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Distal tephra found in a Viking boathouse: the potential for tephrochronology in reconstructing the Iron Age in Norway

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Abstract: Distal tephra deposits from Icelandic volcanic eruptions have been found in Norway and can be used to precisely date a variety of sedimentary environments. Tephrochronology has not yet been applied to archaeological investigations in Norway because tephra are generally not found as visible layers, but are present in very low concentrations as cryptotephra. In this study, we present results from the analysis of tephra found in an Iron Age boathouse in northern Norway. The boathouse was associated with the chieftain center at Borg on Vestvågøy in the Lofoten Islands. In 2003, a trench was excavated and the stratigraphy of the boathouse was described. Radiocarbon ages from cultural deposits show that it was constructed in the Early Iron Age c. AD 540-660 and the main period of use was at the end of the Iron Age between c. AD 1030 and AD 1270. Tephra were isolated from sediment samples collected above and below this unit. Electron microprobe analysis of the tephra shows that the lower sample resembles the AD 860 Layer B tephra and tephra from the upper sample resembles tephra erupted from the Hekla volcanic system between AD 1104 and AD 1300. Tephra dates agree with radiocarbon ages and possibly further constrain the boathouse's main period of use to c. AD 1030-1104. These results demonstrate the value of using tephrochronology for archaeological studies in Norway and the potential for finding tephra from other large explosive volcanic eruptions during the Iron Age.
June 24, 2010

Editor
Journal of Archaeological Science

Dear Editor:

Please find attached our manuscript entitled, “Distal tephra found in a Viking boathouse: the potential for tephrochronology in reconstructing the Iron Age in Norway.”

Here we report the identification of tephra (volcanic ash) in sediments surrounding cultural horizons within a Viking boathouse in the Lofoten Islands, Norway. Tephra were geochemically matched to known volcanic eruptions and we discuss their implications for dating the construction and use of the structure. The applications of tephrochronology have been expanding with improved techniques to isolate and identify extremely low concentrations of tephra in distal sedimentary archives. We feel this research highlights the potential for tephrochronology in Norwegian archaeological investigations and in other regions far from volcanic centers.

As requested, we have listed potential reviewers. These scientists are familiar with Icelandic tephrostratigraphy and the application of tephra to archaeological studies:

- Dr. Andrew J. Dugmore – University of Edinburgh – andrew.dugmore@ed.ac.uk
- Dr. Anthony J. Newton – University of Edinburgh – anthony.newton@ed.ac.uk
- Dr. David J. Lowe – University of Waikato – d.lowe@waikato.ac.nz
- Dr. Siwan Davies – University of Wales Swansea – siwan.davies@swansea.ac.uk

Feel free to contact me if you have any questions.

Sincerely,

Nicholas L. Balascio
Corresponding Author
Distal tephra found in a Viking boathouse: the potential for tephrochronology in reconstructing the Iron Age in Norway

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Abstract

Distal tephra deposits from Icelandic volcanic eruptions have been found in Norway and can be used to precisely date a variety of sedimentary environments. Tephrochronology has not yet been applied to archaeological investigations in Norway because tephra are generally not found as visible layers, but are present in very low concentrations as cryptotephra. In this study, we present results from the analysis of tephra found in an Iron Age boathouse in northern Norway. The boathouse was associated with the chieftain center at Borg on Vestvågøy in the Lofoten Islands. In 2003, a trench was excavated and the stratigraphy of the boathouse was described. Radiocarbon ages from cultural deposits show that it was constructed in the Early Iron Age c. AD 540-660 and the main period of use was at the end of the Iron Age between c. AD 1030 and AD 1270. Tephra were isolated from sediment samples collected above and below this unit. Electron microprobe analysis of the tephra shows that the lower sample resembles the AD 860 Layer B tephra and tephra from the upper sample resembles tephra erupted from the Hekla volcanic system between AD 1104 and AD 1300. Tephra dates agree with radiocarbon ages and possibly further constrain the boathouse’s main period of use to c. AD 1030-1104. These results demonstrate the value of using tephrochronology for archaeological studies in Norway and the potential for finding tephra from other large explosive volcanic eruptions during the Iron Age.

Keywords

cryptotephra, tephrochronology, Icelandic volcanic eruptions, Iron Age, boathouse, Lofoten Islands, northern Norway
1. Introduction

Tephrochronology is a dating technique based on the identification of pyroclastic deposits, typically ash (≤2 mm in diameter), in sedimentary environments (Alloway et al., 2006). Tephra form time synchronous horizons that can be geochemically matched to known volcanic eruptions or used as marker horizons to correlate between deposits. Tephra can provide age control in sediments void of material suitable for other dating techniques or can supplement existing chronologies. In particular, it can improve radiocarbon chronologies where reworking is suspected or where plateaus exist in the calibration curve. Tephrochronology is limited to the area covered by identifiable fallout and is typically applied near large volcanic centers where visible tephra layers are found. However, in some cases it may be possible to isolate and identify finely dispersed tephra grains (cryptotephra) which are not visible as tephra layers.

In the North Atlantic region, the volcanic systems of Iceland have been the most significant producers of tephra. The volcanic history has been well studied and there are a number of historic and prehistoric explosive eruptions that have produced tephra which form discrete layers useful for paleoenvironmental reconstructions (Haflidason et al., 2000; Larsen and Eiríksson, 2008; Larsen et al., 1999; Thordarsen and Höskuldsson, 2008; Thordarsen and Larsen, 2007). Archaeological investigations in Iceland take advantage of the robust tephra stratigraphy and have used tephrochronology to date settlement periods, landscape change, and soil erosion (e.g. Dugmore et al., 2000, 2005, 2009; Thorarinsson 1981). The initial settlement of Iceland has even been constrained using tephrochronology. The timing of this event coincides with deposition of the precisely dated Landnám Tephra (871 ± 2 AD; Grönvold et al., 1995) that is
spread across most of Iceland marking the beginning of human occupation (Dugmore et al., 2005).

Tephra fallout from Icelandic volcanic eruptions is not limited to local sites. The largest Icelandic eruptions have deposited tephra around the North Atlantic region. Tephra have been found as visible horizons in northern Europe (Birks et al., 1996; Davies et al., 2001; Mangerud et al., 1984), but are more often found in low abundances and as extremely fine-grained particles that are invisible to the naked eye. These are referred to as cryptotephra, a term derived from the Greek kryptein, which means to hide (Alloway et al., 2006; Lowe and Hunt, 2001). The first cryptic Icelandic tephra was found in Scotland (Dugmore, 1989) and the more recent development of density separation techniques (Turney, 1998) has led to the identification of tephra from specific eruptions across a wider geographic area and has expanded the use of tephrochronology to more distal regions.

In Norway, a few Icelandic tephras have been found as visible layers (Birks et al., 1996; Mangerud et al., 1984), but more commonly they occur as cryptotephra. An investigation of the Holocene cryptotephra stratigraphy in northern Norway identified twenty-three tephras (Pilcher et al., 2005). These results demonstrate the potential for expanding the use of tephrochronology in Norway. The use of crypto-tephrochronology has been applied to a few paleoenvironmental studies (Balascio et al., accepted; Mills et al., 2009; Vorren et al., 2007), but we wanted to test its application to constrain the age of cultural horizons in Norway. In this study we examined tephra in sediment samples collected during the excavation of a Viking boathouse in northern Norway on the island of Vestvågøy in the Lofoten Islands (Fig. 1) (Wickler and Nilsen, 2005).
We isolated tephra from two stratigraphic units, geochemically matched their composition to known eruptions, and compared our results to radiocarbon ages from the boathouse and similar contexts in the area.

2. Site Description
The boathouse, Naust 48, is located on the western shore of Inner Borgpollen (68°14.94’N; 13°46.69’E) at the settlement of Borg on the island of Vestvågøy in the Lofoten Islands (Fig. 1). Borg was the location of an Iron Age chieftain center and Borgpollen provided a protected natural harbor around which the remains of 20 Iron Age boathouses have been recorded (Munch et al., 2003; Nilsen, 1998). Previous investigations have examined the local distribution of boathouses in the context of the maritime history of the islands (Nilsen, 1998; Wickler, 2004; Wickler and Nilsen, 2005). The structures around Borgpollen are currently c. 1-3 meters above sea level as a result of continued glacial-isostatic rebound (Mills et al., 2009; Møller, 1986). Based on estimates of former shorelines and radiocarbon ages from excavations, these boathouses span most of the Iron Age and extend into the Medieval Period, c. AD 1-1300 (Nilsen, 1998; Wickler, 2004). A majority of the structures are large and five are over 15 meters in length, although four of the structures would have housed boats less than six meters in length.

The remains of the boathouse are visible on the surface as linear mounds marking the collapsed walls of a rectangular structure constructed of stone, peat, and soil with an opening facing the water (Wickler and Nilsen, 2005). The Naust 48 boathouse is situated 8 m from the water at an elevation of 1.3 m and has interior dimensions of ~ 21 x 3.2 m. In 2003, a 3 x 0.5 m trench was excavated perpendicular to the long axis of the structure between the walls near the entrance.
The trench profile revealed a stratigraphic sequence with a cultural deposit up to 15 cm in thickness (Fig. 2). There appeared to be two distinct phases of use separated by an extensive zone of dense charcoal with fire-cracked rock interpreted as the remains of multiple hearths. Radiocarbon samples from this zone and slightly above gave dates of 902 ± 40 $^{14}$C years BP and 860 ± 75 $^{14}$C years BP, respectively. A second concentration of charcoal and fire-cracked rock from a hearth at the base of the cultural deposit produced a date of 1450 ± 45 $^{14}$C years BP. The dates correspond with 2-sigma calibrated ages of AD 538-662 for initial construction and AD 1030-1271 for the main period of use (Table 1; Wickler and Nilsen, 2005). Two sediment samples were collected for tephra analysis. One was taken from the middle of the Layer Ib cultural deposit (CAT-6) and the other from the stratigraphic unit Layer Ia above the cultural deposit (CAT-5).

3. Tephra Analysis

Sample Naust 48 CAT-5 and CAT-6 were treated with nitric acid (HNO$_3$) and then placed in an 80°C water bath for 3 hours to remove the organic components of the sediment. The remaining material was washed in deionized water over two staked sieves with mesh sizes of 63 µm and 20 µm to isolate grain sizes typical of distal tephra particles. Heavy liquid density separations were then performed using sodium polytungstate (Na$_6$(H$_2$W$_{12}$O$_{40}$)H$_2$O) between 2.3-2.5 g cm$^{-3}$ to concentrate tephra from the remaining mineral grains (Turney, 1998). Samples were mounted in epoxy resin and tephra particles were identified using a polarizing light microscope. Slides were then polished to expose the grains and then analyzed with a Cameca SX50 electron microprobe at the University of Massachusetts Amherst using wavelength dispersal spectrometry with an accelerating voltage of 15 keV, a beam current of 10 nA, and beam size of 5-10 µm. Results are
reported as non-normalized major oxide concentrations. Geochemical results were then
compared to samples of known age found in other locations around the North Atlantic region and
using the TephraBase database (Newton et al., 2007; http://www.tephrabase.org).

4. Results
Both CAT-5 and CAT-6 contained colorless vesicular tephra grains that were 40-60 µm in
diameter (Fig. 3). Tephra grains in CAT-6 were generally smaller and had much thinner walls
than those found in CAT-5, which made microprobe analysis difficult and resulted in low
analytical totals for some grains. However within each sample, the major oxide concentrations
grouped into distinct geochemical populations.

In CAT-5, nine tephra grains were analyzed (Table 2). Results for each grain are the average of
between 4 and 7 separate analyses. The number of analyses per grain depended on the size of
the exposed surface area of each grain. Totals less than 96% were not included in the average.
The data fall within three geochemical populations, which are distinguished mainly by their
SiO$_2$, FeO, and MgO content, with the largest group showing the highest precision (Fig. 4).

In CAT-6, seven tephra grains were analyzed (Table 2). Additional tephra shards were identified
with the microprobe, but because of thin grain walls and the vesicular nature of the shards their
analytical totals were too low to report (<90%). All of the results generally fall within one
geochemical population with the exception of one grain that has a lower SiO$_2$ and higher FeO
and Al$_2$O$_3$ composition (Fig. 4). There is some scatter in the data that can probably be attributed
to the low analytical totals.
5. Discussion

Geochemical results from CAT-5 and CAT-6 resemble the composition of tephra from known volcanic eruptions that occurred around the time the boathouse, Naust 48, was in use (c. AD 540-1270; Wickler and Nilsen, 2005) (Table 3; Fig. 4).

5.1. CAT-5

The major oxide concentrations of tephra in CAT-5 resemble tephra from the historic eruptions of the Icelandic Hekla volcanic system in AD 1104, AD 1158, and AD 1300 (Table 2). Figure 4 compares results from CAT-5 to tephra identified from these eruptions found in Iceland, Ireland, and the UK (Boygle, 1994; Hall and Pilcher, 2002; Larsen et al., 1999; Pilcher et al., 1995, 1996). The geochemistry of tephra from these eruptions can be distinguished by differences in SiO$_2$, FeO, MgO, CaO, and TiO (Fig. 4). The largest geochemical population clusters tightly near the compositional range of the Hekla AD 1158 tephra and supports the interpretation of the presence of this tephra in CAT-5. We speculate that two of the other grains are from the Hekla AD 1104 tephra. This tephra is distinguished from the Hekla 1158 tephra by having a higher SiO$_2$ and lower FeO content. There is also a single grain we attribute to the Hekla AD 1300 eruption. This interpretation is based primarily on comparison of the distinctively high FeO content of tephra from this eruption, which is not found in any of the other tephra from this period (Table 3). However, a much larger sample is required to make a more definite statement about the presence of tephra from this event.
The Hekla volcanic system is located in the East Volcanic Zone of Iceland and is one of the country’s most historically active volcanoes (Thordarson and Larsen, 2007). The AD 1104 eruption was the first historic eruption of Hekla (Thorarinsson, 1967). The eruption was purely explosive and produced an estimated 2 km$^3$ of tephra (Thordarson and Larsen, 2007). The AD 1158, and 1300 eruptions also produced significant volumes of tephra, estimated to be 0.33 km$^3$ and 0.5 km$^3$, respectively. Isopach maps created from the fallout on land from these eruptions indicate the main direction of the tephra plumes were generally to the north and northeast, ideal for transport to northern Norway (as reviewed by Haflidason et al., 2000).

We have strong evidence for the presence of the Hekla AD 1158 tephra based on the number of grains and the precision of the geochemical data within this group. There is less certainty in our attributions of the other grains to the AD 1104 and AD 1300 eruptions. However, because of the close timing of the AD 1104 and 1158 eruptions, it is not surprising that they would both be present. Pilcher et al. (2005) also found both tephra mixed within multiple horizons and they also found the AD 1158 tephra was in greater abundance than the AD 1104 tephra.

5.2. CAT-6

The major oxide concentrations of tephra in CAT-6 resemble the AD 860 tephra Layer B. Figure 4 compares results from CAT-6 to tephra identified from this eruption found in northern Ireland (Hall and Pilcher, 2002; Pilcher et al., 1995; Swindles, 2006). This tephra is distinguished from others in this time period by its relatively high SiO$_2$ and low FeO and MgO composition (Table 2 & 3).
The AD 860 tephra was originally identified as a distal deposit in northern Ireland and was not attributed to a specific Icelandic eruption (Pilcher et al., 1995). It was found with two distinct populations, Layer A and B, and the age (AD 860 ± 20) was derived from radiocarbon wiggle matching techniques (Pilcher et al., 1995), although it was later correlated to deposits found in Iceland (Wastegård et al., 2003). The AD 860 Layer A has only been found in northern Ireland, but Layer B is more widespread and in addition to Ireland (Hall and Pilcher, 2002) it has been found in northern Germany (van den Bogaard and Schmincke, 2002) and in the Lofoten Islands, within a sediment core from Inner Borgpollen (Pilcher et al., 2005).

5.3. The Timing of Boathouse Use at Inner Borgpollen

Samples for tephra analysis were taken from the middle of the cultural deposit (CAT-6) and from above the cultural deposit (CAT-5) in Naust 48. Ages interpreted from these samples indicate that the initial construction of the boathouse took place before AD 860 and that the main period of use was between AD 860 and AD 1104. Radiocarbon ages establish the timing of the initial construction of Naust 48 at c. AD 538-662 and the main period of use was from c. AD 1030-1271 (Wickler and Nilsen, 2005).

Tephra results from CAT-6 support the radiocarbon age range for the construction of the boathouse and suggest that the main period of use may be as early as AD 860. Tephra found in CAT-5 provide a more precise upper limiting age and suggest a shorter period of use that ended before at least AD 1158 and probably before AD 1104. This new age range for the main period of use at Naust 48 also fits well with radiocarbon ages from a second Iron Age boathouse a short distance to the north along the western shore of Inner Borgpollen. This boathouse, Naust 61, has
five radiocarbon dates establishing a main period of use during the Viking Age between AD 770 and AD 1050. This structure also had an earlier use phase during the Early Iron Age with a hearth dated to 1850 ± 74 \(^{14}\)C years BP (2-sigma calibrated age of AD 2-350) (S. Wickler, *unpublished data*). Both boathouses are characterized by long-term use with two temporally distinct periods represented.

Overall, these results demonstrate the potential for using tephrochronology in this environment. The processing of larger sediment samples from these horizons and the analysis of more tephra grains would help verify the presence and relative abundances of these tephra. The analysis of additional sediment samples from Naust 48 and Naust 61 can also be expected to produce new tephra evidence.

6. Tephrochronology during the Iron Age

Radiocarbon dating is one of the most widely used absolute dating techniques for determining the age of cultural horizons in archaeological investigations. However, to determine ages on an absolute timescale, measured radiocarbon dates must be calibrated due to variations in the atmospheric radiocarbon content (Stuiver and Suess, 1966). During the Holocene, where tree rings are used for the calibration, the errors are usually small. However during certain intervals, “plateaus” in the calibration curve can produce a large range of statistically possible calendar ages for a given radiocarbon age and provide a temporal resolution that is insufficient for some applications (Guilderson et al., 2005).
During the Iron Age and up to the early Medieval Period in Norway (c. AD 300-1200) there are two main intervals where plateaus occur in the radiocarbon calibration curve, c. AD ~700-900 and c. AD 1050-1200 (Reimer et al., 2009) (Fig. 5). Radiocarbon ages that fall within these plateaus produce calibrated calendar ages with overlapping uncertainties and hamper detailed interpretations of archaeological findings. Tephrochronology can supplement radiocarbon chronologies to improve temporal resolution.

There are a number of explosive, tephra-producing volcanic eruptions that occurred during the Iron Age (Table 3; Fig. 5) (Haflidason et al., 2000; Larsen et al., 1999). Tephra from these events have distinct geochemical compositions and many of have been found in Norway (Balascio et al., accepted; Pilcher et al., 2005). This demonstrates the potential for tephra as marker horizons or for absolute age control, although, the uncertainty in the ages of each tephra must be considered. The historic eruptions have been dated using written accounts, which can pinpoint the day or month of an eruption (e.g. Thorarinsson, 1967). Some prehistoric tephras have been found in Greenland ice cores and can be precisely dated using layer counting (Grönvold et al., 1995; Zielinski et al., 1995), while the ages of other prehistoric tephra are known from compilations of radiocarbon dates from multiple sites.

7. Conclusion

We were able to isolate tephra from sediments in a Viking boathouse and match them to known Icelandic volcanic eruptions. We identified the AD 860 Layer B tephra and tephra from historic eruptions of the Hekla volcanic system in 1104, AD 1158, and AD 1300. These results help
constrain the timing of the boathouse’s use and demonstrate the potential for tephrochronology as a geochronologic tool for archaeologists in Norway.

Acknowledgements

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References


Figure Captions

Fig. 1. Location of Viking settlement at Borg on Vestvågøya in the Lofoten Islands, northern Norway (A). Location of the boathouse Naust 48 on the western shore of Inner Borgpollen (B).

Fig. 2. East face stratigraphic profile of the Naust 48 boathouse excavation trench (Illustration: S. Wickler). Radiocarbon ages from Wickler and Nilsen (2005) and results from tephra analysis.

Fig. 3. Scanning electron microscope images of tephra isolated from Borg boathouse Naust 48 CAT-5.

Fig. 4. Comparison of the geochemical compositions of tephra isolated from Borg boathouse Naust 48 samples CAT-5 and CAT-6 to tephra from Icelandic eruptions, including: Hekla AD 1104 (Hall and Pilcher, 2002; Larsen et al. 1999; Pilcher et al., 1995, 1996), Hekla AD 1158 (Hall and Pilcher, 2002; Larsen et al., 1999), Hekla A.D. 1300 (Boygle, 1994), and AD 860 Layer B (Hall and Pilcher, 2002; Pilcher et al., 1995). The majority of tephra shards isolated from CAT-5 resemble tephra from the Hekla AD 1158 eruption and the majority of tephra shards isolated from CAT-6 resemble the AD 860 Layer B tephra (circled).

Fig. 5. Radiocarbon calibration curve around the Iron Age (Reimer et al., 2009). Shaded age ranges (c. AD 700-900 & AD 1050-1200) mark plateaus in the calibration curve. Icelandic volcanic eruptions with potential for tephrochronologic studies in Norway are indicated by the vertical bars (see Table 3).
Table 1.
Radiocarbon dates from boathouse Naust 48.

<table>
<thead>
<tr>
<th>Context</th>
<th>Lab. Ref.</th>
<th>Charcoal Taxa</th>
<th>Sample Size (g)</th>
<th>Conventional Age (14C years BP)</th>
<th>δ13C (‰)</th>
<th>Calibrated Age (1 σ / 2 σ)*</th>
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</thead>
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<tr>
<td>Layer Ib</td>
<td>T-16931</td>
<td>birch, willow, aspen</td>
<td>3.7</td>
<td>860 ± 75</td>
<td>-27.8</td>
<td>AD 1151-1256 / 1030-1271</td>
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<td>(main cultural</td>
<td></td>
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<td></td>
<td></td>
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<td>deposit)</td>
<td>Wk-16039</td>
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<td>4</td>
<td>902 ± 40</td>
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<td>AD 1044-1098 / 1034-1213</td>
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<tr>
<td>Layer Ib</td>
<td>T-16932</td>
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<td>4.5</td>
<td>1450 ± 45</td>
<td>-27.3</td>
<td>AD 579-645 / 538-662</td>
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<tr>
<td>(base of cultural deposit)</td>
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</table>

*Reimer et al., 2009
Table 2.
Major oxide concentrations of tephra shards from boathouse Naust 48 samples CAT-5 and CAT-6. Results are only reported for analyses with totals greater than 90%. Totals less than 95% are in italics.

<table>
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<tr>
<th>No.</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
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Table 3.

Geochemical compositions of tephra from explosive volcanic eruptions found around the North Atlantic that occurred during the Iron Age compiled from TephraBase (Newton et al., 2007; http://www.tephrabase.org).

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* Geochemical results are only from the rhyolitic component of the Landnam tephra

** MnO values not reported for all analyses: Öraefjökull (n=15), Hekla 1300 (n=40), Hekla 1158 (n=12), Hekla 1104 (n=14), Landnam (n=9), 860B (n=9), Tjornvik (n=42)