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Rhyolitic tephra horizons in northwestern Europe and Iceland from the AD 700s–800s: a potential alternative for dating first human impact

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Abstract: The distribution and geochemistry of four rhyolitic tephra horizons from Iceland dated to the AD 700s–800s is assessed. These include the rhyolitic phase of the Landnám tephra (AD 870s), the AD 860 layer, a previously unrecorded tephra called the GA4–85 layer (*c.* AD 700–800) and the Tjørnuvík tephra (*c.* AD 800s). The AD 860 and GA4–85 layers were first found in peat bogs in north Ireland. They are here correlated with equivalent horizons on Iceland which were found below the Landnám tephra (*c.* AD 870s). This time period is considered important in the North Atlantic region, because it coincides with a phase of human settlement in Iceland and the Faroe Islands. The establishment of a detailed tephrochronology may provide a tool for exact dating of sediment successions and sediments associated with archaeological excavations. Caution must be taken especially on Iceland where the Landnám tephra is often used for dating archaeological sites. This investigation show that several rhyolitic tephra horizons occur close in time to the Landnám tephra, and that mistakes can be made if detailed geochemical analyses are not carried out, especially in areas which are distal to the source of the Landnám tephra (the Veidivötn and Torfajökull volcanic systems, southern Iceland).

Key words: Iceland, Ireland, Faroe Islands, Germany, tephra, Landnám, human impact.

Introduction

Tephra horizons enable exact correlations of deposits of different origin and over wide geographical areas. Correlation of different late-Weichselian and early-Holocene sedimentary archives has been possible around the North Atlantic area through the use of two widespread tephra horizons, the mid-Younger Dryas Vedde Ash (10300 ^{14}C years BP) and the Preboreal/Boreal Saksunarvatn tephra (*c.* 9000 ^{14}C years BP) (e.g., Haflidason *et al.*, 1995; Birks *et al.*, 1996; Lowe *et al.*, 1999). Mid- and late-Holocene tephra horizons have been described outside Iceland from the British Isles, northern Germany, the Faroe Islands and Fennoscandia (e.g., Persson, 1971; Dugmore, 1989; Pilcher and Hall, 1992; van den Bogaard *et al.*, 1994; 2002; Dugmore *et al.*, 1995; Pilcher *et al.*, 1995; Boygle, 1998; Dugmore and Newton, 1998; Wastegård *et al.*, 2001; Hall and Pilcher, 2002; van den Bogaard and Schmincke, 2002; Zillén *et al.*, 2002). Most of these have a rhyolitic or silicic composition (>63% SiO_2) and many originate

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from the Hekla volcano. A detailed tephrochronology for the last *c*. 900 years on Iceland is possible due to historically documented dates of Icelandic eruptions (e.g., Larsen *et al.,* 1999).

The possibility of dating prehistorical Icelandic tephra horizons has been greatly improved by the use of ice-core dating. The dating control for the Holocene epoch is especially good, and a tephra horizon or a volcanic signal (sulphate peak, ECM) can often be dated with an accuracy of as good as 10 years. Tephra horizons also provide chronological links between the different ice cores (e.g., Zielinski *et al.,* 1997).

The Landnám tephra, dated in GRIP and GISP2 ice cores to the AD 870s (Grönvold *et al.*, 1995; Zielinski *et al.*, 1997) is visible in many parts of Iceland, and the distribution also includes the Faroe Islands, at least for the basaltic component. Distal tephras, close in age to the Landnám tephra, have also been described from Ireland, the Faroe Islands, Sweden, Norway and northern Germany (e.g., Persson, 1966; 1971; Pilcher and Hall, 1992; Hall *et al.,* 1993; Pilcher *et al.,* 1995; Hannon *et al.,* 1998; Wastegård *et al.,* 2001; Hall and Pilcher, 2002; van den Bogaard and Schmincke, 2002). These tephras, although also from the AD *c*. 800s, have separate geochemical signatures.

We now have a suite of tephras from the AD 700s–800s, which are distributed extensively around the North Atlantic seaboard. These include three rhyolitic tephra horizons identified from peat and lacustrine sediments on the Faroe Islands, Ireland and northern Germany (Figure 1). One of these, the AD 860 layer, has been reported both from Northern Ireland (Pilcher *et al.*, 1995) and Germany (van den Bogaard and Schmincke, 2002). Up until now, the AD 860 layer had not been correlated with any known horizons on Iceland.

New geochemical investigations of tephra horizons from Ireland, reported here, show the discovery of the two tephra horizons, the AD 860 and the GA4–85 layers. They occur stratigraphically below the Landnám tephra, and thus must be older.

Methods and materials

Samples for geochemical analyses have been taken either from cores (Ireland, Germany, the Faroe Islands), or from open sections (Iceland). Distal tephra horizons have been detected with the combustion technique described by Pilcher and Hall (1992). Contiguous samples were taken in 4 cm to 6 cm intervals. For samples in which tephra shards were detected as a result of this initial application, the equivalent sediment interval was retreated using 1 cm slices, in order to determine more precisely the distribution and concentration of tephra particles in each sample. Samples from Iceland were retrieved either from archaeological excavations or from monoliths taken in peat sections (Ásólfsstaðir). The preparation for microprobe analysis and subsequent analytical procedures follow Dugmore *et al.* (1995). Some samples from lakes on the Faroe Islands were first treated with the density separation technique described by Turney (1998). The fraction between 2.3 and 2.5 g/cm^3 was used for microprobe analyses.

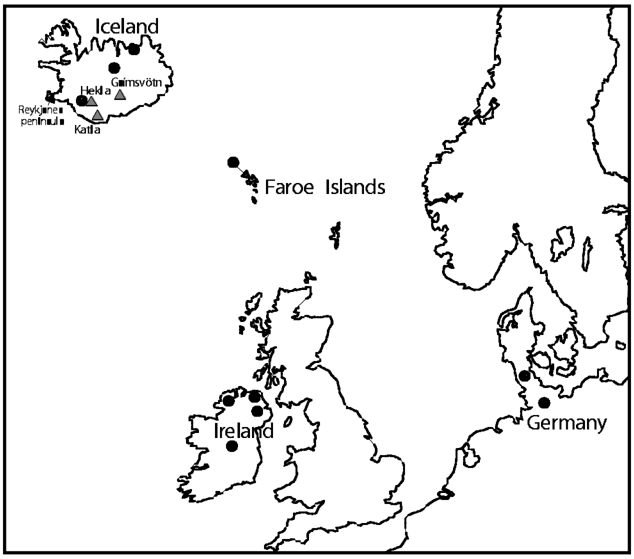

Figure 1 Map showing northwestern Europe with the location of volcanic systems on Iceland and investigated sites: (1) Ásólfsstaðir; (2) Eyjafjarðardalur; (3) Bláskógar; (4) Tjørnuvík; (5) Barnsmore; (6) Garry Bog; (7) Sluggan Bog; (8) Clara; (9) Jardelunder Moor; (10) Dosenmoor.

Rhyolitic tephra horizons dated to the AD 700s–800s

The Landnám tephra (AD 870s)

This two-coloured tephra was deposited closely in time to the first human settlement on Iceland, and was therefore called the 'Settlement layer' or the 'Landnám tephra' (Thorarinsson, 1944). The tephra was deposited during a simultaneous eruption of two magma chambers in the Veidivötn volcanic system and the Torfajökull complex, resulting in two components of tephra, one rhyolitic and one basaltic (Larsen, 1984; Larsen *et al.,* 1999). We present new analyses from the Ásólfsstaðir section in SW Iceland (Figures 2–4; Tables 1–2). The geochemistry has been described by, for example, Larsen (1984), Haflidason *et al.* (1992) and Larsen *et al.* (1999). It was first assumed that a sulphate peak in the Greenland ice cores dated to AD *c*. 898 corresponded to this eruption (Hammer *et al.*, 1980). Tephra of both components has now been found in both the GISP2 and GRIP ice cores, dated to AD 871 ± 2 in GRIP (Grönvold *et al.*, 1995) and 877 ± 4 in GISP2 (Zielinski *et al.*, 1997).

The Landnám tephra has been identified in most parts of Iceland. In SW Iceland the layer is two-coloured, with a lower light-coloured part and an upper dark-coloured part (e.g., Larsen, 1984; Dugmore *et al.,* 2000). On northern Iceland, only the dark-coloured basaltic phase (VIIa) is visible in sections, although it is possible that the rhyolitic component (VIIb) could be traced. The volume of the rhyolitic part is much smaller than the basaltic tephra (Larsen *et al.,* 1999).

The rhyolitic component of the Landnám tephra has been found outside Iceland in the Greenland ice cores (Grönvold *et al.,* 1995; Zielinski *et al.,* 1997). The basaltic phase has recently been found on the Faroe Islands slightly above the first palaeobotanical evidence for human settlement (Hannon and Bradshaw, 2000; Wastegård *et al.,* 2001).

The timing of first settlements on Iceland is under renewed discussion (Nordahl, 1988; Hallsdóttir, 1987; Hermanns-Auðardóttir, 1989; 1991; 1992; Vilhjálmsson, 1991; Buckland *et al.,* 1995; Olsson, 1997, 1999; Theodórsson, 1997; 1998; Ólafsson, 1998; Dugmore *et al.,* 2000). In Reykjavík, over half of the radiocarbon dates of the excavated cultural horizons indicated the AD mid-700s (Nordahl, 1988; Hermanns-Auðardóttir, 1989; 1991; 1992; Vilhjálmsson, 1991; Myhre, 1993; Theodórsson, 1998) although the earliest archaeological material in Reykjavík was considered by Nordahl (1988) to reflect the traditional dating of the colonization of Iceland to AD 870–874. Hermanns-Auðardóttir (1989; 1992) has reported equally early radiocarbon results from Vestmannaeyjar (Westman Islands), S Iceland, and she started the discussion of an earlier colonization of Iceland referring to Norse settlement remains and palaeobotanically determined human impact beneath the Landnám Tephra in S and SW Iceland (Einarsson, 1963a; 1963b; Hallsdóttir 1987; Nordahl, 1988). In the palaeobotanical record, an increase in pollen percentages of large (wild) Gramineae is characteristic for settlement on Iceland

Table 1 Microprobe analyses of samples from the Ásólfsstaðir section, SW Iceland. Analyses below 95% have been discarded. n = analyses. Ásólf-1 is correlated with the Eldgjá tephra, which is dated to the AD mid-930s (Zielinski *et al.,* 1995)

	Ásólf-1 n = 9	Ásólf-2 n = 12	Ásólf-3 n = 8	Ásólf-4a n = 6	Ásólf-4b n = 6	Ásólf-5 n = 8	Ásólf-6a n = 11	Ásólf-6b n = 6
SiO_2	45.92 ± 0.47	48.18 ± 0.35	70.26 ± 0.76	46.67 ± 0.55	49.33 ± 0.77	46.34 ± 0.54	46.95 ± 0.55	66.41 ± 0.73
TiO_2	4.59 ± 0.50	1.92 ± 0.07	0.30 ± 0.03	4.59 ± 0.16	3.87 ± 0.06	4.56 ± 0.09	4.59 ± 0.18	1.07 ± 0.07
Al_2O_3	12.26 ± 0.53	13.11 ± 0.18	14.31 ± 0.24	12.40 ± 0.20	12.60 ± 0.22	12.29 ± 0.23	12.63 ± 0.30	13.79 ± 0.14
FeO_{tot}	15.05 ± 0.88	12.61 ± 0.23	2.45 ± 0.13	14.28 ± 0.28	13.34 ± 0.45	14.63 ± 0.47	14.52 ± 0.86	5.47 ± 0.21
MnO	0.27 ± 0.04	0.25 ± 0.03	0.07 ± 0.02	0.27 ± 0.01	0.28 ± 0.01	0.28 ± 0.05	0.25 ± 0.04	0.19 ± 0.03
MgO	5.19 ± 0.35	6.49 ± 0.15	0.27 ± 0.02	4.80 ± 0.12	3.95 ± 0.12	4.81 ± 0.15	4.92 ± 0.48	0.91 ± 0.04
CaO	10.37 ± 0.76	11.13 ± 0.26	0.92 ± 0.06	9.57 ± 0.34	8.50 ± 0.20	9.43 ± 0.23	9.85 ± 0.44	2.63 ± 0.09
Na_2O	2.82 ± 0.29	2.54 ± 0.07	4.42 ± 0.32	3.20 ± 0.06	3.54 ± 0.10	3.28 ± 0.10	3.21 ± 0.19	3.97 ± 0.40
K_2O	0.69 ± 0.19	0.24 ± 0.03	4.52 ± 0.11	0.87 ± 0.03	1.04 ± 0.08	0.82 ± 0.09	0.83 ± 0.10	2.80 ± 0.17
Total	97.15	96.48	97.52	96.65	96.43	96.42	97.75	97.24
Correlation	Eldgjá	Landn. VIIa	Landn. VIIb	Katla	Katla (?)	Katla	Katla	Katla

Table 2 Mean geochemical analyses and standard deviations (1 σ) of the AD 860 tephra, groups A and B and the rhyolitic component of the Landnám tephra. n = number of analyses. Sites (Figure 1): SLB = Sluggan Bog, N Ireland; BLA = Bláskógar, NE Iceland; EYJ = Eyjafjarðardalur, N Iceland; ASO = Ásólfsstaðir, SW Iceland; GRIP ice core, Greenland (no standard deviations given; Grönvold *et al.*, 1995). Sites in northern Germany are Jardelunder Moor and Dosenmoor

	AD 860 tephra, group A			AD 860 tephra, group B			Landnám tephra (VIIb)	
	SLB Ireland n = 8	BLA Iceland n = 10	EYJ Iceland n = 6	SLB Ireland n = 17	Clara Ireland n = 9	N Germany n = 10	ASO Iceland n = 8	GRIP n = ?
SiO_2	74.09 ± 1.85	73.68 ± 1.16	73.74 ± 0.50	71.89 ± 1.14	71.66 ± 1.74	71.99 ± 0.47	70.26 ± 0.76	71.8
TiO_2	0.21 ± 0.01	0.17 ± 0.05	0.18 ± 0.04	0.28 ± 0.08	0.25 ± 0.02	0.21 ± 0.20	0.30 ± 0.03	0.35
Al_2O_3	12.76 ± 0.33	12.68 ± 0.28	12.27 ± 0.17	14.43 ± 0.61	14.82 ± 1.18	14.17 ± 0.16	14.31 ± 0.24	14.3
FeO_{tot}	1.66 ± 0.09	1.76 ± 0.18	1.69 ± 0.07	1.54 ± 0.05	1.52 ± 0.09	1.46 ± 0.08	2.45 ± 0.13	2.30
MnO	n.a.	0.05 ± 0.03	0.03 ± 0.03	n.a.	n.a.	0.09 ± 0.05	0.07 ± 0.02	0.13
MgO	0.08 ± 0.03	0.11 ± 0.05	0.10 ± 0.02	0.42 ± 0.03	0.44 ± 0.04	0.27 ± 0.14	0.27 ± 0.02	0.28
CaO	0.83 ± 0.06	0.92 ± 0.38	0.95 ± 0.04	1.88 ± 0.09	2.03 ± 0.09	1.91 ± 0.12	0.92 ± 0.06	0.91
Na_2O	4.08 ± 0.37	4.07 ± 0.27	4.11 ± 0.18	3.97 ± 0.49	4.10 ± 0.12	3.87 ± 0.13	4.42 ± 0.32	5.53
K_2O	3.76 ± 0.23	3.66 ± 0.20	3.61 ± 0.09	3.26 ± 0.58	3.21 ± 0.19	3.13 ± 0.11	4.52 ± 0.11	4.45
Total	97.47	97.08	96.72	97.68	98.04	97.10	97.52	100.0

in addition to cultivated crops (Einarsson, 1963a; 1963b). In more recent palaeobotanical investigations, single occurrences of Cerealia-type pollen (with the *Hordeum* sculpture type) were recorded below the Landnám tephra at Vatnsmýri in Reykjavík and at Mosfell, SW Iceland (Hallsdóttir, 1987: 20, 26, 33–34), giving rise to the speculation that settlement may have been older than previously assumed. This archaeological and palaeobotanical evidence has sparked a debate about the timing of first settlement, as the established timing on Iceland, as described in the *Íslendingabók* (compiled in the early twelfth century), reputedly took place at the time of the Landnám tephra, AD *c.* 870s.

The AD 860 layer

This tephra was first described from Sluggan Bog in Northern Ireland (Figure 1) and was dated there by wiggle-matching of dates derived from peat to AD 860 ± 20 (Pilcher *et al.*, 1995). Two geochemically distinct groups occur, of which group A has a similar geochemistry as the rhyolitic part of the Landnám tephra (Figure 3). This gave rise to the suggestion that the AD 860 layer and the Landnám tephra derived from the same eruption (Grönvold *et al.*, 1995: 153). A closer look at the geochemistry, however, reveals that these horizons are geochemically distinct (Table 2; Figures 3 and 4) and most probably originate from different eruptions and volcanic systems.

Tephra with the geochemistry of the group B component has been found in several other sites in Ireland and has also been reported from northern Germany (Figures 1, 3 and 4; Table 2; Hall and Pilcher, 2002; van den Bogaard and Schmincke, 2002). This component occurs in many sites in northern and central Ireland, although the other component (A) has so far only been found at the Sluggan Bog site.

Tephrochronological investigations carried out in northern Iceland show that several tephra horizons were deposited close in time to the first human settlement in the AD 800s. All these layers belong to the so called ‘Landnámssyrpa’ or ‘Landnám group’ (LNS) which spans at least three centuries (Sigurgeirsson, 1999). In NE Iceland the uppermost tephra layer of the LNS was formed in the mid-tenth century AD. The second tephra layer from the top is most probably the basaltic phase of the Landnám tephra. Usually two to three basaltic tephra layers are situated below the Landnám tephra. The most prominent tephra of the LNS is a two-coloured horizon dominated by basaltic glass shards. In Eyjafjarðardalur in north Iceland (Figure 1), this tephra is divided by a light-coloured band of rhyolitic tephra, 1–2 mm thick. This horizon has the same geochemistry as a rhyolitic tephra identified at an archaeological site at Bláskógar, NE Iceland (Figures 1, 3 and 4; Table 2). The tephra is characterized by SiO_2 contents between *c.* 73 and 76% and K_2O contents between 3.6 and 4.1%. The two-coloured tephra is most probably equivalent to the so-called Twilling Layers, the ‘b’ and ‘c’ layers described from the Mývatn

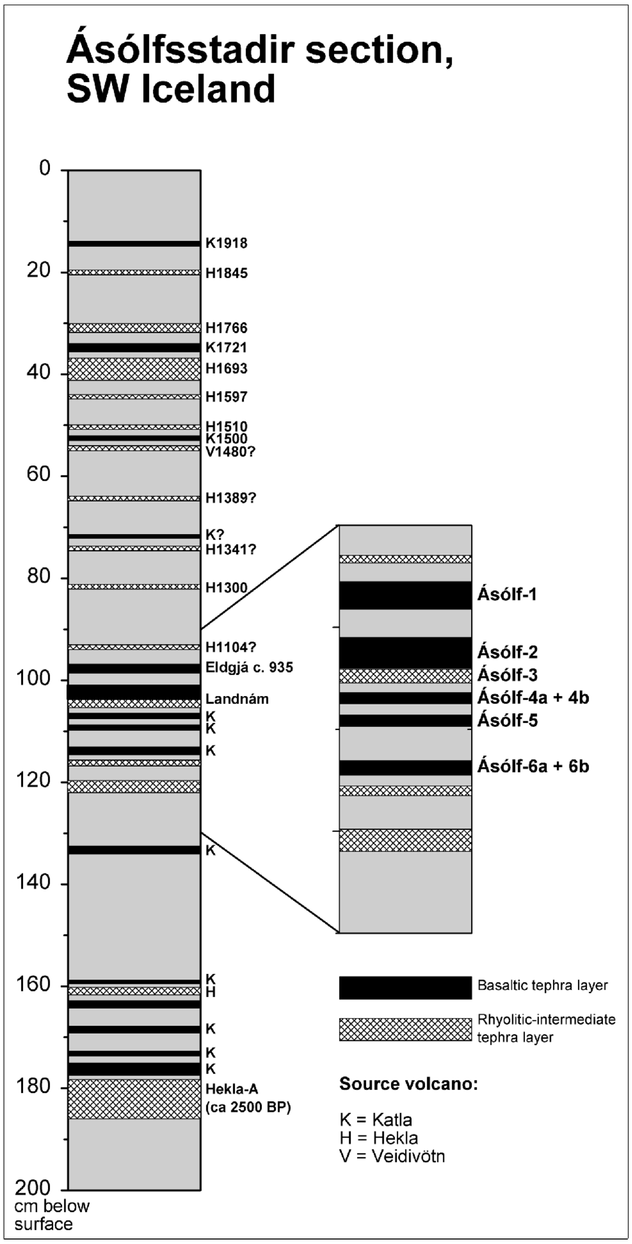

Figure 2 The stratigraphy of the Ásólfsstaðir bog section, SW Iceland (Figure 1). Left column shows tephra horizons described in the field. Right column shows an enlargement of the section between 90 and 130 cm below surface and shows layers that were geochemically analysed (Table 1).

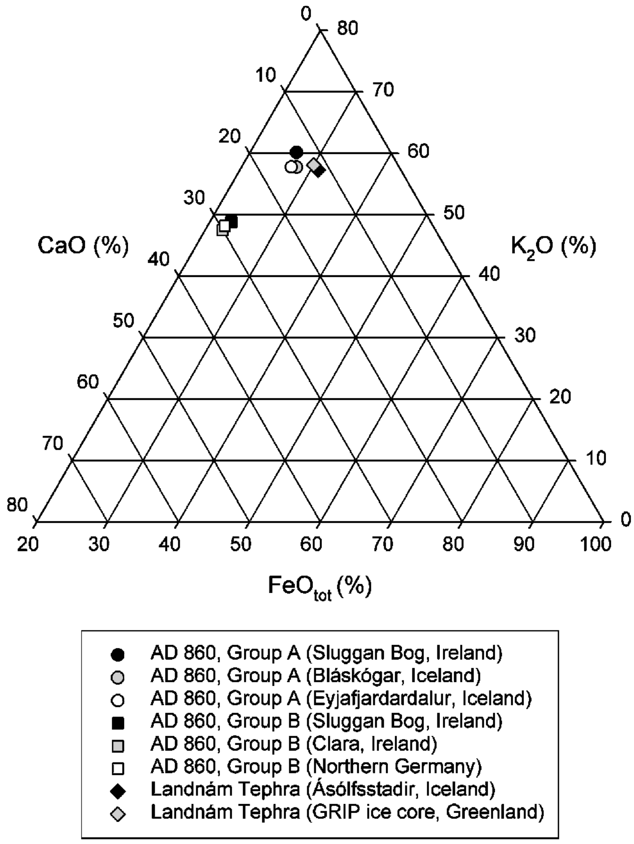

Figure 3 Ternary plot of FeO_{tot}, K_2O and CaO of the AD 860 layer and the Landnám tephra from sites in Iceland, Ireland, Germany and the GRIP ice core. The symbols show mean values (Table 2).

area, north Iceland (Thorarinsson, 1951; Einarsson *et al.,* 1988; Sæmundsson, 1991; Haflidason *et al.,* 2000).

Microprobe analyses of shards from Bláskógar and Eyjafjarðardalur show that the rhyolitic component of the LNS/Twilling Layers can be correlated with the group A component of the AD 860 layer (Table 2; Figure 4). Based on geochemistry on the tephra layers in Eyjafjarðardalur, Sigurgeirsson (1999) postulates that the rhyolitic tephra most probably originates in the Grímsvötn volcanic system.

GA4–85

This brown tephra has been found in two Irish peat bogs, Barnsmore and Garry Bog (Figure 1) just below the AD 860 layer (Hall and Pilcher, 2002). SiO_2 contents range between 65 and 67% and MgO and K_2O show *c.* 0.9% and 2.9%, respectively (Table 3). The age of the GA4–85 tephra is estimated to AD 800, which is based on extrapolation from the AD 860 tephra.

The stratigraphy of the Ásólfsstaðir bog section sequence is shown in Figure 2. This site is situated in the southwestern margin of the valley Thjórsárdalur, southwest Iceland, close to many volcanic systems, e.g., Katla and Hekla (Figure 1). Microprobe analyses of tephra layers around the Landnám tephra (Ásólf-2 and 3), are shown in Table 1. The two black layers (Ásólf-4a + b and 5) below the Landnám tephra are probably equivalent to the layers VIIc and VIId described by Thorarinsson (1944). Basaltic tephra from the Katla volcanic system dominate these layers, although an uncorrelated basaltic component (Ásólf-4b) also occurs. The source of this component is probably also the Katla volcanic system (see compositional fields in Lacasse *et al.,* 1998). A third blackish tephra (Ásólf-6) below these horizons is also dominated by basaltic tephra from Katla (Ásólf-6a), but a subordinate rhyolitic component also occurs (Ásólf-6b). This component has SiO_2 contents between 65 and 68% and K_2O contents between 2.75 and 3% (Table 3). It has a geochemistry similar to most rhyolitic tephra layers erupted from Katla during the Holocene and the source of this component is probably also the Katla volcanic system (cf. Larsen *et al.,* 2001). Some elements, e.g., TiO_2 and MgO, are lower than the youngest rhyolitic Katla tephra (SILK-YN, *c.* AD 400s; Dugmore *et al.,* 2000; Larsen *et al.,* 2001). We suggest that the rhyolitic component in the Ásólf-6 layer might be correlated with the GA4–85 tephra found in Irish peat bogs (Figure 4). This would infer that the GA4–85 tephra is the first Holocene rhyolitic Katla tephra layer found outside Iceland.

The Tjørnuvík tephra

Modern tephrochronological investigations on the Faroe Islands (Dugmore and Newton, 1998; Hannon *et al.,* 1998; Wastegård *et al.,* 2001) have not recognized any of the rhyolitic tephra horizons described from Northern Ireland and Iceland dated to the AD *c.* 800s. The only distinct rhyolitic tephra horizon found to date is the Tjørnuvík tephra. This layer has been recovered from

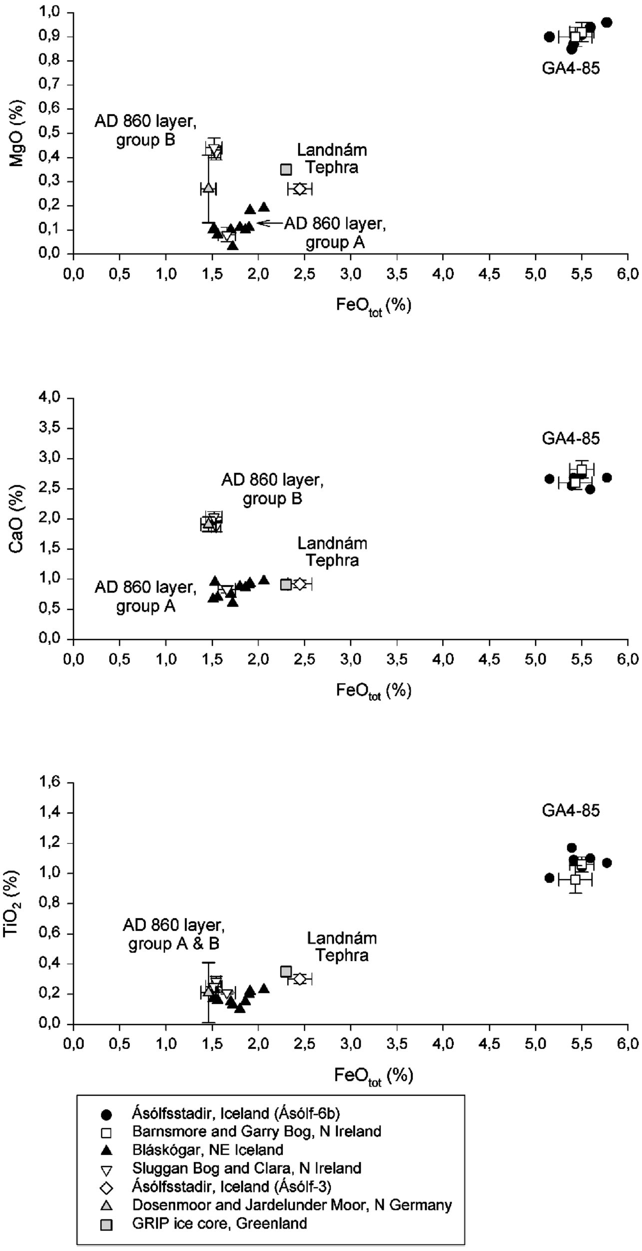

Figure 4 Binary plots of FeO_{tot} versus MgO, FeO_{tot} versus CaO and FeO_{tot} versus TiO_2 for the Landnám tephra, the AD 860 layer and the GA4–85 tephra from sites in Iceland, Ireland and Germany.

Table 3 Geochemistry of the GA4–85 tephra from sites in Northern Ireland and the Ásólfsstaðir bog section, SW Iceland (sample Ásólf-6b) (Figures 1 and 2). n.a. = not analysed; n = number of analyses

	Barnsmore = 11	Garry Bog n = 15	Ásólfsstadir n = 6
SiO_2	66.71 ± 0.86	65.62 ± 0.87	66.41 ± 0.76
TiO_2	1.06 ± 0.05	0.96 ± 0.09	1.07 ± 0.07
Al_2O_3	14.17 ± 0.18	14.23 ± 0.21	13.79 ± 0.14
FeO_{tot}	5.50 ± 0.13	5.43 ± 0.18	5.47 ± 0.21
MnO	n.a.	n.a.	0.19 ± 0.03
MgO	0.92 ± 0.04	0.90 ± 0.04	0.91 ± 0.04
CaO	2.82 ± 0.14	2.60 ± 0.11	2.63 ± 0.09
Na_2O	4.41 ± 0.21	4.28 ± 0.56	3.97 ± 0.40
K_2O	2.88 ± 0.11	2.86 ± 0.07	2.80 ± 0.17
Total	98.41	96.88	97.24

at least three sites on the Faroe Islands, including the type site Tjørnuvík (Figure 1), some centimetres above the first settlement as inferred from palaeobotanical data (Hannon *et al.,* 1998; Hannon and Bradshaw, 2000; Wastegård *et al.,* 2001). The settlement phase is dated through secondary Mediaeval records to AD 825 (Debes, 1990), but new AMS dates from the Faroes have shown that the first occurrence of cultivated crops from three locations dated from as early as the AD 500s (Hannon and Bradshaw, 2000; Hannon *et al.,* 2001). This was older than implied from previous archaeological and historical studies (Arge, 1991) but consistent with earlier palaeoecological investigations (Jóhansen, 1971; 1985). Buckland and Dinnin (1998) regard early settlement as unproved at Tjørnuvík from their work on the fossil insect faunas, but, as their sediment cores were not radiocarbon dated, it was not clear that they had located the relevant horizon accurately (Hannon *et al.,* 1998). The age of the Tjørnuvík tephra to the AD 800s is supported by the fact that the basaltic phase of the Landnám tephra (VIIa) occurs in the same samples (Wastegård *et al.,* 2001).

Two rhyolitic populations occur in the Tjørnuvík tephra (A and B). The larger (A) consists of glass with SiO_2 content between 65 and 76%, and exhibits low TiO_2 (0.1–0.6%) and MgO contents (0.0–0.6%) (Table 4). The geochemistry of this group shows affinities to the Hekla volcanic system (cf. Larsen and Thorarinsson, 1977; Larsen *et al.*, 1999). A second subordinate population (B) has a SiO_2 content of *c.* 63%, and distinctly higher TiO_2 and MgO contents than the main population (Table 4). The Tjørnuvík tephra can possibly be correlated with a recently identified tephra from the Hekla volcano that has been traced on the Reykjanes peninsula, SW Iceland (Figure 1; Sigurgeirsson, 1992). The age of this tephra has been estimated to the AD 600s–700s.

Discussion and conclusions

The discovery of several widespread tephra horizons dated to the AD 700s–800s opens new possibilities for fine-tuning the date of first human impact in Iceland and in the Faroe Islands. While the coincidence of a radiocarbon 'plateau' at this time restricts dating precision using radiocarbon alone, in the Faroes first settlement indicators (cultivated crops) are recorded below the basaltic phase of the Landnám tephra (Hannon *et al.*, 1998; 2001; Hannon and Bradshaw, 2000; Wastegård *et al.*, 2001). The AD 860 layer and the GA4–85 tephras have not been found to date on the Faroe Islands, except for a few shards in a mixed tephra layer from a blanket peat on Streymoy which can be correlated with the group A component of the AD 860 layer.

The AD 860 tephra layer has a wide distribution, which may include larger parts of the British Isles and northern Germany. It may thus be one of the most widely dispersed tephra horizons in northwestern Europe. It remains to be proven if it also can be found in Scandinavia. Some of the tephra horizons that Persson (1966; 1971) reported from Norwegian and Swedish peat bogs were dated to *c.* AD 800–1200, which might suggest this. Alternatively, these tephra horizons are from the Hekla-1 eruption (AD 1104) or the rhyolitic component of the Landnám tephra.

Several sulphate peaks occur in the ice cores sequences dated to the AD 800s (Zielinski *et al.*, 1994), e.g., at AD 822, 823, 853 and 875 (GISP2), but so far tephra has been found only from the 'Landnám' eruption at *c.* AD 875 (Grönvold *et al.,* 1995; Zielinski *et al.*, 1997). The origins of the other peaks are unknown or thought to be from eruptions on the Azores or Japan, but an Icelandic source should be equally possible.

The Landnám tephra is often used in archaeological excavations in Iceland to date the first signs of human settlement. The results presented here suggest that the ongoing debate about timing of settlement may be resolved using a more detailed tephrochrono-

Table 4 Representative analyses of the Tjørnuvík tephra from sites on the Faroe Islands; see also Hannon *et al.* (1998) and Wastegård *et al.* (2001)

SiO_2	75.94	74.60	73.54	73.49	73.38	71.98	71.67	67.64	66.42	65.64	63.63	63.52	63.09
TiO_2	0.11	0.09	0.11	0.11	0.07	0.28	0.22	0.40	0.43	0.55	1.52	1.44	1.42
Al_2O_3	13.35	13.04	12.66	12.54	13.12	12.95	13.73	14.92	14.74	14.46	13.86	13.66	13.89
FeO_{tot}	1.90	2.10	1.85	1.71	1.98	2.52	2.93	5.35	5.22	7.32	6.13	5.99	6.37
MnO	0.08	0.10	0.07	0.26	0.09	0.12	0.10	0.16	0.13	0.26	0.19	0.22	0.22
MgO	0.05	0.09	0.05	0.12	0.05	0.43	0.13	0.52	0.52	0.37	1.51	1.52	1.45
CaO	1.37	1.31	1.37	1.34	1.34	1.83	1.80	3.25	3.21	3.75	3.56	3.42	3.49
Na_2O	3.48	4.00	3.72	3.83	3.89	3.64	3.98	2.99	3.99	4.12	4.28	3.80	4.53
K_2O	2.81	2.80	2.98	2.93	2.82	2.61	2.67	1.97	2.11	1.92	2.65	2.56	2.55
Total	99.09	98.13	96.35	96.33	96.74	96.36	97.23	97.20	96.77	98.39	97.33	96.13	97.01
Group	A	A	A	A	A	A	A	A	A	A	B	B	B

logy, as more exact dates can be achieved if other rhyolitic tephra horizons are used in addition to the Landnám tephra. In contrast to basaltic tephra horizons, rhyolitic tephras often have a more variable geochemistry, so that not only can volcanic systems be distinguished but also tephra from different eruptions within the same volcanic system. It is recommended that geochemical analyses are carried out routinely, especially on northern Iceland where other rhyolitic horizons occur in connection with the supposed first settlement phase.

A future aim must be to geochemically identify further tephra horizons in the Greenland ice cores during the AD 800s. Dating tephra horizons in Iceland and more distal areas could also be more precisely achieved by wiggle-matching AMS dates around the tephra horizons, such as has been carried out from peat profiles in Northern Ireland and northern Germany (Pilcher *et al.*, 1995).

The occurrence of widespread rhyolitic tephra horizons in areas far from Iceland once again shows the great value and potential of a detailed tephrochronological framework. The tephra horizons described in this paper have only been recently described. This suggests that tephra horizons other than the classical Hekla tephras may be searched for, and found, in wider areas of Europe.

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References

Arge, S.V. 1991: The Landnám in the Faroes. *Arctic Anthropology* 28, 101–20.

Birks, H.H., Gulliksen, S., Haflidason, H., Mangerud, J. and **Possnert, G.** 1996: New radiocarbon dates for the Vedde ash and the Saksunarvatn ash from western Norway. *Quaternary Research* 45, 119–27.

Boygle, J. 1998: A little goes a long way: discovery of a new mid-Holocene tephra in Sweden. *Boreas* 27, 195–99.

Buckland, P.C. and **Dinnin, M.H.** 1998: Insect faunas at Landnám: a palaeo-entomological study at Tjørnuvík, Streymoy, Faroe Islands. *Fróðskaparrit* 46, 277–86.

Buckland, P.C., Edwards, K.E., Blackford, J.J., Dugmore, A.J., Sadler, J.P. and **Sveinbjarnardóttir, G.** 1995: A question of Landnám: pollen, charcoal and insect studies on Papey, eastern Iceland. In Butlin, R.A. and Roberts, N., editors, *Ecological relations in historical times – human impact and adaptation*, Oxford (UK) and Cambridge, MA: Blackwell, 247–64.

Debes, H.J. 1990: Føroya søga. Tórshavn: Nordurlond og Føroyar.

Dugmore, A.J. 1989: Icelandic volcanic ash in Scotland. *Scottish Geographical Magazine* 105, 168–72.

Dugmore, A.J. and **Newton, A.J.** 1998: Holocene tephra layers in the Faroe Islands. *Fróðskaparrit* 46, 191–204.

Dugmore, A.J., Larsen, G. and **Newton, A.J.** 1995: Seven tephra isochrones in Scotland. *The Holocene* 5, 257–66.

Dugmore, A.J., Newton, A.J., Larsen, G. and **Cook, G.T.** 2000: Tephrochronology, environmental change and the Norse settlement of Iceland. *Environmental Archaeology* 5, 21–34.

Einarsson, Á, Haflidason, H. and **Óskarsson, H.** 1988: Mývatn: saga lífríkis og gjóskutímatal í syðriflóa. *Fjölrit* 17, Reykjavík: Náttúruverndarráð, 96 pp.

Einarsson, Th. 1963a: Vitnisburður frjógreiningar um gróður, veðurfar og landnám á Íslandi. *Saga* 1962, 442–69.

—— 1963b: Pollen-analytical studies on vegetation and climate history of Iceland in late and post-glacial times. In Löve, Á. and Löve, D., editors, *North Atlantic biota and their history*, Oxford: Pergamon Press, 355–65.

Grönvold, K., Óskarsson, K., Johnsen, S.J., Clausen, H.B., Hammer, C.U., Bond, G. and **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, 149–55.

Haflidason, H., Eiríksson, J. and **van Kreveld, 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.

Haflidason, H., Larsen., G. and **Olafsson, G.** 1992. The recent sedimentation history of Thingvallavatn, Iceland. *Oikos* 64, 80–95.

Haflidason, H., Sejrup, H.P., Kristensen, D.K. and **Johnsen, S.** 1995: Coupled response of the late glacial climatic shifts of northwest Europe reflected in Greenland ice cores: evidence from the northern North Sea. *Geology* 23, 1059–62.

Hall, V.A. and **Pilcher, J.R.** 2002: Late Quaternary Icelandic tephras in Ireland and Great Britain: detection, characterization and usefulness. *The Holocene* 12, 223–30.

Hall, V.A., Pilcher, J.R. and **McCormac, F.G.** 1993: Tephra dated lowland landscape history of the north of Ireland, AD 750–1150. *New Phytologist* 125, 193–202.

Hallsdóttir, M. 1987: Pollen analytical studies of human influence on vegetation in relation to the Landnám tephra layer in southwest Iceland. *LUNDQUA Thesis 18,* 45 pp.

Hammer, C.U., Clausen, H.B. and **Dansgaard, W.** 1980: Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. *Nature* 288, 230–35.

Hannon, G.E. and **Bradshaw, R.H.W.** 2000: Impacts and timing of the first human settlement on vegetation of the Faroe Islands. *Quaternary Research* 54, 404–13.

Hannon, G.E, Hermanns-Auðardóttir, M. and **Wastegård, S.** 1998: Human impact at Tjørnuvík in the Faroe Islands. *Fróðskaparrit* 46, 215–28.

Hannon, G.E., Wastegård, S., Bradshaw, E., Bradshaw, R.H.W. and **Hermanns-Auðardóttir, M.** 2001: The role of human impact on Late Holocene vegetation dynamics on the Faroe Islands. *Proceedings of the Royal Academy of Ireland* 101B, 1–2, 129–39.

Hermanns-Auðardóttir, M. 1989: Islands tidiga bosättning. *Studia Archaeologica Universitatis Umensis* 1, 184 pp.
—— 1991: The early settlement of Iceland, with comments by S. Kaland, B. Crawford, D. Mahler and C. Malmros, C.D. Morris and H. Sigurdsson. *Norwegian Archaeological Review* 34, 1–33.
—— 1992: The beginning of settlement in Iceland from an archaeological point of view. *Acta Borealia* 2, 85–135.
Jóhansen, J. 1971: A palaeobotanical study indicating a previking settlement in Tjørnuvík, Faroe Islands. *Fróðskaparrit* 19, 147–57.
—— 1985: Studies in the vegetational history of the Faeroe and Shetland Islands. PhD thesis, Copenhagen University, 117 pp.
Lacasse, C., Carey, S. and **Sigurdsson, H.** 1998: Volcanogenic sedimentation in the Iceland Basin; influence of subaerial and subglacial eruptions. *Journal of Volcanology and Geothermal Research* 83, 47–73.
Larsen, G. 1984: Recent volcanic history of the Veiðivötn fissure swarm, southern Iceland – an approach to volcanic risk assessment. *Journal of Volcanology and Geothermal Research* 22, 33–58.
Larsen, G. and **Thorarinsson, S.** 1977: H4 and other acid Hekla tephra layers. *Jökull* 27, 28–46.
Larsen, G., Dugmore, A.J. and **Newton, A.J.** 1999: Geochemistry of historical-age silicic tephras on Iceland. *The Holocene* 9, 463–71.
Larsen, G., Newton, A.J., Dugmore, A.J. and **Vilmundardóttir, E.G.** 2001: Geochemistry, dispersal, volumes and chronology of Holocene silicic tephra layers from the Katla volcanic system, Iceland. *Journal of Quaternary Science* 16, 119–32.
Lowe, J.J., Birks, H.H., Brooks, S.J., Coope, G.R., Harkness, D.D., Mayle, F.E., Sheldrick, C., Turney, C.S.M. and **Walker, M.J.C.** 1999: The chronology of palaeoenvironmental changes during the Last Glacial-Holocene transition: towards an event stratigraphy for the British Isles. *Journal of the Geological Society, London* 156, 397–410.
Myhre, B. 1993: The beginning of the Viking Age: some current archaeological problems. *Viking Revaluations: Viking Society Centenary Symposium 14–15 May 1992,* Viking Society for Northern Research, London: University College.
Nordahl, E. 1988: Reykjavík from the archaeological point of view. *Aun.* 12, 1–150.
Ólafsson, G. 1998: Fylgsnið í hellinum víðgelmi. In Snæsdóttir, M., editor, *Árbok, Hins Íslenzka Fornleifafélags*, Reykjavík: Eid Íslenzka Fornleifafélags, 125–42.
Olsson, I.U. 1997: Kol-14 Datering. Metoden och diskussion av speciella problem med isländska prov och redovisning av två serier dateringar av arkeologiskt material. The Ása G. Wrights Memorial Lectures IX, National Museum of Iceland, 63 pp.
—— 1999: Geophysical aspects of problems in interpretation of Icelandic radiocarbon dates in archaeological samples. *Norwegian Archaeological Review* 32, 95–110.
Persson, Ch. 1966: Försök till tefrokronologisk datering av några svenska torvmossar. *Geologiska Föreningens i Stockholm Förhandlingar* 88, 361–95.
—— 1971: Tephrochronological investigation of peat deposits in Scandinavia and on the Faroe Islands. *Sveriges Geologiska Undersökning C656*, 34 pp.
Pilcher, J.R. and **Hall, V.** 1992: Towards a tephrochronology for the Holocene of the north of Ireland. *The Holocene* 2, 255–59.
Pilcher, J.R., Hall, V.A. and **McCormac, F.G.** 1995: Dates of Holocene Icelandic volcanic eruptions from tephra layers in Irish peats. *The Holocene* 5, 103–10.
Sæmundsson, K. 1991: Jarðfræði Kröflukerfisins. In Garðarsson, A. and Einarsson, Á., editors, *Náttura Mývatns,* Reykjavík: Hiðíslenska náttúrufræðifélag, 24–95.
Sigurgeirsson, M.Á 1992: Tephra studies on the Reykjanes peninsula. Masters thesis, University of Iceland, 114 pp. (in Icelandic).
—— 1999: Gjóskulagarannsóknir á hofstöðum 1992–1997. *Archaelogia Islandica* 1, 110–18.
Theodórsson, P. 1997: Aldur landnáms og geislakolsgreiningar. *Skírnir* 171, 92–110.
—— 1998: Norse settlement of Iceland – close to AD 700? *Norwegian Archaelogical Review* 31, 29–38.
Thorarinsson, S. 1944: Tefrokronologiska studier på Island. Thjórsárdalur och dess förödelse. *Geografiska Annaler* 26, 1–217.
—— 1951: Laxárgljúfur and Laxárhraun. A tephrochronological study. *Geografiska Annaler* 1–2, 1–89.
Turney, C.S.M. 1998: Extraction of rhyolitic component of Vedde microtephra from minerogenic lake sediments. *Journal of Paleolimnology* 19, 199–206.
van den Bogaard, Ch. and **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 den Bogaard, Ch., Dörfler, W., Glos, R., Nadeau, M.-J., Grootes, P.M. and **Erlenkeuser, H.** 2002: Two tephra layers bracketing Late Holocene paleoecological changes in northern Germany. *Quaternary Research*, 957, 314–24.
van den Bogaard, Ch., Dörfler, W., Sandgren, P. and **Schmincke, H.-U.** 1994: Correlating the Holocene records: Icelandic Tephra found in Schleswig-Holstein (northern Germany). *Naturwissenschaften* 81, 554–56.
Wastegård, S., Björck, S, Grauert, M. and **Hannon, G.E.** 2001: The Mjáuvøtn tephra and other Holocene tephra horizons from the Faroe Islands: a link between the Icelandic source region, the Nordic Seas, and the European continent. *The Holocene* 11, 101–109.
Vilhjálmsson, V.Ö. 1991: The application of datings methods in Icelandic archaeology. *Acta Archaeologica* 61, 97–107.
Zielinski, G.A., Germani, M.S., Larsen, G., Baille, M.G.L., Whitlow, S., Twickler, M.S. and **Taylor, K.C.** 1997: Volcanic aerosol records and tephrochronology of the Summit, Greenland, ice cores. *Journal of Geophysical Research* 102, 26625–40.
Zielinski, G.A., Mayewski, P.A., Meeker, L.D., Grönvold, K., Germani, M.S., Whitlow, S.I., Twickler, M.S. and **Taylor, K.** 1995: Evidence of the Eldgjá (Iceland) eruption in the GISP-2 Greenland ice core: relationship to eruption processes and climate conditions in the tenth century. *The Holocene* 5, 129–40.
Zielinski, G.A., Mayewski, P.A., Meeker, L.D., Whitlow, S.I., Twickler, M.S., Morrison, M.C., Meese, D.A., Gow, A.J. and **Alley, R.B.** 1994. Record of volcanism since 7000 BC from the GISP2 Greenland ice core and implications for the volcano-climate system. *Science* 264, 948–52.
Zillén, L., Wastegård, S. and **Snowball, I.** 2002: Three Mid-Holocene tephra layers dated by annually laminated lake sediments from W Sweden. *Quaternary Science Reviews,* 21, 1583–91.