250	ca 10.300-10.400	ca 10.350-10.450
Tephra peak depth	315-316 cm	320-321 cm	324-327 cm	329-330 cm	338 cm	345 cm
Layer*	Havn-0*	Havn-1*	Havn-1	Havn-2	Havn-3	Havn-4
Analyses	7	10	17	14	15	19
SiO ₂	49.06 ± 0.48	49.36 ± 0.64	49.16 ± 0.43	49.04 ± 0.53	49.07 ± 0.44	49.12 ± 0.61
TiO ₂	2.97 ± 0.09	3.03 ± 0.12	3.07 ± 0.11	2.94 ± 0.25	3.00 ± 0.10	2.99 ± 0.10
Al ₂ O ₃	13.11 ± 0.25	12.91 ± 0.17	12.96 ± 0.27	12.97 ± 0.33	13.01 ± 0.22	13.02 ± 0.28
FeO	13.90 ± 0.22	14.07 ± 0.40	14.13 ± 0.31	13.84 ± 0.41	13.91 ± 0.31	13.95 ± 0.25
MnO	0.23 ± 0.01	0.24 ± 0.01	0.24 ± 0.01	0.23 ± 0.01	0.24 ± 0.01	0.23 ± 0.01
MgO	5.63 ± 0.14	5.55 ± 0.18	5.57 ± 0.15	5.63 ± 0.43	4.69 ± 0.18	4.60 ± 0.18
CaO	9.93 ± 0.29	9.75 ± 0.25	9.86 ± 0.14	9.84 ± 0.48	9.83 ± 0.14	9.87 ± 0.18
Na ₂ O	2.75 ± 0.07	2.70 ± 0.15	2.75 ± 0.22	2.62 ± 0.22	2.60 ± 0.12	2.48 ± 0.16
K ₂ O	0.42 ± 0.03	0.47 ± 0.03	0.46 ± 0.03	0.44 ± 0.07	0.47 ± 0.05	0.46 ± 0.04
P ₂ O ₅	0.32 ± 0.03	0.32 ± 0.03	0.33 ± 0.01	0.31 ± 0.03	0.30 ± 0.02	0.30 ± 0.01
Total	98.32	98.41	98.52	97.88	97.12	97.02

Published geochemical data for the Saksunarvatn Ash (from West to East), mean and 1 s.d. except when indicated. Ages in cal yr BP except when indicated.

References: (1) Mortensen et al., 2005; age in ice core years BP SS09 timescale; (2) Jennings et al., 2002; (3) Jennings et al., 2014; (4) Eiriksson et al., 2004; (5) Lloyd et al., 2009; (6) Björck et al., 1992; (7) Thornalley et al., 2011; (8) Wastegård et al., 2011 and this paper; (9) Mangerud et al., 1986 and Bramham-Law et al., 2013; analyses shown with 2σ; (10) Rasmussen et al., 2011; (11) Bunting, 1994 and Timms et al., 2017; (12) Kelly et al., 2017, (13) Birks et al., 1996 and Lohne et al., 2013; (14) Lind et al., 2013; (15) Bramham-Law et al., 2013; analyses shown with 2σ; (16) Merkt et al., 1993. n.a. = not analysed.

Site	NGRIP	JM-96-1214/2-GC	MD99-2322	MD99-2322	MD99-2322	MD99-2275
Tephra peak depth	1409.9 m	138-140 cm	1617.5 cm	1719.5 cm	1797.5 cm	2549-2560 cm
Age	10,265-10,267	n.a.	10,031	10,186	10,390	n.a.
Reference	(1)	(2)	(3)	(3)	(3)	(4)
Analyses	13	10	17	10	22	5
SiO ₂	48.80 ± 0.54	48.80 ± 0.49	49.83 ± 0.39	49.13 ± 0.53	49.27 ± 0.47	50.38 ± 0.37
TiO ₂	2.77 ± 0.09	3.12 ± 0.09	3.14 ± 0.11	2.99 ± 0.14	3.11 ± 0.13	3.03 ± 0.11
Al ₂ O ₃	13.59 ± 0.22	13.70 ± 0.30	12.99 ± 0.22	13.07 ± 0.23	12.93 ± 0.20	13.05 ± 0.19
FeO	13.68 ± 0.42	14.40 ± 0.33	14.27 ± 0.36	14.14 ± 0.32	14.14 ± 0.36	14.83 ± 0.32
MnO	0.23 ± 0.02	0.24 ± 0.01	0.24 ± 0.01	0.24 ± 0.01	0.24 ± 0.01	n.a.
MgO	5.37 ± 0.28	5.39 ± 0.06	5.36 ± 0.14	5.43 ± 0.32	5.44 ± 0.30	5.58 ± 0.10
CaO	10.29 ± 0.25	9.47 ± 0.34	9.73 ± 0.17	9.81 ± 0.24	9.80 ± 0.30	9.98 ± 0.16
Na ₂ O	2.44 ± 0.10	2.68 ± 0.07	2.69 ± 0.14	2.64 ± 0.09	2.62 ± 0.27	2.56 ± 0.14
K ₂ O	0.39 ± 0.06	0.47 ± 0.02	0.49 ± 0.03	0.42 ± 0.04	0.46 ± 0.05	0.43 ± 0.05
P ₂ O ₅	0.31 ± 0.05	0.40 ± 0.27	0.28 ± 0.02	0.33 ± 0.03	0.30 ± 0.02	0.34 ± 0.05
Total	97.87	96.92	99.03	98.18	98.30	100.11

Site	Bjarkarlundur area	L. Torfadalsvatn	17-5P	L. Mjávötn	L. Saksunarvatn	LINK14
Tephra peak depth	4 sites	10.30-10.52 m	862 cm	831 cm	29.85-30.30 m	185 cm
Age	n.a.	n.a.	10,297 ± 118	n.a.	9000 ¹⁴ C y BP	10,085-10,526
Reference	(5)	(6)	(7)	(8)	(9)	(10)
Analyses	41	9	5	16	39	10
SiO ₂	48.89 ± 0.32	48.91 ± 0.45	48.69 ± 0.98	48.23 ± 0.53	49.51 ± 0.67	48.76 ± 0.44
TiO ₂	3.05 ± 0.06	2.84 ± 0.16	2.95 ± 0.17	2.98 ± 0.18	2.88 ± 0.36	2.89 ± 0.17
Al ₂ O ₃	12.86 ± 0.14	13.43 ± 0.43	12.83 ± 0.12	12.76 ± 0.25	13.08 ± 0.34	13.02 ± 0.16
FeO	14.20 ± 0.20	13.76 ± 0.23	13.84 ± 0.38	13.77 ± 0.64	14.04 ± 0.93	14.00 ± 0.42
MnO	0.25 ± 0.03	0.27 ± 0.04	0.24 ± 0.02	0.28 ± 0.04	0.23 ± 0.11	0.25 ± 0.03
MgO	5.69 ± 0.08	6.02 ± 0.29	5.72 ± 0.32	5.60 ± 0.21	5.68 ± 0.77	5.66 ± 0.21
CaO	9.79 ± 0.14	10.60 ± 0.33	10.15 ± 0.44	9.85 ± 0.48	10.04 ± 0.87	10.08 ± 0.32
Na ₂ O	2.81 ± 0.08	2.56 ± 0.23	2.74 ± 0.08	2.76 ± 0.17	2.50 ± 0.38	2.60 ± 0.22
K ₂ O	0.45 ± 0.03	0.43 ± 0.05	0.44 ± 0.04	0.44 ± 0.04	0.41 ± 0.08	0.43 ± 0.06
P ₂ O ₅	0.33 ± 0.02	n.a.	0.32 ± 0.04	n.a.	n.a.	0.32 ± 0.03
Total	98.32	98.82	97.98	96.66	98.37	98.01

Site	Quoyloo Meadow	L. Ashik	Kråkenes	Grønli	Potremser Moor	Eversener See
Tephra peak depth	160 cm	515-516 cm	673.5 cm	401 cm	455 cm	850 cm
Age	n.a.	n.a.	10 210 ± 35**	n.a.	n.a.	n.a.
Reference	(11)	(12)	(13)	(14)	(15)	(16)
Analyses	31	19	20	16	8**	16
SiO ₂	49.42 ± 0.38	49.13 ± 0.43	49.81 ± 0.60	49.03 ± 0.73	49.72 ± 1.37	48.11 ± 0.56
TiO ₂	3.06 ± 0.17	3.11 ± 0.11	2.80 ± 0.23	2.76 ± 0.14	2.93 ± 0.32	3.06 ± 0.13
Al ₂ O ₃	12.99 ± 0.27	12.67 ± 0.14	12.64 ± 0.34	13.19 ± 0.42	13.11 ± 0.52	12.62 ± 0.16
FeO	14.32 ± 0.61	13.59 ± 0.32	13.46 ± 0.49	13.59 ± 0.47	13.62 ± 1.18	14.19 ± 0.53
MnO	0.23 ± 0.01	0.22 ± 0.04	0.21 ± 0.06	0.23 ± 0.02	0.24 ± 0.07	0.21 ± 0.06
MgO	5.46 ± 0.45	4.75 ± 0.18	5.47 ± 0.48	5.72 ± 0.36	5.32 ± 0.70	5.25 ± 0.18
CaO	9.85 ± 0.37	9.88 ± 0.17	10.17 ± 0.48	10.14 ± 0.36	9.55 ± 0.97	9.62 ± 0.21
Na ₂ O	2.81 ± 0.18	2.93 ± 0.10	2.67 ± 0.21	2.47 ± 0.21	2.23 ± 0.53	2.70 ± 0.16
K ₂ O	0.47 ± 0.06	0.48 ± 0.03	0.42 ± 0.07	0.41 ± 0.04	0.44 ± 0.18	0.46 ± 0.04
P ₂ O ₅	0.32 ± 0.05	n.a.	n.a.	0.29 ± 0.02	0.29 ± 0.02	n.a.
Total	98.92	96.73	97.64	97.84	97.52	96.22