Recent Icelandic tephra in a Swedish Peat Deposit

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Abstract

Two eruptions from Icelandic volcanoes have in the last years caused widespread dispersal of volcanic ash in the atmosphere. The transportation of tephra from Iceland to mainland Europe is not an uncommon event and it can cause large disruptions to society. In this thesis I present the findings of a tephrochronological study of recent sediment from a bog called Trolls mosse in southern Sweden. The results show the presence of recent tephra from what is most likely the Grímsvötn eruption in May 2011, but geochemical analysis of the tephra could not confirm the exact origin of it, and a possibility that the Eyafjallajökull eruption also has contributed exists. By correlating atmospheric data about the location of the ash clouds produced during the eruptions and tephrochronological studies of where tephra fallout has occurred could improve our understanding of tephra fallout dynamics and could help understand complex fallout patterns for past eruptions.
Chapter 1

Introduction

1.1 Introduction

Tephrochronology is a method for dating and correlating geological and environmental sequences using tephra layers. Tephra (Greek meaning *ash*) is any unconsolidated pyroclastic material from volcanic eruptions, ranging from tiny ash particles to larger masses. The power of dating and linking sequences with tephra is that it is deposited instantaneously when compared to geological time-scales, so that a tephra layer found in two different places will always have the same age. In later years what has come to be known as cryptotephrochronology has become increasingly important to tephrochronological studies, cryptotephra is any tephra concentration that is not visible to the naked eye. The advent of better methods for extracting tephra has made cryptotephra studies an important tool for extending the geographical limits of known eruptions.

Two eruptions from Icelandic volcanoes (Eyjafjallajökull 2010 and Grímsvötn 2011) have in the last two years caused widespread atmospheric dispersal of volcanic ash over Europe. Both eruptions caused disruptions in air travel and the Eyjafjallajökull eruption caused a several days flight ban over parts of Europe. Forecasts made by the UK Met Office Volcanic Ash Advisory Center, tasked with providing models of the movement of ash particles in the atmosphere, indicate that both eruptions produced ash clouds that covered large areas of northern Europe including Sweden. Pollen counts from the Swedish Natural history museum (NRM), Stockholm and the University of Gothenburg also show that ash reached Sweden during the Grímsvötn eruption (Kübler, Dahl pers.comm).

Eruptions producing ash fallout over northern Europe are not uncommon. Wastegård and Davies (2009) outline 18 tephra horizons during the last 1000 years that are from Iceland, Jan Mayen and of unknown origin. Swindles et al. (2011) also show that over the last 7000 years tephra have regularly been transported to northern Europe. Table 1.1 shows the distal tephra layers found in Europe over the last ca. 12 000 years prior to 2010.

The aim of this thesis are:

- To look for tephra from Eyjafjallajökull and/or Grímsvötn in a Swedish peat deposit.
- To examine the evidence for the extent of the ash clouds over Europe.
- To search for other historical tephra.

The study site, called Trolls mosse, is located in southern Sweden (57°40’25” N, 14°29’45” E). During the Grímsvötn eruption in 2011 high concentrations of glass particles, presum-
### Table 1.1: Table showing distal tephra layers in Europe during the last 12,000 years. The list is only complete for the last 1,000 years.

<table>
<thead>
<tr>
<th>Layer name</th>
<th>Age</th>
<th>Source volcano</th>
<th>Location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hekla-1947</td>
<td>1947</td>
<td>Hekla</td>
<td>Central and N. Ireland, S Finland</td>
<td>A</td>
</tr>
<tr>
<td>Grímsvötn-1903</td>
<td>1903</td>
<td>Grímsvötn</td>
<td>Svalbard</td>
<td>A</td>
</tr>
<tr>
<td>Askja-1875</td>
<td>1875</td>
<td>Askja</td>
<td>Norway and Sweden</td>
<td>A,B</td>
</tr>
<tr>
<td>Hekla-1845</td>
<td>1845</td>
<td>Hekla</td>
<td>Faroe Islands, Orkney</td>
<td>A</td>
</tr>
<tr>
<td>Laki-1783</td>
<td>1783</td>
<td>Laki</td>
<td>Ireland</td>
<td>A</td>
</tr>
<tr>
<td>PMG-5</td>
<td>1600</td>
<td>Jan Mayen</td>
<td>Ireland</td>
<td>A</td>
</tr>
<tr>
<td>QUB-384</td>
<td>1650-1750</td>
<td>Katla(?)</td>
<td>N. Norway</td>
<td>A</td>
</tr>
<tr>
<td>SLU-5</td>
<td>1600-1700</td>
<td>?</td>
<td>Ireland</td>
<td>A</td>
</tr>
<tr>
<td>Hekla-1510</td>
<td>1510</td>
<td>Hekla</td>
<td>Scotland, Ireland</td>
<td>A</td>
</tr>
<tr>
<td>Lóigh Portain-B</td>
<td>1510</td>
<td>Hekla(?)</td>
<td>Scotland</td>
<td>A</td>
</tr>
<tr>
<td>Veðviötn</td>
<td>1477</td>
<td>Veðviötn</td>
<td>W. Ireland</td>
<td>A</td>
</tr>
<tr>
<td>MOR-T2</td>
<td>1400</td>
<td>Jan Mayen</td>
<td>W. Ireland, Sweden</td>
<td>A</td>
</tr>
<tr>
<td>Örafjöökull</td>
<td>1362</td>
<td>Örafjöökull</td>
<td>Ireland, N. Norway</td>
<td>A</td>
</tr>
<tr>
<td>GB4-50</td>
<td>1250</td>
<td>?</td>
<td>N. Ireland, N. Norway</td>
<td>A</td>
</tr>
<tr>
<td>Hekla-1158 (GB4-57)</td>
<td>1158</td>
<td>Hekla</td>
<td>Scotland</td>
<td>A</td>
</tr>
<tr>
<td>BGMT-1</td>
<td>1120</td>
<td>?</td>
<td>Scotland</td>
<td>A</td>
</tr>
<tr>
<td>Hekla-1104</td>
<td>1104</td>
<td>Hekla</td>
<td>Ireland, N. Norway</td>
<td>A</td>
</tr>
<tr>
<td>MOR-T4</td>
<td>1000</td>
<td>?</td>
<td>W. Ireland</td>
<td>A</td>
</tr>
<tr>
<td>Eldgíja</td>
<td>934</td>
<td>Katla</td>
<td>Greenland</td>
<td>C</td>
</tr>
<tr>
<td>Settlement Layer</td>
<td>870</td>
<td>Veðviötn and Tøfjöökull</td>
<td>Faroe Is., Greenland, Norway</td>
<td>C</td>
</tr>
<tr>
<td>Glen Garry</td>
<td>2176 BP</td>
<td>?</td>
<td>Scotland, England, Germany</td>
<td>C</td>
</tr>
<tr>
<td>Hekla 3</td>
<td>3000 BP</td>
<td>Hekla</td>
<td>Sweden, Germany</td>
<td>C</td>
</tr>
<tr>
<td>Kebister/Hekla S</td>
<td>3720 BP</td>
<td>Hekla</td>
<td>Sweden, Faroe Is., Germany, Shetland Is.</td>
<td>C</td>
</tr>
<tr>
<td>Hekla 4</td>
<td>4200 BP</td>
<td>Hekla</td>
<td>Sweden, Norway, Faroe Is., Orkney Is., Scotland, Ireland, Germany, Estonia</td>
<td>C</td>
</tr>
<tr>
<td>Lairg-B</td>
<td>6675 BP</td>
<td>Tøfjöökull</td>
<td>Ireland, Scotland, Germany</td>
<td>C</td>
</tr>
<tr>
<td>Hekla 5/Lairg-A</td>
<td>6735 BP</td>
<td>Hekla</td>
<td>Sweden, Germany, Ireland, Scotland, Norway</td>
<td>C</td>
</tr>
<tr>
<td>Saksunárvatn Ash</td>
<td>10347 ± 45 yr b2k</td>
<td>Grímsvötn</td>
<td>Shetland Is., Orkney Is., Faroe Is., Norway, Germany</td>
<td>C</td>
</tr>
<tr>
<td>Askja</td>
<td>10820 ± 250</td>
<td>Askja</td>
<td>Sweden, Norway, Ireland</td>
<td>C</td>
</tr>
<tr>
<td>Vedde Ash</td>
<td>12171 ± 57 yr b2k</td>
<td>Katla</td>
<td>Scotland, Ireland, Norway, Sweden, Russia, Netherlands, Germany</td>
<td>C</td>
</tr>
</tbody>
</table>

**References:** A: (Wastegård and Davies, 2009), B: (Wastegård, 2005), C: (Davies et al., 2010) supporting information
ably volcanic ash were observed in pollen slides from the nearby town Nässjö, simulations by the VAAC also suggests that ash was present in the atmosphere over the area 1.1. If these tephra are found they will form the first step into mapping out the extent of the tephra fallout from these two eruptions. Mapping out the fallout pattern is important because we can then couple that with observations of the ash cloud to better understand tephra fallout dynamics.

There are also two historical tephra layers that can possibly be found in the cores. In 1947 Hekla erupted and tephra has been observed in both the British Islands and southern Finland (Davies et al., 2010) making tephra fallout over Sweden a possibility. The 1875 Askja eruption have been found over large parts of central Sweden (Wastegård, 2005) but has not been observed this far south.

As a part of this study I have also made a literature review of the published material to create a map of were the ash clouds were observed in Europe. This can later be compared with the extent of other historical tephras to put these two eruptions into a larger context.

1.2 Eyjafjallajökull eruption

Eyjafjallajökull is a stratovolcano at about 1666 m above sea level. It is located at the southern coast of Iceland. In historic time only two other eruptions from Eyjafjallajökull are known in 1613 and 1821, the later lasting for two years (Larsen et al., 1999). Tephra from these eruptions are not believed to have reached overseas.

The 2010 Eyjafjallajökull eruption can be divided in two distinct phases. The first phase began on March 20. This eruption produced lava flows and a small ash plume and ended on April 12. Two days later Eyjafjallajökull started to erupt again. This phase was more explosive and started to produce a plume that eventually reached about 10 km (Flentje et al., 2010) and tephra from this phase was transported by winds and reached Europe. The total ash volume estimated to have been ejected into the atmosphere is 270 million m$^3$ (Dellino et al., 2012). The eruption had subdued by June 15 and reports from the Icelandic meteorological office show that the eruption ended by June 23.
1.3 Grímsvötn eruption

Grímsvötn is a caldera volcano that lies 1722 m above sea level under the Vatnajökull ice-cap. In historical time Grímsvötn has been one of Iceland's most active volcanoes with some 64 confirmed eruptions since AD 1200 (Thordarson and Larsen, 2007).

Grímsvötn started to erupt on May 21, 2011. This eruption was larger but much shorter than the 2010 eruption of Eyjafjallajökull and produced an eruption plume reaching 17 km in height (Institute of Earth Science, University of Iceland, 2011). Simulations made by the VAAC suggest that the ash cloud traveled as far as northern Canada and parts of Russia, but not as far south as Eyjafjallajökull. The eruption officially ended on May 28. The ash cloud that the eruption produced is believed to have been observed in both Norway, Sweden and Finland during 24-25 of May (Kerminen et al., 2011) and in pollen counts in Sweden (Kübler, Dahl pers.commm).

Chapter 2

Methods

2.1 Sampling

Three cores where taken at Trolls mosse (TM-01: 0-44.5 cm, TM-02: 0-88.4 cm, TM-03: 50-144 cm) 2.1. Two cores were acquired with a Russian peat corer and one core was taken using a PVC tube pressed into the peat hummock, these cores were placed in PVC-pipes and then wrapped in plastic. Due to the patchy nature of tephra fallout (e.g. Bergman et al., 2004) a surface sample was also taken from the surrounding area.

2.2 Literature review

To compile the relevant literature two main databases were used: Google Scholar and Web of Science. Searches were also performed using individual journals own search implementation. Keywords used were: Eyjafjallajökull, Grímsvötn, tephra fallout, ash cloud and constraining searches to only the years 2010-2012. Only publications that measured, or in some way, provided physical proof of the ash clouds were included.

2.3 Tephra Extraction

The cores were sampled every 5 cm and for TM-01 the first 10 cm were sampled every centimeters. Three surface samples from TM-01 were also acquired. These sampled were then heated over night in a oven at $550^\circ C$ to remove organic material. The samples were then transferred to 25 ml plastic bottles filled with 10% HCl for 1 hour in order to clean the samples of leftover organic material. After that the samples were centrifuged three times. First in $HCl$ and then in distilled water. Samples were then transferred to glass
slides and encased in resin.

For three surface samples one Lycospodium tablet containing 18583 spores were added to each sample. This was in order to calculate the tephra shard density.

2.3.1 Extraction for geochemical analysis

The method used for extracting tephra for geochemical analysis differs from the process of extracting them for microscopic analysis. This is because the method used above would cause a change in the geochemical signature of the tephra. First samples of the peat were placed in flasks and then 90% sulfuric acid ($H_2SO_4$) was poured in the flask until it covered the samples. This was then boiled until the organic matter in the samples had been dissolved, resulting in a clear liquid, during this drops of concentrated nitric acid ($HNO_3$) was added. The samples where then centrifuged four times, one time in the acid solution and three times in distilled water.

2.4 Humification analysis

A humification analysis was performed on cores TM-02 and TM-03 (the sampling of TM-03 began at 88 cm were TM-02 ended). The humification analysis was done in order to investigate whether climate data could be obtained from the core. The cores were sampled with 8 cm intervals and each sample was 1 cm in length. The method used was a modified version of Borgmark (2005) developed by Päivi Kaislahiti Tillman in 2008. First the samples were homogenized with a pestle and mortar, 50µg of each sample was weighed and placed in 50 ml tubes. 25 ml of 8% NaOH solution was added to the tubes and placed in a 95°C water bath for one hour. Two hours after the water bath the samples were
centrifuged and filtered before they were analyzed with a photospectrometer. In order to reduce the memory effect in the machine distilled water was run through the machine after each sample.

2.5 Age model

No dating was performed on the cores so in order to put the results in a meaningful context a age model was constructed. Using data from an previous study that included Trolls mosse by Brännvall et al. (1997) a regression curve was fitted to the data (Fig. 2.2). A cubic fit provided the best model for the data. One characteristic of this age model will be that age 0 is 1997 when the dating was done (meaning that the function below will, when given \( x = 0 \) provide \( y = 15 \)).

From this a function expressing the relation between age and depth was given to be: 
\[
y = -1.2175e^5 * x^3 + 0.019712 * x^2 + 6.5636 * x + 15.011.
\]

Where \( x = \text{depth (cm)} \) and \( y = \text{\(^{14}\text{C Age}\)} \). The \(^{14}\text{C}\) ages where then converted to calendar ages (AD) with the CalPal online (http://www.calpal-online.de) tool. It should be noted that this function is only used to provide a crude reference for how the humification have varied over time in this bog.

![Age-Depth model for Trolls mosse](image)

**Figure 2.2:** Age-depth model for the three cores taken at Trolls mosse. The model is based on dating from Brännvall et al. (1997) from a core taken from the northern part of the same bog (Bindler, pers comm., 2011). This model should not be used for absolute dating depths in the bog but can be used to put results from the bog into a historical context.

2.6 Geochemical analysis

The geochemical analysis was performed at the Department of Geological Sciences at Stockholm University. The analysis was made using a XL30 ESEM-FEG electron mi-
croscope outfitted with an Oxford EDS INCA for geochemical analysis. The machine was setup to be at low-vacuum (0.3 mB) and the detector was a back-scatter detector.

Chapter 3

Results

3.1 Humification Analysis

Raw absorption values are presented for the humification analysis in Fig 3.1, note also that in this graph the conversion from depth to ages have not been done. One value for the last run was discarded due to the tube that takes in the sample went above the liquid and started to pump in air for about half of the sampling time. All other samples were inside the error margin of the machine.

![Figure 3.1: Results for the humification analysis showing the absorbance plotted versus the depth](image)

3.2 Tephra

Tephra was only found in the uppermost layer where the Grímsvötn and Eyjafjallajökull could be expected to be found, no other depths where historical tephras could be expected to be found were present in the peat bog. The tephra shard density for the three surface samples is presented in table 3.1. Pictures of some of the tephra shards that were found was also acquired and is seen in figure 3.2.
3.2.1 Geochemical Analysis

The results of the geochemical analysis are shown in figure 3.2.1. Here the $SiO_2$ is plotted against $Na_2O + K_2O$. The plot also includes values for chemical compositions for both Eyjafjallajökull and Grímsvötn eruptions in 2010 and 2011, respectively (Óskarsson (2010), Óskarsson and Sverrisdóttir (2011)).

![Figure 3.2](image)

**Figure 3.2**: Two tephras found in sample TM-YP3, these show the two largest tephra particles found in the samples. Most were significantly smaller, between 1-5 µm.

### Table 3.1: Tephra shard count for the surface samples from core TM-01

<table>
<thead>
<tr>
<th>ID</th>
<th>Tephra Count</th>
<th>Volume (cm$^3$)</th>
<th>Shard Density (Shards/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YP-01</td>
<td>98</td>
<td>2.1</td>
<td>46</td>
</tr>
<tr>
<td>YP-02</td>
<td>84</td>
<td>2.3</td>
<td>36</td>
</tr>
<tr>
<td>YP-03</td>
<td>102</td>
<td>3.6</td>
<td>39</td>
</tr>
</tbody>
</table>

3.3 Literature review

The results from the literature review can be seen in Fig. 3.3. Three different papers that provided data on where the ash cloud had been observed were included in the results. Note that there are more papers that also give data on where the Eyjafjallajökull ash cloud was observed that overlapped with (Schumann et al., 2011) and were therefore redundant to include.
Figure 3.3: Geochemical analysis for three tephra shards in the peat from Trolls moss. The shards were measured multiple times in order to get a better result but as can be seen there is still a large spread of the values. Also included in the plot is the geochemical signal for both the Eyjafjallajökull and Grímsvötn eruptions. References: Grímsvötn: Óskarsson and Sverrisdottír (2011), Eyjafjallajökull: Óskarsson (2010).

Chapter 4

Discussion

4.1 Humification

Humification can be used in order to reconstruct shifts in bog surface wetness and can therefore be used to infer changes in humidity (Blackford and Chambers, 1995). Higher humification is induced by drier climate, higher absorption means a higher humification rate. Looking at figure 4.1 we see that the biggest shift occurs at around 1200 AD, this would correspond with the Medieval climate anomaly (MCA) and might confirm that the age model is usable also for the cores taken in this study.
Figure 3.4: Locations of where the ash clouds have been measured over Europe. References: Schumann et al. 2011, Rossini et al. 2012, Tesche et al. 2012

Figure 4.1: Absorbance values showing the humification in historical time, the shifts are interpreted as shifts in wetness in the bog. Higher absorbance values are attributed to a drier/warmer period. The highest values occur around 1200 AD and are here thought to be a result of the medieval climate anomaly.
4.2 Tephra

As noted in the results, the three surface samples from the core did contain tephra. The question is whether the tephra originated from the Grímsvötn or Eyjafjallajökull eruption. The geochemical analysis on the tephra turned out to be too ambiguous to give any conclusive answer to where the tephra originated. Firstly the number of tephra shards analysed would have to be larger, there were only four shards analysed and as can be seen in figure 3.2.1 there is large spread between different measurements of the same shard. There is some indication in the data that tephra from both the Eyjafjallajökull and Grímsvötn tephra is present in the peat, one shard with quite high $SiO_2$ values and one with a bit lower values. But with so few shards analysed and the large margin of error that the EDS analysis provides it is hard to conclusively say where the tephra originated.

What we can say is that during the Grímsvötn eruption there were observations in pollen traps of what is presumed to be tephra shards. There were also particle measurements that showed that the air particle mass increased significantly during the time of the eruption ((Tesche et al., 2012)). All of this lead to the conclusion that most of the particles found in the sediment probably comes from Grímsvötn. But there is also the possibility that some small particles from Eyjafjallajökull also are present.

As seen in table 3.2.1 the tephra shard count was very low. Tephra fallout is affected by wind patterns and precipitation (Davies et al., 2010), combining unfavorable weather and the fact that most particles found were also small (ranging from 1-25 $\mu$m) which would make them more likely to be transported further by winds could explain why there were so few particles.

During both eruptions, but most notably during Eyjafjallajökull, there were quite a few $in situ$ measurements showing the ash clouds impact on the air quality over Europe (e.g Schumann et al. 2011, Rossini et al. 2012, Colette et al. 2011).

Figure 4.2: Image from a pollen sample taken in Nässjö during the Grímsvötn eruption, the small transparent object are believed to be tephra shards.
Recent Icelandic tephra in a Swedish Peat Deposit

Figure 3.3 shows where those measurements were done, during the time of writing the published data shows that the Grímsvötn ash cloud mainly stayed in the northern parts of Europe and that the Eyjafjallajökull cloud was transported further south even reaching parts of Italy (Rossini et al., 2012) but not reaching as far east. But this does not give the complete picture of where ash has been observed, for example the British Geological Survey collected, with the help of the public, glass shards during the Grímsvötn eruption (British Geological Survey, 2011), which indicates that the published data underestimates the spread of the ash.

By compiling atmospheric measurements and secondary sources such as news reports a better picture of where the ash clouds reached could be obtained. Coupling that picture with studies such as this one to determine where tephra fallout has occurred over Europe. This would provide a good insight into the complex nature of tephra fallout dynamics and create a better understanding of the spread of past eruptions. Both Eyjafjallajökull and Grímsvötn can be considered medium sized eruptions indicated by the relatively low amounts of and small sizes of the tephra.

Chapter 5

Conclusions

In this thesis I have shown the presence of recent tephra in a bog in southern Sweden. Geochemical analysis could not determine whether the tephra was from Grímsvötn or Eyjafjallajökull, but other data show a large number of presumably tephra shards over the nearby area during the Grímsvötn eruption in May 2011 indicating that most of the shards originated from this eruption. I show that it is possible to do a geochemical analysis of very small particles but that it would take a large amounts of measurements in order to determine the origin of tephra.

Further research into the tephra fallout pattern of both eruptions is needed in order to gain insight into tephra fallout dynamics and help create better models and predictions for tephra fallout.

Acknowledgments

I would like to thank my supervisor Stefan Wastegård for his help and guidance, and for peaking my interest in the subject almost one year ago. I would also like to thank Karin Holmgren for taking on the examination for this thesis. Both Krister Jansson and Maria Damberg deserves a thanks for helping out with some administrative troubles.
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Recent Icelandic tephras in a Swedish Peat Deposit


