Formation, cultural use and management of Icelandic wet meadows – a palaeoenvironmental interpretation.

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Statement of Originality

I hereby confirm that this is an original study conducted independently by the undersigned and that the work contained therein has not been submitted for any other degree. All research material has been duly acknowledged and cited.

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Date: 30 September 2016

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Abstract

This thesis offers the first detailed palaeoenvironmental analysis of wetland areas within sub-Arctic enclosed homefield's. Significance of meadows were previously mentioned only briefly in the literature, suggesting influences in settlement site selection as well as importance in quality fodder production, producing up to two thirds of total hay resources in a somewhat marginal agricultural landscape. Given the importance of hay resources in Iceland it seems unusual these areas have received so little attention to date, despite extensive research on all other aspects of the Norse farm system.

The organic sediments within the meadows, given their development in-situ over extended time periods, have the ability to record aspects of the intimate relationship between societal and environmental change, and so in a robust and holistic way our methods set integrates radiocarbon measurement, tephrochronology, palynology and thin section micromorphology from the same core; reflecting these findings against existing paleoclimate and archaeological site data. This combined application of the core techniques – palynology and soil micromorphology, has proven successful in creating effective human ecodynamic records from each of the study farms.

Records obtained from the three farm sites in northwest and northern Iceland exposed the varying importance and differing utilisation of these wetland areas. Meadows would appear to have played an import role in choice of settlement site across northern Iceland, through the provision of open areas, and additional and immediately available fodder resources at settlement, in a landscape dominated by dense scrub. Meadows were found to have been in continuous use, albeit at varying levels of intensity, from settlement to the present day. In this respect the semi-natural resources are found to be remarkably resilient, demonstrating little alterations to their composition following severe climatic downturns, including that of the Little Ice Age, and volcanic eruption. Acting as a robust resource and safety buffer for settlements, contributing to fodder resources where reliability of other resources is jeopardised by environmental conditions.

Research in the more marginal northwest peninsula provides the first evidence of artificially created wet meadows in Iceland, developed to give sustained fodder production for over-wintering livestock in an environment that inherently had a short growing season and lacked soil fertility. A further example of the nuanced land management practices adopted in the agriculturally fragile farmscapes of the Norse North Atlantic. The findings of the thesis have wider

implications for understanding the emergence of resilient and sustainable communities in agriculturally marginal environments; to this end there remains many opportunities to use palaeoenvironmental research to study ecosystem responses to natural and anthropogenic stresses, giving us a better understanding of capacities to withstand future stresses.

Table of Contents

Table of Figures

Table of Tables

Chapter 1 Introduction

1.1 General Introduction

In Iceland the traditional introduced North European 'agricultural package' is evidenced in zoo-archaeology and landscape organisation. It included sheep, cattle, goats, pigs, horses and dogs supplemented by marine resources, communal rangelands for grazing, residential longhouses with attached byre and several outhouses, seasonal shielings for milking dairy cattle, outfields for winter grazing and enclosed homefields (Edwards et al., 2005a; McGovern et al., 2007a; Vésteinsson et al., 2002). The homefield - the areas of land directly adjacent to the early Norse dwellings - are evident at most early and historical farms in Iceland and were the location for a range of activities including cereal production (in favourable locations), hay production for winter fodder and aftermath grazing (Adderley et al., 2008; Simpson et al., 2002). With climatically challenging winter conditions in Iceland the homefield and its management was critical to the sustainability of food resources through its provision of high quality winter fodder particularly for milking livestock (Vésteinsson et al., 2002).

Previous studies of sub-Arctic homefields have identified a range of land management practices that developed over time and included manuring 'recipes' using livestock and domestic wastes together with turf to sustain soil nutrient status. Water management through irrigation is also evident and which offset summer soil moisture deficits at a critical stage in the growing season. These management practices helped maintain and enhance yields, even under deteriorating climatic conditions (Adderley et al., 2008; Adderley and Simpson, 2005, 2006; Golding et al., 2014; Simpson et al., 2002). Land management activities have however only been considered and identified in drier areas of the enclosed homefields, on the freely to imperfectly drained mineral based podsols (Greenland and Faroe) and andosols (Iceland); archaeological research has been extensive in these areas expanding both the knowledge of Norse farming systems and individual elements of the Iceland farm, many of which are now understood in detail. Field investigations and soil surveys are however increasingly indicating that there are also significant areas of organic soils and wetland vegetation communities within the enclosed homefield or in close proximity to settlements. Field investigations carried out in the summer of 2009 within the Mývatnssveit district of north Iceland for example revealed a series of wet meadows in close proximity to a range of farm settlements dating from the early Norse to the more modern and present periods. These meadows are evident in various conditions – some abandoned, some still in use and in varying degrees of saturation, with many flooded for brief periods of the year. Importance of the meadows has previously been mentioned in the academic literature, suggesting influences in settlement site selection and their importance in quality fodder production (Huijbens and Pálsson, 2009; Vésteinsson et al., 2002); despite this they have seldom received detailed attention and it is apparent little is known about their formation and development, and, particularly, how they were used in the past.

These wetland areas had potential to contribute fodder production from the somewhat marginal agricultural landscape and the increased recognition of their significance warrants new palaeoenvironmental analyses. The organic soils associated with these wetland areas, because of their anaerobic conditions and development in-situ over extended time periods, provide distinctive preservation conditions with the potential to retain a wealth of cultural and environmental data, enabling exploration of complex human-ecodynamic records linked to aspects of the intimate relationships between societal an environmental change within individual sites.

1.2 Aims and Objectives

This thesis offers the first detailed palaeoenvironmental analysis of wetland areas within sub-Arctic enclosed Norse homefields. The key aim of the study is to develop a better understanding of how wet meadows associated with farms developed and how they were used, viewed and managed in a Norse cultural context. To do so the thesis explores the potential of meadow sediments as environmental and cultural archives, through examination of palaeoenvironmental information within them. In doing so the thesis obtains new and enhanced knowledge of the changing nature of landscapes associated with Norse farms (‘farmscapes’) at the individual farm scale, providing an important contribution to palaeoenvironmental studies focussed on Icelandic farm systems.

The overarching aim is addressed through the following series of objectives:

- Provide an initial description of the current state of meadows and the farms they are associated with by using stratigraphical techniques to examine the state and extent of organic sediments, demonstrating their association with settlement and providing chronological frameworks for organic soil formation during the period of site occupation.
- Establish nature of pre-Landnám vegetation environment within the meadow and immediate farm surrounds, providing a baseline by which anthropogenic changes might

be contrasted. Through use of these baseline conditions asses the impacts of settlement and, where applicable, abandonment using palaeoenvironmental reconstructions specific to the meadow sites.

- Build a comprehensive understanding of wetland sediment formation processes as the result of both environmental conditions and cultural practices (localised land use and management), through the identification of past and present soil processes linked to soil genesis and development and the impacts of land use on sediments.
- Where land management practices are identified determine whether the wet meadows were managed in a complimentary way to the homefields.
- Contextualisation of the dating and palaeoenvironmental analyses with paleo-climatic and archaeological data, identifying cultural landscape changes in response to climate and social change. With focus on reconstructing the cultural landscape at the individual farm scale.
- Consider whether the meadows, given their presence today, were inherently resilient over multi century timescales and with what maintenance intensities; analysing their roles in risk management and adaptive practices within the farm systems.
- Assess using data gathered the extent to which wet meadow presence might have influenced settlement.

To address these objectives in a robust and holistic way three study farms with contrasting meadow systems are selected and where the analytical methods set integrates radiocarbon measurement, (micro-) tephrochronology, sedimentary analysis, high-resolution palynology and thin section micromorphology from the same stratigraphical section. The methods central to the thesis – palynology and soil micromorphology, are assessed based on new insights gained through their combined application. Findings are then reflected against existing paleo-climatic and archaeological site data; in doing so, we highlight the adaptive and nuanced agricultural land management practices of the European sub-Arctic and the contributions that this made to the long-term sustainability and resilience of these communities.

1.3 Introduction to Iceland – Physiography and Climate

1.3.1 Introduction to the study region

Iceland is an island in the centre of the North Atlantic, with an area of 103,000km^2. Situated on the Mid Atlantic Ridge, the country has a long and active volcanic history, with eruptions on average occurring every 5 years. This volcanic history has had a prominent role in shaping the landscape, which has to a large degree, been modified by humans since the country's rapid settlement by the Norse from AD 871±2. Perceptions, practices and technologies were brought with the first settlers from their home countries, imprinting the Norse signatures on new landscapes, modifying and maintaining the new country with established farming and cultural practices. As part of these modifications, widespread landscape degradation was initiated at settlement, exacerbated in particular by grazing. Iceland is in the unique position in that no grazing animals, with the exception of migratory geese were present prior to settlement in the late 9th century, and so with the introduction of livestock, coupled with vegetation clearance for settlement, fragile soils were exposed, leading to extensive areas of soil erosion.

Given that prior to settlement ecosystem dynamics were dictated largely by climate and volcanism, this provides a baseline against which to compare anthropogenic impacts and changes evidenced in environmental records occurring as a result of natural processes. In this respect Iceland provides the ideal study area for palaeoenvironmental research associated with human modifications; where temporal controls allow for comparisons between natural and anthropogenically modified sedimentary records.

1.3.2 Geological setting

Geologically Iceland is a very young country, with the oldest rocks around 16 million years old (Moorbath et al., 1968). It is positioned on the north Atlantic ridge, which stretches across the country southwest to northeast, forming a divergent boundary separating the North American and Eurasian tectonic plates. All bedrock is volcanic in origin, with most of the landscape composed of basaltic lava and the remainder shaped by aeolian, fluvial and glacial deposits (Arnalds, 2004). These feature as part of the two major geological formations found in Iceland - the Basalt and the Palagonite formations (Thorsteinsson et al., 1971). The former dating to the Tertiary period and consisting mostly of basaltic lava sheets, and the younger Palagonite formation present as a mix of subglacial and subaerial eruptives, as well as other glacial, fluvial and aeolian deposits (Thorsteinsson et al., 1971). Land uplift and dynamic sea level change since the last glaciation has shaped the coastline of Iceland, which is presently characterised by a series of raised beaches and marine terraces at approximately 40-110 metres a.s.l. with submerged coastal features suggesting sea level rise of 30-35 metres in the southwest and 40 metres in the north (Hallsdóttir, 1996; Rundgren et al., 1997).

1.3.3 Climate overview

Iceland is positioned in the North Atlantic close to significant atmospheric and oceanic polar fronts. Here the warm air and Irminger current, part of the North Atlantic Drift, meets the cool arctic East Greenland Polar current, with these currents playing a key role in influencing the countries climate (Ogilvie, 1984). The country lies on a shifting boundary line between taiga and tundra biomes, with taiga contracting in cooler years and expanding northwards and in elevation during warmers periods; agricultural frontiers are equally impacted by the changeability (Bergthorsson, 1985).

Climate is maritime, summers are generally cool and winters mild, but with considerable regional differences as a result of the mountainous nature of the island. Mean rainfall varies across the country, ranging from 2200mm a year in Vík Í Mýrdal in southern Iceland, to 465mm per year in Akureyri, northern Iceland (Einarsson, 1963); on a whole weather conditions are somewhat changeable, with climate variable on a decadal to centurial time scale, a product of the low pressure tracts in the North Atlantic, where gulf stream impacts are more powerful and bring milder climate. Sea ice plays a major role in the countries climate, excellent records of the extent and duration of sea ice exists across a series of written documents (Ogilvie, 1984, 1991, 2005). Feedback processes are evident between sea ice and climate, with extent and duration of sea ice increasing in colder periods, with the cooling effects of sea ice on the atmosphere cooling the surrounding air and positive feedback leading to the expansion of sea ice (Bergthorsson, 1985).

Despite shorter term variability, climate throughout the Holocene has been relatively stable. Two key climatic events, of an intensity to impact society and the environment over a prolonged period, have occurred since the settlement period – the Medieval Warm period and the Little Ice Age. Debate exists surrounding the exact timing of these events, which impacted the entire North Atlantic region. Exact start and end dates are unknown, and both would appear to have been spatially variable. The Medieval Warm Period, believed to be warmer than the present climate, brought with it warm and stable conditions from AD c. 900-1200. This was proceeded by the Little Ice Age, generally colder than the present climate, as well as more variable and stormy, the onset of which in Iceland is continually debated (Lawson, 2009). Bradwell et al. (2006) for example provide evidence in the form of geomorphological data, lichenometric measurements and tephrochronology, for the re-advancement of glaciers in the country from as early as the 13th century; Meeker and Mayewski (2002), on the other hand, using their data from Greenland ice cores suggest the major cooling transition occurred regionally AD c. 1400 (Lawson, 2009).

Mounting evidence suggests the Little Ice Age culminated between AD 1750 and 1800 (Bradwell et al., 2006).

1.3.4 Soils

Soils in Iceland are dominated by andosols of basaltic origin (FAO., 2006) (Figure 1.1). With parent materials volcanic in origin, dominated by mixture of tephra and aeolian sediment consisting almost entirely of volcanic glass, the steady flux of aeolian material and tephra contributing to soil formation is unique to Iceland (Arnalds, 2004). Organic contents of the soils are typically low, but increasing with distance from any tephra or aeolian sources (Arnalds, 2004).

Andosols are shown as covering an area of approximately 78,000 km^2, representing 86% of the total soil area of Iceland. Histosols cover an unusually small area – 1%, a small percentage given the general dominance of Histosols at similar latitudes (63-66°N) elsewhere and the relatively frequent occurrence of wetlands throughout the country (Arnalds, 2004, 2005). Tephra and aeolian inputs to these soils reduce their organic content, with these more organic sediments frequently recognised instead as Histic Andosols (Arnalds, 2004, 2005). The Histic, Gleyic and Brown fractions of Andosols cover approximately 48,700 km^2 (54% of all soils) (Arnalds, 2004). Vitrisols comprise 30% of the soil area, however given volcanic inputs to these soil these are classed as both Leptosols and Andosols (Arnalds, 2004).

The properties of these Andosols make them particularly susceptible to erosion. Dominant clay types within the Andosols gives rise to low bulk densities (0.3–0.8 g cm^{-3}), high porosity and high soil water retention coupled with low organic content lead to low bearing capacities and poor soil cohesion, leading to rapid erosion where surface cover is removed or disrupted and soils are exposed to wind or water erosion (Arnalds, 2004; Óskarsson et al., 2004). Soil erosion has accelerated since the Norse settlement, with approximately half of the pre-existing soil cover lost to erosion, creating up to 20,000km^2 of semi-desert with unstable surfaces and accumulations of aeolian deposits several metres deep in other areas (Dugmore and Buckland, 1991), with deposition rates commonly exceeding 2mm/yr. near sandy deserts (Arnalds, 2004). To this end Iceland is recognised as the most degraded country in Europe, with up to 73% of the total land (102,721 km^2) area effected by erosion to some degree (Arnalds, 2004; Simpson et al., 2004). Early studies suggest up to 40% of topsoils have been removed since settlement (Friðriksson, 1972; Thorsteinsson et al., 1971), yet more recent research has indicated, the fragility of soils is such that climatic conditions alone have been sufficient to initiate erosion. With evidence of soil erosion existing prior to Landnám (Ólafsdóttir and Guðmundsson, 2002; Simpson et al., 2004), and believed to a result of large scale environmental change over the past 2000 years (Arnalds, 2005). The erosional features 'Rofabards' - escarpments created as volcanic soils are truncated from the surfaces and left surrounded by bare soils, are a particular issue in Icelandic soils , covering approximately 20 000 km^2 of the Icelandic Landscape (Arnalds, 2000).

In addition to erosion cryoturbation is a common soil process, exacerbated by both the cold, wet climate and properties of Icelandic soils, particularly the high water holding capacities. As a result solifluction features - lobes and terraces are visible on many slopes, with 'Thúfur', large soil hummocks, linked especially to deep seasonal freezing (Van Vliet-Lanoë et al., 1998), common on level vegetated surfaces (Arnalds, 2004).

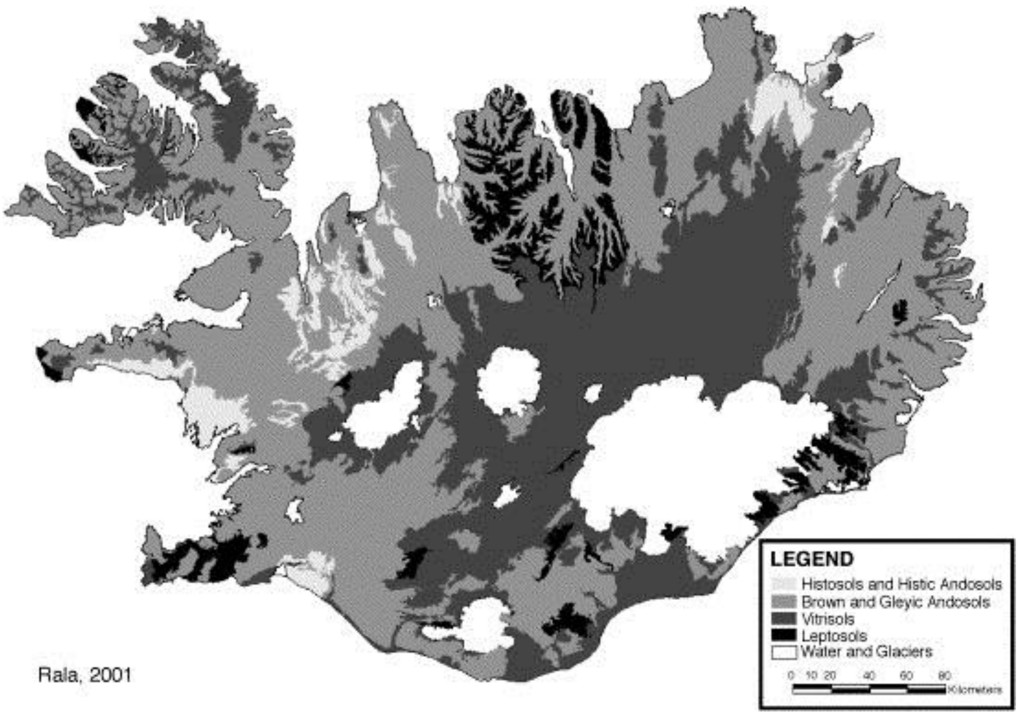


Figure 1.1 A simplified soils map of Iceland based on (Arnalds and Gretarsson, 2001)

1.3.5 Present Vegetation

The current vegetation of Iceland is characterised by shrub and dwarf shrub heaths, mires/wetlands, fell fields and managed hayfields. Lowlands up to about 300m are within the Subalpine vegetation zone (Hallsdóttir, 1996) and where undisturbed should be typified by *Betula* (birch) woodland. Birch woodland, Iceland's natural climax vegetation, and only forest forming species, (Einarsson, 1963; Hallsdóttir and Caseldine, 2005), grows sparsely throughout the country which is today almost devoid of woodland, as a result of severe and rapid deforestation during the settlement period, restricted mostly to the hinterland and in exposed and inaccessible areas (Hallsdóttir, 1987). Experimentation with plantations of exotic tree species since 1899 saw total percentage land coverage of woodland steadily increase throughout the 20th Century , with woodland coverage in Iceland now estimated to cover 1.5% of the total land surface area (Traustason and Snorrason, 2008). Despite this increase woodland coverage remains somewhat insignificant in its percentage coverage in comparison to coverage pre-Landnám Iceland. Above 300m and within outermost coastal reaches in the northwest, north and northeast, arctic alpine vegetation dominates (Hallsdóttir, 1996).

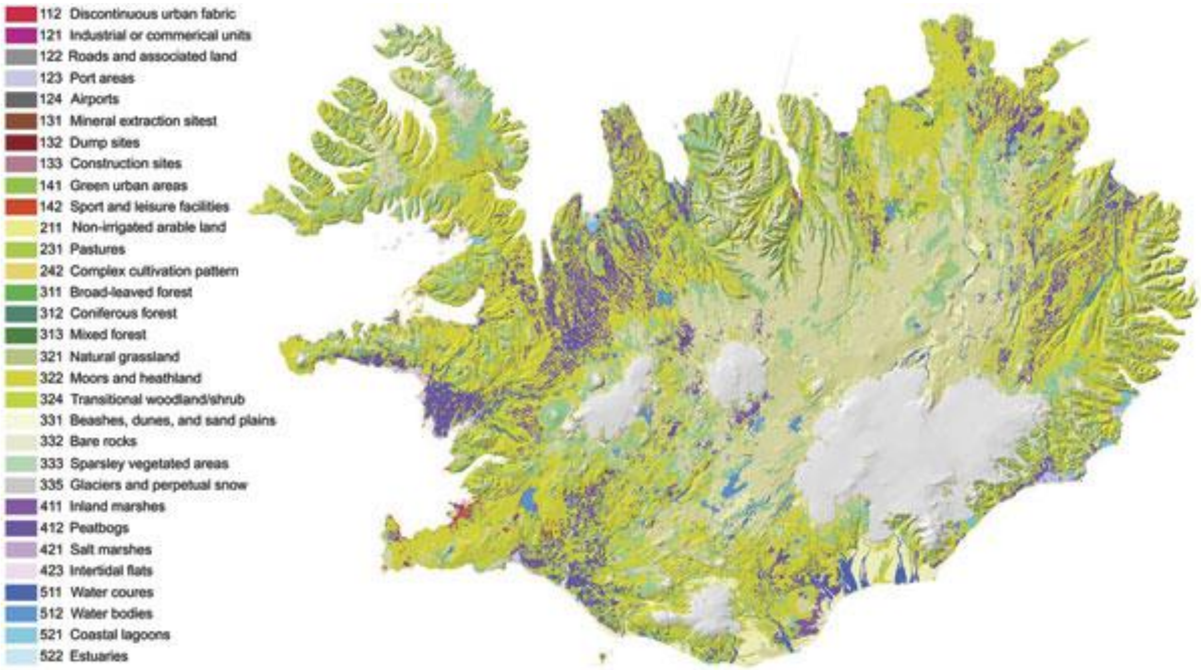


Figure 1.2 2006 CORINE land cover map for Iceland (Árnason and Matthíasson, 2009) showing the key vegetation types. Wetland areas are shown in purple.

1.4 Wet Meadows in Europe, the North Atlantic and Iceland - Current Understanding

1.4.1 General characteristics of Icelandic wetlands and wet meadows

Wetlands cover approximately 23,000km^2 of the land surface area in Iceland, only a small proportion of which is likely to be used in a cultural context, forming most frequently over tertiary bedrock, but also found to dominate large plains of Southern Iceland (Arnalds, 2005) (Figure 1.2). These habitats are divisible into two categories, Flói which are typically topogenic bogs and Hallamýri, mostly precipitation and runoff fed and generally found on hill and mountain sides (Einarsson, 1963). Collectively wet ground, encompassing all wetland types where water reaches the grass roots or floods for at least some part of the year, is referred to as mýrar (mires), with the term also used to describe vegetation on the aforementioned land (Steindórsson, 1975). Despite wet meadows and other wetlands occurring worldwide, those in Iceland are particularly distinctive due to their sedimentary sequences. The two main processes of wetland development include terrestrialisation and paludification, occurring either separately or combined to allow for the formation of peat; it is the presence of this peat (30-40cm depth) that determines classification as mire, (Steindórsson, 1975). This classification however does not apply in Icelandic mires, which tend towards having little or no peat, where mires typically contain less than 35% un-burnable inorganic content (Clymo, 1983; Steindórsson, 1975). This is a result of the mineral enrichment of Icelandic mires through deposition of tephra and aeolian sediment; a product of the active volcanic nature of Iceland and the highly friable Andosols which dominate the landscape. Given the spatially variable deposition of tephra and erodibility of sediments and exposure to agents of erosion, mires will vary throughout the country, peat in the Westfjords for example is generally lower in inorganic material, given limited tephra deposition in this region (Steindórsson, 1975; Tulinius, 2005). Within areas close to sandy erosion deserts inorganic deposition rates are somewhere in the region of 2mm/yr. (Arnalds, 2004), demonstrating their impact on wet meadow soils has the potential to be significant. This rapid minerogenic input is highlighted in the restricted prevalence of organic histosols in Iceland, despite the countries high latitude (63-66^{o}N) and extensive wetland coverage (25%) histosols (>20% carbon in surface horizon) cover 1090 km^2 and Histic andosols (12-20% carbon in surface horizon) 4920 km^2 (Arnalds, 2005).

Despite such different soil characteristics vegetation within Icelandic mires does not appear to be noticeably different, with the exception of a common scarcity of *Sphagnum* (Steindórsson, 1975).

European meadows tend to be characterised by their high species diversity and non-dominance of single species (García, 1992), however due to island biota (Streeter et al., 2015) and latitudinal limitations for vegetation Icelandic wet meadows differ in species richness from their continental counterparts, appearing generally more homogenous, despite this however, the habitats are viewed as rich given grasses grow naturally in very few areas of the country (Ashwell, 1963). Icelandic mires are regarded as hosting up to one third of Iceland's total vegetation (Steindórsson, 1975), despite the latitudinal restrictions to species richness. Wetland vegetation does however vary according to positioning in the landscape and major water sources for the individual wetland.

A specialised symbol was not created for wetlands on Icelandic maps until 1844, where they were represented by small dots, merging into black lines on a blue/green background in the Icelandic Geometric Survey Institute maps (Huijbens and Pálsson, 2009). These wetland habitats are divided into 11 main categories, before further segregations are made according to the 30 plant societies associated with them; in general terms they are known by several names, including Eng (Engi), Mose (Mýri) and Flói, roughly translated as meadows, marsh and fen/swamp respectively (Huijbens and Pálsson, 2009).

1.4.2 How were they used in the past?

With regards to use of wet meadows by early settlers in Iceland and the North Atlantic region as a whole, literature would appear to be somewhat thin. Vasey, (1996) highlights their likely importance in haymaking, suggesting they formed a significant role in this practice until around 1880, yet makes no mention from which period the wetlands are likely to have been used. It is thought despite previous focus on homefields as being the key to successful settlements, wet meadows were potentially used in the production of up to two thirds of the hay resources used to over winter livestock (Vasey, 1996). Given the importance of hay resources in Iceland, it seems unusual these areas to date have received so little attention and it would appear their importance could be underestimated on an extensive scale. Wetlands have been mentioned in a number of early Iceland sagas, where they are represented in often contrasting manners, being viewed in both a positive and negative light. Several sagas mention these areas in an agricultural context. Egil's saga for example specifically mentions these were meadow areas, suggesting their use in grazing:

'*Every spring…. Cattle used to graze on the marsh*' (Eiriksson, 2004; 220).

References to grazing in these areas is also noted in the Laxdæla Saga:

'*the horses were… grazing in (the) meadow down below the fence*' (Magnusson and Palsson, 1975; 133).

In addition to grazing, mowing is also noted in the sagas as occurring in the areas, with an indication of mowing for supplementary winter fodder indicated in Eyrbyggja saga:

'*Today I want you to mow the home meadow and tomorrow we'll gather hay on the ridge*' (Palsson and Edwards, 1989; 131).

In their comprehensive review of the Icelandic sagas, Huijbens and Pálsson (2009) have noted a 'dual use' of wetlands since first settlement on Iceland. Their importance as serving as some of the best hayfields in those areas, subject to cyclical inundation, is often mentioned and hints of the areas having always been used in grazing and cutting are evident; however portrayals of their nefarious nature are also common, particularly with regards to difficulties in passing over the areas. In a European context wet meadows have long been associated with agriculture, including both water meadows, where flooding is engineered by humans and natural flood meadows in low lying sites (Feltwell, 1992), with maintenance of wet meadows for agricultural purposes well documented as common practice in both Scandinavia and the British Isles (Austad et al., 1991; Zutter, 1997). Their primary agricultural roles have included use in grazing – with Feltwell, (1992) describing them as: 'meadows of quality which are abundant and full and make the sheep get fat' and historical sources detailing the lush vegetation as able to support large numbers of livestock. However, wetland meadows are unlikely to have been used exclusively as pasture as cows and sheep grazed purely on wet pasture are liable to contract liver fluke, it is therefore required that a balance is stuck between use of meadows and pasture according to water and seasonality (Haslam, 2003). Instead meadows are shown to have something of a dual purpose in many areas across Europe. For example in Massif, Central France in the Dordonge, Auvergne and Cévennes water meadows are used for both grazing and production of hay crops, grazing for short periods in the summer and subsequently being cut for hay in August. Moving further North, Crickdales North Meadow in Wiltshire is known to have been managed in the same manner for over 800 years, under a system applying to 'Lammas Lands'. Between Lammas day (1st August) and Lady's day (25th March) land is under commons ownership and used to graze livestock, between March and August theses were then under private ownership for use in growing hay crops (Feltwell, 1992). Removal of crops each year has prevented colonisation of the meadows by trees and shrubs, resulting in the continued survival of these meadows to the present day. This dual purpose is also found historically across much of Southern England, in Hampshire the natural flooded fields surrounding the river Avon and found to produce good pasture due to the nutrient rich silts deposited during flooding and the warm waters encouraging grass to grow throughout winter and preventing the underlying soils from freezing (Feltwell, 1992). Here grazing livestock are removed over winter when fields are in their flooded state, in spring drainage is aided by sluices allowing grass to grow, animals can then be grazed or the grass is left to grow and harvested as hay.

Mitchell (1997) stressed the importance of similar meadows in Scotland, describing that prior to the adoption of cultivated grasses and widespread use of introduced fodder crops, bog-hay created from herb rich wet meadow vegetation, seen livestock through harsh winter months. Sedge growth in wet meadows was also found to flush before dryland pasture providing earlier grazing and nutrition for overwintered stock. The wet nature of these areas, particularly when seasonally flooded, would also help in the prevention of overgrazing, discouraging livestock during key growth periods (Zutter, 1997). Throughout the Northern latitudes, especially within Fennoscandinavia, wetlands are well recorded as being utilised in haymaking (Vasari and Väänänen, 1986). Given the harsh nature of Icelandic winters similar uses could have been made of the meadows.

Zooarchaeological and documentary evidence has highlighted the importance of cattle in Norse Iceland. To keep cows milking throughout winter, is necessary for them to be provided with good quality fodder as due to the harsh Icelandic winter they cannot, like sheep and goats, be kept grazing throughout the winter period (Vésteinsson et al., 2002).   Due to the requirements of these cattle, the first settlers were likely to have chosen sites with access to all the resources necessary to support them – in that sufficient summer grazing and more productive areas for production of winter fodder. Vésteinsson et al. (2002) affirms that in medieval time's farm sites tended to cluster around wetland environments, with natural meadows seemingly sought after landscape given their potential for winter fodder growth and production (Vésteinsson et al., 2002). Vésteinsson et al. (2002) indicate those meadows producing the best quality hay, and therefore the meadows most attractive to early settlers were the periodically or permanently submerged meadows of river banks and estuaries which created ideal conditions for the growth of a mixed variety of sedges, producing good quality hay fodder for cattle. Steindórsson (1975) highlighted the importance of the mire vegetation in cultivation, suggesting the greatest proportion of hay crops produced in Iceland up until the 19th century have been produced in uncultivated land, most of which originates in mire tracts. These areas would have been used more intensively in periods of more severe climate. Where the likely sedge based vegetation communities of the wet meadows were to be exploited as hay resources it would be necessary to do so earlier in the summer, as later in the year sedges become more siliceous and less palatable, reducing their value as fodder crops (Hallsdóttir, 1987; Zutter, 1997). Given the wet meadows were often under standing water the growth of mosses within them is often hampered, this adds to the sustainability of hay making as the growth of tall graminids is enhanced by this (Vasari and Väänänen, 1986). Despite the aforementioned importance of cattle, these sedge hays collected in mires are likely to have been more suited to sheep, with cattle known to have difficulties digesting coarse fodder (Bjarnasson and Gudmundsson, 1978).

One of the more extensive tracts of wet meadow is situated within the Mývatnssveit district of Northeast Iceland. High quality meadows are encountered throughout the area, with some of the larger meadows in the region situated within periodically flooded marshland around Reykjalið and in the Framengjar, part of the Kráká delta (McGovern et al., 2007a). In Iceland the association of wetlands with farms is not restricted to the North and North-western peninsula, as is the focus of the current study. In the region of Reykholtsdalur, western Iceland marshland is described as forming 25-87% of the total land area of settlements (Sveinbjarnardóttir et al., 2008), suggested as forming an important winter fodder source; large wetland areas are also present in the south of the country.

Historical practices involving deliberate flooding and irrigation of areas for improved production is noted across much of the sub-arctic region, with the irrigation of grass fields and meadows common practice in all Nordic countries around the mid-19th century (Arneborg, 2005). Irrigation structures are noted in association with a number of Greenlandic settlements, (Buckland et al., 2009; Adderley and Simpson, 2006). Those structures at Igaliku, in the Norse Eastern settlement for example are believed to be associated with a managed wetland area used in the production of hay crops. Similar management systems and extensive irrigation systems are also noted in Norrland, Sweden (Engerlmarks et al., 1976). In this instance however irrigation structures are linked to networks of wooden aqueducts, the timber requirements for which are beyond the natural resource limits for Greenland or Iceland (Buckland et al., 2009). Returning to Sweden, in addition to the irrigation examples note is also made of the watering of naturally oligotrophic bogs, using nutrient rich water alongside manuring to improve yields from these typically unproductive areas (Buckland et al., 2009).

Irrigation systems are also known to have been used in Iceland as a means of nutrient supply to improve fodder crops, and to provide additional insulation for the crops in early summer, protecting them from any late frosts (Buckland et al., 2009; Sveinbjarnardóttir et al., 1982). Specific examples include reports from the 19th century indicating the use of built irrigation systems in Laxa mýri in Northeast Iceland, used to dam river water for the flooding of meadows, increasing their productivity though the rich nutrients supplied by river water (Lárusdóttir, 2006). Laws regarding the construction and use of irrigation channels, illustrated in Iceland's 13th century law book Grágás highlights the practice of irrigation in arable land and meadows from at least this time (Dennis et al., 2000). Zutter (1997) makes further note of irrigation channels, suggesting their frequent enclosure by turf walls and use in the diversion of stream and river water onto land as a means of regulating annual flooding on wetland meadows. The use and maintenance of these meadows in this instance is suggested as forming an important part of farm systems in the medieval cultural landscape, with the sedges flourishing in the flooded areas cut and used as supplementary fodder (Zutter, 1997). Given this knowledge of irrigation systems it may be prudent to suggest naturally occurring wet meadows, with their periodic flooding would perform these activities matter-of-course; enhancing their attractiveness to settlers. In some instances it might also have been preferable to alternate between irrigating and drying the wet meadow areas. Preusser, (1976) suggests an alternation between the two seasonally would work both to improve the productivity of the areas, protecting them from spring frosts through flooding with the key aim to promote the prevention of thúfur, followed by drainage as condition improve, promoting warmer soils and increased vegetative productivity.

1.4.3 Possible Influences on Settlement

Wet meadows may have proven particularly attractive given the dominant nature of Andosols in the country. These soils are highly friable in nature as a result of their silty texture, low bulk density and poor bonding capabilities due to low percentage of clay and organic components; leaving them particularly susceptible to erosion (Simpson et al., 2004). Alongside this inherent susceptibility to degradation, early land management practices and the grazing of large numbers of livestock are believed to have contributed to the post-Landnám landscape scale degradation suffered in Iceland, and for this reason settlers might have had to seek a more resilient soil type upon which to graze livestock or produce the necessary fodder to overwinter them; the highly fertile and organic rich wet meadows would therefore seem idyllic.

Upon arrival of the Norse in Iceland the land was commonly documented as being covered in birch (*Betula sp.*) and willow (*Salix sp.*) scrub and woodland (Dugmore et al., 2005), thus requiring extensive land clearance to allow for the development of settlements. Wetlands and mires however present difficulties for the growth of birch, preventing their growth in these areas or leaving populations vulnerable to even slight pressure (Lawson et al., 2007; Vésteinsson et al., 2002). Wet meadows may therefore have been attractive in that less effort was required to prepare land for settlements, presenting themselves as a valuable addition to any natural resources available to settlers, holding the potential to be valuable for both grazing and fodder production, which as previously mentioned is especially important given the cattle based farming systems. Given associations with open lands, and difficulties for birch growth, Vésteinsson (1998) suggests these areas are liable to have been sought out by the earliest farms. In the late middle ages, the economies of some major estates were based in part on the flooded meadows within their land, Vésteinsson (1998) believes it is reasonable to assume these estates wealth and access to diverse resources centred on their early settlement and choice of location by meadows, increasing the resource base of settlements.

Influence of meadows on settlement locations is also, to some degree supported by place name evidence. With a number of early farms referring to wetland vegetation in their place name, providing some information on how the site might have appeared at Landnám. Place names associated with wetlands are common on major church farms and include names such as – Saurbær, Keldur, Mýri, Seyla and Fitjar (Vésteinsson, 1998).

1.4.4 Other Possible Uses

As the exact use of wet meadows is yet to be affirmed, a number of possibilities for their use remain. Throughout medieval Europe turf was a popular building material cut from local bogs and cultivated field edges; in Iceland turf was preferentially sourced from lowland, organic rich bogs with deep rooting mosses and sedges (Bathurst et al., 2010), with the tough intertwining roots and rhizomes improving its robustness (Steindórsson, 1975). Given the organic nature and bog-type vegetation of wet meadows these might have proven an ideal resource for turf bricks in early settlement.

Alternatively peat in the meadows may have been extracted for fuel use, peat was often extracted alongside turf, demands on use of these as fuel resources would obviously fluctuate with climate and availability of other fuel resources (Hallsdóttir and Caseldine, 2005). It is suggested however peat layers in Icelandic mires are frequently relatively thin, and typically very minerogenic due to the additions of tephra and aeolian material, for this reason they might serve as a poor fuel resource (Steindórsson, 1975).

Prior to the 15th and 16th centuries iron (bog-iron) was also widely extracted from bog ore across Iceland, given high ferric oxide contents within them (Hallsdóttir and Caseldine, 2005; Huijbens and Pálsson, 2009), with this practice demonstrated by excavations across Iceland (Lawson, 2009). This industry was heavily linked to the use of birch charcoal, of which large quantities were required. Availability of birch wood and scrub land would have determined the scale of the industry.

1.4.5 Modern Uses

Wetland areas remain in frequent use across Iceland today, both in their natural and modified states. The Framengjar, an area of wet meadows and ponds (predominantly level and alluvial fens) by the river Kráká in the Mývatnssveit district of Iceland is still adopted in its natural state as a rich grazing resource (Lawson, 2009).

Towards the end of the 19th century agricultural advances have made farming in the meadows easier. Since the late 19th century mowing techniques have been significantly improved, increasing the efficiency in the use of meadows (Friðriksson, 1972). More recently wetlands have been associated with drainage processes, as a means of increasing their agricultural potential. . In Iceland extensive drainage programmes were not initiated on wide scale until the 1920s, becoming more extensive post war with in increased availability of machinery, allowing for creation of mechanically excavated drainage ditches, with this leading to a general replacement of sedges with grass species (Magnússon and Magnússon, Sigurður, 1990). Mires altered through drainage now play an important role in cultivation in Iceland, with a large proportion the land currently under cultivation based on drained mires (Steindórsson, 1975). Former wetlands now also provide large tracts of improved grazing for livestock countrywide, with former wetlands becoming more productive as sedges are replaced by grasses (Friðriksson, 1972; Magnússon and Magnússon, Sigurður, 1990).

1.5 Vegetation History of Iceland

1.5.1 Introduction to Iceland's vegetation history

In the late 12th Century text 'Íslendingabók' (The Book of the Icelanders) Ari the Wise stated Iceland, at settlement, was forested from mountain to coast (Benediktsson, 1968). Scientific assessments since, by means of vegetation modelling and pollen analysis, has to some degree contested this statement, portraying it as an overgeneralisation, suggesting vegetation history in the country has since the last glaciation varied both spatially and temporally, with vegetation community changes prior to settlement more dynamic than previously envisaged (Hallsdóttir, 1995). Despite significant, albeit slow succession and changes in vegetation communities, the actual floristic change prior to the arrival of the Norse, is believed to be somewhat limited, likely as a result of Iceland's isolated, oceanic position. Two species – *Filipendula ulmaria* and *Sorbus aucuparia* are identified as having immigrated at the end of the Boreal (*c.* 10,000-8,500 cal BP) and the Atlantic (*c.* 8,500-5750 cal BP) Chronozones respectively; as well as a few taxa, not identifiable to species level using pollen analysis, occurring post Boreal (Hallsdóttir, 1996).

Prior to Landnám, vegetation modelling simulations suggest over 60% of the land surface had continuous vegetation cover, approximately 15-40% of which was forested, (Ólafsdóttir et al., 2001), by *Betula pubescens*, far less than previously envisaged by scholars, estimates do however vary considerably. With the impacts of settlement, the same modelling simulations estimated vegetation cover to fall from 52% at Landnám to 25% of the total land cover by 1990, during the same period forest cover was estimated as falling from 7% to <1%. These patterns are mirrored by pollen analytical studies, which allow us to interpret patterns across different scales, from regional changes to changes within a single farm.

1.5.2 Pollen analytical Studies - Iceland

Pollen analytical studies are not widespread in Iceland. The technique was adopted for the first time in Iceland by Sigurður Þórarinsson in his 1944 doctoral thesis, analysing pollen samples from peat bogs; the first pollen diagrams from lacustrine sites were published several decades later, in the 1970's. Given Iceland's capacity as an island laboratory, coupled with its late but rapid settlement, palynological studies of human influence on vegetation are particularly interesting, in that initial vegetation evolved without interference from humans or grazing animals, with limited endemic species creating effectively a subset of Palaearctic biota, presenting a wholly natural flora and pristine environment, rapidly impacted by humans. Despite heavy focus on the last 1100 years many studies exist exploring the Holocene vegetation history of Iceland, providing a baseline through which to examine natural fluctuations in Icelandic vegetation since the last glaciation.

1.5.3 Late Glacial to the Preboreal (*c.* 11,500-10,000 cal BP)

The newly deglaciated landscape presented after the last ice age and into the early Preboreal was characterised by sparsely vegetated land, predominantly snow bed and fellfield vegetation (Hallsdóttir and Caseldine, 2005). This vegetation likely colonised the island during the early

Holocene via the ice rafts and flood debris originating from a rapidly decaying Fennoscandinavian ice sheet, with refugia deemed unlikely given the frequency and severity of past glaciations and cold temperature characters of species (Buckland and Dugmore, 1991). Pollen productivity during deglaciation was exceptionally low, with concentrations of <10,000 pollen cm^3 (Hallsdóttir, 1995). Initial herb tundra or fellfield vegetation communities, typical high-middle arctic flora, were rich in Saxifraga oppositifloria, Poaceae, Caryophyllaceae, *Rumex/Oxyria* and *Koeniga islandica*, hardy pioneer species indicating discontinuous vegetation coverage, solifluction and frequent disturbance because of unstable, young soils (Hallsdóttir, 1996; Rundgren, 1995), with slow succession to grass tundra/low arctic heath (Rundgren, 1998a). Succession to low arctic heath was gradual and variable across Iceland, indicating warming climates, with variations across and within regions; two regions in the north for example show differences in succession, with low arctic heath occurring later on the Skagi peninsula (*c.* 10,500 cal BP) than at Flateyjardalur, further to the east (Hallsdóttir, 1990, 1996, Rundgren, 1995, 1998a). Succession of natural vegetation remained slow throughout the early Holocene (Hallsdóttir, 1995), with changes in predominant vegetation communities occurring at timescales of thousands of years.

1.5.4 Late Pre-Boreal to Early Boreal (*c.* 10,000 – 9000 cal BP)

Slow succession during the Preboreal eventually saw the appearance of shrubby taxa and the development of dwarf shrub tundra or low arctic heath, with Salix dominating pollen assemblages (*c.*9800-9700 cal BP) (Hallsdóttir, 1996). Cooling climatic conditions during the Preboreal created hostile conditions for plants, hindering succession of the dwarf shrub and shrub communities (Björck et al., 1992; Hallsdóttir and Caseldine, 2005). Succession did however occur differentially across the country, with dwarf-shrub heath already developed east of Eyjafjördur in the early Preboreal; these differences in spread and succession may be a reflection of differing patterns of colonisations and deglaciation, or alternatively presence of glacial islands (nunataks) aiding vegetation spread (Hallsdóttir, 1996). Towards the middle of the Preboreal dwarf shrub heath was able to successfully expand, with Rundgren (1998) suggesting closed vegetation cover in Northern Iceland at this time.

C. 10,200 cal BP saw the eruption of Grímsvötn and deposition of the Saksunarvatn tephra layer, an important deposit marking the transition from the Preboreal to Boreal Chronozone. The average depth of the tephra was 10cm, sufficient to have a notable impact on vegetation succession and act as a catalyst for decades of environmental instability, with sandstorms and mudflows creating habitats only those plants tolerant of hostile conditions could withstand

(Hallsdóttir and Caseldine, 2005). It is these conditions that are believed to have delayed the succession of *Juniperus communus* in the country, grasses are noted to have expanded following the eruption, but shrubby vegetation is noted as taking 100 years to recover because of complete burial (Eddudottir et al., 2015). Expansion of *Juniperus communus*, as well as other shrub taxa, following this period of instability is notably regarded as the Juniper stage (c.10,000-9,000 cal BP), with much of the country characterised by shrubby and open shrub vegetation, largely *Juniperus-Salix-Betula nana* heath (Hallsdóttir and Caseldine, 2005).

1.5.5 Woodland succession and dynamics during the Late Boreal, Atlantic, Suboreal and Early Subatlantic (*c.* 9500-1200 cal BP)

During these chronozones the most dramatic changes in Pre-Landnám Holocene vegetation occur. Following previously limited presence in Iceland, subalpine *Betula pubescens* woodland is evidenced by pollen and macrofossils, to have expanded within more favourable inland valleys and fjord bottom sites in the central north and south of the country during the late Boreal (Bartley, 1973; Hallsdóttir, 1995, 1996; Hallsdóttir and Caseldine, 2005); with expansion of the species further into the Atlantic Chronozone in western reaches of north Iceland and the northwest peninsula. Following climatic deterioration *c*. 9000-8000 cal BP *Betula* woodland retracted slightly, before once again expanding to more extensive levels than previous (Hallsdóttir, 1996).

Hallsdóttir (1995, 1996) indicates, based on highest relative values from regional diagrams, it is probable *B. pubescens* woodland was at its most extensive during the Middle Atlantic Chronozone around c. 8000-7000 cal BP, with dense coverage of areas across both the north and south of the country, and likely the closest to forested the country has been, with woodland reaching maximum altitudes in the north of up to 500m a.s.l. (Wastl et al., 2001). A regional diagram from Lake Vatnskovatn in northern Iceland produced the highest relative *Betula* pollen accumulation rates of 850-2700 grains $cm^{-2}yr^{-1}$ during this period (Hallsdóttir, 1995, 1996) suggestive of this dense coverage and concurrent with a climate optimum at this time. The extensity of *Betula* coverage includes much of the northwest of Iceland, with a similar lacustrine study from Efstadalsvatn, producing comparable *Betula* influx rates for the same period, with influx rates peaking over 1000 grains $cm^{-2}yr^{-1}$ around 7000 cal BP (Caseldine et al., 2003); here however, it is suggested it is the dwarf species *Betula nana* contributing most toward the *Betula* sum.

Since then peatlands have expanded into areas formerly dominated by woodland and scrubland, and given the pressures on these woodland habitats since (climatic, grazing, clearance) they have had little chance to recover. Hallsdóttir (1995, 1996) describes this 'retrogressive succession' of vegetation within the late Holocene (c.6000-3000 cal BP), where formerly dense woodland became more open and patchy, at the expense of expanding wetland taxa, particularly *Cyperaceae* (Caseldine, 2001), and shade intolerant heathland vegetation (Hallsdóttir and Caseldine, 2005). This demonstrates a natural woodland decline long before the influence of humans, albeit at a much less drastic level; suggesting birch declines initiation by climate deterioration in the Northern hemisphere, but acceleration latterly by humans (Hallsdóttir, 1987). From this initial decline and until settlement, several declines and regenerations of *Betula* woodland are evidenced in pollen studies, with three major expansions of *Betula pubescens* in the late Holocene; these expansions are variable and not witnessed across all diagrams. Declines are attributed to cooling, more humid climate, particularly cooling summer temperatures, volcanic eruptions and edaphic changes in the form of increased instability of soils; the latter evidenced in the Glerárdalur valley southwest of Akureyri, where *Betula* macrofossils were linked to debris flow sediments (5225 ± 75 cal BP) (Hallsdóttir, 1984, 1996).

Considerable debate surrounds these fluctuations due to a mismatch between pollen percentage and concentration values with pollen accumulation rates (influx) within and between sites. In north Iceland the regional diagrams from Lake Vatnskovatn presents downward trends in Betula percentage and concentration values c.6000 cal BP. Influx values for the same profile were however found to have declined in advance of this, at the beginning of the Late Atlantic Chronozone, stabilising around 300 grains $cm^{-2} yr^{-1}$ by c.6000 cal BP, similar patterns of decline are testified to in the South (Hallsdóttir, 1995). It should be noted however these differences may have been influenced by errors associated with calculating pollen influxes, choice of dating level for example might have affected the calculation of sedimentation rates and therefore accurate influx values for each depth (Hallsdóttir, 1996). A further expansion of *Betula* is noted in some diagrams after the Hekla 3 eruption (*c.*2800 cal BP) (Einarsson, 1957, 1961, 1963); Bartley (1973) also noted a similar *Betula* expansion post Hekla 3 at Ytri-Bægisá in the north, where mires had dried out sufficiently for the re-invasion of *Betula*; given the coarse time resolution, less precise dating and large sampling intervals of these early pollen diagrams, accuracy of timing of declines and expansions are impacted, and precisely when the expansion occurred after the eruption is currently unknown. Páhlsson's (1981) studies from the mires at Landeyjar in Lágafell in the south demonstrate a final pre-Landnám expansion event between 1600 and 1050 cal BP. Erlendsson and Edwards (2009) and Edwards *et al*. (2005) also note a final pre-settlement expansion within this time period, linking this to improved flowering conditions and denser woodland coverage in association with short term climate amelioration, during a phase of longer term cooling. The authors note this pattern is seen in several sites across South and West Iceland, but despite widespread prevalence of the species at the time there are no countrywide trends for *Betula* increases, in contrast *Betula pubescens* is witnessed as declining prior to settlement in the majority of diagrams (Andrews et al., 2001; Einarsson, 1957, 1961, 1963).

In summary, the nature of the existing pollen evidence from the last glacial to the arrival of the Norse demonstrates a series of regional variations in vegetation cover and shifting communities reflecting local climatic and edaphic conditions. It is against this backdrop of regional variations and dynamic changes in the vegetation that humans begin to impact the landscape.

1.5.6 Post Landnám vegetation history

In spite of woodlands noted as declining naturally prior to the event, settlement on Iceland played a drastic and rapid role to the detriment of woodland in Iceland, which despite aforementioned overgeneralisations in Íslendingabók (Benediktsson, 1968), did in fact remain a primary habitat type at settlement. Pollen analysis at settlement demonstrated the opening of the landscape further, with woodland replaced by grass heath, dwarf-shrub heath, mires and cultivated land. This change is noted to have occurred over remarkably short time periods, with woodland disappearing from farming areas in the south in around 50 years and a new vegetation equilibrium established by the early 10th century (Hallsdóttir, 1987). Despite evidence for woodland decline prior to settlement this rapid post settlement deforestation is thought to be wholly anthropogenic. Woodland near farms was cut and used for timber and fuel, burned to clear land for farm building and grazing, and used intensively in industry through the use of birch charcoal in the extraction of iron from bog-iron. Continued intensive and extensive grazing to the present day, alongside increased fuel requirements in colder periods has prevented woodland regeneration and opened the landscape further to the fell-field, shrub-heath, mires and hayfields characteristic of the Icelandic landscape presently. Eventually *B. pubescens* regressed to areas either protected by fences or cattle grids (as in Figure 1.3), or those more remote and inaccessible areas.

Figure 1.3 Mature birch woodland within the nature reserve at Þórsmörk, South Iceland. A Good example of one of the few mature woodland fragments found in Iceland today. There is evidence for woodland management post settlement within this area, long after the initial settlement period (Dugmore et al., 2006) demonstrating woodland was not cleared completely in the first few decades post settlement but conserved and managed for long term utilization.

Alteration of woodland habitats is not the only palynological signal of Landnám, although it is noted major changes were in the proportions of existing native species, with no key introduced species acting as indicator species for settlement. Suites of taxa respond to settlement, rather than mass introduction of alien species. In Greenland, for example, *Rumex acetosella* is singled out as the key indicator for Norse presence in an area (Edwards et al., 2011), no species react in this manner in Iceland. A reduction of floristic diversity is often seen as some taxa disappear and monocultures associated with farming activities take over; similar patterns are evidenced elsewhere in the North Atlantic (Erlendsson et al., 2009). Native species characteristic of more open landscapes became more dominant in the pollen spectra, including *Poaceae, Ericales, Gallium, Thalictrum alpinum* and *Cyperaceae*; whilst apophytes flourished and non-native weedy taxa such as *Spergula arvensis, Polygonum aviculare, Urtica sp.* became apparent (Hallsdóttir and

Caseldine, 2005), indicative of disturbance and cultivation practices in the locality. Increased quantities of charcoal are also evident in pollen diagrams post-Landnám; this charcoal would have been produced by domestic and industrial activities, as well as wider scale tree and shrub clearance by burning to create open land for settlements and pasture, this activity is known to manifest itself in the form of charcoal layers and traces of charcoal pits in soil profiles within some farms (Dugmore et al., 2005; Smith, 1995).

It is widely documented that cereal cultivation was introduced and widespread at settlement, promptly becoming restricted to the warmer south and west of the country as climate cooled, until the 15th and 16th centuries when it was abandoned completely (Smith, 1995), with importation prevailing over cultivation from this point. Identification of cereal pollen is therefore a further settlement or anthropogenic signal. However, identification of cereal grains or lack thereof, is by no means conclusive evidence for cereal cultivation onsite. Pollen grain dispersal from cereal species is limited therefore palynological signals for cereal cultivation might be poorly represented, in addition grains are often frequently indistinguishable from wild-type cereal grains, and so where encountered cannot be confidentially determined as domestic cereal crops. Cereal grains have been identified within a number of palynological records from early settlement, amongst those Einarsson (1963) in his investigations at Skálholt, southwest Iceland discovered *Hordeum* type grains associated with the Landnám tephra layer, interpreting this as cultivation from early settlement. Hallsdóttir, in her 1987 thesis has similar findings of cereal grains in and around the Landnám tephra, again attributed to early cereal cultivation; within two sites – Vatnsmýri and Mossfell, *Hordeum* grains were discovered immediately below the Landnám tephra, Hallsdóttir (1987) in this instance implies the possibility of earlier settlement by Celtic Hermits, lack of archaeological evidence to support this, and the possibilities of *Hordeum* type pollen derivation from Lyme grass (*Leymus arenarius*) questions the probability of this. In attempts to distinguish between *Hordeum*-type and Lyme grass, authors latterly began to make more conclusive identifications based on context (Riddell, 2014). At Stóra-Mörk, Vickers *et al.* (2011) ascribes pre-Landnám *Hordeum*-type to Lyme grass, given the absence of other cultural indicator species and the open environment which is beneficial to the species; the author suggests likelihood of *Hordeum* presence post-Landnám given its association with woodland decline and the increased presence of apophytes and species linked to cultivation; it would be sensible to employ similar diagnostics at other sites. Longevity of barley cultivation is limited and for a variety of reasons. Zori et al. (2013) in their investigations at Hrísbrú link cessation of barley cultivations to cooling climates as the Medieval Warm period ended, landscape deterioration and declining power of chieftains, with arable farming becoming too costly to maintain with the cost of labour increasing and importations becoming easier.

The transition from pristine to heavily anthropogenically altered landscapes has resulted in a number of authors choosing to focus on human influence on vegetation as the main objective of their research. Þórarinsson's (1944) doctoral thesis presented the first focus on this matter, followed by the work of Einarsson (1963) and Páhlsson (1981) before significant enhancement of the knowledge of this subject in the eighties and nineties by Hallsdóttir (1982, 1984, 1987, 1992, 1993) and Zutter (1997). In more recent decades knowledge has been furthered through a series of published research articles (Andrews et al., 2001; Eddudóttir et al., 2016; Gathorne-Hardy et al., 2008; Lawson et al., 2007; McGovern et al., 2007b; Vickers et al., 2011) and unpublished undergraduate and master's thesis' (Colquhoun et al., 2010; Dixon, 1997; Nichol, 2014; Riddell, 2014). Studies also include those where pollen samples were extracted from archaeological features onsite (Sveinbjarnardóttir et al., 2007; Zori et al., 2013), including midden and floor deposits as a means of investigating vegetative components directly linked to archaeology. This thesis will therefore provide a further three high resolution study sites as an addition to the growing body of knowledge regarding anthropogenically enhanced landscapes in Iceland. These new studies build on the best approaches to understanding vegetation dynamics at the farm scale, and are unique in that the central focus of their analysis is on the cored wet meadow systems themselves, and their use and management in a cultural context. Given the sampled meadows locations in the homefields of the cases study farms, the studies will be ideally suited to providing insights into farming and landscape processes within the sites.

Despite widespread belief of rapid deforestation impacting the entire country there is an emerging body of evidence suggesting more delayed and muted anthropogenic signals at settlement initially. The original idea that birch woodland was extensive prior to and reduced rapidly after Landnám is based largely on documentary evidence and early pollen diagrams. These diagrams (Hallsdóttir, 1987) are being criticised because cores have been extracted from peat bogs and therefore are not representative of the wider environment, with pollen recruitment from a smaller catchment likely to weaken any signals for birch growing elsewhere in the region. A number of those sites investigated have also focussed within the vicinity of known Landnám farms, in areas likely to have been the first regions impacted, reducing the likelihood of woodland pollen assemblages on more remote sites being identified (Lawson et al., 2007). Peat bogs also present challenging conditions for *Betula*, a species vulnerable to environmental and human impacts; localised stress might therefore be easily picked up within these sediments, particularly where pollen recruitment from the wider landscape is likely to be low. In a contrast to a majority of palaeoenvironmental studies showing large scale destruction, deforestation and landscape instability immediately after Landnám, some are suggestive of variable amplitudes and timings of anthropogenically enhanced environmental change, with complex linkages to climate, landscape and vegetation as well as cultural factors, highlighting the spatial and chronological complexity of vegetation changes, and the subsequent research requirements for more high resolution data at local and regional scales (Vickers et al., 2011). At Stóra-Mörk, in the South of Iceland, the initial impacts of settlement are somewhat subdued initially, with human impacts becoming more visible in the palaeoenvironmental signal and causing shifts in vegetation and insect assemblage some 50 years after initial settlement. This has been linked to the possibility the first settlers avoided labour intensive woodland clearance, settling in natural clearances first. Alternatively the woodland here might have been managed as a resource, prolonging its presence in the palynological record (Vickers et al., 2011). Similar patterns of more gradual and localised deforestation, with pollen and documentary evidence for woodland resource management are found in the Mývatnssveit region of northeast Iceland (Lawson et al., 2007; McGovern et al., 2007a). Lawson et al. (2007) in their Mývatnssveit regional study describes, in contrast to abrupt falls in *Betula* immediately post-Landnám in the majority of previously studied sites, a steadier decline in *Betula*, occurring from Landnám until 1300 AD, this *Betula* was steadily replaced by acidophilic taxa, such as *Empetrum nigrum* and *Sphagnum*, again this is in contrast to the more typical patterns of widespread expansion in grasslands post-Landnám; these patterns give an overall impression of vegetation stability both pre- and post-Landnám. In less densely populated areas changes in woodland coverage are thought to be more subdued; Friðriksdóttir (1973) found in her interior highlands field site *Betula* was in abundance up until C. 1300 AD. It should also be noted a number of sites were relatively unwooded pre-Landnám, within which palynological settlement signals were muted and more difficult to demarcate. Ketilsstaðir, a coastal site in the south of Iceland for example is believed to have been largely unwooded and relatively open prior to settlement, remaining so to the present day, as indicated by low relative and absolute values for tree and shrub taxa, likely as a result of the sites coastal positioning and exposure (Erlendsson et al., 2009). Major vegetation changes at Landnám within this site are therefore not attributed to woodland clearance but to changes in hydrology as a result of settlement, disappearance of grazing sensitive species, and effects of tephra deposition on bog surface drainage, whereby dryland taxa were favoured (Erlendsson et al., 2009). Akin to Ketilsstaðir, a core from the fjord Reykjarfjördur, in the northwest peninsula, shows relatively open vegetation within the coastal site prior to and after settlement (Andrews et al., 2001). Such areas to date have received little research effort, with preference of focus on sites sustaining *Betula* woodland.

1.5.7 Contributions to current palynological knowledge

Despite a growing body of research related to the vegetation history of Iceland studies are relatively limited (compared to continental Europe) and biased spatially. Much of the current palaeoenvironmental research in Iceland is focussed on the generally more accessible South and West of the country (Figure 1.4); with these regional biases occurring as a result of presence of initial settlement farms and accessibility of sites. Inferences from palynological studies are therefore based on a somewhat spatially restricted dataset, with a focus on early settled sites perhaps influencing the generally accepted views of intense deforestation and environmental degradation following settlement, highlighting the need to eliminate biases. More areas have now been investigated, as seen on the map (Figure 1.4), exposing regional differences in human and natural forces on the landscape, and highlighting areas requiring future research. The central highland desert and south-eastern Iceland host a particular scarcity of pollen records, this is reflected in the scarcity of suitable lakes and mires, especially where sandur plains dominate the landscape (Streeter et al., 2015). The northwest peninsula has also received little research effort to date, particular with regards to the human impacts of Landnám in this area. Mývatnssveit, despite over a decades intensive archaeological focus, has received relatively little palynological attention. Multidisciplinary focus on this region is relatively contemporary, and presently there are only one regional (Lawson et al., 2007), and two site specific studies (Colquhoun et al., 2010; Nichol, 2014), these localised diagrams were the focus of a masters and undergraduate respectively, and therefore lack the resolution required for an in-depth study of the sites in question. Given the current limited extent of research in these regions, Mývatnssveit and the Northwest peninsula were selected as focal areas for the current study, with locations of the three new sites marked alongside all existing pollen analytical studies on the map (Figure 1.4).

A further issue with pollen analysis in Iceland lies in the lack of information regarding the taphonomy of Icelandic pollen, particularly given the importance of aeolian transportation and its effects on sedimentation rates and the resultant conditions created for pollen preservation. This means it is difficult to rely on pollen data alone in drawing reliable conclusions from palaeoenvironmental data (Lawson et al., 2007). In an attempt to address this issue this study therefore adopts micromorphology as a complementary method, with the intention of improving the reliability of conclusions drawn from any results.

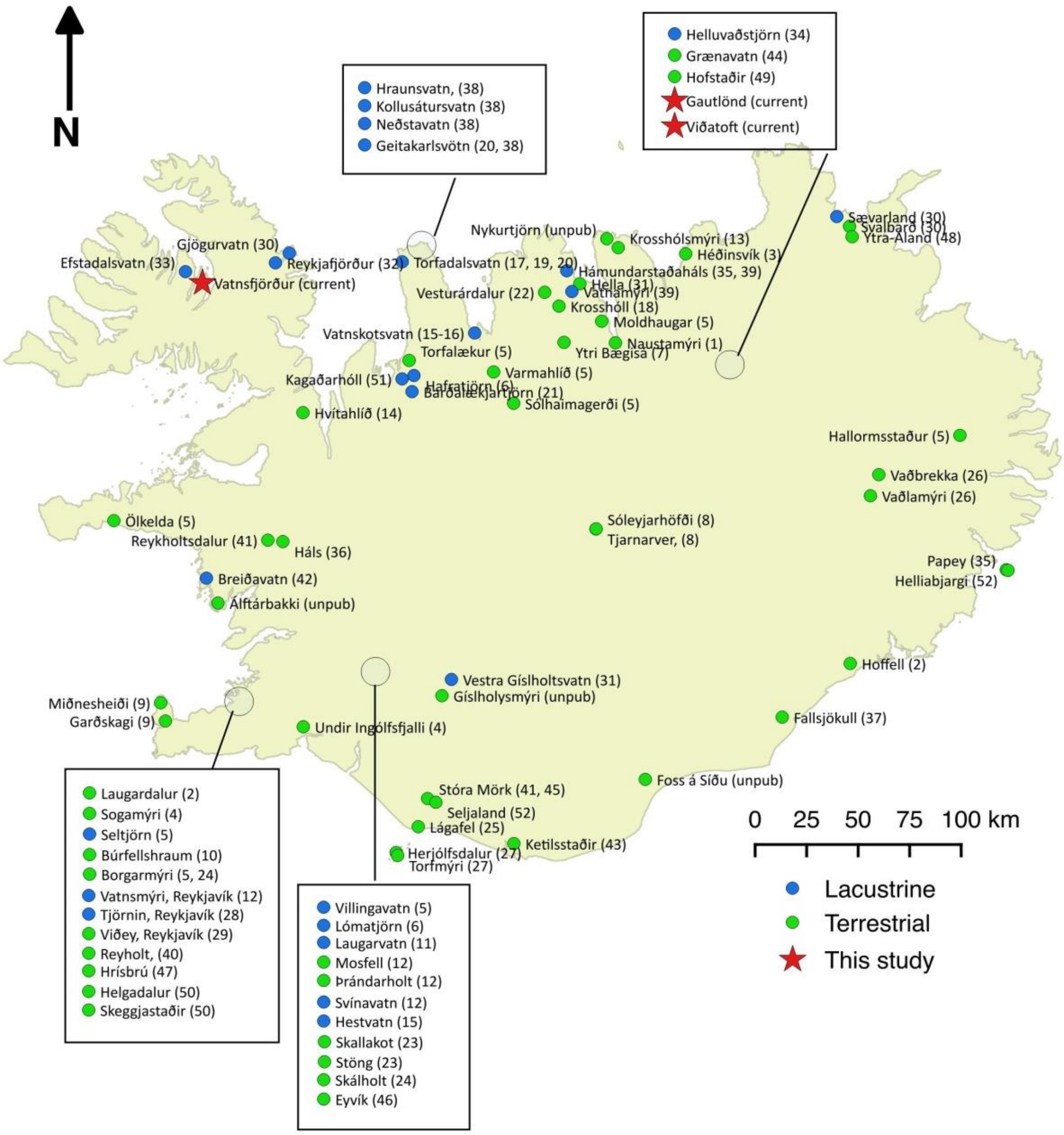


Figure 1.4 Holocene pollen sampling sites in Iceland adapted and updated from Hallsdóttir and Caseldine (2005), including study sites for this thesis. Locations are approximations. Numbers by site names refer to references in Table 1.1.

Table 1.1 References for sites listed in Figure 1.4.

Map Reference number	Reference	Map Reference Number	Reference
1	(Þórarinsson, 1955)	2	(Okko, 1956)
3	(Straka, 1956)	4	(Einarsson, 1957)
5	(Einarsson, 1961)	6	(Vasari and Vasari, 1990)
7	(Bartley, 1973)	8	(Friðriksdóttir, 1973)
9	(Skaftadóttir, 1974)	10	(Sigþórsdóttir, 1976)
11	(Schwaar, 1978)	12	(Hallsdóttir, 1987)
13	(Hallsdóttir, 1991)	14	(Hansom and Briggs, 1991)
15	(Hallsdóttir, 1995)	16	(Hallsdóttir, 1996)
17	(Björck et al., 1992)	18	(Caseldine and Hatton, 1994)
19	(Rundgren, 1995)	20	(Rundgren, 1998b)
21	(Eddudóttir et al., 2016)	22	(Wastl et al., 2001)
23	(Þórarinsson, 1944b)	24	(Einarsson, 1963)
25	(Páhlsson, 1981)	26	(Hallsdóttir, 1982)
27	(Hallsdóttir, 1984)	28	(Hallsdóttir, 1992)
29	(Hallsdóttir, 1993)	30	(Zutter, 1997)
31	(Hallsdóttir and Caseldine, 2005)	32	(Andrews et al., 2001)
33	(Caseldine et al., 2003)	34	(Lawson et al., 2007)
35	(Buckland et al., 1995)	36	(Dixon, 1997)
37	(Rose et al., 1997)	38	(Rundgren et al., 1997)
39	(Caseldine et al., 2006)	40	(Sveinbjarnardóttir et al., 2007)
41	(Erlendsson and Edwards, 2009)	42	(Gathorne-Hardy et al., 2008)
43	(Erlendsson et al., 2009)	44	(Colquhoun et al., 2010)
45	(Vickers et al., 2011)	46	(Karlsdóttir et al., 2012)
47	(Zori et al., 2013)	48	(Karlsdóttir et al., 2014)
49	(Nichol, 2014)	50	(Riddell, 2014)
51	(Eddudottir et al., 2015)	52	(Edwards et al., 2004)

1.6 Settlement and Settlement Processes

Iceland is believed to have been discovered around AD 860 by sailors blown off course on a voyage to the Faeroes, the initial discovery was followed by exploratory voyages to gather information on the countries resources, subsequently followed by colonization voyages from Western Norway and the British Isles (Smith, 1995). Discovery of the new land was particularly welcome at this time due to political and economic problems in the homelands of Norway (Hermanns-Auðardóttir, 1991), from where the majority of settlers originated from. Despite frequent references in the ancient Icelandic literature, there has been no solid evidence, despite extensive research efforts, of Irish hermits, thought to be based in the country before the quoted dates for settlement. This suggests if these people did exist their impacts on the land were minor, perhaps due to limited and sporadic presence or seasonal presence (Vésteinsson, 1998).

Landnám, the initial settlement of Iceland by the Norse is traditionally dated between AD 870 and AD 930 (Smith, 1995). Much of the knowledge of settlement on Iceland comes from ancient texts, for example Íslendingabók (book of Icelanders) (Benediktsson, 1968), the earliest account of settlement; and Landnámabók (book of settlement) an elaboration of Íslendingabók, detailing settlers, farmsteads and land claimed (Smith, 1995). However, these texts are not to be relied upon; as McGovern et al., (2007a) express, much of the information is oversimplified, politically manipulated and was written around three hundred years after the events. Archaeological and scientific research is therefore needed to study Iceland in more detail and produce more reliable data regarding the settlement of the country. Archaeological evidence, in the form of both artefact typology and stratigraphical positioning of artefacts, in association with dated tephra layers, suggest settlement on Iceland as beginning around AD 871. The mapped presence of the *Landnám* tephra, found all over Iceland, with exception of some areas in the far West and Northwest of the country, is crucial to the dating of Landnám in Iceland given its close association with settlement archaeology, and its secure dating via ice core data (Grönvold et al., 1995) to AD 871±2, demonstrating close correlation with referenced dates for settlement in historical documents. Archaeological evidence for settlement is, with few exceptions (3 sites in Southern Iceland (Vésteinsson, 1998)), situated directly above the Landnám tephra, in this respect evidence supports the documentary resources available describing the process of settlement. To date almost all of the medieval sites investigated in Iceland are situated just above the Landnám tephra, including sites both in land and on the coast, suggesting settlement commenced shortly after AD 871±2, but did so countrywide, with the entire country rapidly inhabited by the mid-10th century (Vésteinsson, 1998), in support of suggestions in Landnámabók this occurred within 60 years (Benediktsson, 1968).

The expansion into this new country was largely based on the establishment of agricultural systems. Settlement brought with it the systems of land organization and management that settlers would have been familiar with from their homelands of Norway, and the colonised areas of Orkney and Shetland. Foundations for subsistence based local economies were set by the organisation of land in manner meeting the grazing requirements of livestock, and fuel requirements of settlements (Simpson, 2009). The choice of initial settlement sites was largely dictated by the environmental conditions of the land. Accessibility was a key factor in determining locations of Landnám farms, driven particularly by the specific needs of the pastoral farming systems at the centre of both the economy and food production (Smith and Dugmore, 2006; Vésteinsson et al., 2002). However 'ideal' farm settlement models were not applicable in every part of the county; in the Westfjords for example, landscapes lack flat areas preferred for farming, in this instance the economy would be reliant on other sources for income, such as fishing and coastal and marine resources. Initial settlements were therefore centred around an assortment of resources. Farms favoured good access to the sea for marine resources, not covered by dense woodland but with timber supplies available for fuel, access to good pasture and meadows to sustain livestock, access to a variety of wild resources, access to good water sources and to good hunting ground (Vésteinsson et al., 2002). Large estates often contained all of these features and ended up becoming important political centres, occupied by chieftains and typically hosting a parish church (Vésteinsson et al., 2002).

As previously mentioned Vésteinsson (1998) in one model of settlement suggests natural clearances were sought out, with the favouring of sites on or adjacent to marshy grasses settled first, given the unlikelihood birch would encroach on these wet areas and likely highlighting the importance of mires and clearances for winter fodder. These were seen as advantageous given the relative speed at which farmsteads could be set up, and lack of effort required to clear areas prior to settlement. As this prime land was claimed secondary settlements demonstrated patterns of establishment in less accessible areas, specifically woodland sites (Simpson et al., 2001; Vésteinsson, 1998). Despite clearances being sought out it is likely these would be nearby a woodland of sorts, with these regarded as an important resource in themselves, as sheltered pasture land and a source of firewood, charcoal and construction timber (Vésteinsson, 1998). As land was claimed settlements were established in some regions regarded as being on the limits of agricultural viability, a number of these farms were later abandoned. Rapid settlement of the Þórsmörk area in southern Iceland for example saw the wooded areas rapidly settled in the 9th century and largely abandoned by the 13th century, as a result of extensive environmental degradation – as is frequently linked to farm abandonment (Dugmore and Buckland, 1991; Dugmore et al., 2006; Sveinbjarnardóttir, 1991). Latterly socioeconomic factors are linked to abandonments (Dugmore and Buckland, 1991).

The sea also played a role in the location of early Icelandic settlement, with access to the sea important for marine and coastal resources. Such resources include driftwood, walrus, whales, and fish, with fishing one of the key elements of the Icelandic economy, remaining so until today. Areas suitable for hunting appear also to have been sought out by early settlements, with hunting and fishing likely to have been used to subsidise animal husbandry (Vésteinsson, 1998). Early inland settlements also existed, with reliance here on alternative resources. Mývatnssveit for example used the richness of the freshwater aquatic ecosystems, and the dominance of Lake Mývatn, as a means of compensation for its isolation from the coast (45km) and the wealth of marine and coastal resources offered by settlement locations there (Lawson, 2009). Midden excavations at Hofstaðir, a high status farm near Lake Mývatn, alongside domestic animal bones, revealed large quantities of freshwater trout bones, bird bones and eggshell fragments, suggesting despite the basis of the economy on products of animal husbandry, this was heavily subsidised by local wildlife (McGovern et al., 1996, 2006; Vésteinsson, 1998).

The importance of quality of land and access to natural resources was evidently vital to the self-sustaining farm systems across Iceland making it a key driver in site selection. The application of palynology and sedimentary analysis in this thesis will therefore be of importance in exploring the potential of soils and sediments within the farms and palynology has the power to provide detailed information on the available natural resources surrounding the farm (Erlendsson et al., 2006), through reconstructions of the vegetation cover within and beyond the settlement period.

1.7 Farming and Farm Systems in Iceland

Each farmstead and its landholdings developed as a social unit (Hastrup, 1989), shaping the land using technology, practices and perceptions from the home countries, utilising this landscape for the provision of natural resources to sustain the agricultural and pastoral economies. The Norse farming techniques were centred on an infield-outfield faming system, associated with a system of seasonal transhumance with grazing occurring in the uplands during the summer months. Grass for haymaking and grazing formed the primary crop in Icelandic agriculture, with pastures, cultivated hayfields and fertile meadows forming important aspects of the farmscapes (Bergthorsson, 1985; Friðriksson, 1972), with these key aspects outlined in Figure 1.5. Limited arable cultivation took place in the early centuries following settlement, principally in the warmer south of the country. Most evidence associated with arable agriculture in medieval Iceland is linked to barley cultivation, and this is frequently associated with high status sites (Riddell, 2014; Zori et al., 2013). Any established arable production was marginal and subsistence level, with production even at this level abandoned by the 14^{th} century in association with climatic downturns (Amorosi et al., 1996; Simpson et al., 2002; Smith, 1995).

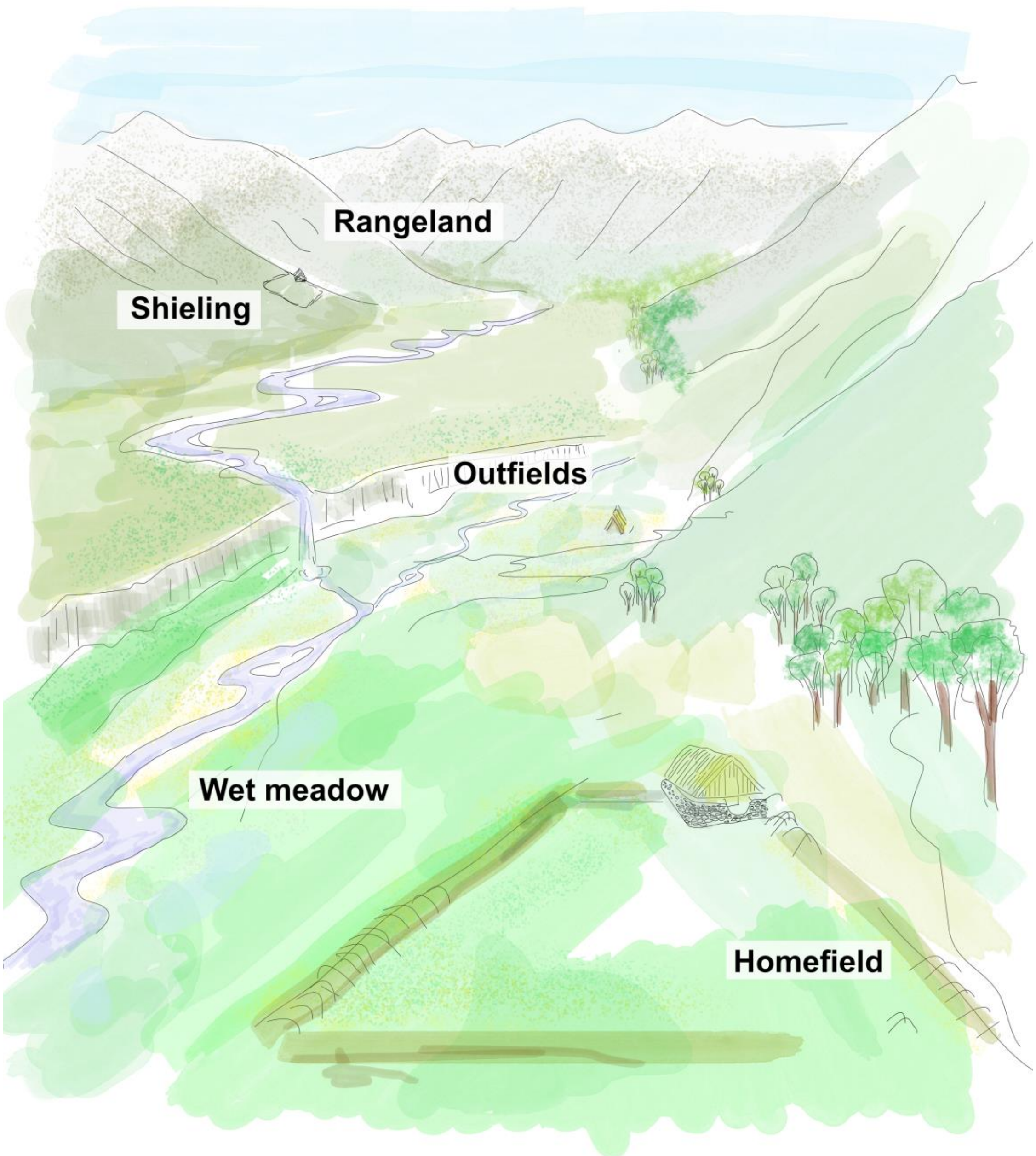


Figure 1.5 An illustrated example of a typical Norse farmscape, highlighting the key elements of the farm system as introduced in Iceland.

The Norse settlers brought with them sheep, goats, cattle, horses and pigs; with the pigs and goats phasing out soon after settlement given their naturally destructive natures and the focus on farming activities around dairy production (McGovern et al., 2007a). Some pigs did remain in Iceland into the early modern period, however they became exceptionally rare following AD 1200 (Brewington et al., 2015). Introduction of these grazing terrestrial animals to a sensitive landscape proved exceptionally destructive, initiating erosion rates far higher than those experienced prior to Landnám, with erosion levels remaining high in some areas to the present day (Dugmore and Buckland, 1991).

The homefield, infield or tún, is the enclosed and intensively managed area adjacent to the domestic dwelling in Viking settlements within which the primary function was to produce winter fodder for the domestic livestock, but variably used for grazing, hay meadows and cereals (Adderley et al., 2008). These are regarded as perhaps the most important element of the farm system, with the success of farms dependant on the management of, and sustainability of food resources produced within them (Adderley et al., 2008). These areas were particularly important given the needs of the dairying economy to keep cattle milking and quality winter fodder requirements associated with the inability of cattle to be grazed outdoors in the harsh Icelandic winter (Vésteinsson et al., 2002). Given their importance it was necessary to manure these areas, typically using barn and household waste to maintain their fertility and associated productivity.

Outfields, typically natural meadows and grass heaths, often enclosed to protect resources from grazing livestock, acted as the primary source of winter fodder up until the 19th century, with manured homefields only playing a small role in this respect (Hallsdóttir, 1987). Hay grown in these areas however is likely to have been of lesser quality than that grown in the homefields, it would therefore have been necessary for livestock to consume more, in order to maintain their energy requirements, Simpson, (2009) suggests the likelihood this hay was more difficult to dry and store properly. Climatic deterioration lead to the need to exploit further resources for the production of winter fodder, wetland areas were therefore exploited by intensive mowing, with those containing *Carex nigra, Carex lyngbyei, Carex canesans* and *Carex rostrata* preferentially selected because of the palatability of these species prior to blooming (Hallsdóttir, 1987); this land use is evident through to the present day.

Outfields generally contained a series of enclosures, serving a multitude of farming activities, including segregation of animals for weaning, shearing or sorting of livestock (Aldred, 2008). Cultivation, activities such as peat and turf cutting for fuel and construction were also frequently carried out in these areas as well as the grazing of certain animals – typically cows, and more vulnerable sheep. These areas tended to host more natural forested and open meadows, wetlands and grass and ericaceous heaths, and were fenced off to protect from livestock, in times when they were to grazed elsewhere (Hallsdóttir, 1987).

A key aspect in the organisation of available land is the provision of suitable land to fit with the seasonality of grazing requirements, with winter and summer grazing occurring within different parts of the farmscape in different seasons. Cattle farming and sheep husbandry were also practiced differently given the animals differing requirements. Cattle were generally grazed close to the farm in the summer for easier milking, with grazing continued in the farm outfields into the winter, stalling the cattle in byres when conditions became too poor outdoors.

During the summer months sheep were grazed in the mountain pastures, mostly above 300-400m (Hallsdóttir, 1987), also known as rangelands or affréttir, some privately owned but the majority were managed as common land and heavily regulated. A necessary system given the low biomass production of Icelandic vegetation, and resultant requirements for large grazing areas (Simpson et al., 2001). Rangeland vegetation typically consisted a mixture of dwarf-shrub heath, willow heath, grasslands and mires, with this found to be preferential to areas of dense birch scrub, which is detrimental to wool production, with sheep found to tear their fleece on this vegetation (Hallsdóttir and Caseldine, 2005). Given the altitude however, floristic diversity within the rangelands tended to be low (Hallsdóttir, 1987). These affréttir were owned by hreppur's - municipalities of over 20 farmsteads whom organised the common grazing resource and collaborated in the autumn for the roundup of sheep, before their movement on to winter pastures. In some instances lambs or sheep for imminent slaughter were kept in pastures closer to the farms. Winter grazing areas away from the main farm, yet within estate boundaries often shared between dependant farms, were also used in the management of sheep. A primary objective here was to maximise the use of available land and biomass, and protect hay resources, as far as possible, to reserving them for cattle. These areas were in use from September, where they would be kept outdoors as far as possible before bringing sheep back on to the affréttir the following May (Simpson et al., 2004).

Within the summer grazing areas a series of semi-permanent, seasonally occupied, structures or shielings were created, often associated with small enclosures, for grazing milking livestock and in support of the transhumant farming practices operating in Iceland (Aldred, 2008). These were normally situated within the outfields, on the edges of estates and at relatively high altitudes away from the main farm dwelling (Brown et al., 2012); by law they had to be within the farm boundary and could not be situated in the common grazing area (affréttir) (Dennis et al., 2000; Sveinbjarnardóttir, 1991) . Activities associated with these shielings include the milking of livestock and production of dairy products (butter, skyr and cheese); for these activities to be carried out successfully it was necessary a number of people would reside in the shielings throughout summer (Brown et al., 2012; Sveinbjarnardóttir, 1991). Later a number of these shielings were established as farms in their own right, with a number of shifts seen between shielings and farms in some areas (Sveinbjarnardóttir, 1991).

1.8 Farm management adaptions

Given Iceland's position close to the polar and oceanic fronts, associated climate systems and nature of Icelandic biota are marginal for farming activities and as a result it has been frequently necessary to adapt management techniques accordingly as a means of maintaining vegetation productivity. Understanding farming land management practices in Iceland is key to unravelling the increased incidences of land degradation following *Landnám*, and given their association with agricultural production, management systems were frequently the key to success of settlements, given the production requirements to support settlements (Adderley and Simpson, 2006). Those practices adopted are frequently confirmed as major causal factors in rapid landscape degradation although adaptive practices are noted throughout the North Atlantic (Simpson et al., 2004), conserving to some extent the fragile landscapes and improving yields in soil condition that might not be considered ideal. The land management practices as adaptions to sediment conditions are now well understood in parts of Iceland and across the North Atlantic, with practices from Norway and the Northern Isles frequently adopted and adapted for use in the soils of the more recently settled Iceland, the Faroe Islands and Greenland.

In Greenland, as well as a cool climate and naturally short growing seasons, the free draining nature of sediments and associated incidence of summer drought also limit agricultural productivity (Adderley and Simpson, 2006; Buckland et al., 2009). In order to maintain grass yields capable of sustaining livestock, adaptive farming practices, typically involving irrigation were mandatory, with irrigation still required periodically today to ensure grass production at a level suitable to sustain sheep populations (Arneborg, 2005). Adderley and Simpson (2006), using a modelling approach, quantified the requirements for irrigation in Greenlandic homefield's, using a combination of soil properties (physical, chemical and soil-water hydraulic data) and climate data. Results suggested frequent irrigation was required to maintain productivity throughout the Norse settlement period and to the present day. Irrigation was required particularly in those years with warm winters, which increases the length of growing seasons and the associated demands on soils; deficits were also noted in exceptionally cold winters, despite shorter growing seasons (Adderley and Simpson, 2006). Settlement induced erosion was noted as further enhancing irrigation requirements, resulting from associated reductions in soil organic matter and soil thickness with soil losses.

Palaeoentomological and archaeological evidence from Igaliku, Eastern Greenland demonstrated a system of irrigation, supplemented by manuring with household and byre waste in order to improve the water holding capacity and productivity of sediments through the effective creation of very wet eutrophic hayfields (Buckland et al., 2009). Similar systems of historical adaptive management are known across Greenland, with irrigation channels noted in farms within both the Eastern and Western settlements (Arneborg, 2005). The hayfields within the settlement at Gården under Sandet, also in the Western settlement, for example were managed under a similar plaggen like system, as means of enhancing productivity in spite of natural drought conditions experienced in sediments (Buckland et al., 2009; Schweger, 1998). Comparisons have also been made between those water management systems uncovered at Igaliku, and systems witnessed in Norway where irrigation of both grass fields and cornfields are known from at least the 16th century (Arneborg, 2005), post-medieval England and the Swiss Alps (*c*.13th century). To this end it is suggested settlers brought with them to Iceland and Greenland a knowledge of agricultural management of soils experiencing water deficits, and that adaptive practices were not local developments, but introduced by settlers already familiar with the methods, adapting them to the new land systems (Arneborg, 2005; Buckland et al., 2009).

Irrigation systems were also found associated with manuring practices in some parts of Greenland, in an attempt to buffer against cooling climatic conditions as well as periods of drought. At Sandhavn in Greenland's Eastern settlement, Golding et al. (2014) provides evidence for irrigation systems, complemented by manuring 'recipes', for the management of fertility and erosion in the homefield. Resources were limited in the settlement, and to this end the homefield was split, managing one area sustainably using mixtures of turf, animal manure and domestic waste, rationing the available resources, whilst the other area was managed in an unsustainable manner, with macro nutrient content increasing and declining respectively.

At the Norse farm Hov, in Suðuroy in the Faroe Isles, the key limitations for agriculture are noted in the inherent lack of soil moisture and ongoing wetting and drying processes. Cultural amendments akin to raised bed systems in southwest Norway and the Northern Isles were identified with the farms infields, adapting the historical land management practice as a means of improving the water holding capacities of agricultural sediments, rather than an amendment to improve soil fertility (Edwards et al., 2005a). Such practices were believed to have been adopted as a means of improving cereal yields and hay yields to sustainable levels to cope with those years experiencing climatic downturns.

In Iceland, key limitations for cultivation and pastoralism lie in the fragility of soil resources. Soil degradation studies in the summer and winter grazing areas of the Mývatnssveit region suggest spatial and temporal variation in the susceptibility of areas to erosion, enhanced by grazing (Simpson et al., 2001, 2004). Evidence for adaptive management practices exists for both of these areas. Within the summer grazing areas it has been suggested through use of grazing models, available biomass is likely to have always be significant to support the documented number of livestock at any given time (Simpson et al., 2001). However, given historical evidence for degradation it is suggested instead this degradation was accelerated by a failure to adapt the conditions in the grazing areas through lack of appropriate shepherding by, for example not spreading the intensity of pressure across the entirety of the grazing areas, or failure to remove livestock from the pastures after the end of the growing season (Simpson et al., 2001). It is believed the occurrence of the degradation was the result of an initial lack of cultural knowledge regarding landscape sensitivities, coupled with environmental change which had the potential to weaken land management practices previously found to be successful (Simpson et al., 2001).

In winter grazing areas Simpson et al. (2004) recognise the likely occurrence of grazing management practices to control and minimise degradation in these sensitive areas. At their study farm Hofstaðir, degradation is shown to reduce following increases in regional rates after Landnám, with landscapes stabilising locally shortly after, to levels of degradation below the regional average. The increase in degradation following settlement would appear to be caused by an initial mismanagement of the land through overgrazing in the sensitive landscapes. In the succeeding years, associated with diminishing rates of degradation, it would appear the farmers understanding of these landscapes improved, leading to grazing management in a manner more sensitive to requirements of the inherent landscapes (Simpson et al., 2004). This more sustainable management of grazing areas is however spatially variable. Neighbouring Sveigakot was found to have suffered irreversible degradation by the 11th century, suggesting landscape position as well as management are key factors contributing to the success or failure of individual farms (Simpson et al., 2004).

The uses of shielings is noted as a further adaptive practice in mitigating erosion and preserving and optimising use of available biomass, in doing so protecting valuable homefields from degradation (Brown et al., 2012). In a study from northern Iceland, using grazing models as an assessment of grazing pressure and soil accumulation rates associated with soil thin sections to assess land degradation; shieling management was seen to be effective against accelerated erosion occurring in the wider landscape. The successful management of these areas is therefore seen as a key contribution to the resilience of upland grazing areas in Mývatnssveit through maintenance of upland vegetation cover and productivity, without instigating mass erosion though time (Brown et al., 2012).

A series of adaptive management techniques are also noted within a range of homefield studies across Iceland. Manuring of homefields is highlighted as a necessary buffer again climate change, alleviating against short term fluctuations in climate and soil conditions. Simpson et al. (2002) found in their investigations of homefields in southwest Iceland producing low levels of barely, that manuring at only low levels was required to sustain yields. To this end, small quantities of manuring materials were discovered in thin sections from homefield soils, including domestic waste, fuel residues and animal manure. Agro-ecosystem modelling in this instance highlighted climatic deterioration would have impacted yields to a lesser degree than previously thought, with successful management of soils and soil properties instead playing a key role in sustainable arable production. Inherently infertile soils from one settlement were demonstrated as having no increased yields on the application of fertiliser, with better homefields within another farm responding to more favourable to manuring techniques, promoting further the concept soil properties were a key limiting factor to production (Simpson et al., 2002).

Adaptive practices were also noted within the homefields of the Mývatn region, in the northeast of Iceland (Adderley et al., 2008). Whereby management was adapted to suit the inherent soil properties and topographic conditions of individual homefields for the production of crops at subsistence level. In this instance management was seen as essential given subsistence levels of production, this suggests if a climatic downturn occurred, impacting the production of crops, subsistence levels would no longer meet the requirements of individual farms (Adderley et al., 2008). It has been suggested as necessary that farmers adapted their management strategies accordingly as longer and shorter term environmental changes occurred in order to sustain production; yet despite adaptions made, in this region of Iceland it would have been too difficult to produce surplus grain (Adderley et al., 2008).

1.9 Summary

With these examples it is clear, particularly for farming activities in the North Atlantic region, marginalised because of their northern extent, climatic marginality and landscape sensitives, local scale adaptions are frequently the key to an individual farms success. Managing the land in a manner which makes agricultural systems sustainable and resilient, bringing food security to a community in the face of climate change is therefore essential for the long term sustainability of settlements, driving new appraisals of archaeological evidence. Given the previous focus on other elements of the Icelandic farm, the complex human eco-dynamic inter-relationships between farmers and cultural wet meadows will now be investigated in the scope of this thesis, investigating whether this resource might have been seen as a means of adaption to inherent landscapes and climate marginality. Through reviewing the existing literature surrounding Icelandic farm systems and Norse farm management techniques it becomes clear the roles of wet meadows within these systems have been largely disregarded, in what is an otherwise crowded academic field. Meadows systems and their potential as a significant fodder resources have clear value to farm systems on the fringe of agricultural viability. This is particularly significant for settlers bringing demanding livestock such as cows, making these systems of great research interest. This thesis will address these short fallings, helping us understand more about the meadows as a natural phenomenon, and about their cultural significance, of which very little is presently know. The organic nature of the sediments will also be exploited as a means of addressing some of the current research gaps in Iceland's palynological record; producing reconstructions of vegetation at the individual farm scale for previously understudied areas, providing insights into farming and landscape processes within these sites, addressing taphonomic issues associated with Icelandic sites by combining pollen with micromorphological analysis.

Chapter 2 Research Design and Methods

2.1 Methodology overview – why stratigraphy, palynology and micromorphology? The power of combination

In order to develop new understanding of wet meadow formation processes and the resultant impacts of their usage, an integrated methodological approach is adopted. Pollen studies complimented by soil micromorphology, attempt to understand better individual farm management, in a method tailored to each case. Pollen will be used as a means of reconstructing the vegetation and land-use history in and around the individual farms and meadow systems, producing a robust narrative (or reconstruction) of environmental and cultural change in the farms (Whittington and Edwards, 1994). The principal aims of the micromorphological analysis are to investigate the formation of the wet meadow systems and land use history retained within them. These methods are set in a chronostratigraphical framework developed by soil stratigraphy, with chronological control set by tephrochronology and radiocarbon dating. This chapter will in turn set out each of the key methods, their associated rationale and the ways in which they will be integrated to address the aims and objectives set out in the introductory chapter, following a description of the site selection processes and the research areas.

These two key methods are frequently adopted in isolation from the other (Kooistra and Kooistra, 2003), despite the relative ease in collecting samples for each methodology during the excavation process. Soil development in archaeological contexts is not straightforward, with paedogenesis on archaeological sites frequently disturbed or accelerated by human practices, including cultivation, soil striping, trampling and manuring; these practices add to the complexities of analysing soil pollen spectra in archaeological context (Tipping et al., 1994), sampling in this thesis has attempted to sample in undisturbed sediments, with good stratigraphical control, further from the main dwellings. Employing the two methods together therefore has the potential to provide an improved understanding of the study site, in terms of landscape change and formation and human impacts, with little additional fieldwork cost and effort involved (Kooistra and Kooistra, 2003). Micromorphology can be used to address the short fallings of palynology in the sense that sedimentation condition, impacting taphonomic processes, can be examined in closer detail. With palynology benefiting micromorphology by allowing cross correlation of dates; with dates being produced from comparative depths in the pollen cores and used to investigate the chronology of processes within and between dateable layers in the thin sections, leaving the samples as intact as possible for thin section preparation. Together the combination of biotic (palynology) and abiotic (micromorphology and lithology) elements aim to produce a more coherent reconstruction of the past environment.

2.2 Site selection criteria

Three sites were selected for analysis, with the intent of investigating three contrasting 'types' of wet meadows within the farms, in from which to provide a more robust understanding of how meadows were used and managed in the past. Sites were selected based on two key factors:

1. A distinctive wet meadow is identifiable within the homefield of the farm, with the presence of organic sediments, and vegetation linked to more saturated soil conditions
2. The farm has previously or is currently being subjected to some degree of archaeological survey to give social contextualisation.

Orri Vésteinsson at the institute of Archaeology, Iceland advised on the availability of archaeological data for farms, resulting in the selection of 3 farms: Vatnsfjörður in the NW Peninsula, and Viðatóft and Gautlönd both within the Mývatnssveit district of north Iceland. These sites were selected as representative sites where palynological and micromorphological samples could be taken adjacent each other.

2.3 Introduction to Research Areas

2.3.1 Westfjords

The northwest peninsula or Westfjords is a remote peninsula of Iceland characterised by a series of mountains, deep fjords and bays. The mountainous nature of the region gives rise to the relative scarcity of farmland in the regions, however in the flatlands of the valleys stretches of good grazing exist (Tulinius, 2005). This area differs from the rest of Iceland geologically, there are no active volcanoes and the geology is characterised by Miocene basalts (Doner, 2003). Climate is typically colder across the region, in the uplands of the Westfjords precipitation (as rain and snow) is around 1000-4000 mm/yr., with 500-1000 mm/yr. in the coastal regions. The region is impacted by the Polar Front, where the warm Irminger current and colder East Greenland and East Iceland currents collide, these colder currents frequent bring polar sea ice (Andrews et al., 2001; Doner, 2003; Ogilvie, 1984, 1991).

The study farm Vatnsfjörður is situated in the centre of the Northwest Peninsula, toward the base of Ísafjarðarjúp. This region does not benefit from the warming effects of the North Atlantic Drift that gives rise to the more Boreal climate of Southern Iceland; climate is therefore cooler and more hostile (McGovern et al., 2007). The farm itself is still in use but features the remains of a Viking age farm, enclosed by a turf boundary wall and a fjord to the east of the settlement. Soils within the farm are generally shallow and poorly suited to agriculture making it an unusual choice for a major power centre. Documentation indicates that towards the late Middle Ages it had been one of the richest farms in Iceland (Edvardsson and McGovern, 2005). A small wet meadow towards the base of settlement, evident because of its sharp contrast to the poorer stony soils throughout the homefield, is therefore an intriguing element of settlement and presents an ideal opportunity for palaeoenvironmental studies associated with the farm.

To date pollen studies are limited in this area to three studies, a lower resolution study from the offshore site at Reykjarfjorður (Andrews et al., 2001), a climate focussed study from the lake Efstadalsvatn, in a study which does not cover the period of human occupation in Iceland (Caseldine et al., 2003) and a further human impact focussed study from the PhD of Zutter (1997). The palynological record generated in this research will provide further palynological data that will provide a more robust understanding of the paleoenvironments in the northwest peninsula.

2.3.2 Mývatnssveit

Perhaps one of the most intensively studied regions in Iceland (Lawson et al., 2007), Mývatnssveit situated in the northeast of Iceland, is renowned for both its archaeological and ecological wealth. The region takes its name from the lake central to the region– Lake Mývatn, a large shallow lake fed by phosphate and silica rich springs (Einarsson, 1982; Einarsson et al., 2004). The bedrock geology consists predominantly of basaltic lavas and hyaloclastites/móbergs, with open fissures, faults and crater rows present throughout the area. Climate within the region is typically more continental than maritime, expressed in the higher annual temperature ranges here (range of up to 15^{o}C), with temperatures generally lower than other parts of the country. The region is the part of the country receive the least precipitation as a result of its position in the rain shadow of Vatnajökull, with annual precipitation of around 400mm/yr., compared to up to 40000mm/yr. elsewhere (Einarsson, 1979).

Intensive multidisciplinary investigations have been carried out on a number of sites, the most important being Hofstaðir, where excavations uncovered the largest Norse longhouse known to date in Iceland. These individual studies have been further enhanced by landscape scale surveys

(Lawson et al., 2007) contributing further to the palaeoenvironmental and archaeological knowledge of the region. Despite this intensive research a number of sites have received limited attention and in spite of the abundance of multidisciplinary research within the region palynological studies are limited to one regional scale diagram (Lawson et al., 2007), and two diagrams of individual farms (Colquhoun et al., 2010; Nichol, 2014) both of which are were submitted as dissertations, with one covering more regional vegetation reconstructions in a shieling site (Colquhoun et al., 2010), and the other a very localised vegetation record (Nichol, 2014); these data sets add to the overall picture in terms of vegetation reconstruction in the area, but lack the intensity and rigour of published studies given their lesser chronological resolution. It is evident more palynological work is required within the region in order to gain a more powerful understanding of vegetation history in the area, in terms of both impact of the Norse settlement and variability with which it impacted sites across the region. Two further Mývatnssveit farms have therefore been identified as suitable to expand palynological knowledge within the region, enhancing specifically knowledge of human and environmental impacts on farms at an individual scale, and use of wetlands within the sites through use of more highly resolved data. These farms offer further unique angles by which to observe the wet meadow phenomenon. The first farm Viðatóft is long abandoned and has a series of mires within the former boundary, characterised by a complex series of dams and ditches, which would appear to have been used to control water onsite when in use, the reasons for which are unknown. The second Mývatnssveit farm Gautlönd, a continuously occupied farm, has an extensive wet meadow, linked to the lake within the farm boundary; the meadows here appear to form part of a natural system.

2.4 Stratigraphy – Lithostratigraphic methods

2.4.1 Initial surveys and basic principles

Each site was initially surveyed using a 2.5cm Eijkelkamp gouge so as to assess the depth and nature of organic sediments, enabling identification of the deepest and most intact sediments for palaeoenvironmental sampling. For illustrative purposes a single cross sectional stratigraphic transect was drawn up for each site, encompassing the homefield or sampled meadow, access dependant. Cross sections detail sedimentary characteristics of the site and any tephra deposits across them. Each profile within the transects was exposed to a point at which bedrock or glacial sands and gravels impacted ease of coring, or to the tephra layer correspondent to the Hekla 3 eruption.

Where tephra's were present, these were used as isochrones within a site to calculate organic sediment accumulation rates (SeAR's) across differing time periods, for that site. In Iceland SeAR's have been used as a proxy for soil erosion (Dugmore and Buckland, 1991; Streeter and Dugmore, 2014), assuming increasing SeAR is linked to increasing erosion as sediments are deposited within accumulation areas in the landscape. These measurements have typically been carried out in loessial andosol deposits, which have a tendency to be greater impacted by erosive process. Given the differing sedimentary processes within wetlands results cannot be directly compared with published figures, and are used for comparisons in relative terms. At Gautlönd where tephras were frequently less distinctive across the mire rough SeAR's were calculated between pollen zones.

2.4.2 Descriptive techniques

Sediments were described in the field using a modification of the internationally recognised Troels-Smith (1955) methodology for the characterisation of unconsolidated sediments. Deposits were described using a combination of deposit elements (Table 2.1), using a five class abundance scale (+, 1,2,3,4, where + is traces, and 4 is 75-100%) to describe the proportion of each element within the deposit together with noting degree of humification and colour of sediments.

Using the dominant sediment type as a means of simplification, the symbols for each sedimentary unit within the pollen core were drawn up in Tilia (Grimm, 2011) and plotted alongside pollen data, as a 'lithology column', allowing comparisons between sedimentary and vegetation shifts.

Table 2.1 Elements of sediments in accordance with Troels-Smith (1955), from Aaby and Berglund (1986)

Class	Symbol	Element	Description
Substansia humosa	*Sh*	*Humous substance*	Homogeneous microscopic structure
Turfa	Tb^{0-4}	*T. bryophytica*	Mosses +/- humous substance
	Tl^{0-4}	*T. lignosa*	Stumps, roots, intertwined rootlets, of ligneous plants +/- trunks, stems, branches etc. connected with these. +/- humous substance
	Th^{0-4}	*T. herbacea*	Roots, intertwined rootlets, rhizomes, of herbaceous plants +/- stems, leaves, etc. connected with these. +/- humous substance
Detritus	*Dl*	*D. lignosus*	Fragments of ligneous plants >2mm
	Dh	*D. herbosus*	Fragments of herbaceous plants >2mm
	Dg	*D. granosus*	Fragments of ligneous and herbaceous plants, an sometimes, of animal fossils (except molluscs) < 2mm >c.0.1mm
Limus	Ld^{0-1}	*L. detrituosus*	Plants and animals (except diatoms, needles of spongi, siliceous skeletons, etc. of organic origin), or fragments of these. Particles < c.0.1mm. +/- humous substance
	Lso	*L. siliceous oranogenes*	Diatoms, needles of spongi, siliceous skeletons, etc. of organic origin, or parts of these. Particles < c.0.1mm
	Lc	*L. calcareus*	Marl, not hardened like calcareous Tufa; lime and the like. Particles <c.0.1mm
	Lf	*L. ferrugineus*	Rust, non-hardened. Particles <c.0.1mm
Argilla	*As*	*A. steatodes*	Particles of clay <0.002mm
	Ag	*A. granosa*	Particles of silt 0.06-0.002mm
Grana	*Gmin*	*G. minora*	Particles of sand 2-0.06mm
	Gmaj	*G. majora*	Particles of gravel 20-2mm

2.4.3 Loss On Ignition

Loss on ignition (LOI) was carried out on the cores to calculate the organic content of sediments following the method of Bengtsson and Enell (1986) as follows. Contiguous 2cm^3 samples were extracted at either 0.5cm or 1cm intervals for each site, dependant on the variability of sediments. These samples were added to desiccated porcelain crucibles (weight of crucible = A), the weight of the wet sample and crucible was then recorded (B). Samples were then oven dried at 105^{o}C for a minimum of 12 hours overnight, after cooling in a desiccator dry samples are then reweighed (C). Samples are then ignited in a muffle furnace for 4 hours at 550^{o}C, cooled and the ash samples reweighed (D).

Loss on ignition is calculated using the following formula, with the organic content of samples expressed as the percentage of dry weight lost:

$$Loss\ on\ Ignition\ (LOI) = \frac{C - D}{C - A}\ X\ 100$$

The core from Vatnsfjörður, the first site analysed, was used as a case study to test micro-tephrochronology in the northwest of Iceland; with the core being split and sent to the University of Oxford for the analysis. To allow this LOI was not carried out for this site.

2.5 Chronology

2.5.1 Introduction

The establishment of a secure chronological framework is essential in palaeoenvironmental reconstructions as it provides a temporal framework from which to analyse data, and allows secure temporal correlations to be made between the study farms and published palaeoenvironmental studies. Given the location of this study, and the time periods to be analysed, tephrochronology and AMS radiocarbon dating are identified as the most appropriate dating techniques; dated tephra layers are preserved in sediments throughout much of the country

2.5.2 Tephrochronology

Iceland's active volcanic environment means tephrochronology is readily applicable in palaeo-environmental investigations. The technique was pioneered in Iceland by Sigurður Þórarinsson (1944), and relies on the use of isochronous marker horizons, in the form of characterised tephra layers, to provide a chronological framework in which to place palaeoenvironmental and archaeological data. The technique is reliant on stratigraphy and the laws of superposition as well as the precise characterisation of tephra deposits, using either physical field characteristics, optical microscopy or geochemical analysis to determine the source of tephra's (Lowe, 2011). Once characterised, dating techniques can be applied to the layers to obtain and age or depth for the layer most appropriate in palaeoenvironmental and archaeological research (Lowe, 2011) and which allows cross comparisons between and within sites. Post settlement tephra layers are generally well recorded in historical documentary records, whereas pre-settlement tephra's are typically dated using annually laminated ice core records and radiocarbon measurements on organic material associated with deposits.

Of those most useful tephra layers the Landnám tephra (Veiðivötn AD 871±2), known to be deposited over much of Iceland shortly before settlement, is unique in the sense that it provides a clear and precise 'litho-chrono-stratigrpahic' marker for the settlement of the country (Streeter et al., 2015). Using this marker horizon provides a means of comparing sediments and the records held within them before and after settlement, enabling comparisons of natural variability versus direct human-environment interactions and anthropogenically enhanced environmental changes. In addition, sequences of tephra layers within a deposit have the potential to provide information on soil formation processes and erosion activity within a site – based on their presence, absences an sediment accumulation between tephra (Einarsson, 1986) (section 3.4.1).

Tephra layers consistently discovered (i.e. those found in the majority of cores) on sites within the Mývatn region (Viðatóft and Gautlönd) were cross correlated, and used as isochrones using the well-defined tephra-stratigraphies for the region (Sigurgeirsson, 1995, 2001, 2010), with the frameworks used recognised and adopted by archaeologists working in the area. The main characteristics of these tephra used to identify layers in the field are summarised in Table 2.2, micromorphological description were used to support field identifications. Other tephra were discovered, including a number of more indistinguishable layers, these tephra's because of their inconsistent presence between cores, were not used in establishing chronological frameworks.

Table 2.2 Dominant Tephra layers and their characteristics, Mývatnssveit (after Ólafsdóttir and Guðmundsson, 2002; Simpson et al., 2004)

Tephra	Origin	Age	Type	Description	Micromorphology Description	Reference and Dating Method
Veiðivötn 1717	Veiðivötn	AD 1717	Basic	Black , coarse sand, typically <0.5cm	Black; coarse sand	(Larsen, 1984) Historic
Veiðivötn 1477 or 'a'	Veiðivötn	AD 1477	Basic	Dark grey, fine-grained (silt loam), distinctive in the majority of profiles, *c.* 4-5cm	Brown and black; fine sand; isotropic, glass; smooth, angular and subangular; common vesicular; common 1^o of irregular line alteration and few 3^o of pellicular core alteration	(Larsen, 1984) Historic
Hekla 1300	Hekla	AD 1300	Basic	Black, fine grained	Black; fine sand	(Þórarinsson, 1967) Historic
Hekla 1104	Hekla	AD 1104	Acidic	White, fine grained. Tendency to be thin and patchy and so difficult to trace	Yellow; silt; isotropic glass; smooth angular lenticellular, few fibrous; 1o or pellicular alterations	(Þórarinsson, 1967) Historic
Landnám	Veiðivötn	AD 871±2	Basic/ Acidic	Two fine grained (silt loam) bands, olive green and white – from 2 separate eruptions. Deposited around the time of Norse settlement.	Brown; fine sand; isotropic glass; smooth angular; rod like to blocky	(Grönvold et al., 1995) Ice core
b/c	Uncertain	*ca.* AD 600-AD 700	Basic	Two black, fine sand, tephras, most commonly appearing as one thick layer.	Black; fine sand; isotropic; smooth subangular	(Sæmundsson, 1991) Radiocarbon
Hverfjall or h	Hverfjall	*ca.* 2500 BP	Basic	Black, Coarse grained (coarse sand), often immediately above $H_{3.}$	Pale brown; coarse sand; anisotropic speckled with rod like and tabular inclusions; smooth subangular and blocky; common vesicular; few 1^o of linear alteration	(Sæmundsson, 1991) Radiocarbon
Hekla 3 or H_3	Hekla	2879±34 BP	Acidic	White, fine grained (silt loam), well defined in Mývatn region, 5-10cm	Yellow; silt; isotropic glass; smooth angular lenticellular, few fibrous; 1o or pellicular alterations	(Dugmore et al., 1995) Radiocarbon
Hekla 4 or H_4	Hekla	4000 BP	Basic/ Acidic	Double layered – black, fine grained (silt loam) upper, white fine grained lower *c.* 3-5cm	Black fine-grained upper portion; white fine-grained lower portion	(Dugmore et al., 1995) Radiocarbon

2.5.3 Cryptotephra

The Northwestern peninsula in Iceland is recognised for its lack of visible tephra deposits, as a result of its isolated position and prevailing wind conditions (Sigurgeirsson, 2006). As a means of producing a chronostratigraphy for the meadow sediments at Vatnsfjörður it was necessary to adopt cryptotephra dating approaches, this was carried out by colleges at the University of Oxford (Anderson *pers comm*). The Vatnsfjörður homefield core was sampled in continuous 2 cm sections to create a tephrostratigraphy, sediment from each section then underwent the procedure used for the extraction of cryptotephra described in Blockley et al., (2005). For sections containing large proportions of cryptotephra, the samples were re-extracted and mounted in water; approximately sixty shards were then isolated using a syringe and mounted in resin stubs for WDS-EPMA. Probe data of major and minor elements was analysed to identify the general composition of the shards and, when possible, to correlate the cryptotephra layer with known eruptions (Dugmore et al., 1995; Payne and Blackford, 2008).

2.5.4 Radiocarbon dating

Radiocarbon dating is a technique developed by Libby et al. (1949) in the late 1940s and involves the measurement of the radioactive decay of unstable ^{14}C in organic materials. The isotope is formed in the upper atmosphere through the bombardment of nitrogen atoms by cosmic rays. ^{14}C is then transformed into carbon dioxide though oxidation allowing its uptake by living organisms. On the death of an organism no more ^{14}C will be absorbed to replace the continuously decaying ^{14}C within the organism. The known rate of decay of ^{14}C (half-life = 5730 ± 30 years) can therefore be used to calculate the date of death of the organism(Lowe and Walker, 1997). Two methods are used to measure residual ^{14}C in a sample - conventional radiocarbon dating, and Accelerator Mass Spectrometry (AMS). The conventional method involves detection and counting of β emissions (i.e. decay through beta transformation) from ^{14}C over a given time period for the calculation of emissions and activity of the sample. In AMS dating the actual number of ^{14}C atoms in a sample are counted, rather than their products of decay; this is carried out using particle accelerators as mass spectrometers (Lowe and Walker, 1997). The latter approach is the most widely used, and is the method adopted in this thesis. This is partly as a result of the advantages of AMS in the relative speed of analysis and the small quantities required for analysis. The small quantities of material required for AMS dating have the benefit of potential for extraction from narrow section in the pollen core, allowing close correlations between pollen and dating horizons.

Given the limited tephra deposits recorded in the sediment stratigraphy at Vatnsfjörður and Gautlönd, AMS radiocarbon dating was used to complete chronostratigraphies for these farms. At Vatnsfjörður two single entities of well-preserved charcoal fragments were extracted from the base of the wet meadow. As ages produced from charcoal relate to the death of the plant the charcoal originated from, it is therefore considered when analysing the dates produced that there is a possibility dates are earlier than the date of incorporation of charcoal into sediments. At Gautlönd plant macrofossils were extracted from the base of organic sediments and one other point in the core. Terrestrial plant macrofossils (Sphagnum moss) were selected for dating here; intact pieces of fragile macrofossils were extracted based on the assumption of the unlikelihood they would have survived reworking, with the terrestrial nature of macrofossils reducing the likelihood of samples suffering the 'hard water effect' (Hatté and Jull, 2007). With the scale of erosion in Iceland extra care must be taken when sampling for radiocarbon dates, given the higher probability of redistribution of sediments in more disturbed environments. Gathorne-Hardy et al.,(2008) for example, in their research in lake sediments by Reykholt, found dated fragments from sediment cores consistently too old, attributing this to erosion causing older carbon from the wider landscape to enter the lake. Palynological methods, specifically pollen preservation, are intended in this study to help in selection of points for the extraction of samples for radiocarbon dating, through revealing, prior to subsampling for dating, periods of potential inputs of reworked sediments in the core.

Extracted samples were submitted to the Scottish Universities Environmental Research Centre (SUERC) facility for AMS analyses, with the dates produced calibrated using the calibration curve INTCAL13 in CALIB 7.0 (Reimer et al., 2013).

2.6 Age-depth modelling – CLAM and BACON

Given resource requirements for calculating the ages of sections within sediment cores, it is unlikely accurate dates will be produced for the entirety of a core, consequently estimations based on selected dated sections of cores, radiocarbon, tephra and sequence surfaces, are approximated using appropriate age depth models. Until relatively recently a number of methods have been used to construct chronologies, with varying success, for palaeoenvironmental studies. Details of models used however, have rarely been published and older models rely on a number of assumptions and lack the ability to include the range of factors which might impact on modelling (Blaauw, 2010).

Two of the most frequently used forms of age-depth modelling are Bayesian models and "classical" models such as linear interpolation or linear/polynomial regression (Blaauw, 2010). Despite Bayesian statistics ability to produce among the most robust age-depth models, classical models remain widely used, particularly in those instances where only a small number of dates are available and Bayesian statistics offer little benefits over classical models. Blaauw, (2010) has therefore suggested improvements for these models through the development of techniques allowing more accountability for the reality of multi-modal and asymmetric natures of calibrated ^{14}C dates. A number of classical interpolation or regression techniques for example assume symmetrical or normal distribution of errors on calibrated ^{14}C dates, and work to reduce ^{14}C ages to a single point, problematic given distribution ranges involved. Point estimates can be improved through the introduction of repeated random sampling through the entire calibrated distribution of dates (by importance, bootstrap or Monte Carlo sampling), calculating age-depth models through all sampled ages; curves may then be fitted though age-depth point estimates, providing a range of age estimations for the entirety of the sedimentary sequence, this is based on the assumption the fitted curve type is a dependable estimate of true accumulation histories onsite (Blaauw, 2010). Blaauw (2010)'s software '*Clam*' ('classical' age-depth models), which runs in open source statistical software '*R*' (R Core Team, 2015) uses point age-depth estimates taken from the age depth model , in an approach accounting for all provided dating information, producing likely accumulation histories for any given site; sound estimates for any depth may therefore be calculated based on the weighted mean of all model iterations at that given depth. Where 'Clam' has been used calibration curves are set to the default calibration curve IntCal13 (Reimer et al., 2013) , and age –depth models selected as deemed appropriate (options: linear interpolation, linear regression, higher polynomial regression, cubic spline and smooth spline), with 'slumps' in models created for deep (>1cm) tephra deposits. 'Clam' in its default setting calculates its best fit model from all calculated age-depth models using the weighted mean of all sampled calendar ages for each depth (Blaauw, 2010). Clam was used at Gautlönd given the presence of a thick tephra deposit; currently no feature in the Bayesian software 'Bacon' (Bayesian accumulation models) has been designed to cope with instances of instantaneous deposition, such as deposition of thick tephra in cores (Blaauw *pers. Comm.*).

At both Vatnsfjörður and Viðatóft the Bayesian software 'Bacon'(Blaauw and Christen, 2011), again running in 'R' (Team, 2015) was used to produce age depth models, given the narrower tephra deposits and larger numbers of available dates, with Bayesian models demonstrated as performing better on higher density dated cores (Blaauw and Christen, 2005, 2011). These models account for the non-normally distributed nature of calibrated ^{14}C dates, as well as allowing for the incorporation of prior information on accumulation rates, helping to eliminate more highly unlikely models, therefore reducing uncertainty and producing more robust and realistic age-depth models of sites. In this respect 'Bacon' aims to produce the most likely simulation of underlying accumulation and sedimentation processes as they might be influenced by environmental processes (Blaauw and Christen, 2011). Given the dynamic sedimentary conditions in Iceland and resultant rapidly fluctuating SeAR's, models designed to incorporate these are important, 'Bacon' is therefore preferred over alternative Bayesian and classical models, with 'Clam' proving most appropriate where thick tephra deposits are to be considered by models.

Choice of model type is discussed further in the relevant site chapters. Each model is produced in cal yrs. BP; initially results are presented in this format as a mean of easier comparisons with publications focusing on longer timeframes. BC/AD dates will also be presented alongside these, with dates presented in this format in the discussion section of site chapters. This allows for easier comparisons with archaeology and tephra layers.

2.7 Pollen Analysis

2.7.1 Pollen site selection

One of the fundamental problems of palynology is understanding the pollen source area in a given study area, this depends to a great extent on the means by which pollen reaches a site. Understanding recruitment processes, particularly transport processes and production and dispersal properties of pollen types, is therefore essential in producing robust interpretations of the pollen data. Pollen reaches a site through both autochthonous and allochthonous sources. The former associated with pollen incorporated into the sediment from plants growing near the sampling point, and the later regarding pollen incorporated into the sedimentary surface from plants growing further afield. The different sources of pollen rain will be largely influenced by the area intended for study, general models for pollen dispersal (for example: Jacobson and Bradshaw, 1981; Tauber, 1965) should be adapted to accommodate the sites and deposits investigated. These factors are linked to the Relevant Source Area of Pollen (RSAP), which describes the degree to which pollen loading within a given sample reflects the surrounding vegetation, of which increasing the size of the sampling area does not improve reflections of the local vegetation; in other words the appropriate spatial scale within which it is possible to detect local scale vegetation change in pollen record (Sugita, 1994; Sugita et al., 1999).

Degree of openness is a major factor in influencing the pollen rain reaching a site and the resultant RSAPs (Bradshaw, 1981; Calcote, 1995; Sugita et al., 1999); with greater percentages of pollen from sample sites in closed woodlands recruited from a smaller area, and dilution of local pollen signals in more open canopy assemblages, with pollen recruited from a larger area (Calcote, 1995; Jackson and Wong, 1994; Jacobson and Bradshaw, 1981). Given the near absence of woodland cover and resultant openness of landscapes in Iceland today pollen sourced from canopy and trunk space will be of minor importance, this should be considered when interpreting pollen rain studies in Iceland and making comparisons with data sets from places with more prominent woodland. Pollen productivity estimates (PPE's) for individual species should also be considered, especially in open landscapes like those in Iceland. Herb taxa generally have lower PPEs than tree taxa and therefore given the more significant PPEs for tree species (*Betula pubescens* in Iceland), where trees are present in open areas, there is a risk of overrepresentation of trees and resultant underestimations of the degree of openness (Andersen, 1970; Broström et al., 2004).

A general relationship between basin size and pollen source area is well recorded, based on both empirical and modelling studies, whereby larger sedimentary basins recruit pollen from a wider source area than smaller, more enclosed basins (Bradshaw and Webb III, 1985; Calcote, 1995; Jacobson and Bradshaw, 1981; Prentice, 1985; Sugita, 1994). This well established relationship therefore allows for the research questions to guide the choice of sampling site for the resolution required in a given study (Bradshaw and Webb III, 1985; Jacobson and Bradshaw, 1981). Given their potential for recoding finer scale vegetation changes, small basins are preferential in a cultural context with regional scale palynological work tending more to mask detail in studies of human impact (Faegri et al., 1989; Tipping, 1998; Whittington and Edwards, 1994). For those reasons, and the cultural focus of the current study, small basins will be selected for sampling where possible.

Choice of sampling site is a further consideration for palynologists. Choice of mire, lake or archaeological sediments for sampling is again dependant on the questions being asked of the data. Key to this study was collection of samples at the individual farm scale, proximity to farm/archaeology was therefore important, with intact suites of tephra for chronological construction where possible. Site selection from within an archaeological site allows for the correlation of excavations and palaeoenvironmental data, providing a better understanding of how communities interacted with their environment on a local scale (Hallsdóttir, 1987; Hallsdóttir and Caseldine, 2005). Stratigraphies within archaeological contexts are often confused, given potential for disruption by anthropogenic activities, including peat cutting for fuel or construction, deposition of waste and cultivation, or disruption of sections through ongoing archaeological investigations (Faegri et al., 1989).

Sampling in lacustrine sites is typically linked to regional analysis, especially with the influences of in washed pollen from catchment drainage and in washing. Of those existing studies in Iceland, pollen analysis from lacustrine sediments has proved more beneficial in long-term reconstructions of vegetation history on a regional scale, with detritus forming lake sediments soon after deglaciation. With the majority of mire studies conducted within sloping fens (hallamýri), a hiatus is often present in records, with peat initiation often after hundreds, or in some cases thousands of years. Topogenous fens (flói), often originating from lakes, tend not to be affected by such a hiatus, pollen studies from such locations are however somewhat limited presently (Hallsdóttir, 1995). Given the human related focus of this study however, records from the last glaciation are not required. The human impact focus at the single farm scale also lends itself better to terrestrial rather than lacustrine sampling. This increases the chance of pollen recruitment from the locality, as opposed to the wider catchment thought limiting input of pollen from allochthonous sources, making local-scale changes associated with individual farms or smaller localities easier to interpret. Issues with bioturbation and turbulence within lakes creating re-suspension and re-deposition of sediment and pollen, might also provide an issue for higher resolution studies of human impact, given the smoothing effects on the pollen record and subsequent impacts on the sensitivity of records this might have.

The meadows within the farm boundaries have the advantage in that wet conditions provide better conditions for pollen preservation that might traditionally be associated with archaeological sites. Small basins within farms were therefore selected for sampling to allow for the construction of past vegetation communities at a scale relevant to the archaeology, with the aim of reconstructing vegetation changes within farms at the individual scale. Despite mire not being impacted by the re-suspension and turbulence issues of lakes, these sites do not come without their own issues. Mires, for a number of reasons are at risk of becoming periodically aerated, perhaps creating issues for the preservation of pollen within them. This is an important consideration for the sites studies here, given their association with farms, and associated risks of anthropogenic disturbances. Within mires local pollen, growing on the mire surface is often over represented given the importance of the gravity component in the methods by which the pollen rain reaches the mire surface, diluting signals from the wider landscape (Bunting, 2008). This has the negative impact of creating difficulties in estimating the pollen source area of sites with many of the pollen types growing on the mire surface also liable to be growing in the wider landscape due to the ambiguity of plant taxa, with no means to separate the two in the pollen signal (Bunting, 2008; Jacobson and Bradshaw, 1981). Diagrams from such deposits are also frequently found to be spikey in appearance, given the temporal variability in pollen depositions. This is the result of three key factors, the impacts of which will be addresses as far as possible by the methodologies adopted – local over representation of some taxa, linked to uneven distributions of plants growing on the vegetation surface, uneven growth rates of peats and defective methods for the volumetric sampling of sediments (Jacobson and Bradshaw, 1981).

It was the intent of the palynological sampling to sample beyond the period of human occupation of the sites, identifiable in some cases by presence of known tephra and obvious cultural layers. The gradient between the natural site conditions associated with the pre-occupational phase and modified conditions associated with settlement and occupation can therefore be examined (Faegri et al., 1989), demonstrating more clearly the influence of humans on the farms, potential aiding interpretations of any direct impacts on the meadows themselves.

2.7.2 Coring and Storage

Series of overlapping cores from each site were sampled using a 0.5m long Russian corer (Jowsey, 1966). The corer failed to sample the upper portions of the stratigraphy at Viðatóft and Gautlönd, as a result of the saturated conditions, and so these sections were extracted separately and placed directly into layflat.

All cores were placed in labelled guttering, wrapped and sealed in layflat plastic, to prevent water loss and contamination and stored in the cold stores at the University of Stirling at 4^{o}C until required for subsampling.

2.7.3 Subsampling

Samples of 1cm^3, measured by volumetric displacement in HCl 10% (Bonny, 1972) which acts on samples to remove carbonates, were extracted from the cores at known intervals, using a scalpel and spatula, cleansed with distilled water between extractions. High resolution was the key focus of subsampling and where appropriate continuous subsampling was applied, especially around the Landnám period.

2.7.4 Laboratory procedures

Extraction of fossil pollen from sediment materials was carried out following standardised processing techniques outlined in Faegri and Iversen (1992) and Moore et al (1991) and those procedures adopted within the palaeoenvironmental lab at the University of Stirling. A spore tablet of a known concentration of exotic *Lycopodium clavatum* grains was added to each sample in HCl 10% to calculate pollen and charcoal concentration (Stockmarr, 1971). Upon full dissolution of the spore tablet, samples were centrifuged and supernatants decanted before progressing to the next step – disaggregation and removal of soluble humic acids. This involved the addition of NaOH to samples, before placing them in a boiling water bath for 30 minutes, stirring occasionally, centrifuging and discarding the supernatant. Humic acids were then washed away using distilled water, mixing this through the sample, centrifuging and decanting supernatant, before repeating this step until supernatant runs clear.

Samples were then sieved though an 180µm sieve mesh for the removal of coarse debris, spraying gently with distilled water to help fine material through the mesh. Sample passing though the mesh was retained and passed into a 10µm sieve, discarding material left behind in the sieve. Debris less that 10µm is allowed to pass through into the sink, retaining sediment within the 10µm sieve for further processing, before transferring back into a centrifuge tube, centrifuging and decanting the supernatant.

Given the often mineral rich sediments treatment with HF 40% was required for the chemical removal of silica debris. Samples were left overnight in HF 40% acid, balancing the tubes with HCl 10% following the completion of the acid digestion, to aid dispersal of any sample clumping in the HF 40%. These samples were centrifuged and supernatants discarded before a further treatment with HCl for the removal of fluorides formed in the digestion and any traces of HF 40% remaining in samples.

Samples were then hydrolysed by process of acetolysis for the removal of lignin and cellulose. Prior to this it was necessary to dehydrate the samples using acetic acid glacial >99%, given the violent reactions caused by contact between sulphuric acid and water. Following this acetolysis solution was made using 9 parts Acetic anhydride acid >97% to 1 part Sulphuric acid concentrate >98% SLR. The solution was added to samples, before placement in a boiling water bath for 3 minutes, stirring occasionally, then centrifuging decanting supernatant and further treatments with Acetic acid glacial >99%, then distilled water, to dehydrate and remove traces of acetolysis solutions before proceeding to the final stages of laboratory preparations.

Samples were dehydrated using Tert-Butyl Alcohol >99% SLR, to removal all water from samples, Following centrifuging and decanting supernatants, samples were transferred into glass specimen tubes containing approximately 0.3ml silicon oil. Samples were once more centrifuged and supernatants discarded, before placing samples in a heat block, heated to 45^{o}C for 8-12 hour, ensuring evaporation of any Tert-Butyl Alcohol >99% SLR residue. Each sample was then carefully mixed and sealed ready for counting.

2.7.5 Slide mounting and pollen analysis

Pollen samples were mounted on standard slides under 22x22mm coverslips. Slides were then analysed using a transmitted light microscope (Olympus BX41) by systematically scanning the slide with evenly spaced traverse, ignoring the outermost edges of slides to avoid any edge effects. 400 x magnification was used as standard, switching to 1000 x magnification under oil emersion where extra precision was required.

A minimum sum of 300 identifiable land pollen grains (TLP) was employed. *Cyperaceae* was not included in the TLP count as this group of species has the tendency to dominate wetland habitats as well has being noted as a prolific pollen producer, therefore limiting the signal from other species; it is noted in doing so those *Cyperaceae* species present out with mire and within drier habitats, particularly rush and sedge heath, are also excluded (Hallsdóttir, 1995). *Cyperaceae* was therefore treated as an extra count, with spores and aquatics treated in the same way. Exotics pollen markers were also counted and recorded alongside other species.

2.7.6 Pollen ID and taxonomy

Pollen was identified with reference to the Pollen and Spore key and glossary produced by Moore et al. (1991) and the pollen type slide collection at the University of Stirling. Where further clarification was required reference was also made to descriptions in Faegri et al. (1989) and images in Beug (2004).

Table 2.3 Species included in plotted pollen types, adapted from Hallsdóttir (1987) using Erlendsson, (2007) and Löve (1983)

Pollen Type	Potential Species
Betula	*B. pubescens, B. nana*
Salix	*S. glauca, S.lanata, S. phylicifolia and S. herbacea*
Empetrum	*E. nigrum, E. hermafroditum*
Ericaceae	*Vaccinium, Loiseloria, Cassiope* and *Arctostaphylos*
Ericales undiff.	*All individuals of either Empetrum nigrum* or *Ericaceae* that could not be identified to lower taxonomic level
Umbelliferae	*Angelica sylvestris, Archangelica officinalis, Ligusticum scoticum* and *Carum carvi*
Sedum	*S. acre, S. annuum, S. roseum* and *S. villosom*
Cruciferae	*Cakile, Capsella, Cochlearia, Draba, Erophila, Cardamine, Arabis, Cardaminopsis, Rorippa, Erysimum*
Labiatae	*Prunella vulgaris* and *Thymus arcticus*
Fabaceae	*Lupinus nootkatensis, Melilot albus, Trifolium repens, T. hybridum, T. pratense, Anthyllis vulneraria, Lotus corniculatus, Vicia cracca, V. sepium*
Potentilla type	*Fragaria vesca, Sibbaldia procumbens, Comarum palustre, P. anserina, P. crantzii* and *Geum rivale*
Rosa	*R. Taeckholmii, R. vosagiaca*
Triglochin type	*T. palustre, T. maritimum* (and *Potamogeton*)
Rhianthus type	*R. minor, R. groenlandicus* and *Bartsia alpine*
Cyperaceae	Around 50 species
Poaceae	Around 40 species
Rosaceae	Around 17 species
Saxifragaceae	Around 17 species
Gallium	*G. boreale, G. trifidum, G. verum, G. pumilum, G. uliginosom*
Gentiana	*G. nivalis, G. aurea, G. detonsa, G. tenella*
Rumex type	*R. acetosa, R. acetosella* and *Oxyria digyna*
Rannunculus	*R. acris, R. repens* and *R. reptans*
Trifolium	*T. hybridum, T. pratense, T. repens*
Urtica	*U. urens, U. dioica*
Vaccinium	*V. gaultherioides, V. myrtillus, V. ulginosum, V. vitis-idaea*
Valeriana	*V. collina, V. excelsa, V. officinalis, V. sambucifolia, V. Wallrothii*
Viola	*V. arvensis, V. canina, V. epipsila, V. palustris, V. Riviniana, V. tricolor*
Caryophyllaceae	*Stellaria, Cerastium, Sagina, Honckenya, Minuartia, Arenaria, Viscaria, Lychnis* and *Silene*
Lactuaceae	*Taraxacum, Leontondon, Crepis* and *Hieracium*
Asteraceae	*Cirisium, Erigeron, Antennaria, Gnaphalium, Achillea* and *Matricaria*
Chenopodiaceae	*C. album, Atriplex patula, A. glabriuscula*
Cerealea type	*Avena sativa, Hordeum vulgaris, Elymus arenaria, Agropyron caninum, Glyceria fluitans*
Polypodiaceae	Polypodiacae *excluding Dryopteris, Linnaeana* and *Polypodium vulgare*
Equisetum	*E. arvense, E. pratense, E. palustre, E. fluviatile, E. variegatum* and *E. hiemale*
Botrychium	B. *lunaria (B. lanceolatum)*
Lycopodium	*L. annotinum* (almost entirely) and *L. alpinum*
Myriophyllum	*M. alterniflorum, M. spicatum*
Potamogeton	*P. pusillus, P. natans, P. alpinus, P. gramineus, P. perfoliatus, P. praelongus* and *Triglochin palustre, T. maritimum*

Pollen nomenclature follows Bennett (1994, 2007), amended by Erlendsson (2007) and Hallsdóttir (1987), for more applicability to Icelandic flora. Species linked to plotted pollen types are presented in Table 2.3. *Rumex acetosella/Oxyria digyna*, are linked throughout given the indistinguishable nature of many grains, particularly where impacted by biochemical degradation; the majority of the grains however are believed to be *O. digyna* (Rundgren, 1998a). Where taxonomic precision is not to species level, or there is any degree of uncertainty, nomenclature follows the system of convention presented by Birks and Birks (1980). Plant nomenclature follows Kristinsson (2010) and Löve (1983).

Counts of the green freshwater algae *Pediastrum* were made alongside pollen, to plot alongside pollen and spore data. Using the key in Komarek and Jankovská (2001) specimens were identified, recording them at the lowest taphonomic level possible. *Pediastrum* is hereafter referred to as simply 'algae'.

2.7.6.1 Betula measurements

In Iceland two key *Betula* species are widely recognised – Icelandic downy birch (*B. pubescens*) and dwarf birch, (*B. nana*). Considerable debate exists regarding the number of subspecies of *B. pubescens*, with different floras listing several forms of tree or shrub birch (Caseldine, 2001). However, for the purposes of this thesis all tree and shrub birch will be classified as *Betula pubescens,* with any indistinguishable *Betula* regarded as *Betula sp.* It is palynologically difficult to differentiate the two however, it is important to do so given its prominence and significance in Icelandic vegetation history and for the more accurate interpretation of past ecology (Karlsdóttir et al., 2007).

Different authors have adopted different approaches to separate the pollen of the *Betula* species. A morphometric separation of *Betula* species was first introduced by Jentys-Szaferova (1928), since then a number of morphological and morphometric approaches have been adopted. Using the morphological approach, researchers attempt to separate *Betula* species based on morphological characteristics alone. Given the subjectivity of descriptions however, the repeatability of this method is questionable, particularly in Iceland where preservation conditions might not be ideal. Morphometric techniques on the other hand are more objective, and involve measurement of the pollen diameters. Given the degree of overlap between species (Figure 2.2; Table 2.4) Birks (1968) included measurements of pore depths along with diameter measurements, using these to calculate a diameter/pore depth ratio for the separation of species.

Karlsdóttir et al. (2007) found for this latter method overlaps between *B. nana* and *B. pubescens* of up to 84%, nullifying its usefulness on Icelandic *Betula* pollen. Palynological research from Iceland has shown *Betula* to have been treated in many ways. Some studies have not attempted to separate species (Bartley, 1973; Caseldine and Hatton, 1994; Einarsson, 1961, 1963; Páhlsson, 1981; Vasari and Vasari, 1990). One attempt has been made at separating the species based on morphological analysis (Hallsdóttir, 1987), several studies by Rundgren have used combination of morphological criteria and size measurements (Rundgren, 1995, 1998b; Rundgren et al., 1997); however, the majority of the others have adopted a morphometric approach to distinguishing between the species.

In a review of means of separating species, Mäkelä (1996), expresses preferences for the use of the morphometric approach, given the subjectivity in analysing morphological characteristics of grains. In her study, which measures only grain diameter a clear size separation is demonstrated between *B. nana* and *B. pubescens*, with little overlap shown between the two. Although given the research was undertaken on modern pollen material she suggests there are likely to have been changes in size of *Betula* pollen within Holocene records, particularly *B. pubescens* which is impacted by hybridisation and introgression, with fossil pollen also noted as altering during the fossilisation process (Mäkelä, 1996).

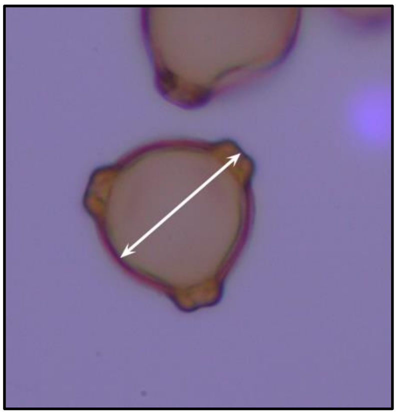


Figure 2.1 Arrow depicting the measurements made for *Betula* grains – extending from the tip of the pore to the outer margin of the opposite wall.

This morphometric approach will therefore be adopted in this thesis. New measurements were made for all fossil *Betula* grains encountered, measuring the diameter from the tip of the pore to the outer margin of the wall directly opposite (Figure 2.1), with the grain orientated in polar or semi-equatorial view, where one pore was found to be measurable (Karlsdóttir et al., 2012). Pore depths were not included for efficiency of measurements, as require measurements at the limit of that which can be offered by standard light microscopy. Measurements were then plotted in a series of size-frequency distribution plots for each pollen zone, allowing easy comparisons of changes in *Betula* populations through time, as well as allowing for comparisons with published size distributions prepared using identical laboratory treatments (mounting in silicon oil) (Table 2.4, Figure 2.2). Despite comparisons with published results, data for each site was scrutinized in its own right, given the notable differences between published measurements of fossilized and modern pollen (Mäkelä, 1996) and differences illustrated between samples from differing locations and populations (Karlsdóttir et al., 2007). At Vatnsfjörður where *Betula* pollen percentages were lower and many poorly preserved all *Betula* grains were recorded as *Betula* sp. so as not to dilute assemblage interpretations. No attempts were made to split grains into the two species at Viðatóft either, with the higher proportions of mechanical and biochemical degradation found at the site affecting the ease of measurements. Non-triporate *Betula* grains were also recorded given their associations with hybridisation (Karlsdóttir et al., 2014). Insufficient quantities of these were encountered and therefore did not warrant any further analysis. However, recent studies have suggested the effects of hybridisation in Iceland have led to a closing gap in the size differences between the species, a further issue in separating the two accurately (Karlsdóttir et al., 2009).

Table 2.4 Measurements of *Betula* pollen diameters (±1σ) from published papers in Iceland and Fennoscandia.

Source	Taxon	Size (µm)	Mounting medium
(Karlsdóttir et al., 2014)	B. nana	19	Silicon oil
	B. pubescens	23	
(Karlsdóttir et al., 2007)	B. nana	20.42±2.29*	Silicon oil
	B. pubescens	24.20±2.36*	
(Caseldine, 2001)	B. nana (N.Iceland)	19.23 ± 1.43*	Silicon oil
	B. pubescens ssp. tortuosa (N. Iceland)	24.06 ± 1.90*	
	B. pubescens ssp. tortuosa (S.Iceland)	26.94 ± 2.10*	
(Rundgren, 1998b)	*B. pubescens* ssp. *Tortuosa*	> 27.2 or 24-27 + morph	Glycerol
	Betula undiff	24-27	
	B. nana	24-27 + morph	
	B. nana	< 24 + pore depth < 4.1	
(Hallsdóttir, 1990)	*B. nana*	23.5	Glycerol
	B. pubescens	30	
(Mäkelä, 1996)	*B. nana*	17.31 ± 0.88*	Silicon oil
	B. pubescens ssp. *Tortuosa*	22.06 ± 2.25*	
	B. pubescens ssp. *Tortuosa*	25.98 ± 2.30*	
	B. pubescens hybrid	24.26 ± 1.59	
(Birks, 1968)	*B. nana*	18.71 ± 1.30*	Silicon Oil
	B. nana	18.60 ± 1.09*	
	B. nana	18.72 ± 1.21*	
	B. pubescens	22.63 ± 1.43*	
	B. pubescens	23.31 ± 1.59*	
	B. tortuosa	26.42 ± 1.60	
	B. tortuosa	23.43 ± 1.38	
	B. tortuosa	26.07 ± 1.72	
(Eneroth, 1951)	*B. nana*	19.4	Glycerol
	B. pubescens	25.0	
	B. tortuosa	26.1	

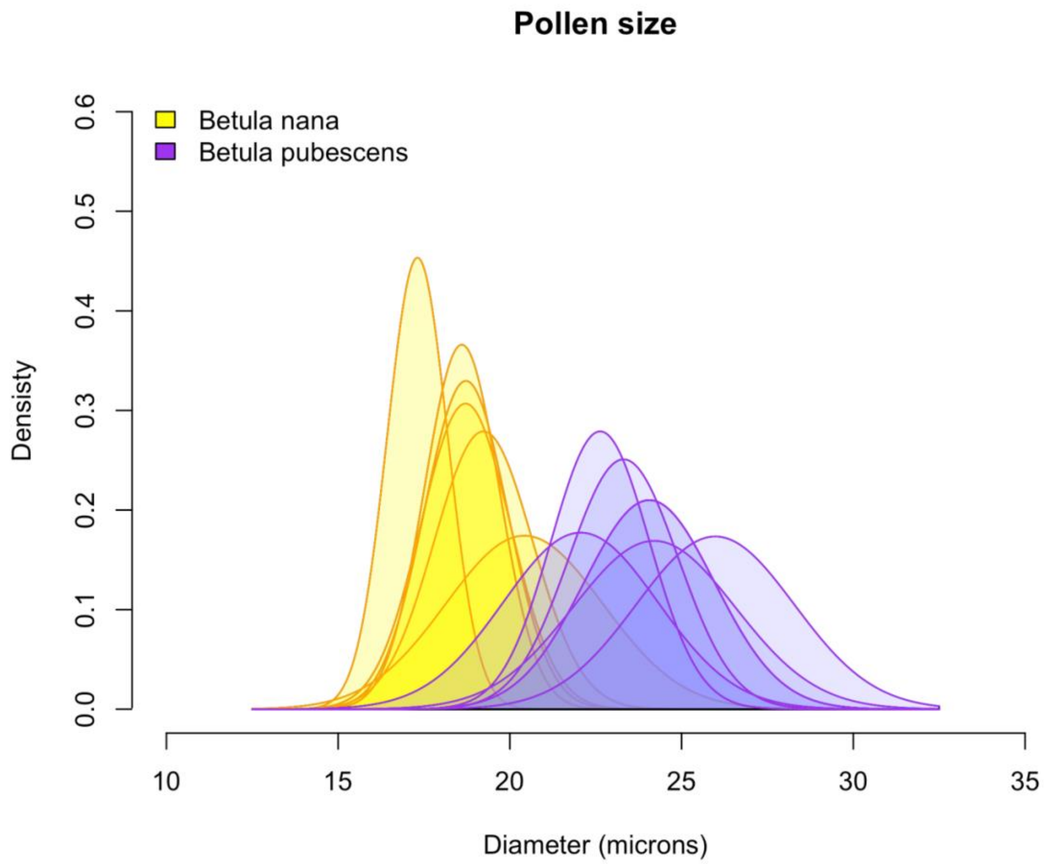


Figure 2.2 Published diameters of *B. nana* and *B. pubescens* (values marked with * in Table 2.4), demonstrating much variability in size between the two.

2.7.6.2 Cereal measurements

Cereal pollen is widely regarded as an anthropogenic indicator in pollen diagrams, and is noted as an important indication of human settlement in Iceland, particularly in those sites where dense woodland is not present at Landnám. Given the limited dispersal of cereal pollen, linked to its self-pollinating nature, decreasing the likelihood of encountering it in standard pollen counts, a 'rapid scanning' technique was adopted so as to optimise detection of cereal pollen within the samples. The entirety of the slide was scanned quickly at the lower magnification of x200, counting exotics at the same time to calculate frequencies of cereal pollen, in a technique similar to that developed by Edwards et al. (1986). Any Poaceae >30µm were measured more precisely in grain and annulus diameter, and compared with published descriptions in Andersen, 1979; Dickson, 1988; and Tweddle et al., 2005 to allow for separation of cereal grains from wild grasses. Despite extra efforts no cereal grains were encountered in any of the sites

2.7.7 Pollen preservation

The analysis of differential preservation patterns in sub-fossil pollen assemblages is a useful and arguably necessary addition to pollen analytical studies (Havinga, 1967; Tipping, 2000), particularly for those sites in which preservation conditions might not be ideal. Analysis of preservation has the power to provide insight into whether our fossil pollen assemblage is of suitable preservation status to interpret past vegetation communities, indicating whether a sample might have been biased by forms of changing taphonomy and selective loss, particularly given the assumption pollen data, for any given point, is reflective of the environment in which it was deposited (Bunting and Tipping, 2000; Cushing, 1967; Delcourt and Delcourt, 1980; Tipping, 2000; Tweddle and Edwards, 2010). The addition of preservation analysis to classic studies is most useful in determining whether vegetation shifts are genuine or an artefact of the depositional or preservation environment (Tweddle and Edwards, 2010). Pollen preservation data can also be used as a tool to infer environmental change, given links between depositional environments and pollen exine deterioration (Birks, 1970).

In this study preservation state of each determinable grain has been assessed based on five categories (Table 2.5, following Cushing (1967)) and recorded based on order of significance, with grains suffering two forms of deterioration being classified by the more significant preservation class. Examples of each class on Poaceae pollen from Iceland are demonstrated in Figure 2.3. Degraded is regarded as the most significant class, followed by corroded, crumpled and broken. Certain taxa have a higher susceptibility to classification under particular preservation classes; *Cyperaceae* for example, given its thin exine is highly susceptible to crumpling, whereas *Juniperus* pollen is frequently broken. Within this study these taxa have been excluded from preservation analysis so as not to skew interpretations. Indeterminable grains have also been counted, and have been plotted alongside percentage data classified as ‘unidentifiable’; this includes obscured grains and those indeterminable because of intensive deterioration.

Table 2.5 A description of the five categories of pollen preservation used in this study and their causes (Cushing, 1967; Delcourt and Delcourt, 1980)

Type	Deterioration	Description	Causes
Biochemical	Degraded	Structural and sculptural features difficult to determine. Often affects whole exine, wall may appear amorphous	Chemical oxidation – within aerial and subaerial environmental
	Corroded	Pitted or etched exines, corroded areas randomly distributed	Biochemical oxidation linked to localised fungal and bacterial activity; Chemical oxidation, repeated wet and dry cycles, bacterial and fungal activity
Mechanical	Crumpled	Folded, twisted, wrinkled or collapsed grains	Damages accrued during transport; syn- and post-depositional compaction within sediments; during sample preparation
	Broken	Distinctly ruptured exine, with break extending through exine	
	Normal	Not damaged	N/A

Preservation diagrams are based on percentage data, whereby sums are generated using values of all preservation classed as well and normally preserved grains. Preservation data is presented only for those taxa forming a significant portion of the TLP sum (*Betula, Salix, Poaceae*) with values for other TLP taxa summed and presented on the diagram as ‘other’.

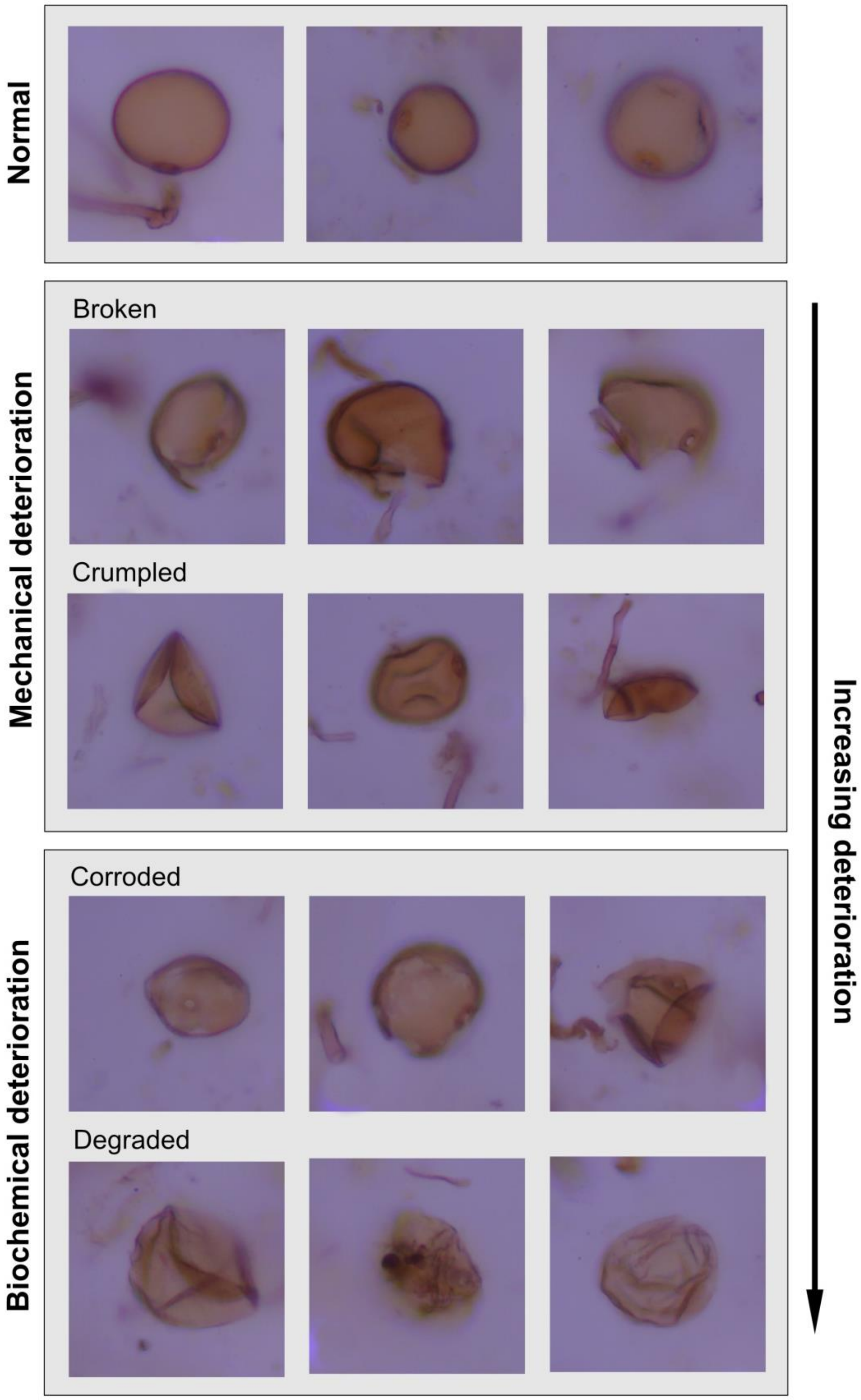


Figure 2.3 Poaceae grains from Icelandic samples demonstrating the five categories of pollen grain preservation in increasing degree of significance; normal, broken, crumpled, corroded and degraded

Because of constant input of tephra and aeolian sediments, Icelandic peats tend to be highly inorganic and basic in nature, creating preservations issues and increased likelihood of deterioration in situ; in comparison with more organic and acidic soils classically chosen for pollen analytical studies. The highly active erosion effecting of Iceland, also creates somewhat unique deposition environment, increasing the likelihood of eroded and redistributed pollen being incorporated in modern samples. Pollen preservation data should therefore be interpreted with caution given the increased likelihood of poorly preserved grains and resultant post depositional biasing. A means to counteract this is testing for post depositional biasing using a series of tests developed by Bunting and Tipping (2000) (Table 2.6). These were applied to pollen data sets with the aim of highlighting whether samples are capable of supporting interpretations and environmental reconstructions as intended. It is recommended entire samples are not rejected on failure of a single test, rather tests are used ambiguously to highlight potentially problematic samples; samples should be excluded from interpretations where the conditions for several tests are not met (Bunting and Tipping, 2000).

Table 2.6 Summary of properties of pollen assemblages indicating post-depositional biasing; and the thresholds at which those tests are failed in a given assemblage. After Bunting and Tipping, (2000).

Test	Failure Threshold/basis sum TLP or TLP+group	Reasoning
Total land pollen sum (TLP)	<300	Low counts effect reliability of percentage data; minor taxa (often those indicating human activity) impacted most.
Total pollen concentration	<3000 grains cm^{-3}	Low concentrations indicate samples vulnerable to contamination during collection and preparation, or from in-situ reworking
Number of main sum taxa	<10	Dominance of one or a few taxa, particularly where species decay resistant, can point to post-depositional losses.
Percentage severely degraded grains	>35%	Possible indicator of assemblage distortion by differential pollen preservation or mixing with older material.
Percentage indeterminable	>30%	Not necessarily correlated with increases in decay, regardless of this high numbers indicate potential biasing.
Percentage resistant taxa (e.g. thick walled/robust grains – *Tilia, Caryophyllaceae, Chenopodiaceae, Asteraceae (Lactuceae), Artemisia* type, *Brassicaceae*	>6%	High percentages of taxa resistant to decay and easily recognisable when decays can indicated distorted assemblages, where some species may be lost.
Percentage Pteropsida (monolete) indet.	>40%	Spores highly resistant to deterioration. This method excludes habitat specific spores e.g. *Pteridium aquilinum*
Spore : pollen concentration ratio	>0.66	Spores highly resistant to deterioration.
Spore : pollen taxa ratio	>0.66	Spores highly resistant to deterioration.

2.7.8 Microscopic charcoal

Standard pollen preparation techniques used here have the benefit of allowing for the quantification of charcoal particles within the samples, which can be counted alongside pollen

(Tolonen, 1986). Charcoal fragments were identified as black, opaque and angular (Patterson et al., 1987), with fragments appearing only partially blackened and brown in areas excluded from counts, so as to avoid inclusion of oxidised organic matter. Charcoal fragments where counted and recorded in five diameter size classes <25 µm, 25-50 µm, 50-75 µm, 75-100 µm, >100 µm. The input of those fragments ≤25 µm is considered continuous in most areas, with particles in the larger size categories a proxy record of past fires in the local area; frequencies of small and large fragments do tend however to demonstrate strong correlations (Tolonen, 1986).

Charcoal data is presented alongside pollen data as concentrations (No. per cm^3), rather than as a percentage of TLP. This is because the mechanisms by which charcoal fragments are produced, dispersed and incorporated into sediments differ from pollination strategies.

2.7.9 Data processing and presentation

2.7.9.1 Diagram construction and zonation

Frequency, concentration and preservation diagrams were prepared using TILIA (version 1.7.16) (Grimm, 2011). Pollen and spore percentages were calculated as a percentage of TLP, which consists of the total number of land pollen grains excluding unidentified pollen, *Cyperaceae* and aquatics and spores. Percentages values for these taxa out with the TLP sum were calculated as TLP + taxon, algae was also treated in this way.

For ease of description of vegetation communities and changes within them diagrams were sorted into local pollen assemblage zones (LPAZ) using CONISS (Constrained Incremental Sum of Squares) (Grimm, 1987). These LPAZ were defined using all those terrestrial pollen species present at frequencies of greater than or equal to 2%, dendrograms produced through this analysis are used for all pollen diagrams within each site. Statistical zonation is preferential to zonation by eye as avoids any bias or preconceptions that might be introduced by the analyst (Birks and Birks, 1980).

2.7.9.2 Concentration and Influx?

Pollen concentration values were also calculated and plotted for each of the farms. Concentration is an absolute measurement of pollen frequency and allows each pollen type to be considered independently of other pollen types present. This provides the benefit over the percentage diagram, which as a result of the use of percentages suffers interdependence issues. Percentages values are therefore highly dependent on all other taxa in pollen sum; for example, where one taxon expands and percentages increase percentages of all other taxa are seen to decrease, with every sum having to equal 100, this might not necessarily be a true representation of vegetation change (Prentice, 1988).

Absolute values also come with their associated disadvantages and error sources. Potential sources of error in calculating pollen concentrations include: inaccuracies in the volumetric displacement of samples, loss of exotic *Lycopodium* spores during processing, error ranges on quantities of exotics per tablet and biasing caused by non-random distribution of grains (exotic and fossil) on the slide (Maher, 1881).

Pollen accumulation rates or Influx values (grains $cm^{-2}yr^{-1}$) are also frequently included as absolute pollen measurements. Influx or pollen accumulation rates rely heavily on accuracy of sedimentation rates or deposition time at the site. Given the impossibility of calculating values for each level interpolated values from between securely dated levels are used (Hicks and Hyvärinen, 1999). Peat samples are particularly liable to inaccuracies as peat growth is affected by changes in degrees of decomposition and compactions, abrupt changes and irregularities in peat growth are therefore somewhat common (Hicks and Hyvärinen, 1999). Slow and even sediment accumulation/fast growing, uniformly humified peat comprised of a single moss species is therefore preferable in the calculations of influx values. For the sites presented here sediment accumulation rates were seen to vary substantially within and between sites, with chronological control varying in levels of sufficiency, for these reasons it was decided to include pollen concentration as the only absolute pollen frequency measurement, avoiding the addition of any further sources of error.

Using the counts in samples of the exotic spores (Stockmarr, 1971), pollen concentrations where calculated in TILIA (Grimm, 2011) using the following equation (Berglund and Ralska-Jasiewiczowa, 1986):

$$Pollen\ Concentration = \frac{Spores\ added}{Spores\ counted} \times \frac{Fossil\ pollen}{Volume\ cm^{-3}, grains, cm^{-3}}$$

Concentrations were presented on a separate diagram, showing only key taxa alongside total land pollen concentrations. An exaggeration factor of x10 was applied to all taxon to improve visibility on the figure.

2.7.10 Statistical analysis of pollen data – rarefaction

Estimation of floristic diversity is a useful method in interpreting pollen data, as has the potential to provide information with regards to disturbance in an ecosystem, anthropogenic or otherwise. The number of taxon in any one sample is a coarse measurement of palynological richness at that point, however, in order to compare palynological richness between points it is first necessary to standardise them to counts of the same size, removing any bias created by varying pollen counts. Rarefaction analysis allows for this estimation of palynological richness where all samples are the same size. Birks and Line (1992;2) summarize this method as providing 'minimum variance unbiased estimates of the expected number of taxa (*t*) in a random sample of *n* individuals taken from a collection of *N* individuals containing *T* taxa'.

Using the 'rarefy' function in the R package vegan (Oksanen et al., 2016) and a standardised count of 300 (the lowest sum in any level), to enable comparisons of palynological richness within sites rarefaction analysis was conducted. Rarefied counts were presented alongside pollen frequency data using TILIA (Grimm, 2011). It should be considered when observing the rarefied counts that taxa are frequently not identifiable to species level, limiting taxon included in species counts. Taphonomic issues also have the potential to alter results; it is generally presumed fossil pollen incorporated into sediments is an accurate reflection of past vegetation, as well as having good preservation of pollen and little input of allochthonous material.

2.7.11 Interpreting pollen data

Interpretations of the pollen data will be made with regards to all pollen diagrams, comparing pollen data to modern day vegetation communities. An indicator species approach will be adopted for the analysis of pollen data in this study, with a focus on anthropogenic indicators (Behre, 1986), more specifically those species associated with human disturbance in Norse sites (Edwards et al., 2011). This allows for reconstruction of human impacts on the vegetation using the indicator species ecology, as linked to man induced aspects of the local environments. For example, changes linked to fire, soil erosion and disturbance, clearance and subsequent opening of the landscape and crop growth and management (Moore et al., 1991).

2.8 Micromorphology

2.8.1 Micromorphology overview

Micromorphological analysis allows for the microscopic analysis of undisturbed soil features in thin section, including arrangements of soil particles, pore spaces and linings, linking identifiable soil features to active and past soil processes, occurring as a result of archaeological, cultural and environmental activity – including information on soil genesis and development and the impacts of land use on sediments. In this study micromorphology will also be used to verify SeAR's, demonstrating sources of sediment accumulation, pollen taphonomic processes might also be highlighted, for example where an increase in aeolian sediments is shown in thin section, pollen within the samples from those points is potentially redistributed (Tipping, 2000).

2.8.2 Field Sampling techniques

Undisturbed sample for micromorphological analysis were collected in Kubiena tins, from soil pits exposed next to pollen cores, or in wetter sediments where this proved difficult, directly extracted from cores taken next to pollen cores. Upon extraction of these samples tins and cores were wrapped and sealed and stored in the cold store until required for thin section preparation.

2.8.3 Thin section preparation

Thin sections were prepared in the Micromorphological Laboratory, at the University of Stirling, using standard procedures (http://www.thin.stir.ac.uk), as adapted from Murphy (1986). Given the highly organic nature of the meadow soils sampled for this research, and the susceptibility of soil organic matter to shrinkage and typically high water contents, much care was taken in the production and interpretation of the thin sections, because sections from highly organic soils have a tendency to contain high numbers of artefacts from the production process (Stolt and Lindbo, 2010). Samples were initially dried using solvent exchange in the vapour phase using acetone, this methodology reduces likelihood of shrinkage and cracking whilst drying, as well as avoiding dissolution of organic material in the samples. Once dry, samples were impregnated with polyester (crystic 7449) resin under a vacuum. When cured samples were bonded to a slide, cut and ground to the desired thickness (30µm) before polishing and coverslipping ready for analysis.

2.8.4 Thin section analysis

Thin sections were analysed by initially dividing the analytical area of each slide into micro-strata using a light box and magnifying glass. Samples were then observed using an Olympus BX-50 petrological microscope, a range of magnifications (x10 – x400) and a range of light sources – plane polarised light (PPL), cross polarised light (XPL) and oblique incident illumination (OIL).

Descriptions were made using internationally accepted terminology (Bullock et al., 1985; Stoops, 2003) supplemented by the work of Fitzpatrick (1993), which allowed semi-quantitative description of coarse and fine mineral and organic materials, pedofeatures and soil micro-structures. In addition to more typical descriptive categories, and given the origin of samples from wetland contexts, microhorizons were further categorised by degree of organic material decomposition (Table 2.7) and siliceous content in accordance with descriptions provided by Stolt and Lindbo (2010) and Gutiérrez-Castorena and Effland (2010). Interpretation of descriptions was based on comparisons with published micromorphological studies based on observations of typical Icelandic, anthropogenic and wetland sediments. Studies of expected micromorphological features were derived from ethnographical approaches (Adderley et al., 2006), experimental analysis (Simpson et al., 1999, 2003) and samples from known environmental contexts or stratigraphic positions (Bouma et al., 1990; Gutiérrez-Castorena and Effland, 2010; Romans et al., 1980; Sedov et al., 2010; Stoops, 2007).

Table 2.7 Degree of decomposition in organic matter horizons and their defining characteristics. (After Stolt and Lindbo, 2010)

Degree of Decomposition	Characteristics
Fibric	• Poorly decomposed plant residues dominant (up to 70% >2mm) • Yellowish-brown colours • Occasional darker fragments similar to decomposition of hemic/sapric horizons • Residues originating from herbaceous materials, e.g. sedges, grasses, wood, mosses and seeds
Hemic	• Coarse plant residues dominate, large proportion groundmass well decomposed plant residues and organic fine material • Darker in colour than Fibric horizons • Fabric typically loosely packed, porous • Dense, poor defined excrements dispersed among coarse tissue residues
Sapric	• Black/dark brown organic fine material (OIL) • Residues predominantly dark brown and well decomposed • Horizons denser than hemic or fibric • Range of pore types (vughs, channels, packing voids) • Often with visible excrement (earthworms, mites)

2.9 Methodological Summary

The chronostratigraphical, palynological and micromorphological methods presented above will be integrated and employed as a robust and methods set to develop a better understanding of the wet meadows in the three case farms Vatnsfjörður, Viðatóft and Gautlönd; presented in chapters 3, 4 and 5 respectively. In each case proving a comprehensive analysis of how the meadows developed, and how they were used and managed in a Norse cultural context, in doing so exploring the potential of the organic meadow sediments as environmental and cultural archives.

Chapter 3 Vatnsfjörður, meadows as adaption to farming in inherently infertile areas

3.1 Introduction and Site Description

Because of its hostile climate, limited agricultural resources and isolated position it was previously accepted, with little supporting evidence, that the Northwest peninsula was the last area of Iceland to be settled and, when settled, was done so by poorer immigrants (Edvardsson and McGovern, 2005; Tulinius, 2005). However, excavations at Vatnsfjörður (Figure 3.1) are revising these views through the uncovering of a longhouse, dated to the 10th century, with associated field systems and Norse landscape organisation in place. Farm sites selected tended to be naturally fertile or heavily improved; at Vatnsfjörður soils appear to be relatively shallow reducing their agricultural potential (Milek, 2006), with early investigations of the homefield soils suggesting no attempts were made to fertilise or improve the inherently free draining and fertility limited soils. Given the high status of the site, this raises a series of questions as to why homefield soils, unlike homefields elsewhere in Iceland and the North Atlantic region in general, were not intensively managed.

In addition to these environmental factors, the region has differed culturally from the rest of the country, because of its isolation from centralised ecclesiastical power. No monasteries or Bishops sees are found in the region, and instead a dynamic lay culture is believed to have thrived from the 13th to 17th century (Tulinius, 2005). Historical documentary resources have also indicated the farm was a major power centre for the region, becoming one of the richest Icelandic farms in the Late Middle Ages (Edvardsson and McGovern, 2005), unusual given the site's limitations to production and the perceived reliance of the Icelandic economy on agriculture. This environmental and social context makes the site a particularly important location to consider human adaption and resilience in challenging physical locations.

Figure 3.1 Location of Vatnsfjörður and its subsidiary farm, NW Peninsula.

Archaeological research has been ongoing since 2003 (Friðriksson et al., 2005). Work has focused on two main areas of the site; the Viking age farm and associated domestic dwellings, workshops, storage buildings and animal buildings, and the more modern 17th-19th century area of the site, characterised by a large domestic dwelling, industrial areas and middens. The site is occupied to the present day, with the modern house and church (Figure 3.2) still in use, and farming activities ongoing. The site is currently dominated by grass species (Figure 3.3), particularly in the more intensively used areas; ruderal species commonly associated with disturbance and agricultural activity are also noted throughout the farm, including *Taraxacum sp., Rumex sp. and Plantago sp.*. Sedges and *Equisetum sp.* are also dominant features of the vegetation assemblage, particularly towards the edges of the more intensively used areas. *Angelica sylvestris* and *Ranunculus* are dominant features of the lower, wetter portion of the farm, with *Ranunculus* a dominant species in the meadow east northeast of the modern house. Shrubby species become more frequent in the dryer upper reaches of the site, with *Betula nana, Salix lanata, Vaccinium* and *Empetrum* all encountered on these slopes.

The *Angelica sylvestris* and *Ranunculus* dominated wet meadow situated below the modern farm house, is a curious feature of the site, with sediments here holding more moisture and organic matter, despite the addition of recent drainage ditches, than the shallow, free draining and unmanaged soils elsewhere in the homefield. Given this contrast to the rest of its homefield, as well as the interesting social and cultural nature of the site, the meadows here were selected for palaeoenvironmental analysis, using Vatnsfjörður as a case study for wet meadow development, use and management in a high status, and otherwise inherently infertile site. In order to address the aims set out in Chapter 1, the present state of meadows and their development though time will be established by developing complex chronostratigraphies for the meadow soils. Pollen analysis and soil micromorphology will then be used to investigate the cultural and environmental records held within the meadow sediments; where applicable using this record to establish pre-Landnám conditions, impacts of settlement on the meadows and impacts and evidence of their past use and management, contrasting this information, where possible against existing archaeological and environmental data.

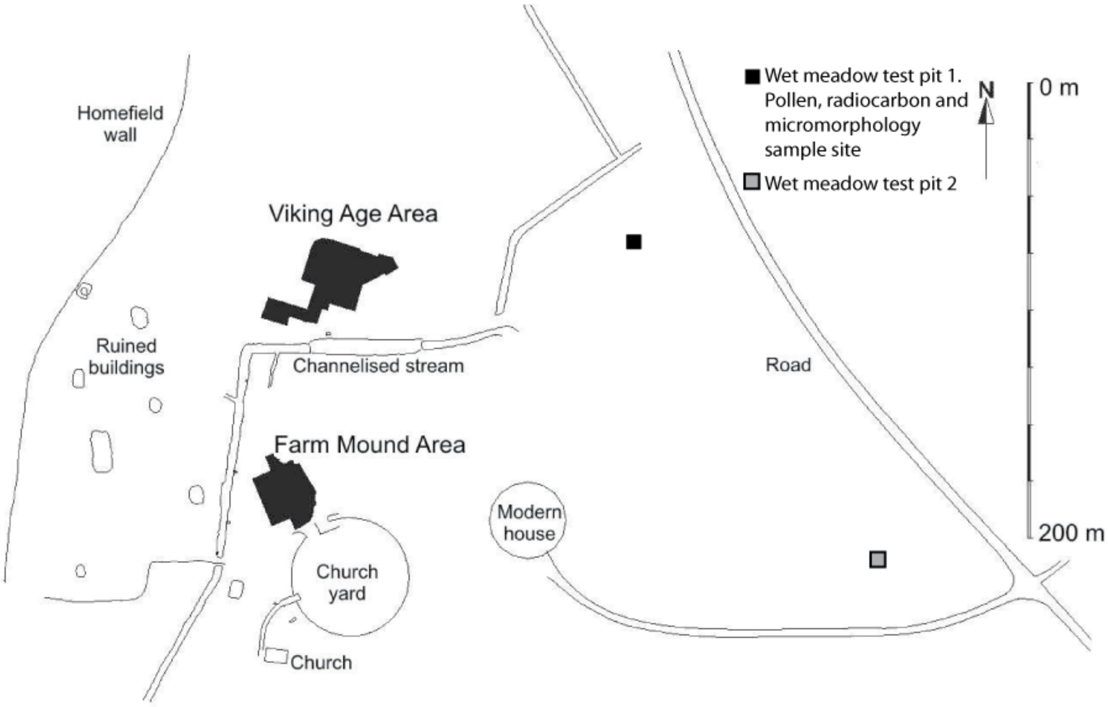


Figure 3.2 Homefield Map detailing sample sites (Map after Gísladóttir (2007))

Figure 3.3 View northeast from Vatnsfjörður farm; grass and Ranunculus are the dominant vegetation types in much of the site.

3.2 Fieldwork and Lithology

To characterise the farm homefield a soil transect survey was carried out by hand auger, incorporating land from just above the upper boundary wall to the fjord, east of the settlement; the survey avoided direct disturbance of archaeological features. Soil assessment was made at 50m intervals and depth, Munsell colour, texture and cultural inclusions together with slope angle were recorded at each point.

The scaled cross sectional transect diagram (Figure 3.4), representing the Vatnsfjörður homefield was produced using the results of the auger survey. The cross section spans the 372m from the homefield's upper boundary to the fjord at the base of the settlement and indicates a slope related sequence of soils (catena). Upper, steep slopes to the west are characterised by shallow soils underlain by basaltic bedrock. Soils increase slightly in depth on descent into the residential area of the homefield, increasing again beyond the archaeology. Two profiles - 6 and 7, were excavated further within the transect demonstrating that this area is underlain by well drained beach gravels with evident iron leaching and mottling, creating shallow nutrient depleted podsols derived from andic material (FAO 2006). Such podsolised conditions are rarely witnessed in Iceland. They are however not dissimilar to those soils experiencing soil moisture deficit in Greenland's eastern settlement (Adderley and Simpson, 2006; Milek, 2006).

Peat accumulation is found behind a raised beach deposit, forming a wet meadow in the lower part of the transect and is in sharp contrast to the other areas of the homefield. Gravely substrate beneath the peat would tend to give rise free draining conditions, limiting to organic matter accumulation; however, gleyic colour patterns of mineral material within these histosols (FAO, 2006) indicate the peat was poorly drained and suggest hydromorphism, waterlogging and anoxic conditions. The homefield shows contrasting wet and dry areas (Figure 3.4); steeper upper slopes, characterised by shallow organic silt soils underlain by bedrock, impeding drainage and allowing for accumulation of organic matter, meadow soils are unusually saturated and peaty whereas for the most extensive part of the homefield soils are silty and dry in nature.

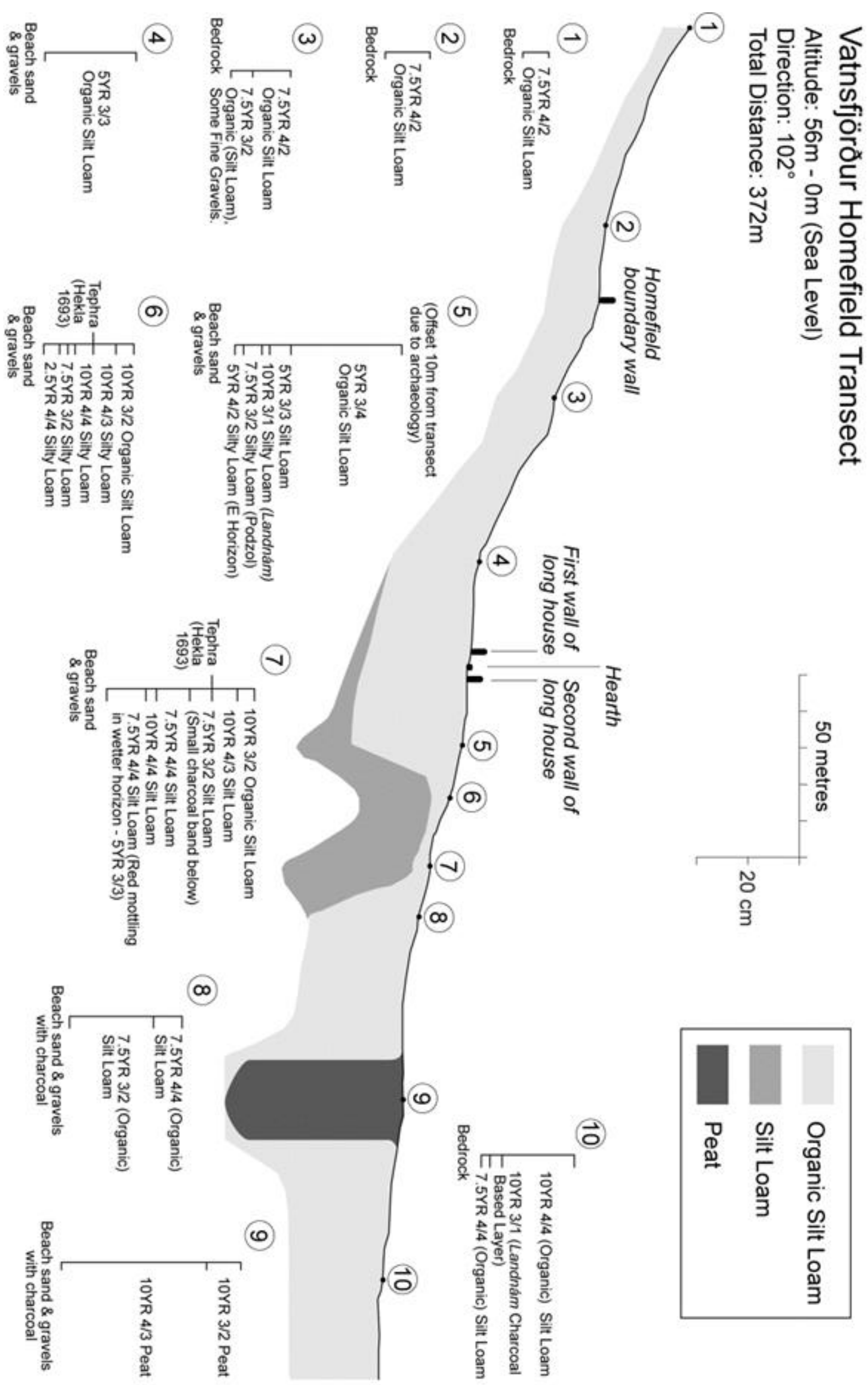
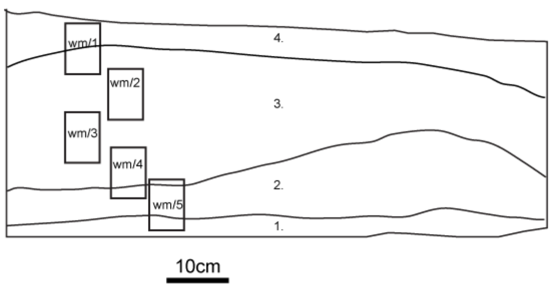


Figure 3.4 Vatnsfjörður homefield transect – a stratigraphical interpretation of the farm site from the slopes above the homefield upper boundary wall to the modern road at the base of settlement.

Two test pits were created at either end of the wet meadow to further define the stratigraphy within Figure 3.4. With test pit 1 re-excavated after its use in archaeo-entomological studies the previous year, and text pit 2 selected so as to represent the opposite side of the meadow (wet meadows test pits 1 and 2, Figure 3.5). Substrates generally consisted of beach sands and gravels overlain by deep organic deposits. Test pit 2 showed the basal horizon comprising blue-grey silts, of potential marine origin, suggestive of a natural basin prior to sea levels dropping in the area. The present sea level has been gradually regressing since 3.1 ka cal. BP, following a late Holocene rise (Lloyd et al., 2007). Novel tephrochronological methodologies adopted on the site by Mikołajczyk et al., (2015) for the calculation of recent sea level change, have suggested a relative sea level change of approximately 1.4m/ka in the area. This indicates a fall in sea level of 0.46m from AD 1693 to the present day, calculated using the Hekla 1693 tephra deposit.

Wet meadow test pit 1



1. Ag2As1Sh1, dark brown, well humified organic matter and silts, combined with gravels (1-2cm)(Gmaj4), combined with charcoal fragments.

2. Sh3Ag1, very dark brown, clayey silts and moderately-well humified peat.

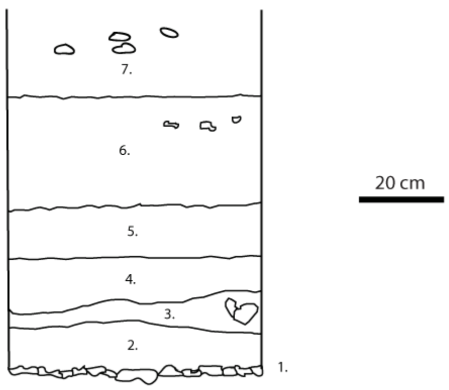
3. Sh2Tb1Ag1, dark yellowish organic silts with moderately humified, fibrous organic material.

4. Sh1Tb1Th2, very dark brown, well humified organic silt/peat with abundant roots, current A horizon.

Profile is East facing.

Pollen Core Taken from 6-45cm.

Wet meadow test pit 2



1. Gmaj4 rounded/subrounded beach pebbles 1-10cm. Uneven surface due to wave deposition.

2. Ag3Gmin1Gmaj+, very dark grey-blueish fine sandy silt. Pebbles throughout profile

3. Ag3As1, very dark grey silts. Two clasts of silt/sandy material in horizon. Larger clast Gmin4, smaller clast Ag3Gmin1Gmaj+.

4. Sh3Ag1, very dark greyish-brown, well humified peat.

5. Sh2Dh2Ag+, dark greyish brown, moderatley humified peat. 25-28cm layering appearance.

6. Sh3Ag1Gmaj+, very dark greyish brown, humified Peat. Small stones in profile at 58cm.

7. Sh1Th3Gmaj+, reddish brown, moderatley humified peat. Stones 2-6cm diameter in profile at 74cm.

Profile is East facing.

Figure 3.5 Scaled profile drawings of wet meadow test pits 1 and 2 as marked on map in Figure 3.2. Sediments described using a Troels-Smith modification.

Given the depth of peat informed by the initial stratigraphical cross section, and therefore suitability for pollen preservation the wet meadow area was selected for pollen analysis. A 2.5cm internal diameter Eijkelkamp gouge was used to survey peat depth and condition across two transects of the meadow, sampling at 20m intervals to locate an appropriate peat deposit for extraction of a representative core. Due to the modern addition of drainage ditches across the meadow, peat preservation was variable, and it was decided to use wet meadow test pit 1 for further analysis based upon its good preservation status, representative peat depth and the use of sediments in other studies which provide the potential for future comparison. A vertical cleared section (6-45 cm), for use in pollen analysis, was directly extracted from this pit using plastic guttering. With the basin's 100m diameter, the pollen source area is likely of moderate size, with most pollen entering the mire from local and extra local sources (*sensu lato* Jacobson and Bradshaw, 1981). Five Kubiena tins were extracted from the same profile, in a continuous stratigraphical unit culminating in the B horizon at the base of the exposed stratigraphy (Figure 3.5). These were adjacent to the pollen core, allowing for analysis of the profile in its entirety and to enable direct comparisons with the pollen data. Given the natural variability of soils the micromorphological samples span a slightly more compressed depth of 38cm.

3.3 Chronology

Well preserved charcoal fragments of up to 0.5cm diameter were extracted from the base of test pit 1 (Figure 3.5) for radiocarbon dating so as to give an approximate age for peat development, and basal date of the pollen core. Two single entity samples were submitted to the Scottish Universities Environmental Research Centre (SUERC) facility for Accelerated Mass Spectrometry (AMS) analyses, and later re-calibrated using INTCAL13 in CALIB 7.0 (Reimer et al., 2013).

Radiocarbon dates produced from the samples are presented in Table 3.1. The sample positively identified as *Pinus sylvestris* was rejected from further analysis given the absence of the species in Iceland and the likelihood of the charcoal being derived from driftwood or imported material. Given the native status of *Betula* in Iceland, and likelihood charcoal is of local origin, this sample (SUREC-8386) was selected to provide a reliable date for the start of peat accumulation onsite and for use in the age-depth model. The dates generated are within the traditional Landnám timeframe, suggesting peat initiation is likely to have post-dated settlement.

In order to complete the chronostratigraphy for the meadow, tephra dates were used. However, as a result of prevailing wind conditions, the Northwest peninsula has only sporadic and limited deposition of tephra (Lawson et al., 2005; Sigurgeirsson, 2006), with post-settlement tephra exceptionally limited. Cryptotephra dating approaches, carried out at the University of Oxford, have therefore been utilised as means of providing further chronological control. The homefield core was sampled in continuous 2cm sections to create a tephrostratigraphy, sediment from each section then underwent the procedure used for the extraction of cryptotephra described in Blockley et al., (2005) (Chapter 2, section 2.5.3). This analysis produced a further 3 dates for use in the age-depth model for the meadow site (Table 3.2), with tephra shards correlated with 3 separate Hekla eruptions from AD 1300, 1693 and 1766.

Using the cryptotephra and basal radiocarbon dates it has been possible to calculate soil accumulation rates within the meadow for the post settlement period (Table 3.3). Peat in the meadow shows a steady SeAR of 0.4-0.5 mm/yr., increasing to 0.8mm/yr. during the period AD 1693-1766. These values are however generated using a single point because of the lack of tephra deposits within stratigraphical units in the meadow. It is therefore not possible to present errors with the values, and so interpretations made from these figures are limited.

Table 3.1 Radiocarbon results from the base of Vatnsfjörður wet meadow. Dates have been recalibrated using INTCAL13 in CALIB 7.0 (Reimer et al., 2013) since initial calibrations used an older calibration curve.

Lab Code	Material	Site	^{14}C Age	Error ±	cal BC/AD (±1σ)	cal BC/AD (±2σ)	$\delta^{13}C$ (%)
SUREC-8386	Charcoal – Betula	Wet Meadow Base	1090	35	AD 898-991	AD 889-1017	-26.7
SUREC-8391	Charcoal – Pinus sylvestris	Wet Meadow Base	1050	35	AD 972-1022	AD 896-1030	-24.5

Table 3.2 Cryptotephra identified in the meadow core.

Depth Range/cm	Tephra source	Eruption/AD
31-33	Hekla	1300
17-19	Hekla	1693
11-13	Hekla	1766

Table 3.3 Vatnsfjörður histosol accumulation rates (SeAR) (mm/yr.)

	SeAR (mm/yr.)			
Period/Ad	997-1300	1300-1693	1693-1766	1766 – Present (2008)
SeAR	0.5	0.4	0.8	0.5

Given the radiocarbon and cryptotephra dates, the palaeoenvironmental record could be constrained using a series of 5 dates (radiocarbon basal date, 3 cryptotephra dates and sampling date). These dates were used in the age-depth model for the site, with a calibrated age-depth model produced using the Bayesian program 'Bacon' (Blaauw and Christen, 2011), from which the weighted mean average age for each cm^2 was plotted on the y-axis of the pollen diagrams. The model passes through each of the plotted points, as well as close to the central value for the plotted chronological range of the radiocarbon basal date. The resultant age-depth curve (Figure

3.6) shows a relatively linear age-depth relationship, with the increasing accumulation rate between AD 1693 and AD 1766 represented by a short steepening in the curve.

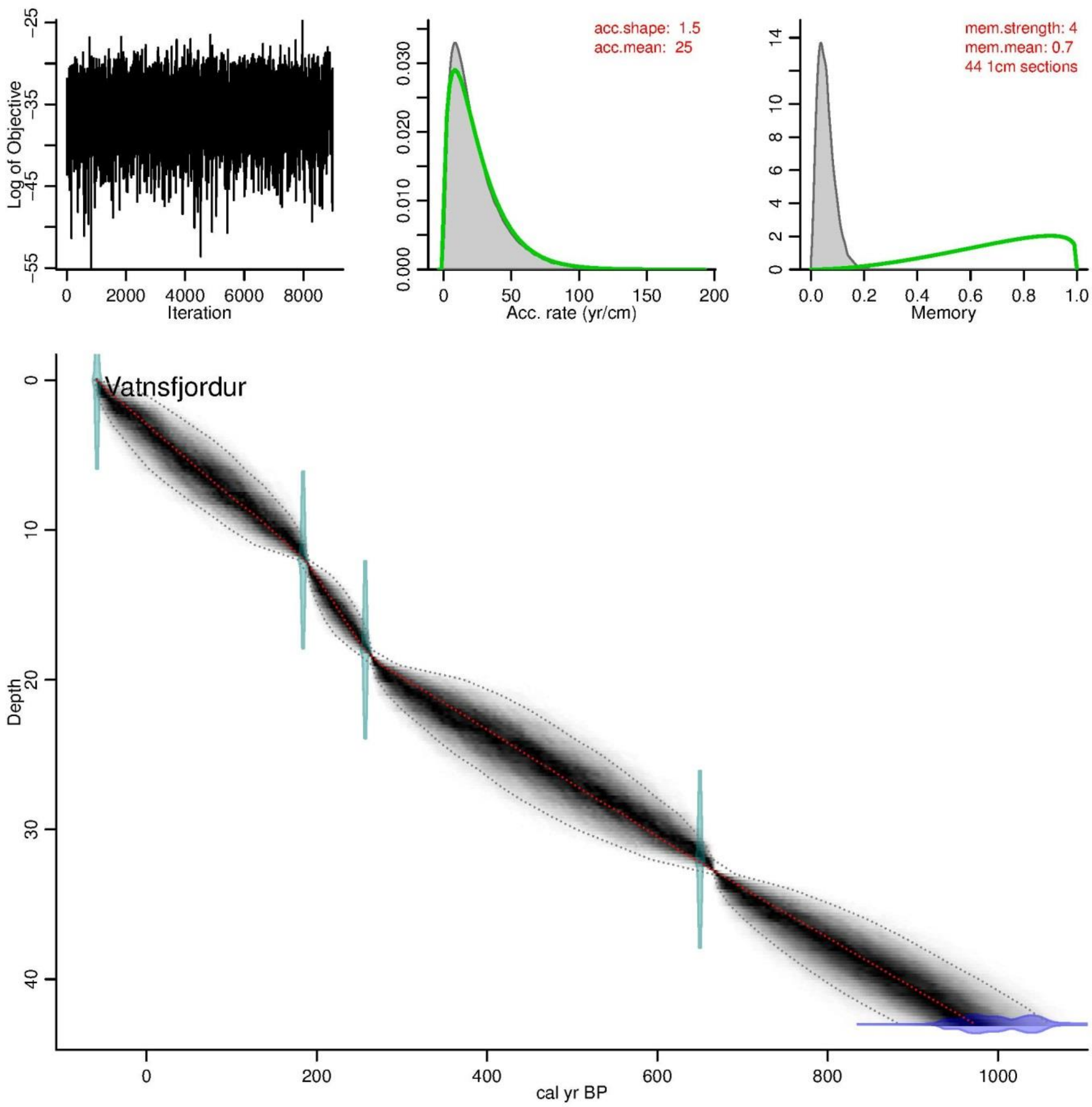


Figure 3.6 Age-depth model for Vatnsfjörður generated using Bacon. The shaded portion represents all probable age-depth models, darker areas signify increased probability; the 2σ age range constrained within the black dotted lines; the dotted red line indicates the weighted-mean average.

3.4 Pollen Analytical Results

3.4.1 Zonation and preservation tests

Prior to interpretations all pollen data was run through the tests proposed by Bunting and Tipping (2000) (Table 3.4) for determining the likelihood of post depositional taphonomic issues and suitability of data for the support of interpretations. All tests were passed with the exception of the 'Percentage resistant taxa test' with *Lactuceae* exceeding 6% in all but 3 depths (12.75cm, 24.5cm, and 33cm). Given the prevalence of *Lactuceae* in Icelandic grasslands and in particular homefield's, samples were not excluded from further analysis based on the single test failure.

Table 3.4 Pollen preservation tests, pollen data, Viðatóft Tests after Bunting and Tipping (2000).

Test	**Failure Threshold/basis sum TLP or TLP+group**	**Pass (✓/✗)**
Total land pollen sum (TLP)	<300	✓
Total pollen concentration	<3000 grains cm^{-3}	✓
Number of main sum taxa	<10	✓
Percentage severely degraded grains	>35%	✓
Percentage indeterminable	>30%	✓
Percentage resistant taxa (e.g. thick walled/robust grains – *Tilia, Caryophyllaceae, Chenopodiaceae, Asteraceae (Lactuceae), Artemisia* type, *Brassicaceae*	>6%	✗ (Lactuceae fails in all bar 3 depths – 12.75cm, 24.5cm, 33cm)
Percentage Pteropsida (monolete) indet.	>40%	✓
Spore : pollen concentration ratio	>0.66	✓
Spore : pollen taxa ratio	>0.66	✓

Six local pollen assemblage zones (LPAZ) were created using CONISS (Grimm, 1987) as a guide – Vatn- 1 a and b, Vatn- 2, Vatn- 3 a, b and c, based on local similarities between the communities. Given the basal data of the core, all zones represent the post Landnám period for the farm site. The pollen assemblage data suggest that the wet meadow site is predominately a grass, herb and sedge rich grassland and remains so for the time recorded in this diagram. Throughout the peat core Poaceae dominates with percentage never falling below 65% and species diversity appears to be low, with species displaying little percentage fluctuations between zones. Species present throughout tend towards those indicating wet meadow pasture type habitats (Behre, 1986) – *Caryophyllaceae, Polygonum aviculare, Cruciferae, Lactuceae, Trifolium, Ranunculaceae, Plantago lanceolata, P. major, Aster, Cyperaceae, Succisa*. Fluctuations in charcoal concentrations reflect variations in the smaller sized fragments (< 50µm), concentrations of larger charcoal fragments (>50µm) are consistent over time.

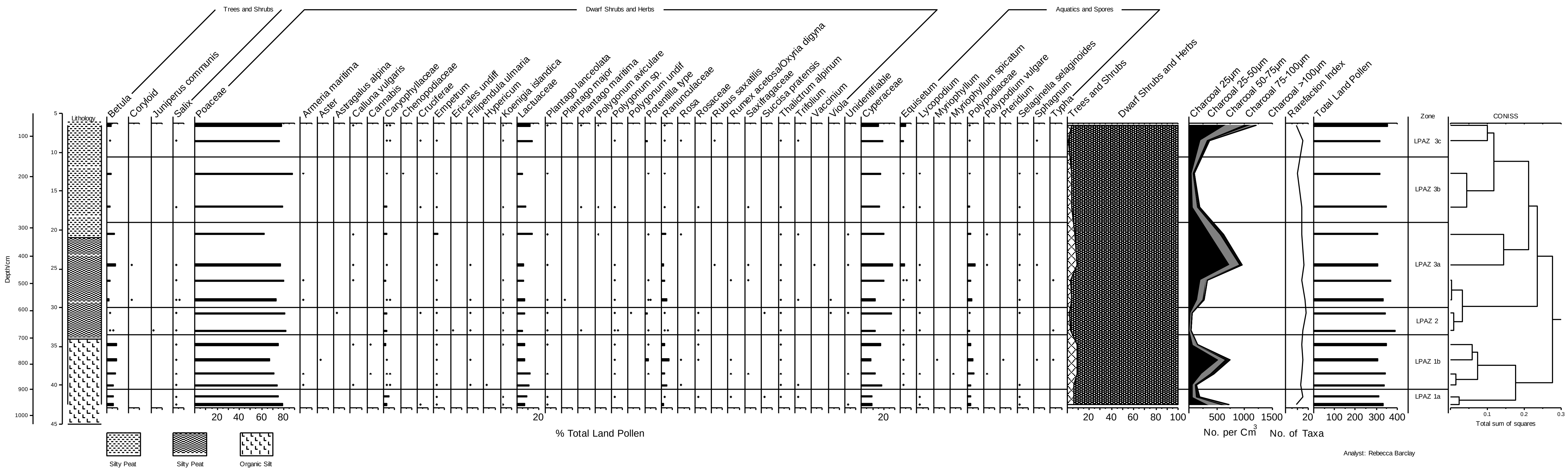


Figure 3.7 Percentage pollen diagram for Vatnsfjörður. The + symbol indicates taxon present at less than 2%. Percentage calculations are based on a sum of total land pollen (TLP) for all terrestrial pollen taxa, and TLP+ Cyperaceae and TLP + aquatics and spores, for Cyperaceae and Aquatics and Spores respectively. Lithological components, age in Cal yr. BP, charcoal concentration/ no. fragments per cm^3 and Rarefaction Indexes/expected species are also presented on the diagram

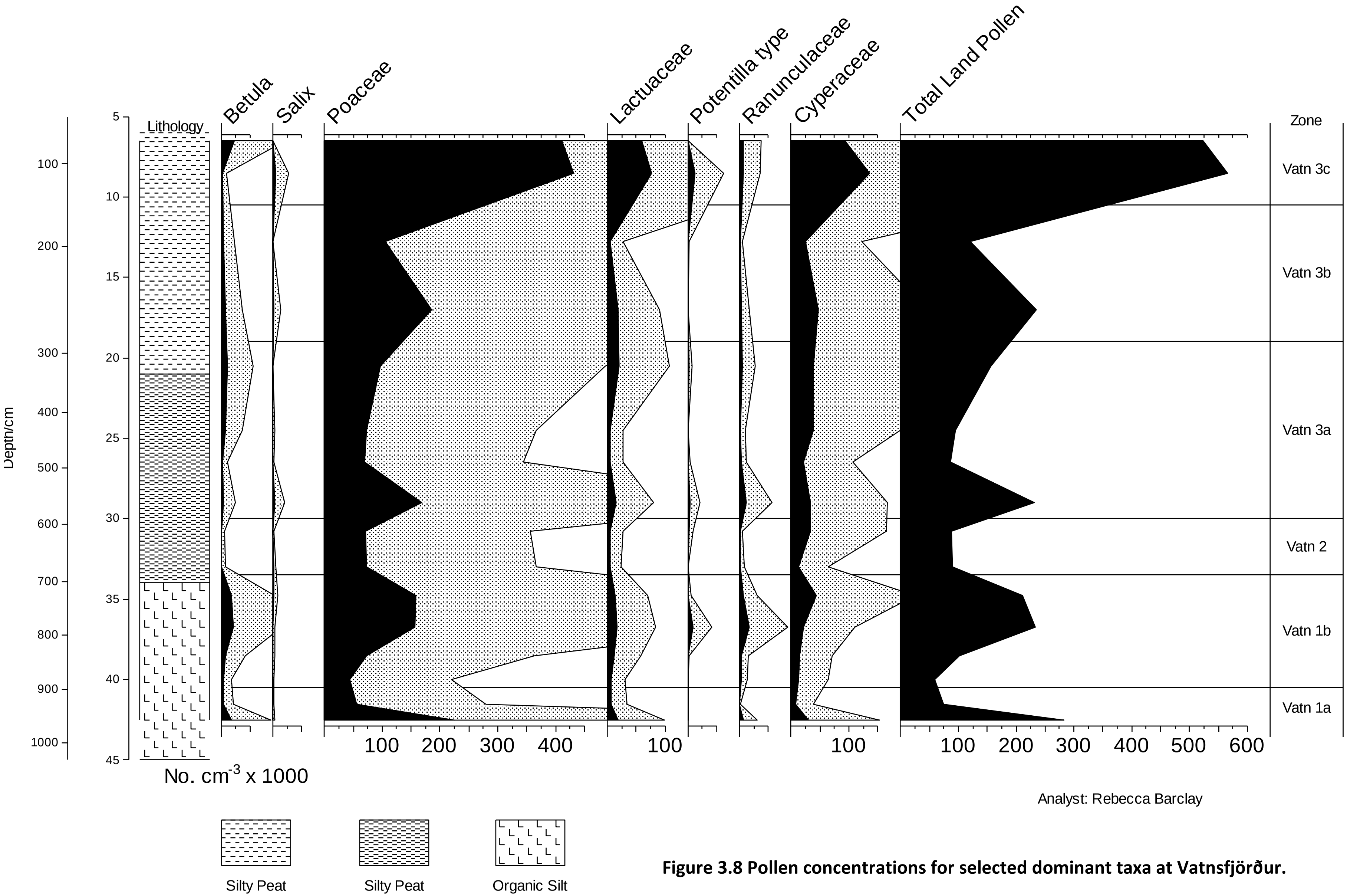


Figure 3.8 Pollen concentrations for selected dominant taxa at Vatnsfjörður.

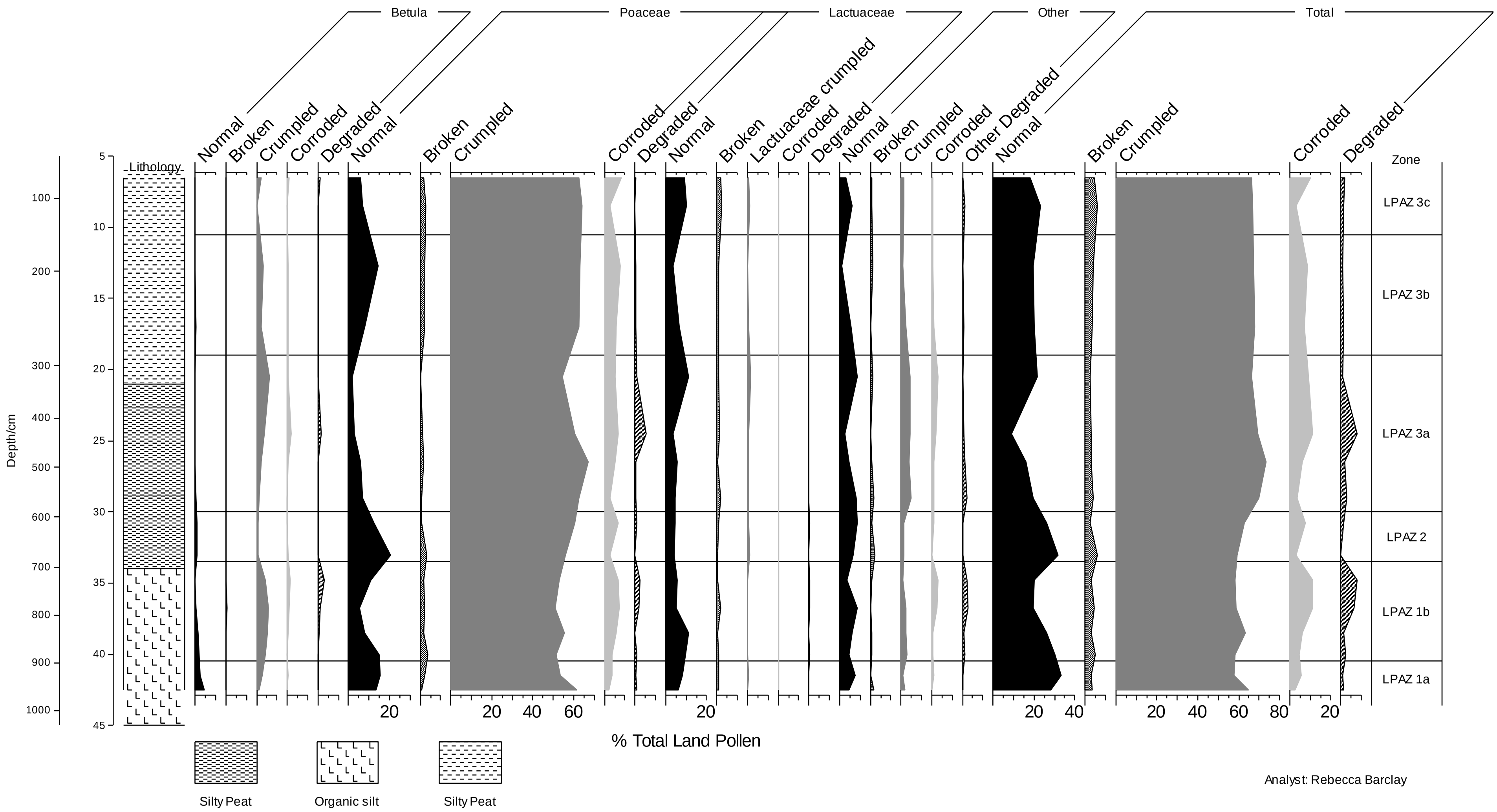


Figure 3.9 Pollen preservation data for selected dominant taxa, presented as % Total Land Pollen for the preservation categories – normal, broken, crumped, corroded and degraded.

3.4.2 LPAZ Vatn-1a (*c.*898-973 cal. BP)

This short zone (~ 75 years) is characterised by high percentages of *Poaceae*, initially >80%, falling later to 75%. This initial high percentage of Poaceae is mirrored by an exceptionally high peak in *Poaceae* concentration (around 225,000 grains cm^{-3}) (Figure 3.8). Species richness is initially low as indicated by the rarefied count, suggesting something of a monoculture on site. As Poaceae percentages fall, species richness increases, with increased percentages of other herb species, particularly apophytic taxa and species indicative of disturbance – *Lactuceae*, *Caryophyllaceae*, *Plantago lanceolata, Polygonum bistorta, Ranunculaceae, Rumex acetosa* and *Thalictrum.* These are also typically grazing tolerant, and linked to pasture-type habitats; presence of grazing intolerant species is limited within the zone.

Tree and shrub presence in the zone is marked by a small, but continuous presence of both *Betula* and Salix, with the former present at levels >5%, which although low is a relatively significant value in comparison with other zones. These percentages are likely linked to the longer distance transport of pollen, possibly extra-local from the sloping sides of the farm and within the valley, especially given the prolific pollen production of *Betula,* and its frequent over-representation in pollen diagrams (Rymer, 1973). In addition to the general lack of tree and shrub species present within the zone, the open nature of vegetation is expressed in the presence of those species requiring open canopy conditions, or closely cropped swards - *Koeniga islandica, Selaginella* and *Thalictrum*. Those most frequent species out with the total land pollen (TLP) sum include *Cyperaceae* and *Polypodiaceae*. Percentage values of *Cyperaceae* within the zone are low in comparison with others, at around 10%. Charcoal concentrations demonstrate an initial sharp peak (750/cm^3), falling after this to <250/cm^3.

Pollen preservation throughout the zone is good, despite high percentages of crumpled grains (up to 65%). Percentages of well-preserved grains (normal) reach up to 35%, the highest figure for the site. The total percentage of crumpled grains is predominantly made up of crumpled *Poaceae*, a species typically more susceptible to mechanical damage of pollen grains (Tipping, 2000).

3.4.3 LPAZ Vatn-1b (*c.* 688-898 cal. BP)

Poaceae, although relatively consistent and dominant in percentage terms throughout the zone, demonstrates a small drop in percentage to <70% around 790 cal. BP (*c.*AD 1160), rising again after this time. High concentration values for the species at the same point suggest this is an artefact of percentage data, and the result of increasing percentages of other herb species, not decreased *Poaceae* abundance. *Betula* dominates the tree and shrub classification (6-9%), some of the highest percentages for the site, with *Salix*, appearing in low percentages (<1%) throughout; again this likely represents longer distance transport. Dwarf Shrubs are present throughout the zone, in very low percentages (<2%). *Empetrum* is present in all levels, with occasional *Calluna vulgaris*. These dwarf shrubs are generally considered warm loving species, which alongside enhanced percentages and concentrations of thermophilous *Betula*, and the presence of *Filipendula ulmaria* and *Myriophyllum alterniflorum*, generally regarded as temperature indicators in Iceland (Hallsdóttir, 1996; Kristinsson, 2010), suggests potentially warmer climate at this time.

In general, species diversity appears to have increased from the previous zone, as indicated by the rarefaction index values, and remains relatively stable throughout the zone. Herb species make up the general diversity for the zone. *Potentilla* and *Ranunculaceae* become more prominent in the species assemblage, increasing in both percentage and concentration, peaking in the centre of the zone, 790 cal. BP (*c.* AD 1160) (around 4% and 7%, >8000 grains cm^{-3} and >16500 grains cm^{-3} respectively). These genera are typical of damper environments. A further damp loving species *Filipendula ulmaria* is also present at this point, which together with the aforementioned genera might point to localised wetter conditions in the meadow. Presence of grazing sensitive *Filipendula ulmaria* also points to the likelihood of restricted grazing onsite, perhaps in the meadow or elsewhere in the homefield. Other species present are typically apophytic and or taxa commonly considered disturbance indicators (*Rumex sp., Plantago lanceolata*). These point to the ongoing activity onsite, with specific emphasis on agricultural activity.

Cyperaceae, although excluded from the TLP count, is prominent in the zone with frequencies fluctuating around 10-20%. Polypodiaceae spores are present throughout the zone fluctuating around 5%, and peaking *c*. 830 cal. BP (*c.* AD 1120) (>6%). Other aquatic and spore species present include *Typha latifolia*, *Myriophyllum spicatum, Equisetum*, *Lycopodiaceae*, *Selaginella* and *Pteridium*.

Charcoal concentrations vary within the zone. A pronounced peak in concentration is evident at around 790 cal. BP (*c.* AD 1160) (<750,000 grains per cm^{-3}). This peak appears to coincide with rising *Betula* pollen values, percentage and concentration. Both *Betula* pollen and charcoal concentrations then fall towards the top of the zone.

Pollen preservation is broadly similar to the previous zone, with crumpled grains (predominantly *Poaceae*) dominating the assemblage. From *c.*700-765 cal. BP (*c.*AD 1250-1185), an increase, albeit a minor increase, in proportions of crumpled and degraded grains is witnessed, with values >10% and <10% respectively.

3.4.4 LPAZ Vatn-2 (*c.* 587-688 cal. BP)

Another short zone (~102years) characterised by the absence or exceptionally low percentages and concentration values for *Betula*. This reduction in *Betula* is mirrored in the zone by a sharp decrease in charcoal, persisting for the entirety of the zone. Species diversity remains relatively consistent, as indicated by the rarefaction curve. The species present change little from the previous zone, with the pollen assemblage here dominated by *Poaceae,* with *Lactuceae* and *Caryophyllaceae* present at low percentages (<5%) throughout the zone. *Potentilla* is present (<5%) around *c*. 610 cal. BP (*c.*AD 1340), and is associated with a peak in *Cyperaceae* values (30%), both of which are tolerant of wetter conditions. Other herb species are present but at very low levels, around 1% of the TLP sum.

Presence of degraded pollen decreases within this zone, with increases in normally preserved pollen increases in the light of this.

3.4.5 LPAZ Vatn-3a (*c.* 275-587 cal. BP)

This zone is marked by the reappearance and rise in *Betula* pollen values (~5-10%), with total proportions of tree and shrub species increasing overall. Peak values for *Betula* (~10%) are recorded at *c.* 420 cal. BP (*c.*AD 1530), and are coincident with minor increases in grazing tolerant apophytes Lactuceae and *Ranunculaceae*, and a pronounced peak in *Empetrum*. Within this zone there are slight variations in the herbaceous taxa, in particular Caryophyllaceae*, Ranunculaceae* and *Lactuceae* but these taxa are present at < 10% throughout the zone. Throughout this zone overall palynological diversity remains consistent with that in other zones, with a high and relatively stable rarefaction curve; this is predominantly made up of grasses and weedy taxa. Grazing sensitive species *Salix, Filipendula ulmaria* and *Sphagnum*, present throughout much of the zone, disappear from the pollen spectra *c.* 420 cal. BP (*c.*AD 1530), possibly a result of increased grazing pressures, or alternatively a result of increased populations of other species.

Poaceae values appear to drop off towards the upper zone boundary, yet given the contrasting concentration values for the same points (a peak in *Poaceae* pollen is observed here), it is likely

Poaceae values remain relatively consistent, with this drop instead an artefact of increased presence of other herb species. A sharp peak in *Poaceae* pollen concentration (170,000 grains cm^{-3}) is also noted at the bottom of the zone (560 cal. BP) (*c.*AD 1390); the same point marked by a declining *Poaceae* on the percentage diagram, demonstrating a real increase in *Poaceae* at this point.

This zone also records a sharp, well defined peak in charcoal concentration with the maximum concentration occurring at *c*. 430 cal. BP (*c.*AD 1520). Charcoal concentration values then decline until the end of the zone. Increases in percentage values for *Betula* and the rise in charcoal concentration values are near synchronous with the peak in *Betula* percentage values occurring just after the peak in charcoal concentration.

Pollen preservation remains relatively good throughout the zone. With assemblages dominated by normal and crumpled grains, as a result of high percentages of mechanical damage susceptible *Poaceae*. A small peak in corroded and broken pollen is found *c*. 430 cal. BP (*c.*AD 1520), with the peak created by increased percentages of corroded and degraded *Poaceae* and *Betula.*

3.4.6 LPAZ Vatn-3b (*c.*157-275 cal. BP)

With the exception of Poaceae (80-95%), this zone is characterised by relatively low percentage pollen values for other species (mostly < 5%). Species diversity drops towards the upper zone boundary, with the rarefied count dropping to 10 species, indicating further dominance of *Poaceae*. *Betula* remains at consistently low percentages <5%) throughout the zone, with this reflected in the concentration diagram. Cyperaceae values remain constant throughout the zone at around 20%, remaining a significant component of the vegetative assemblage for this period. Charcoal concentration once again drops to relatively low concentrations (<200,000 grains cm^{-3}), remaining so throughout the zone.

3.4.7 LPAZ Vatn-3c (*c.*-58-157 cal. BP)

Pollen values for this upper zone are marked by sharp increases in pollen concentration values (>500,000 grains cm^{-3}), composed for the most part of *Poaceae* (>400,000 grains cm^{-3}). This may reflect changes in the peat structure with peat beginning to dry out as a result of modern drainage ditches. Pollen preservation would seem not to have suffered as a result of this, with percentages of corroded and degraded pollen remaining relatively low, suggesting the drawing down of the water table has not been too severe, and has not left peat continuously dry on a long term basis (Davies et al., 2015).

Overall patterns suggest tree and dwarf shrub presence generally decreases, with further expansion of herb species, despite *Betula* increasing slightly towards the present day. *Equisetum* and *Lactuceae* increase across this zone, which alongside high percentages of *Poaceae* and the presence of *Ranunculus* would appear to have similar vegetation composition to present day Vatnsfjörður (Figure 3.10). Charcoal concentration values also show an increase towards the top of the zone, peaking at around 1,250,000 grains cm^{-3}.

Figure 3.10 The turf homefield boundary wall at Vatnsfjörður. The image demonstrates the sites dominance by *Poaceae, Equisetum* and *Ranunculaceae.*

3.5 Micromorphology Results

Micromorphological analysis allowed for fuller understanding of pedogenic processes operating within the meadow soils, reaffirming field observations with particular focus on soil formation, function and management. Specifically, this includes cultural amendments, and periods of accumulation and decomposition. Results for the meadow thin sections are summarised in Table 3.5, with key features from within the table highlighted and interpreted further.

Throughout much of the profile, coarse mineral material is virtually absent, with the exception of traces of cryptotephra and rare fragments of igneous (basaltic) rock; the latter becoming concentrated in the bottom most horizon. Sample 1/5 (26-34.5cm), the basal sample demonstrates the changing soil environment between pre and post settlement Vatnsfjörður, confirmed by radiocarbon dating. Sub angular and rounded weathered igneous rock fragments are consistent with field observations of beach sands and gravel (B-horizon), the original land surface above which soils developed (Figure 3.11, A). Typical Icelandic freeze thaw conditions are witnessed in the lowermost microhorizons. Evidence for this includes platy soil microstructures and silt coatings on the beach gravels, linked to the pedoturbation of fine silt material by cryoturbation (Romans et al., 1980). Post settlement peat initiation is marked by dominant organic fine materials directly above the original land surface, predominantly Amorphous brown. However, presence of Amorphous black demonstrated that peats are older and more decomposed within the lower soil profile.

Frequent-dominant diatoms suggest wet conditions within the meadows soils (Bouma et al., 1990) from early formation. Indicators of biological activity throughout the sample suggest otherwise. High incidence of excremental pedofeatures (few-common), as well as granular and crumb microstructures, indicate soil conditions were suitable to support micro and macro fauna. Soils might therefore have been saturated periodically in order to support diatoms, followed by drier periods supporting other soil fauna. Alternatively, modern drainage of the meadow soils could have instead created conditions more suitable to support higher biological activity later; overprinting these features on past soil records. Wetting and drying conditions are further expressed within other iron based soil features – namely traces of amorphous cryptocrystalline pedofeatures and stone rims, again these may be the result of soil processes related to the cultural period or overprinting from more recent environmental processes.

Table 3.5 Vatnsfjörður micromorphology summary table.

								Siliceous Features		Coarse Mineral material >63 µm					Cultural Materials				Pedofeatures					
Thin Section Sample	Microhorizon (Fibric/ Hemic/ Sapric/ Biosilicate)	Micro-Structure	Parenchymatic	Fungal Sclerotia	Amorphous (light Brown)	Amorphous (brown)	Amorphous (black)	Phytoliths	Diatoms	Igneous Rock	Tephra	Coarse Material Arrangement and Sorting	Fine mineral material	Groundmass b fabric	Bone	Turf fragments	Charcoal	Rubified minerals	Amorphous crypto-crystalline	Calcium Spherulites	Stone Rims	Silt Coatings	Excrement (mamilate)	Excrement (spheroidal)
1/1	A Fibric	Granular, crumb	•••						•				· Brown organo-mineral	Speckled			*t*	*t*	*t*				••••	•••
	B Hemic	Platy, channel, Crumb	••		*t*	•••	*t*		••				··· Brown organo-mineral	Speckled			•	*t*	*t*				••	••
	C Hemic	Granular	••		*t*	•••			•				··· Brown organo-mineral	Speckled			*t*	*t*	*t*				••	••
1/2	A Biosilicate/ Hemic	Platy, subangular blocky, granular, crumb, channel	••	*t*	•••	•			•••	*t*	••	Moderately sorted, random, linear (tephra)	··· Brown organo-mineral	Speckled			*t*	*t*	*t*				••	••
	B Hemic/ Biosilicate	Crumb, subangular blocky	•		•••				••••				· light brown organo-mineral	Speckled			•	*t*		*t*			•	
1/3	A Biosilicate/ Hemic	Granular, crumb, channel and chamber	••			•••			••••	*t*		Random	···· Brown organo-mineral	Speckled			•	*t*	*t*				••	••
	B Hemic/ Biosilicate	Platy, channel, Crumb	••		•	••••	·		••••				·· Brown organo-mineral	Speckled			•	*t*	*t*				•	•
1/4	A Biosilicate	Granular, channel	••		•••	*t*	*t*		••••				·· Brown organo-mineral	Speckled			*t*	*t*	*t*				•	•
	B Biosilicate/ Hemic	Platy, granular, crumb	••		•	••••	·		••••	*t*		Random	·· Brown organo-mineral	Speckled			•		*t*			*t*	•	•
	C Biosilicate/ Hemic	Platy, granular, crumb	••	*t*	*t*	•••	•		••••		•	Linear (tephra)	·· Brown organo-mineral	Speckled	*t*		••	*t*	*t*			*t*	•	••
1/5	A Hemic/ Biosilicate	Granular, crumb	•		*t*	••••	•		•••				·· Brown organo-mineral	Speckled			•	*t*	*t*				•••	•••
	B Hemic/ Biosilicate	Granular, crumb, platy	••		•	••••	*t*		••••				··· Brown organo-mineral	Speckled		•	•	*t*	*t*				•••	•••
	C Hemic/ Biosilicate	Granular, crumb	••	*t*	*t*	••••	•		••	•••		Random	··· Brown organo-mineral	Speckled			•	*t*	*t*		*t*	*t*	••	••

Frequency class refers to the appropriate area of section (Bullock *et al.* 1985)

t Trace · Very few ·· Few ··· Frequent/common ···· Dominant/very dominant

Highly organic, decomposed and biologically active soils suggest a high degree of landscape stability at this time. Aeolian input is generally low and well dispersed throughout the profile, with no significant wind blow events evident despite slightly higher values of aeolian input immediately post settlement (Figure 3.11, B). Peat accumulation and subsequent decomposition is therefore the dominant soil forming process at this level, with relative landscape stability expressed in the limited aeolian inputs and high incidence of indicators of biological activity. Anthropogenic activity is expressed throughout, with additions of charcoal, rubified minerals and turf fragments (Figure 3.11, C) playing a minor role in soil formation processes.

These stable conditions are further expressed, albeit to a lesser extent, in thin section sample 1/ 4 (20-28cm). Within this sample evidence of biological activity remains constant, but at lower frequencies than the previous sample (very few-few excremental pedofeatures). This sample is instead dominated by biosilicate microhorizons, composed exclusively of diatoms, giving the appearance of organic-biosilicate banding across much of the thin section, with diatoms present in some areas as dense clusters of silicates (Figure 3.11, F). The banded nature of silicates suggests periods of, rather than permanent saturation in the meadow. Given the unlikeliness that diatoms would have survived in dryer, acidic peats water must have pooled within or been brought into the meadow area. Wetting and drying conditions are also expressed in this section. Organic remains, particularly in microhorizon B, are iron stained, as well as having traces of amorphous cryptocrystalline and stone rims.

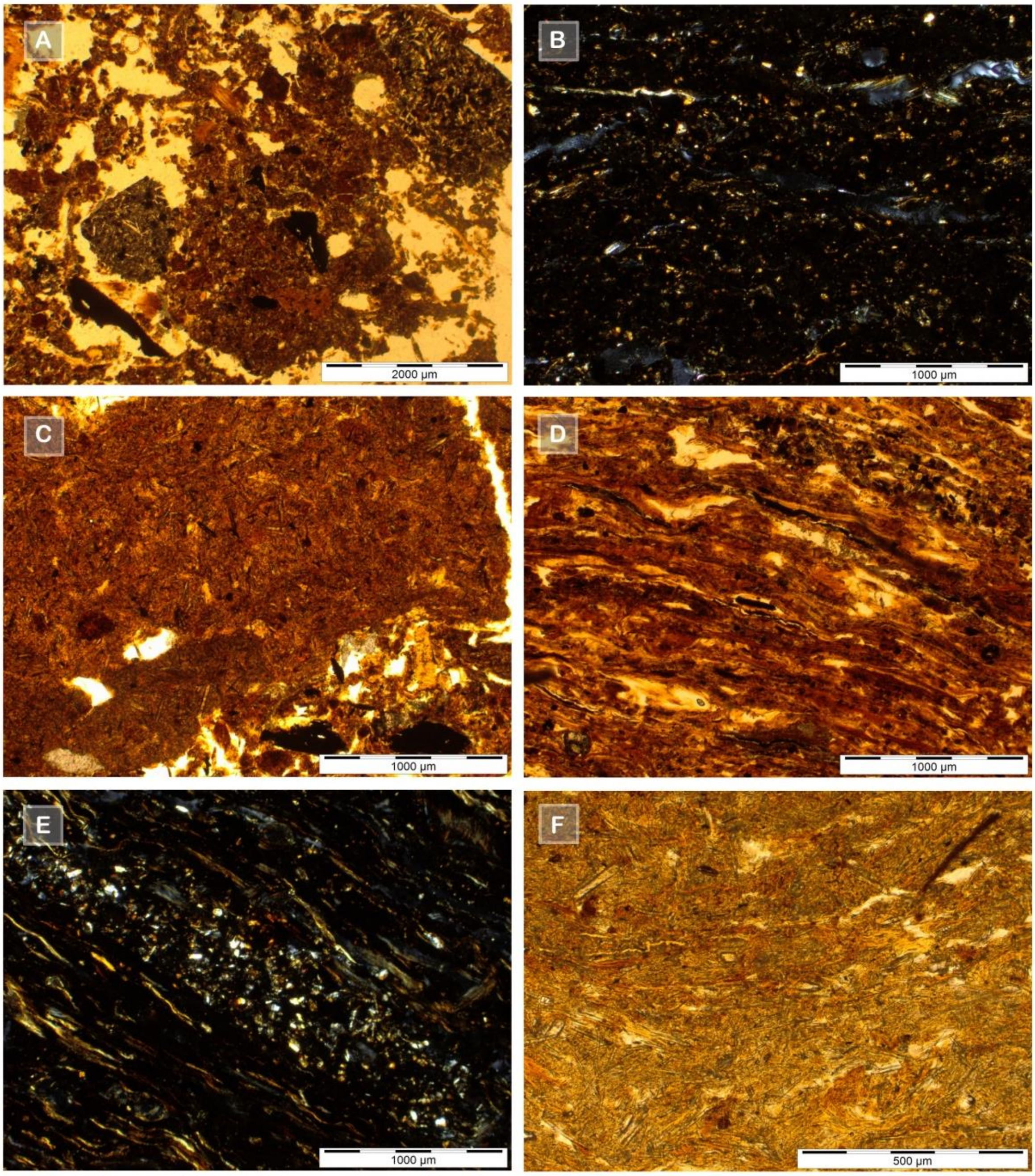
Reduced frequencies of aeolian fine mineral material at this point indicate a likely period of stability in the wider landscape. Here anthropogenic materials play a bigger role in soil accumulation processes, particularly in microhorizon C, which exhibits an increased frequency of charcoal (few) as well as traces of bone, possibly from midden material. Input of tephra material also plays a role in soil accumulation processes, albeit relatively limited, with small quantities of cryptotephra material identified within this section (Figure 3.11, D, E).

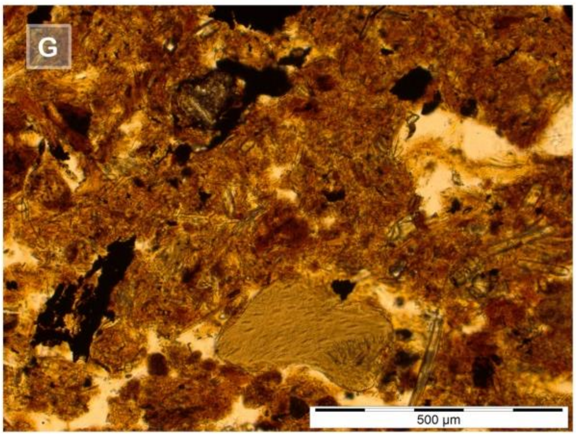
Lighter amorphous materials (light brown and brown) are collectively dominant through much of the rest of the profile where soils are moderately decomposed (hemic), expressed by the presence of parenchymatic materials throughout and by less abundant amorphous black. Parenchymatic tissues become more frequent at the top of the soil profile (few-common), where fresh tissues are being added and broken down gradually. Here (1/1, Microhorizon A) organic materials appear to some extent dried out, appearing as dry dewatered and biologically worked peat. This working of the peat is expressed through the presence of excremental pedofeatures, both mamilate and spheroidal. These are visible throughout the profile but increasingly towards the top (frequent-very dominant) where fresh organic inputs are being actively reworked. Further evidence of biological activity is in granular, crumb, channel and chamber microstructures typical of these soil processes. Other microstructures identified – sub-angular, blocky and platy – are more indicative of environmental influences on soils, wetting, drying and freeze thaw respectively. Traces of amorphous cryptocrystalline, stone rims and silt coatings also support the actions of these environmental influences.

Dispersed randomly throughout the organic material in sections 1/1, 1/2 and 1/3 is fine mineral material, likely aeolian silts. Quantities of this are enhanced directly above the B Horizon and in a band across the centre of the profile 1/3 (approximately 19cm) and again with the B and C microhorizons of section 1/1 (5-8.5cm) pointing to more intensified periods of wind blow. In apparent association with these more intense deposits of aeolian material, parenchymatic tissues appear horizontally aligned within the profiles. This is not an uncommon ecofact of Icelandic soils and has frequently been observed within other parts of Iceland, associated in these cases with large wind blow events and tephra deposits (Romans et al., 1980; Simpson et al., 1999; Stoops, 2007; Stoops et al., 2008). Fine mineral material becomes less frequent towards the top of the profile and in a particularly siliceous microhorizon – 1/2 B, suggesting increasing stability in the wider landscape during these times.

Diatoms continue in their dominance throughout sections 1/2 and 1/3, with all microhorizons described as biosilicate, and diatoms generally dominant-very dominant, therefore a prominent component of soil accumulation processes. This suggests exceptionally wet and possibly frequently inundated conditions here (Clarke, 2003). Diatom abundance contracts in section 1/1, with soils appearing dryer and with decomposition of parenchymatic material as the primary soil forming process.

Cultural signals continue through the entire profile. Charcoal is present throughout, present in larger fragments in 1/4 and 1/5, suggesting deliberate additions. Smaller fragments are however evident throughout the entirety of the profile, likely originating from on-going domestic and industrial activities onsite and subsequently blown into the meadow; the small sizes of the fragments and spread through the profile points to this rather than dumping of materials or direct burning of meadow vegetation, which would instead produce variable deposits, and a mix of larger and smaller fragments. Traces of rubified mineral observed throughout are also indicative of burning activities in the locality. Other cultural materials include bone and turf fragments, and potential midden material, all commonly associated with homefield improvements in the North Atlantic (Buckland et al., 2009; Zori et al., 2013: Golding et al., 2015). Fungal sclerotia and calcium spherulites - animal dung indicators - also suggest cultural activity, potentially linked to the introduction of grazing animals to the meadow, or through the application of animal manure on the site.





A) Vatnsfjörður 1/5 (26-34.5cm): weathered beach pebbles and large charcoal fragments (PPL).
B) Vatnsfjörður 1/5 (26-34.5cm): post settlement increase in aeolian material (XPL).
C) Vatnsfjörður 1/5 (26-34.5cm): cultural materials - turf fragment and charcoal (PPL).
D) Vatnsfjörður 1/4 (20-28cm): post settlement peat development, micro-tephra visible (PPL).
E) Vatnsfjörður 1/4 (20-28cm): micro-tephra (XPL).
F) Vatnsfjörður 1/4 (20-28cm): diatoms in biosilicate horizon (PPL).
G) Vatnsfjörður 1/4 (20-28cm): diatoms and cultural materials – bone and charcoal (PPL).

Figure 3.11 Key micromorphological features in Vatnsfjörður thin sections

3.6 Discussion

Human activities which instigate peat development generally include the removal of vegetation and the grazing of livestock preventing the regeneration of such vegetation (Bunting, 1996; Charman, 1992; Moore, 1975, 1993; Solem, 1989). Removal of tree cover enhances the supply of ground water by reducing transpiration losses and re-evaporation of precipitation through canopy interception (Moore, 1993). This encourages the waterlogged and anoxic conditions that favour the development of peat by the depression of decomposition rates. As a result, decomposition fails to match the levels of primary production, giving rise to peat accumulation (Moore, 1975). The addition of charcoal to soils by burning in-situ to remove vegetation is also widely referenced as favouring peat development, as a result of microscopic charcoal fragments altering drainage, reducing porosity and percolation and increasing water retention (Caseldine and Hatton, 1994; Mallik et al., 1984; Moore, 1993). The alteration of hydrology as an aftermath of vegetation removal and increased water retention in soils relating to charcoal fragments is however likely only to have been a supplementary influence in the creation of the wet meadow at Vatnsfjörður. Aforementioned examples of peat instigation through anthropogenic alterations of hydrological balance generally relate to blanket mires, spanning extensive areas, whereas here the wet meadow is on a much smaller and more defined scale. Charcoal is also less likely to have a profound effect on the beach gravels underlying the wet meadow peats as large pores are generally not affected (Charman, 1992), micromorphology demonstrated charcoal fragments were typically finer and created no obstruction to pores in the basal sample analysed.

An alternative explanation is that the area was deliberately flooded or irrigated in order to create the anoxic conditions required for peat development; a task which would have require substantial effort and channelling of stream water to flow through the homefield. Evidence of irrigation systems throughout the North Atlantic region, in particular for homefield irrigation, has been recorded in Greenland where complex irrigation systems have been discovered. Observations suggest that these were created to divert water from the mountains to the homefield edge (Adderley and Simpson, 2006; Schofield et al., 2008). Despite water availability generally being described as non-limiting to productivity in Iceland (Adderley et al., 2008; Adderley and Simpson, 2006), irrigation systems have also been uncovered here through the evaluation of place name evidence (Adderley and Simpson, 2006) and in Grágás, the 13th century law book in which the use of irrigation in Icelandic arable land and meadows is mentioned (Dennis et al., 2000). Evidence of homefield irrigation practices in Iceland has been extracted from a church deed regarding Mela churches land in Borgarfjord in Diplomatarium Islandicum (Diplomatarium Islandicum, 1181).

Within this deed, fields with landslips are described in which water was diverted to the homefield lands and kept running properly by the erection of a fence. It may therefore be possible that homefield irrigation was not unusual practice in Iceland, and consequently may be considered as an explanation for wet meadow development at Vatnsfjörður. However, no direct evidence of irrigation was found in either pollen or soils data, despite the appearance of biosilicate microhorizons with the soil profile, nor have any irrigation features been identified in the archaeology to date.

The third proposed mechanism behind peat development is the wet meadow developing naturally as a result of the building of the homefield boundary wall. It is proposed upon its construction the turf wall impeded drainage on the eastern edge of the part of the homefield developing into the wet meadow. A similar phenomenon is often found upslope of turf walls (Milek, *pers* comm), including above the western edge of the homefield boundary wall at Vatnsfjörður. Given the identification of lacustrine sediments within test pit 2 in the meadow (Figure 3.5), it may be inferred that organic deposits expanded from areas of organic soils existing in natural basins prior to settlement, exacerbated by anthropogenic modifications of the site. These basins formed as a result of diminishing sea levels (Mikołajczyk et al., 2015).

It is likely the explanations proposed for peat formations did not operate in isolation; any combination of the three might have influenced peat development at any given time, making it difficult to decipher which was the most influential in initiating the organic accumulation.

Meadow soils are in sharp contrast to those soils in the surrounding homefield, which were generally identified as shallow, lacking in organic matter and leached of nutrients. Such soils are uncharacteristic in Iceland where soils are more usually an average of one metre in depth and podsols are rare in occurrence (Friðriksson, 1972). Soils onsite therefore bear more resemblance to Greenlandic soils which are generally coarser in texture with low water holding capacity and with podsols more frequent in occurrence (Edwards et al., 2008; Frendskild, 1988; Milek, 2006). Podsols are naturally low in fertility because of pronounced leaching. It is also likely, given the free draining substrate, the podsols at Vatnsfjörður experienced periods of drought. The nature of these soils therefore presents a limitation to productivity. The site in itself presents additional limitations to production, as Aldred (2005) describes, the area is enclosed by a fjord and a long ridge extending north to south along the western edge of the farm; in a site of such topographic variability, problems regarding ease of production and land management techniques arise. The extent of land use and farm expansion will also be restricted by the topography in this region, a limitation similar to that experienced by settlers in the Faeroe islands (Adderley and Simpson, 2005). Unfavourable climate is another factor limiting productivity on site; it may therefore be assumed each of the proposed limitations to productivity in turn would call for an increase in management techniques.

Within the main homefield area at Vatnsfjörður there is therefore the lack of evidence identified for management strategies having been implemented to improve an inherently infertile site. Milek (2006) highlights that in preliminary investigations on site no evidence was found to suggest fertility improvements in the form of manure application or other management strategies. This is contradictory to other studied sites in Iceland, and the North Atlantic region in general, particularly the Northern Isles of Scotland where extensive and labour intensive manuring practices have been identified (Simpson et al., 2002). In contrast to the homefield, evidence of management was discovered within meadow soils. Micromorphological analysis suggests cultural amendments were made to meadow soils; charcoal, bone and turf are evident in micro-horizons within the wet meadow with random fragments also scattered throughout. This is indicative of manuring practice with midden materials, common practice in the North Atlantic and identified in a number of farms in Iceland (Buckland et al., 2009; Sveinbjarnardóttir et al., 2007; Zori et al., 2013). This small area may therefore have been actively managed for the production of fodder to over winter livestock, perhaps as a means of coping with inherent infertility and soil moisture deficits in the surrounding podsols.

The pollen evidence for Vatnsfjörður suggests that since the early developmental stages of the wet meadow species composition has not varied considerably. Poaceae has dominated the species assemblage, remaining at a relatively stable and high percentage value until the present day. Various herb species have grown alongside *Poaceae*, although in much smaller quantities and never dominating the species assemblage. It is suggested that the habitat type of a wet, grass rich meadow once established persisted until the present day. Here it is proposed that maintaining this grass rich meadow would have required some form of intervention, to prevent the encroachment or dominance of other species such as Cyperaceae, or would have required disturbance at a level to prevent plant succession to climax communities. Management could have been either through removal of the vegetation for fodder or through grazing. Micromorphological evidence supports presence of grazing livestock through the presence of calcium spherulites and fungal sclerotia, features commonly associated with grazing livestock and manure. This does not necessarily indicate grazing with the meadow, with these features potentially linked to the application of animal manure and general barn waste to meadow soils.

The herb species diversity may also indicate that there has been some form of management to maintain this modest level of diversity, as vegetation diversity has been shown to increase with low level disturbance (intermediate disturbance hypothesis (Connell, 1978)). Potential manuring strategies, identified using micromorphology techniques, might have maintained enhanced levels of *Poaceae* throughout the period of occupation, suggesting use of this area as a hay meadow. Appearance and disappearance of grazing sensitive tall herbs (*Filipendula*) might point to varying uses of the meadow through time, with this pollen deposited either directly onto the meadow from plants growing on site, or pollen transported from areas of site fenced off to grazing mammals.

What is less clear from the pollen analysis is whether the water table at the site was maintained through irrigation or if once peat began to accumulate, drainage was impeded sufficiently to sustain the wet meadow. Aquatic taxa are present in low values throughout the profile and would suggest that wet conditions persist, but do not dominate. In addition, the continued accumulation of peat also requires wet anaerobic conditions to allow for the preservation of organic material. Evidence of these wet conditions is supported by the presence of enhanced numbers of diatoms identified throughout the soil thin sections from the meadow. Such quantities would typically be associated with standing water and poorly drained environments (Bouma et al., 1990; Clarke, 2003; Gutiérrez-Castorena and Effland, 2010), suggesting frequent inundation within the meadow. Diatoms clustering in microhorizons provide further evidence of recurrent inundation events. Documentary resources have mentioned the flooding of meadows in early spring so as to insulate and prevent freezing of plants, with the intent to promote earlier yields (Buckland et al., 2009; Sveinbjarnardóttir et al., 1982). This became a common land management practice in medieval Iceland (Zutter, 1997). Presence of abundant faecal material and microstructures indicative of soil faunal processes, on the other hand, are more suggestive of dryer soil conditions (Bouma et al., 1990). However, these may be more contemporary and associated with drainage of the meadow area in more recent years to allow for more mechanised farming practices.

Concentration values of larger charcoal fragments (>50 µm) remain constant throughout the profile. This would indicate that the overall changes in charcoal concentration values were not as a result of processes such as in-situ or very localised burning which would generate mixed sizes of charcoal fragments, stratified throughout the horizon at apparently random times. Accordingly the variations in charcoal concentrations noted in Figure 3.7 are in response to changes in the smaller fraction size (<50 µm) suggesting changes in inputs from windblown sources. These sources are likely to be industrial from the smithy within the farm and/or from domestic activity elsewhere in the farm settlement. Micromorphology suggests charcoal becomes more frequent towards the base of the profile, above beach sediments; this is a typical feature of normal settlement practice in Iceland, where vegetation is burned during land clearance for agriculture.

The results highlight that changes in charcoal concentration values correlate well with percentage values for *Betula* pollen; the synchronicity of these changes could suggest a link to fuel resources. After settlement, charcoal concentration values indicate domestic activity and fuel combustion and birch pollen values indicate a local presence of birch. Between *c*. AD 1363-1262 (*c.* 587-688 cal. BP) charcoal concentrations are very low and birch pollen is virtually absent. This could suggest that there may have been a switch away from the use of wood as a fuel resource which would have resulted in less charcoal being produced. This switch may have been in response to reduced amounts of wood (*Betula*) available to burn as fuel. A reduction in charcoal concentration may also reflect reduced levels of activity on the site at this time. A short lived peak in charcoal concentration values at *c.*AD 1520 (*c.* 430 cal. BP) suggests an increase in activity on the site either through increased domestic activity or perhaps industrial activity such as smelting. The pollen evidence for the same time period suggests that there has been a recovery in the amount of birch, although the percentage values are still low. Post *c.*AD 1520 (*c.*430 cal. BP) charcoal concentration values fall and a second phase of very low values is recorded between *c.* AD 1793-1675 (*c.*157-275 cal. BP) again suggestive of either low levels of activity on site or a switch in fuel resource use. During this phase birch pollen values are declining but percentage values suggest that birch is still present. The link of this later decline in charcoal concentration values to fuel use is supported, to some degree, by extracts from Jarðabók, from an overlapping time period (AD 1710). Referring to a period of marginality suffered at Vatnsfjörður, Jarðabók describes the scarcity of fuel materials including inadequate supplies of birch and the use of roots to supplement fuels. Given the lack in fuel materials, charcoal production from domestic and industrial activities are likely to have decreased (Magnússon and Vídalín, 1990).

Soils within the meadow display a relative level of stability. This is unusual for Iceland where extensive landscape disturbance is widely acknowledged, with early land management thought to play a large role in the wide scale erosion problem effecting 73% of the country's soils (Simpson et al., 2004). The highly friable nature of Icelandic soils, due to their low organic content and poorly developed structures, makes them highly susceptible to wind and water transport when exposed as a result of vegetation removal (McGovern et al., 2007; Ólafsdóttir et al., 2001), for example during the large scale land clearance at Landnám. These aeolian materials are also evident throughout the meadow soils, although as a small proportion relatively to the organic material, lessening the impacts more extensive deposition might have had on agricultural potential. Aeolian materials increase in frequency immediately post settlement, this pattern is seen across much of Iceland as previously pristine soils were disturbed during normal settlement activities. Several more intense erosion events are noted within the soils (19cm, 5-8.5cm), and align with an increase in SeAR for the same period, likely linked to increased storminess associated with the Little Ice Age (Ólafsdóttir and Guðmundsson, 2002). Pollen results do not reflect these increases in erosion vegetation assemblages remain relatively stable and no increased frequency of corroded and degraded pollen is witnessed, as would often be associated with increased input of eroded and redistributed sediment (Cushing, 1964; Tipping, 2000). The small peaks in corroded and degraded pollen displayed on the preservation diagram might instead be linked to repeated wet and dry cycles, highlighted in the micromorphological analysis, triggering bacterial and fungal activity and subsequent microbial attack on pollen (Tweddle and Edwards, 2010).

The choice of a site like Vatnsfjörður for settlement in the early phases of colonisation, as now confirmed by radiocarbon dating, is unusual in that it does not fit in with the general pattern of settlement in Iceland. Power centres were generally amongst the first sites settled, as is the case for Vatnsfjörður, and were therefore in a position to claim the best land, allowing for the retention of their status (Erlendsson et al., 2006). The land at Vatnsfjörður is therefore contradictory to that generally claimed in the early phases of settlement. Edvardsson and McGovern (2005) have suggested in this case the sea may have dictated settlement and the enclosed fjords would have provided a safe harbour for ships and provided settlers with a prime position to monitor traffic both on the fjords and over land, controlling all major routes in the region. The accessibility advantage of its strategic positioning in the centre of the peninsula is likely to have aided in its power centre performance. Ísafjarðarjúp, the deepest, widest and longest of the fjords on the peninsula, provides a communication link with many areas with the numerous smaller fjords and bays opening up into it. The mountain passes surrounding the site provide access to other parts of the peninsula and the resources offered there, as well as access to other regions in the country (Tulinius, 2005).

It is also suggested in some early sources that a number of settlers came to Iceland looking for such a settlement location, including those from similar fjord systems in Norway where economies were based largely on marine resources (Edvardsson and McGovern, 2005). Marine resources were latterly found to play a key role in Iceland's economy. Whaling and more importantly fishing are thought to have played roles in the resource base for the region, with the later having profound social and economic implications for farmers in the region (Tulinius, 2005) From the 14th century the richest men in Iceland were located in the Westfjords, linked to the rising importance of fishing in the Icelandic economy from the late 13th century and increased foreign trade, particularly with England in the 14th and 15th centuries with domestic trade also having a prominent role in wealth generation (Tulinius, 2005). Driftwood is another valuable resource in this part of the country where trees are typically lacking, an observation based on the current state of the region and the palynological research conducted here. Given the peninsulas openness and exposure to the Atlantic Ocean, driftwood has the tendency to wash up on the shores, especially on the eastern reaches of the peninsula (Tulinius, 2005).

Homefield management has been identified as a key factor for gaining status, success and sustainability in Iceland, with soil management playing a major role in determining yield and buffering against climatic downturns (Adderley et al., 2008; Adderley and Simpson, 2005; Sveinbjarnardóttir et al., 2006); particularly in a country for which economic sustainability is heavily reliant on grazing and fodder production (Edwards et al., 2005). Despite site limitations and minimal effort to improve productivity, suggesting soils were found not to be of value and worth improving (Milek, 2006), Vatnsfjörður retained its high status for some time and continued to flourish as a seat of power. This indicates a reliance on aforementioned alternative resources, rejecting pasture and crop production as being the general source of wealth as was the case in other regions (McGovern et al 2007). A similar situation has been identified in the high status farm of Hofstaðir in the Mývatn region of Iceland where the site was similarly inherently unproductive. Despite this, the farm retained its status through regulation of regional resources (Adderley et al., 2008), highlighting the fact that factors other than site productivity can influence status. All homefield efforts have therefore focused in the meadow area, with a suite of potential management techniques have been revealed by soil and pollen evidence. This is thought to be employed in an effort to produce subsistence level fodder to see livestock through the harsh Icelandic winter. Efforts appear to have been sufficient to maintain productivity at a level able to preserve the settlement's wealth and high status, and to buffer external influences of climatic and socio-economic downturns experienced across Iceland. This is demonstrated by the relative stability of meadow soils and vegetation within this area throughout the occupation period.

3.7 Site Summary

In addition to the recent excavation of a 10th century longhouse and the discovery of 9th and 10th century artefacts indicative of high status (Edvardsson and McGovern 2005; Aldred 2005), radiocarbon measurement of Betula charcoal samples produced calibrated ages that accord with Landnám. This provides evidence that the northwest of Iceland, and Vatnsfjörður in particular, was settled much earlier than previously believed, and that it held a high status from the early years of settlement. Isolated position, poor agricultural resources, difficult topography and unfavourable climates were clearly not perceived as exceptional hindrances to early settlers, and despite the poor conditions for homefield development, settlers could tolerate and adapt to unpromising terrain.

Soils at Vatnsfjörður have demonstrated their potential as successful historical archives, preserving important human-ecodynamic records, including information on both cultural activities and environmental conditions onsite. Combining soils and pollen data has been effective in building a stronger picture of site conditions, with the ability of the two techniques to complement one another making this a more powerful approach than the application of any singular method. Homefield soils on site were generally found to be of poor agricultural potential, and the absence of active management to improve soils appears to indicate they have been perceived to be of little value. These homefield attributes are particularly unusual given that homefield management has been identified as a key management system in gaining success and sustainability, particularly in a country like Iceland, approaching the latitudinal limits for many plant species, yet where economic sustainability is heavily reliant on grazing and fodder production (Adderley et al., 2008; Adderley and Simpson, 2005; Edwards et al., 2005; Simpson et al., 2002; Sveinbjarnardóttir et al., 2006).

In contrast to the soils in the upper homefield, an organic soil deposit in the lower homefield has been discovered to have developed only after settlement, with the area appearing to have been managed to some degree with cultural amendments and practices such as cutting and grazing. It is suggested therefore that the meadow area had been managed for the production of subsistence level fodder to see livestock through the harsh Icelandic winter. Given the sites inherent infertility and harsh climate this is part of the settler’s resilience strategy to continue to thrive in the challenging Icelandic environment.

Chapter 4 Viðatóft, investigations of the wet meadows from an early and abandoned farm.

4.1 Introduction and Site Description

The abandoned farm Viðatóft is situated on the southwest corner of Lake Másvatn, in the Mývatnssveit region (Figure 4.1). Viðatóft is not the original name of the site and is thought to have been named after its original inhabitation, for which there is no documentary record. Preliminary archaeological investigations were carried out here in 2002, followed by more extensive excavations in 2010. Modern infrastructure, namely the construction of a track to the eastern edge of the farm and a road passing Lake Másvatn, has damaged the site to a small degree and a gravel quarry has disturbed much to the Northern side of the outer boundary wall. However the interior of the site appears undisturbed, retaining its significance for palaeoenvironmental studies; its original extent can be inferred from remaining structures (Vésteinsson, 2011).

The site comprises a pair of almost circular enclosures, the smaller of which lies within the other, and a series of putative dams and channels within an upper boundary, likely leading water away from the homefield. Similar double or treble earthworks exist elsewhere in Mývatnssveit, and across Iceland (Vésteinsson et al., 2011). This site, however, is unique in the fact that the inner circular enclosure is very small, a size not sufficient for excess fodder production, its past function is therefore currently unknown (Vésteinsson *pers comm.*). Vésteinsson et al. (2011) indicate that the enclosures were likely constructed to protect cultivations efforts, with the internal enclosure pre-dating the larger one. This could be linked to a switch from small scale intensive practices to more extensive manuring activities. It has been suggested using modelling (Adderley et al., 2008), that productivity in homefields increased rapidly in the decades following settlement, levelling out after around 80 years. With this in mind, the smaller enclosure might indicate initial intensified manuring on a small area and, once productivity levels began to level out, a switch might have been made to wider scale manuring practices, with manure spread thinly across a larger area, perhaps protected by the bigger enclosure (Vésteinsson et al., 2011). A switch between management systems perhaps reflects the farmer's lack of knowledge surrounding or adaption to new lands, and its potential productivities, with initial overestimations of productivity possible. It is believed the dam and channels were constructed as a means of draining the naturally boggy area, fed predominantly by runoff from upslope as well as by a spring in the southern part of the settlement (labelled 'well', Figure 4.2), with the circular enclosures acting as an additional barrier to the runoff (Vésteinsson et al., 2011). It is clear much effort has been put into controlling water onsite, but unclear as to whether the current flooding was intentional – perhaps as a means of retaining some of the diverted water onsite – or if this was a post abandonment feature. Structures within the homefield areas are small, the largest of which is 10m long and situated between the two circular boundaries in two clusters. Test trenches dug during the 2010 site survey suggest the farm is likely to have been settled during the early settlement period and abandoned in the late 11th century. Cultural layers are overlain by the H-1104/H-1158 and V-1159 tephra layers (Vésteinsson, 2011), demonstrating that despite considerable efforts made to construct water management features, the site was abandoned after a relatively short period of time. Large scale farm reorganisation did occur within Mývatnssveit during the 12th century, suggesting its abandonment was a factor of regional reorganisation rather than as a result of the farm failing.

Since abandonment, drainage features have become obsolete and the circular boundaries now enclose a very wet bog area with shallow standing water covering much of the former homefield. The site is presently not used intensively but is likely to be subject to light grazing as is much of the surrounding area. The site is currently dominated by a dwarf shrub community (*Betula nana, Salix lanata, Salix phylicifolia, Vaccinium sp., Erica tetralix, Arctostaphylos uva-ursi, Empetrum nigrum*) with an understory comprising mosses, grasses, sedges and herbs (*Equisetum sp., Thymus praecox, Gallium sp., Koeniga islandica, Armeria maritima, Dryas octopetula, Thalictrum alpinum, Bartsia alpina, Parnassia palustris, Loiseleuria procumbens, Taraxacum sp., Rumex sp., Cardamine pratensis, Hieracium sp., Erigeron sp., Alchemilla alpina*). Mire and tall herb species (*Carex, Eriophorum sp*., *Ranunculus sp., Geum rivale*) are present in the lower, wetter reaches of the farm and *Juniperus communis* and *Betula pubescens* dominating the dryer, upper reaches of slopes.

The farm was selected as a case study based on the current bog conditions within the homefield boundaries; an ideal opportunity for palaeoenvironmental study. Added interest in the site comes from its abandonment prior to AD 1104, and the presence of water management features and peculiar circular structures at the farm. Viðatóft will therefore be used as a case study to systematically deliver the objectives set out in the introduction for a small, previously intensively managed and abandoned farm. Chronostratigraphies will be developed for the assessment of the sites development through time, with the sediments within the wet meadows investigated for their potential as environmental and cultural archives, exploring vegetation changes onsite, as well as records of land management held within the sediments, changes within the site will be reflected against those occurring in the wider environment.

Figure 4.1 Map showing the position of Viðatóft and Gautlönd (Chapter 5) in relation to Lake Mývatn. The Mýri, likely associated with the main farm at Viðatóft is highlighted. The map also shows Gautlönd's main shieling (utilised extensively until 1900) (Vésteinsson et al., 2011), and the portion of the Framengjar wetland area the farmers at Gautlönd would have accessed. Helluvaðstjörn is the small lake NW of the main farm at Gautlönd.

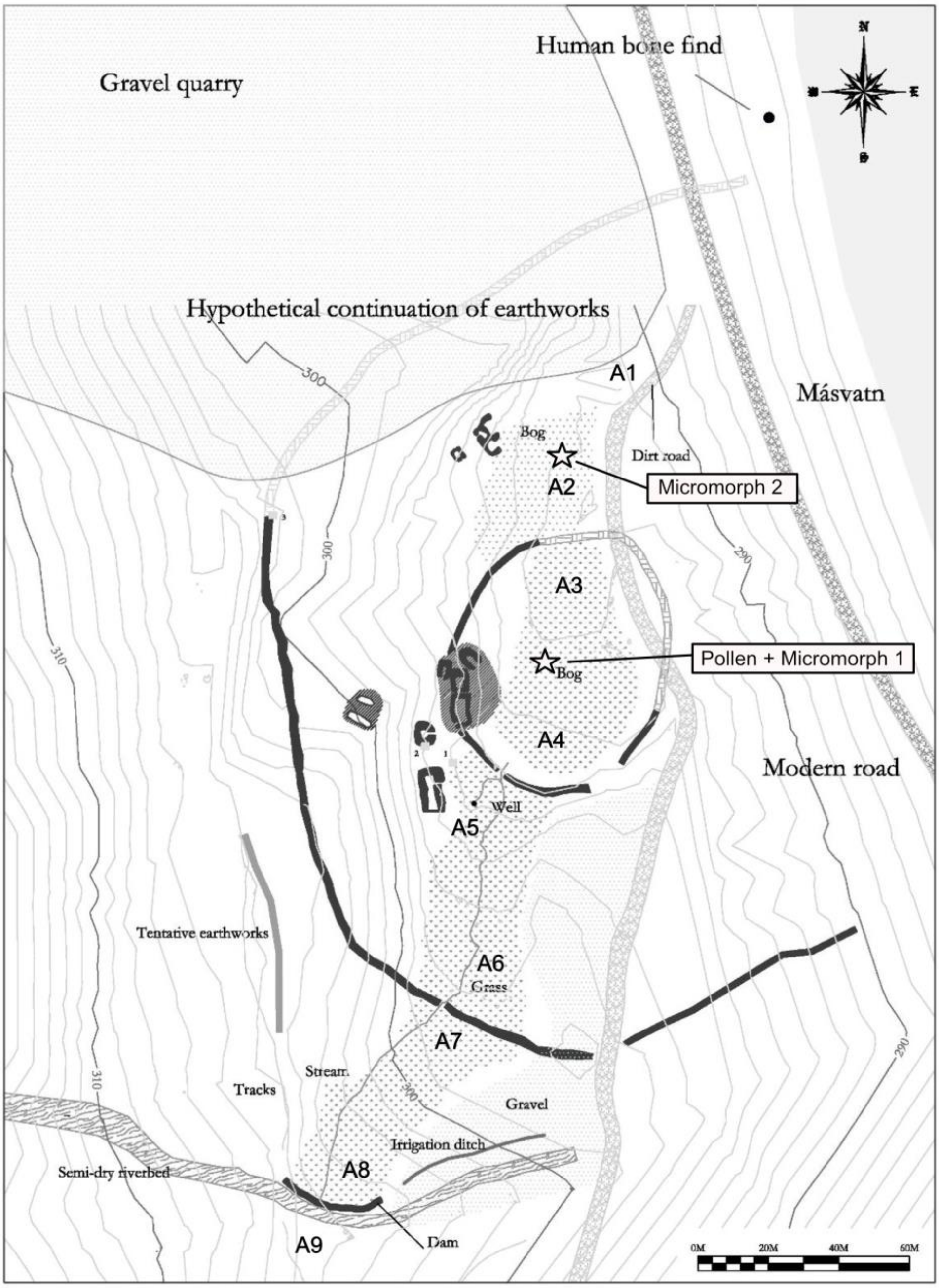


Figure 4.2 Viðatóft site map detailing archaeological sites and finds. Sampling sites are indicated on the diagram, with stratigraphical survey points labelled A1-A9, and pollen and micromorphology sample sites represented by stars and labelled accordingly. Adapted from the sketch map by Gísli Pálsson (Vésteinsson, 2011)

Figure 4.3 View East over Viðatóft, dwarf shrub vegetation dominates, with wetland taxa more prominent toward the lake end of the site.

4.2 Fieldwork and Lithology

The scaled stratigraphical transect (Figure 4.4) represents a vertical cross section covering what is assumed to be the remnants of the homefield at Viðatóft. The stratigraphical sequence begins by the modern road, extending 208m upslope, passing through major archaeological boundaries to a point above the dam boundary, with each stratigraphic unit sampled to Hekla 3, or bedrock.

The cross section provides a broad overview of soil and sediment conditions throughout the homefield; general trends indicate a pattern of peats and organic silts overlaying the AD 1477 tephra, with significantly less organic matter below this point, confirmed by siltier soils, within which the Landnám tephra is frequently encountered. Shallower, and less organic sedimentary records are found in the upper homefield (A5-A9), with more organic sediment in the lower half of the homefield where ground conditions were significantly wetter, with water pooling across flatter surfaces. Soils appear deepest between A3 and A5, confirmed by further horizontal auger transects across each point (A1-A9).

A clear sequence of tephra deposits are displayed across much of the site and stratigraphical relations of the key, easily recognisable, tephra horizons (Chapter 2, Table 2.2) have been labelled where appropriate. These historical and prehistoric tephras have been used to develop a chronology for the site. Using these tephras it is possible to examine variability in soil accumulation rates (SeAR) onsite. Table 4.1 describes these accumulation rates before and after Landnám, as well as dividing the latter into two time periods (Landnám- AD 1477 and AD 1477-present) based on the consistency of tephra presence within each stratigraphic unit. Viðatóft SeARs display consistency with results of previous SeAR studies carried out in Mývatnssveit, in sites of comparable elevation and vegetation composition (Brown et al., 2012; Ólafsdóttir and Guðmundsson, 2002). Prior to settlement SeAR rates within the site are low (0.12 mm/yr.) and less variable than that post-Landnám. SeAR's are found to increase almost threefold post Landnám (0.12- 0.33mm/yr.); with the majority accounted for during the period AD 1477-present. This period follows the extremely thick AD 1477 tephra deposit, as well as a period of cooler climate, lasting until the end of the 18th century (Little Ice Age) which alongside anthropogenic activity is likely to have helped accelerate land degradation in the surrounding area. This value is likely to have been further enhanced by the widespread regional increase in SeAR's post AD 1717 (Ólafsdóttir and Guðmundsson, 2002; Vésteinsson pers. comm.), a speculation, given the absence of the AD 1717 tephra onsite.

Results from this stratigraphical survey were used to inform palaeoenvironmental sampling onsite. Given the depth and organic nature of sediments within the circular enclosure two overlapping cores spanning 1-96cm were taken at two adjacent points next to each other, between A3 and A4 (N 65^{o} 37.403' W 17^{o} 14.883'). Coring the top 0-15cm proved difficult and so a section was hand dug and wrapped to represent to the top 18cm. Despite depth of peat in this section being slightly shallower, and therefore less suitable for ideal pollen preservation, the section was selected for pollen analysis to maximise distance from the boundaries of the archaeological structure. Given the diameter of the mire within the enclosure (40m), and enclosed nature of the site, the pollen source area is expected to be small, with the majority of pollen recruited from the local vegetation (*sensu lato* Jacobson and Bradshaw, 1981). A further two cores were taken for the preparation of soil thin sections, one within 50cm of the pollen cores to enable direct comparison with the pollen data, and a second by point A2, to provide a comparison between conditions inside and outside the circular enclosure. Each soil core spanned the depths 20-70cm, encompassing pre- and post-settlement conditions.

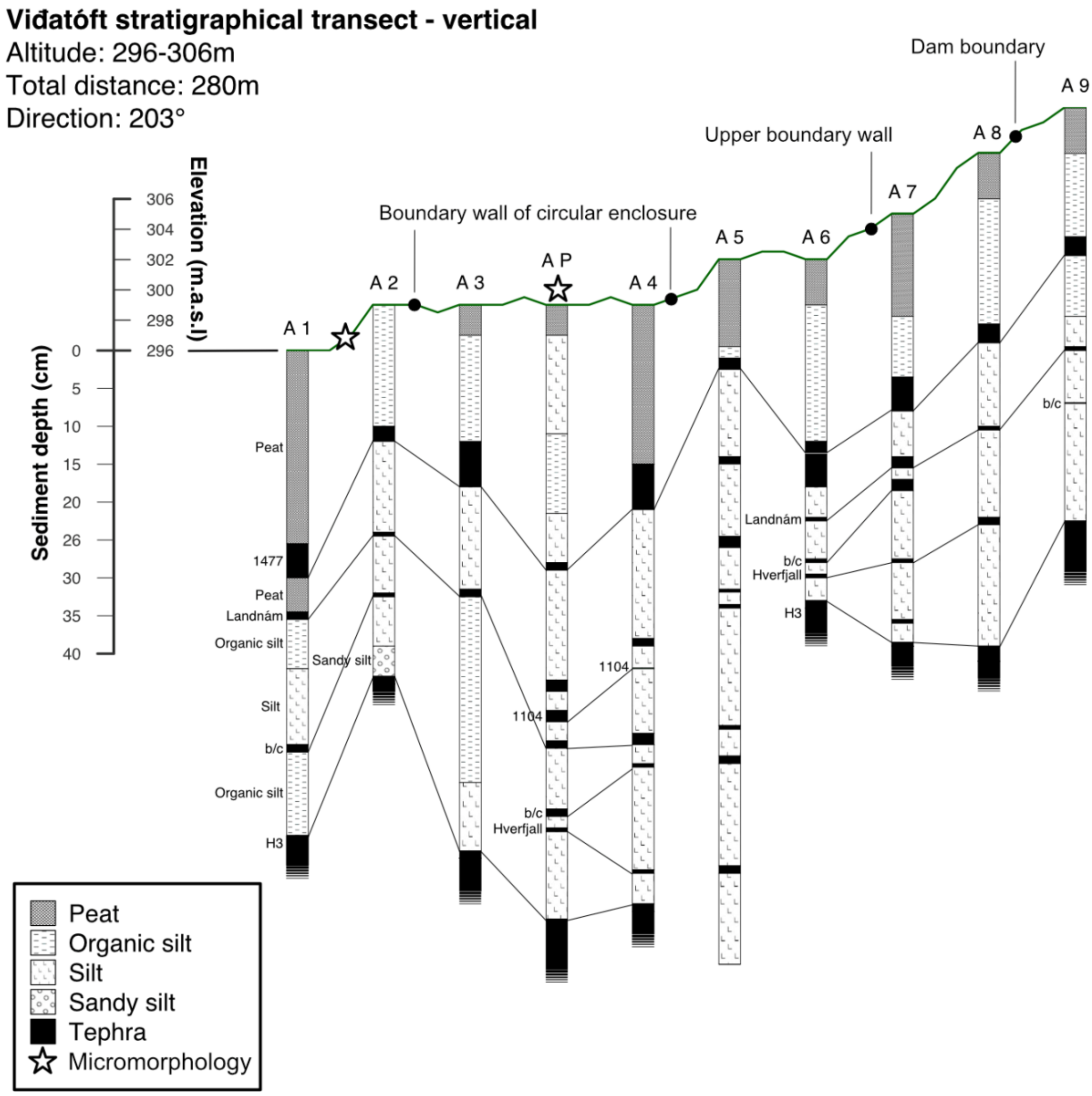


Figure 4.4 Stratigraphical interpretation of Viðatóft; a vertical transect from modern road to beyond the upper farm boundary.

Table 4.1 Viðatóft soil accumulation rates (SeAR) (mm/yr.) by time period.

SeAR (mm/yr.)				
Period	Pre Landnám (H3-Landnám)	Post Landnám (Landnám-Present)	Landnám – AD 1477	AD 1477 – Present (2011)
Mean	0.12	0.33	0.26	0.44
Std Error	0.01	0.03	0.04	0.03

The lithology of the pollen cores were expanded and are presented in Table 4.2, pollen samples were extracted between 1cm and Hekla 3 at 81cm, sediments are described to 96.5 cm. The sequence comprises a series of peats, silts and tephras, implying a terrestrial environment throughout the period of study. The upper 8cm are relatively peaty and underlain by a 9cm silt layer, reflected by a sharp fall in LOI (Figure 4.6). This is perhaps reflective of a period of enhanced aeolian activity, an episode likely contributing to the enhanced SeAR's post AD 1477. A further 10.5cm (17-27.5cm) of organic material is noted below this deposit, and again at 31.5-34cm and 37-42cm. Sediments below this are characterised by predominantly silty sediments, with interspersed tephra layers. These observations are reflected in the LOI (Figure 4.6) with peaks noted in accordance with organic sediments.

Table 4.2 Detailed stratigraphical analysis of Viðatóft pollen core sequence.

Depth/cm	Troels- Smith	Unit Description
0-4	$Tb^3\ Th^1\ Ag^+$	Dark brown peat
4-8	$Sh^2\ Ag^1\ Dh^1$	Dark brown silty peat
8-17	$Ag^{2\text{-}3}\ Sh^1\ Dh^1$	Orange brown silt with organic plant fragments
17-27.5	$Sh^2\ Ag^2\ Dh^+$	Dark brown/black peaty silt
27.5-31.5	$Ag^4\ Sh^+\ Dh^+$	Dark brown/orange silt
31.5-34	$Ag^{2\text{-}3}\ Sh^{1\text{-}2}\ Dh^+$	Dark brown organic silt
34-35	$Gmin^4$	Black coarse (fine sand) tephra (Veiðivötn AD 1477)
35-37	Ag^4	Orange silt
37-42	$Ag^3\ Sh^1\ Dh^+$	Dark brown organic silt
42-46	$Ag^2\ AS^1\ Sh^1\ Dh^+$	Grey green/brown very fine silt
46-49.5	$Ag^4\ As^+\ Sh^+\ Dh^+$	Dark orange/dark brown silt
49.5-51	$Gmin^4$	Black grey/black coarse (fine sand) tephra (Hekla AD 1300)
51-53.5	$Ag^4\ Sh^+\ Dh^+$	Greyish brown silt
53.5-55	As^4	Cream/grey/black tephra, fine grained (silt) (Hekla AD 1104)
55-57.5	$Ag^2\ Sh^2\ Dh^+$	Dark orange/brown silt
57.5-58.5	$Ag^3\ Gmin^1$	Grey/green coarse (fine sand) tephra (Landnám AD 871±2)
58.5-66.5	$Ag^3\ Sh^1\ Dh^+$	Grey/brown/orange silt
66.5-67.5	As^4	Cream/grey/brown (tephra?)
67.5-69	$Ag^2\ As^2\ Sh^+\ Dh^+$	Bright orange/brown silts
69-69.5	$Gmin^4$	Grey black sands (tephra?)
69.5-81	$Ag^2\ As^2\ Sh^+\ Dh^+$	Bright orange brown silt
81-94.5	As^4	Cream fine (silt) tephra (Hekla 3 2879±34 cal. BP)
94.5-96.5	$Ag^2\ As^2$	Orange light brown silt

4.3 Chronology

The chronology of the core is constrained by the 5 key tephra layers (Chapter 2, Table 2.2) (Veiðivötn 1477, Hekla 1300, Hekla 1104, Landnám, Hekla 3) described in Table 4.2. Given the number of layers, and use of Hekla 3 as a basal date, no further samples were required for radiocarbon dating.

Calibrated age depth model was produced using the Bayesian programme 'Bacon' (Blaauw and Christen, 2011) as means of constraining the palaeoenvironmental record, plotting the weighted mean average calendar age for each cm^2 on the age-depth axis on each of the pollen diagrams. The model passes through each of the dates, demonstrating fluctuating accumulation rates between each point. The weighted mean average passes through the younger end of the calibrated age range of Hekla 3, pollen diagrams are therefore based on this age.

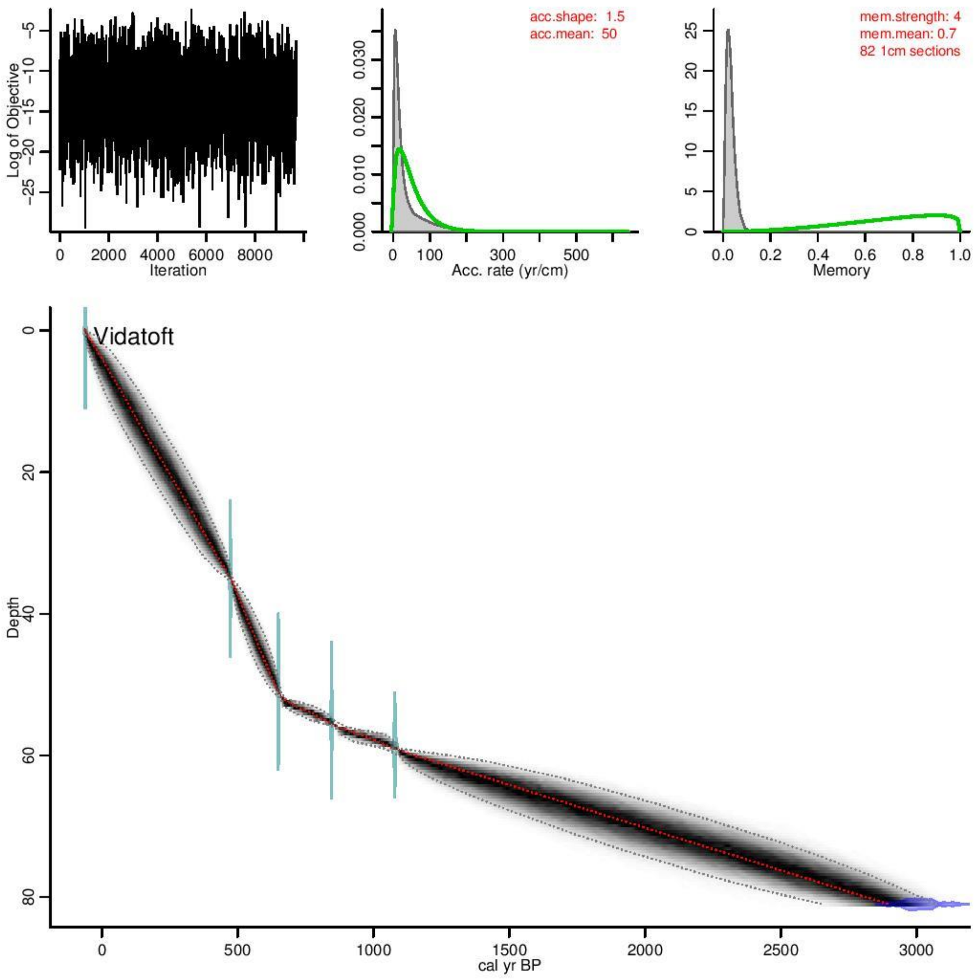


Figure 4.5 Age-depth model for Viðatóft generated using Bacon. The shaded portion represents all probably age-depth models, where this is darker probability is greater. The 2σ age range constrained within the black dotted lines. The dotted red line indicates the weighted-mean average.

4.4 Pollen Analytical Results

4.4.1 Zonation and preservation tests

The pollen data have been divided into 6 local pollen assemblage zones (LPAZ) using CONISS (Grimm, 1987); these zones are outlined on the percentage, concentration and preservation diagrams. Given the taphonomic and preservation issues experienced in Iceland (Lawson et al., 2007) all data were run through the series of tests proposed by Bunting and Tipping (2000) (Chapter 2, Table 2.6). These are used to determine suitability for supporting interpretations and indicating post depositional biasing. All tests, with the exception of the percentage of resistant taxa test, were passed for all levels. On further investigation it was found the failure was based on high percentages of *Lactuceae.* Because of the prevalence of *Lactuceae* in grasslands and homefields in Iceland (Kristinsson, 2010; Löve, 1983) and agricultural contexts in general, it is felt unnecessary to exclude samples from further interpretations, based on failure of this test alone, and all samples are deemed suitable for further analysis.

Table 4.3 Pollen preservation tests based on Bunting and Tipping (2000), pollen data – Viðatóft.

Test	Failure Threshold/basis sum TLP or TLP+group	Pass (✓/✗)
Total land pollen sum (TLP)	<300	✓
Total pollen concentration	<3000 grains cm^{-3}	✓
Number of main sum taxa	<10	✓
Percentage severely degraded grains	>35%	✓ (81cm=35.6%)
Percentage indeterminable	>30%	✓
Percentage resistant taxa (e.g. thick walled/robust grains – *Tilia, Caryophyllaceae, Chenopodiaceae, Asteraceae (Lactuceae), Artemisia* type, *Brassicaceae*	>6%	✗ (*Lactuceae* frequently exceeds)
Percentage Pteropsida (monolete) indet.	>40%	✓
Spore : pollen concentration ratio	>0.66	✓
Spore : pollen taxa ratio	>0.66	✓

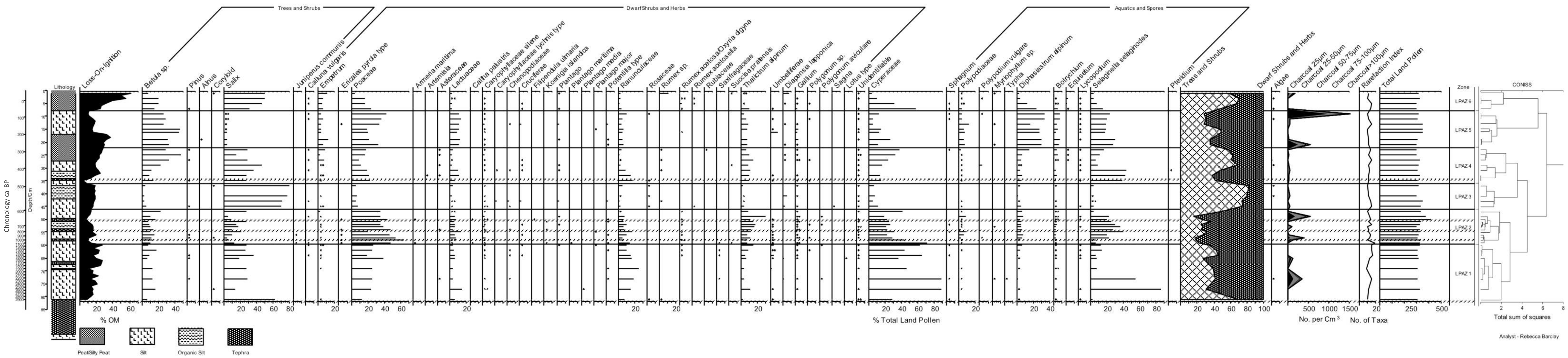


Figure 4.6 Percentage pollen diagram for Viðatóft. The + symbol indicates taxon present at less than 2%. Percentage calculations are based on a sum of Total Land Pollen (TLP) for all terrestrial pollen taxa, and TLP + Cyperaceae and TLP + aquatics and spores, for Cyperaceae and Aquatics and Spores respectively. Lithological components, age in cal. BP, charcoal concentration/No. fragments per Cm^3 and rarefaction indexes/expected species are also presented on the diagram.

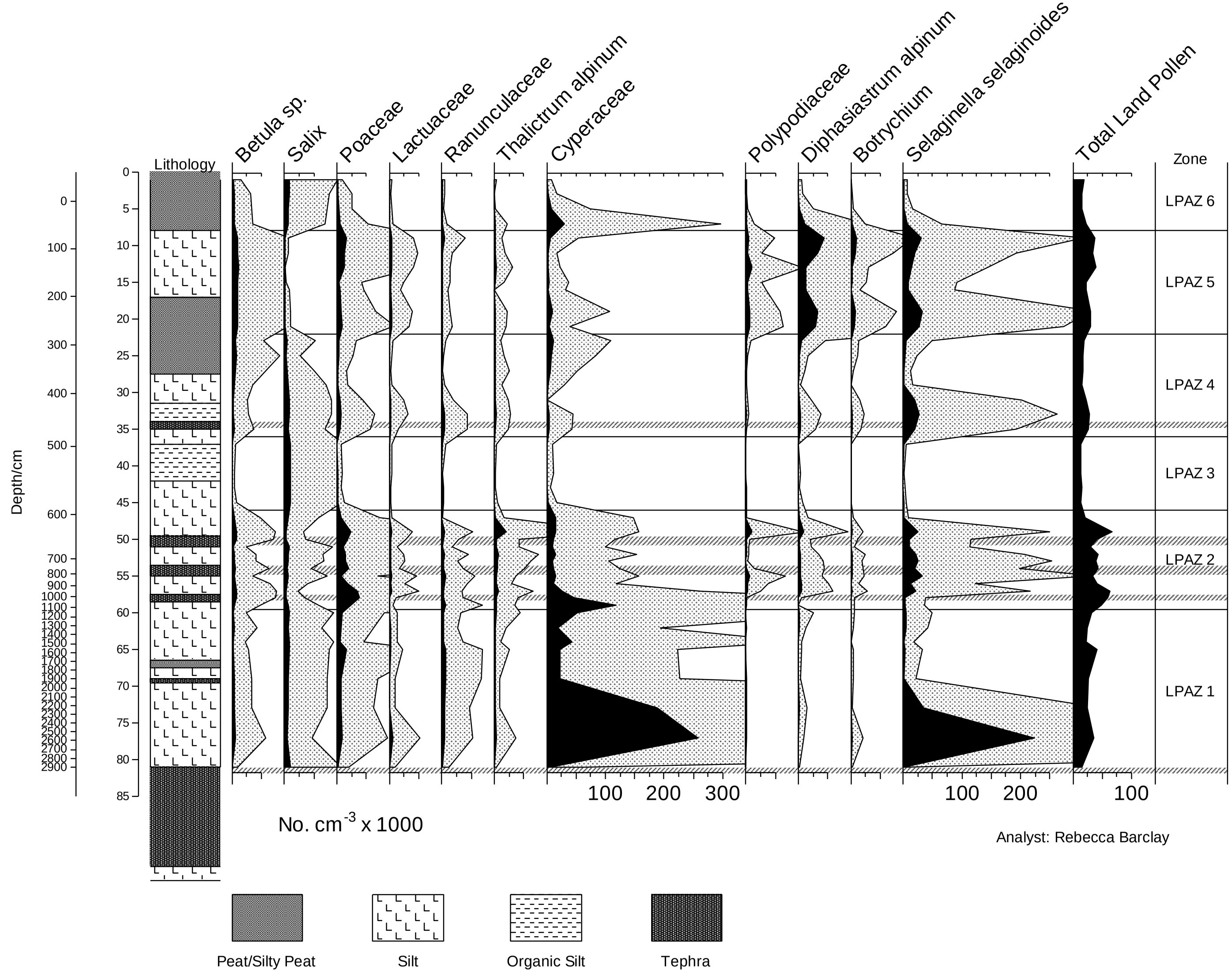


Figure 4.7 Pollen concentrations for selected dominant taxa at Viðatóft.

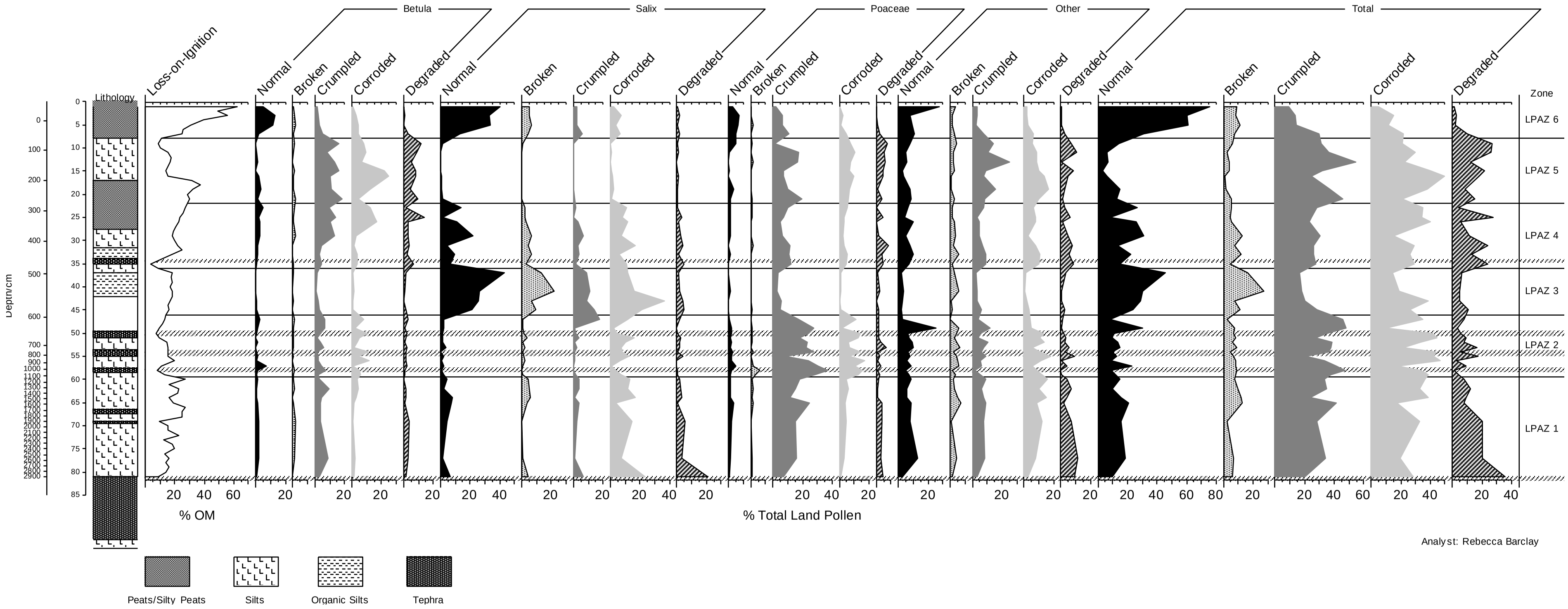


Figure 4.8 Pollen preservation data for selected dominant taxa, presented as % Total Land Pollen for the preservation categories - normal, broken, crumpled, corroded and degraded LPAZ 1 (*c.* 1157-2899 cal. BP)

4.4.2 LPAZ1 (*c.* 2900-1157 cal. BP)

This zone represents the pre-Landnám environment, summarising vegetation changes from the deposition of Hekla 3, until the settlement period. Sediment accumulation rates are slow during this period, with 22.5cm sediment accumulation in *c.*1742 years. SeAR calculations (Table 4.1) suggest values in the order of a third of post-Landnám values. Throughout the zone loss on ignition (LOI) of the predominantly silty sediments fluctuates between 10 and 30%; with LOI values lowest immediately after Hekla 3 (<10%), likely a result of the eruption aftermath. Immediately above Hekla 3 the pollen assemblage is dominated by tree and shrub type species, predominantly *Salix* (>60%), with low levels of *Betula* (<10%). Herb species form around 30% of the pollen assemblage; *Lactuceae* and *Ranunculaceae* are most prominent (6-8%) with other species occurring only at presence levels. *Cyperaceae* percentages, calculated independently of TLP, are low in comparison with the rest of the zone. Within this sample pollen preservation is particularly poor, with over 35% of grains degraded, and around 30% corroded. Preservation improves from this point, although values for corrosion and crumpling still remain over 20% each throughout.

From around *c.*2600 cal. BP (*c.*650 BC) tree and shrub percentages fall, with herb taxa becoming more dominant, remaining so throughout the zone; unusual given presumptions of *Betula* and *Salix* scrub dominance prior to settlement. This is suggestive of a slightly more open pre settlement environment, although perhaps only at the farm scale given the sheltered nature and associated localised pollen signal of the basin. *Salix* percentages fall, from the initial 60%, fluctuating between 12% and 40% in the rest of the zone. *Poaceae* (fluctuating 20-40%) and *Betula* (fluctuating 7-18%) become more dominant in the rest of the zone. *Pinus* is the only other tree species noted with the zone, presence is infrequent however and percentages no more that 1%, likely representing long distances transport of grains. Herb species also become more apparent in the pollen assemblage, notably *Ranunculaceae* increasing from its initial 7% to between 10% and 25%; additionally *Thalictrum* and *Lactuceae* are constants throughout.

Cyperaceae, after its initial low percentages, increase rapidly from *c.*2600 cal. BP (*c.*650 BC), not falling below 35%, and reaching as much as 90% *c.*2600-2300 cal. BP (*c.*650-350 BC). Those values around 90% are coincident with peaks in *Selaginella* species. Other aquatic and spores are present in the zone but none with the prominence of *Selaginella*, a spore producing species. Towards the top of the zone boundary more herb species are contributing to the pollen sum. *Umbelliferae* becomes more prominent (2-5%), as do other herb and dwarf shrub species, despite percentages of individual species remaining below 2%. Charcoal is present intermittently throughout the zone, with no apparent patterns in its presence, irrespective of fragment size.

4.4.3 LPAZ 2 (*c.* 594-1157 cal. BP)

This zone spans 563 years, incorporating what is considered to be the traditional Landnám period, delineated by the Landnám tephra; as well as the assumed abandonment period for the farm buildings onsite – believed prior to the AD 1104 Tephra. A third tephra (AD 1300) is also present within the zone. LOI fluctuates throughout the zone, highlighting these tephra layers, although values are typically low (<20%). Aforementioned settlement, abandonment and multiple tephra fallouts complicate interpretation of the zone, with multiple factors affecting vegetation assemblages, at both a local and regional scale. Due to increased sampling frequency around the Landnám and AD 1104 tephras, higher resolution data is available for the period of presumed site occupancy.

The summary diagram shows an association between the Landnám tephra (settlement period) and total percentages of trees and shrubs and dwarf shrubs and herbs. At this time dwarf shrubs and herbs are the dominating elements of the pollen assemblage, with grass species emerging as the most important flora component (45-65%) post Landnám. Cyperaceae species are also dominant, particularly immediately prior to the Landnám tephra fallout (71%), but also during the period coinciding with the tephra, where percentages remain over 40%. *Poaceae* remains the dominant species throughout the zone 35-65%, suggesting an expansion of more open grassland, particularly during the traditional settlement period (AD 870 – 930). An exception is noted at 55cm, with *Poaceae* at a much lower percentage - 20%, immediately below the AD 1104 tephra fallout, thought to signify abandonment of the site (Vésteinsson et al., 2011). This appears to be associated with a rise in *Salix*, an increase in which is again found coincident with the AD 1300 tephra fallout. *Cyperaceae* on the other hand falls after its initial higher percentages at Landnám fluctuating around 20%, until its increase at the upper zone boundary, demonstrating significantly lower percentages than in the previous LPAZ. *Salix* and *Betula* also increase towards the upper zone boundary, along with dwarf shrub species *Empetrum*. These are perhaps replacing *Poaceae* which is steadily declining suggesting the more open grassland site associated with settlement is gradually being replaced by the emergence of shrubby dwarf woodland vegetation. The pattern is echoed in a number of the herb species, with *Lactuceae, Ranunculaceae, Umbelliferae, Polygonum sp., Polygonum aviculare, Potentilla, Cruciferae, Koeniga islandica* and *Thalictrum* declining or disappearing towards the upper zone boundary after presence throughout.

Thalictrum also shows a significant increase to around 30% before this drop, mirrored by a fall in tree and shrub species before their expansion. Apophytes traditionally associated with the Norse, such as *Rumex acetosa* and *Plantago sp.* appear to have increased around settlement, the latter together with other herbs, decreasing towards the upper zone boundary.

Spore percentages fluctuate through the zone, *Selaginella* is the most prominent, increasing post-Landnám to around 20%, increasing again to around 40% coincident with the 1104 tephra and declining steadily to the upper zone boundary. *Botrychium, Diphasiastrum,* and *Polypodiaceae* are also found to increase post –Landnám after presence at only low percentages in the previous zone.

Peaks in percentages of corroded pollen grains coincide with tephra deposits within the zone. Percentages of crumpled grains appear to increase following tephra deposits. *Poaceae* is particularly impacted by crumpling with increased crumpled grains linked to increases in percentage of *Poaceae* shown on the diagram during these periods. Charcoal fragments are present in samples throughout much of the zone, particularly abundant from Landnám to the period after the AD 1300 tephra fallout, with the most common fragments from the lower size categories.

4.4.4 LPAZ 3 (*c.* 486-594 cal. BP)

This short zone encompasses only 108 years, within which LOI values show a slight increase as sediments become more organic, coupled with improved preservation of pollen. The zone is characterised by dominance of *Salix*, which fluctuates between 70% and 80% throughout the zone. No other species, with the exception of *Cyperaceae* (11%) at the lower zone boundary, reach percentages above 10%, suggestive of local dense coverage *Salix* scrub on site. Charcoal fragments are present but at lower values and again tend to be from lower size fractions.

4.4.5 LPAZ 4 (*c.* 277-486 cal. BP)

LPAZ 4 is initiated following the deposit of the AD 1477 tephra. Stratigraphy varies throughout, becoming more organic towards the upper zone boundary, instigating a slight increase in LOI towards this point. No obvious correlation exists between pollen preservation and LOI within this zone, with preservation varying throughout.

Deposition of the AD 1477 tephra appears to coincide with a shift in the species assemblage where *Salix*, previously the most abundant taxon, falls sharply from 80% to 30%, suggesting the vegetation onsite opens up from a dense shrubby assemblage to one dominated by grass and herb species. T*halictrum*, *Ranunculaceae* and *Lactuceae* in particular demonstrate increases percentages here, up to 15%, 17% and 11% respectively.

Following its sharp decline *Salix* steadily re-emerges to around 45% *c*.400 cal. BP (*c.*AD 1550), from which point *Betula*, previously increasing parallel to *Salix,* becomes the more dominant tree/shrub species (up to 47%). With this *Empetrum* (0 to 7%) and *Calluna* (0 to 1%) percentages increase which, together with decreases over the majority of herb taxa, leads to trees and shrubs again dominating the site. With the re-emergence of the shrubby vegetation comes and increase in *Cyperaceae* up to nearly 40%; as well as increases in the spores of *Polypodiaceae, Diphasiastrum, Botrychium* and *Equisetum. Selaginella* also presents increasing values towards the upper zone boundary, however values are higher (around 45%) around the deposition of the AD 1477 tephra when the site vegetation might have been more grass/heathland. Charcoal is present throughout the zone in low amounts with fragments typically measuring less than 50µm.

4.4.6 LPAZ 5 (*c.* 63-277 cal. BP)

The zone is characterised by a change in sediment from silty peats to silts, with the drop in organic content of sediments highlighted by the reduction in LOI from 30-40% to 10-15%. Vegetation community changes also appear associated with this increase in minerogenic material, with trees and shrubs gradually being replaced with more grassland/heathland vegetation throughout the zone. Initial high percentages of *Betula* fall down to as low as 26%, coincident with an increase in *Poaceae* (19 to 26%) suggesting a replacement of woodland and scrubland by more open grass and heathland. *Ranunculus*, typical of grassland, also expands synchronous with the expansion in *Poaceae.* The opposite is true of *Cyperaceae,* which appears to decrease in its presence on site, from 26% to as low as 5%, a change reflected by the transition to a drier part of the sedimentary sequence.

Pollen preservation is typically poor throughout the zone. Increased frequencies are noted for both mechanically and biochemically damaged pollen. With Increases most notable in crumpled, corroded and degraded grains. Frequencies of 'normally' preserved pollen are the lowest for all zones, broken pollen grains are also infrequent. The latter however is more likely a reflection of the increasing level of severity of degradation, rather than a decrease in the breakage of grains.

Within the zone, *Salix* is present in unusually low percentages (<4%), where it has previously been one of the more dominant taxon. This is likely at the expense of the expansion in *Betula* (up to 47%) within the middle of the zone. Some species of dwarf shrub and herbs seem less affected by this switch in community with *Empetrum, Lactuceae, Caryophyllaceae silene, Thalictrum* and *Gallium* retaining generally consistent percentages throughout.

For the duration of the zone spore species are relatively abundant. *Polypodiaceae* fluctuates from 2-12%, *Diphasiastrum* 15-35%, *Botrychium* 3-5% and *Selaginella* 19-30%; all taxa have seldom been represented by such high percentages elsewhere in the assemblage. The aquatic species *Myriophyllum alterniflorum* is noted as present in low frequencies within the zone, this likely reflects nearby presence of standing water.

Charcoal is present in greater quantities within this zone than in previous zones, especially in the sample towards the upper zone boundary. Particle sizes are counted over most size categories, but tend to be of a smaller size.

4.4.7 LPAZ 6 (*c.* -61-63 cal. BP)

Another short zone, representing 124 years until the present day. Sediments analysed from the zone were typically the most organic encountered within the core, organic peats with a silty fraction, subsequently LOI values are also highest in this zone. The organic nature of sediments is reflected in the preservation of pollen, with increasing organic content of sediments creating better preservation conditions for pollen. There is a consistent but small background charcoal signal throughout the zone.

Pollen assemblages are characterised by a dominance of tree and shrub taxa, suggesting dominance of woodland, scrub and dwarf-shrub heath, with *Salix* re-emerging, from its muted presence in the previous zone, as the most abundant pollen producer within the site; percentages increasing from 30% at the lower boundary to 50%. *Betula*, decreasing in abundance from the previous zone remains an important part of the vegetation assemblage, representing around 20% of the pollen assemblage; this is likely from *Betula* growing around the drier site edges comparable with vegetation patterns present on the site today. Increasing *Empetrum* counts (4-10%) and *Calluna* (varying around 1%) indicate potential dwarf shrub hummocks, likely throughout the mire surface and site edges. Grasses and sedges continue to form a significant proportion of the assemblage, 25% falling to 5% and 55% to 5% respectively, indicating presence of grassland and sedge communities within the scrub and heath areas. A variety of herbs linked to heathlands and grasslands – *Lactuceae, Caryophyllaceae, Cruciferae, Thalictrum*, and *Gallium* are present in low frequencies, likely undergrowth species within the scrub and heath communities. Apophytes – *Plantago* and *Rumex* – are present throughout, the latter showing a marked increase towards the upper zone (>10%) perhaps indicative of ongoing, potentially increasing disturbance. Arctic herb *Diapensia lapponica* also shows increased frequencies (5-10%) towards the upper zone boundary, the species is somewhat rare, but is typically found on moist heath soils as suggested for LPAZ 6.

4.5 Micromorphology Results

4.5.1 Slide production and analysis

Thin sections were made using the 'soils cores' (marked on Figures 4.2 and 4.4), with five continuous slides produced using the core from within the circular enclosure (Viðatóft I) and a further four taken from the core in the wet area outside of the enclosure (Viðatóft II). Micromorphological analysis of these thin sections allows enhanced understanding of pedogenic and taphonomic processes within the Viðatóft homefield, and of how these soil forming processes changed though time. Soils were also analysed for evidence of human impact, in terms of management, indirect or direct, and associated anthropogenic inclusions in soil. Results for each of these sampling points are summarised within Tables 4.4 (Viðatóft I) and 4.5 (Viðatóft II); key features from the tables are highlighted and described in accordance with their associated phase of site activity. Given issues with shrinkage in the preparation of thin sections from wetland environments, and despite efforts to reduce this impact for this site using acetone replacement in the manufacturing process (Stolt and Lindbo, 2010), no absolute dates were available for the samples. Instead, presence of the Landnám tephra in soils cores allowed for distinction between pre- and post-Landnám soil conditions. Where present in the samples, the historic tephras Hekla 1300 (Viðatóft I) and Veiðivötn 1477 (Viðatóft I and II) allow for further assessment of soil conditions in the later phases of settlement, including the period after the sites abandonment. Thin sections from Viðatóft I also incorporate the pre historic tephra Hverfjall *c.* 2500 cal. BP (*c.* 550 BC), providing further chronological control within the pre-Landnám context.

4.5.2 Pre-Landnám Soils

Samples Viðatóft I 61-70cm and 50-60cm (microhorizons B, C), and Viðatóft II 60-69cm, 50-60cm and 40-50cm (microhorizon C) are representative of the pre settlement environment. Soils are predominantly minerogenic, comprising mostly brown silts, and coarser tephra materials, this is consistent with previous micromorphological analysis results for Icelandic soils, with aeolian material, predominantly volcanic glass and tephra deposits recognised as the parent materials of the majority of Icelandic soils (Arnalds, 2004; Stoops et al., 2008). Tephra materials are randomly distributed and well sorted throughout much of the pre-Landnám sediment, suggestive of aeolian deposition and reworking of tephra materials within sediments. Direct tephra deposits are also a feature of the sediments; some incidence of tephra microstrata appear within the pre-settlement deposits, marked by increasing frequencies of coarse volcanic material and poorer sorting of these materials.

Sediments are compact, with little pore space evident, demonstrated by prevalence of compact and crack microstructures. Microstructures associated with freeze-thaw activity (sub-angular blocky, lenticular) are also frequent. With freeze-thaw further expressed in poro- and mono-striated groundmass b fabrics (Van Vliet-Lanoë, 2010) as well as textural pedofeatures forming, through the movement and redistribution of fine silts, creating silt coating on coarse mineral material within the matrix. These ‘cappings’ are frequently observed in Icelandic soils, and are attributed to the pedoturbation of soil material by cryoturbation, the presence of permafrost and freeze thaw activity (Romans et al., 1980; Stoops et al., 2008).

Perhaps the most distinguishing feature of the pre-Landnám sediments are the high frequencies of diatoms. Typically frequent to very dominant throughout the portion of the pre-Landnám environment examined, the diatoms indicate wet and frequently inundated conditions, potentially from seasonal or permanent flooding (Clarke, 2003). Within Viðatóft II, diatoms are particularly abundant with interspersed clusters of diatoms in some sections forming distinctive biosilicate microhorizons comprised almost entirely of diatoms (Figure 4.9 (G)). These accumulations appear relatively undisturbed within the matrix, suggesting stability during their formation period, as well as a lack of post-depositional bioturbation. Microstrata of varying materials, particularly plant residue and more extensively decomposed organic matter, are commonplace in Icelandic soils, with their preservation a result of minimal bioturbation and repeated deposits of tephra (Stoops, 2007).

Organic material is present throughout, yet biological activity appears limited. Excremental pedofeatures are absent from most of the pre-settlement microhorizons; where present only at trace levels, or very few in two of the microhorizons. Lack of faecal material is common in saturated soils, which create inhospitable conditions for soil fauna, as well as the potential for disintegration of faecal material with alternating wetting and drying conditions (Bouma et al., 1990). Microstructures associated with biological activity also remain restricted, with just small areas of granular microstructures witnessed within two microhorizons in Viðatóft I. However, granular microstructures, despite their common linkages with intense biological activity, might be associated instead with the general makeup of the andosols. Granular microstructures are universally witnessed in andosols, thought to be linked to their composition and resultant resistance of colloids to freeze-thaw processes (Sedov et al., 2010; Stoops et al., 2008). Organic material does however fluctuate throughout the pre-Landnám sediments. Within Viðatóft II, fine mineral material is frequently described as organo-mineral, and organo-mineral microhorizons alternate with mineral ones here. Where fine organo-mineral material occurs, organic materials tend to increase, particularly parenchymatic material. Frequencies of organic materials also fluctuate within the pre settlement sediments at Viðatóft I. Here the sediments immediately prior to Landnám are characterised by few to frequent parenchymatic materials, with increases in amorphous materials. This pre-Landnám increase in organic material is mirrored, albeit to a more restricted extent, in Viðatóft II.

Iron based amorphous cryptocrystalline pedofeatures are present throughout, suggestive of imperfectly drained conditions and the wetting and drying of sediments within both sample locations. These features may be associated with wetting and drying at the time of deposition or might have formed latterly. These dominant biochemical soil processes as well as aforementioned high frequencies of diatoms, the lack of biological activity and dense microstructures are all features commonly associated with saturated conditions (Bouma et al., 1990).

4.5.3 Settlement, site occupation and abandonment (Landnám – AD 1477).

The microhorizon boundary A-B, Viðatóft I 50-60cm, is marked by an increase in mineral material, partly tephra from the Landnám deposit and partly silts and other tephra fragments, likely of aeolian origin. Viðatóft II displays a similar increase in coarse mineral material associated with the settlement period, although boundaries are not so clearly defined. Speckled groundmass b fabrics and well sorted randomly distributed coarse mineral arrangements within each sampling location suggest continual input of predominantly aeolian materials.

Aeolian and tephra input remain the key accumulation processes throughout this period, however phases of organic accumulation are also evident within each site. This is pronounced within sections of Viðatóft I 30-40cm and 50-60cm; 30-40cm B for example is characterised by frequent brown organo-mineral fine materials, as well as increased amorphous and parenchymatic material. Microstrata of accumulations of organic material, amorphous and parenchymatic, with increases frequencies of excremental pedofeatures and granular microstructures, potentially associated with faunal activity, are present within Vid I 40-50cm A and 30-40cm A,C and D.

Increases in cultural material, frequently associated with settlement are not readily evident in the samples, with only trace levels of rubified minerals, commonly associated with domestic burning activities, found in the sediments. Charcoal frequencies are commonly found to increase during the Landnám period, however, no fragments were identified within the thin sections in the period immediately post settlement. This is in contrast to the pollen records where fine charcoal fragments were identified; perhaps suggesting fragments were predominantly windblown, and too small to be identified using the magnifications adopted for the micromorphological analysis. One single turf fragment is found within the 40-50cm section, however given its isolation and the lack of other cultural materials, this is treated as a random deposit, as opposed to assuming association with manuring activities.

One feature associated with sediments immediately post Landnám is a decrease in biogenic siliceous features, particularly diatoms, with few and very few witnessed at Viðatóft I and II respectively. Diatom frequencies do return to former amounts, but fluctuate between very few and very dominant in the given time period. Frequencies appear particularly low (very few) in Viðatóft I 30-40cm in association with increased frequencies of organic material. The presence of amorphous cryptocrystalline features all through indicates wetting and drying conditions throughout, although these are potentially associated with post-depositional processes. Features associated with freeze thaw remain prevalent; lenticular and sub-angular blocky microstructures, and poro-, mono- and cross striated groundmass b fabrics are observed throughout the section (Van Vliet-Lanoë, 2010).

4.5.4 Sedimentary records from AD 1477

Micromorphological records for post AD 1477 sediments are limited given the depths analysed (20-70cm). Post AD 1477 sediments within Viðatóft I, are characterised by high frequencies of both coarse and fine mineral material, predominantly aeolian silts and dark and light tephra materials of differing origins, likely rapidly accumulating within the site. Very few- few diatoms are present, suggesting reasonably wet conditions, attested by increases frequencies of amorphous cryptocrystalline features. Organic material is somewhat limited within this section, although more common in microhorizon B where accumulations of organic material, particularly parenchymatic material is witnessed alongside traces of excremental pedofeatures. Traces of cultural materials – rubified minerals and charcoal, are found throughout the sections, they can be attributed to long distance transport given their small size and the sites current state of abandonment; it is equally probably the materials are naturally occurring and associated with volcanic activity.

Post AD 1477 sediments within Viðatóft II appear more organic and siliceous than corresponding sediments in Viðatóft I. Suggesting wetter conditions, preventing breakdown of organic inputs to soil. Common-frequent parenchymatic materials appear horizontally aligned, a feature associated with a number of micromorphological studies in Iceland (Romans et al., 1980; Simpson et al., 1999; Stoops, 2007; Stoops et al., 2008). This phenomena is most plausibly interpreted as rapid burial of litter layers, by tephra or aeolian deposits, before humification of organic materials takes place (Stoops et al., 2008). Lenticular microstructures highlight further effects of freeze thaw; freeze thaw activity is not obviously expressed within sediments from Viðatóft I. Redoximorphic processes are highlighted by the presence of traces of very few amorphous cryptocrystalline features at Viðatóft II, and few within Viðatóft I for the same period.

Table 4.4 Micromorphology Results – Viðatóft 1

Thin Section Sample	Microhorizon (Fibric/ Hemic/ Sapric/ Biosilicate)	Micro-Structure	Organic Material: Cell Residue	Organic Material: Parenchymatic	Organic Material: Fungal Sclerotia	Organic Material: Amorphous (light Brown)	Organic Material: Amorphous (brown)	Organic Material: Amorphous (black)	Siliceous Features: Phytoliths	Siliceous Features: Diatoms	Coarse Mineral material >63 µm: Igneous Rock	Coarse Mineral material >63 µm: Tephra (deposit)	Coarse Mineral material >63 µm: Light volcanic material	Coarse Mineral material >63 µm: Dark volcanic material	Coarse Material Arrangement and Sorting	Fine mineral material	Groundmass b fabric	Cultural Materials: Bone	Cultural Materials: Turf fragments	Cultural Materials: Charcoal	Cultural Materials: Rubified minerals	Pedofeatures: Amorphous crypto-crystalline	Pedofeatures: Calcium Spherulites	Pedofeatures: Stone Rims	Pedofeatures: Silt Coatings	Pedofeatures: Excrement (mamilate)	Pedofeatures: Excrement (spheroidal)
20-30	A	Crack		··		·	·	·	·	··	*t*		···	···	Random, well sorted	··· brown mineral	Speckled, poro striated			*t*	*t*	··					
	B	Granular, crumb	*t*	··	*t*	·	·		·	·	*t*		··	··	Random, well sorted	··· brown mineral	Speckled			*t*	*t*	··					*t*
30-40	A	Granular, fissure		·	*t*	·	·		*t*	··	*t*		··	·	Random, well sorted	··· brown mineral	Speckled			*t*	*t*	·				*t*	·
	B	Massive		·			··			·			·	··	Random, well sorted	··· brown organo mineral	Speckled					···					
	C	Sub-angular, blocky		·		·	··			·			··	··	Random, well sorted	·· brown mineral	Speckled, poro-mono-cross striated					··					·
	D	Granular, crack		*t*	*t*	*t*	··		*t*	···	*t*		·	··	Random, well sorted	·· brown organo mineral	Speckled, random striated					···					
40-50	A1 (mottle)	Crack, compact grain, granular		··	*t*	·	··		*t*	···	*t*		··	··	Random, well sorted	··· brown mineral	Speckled, mono-poro striated					···				·	··
	A2	Crack, compact grain, granular	*t*	·	*t*	·	·			···			··	··	Random, well sorted	··· brown mineral	Speckled, mono-poro striated		*t*			··				·	·
	B	Crack, compact grain		·	*t*	*t*	*t*		*t*	····			···	··	Random, well sorted	··· greyish brown mineral	Speckled				*t*	*t*					
50-60	A	Crack, subangular, lenticular, blocky, compact grain, granular		··	*t*	··	··		*t*	··			··	···	Random, well sorted	·· brown mineral	Speckled										
	B1	Compact grain, crack		··	*t*	·	·			···	*t*		··	··	Random, well sorted	·· light brown mineral	Speckled										
	B2	Crack, subangular blocky		···	*t*	·	···		*t*	···			·	·	Random, well sorted	·· brown mineral	Speckled				*t*					·	·
	C	Crack		*t*	*t*	*t*	*t*		*t*	····			*t*	*t*	Random, well sorted	· light brown mineral	Speckled					*t*					
61-70	A	Compact grain, bridged grain, intergrain micro aggregate		*t*		·	·		*t*	*t*	··	····	···	···	Random, well sorted	··· brown mineral	Speckled					·			··	*t*	*t*
	B1	Compact grain, crack		*t*	*t*	·	·		*t*	···			··	··	Random, well sorted	··· light brown mineral	Speckled				*t*	*t*					*t*
	B2	Compact grain, bridged grain, granular		·	*t*	·	·		*t*	··			·	··	Random, well sorted	··· brown mineral	Speckled					···			*t*	*t*	·

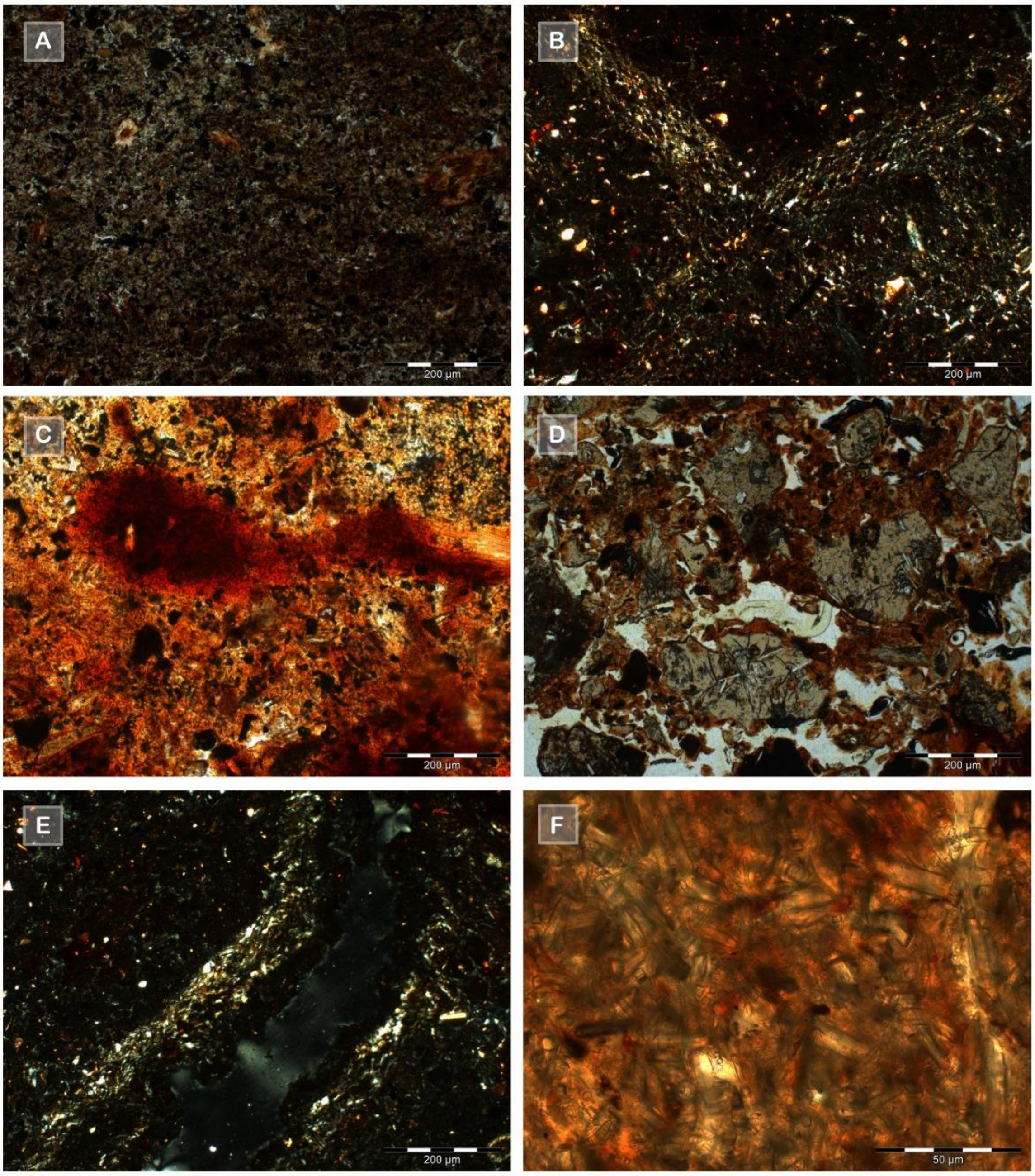
Frequency class refers to the appropriate area of section (Bullock *et al.* 1985)

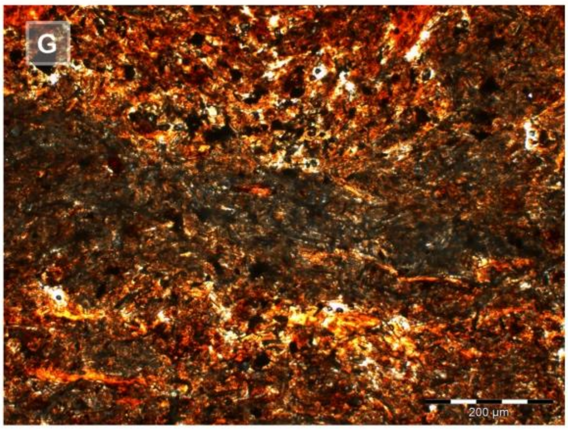
t Trace · Very few ·· Few ··· Frequent/common ···· Dominant/very dominant

Table 4.5 Micromorphology Results – Viðatóft 2

Thin Section Sample	Microhorizon (Fibric/ Hemic/ Sapric/ Biosilicate)	Micro-Structure	Organic Material						Siliceous Features		Coarse Mineral material >63 µm				Coarse Material Arrangement and Sorting	Fine mineral material	Groundmass b fabric	Cultural Materials				Pedofeatures					
			Cell Residue	Parenchymatic	Fungal Sclerotia	Amorphous (light Brown)	Amorphous (brown)	Amorphous (black)	Phytoliths	Diatoms	Igneous Rock	Tephra (deposit)	Light volcanic material	Dark volcanic material				Bone	Turf fragments	Charcoal	Rubified minerals	Amorphous crypto-crystalline	Calcium Spherulites	Stone Rims	Silt Coatings	Excrement (mamilate)	Excrement (spheroidal)
20-30	A	Compact, lenticular	t	···	t	t	··		t	···	t	·	···	···	Random, well sorted	··· brown mineral	Speckled					·					
	B	Compact		·					t	···	t	····	···	···	Random, well sorted	···· grey-brown mineral	Speckled					t					
	C	Compact, lenticular		···	t	t	··		t	···	t		··	··	Random, well sorted	··· brown mineral	Speckled					·				t	t
	D	Bridged		t			t			··		····	···	····	Random, moderately sorted	·· grey brown mineral	Speckled					t					
30-40	A	Bridged		·			t			··	t	····	···	···	Random, moderately sorted	··· grey-brown mineral	Speckled				t	·					
	B biosilicate bands	Compact, crack, lenticular		·	t	·	·			····	t		··	··	Random, well sorted	··· brown mineral	Speckled				t	·				t	t
40-50	A	Compact, crack,	t	·	·		·		t	··			···	···	Random, well sorted	··· brown mineral	Speckled				t	·				t	t
	B	Bridged, compact		·			·			·	t		···	···	Random, moderately sorted	·· brown mineral	Speckled					·					
	C	Compact, subangular blocky	t	·	t		·			····	t		··	··	Random, well sorted	·· brown organo mineral	Speckled					·					t
50-60	A	Compact, crack, lenticular		·	·	t	·			···			···	··	Random, well sorted	··· brown mineral	Speckled, poro striated					·					t
	B biosilicate	Compact, subangular blocky, lenticular		··	t	·	·			···/····	t	·	··	··	Random, well sorted	· brown organo mineral	Speckled					·				t	t
	C biosilicate	Compact		·						····			t	t	Random, well sorted	t brown mineral	Speckled					t					
60-69	A biosilicate	Subangular blocky, compact		·	t	t	·		t	····	t		·	··	Random, well sorted	··· brown organo mineral	Speckled, mono striated					·					
	B	Bridged grain		t			t			t	··	····	····	···	Random, moderately sorted	·· brown mineral	Speckled					·			·		
	C	Compact, subangular blocky		·	t		·			···	t		··	··	Random, well sorted	·· brown organo mineral	Speckled, mono striated					··					

Frequency class refers to the appropriate area of section (Bullock *et al.* 1985)
t Trace · Very few ·· Few ··· Frequent/common ···· Dominant/very dominant





A) Viðatoft I 20-30: soil compaction (PPL).
B) Viðatoft I 30-40: cross striated groundmass b fabric (XPL).
C) Viðatoft I 30-40: iron staining and compaction (PPL).
D) Viðatoft I 61-70: silt coatings on volcanic glass (PPL).
E) Viðatoft II 50-60: Poro-striated groundmass b fabric (XPL).
F) Viðatoft II 50-60: Diatom clustering (PPL).
G) Viðatoft II 50-60: Diatom banding (PPL).

Figure 4.9 Key micromorphological features in Viðatóft thin sections

4.6 Discussion

4.6.1 The pre-Landnám environment at Viðatóft LPAZ 1

The primary pollen zone represents the pre-Landnám environment at Viðatóft from the deposition of the Hekla 3 tephra to the settlement period. Contemporaneous with the Hekla 3 deposit is a peak in *Salix*. Given the thickness of the tephra deposit this is likely a response factor, with tephra completely enveloping and creating hostile habits for many of the low lying arctic species previously present onsite. Given its height advantage (Arnalds, 2013; Rundgren, 1998), it is suggested that *Salix* survived the deposition, thriving where other species were no longer able to complete. Preservation immediately ensuing Hekla 3 is noted as poorer than in the rest of the zone, with enhanced frequencies for deteriorated and corroded pollen grains, perhaps linked directly to the detrimental effects of the tephra material itself or as a result of a period of landscape instability initiated by the tephra. Increased degradation and corrosion of pollen grains is frequently linked to the redistribution of pollen in eroded sediments (Cushing, 1964; Tipping, 2000). An influx of eroded soil from the wider catchment, for example, might have artificially inflated high *Salix* values for the site. The presence of aeolian materials within pre-Landnám soils however remain at moderate levels, suggesting disturbance is unlikely to have had a profound effect on pollen. Increases in corrosion and degradation might alternatively be linked to the drying out of the basin which can lead to rapid oxidation of sediments and result in biochemical damage to pollen (Lowe, 1982). Tephra deposits are widely recognised as having a drying effect on mire surfaces, creating temporary free draining conditions (Edwards et al., 2004; Erlendsson et al., 2009), with the potential to impact pollen preservation conditions. Following the deposit of Hekla 3 damp loving *Cyperaceae* is found at low levels, suggesting this may be the case.

After the initial impacts of the Hekla 3 tephra, natural sediment accumulation resumes, signified by increased LOI, perhaps improving water holding capacities onsite (Vickers et al., 2011). With this change a herb rich flora established, with a striking dominance of *Cyperaceae*, which alongside the moisture tolerant *Salix* and *Potentilla,* is suggestive of an open wet meadow. The heterogeneous nature of the site is indicated by the presence of several taxa with dry habitat preference, with *Betula, Lactuceae, Saxifragaceae, Gallium* and *Umbelliferae* likely occupying the dryer fringes and sloping sides of the site. Micromorphological evidence supports interpretations of a wetland environment, the high frequencies of diatoms within the sediment, at depths linked to pre-Landnám conditions, strongly suggests periods of standing water, perhaps seasonal. Similar, but more extensive and deeper diatom deposits have been discovered in other sedge peat deposits in Iceland; at Reykholtsdalur 20.5cm of diatomite are visible in the soil stratigraphy, attributed to an extended period of standing water within the paleo-channel sampling site (Erlendsson, 2007). Further observations of materials linked to saturated conditions provided additional support these interpretations, including a general lack of biological activity and a prevalence of dense microstructures (Bouma et al., 1990), present throughout the pre-Landnám sediments.

Given the absence of humans and grazing mammals on Iceland prior to Landnám, all changes in vegetation composition pre-Landnám can be attributed to natural causes, particularly volcanism and climate change. In addition to responses to the substantial deposit of the Hekla 3 tephra, subtle and climatically induced fluctuations are evident within certain taxa. Betula contractions and regenerations, linked to short term climate amelioration and cooling are noted during the same period (Hekla 3 – settlement) in a number of diagrams from across Iceland (Andrews et al., 2001; Baillie, 1991; Bartley, 1973; Einarsson, 1957, 1961, 1963; Erlendsson and Edwards, 2009; Páhlsson, 1981). At Viðatóft, *Betula* percentages tend towards a contraction in the centuries prior to settlement, a pattern witnessed in the majority of diagrams (Andrews et al., 2001; Einarsson, 1957, 1961, 1963). These percentages do however increase, albeit at a low level, immediately prior to Landnám, with similar patterns witnessed in the south and west of the country (Erlendsson and Edwards, 2009; Páhlsson, 1981). Increases in these thermophilous taxa may be linked to warmer temperatures at this time (Ogilvie, 1984, 1991). *Betula* pollen productivity for example is linked closely to summer temperatures in the previous year, with observations further supported by the presence of other warmth loving species (*Calluna vulgaris, Empetrum* nigrum) during the same time period in the pollen spectra (Broström et al., 2008; Eddudottir et al., 2015). It should, however, be noted that percentage differences are relatively small, and may instead be linked to the 'relative' nature of pollen percentage data, i.e. percentage values are dependent on abundance of other taxa within the pollen sum (Prentice, 1988). Soils immediately below Landnám tephra deposits support suggestions of warmer temperatures. Soils within both cores demonstrate small increases in organic material directly below Landnám. This suggests soils become freer draining, creating more hospitable conditions for soil biota leading to an increase in the addition and breakdown of organic material, pedogenic processes frequently related to climate amelioration.

Sediments observed in thin section are reflective of the lower levels of sediment accumulation calculated during the pre Landnám period. Dominance of mineral material is reflective more of parent materials and gradual additions to sediments rather than rapid aeolian deposition within the site. This inherited stability is expressed in features such as the siliceous microstrata, indicating minimal disturbance and well preserved expressions of freeze thaw activity, including associated microstructures and silt coatings.

4.6.2 Environment of settlement and subsequent abandonment of the farm at Viðatóft LPAZ 2

With regional and site settlement an alteration of the vegetation character of the site is witnessed, through the transition of vegetation communities from natural to anthropogenically modified communities.

From this point sediment accumulation rates are noted as increasing, a factor commonly associated with the Norse Landnám in Iceland (Dugmore and Buckland, 1991), exemplary of the intensification of land use and disturbance in a previously pristine landscape. An increase, witnessed in thin section, of the coarse mineral fragment of sediments following Landnám, verifies these observations of increased disturbance and aeolian inputs following settlement and points to a period of instability in the wider landscape. Immediately post Landnám percentages of corroded and degraded pollen grains, typically associated with periods of soil instability and reworking of sediments (Cushing, 1964; Tipping, 1995, 2000), appear to fall, suggesting alongside a relatively intact suite of tephras from across the site during this period, the site was not directly impacted, or impacted only to a limited scale. Given these observations the degree of impact erosion has on the taphonomic processes onsite may be limited, implying much of the pollen counted will have been recruited, for the given time period, from within the site itself. This may be linked to the sites open nature at settlement, with limited requirements to clear the land for farm development which often led to the instigation of soil erosion. Although charcoal counts in pollen are noted as increasing during the period of settlement, there are no sharp increases which might suggest land clearance by burning. Charcoal values are relatively subdued in their increase and instead are more likely indicative of ongoing domestic activity within the vicinity. These limited proportions are mirrored within the thin sections, with only small fragments of charcoal witnessed at trace levels.

Despite increasing SeAR values and evidence of increasing aeolian coarse mineral material following settlement, windblown material and tephra deposits are not the only contributors to SeAR's between Landnám and AD 1477. Several short incidences of organic accumulations are noted throughout the thin sections, suggesting intermittent periods of landscape stability where surface processes, including decomposition of organic materials and faunal activity take place. Similar standstill phases against a background of sustained and dominant instability are witnessed elsewhere in the Mývatn region, across similar time frames (Brown et al., 2012). These observations highlight the issues in oversimplifying processes contributing to SeAR in Iceland. Previously accepted assumptions that SeARs link to erosion processes in the wider landscape (Dugmore and Buckland, 1991) are brought into question here with more complexities observed in soil processes. These suggest accumulation rates are not solely the product of aeolian and tephra inputs, and that discrete periods of organic matter accumulation in intermittent phases of landscape stability are also a significant component of soil accumulation.

The palynological impacts of Landnám within the farmscape of Viðatóft mirror to some extent the majority of early settlement farms in Iceland, with the impacts of settlement clearly evident within the pollen profile for the farm. Here however, the impacts were largely muted given the openness of the site prior to settlement, as interpreted by wet meadow species, and wet conditions in the soil, which would have prevented encroachment of *Betula*. Perhaps most evident are the increases in open grassland at Landnám, generally at the expense of trees, shrubs and sedges, as the land surrounding the farm was opened up and hayfields for the production of fodder crops were developed within the farms infields. This suggests to some extent the development of a pastoral farming system, with the change occurring directly above the Landnám tephra deposit, and therefore associated with early settlement. Domestic animals introduced by settlers and linked to expansion of hayfields and grasslands are also evident within the pollen profile. Subsequent exposure of the farm to grazing pressures is evidenced in the changing frequencies of grazing intolerant and tolerant species. Grazing intolerant species (*Betula*, *Umbelliferae*, *Sphagnum, and Salix*) become more infrequent and in some cases vanish from the site, being replaced by those species more tolerant of grazing (*Rumex, Thalictrum, Gallium, Equisetum, Selaginella, Lactuceae*). Notable expansion of *Botrychium* suggest levels of grazing within some parts of the farm, capable of producing closely cropped swards of grass, with these spores spreading more readily with the increasingly open nature of the site. Presence of grazing intolerant tall herbs, albeit at low levels, throughout the occupation phase, despite evidence for increased grazing pressure, suggest the pollen samples were extracted from a portion of the site within or nearby an area enclosed and protected from grazing animals, as has previously been found in Iceland where infield hay meadows are protected from livestock (Vickers et al., 2011). Given the presence of the circular enclosures at Viðatóft, suggested by Vésteinsson (2011) as protecting improved cultivated ground, and within which the pollen samples were taken, pollen from the grazing intolerant species might have been directly recruited from here, with the structures shielding the enclosed land from grazing. Despite suggestions of manuring within the enclosed areas, no evidence of these practices is visible within the micromorphology.

Expansions are also noted in apophytic taxa (*Gallium, Rumex acetosa, Lactuceae*), from Landnám – a further characteristic signal of Iceland, and a result of increased disturbance, linked to development of the farm onsite. No indication of cereal cultivation was found in the wetland area, although absence of cereal pollen is not conclusive evidence for absence of cultivation within the farm, given the limited dispersal ability of cereal pollen.

Wet loving species decline during the occupational phase at Viðatóft. *Salix, Empetrum, Caltha palustris, Potentilla* and *Cyperaceae*, are noted as in declination or absent whilst the farm is occupied. Perhaps indicating the now defunct structures at Viðatóft were indeed once successful in draining the land within the homefield and infields of the farm. Trends for the reduction in these species might also be associated with climatic trends across the same period. The settlement period is understood has having coincided with the Medieval Warm Period. Allowing more thermophilous (*Betula*, *Selaginella* (Eddudottir et al., 2015)) taxa to flourish at the expense of cool and damp loving sedges. Micromorphological analyses support these observations with reductions in diatoms simultaneous for pollen evidence of drying conditions.

Palynological data offers support to the observations made by Vésteinsson et al. (2011) of the sites abandonment prior to the deposition of the AD 1104 tephra. Immediately below this deposit, grasses reduce in frequency, replaced by expansions in sedges and *Salix*, suggesting upon their abandonment, former areas of hayfields are colonised by sedges and *Salix.* These observations however are based upon moderate changes in the percentages of these species; therefore care must be taken with interpretations given their potential link to natural variability and error in frequencies. Despite abandonment of the farm at Viðatóft, palynological evidence supports the continuation of grazing here. Figures for grazing sensitive species remain consistent, as do those for grazing tolerant species. From Landnám and into the 13th century the increased incidence of *Botrychium* suggests grazing in the surrounds at level suitable to maintain a close cropped sward. Increased frequencies of the anthropogenic taxa *Polygonum aviculare* and *Plantago sp.* as well as the apophytic taxa *Caryophyllaceae*, *Rumex sp*. support this observation, perhaps indicating trampling and grazing at a level capable of exposing bare ground, allowing establishment of these pioneer, weed species associated with farm sites, even post abandonment.

Further complicating the anthropogenic signals in the palynological record between the 9th and 14th centuries is the deposition of tephra, with three found throughout the site during this period? Following each eruption, deposition of tephra would appear to improve drainage conditions temporarily within the site. Each tephra layer is linked to an increase in grasses and a decrease in sedges; as well as an increase in other dry loving taxa – *Betula* and *Lactuceae*. Each tephra layer might also be linked to changes in pollen preservation. Coincident with each tephra is an increase in crumpled pollen. This is likely linked to the aforementioned expansion of grasses, with *Poaceae* pollen regarded as particularly susceptible to mechanical damage (Tipping, 2000). In addition to this, peaks in corroded pollen follow these peaks in crumpling. This might be linked to the drying of sediments with the deposition of tephra. Whereby increased oxygenation of sediments, increases the likelihood of microbial attack on pollen, and therefore increase the probability of pollen becoming corroded (Havinga, 1964). Fluctuations in diatom frequencies observed in thin section throughout this period appear linked with these drying episodes, demonstrating sustained periods of wetter and dryer conditions within the site. Diatoms steadily increase following the contraction in frequency associated with settlement; this potentially illustrates the failure of drainage structures following the sites abandonment.

Akin to regional signals for the prevalence of birch woodland and scrub in Mývatnssveit (Lawson et al., 2007), birch within Viðatóft remains relatively stable at low levels, despite minor contractions, throughout the period of occupation and up to the 15th century. This is contradictory to the general belief of complete deforestation within decades of Landnám (Hallsdóttir, 1987). In this instance Betula pollen is likely recruited from the dryer edges of the site, with a small percentage recruited from slightly further afield, rather than occurrence as a dominant species within the site. This is consistent with archaeological evidence from within the region. In a regional survey Church et al. (2006) discovered a series of 11th and 12th century charcoal production pits, utilising birch wood as the primary charcoal resource. Simpson et al. (2003) also note the use of birch charcoal in fuel residue research at high status site Hofstaðir. Presence of birch in the archaeological record therefore supports palynological data, which indicate its continued presence in the region and its utilisation at only high status sites (lower status sites had to make use of poorer fuels, such as animal manures) suggesting there may have been management and restricted access to the woodland resources (Lawson et al., 2007; Simpson et al., 2003).

4.6.3 Cessation of grazing – Impacts of Plague? LPAZ 3

From the late 14th to mid-15th centuries, several hundred years after the farms abandonment, the land surrounding the farm buildings became monopolized by *Salix* scrub, relatively dense in nature, with a closed canopy indicated by disappearance of *Koeniga islandica*. Apophytes and disturbance indicator species have both declined and disappeared from pollen sums across this period, suggesting little to no disturbance within the site at this time, and perhaps a hiatus in grazing pressures in the wider landscape. Sedimentation rates are demonstrated as increasing during this period, however, it is suggested by the increased organic content of sediments and dense *Salix* coverage that soil formation processes are influenced more by breakdown of litter than aeolian input. Furthermore, protection from erosion pressures (e.g. weathering and grazing) of newly formed soils is provided by the dense scrub in the immediate vicinity, increasing landscape stability. These processes are echoed in observations from thin section from the same time period, with a sustained phase of landscape stability indicated by increases in organo-mineral, as well as parenchymatic and amorphous organic materials. These, together with granular microstructures and increased incidence of excremental pedofeatures, point to active surface processes acting under stable vegetation covered landscapes.

Cessation of grazing at Viðatóft in the early 15th century may to some extent be a consequence of reduced population as a result of the plague epidemic (AD 1402-1404) (Karlsson, 1996). This plague was the first of two major plagues to impact Iceland in the 15th century, and is believed to have killed up to two thirds of the population at the time. This significant demographic decline resulted in mass farm abandonment and a number of farms becoming under management of the church as gifts from dying people (Karlsson, 1996). It is understood that for some 40 years after the plague, up to 20% of farms remained desolate (Streeter et al., 2012). Associated with this, stocks of grazing mammals are thought to have declined, reducing grazing impacts on the surrounding landscape. Studies in southern Iceland mirror these patterns of lower landscape instability following the plagues (Streeter et al., 2012), with linkages being made between reduction in grazing pressure and resultant easing of environmental pressure associated with population collapse.

4.6.4 Cooling climates and Volcanism LPAZ 4

Following the deposition of the AD 1477 tephra, vegetation communities are again altered, with the tephra deposit initiating a transformation of the site from dense *Salix* scrub to more open grassy habitat, highlighted by the increasing presence of *Thalictrum*. Again the drying impacts of tephra on the sediment surface are noted, with enhanced drainage favouring dryland taxa – *Poaceae, Lactuceae, and Selaginella* – over damp loving species. Re-emergence of tall herb species (*Umbelliferae*) at this point might also suggest restrictions on grazing in the vicinity, perhaps as livestock are lost to or kept indoors to protect from fluorosis (Edwards et al., 2004). Alternatively, return of grazing sensitive species could be linked to reductions in regional grazing pressure following a further outbreak of the plague, some 17 years after the eruption (AD 1494-1495). This second outbreak is thought to have killed 30-50% of the population, with potentially serious consequences for the farming economy at that time (Karlsson, 1996). Cessation of grazing and related disturbance may be linked to the small increases of organic materials observed in limited portions of post AD 1477 thin section sediments.

General micromorphological characteristics mirror rapidly increasing SeAR's for this period. Post AD 1477 sediments demonstrate a marked increase in randomly distributed coarse and fine mineral material, as well as horizontally aligned parenchymatic material. These features indicate a sustained period of instability in the surrounding landscape, with horizontal alignment of organic materials frequently linked to rapid burial of litter by tephra and aeolian deposits which prevent biological breakdown of the materials (Simpson et al., 1999; Stoops, 2007; Stoops et al., 2008). Viðatóft itself does not seem to have been impacted by the erosion at this point, acting instead as a point of soil accumulation, a result of disturbance on the site being limited.

Following further accumulation of sediment, improving the water holding capacities of sediments onsite, potentially enhanced by cooling climates in the Little Ice Age (Ólafsdóttir and Guðmundsson, 2002) shrubs and dwarf shrubs expand. As does *Cyperaceae* which, given the arctic character of many species within the family and a general preference for damp conditions, is able to tolerate cooler and wetter conditions (Erlendsson and Edwards, 2009; Kristinsson, 2010). Habitat heterogeneity is likely to have increased, creating a mosaic of vegetation communities similar to the present day. Increases frequencies of diatoms in thin section, particularly in Viðatóft II, supports observations of increases wetness and heterogeneity in the site, with conditions appearing wetter in sediments at this point. A peak in Betula witnessed in the mid-17th century can be attributed to increased landscape instability at this time. This peak is linked to a sharp increase in degraded pollen, the biggest contribution to which is *Betula.* The instability is likely to result in erosion and redistribution of pollen from external sources, artificially inflating values within the farm. This period of instability might be a result of the increased storminess associated with the Little Ice Age, specifically the cooling climates at this time increasing vulnerability of surrounding sediments.

4.6.5 Increasing Instability LPAZ 5

Palynological and soil evidence suggests the period from the late 17th to mid-19th century was one of severe environmental instability. Enhanced SeAR and increasing mineral content of soils suggests rapid accumulation of soils, with the predominantly silty nature of soils pointing to aeolian activity during erosive phases. Likely exacerbated by the severe climates increasing landscape vulnerability during this phase of the Little Ice Age (Ólafsdóttir and Guðmundsson, 2002). In addition the absence of a clear AD 1717 tephra deposit within Viðatóft cores, points to potential erosion and reworking of soils within the site itself. Thin sections are not available for sediments at this point; observations therefore cannot be further verified.

Soil conditions are linked to increasing frequencies of crumpled, corroded and degraded pollen across the same period, across all types. Increases in biochemical degradation (corroded and degraded grains) in particular is linked to the increased exposure and oxygenation of sediments (Cushing, 1964; Tipping, 2000). Simultaneous increases in spore taxa support these observations, with inflation in spore taxa commonly linked to such conditions as a result of their resistance to corrosion (Bunting and Tipping, 2000). Given the widely documented erosion issues in Iceland during this period (Dugmore and Buckland, 1991; Ólafsdóttir and Guðmundsson, 2002; Vésteinsson pers. comm.), and the taphonomic issues associated with erosion, it is likely that the pollen record for this time period has been distorted though reworking of catchment soils, and palynological contamination with old pollen. This is likely to render samples from this period to a great extent unreliable for interpreting the sites vegetation history during this period.

4.6.6 Stability and the formation of the modern day vegetation communities. LPAZ 6

Following the period of instability during the Little Ice Age, slow improvements in climate and increasing stability is noted within the palaeoenvironmental evidence on site. Sediments have become increasingly organic and stable, consequently improving conditions for pollen preservation. Vegetation succession is noted during the mid-19th century until the present day, with the formerly disturbed habitat developing into a predominantly shrubby community, as found on the site today. The low prevalence of disturbance indicators in the pollen profile (*Rumex sp., Plantago sp.*) suggests minor disturbance, likely low level grazing, helping maintain the habitat mosaic (scrub, heath, mire) and species diversity thought the past decade.

4.7 Site Summary

Pollen and sedimentary analysis indicate that Viðatóft, at settlement appeared to be a stable wetland site, with low areas of the site likely to flood periodically. As such, results from this site provide a further example of settlement of an open site, dominated by herb vegetation rather than dense scrub. To date, few pollen studies in Iceland have focussed on human-environmental relationships in areas not sustaining *Betula* pollen prior to settlement (Erlendsson et al., 2009). This data can therefore be used in contrast to the commonly accepted Landnám signal for early settlement farms, where woodland and grazing sensitive taxa decline, and are replaced by a suite of apophytes, grassland taxa and cereals (Edwards et al., 2011). Accordingly, the site conforms to Vésteinsson's (1998) settlement model of early farmers attracted to natural clearings in the Icelandic landscape, situated close to wetlands for use as an additional source of winter fodder. In addition, the site is characterised by minimal change in floral composition immediately following settlement, and relative soil stability, perhaps biased by the open nature of the site being more welcoming to settlers, reducing the need for heavy anthropogenic intervention.

The wetland area within the site appears to have influenced choice to settle at this location on the grounds of wet conditions preventing the encroachment of *Betula* into the flat areas of the site, rather than viewing it as an additional resource to manage intensively. Palaeoenvironmental evidence discussed here points to drainage of this wetland upon settlement of the site. There is no evidence of cultural amendments in the sediments that would indicate intensive management, despite suggestions enclosed spaces within the homefield were used to protect intensively cultivated areas. The open area associated with the wetland was potentially seen as beneficial in that requirement for clearance of dense scrubland and trees would not have been required. This is echoed by the limited presence of charcoal fragments in Landnám sediments. Within the majority of Norse farms a sharp increase in charcoal is found in sediments associated with settlement, as vegetation was cleared by burning to prepare for construction of farms. Following the sites early abandonment, wet meadow conditions were seen to gradually re-emerge on the site, returning over centuries to the current site conditions.

From settlement, wetland sediments at Viðatóft have proved excellent cultural and environmental archives, with site responses to social and environmental changes at the individual farm scale recorded effectively across both pollen and sedimentary data. Responses to tephra deposition are recorded within these sediments, including being found generally to improve drainage conditions on the site, leading to vegetation shifts from wetland to dryland taxa, as well as reducing frequencies of wetland features in sediments at these points. In addition to this, climatic downturns are reflected in both pollen and soils data, with the instability, cooling conditions and increased storminess associated with the Little Ice Age reflected to some extent in pollen and soils. Key responses to these changes were reflected in the soils. An increased presence of aeolian material visible at the microscale reduced organic content and increased sediment accumulation rates, reflect severe erosion in the surrounding region. These patterns were reflected in the pollen data as increases in poorly preserved pollen, suggesting inputs from secondary sources due to erosion. A key association is also observed between the incidence of plague in Iceland and the wetland records at Viðatóft, where vegetation canopies close in, grazing intolerant species reappear, and soils demonstrate accumulations of organic matter associated with increased stability, contemporaneous with plague and associated reductions in population and livestock numbers.

Given the absence of wetland conditions during the farm's occupation, portrayed by soil and pollen evidence, it is suggested the key role of the wet meadow in this study farm was its influence on choice and establishment of settlement site, linked to the site's formerly open nature, as a result of *Betula's* inability to grow in wet meadow soils. In this respect, the site would have required less effort in terms of land clearance for farm establishment, making it attractive to the settler, who on establishment of the farm worked to reduce wetness. Despite this drying of sediments the cultural and environmental records held within them have proved effective throughout the settlement period, allowing for comparisons to be made between changes occurring within the farm and with the wider environment.

Chapter 5 Gautlönd, large natural meadows within a long established farm

5.1 Introduction and Site Description

The Gautlönd farm is the second study site to be located in the Mývatnssveit region. This farm is situated SW of Lake Mývatn, with the main farm buildings and homefields located south of the small freshwater lake Arnarvatn (Chapter 4, Figure 4.1). Despite its close proximity to the initial Mývatnssveit study farm Viðatóft, the longevity of the farm is in contrast to Viðatóft, with Gautlönd surviving and thriving until the present day. It is both a successful and early settled farm, with much of the farm under intensive agricultural use today, and much of the land under farm ownership vegetated, despite widespread erosion in the vicinity. Gautlönd is believed to be an early settled farm. The direct association of the site with pagan burials (human and dog bones radiocarbon dated to 1175-1200±35 cal. BP (*c.* AD 775-750) (McGovern et al., 2007)) suggests that, although written records are absent, the site was among the first settled in Mývatnssveit (Vésteinsson, 2008).

The study farm has the advantage of its close proximity (3km) to lake Helluvaðstjörn, the site of a multi-proxy regional palaeoenvironmental reconstruction for the Norse and Medieval periods in Mývatnssveit (Lawson et al., 2007). This allows comparison between regional pollen signals from Helluvaðstjörn, and the marginally more localised pollen input associated with pollen records from Gautlönd, the latter of which will be more powerful in identifying activity associated with the meadows themselves. It was also selected as a case study in the thesis of Brown (2010), from which geoarchaeological and ethnographical information regarding the past management of the farm, most specifically the homefields, is available. Brown's (2010) ethnographical research revealed farm access to, and past use of, three separate wetland areas: one by the main farm forming a large portion of the homefield, one as part of the shieling and one area in the Framengjar, a periodically flooded marshland, formed on the delta created by the Kráká river (McGovern et al., 2007). The latter area was formerly a less productive meadow, deliberately flooded by the current farmer's grandfather to improve the area for growing grass, where productivity had declined as a result of sands brought in by the river. This area was split into two portions, with one portion used for grazing and the other for hay, swapped each year to maintain fertility. The farmer also mentions the meadow areas were inundated annually on the 17th of June for a period of one month, building many ditches and dams to achieve this effectively; it is unclear from the interview transcriptions which areas this applies to, although there was mention of channels constructed to bring water from a stream closer to the land and homefield. He also states all of these meadows were used for haymaking (Brown, 2010).

Much of the vegetated area is currently used for sheep and cattle grazing, with cattle and horses grazing the areas closest to the modern farm buildings (Figure 5.2). Intensively cultivated hayfields also dominate the area close to the farm buildings; these can be seen clearly in the satellite image (Figure 5.1). The vegetation surrounding the cultivated fields is a mosaic of *Poaceae/Cyperaceae* dominated herbaceous communities with *Potentilla palustris*, *Cardamine pratensis, Equisetum arvense, Bartsia alpina,* and *Koeniga islandica* common throughout, and *Parnassia palustris, Gentiana nivalis*, *Achillea millefolium, Hieracium sp., Gallium sp.,* and *Rhinanthus minor* common in the drier grassy areas. Saturated stretches of mire are dominated by *Carex* and *Eriophorum.* Dwarf shrub communities of *Betula nana, Empetrum nigrum, Vaccinium sp., Salix lanata,* and *Salix phylicifolia* dominate dryer tussocks within the mire as well as other areas surrounding the farm. *Betula pubescens* does not presently exist in the immediate farm area but is noted as occurring on stretches of the rough lava fields the east of Mývatn (Lawson et al., 2007).

Previous research carried out onsite by Brown (2010) provides more information by which to contextualise and interpret the new findings in this thesis. Given the knowledge of active management in the meadows in recent centuries obtained through interviews, we can test whether there is evidence of the cutting and grazing preserved in the palaeoenvironmental records, during this time period and previous to this, making this a key objective specific to this site. Soils and pollen from the meadow sediments will therefore be examined carefully for evidence of disturbance or management, particular attention will be given to three paleo-characteristics of mire mowing outlined by Hallsdóttir (1987):

1) Decreasing LOI
2) Decreasing *Cyperaceae* and *Equisetum* in the pollen spectra
3) No increase in pollen corrosion

These are suggested as being representative of mowing activities. Where mineral content of sediments increases and pollen corrosion does not increase, regular biomass removal is considered to have occurred, preventing its incorporation into sediments and subsequently reducing organic matter. This process can be contrasted with decreasing loss on ignition indicating the input of aeolian or fluvial sediments, liable to bring with them significant quantities of reworked, corroded pollen (Tipping, 2000). Furthermore, when mires are mown it is typically in early summer, before sedges become less palatable as their siliceous content increases, subsequently reducing its usefulness as winter fodder. At this stage flowering of a number of taxa is unlikely to have occurred, subsequently reducing *Cyperaceae* and *Equisetum* in the pollen rain at the site (Hallsdóttir, 1987).

Given the existence of the large, natural meadows associated with the homefield at Gautlönd coupled with the existing research exploring cultural environments associated with the site (Brown, 2010), Gautlönd presents itself as an ideal case study to consider the development, use and management of wet meadows within a long established and successful farm. It will allow exploration of the potential of the wetland sediments in this natural meadow to act as a cultural and environmental archive. To this end the aims outlined in Chapter 1 will be addressed through the development of chronostratigraphies providing a chronologically constrained analysis of the formation and development of meadow sediments through time. Records held within these meadow sediments are then analysed further using pollen analysis and soil micromorphology to investigate the pre-Landnám environment in the farmscapes of Gautlönd. This is used as a baseline measure by which to contrast environmental and cultural changes in vegetation and sediments from the settlement period to the present day. The results will be contextualised using existing archaeological and palaeoenvironmental research.

Figure 5.1 Satellite image of Gautlönd, the areas under intensive management - hayfields and grazing, appear more vibrant green, with clear angular field boundaries. The modern farm and pollen sampling site are marked on the photo (Image Source: Google Earth (Google, 2016)).

Figure 5.2 Cattle grazing in the wetland areas of the homefield (2011), view northwest. The foreground is dominated by wetland species *Hippuris vulgaris* at the edge of the lake Arnarvatn, with grasses dominating elsewhere. Small erosion scars can be seen in the steeper upper slopes, this area has been fenced off to grazing animals.

5.2 Fieldwork and Lithology

With the homefield sediments in the immediate vicinity of the farm dwellings at Gautlönd previously studied by Brown (2010), the decision was made to focus on the meadow area closest to the farm. This allowed cross comparisons between environmental and cultural records from the two areas to be made, where appropriate, evaluating whether any changes were operating at the farm scale, or specific to individual farm elements. An Eijkelkamp gouge corer was used initially to assess the sediment depth, by means of a series of trial borings. Where the deepest sediments were found a short stratigraphical transect was made to explore sedimentary records across the meadow further (Figure 5.3). The stratigraphy shows a general trend for a series of fibrous peats developing across silty and sandy sediments. Sediments are not evenly distributed across the meadow with a great deal of variation in sediment stratigraphy across the meadow. This lack of uniformity is expressed in the tephra deposits across the meadow, many of which are diffuse and difficult to trace within the organic sediments. More easily recognisable tephras also vary, in terms of the thickness of the deposit and depth within each stratigraphical unit. This is likely to be linked to post depositional disturbance or the development of sediments and deposition of tephra on a surface affected by thúfur.

The stratigraphical survey was used to inform suitability of location for the pollen core for the site. The lack of uniformity would generally be regarded as problematic for pollen analysis given the potential for disturbance and influences on pollen accumulation rates in sediments across the mire. However, with previous research carried out on the site and the presence of highly organic sediments suited to pollen preservation, the site can be regarded as an ideal opportunity to use the existing rich oral, documentary and archaeological evidence alongside new palaeoenvironmental evidence in order to satisfy the study aims. Given the depth and organic nature of sediments at point AP (Figure 5.3), as well as its isolation from the functioning and obsolete dams and channels constructed within the meadow which would have the potential to disrupt sedimentary records, this point was selected for coring (N 65^{o} 33.566’ W 17^{o} 7.825’). Two overlapping cores were taken from this point 33-83cm and 54-104cm, as well as a further dug out section (0-32cm), extracted and wrapped separately to compensate for the material lost from the corer in the wet conditions. Sandy sediments from 94cm prevented coring beyond 104cm. Given the mire diameter (c. 200m) and the open nature of the vegetation onsite the pollen source area for the sampled core is liable to include alongside the direct input from mire surface vegetation, a high percentage of regional pollen (*sensu lato* Jacobson and Bradshaw, 1981).

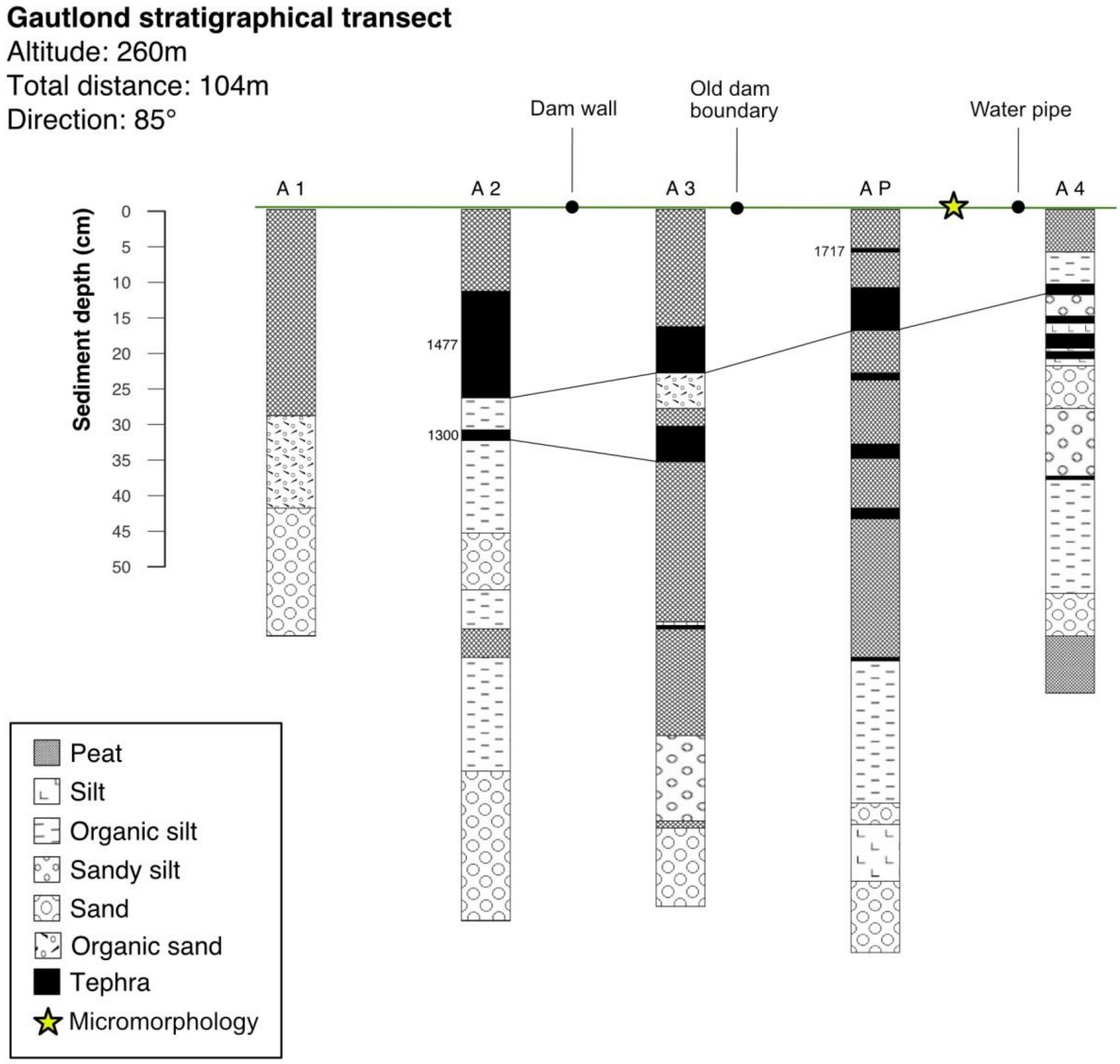


Figure 5.3 A stratigraphical interpretation of the homefield meadow at Gautlönd. A cross sectional transect from the shore of Lake Arnarvatn, across the wet meadow, Pollen (AP) and Micromorphology sample locations presented on the diagram, with micromorphology sample offset from pollen cores to prevent disturbance in wetland system.

Pollen core lithology was expanded and presented in Table 5.1. A total of 76 samples for pollen analysis were extracted from the cores at closely spaced intervals between 1cm and 81cm, sediments are described up to 104cm. Fibrous peat with intermittent tephra and fluvial sand type deposits (possible flood sediments) dominating the top 63cm of the sequence. These intermittent minerogenic inputs are reflected in the fluctuating nature of the loss on ignition values for the core (Figure 5.8). The organic nature of sediment is retained until 83cm although these sediments are predominantly silt based reflected in the overall trend for lower LOI. From 94cm the sediment sampled is exclusively sand.

Six Kubiena tins were extracted from a near continuous profile, culminating at the water table (Figure 5.4), within a soil pit dug in close proximity to the pollen coring site (Figure 5.3), so as to avoid the further disturbance initiated by coring. Sediment stratigraphy is broadly similar to those in the cross sectional diagram (Figure 5.3). The tephra's however do not correspond exactly with those found within the pollen core. Within the soil micromorphology profile the tephra layers lack absolute distinction, appearing diffuse within the stratigraphy. Given the uneven sedimentary characteristic of the meadow area, depths within the micromorphology samples don't correlate exactly with depths in the pollen core. The Veiðivötn 1477 tephra has been used as a key chronological marker to tie the two data sets together.

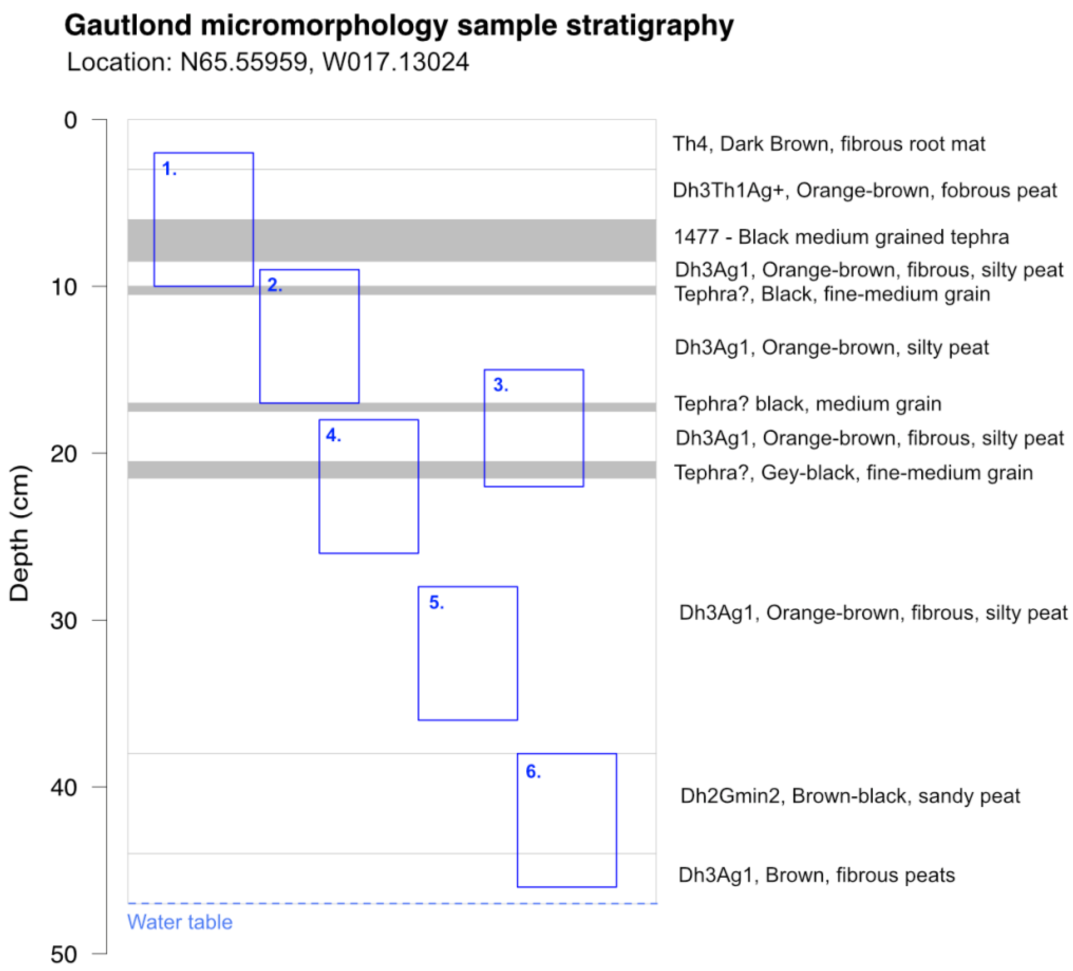


Figure 5.4 Scaled profile drawing of stratigraphy exposed for micromorphological sampling. Tephra marked on the diagram are diffuse in nature.

Table 5.1 Detailed stratigraphical analysis of Gautlönd pollen core sequence.

Depth/cm	Troels-Smith	Unit Description
0-2	Th4	Vegetation and root mat
2-5.5	Dh3Th1Ag+	Dark brown fibrous peat
5.5-6	Gmin4	Grey-black coarse tephra (**Veiðivötn 1717**)
6-11	Dh3Ag1Sh+	Brown fibrous peat
11-17 (diffuse)	Gmin4	Grey-black medium tephra (**Veiðivötn 1477**)
17-23	Dh3Ag1	Brown fibrous peat
23-24	Gmin4	Black med-coarse tephra
24-32	Dh3Ag1Sh+	Brown fibrous peat
33-35	Ag4	Dark grey-black silt (tephra?)
35-42	Dh3Ag1	Dark brown fibrous peat
42-43.5	Gmin4	Coarse black sands (tephra?)
43.5-54	Dh3Ag1	Dark brown/orange fibrous peat
54-54.5	Ag3Gmin1	Black medium grained tephra
54.5-63	Dh3Ag1	Dark brown/orange fibrous peat
63-73	Dh2Ag2	Grey brown silty peat with common organic fragments
73		Wood Fragment, *Betula*
73-83	Sh1Ag3Dh+	Grey brown organic silt
83-86	Gmin3Ag1	Grey black fine sand
86-94	Ag3Gmin1	Grey brown medium-coarse silt
94-104	Gmin4	Black brown fine-medium sand

5.3 Chronology

The chronology of the pollen core is constrained using the two Veiðivötn tephras identified in Table 5.1 – Veiðivötn 1717 and 1477, as well as two radiocarbon dates from the depths 54-55cm and 80-81cm, the later acting as a basal date for the pollen core, given the increased mineral content in sediments and likelihood of poorer pollen preservation below this point. Terrestrial plant macrofossils were extracted from the core at these depths and sent to SUERC for AMS analyses. The radiocarbon dates generated from the samples are presented in Table 5.2.

Table 5.2 Radiocarbon results from the Gautlönd pollen cores. Dates calibrated using INTCAL13 in CALIB 7.0 (Reimer et al., 2013)

Lab Code	Material	Site	^{14}C Age	Error ±	cal BC/AD (±1σ)	cal BC/AD (±2σ)	δ^{13}C (%)
SUREC-62670	Plant macros Sphagnum	Gautlönd core 54-55cm	713	34	AD 1264-1295	AD 1227-1232 (0.8%) AD 1244-1309 (82.7%) AD 1361-1387 (11.9%)	-26.8
SUREC-62674	Plant macros Sphagnum	Gautlönd core 80-81cm	1614	34	AD 396-433 (31.7%) AD 459-467 (4%) AD 489-533 (32.5%)	AD 359-362 (0.4%) AD 381-542 (95.0%)	-30.5

Given the current inability of Bacon to cope with large instantaneous deposits such as tephra layers (Blaauw *Pers Comm*), and the 6cm depth of the 1477 tephra at this site (in the pollen core), Bacon was rejected for the production of the age-depth model for this site. Instead a 'classical method' using Clam (Blaauw, 2010) was adopted, within which 'slumps' may be added to account for deeper tephra deposits. Slumps were added into the model where tephra deposits were over 1cm thick (11-17cm, 23-24cm, 33-35cm, 42-43.5cm), deposits thinner than this were presumed to have little impact on accuracy of the model. Several Clam models were run fitting age depth curves using smoothed splines, polynomial regression and linear interpolation. However these were deemed inappropriate in the case of smooth models because of the variability of sediment accumulation rates in Iceland, due to tephra deposition and landscape instability, particularly after Landnám. Linear interpolation, although useful where changes in accumulation rates occur, should be treated with caution as it makes the assumption that changes in accumulation rates occur at dated points. In this instance the cubic spline model found to be the best fit and is therefore the curve fitted in the final model (Figure 5.5).

The fitted curve passes through most of the data points, with the exception of the Veiðivötn 1477 tephra where dates are plotted as marginally younger. This is thought to be the result of the rapidly increasing sedimentation rate highlighted by the age depth model after the second radiocarbon date (54-55cm) where the curve steepens. Given the vegetated nature of sediments surrounding the point sampled for radiocarbon dating, as indicated by the fibrous nature of peats, there is a small possibility that dates are inaccurate; penetration of roots might have led to percolation of organic material through the soil, producing radiocarbon dates of too young an age and artificially enhancing sedimentation rates. The sedimentary sequence however shows no signs of disruption and there were no obvious signs of root penetration in the core, the dates therefore are presumed accurate (Bunting and Tipping, 2004). Following the deposition of the Veiðivötn 1717 tephra the age depth curve again begins to level out. These changes in accumulation rates produce an 'S' shaped curve in the age-depth model, such patterns have previously been seen in systems with fluctuating sedimentation processes, or when the process of hydroseral succession takes place (Bunting and Tipping, 2004).

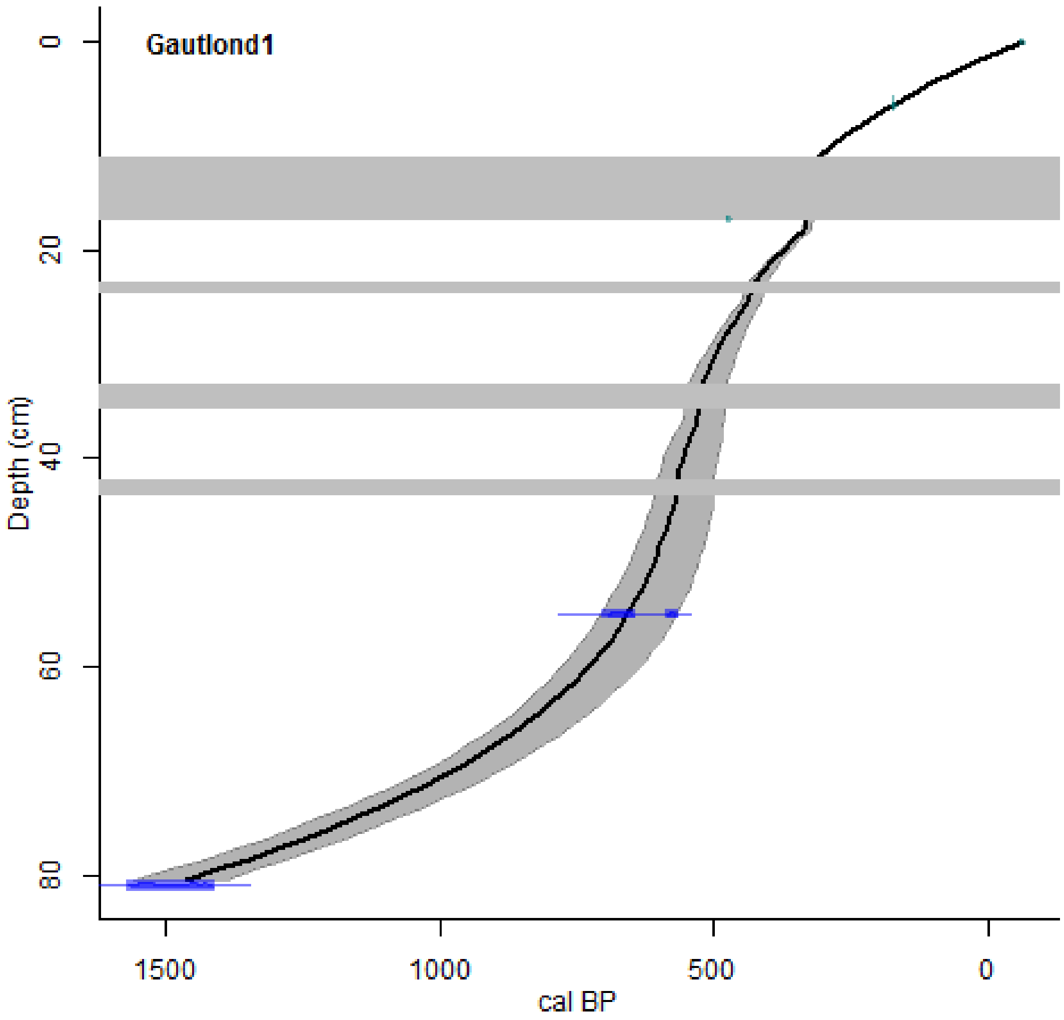


Figure 5.5 Clam age-depth model for Gautlönd with a cubic spline model fitted though the dates. The grey envelope represents 95% confidence intervals, around the weighted mean average as represented by the black line. Grey horizontal lines show 'slumps' representing instantaneous tephra deposits over 1cm.

5.4 Pollen Analytical Results

5.4.1 Zonation and preservation tests

Given pollen sampling in archaeological contexts might be less than ideal for pollen preservation, all pollen data was subject to testing by the series of tests proposed by Bunting and Tipping (2000) for determining likelihood of post depositional biasing. The results of the tests are presented in Table 5.3. The tables shows four of the nine tests performed on the data hold failures for at least one level in the core, points of failure were investigated further to determine whether or not they should be analysed further.

The first failure is found in the test for 'total pollen concentration'. Here a failure is found at only one level (60cm) and fails only marginally, by 118 grains cm^{-3}. No other failures are found at this level and preservation tends to be good, it was decided therefore to include the level in further analysis. A number of failures were highlighted on performing the test for 'number of main sum taxa', albeit only marginally (by 1 or 2 taxa). On further investigation of the failed levels, no cause for concern was identified with failures only marginal. Presence of decay-resistant taxa commonly associated with post depositional loss reducing diversity is minimal. Preservation is good overall, preservation and taxa numbers are typically linked to apparent monocultures of *Poaceae,* particularly between 2cm and 4cm. Such monocultures are commonly associated with human activity (Bunting and Tipping, 2000). Further failures were found within the 'Spore: pollen concentration ratio'. Within each of the levels not passing, high concentrations of the aquatic species *Hippuris vulgaris* were noted. Failures are therefore likely to represent changing conditions and water level onsite, rather than post depositional biasing in the form of contamination or loss of taxa more sensitive to decay. Failures were also noted in the test for 'Spore : pollen taxa ratio', within each of the failed samples margins of failure were very small, with ratios in the failed samples ranging from 0.7 to 0.78, compared to the pass value of 0.66.

Given the obvious explanations for failures or marginal failures of tests, as well as no single sample failing all tests it was decided samples did not suffer post depositional biasing and were of a preservation quality suitable for further analysis. From the data nine separate local pollen assemblage zones (LPAZ) were created, based on local similarities between vegetation communities, using CONISS (Grimm, 1987). Each of these zones – LPAZ 1, 2, 3, 4, 5, 6a, 6b, 6c and 7 were marked on the pollen percentage, concentration and preservation diagrams, providing a means by which to describe community changes and compare sections of each diagram. The entire diagram covers the period *c.* 1491 cal. BP (*c.* AD 459) to the sampling date -61 cal. BP (AD 2011), therefore covering several centuries pre-Landnám, the sites settlement and its entire occupational phase until the present day. The pollen assemblage, for the most part is dominated by ‘dwarf shrubs and herbs’ especially in LPAZ 1-4 and 7, where at no point total percentages of ‘trees and shrubs’ increase beyond 40%. Percentages of trees and shrubs do seem to increase between LPAZ 5 and LPAZ 6c with fluctuating peaks exceeding 40%, grasses and dwarf shrubs do however remain the dominant vegetation type with *Poaceae* and *Cyperaceae* dominating throughout, suggesting a generally open site, supported by the continued presence of significant quantities of light, easily dispersed pollen and spores from *Thalictrum*, *Selaginella*, and *Botrychium.*

Betula is seen to persist in a well preserved state throughout the diagram, grain size statistics were collected for the *Betula* and are presented in Figure 5.6 alongside published values for *Betula pubescens* and *Betula nana* as well the threshold value used for separating the two species at nearby Helluvaðstjörn (Lawson et al., 2007). The binomial shape, that might be expected where two distinct populations are present is visibly absent in many of the density plots. It is widely recognised however, that there is considerable overlap between the two species, especially given the hybridisation of species in Iceland (Karlsdóttir et al., 2007). It should also be noted that grain diameter can change during fossilisation and chemical lab procedures (Mäkelä, 1996), and so in this instance separation will be attempted as a general observation only. Within the site *Betula* diameters appear to encompass published figures for *B. pubescens* and *B. nana* with only minor shifts in the spread of data between the zones, values falling either side of the 20µm threshold set by Lawson et al. (2007) would also appear to shift very little. It is reasonable to suggest therefore both species have existed, in similar proportions, thought the farmscape, from pre-Landnám until the present day.

Table 5.3 Pollen preservation tests based on Bunting and Tipping, 2000, pollen data – Gautlönd.

Test	**Failure Threshold/basis sum TLP or TLP+group**	**Pass (✓/✗)**
Total land pollen sum (TLP)	<300	✓
Total pollen concentration	<3000 grains cm^{-3}	✗ (marginal fail at 60cm = 2882 grains cm^{-3})
Number of main sum taxa	<10	✗ (2,3,4,40cm = 8 sp. TLP; 48,57cm = 9 sp. TLP)
Percentage severely degraded grains	>35%	✓
Percentage indeterminable	>30%	✓
Percentage resistant taxa (e.g. thick walled/robust grains – *Tilia, Caryophyllaceae, Chenopodiaceae, Asteraceae Lactuceae, Artemisia* type, *Brassicaceae*	>6%	✓
Percentage Pteropsida (monolete) indet.	>40%	✓
Spore : pollen concentration ratio	>0.66	✗ (failure 73, 75, 77, 79 and 81cm)
Spore : pollen taxa ratio	>0.66	✗ (Marginal failure 39. 40. 48 and 73cm; ratios 0.7-0.78)

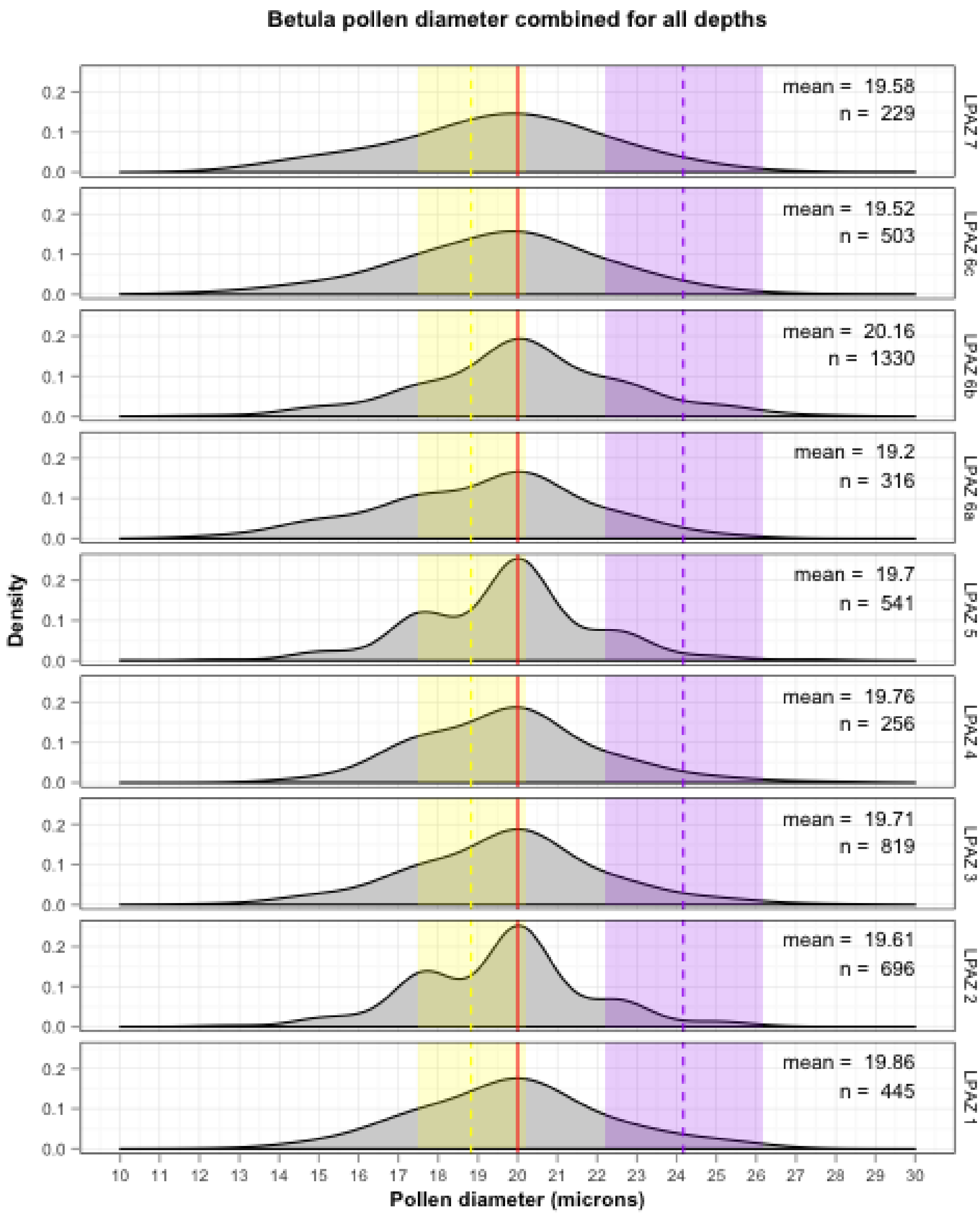


Figure 5.6 Measured diameters (µm) of *Betula* pollen grains for each pollen zone. The yellow dotted line and shaded area represents the mean and standard deviation of published measurements for *Betula nana*, with the purple dotted line and shaded area representing the same for *Betula pubescens* (Values from: Birks, 1968; Caseldine, 2001; Karlsdóttir et al., 2007; Mäkelä, 1996). The solid red line depicts the threshold value (20µm) selected to split species at Helluvaðstjörn (Lawson et al., 2007).

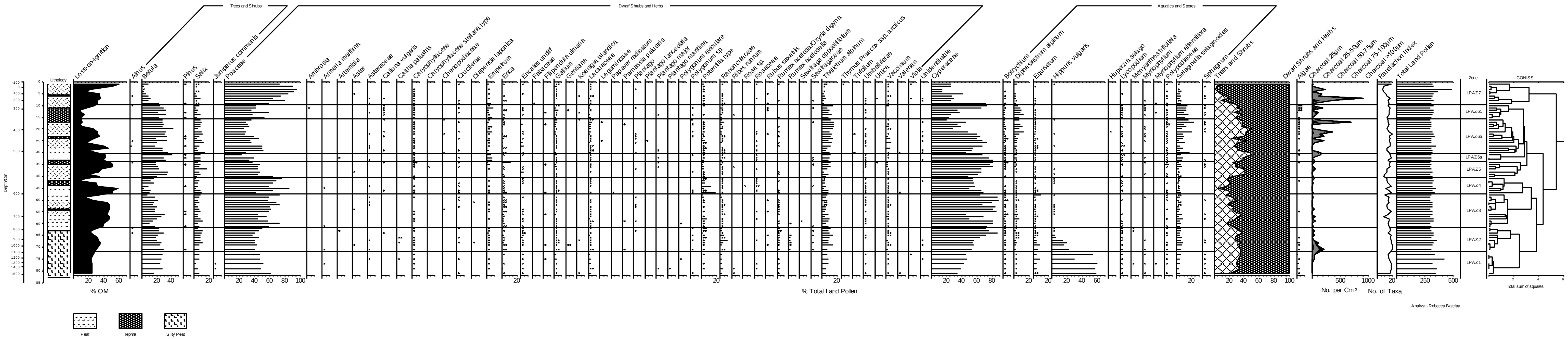


Figure 5.7 Percentage pollen diagram for Gautlönd. The + symbol indicates taxon present at less than 2%. Percentage calculations are based on a sum of total land pollen (TLP) for all terrestrial pollen taxa, and TLP+ *Cyperaceae* and TLP + aquatics and spores, for *Cyperaceae* and aquatics and spores respectively. Lithological components, age in Cal yr. BP, Charcoal concentration/ No. fragments per cm^3 and Rarefaction Indexes/expected species are also presented on the diagram.

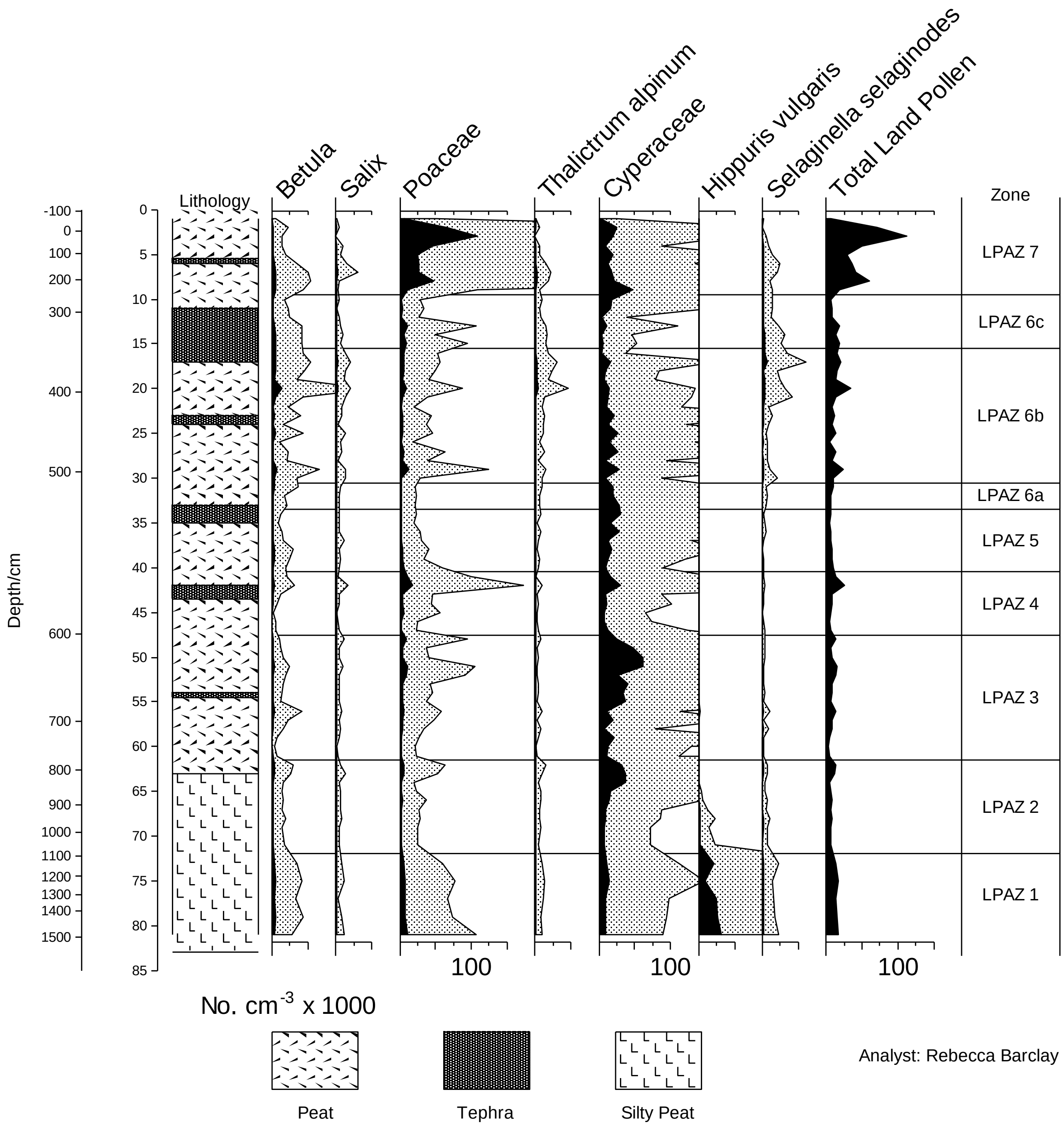


Figure 5.8 Pollen concentrations for selected dominant taxa at Gautlönd.

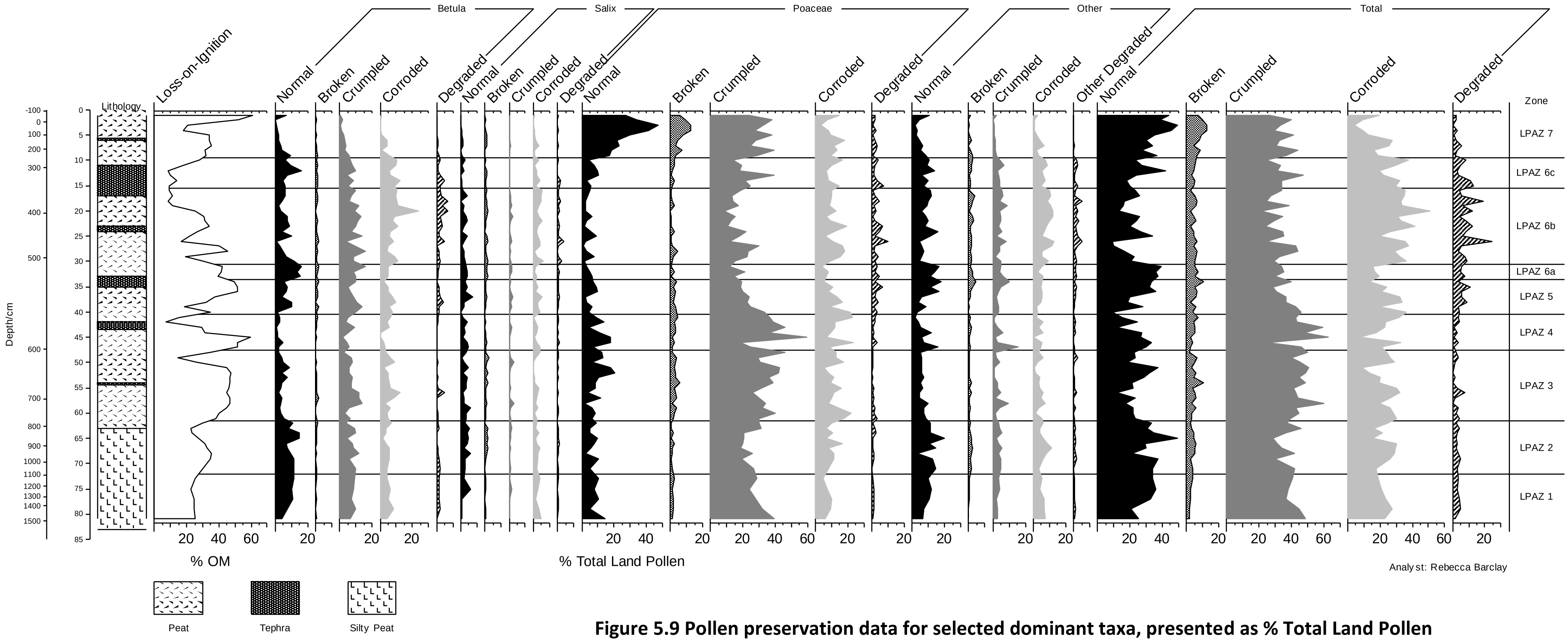


Figure 5.9 Pollen preservation data for selected dominant taxa, presented as % Total Land Pollen for the preservation categories – normal, broken, crumpled, corroded and degraded

5.4.2 LPAZ 1 (*c.* 1091-1491 cal. BP)

LPAZ 1 opens *c.* 1491 cal. BP (*c.* AD 459), continuing until *c.* 1091 cal. BP (*c.* AD 859), thus representing the 400 years prior to Landnám. The zone is characterised by a relative stability in sediments and vegetation communities, with little fluctuation in either of these components. Silty peats, with organic content of approximately 25% accumulate throughout the zone at a rate of approximately 0.23 mm/yr. Sediment accumulation rates for the pre-Landnám zone are therefore the slowest noted throughout the core. The aquatic species *Hippuris vulgaris* dominates the pollen assemblage, with percentages around 60% throughout, with the exception of a fall to 30% around 1250 cal. BP (*c.*AD 700); a decrease represented in both the percentage and concentration diagrams. Following this drop, percentages increase to former levels towards the upper level in the zone. Smaller frequencies of the aquatics *Menyanthes trifoliata* and *Myriophyllum sp.* (<1%), as well as elevated frequencies of algae (1-5%) alongside these high percentages of *Hippuris vulgaris* suggest the presence of permanent standing water.

Cyperaceae, also frequently associated with wet conditions, is present at lower percentages than subsequent zones, although is seen to increase from *c.*35% to *c.*45% from the basal sediments to the upper zone boundary. These *Cyperaceae* spores are potentially recruited from nearby mires, rather than the direct vicinity of the core, the locality of which appears to be submerged at this point. *Equisetum* spores demonstrate high percentages relative to other zones here, with percentages fluctuating between 2% and 9% throughout. *Selaginella* spores also form an important part of the spore assemblages, varying around 4% throughout the zone.

Despite contributing to less of the total terrestrial pollen assemblage (c.30%) than dwarf shrubs and herbs, arboreal pollen makes up a significant portion of the pollen assemblage throughout the zone. *Betula* contributing the greatest percentage, with *c.* 25%, suggesting substantial thickets in the locality. *Salix* forms a lesser, yet significant and constant portion of the assemblage (5-10%), with smaller frequencies of *Juniperus communis* also contributing to the overall arboreal pollen percentages.

Of those dwarf shrub and herb species dominating the terrestrial pollen assemblage, *Poaceae* is the most prevalent within the zone. Percentages range from 45% to 60%, with most levels around 45%. Despite being an important contribution to the terrestrial pollen assemblage for the zone, *Thalictrum, Ranunculaceae, Lactuceae,* and *Gallium* form consistent and significant proportions of the non-arboreal pollen assemblage, with continual presence at low percentages – 5-9%, 2-4%, 2-3%, and 1-4% respectively. The herbs *Rumex acetosa, Caryophyllaceae,* and

Potentilla are also present, but at less significant proportions throughout. Dwarf shrubs *Empetrum, Erica, Ericales,* and *Vaccinium* are noted at low percentages (<2%) throughout. However, when combined and given the entomophilous nature of many dwarf shrub species, it is likely these formed an important part of the surrounding vegetation communities onsite.

Grazing sensitive species are present throughout. With trace levels of tall herbs *Umbelliferae* and F*ilipendula ulmaria* noted periodically throughout the zone. Alongside the aforementioned steady percentages of *Salix*, some species of which are intolerant to grazing, and a constant, but low level of *Sphagnum*.

Within the zone pollen preservation appears consistently good. Assemblages are dominated by normal and crumpled grains, with percentages of around 30% and 40% respectively. Of those grains found to be crumpled, the majority are found to be *Poaceae*, of which raises no cause for concern given its susceptibility to mechanical damage (Tipping, 2000).

Charcoal fragments are absent throughout much of the zone, becoming apparent in the upper levels. Fragments are however from the smaller size fractions (<50µm), and are present at very low concentrations (<50 per cm^3).

5.4.3 LPAZ 2 (*c*.756-1091 cal. BP)

LPAZ 2 encompasses the traditional Landnám time frame. Despite this, there is no obvious, immediate increase in sediment accumulation rates, which remain low at 0.31mm/yr. and no change in the overall vegetation structure within the site, with relative proportions of trees and shrubs, and dwarf shrubs and herbs changing very slightly from the previous zone. However, key transitions are noted within *Cyperaceae,* aquatic and spore taxa groups, species of which are excluded from TLPs sums. *Cyperaceae* is the dominant taxon in the zone, increasing progressively throughout (*c.*55-90%), apparently at the expense of *Hippuris vulgaris,* which despite its dominance in LPAZ 1 reduces significantly to presence levels (<1%) towards the upper part of the zone. Alongside this reduction, moisture tolerant *Equisetum* is seen to fall in percentage from >8% to <1%, and *Myriophyllum* and algae concurrently disappear from the upper part of the zone signifying a switch from an aquatic to terrestrial system. Also mirroring the switch in systems is the organic content of sediments. These predominantly remain silty peat; however LOI demonstrates a fall from a peak of *c.*35% to *c*.25%, corresponding to the decrease in aquatic species. Despite dwindling proportions of aquatic species, increased presence of moisture tolerant terrestrial species, suggest ground conditions remain saturated. *Caltha palustris* appears within the zone (*c*.1%), and percentages of damp loving *Salix* (*c*.5-11%) and *Potentilla* (*c*.1-2%) increase throughout, present at greater proportions than in LPAZ 1.

Overarching the described changes in the proportions of terrestrial species are small, subtle increases in species numbers which can be seen in the rarefaction curve, where modelled total species numbers of >19 are noted within the zone. Despite coincidence with the Landnám period, *Betula* values appear to drop only slightly (*c.*19-29%); this fall is mirrored in the concentration diagram, with concentrations falling to *c.*1375-2925 grains cm^{-3} in comparison to concentrations of up to *c.4350* grains cm^{-3} in LPAZ 1. Increases in the percentages of dwarf shrubs are notable in the zone, with percentages of *Empetrum, Erica, Ericales,* and *Vaccinium* all increasing continuously through the zone, up to *c.*3%, perhaps as a response to decreases in aquatic taxa.

Key changes within the terrestrial pollen assemblage include minor reductions in *Gallium* and *Lactuceae,* relative to the previous zone, with percentages in LPAZ 2 typically <2% in contrast to those >3% in LPAZ 1. *Poaceae* also displays a decrease in relative abundance, falling to *c*.38% in some areas of the zone, a fall mirrored by the contracted concentrations of *Poaceae* in the same zone in Figure 5.7. Species associated with anthropogenic related activity, such as disturbance and grazing are seen to increase within the zone, including *Polygonum* sp., *Rumex acetosa*, *Rumex acetosella/Oxyria* (absent from the previous zone), *Thalictrum,* and *Selaginella*. However, at the same time grazing intolerant species, *Sphagnum, Umbelliferae, Filipendula ulmaria,* and *Salix* maintain presence within the zone.

Pollen appears similarly preserved to that in LPAZ 1, with normal and crumpled pollen dominating the assemblage, again with *Poaceae* as the biggest contributor to the overall crumpled percentage. At *c.*900 cal BP (*c.* AD 1050), approximately 100 years after Landnám, a peak in corroded pollen (30%) is noted, again this is predominantly from increases in corroded *Poaceae.*

Charcoal is found to increase within the zone, peaking at the base of the zone (>200 per cm^3), with fragments largely 25-75µm. This peak drops to lower levels after 150 years; charcoal however remains present at low levels throughout.

5.4.4 LPAZ 3 (c. 593-756 cal. BP)

This zone is characterised by a change in sediments from silty peats to peats, highlighted by the increasing LOI to around 45% for much of the zone. LOI does drop sharply towards the upper zone boundary, likely a mismatch between LOI calculations and the tephra identified within the zone. With this change in sediment type, an almost threefold increase in SeAR to 0.86 mm/yr is seen in the zone. Pollen preservation is similar to that in LAPZ 1 and 2, with a small peak in degraded pollen evident *c.*700 cal BP (*c.* AD 1250) (>5%).

The overall pollen assemblage is similar to that of the previous zone, with dwarf shrubs and herbs dominating. Trees and shrubs appear at slightly lower frequencies, fluctuating around 20%, although more defined peaks and troughs are noted within the zone. *Betula* is found to drop to *c.*10% at the lower boundary of the zone, and again towards the upper boundary (<10%). Returning to percentages similar to previous zones between these dips. Of note is a sharp increase in *Betula c.*700 cal BP (*c.* AD 1250), where percentages increase to 30%. This is mirrored by an increase in *Betula* concentration, as well as a small peak in degraded *Betula* (5%), the key contributor to the aforementioned peak in overall pollen degradation. With the initial dip in *Betula,* increases are seen in both *Poaceae* and *Cyperaceae*; the latter dip however is mirrored by an increase only in *Poaceae*, with *Cyperaceae* percentages and concentrations falling, coincident with *Betula.* This later dip can also be correlated with the rapidly decreasing LOI, at the upper zone boundary. *Cyperaceae*, despite periodic downturns appear to be the most dominant taxa, with percentages over 90% and the highest concentrations (>61,000 spores cm^3 year). This is most likely as a result of direct input of pollen, from plants growing on the mire surface. *Poaceae* dominates the land pollen component, with percentages and concentration increasing from the previous zone.

The zone demonstrates a more definitive transition from an aquatic to a terrestrial system with aquatics *Hippuris vulgaris* and *Myriophyllum* as well as algae present only sporadically throughout, and at low percentages (<1%) when present. This near absence of aquatics continues throughout the rest of the pollen assemblage.

All other taxa exist in similar quantities to LPAZ 2. Strong presence of dwarf shrub communities prevails, as do herbs of varying tolerance to moisture and grazing. Charcoal fragments fluctuate at low concentrations throughout the zone.

5.4.5 LPAZ 4 (*c.* 565-593 cal BP)

This short zone covers a time period of only 39 years. Sediments within the zone are characterised by a tephra deposit amongst organic sediments, with a sharp increase in SeAR to 2.5 mm/yr. Prior to this deposit, LOI indicates sediments are amongst the most organic within the core, with percentages reaching around 55%. This high LOI is reflected in the preservation diagram, with more well preserved pollen found in these highly organic sediments. Conversely, corroded pollen increases where the tephra is visible in the lithology. A background signal of charcoal is visible, fluctuating at low concentrations throughout the zone.

The zone presents a shift to a more dwarf shrub and herb rich pollen spectra, especially around 45cm where percentages of trees and shrubs make up just over 5% of the total land pollen. This is the result of a sharp drop in *Betula* pollen to >4%, with *Betula* concentration also falling at this point, giving way to an expansion of *Poaceae* (*c.*86%). *Betula* percentages do recover after this point, but remain below 16%.

Generally the zone is characterised by an overall fall in percentages and concentrations of *Cyperaceae* (*c.*50-69%, .*c.*6500-16,000 grains cm^3), and generally increasing *Poaceae* (*c.*42-86%, *c.*2250-17,300 grains cm^3). Another key change in the pollen spectra is the increase in *Potentilla* throughout. Percentages increase up to >19%, at the opening of the zone, at the apparent expense of *Poaceae*, with the species present in substantial quantities throughout the zone. *Potentilla* percentages reduce again towards the upper zone boundary, following the tephra deposit in the zone. *Poaceae* is shown to increase again at this point (>75%).

5.4.6 LPAZ 5 (*c.* 526-565 cal. BP)

Following its decline in the previous zone, *Betula* initially demonstrates a recovery in the short zone (~39 years) LPAZ 5, with percentages increasing to *c.*35%, emulated in the *Betula* concentrations for the same point. *Salix* also expands within the zone, with peak percentages (>17%) following the initial rise in *Betula.* Together, these expansions increase overall percentages of trees and shrubs, forming >40% of the total pollen assemblage for part of the zone. Associated closing of the canopy creates an apparent reduction in species richness, indicated by the drop in the rarefaction curve at this point. Along with the general decline in species richness, several of the grazing sensitive species appear to have disappeared or become less prominent in the spectra earlier in the zone – namely *Salix*, *Filipendula ulmaria, Umbelliferae, Sphagnum,* and *Empetrum.* Conversely, the signal for more grazing tolerant species remains persistent – *Gallium, Ranunculaceae, Rumex acetosa, Thalictrum, Equisetum,* and *Selaginella.*

Following spikes in their populations *Betula* and *Salix* do decline once more (from 37cm), with an apparent replacement by the expansion in dwarf shrubs – *Empetrum* (2-4%) *, Erica* (>12%)*, Calluna* (<1%) and *Vaccinium* (3%)*,* and herbs *Caryophyllaceae* (*1-2%), Potentilla* (2-3%)*, Ranunculaceae* (0.5-2%)*, Cyperaceae* (*c.*80%)*, Botrychium* (>1%)*, Diphasiastrum* (1-3%)*, Equisetum*

(1-2%), *and Selaginella* (2-8%). Expansions across these dwarf shrubs, spores and herbs consummate in increased species richness, with rarefied species counts increasing to >15. These latter vegetation shifts occur, in approximation with the tephra deposit in the zone.

Apparent rapid peat development produces a continuing high SeAR of 1.79 mm/yr. No preservation issues are noted in accordance with this, with pollen predominantly well preserved throughout. Peaks in corrosion do occur (30-35%), within the bottom half of the zone, mostly due to contributions from corroded *Poaceae* (13-20%), following tephra deposits in the previous zone. Crumpled *Poaceae* also makes a substantial contribution to total crumpled pollen in the first half of the zone, with percentages 35% and 45% respectively. Again charcoal fluctuates at low concentrations throughout the zone.

5.4.7 LPAZ 6a (*c.* 511-526 cal. BP)

The shortest zone in the sequence, LPAZ 6a comprises ~15 years. Within the zone, SeAR remains relatively high at 2 mm/yr. and sediments appear increasingly organic with peats increasing in LOI to over 40%, a factor likely linked to the predominantly well preserved pollen in the zone.

Cyperaceae continues to dominate the assemblage as it fluctuates between 67% and 82%. Key shifts in the vegetation assemblage include a further resurgence of *Betula* (30-40%), increasing the overall tree and shrub percentages in the assemblage up to 45%. *Poaceae* again declines in importance in the zone, decreasing to between 22-38%, with reductions also shown in concentrations (down to between 2000-2300 grains cm^{-3}). *Empetrum* appears to be one of the key beneficiaries of the decreasing *Poaceae*, with percentages increasing to 6-8%. *Gallium*, *Ranunculaceae, Potentilla, Thalictrum, Diphasiastrum,* and *Selaginella* remain stable and key components of the pollen spectrum.

Charcoal is present throughout, with concentrations, particularly of smaller fragments, peaking at the upper zone boundary, at around 150 fragments/cm.

5.4.8 LPAZ 6b (*c.* 335-511 cal. BP)

Within LPAZ 6b, trees and shrubs maintain a significant proportion of the pollen assemblage, with up to >40% of the total pollen assemblage linked to arboreal pollen at some points. Despite this, non-arboreal pollen continues to dominate, with this dominance mainly linked to *Poaceae.* Despite its exclusion from the TLP sum *Cyperaceae* also continues its dominance within the zone.

Despite their prevalence, *Cyperaceae* and *Poaceae* numbers fluctuate throughout this zone, with links often noted between these and arboreal pollen. Initially percentages of *Poaceae* and *Cyperaceae* are relatively low, *c.*29% and *c.*47% respectively, with high percentages of *Betula* and *Salix* visible at the same time, *c.*35% and *c.*14%. *Poaceae* then expands rapidly (>50%), reflected in the concentration for the same point (*c.*12, 500 grains cm^{-3}) with *Salix* declining to *c.*5%, and *Betula* maintaining relatively high proportions (~27%). *Cyperaceae*, despite increasing, does so much more slowly, lagging behind the increases in *Poaceae*. At *c.* 466 cal BP, *Cyperaceae* (>73%) and *Salix* (13%) show expansions in populations, at the expense of declining *Poaceae* (35%) and *Betula* (20%). Relative proportions of *Betula* again increase, peaking around 43% *c.*393 cal BP (*c.* AD 1557), where it becomes the dominating species in the assemblage, after which point percentages level out to 27-29%. Where the prominent *Betula* peak occurs, peaks in corroded *Betula* also occur, with >20% of all *Betula* in the sample corroded.

Dwarf shrub communities continue to prevail throughout, with substantial presence of *Empetrum* (<1- 7%), *Erica* (<1->3%), *Ericales* (<1-*c.*4%), and *Vaccinium* (<1->6%). Herb communities persist in similar quantities as the previous zone. *Polygonum sp.* and *Rumex acetosella/Oxyria* do appear to reappear and expand however, particularly within the upper half of the zone. Spores of *Botrychium* (<1-4%), *Diphasiastrum* (<1-12%), *Polypodiaceae* (0.5-2%), and *Selaginella* (8-23%) also demonstrate expansions here.

With the deposit of the Veiðivötn 1477 tephra towards the top of this zone, *Cyperaceae* falls from 46% to less than half its former percentage (20%). *Potentilla,* like *Cyperaceae* also found present in moist habitats, is seen to decline and disappear at this point. LOI mirrors these changes, falling to around 10% toward the top of the profile, as the tephra is incorporated into the peaty sediments. SeAR has fallen within the zone to 0.8 mm/yr.

Charcoal concentrations demonstrate great fluctuation within this zone, and are present at higher concentrations than previous zones. A notable sharp peak of >600 fragments cm^{-3} is found, coincident with the bottom of the Veiðivötn 1477 tephra deposit.

5.4.9 LPAZ 6c (*c.* 275-335 cal. BP)

The pattern of low percentage *Cyperaceae* continues into much of this zone. Recovering to its former extent (>70%) only towards the upper zone boundary, a point where tephra deposits give way to peat sediments, and LOI increases to 30%. Alongside this expansion *in Cyperaceae*, Algae reappears in the spectra, at percentages >1%. *Empetrum* also demonstrates a recovery for much of this point, increasing to 9% of the TLP, from <1%. Grazing sensitive species *Filipendula ulmaria* and *Umbelliferae*, in contrast to their presence lower in the zone, disappear from the assemblage when *Cyperaceae* re-expands. *Poaceae* instead dominated the initial depths in the zone (Up to 58%), before contracting to 36-41%, highlighted by a fall in concentration (4875-10756 grains cm^{-3} to 2700-3300 grains cm^{-3}).

Arboreal pollen continues to prevail throughout the zone, with *Betula* continuing to contribute the greatest proportion of this, remaining significant at 22-33%. Throughout the zone *Selaginella* and *Diphasiastrum* become increasingly more important parts of the assemblage (9-16%, 4.5-12%), and *Thalictrum, Ranunculaceae, Lactuceae, Gallium,* and *Caryophyllaceae*, continue to act as important contributors to the spectra. Charcoal is present throughout, and SeARs are similar to the previous zone (1 mm/yr.).

5.4.10 LPAZ 7 (*c.* -61-275 cal. BP)

The penultimate zone, LPAZ 7 shows a substantial shift in vegetation, with trees and shrubs, forming a very small proportion of the total pollen assemblage (<10%) by the present day. The key driver in this shift is the rapid disappearance of *Betula*, falling from *c.*25% at the lower zone boundary, to *c.*8% at the top, and as low as 1% in places. Formerly significant proportions of *Salix* are now also <8%. Arboreal species are not the only ones affected, with significant declines across all species in the zone, and disappearance of *Umbelliferae* and *Filipendula ulmaria*. The only apparent beneficiary of this is *Poaceae*, which is present as something of a monoculture (65-96%) throughout the zone, increasing up to 108500 grains cm^{-3}. Percentages and concentrations of *Poaceae* are highest following the deposit of the Veiðivötn 1717 tephra, *Cyperaceae* drops to exceptionally low values here (14-15%), as do other moisture tolerant species, with *Salix* reducing to < 2%, *Potentilla* <1% and *Sphagnum* and aquatics disappearing from the spectrum.

Of note is the sharp increase in charcoal concentration within the zone. Total charcoal peaks *c.*200 cal BP (*c.*AD 1750), with around 9000 fragments cm^{-3}, significantly higher than in any of the previous zones and is continuously present throughout. Sediments retain the organic peaty characteristics of the zones preceding LPAZ 7, with LOI increasing from around 40% to >60%, dropping to <20% in association with the Veiðivötn 1717 tephra incorporated in the zone. SeAR's fall further in the zone, to 0.28mm/yr., only slightly greater than pre-Landnám rates of 0.23mm/yr.

5.5 Micromorphology Results

5.5.1 Slide production and analysis

Micromorphological analysis of the six thin sections prepared from meadow sediments was intended to advance knowledge on anthropogenic, environmental and pedogenic processes operating within the meadow. Given the inconsistencies between sediments in the meadow area, no absolutes dates are known for the samples. Sediments pre and post AD 1477 (473 cal. BP) can be assessed based on the presence of the Veiðivötn tephra in sample 1. With the diffuse nature of tephra in the micromorphology stratigraphy, direct comparisons between micromorphology and pollen samples were not possible. Focus on pre-1477 sediments will therefore be analysed in general terms. It is assumed however, given consistencies in sediments between the dated pollen core and sedimentary sequences within the micromorphology stratigraphy section, that all samples were taken from post Landnám sediments. Pre-Landnám sediments (according to radiocarbon dates and age depth modelling) within the pollen core demonstrate a tendency towards more minerogenic sediments, with highly organic sediments accumulation on top of these, a pattern visible across the site (Figure 5.7). Tins extracted for micromorphological analysis are taken from similar organic sediments, slightly offset from the pollen core supporting these assumptions. Results from the thin section analysis are summarised in Table 5. 4, with the key features described further.

Table 5.4 Micromorphology results – Gautlönd

Thin Section Sample	Microhorizon (Fibric/ Hemic/ Sapric/ Biosilicate)	Micro-Structure	Organic Material: Cell Residue	Organic Material: Parenchymatic	Organic Material: Fungal Sclerotia	Organic Material: Amorphous (light Brown)	Organic Material: Amorphous (brown)	Organic Material: Amorphous (black)	Siliceous Features: Phytoliths	Siliceous Features: Diatoms	Coarse Mineral material >63 µm: Igneous Rock	Coarse Mineral material >63 µm: Tephra (deposit)	Coarse Mineral material >63 µm: Light volcanic material	Coarse Mineral material >63 µm: Dark volcanic material	Coarse Material Arrangement and Sorting	Fine mineral material	Groundmass b fabric	Cultural Materials: Bone	Cultural Materials: Turf fragments	Cultural Materials: Charcoal	Cultural Materials: Rubified minerals	Pedofeatures: Amorphous crypto-crystalline	Pedofeatures: Calcium Spherulites	Pedofeatures: Stone Rims	Pedofeatures: Silt Coatings	Pedofeatures: Excrement (mamilate)	Pedofeatures: Excrement (spheroidal)
1	A Hemic	Spongy, granular, crumb		···	*t*	·	··		*t*	·	*t*		··	··	Random, well sorted	··· brown organo mineral	Speckled					··				··	··
	B	Compact, intergrain microaggrgate		·	*t*	*t*	*t*			*t*	·		···	···	Random, well sorted	·· brown organo mineral	Speckled					·					
2	A Hemic	Compact, spongy, lenticular		···	*t*	*t*	··		*t*	··	*t*		··	··	Random, well sorted	·· brown organo mineral	Speckled			··		·				*t*	*t*
	B	Intergrain microaggregate, single grain		·			*t*			*t*	*t*	····	····	··	Random, well sorted	*t* brown organo mineral	Speckled					*t*					
3	Hemic	Spongy, lenticular		····	*t*	·	··		*t*	··			··	··	Random, well sorted	··· brown organo mineral	Speckled			*t*	*t*	·				*t*	·
4	Hemic	Spongy, lenticular		····	*t*	*t*	··		*t*	···	*t*	*t*	··	··	Random, well sorted	·· brown organo mineral	Speckled				*t*	···					*t*
5	Hemic	Spongy, compact		····	*t*	*t*	··			···			··	··	Random, well sorted	··· brown organo mineral	Speckled					··					*t*
6	A	Spongy, compact	*t*	····	*t*	*t*	··			··	··	····	··	··	Random, well sorted	·· brown organo mineral	Speckled					··					*t*
	B	intergrain microaggregate		··			*t*			·			···	···	Random, well sorted	··· grey brown mineral	Speckled					·					

Frequency class refers to the appropriate area of section (Bullock *et al.* 1985)
t Trace · Very few ·· Few ··· Frequent/common ···· Dominant/very dominant

5.5.2 Sedimentary records post settlement – Veiðivötn 1477

Throughout much of this analysed section of the stratigraphy (thin section samples 2-6), samples are dominated by the presence of poorly decomposed organic material, mostly hemic in nature, with parenchymatic tissues frequent-very dominant within the majority of microhorizons. The peaty nature of these sediments is expressed in the spongy microstructures noted throughout the sections. Few (5-15%) amorphous brown organic materials are also noted throughout the samples, with the exception of microhorizons 2B and 6B where only traces are accounted for, indicating some decomposition of the organic material. High frequencies of poorly decomposed organic matter are common within Icelandic profiles, due to restricted breakdown under cryic conditions (Stoops, 2007; Stoops et al., 2008). Lenticular microstructures, found in samples 2, 3 and 4, back up this observation given their frequent association with freeze thaw activity and cryic conditions (Romans et al., 1980; Stoops, 2007).

Lack of decomposition is likely also linked to a near absence of faunal activity in the samples, with excremental pedofeatures only visible at trace levels throughout, and one occurrence of 'few' spheroidal excremental pedofeatures within sample 3. Fungal sclerotia are also limited in presence throughout, consistently found only at trace levels. Diatoms on the other hand are generally more prevalent throughout this section, with few to frequent occurring in most microhorizons (2B and 6B exceptions). Together these features are indicative of saturated soil conditions (Bouma et al., 1990), demonstrated further by the presence of amorphous crypto crystalline pedofeatures throughout – iron based features as the result of redox processes associated with periodic waterlogging.

Mineral materials are generally well distributed throughout. There are no areas of concentrated aeolian minerals, or microhorizons composed entirely of aeolian minerals. These are commonly associated with intense wind-blow events and so their absence highlights relative stability within the meadows during this time period. These observations are further supported by the speckled nature of the groundmass b fabric, demonstrating no stratification of minerals which might be linked to one off events. Tephra materials are generally randomly distributed throughout the sediments, few-frequent in occurrence, with tephra materials incorporated into sediments as parent material and windblown additions of tephra fragments, giving the appearance of typical histic-andosol sediments (Figure 5.10,A). Despite several tephra layers noted within Figure 5.4, these are not present as clearly defined bands in the thin sections, and are instead more dispersed throughout sections, suggesting some localised mobility of tephra following deposition.

Tephra materials are more concentrated within microhorizons, 2B and 6B, where they comprise up to over 70% of the sedimentary structures, creating the aforementioned muted presence of diatoms and organic matter within these microhorizons. 6B is particularly dominated by mineral materials with common-frequent grey brown fine mineral materials also reported for the microhorizon. Pedoturbation of fine mineral materials, linked to previously cited freeze thaw activities, is also seen in the section, with tephra and fine mineral material seen to fill pore spaces in samples 4 and 5, a feature typical with cryoturbation of Icelandic sediments (Romans et al., 1980).

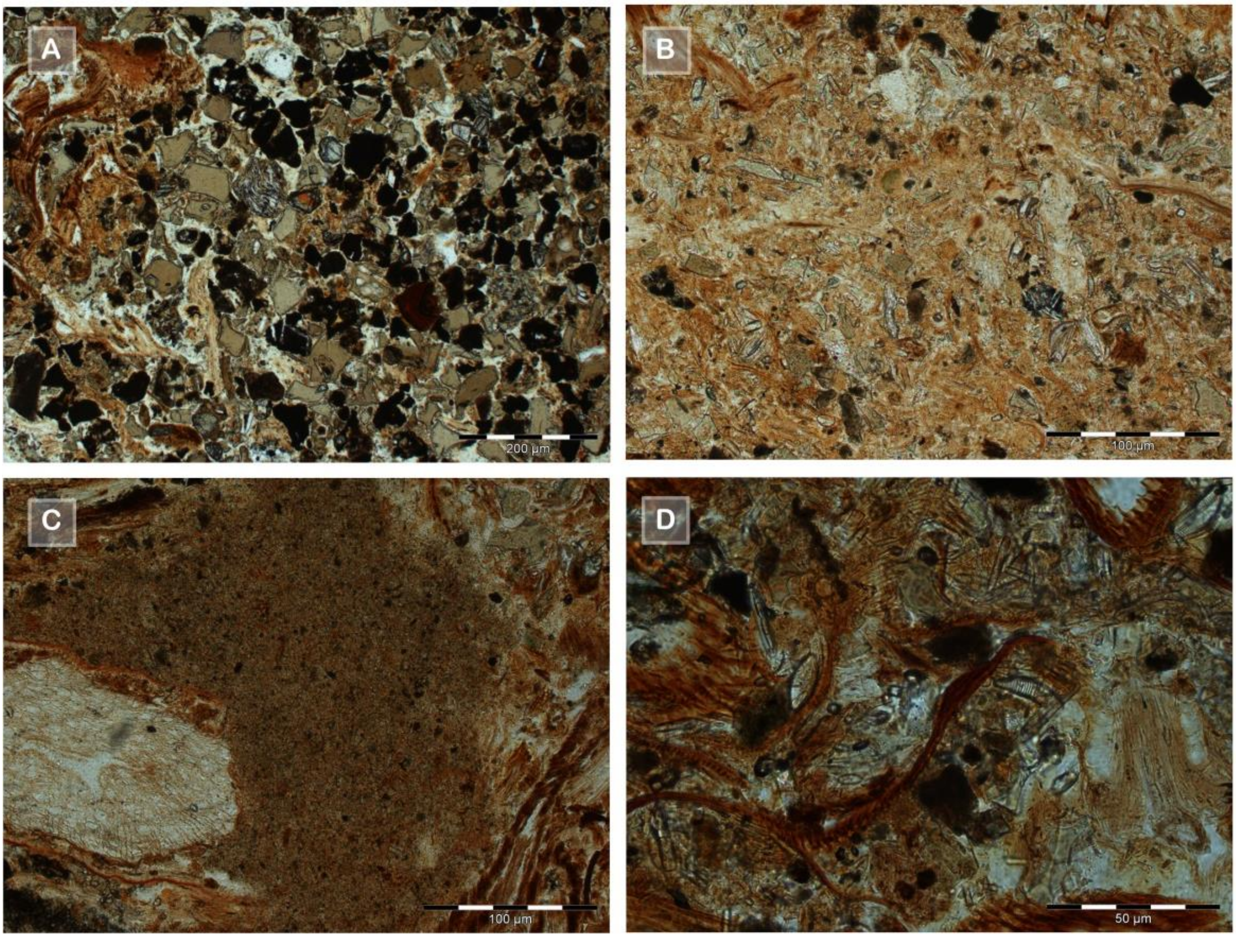
Cultural materials are limited within the section, with only traces of rubified minerals in samples 3 and 4, traces of charcoal in sample 4, and an increasing occurrence of charcoal in sample 2A, where few charcoal fragments are visible in the matrix. This increase is particularly linked to a disturbance feature (Figure 5.10, C), which given the increased quantities of charcoal is likely anthropogenic in nature. Here the movement of fine material into pore spaces, similar to that in samples 4 and 5, can be seen. No other features commonly associated with settlement are noted in the samples, suggesting no direct inputs, such as manuring materials, to sediments in the sampled section.

Combined, these observations suggest rapid accumulation of organic matter which along with restricted decomposition due to wet and cold conditions, were the dominant soil forming processes throughout this period. High SeARs up to 2.5 mm/yr. are noted. Aeolian and tephra deposition also provide minor contributions; however, given their uniform distributions throughout the sediments, environmental conditions are considered relatively stable.

5.5.3 Sedimentary records post Veiðivötn 1477

The lowermost microhorizon (1B), within sample 1 comprises much of the Veiðivötn 1477 tephra materials (Chapter 2, Table 2.2), along with a limited number of heavily iron stained tephra fragments, likely the product of wider erosion and blown into the meadow sediments at Gautlönd. Above this (1A), sedimentary conditions remain similar, with organic materials, particularly parenchymatic tissues, continuing to dominate. However, a reduction in diatoms (very few) suggests less saturated conditions, with subsequent increases in biological activity leading to an increase in excremental pedofeatures (few mamilate, few spheroidal) and associated granular and crumb microstructures. Following the Veiðivötn 1477 deposition no further cultural materials are noted within the sediments.

Continuing input and biological working of organic materials within the sample, points to continuing vegetation cover and landscape stability within the meadows, despite the slight drying of sediments. Aeolian input is therefore a minor soil forming process in relation to organic matter accumulation and degradation.



A) Gautlönd 1 (2-10cm), B. Tephra fragments (PPL)
B) Gautlönd 2 (9-17cm), A. Typical histic andosol (PPL)
C) Gautlönd 2 (9-17cm), A. Fine materials and charcoal accumulating and compacting in pore space - disturbance feature (PPL)
D) Gautlönd 4 (18-26cm). Parenchymatic organic material and diatoms (PPL)

Figure 5.10 Key micromorphological features in Gautlönd thin sections.

5.6 Discussion

5.6.1 The Pre-Landnám environment at Gautlönd (LPAZ 1)

Pre-Landnám conditions, revealed by pollen analytical results, are suggestive of a site with an expansive open and wet valley floor in the 400 years prior to the arrival of the Norse, presenting the vision of a landscape differing from the *Betula* dominated lowlands across Iceland at this time. Dominance, via high autochthonous pollen input, of the aquatic species *Hippuris vulgaris* along with enhanced frequencies of algae signifies localised standing water. This indicates the former extent of Lake Arnarvatn was more expansive than at present. Wet sedge mires were likely to have surrounded the more expansive lake, given the associated high frequencies of *Cyperaceae* observed. Natural dry grass meadows would have occupied the freer draining areas of the site, and perhaps within the wider landscape, highlighted by the extensive frequencies of *Poaceae*, and species characteristic of dry meadows - *Gallium, Lactuceae, Thalictrum,* and *Ranunculus.* The extensiveness of these mires and grasslands, as indicated by the pollen spectra, suggests the locality was relatively open in character, as opposed to the dense and shrubby habitats described in Íslendingabók.

Despite prevalence of grass meadows and mires, trees and shrub vegetation were also important components of the habitat at Gautlönd. Heathland vegetation in particular, is likely underrepresented in the pollen diagrams given its entomophilous nature, leading to low pollen production (Rymer, 1973). Species such as *Arctostaphylos uva-ursi*, common in the surrounding area today are also present in the pollen records (Lawson et al., 2007) suggesting heaths were potentially more extensive and species rich than suggested by the pollen records for the site. These shrubs likely occupied drier edges of the site, or drier hummocks (thúfur) within the wetland area surrounding the lake. The extent of the lake and surrounding sedge mires pre-Landnám, giving rise to wet and waterlogged conditions, provides unsuitable habitat for moisture intolerant *Betula* (Hallsdóttir, 1990). *Betula* woodland or scrub is therefore likely to have existed on the drier site edges, as well as entering the pollen spectra through long distance transport. Given the relatively high *Betula* frequencies, comparable with those at nearby Helluvaðstjörn (Lawson et al., 2007), it is likely to have existed in substantial thickets within the locality.

Betula present around Gautlönd is seen to be from a relatively stable population, based on few fluctuations in the pollen data within LPAZ 1. Similar long term stability, as well as the aforementioned similar frequencies, is noted within Helluvaðstjörn, indicating perhaps an even coverage of *Betula* across the region. A slight peak in *Betula* is noted in the zone. However, given application only to the lower most sample, it is unknown whether this is part of longer term increases or fluctuations, or if perhaps changes are an artefact of error limits in the data. Despite widespread declines demonstrated in most diagrams, similar *Betula* increases have been noted elsewhere in the centuries prior to Landnám. These patterns prevail predominantly in the south, with Páhlsson's (1981) research at Landeyjar in Lágafell (South Iceland) showing an expansion of *Betula* between 1600 and 1050 yr. BP, and Erlendsson and Edwards (2009) also noting a final pre-settlement expansion in sites in south and west Iceland across the 300 years prior to settlement. In these instances the expansions were linked to short term climate amelioration, favouring thermophilous *Betula*, leading to improved flowering conditions and denser coverage. If a pre settlement expansion did occur at Gautlönd, it did not continue into the centuries immediately prior to Landnám, with populations stabilising around AD 500 (*c.*1450 cal. BP).

With the exception of this minor fluctuation, the zone is characterised by a relative stability in vegetation cover, with no major shifts or disturbances in the habitats noted across the 400 years prior to Landnám. This stability is echoed within the sediments at the site. The sedimentary record within LPAZ 1 is characterised by silty peats accumulating at lower rates than any other zone. No micromorphological samples are available to verify these sedimentary records. However, comparably low rates are noted for the Gautlönd homefield by (Brown, 2010) (albeit higher values given different sedimentary conditions) for the period *c.* 550 BC (*c.* 2500 cal BP)-Landnám, suggesting stable conditions across the site at the time.

Gautlönd, with its open nature prior to Landnám, characterised by extensive grasslands and mires, would have been viewed by potential settlers as attractive because of its grazing and fodder production potential (Vésteinsson, 1998). It can be said with confidence that the site character differed markedly from that which is traditionally associated with pre-Landnám Iceland. Shrubs and grazing intolerant taxa formed only a small part of the vegetation assemblage here, again this would have been attractive to settlers, requiring less effort to clear the land before setting up of farmsteads. Woodland was however available within the locality, providing a further easily accessible resource.

5.6.2 Impacts of Landnám? (LPAZ 2)

From Landnám a shift in the vegetation dynamics of the site is noted in the pollen spectra. The key palynological shift here however, is not that that traditionally associated with Landnám. The most prominent vegetation change instead represents a hydrological shift and the terrestrialisation of Lake Arnarvatn, with the aquatic species *Hippuris vulgaris,* which dominates

LPAZ 1, gradually declining and disappearing within LPAZ 2, decreasing rapidly around AD 1036 (945 cal. BP), some 100 years following settlement. *Hippuris vulgaris*, would have formerly appeared as a band of tall vegetation surrounding the shallow perimeter of the lake, as is the case presently (Figure 5.2), suggesting the terrestrialisation was of the scale of tens of metres square. This contraction in the former extent of the lake is also supported by the coincident disappearance of algae and *Myriophyllum sp.* Cyperaceae would appear to be the taxa benefiting most from this decline, suggesting that as the lake margin retreated, the mire surrounding the lake expanded to occupy those damp areas formerly holding standing water. Wet loving taxa *Salix, Caltha,* and *Potentilla* support this transition to sedge mire or wet grassland, due to their prevalence and increased frequencies in the zone. The exact cause of this retreat is unclear; however, it is likely the result of the combination of natural and anthropogenic forces, with the reasoning behind the association with anthropogenic forces highlighted by the initial timing of lake margin retreat (*c.* AD 900/1163 cal. BP), and its synchronicity with the settlement period. The lake potentially retreated with the encroachment of mire vegetation, and natural infilling processes, with these processes enhanced by infilling of the lake as sediments were mobilised through wider landscape degradation associated with settlement.

Palynological signals typically associated with Landnám are somewhat muted at this location, with no pronounced transition from natural to anthropogenic habitats discernible in the pollen or sediment data. Among the more notable signals is the small peak in charcoal at the lower zone boundary, frequently a settlement feature in Icelandic pollen diagrams, where dense woodland and scrub were cleared to make way for settlement. Here the grain size of charcoal is of a fine fraction (<50µm), indicating input from further afield, not necessarily from the farm at Gautlönd itself. Burning in situ in the sedge mires would have been unnecessary, given the low height and utilisable nature of the vegetation. The peak visible from the early Landnám period, supports to some degree suggestions the site was settled within the early years of Landnám (Vésteinsson, 2011).

Aside from some drying out of the site, stability again would appear to be a key feature of the zone. Overall proportions of 'trees and shrubs', and 'dwarf shrubs and herbs' are similar to that in the previous zone. In addition to this, sediment accumulation rates increase only slightly (by 0.08mm/yr. to 0.31mm/yr.), from LPAZ 1. Brown (2010) found similar subtle increases in SeAR within the homefield soils at Gautlönd following settlement, suggesting the site on a whole was relatively stable during this period, and not impacted by the landscape scale disruption commonly associated with the Norse (e.g. sediment loss or input of windblown materials). The lack of aeolian input is reflected in the pollen preservation within the zone, which is predominately well preserved. This is further supporting evidence for the durability of sediment and vegetation cover within the site, given associations between pollen deterioration and redistribution of sediments following erosive processes (Cushing, 1964). This observation would suggest that degradation is not happening at a scale that would give rise to increased sedimentation and infilling of the lake margin, although may still have made a minor contribution.

The typical Landnám palynological signals of opening landscapes through rapid deforestation and replacement of woodlands with grass heaths, dwarf-shrub heath, mires and cultivated land is not a feature of the site at Gautlönd. In the majority of studies of the anthropogenic impacts of Landnám rapid deforestation and new landscape equilibriums are seen to establish in as little as 50 years following settlement. This site provides further evidence to support the emerging patterns of habitats not sustaining dense woodland and scrub prior to settlement, and not displaying signals of rapid deforestation following settlement. Birch and willow scrubs remain relatively stable within the zone, with populations in the region obviously protected from the rapid deforestation common elsewhere in Iceland in the centuries, or frequently in the decades (Hallsdóttir, 1987), following Landnám. Tree birch percentages would appear to fall slightly following Landnám, given the slight leftwards shift in the population data, and decreasing mean diameters of *Betula* pollen with smaller diameters linked to *B. nana* (Figure 5.6). This is short lived however, with both *Betula nana* and *B. pubescens* persisting throughout this zone, and the rest of the diagram, suggesting no overexploitation or sustainable use of the woodland resource. Similar patterns of sustained presence of *Betula* following settlement are noted in nearby Helluvaðstjörn, with the possibility of distortion though the incorporation of eroded sediments from the surrounding area, with reworked, secondary pollen contributing to sustained presence of the species (Lawson et al., 2007). Betula within the zone however is predominantly well preserved, not showing any signs of excessive corrosion or degradation, as is often associated with exposed, oxidised and reworked pollen (Cushing, 1964, 1967).

Increased presence of grazing tolerant species *Polygonum sp., Rumex acetosa, Rumex acetosella/Oxyria, Thalictrum alpinum,* and *Selaginella*, frequently associated with anthropogenic disturbance, is perhaps the strongest indication of human disturbance associated with farming activities at the site. Despite this grazing intensity would appear low, with a suite of grazing intolerant species – *Sphagnum, Umbelliferae, Filipendula ulmaria, and Salix sp.,* present across the zone. *Filipendula ulmaria* is particularly vulnerable to anthropogenic impacts (Kristinsson, 2010), its sustained presence therefore suggests growth in areas fenced off or naturally inaccessible and unattractive to grazing animals introduced at settlement, such as ditches, hayfields, or damp areas of the sedge mire (Erlendsson et al., 2009). No evidence of cereal cultivation, in the form or cereal pollen, as is frequently associated with early settlements, is found within the zone, or indeed any of the following zones. Given the limited dispersal abilities for cereal pollen (Tweddle et al., 2005) this does not rule out cereal cultivation within the farm, although cereals are unlikely to have been cultivated on the mire itself. Expansions in *Poaceae*, as woodland gives way to expanding hayfields, another common occurrence at Landnám, is also not a feature of the Gautlönd pollen spectra, with grasses in fact contracting at some points. The contraction in *Poaceae*, given its short lived nature, potentially indicates periods of intensive grazing of grasslands in the drier surrounds of the mire, with intensive grazing leading to reduced pollen production in pasture grasslands due to removal of vegetation throughout the flowering season (Broström et al., 2008; Waateringe, 1993).

Species numbers are seen to increase at Gautlönd following Landnám, highlighted by an increase in palynological richness indicated by the increasing rarefaction curve in the zone. This is unusual given the reduction in floristic diversity often seen at Landnám, where species are seen to disappear and are replaced by monocultures as farms are established in the landscape (Erlendsson et al., 2009). At Gautlönd increasing species counts are likely to be a reflection of the aforementioned habitat heterogeneity, with the limited expansion of the anthropogenic elements in the flora also contributing to this. Dwarf shrubs are also seen to expand within the zone, contributing further to increased palynological richness. *Empetrum, Erica, Ericales,* and *Vaccinium* are all found to progressively increase throughout the zone, likely occupying the drier fringes of the sedge mires as hydrological conditions adjust, or growing on the drier crests of thúfur present within the mire, similar to the present day vegetation communities.

The muted impacts of settlement visible in the pollen spectra in LPAZ 2 is perhaps a reflection of the heterogeneity of vegetation, providing a mixed natural resource base available to the Norse at settlement, which, alongside access to other resources such as fishing within lakes Arnarvatn and Mývatn, perhaps reduced the need to exploit and alter vegetation communities within the farmscape to the point that new equilibriums in these communities had to be established. In addition, the open character of Gautlönd at settlement lends itself to a less obvious anthropogenic signal marking Landnám in the pollen spectra, with rapid reduction in woodland cover at other sites post settlement impacting the vegetation assemblages as a whole. There is also real risk however that the 'palynological visibility' of any human activities is diluted by the continuing presence of the wetland communities throughout the zone (Bunting and Tipping, 2004).

5.6.3 A stable and resilient site (LPAZ 3-6b)

Throughout the remainder of the 12th, 13th, 14th, and 15th centuries, the site retained its vegetative heterogeneity, and relative stability with sedge mires, grass meadows and heaths dominant features of the farmscape. Shifts are observed in the vegetation across this time period; however mostly occur in *Poaceae, Cyperaceae,* and *Betula*, none of which vanish from the spectra at any point. This relative stability is mirrored in the observations from micromorphology, with sediments suggesting wet and stable conditions in the mire area. Samples consist predominantly of poorly decomposed organic matter, with very little aeolian mineral material, or anthropogenic inputs contributing to matrixes. Rapidly increasing SeAR's through these zones are therefore attributed to rapid build-up of poorly decomposed organic matter, under wet and cold conditions. This is indicated by the presence of diatoms, linked to continued presence of standing water, and microstructures linked to freeze-thaw conditions. These are evidence of conditions restricting biological activity and therefore efficient breakdown of organic material (Bouma et al., 1990). The rapidly increasing accumulation rates are unique to the mire area of the site during this time period, perhaps linked to the more productive vegetation in the newly formed mires, with no enhanced SeARs highlighted in the homefield sediments (Brown, 2010).

Birch, a population consisting of both *B. pubescens* and *B.* nana throughout (Figure 5.), demonstrates episodic fluctuations, whereby periods of retreat and regrowth are witnessed throughout these centuries. *Betula* initially retreats at the beginning of LPAZ 3 c. AD 1185 (766 cal. BP), within a century of a regional decline manifesting within the regional diagram from Helluvaðstjörn (AD 1050) (Lawson et al., 2007). At Helluvaðstjörn a landscape scale decline is noted as being triggered at this point, albeit a steady decline over 250 years, following which a new lower equilibrium is set in birch populations. This is not the case at Gautlönd however, where values fluctuate around and below pre Landnám levels throughout the aforementioned centuries. Following its initial decline in the pollen spectra at Gautlönd, *Betula* populations recover, peaking again around 1266 AD (c.684 cal. BP). It should be noted however an increase in mechanical and biochemical damage to *Betula* pollen is witnessed around this peak, which given enhanced levels of landscape instability in Iceland following settlement in the Mývatnssveit region (Ólafsdóttir and Guðmundsson, 2002), and associations between mechanical and biochemical degradation of pollen and the exposure, oxidation, and redistribution of sediments suggests the likelihood of periods of reworking of secondary pollen from eroded, older strata (Cushing, 1964; Delcourt and Delcourt, 1980; Tipping, 2000). Micromorphological observations support the short lived nature of any inputs of eroded material into the mire, given no clear periods of sustained input of eroded materials is witnessed within the samples during this time period. It should also be noted no substantial change in preservation state occurs following settlement, with frequencies similar to that of pre Landnám values. The sheltered nature and currently fully vegetated nature of the site would also appear to have protected farmland from windblown material. Sand deposition and its detrimental impacts on surrounding farms are noted in Jarðabók for a number of the surrounding farms, but not Gautlönd. In support of this, ethnographical work by Brown (2010) demonstrates the current residents recognition of its rich vegetation resources and sheltered nature as a strength of the site. In her micromorphological studies from Gautlönd and surrounding Mývatn farms, Brown (2010) observed minimal quantities of coarse mineral aeolian material at Gautlönd, compared to observations of considerably greater amounts in thin section in samples from the surrounding farms. This reinforces interpretations of the sheltered nature of Gautlönd, highlighted by a lack of aeolian inputs at a time when other sites experienced considerable instability. Any potential for eroded and redistributed pollen impacting reliability of pollen records for the site should therefore be minimal.

Betula reaches some of its lowest frequencies around the mid-14th century, re-emerging to its former levels within decades; its coincidence with a sharp increase in *Poaceae* suggests a likelihood *Betula* suffered as a result of increasing intensity of farming at this point, giving the frequent association of increases in *Poaceae* pollen and expanding hayfields. Alternative suggestions include cooler temperatures, as suggested by historical documentary resources for a number of decades in the 14th century (Ogilvie, 1984, 1991) impacting the pollen production of thermophilous *Betula* (Erlendsson and Edwards, 2009), or increased use of *Betula* as a fuel resource at this time.

Fluctuating *Poaceae* percentages throughout LPAZ 3-6b can be linked to a number of factors. Periods of increasing *Poaceae,* may be linked to more intensive use of hayfields or drying conditions (climatic or sedimentary) impacting the farm. Grazing pressures also impact *Poaceae* presence in the palynological signal, with increasing grazing pressures linked to decreasing grass and herb pollen production, due to continual removal of vegetation in pasture during the growing season (Broström et al., 2008). Moderate to low grazing pressures on the other hand has been shown to stimulate flowering of *Poaceae,* through the formation of more, but smaller shoots in plants (Waateringe, 1993). Decreasing *Cyperaceae* may be linked to drier conditions across the farm, although micromorphological observations suggest for no sustained period of time. There is also the potential this is linked to the removal of mire vegetation for fodder crops, which would frequently occur in early summer before sedges became more siliceous and less palatable, thus reducing Cyperaceae values in the pollen rain (Hallsdóttir, 1987). Mire mowing tends also to be linked to decreasing LOI and a relative stability in biochemically degraded pollen, which, given the fluctuations in both of these paleo-characteristics between LPAZ 3 and 6b, has meant that no firm conclusions can be drawn in this respect.

Tephra deposition is potentially another cause of shifts in vegetation within these zones. There is some indication that following the fallout of tephra *Poaceae* expands and *Cyperaceae* contracts within the farm. This signal is however typically short-lived and subtle. Short term patterns of replacement of wetland taxa with more dryland ones is frequently noted in pollen studies across Iceland, however signals may be complicated by a number of factors with similar impacts, including increases in erosion, peat drainage and trampling by livestock (Erlendsson et al., 2009; Rundgren, 1998; Vickers et al., 2011). These limited responses to tephra and rapid recovery are highlighted by micromorphological analyses. In thin section, the tephra present prior to Veiðivötn 1477 appear relatively diffuse in nature and, contrary to the aforementioned responses within the vegetation communities, demonstrate no signs of drying conditions following their deposition. This provides further evidence that the impacts of these tephra on the farm were minimal, and in doing so highlights the resilient nature of mire, and consequently of the farm.

Anthropogenic impacts appear varied across the site throughout the centuries constrained within the zones. Presence of species indicating disturbance appears limited, the entire farm is therefore unlikely to have been used heavily, perhaps a product of the wide variety of natural resources available to the farm, preventing the need to overexploit any one resource. Grazing-sensitive species are also prevalent throughout most of these zones, indicating some areas of the farm remain protected from or inaccessible to livestock. This is not the case in LPAZ 5, where grazing-sensitive species disappear from the spectra. No evidence of other forms of agriculture is noted in the sediments from the site during these centuries; no cereal grains identified in the pollen spectra and no evidence of active management in wet meadow sedimentary record. Additions of domestic waste to homefield sediments across the same time period, likely used as manure (Brown, 2010), indicate active management of other areas of the farm at this time.

5.6.4 Tephra fallout - responses and recovery (LPAZ 6C)

LPAZ 6C is coincident with the fallout of tephra from the Veiðivötn 1477 eruption. This thicker and more prominent deposit would appear to have more profound drying impacts on the mire surface. *Cyperaceae* contracts, with *Potentilla*, frequently associated with damp conditions, waning and disappearing from the spectra. These drying conditions are reflected within the sedimentary records, as features associated with less waterlogged conditions increase – including increased presence of excremental pedofeatures and granular and crumb microstructures associated with increased biological activity (Bouma et al., 1990). Within the same microhorizon diatom frequency, associated with wet conditions, is found to decrease.

Former conditions are restored shortly after, as sediment begins to accumulate on top of the tephra deposit, increasing water holding capacity. *Cyperaceae* rapidly expands towards the upper zone boundary demonstrating rewetting of the mire, with simultaneous increases in algae supporting this. Micromorphology demonstrates a small increase in mineral material following the tephra deposition, predominantly iron stained tephra fragments, likely to have been eroded and redeposited at Gautlönd from elsewhere in the catchment. This contributes to only a minor portion of the now decreasing SeAR at the site. Other additions include continual input and breakdown of organic material, demonstrated in thin section analysis which indicates reestablishment of stable conditions in the meadow following the tephra deposition.

5.6.5 Intensification and monocultures (LPAZ 7)

The most prominent vegetation change within the pollen spectra for Gautlönd is illustrated in LAPZ 7. A substantial shift is witnessed with a change from a previously heterogeneous site to something of a monoculture, with palynological diversity diminishing at the point of grassland expansion from around AD 1675 (275 cal. BP). This grassland expansion is likely to be a result of the growth and intensified use of hayfields within the farm. Modern drainage is likely to have contributed to the increased productivity of grasses, as they expand into formerly sedge dominated parts of the farm (Hallsdóttir, 1987). Two drainage ditches of varying sizes and ages are witnessed within the present day mires, and were likely to have contributed to increasing the productivity of the farm. The disappearance of grazing sensitive *Umbelliferae* and *Filipendula ulmaria* from the spectra indicates low level grazing is also likely to have occurred throughout the farm at this time, although not at a level to decrease grass pollen production.

SeARs across the zone decrease to rates lower than pre-Landnám rates. This suggests increasing landscape stability, perhaps though increased breakdown and reduced build-up of organic material as fields are drained or reduction in organic matter input through decomposition as vegetation is removed through mowing for the production of winter fodder. SeARs elsewhere in the homefield are seen to increases during the same period, as micro-horizons of coarse mineral material suggest increases aeolian inputs to homefield soils, and inputs of household waste to homefield's increase, perhaps as a means of counteracting damage from sand storms (Brown, 2010). These micro-horizons do not appear within the imperfectly drained meadow sediments, suggesting the possibility that meadow sediments mask these environmental impacts to some degree.

Arboreal pollen decreases rapidly within the zone, especially noticeable in *Betula,* which is present here in frequencies less than that pre-Landnám, potentially as a result of the increasing intensification within the farm. No trees are present within the farm itself at the present day, with pollen input likely from shrub birch and remnant copses in the region, perhaps a reflection of lack of management of the resource here. Despite its decline in this zone, the continual presence of *Betula* in the centuries following settlement is a commonly emerging feature of palynological and archaeological studies from the Mývatnssveit region. With prominent *Betula* signals in the palynological studies carried out on both a regional scale at Helluvaðstjörn, and farm level studies from both Viðatóft (this thesis) and Hofstaðir (Tisdall *et al.*in press). This suggests that further research, at a finer spatial scale is required to examine the full impacts of Landnám on vegetation and natural resources in Iceland. Archaeological evidence for continued presence of *Betula* post Landnám exists in the excavations of several hundred charcoal production pits, from Höskuldsstaðir, a farm from the Mývatnssveit region, and approximately 35km north of Gautlönd (Lawson et al., 2007). Radiocarbon dating of remnant charcoal from the pits demonstrates their continued use throughout the 11th and 12th centuries, identifying *Betula* branch wood as a key component of the charcoal assemblages (Church et al., 2006). In addition to this, fuel material research by Simpson et al. (2003), highlights the use of *Betula* as fuel within the high status site Hofstaðir up to the late 10th century, following the identification of *Betula* fuel as residues in the micromorphological analysis of midden materials from the farm. The authors go on to suggest the potential regulation and management of woodland resources given that, within the lower status site Sveigakot, no *Betula* ash residue was recorded in documentary resources or micromorphological research. Instead, this farm relied on poorer quality materials as their key fuel source. Alongside continued presence of *Betula pubescens* in some more inaccessible and protected areas of Mývatnssveit, this supports the pollen evidence for the prevalence of *Betula* around the farm.

5.7 Site Summary

The results from Gautlönd provide a further example of a site not carpeted by dense woodland and scrub prior to settlement, as is the commonly constructed and generalised perception of pre-Landnám Iceland. Instead, the site supported more open vegetation, heterogeneous in nature, with wet meadows, dry grasslands, heaths and woodland all likely to have been present in and around the area prior to settlement. Pollen and sedimentary analysis, set in a chronological context, suggests these vegetation communities were present and relatively stable in the 400 years prior to settlement. This stability is echoed in sediments both in the wetland where sediments accumulated slowly and in the area later supporting the farm homefield (Brown, 2010). The large natural wetland area as well as the mix of vegetation communities and ease of access to the lake and river gives the site the advantage of a wealth of natural resources, making it attractive to early settlers in terms of resource availability. In addition to this it provides an ease of setting up farms, with the open site reducing the need for clearance of dense woodland and shrubs prior to establishing new farm settlements. This follows Vésteinsson's (1998) model for early settlement, where it is suggested sites sought out first for settlement were the ones with access to a variety of resources, including flat wetland areas for fodder production.

Given the open nature of the site prior to the settlement period, the farm does not display the typical palaeoenvironmental features of Landnám. No rapid deforestation and hayfield expansion is observed in the pollen data, and no increased input of eroded materials is evident within the sedimentary record. Landnám signals are therefore somewhat muted in the palaeoenvironmental record; there is no prominent transition from a natural to an anthropogenic habitat, and only a small increase in apophytes and grazing tolerant species seen following Landnám, together with survival of tree birch until the present day. The key change in the site at Gautlönd in association with the Landnám period was the retraction of the lake margin, with pollen evidence suggesting the pollen coring site was formerly under standing water. Given its synchronicity with settlement it might be suspected anthropogenic activity influenced this, however there is not clear evidence human activity influenced this in a big way, perhaps contributing instead to the natural process of terrestrialisation.

Environmental and cultural records held within the wetland sediments suggest the relative stability at Gautlönd featured throughout much of the settlement period. Fluctuations in vegetation were limited, with *Betula*, which is found to decline rapidly in the majority of pollen diagrams following Landnám, demonstrating only a very limited decline following settlement, remaining in the locality until more recent centuries. These stable conditions are reflected in the sediments throughout, which have demonstrated only minor inputs of aeolian material with no negative effect. Resilience therefore features as a key benefit of the site, with meadow sediments showing little response to environmental or socioeconomic perturbations. Recoveries following tephra fallouts are for example very rapid, with the very wet conditions evidenced in thin section acting to diffuse impacts of tephra fallout on vegetation experienced elsewhere in Iceland. Only the substantial fallout of the Veiðivötn 1477 tephra caused any substantial shifts in vegetation or soil conditions, and recovery to pre fallout conditions was rapid.

Given the palynological records explored in this chapter the exact extent to which the wet meadows were used at Gautlönd remains unclear. Limited fluctuations in *Cyperaceae* and *Poaceae* percentages from the 12th to the 15th centuries suggest periodic cultivation, through cutting or grazing, though not at a level causing degradation in the site. Nor was it sufficient to satisfy the palaeo-characteristics of mowing outlined by (Hallsdóttir, 1987). However, given the ethnographical information obtained by Brown (2010) regarding cutting and grazing within the farm's meadow resources, this type of management is likely to have occurred within this wet meadow at limited intensities throughout these centuries. More intensive use occurring from AD c.1675 is represented by substantial shifts in vegetation, and visual evidence of modern drainage ditches in some areas of the meadow.

To this end it is evident the natural wet meadows at Gautlönd have proved valuable for settlement, acting to attract settlers to the area, given the large tract of open land associated with them, and adding to the natural resource base of the site. These meadows have acted as a buffer to a series of environmental and climatic downturns since settlement, proving to be resilient to impacts such as tephra fallout and increased instability associated with the Little Ice Age. As such they have a stable resource for the farm occupants, from settlement to the present day,

Chapter 6 Synthesis, Discussion and Conclusions

6.1 Introduction

This chapter returns to the central aim set out in the beginning of the thesis – to develop a better understanding of how the wet meadows associated with farms developed and how they were used and managed in a Norse cultural context, explored through the evidence of sediments as environmental and cultural archives. The research has focussed most specifically on the influence of wet meadows on site selection at settlement, as well as the ways in which meadows were managed in relation to the rest of the homefield, determining the extent to which they acted as a resilient resource or safety buffer for farms during climatic downturns. To do so three case study farms were selected, each with a series of unique features – Vatnsfjörður (Chapter 3), a historical power centre in the northwest of the country, where a small defined wet meadow is present within wider inherently infertile homefields; Viðatóft (Chapter 4), a small abandoned farm in the Mývatnssveit district (north east Iceland), within which the area surrounding the dwellings is waterlogged and where a series of defunct water management structures exist; and Gautlönd (Chapter 5), also within Mývatnssveit, a successful farm which has been under permanent occupation from the early settlement period and within which a large natural wet meadow exists.

In order to fulfil the aims central to this thesis the following sections synthesise results from each of the case study chapters with reference to the research objectives. The pre-Landnám baseline conditions (Section 6.2) at each site are initially compared, investigating how the meadows developed and how they would have appeared to settlers on their arrival. Comparisons are then made between the impacts of settlement within each of the sites (Section 6.3). Records of environmental conditions and processes, and any environmental impacts on the meadows and farmscapes are then contrasted between sites (Section 6.4). This is followed by comparisons between palaeoenvironmental evidence for cultural practices occurring within the meadows and the wider farmscapes for each study farm (Section 6.5). Where appropriate, data from the sites is contextualised with existing palaeo-environmental, palaeo-climatic and archaeological data as a means of contrasting environmental and cultural shifts in the farms with larger scale climate and social change. The thesis concludes with a summary of the new and enhanced knowledge of farmscapes operating within sub-arctic environments, with specific focus on wet meadows and their varying presence, development and functions as resources in these challenging environments.

6.2 Pre-Landnám (baseline) conditions

Establishing pre-Landnám or 'baseline' conditions within the meadows and wider farmscapes is one of the key objectives of the research. Chronostratigraphical and micromorphological techniques were used to uncover the presence of organic soils and formation processes prior to settlement, together with the use of palynology to establish pre-Landnám vegetation both within meadows and in the immediate farm surrounds. These baseline conditions provided a reference point against which anthropogenic changes might be contrasted.

Of the three farms investigated, two of the meadows were shown to exist prior to the arrival of the Norse. The age of organic sediments at the third farm, Vatnsfjörður, determined by radiocarbon dating, showed these existed only after the settlement period. Given the absence of organic sediments prior to settlement, palynological evidence for pre-Landnám vegetation is not available for this site. Pre-Landnám conditions have therefore been determined though a descriptive analysis of homefield sediments. Stratigraphical data was obtained though the creation of a scaled catena. This revealed the presence of shallow, free draining soils across the Vatnsfjörður homefield area indicating that on encountering the site encountered the Norse would have experienced similar limitations to agriculture across the whole farm site, as is experienced today. Formation of the homefield soils over beach sands and gravels provides further evidence this would have been the case, with this substrate creating free draining conditions as demonstrated by the presence of podsolised, and therefore nutrient depleted, sediments observed across the homefield. It is likely, given the similarities with Greenlandic soils (Milek, 2006) and the evidence of podsolization, that the availability of water in the soils might be limiting (Adderley and Simpson, 2006), rendering them poor agriculturally. Soil conditions, coupled with the isolated location do not fit in with the assumed models of early settlement (Vésteinsson, 1998). This is despite archaeological evidence indicating the presence of 10th century structures and new early dates produced in this study (AD 896-1030±35) which validate the proposition that the site was occupied in the early years of Icelandic settlement. This indicates the site might have instead been valued because of its sheltered and defendable fjord position, for ease of access to marine resources and its communication links associated with the mountain passes and fjord networks linked to the site (Tulinius, 2005).

Organic sediments within Viðatóft and Gautlönd on the other hand, have been shown to have developed before settlement, with wetlands of varying degrees of saturation present in a natural context at the time settlers encountered these locations. In the years following the deposition of the Hekla 3 tephra, pollen analysis at Viðatóft suggests the development and dominance of wet meadow type vegetation covering most of area later enclosed by the homefield, with *Cyperaceae* dominating alongside species such as *Potentilla* that are tolerant of wet ground conditions. Few fluctuations are seen in the pollen spectra, suggesting stable conditions in the centuries prior to Landnám. Features observed in thin section support the premise of wet conditions, pre- Landnám sediments being dense in nature, displaying high quantities of diatoms. The show minimal evidence of biological activity, likely to have been restricted due to saturation (Bouma et al., 1990). A banded appearance of diatoms in thin section points to distinct periods of wetness perhaps linked to seasonal fluctuations in water table level, creating periods of inundation. The preservation of the diatom microhorizons, as well as the steady rates of soil accumulation, further highlight the relative stability of this site.

At Gautlönd the Norse would have encountered a larger freshwater lake than is currently present within the farmscape. Support that this was the case in the *c*.400 pre-Landnám years is provided by analysis of the cored section which revealed the dominance of *Hippuris vulgaris*, a species typical of shallow lake edges in Iceland (Kristinsson, 2010), together with a greater proportions of algae, indicative of standing water. An open environment is likely to have surrounded the more extensive early lake with proportions of *Cyperaceae* suggesting presence of sedge mires across the valley floor, and natural dry grasslands and shrubs present on the drier sloping edges of the valley creating a heterogeneous landscape. Like Viðatóft, Gautlönd demonstrates stability in the surrounding soils and vegetation, with the slow accumulation of organic rich sediments at the lake edges in the centuries prior to settlement. These observations are supported by low sediment accumulations rates in the farm homefields pre-Landnám (Brown, 2010), as well as few fluctuations in the vegetation communities, as indicated by an observed lack of change in the pollen spectra throughout this time period. Pre-Landnám stability is also highlighted in the regional pollen diagram from Helluvaðstjörn (Lawson et al., 2007).

Despite indications from the pollen data that both Viðatóft and Gautlönd did not support dense woodland at the time of settlement, most likely a result of the wet ground conditions at these sites being unfavourable to the growth of *Betula pubescens*, pollen records do suggest the presence of *Betula* in the vicinity of the farms. At Viðatóft levels of *Betula* appear relatively stable with a possible minor increase in the species around 200 years prior to settlement; similar minor expansions pre-settlement are also noted in analyses from the south and west of the country (Erlendsson and Edwards, 2009; Páhlsson, 1981). This might be linked to natural variability in pollen accumulation, or potentially linked to climate amelioration given that *Betula's* thermophilous nature would be suited to the warmer climatic conditions highlighted through ice core data analysis for the period AD 700-800 (Meeker and Mayewski, 2002). If indeed the greater pollen percentages are linked to an expansion, this could be in the form of a physical expansion, or increased pollen production, with *Betula* known to produce more pollen associated with increased flowering in warmer conditions (Autio and Hicks, 2004). However, given the generally slow response of vegetation to climate change (Prentice, 1986) the latter scenario is more likely. Sediments immediately below the Landnám tephra deposit are also suggestive of a landscape responding to a warming climate, with increases in the amount of biologically active organic material and less waterlogged conditions. *Betula* at Gautlönd is present in similar frequencies to those recorded at Viðatóft, with higher resolution sampling here able to detect a more stable presence of the species, similar to regional signals picked up in the pollen spectra at Helluvaðstjörn (Lawson et al., 2007). Where clear landscape stability is evident from around AD 500 (1450 cal BP).

To date, few palynological studies from Iceland have focussed on sites that are relatively open and non-wooded at the time of settlement. Previously observed sites shown to have sustained mires and a more open vegetation structure prior to settlement, tend to be more exposed, island and coastal sites, such as Papey an island off the east coast (Buckland et al., 1995), Ketilsstaðir on the south coast (Erlendsson et al., 2009), and Reykjarfjördur in the northwest (Andrews et al., 2001). The Mývatn sites studied for this research offer palynological records for inland locations providing evidence of open and heterogeneous vegetation communities prior to settlement. The valuable additional information on the unaltered vegetative habitats present pre-settlement provides a record from which to assess impacts of settlement in these environments, while highlighting the importance of finer spatial scale resolution studies in identifying variations in regional vegetation patterns (Davies and Tipping, 2004). These relatively open areas and the local spatial diversity that characterises the landscape are not well represented in the diagram produced from lake Helluvaðstjörn, which likely recruited pollen from a much wider area of the Mývatn region (Lawson et al., 2007). New data collected here suggests the landscape would have appeared more variable to the Norse on their arrival in the region. The diversity of the vegetation types across Mývatn may have been an attractive feature of the region, with the natural wetlands viewed by the first settlers as a valuable, additional resource for grazing and fodder production, maximising the natural resource base for the farms. The value of these wetland habitats, alongside the freshwater, wild non-farm-related resources and milder climates would have made Mývatn an attractive area for settlement, supporting a farm’s self-sufficiency and resilience, despite its inland position and isolation from marine resources.

6.3 Impacts of settlement, palaeoenvironmental reconstructions of Landnám in the wet meadows

Given the distinctions between each of the farmscapes, the impact of Landnám was experienced differently across the sites. With the absence of heavily wooded areas within any of the studied sites at the time of settlement it is expected that vegetation changes in response to human impacts at Landnám, and the associated palynological signals, will be more muted than those associated with the majority of pollen diagrams covering the same period elsewhere in the country. Other diagrams are able to show rapid decline in woodland and opening of the landscape as a key Landnám indicator. Nevertheless there are a series of environmental shifts associated with this period observed in the data collected from each of the study farms, despite not conforming to the traditionally accepted view of the anthropogenic impacts linked with Landnám.

At Vatnsfjörður the key change associated with occupation of the site is initiation of a thick peat deposit in the lower settlement area. Radiocarbon dates for material extracted from the bottom of this deposit linked this change to the early Landnám period. Post settlement formation of organic soils is not unique to Vatnsfjörður, humans have long been associated with peat development, where cultural activities alter hydrological balances (Charman, 2002). However, given finds of similar, much smaller deposits elsewhere in the region developing in association with turf walls (Milek *pers* comm) it has been suggested peat development at Vatnsfjörður was initiated following the construction of the turf wall enclosing the homefield, with this acting to impede drainage, creating the waterlogged and anaerobic conditions required to prevent biological breakdown of organic material initiating peat development. Alternative but compatible hypotheses include the emergence of new hydrological regimes onsite in response to the removal of vegetation. This process is more frequently linked to the development of blanket mire and, given the smaller and more defined scale of the peat deposit at Vatnsfjörður, it is unlikely to have been an independent factor in its development. The charcoal at the base of the deposit, linked to land clearance at settlement, potentially contributed to waterlogging, given charcoal's common association with reduced porosity and water retention in sediments (Caseldine and Hatton, 1993; Mallik et al., 1984; Moore, 1993). Deliberate flooding, watering or irrigation might also have occurred within the meadows; however given the lack of archaeological structures associated with this type of management and the lack of palaeoenvironmental evidence, if this did occur it was presumably at a small scale.

Impacts of settlement observed at Vatnsfjörður and more typically associated with Landnám include the layer of charcoal in both the stratigraphical section base and thin section collected from the base of the wet meadow. Similar deposits are commonly found in early settlement farm stratigraphies. Even with the apparent burning of vegetation for land clearance, and associated consequences for landscape stability, data from thins sections indicate only small inputs of windblown aeolian material to Vatnsfjörður's wet meadow. This suggests relative stability within the region post settlement, despite Landnám's frequent association with accelerated erosion. Grasses are found to dominate the pollen spectra from early settlement; the expansion of grasslands following settlement is generally linked to replacement of woodland by more open vegetation such as managed hayfields (Hallsdóttir, 1987). These inflated percentages of *Poaceae* might therefore signify the establishment of hayfields on the site. However, the presence of aquatic taxa and the high frequencies of diatoms in thin section indicate wet conditions in the homefields, suggesting conversion to managed wet grasslands. This habitat type is naturally more productive than the sedge mires which would otherwise be found on wet peat rich sediments, with these semi natural habitats maintained only through human action (Káplova et al., 2011).

Impacts of Landnám at Viðatóft, appear similar to generalised responses to settlement associated countrywide with the transition from a natural to anthropogenically modified landscape, yet are more muted and with some elements unique to the site. Following deposition of the Landnám tephra at the site, sediment accumulation rates are seen to increase. This is supported by an observed increase in the input of coarse minerals, predominantly aeolian materials in thin section, as is common occurrence following Landnám (Dugmore and Buckland, 1991). Despite this, no obvious indication of erosion is recorded within the site itself, with complete and undisturbed tephra sequences prominent across the site and intact microstrata evident in thin section. Lack of disturbance at the individual farm scale may be related to the open sedge dominated habitat, with no requirement to clear the site of trees and shrubs prior to settlement. Evidence for the limited input of eroded aeolian materials is supported by the preservation state of pollen in the post-Landnám stratigraphy. Samples show decreased quantities of corroded and degraded pollen that might otherwise be associated with inputs of secondary pollen from eroded sediments. Demonstrably muted inputs of charcoal are also present within the palaeoenvironmental records for Viðatóft. Only small increases in charcoal fragments are observed within the pollen records, and very minor increases shown in thin sections, emphasising that requirements for clearance through burning in this more open settlement site must have been minimal.

Palaeo-signals from Viðatóft's pollen record do mirror to some extent typical settlement signals evident at other locations in Iceland. Most evident is the expansion of grasses at the expense of shrubs, signifying the development of pastoral farming systems and creation of hayfields at this time. The apparent introduction of grazing livestock also creates a more typical change pattern, with grazing intolerant species (*Umbelliferae, Sphagnum, Salix*) waning and then vanishing from the sites pollen spectra, and ultimately being replaced by more grazing-tolerant apophytic species (*Rumex, Thalictrum, Gallium, Equisetum, Selaginella, Lactuceae*) typically linked to disturbance in farmscapes. Expansion of *Botrychium*, from which spore spread rapidly in open locations, is indicative of grazing at an intensity that promotes creation of closely cropped swards of vegetation. Contradictory to typical vegetation shifts at Landnám, *Betula* here retains its steady and low pre-settlement percentages though the initial Landnám years.

Much of the expansion of grasses within the site following settlement can be linked to drying conditions on the farm, with this becoming the key distinguishing element between pre- and post-Landnám palaeoenvironmental records at Viðatóft. The palynology reveals a decline in moisture tolerant species (*Salix, Empetrum, Caltha palustris, Potentilla, Cyperaceae*), which would fit with hydrological changes to the meadow following occupation, such as through the creation of the series of dams and ditches in the homefield, aimed at improving growing conditions for grasses. Patterns of drying are further complicated by the influence of the warm climate around the time of settlement as part of the Medieval Warm Period, as well as inputs of tephra, frequently documented as creating free draining conditions in sediments (Erlendsson et al., 2009). Micromorphological analysis supports the drying out of the site at this point, with a marked reduction in the frequency of diatoms, associated with wet conditions and standing water, witnessed in the thin sections at settlement.

A hydrological shift is also identified as occurring concurrently with Landnám at Gautlönd. A shift in the palynological record representing terrestrialisation of the lake (Arnarvatn) with gradual replacement of shallow lake margin species *Hippuris vulgaris* by *Cyperaceae,* as well as increases in damp loving taxa over the same period (*Salix, Caltha palustris, Potentilla*). This demonstrates a transformation in the pollen sampling area from shallow, standing water to sedge mire. Given the timing of lake retreat is aligned with Landnám, settlement induced degradation processes may have had a role in the infilling of the basin. This would require the erosion and mobilisation of sediments from the surrounding area, which has been described for other sites. Sand deposition in the Mývatn region affected wetlands and lakes, not only soils, with a number of the small lakes in the Framengjar, south of Lake Mývatn identified as infilled both partly and entirely due to sedimentation (Brown, 2010; Lawson, 2009). However, sediment accumulation rates with the onset of settlement at Gautlönd are limited (0.08mm/yr), with this small increase in sedimentation rates mirrored in patterns in the homefield soils (Brown, 2010). There is not the evidence to suggest that SeAR associated with instability following Landnám was sufficient to infill Lake Arnarvatn, even partially. To this end it is suggested the basin infilled by hydroseral succession, with repeated inputs of tephra enhancing sedimentation rates. As with Viðatóft the potential drying patterns are complicated by the warmer climate during the settlement period as part of the Medieval Warm Period.

Other indicators of change from a natural to an anthropogenic landscape are muted within Gautlönd. There would appear to be low grazing intensity, or grazing management at the site, with the mire itself potentially protected from, or inaccessible to grazing livestock, evident through the continued low level presence of grazing sensitive species, particularly *Filipendula ulmaria*, post-settlement. Grazing likely occurred elsewhere within the farmscape however, as minor reductions in *Poaceae* can be linked to intensive grazing, through a process of continued removal of grasses in pastures preventing flowering and subsequent pollen dispersal (Broström et al., 2004). Small increases in the levels of grazing-tolerant species, frequently associated with anthropogenic disturbance is observed here, albeit at low levels. This is reflected in the increasing number of species post-Landnám, as determined by rarefaction analysis. Species numbers are usually found to decline at Landnám as hayfields expand and farming areas become associated with monocultures (Erlendsson et al., 2009). Despite the small increases in species numbers, the relative stability of the overall pollen spectra suggests anthropogenic pressures associated with settlement on the site were not excessive. The lack of dense woodland and scrub together with the open wetland areas meant that very little clearance was required to set up the farm, while mixed habitats reduced the need for excessive pressures on any one resource.

At Gautlönd *Betula* remains at pre-settlement levels following Landnám, and so despite neither Gautlönd nor Viðatóft supporting dense woodland prior to settlement, woodland remains present around the Mývatn sites. This observation provides further evidence that rapid declines in woodlands immediately following settlement post Landnám were not necessarily countrywide, in some areas *Betula* declines were clearly more muted and localised, highlighting the need to consider sites on an individual basis to build a more robust interpretation of Landnám impacts in Iceland.

Contrary to previously published reports of widespread high impact human settlement in Iceland, this study provides a set of high-resolution examples of landscape responses to settlement that varying markedly at the local scale and indicate responses in some sites were initially muted. This highlights the complex nature of relationships between people and the Icelandic environment, with the scale of impact a multifaceted interaction between several factors - climate, vegetation, landscape and cultural impacts (Vickers et al., 2011). Landscape responses within each of the study farms have been shown to vary between the three sites, however, stability is a key feature in all of them. The muted impacts of settlement within the Mývatn farms might be considered primarily to be a consequence of the occurrence of wetlands at settlement, reducing the need for clearance, which would otherwise have led to accelerating land degradation. The choice of sampling sites within the meadows might however have shaped the muted settlement signals; the presence of wetland habitats potentially diluting the palaeo-visibility of anthropogenic impacts, limiting available niche spaces for the anthropogenic species, in the direct vicinity of coring locations (Bunting and Tipping, 2004). Meadow vegetation communities contributing to the pollen spectra are unlikely to change radically unless subjected to considerable stress. In this respect the ability to withstand the impact of minor stresses could be considered a key strength of the wetlands as a resource.

6.4 Environmental impacts and processes

As part of understanding how meadows developed and how they were used by Norse communities, it is important to understand the extent to which environmental impacts on the meadows influenced their development. To this end, one of the objectives of the research is to collect and study records of environmental conditions and processes operating within the farms and interpret them in terms of environmental impacts on the meadows and farmscapes, comparing results between sites.

One of the key drivers of change within the wet meadows is the impact of tephra deposition on the sites, with different deposits impacting the meadows in different ways. These patterns are witnessed only within the two Mývatn meadows, as there is only limited occurrence of tephra deposition on the northwest peninsula where the third farm is located. The tephra depositions tending to drive most change in the meadows are those with thicker deposits. Following the deposition of Hekla 3 at an average of 10cm thick across the Viðatóft settlement location, dominance by *Salix* is evident. This is thought to be a direct response to the Hekla 3 deposition giving the taller shrubs a competitive advantage over other lower lying arctic species (Arnalds, 2013; Rundgren, 1998). Increased presence of biochemically degraded pollen in the Viðatóft pollen spectra, following Hekla 3 is indicative of a drying effect of this tephra deposition on the meadows, creating temporary free draining conditions and oxygenated sediments. These conditions are poor for the preservation of pollen, as well as reduced habitat suitability for the *Cyperaceae* species later dominating the site. The substantial Veiðivötn 1477 deposit has also been demonstrated as having an significant impacts on vegetation communities; the dense *Salix* shrub present at Viðatóft prior to this eruption, opening up leaving a grass rich habitat in the years following deposition. Evidence of drying impacts are also associated with the Veiðivötn 1477 tephra, with replacement of moisture tolerant species by dryland vegetation. Another key feature associated with this deposit has been evidence of its impact on grazing-sensitive species, which emerge across the Viðatóft site following the deposition. Similar occurrences have been noted elsewhere in Iceland following eruptions, with livestock being lost to, or kept indoors to protect from, the toxicities of volcanic ash which can cause fluorosis (Edwards et al., 2004). Here however, impacts from multiple factors are difficult to tease apart. Documentary records indicate the onset of a plague pandemic within two decades of the eruption creating complex ecodynamic interactions that cannot be linked to any single causation factor.

Thinner deposits of the Landnám tephra, as well as the fallout of tephra from the eruptions of AD 1104 and AD 1300, demonstrate similar, albeit more restricted environmental changes within the Viðatóft farmscape. Improved drainage conditions linked to tephra deposition occurred parallel to increasing grasses at the expense of moisture tolerant sedges. Alongside these species composition changes, relative values of corroded pollen increased, indicating aeration of formerly saturated sediments.

Ecological recovery following tephra deposition is equally well recorded in the sediment and pollen data, with organic soils acting as an effective historical archive. Landscape recovery following the deposition of the Hekla 3 tephra at Viðatóft is, for example, demonstrated though a combination of evidence sources; increasing 'Loss on Ignition' indicating a resumption of organic sediment accumulation processes, a switch to wetland vegetation communities as the water holding capacities of sediments recovers, and the increased presence of diatoms in thin section supporting evidence for wetter conditions observed in the pollen spectra.

Responses to tephra deposition appear more subdued within the meadows at Gautlönd, than at Viðatóft. Drying conditions following tephra deposition here appear minimal, highlighted by the rapid recovery to former levels of vegetation coverage and composition, with little evidence of drying conditions in thin section. The limited impacts experienced within this site illustrate the potential resilience of mire sediments and their ability to withstand the shock of tephra deposition. The particularly extensive AD 1477 tephra deposition however, is an exception having have had a more substantial impact on the farm than the other tephra noted within the meadow deposits. Pollen data for this period highlight an apparent drying of mire conditions in the period following deposition, with Cyperaceae and other damp loving species reducing. This is supported by micromorphological analysis, where dryer, more biologically active conditions are apparent. Recovery is however rapid, with organic sediments accumulating on top of the tephra, increasing water holding capacities of sediments and promoting the return of wetland species.

Certain aspects of climatic conditions are also recorded within the meadow sediments. As indicated in discussions on pre-Landnám conditions at Viðatóft, increases in thermophilous *Betula* have been linked to sediment horizons which indicate the occurrence of pedogenic processes of organic matter breakdown associated with slightly dryer sediments and suggestive of warmer conditions.

One key aspect pertaining to stability within the Mývatnssveit sites is the prevalence of *Betula* in the centuries following settlement. The species is evident throughout Viðatóft cores and demonstrates only minor fluctuations in presence, with its pollen likely recruited from the dryer sloping edges of the site or from more inaccessible or protected tracts elsewhere in the region. Gautlönd's pollen spectra also demonstrates that *Betula* maintains stable populations in the centuries following Landnám, with minor episodic fluctuations reported infrequently. These observations are supported; by data from the regional scale study at Helluvaðstjörn, in which *Betula* evident until the 15th Century, by archaeological evidence following the discovery of 11-12th century charcoal production fire pits (Church et al., 2006), and by micromorphological evidence showing the continuous use of birch as fuel within the high status site Hofstaðir (Simpson et al., 2003). Given the continued presence of *Betula* within the area it is highly likely that this resource must have been protected or managed to prevent its depletion (Lawson et al., 2007; Simpson et al., 2003).

An important aspect of pedogenic processes recorded within the thin sections is variability in soil processes recorded at the microscale. Where periods of instability are witnessed within the wider landscape and at a site scale, closer examination of sediments revealed complexities associated with soil formation processes. Following settlement at Viðatóft until AD 1477 sediment accumulation rates are seen to increase at both field and microscale. However discrete entities of organic material are visible within these sediments, featuring as organic microstrata within a silt-rich matrix. These organic accumulations are representative of 'standstill phases' within a framework of more prevalent unstable conditions, indicating short periods where breakdown of organic matter and faunal activity were dominant soil forming processes. Similar micro-scale temporal variations in soil accumulation processes are noted at other farms in the region and across similar timeframes (Brown et al., 2012), where periods of soil stability are evident within a wider context of instability. These findings highlight the need to examine soil forming processes in post-Landnám Iceland more closely and suggest soil accumulation rates are more complicated than the extensively simplified associations often made between deposition of eroded materials and periods of instability. Phases of landscape stability with organic material accumulation may also be contributing to SeARs.

These patterns are evident within the sedimentary records at Viðatóft, to a slightly greater extent, with episodes of soil stability appearing in synchrony with the periods of depopulation associated with plague epidemics (AD 1402-1404 and AD 1493-1495). Again observations in thin section indicate decomposition and accumulation of organic matter is the primary soil forming process at this time, rather than the aeolian deposition more commonly associated with increasing SeARs. Pollen records for this time period suggest dense coverage of *Salix* scrub, with the closing of canopies highlighted by the disappearance of *Koeniga islandica*. Grazing and disturbance indicators are also found to be absent from the pollen spectra, indicating cessation of grazing, with stability in vegetation cover maintaining soil stability. These reduced grazing pressures may be linked to demographic declines following the initial epidemic (AD 1402-1404), with the country losing up to 60% of its population (Karlsson, 1996). Following population collapse, and the consequent contraction in labour supply, livestock are known to have impacted the landscape through lack of grazing management. In some areas the impact is through grazing of areas further from the abandoned home farms by feral animals. In others areas the lack of workforce meant livestock had to be kept closer to the farms, resulting in intensive grazing pressure here. At Viðatóft the formerly lightly grazed site appears to have been abandoned at this time, reducing grazing pressures. Comparable patterns of landscape resilience, over similar timescales (~50 years) are uncovered in the south of the country, with declines of geomorphological activity following each of the major plague events (Streeter et al., 2012). The second episode of plague (AD 1493-1495) can also be correlated with short periods of sediment stability at Viðatóft, although, as highlighted earlier, grazing reduction at this time can also be attributed to the harmful effects of tephra deposition on livestock survival. No changes in the palaeoenvironmental records at Vatnsfjörður and Gautlönd are associated with outbreaks of plague where the sedimentary conditions demonstrate more prolonged stability.

Following the deposition of the AD 1477 tephra at Viðatóft, SeARs increase rapidly compared to other historical periods. Micromorphological analysis of thin sections for the period are characterised by high frequencies of aeolian materials. These observations suggest a period of instability in the surrounding environment and synchronous with this is an increase in degraded pollen. Such increases are frequently associated with inputs of secondary pollen from eroded materials. So the increase in degraded pollen and the appearance of aeolian material during this period provides confidence that these are reworked grains sourced from eroded materials. Instability and reworking of pollen are again highlighted within the same core from the late 17th to mid-19th century. In this instance landscape instability is thought to have been exacerbated by deteriorating environmental conditions associated with the Little Ice Age and its accompanying patterns of increased geomorphic instability (Ólafsdóttir and Guðmundsson, 2002). Despite the prolonged period of instability, Viðatóft demonstrates its resilient nature with sediments becoming more organic and stable and mires dominating the site once more indicating a gradual improvement of environmental conditions to the present day. Stability and resilience appears also to be a key feature of the wetland at Gautlönd, from pre-settlement to the present day. Stability within the site continues from Landnám into the 15th century, with little further changes in the vegetation across this time, and is mirrored in the micromorphological analysis highlighting the limited extent of aeolian deposition.

Patterns of relatively intensive landscape instability during the Little Ice Age are identifiable in the thin sections from Vatnsfjörður and as increases in SeARs across the same time period, suggesting that the increased storminess had significant local impacts as well as the widely established regional ones (Ólafsdóttir and Guðmundsson, 2002). The organic sediments from the homefield of this site, however, have been robust, showing resilience to environmental change, with input of aeolian material during potential storm events appearing only as minor features in the stratigraphy. The limited proportion of collected sediments composed of aeolian materials is complemented by palynological evidence, in that peaks in corroded and degraded pollen, that would be expected to occur as a result of eroded and redistributed sediments (Cushing, 1964; Tipping, 2000), are largely absent. Analysis and comparisons between the three sites therefore suggests stability and resilience within the wet meadows was common to the three case studies.

6.5 Cultural impacts and management, from settlement to the present day

One of the key objectives of the study was to investigate cultural use and management of the wet meadow areas. To this end comparisons will be made between the local land use and management practices adopted within the three sites, as highlighted by palaeoenvironmental evidence, placing these meadows and their roles in the context of their wider farmscapes.

With the observed infertility of the homefields at Vatnsfjörður, it is likely the organic sediments within the meadow areas were recognised, developed and cultivated as an adaptive management practice for farming at subsistence levels in this landscape. The occurrence of this peat development on formerly free draining sediments is not unique to Vatnsfjörður. At the Norse settlement Igaliku, in Greenland's Eastern Settlement an abrupt change of lithology can be observed in the sediments of exposed fields. A change from sandy silty sediments to organic rich deposits, evidence in modern ditches excavated around the site, hints at a dramatic change in the local landscape following settlement (Buckland et al., 2009). Archaeological and palaeoentomological evidence points to the creation of these 'wet eutrophic hayfields/ anthropogenic fens' through the watering of fields using extensive irrigation systems that have been uncovered by archaeological surveys, and to the subsequent manuring of these wet areas creating extensive peat deposits over areas for improved hay yields (Buckland et al., 2009). No archaeological evidence for such extensive irrigation systems exist at Vatnsfjörður, nor indeed within any of the study farms. Furthermore, there is no clear evidence of irrigation in sediments, such as stratified layers of mineral material where inputs of mineral rich material are brought into the system by flood or irrigation waters (Vasari and Väänänen, 1986). The lack of evidence for irrigation at Vatnsfjörður is not conclusive, and there remains a possibility meadows were irrigated or that they periodically inundated naturally, which may account for the appearance of biosilicate micro-horizons observed in thin sections from the wet meadow. This interpretation is supported by historical evidence of homefield irrigation from other parts of Iceland with irrigation used to protect fodder crops from early summer frosts and as a natural supply of nutrients to encourage more productive land (Buckland et al., 2009; Sveinbjarnardóttir et al., 1982). However, site hydrology in the study farms might have provided these functions naturally, with seasonal periods of inundation protecting the grasses and sedges that dominate the areas and enhancing their resource value for use as winter fodder crops. With drying conditions also noted in the sediments at Vatnsfjörður, the grasses growing at the site would also benefit from the protection from frosts and thúfur development during periods of inundation, while dry periods would continue to enhance vegetation productivity during warmer periods as sediments heat up naturally, as is seen elsewhere in Iceland (Preusser, 1976).

In contrast to the unusual absence of improved homefield sediments at Vatnsfjörður, evidence of cultural additions to the meadow sediments are noted in thin section is present as micro horizons of manuring materials comprising household waste – charcoal, bone and turf - within the organic matrix. Manuring of meadows is not unique to Vatnsfjörður, with Zori et al. (2013) encountering bone and charcoal in a pollen core from Hrísbrú, thought to indicate that midden waste was spread onto the mires as fertilizer. The mires in this study are also likely to have been utilised as hayfields and the micro horizon material at Vatnsfjörður could be taken as evidence of this. An alternative explanation for the occurrence of this material in the meadow cores is sheetwash from surrounding managed fields as in Buckland et al., (2009), however presence of multiple discrete microhorizons of these materials suggest this is unlikely. This indicates the meadows were actively managed for the production of fodder crops, to see cattle through the harsh Icelandic winters, perhaps focussing on intensifying limited resources in a defined area to achieve greater productivity. At Vatnsfjörður these adaptive management practices were necessary as a coping strategy for dealing with the sites inherent infertility and in the face of limited resource availability, a pervasive issue for farms at the northern limits of agriculture.

Use and management of this area is further highlighted by the dominance of *Poaceae* in the pollen spectra immediately following settlement, remaining prevalent until the present day. This has prevented encroachment of sedges given the sites natural wet conditions, or succession to dense shrubby vegetation as is present in the undisturbed areas currently surrounding the site. Pollen and soils suggest both grazing and cutting activities potentially occurred within this wet meadow. Some grazing indicators are noted within the thin sections, including the presence of fungal sclerotia and calcium spherulites, frequently associated with grazing livestock. Dominance of *Poaceae* throughout further highlights this, with grasses under permanent and heavy grazing being continually removed prior to flowering and therefore unlikely to have produced the levels of pollen seen in the meadows (Waateringe, 1993). However, the variable presence of grazing sensitive tall herbs in the pollen record suggest the area was not exclusively used for grazing, suggesting perhaps aftermath grazing following the removal of grasses for winter fodder. Efforts made to sustain the meadow within the homefield appear to have been sufficient for the provision of adequate fodder and grazing for livestock at this farm and at a level suitable to help maintain the sites high status and wealth. This meadow area was resilient and able to withstand, with little detriment, the climatic downturns and increased storminess associated with the Little Ice Age.

Use and management of land resources within the Gautlönd farmscape appear variable from the settlement period onwards. Evidence of hayfield creation and intensive grazing took place in the drier areas surrounding the mire immediately after settlement, with grasses contracting in some parts of the pollen spectra. Intensive grazing may have caused this reduction, given that grass pollen productivity is known to decline where intensive grazing prevents its flowering (Broström et al., 2008; Waateringe, 1993). Fluctuations in *Poaceae* and *Cyperaceae* percentages in the pollen spectra are indicative of variable management practices including grazing and mowing, however given fluctuations in their occurrence and the absence of other evidence supporting these management techniques, it is not possible to confirm the nature and scale of these activities. Despite ethnographical records suggesting its occurrence, limited evidence for the frequency of mowing has been uncovered in palaeoenvironmental analysis, with palaeo-characteristics of mire mowing (Hallsdóttir, 1987) diluted by the complex nature of multiple human-ecodynamic processes operating within the meadows .

Latterly at Gautlönd a prominent vegetation shift is seen to occur, reflecting more modern farming techniques within the mires, as grasses expand within the site, explained by expansion and intensified use of parts of the farmscape and perhaps linked to modern drainage. At the same time grazing sensitive tall herbs vanish from the spectra, suggesting grazing is a dominant land use activity.

Of the three sites studied, Viðatóft is the only farm not continuously occupied, with the farm abandoned in the late 11th century. Following its abandonment however, low level grazing continued across the site, as suggested by continual absence of grazing sensitive species up to the 14th century. Farmscape scale processes associated with its abandonment are evident in the wetland sediments; *Salix* and *Cyperaceae* for example, encroached on the former hayfields following abandonment, and as former water management structures cease to operate. These re-wetting processes are mirrored within the wetland sedimentary records, as frequencies of diatoms steadily increase across thin sections.

Although limited in its palaeo-environmental evidence, the importance of these wetland areas appears to have been enhanced as severity of climate increased. With poorer winters comes a requirement to keep grazing animals indoors over an extended period, resulting in increased fodder resource requirements. Where outfield resources were exhausted or limited, wetland area were utilised as supplementary resources. Sedge communities when cut early, prior to blooming – when plants become more siliceous and less palatable to grazing livestock – provide a number of palatable species. Wetlands rich in palatable species that includes *Carex nigra, Carex lyngbyei, Carex canescens, Carex rostrata, Equisetum palustre and Equisetum fluviatile* were particularly attractive and were mown extensively in the past and continued until the last century (Hallsdóttir, 1987).

6.6 Issues and scope for further work improvements

The research developed in this thesis has been successful in identifying the long-term processes of wet meadow formation and how they were utilised in the Icelandic Norse farmscape context. Nevertheless a number of areas have been identified where the robustness of the results could be enhanced, with these presented as opportunities for future research.

One key issue for rigorous interpretation of Icelandic pollen data is lack of information on pollen taphonomy in the Icelandic environment. To date only one study exists investigating pollen-vegetation relationships in Iceland (Rymer, 1973). This paper is dated and limited in content; demonstrating relationships between modern vegetation and pollen production for only a restricted range of habitat types present in Iceland and does not include any quantifications of pollen rain associated with farm environments. Furthermore, there is no representation of historical landscapes which have been substantially altered in comparison with the present day vegetation. The current lack of research into Icelandic pollen taphonomy renders it difficult to draw conclusions on landscape change from pollen data alone. In this study interpretation of the pollen diagrams, particularly with regards to proximity of vegetation communities, has been drawn from published pollen diagrams, as well as comparing values with studies from other North Atlantic and Northern European countries. However it is unlikely that Icelandic values will be the same given the scale of aeolian sediment transport and conditions for pollen preservation within the soils (Lawson et al., 2007). This highlights an urgent requirement for renewed modern surface sampling to produce estimates of relative pollen productivities in the varied landscapes across Iceland and with specific focus on farmscapes. This would allow a more robust understanding of palynological visibility of a wider range of habitats and specific farm practices in Iceland, ultimately leading to more accurate interpretation of pollen diagrams.

Within this thesis pollen data was interpreted using indicator species approaches (Behre, 1986). More quantitative means of interpreting pollen data do exist; these include the simple ring source modelling approach used in POLLSCAPE (Sugita, 2007a, 2007b; Sugita et al., 1999), and the more complex multiple source modelling in HUMPOL (Bunting and Middleton, 2005). These approaches assist in the quantitative reconstruction of past vegetation cover from pollen assemblages, helping visualise how farms might have appeared to the Norse as they created, and worked within farmscapes. However, these models have only been verified to a limited extent in open arctic and sub-arctic environments (Ledger, 2007), with one recent study focussing on calculating the estimates of relative pollen productivity for certain taxa in Greenland (Bunting et al., 2013). Given the absence of such studies in Iceland to date their applicability in Icelandic pollen studies at present would be ambiguous, highlighting once more the imperative for modern surface pollen samples, required for estimation of relative pollen productivities of taxa as input for these models.

One taphonomic issue that has been resolved in this thesis is the degree to which aeolian processes impact pollen records at any one point in a stratigraphical section. Through the combination of pollen analysis and soil micromorphology, frequencies of aeolian inputs can be compared with pollen values, with a particular focus on frequencies of biochemically deteriorated pollen, frequently regarded as being sourced from eroded deposits (Tipping, 2000). Relative comparisons of the two methods have been used to decipher whether the pollen spectra provides a reliable indication of past vegetation or has been the result of pollen input from eroded and redistributed sediments.

Taxonomic precision available to palynologists creates issues for interpretation of pollen records, with local scale changes between dryland and mire communities difficult to interpret in the pollen signal, because of a spread of many species within both communities. For future studies this may be improved through application of other palaeoenvironmental proxies which provide more local level environmental studies such as plant macro or phytolith analysis. Application of these methodologies may also overcome the taxonomic limitations of pollen data where taxa are often only identifiable to genus level. Phytolith and plant macro may allow identification of more plants to species level. Where this information is available nutritive content of the species present, especially grasses and sedges, could then be assessed, helping understand the past value of these meadow areas in terms of their nutritive content and therefore significance as a resource for grazing or fodder production.

Notwithstanding the issues highlighted above, the methods employed in this thesis have proven to be successful in their own right, with new understandings emerging from the combination of sediment stratigraphy, pollen analysis and soil micromorphology. Given the relative ease of sampling and the possibilities of extracting large quantities of information from a pair of adjacent cores, this methodology could be easily employed in similar wetland habitats associated with archaeological sites. Wetlands areas associated with homefields in Greenland for example would present ideal opportunity to further test these methods.

6.7 Conclusions

The aim of this thesis was to develop a better understanding of how wet meadows associated with farms developed, and how they were used and managed in a Norse cultural context linking their management to overall farm management and resilience and investigating their impacts on settlement site choice. In order to address this aim three meadows were selected and analysed using an integrated method set combining chronostratigraphy, soil micromorphology and high resolution palynology, and the findings reflected against existing palaeo-climatic and archaeological data, going on to assess cryptotephra how well these methods work together. The results from these methods uncovered three very different meadow systems associated with the farms.

Of the three farms investigated, two of the farms – Gautlönd and Viðatóft - both within the Mývatnssveit district of northern Iceland, had natural wet meadows present prior to settlement. Meadows at Vatnsfjörður in northwest Iceland developing only after the sites occupation; with no organic soils evident prior to settlement. Palaeoenvironmental analysis of organic sediments from the Mývatn sites indicate the presence of wet meadows in largely open sites, with a variety of vegetation types present within their farmscapes. The initial cultural functions of these meadows were in the provision of attractive settlement sites, supporting the suggestions of Vésteinsson's (1998) model for early settlement. In this model early farmers were attracted to sites with mires because of their natural clearances, allowing for ease of setting up farms, and the mire produced quality fodder resources. Palynological evidence further highlights their attractiveness in contributing to the variable nature of vegetation communities present within the farmscapes. This variability included the natural mires, grasses, shrubs and woodland, which alongside close proximity to lakes, with the potential to supply freshwater resources, indicates a rich natural resource base for these sites. In contrast, Vatnsfjörður is more unusual in this respect in that despite its early settlement, the site selected demonstrated inherent infertility, with the location likely appealing to settlers as a result of its easy access to marine resources.

Given these observations, the new data gathered and interpreted in this thesis brings greater clarity to the emerging school of thought that more variable landscapes than previously assumed existed prior to settlement. The new evidence suggests a landscape supporting tracts of open wetland vegetation, not solely dense coverage of trees and shrubs, as suggested in early documentary resources and pollen studies (Hallsdóttir, 1987; Magnússon and Vídalín, 1990). This study makes a valuable contribution to the understanding of the environmental history of Iceland, helping change opinions of vegetation since settlement by proving further evidence of variability in the landscapes at Landnám, and challenging theories of widespread disturbance following settlement. Each of the study sites demonstrates very little change in vegetation community structure and experienced only minor instability following settlement. In this respect stability may be considered as a key feature of wet meadow localities and demonstrate a higher tolerance threshold to anthropogenic impacts. This stability is evident in the meadow sites with respect to environmental impacts, with meadow sites generally remaining stable, or demonstrating a high degree of resilience following environmental impacts such as tephra deposition and climatic changes, both during and prior to the settlement period. These findings strongly support the necessity to consider the sites at the farm scale complemented by landscape scale analyses.

In addition to their varying status at settlement, a key finding of the study is identification of the variable uses and management practices associated with the mires. At Vatnsfjörður the meadow created following settlement was found to have been intensively managed, with evidence of manuring as well as mowing and grazing for enhanced provision of fodder to see livestock through Iceland's harsh winters. The meadows at Gautlönd appear not to have been managed so intensively, with more muted evidence of mowing and grazing recorded in the sedimentary records. Here the meadows were more likely used as a supplementary resource within a wider and rich resource base. They were a resilient buffer for a series of environmental and climatic downturns since settlement contributing to overall stability of the farm resource base. At Viðatóft the wet meadows were perhaps considered less important a fodder resource and were more significant in providing an open site for the ease of farm establishment. Here, following settlement, the wet meadows appear to have been drained, with subdued evidence for grazing and hayfields during the period of occupation. This grazing continued at low levels following the sites abandonment and return to wetter conditions.

Adaptive land management practices evidenced within the wet meadows provides further examples of nuanced resource management techniques adopted in the agriculturally fragile farmscapes of the Norse North Atlantic, maintaining and enhancing vegetation productivities even under deteriorating climatic conditions (Adderley et al., 2008; Adderley and Simpson, 2005, 2006; Golding et al., 2014; Simpson et al., 2002). New understandings gained from wetland sediments considered in this study are an important addition to existing knowledge of careful management of environmentally sensitive landscapes in the North Atlantic. A range of sustainable land management practices appropriate to the fragile North Atlantic environment have been identified in a number of studies. Regulation of fuel resource use and management, where these resources are limited, have been identified in a number of settlement sites (Simpson et al., 2003); environmentally sensitive grazing practices have been evidenced (Brown et al., 2012; Thomson et al., 2005; Thomson and Simpson, 2007) and homefield management strategies including adaptive irrigation systems and manuring recipes for the sustainable production of cereals and fodder crops have been observed (Adderley et al., 2008; Golding et al., 2014; Simpson et al., 2002). This work has provided a fuller and more comprehensive understanding of the elements of the Norse farm systems and its operation in Iceland.

Given their variable presence and use across farms, it is clear wet meadows were not a prerequisite for settlements. They did however provide open areas at settlement, through inability of birch woodland to thrive on wetland areas, and so made the establishment of farms in a potentially dense shrubby landscape easier, as extensive clearance was not required. Perhaps more importantly they were used as an additional natural resource, creating a more robust and resilient resource base for settlements, and would have been especially useful in those years experiencing climatic downturns, contributing to fodder resources and where flooded, protecting the ground from hard frost thus promoting earlier productivity.

With the advent of modern agricultural techniques these areas may have now lost their economic value, but given the wealth of palaeo-environmental information held, they are of major importance because of their contribution to understanding ecological and cultural heritage. In this respect the techniques developed in this thesis can now be readily applied to wet meadows in other areas of the North Atlantic region, helping to enhance understanding of the early Icelandic farming system and improve the spatial scale of palaeoenvironmental research in Iceland, which to date is not comparable with that elsewhere in northwest Europe (Hallsdóttir and Caseldine, 2005). Given the wealth of archaeological excavations in Iceland there are major opportunities to explore the complexities of human-environment relationships further at similar sites.

Palaeoenvironmental research continues to teach us more about ecosystem responses to natural and anthropogenic stresses, allowing us better understanding of how we might best respond to future stresses. This will remain a key issue for the foreseeable future in our time of global uncertainty.

Chapter 7 References

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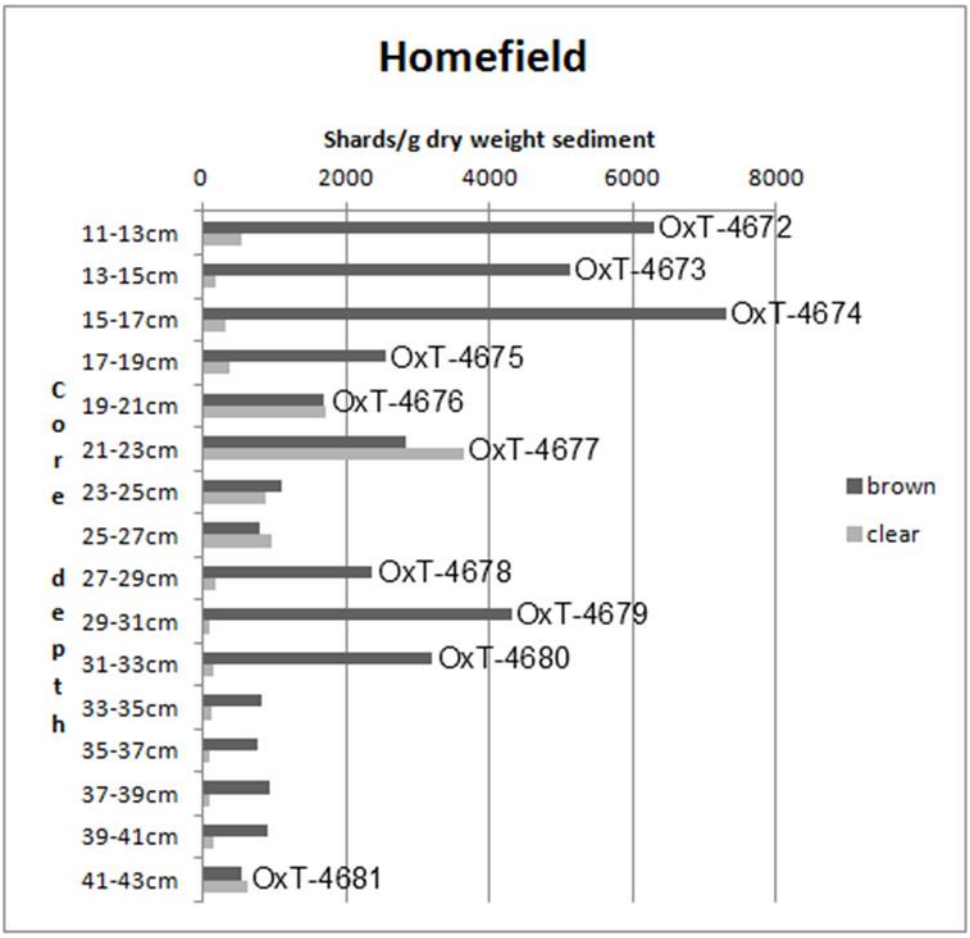
Appendix 1

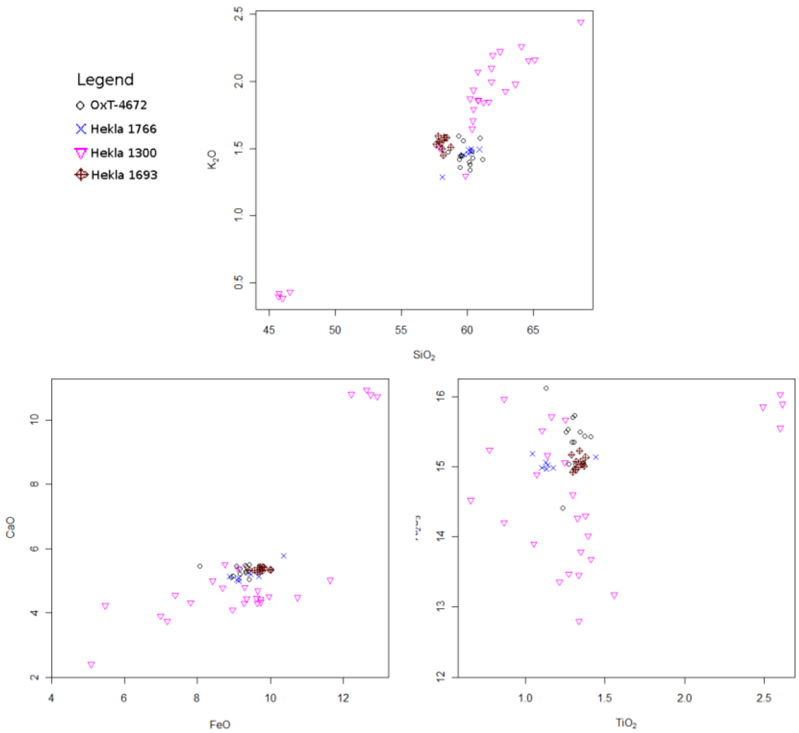
Vatnsfjörður Tephra Layers Data



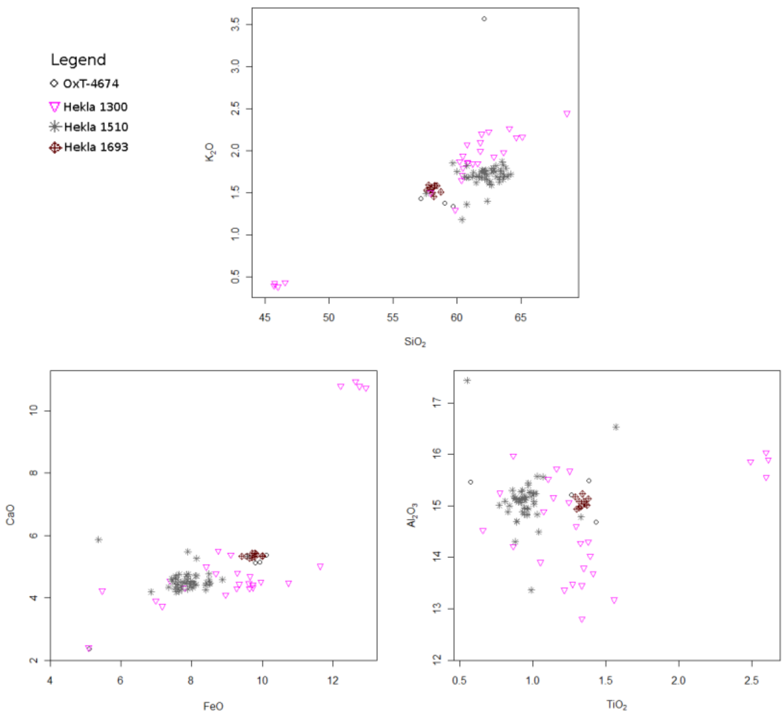
Tephrostratigraphy for the Vatnsfjörður homefield core

Summary WDS-EPMA data (after filtering) for the samples extracted from the Homefield core. This table shows the average compositional percentage and standard deviation to 1σ. Where applicable, the data have been divided into compositional groups based on shard colours. The data in this table have not been normalised.

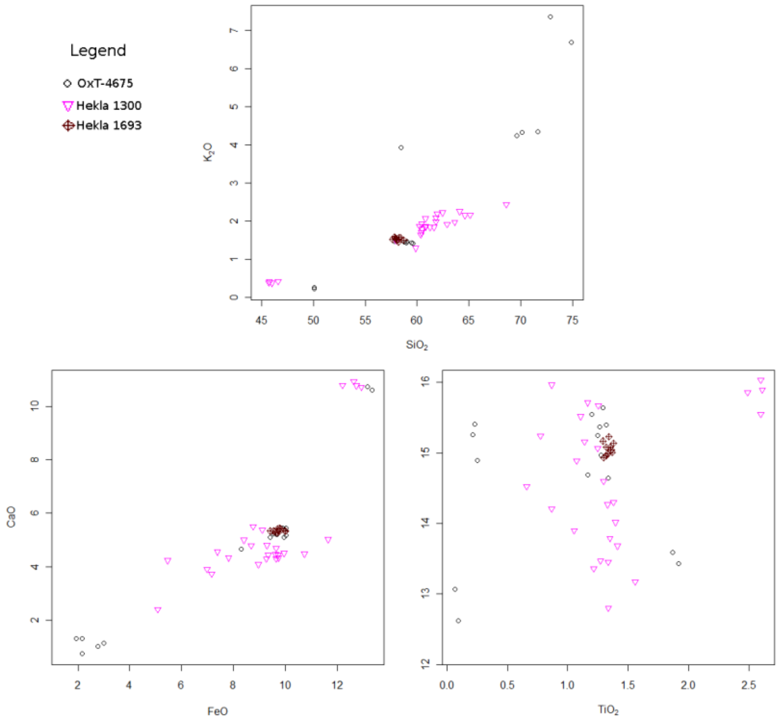
Sample	OxT-4672	n=15	OxT-4674	n=4	OxT-4675 I	n=11	OxT-4675 I	n=5	OxT-4676	n=8	OxT-4677 I	n=8	OxT-4677 I	n=8	OxT-4679	n=22	OxT-4680	n=17	OxT-4681	n=16
	mean	standev	mean	standev	mean	standev	mean	standev	mean	standev	mean	standev	mean	standev	mean	standev	mean	standev	mean	standev
SiO2	59.91	0.68	58.65	1.32	58.53	0.97	71.07	1.48	60.68	2.09	49.23	1.31	59.37	0.44	59.83	0.42	59.58	0.71	62.56	6.22
TiO2	1.30	0.07	1.36	0.09	1.28	0.08	0.19	0.07	1.13	0.35	3.65	1.07	1.29	0.04	1.29	0.09	1.29	0.08	0.95	0.56
Al2O3	15.35	0.40	15.13	0.41	15.17	0.36	14.55	1.30	14.81	0.89	13.05	0.26	15.35	0.18	15.57	0.52	15.39	0.19	14.96	1.15
FeO	9.22	0.39	9.95	0.16	9.60	0.53	2.47	0.50	8.54	1.98	14.41	0.89	9.47	0.22	9.46	0.45	9.51	0.21	6.35	3.17
MnO	0.25	0.05	0.27	0.11	0.29	0.06	0.12	0.09	0.25	0.05	0.20	0.07	0.26	0.04	0.24	0.04	0.27	0.07	0.19	0.06
MgO	1.77	0.15	1.87	0.03	1.84	0.14	0.09	0.09	1.28	0.52	5.22	0.52	1.84	0.06	1.76	0.13	1.80	0.08	1.55	2.07
CaO	5.32	0.15	5.21	0.13	5.20	0.25	1.05	0.24	4.58	1.20	9.79	0.63	5.34	0.09	5.33	0.23	5.33	0.20	3.97	3.18
Na2O	3.51	0.40	3.58	0.06	3.74	0.31	4.43	1.69	4.36	0.96	1.20	0.23	3.55	0.43	3.65	0.50	3.39	0.69	4.38	1.33
K2O	1.45	0.08	1.38	0.05	1.74	0.82	5.07	1.53	1.86	0.65	0.60	0.21	1.42	0.06	1.42	0.15	1.42	0.08	2.60	1.51
Correlation	Hekla 1766		Hekla 1693 upper limit?		Hekla 1683		Unknown		Hekla?		Hekla 1300 upper limit? and/or Katla 1357?		unknown		Hekla 1300		Hekla 1300 lower limit		Mixed population and rhyolitic component of landnám?	



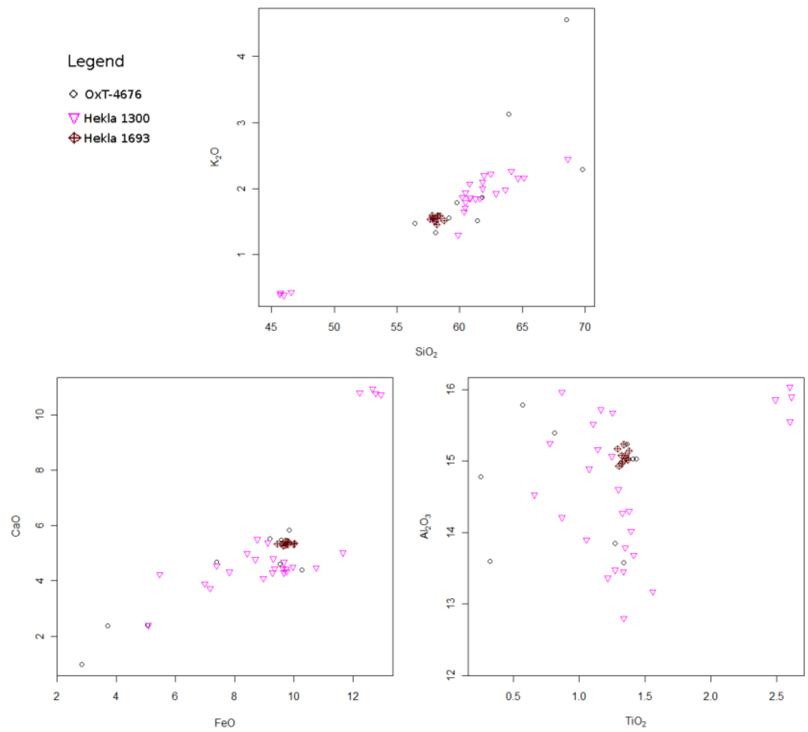
Comparison of OxT-4672 with published proximal data for Hekla 1300, Hekla 1693 (Dugmore et al. 2007), and Hekla 1766 (Larsen et al. 2011). All units are in wt-%.



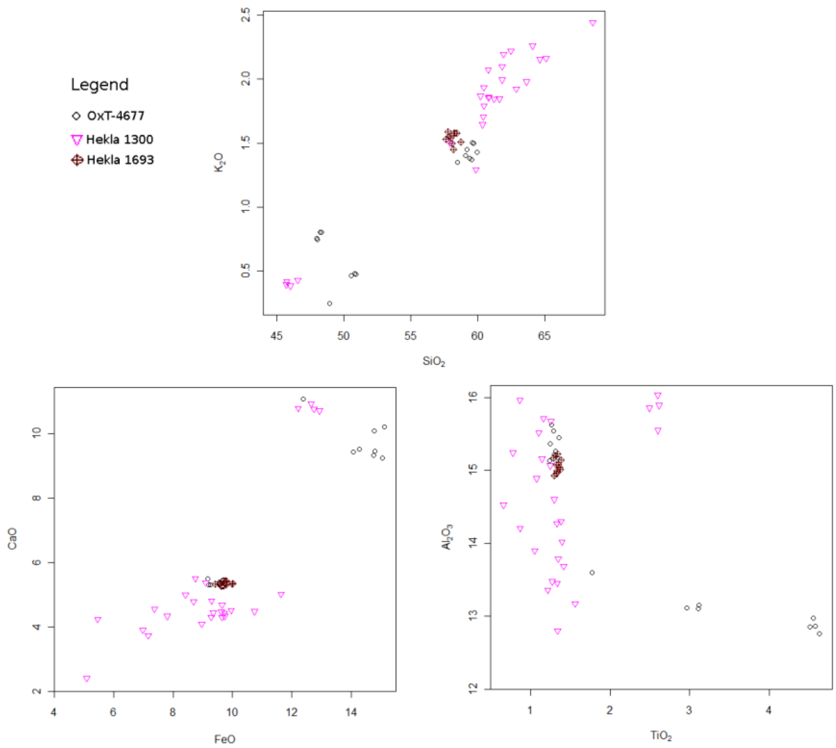
Comparison of OxT-4674 with published proximal data for Hekla 1693, Hekla 1300 (Dugmore et al. 2007), and Hekla 1510 (Larsen et al. 1999). All units are in wt-%.



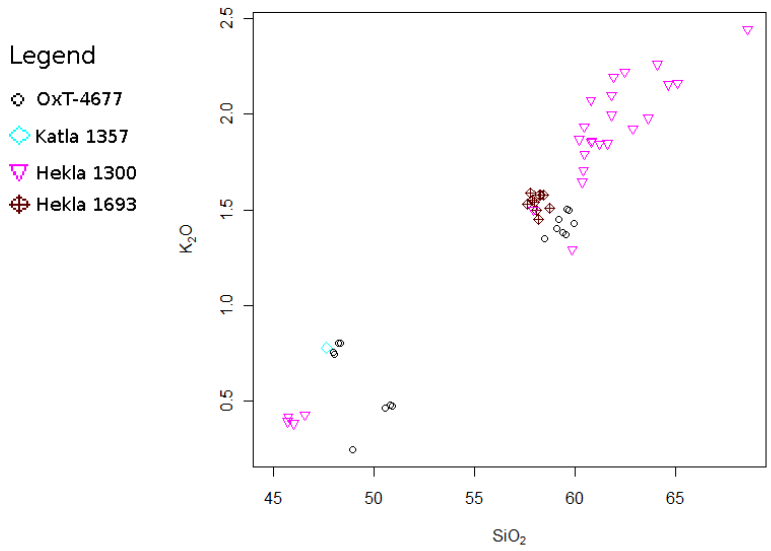
Comparison of OxT-4675 with published proximal data for Hekla 1693 and Hekla 1300 (Dugmore et al. 2007). All units are in wt-%.



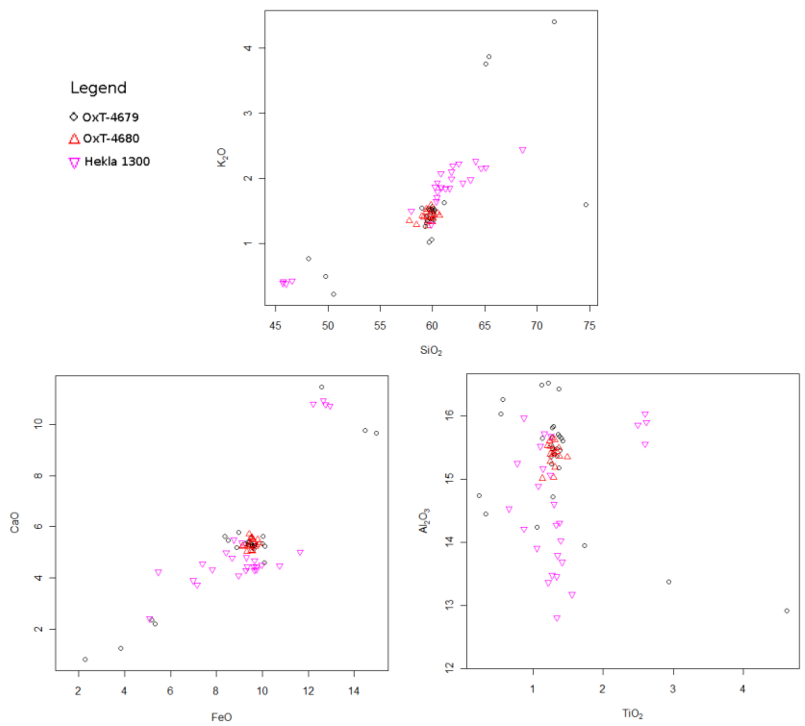
Comparison of OxT-4676 with published proximal data for Hekla 1693 and Hekla 1300 (Dugmore et al. 2007). All units are in wt-%.



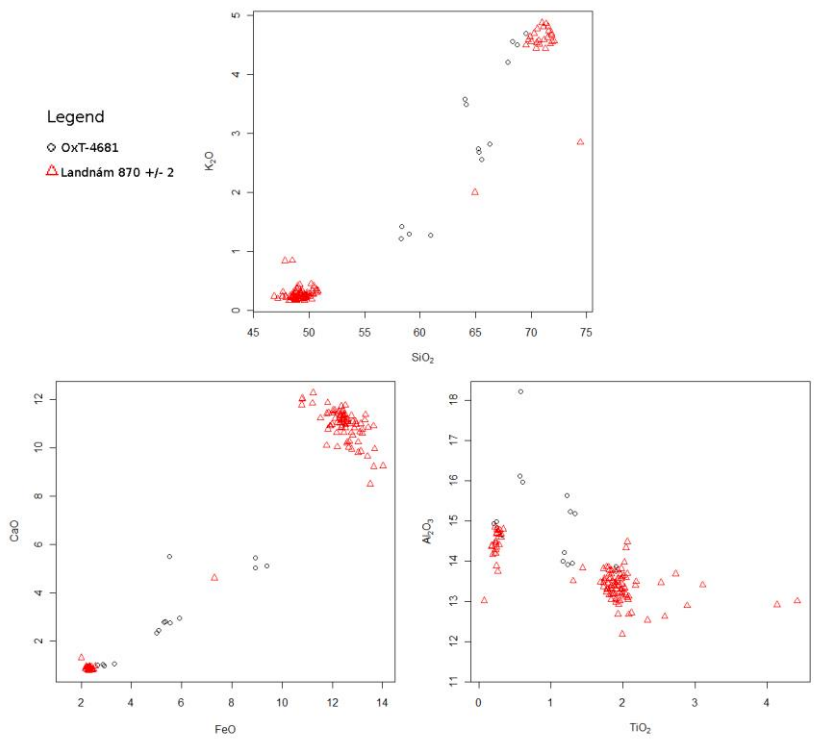
Comparison of OxT-4677 with published proximal data for Hekla 1300 and Hekla 1693 (Dugmore et al. 2007). All units are in wt-%.



Comparison of OxT-4677 with published proximal data for Katla 1357 (Einarsson et al. 1980), Hekla 1693, and Hekla 1300 (Dugmore et al. 2007). All units are in wt-%.



Comparison of OxT-4679 and OxT-4680 with published proximal data for Hekla 1300 (Dugmore et al. 2007). All units are in wt-%.



OxT-4681 is shown with the Landnám tephra, which dates to ca. AD 870 (Grönvold et al. 1995).