Vegetation History of Fljótsdalshérað during the last 2000 years

A Palynological study

MSc. Thesis. May 2009

Sverrir Aðalsteinn Jónsson

Supervisors: Ólafur Ingólfsson and Ólafur Eggertsson

HÁSKÓLI ÍSLANDS Jarðvísindadeild

Declaration

I declare that this thesis is my own composition and has not been submitted for a higher degree previously, neither partly nor as a whole.

Sverrir Aðalsteinn Jónsson

Hella, Iceland, May 2009

Abstract

The main purpose of this investigation is to obtain data that can highlight the vegetation history of *Fljótsdalshérað* for the last 2000 years, and one objective of this study is to understand the main reasons for the observed forest decline. The investigation was based on two different datasets. Firstly, an extensive literature study was carried out on all available historical records concerning vegetation and climate in eastern Iceland since the settlement of the country. Secondly, a pollen analytical study was performed on samples from a sediment core from a small pond within the present border of *Hallormsstaðarskógur* forest. The studied core segment covers roughly the last 2000 years.

The core consisted of homogeneous limnic sediment with multiple tephra layers. A tephrocronology was constructed for the core using six identified tephra layers. The pollen analytical results are divided up into six *pollen assembly zones,* each representing a different vegetation condition. These zones were used to interpret the vegetation history. By the time of the settlement, forest covered the area around the pond, however the forest retreated fast after the settlement. In the 15^{th} century the forest re-advanced and was rather abundant until the middle of the 18^{th} century when it started to retreat fast. This retreat continued until the beginning of the 20^{th} century when the forest was protected.

From the results of this study it can be assumed that human activity seems to have been the dominating factor over climate in the condition of the forest since the settlement.

Ágrip

Aðaltilgangurinn með þessari rannsókn var að afla gagna sem gætu skýrt gróðurfarssögu Fljótsdalshéraðs síðastliðin 2000 ár og kanna orsakir hnignum skóga héraðsins. Rannsóknin var gerð á tveimur mismunandi gagnasöfnum. Í fyrsta lagi var gerð nákvæm rannsókn á öllum sagnfræðilegum heimildum um gróðurfar og veðráttu á Austurlandi frá landnámi. Í öðru lagi var gerð frjókornarannsókn á sýnum úr setkjarna er tekinn var úr tjörn innan Hallormsstaðarskógar. Sá kjarni spannar um það bil 2000 ár.

Setið í kjarnanum var einsleitt vatnaset er innihélt mörg öskulög. Öskulagatímatal var útbúið fyrir kjarnann og við það notuð sex þekkt öskulög. Niðurstöðum frjókornarannsóknarinnar var skipt upp í sex kafla (zones) og hver þeirra táknaði mismunandi gróðurfarsaðstæður. Þessir kaflar voru síðan notaðar til túlkunar gróðurfarssögu svæðisins. Við landnám var svæðið umhverfis tjörnina þakið skógi, en skógurinn hörfaði hratt eftir landnám. Á 15. öld sótti skógurinn fram á ný og var frekar gróskumikill allt fram á miðja 18. öld en þá hörfaði hann hratt. Þessi hörfun hélt áfram allt til upphafs 20. aldar þegar skógurinn var friðaður.

Áhrif mannsins virðast hafa skipt sköpum hvað varðar ástand skógarins eftir landnám en verðurfar virðist hafa haft minni áhrif.

Acknowledgements

I would like to thank my supervisors, professor Ólafur Ingólfsson and Dr. Ólafur Eggertsson for giving me the opportunity to do research in this field and for supporting me during my research both in practical and theoretical aspects.

I would like to thank Dr. Margrét Hallsdóttir for her assistance in the pollen lab and during the pollen analytical work. I would like to thank Dr. Egill Erlendsson for his assistance in the pollen lab and for giving me advice on the computer analysis. Also I would like to thank Lilja Karlsdóttir for giving me information on her ongoing research. My thanks also go to Guðrún Larsen for her expert advise on the tephrocronology and Kurt Kjær for the analytical work on the tephra samples.

I would like to thank Mats Rundgren and Thomas Persson for their assistance at Lunds Universitet.

This research was financially supported by Rannís – The Icelandic Centre for Research (grant no. 060239), Héraðs- og Austurlandsskógar and the Research Fund of the University of Iceland. Iceland Forest Service and the Icelandic Institute of Natural History are thanked for allowing their facilities to be used.

I would especially like to thank my father Jón Árni Friðjónsson for his expert advice on historical background information and moral support. My grandfather Friðjón Árnason is thanked for allowing me to use his library. My lovely Dr. Charlotta Oddsdóttir is thanked for both assistance on language and construction of the thesis.

Index

List of figures and tables

1 Introduction

According to popular belief, Iceland was widely covered with birch forest at the time of the settlement in the late ninth century (Þórarinsson 1974). This has been supported to some extent by various pollen studies (Thorarinsson 1944, Einarsson 1962, Hallsdóttir 1987 and Erlendsson 2007), but some studies suggest that the birch forest declined and disappeared rapidly after the settlement (Einarsson 1962, Hallsdóttir 1987). However, most studies have been carried out in the southern and south-western parts of Iceland and in areas where there is little or no forest today. Therefore, late Holocene woodland development has not been studied in those regions of Iceland where there is forest today.

The *Hallormsstaðaskógur* forest is the largest natural forest in Iceland, but it is not clear if it is a leftover from the large forest said to have covered Iceland by the time of the settlement.

In historical records it is suggested that the decline of woodland in eastern Iceland was due to cold climate and tephra fall (Gunnarsson 1873) but more recent theories suggest that the decline in general was partly due to deteriorating climatic conditions accelerated by human activity (Einarsson 1962, Hallsdóttir 1987).

To investigate the forest history of *Fljótsdalshérað* it is important to find out what written records report about the forests and how the people in area used the forests, changes in population and climate during the period investigated, as well as carrying out a pollen analysis on a sediment core taken from the present day *Hallormsstaðaskógur* forest.

2 Literature Background

2.1 Historical background

Iceland was settled in the latter part of the 9th century. Around the year 870 the first settlers came to Iceland and by the year 930 the country was fully settled (Íslendingabók 1968). The settlers came mainly from Norway but also from Ireland and Britain. The main reason for people to leave Norway and to risk the journey across open seas is considered to have been the oppression of Haraldur hárfagri, who is mostly known for uniting Norway through force. Additionally, overpopulation and lack of farmland in Norway must have been a factor together with improving sailing methods (Þorsteinsson 1978).

Ari fróði, (Ari the wise), wrote sometime between 1122 and 1133 a description of the settlement of Iceland in *Íslendingabók* (The book of the Icelanders). He writes: „Í þann tíð vas Ísland viði vaxit á miðli fjalls ok fjoru“, in English: „During that time Iceland was covered with wood from the mountains down to the coast“ (Íslendingabók 1968, p. 5). This tells two things, it is likely that Iceland was indeed covered with forest to a larger extent by the time of the settlement, and by the first half of the 12th century this was not the case any more since it had to be mentioned.

2.1.1 Climate in Iceland

Climate in Iceland has been of great interest for scholars as the island is situated at a meeting point of cold polar air and warmer air from the Atlantic. Close to Iceland, the warm Irminger current and the cold East Greenland current meet, and small changes in the position of these currents can have an immense influence on the weather in Iceland (Einarsson 1976).

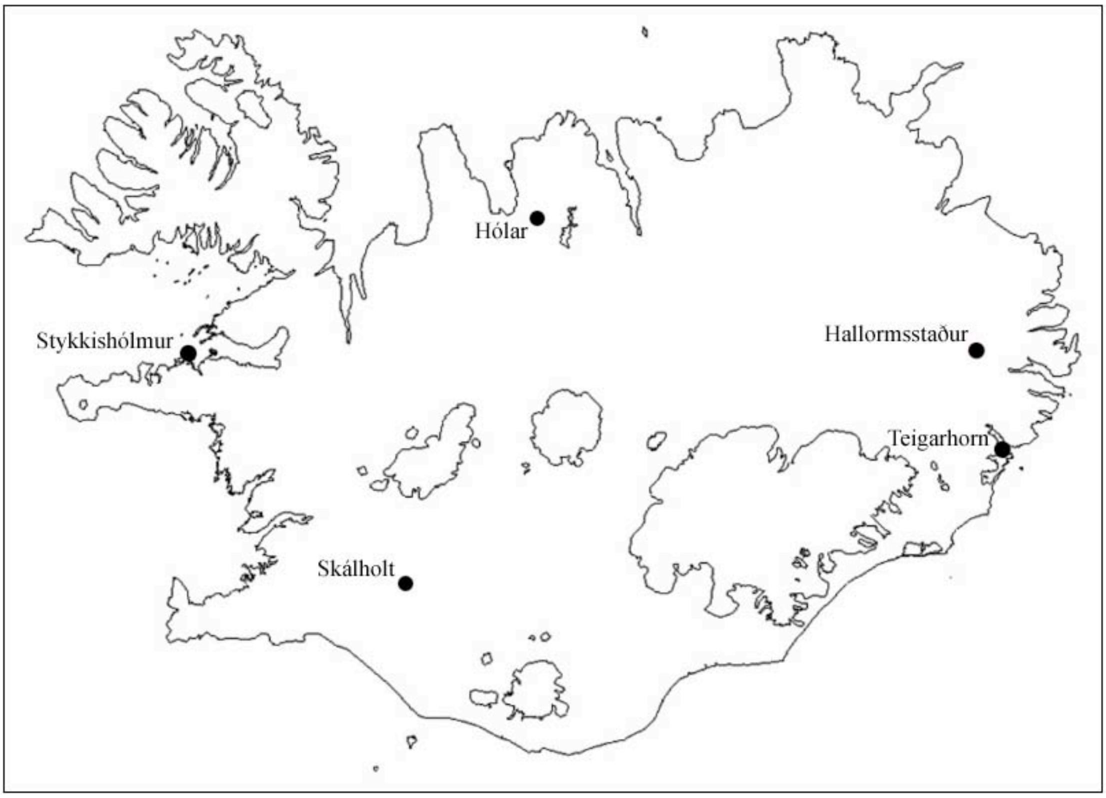


Figure 2.1 Sites mentioned in the text. Map base from Landmælingar Íslands (2009a)

Extensive historical records concerning climate exist in Iceland and the historian Astrid Ogilvie (1991, 1995) has constructed an overview of the climate from the 9th century and until systematic instrumental measurements began in *Stykkishólmur* (Figure 2.1), western Iceland, in the early 19th century (Figure 2.2).

Before the 12th century there are not many historical records preserved, however based on other evidence such as the fact that two farms settled in this time were engulfed by glaciers in the early 18th century (Þórarinsson 1974), it can be assumed that the climate during this period was relatively mild. In the beginning of the 13th century the descriptions of harsh climate are many and although mild years are reported in between, the climate seems to get colder.

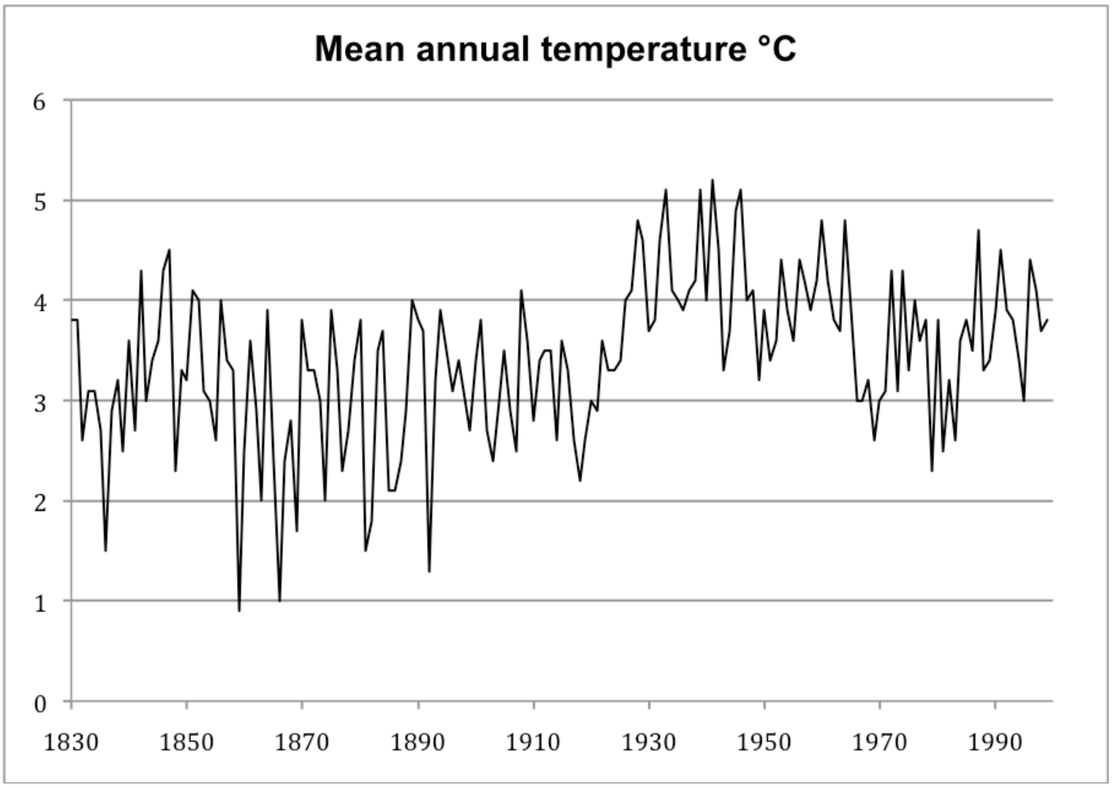


Figure 2.2 Mean annual temperature in *Stykkishólmur* (Veðurstofa Íslands 2009).

By the end of the 13th century the climate was almost certainly harsh. The climate in the 14th century varied a lot, with the first decades rather mild and the 1360s and 1370s are likely to have been cold. By the year 1364 the sea ice on the sailing route to Greenland is said to have increased. There are not many records on the 15th century climate, but is seems to have been relatively mild. By the mid 16th century the climate was undoubtedly cold with much sea ice (Ogilvie 1991).

There seems to have been a cooling trend by the end of the 16th century and the beginning of the 17th. The latter part of the 17th century was however rather mild save for the 1690s that were very cold. The first part of the 18th century seems to have been milder and stayed so until the 1730 when there was a shift to a colder climate. The next three decades were quite severe, especially the 1750s. The next decades, the 1760s and 1770s, were not as cold but were followed by probably the coldest decade in the history of Iceland, the 1780s. During this decade also sea ice around Iceland occurred most often (Ogilvie 1995).

There are not many evidences for the climate optimum during and shortly after the settlement of Iceland like often is assumed (Þórarinsson 1974), however there is evidence for mild climate up to the late 12th century. From the latter part of the 12th century and until the 16th century, short periods of harsh climate occurred periodically (Ogilvie 1991). Ogilvie on the other hand suggests that the „Little Ice Age“ in Iceland starts around 1750 and finishes around 1900 (Ogilvie 1995).

The 1750s and the 1780s were the most severe in the history of Iceland. The hardship in the 1780s is well known, with many factors coinciding. The eruption of *Laki*, cold climate and sea ice resulted in the greatest decrease in the population of Iceland (Hálfdanarson 1984). The 1750s have not been studied to the same extent, however evidence suggests that the climate was not much better then than in the 1780s. In the 1750s the cold climate was accompanied by sea ice and a highly inefficient trade monopoly (Jörundsdóttir 2006 and Ólafsson 1968).

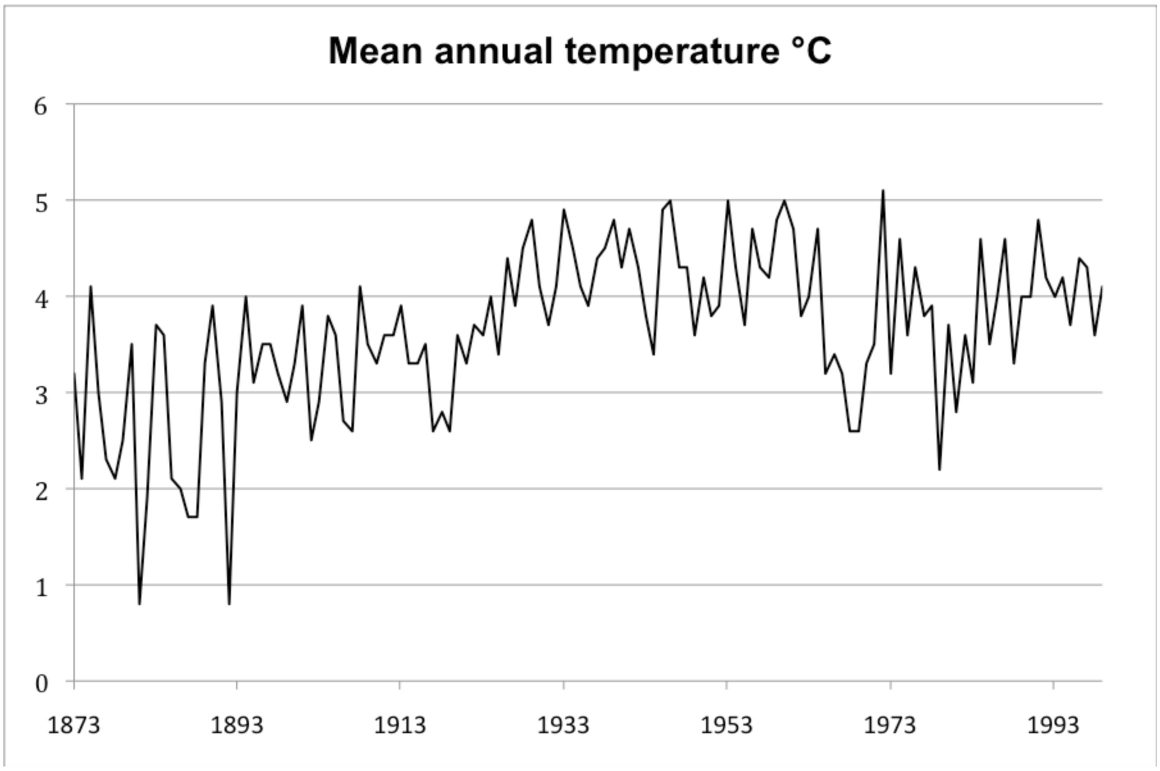


Figure 2.3 Mean annual temperature in *Teigarhorn* (Veðurstofa Íslands 2009).

The longest complete temperature record from the eastern part of Iceland is from *Teigarhorn* (Figure 2.1) and goes back to the year 1873 and can be seen in figure 2.3.

A temperature record for *Hallormsstaður* only covers the years 1961 to 1989 and can be seen in figure 2.4.

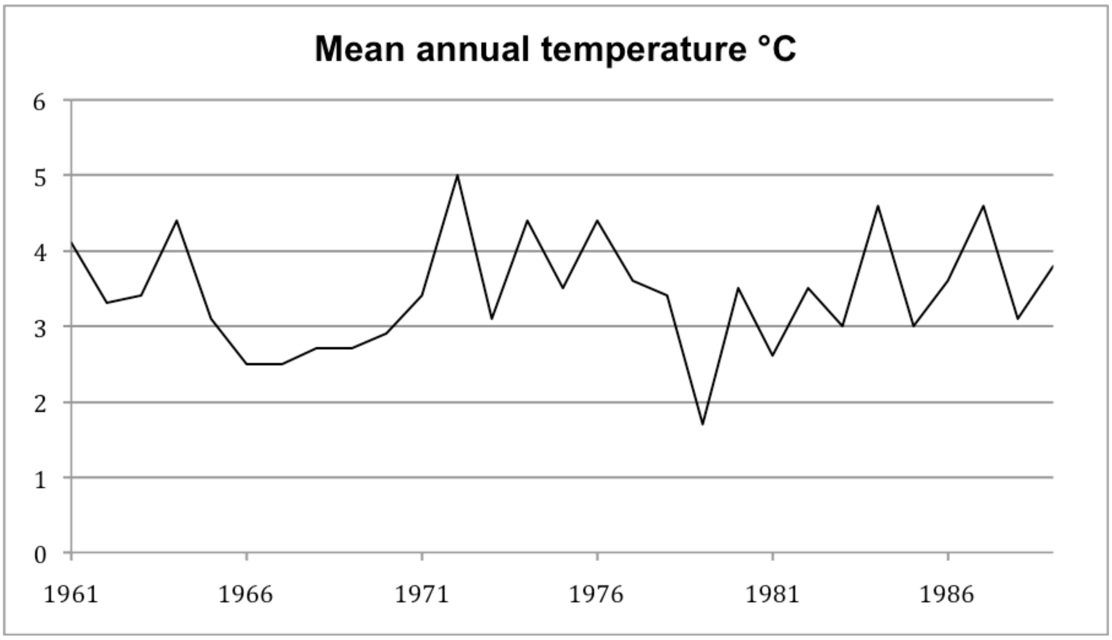


Figure 2.4 Mean annual temperature in *Hallormsstaður* (Veðurstofa Íslands 2009).

2.1.2 Population of Iceland

In the year 1703 the first complete census was done in Iceland. At that time the total population was 50.358. By using later censuses and registers from churches, the population each year from 1735 has been calculated and can be seen in figure 2.5. As can be seen from the figure it was not until the year 1825 that the population exceeded 50.000 again (Hagstofa Íslands 2009).

The usual explanation of the drop in population when it reaches 50.000 people is the lack of ability of the Icelandic 18th century society to feed more people (Steffensen 1975, Karlsson 1975). Others believe that diseases were the dominating factor in the growth, or the lack of growth, of the population of Iceland from the 15th to the 19th century (Ísberg 1997).

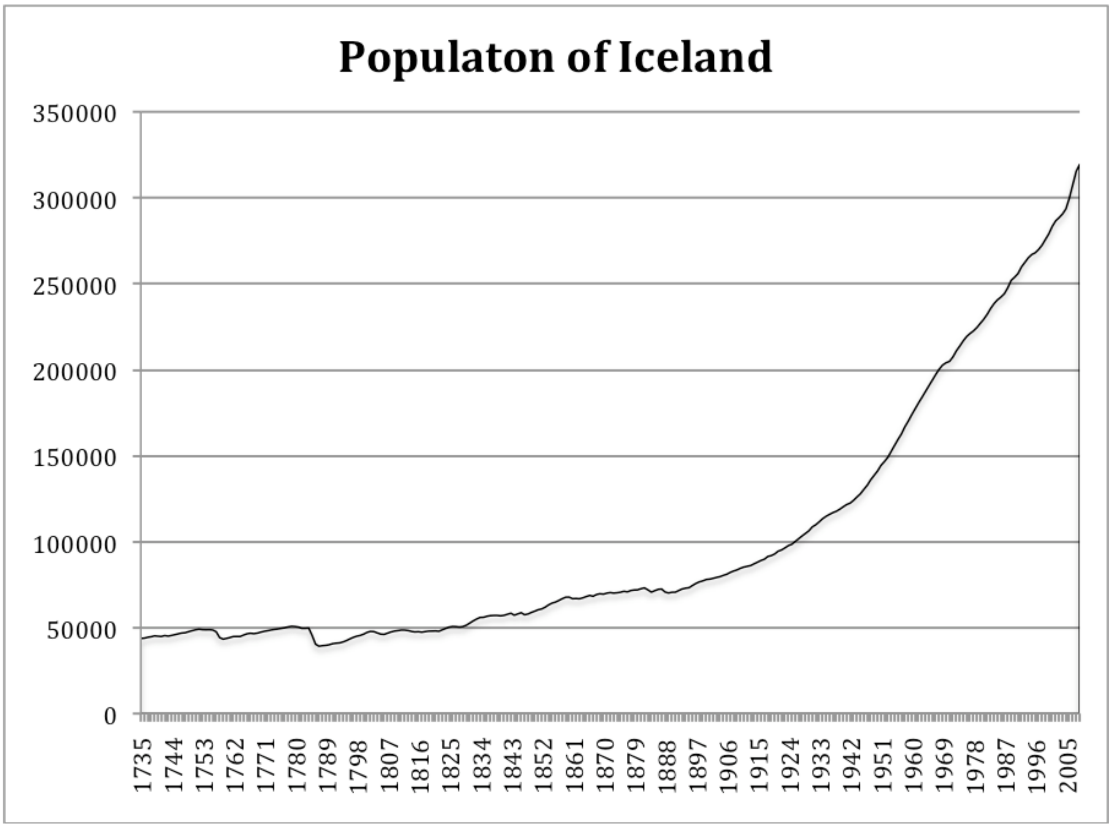


Figure 2.5 Population of Iceland (Hagstofa Íslands 2009).

The population before the year 1703 is unknown and can only be speculated about. Steffensen (1975) uses different methods to estimate the population since the settlement. He states that his results are highly speculative and should be viewed according to that. He estimates that by the time the settlement is over, around 20.000 people lived in Iceland, and by the year 1000 he believes 33.000 people live in the country. The year 1150 the population should have been 74.000 people and by the year 1200 78.000 lived in Iceland, according to Steffensen's estimation. However, the growth of the population stops in 13th century and there is even some decline in the population. In the 14th century the decline was even greater and in the 15th century the plague killed one third of the population (Steffensen 1975). Other scholars have estimated the total population of Iceland around the year 1100 to have been between 40-60 thousand (Karlsson 1975)

2.1.3 Fljótsdalshérað

Due to geographical reasons the eastern part of Iceland has through history been the most remote region of the country and the fewest written documents from this area have been preserved (Stefánsson 1958). The main centers of political power were during the catholic era at the bishops seats in *Skálholt* in the southern lowland, in *Hólar* in *Skagafjörður* and at the residence of the king's sheriff in *Bessastaðir,* close to *Reykjavík.* (Figure 2.1;Laxness 1998a).

The eastern part of Iceland belonged to the diocese of the bishop in *Skálholt*. To get from *Skálholt* to the eastern part one had to go by ship or cross braided glacial rivers running across the sandur plains south of *Vatnajökull* glacier or even across the glacier itself as the glacial rivers were often impossible to cross. Travelling from *Hólar* to *Fljótsdalshérað* meant crossing *Möðrudalsöræfi*, a vast stretch of unvegetated wilderness. Due to lack of authoritative incentive few written documents concerning the area have been preserved. After Icelanders converted to the protestant religion the Danish kingdom increased its power in Iceland, until the formal installation of divine monarchy in the middle of the 17th century. This meant no improvement for the eastern fjords concerning the preservation of written record since the central power now came across the Atlantic from Europe to *Bessastaðir*, which was the residence of the king's representative in Iceland.

The best document record about vegetation in Iceland is *Jarðabók Árna Magnússonar og Páls Vídalíns*, a detailed description of every farm in Iceland made in the beginning of 18th century. However during a catastrophic fire in Copenhagen in the year 1728 the part about eastern Iceland was lost (Jónsson 1998).

Since *Hallormsstaðarskógur* forest is the biggest natural forest in Iceland, it has been the center of attention for historians during the 20th century and quite a number of documents have been brought to light.

2.1.4 Older documents

One of the Icelandic sagas, *Fljótsdælasaga*, takes place in *Fljótsdalshérað*. It says: „Sá var siður víða í fyrndinni að lítt voru baðstofur og höfðu menn þá baksturelda stóra. Var þá víða gott til eldibranda því að öll héruð voru full af skógum“ (*Fljótsdæla saga* 1950). In translation to English it says: „It was widely practiced in the past not to build *baðstofa* but long fires. It was easy to get firewood as the countryside was full with forest." The typical house built in Iceland first after the settlement was called *skáli.* The *skáli* was 20-30 m long and 4-6 m wide, there was just one room inside with long fire in the middle (Eldjárn 1974). The Icelandic house building tradition changed however in the late Middle Ages and houses were divided up into many small rooms connected with long corridors. This is believed to have happened due to lack of firewood and deteriorating climate (Ágústsson 1989). The *Baðstofa* became the main living and sleeping room, usually the biggest room in the traditional Icelandic farm.

In the catholic era people often gave their belongings to the churches both for a safer place in heaven, to get a secure place to stay in their old age and for the well being of poor people in the parish (Laxness 1998b). Because of this the churches often had quite a lot of assets. *Máldagi (plural: máldagar)* is a kind of register of these assets (Laxness 1998b). In *máldagar* from 1397 we can see that all the main churches in *Fljótsdalshérað, Múli, Vallanes, Hallormstaður* and *Valþjófsstaður* (Figure 2.6) had listed forests or forest use (*Íslenzkt fornbréfasafn IV* 1897, p. 203-212).

The fact that this is listed tells us two things, first of all it means that in *Fljótsdalshérað* there were valuable forests and secondly it means forests were somewhat limited goods and it was important to document to whom they belonged.

Another *máldagi* is preserved from the year 1471 for *Vallanes* and *Valþjófsstaður*. All the same forest patches are listed belonging to both churches as 74 years before (*Íslenzkt fornbréfasafn V* 1899-1902, p. 629-632).

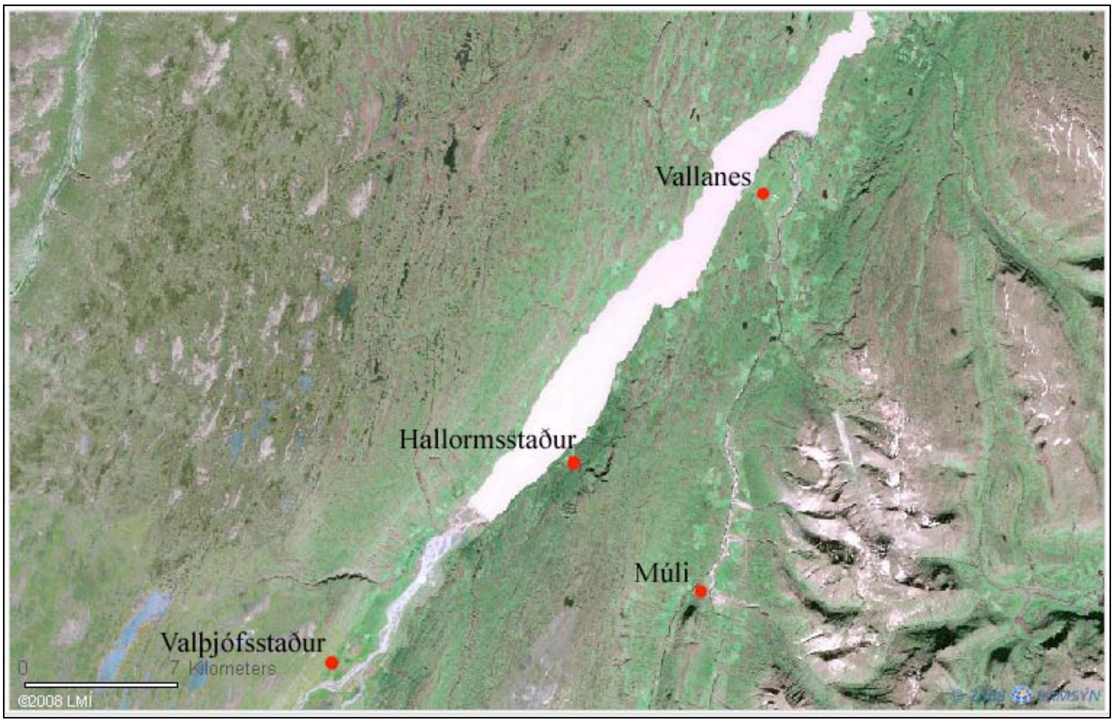


Figure 2.6 The Church farms in *Fljótsdalshérað*. Based on an aerial photo from Landmælingar Íslands (2009c)

In a document from 1467 there is a description of boundaries and assets for *Víðivellir* farm in *Fljótsdalur*. This description says „suo wissu wid ad wijdivellir ytri ættv skog vt vid gilsa j rana. og annañ skogarpart fram a stullaflaut.“ (*Íslenzkt fornbréfasafn X* 1911-1921, p. 23). In translation to English: „*Víðivellir* owned one forest in *Gilsárrani*, later called *Ranaskógur*, and another one in *Stullaflaut* [Sturluflöt?]*“*.

The 4th of august 1541 Gissur Einarsson bishop over Iceland signed a document stating that a certain forest patch in *Hallormstaðaskógur* belonged to farmer Torfi Þorsteinsson and his heirs (*Íslenzkt fornbréfasafn X* 1911-1921, p. 647).

Máldagi is preserved from 1576 for *Valþjófsstaðir, Hallormstaðir, Vallanes* and *Múli*. The same forest patches belonged to *Valþjófstaður, Hallormstaður* and *Vallanes* as in the previous máldagar but *Múli* seems to have lost one of its forests, which was in the land of *Sandfell*, but the other churches do own forests in that land (*Íslenzkt fornbréfasafn XV* 1947-1950, p. 681-685).

It should be noted that all the descriptions of the forests belonging to the churches in *Fljótsdalshérað* are identical and the more recent ones were probably written using an older edition as a template. This does not necessarily mean that the younger documents are less reliable since it is not likely that the church would claim rights over non-existing woods.

2.1.5 Travel descriptions

Now the historical sources get more abundant and at least two descriptions from travellers have been preserved from the 18th century. In the years 1756 and 1757 Eggert Ólafsson and Bjarni Pálsson travelled around eastern Iceland (Bjarnason 1972-1973). They do not make points on the forests in *Fljótsdalshérað* other than that they exist and are big enough to provide wood for house building (Ólafsson 1974).

Twenty years later another traveller documented a description of *Fljótsdalshérað*. Ólafur Olavius travelled around Iceland in the years 1775-1777 and made more accurate and detailed notes on the forest in *Fljótsdalshérað* (Bjarnason 1972-1973). Ólafur gives a description of each parish in *Fljótsdalshérað*.

For *Þingmúli (Múli)* he says: „Í sveitinni skiptast á þurrlendi og mýrar og flóar, og á nokkrum stöðum er smávaxinn birkiskógur og kjarr“ (Olavius 1965, p. 119). In translation to English: „The countryside is either dry fields or wetlands, in a few sites forests of small birch trees and shrubs can be found“.

For *Vallanes* Olavius writes: „Landslagi er svo háttað, að þar eru lágir ásar vaxnir birkiskógi og kjarri, en á milli þeirra eru grösug mýra- og flóasund,“ (Olavius 1965, p. 119). In translation to English: „The nature of the landscape is such that there are small hills with birch forest and shrubs, interrupted by wetlands“.

He describes *Hallormsstaður* like this: „Í norðurhlíð Hallormsstaðarháls … er hinn frægi Hallormsstaðarskógur, sem talinn er vera þriðji stærsti skógur á Íslandi. En sakir illrar meðferðar er honum nú tekið greinilega að hnigna, líkt og öðrum skógum á landinu. Annars liggur sveitin í fjallshlíð, sem sögð er alvaxin grasi og skógi. Er hún því einkar vel til sauðfjárræktar fallin, því að á vetrum getur féð lifað á skóginum, þegar ekki næst til jarðar fyrir snjóþyngslum, en einnig veitir skógurinn því skjól í illviðrum.“ (Olavius 1965, p. 119). In translation to English: „The north side of Hallormsstaðarháls is covered by the famous *Hallormsstaðarskógur* forest, which is believed to be the third largest forest in Iceland. However due to ill treatment it is obviously in decline, as other forests in Iceland. Apart from this, the countryside is on a mountainside, said to be completely covered with grass and forest. Because of this it is especially good for sheep herding, as in the winter the sheep can graze on the trees when the meadows are covered with snow, and the forest gives shelter in bad weather".

On *Valþjófsstaður* Olavius writes: „Víða í sókn þessari, einkum þó í henni austanverðri, vex birkiskógur, víðir og kjarr, en annars er þar þurrlent og sléttlent og jarðvegur sendinn" (Olavius 1965, p. 118). In translation to English: „In many places in this parish and especially in the eastern part there grows a birch forest, willow and shrubs, but the rest are dry and flat fields with sandy soil".

2.1.6 Descriptions of the parishes from 1840

In the year 1840 *Hið Íslenska bókmenntafélag* (The Icelandic Literature Association) sent a letter to the priests and sheriffs in Iceland containing detailed questionnaires concerning the parishes. The answers to these questions were to be used in the construction of a complete description of Iceland but that task was newer completed. Included in the questionnaires were questions about vegetation and forests. Around the year 1870 these lists were again sent to few priests, the reason for this is not known but this provides us with additional information on some of the parishes (Karlsson *et al* 2000).

Guttormur Pálsson priest in *Vallanes* describes the *Vallanes* parish in the following way in the year 1840: „Landslag í sókn þessari er á flatlendinu flóar og mýrarsund með smáásum, holtum og móum á milli, er áður voru allstaðar birkiskógi vaxin og ennþá er það á sumum stöðum…Þó ganga skógar þessir mjög til þurrðar ár frá ári og kali og allur hinn gamli skógur, sem var stærri, er fallinn." (Pálsson 2000, p. 299). Translated to English: „In this parish the landscape includes wet areas with low hills, which used to be covered with birch forest and still are in some places… However these forests decline every year also due to frost damage and all the old forest, which contained bigger trees, has fallen".

Hjálmar Guðmundsson, priest in *Hallormsstaður* gives this description of the parish in 1840: „Land þettað … var fyrrum þétt vaxið stórum birkiskógi og má ráða af stofnum þeim, er til skamms tíma hafa staðið og einstaka röftum í húsum, að þeir digrustu stofnar þeirra hafa verið frá 10 til 12 þuml. í þvermál. … Nú er allur hinn gamli skógur gjörfallinn og eyddur, mest af elli og fúa en víða upp vaxinn buskaskógur hentugur til kolviðar og brennslu en valla til rafts og tekur hann aftur á sumum að kala og spreka. Einstaka víðir- og reyniviðartré uxu í þeim gamla skógi en eru nú, eins og hann, útdauð.“ (Guðmundsson 2000, p. 314). Translated to English: „This area was before covered by a large birch forest and from old trunks and occasional roof rafters it can be seen that the widest tree trunks were 10 to 12 inches wide. Now all the old forest has completely fallen and is destroyed, mostly by old age and decay but now a shrubby forest has emerged that can be used for fuel and to make charcoal but not for building. Occasional willow and rowan trees grew in the old forest but are now extinct along with the rest of the forest“.

Stefán Árnason in *Valþjófsstaður* writes the following in 1840 concerning the forests in *Fljótsdalshérað*: „Að skógar í Fljótsdal eru bæði undir lok liðnir, og líka ekki meiri en nú eru þeir, kemur væntanlega af illri meðferð þeirra, og að þeir fyrir ellisakir ei hafa getað staðið heldur fúnað, sprekað og fallið af sjálfu sér.“ (Árnason 2000, p. 143). In English translation: „The fact that the forests in *Fljótsdalur* have declined, and are not more widespread than now is, is most likely due to ill treatment and deterioration due to old age“.

2.1.7 Early historians

Sigurður Gunnarsson was a priest in *Hallormsstaður* from 1861 to 1878 but he first came to *Fljótsdalshérað* in the year 1830. As a young man he worked as an assistant geographical surveyor in the central highland. After this he had a special interest in nature observations (Hallgrímsson 1994).

In the year 1872 he wrote a description of the forests in *Fljótsdalshérað* both from his own observation and based on what elderly men in the area recollected of their personal experience, and what they had been told in their youth about the story of the woods (Gunnarsson 1872).

Sigurður writes:

> Um miðja 18. öld var Fljótsdalshjerað mjög víða skógi vaxið inn til dala og út um allar hlíðar, hálsa og ása, út um sveitir, allt út að eyjum eða láglendinu inn af Hjeraðsflóa, nema á Jökuldal voru skógar víðast hvar

> horfnir um þær mundir og ekkert eptir nema örnefni, sem minntu á gamla skóga, t.a.m. Brúarskógur (Gunnarsson 1872, p. 63).

According to Sigurður, *Fljótsdalshérað* was covered with woodland to a large extent in the middle of the 18th century. Some of these forests had trees big enough to build all smaller houses and partly the larger ones. Sigurður himself once tore down a *baðstofa* that had been built in the latter part of the 18th century almost exclusively of Icelandic birch (Gunnarsson 1872).

According to Sigurður, during an eruption in *Katla* in 1755, the leafs and small branches on the trees in the forest dried up and cracked due to the heat and lack of moisture. After this the forest started to decline:

> Sumarið 1755, þegar Katla gaus, fjell aska yfir Austurland, sem olli „móðuhallærinu fyrra“. Þá var svo mikill hiti og þyrringur í lopti, að lauf skorpnaði á skógum og grannar limar skrælnuðu og urðu að spreki. Eptir þetta fóru stórskógar hjer að visna að ofan og kom í þá uppdráttur, en lágskógur sem hinn hærri skýldi og var græzku meiri, varðist nokkuð betur.
>
> Tóku nú, þegar frá leið, að falla hinir stærri skógar, einkum frá 1770 til 1783. Þá var og óspart gengið á þá og eytt með öllum hætti. … Þó voru enn eptir miklir skógar og víða; þegar Síðueldurinn kom upp 1783. Þá bar að nýju mikla ösku yfir Austurland, einkum Fljótsdalshérað, sem varð undirrót „móðuhallærisins seinna“. Fjell þá næsta vetur nálega allur sauðfjenaður í Hjeraði, en töluvert slórði af í Fjörðum. … Síðueldssumarið fór eins of fyrr af Kötlugosinu, eða verr, að lauf skorpnaði á skóginum og greinar sprekaði af þyrringu í lopti og öskufalli. Nú herti enn meira á fallinu í öllum skógum og fjellu þeir upp frá því unnvörpum.
>
> Um næstliðin aldamót og rjett eptir þau voru hjer allir stærri skógar fallnir (Gunnarsson 1872, p. 63).

In the years from 1770 to 1783 all the woods were falling. At the same time the woods were heavily cut and more than before. 1783 the *Laki* eruption began and *Fljótsdalshérað* suffered heavily, with almost the entire sheep stock dying that winter. This eruption continued, if not increased, the detrimental effect on the woods and the falling of trees increased rapidly. By 1800 all the larger trees had fallen.

Sigurður is an eyewitness of the forest in the beginning of the 19th century, having observed that when he came to *Fljótsdalshérað* in 1830 there were some usable forests left. „Eyðaskógur, Miðhúsaskógur, Dalaskógur, í Eyða þinghá; Egilsstaða, Höfða, Ketilstaða, Sandfells- og Sauðahagaskógur á Völlum; Mjóaness, Hafursá og Hallormstaða skógur í Skógum, Ranaskógur og nokkrir reitir í Fljótsdal" (Gunnarsson 1872, p. 63). However none of these were tall, as no trees were taller than 3 meters.

At the time Sigurður documented his description, the small forests that lingered 50 years before had all disappeared except for small remains in *Hallormsstaður*, *Ranaskógur* and in *Miðhúsaland* (Gunnarsson 1872).

Even though Sigurður believes that the main reason for this decline is the influence of the eruptions he realizes that part of the reason is the heavy use and grazing of sheep all year round (Gunnarsson 1871).

Guðmundur Jónsson was born in the year 1862 in *Fljótsdalshérað* and lived there until the year 1903 when he moved to America. He wrote descriptions of life in *Fljótsdalshérað* later on that were published after his death in the year 1955. Among his subjects are the forests of *Fljótsdalshérað* (Bjarnason 1972-1973). In one account farmer Björn Hallsson describes to him the fate of the forest *Fleki* in the land of *Kirkjubœr*. The farmer on the next farm had 100 sheep but no hay for the winter. The farmer made a deal with the priest in *Kirkjubœr* and was allowed to graze the sheep in the forest the whole winter. All the sheep survived the winter but the forest did not, as all the birch trees where stripped of their bark (Jónsson 1955).

2.1.8 Fljótsdalshérað in the year 1893

In the year 1893 Sæmundur Eyjólfsson travelled around *Fljótsdalshérað* to investigate the forests on behalf of the *Búnaðarfélag Suðurlands* (the agricultural association of southern Iceland) and the year after he wrote a description on the matter (Þórðarsson 1955). He writes that now there are little forests left in *Fljótsdalshérað* though they were great in the past. Sæmundur inspects

Hallormsstaðarskógur forest, which according to him is the largest in the whole country. The condition of the forest is bad, as the owner, the daughter of Sigurður Gunnarsson mentioned above, still uses it as a grazing land for sheep, although she has stopped cutting trees. This has damaged all the younger trees in the forest which all are small and crooked. The larger trees are old and few and Sæmundur says that unless the forest will be completely protected it will not have any future (Eyjólfsson 1894).

Sæmundur met an old farmer, Jón Einarsson, who lived on the farm *Ytri Víðivellir* all his life. Jón told Sæmundur that when he was young the forest was so dense that it was difficult to bring the sheep to the fields. The forest was cut and destroyed in every way until it was almost completely gone and Jón said that it was no pity. The forest had been of no use and although the land would probably erode heavily after the forest was gone it would not matter since he himself would be dead by then. Sæmundur comments that Jón's point of view was not exceptional for a farmer in *Fljótsdalshérað* and he did not use his forests any differently than others (Eyjólfsson 1894).

Sæmundur concludes his description by saying that in no other place has he seen such great and evident destruction of forests in later times as in *Fljótsdalshérað*.

2.1.9 Later historians

In 1948 Guttormur Pálsson published an essay on the history of the forests in Fljótsdalshérað. Just as Sigurður Gunnarsson, Guttormur lived in *Hallormstaður* and was both a farmer as well as a head forester from the year 1909 until 1955 (Guttormsson and Blöndal 2005). He writes about Sigurður's description and continues the story. He writes that the forests in *Fljótsdalshérað* did decline until 1870 and by that time only 4-5 farms had forests in their land. After this point the retread stopped and at the turn of the century 20-25 farms had forests in their land. By the year 1947 forest was growing in the land of 37 farms, covering 5000-5500 ha (Pálsson 1948, p. 68-70).

2.1.10 Changes in the number of grazing animals

There is a rather complete record of the number of livestock in Iceland from the year 1703 (Hagstofa Íslands 1997, p. 277-278) but it is difficult to find older information. However, the *máldagi* for the churches in *Fljótsdalur* can give some information.

In the oldest *máldagar* from the year 1397 the following livestock are recorded to belong to the churches. *Múli*: 9 cattle, 86 sheep and 3 horses. *Vallanes*: 27 cattle, 122 sheep and 7 horses. *Hallormsstaður*: 22 cattle, 68 sheep and 3 horses. *Valþjófsstaður*: 24 cattle, 106 sheep and 4 horses (*Íslenzkt fornbréfasafn IV* 1897, p. 203-209).

In the *máldagar* from 1471 there is a record of the livestock belonging to *Vallanes* and *Valþjófsstaðir*. *Vallanes*: 43 cattle, 231 sheep and 12 horses. *Valþjófsstaðir*: 26 cattle, 139 sheep and 36 sheep worth *(ærgildi)* in horses, the exact number of horses is uncertain but could have been half a dozen (*Íslenzkt fornbréfasafn V* 1899-1902, p. 629-632).

In the year 1541, a *máldagi* for *Vallanes* was written: 10 cattle, 86 sheep and 7 horses (*Íslenzkt fornbréfasafn X* 1911-1921, p. 696-697).

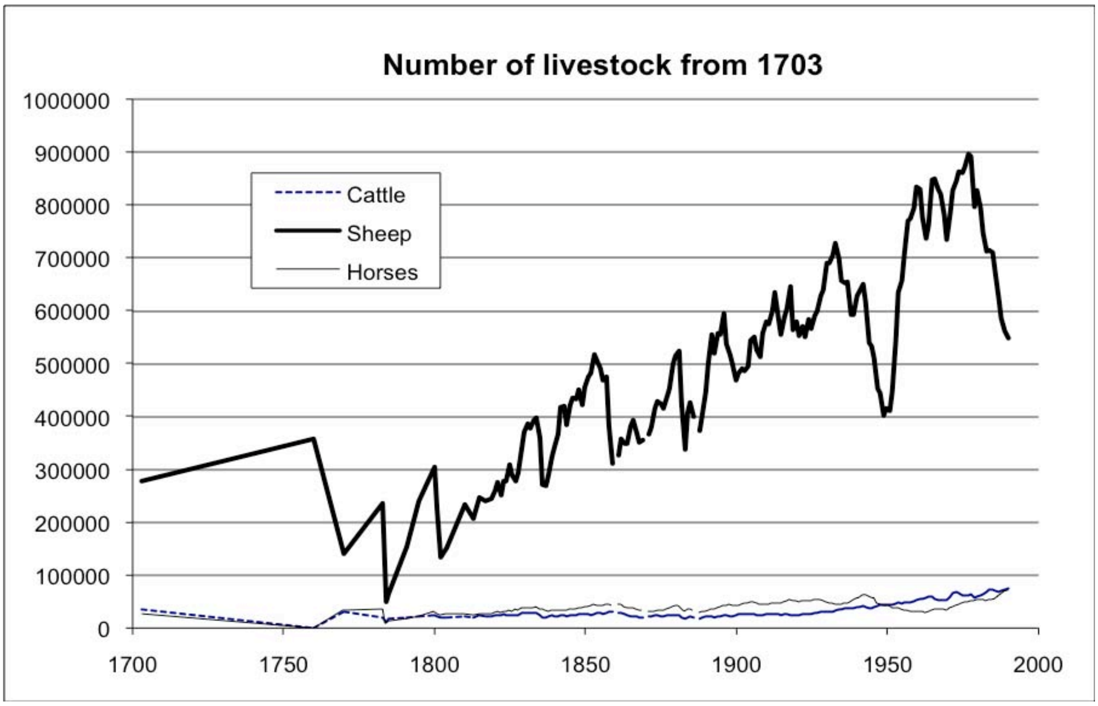
From 1553 there is a document stating the belongings of the church in *Valþjófsstaður* because a new priest was appointed. It states the following: 12 cattle, 60 sheep and 12 horses (*Íslenzkt fornbréfasafn XII* 1923-1932, p. 644).

In the year 1570, another *máldagi* is made for *Múli*, *Vallanes*, *Hallormstaður* and *Valþjófsstaður*. *Múli*: 6 cattle, no other livestock are listed. *Vallanes*: 23 cattle, 8 sheep and 30 sheep worth *(ærgildi)* in horses. *Hallormstaður*: 10 cattle, 72 sheep and 4 horses. *Valþjófsstaður*: 15 cattle, 60 sheep and 36 sheep worth *(ærgildi)* in horses, the exact number of horses is uncertain but could have been half a dozen (*Íslenzkt fornbréfasafn XV* 1947-1950, p. 681-685).

Múli	1397	1471	1541	1570
Cattle	9			6
Sheep	86			
Horses	3			
Vallanes				
Cattle	27	43	10	23
Sheep	122	231	86	8
Horses	7	12	7	5?
Hallormsstaður				
Cattle	22			10
Sheep	122			72
Horses	7			4
Valþjófsstaður				
Cattle	24	26		15
Sheep	106	139		60
Horses	4	36		6?

Table 2.1 Livestock numbers on the Church farms.

An overview over the changes in the number of grazing animals according to the *máldagar* can be seen in table 2.1. The number of livestock changes quite a lot through this period but it is interesting to see that it is not increasing, there are fewer grazing animals belonging to the church farms at the end of the 16th century than there are at the end of the 14th.



Figur 2.7 Number of livestock in Iceland from the year 1703 - 1990 (Hagstofa Íslands 1997)

2.1.11 Iron production and fuel utilization in Iceland

There are both literary (Jónsson 1906, Jóhannesson 1943, Þórðarsson 1943) and archeological (Sigurðardóttir 2004) evidence that iron was produced in Iceland in the centuries after the settlement. This iron was produced from bog-iron and for that procedure a large amount of fuel was needed, usually charcoal made from birch wood.

It has been suggested that Icelanders were self-sufficient with iron production during the first centuries after the settlement and even as late as 15th century (Jóhannesson 1943, Þórðarsson 1943) when a massive import of cheap iron from Sweden started (Jóhannesson 1943, Laxness 1998a,b). However, in the smelting sites investigated, the most recent radiocarbon dates on birch charcoal are from the 13th century (Sigurðardóttir 2004).

Evidence indicates that, at least in some places in *Fljótsdalshérað* the iron production was quite massive. Estimated from the amount of slag found in *Eiðar* in *Fljótsdalshérað*, it has been suggested that between 500-1500 metric tons of iron were produced in *Eiðar* (Þórarinsson 1980). This production would require an extreme amount of fuel.

After bog-iron production was stopped charcoal was still needed to work on the imported iron and especially for sharpening scythes. Charcoal made from the birch woodland in *Fljótsdalshérað* was used for this until the 19th century (Eyjólfsson 1894, Gunnarsson 1872, Jónsson 1955).

In pre-industrial Iceland, fuel was of great importance for the inhabitants. Apart from the birch wood, peat, dried turf, and sheep and cow dung was the most commonly used fuel in Iceland (Vésteinsson and Simpson 2004). Although it is a rather well established belief that the forests in Iceland declined rapidly after the settlement to near extinction (see next chapter) evidence suggest that forest patches were preserved late into the middle ages. These patches were carefully managed and supplied birch for fuel along side other fuel sorts (Vésteinsson and Simpson 2004). It has been suggested by Vésteinsson and Simpson that in the 17th century there was some sort of a change in this system, peat pits were abandoned and the remaining forests more heavily exploited and rapidly destroyed.

2.2. Previous pollen analytical studies

The first pollen study carried out in Iceland was done by Sigurður Þórarinsson in the year 1935 but it was not published until 1955 (Þórarinsson 1955). It is a simple pollen diagram that covers the whole of *Holocene* with the author addressing the problem of distinguishing between *Betula pubescens* and *Betula nana.* Thorarinsson (1944), the same author, also published two pollen diagrams from *Þjórsárdalur* valley, linked to an archeological research in the valley.

Later Þorleifur Einarsson took over the palynological study in Iceland. In Einarsson (1957a, 1957b) pollen diagrams are published from sites close to and in *Reykjavík* and close to the town of *Selfoss*. Einarsson divides *Holocene* into four zones, each representing different climates. The first zone is the post-glacial time and is characterized by the complete lack of birch pollen. The second zone starts around 9000 years BP and Einarsson refers to it as the earlier birch era, characterized by an increase in birch pollen. By the end of this zone, around 6000 BP, precipitation increased with a decline in birch and increase in *Sphagnum*. The third era starts around 5000 BP and is characterized by an increase in birch. This zone is referred to as the latter birch era and later the author describes this era as the *Holocene* thermal maximum in Iceland (Einarsson 1962). However, by the end of this era the climate had started to deteriorate. The fourth era starts with the settlement, here the birch declined rapidly and grass pollen became more abundant.

Einarsson (1962) is the first extensive paper on pollen studies and vegetation history in Iceland, This study reported problems with distinguishing between cultivated grains and *Leymus arenarius*. This question was of interest since tales of grain fields in the first centuries after the settlement have long been known. The cultivation of grains probably stopped in the 16th century and was not resumed until the end of the 20th century (Guðmundsson *et al* 2002-2003). Einarsson explains that pollen analysis cannot be used to construct climate history after the settlement since the influence of man far outweighs the effects of climate change. In Einarsson (1963) an overview is given over the palynological work done in Iceland, no new results are published but the author suggests that birch may have survived in some ice-free areas in northern Iceland during the ice age due to its fast migration into areas where the ice had retreated.

Hallsdóttir (1982) published two detailed pollen diagrams from *Hrafnkellsdalur* valley in a study linked to archeological research in the valley. In this study the author distinguishes between *Betula pubescens* and *B. nana* but discusses the problem of identifying cultivated grain. Hallsdóttir (1987) then focuses on the influence of the settlement. The main characteristic of the human settlement of the country is a disappearance of birch, the only woodland-forming tree. One site in *Reykjavík* and two sites in the southern lowlands were studied. The pollen record from the southern lowlands suggest that climate in Iceland started to deteriorate around 2500 BP with a cooler and more humid climate and a decline in *Betula* pollen. However a short lived increased in *Betula* pollen shortly before the deposit of LNL 871 tephra layer, this increase seems to have had culminated before the settlement of Iceland. After the settlement, the already begun retreat in birch forest was accelerated by human activity.

After those pioneering works in pollen analysis in Iceland where the impact of the settlement was of main interest, post-glacial time is next to be studied. Hallsdóttir (1990), Björck *et al* (1992), Rundgren (1995, 1997) all focus on postglacial time and the early Holocene time. The theory from Einarsson that birch may have survived during the ice age is discussed (Rundgren and Ingólfsson 1999). The authors speculate that since plants survived the *Younger Dryas* cooling at the investigated site it is likely that plants survived through the whole *Weichselian*, although no definite conclusion can be made on that matter.

In Caseldine (2001) the problem of distinguishing between *Betula pubescens* and *Betula nana* is readdressed. The author points out that the origin of the Icelandic birch is not known and the method of distinguishing between *B. pubescens* and *B. nana* based on size alone is insufficient.

Pollen analysis has been used in *multi-proxy* studies (Caseldine *et al* 2003, Caseldine *et al* 2006) where the main focus is on *the Holocene thermal maximum*, however *Chironomid*[*] analysis has taken over as the main tool for paleoclimate (Axford *et al* 2009). This is mainly due to uncertainty of the origin of the Icelandic birch and the delay of vegetation response to climate change, as trees are stationary organisms as opposed to midges.

Erlendsson (2007) studied the effects of the settlement on the vegetation in a study that focused on the period from 500-1500 AD. This study was done on three different sites, in *Mýrdalur* and *Eyjafjöll* Southern Iceland and *Reykholtsdalur* in western Iceland and those sites yielded different results. In one location there was no forest at the time of the settlement and the effect of that event on the vegetation was minimal. At the other locations there was forest at the time of the settlement that declined quite rapidly in the vicinity of the farms but farther away the forests lingered into the late medieval times. There was massive soil erosion where the forest had disappeared.

During recent years the origin of the Icelandic birch and a possible hybridization between *Betula pubescens* and *Betula nana* have been studied (Karlsdóttir *et al* 2007, Karlsdóttir *et al* in press) as well as the method of distinguishing between *B. pubescens*, *B. nana* and a possible hybrid. The results of these studies show that hybridization has occurred and also show that the method of distinguishing *Betula* pollen by size is highly unreliable.

---

[*] Chironomidae are non-biting midges that in their larva form develop robust head capsules. These head capsules are often well preserved and extremely abundant in fresh water sediments. Studies have shown that the distribution and abundance of chironomid species are strongly influenced by summer surface water temperature, especially in arctic and alpine environments (Lowe and Walker 1997).

3 Hypothesis and study aims

Some evidence suggests that the forests in Iceland were already retreating by the time of the settlement. This has however not been tested for the forests in *Fljótsdalshérað* even though this is the site of the largest natural forests in Iceland. The historical records report that the forests were mostly affected by tephra fall although some recognise human activity as a factor. The main purpose of this investigation is to obtain evidence on the vegetation history of *Fljótsdalshérað* for the last 2000 years, especially to delineate the main reasons for forest decline. This investigation has the following aims:

1. To determine the status of forests in *Fljótsdalshérað* by the time of the settlement and to see if it had been changing in pre-settlement time.
2. To investigate the development of the forest in *Fljótsdalshérað* after the settlement and until it was protected at the beginning of 20^{th} century.
3. To compare the historical and palynological records.
4. To highlight the dominating factor in declining of woodland in Iceland.

4 Field Work and Methods

4.1 Study site

The site selected for this study was a small pond, *Helgutjörn* in *Fljótsdalur* within the current border of *Hallormsstaðarskógur* forest. Location 65° 05,801 N and 14° 42,875 W, 191 meters over sea level see figure 4.1.

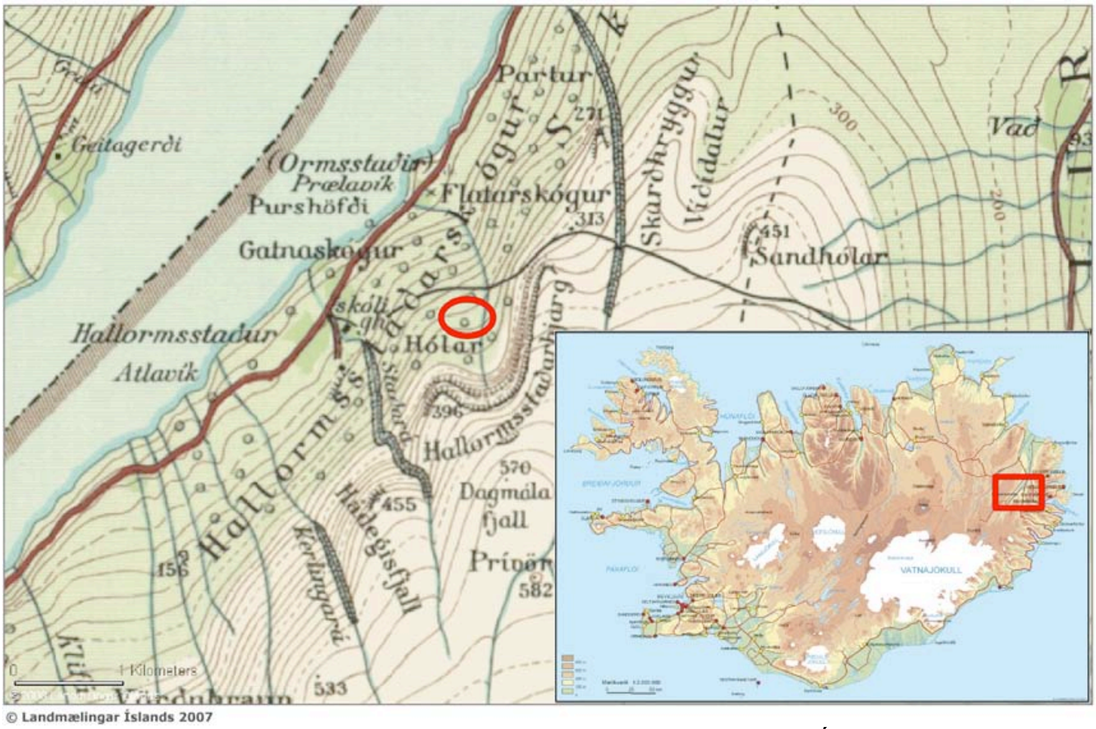


Figure 4.1 The study site. Based on a map from Landmælingar Íslands (2009a,b)

The pond is located in the upper part of a big landslide as can be seen in figure 4.2 which is a 3D satellite photo. This landslide, named *Hólar* is 1,5 km wide and covered with big boulders in the upper part and smaller rocks in the lower part. The *Saksunarvatn* tephra, 10 200 years BP, has been found just under the landslide giving it a maximum age of around 10 thousand years BP (Guttormsson and Blöndal 2005). This age is also the maximum age of sediments occurring in *Helgutjörn*. The landslide *Hólar* belongs to the old church farm *Hallormstaður*. The Icelandic state bought the farm in the year 1902 and dedicated the land to forestry (Guttormsson and Blöndal 2005).

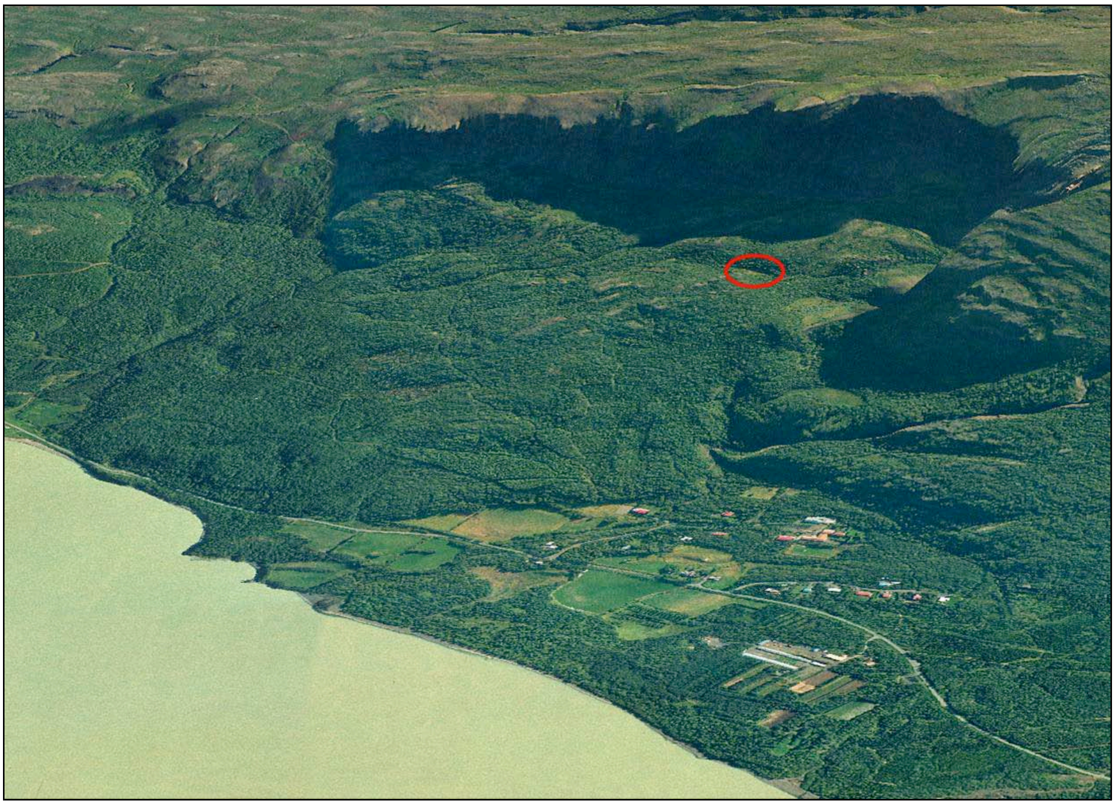


Figure 4.2 A 3D satellite photo showing *Helgutjörn*, the study site, with *Hallormsstaður* in the foreground. Photo from Skógrækt Ríkisins with permission from Loftmyndir ehf.

At the present day *Helgutjörn* is surrounded by a shrubby birch forest, in which the oldest trees are estimated by a dendrochronologist to be between 50-100 years old (Eggertsson, *personal communication* 2007). Currently, *Salix lanata* and *Salix phylicifolia* grow around the pond. *Ranunculus, Eriophorum angustifolium*, *Equisetum, poaceae, cariophyllacea, sphagnum* and *Rumex* can also be found growing around the pond.

Helgutjörn has one outlet and water enters from two springs by the bank in the southern end of the pond (Figure 4.3). The temperature of the water in those springs was measured 3,1°C and 2,5°C in the afternoon of a sunny day, while the air temperature was 10°C. The temperature in the center of the pond was at this same time 8,6°C and 13,6°C in the northern end close to the outlet. The deepest part of the pond is around 70 cm deep.

Figure 4.3 Looking north over *Helgutjörn* during a field trip in April 2008.

4.2 Field sampling

Two cores were taken in *Helgutjörn*. In June 2007 a core was obtained near the western bank of the pond, coring was continued as deep as possible. It was 316 cm long and was called the „Hóla" core. In April 2008 another core was retrieved from the pond and this time near the center using a small boat, coring was continued as deep as possible. It was 310 cm long and was called the „Helga" core.

For the coring, a 12 mm diameter, 1m long russian corer was used. Successive cores with 50 cm overlap were taken. The core was described in the field and all tephra layers were documented. The cores were then wrapped in plastic and placed in PVC tubes. The tubes were kept refrigerated at 3°C at all times after being brought to *Reykjavík*.

4.3 Laboratory sampling

From the „Hóla" core the following samples were taken.

- Pollen. 21 samples of volume 1 cm^3 were taken for pollen analysis every 10 cm from the top down to 200 cm. Due to problems in the chronology of the core these samples were not analyzed or used in this study and another batch of samples was obtained from the „Helga“ core in their place.

- ^{14}C. 9 samples where taken for ^{14}C analysis. See figure 5.3.

From the „Helga“ core the following samples where taken.

- Pollen. 22 samples of volume 2 cm^3 were taken for pollen analysis every 10 cm from the top down to 210 cm. These samples were analyzed and used for the study.

- Tephra. 13 small samples were taken for chemical analysis of chosen tephra layers. See figure 5.5.

4.4 Laboratory methods

4.4.1 Pollen preparation

Pollen was prepared as previously described by Erlendsson (2007), following the standard guidelines provided by Moore *et al* (1991)

1. Two *Lycopodium* tablets were placed in a centrifuge tube containing 10% HCl. One pollen sample was placed in a centrifuge tube each and stirred, after which they were centrifuged at 4000 rpm for 3 minutes and decanted. The samples were washed with distilled water, centrifuged and decanted. This process was repeated twice.

2. The tubes were then filled with NaOH, stirred and placed in a hot water bath in a fume cupboard for 10 minutes, stirring every 2 minutes.

3. The contents of the tube was emptied trough a sieve, mesh 180 μm, resting on a funnel sitting inside a centrifuge tube. The tube and the sieve was rinsed with distilled water, and sieve and contents discarded. The samples were centrifuged for 3 minutes at 4000 rpm. The samples were washed with distilled water, centrifuged and decanted. This process was repeated twice.

4. The tubes were then filled with 10% HCl, stirred and placed in a hot water bath in a fume cupboard for 10 minutes. Centrifuged for 3 minutes at 4000 rpm and decanted.

5. The tubes were then filled with 40% HF, stirred carefully and placed in a hot water bath in a fume cupboard for 20, stirring every 5 minutes. Centrifuged and decanted carefully into a beaker. HCl was then added to the tubes, stirred and placed into a hot water bath in a fume cupboard for 3 minutes, stirring every minute. Centrifuged and decanted. The samples were washed with distilled water, centrifuged and decanted. This process was repeated twice.

6. The tubes were filled with glacial acetic acid, stirred, centrifuged and decanted into a beaker. Acetolysis mixture was mixed in a dry measuring cylinder. The ration of the mixture was 9:1 acetic anhydride to conc. sulphuric acid (with the acid added to the acetic anhydride). The acetolysis mixture was added to the tubes until ½ full, stirred and boiled in water bath in fume cupboard for 2 minutes. Centrifuged and the contents were emptied into the beaker containing the glacial acetic acid. The contents of the beaker were carefully emptied down the sink in the fume cupboard and flushed with running water. Glacial acetic acid was added to the tube, stirred, centrifuged and decanted. The samples were washed with distilled water, centrifuged and decanted. This process was repeated twice.

7. The residue was washed with 95% ethanol, centrifuged and decanted. Then washed with absolute ethanol, centrifuged and decanted. A small amount of tertiary-butyl-alcohol was added to the sample, stirred and centrifuged at slow speed (approx 2000 rpm). Most of the alcohol was decanted and the pellet of pollen was transferred to a vial containing silicone (12,500 viscosity). The alcohol was allowed to evaporate at 60°C before it was mixed well with a small stirring rod.

4.4.2. Pollen analysis

Identification of pollen and spores was mainly done with the aide of a reference collection belonging to the Icelandic Natural Museum, an unpublished manuscript from Hallsdóttir, personal communication with Margrét Hallsdóttir and the pollen handbooks Faegri and Iversen (1989) and Moore *et al* (1991). Kristinsson (1998) and Mossberg & Stenberg (2006) were used as a reference on the Icelandic flora.

A Nikon Eclipse 50i high-powered light microscope was used for counting, using x400 or x600 magnification.

The size of *Betula* pollen was measured and those over 22,3 μm were counted as *B. pubescens* and those under as *B. nana*. This was based on Karlsdóttir *et al* (2007) but in Karlsdóttir *et al* (in press) the results show that age and type of sediment have an effect on the size of the *Betula* pollen grain. Based on this it was decided not to distinguish between *Betula pubescens* and *Betula nana* and all *Betula* pollen are categorized as *Betula undiff.* in the pollen diagrams.

4.4.3. Pollen data handling

The computer program TILIA 2 (Grimm 1993) was used to convert the dataset to percentages using the base sum of total land pollen. Percentage diagram and concentration diagram were made using TILIA 2 and TGView 2.0.2 (Grimm 2004).

4.5. ^{14}C-dates

4.5.1 Laboratory

Samples taken for ^{14}C analysis were analyzed in the Radiocarbon Dating Laboratory at Lund University, Sweden. The Radiocarbon Dating Laboratory in Lund base their analysis on Accelerator Mass Spectrometry (AMS).[1]

---

[1] http://www.geol.lu.se/c14/en/

4.5.2 Calibrating

The ^{14}C dates were calibrated using OxCal v4.0.5 Bronk Ramsey (2007) and IntCal atmospheric curve (Reimer *et al* 2004).

4.6. Tephrochronology

Tephrochronology is a valuable tool both in palaeoecological and archeological work in Iceland (Larsen 1996). Eruptions often produce enormous amounts of ash that cover large parts of Iceland. Many of those tephra layers are well known and have been dated using historical records, ice core records (Grönvold *et.al.* 1995), ^{14}C dating or using sedimentation rate calculations.

Tephra layers were identified in the core based on Larsen (1982) and Sigurgeirsson (2002). Samples were taken for chemical analysis to confirm the identification.

4.6.1. Important tephra layers

Here is a list of tephra layers of importance for this study.

Katla ~700 AD. This layer has not been dated accurately but based on tephrochronology from *Jökuldalur* valley, a neighboring valley to *Fljótsdalur* valley (Larsen 1982) it was dated to around 700 AD using sedimentation rate calculations (Larsen 2009, *personal communication*). The date will be refined in an ongoing research on tephra layers in the *Kárahnjúkar* area.

LNL 871±2 AD. This tephra layer is highly important in Iceland since it is considered to have fallen about the time Iceland was settled and is used as a marker for that event. This layer actually consists of two layers in some parts of the country, a white-yellow lower layer and a gray-green upper layer, but in other parts of the country only the upper layer is preserved (Larsen 1996). This layer has been dated in an ice core from Greenland to the year 871±2 AD (Grönvold *et. al.* 1995).

Veiðivötn 915±15 AD. This is not one of the better known tephra layers in Iceland but was described in *Jökuldalur* valley (Larsen 1982). Later this layer was dated to 915±15 using sedimentation rate calculations (Larsen, 2009, *personal communication*).

Katla 1262 AD. This eruption is reported in four old annals, they say great darkness so the sun disappeared came with this eruption (Þórarinsson 1975). The tephra from this eruption was carried to the north east (Larsen 2000).

Öræfajökull 1362 AD. This tephra originates from a catastrophic eruption in *Öræfajökull* in the year 1362. In this eruption a whole region, called *Litlahérað*, was devastated (Larsen and Thordarson 2007, Björnsson 1982).
A-layer 1477 AD. This tephra came from an eruption in *Veiðivötn* in the year 1477 and is one of the largest tephras deposited in Iceland in historical time, together with *Öræfajökull* 1362 and an eruption in *Eldgjá* (Thordarson and Larsen 2007). This is the thickest tephra found in the eastern part of the Iceland (Larsen 1982).

Askja 1875 AD. This was a large eruption with heavy ash fall all over the eastern part of the country. The eruption started in January 1875 (Sigvaldason 1982) and the tephra cover was up to 20 cm deep. After this eruption many poor farms in the already overpopulated eastern countryside were abandoned (Stefánsson 1952). This tephra is thick, white to yellow and very easily identified in the eastern part of Iceland.

4.6.2. Laboratory

Preparation and microprope analysis of tephra samples from the cores were carried out at the Department of Geography and Geology at Geocenter Danmark.

5 Results

5.1 Sediment stratigraphy

The „Hóla“ core (Figure 5.1) is 316 cm long. Its upper part is a rather homogeneous limnic sediment. At a depth of 210 cm the core cut through a birch log, 12 cm in diameter.

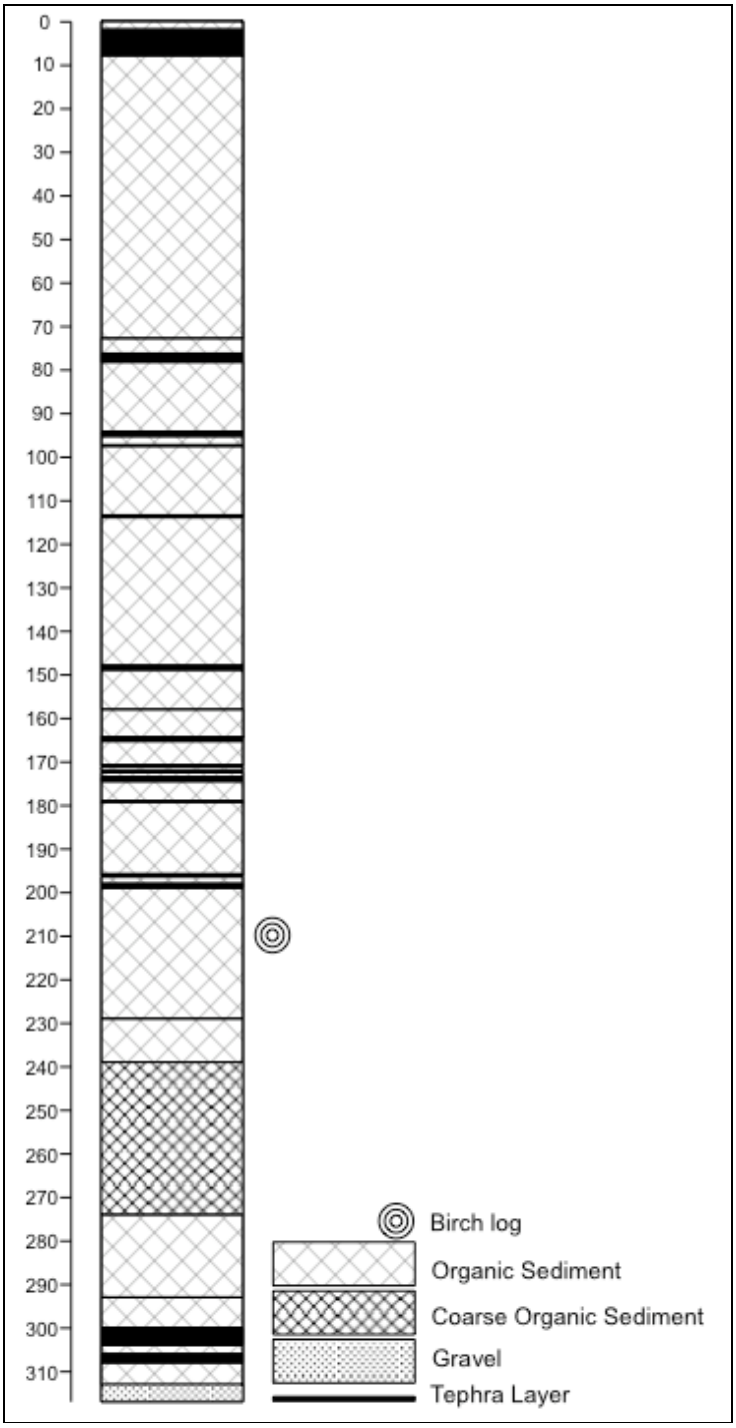


Figure 5.1 Sediment stratigraphy for „Hóla“ core

At a depth of 240 cm there is a layer of coarser dark brown organic material, possibly caused by a drying up of the pond, changing from lake sediment to peat formation. Under this layer the limnic sediment continues down to the bottom of the core were there is a gravel layer. This gravel layer represents the bottom of the sediment depression in which the pond is located. There are multiple tephra layers in the core. Quite a few of them were identified in the field but a tephra analysis was not done on this core.

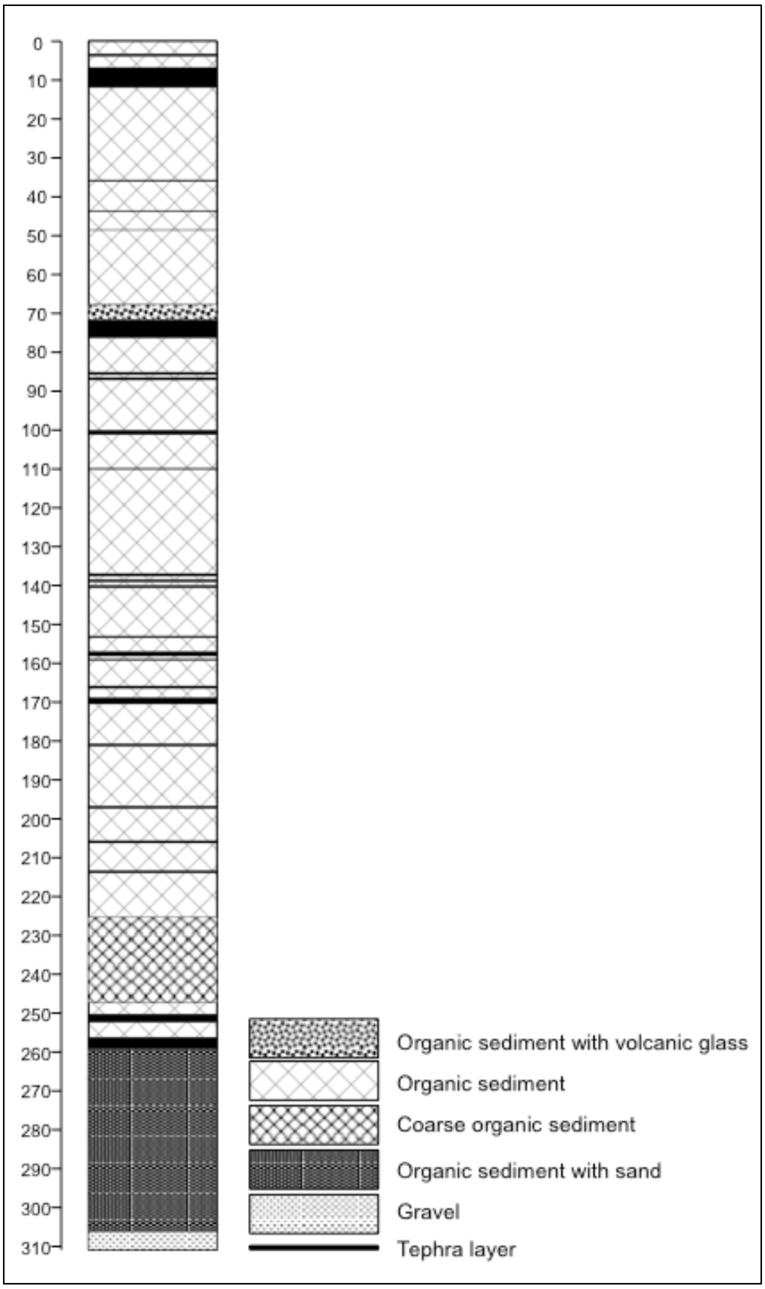


Figure 5.2 Sediment stratigraphy for „Helga“ core.

The „Helga“ core (Figure 5.2) is 310 cm long, it is similar to the „Hóla“ core and they could be linked together using the tephralayers. The upper part consists of homogeneous limnic sediment. It has the same layer of coarser organic material as the „Hóla“ core but it is some 15 cm higher in the core. In the lowest part the limnic sediment is mixed with sand. At the bottom there is the same gravel as in the „Hóla“ core, indicating that no older sediments can be found in this pond. However, the sediment record may extend further towards the present at the top of the „Helga” core than the sediments found in the „Hóla“ core. The „Helga“ core seems to contain a few more tephra layers than the „Hóla“ core. Many tephra layers were identified in the field and later confirmed by Guðrún Larsen (Larsen, 2008, *personal communication)*.

5.2 ^{14}C-dates

Nine samples were taken for ^{14}C analysis. Figure 5.3 shows the location of these samples and the material used for analysis from each location. All samples except for one were identified as macrofossils. All those samples gave a result except for the unidentified mixed organic material in sample *Hola 1.*

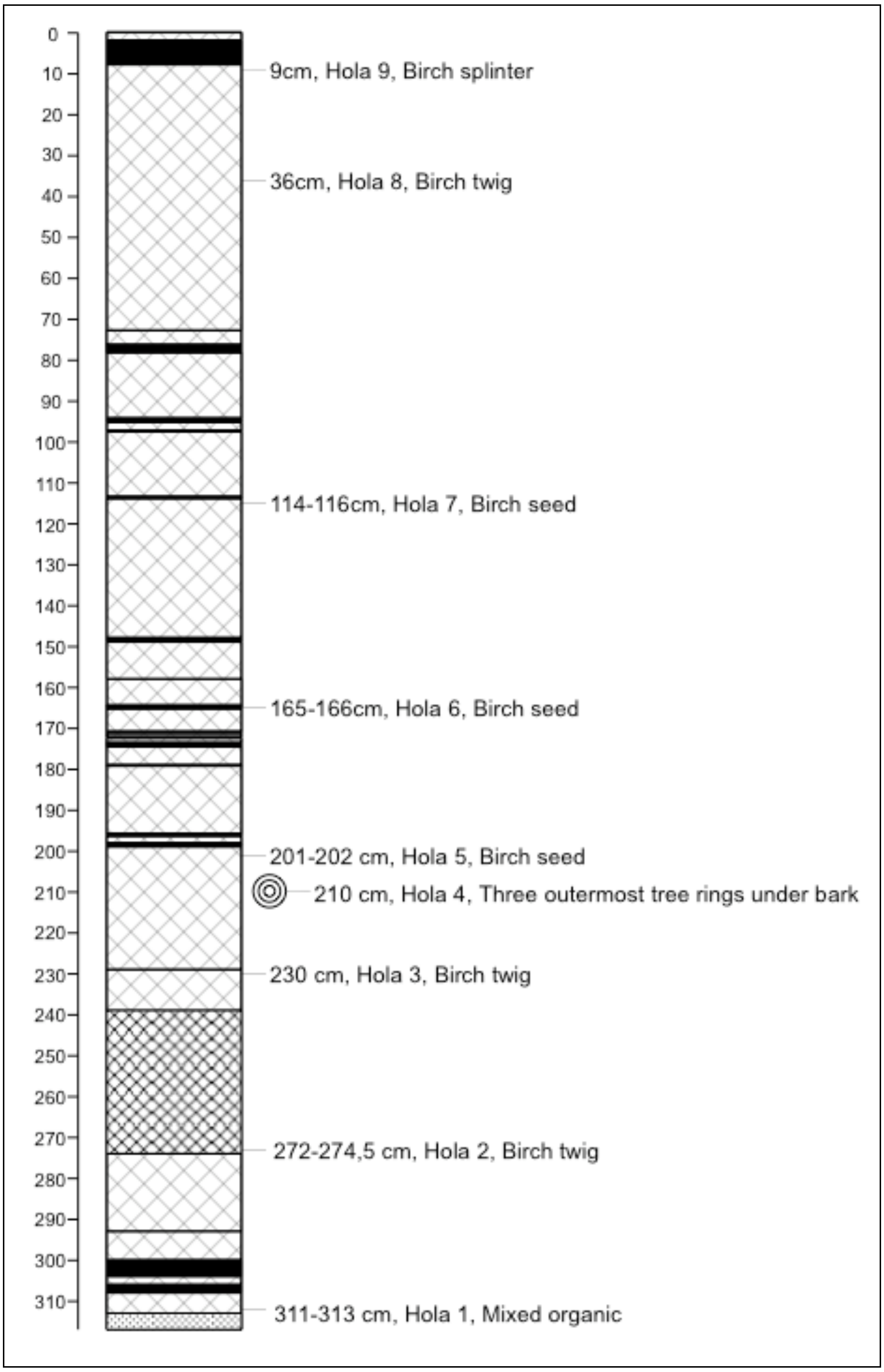


Figure 5.3 Samples taken from the „Hóla“ core for ^{14}C analysis.

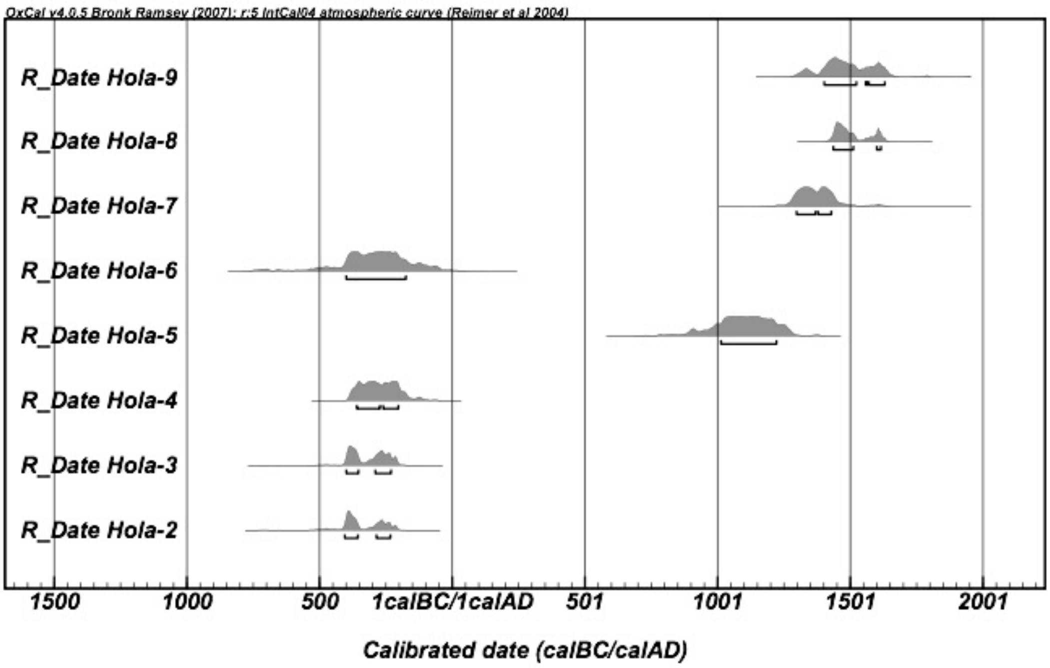


Figure 5.4 Calibrated ^{14}C dates.

In figure 5.4 the dates can be seen, calibrated on a BC/AD scale. All the dates can be found in the appendix 10.1. Since these dates do not give good enough results for constructing a chronology for the core, a decision was made to rely on tephrochronology instead.

5.3 Tephrochronology

5.3.1 Tephra identification

Tephra layers were identified in the field and based on laboratory advice from Guðrún Larsen, 14 tephra samples were taken from the „Helga“ core. Those samples were chemically analyzed. In figure 5.5 each sample is marked with a letter and identified tephra layers are labeled.

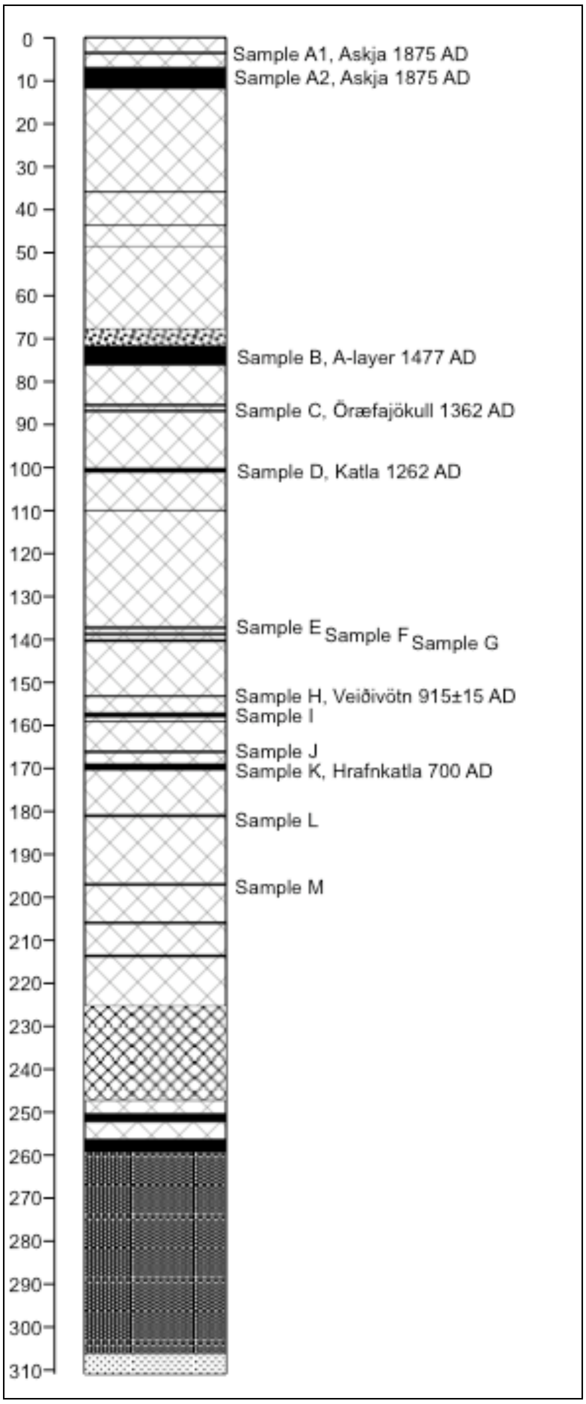


Figure 5.5 Tephra samples and known tephra layers.

At a depth of 3 cm in the core there is a thin black tephra layer, this tephra was at first thought to be from the eruption in *Grímsvötn* 1922 but chemical analysis gave the same chemistry as *Askja* 1875. This indicates that a runoff from the area around the pond must have brought it in after the original *Askja* 1875 layer was formed.

At the depth of 10 cm there is a 2 cm thick tephra layer, white to yellow in colour. This tephra layer was identified in the field as the *Askja* 1875 eruption. This is a well known tephra layer from this part of the country and easy to recognize. Later the chemical analysis proved this to be right.

This layer is followed by two unidentified thin black tephra layers.

Next there is a tephra layer at the depth of 75 cm. It is black, 3 cm thick and was identified in the field as the „A-layer“ from an eruption in *Veiðivötn* in the year 1477. This is also a well known tephra layer from this part of the country. The chemical analysis confirmed this identification.

At the depth of 87 cm there is a thin white to yellow tephra layer. Since most tephra layers are black those few white ones that are found are easily identified. This tephra layer was identified in the field as coming from the large eruption in *Öræfajökull* in the year 1362. This was later confirmed by chemical analysis. On top of this white layer there is a very thin black tephra layer that could not be identified.

There is a distinct black tephra layer at a depth of 101 cm. This tephra layer was not identified in the field but later identified in the lab as from the *Katla* 1262 eruption (Larsen, 2008, *personal communication*). This was later confirmed by chemical analysis.

At 110 cm depth there is an unidentified black tephra layer.

Next there are six black tephra layers, each considered to be a candidate for the LNL 871 layer (Grönvold *et al* 1995), sample E-J. None of those turned out to be the LNL tephra layer. Sample H had the same chemical signal as tephra layer 23 in Larsen (1982) and believed to be the same layer. This tephra comes from the same volcanic system as LNL, *Veiðivötn*, but from a different eruption. The tephra 23 has been dated to 915±15 (Larsen, 2009, *personal communication*) calculated from sedimentation rate.

At 170 cm depth there is a thick black tephra layer, not identified in the field but later in the laboratory it was identified as coming from an eruption in *Katla* 700 AD. The chemical analysis confirmed this.

Two more samples were taken, sample L and sample M. Sample L contained no volcanic glass indicating that the layer was not tephra at all but a layer of some darker organic matter. Sample M was taken from a black tephra layer at a depth of

198 cm believed to be from *Veiðivötn* 200 AD. The chemical analysis showed this sample to be from *Grímsvötn* and since there are multiple tephra layers from *Grímsvötn* below *Katla* 700 AD this tephra could not be identified further.

Interpretations of the chemical analysis can be found in table 5.1.

Sample	Level (cm)	Age (AD)	Origin of tephra	Volcanic system
A1	3	1875 reworked	Askja	Dyngjufjöll 1
A2	10	1875 original	Askja	Dyngjufjöll 1
Hb	75	1477	Veiðivötn	Veiðivötn/Dyngjuháls/Dyngjufjöll
Hc	87	1362	Öræfajökull	Öræfajökull
Hd	101	1262	Katla	Katla
He	138	??	??	??
Hf	139		Grímsvötn	Grimsvötn-Kverkfjöll
Hg	141	??	??	??
Hh	153	915±15	Veiðivötn	Veiðivötn/Dyngjuháls/Dyngjufjöll
Hi	158		Grimsvötn	Grimsvötn-Kverkfjöll
Hj	167		Grimsvötn	Grimsvötn-Kverkfjöll
Hk	170	700	Katla	Katla
Hl	181	N/D	N/D	N/D
Hm	198		Grimsvötn	Grimsvötn-Kverkfjöll

Table 5.1 Interpretation of the chemical analysis of tephra layers in the „Helga“ core.

The complete results from the chemical analysis can be found in Appendix 10.2.

5.3.2. Constructing tephrochronology

Using the tephra layers a good absolute chronology can be constructed for the core and based on this information a sedimentation model could be made. There is no „bottom“ date for the research since the believed *Veiðivötn* 200 AD tephra turned out to be wrong. There is also no exact position for the settlement in the core as LNL 871 was not identified in the core.

The exact timing of the settlement and the age of the oldest pollen samples needed to be calculated using the sedimentation rate.

The sedimentation rate between the 915±15 AD layer and 700 AD can be used to calculate an age for the oldest pollen samples. This calculation is likely to be an underestimate since the sedimentation rate usually increases after the settlement (Þórarinsson 1974). However, since only 44 years of this 215 year period are post settlement the error should be minimal. An age/depth model for the „Helga“ core can be seen in figure 5.6.

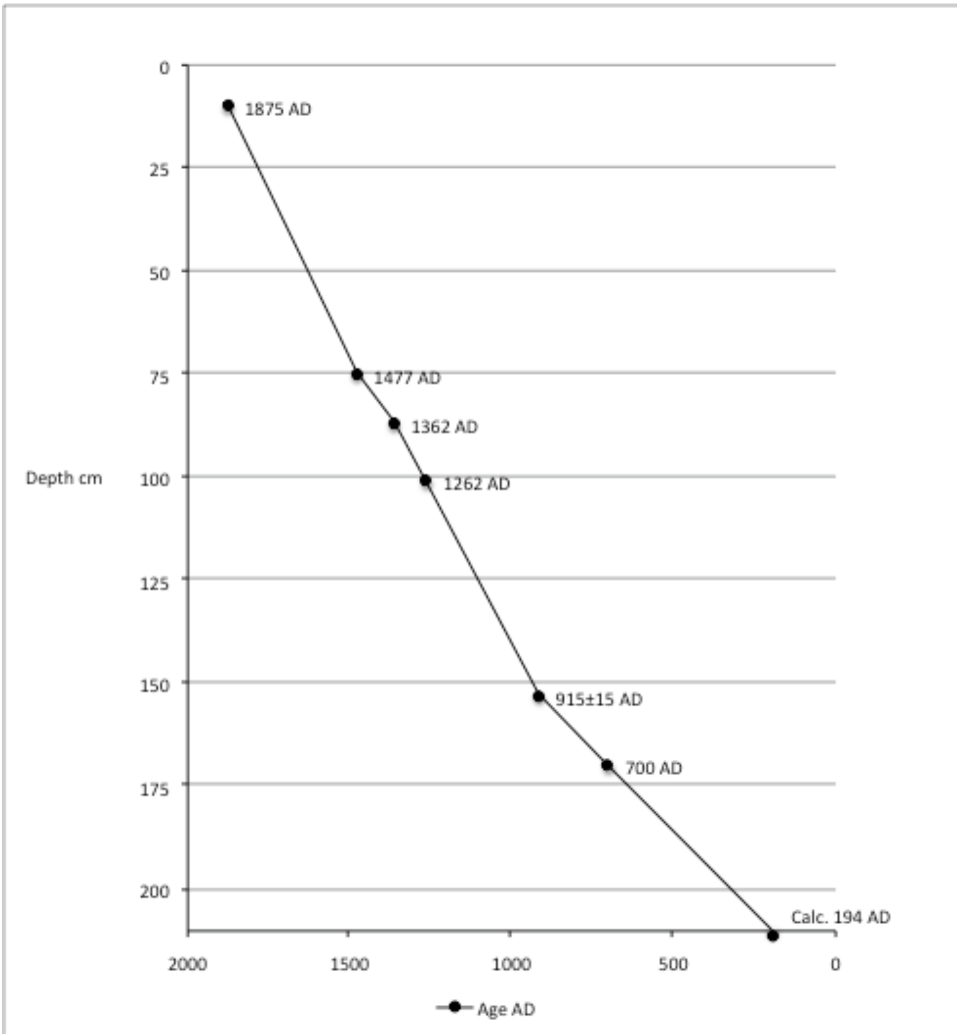


Figure 5.6 Age/depth model for the „Helga" core. The last date is calculated based on the sedimentation rate between 915±15 AD and 700 AD.

Using the same method, the core location of the settlement can also be calculated. If a constant sedimentation rate between 700 AD and 915±15 is used in the calculation, the settlement layer would be at a dept of 157 cm. However since a slower sedimentation rate can be assumed before the settlement than after the settlement it can be concluded that the country must have been settled some time between pollen sample 16, at 160 cm depth, and pollen sample 17, at 170 cm depth.

5.4 Pollen results

The pollen diagrams are shown in figure 5.7 and 5.8. Figure 5.7 is a percentage pollen diagram for *Helgutjörn* and figure 5.8 is a concentration diagram. Twenty-one samples were analyzed at 10 cm intervals starting from the top (depth 0 cm) continuing down to 210 cm depth. As mentioned in chapter 4.4.2, during the pollen analytical work all pollen grains over 22,3 μm were counted as *Betula pubescens* and those under as *Betula nana*. It was later decided not to distinguish between *Betula pubescens* and *Betula nana*. It should however be mentioned that most of the *Betula* pollen grains measured were around 22,3 μm. The pollen diagrams are divided into 6 pollen assembly zones as shown in figure 5.8, this was partly based on Coniss calculations with increased significance on *Betula* values.

5.4.1 Pollen assembly zones

- **PAZ 1.** The main characteristic of this zone is a high amount of *Betula* pollen. *Betula* pollen increases during the period with the highest concentration at the depth of 180 cm, then decreasing slightly at the top of the zone. There is not a large amount of *Salix* pollen in the zone and *Salix* seems to decrease at the same time as *Betula* increases. *Carex* follows the same pattern as *Betula*, increasing in the upper part of the zone. *Ericales undiff.* peak slightly in the middle of the zone as well as *Poaceae* and *Polypodiaceae*. *Ranunculus* type decrease at the same time as *Betula* increases. The total concentration of terrestrial pollen increases slightly in the latter half of the zone.

- **PAZ 2.** This zone represents a rather drastic fall in the amount of *Betula* pollen throughout the zone. In the first sample of the zone the amount of *Betula* decreases heavily. However, it increases again in the next sample but then decreases trough out the zone. *Salix* has a rather large peak in the middle of the zone and at the same time *Juniperus* and *Ericales undiff.* increase slightly. *Carex, Poaceae* and *Ranunculus* type all peak near the middle of the zone. *Lycopodium annotium* and *Polypodiacea* both have a big peak in the latter part of the zone. Total concentration of terrestrial pollen increases in the zone and peaks in the latter part of the zone.

- **PAZ 3.** This zone is mainly characterized by a low concentration in *Betula* pollen and a decrease in total pollen concentration throughout the zone. There are little changes in the amount of *Betula*, the concentration remains low throughout the zone. *Carex* and *Poaceae* increase slightly in the middle of the zone but decrease again while the *Ranunculus* type increase. As said before there is a continuous decrease in the total concentration of terrestrial pollen through the zone.

- **PAZ 4.** In this zone there is an increase in the amount of *Betula* pollen. In the first sample of the zone there is a big increase in *Betula* pollen but in the second sample *Betula* decrease. In the last sample *Betula* increases again. There is a low concentration of most other species except for the *Ranunculus* type. The *Ranunculus* type start with a rather high concentration in the beginning of the zone and increase with a peak in the latter part, then the concentration decreases again. The peak in the *Ranunculus* type is at the same depth as the low in *Betula* pollen concentration. The total concentration of terrestrial pollen stays low through the zone.

- **PAZ 5.** In this zone there is a steady decrease in *Betula* pollen reaching an all time low in the top of the zone. *Ericales undiff.* pollen concentration increases in the zone and reaches a peak in the middle, however it decreases again and is quite low in the top. There is a slight increase in *Carex* pollen concentration in the middle of the zone and the concentration of the *Ranunculus* type changes quite a lot and ends at a very low level. There is very little change in the total terrestrial pollen concentration through the zone.

- **PAZ 6.** This zone is characterized by a rapid increase in the concentration of *Betula* pollen. The pollen concentration of other species does not change to any significance in this zone. There is a slow increase in the total terrestrial pollen concentration in the zone.

5.4.2 Pollen diagrams

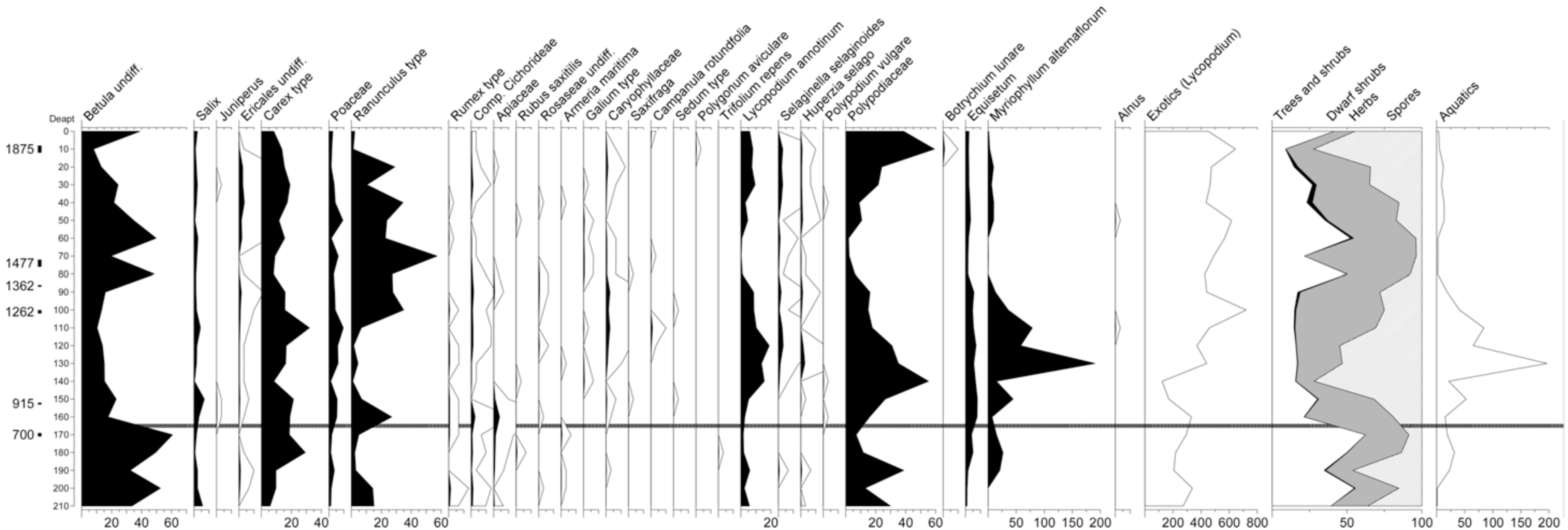


Figure 5.7 A percentage pollen diagram for *Helgutjörn*. The timing of the settlement is marked in with a thick line.

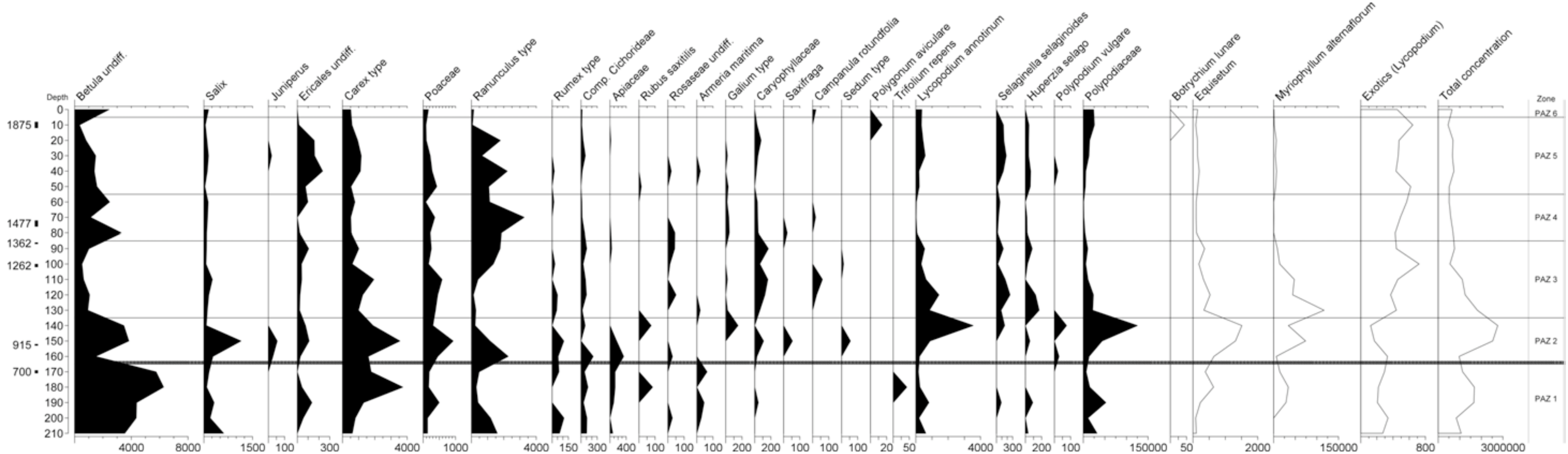


Figure 5.8 A concentration diagram for *Helgutjörn*. The timing of the settlement is marked in with a thick line.

6 Interpretation of the local vegetation history

- **PAZ 1. Pre-settlement era (ca. 190 AD – 870 AD).** Within this zone the area is covered with a birch forest that grows and increases during the period. There are some willow shrubs, mostly in the beginning but as the birch forest increases the shrubs decline. The *Ericales* dwarf shrubs come in as the willow shrubs decline but in the end the dwarf shrubs also have to give in to the tight birch forest. The herbs are changing, at first the *Ranunculus* type*s* are dominating, only to be overtaken by the grasses in the middle and sedge in the end.

- **PAZ 2. The Settlement era (ca. 870 AD – 1070 AD).** In this zone the birch forest starts to diminish and by the end of the zone the forest is quite limited. When the birch forest retreats, shrubs of both willow and juniper fill up the niche and the willow becomes quite widespread in the middle of the zone. However, the shrubs do lose ground eventually, with the juniper disappearing completely and the willow almost disappearing by the end of the zone. The dwarf shrubs also increase when the birch forest diminishes. The dwarf shrubs decrease again in the end of the zone but they hold out longer than the shrubs. The herbs gain from opening up of the area and get quite widespread in the middle of the zone only to decline at the end of the zone. By the end of the zone the area was probably only scarcely vegetated.

- **PAZ 3. High Middle Ages (ca. 1070 AD – 1430 AD).** During this period there is hardly any birch forest in the area to speak of. Shrubs are hardly existing and dwarf shrubs quite scarce. The vegetation is dominated by sedge and grass until in the end of the zone when the *Ranunculus* types take over. Overall, the vegetation cover is decreasing during the period.

- **PAZ 4. Late Middle Ages (ca. 1430 AD – 1630 AD)** In this period the birch forest gains foot again in the area. Birch is now growing around the pond and dominating the vegetation. The *Ranunculus* types also have a strong position in the undergrowth and probably in the pond. In the middle of the zone there is a thick tephra fall in the area. This slows down the growth of birch and the

Ranunculus types increase their cover when the landscape opens up. However, the birch recovers following the tephra fall and gains again its position at the cost of the *Ranunculus* types by the end of the zone.

- **PAZ 5. The coldest part of the Little Ice Age (ca. 1630 AD – 1900 AD).** The character of this period is a slow but constant retreat of the birch forest and by the end of the period the forest has almost completely disappeared from the area. The area is opening up giving way for the lower plants. At the same time the dwarf shrubs cover the area with sedge and the *Ranunculus* types.

- **PAZ 6. The 20th Century (ca. 1900 AD – 1940 AD).** In this period the birch forest is starting to grow back and gain a dominating role in the vegetation. The dwarf shrubs disappear from the area.

7 Discussion

7.1 Chronological difficulties

It is difficult to explain the problems encountered in the ^{14}C dating. There are a few different ways to get erroneous results in ^{14}C dates and in this case there seem to have been more than one.

The three lowest samples, *Hola 2, Hola 3, Hola 4*, all seem to have nearly the same age, about 300 BC. The sample *Hola 6* gives about the same age as these three. However, *Hola 5* gives an age close to 1100 AD. The two highest samples, *Hola 9* and *Hola 8,* both seem to have the same age, around 1500. The sample below them, *Hola 7,* gives a slightly higher age.

It must be assumed that all those samples giving an age around 300 BC must have been affected by the same error. They could have all been eroded from the same old material around the pond and brought in at a different time. This would explain the peculiarity of sample *Hola 5* which would then not be reworked in any way and would represent the true time of the sedimentation. The problem with this explanation is the fact that the materials sampled for the ^{14}C analysis where both macrofossils and an identified birch tree trunk. It is difficult to explain how a 12 cm diameter tree trunk could be eroded away and redeposit the same way as birch seed and twigs.

Another explanation could be that all those samples were affected by the ground water flowing in the pond, called *hard water effect* (Lowe and Walker 1997, Bradley 1999). If this explanation is used the only way to explain the age of samples *Hola 5* and *Hola 6* is to assume they got mixed up sometime during the dating procedure although it seems unlikely. The problem with this explanation is that hard water effect is only described on limnic organisms and in this incident the samples were either identified birch macrofossils or an identified birch megafossil. Further research is needed to determine if hard water effect is possible on non-limnic organisms.

It is easer to explain the other samples, *Hola 9, Hola 8* and *Hola 7*. If the ages are assumed to have fallen close to the error margin and not necessarily in the middle of the time span of each date it can be argued that they are correct. The first two dates, *Hola 9* and *Hola 8* are both a little too old. On the other hand *Hola* gives slightly too young an age.

Over all it can be concluded that ^{14}C dating is not accurate enough to base the age model on, even though in this research an AMS method was used on identified macrofossils that are less prone to contamination than the conventional bulk analysis (Bradley 1999, Lowe and Walker 1997).

7.2 Pre-settlement vegetation development

Since the settlement of Iceland is well documented and has been linked to a rather well known tephra layer, Iceland offers unique opportunity for investigation on vegetation development without the influence of man. This investigation focused mainly on the effect of man on the vegetation, however it is important to establish a good picture of the pristine pre-settlement vegetation.

Pollen assembly zone 1 (PAZ 1) represents the vegetation before the settlement. It is interesting to see that the birch cover seems to be increasing through this zone. This increase seems, however to have culminated just before the settlement. This is in very good agreement with the results of Hallsdóttir (1987), however the results of Erlendsson (2007) do not show this trend.

This would indicate that birch was well established in the area by the time of the settlement, although this research does not extend far enough back in time to identify the often reported cooling around 3300 - 2500 BP (Ólafsdóttir and Guðmundsson 2002, Wastl et al 2001, Norðdahl et al 2008) at this site.

7.3 The settlement and post-settlement period until 1300

The immediate effect of the settlement is a steady decline in the birch forest and increase in the sedimentation rate. Even though this birch decline is perhaps not as rapid as reported by Hallsdóttir (1987), it is still relatively rapid. By the year 1070, according to the sedimentation model, the forest around the pond has almost disappeared. This is interesting when it is considered that the *Helgutjörn* pond is not in close vicinity of the *Hallormsstaður* farm but up in the mountainside (Figure 4.2). Before the forest around the pond would be cut for fuel or burned down to clear fields for easier grazing, the forest around the farm would probably have been used. Erlendsson (2007) did a study on *Breiðatjörn*, in *Reykholtsdalur* valley, which is in comparably distant from the surrounding farms, 1-1,5 km, as *Helgutjörn*. Around *Breiðatjörn* the birch forest lingered into the late Middle Ages.

It is possible that the forest around *Breiðatjörn* was preserved late into the middle ages not because of the distance from the surrounding farms but because it was managed and the use of it was controlled (Vésteinsson and Simpson 2004). The forest around *Helgutjörn* was not needed in the same manner since other forest patches were available in *Fljótsdalshérað,* as can be seen from the old *Máldagi*. These patches still existed in the 19th century even though they were reported to be small and damaged.

Once the forest has retreated around the year 1070 the vegetation continues to diminish in the area, probably due to erosion and/or overgrazing until the end of PAZ 3.

7.4 The late Middle Ages birch re-advance

Around the year 1430, according to the sedimentation model, there is a distinctive increase in the amount of *Betula* pollen. A similar increase in *Betula* has been seen in other pollen studies (Erlendsson 2007, Lawson *et al* 2007, Hallsdóttir 1987) but in all of those other incidents the increase was a lot less than in *Helgutjörn*. Erlendsson (2007) and Lawson *et al* (2007) explain this by an increase in erosion that brings old pollen into the site.

This could also be the case in *Helgutjörn*, but to get a clearer view on this an additional proxy would be needed to determine the amount of reworked material coming into the pond. A loss of ignition analysis coupled with magnetic susceptibility measurement would yield additional information on the matter. However, other explanations are possible on this. It is logical to expect an error when increased birch cover is measured during a cooling trend in a totally birch free area. There were forests in *Fljótsdalur* around 1430 according to the historical sources and there is no reason to disbelieve the pollen record. The number of damaged pollen grains is often considered to be an indicator of reworked old pollen being brought into the site. No increase in the number of damaged *Betula* pollen was observed during this period in *Helgutjörn*.

The most logical explanation for a re-advance of birch is that the forest use has changed and although this is during a cooling period (Geirsdóttir *et al* 2009, Axford *et al* 2009) the climate is not the dominating factor. Although it was expected, there did not seem to be a connection between the number of grazing animals and the condition of the forest. However, the Black Death came to Iceland in the year 1402, with fatalities speculated to be as high as 45% of the total population of Iceland (Ísberg 1997). Jón Steffensen has reported as many as 10 epidemics of bubonic plague during the period from 1430 until 1707 (Steffensen 1975). This drastic decrease in the population of the nation must have had some effect on the exploited land. Another factor that came in during the same time is the import of iron. It is believed that once imported, cheap iron of good quality was available in Iceland during the 15th century, the production of bog-iron was discontinued. Although charcoal was still being made from shrubby birch until the 19th century (Eyjólfsson 1894, Gunnarsson 1872, Jónsson 1955), the fact that the extremely energy-consuming iron production was stopped must have meant drastic change in the use of forests.

The main difference between *Fljótsdalshérað* and those other investigated sites (Erlendsson 2007, Lawson *et al* 2007, Hallsdóttir 1987) is the fact that the forest in *Fljótsdalshérað* did not go extinct before the 15th century population decrease occurred. The remaining forest in *Fljótsdalshérað* supplied the re-advance with seeds, however since no birch trees remained at the other sites a re-advance was impossible.

7.5 The forests in *Fljótsdalshérað* during the coldest part of the Little Ice Age

Through most of the period usually called the Little Ice Age the forest around *Helgutjörn* is lingering. It is not until the 1750s, according to the sedimentation model, that the *Betula* pollen starts to dwindle and reaches an all time low after the fall of the 1875 tephra. It is rather remarkable how well this consists with the historical record. Gunnar Sigurðsson wrote in his report about the history of the forests in *Fljótsdalshérað* that the big forests started to fall in the 1750s.

Both from the historical and from the palynological evidence we can conclude that by the end of the 19th century the forests in *Fljótsdalshérað* were on the edge of being extinct. The fact that people started to show interest for the forests in the latter part of the 19th century and finally decided to completely protect the forest in the land of *Hallormsstaður* in the beginning of the 20th century probably saved the forests in *Fljótsdalshérað* from total extinction. Also there was a drastic change towards warmer climate at the turn of the century.

It is perhaps difficult to determine with any precision which of the two major factors was the dominating one in the salvation of the forests in *Fljótsdalshérað*. However, based on the effect the declining population and cessation of iron production had in the 15th century one can wonder if the human effect was indeed not the most important factor in the 19th and the 20th as in the 14th and the 15th centuries.

7.6 The influence of tephra fall on the forests in *Fljótsdalshérað*

According to the historical record it was mainly the influence of tephra fall that damaged the forests in *Fljótsdalshérað*. Since no research has been done in Iceland on the effect of tephra fall on birch forests other studies have to be examined. The effect of tephra fall on conifer tress has been studied both on Mount St. Helen in the United States (Hinckley *et al* 1984, Yamaguchi 1985) and Volcán de Fuego de Colima in Mexico (Biondi *et al* 2003). All of these studies report a reduction in the growth, both in diameter growth and height growth. Furthermore, there is a strong relationship between the thickness of the tephra layer and the reduction in growth. Yamaguchi even reports that thickness and grain size of the tephra layer controls if trees will survive at all. However it should be noted that in that incident the thickness of the tephra layers varied from 30 to 130 cm, which is far more than can be found in *Helgutjörn*.

Furthermore, it can be expected that the effect of tephra fall on broad-leaved trees like birch is different, especially if the tephra fall takes place outside of the growing season.

When considering descriptions of the tephra fall from the 1755 eruption in *Katla*, inconsistencies are evident. Sigurður Gunnarsson had been told by older inhabitants of *Fljótsdalshérað* how the leaves of the trees shriveled up and fell off due to the tephra fall. However, this cannot be true since the eruption of *Katla* in the year 1755 started the 17th of October and even though the eruption is believed to have lasted for 4 months (Larsen 2000) the tephra should never have affected the leaves of the forest.

It should also be considered that no tephra was found in the core at this depth that could correlate to this eruption. On the other hand, the thickest tephra fall in this part of Iceland in historical time, and indeed the thickest tephra layer found in this core, is the A-layer, from the 1477 eruption in *Veiðivötn*. This tephra fall did have an effect on the birch forest, both the concentration values and the percentage of *Betula* was lower just after the tephra fall. This effect is however not long lasting and at the next sample the percentage value of *Betula* is the same as before the tephra fall, the concentration value is a little lower after the tephra fall than before.

The account given to Sigurður about the 1755 tephra fall must either be some kind of a misunderstanding or even a reconstruction of the truth. The people who were destroying the forests with overuse and ill treatment either did not want to admit it to themselves or to the enthusiastic forest researcher Sigurður. According to Sæmundur Eyjólfssons account people at the end of the 19th century did not try to deny the fact that the forests were being destroyed by human activity.

7.7 How do the historical and palynological records compare?

When considering how the historical and palynological record compare, two different answers appear. In the first place the historical sources gives good information on the condition of the forest in *Fljótsdalshérað* at different times as far as that goes. The main point is that the written descriptions of the forests only go back to the middle of the 18th century. However, the timing of the decline of the forests is in good agreement with the pollen record. Also, the pollen record agrees with the written record on how the forest continued to decline until the end of the 19th century.

On the other hand, the historical records give incorrect information on the reason for the mid 18th century decline. This inaccuracy is to be expected since the source was written more than 100 years after events took place. When judging historical sources it is considered necessary to have first hand descriptions of the events. In the same manner the Icelandic sagas can only be considered as the perception of 13th century people of life in the 9th and 10th century.

Considering this it must be said that the historical records hold very well up against the palynological record.

8 Conclusions

1. The forests in *Fljótsdalshérað* appear to have been in their prime immediately prior to the settlement and had been advancing. However, the growth had culminated just before the settlement and the forests had started retreating slightly.

2. The forests in *Fljótsdalshérað* seem to react to the settlement in a similar way as in other sites in Iceland. There is a drastic fall in *Betula* immediately after the settlement and by the year 1070 the forests have retreated greatly and continues to decline slowly. However, something happens in the beginning of the 15th century that causes the forests to re-advance again. This re-advance is the main difference from what happens elsewhere in the country and is probably the main reason for the fact that forests in *Fljótsdalshérað* managed to survive into the 20th century. During a climatic cooling the forests get stronger, most likely due to reduced human effect. Later in the Little Ice Age the forests start to retreat again slowly and the retreat is accelerated by the mid 18th century with the forest reaching an all time low just before their protection by the end of the 19th century.

3. The historical record and the palynological record compare quite well for the forests in *Fljótsdalshérað*. The historical sources are accurate concerning the timing of major events during the time it covers, which is not very long. However, the explanation for forest retreat given in the historical record is inaccurate. This could be so for a number of reasons. The time from the actual events took place until the writing of the documents was too long for the source to be reliable. It is quite likely that the people that gave the account did not have good enough knowledge to understand the nature around them. It is also possible that people did not want to admit to themselves or to the enthusiastic forest researcher asking them, that it was their own fault that the forests were damaged.

4. It is difficult to determine the dominating factor in the retreat of the forests in *Fljótsdalshérað* and there could be different factors at different times. The drop in *Betula* pollen just after the settlement must be considered to be caused by human activity. This is further supported by the fact that in the 15th century when there is a drop in the in the population in Iceland and iron production ceases to a larger extent,

the birch advances even though this is during an era of climatic cooling. The dominating factor in the forest decline during the Little Ice Age is more difficult to determine. This was during the coldest period in the history of Iceland when famines where common. During a time of famine all the natural resources must have been used to the fullest, without a thought on the effect on the environment. Extreme exploitation during a period of the harshest climatic conditions recorded in Iceland was a combination the forests could not withstand. However, when considering that the human factor was enough to almost destroy the forests during a time of mild climate the human factor must be considered to have been the dominating one in the Little Ice Age as well. This research concurs with the conclusion of previous studies that pollen analysis cannot be used to construct a climate history after the settlement since the influence of man outweighs the effects of climate change.

Future studies should include a more thorough investigation of the increase in *Betula* pollen in the 15th century. This could determine if the *Betula* increase in *Fljótsdalshérað* is due to other influencing factors than those proposed for other investigated sites in Iceland showing the same trend. Also studies are needed on the effect of tephra fall on birch trees in Iceland.

9. References

Axford, Y., Geirsdóttir, Á., Miller, G. H. and Langdon, P. G. 2009: Climate of the Little Ice Age and the past 2000 years in northeast Iceland inferred from chironomids and other lake sediment proxies. In *Journal of Paleolimnology* 41. 7-24.

Ágústsson, H. 1989: Húsagerð á síðmiðöldum. In Líndal, S. (ed.) *Saga Íslands IV.* Hið íslenzka bókmenntafélag, Sögufélagið. Reykjavík. 261-300.

Árnason, S. 2000: Valþjófsstaðasókn 1840-1841. In *Múlasýslur: Sýslu og sóknarlýsingar Hins íslenska bókmenntafélags.* Sögufélag and Örnefnastofnun Íslands. Reykjavík. 129-155.

Biondi, F., Estrada, I. G., Ruiz, J. C. G. and Torres, A. E. 2003: Tree growth response to the 1913 eruption of Volcán de Fuego de Colima, Mexico. In *Quaternary Research* 59. 293-299.

Bjarnason, H. 1972-1973: Þættir um skóga á Austurlandi. *Ársrit Skógræktarfélags Íslands.* 21-26.

Björck, S. Ingólfsson, Ó. Hafliðason, H. Hallsdóttir, M. Anderson, H. J. 1992. Lake Torfadalsvatn: a high resolution record of the North Altantic ash zone I and the last glacial-interglacial environmental changes in Iceland. *Boreas* 21. 15-22.

Björnsson, S. 1982: „Lifði engin kvik kind eftir“?. In Þórarinsdóttir, H., Óskarsson, Ó.H., Steinþórsson, S. and Einarsson, Þ. (eds.) *Eldur er í norðri.* Sögufélagið. Reykjavík. 353-359.

Bradley, R. S. 1999: *Paleoclimatology: Reconstructing the Climates of the Quaternary.* Second edition. International Geophysics series, volume 68. Elsevier Academic Press.

Bronk-Ramsey, C. 2007: *Oxcal v4.0.5.* University of Oxford. Oxford. Downloaded from site: http://c14.arch.ox.ac.uk/embed.php?File=index.html

Caseldine, C. 2001: Changes in *Betula* in the Holocene record from Iceland-a palaeoclimatic record or evidence for early Holocene hybrydisation? *Review of Palaeobotany & Palynology* 117. 139-152.

Caseldine, C. Geirsdóttir, Á. Langdon, P. 2003: Efstadalsvatn – a multy-proxy study of a Holocene lacustrine sequence from NW Iceland. *Journal of Paleolimnology* 30. 55-73.

Caseldine, C. Landon, P. Holmes, N. 2006: Early Holocene climate varability and the timing and extent of the Holocene thermal maximum (HTM) in northen Iceland. *Quaternary Science Reviews* 25. 2314-2331.

Einarsson, M. Á. 1976: *Veðurfar á Íslandi.* Iðinn. Reykjavík.

Einarsson, Þ. 1957a: Frjógreining fjörumós úr Selatjörn. *Náttúrufræðingurinn* 26. 194-198.

Einarsson, Þ. 1957b: Tvö frjólínurit úr íslenzkum mómýrum. *Ársrit Skógræktarfélags Íslands.* 89-97.

Einarsson, Þ. 1962: Vitnisburður frjógreiningar um gróður, veðurfar og landnám á Íslandi. *Saga: Tímarit sögufélagsins* 24. 442-469.

Einarsson, Þ. 1963: Pollen-analytical studies on the vegetation and climate history of Iceland in late and post-glacial times. *North Atlantic biota and their history.* 355-365.

Eldjárn, K. 1974: Fornþjóð og minjar. In Líndal, S. (ed.) *Saga Íslands I.* Hið íslenzka bókmenntafélag, Sögufélagið. Reykjavík. 101-152.

Erlendsson, E. 2007: *Environmental change around the time of the Norse settlement of Iceland.*

Eyjólfsson, S. 1894: Ferð um Þingeyjarsýslu og Fljótsdalshjerað. In *Búnaðarrit* VIII. 1-73.

Faegri, K. and Iversen, J. 1989: *Textbook of Pollen Analysis.* Fourth edition. John Wiley & Sons. New York.

Fljótsdæla saga. 1950. in *Íslenzk Fornrit. XI. Bindi Austfirðinga Sögur.* Hið Íslenzka Fornritafélag. Reykjavík.

Geirsdóttir, Á., Miller, G. H., Thordarson, T. and Ólafsdóttir, K. B. 2009: A 2000 year record of climate variations reconstructed from Haukadalsvatn, West Iceland. In *Journal of Paleolimnology* 41. 95-115.

Grimm, E. C. 1993: *Tilia and Tilia.Graph 2*. Illinois State Museum. Springfield.

Grimm, E. C. 2004: *TGView 2.0.2*. Illinois State Museum. Springfield.

Grönvold, K., Óskarsson, N., 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.

Guðmundsson, G., Snæsdóttir, M., Simpson, I., Hallsdóttir, M., Sigurgeirsson, M. Á., Árnason, K. 2002-2003: Fornir akrar á Íslandi: Meintar minjar um kornrækt á fyrri öldum. In Snæsdjóttir, M. (ed.) *Árbók hins Íslenzka fornleifafélags.* Hið Íslenzka Fornleifafélag. Reykjavík. 79-106.

Guðmundsson, H. 2000. Hallormstaðasókn 1840. In *Múlasýslur: Sýslu og sóknarlýsingar Hins íslenska bókmenntafélags.* Sögufélag and Örnefnastofnun Íslands. Reykjavík. 311-317.

Gunnarsson, S. 1872: Skógur á Austurlandi milli Smjörvatnsheiðar og Lónsheiðar frá 1755 til 1870. In *Norðanfari* 29-30. 63-64. Downloaded from the Vestnord homepage *timarit.is*. At site: http://timarit.is/view_page_init.jsp?pubid=88&lang=is

Guttormsson, H., Blöndal, S. 2005. *Hallormstaður í Skógum: Náttúra og saga höfuðbóls og þjóðskógar.* Mál og menning. Reykjavík.

Hagstofa Íslands 2009: Lykiltölur mannfjöldans 1703-2009. Downloaded from the Statistics Iceland homepage *hagstofa.is*. At site: http://hagstofa.is/Hagtolur/Mannfjoldi/Yfirlit 30.4.2009

Hagstofa Íslands 1997: In Jónsson, G. and Magnússon, M. S. (eds.) *Hagskinna: Sögulegar hagtölur um Ísland.* Reykjavík.

Hallsdóttir, M. 1982: Frjógreining tveggja jarðvegssniða úr Hrafnkelsdal: Áhrif ábúðar á gróðurfar í dalnum. In Þórarinsdóttir, H., Óskarsson, Ó.H., Steinþórsson, S. and Einarsson, Þ. (eds.) *Eldur er í norðri.* Sögufélagið. Reykjavík. 253-265.

Hallsdóttir, M. 1987: *Pollen analytical studies of human influnce on vegetation in realation to the landnám tephra layer in southwest Iceland.*

Hallsdóttir, M. 1990: Studies in the vegetational history of North Iceland. A radioncarbon-dated pollen diagram from Flateyjardalur. *Jökull* 40. 67-81.

Hallgrímsson, H. 1994. Fáein orð um Sigurð Gunnarsson. In. *Glettingur* 4(1). 14-15.

Hálfdanarson, G. 1984: Mannfall í Móðuharðindum. In *Skaftáreldar 1783-1784: Ritgerðir og heimildir.* Mál og menning. Reykjavík. 139-162.

Hinckley, T. M., Imoto, H., Lee, K., Lacker, S., Morikawa, Y., Vogt, K. A., Grier. C. C., Keyes, M. R., Teskey, R. O. and Seymour, V. 1984: Impact of tephra deposition on growth in conifers: the year of the eruption. In *Canadian Journal of Forest Research* 14. 731-739.

Ísberg, J. Ó. 1997: Svartidauði, sóttir og fólksfjöldi. In *Sagnir: Tímarit um söguleg efni* 18. 91-97.

Íslendingabók . 1968: in *Íslenzk Fornrit. I. Bindi. Íslendingabók Landnámabók.* Hið Íslenzka Fornritafélag. Reykjavík.

Íslenzkt fornbréfasafn, fjórða bindi 1265-1449. 1897. Hið íslenzka bókmenntafélag. Kaupmannahöfn.

Íslenzkt fornbréfasafn, fimta bindi 1330-1476. 1899-1902. Hið íslenzka bókmenntafélag. Kaupmannahöfn.

Íslenzkt fornbréfasafn, tíunda bindi 1169-1542. 1911-1921. Hið íslenzka bókmenntafélag. Kaupmannahöfn.

Íslenzkt fornbréfasafn, tólfta bindi 1200-1554.1923-1932. Hið íslenzka bókmenntafélag. Kaupmannahöfn.

Íslenzkt fornbréfasafn, fimmtánda bindi 1567-1570. 1947-1950. Hið íslenzka bókmenntafélag. Kaupmannahöfn.

Jóhannesson, Þ. 1943: Járngerð. In Finnbogason, G. (ed.) *Iðnsaga Íslands II.* Iðnaðarmannafélagið í Reykjavík. Reykjavík. 40-58.

Jónsson, G. 1955. Sagnaþættir Guðmundar frá Húsey. In Bjarnason, Á. (ed.) *Að vestan, sagnaþættir og sögur. Fjórða bindi.* Bókaútgáfan Norðri. Akureyri.

Jónsson, J. 1906: *Gullöld Íslendinga: Menning og lífshættir feðra vorra á söguöldinni*. Reykjavík.

Jónsson, M. 1998: *Árni Magnússon: Ævisaga.* Mál og menning. Reykjavík.

Jörundsdóttir, S. H. 2006: Sauðfé frýs í hel að degi til í maí: Harðindin í Norður-Múlasýslu 1755-1759. In *Sjöunda landsbyggðarráðstefna Sagnfræðifélags Íslands og Félags þjóðfræðinga á Íslandi. Haldin á Eiðum 3-5 júní 2005. Ráðstefnurit.* Héraðsnefnd Múlasýslna og Sagnfræðingafélag Íslands. Egilsstöðum. 55-61.

Karlsdóttir, L., Thórsson, Æ.T., Hallsdóttir, M., Sigurgeirsson, A., Eysteinsson, T., Anamthawat-Jónsson, K. 2007: Differentiating pollen of *Betula* species from Iceland. *Grana* 46, 78-84.

Karlsdóttir, L., Hallsdóttir, M., Thórsson, Æ. Th., Anamthawat-Jónsson, K. In press: Evidence of hybridisation between *Betula pubescens* and *B. nana* in Iceland during the early Holocene. *Review of Palaeobotany and Palynology*.

Karlsson, F.N., Gíslason, I., Pálsson, P. 2000: Inngangur. In *Múlasýslur: Sýslu og sóknarlýsingar Hins íslenska bókmenntafélags.* Sögufélag and Örnefnastofnun Íslands. Reykjavík. VII-XV

Karlsson, G. 1975: Frá þjóðveldi til konungsríkis. In *Saga Íslands II*. Reykjavík. 3-54.

Kristinsson, H. 1998: *Plöntu handbókin: Blómplöntur og byrkingar.* Mál og menning. Reykjavík.

Landmælingar Íslands 2009a: Ókeypis kort. Downloaded from the National Land Survey of Iceland homepage *lmi.is*. At site: http://lmi.is/pages/kort/okeypis-kort/okeypis-kort/ 5.5.2009.

Landmælingar Íslands 2009b: Atlaskort. Downloaded from the National Land Survey of Iceland homepage *lmi.is*. At site: http://atlas.lmi.is/atlaskort/ 5.5.2009.

Landmælingar Íslands 2009c: Kortaskjár - IS 50V. Downloaded from the National Land Survey of Iceland homepage *lmi.is*. At site: http://atlas.lmi.is/is50v/ 8.5.2009.

Larsen, G. 1982: Gjóskulagatímatal Jökuldals og nágrenis. In Þórarinsdóttir, H., Óskarsson, Ó.H., Steinþórsson, S. and Einarsson, Þ. (eds.) *Eldur er í norðri.* Sögufélagið. Reykjavík. 51-65.

Larsen, G. 1996: Gjóskutímatal og gjóskulög frá tíma norræns landnáms á Íslandi. In Grímsdóttir, G.Á. (ed.) *Um landnám á Íslandi – fjórtán erindi.* Vísindafélag Íslendinga. Reykjavík. 81-106.

Larsen, G. 2000: Holocene eruptions within the Katla volcanic system, south Iceland: Characteristics and environmental impact. *Jökull* 49. 1-28.

Larsen, G. and Thordarson, T. 2007: Volcanism in Iceland in historical time: Volcano types, eruption styles and eruption history. In *Journal of Geodynamics* 43. 118-152.

Lawson, I. T., Gathorne-Hardy, F. J., Church, M. J., Newton, A. J., Edwards, K. J., Dugmore, A. J. and Einarsson, Á. 2007: Environmental impacts of the Norse settlement: palaeoenvironmental data from Mývatnssveit, northern Iceland. In *Boreas* 36. 1-19

Laxness, E. 1998a. *Íslandssaga – I. bindi a-h*. Vaka-Helgafell. Reykjavík. 2. útgáfa.

Laxness, E. 1998b. *Íslandssaga - II. bindi i-r.* Vaka-Helgafell. Reykjavík. 2. útgáfa.

Lowe, J. J., and Walker, M. J. C. 1997: *Reconstructing Quaternary Environments. Second edition.* Person Education Limited. Harlow, England.

Moore, P. D., Webb, J. A. and Collinson, M. E. 1991: *Pollen Analysis.* Second edition. Blackwell Science. Oxford.

Mossberg, B. and Stenberg, L. 2006: *Svensk Fältflora*. Wahlström & Widstrand. Stockholm.

Norðdahl, H., Ingólfsson, Ó., Pétursson, H. G. and Hallsdóttir, M. 2008: Late Weichselian and Holocene environmental history of Iceland. In *Jökull* 58. 343-364.

Ogilvie, A. E. J. 1991: Climatic changes in Iceland A.D. c. 865 to 1598. In *Acta Archaeologica* 61. 233-251.

Ogilvie, A. E. J. 1995: Documentary evidence for changes in the climate of Iceland, A.D. 1500 to 1800. In Bradley, R. S. and Jones, P. D. (eds.) *Climate since A.D. 1500*. London, New York. 92-117.

Olavius, Ó. 1965: *Ferðabók: Landshagir í norðvestur-, norður- og norðaustursýslum Íslands 1775-1777, ásamt ritgerðum Ole Heckels um brennistein og brennisteinsnám og Christian Zieners um surtarbrand*. Bókfellsútgáfan. Reykjavík. II volume.

Ólafsdóttir, R. and Guðmundsson, H. J. 2002: Holocene land degradation and climatic change in northern Iceland. In *The Holocene* 12,2. 159-167.

Ólafsson, B. 1968: Mannfall í harðindunum 1751-1758. In *Mímir* 7. Reykjavík. 13-19.

Ólafsson, E. 1974: *Ferðabók Eggerts Ólafssonar og Bjarna Pálssonar um ferðir þeirra á Íslandi árin 1752-1757.* Bókaútgáfan Örn og Örlygur. II volume.

Pálsson, G. 1948: Skógar á Fljótsdalshéraði fyrrum og nú. *Ársrit Skógræktarfélags Íslands*. 64-79.

Pálsson, G. 2000: Vallanessókn 1840. In *Múlasýslur: Sýslu og sóknarlýsingar Hins íslenska bókmenntafélags.* Sögufélag and Örnefnastofnun Íslands. Reykjavík. 295-310.

Reimer, P.J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Bertrand,C. J. H., Blackwell, P. G., Buck, C. E., Burr, G. S., Cutler, K. B., Damon, P. E., Edwards, R. L., Fairbanks, R. G., Friedrich, M., Guilderson, T. P., Hogg, A. G., Hughen, K. A., Kromer, B., McCormac, G., Manning, S., Ramsey, C. B., Reimer, R. W., Remmele, S., Southon, J. R., Stuiver, M., Talamo, S., Taylor, F. W., van der Plicht, J. and Weyhenmeyer, C. E. (2004). Intcal04 Terrestrial Radiocarbon Age Calibration, 0-26 cal kyr BP. In *Radiocarbon* 46,3. 1029-1059.

Rundgren, M. 1995: Biostratigraphic Evidence og the Allerød-Younger Dryas-Preboreal Oscillation in Northen Iceland. *Quaternary Research* 44. 405-416.

Rundgren, M. 1997: Early-Holocene vegetation of the northern Iceland: pollen and plant macrofossil evidence from the Skagi peninsula. *The Holocene* 8. 553-564.

Rundgren, M. Ingólfsson, Ó. 1999. Plant survival in Iceland during periods of glaciation? *Journal of Biogeography 26.* 387-396.

Sigurðardóttir, K. H. 2004: Provenance studies of iron from Iceland. In Guðmundsson, G. (ed.). *Current Issues in Nordic Archaeology: Proceedings of the 21st Conference of Nordic Archaeologists, 6-9 September 2001, Akureyri, Iceland.* Society of Icelandic Archaeologists. Reykjavik. 119-123.

Sigurgeirsson, M. Á. 2002: Skriðuklaustur í Fljótsdal – fornleifarannsókn 2002: Gjóskulagagreining. *Greinargerð 03/2002*. 1-2.

Sigvaldason, G. E. 1982: Samspil vatns og kviku: Öskugosið 1875. In Þórarinsdóttir, H., Óskarsson, Ó.H., Steinþórsson, S. and Einarsson, Þ. (eds.) *Eldur er í norðri.* Sögufélagið. Reykjavík. 37-49.

Stefánsson, H. 1952: Þættir úr sögu austurlands á 19. öld. In Stefánsson, H., Vilhjálmsson, B. and Ólafsson, J. (eds.) *Austurland: Safn austfirzkra fræða*. Norðri. Akureyri. IV Bindi.

Stefánsson, H. 1958: Saga austurlands 930-1800. In Stefánsson, H., Vilhjálmsson, B. and Ólafsson, J. (eds.) *Austurland: Safn austfirzkra fræða*. Norðri. Akureyri. V Bindi.

Steffensen, J. 1975: Fólksfjöldi á Íslandi í aldanna rás. In *Menning og meinsemdir: Ritgerðasafn um mótunarsögu íslenzkrar þjóðar og barátta hennar við hungur og sóttir.* Sögufélagið. 434-449.

Thorarinsson, S. 1944: *Tefrokronologiska studier på Island: Þjórsárdalur och dess föröndelse*. Ejnar Munksgaard. Köbenhavn.

Thordarson, T., Larsen, G. 2007: Volcanism in Iceland in historical time: Volcano types, eruption styles and eruptive history. *Journal of Geodynamics* 43, 118-152.

Veðurstofa Íslands 2009: Tímaraðir fyrir valdar veðurstöðvar. Downloaded from the Icelandic Meteorological Office homepage *vedur.is*. At site: http://vedur.is/vedur/vedurfar/medaltalstoflur/ 3.5.2009.

Vésteinsson, O., Simpson, I.A., 2004: Fuel utilisation in pre-industrial Iceland. A micro-morphological and historical analysis. In Guðmundsson, G. (ed.). *Current Issues in Nordic Archaeology: Proceedings of the 21st Conference of Nordic Archaeologists, 6-9 September 2001, Akureyri, Iceland.* Society of Icelandic Archaeologists. Reykjavik. 119-123.

Wastl, M., Stötter, J. and Caseldine, C. 2001: Reconstruction of Holocene variations of the upper limit of tree or shrub birch growth in Northern Iceland based on evidence from Vesturárdalur-Skíðadalur, Tröllaskagi. In *Arctic, Antarctic and Alpine Research,* 33, 2. 191-203.

Yamaguchi, D. K. 1985: Tree-ring evidence for a two-year interval between recent prehistoric explosive eruptions of Mount St. Helens. In *Geology* 13. 554-557.

Þórarinsson, S. 1955: Nákuðungslög við Húnaflóa í ljósi nýrra aldursákvarðana. *Náttúrufræðingurinn* 25, 172-186.

Þórarinsson, S. 1974: Sambúð lands og lýðs í ellefu aldir. In Líndal, S. (ed.) *Saga Íslands I.* Hið íslenzka bókmenntafélag, Sögufélagið. Reykjavík. 29-97.

Þórarinsson, S. 1975: Katla og annáll Kötlugosa. In Jónsson, P. (ed.) *Árbók Ferðafélags Íslands.* 125-149. Ferðafélag Íslands.125-149.

Þórarinsson, Þ. 1980: Ísarns meiður á Eiðum. *Múlaþing* 10. 31-55.

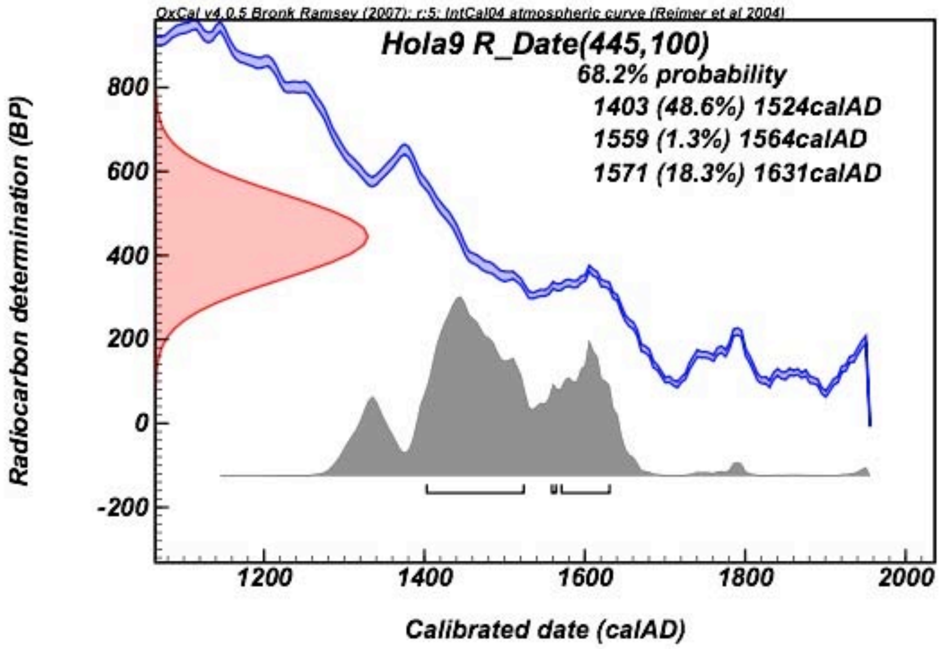
Þórðarson, S. 1955: Úr sögu skóga á Austurlandi. In *Árbók Skórœktarfélag Íslands.* 19-30.

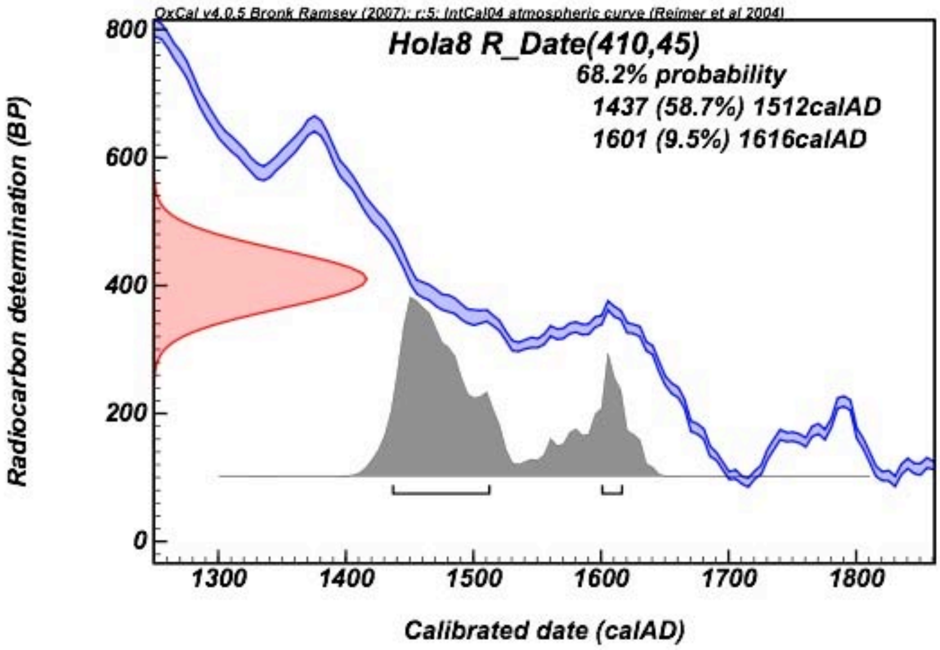
Þórðarson, M. 1943: Málmsmíði fyrr á tímum. In Finnbogason, G. (ed.) *Iðnsaga Íslands II.* Iðnaðarmannafélagið í Reykjavík. Reykjavík. 254-335.

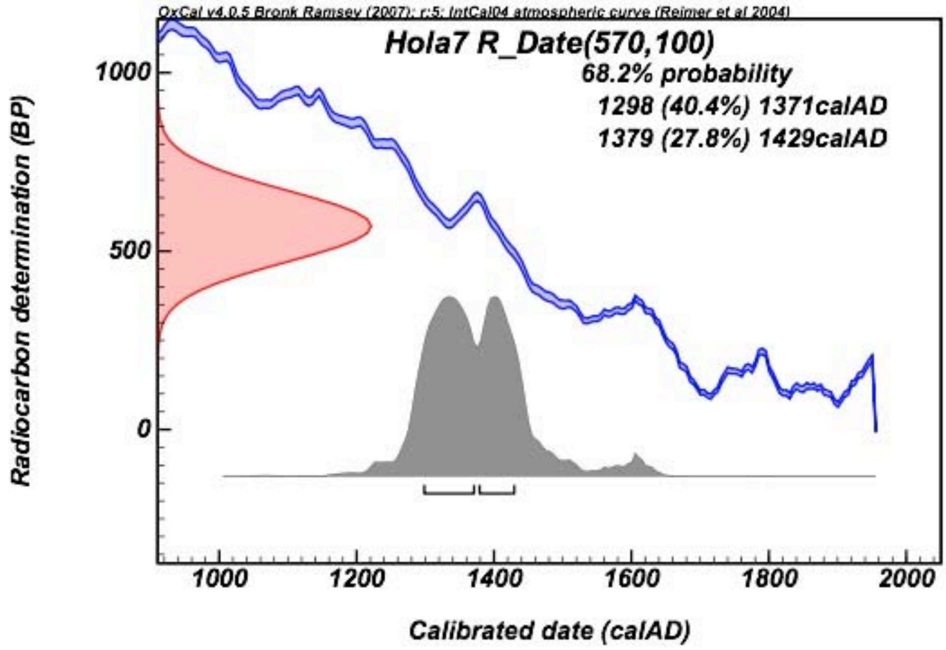
Þorsteinsson, B. 1978: *Íslensk miðaldasaga.* Sögufélagið. Reykjavík.

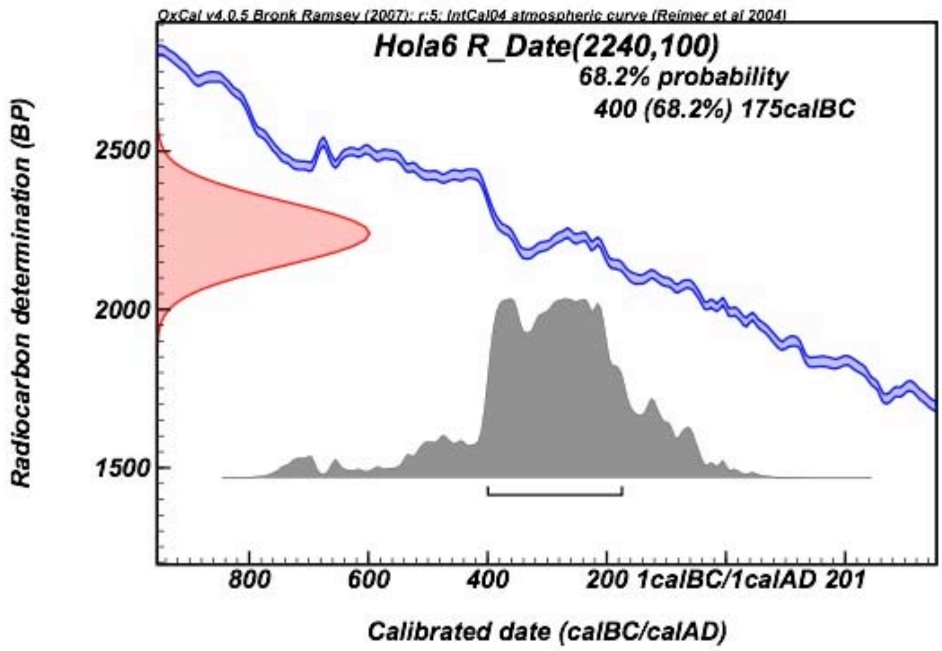
10. Appendices

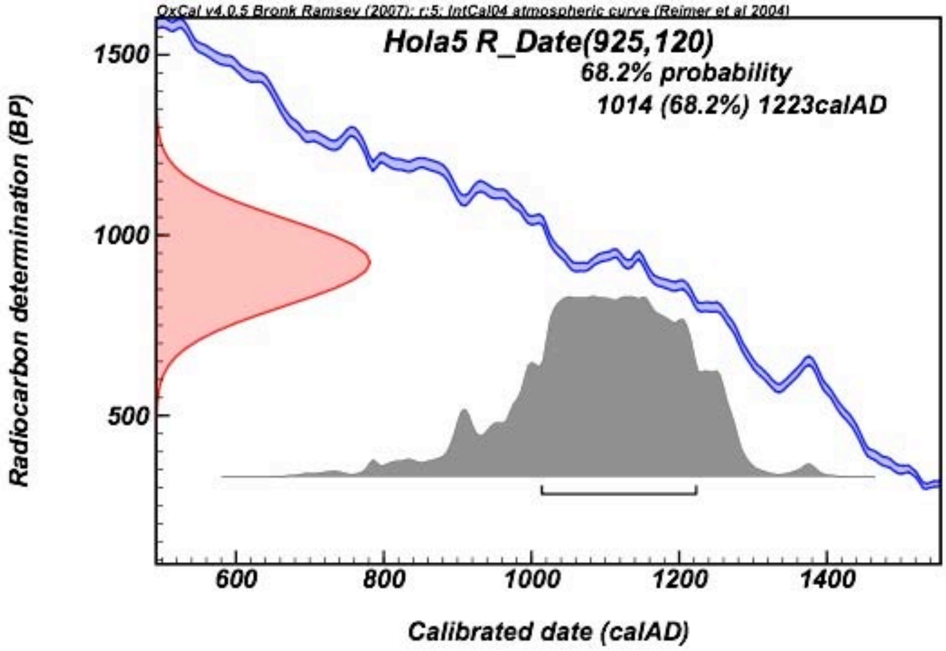
10.1. ^{14}C-dates

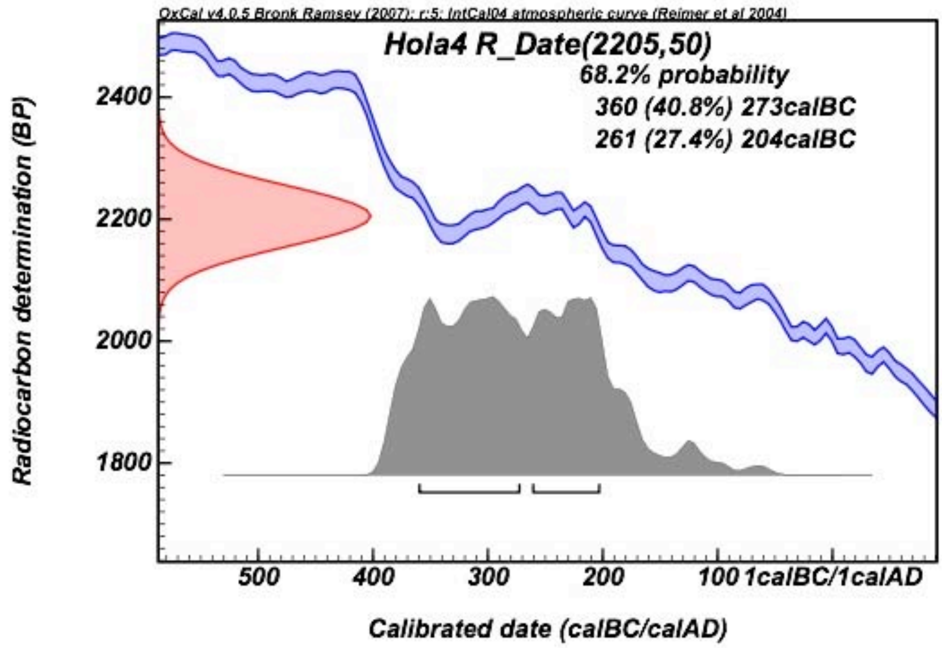


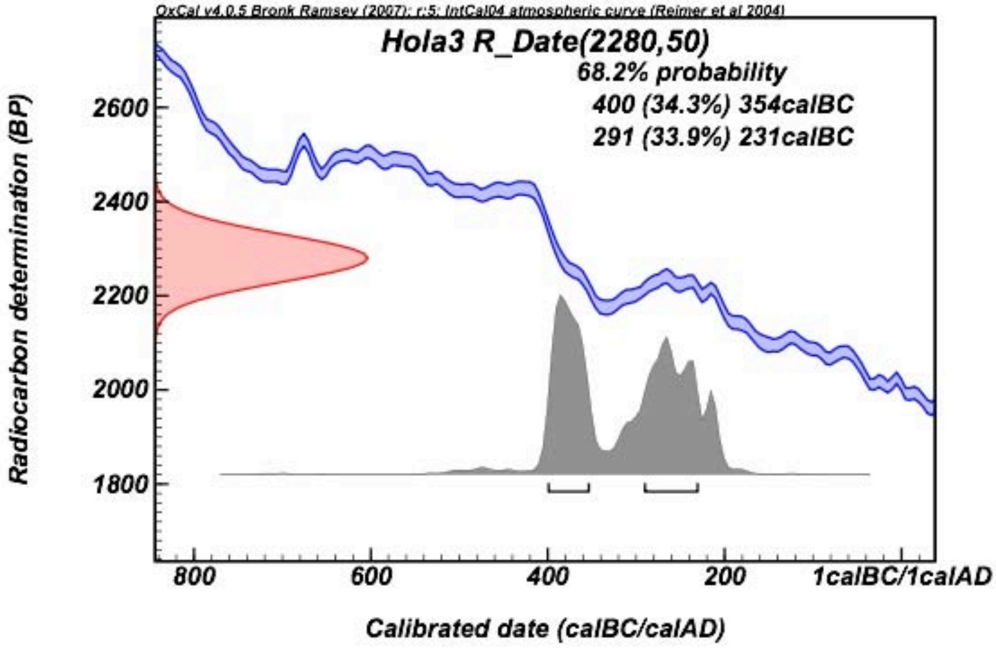


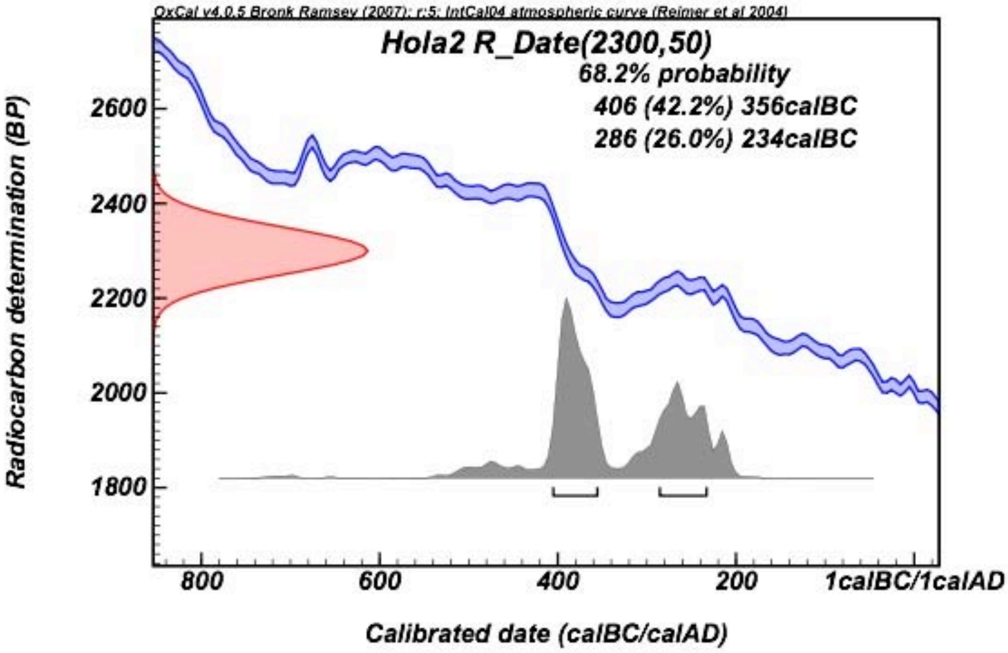

OxCal v4.0.5 Bronk Ramsey (2007); r:5; IntCal04 atmospheric curve (Reimer et al 2004)
Hola7 R_Date(570,100)
68.2% probability
1298 (40.4%) 1371calAD
1379 (27.8%) 1429calAD
Radiocarbon determination (BP)
1000
500
0
1000
1200
1400
1600
1800
2000
Calibrated date (calAD)


OxCal v4.0.5 Bronk Ramsey (2007); r:5; IntCal04 atmospheric curve (Reimer et al 2004)
Hola6 R_Date(2240,100)
68.2% probability
400 (68.2%) 175calBC
Radiocarbon determination (BP)
2500
2000
1500
800
600
400
200 1calBC/1calAD 201
Calibrated date (calBC/calAD)


OxCal v4.0.5 Bronk Ramsey (2007); r:5; IntCal04 atmospheric curve (Reimer et al 2004)
Hola5 R_Date(925,120)
68.2% probability
1014 (68.2%) 1223calAD
Radiocarbon determination (BP)
1500
1000
500
600
800
1000
1200
1400
Calibrated date (calAD)


OxCal v4.0.5 Bronk Ramsey (2007); r:5; IntCal04 atmospheric curve (Reimer et al 2004)
Hola4 R_Date(2205,50)
68.2% probability
360 (40.8%) 273calBC
261 (27.4%) 204calBC
Radiocarbon determination (BP)
2400
2200
2000
1800
500
400
300
200
100 1calBC/1calAD
Calibrated date (calBC/calAD)


OxCal v4.0.5 Bronk Ramsey (2007); r:5; IntCal04 atmospheric curve (Reimer et al 2004)
Hola3 R_Date(2280,50)
68.2% probability
400 (34.3%) 354calBC
291 (33.9%) 231calBC
Radiocarbon determination (BP)
2600
2400
2200
2000
1800
800
600
400
200
1calBC/1calAD
Calibrated date (calBC/calAD)


OxCal v4.0.5 Bronk Ramsey (2007); r:5; IntCal04 atmospheric curve (Reimer et al 2004)
Hola2 R_Date(2300,50)
68.2% probability
406 (42.2%) 356calBC
286 (26.0%) 234calBC
Radiocarbon determination (BP)
2600
2400
2200
2000
1800
800
600
400
200
1calBC/1calAD
Calibrated date (calBC/calAD)

10.2 Chemical analysis of tephra layers

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra layer
1	12.13	3.58	2.41	0.84	3.76	72.12	0.158	2.57	0.624	0	98.192	A1
2	10.12	2.71	1.89	0.677	2.68	67.04	0.089	2.12	0.551	0	87.877	A1
3	12.4	3.5	2.37	0.887	3.68	73.79	0.02	2.53	0.692	0	99.868	A1
4	12.17	3.8	2.45	0.811	3.85	74.6	0.069	2.58	0.678	0	101.008	A1
5	11.06	3.61	2.36	0.828	1.91	70.39	0.205	2.52	0.542	0	93.425	A1
6	12.36	4.19	2.4	0.898	3.92	72.3	0.157	2.64	0.771	0	99.637	A1
7	12.51	3.97	2.36	0.883	3.56	73.14	0.217	2.62	0.744	0	100.003	A1
8	11.99	3.52	2.36	0.755	3.66	73.09	0.158	2.4	0.609	0	98.542	A1
9	12.35	4.01	2.43	0.926	3.88	73.18	0.089	2.44	0.664	0	99.969	A1
10	12.16	3.46	2.55	0.768	3.46	74.52	0.01	2.07	0.497	0	99.495	A1
11	11.9	3.04	2.49	0.767	3.56	73.94	0.118	2.04	0.525	0	98.38	A1
12	11.46	3.62	2.35	0.911	2.04	69.67	0	2.37	0.59	0	93.011	A1

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra layer
1	12.05	3.88	2.38	0.803	3.73	73.03	0.108	2.56	0.793	0	99.334	A2
2	12.3	3.31	2.42	0.875	3.41	73.22	0.108	2.35	0.753	0	98.747	A2
3	11.81	3.7	2.41	0.815	3.64	73.3	0.079	2.51	0.718	0	98.982	A2
4	11.8	3.58	2.43	0.849	3.66	72.88	0.079	2.43	0.722	0	98.43	A2
5	11.92	3.45	2.39	0.86	3.36	73.69	0.236	2.41	0.742	0	99.058	A2
6	12	3.22	2.59	0.806	3.8	74.17	0.148	2.22	0.628	0	99.582	A2
7	11.98	3.73	2.52	0.899	3.37	73.14	0.177	2.33	0.713	0	98.859	A2
8	12.47	3.93	2.39	0.835	3.68	71.39	0.049	2.55	0.747	0	98.041	A2
9	11.95	3.88	2.48	0.921	3.68	72.68	0.098	2.5	0.714	0	98.904	A2
10	11.75	3.05	2.65	0.711	3.98	74.76	0.039	2.09	0.563	0	99.594	A2
11	12.29	3.33	2.39	0.786	3.92	72.16	0.089	2.6	0.648	0	98.213	A2
12	12.2	3.83	2.48	0.836	3.66	73.62	0.266	2.43	0.644	0	99.966	A2

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra Layer
1	13.5	13.03	0.22	1.96	2.7	49.44	0.314	11.48	6.87	0	99.514	Hb
2	13.64	13.02	0.214	1.99	2.95	50.24	0.206	11.04	6.6	0	99.9	Hb
3	13.47	12.97	0.23	1.96	2.68	49.49	0.226	11.31	6.89	0	99.226	Hb
4	13.65	13.31	0.244	1.97	2.63	50.03	0.059	11.32	6.67	0	99.883	Hb
5	13.41	13.41	0.246	1.98	2.83	49.62	0.285	11.4	6.76	0	99.94	Hb
6	13.26	12.88	0.226	1.87	2.91	50.55	0.324	11.25	6.72	0	99.99	Hb
7	13.57	12.99	0.229	2	2.77	49.48	0.137	11.11	6.83	0	99.116	Hb
8	13.3	13.51	0.217	1.95	2.82	49.77	0.108	11.37	6.62	0	99.665	Hb
9	13.18	13.46	0.214	2.02	2.69	50.12	0.098	11.48	6.73	0	99.992	Hb
10	13.34	13.28	0.189	1.92	2.86	49.86	0.236	11.01	6.5	0	99.195	Hb
11	13.47	12.51	0.207	1.91	2.81	50.29	0.305	11.39	6.74	0	99.632	Hb
12	13.27	13.2	0.24	1.91	2.68	50.07	0.216	11.62	6.83	0	100.037	Hb
13	13.45	12.88	0.209	1.93	2.67	50.25	0.216	11.25	6.59	0	99.446	Hb
14	13.73	12.35	0.164	1.79	2.66	49.61	0.246	11.77	6.77	0	99.09	Hb
15	13.38	12.49	0.251	1.92	2.82	48.75	0.197	11.26	6.64	0	97.708	Hb
16	13.43	12.79	0.181	1.85	2.57	49.81	0.148	11.59	6.98	0	99.349	Hb
17	13.27	12.93	0.206	1.91	2.73	50.53	0.285	11.21	6.67	0	99.741	Hb
18	13.39	13.21	0.209	1.91	2.61	49.63	0.265	11.53	6.8	0	99.555	Hb
19	13.12	12.93	0.24	1.95	2.84	50.37	0.148	11.37	6.91	0	99.877	Hb
20	13.35	13.18	0.219	2.01	2.72	49.95	0.404	11.4	6.85	0	100.082	Hb
21	13.43	12.68	0.23	1.9	2.95	50.01	0.157	11.5	6.56	0	99.417	Hb
22	13.4	12.99	0.245	1.86	2.63	49.68	0.138	11.05	6.93	0	98.922	Hb

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra layer
1	12.74	3.2	3.65	0.269	5.32	73.05	0.109	0.924	0.029	0	99.29	Hc
2	12.45	3.3	3.36	0.275	5.2	72.8	0.159	1.044	0.019	0	98.606	Hc
3	12.63	2.98	3.36	0.261	5.53	72.96	0	0.909	0.042	0	98.673	Hc
4	12.92	3.49	3.5	0.233	5.15	71.85	0.119	0.957	0.011	0	98.23	Hc
5	12.66	3.06	3.55	0.271	5.25	72.28	0.149	1.038	0	0	98.257	Hc
6	12.82	3.07	3.44	0.238	5.49	72.24	0	1.074	0.021	0	98.392	Hc
7	13.01	3.34	3.37	0.266	5.73	72.35	0.109	0.998	0.018	0	99.191	Hc
8	12.61	3.06	3.46	0.235	5.48	72.7	0	0.97	0	0	98.515	Hc
9	12.72	3.43	3.4	0.254	5.49	72.25	0.079	0.967	0.024	0	98.615	Hc
10	12.82	3.25	3.32	0.244	5.21	71.68	0	1.014	0.02	0	97.558	Hc
11	12.85	3.07	3.47	0.312	5.65	72.46	0.089	1.06	0.045	0	99.006	Hc
12	12.97	3.62	3.49	0.257	2.86	73.33	0.04	1.119	0.04	0	97.725	Hc
13	13.02	3.66	4.2	0.276	4.22	72.92	0.14	1.094	0.026	0	99.557	Hc
14	12.83	3.47	3.4	0.287	5.23	70.31	0	0.913	0.021	0	96.46	Hc
15	12.72	3.22	3.36	0.23	4.78	71.56	0.02	0.978	0.007	0	96.875	Hc
16	12.86	2.99	3.35	0.268	5.27	71.41	0.159	0.992	0.007	0	97.306	Hc
17	12.79	3.14	3.23	0.268	5.3	71.35	0.069	0.964	0.036	0	97.147	Hc

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra layer
1	12.57	15.34	0.898	4.67	3.56	48.16	0.165	9.55	4.8	0	99.712	Hd
2	12.5	14.77	0.837	4.74	3.41	48.1	0.194	9.37	4.86	0	98.781	Hd
3	12.37	14.77	0.831	4.69	3.51	48.31	0.301	9.5	4.79	0	99.071	Hd
4	12.56	15.18	0.804	4.71	3.59	48.34	0.281	9.34	5.04	0	99.845	Hd
5	12.66	14.9	0.858	4.58	3.48	48.28	0.242	9.15	5	0	99.15	Hd
6	12.91	14.63	0.848	4.65	3.7	48.86	0.281	9.21	4.74	0	99.83	Hd
7	12.93	15.34	0.919	4.63	3.52	48.23	0.301	9.2	4.95	0	100.02	Hd
8	12.56	14.74	0.877	4.75	3.42	48.45	0.291	9.54	4.82	0	99.448	Hd
9	12.81	15.46	0.82	4.56	3.49	47.87	0.252	9.25	4.99	0	99.502	Hd
10	12.77	13.99	0.852	4.75	3.32	49.24	0.224	9.83	5.09	0	100.065	Hd
11	12.75	14.73	0.923	4.7	3.52	48.12	0.242	9.5	5.01	0	99.496	Hd
12	13.12	14.95	0.836	4.9	3.42	48.14	0.282	9.47	4.9	0	100.017	Hd
13	12.82	14.82	0.745	4.7	3.18	49.09	0.058	9.81	5.01	0	100.233	Hd
14	12.77	15.11	0.832	4.75	3.75	48.19	0.252	9.2	4.78	0	99.634	Hd
15	12.78	14.95	0.903	4.78	3.63	47.85	0.349	9.12	4.97	0	99.332	Hd
16	13.51	13.01	0.234	1.86	2.81	50.18	0.205	11.29	6.27	0	99.368	Hd
17	12.71	15.35	0.797	4.68	3.3	47.98	0.165	9.32	4.9	0	99.202	Hd
18	12.84	15.2	0.932	4.71	3.49	48.73	0.175	9.04	4.78	0	99.897	Hd
19	12.55	15.06	0.854	4.61	3.41	48.19	0.058	9.42	4.8	0	98.952	Hd
20	12.86	15.36	0.851	4.74	3.39	48.64	0.252	9.27	4.82	0	100.184	Hd
21	12.68	14.68	0.867	4.51	3.64	48.63	0.233	9.39	4.9	0	99.53	Hd
22	12.62	15.27	0.9	4.44	3.46	48.65	0.223	9.05	4.8	0	99.413	Hd
23	13.1	14.53	0.83	4.25	3.45	48.17	0.204	9.55	5.14	0	99.223	Hd
24	12.68	15.12	0.783	4.71	3.46	48.24	0.223	9.47	4.92	0	99.606	Hd
25	12.71	15.4	0.821	4.72	3.11	48.73	0.252	9.63	4.87	0	100.243	Hd

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra Layer
1	13.51	12.66	0.382	2.61	2.71	49.49	0.243	10.78	6.24	0	98.624	He
2	14.18	10.85	0.189	1.505	2.19	48.79	0.214	12.42	7.84	0	98.178	He
3	13.91	12.14	0.223	2	2.53	49.51	0.165	11.53	6.66	0	98.668	He
4	13.72	11.11	0.33	2.69	2.74	49.7	0.224	12.02	7.48	0	100.014	He
5	14.09	10.07	0.146	1.321	1.94	49.61	0.351	13.26	8.62	0	99.407	He
6	14.41	11.65	0.294	2.26	2.62	49.62	0.068	12.31	6.74	0	99.972	He
7	13.44	12.55	0.393	2.63	2.58	49.31	0.359	10.86	6.47	0	98.592	He
8	14.04	11.05	0.119	1.411	2.07	49.21	0.195	12.77	8	0	98.865	He
9	13.44	13.5	0.414	2.63	2.46	50.63	0.204	10.59	6.17	0	100.038	He
10	13.66	10.43	0.402	2.7	2.58	49.37	0.097	12.06	7.48	0	98.779	He
11	13.62	12.73	0.349	2.58	2.72	49.65	0.184	11.05	6.52	0	99.403	He
12	13.15	12.81	0.414	2.57	2.79	49.2	0.116	10.86	6.21	0	98.121	He
13	13.43	12.53	0.385	2.65	2.73	49.05	0.155	10.82	6.52	0	98.27	He
14	13.13	12.87	0.309	2.61	2.6	48.35	0.136	10.78	6.33	0	97.114	He
15	13.7	12.38	0.15	1.472	2.22	49.26	0.214	12.26	7.44	0	99.096	He
16	13.24	13.13	0.403	2.55	2.74	50.52	0.359	10.98	6.37	0	100.292	He
17	13.64	12.97	0.337	2.62	2.78	49.77	0.194	11.03	6.42	0	99.761	He
18	12.59	13.97	0.642	2.95	3.2	49.82	0.358	8.98	4.91	0	97.42	He
19	13.82	12.17	0.302	2.2	2.61	49.38	0.204	11.57	6.81	0	99.066	He
20	13.01	12.51	0.431	2.6	2.9	49.6	0.165	10.89	6.17	0	98.276	He
21	13.44	12.65	0.377	2.61	2.79	49.54	0.213	10.91	6.28	0	98.81	He
22	13.83	13.1	0.364	2.51	2.93	49.2	0.194	10.5	6.21	0	98.838	He
23	13.87	12.08	0.312	1.67	2.57	49.44	0.107	11.88	7.35	0	99.279	He
24	13.98	11.1	0.334	2.03	2.7	49.77	0.204	11.74	7.31	0	99.168	He

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra layer
1	13.47	12.98	0.368	2.52	3.03	50	0.234	10.83	6.07	0	99.502	Hf
2	13.75	12.64	0.389	2.63	2.77	50.62	0.273	10.72	6.2	0	99.992	Hf
3	13.36	13.5	0.373	2.66	2.68	50.64	0.146	10.56	5.91	0	99.829	Hf
4	13.75	13.14	0.387	2.71	2.78	50.46	0.176	10.65	6.22	0	100.272	Hf
5	13.42	12.68	0.348	2.56	3.09	49.73	0.282	10.68	6.26	0	99.051	Hf
6	13.61	12.92	0.372	2.56	2.72	49.47	0.214	10.68	6.23	0	98.776	Hf
7	13.45	12.87	0.4	2.63	3.04	50.43	0.146	10.67	6.27	0	99.906	Hf
8	13.79	12.78	0.303	2.52	2.7	49.84	0.214	10.79	6.25	0	99.188	Hf
9	13.68	12.58	0.377	2.72	2.75	50.78	0.137	10.94	6.26	0	100.223	Hf
10	13.55	13.33	0.406	2.68	2.97	50.29	0.166	10.74	6.12	0	100.252	Hf
11	13.16	12.51	0.403	2.61	2.94	50.29	0.185	10.71	6.46	0	99.268	Hf
12	13.65	12.83	0.367	2.58	2.97	50.51	0.283	10.76	6.35	0	100.299	Hf
13	14.16	13.18	0.417	3.08	3.72	51.22	0.156	10.58	3.78	0	100.293	Hf
14	13.49	12.77	0.403	2.54	2.97	49.94	0.175	10.74	6.13	0	99.158	Hf
15	13.48	13.01	0.348	2.58	2.81	50.07	0.331	10.7	6.39	0	99.719	Hf
16	13.42	12.81	0.352	2.7	2.87	50.4	0.02	10.68	6.45	0	99.701	Hf
17	13.56	12.93	0.383	2.67	2.95	50.39	0.097	10.73	6.32	0	100.031	Hf
18	13.74	13.19	0.381	2.6	2.8	50.06	0.254	11.03	6.28	0	100.335	Hf

1	13.84	12.79	0.175	1.71	2.61	49.86	0.253	11.77	7.1	0	100.108	Hh
2	13.56	13.22	0.217	1.75	2.63	49.36	0	11.61	7.04	0	99.387	Hh
3	13.87	12.2	0.237	1.74	2.58	48.64	0.273	11.58	6.94	0	98.059	Hh
4	14.02	12.83	0.197	1.72	2.6	49.06	0.156	11.58	6.96	0	99.123	Hh
5	14.15	12.81	0.215	1.72	2.55	49.42	0.194	11.83	7.12	0	100.01	Hh
6	14.33	11.62	0.208	1.45	2.28	49.5	0.146	12.91	7.69	0	100.134	Hh
7	14.08	12.03	0.166	1.537	2.27	49.71	0.234	12.59	7.64	0	100.257	Hh
8	14.07	12.86	0.231	1.7	2.57	50.12	0.165	11.59	6.78	0	100.086	Hh
9	14.45	12.79	0.147	1.528	2.3	48.49	0.184	12.42	7.13	0	99.439	Hh
10	14.09	12.91	0.266	1.73	2.46	48.69	0.233	11.38	6.42	0	98.179	Hh
11	13.48	12.92	0.261	1.84	2.72	50.18	0.204	11.29	6.64	0	99.535	Hh
12	14.68	13.35	0.306	1.91	2.79	49.7	0.301	11.59	5.7	0	100.327	Hh
13	14.06	12.92	0.201	1.85	2.63	49.64	0.165	11.51	7.06	0	100.036	Hh
14	14.27	11.44	0.152	1.469	2.32	49.64	0.185	12.55	7.69	0	99.716	Hh
15	14.25	11.35	0.172	1.552	2.39	48.67	0.166	12.58	7.77	0	98.9	Hh
16	14.05	12.72	0.195	1.69	2.7	49.27	0.175	11.54	6.86	0	99.2	Hh
17	13.78	13.32	0.225	1.89	2.69	50.22	0.272	11.01	6.51	0	99.917	Hh
18	13.62	12.97	0.268	1.82	2.55	49.34	0.32	11.65	6.8	0	99.338	Hh
19	13.66	12.83	0.264	1.81	2.38	50.83	0.195	11.69	6.85	0	100.509	Hh
20	13.99	13.14	0.276	1.83	2.7	50.38	0.311	11.78	6.84	0	101.247	Hh
21	14.38	11.15	0.16	1.592	2.28	49.72	0.166	12.5	7.53	0	99.478	Hh

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra Layer
1	13.04	11.99	0.409	2.42	2.89	48.93	0.155	10.62	6.2	0	96.654	Hi
2	13.43	12.29	0.384	2.54	2.97	48.77	0.204	10.58	6.26	0	97.427	Hi
3	12.91	12.41	0.336	2.52	3.03	48.27	0.194	10.65	6.34	0	96.66	Hi
4	13.09	12.36	0.344	2.56	2.71	48.47	0.078	10.71	6.25	0	96.572	Hi
5	12.76	12.68	0.352	2.5	2.91	48.21	0.146	10.33	6.02	0	95.907	Hi
6	13.38	10.89	0.253	1.97	2.63	47.48	0.156	11.57	7.2	0	95.529	Hi
7	13.1	12.62	0.362	2.57	2.93	49.01	0.233	10.41	6.4	0	97.635	Hi
8	13.47	11.21	0.332	2.02	2.5	47.27	0.156	11.38	7.33	0	95.668	Hi
9	13.14	11.91	0.306	2.56	2.85	47.91	0.272	10.19	6.37	0	95.508	Hi
10	13.27	12.37	0.307	2.58	3.15	49.21	0.262	11.04	6.29	0	98.479	Hi
11	12.8	12.56	0.373	2.59	2.82	47.75	0.281	10.24	6.14	0	95.555	Hi
12	13.28	11.46	0.288	2.49	3.13	48.48	0.087	11.17	6.64	0	97.025	Hi
13	13.2	12.35	0.346	2.58	3	48.57	0.233	10.35	6.29	0	96.919	Hi
14	13.58	11.23	0.162	2.33	2.97	49.86	0.126	11.51	7.22	0	98.989	Hi
15	12.65	12.33	0.441	2.31	3.11	47.8	0.281	8.92	8.22	0	96.063	Hi
16	13.55	12.61	0.405	2.51	3.03	48.65	0.233	10.51	6.35	0	97.848	Hi
17	13.69	11.81	0.417	2.48	2.95	48.96	0.078	10.33	6.32	0	97.035	Hi
18	13.81	11.25	0.366	2.53	2.98	49.98	0.224	10.9	6.73	0	98.77	Hi
19	13.39	13.12	0.352	2.62	2.93	49.46	0.068	9.85	5.84	0	97.63	Hi
20	13.11	12.43	0.343	2.62	3.09	49.08	0.204	10.28	6.27	0	97.427	Hi
21	13.25	12.22	0.371	2.63	2.91	49.35	0.117	10.29	6.31	0	97.448	Hi
22	13.4	11.6	0.417	2.52	3.02	48.54	0.301	10.61	6.42	0	96.828	Hi
23	13.29	11.53	0.346	2.51	2.88	48.44	0.194	10.51	6.34	0	96.04	Hi
24	13.79	12.05	0.384	2.57	2.94	48.92	0.029	10.53	6.29	0	97.503	Hi
25	12.89	12.61	0.429	2.88	3.26	48.67	0.039	9.52	5.74	0	96.037	Hi
26	13.18	13.8	0.372	2.6	3.04	49.3	0.262	9.7	5.47	0	97.724	Hi
27	13.5	11.95	0.361	2.58	3.11	49.02	0.301	10.44	6.27	0	97.532	Hi
28	13.72	11.15	0.323	2.47	2.71	49.34	0.165	11.52	7.8	0	99.198	Hi
29	13.36	12.44	0.368	2.47	3.17	49.46	0.272	9.76	6.76	0	98.06	Hi
30	13.34	11.66	0.333	2.44	2.9	49.11	0.253	10.08	6.85	0	96.966	Hi

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra Layer
1	13.79	11.8	0.3	2.05	2.66	49.96	0.264	12.12	7.23	0	100.173	Hj
2	14.13	11.55	0.302	2.14	2.61	49.12	0.127	11.76	7.18	0	98.919	Hj
3	13.74	11.87	0.262	2.12	2.69	49.13	0.205	11.94	7.06	0	99.016	Hj
4	13.81	11.15	0.303	2.05	2.53	49.07	0.224	11.81	7.16	0	98.108	Hj
5	13.66	11.42	0.274	2.08	2.51	50.11	0.146	11.87	7.15	0	99.22	Hj
6	13.79	11.37	0.289	2.07	2.87	50.13	0.058	11.73	7.36	0	99.667	Hj
7	13.92	11.6	0.315	2.07	2.43	50.54	0.313	12.09	7.21	0	100.488	Hj
8	13.71	11.3	0.28	2.11	2.73	49.6	0.156	12.05	7.17	0	99.106	Hj
9	13.97	11.41	0.235	2.11	2.69	50.19	0.166	11.92	7.35	0	100.041	Hj
10	13.79	11.63	0.299	2.06	2.54	50	0.195	11.96	7.3	0	99.774	Hj
11	13.94	11.66	0.283	2.1	2.71	50.23	0.283	11.93	7.04	0	100.177	Hj
12	14.24	10.48	0.288	2.54	2.69	50.88	0.108	12.47	7.21	0	100.906	Hj
13	14.08	11.83	0.297	2.06	2.44	49.95	0.195	12.15	7.07	0	100.072	Hj
14	13.82	11.39	0.262	2.08	2.48	50.27	0.156	12.02	7.34	0	99.818	Hj
15	14.16	11.25	0.293	2	2.73	49.51	0.322	12.17	7.21	0	99.645	Hj
16	13.56	11.62	0.323	2.2	2.68	49.25	0.127	12.02	7.39	0	99.17	Hj
17	14.22	11.72	0.292	2.05	2.53	49.52	0.244	12.03	7.29	0	99.896	Hj
18	13.92	11.63	0.23	2.16	2.75	50.1	0.156	12.06	7.42	0	100.426	Hj
19	14.07	11.41	0.288	2.13	2.77	50.06	0.244	11.98	7.12	0	100.072	Hj
20	14.02	11.74	0.313	2.08	2.75	49.61	0.136	11.96	7.25	0	99.86	Hj
21	14.22	11.31	0.335	2.04	2.73	49.96	0.147	12.07	7.28	0	100.092	Hj

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	Comment
74	12.83	14.85	0.802	4.63	3.02	46.03	0.341	9.4	4.88	Hk
75	12.78	15.4	0.709	4.38	3.2	45.54	0.253	9.25	4.84	Hk
76	12.94	15.3	0.775	4.57	3.34	46.5	0.204	9.61	4.85	Hk
77	12.86	15.23	0.783	4.48	3.15	45.78	0.233	9.25	4.85	Hk
78	12.7	14.78	0.714	4.51	3.04	45.97	0.146	9.27	4.78	Hk
80	12.32	15.18	0.857	4.63	3.09	46.83	0.049	9.37	5.18	Hk
81	12.84	15.28	0.782	4.58	3.22	46.93	0.136	9.47	5.03	Hk
82	12.61	14.92	0.821	4.68	3.22	46.81	0.244	9.42	4.91	Hk
83	12.69	15.8	0.868	4.67	3.06	46.84	0.175	9.49	4.97	Hk
84	13.13	15.56	0.707	4.52	3.32	46.91	0.214	9.54	4.82	Hk
85	12.79	14.88	0.738	4.51	3.18	46.73	0.263	9.5	4.95	Hk
86	12.8	14.75	0.766	4.57	3.01	46.52	0.214	9.29	4.83	Hk
87	12.8	15.04	0.731	4.56	3.06	46.84	0.107	9.38	5.06	Hk
88	12.89	14.62	0.756	4.56	3.36	46.87	0.273	9.49	4.81	Hk
89	12.69	15.3	0.846	4.6	3.09	46.78	0.165	9.58	4.71	Hk
90	12.7	14.94	0.743	4.57	3.24	47.13	0.282	9.49	4.92	Hk
91	12.71	14.68	0.8	4.47	3.13	47.2	0.312	9.48	4.82	Hk
92	12.62	14.85	0.771	4.73	3.21	46.91	0.244	9.37	4.94	Hk
95	12.97	14.52	0.738	4.5	3.44	47.46	0.234	9.56	4.96	Hk
96	12.7	15.11	0.829	4.53	3.36	47.63	0.263	9.62	4.9	Hk
98	12.8	15.1	0.773	4.43	3.52	47.37	0.263	9.67	4.86	Hk
100	12.68	15.13	0.774	4.43	3.49	47.2	0.117	9.41	5.06	Hk
101	12.79	15.03	0.775	4.59	3.4	47.35	0.244	9.16	4.92	Hk

No.	Al2O3	FeO	K2O	TiO2	Na2O	SiO2	MnO	CaO	MgO	O	Total	Tephra Layer
1	13.53	11.44	0.271	2.1	2.66	49.28	0.107	11.98	7.26	0	98.628	Hm
2	13.67	11.69	0.343	2.24	2.86	50.01	0.136	11.41	6.86	0	99.219	Hm
3	12.83	15.21	0.656	3.08	3.14	49.41	0.126	9.07	4.87	0	98.392	Hm
4	14.12	15.02	0.357	1.86	3.18	49.59	0.204	10.4	6.32	0	101.05	Hm
5	13.72	11.67	0.359	1.99	2.6	49.36	0.253	11.92	7.37	0	99.241	Hm
6	14.04	10.93	0.279	2.07	2.6	50.87	0.38	12.03	7.29	0	100.489	Hm
7	13.78	11.05	0.304	2.13	2.49	49.84	0.029	12.01	7.34	0	98.974	Hm
8	13.99	11.36	0.356	2.06	2.53	50.15	0.146	11.78	7.38	0	99.752	Hm
9	13.9	11.89	0.174	1.627	2.38	49.8	0.175	12.36	7.98	0	100.287	Hm
10	14.09	11.41	0.21	2.06	2.69	49.85	0.146	12.03	7.49	0	99.976	Hm
11	13.83	11.61	0.322	2.09	2.63	49.63	0.194	12.23	7.3	0	99.836	Hm
12	14.01	11.67	0.278	2.13	2.6	49.52	0.136	11.6	7.23	0	99.174	Hm
13	14.11	11.84	0.26	2.03	2.82	49.49	0.204	11.56	7.01	0	99.324	Hm
14	14.14	11.4	0.334	2.18	2.61	49.79	0.282	11.87	7.33	0	99.936	Hm
15	13.87	11.34	0.332	2.1	2.49	49.62	0	12.34	7.31	0	99.402	Hm
16	13.95	11.21	0.283	2.1	2.63	49.93	0.126	11.97	7.6	0	99.799	Hm
17	14.18	10.68	0.29	1.98	2.86	50.47	0.166	11.67	7.36	0	99.656	Hm
18	13.55	11.42	0.299	2.05	2.93	49.65	0.262	11.78	7.38	0	99.321	Hm
19	13.11	10.54	0.294	1.9	2.4	46.86	0.107	10.9	6.71	0	92.821	Hm
20	14.12	10.99	0.24	2.06	2.65	49.07	0.117	11.57	7.2	0	98.017	Hm
21	13.93	11.36	0.312	2.14	2.62	49.42	0.292	12.1	7.16	0	99.334	Hm
22	13.99	11.25	0.311	2.14	2.71	50.26	0.311	11.54	7.34	0	99.852	Hm
23	13.96	11.71	0.289	2.09	2.85	49.91	0.204	11.51	7.13	0	99.653	Hm
24	14.04	11.23	0.271	2.04	2.55	49.94	0.311	11.61	7.41	0	99.402	Hm
25	14.18	11.36	0.273	2.05	2.67	50.14	0.127	11.96	7.31	0	100.069	Hm