Human responses, resilience and vulnerability:

An interdisciplinary approach to understanding past farm success and failure in Mývatnssveit, northern Iceland

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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.

Signature of candidate:

Date: 05/06/10

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Abstract

This thesis presents a new perspective on the study of past farm success and failure; it builds on the concepts of resilience and vulnerability to construct a theoretical framework which integrates environmental, historical and ethnographical data. The basic framework establishes that the resilience or vulnerability of a social-ecological system is a function of three factors: *i*) the exposure of the system to external (environmental) stresses, *ii*) the sensitivity of the system to these stresses and *iii*) the ability of the human component of the system to respond to them. The research focused on the component of human capacity of response (the sum of coping and adaptive capacity) within this framework. The temporal scale of the study was the 18th century, although reference is made to earlier periods for comparison. The location of the study area was Mývatnssveit, a livestock-based farming community in northern Iceland, while the spatial scale of the study is that of individual farms in the area.

The results showed that successful farms had a higher capacity of response than failed farms, and that this was conferred by a greater availability and quality of resources, including human resources, natural resources and productive resources (those directly involved in agriculture). Human resources were assessed by records of number of servants per farm and by evidence of learning/knowledge transfer obtained via micromorphological analyses of home-field soils. Natural resources considered to be of particular importance were fish and eggs. Indicators of productive resources included tax value, land rent, livestock numbers and phosphorus content in home-fields. The latter revealed that the soil condition pre-settlement was linked to its post-settlement quality.

An analysis of present day perceptions of historical farm abandonment in the area corresponds with the conclusions reached through the data integration in placing the human factor above the environmental one in influencing success and failure. The thesis concludes by highlighting the individuality of the study farms and the historical resilience of the livestock-based farming system. Additionally, areas of potential for future research are identified.

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Chapter 1 -Introduction and aims: the success and failure of societies under environmental stress

1.1 Introduction

Throughout history societies that depended mainly on renewable resources for their subsistence have risen and then fallen (Pezzey and Anderies, 2003). One of the most popular explanations for the collapse of civilizations has been unfavourable environmental change (Huntington,1915; Miller Rosen, 1995). However, studies considering solely the climatic explanation are too simplistic and increasingly more research projects acknowledge as multi-causal the collapse of civilizations (Tainter, 1988; Miller Rosen, 1995; Diamond *et al.*, 2005). Most studies exploring multiple causes of collapse have successfully identified external stresses to societies but have failed in analysing the complexity of human responses to these stresses. Moreover, the use of the term “collapse” in this context has been contested (Eisenstadt, 1988; Tainter, 2006; McAnany *et al.*, 2010). Most of the “classical” examples of societal collapse, for example the Mayas and Easter Island did not result in the complete extinction of the population but in changes in political forms, economies and landscapes. It has been recognized by some researchers that notwithstanding the external stresses a society is exposed to, generally complex societies have built-in social, economical, and technological mechanisms to deal with and adapt to these stresses (Kirch, 1980; Butzer, 1982; Holling *et al.*, 2002b). Many other researchers have raised the question of why then a society fails to adapt to changing environmental conditions (e.g. Thorarinsson, 1961a; de Vries, 1980; Green, 1980; McGovern *et al.*, 1988). In these studies, adaptation and human responses to stresses are generally studied at the level of the whole nation or society. However, complex societies do not respond to environmental change in a uniform manner, different segments of society may respond to stress in completely opposite ways (Miller Rosen, 1995). Moreover, the major part of humanity's adaptation comes at the local level (McIntosh *et al*., 2000). In this context, the aim of this thesis is to reach a better understanding of human responses and adaptation to environmental change in rural societies in relation to farm success and failure.

The study of societal-environmental interactions, in particular impacts and adaptation to climatic and landscape change, has gained attention in recent decades as a result of global warming prognostics. Research aiming to influence policy has typically focused on studying the present and future of these societal-environmental interactions and not historical situations. Exceptions to this are Fraser's (2006; 2007) studies using the famine situations of Ireland in 1845 (the "great Irish potato famine"), Asia during the Colonial period and Ethiopia between 1965 and 1997 as case studies. Fraser's studies show how changes over time in three key areas: resilience of the agro-ecosystem, livelihood options (diversity of resources) and institutions of help modify the vulnerability of agricultural societies to environmental change. An important aspect of this research is that it highlights that the systems under study are not static and in some cases even small changes over time can produce the collapse of the system. The study of historical situations and long term dynamics can provide important insights into societal adaptation processes and the factors that contribute to a stress resulting in an impact or not. This better understanding of the past can translate into important lessons for the present and future.

The focus of the present research is the historical success and failure of farms in a marginal North Atlantic environment (i.e. Iceland). The term marginal is applied here not only in the geographical sense of the word but also in the political and economic sense. As Mondini and Muñoz (2004) assert, marginality is “a dynamic concept”, being relative to the properties of the areas, environments and populations involved, which vary through history. The term “farm”, on the other hand, refers not only to the physical environment but also to the social component interacting with it. In this sense, “farm” matches the definition of social-ecological system (SES) defined by (Gallopín, 1991) as “a system that includes societal (human) and ecological (biophysical) subsystems in mutual interaction”. This study will require the integration of variables from both the social and the ecological components of the system; thus it is necessary to define a theoretical framework that allows this.

1.2 Theoretical framework

The terms resilience, vulnerability and adaptive capacity have been used recently in numerous interdisciplinary studies regarding the interactions between people and nature. The difficulties in defining these concepts have been acknowledged (e.g. Walker *et al.*., 2004) and have resulted sometimes in the ambiguous use of the terms, or differences in their meaning according to the discipline and context in which they are used. A review of the origins and particular connotations of the terms used in this study is given below.

1.2.1 Resilience

The term resilience was originally used in the natural sciences as a measure of the ability of natural systems to absorb changes and persist (Holling, 1973). Since then, different meanings of the term have been proposed (see Gunderson, 2000 for a review).

For example, resilience has been connected with the idea of stability or the tendency of a system to return to an equilibrium state when disturbed (Ludwig *et al*., 1997). In this sense, two types of resilience or levels of stability are generally defined: a) local stability or engineering resilience and b) ecological or ecosystem resilience. Engineering resilience makes the assumption that systems have a single or global equilibrium condition (Holling, 1995; Gunderson, 2000; Holling *et al*., 2002b), and hence resilience is measured by the ability of the system to resist perturbation and the speed at which the system returns to the equilibrium condition after perturbation (Pimm, 1984). With ecological resilience, systems are considered to have multiple equilibrium states or "stability domains". In this case, resilience is measured in terms of the amount of change the system can undergo before changing to another stability domain (Holling, 1973; Gunderson, 2000; Holling *et al*., 2002b; Turner, 2003). The "stability landscape" (Walker *et al*.., 2004) and the "marble-in-a-cup" or "ball-and-cup" (DeAngelis and Waterhouse, 1987; Scheffer, 1997; Gunderson, 2000; Carpenter and Gunderson, 2001; Scheffer *et al*., 2002) metaphors have been commonly used to illustrate both definitions. Figure 1 shows a ball-and-cup diagram where the ball represents the system and the cup represents the stability domain or basin of attraction. "A" represents engineering resilience where only one cup exists, in here the slopes of the cup determine the return time of the ball when it moves. In "B" and "C" there are multiple cups and therefore illustrate ecological resilience. In "B" the ball is in a desirable cup but mismanagement or maladaptive strategies and external stresses can change the shape of the cup (C) making the ball fall into an undesirable one. The number and shape/depth of the cups is changing continually due to external (e.g. climate) and internal (e.g. management practices) stresses. The objective of the social component of the system (the people) is to identify the desirable cup and prevent the ball from falling into an undesirable one from which it may be difficult or impossible to get out.

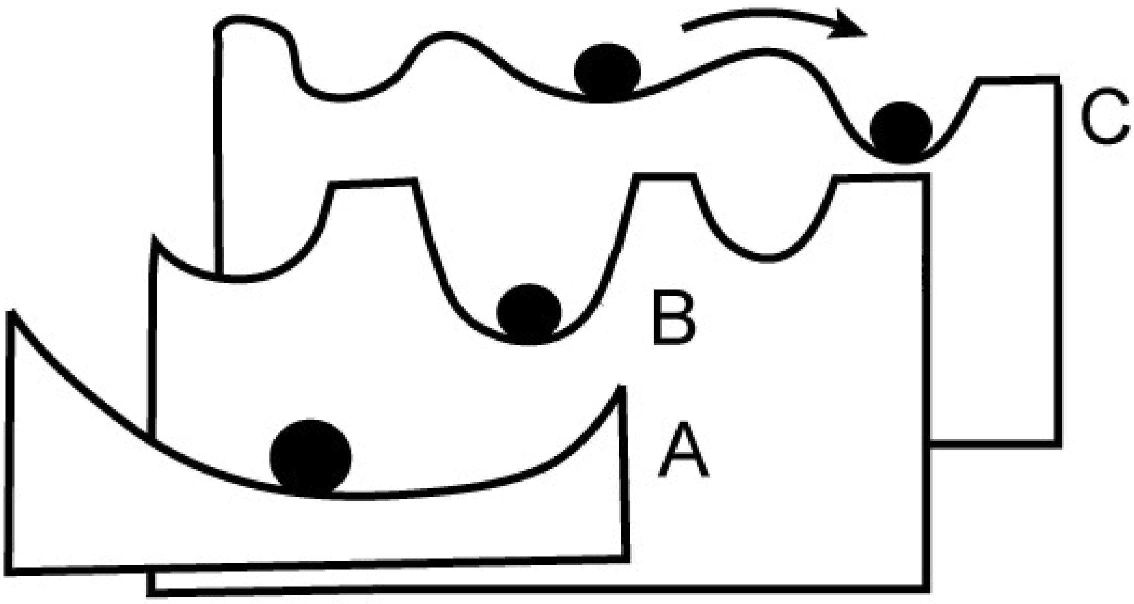

Figure 1- "Ball and Cup" Metaphor (Gunderson, 2000).

A good example of this process is vegetation degradation in arid ecosystems (Rietkerk and Van de Koppel, 1997; Scheffer *et al.*, 2002). In this example, three main different vegetation states can be distinguished in arid and semiarid areas, according to the amount and type of biomass present: woodlands, perennial herbaceous vegetation and desert. Each of these states represents a basin of attraction; an increase in grazing pressure can cause the change of the woodland state into any of the other two states. Woodlands, once lost, often do not recover due to grazing of seedlings. In the desert state, on the other hand, erosion, sun-burning of seedlings, and lack of capacity of the soils to retain water can prevent plant re-colonisation even if all the grazers are removed. These shifts represent catastrophic transitions to alternative stable states, which are difficult to revert (Scheffer *et al*., 2000; Scheffer *et al*., 2002). Although this example is typically applied to desertification in arid rangeland systems, it can also be applied to the historical transformation in Iceland of many woodland areas into rangelands and these into arctic deserts afterwards.

This concept of ecosystem resilience is considered by Holling and Gunderson (2002b) in their "Panarchy" framework. In this framework, resilience is one of three properties of an adaptive cycle consisting of periods of colonisation (exploitation), resource accumulation (conservation), collapse (release) and reorganisation. The other two properties of the cycle are connectedness and potential (Figure 2). Connectedness refers to the degree or strength of connectivity of individuals in the ecosystem both in space and time, and provides an indication of the degree to which a system can be controlled by external factors. Potential is defined by the accumulated resources which determine the potential for other uses or future options. For example, in terrestrial ecosystems after a disturbance there is rapid colonization by r-strategists (organisms characterised by high dispersal ability and rapid growth) and accumulation of biomass which leads to an increase in the potential for change. New species fill available ecological niches and connectivity increases, K-strategists (more competitive species with slower growth rates) out competes less successful species and diversity decreases. At this stage the system is vulnerable to disturbances, a disturbance then releases accumulated resources and returns the system to a state of higher diversity, less connectivity, and less wealth.

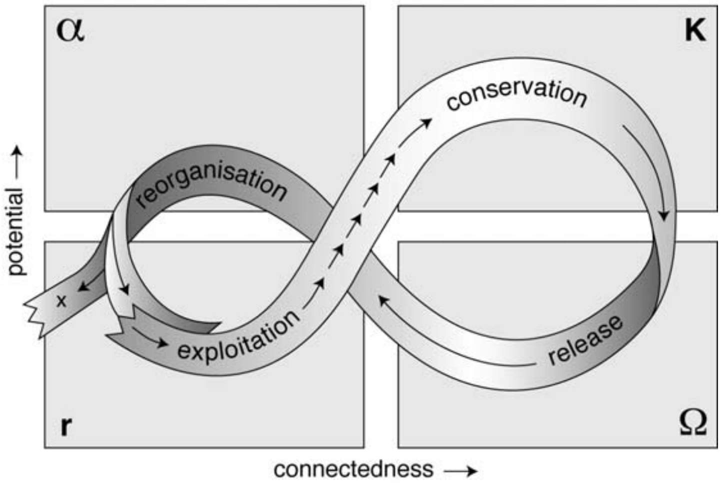

Figure 2- Adaptive cycle metaphor from the Panarchy framework. The squares show ecosystem functions (r, K, Ω, α). Closely spaced arrows indicate slowly changing conditions and long arrows rapidly changing conditions. The Y axis represents the potential in the accumulated resources and the X axis the degree of connectedness among controlling variables. The exit (x) suggests the stage where a flip from state is most likely to happen. After Holling and Gunderson (2002).

There are many limitations to this framework; Holling and Gunderson (2002b) acknowledge that the adaptive cycle is a metaphor that is too general to be viewed as a testable hypothesis. Also, it was developed specifically for productive temperate ecosystems so it does not work in all ecosystems. Fraser (2006) considers that the Panarchy framework is not particularly relevant to human managed ecosystems such as those found on farms, where farmers can and do adapt to changing environmental circumstances by using their own knowledge and experience, and that of those with whom they have contact.

1.2.2 Vulnerability

Vulnerability in its most general meaning can be defined as the susceptibility to be harmed (Blaikie *et al.*, 1994; Moss, *et al.*, 2002; Luers, 2005; Adger, 2006). In this sense, vulnerability is considered the reciprocal state or antonym of resilience (Vincent, 2004). Although most of the literature coincides with this point (Holling and Gunderson, 2002; Vincent, 2004; Folke, 2006; Ford *et al*., 2006), there is in general, little integration between the research literature on resilience and that on vulnerability. Thus, in the vulnerability literature two main research traditions can be distinguished; the analysis of vulnerability as "lack of entitlements" and the analysis of vulnerability to "natural hazards". In the "entitlements" approach, vulnerability is defined as the state of individuals, groups or communities in terms of their ability to cope with and adapt to external stresses, where this ability is determined by the extent to which they are entitled to make use of resources (Sen, 1981; Adger and Kelly, 1999). In this approach people are vulnerable when they have insufficient income and wealth. The advantage of this approach is that it can be used to explain situations where populations are vulnerable to famine even when there are no absolute shortages of food or obvious environmental stresses at work. However, in highlighting the social component of vulnerability, this approach underestimates ecological and physical risk (Adger, 2006). The hazards tradition developed into three overlapping areas: natural hazards, human/political ecology, and the so called pressure and release model (PAR) that bridges the first two. The natural hazards approach emphasizes environmental stress, and so vulnerability is viewed as the risk of exposure of a system to a hazard (Vincent, 2004). When compared to the entitlements view, this approach overlooks the social component of the system. In the human/political ecology tradition, vulnerability refers to a social unit of exposure and the economic, political and social institutions and structures that govern human lives (Vincent, 2004; Adger, 2006). The PAR model (Blaikie *et al*., 1994), on the other hand, is based on the idea that disaster is the result of two opposing forces; physical or biological on one side and the processes generating vulnerability on the other. The "release" idea refers to the relief of the pressure by reducing vulnerability in order to avoid disaster.

In general, traditions of "resilience" and "vulnerability" reflect their origins in ecological and sociological research, respectively. Therefore, in SES research the terms are used as antonyms.

1.2.3 Adaptive and Coping Capacity

The term "adaptation" like resilience, has its origins in the natural sciences, where it is generally defined as the development of genetic or behavioural characteristics by organisms in order to survive and reproduce in the face of environmental change (Futuyama, 1979; Winterhalder, 1980; Kitano, 2002). In SES, adaptations can be viewed as changes the system undergoes in order to deal with stresses and sensitivities. The relative ease with which adaptations can occur is termed the "adaptive capacity" of a system (Smit and Wandel, 2006).

The terms "adaptive capacity", "coping capacity" and "capacity of response" are generally seen as synonyms. However, some researchers make an important distinction between capacity to cope or respond and adaptive capacity (see for example Moss *et al*., 2002; Turner, 2003; Gallopín, 2006; Smit and Wandel, 2006). The main difference between coping and adapting is in terms of time scales: coping strategies are short-term responses to abnormal periods of stress (Moss *et al*., 2002), whereas adaptation is the restructuring of the system after the responses taken for longer term, more sustained adjustments (Vogel, 1998; Turner, 2003). Both factors influence vulnerability and resilience. For example, Brooks *et al*. (2005) highlighted that the vulnerability to hazards associated with climate variability that may occur in the immediate future will be related to a system's existing short-term coping capacity rather than its ability to pursue long-term adaptation strategies. "Thresholds" or "coping ranges" diagrams have been used to analyze adaptive and coping capacity (e.g. Smit *et al*., 1999; Vincent, 2004; Smit and Wandel, 2006).

Figure 3 shows a threshold diagram illustrating the differences between coping and adaptive capacity. Coping and adaptive capacities are not static. If a stress is weak and short-lived (A) as in many natural hazards, the coping range may be unaffected. A more prolonged or intense disruption (B) may result in the coping range being reduced immediately after the exposure as resources are diverted into coping mechanisms (C), thus if there is a further hazard exposure within a short time period vulnerability might be higher than otherwise. However, continued exposure to stresses may promote social learning and the expansion of adaptive capacity (D).

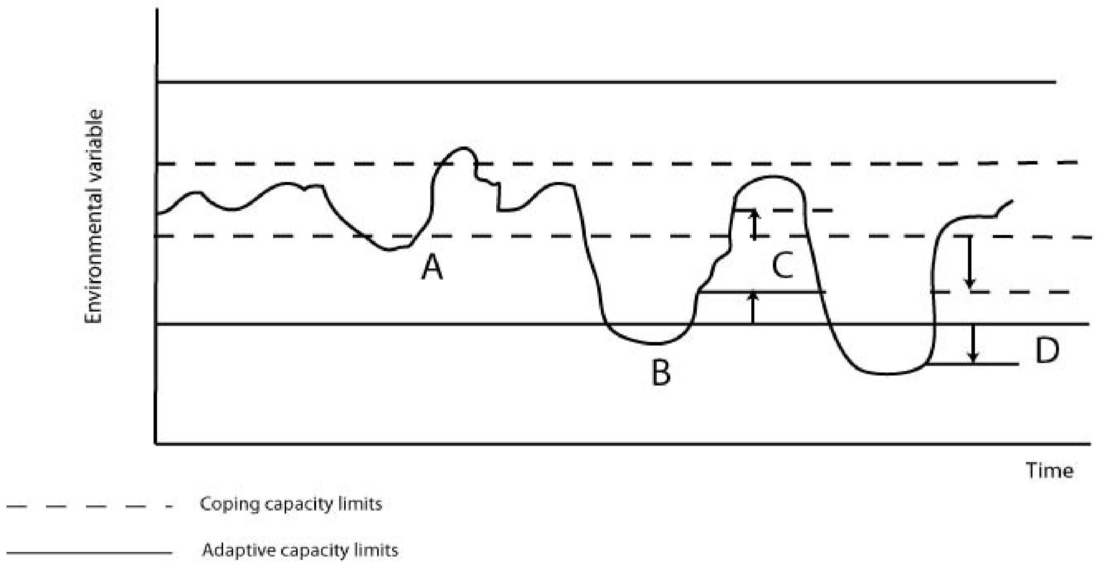

Figure 3- Coping-adaptive range diagram (Adapted from Vincent, 2004). A: coping capacity is exceeded but is within the adaptive capacity; B: the adaptive capacity is exceeded. In C both the coping and adaptive capacities are reduced after a previous exposure. In D the continued exposure to stresses has promoted social learning thus increasing the coping and adaptive capacities.

Thus, both coping and adaptive strategies can be considered as components of resilience and vulnerability. In SES the adaptive capacity is mainly a function of the social component, but has an extra aspect, which is the capacity of the system to improve its condition in relation to its environment even if this does not change (Gallopín, 2006). At a local level, the adaptive capacity of a SES is determined by the amount of resources, including human, natural, technological and financial available to the system (Adger and Kelly, 1999; Smit *et al*., 2001; Klein *et al*., 2003; Abel *et al*., 2006); the nature of the institutional environment and political influence (Smit and Wandel, 2006; Abel *et al.,* 2006); the social status of individuals within the system (Adger and Kelly, 1999); the perception of the source of stress and of the significance of the exposure (Yohe and Tol, 2002), and the learning and transfer of knowledge (Carpenter *et al*., 2001).

1.2.4 An Integrative Framework

The main points in common in most of the literature reviewed are that the resilience or vulnerability of a SES is as a function of three factors: a) the exposure of the system to external stresses, b) the sensitivity of the system to these stresses and c) the ability of the human component of the system to respond to them (Watts and Bohle, 1993; Blaikie *et al*., 1994; Luers *et al*., 2003; Adger, 2006; Smit and Wandel, 2006). Exposure is considered to be the degree, duration and extent to which the system is in contact with or subject to hazardous conditions (Kasperson *et al*., 2005; Adger, 2006; Gallopín, 2006). Sensitivity, on the other hand, is defined as the degree to which the system is affected by the hazardous conditions (Watson *et al*., 1996; Luers, 2005; Adger, 2006). In this manner, exposure and sensitivity are almost inseparable components of a system and the result of interactions between the characteristics of the system and of the stress

(Luers, 2005; Smit and Wandel, 2006). Thus resilience is associated with the sustainability of SESs in the face of surprise and unpredictability (Carpenter *et al.*, 2001; Carpenter and Gunderson, 2001; Folke *et al*., 2002).

The framework considered in this study is based on the points summarised above and is illustrated in Figure 4. SESs with a given sensitivity are exposed to external environmental stresses. The social component of the system reacts to these stresses according to its coping and adaptive capacity. Coping capacity is the ability to respond to short-lived stresses and is determined by the relative amounts of natural, human, financial and technological resources in the system. Adaptive capacity, on the other hand, involves responses which aim at producing long term sustainable solutions. The adaptive capacity of the system is therefore determined not only by the sum of available resources but also by the processes of learning and knowledge transfer. At the same time institutions of governance can enhance or constrain this adaptive capacity. Coping and adaptive capacity are not static. A high coping capacity can result in success to stresses in the short term. However, prolonged or continual exposure to stresses can lead to the exhaustion of resources and subsequent reduction of the coping capacity of the system. The reduction of the coping capacity increases the vulnerability of the system leading to failure. A high adaptive capacity can produce sustainable adaptive strategies which increase the resilience of the system leading to long term success.

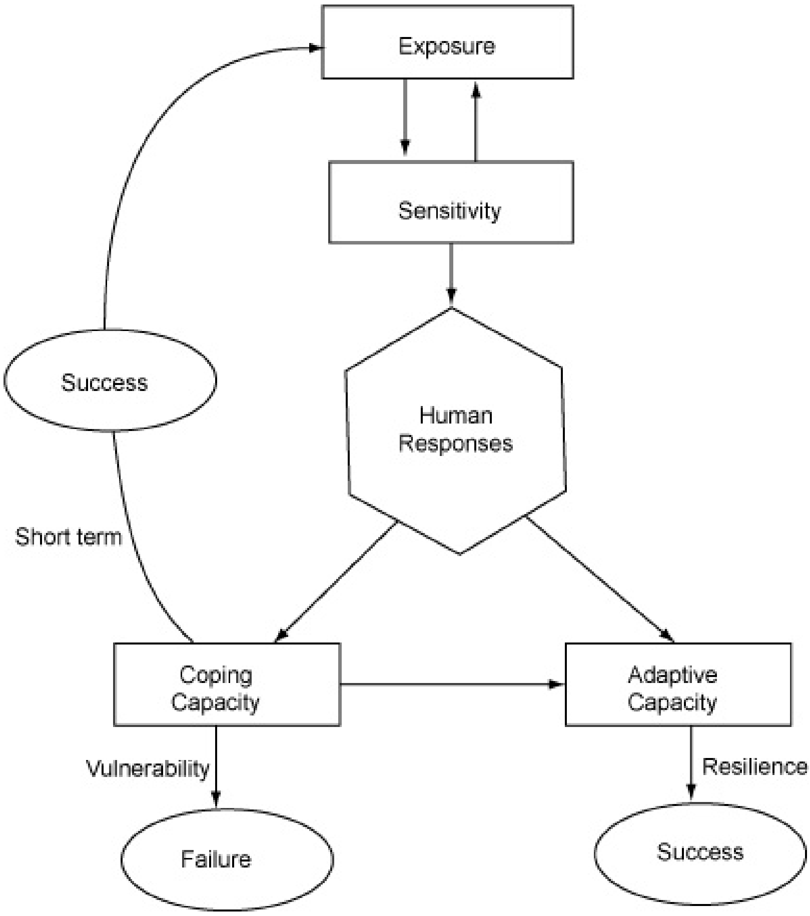

Figure 4- Theoretical framework. Social-ecological systems with a given sensitivity are exposed to external stresses. The social component of the system reacts to these stresses according to its coping and adaptive capacities. High coping capacity can lead to short-term success but continual exposure reduces this capacity, making the system vulnerable and leading to failure. High adaptive capacity leads to sustainable responses increasing resilience and leading to long-term success.

This research focuses on historical human responses, assessed by coping and adaptive capacities, of rural societies to environmental change. The study will concentrate on the local level by analysing long term dynamics of farm systems and linking the concepts of resilience and vulnerability to farm success and failure, respectively.

1.3 Aims and objectives

As has been expressed by many researchers (i.e. Bar-Yam, 1992; Kauffman, 1995; Fraser, 2003), the challenge in the study of SESs is to combine social and environmental data in meaningful ways, which respect the differences between these systems but also allow for more complexity. The resilience, vulnerability and coping and adaptive concepts detailed above provide a useful framework for the integration of these different data sets. This framework has been applied in recent years to explore present and future vulnerabilities of different communities to climatic change with the aim of improving the adaptive capacity of vulnerable areas. However, the use of this framework to study long-term historical situations has been limited and the data used restricted. The need for the application of resilience/vulnerability studies to a variety of past historical stresses has been acknowledged (Redman and Kinzig, 2003; Vincent, 2004).

This research presents a new perspective to the study of farm success and failure and is a pioneering analysis of the historical resilience of farms to environmental change in Mývatnssveit, northern Iceland. The overall aim of this research is to analyse the historical capacity of response (the sum of coping and adaptive capacity) to variable environmental conditions of livestock-based north European farming systems. By analysing how the capacity of response has affected the resilience of farms in Mývatnssveit, northern Iceland this thesis seeks to contribute to the debate on farm success and failure and to the understanding of societal adaptation. In this context this thesis seeks to address the following questions: Given uniform environmental change in an area of similar characteristics what contributes to some farms succeeding and others failing? Can the capacity of response explain why some farms were more vulnerable than others? Do all successful farms have a similar capacity of response? Based on these questions the objectives of this research are to:

1. Assess the historical capacity of response of farms in Mývatnssveit in relation to environmental change and assess how this capacity has

contributed to their resilience or vulnerability. To achieve this it is necessary to:

- Identify appropriate indicators of adaptive and coping capacity.
- Develop an appropriate method of integrating these indicators.
- Measure and compare the capacity of response of successful and failed farms.

2. To consider and analyse the usefulness of this framework and of the indicators selected in the study of historical vulnerabilities.

The thesis is organised in eight chapters; Chapter 2 describes the Icelandic context of the study. It includes a description of the physical environment of Iceland and a summary of its climatic and socio-political history. Additionally, Chapter 2 presents a background for the historical farming system subject of this study and a review on historical farm success and failure in the country. Chapter 3 describes the study area and the research design. Also in Chapter 3 is a rationale for the selection of the successful and failed farms and of the time periods of study, followed by a description of the data sources and dating techniques employed. The results and discussions are presented in the following three chapters, divided by data source. Thus, the results for the soils data can be found in Chapter 4, the historical records results are in Chapter 5 and the findings from the ethnographic sources are in Chapter 6. In Chapter 7 the selection of indicators from the data sources is explained along with two approaches for their integration. Finally, Chapter 8 discusses wider applications of the theoretical framework and indicators employed in this thesis. In addition, Chapter 8 presents recommendations for future research and concluding remarks.

Chapter 2 -Icelandic context

This section provides a context for the emerging research questions including a review of the physical environment of Iceland and its climatic and socio-political history. Additionally, it describes the historical Icelandic farming system together with a review of farm success and failure. The climatic and socio-political aspects described here are part of the "exposure" element of the resilience framework, to which all farms would have been subjected. The methodology and data sources selected in this study are based on the characteristics of the traditional farming system.

2.1 The physical environment of Iceland

Iceland is an island of 103,000 km^2, located in the North Atlantic Ocean between Greenland and Norway at 63º23' to 66º30' N, just south of the Arctic Circle (Figure 5). The landscape is predominantly mountainous, with lowland (defined as less than 300m) accounting for less than 35% of the land area. Glaciers, rivers and lakes cover around 20 % of the land area; more than 35 % is barren desert, *c*. 15% has limited plant production and only *c*. 28% of the country's area is vegetated, of which the majority lies below 200 m elevation (LMI, 1993).

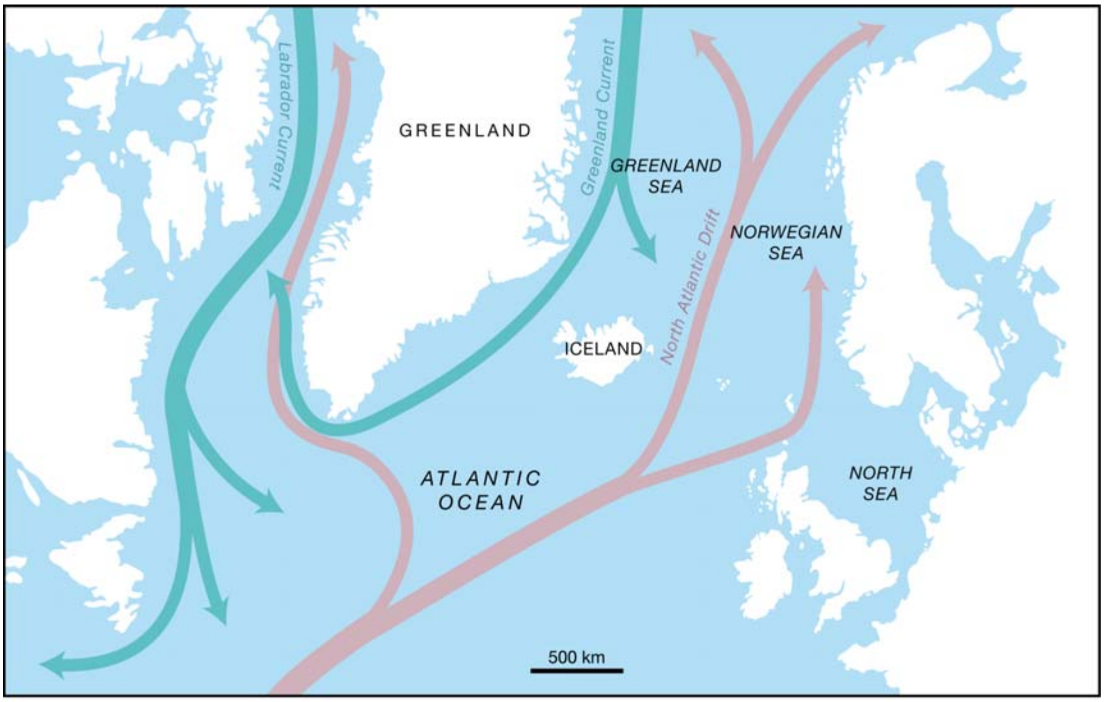

Figure 5- Location of Iceland and main ocean circulation currents.

The climate of Iceland is influenced by two climatic zones; the temperate zone in the south and the Arctic zone in the north. In general, the climate is described as maritime with cool summers and mild winters but with conditions highly variable throughout the country (Einarsson, 1979).

Geologically, Iceland is very young. All of Iceland's rocks were formed within the past 25 million years. Its stratigraphical succession spans the Tertiary and Quaternary geological periods (Thordarsson and Hoskuldsson, 2002). The country is volcanically active. It is situated on the North-Atlantic Ridge where the boundaries of the American and Eurasian tectonic plates are constantly spreading apart and which runs from the southwest to the northeast of the country. About 90% of the land mass is made up of volcanic rocks, mainly basalts, and the remainder is covered by aeolian, fluvial and glacial deposits (Jakobsson, 1979; Arnalds, 1990). Currently glaciers cover *c.* 10% of the land surface and include the largest ice cap in Europe, Vatnajökull. However, during the Pleistocene period most of the country was covered by glaciers. Deep U-shaped valleys and fjords have been cut by glaciers and glacial moraines are frequent. The erosive action of glaciers is still great. *Jökullhlaups* (floods caused by the bursting of ice-dammed lakes or by sub-glacial volcanic eruptions) are the cause of extensive erosion. The material carried by these floods has formed large depositional plains, known as *sandar*, along the southern coast of Iceland. These *sandar* are a significant source of loessial material (Jóhannesson, 1960; Thorarinsson, 1979).

Icelandic soils can be divided, according to the FAO soil classification, into three main categories: Histosols, Andosols and regolithic soils (Arnalds, 1988). Histosols are organic soils formed by the accumulation of partially decomposed organic material in anaerobic or cool environments. Andosols, or Andisols according to the US Soil Taxonomy (Soil Survey Staff, 1998), are characterized by high organic matter content, low bulk density, high water holding capacity, and a mineralogy dominated by short-range order minerals (Arnalds, 1990). These characteristics make Andosols highly susceptible to frost heave, land-slides, and erosion by wind and by water (Arnalds, 2000). The regolithic soils are often of glacio-fluvial origin; coarse in texture, lacking in organic material and infertile. As a consequence of these natural soil characteristics combined with variations in climate and human activity, 73% of Iceland is affected by soil erosion, with 16.2% classified as severe or very severe erosion (Arnalds *et al.*, 2001b).

2.2 Climate history

The term "climate change" involves a combination of factors, which include gradual changes in long term average conditions, greater variability in the range of "normal conditions" and changes in the types, frequency, magnitude, and distribution of extreme events (Hare, 1991). A number of factors contribute to the variability of the climate in Iceland, the most significant being atmospheric pressure systems, air currents and surface ocean circulation. Iceland is situated close to one of the main points of cyclonic activity in the northern hemisphere, the "Iceland Low". The Iceland Low and the North Atlantic Westerlies influence the northern hemisphere atmospheric circulation patterns (Ogilvie, 1984). Iceland is also at a meeting point for cold air from the arctic and warmer air from the Atlantic resulting in strong baroclinicity which increases atmospheric instability. With respect to ocean circulation, the island is influenced mainly by two contrasting currents (Figure 5), the warm water from the North Atlantic Drift (Irminger current) and the cold water from the arctic (East Greenland current) (Ogilvie, 1984; Ogilvie, 1991; Stötter *et al.*, 1999). The East Greenland current transports sea ice to Iceland most frequently from late winter to early spring and affects most commonly the northwest, northern and eastern coasts. It has been demonstrated that there is a strong negative correlation between annual temperature and annual sea ice incidence in Iceland (Bergthórsson, 1969; Ogilvie, 1984). However, because the presence of sea ice depends not only on temperature, but also on ocean currents and conditions in the Greenland Sea and the Polar basin, severe years without sea ice can also occur (Ogilvie, 1984). Volcanic activity has also had an influence on the climate in Iceland, where volcanic eruptions occur on average once every five years (Bergthórsson, 1969). The effects of volcanic eruptions on climate, however, are not fully understood; it is generally believed that they cause a decrease of temperatures in the seasons following the eruption, but this has not always been the case. For example, the Laki or *Skaftáreldar* eruption of 1783-1784 in the south of Iceland produced an ash-fall in all Europe known as "the great dry fog" which was associated with a very warm summer and an extremely cold winter (Demarée *et al*., 2001).

The location of Iceland in the Subarctic means that these climatic variations have marked ecological effects (Stötter *et al.,* 1999). For example, the absolute northern limit of viable grassland passes through the country and relatively small changes in temperature can produce a shift of this limit (Bergthórsson, 1969). Because cattle and sheep husbandry have historically been the main economic activity of the country, the effect of climate on grassland can cause serious economic impacts. Grass is affected by "winter kill" which can occur by low temperatures or by extended periods of snow cover frequently melting during brief thaws and then refreezing (Bergthórsson, 1985; Bergthórsson *et al*., 1988). Cold seasons produce poor hay yield not only due to winter kill, but also by delaying growth and reducing the length of the growing season. Moreover, long cold winters increase the livestock's need of fodder. Severe years also reduce the carrying capacity of rangelands (Bergthórsson, 1969). These effects are aggravated by the fact that severe years often occur in clusters as can be seen in Table 1, which presents a summary of climatic conditions from Settlement (AD 871 ± 2) based on temperatures in Iceland and according to different data sources. Temperature is considered to be the main constraint on hay production, although precipitation is locally important during certain years (Bergthórsson, 1969).

Instrumental meteorological recording first started in Iceland in the mid-19th century (Stötter *et al.,* 1999). However, historical climatic data have been derived from a number of proxies such as glacier and small ice caps' fluctuations (Mackintosh *et al*., 2002; Casely and Dugmore, 2007), ice cores in Greenland (Dansgaard *et al*., 1975), marine-sediment core records (Ogilvie *et al*., 2000), sub-fossil chironomid assemblages (Axford *et al*., 2007), tree-ring records (Briffa, 2000) and historical records (Lamb, 1977; Ogilvie, 1984) giving a general picture of the climate in Iceland from settlement. Although not enough evidence exists for the existence of a "climatic optimum" during the period AD 870-930 (Ogilvie, 1991), the sources summarised in Table 1 suggest that a warm episode occurred at some point during the settlement period. For example, the oxygen isotope analysis made by the Greenland Ice Sheet Program (GISP) from the ice cores DYE 3 and Milcent, in southern and central Greenland respectively, suggests there was a rapid climatic warming late in the 9th century (Dansgaard *et al.,* 1975), whereas foraminifera and lithofacies data from marine-sediment core records off eastern Greenland, suggest the warm interval spanned from AD 730-1100. (Ogilvie *et al.,* 2000). According to historical records, the 11th century was mild but with some periods of severe starvation related to cold weather. Caution needs to be taken here since the historical sources that cover the period *c*. AD 865 to 1099 are not contemporary and only negative weather is mentioned. It is likely that because severe seasons were rare in this time period their occurrence was emphasised (Ogilvie, 1991). There is limited data from this period up to AD 1600; historical records suggest that there was great variability with alternating periods of mild and cold conditions, after which the coldest period of historic times, known as the "Little Ice Age" (LIA), occurred. The onset and duration of this period in Europe has for a long time been the cause of debate; the most frequently suggested time frame has been from *c*. AD 1550-1850 (Lamb, 1965; Lamb, 1977). However, Equilibrium-Line Altitude record, GISP2 accumulation record from central Greenland and foraminifera record from a marine core in east Greenland show evidence of a LIA event between AD 1750 and 1920 (Mackintosh *et al.,* 2002).

Table 1- Historical climatic conditions in Iceland. Time periods are expressed in centuries and years AD.

Time period		Climatic conditions		Source	
Period	**Specific years or decades (AD)**	**General trend of period**	**Conditions in specific years or decades**	**For general trends**	**For specific years or decades**
8th, 9th and 10th century	730-1100	Warming, climatic optimum	Warm and stable	(Dansgaard *et al.*, 1975)	MS (Ogilvie *et al.*, 2000)
	870-1170		Mild		HD (Ogilvie, 1984)
	870-930				(Lamb, 1977)
11th century	1055-1058 and 1078	Generally mild	Severe-starvation periods	(Lamb, 1977)	HD (Ogilvie, 1991)
12th century	1180-1210	Generally mild	Severe	(Lamb, 1977)	HD (Ogilvie, 1984)
13th century	1233-1236	Variable	Cold	HD (Ogilvie, 1984; Ogilvie, 1991)	
	1261,1274 and 1275 1280-1300		Severe (sea ice off Iceland)		
14th century	1300-1319	Variable	Mild	HD (Ogilvie, 1984; Ogilvie, 1991)	
	1320's		Harsh, sea ice, severe weather		
	1330's		Mild		
	1340's		Cold		
	1350's		Mild		
	1360's		Cold		
	1370's		Cold		
15th century	1405, and 1422-1426	Mild/ variable	Cold	(Ogilvie, 1984; Ogilvie, 1991)	
	1470-1500		Severe		
AD 1550-1850	1570's and 1640-1670	Severe/sea ice/variable "Little Ice Age"	Mild	(Lamb, 1965; Lamb, 1977)	HD (Ogilvie, 1984; Ogilvie, 1991)
	1690		Very cold		
	1700-1750		Warming		GF (Mackintosh *et al.*, 2002)
	1750-1800		Coldest period in historic times/LIA		
1900's	1900-1920	Variable	Cold/LIA	GF (Mackintosh *et al.*, 2002)	
	1920-1940		Warming		
	1940-1980		Cooling		

Data sources key: GF: glacier fluctuations, HD: historical data, MS: marine-sediment core records.

As the data collected in the table are qualitative, the sea-ice-climate-glacier relationships established for northern Iceland and calibrated with the period of meteorological measurements (Stötter *et al.,* 1999) can be used to define what "cold" or "mild" might mean in northern Iceland. This calibration period has shown climatic conditions close to, or even at, both Holocene minimum and optimum levels and has been used in modelling (e.g. Thomson, 2003; Thomson and Simpson, 2006). The temperature records used for this derive from the Akureyri meteorological station, where recording goes back to 1881, and extrapolated with the Stykkishólmur temperature data, where continuous records exist from 1845. Cold conditions in north Iceland were probably comparable to extreme conditions in the second half of the 19th century, with an annual average temperature at sea-level of *c.* 1.5 ºC, summer (May-September) temperature of *c.* 7 ºC and winter (October-April) temperature of *c.* -2.5 to -3 ºC, with high occurrence of drift ice at the northern coasts. In warm periods temperatures were probably as high as in the 1930s, during this time annual average temperature at sea-level reached *c.* 4.5 ºC, summer temperature almost 10 ºC and winter temperature almost 1 ºC and drift ice was absent from the sea shore (Stötter *et al.,* 1999).

2.3 Socio-political history

The main social and political events that have influenced Iceland since settlement are summarised in two tables. Table 2 covers the period from settlement until the 15th century and Table 3 the events occurred in the 16th-19th century. A volcanic ash layer in Icelandic soils, known as the *Landnám* (Old Norse: land take) tephra, marks the presence of humans in the island and has been dated to AD 871 ± 2 (Grönvold *et al.*, 1995). Some signs of human impact on the soil have been found below this layer but they are estimated to be not much earlier than the tephra layer itself (Þorláksson, 2004). Because of this and the accounts in *Íslendingabók* (Book of Icelanders) indicating that Iceland was settled around AD 870, the so-called settlement or *Landnám* period covers from AD 870 until 930, the year of formation of the General Assembly (*Alþingi* or Althing) (Ogilvie, 1984; Byock, 1993; Þorláksson, 2004). During this time, people from mainland Scandinavia and from Norse settlements in the British Isles (Þorláksson, 2004) came to Iceland and established independent households on dispersed farmsteads, introducing livestock and management practices from Scandinavia (Thorsteinsson *et al*., 1971; Amorosi *et al*., 1997). Norse settlers also introduced the pattern of government customary in many parts of Scandinavia at the time, where power was not in the hands of a single ruler but was shared between a number of chieftains (Sawyer *et al*.,1993). Before the establishment of the Althing chieftains were also religious leaders and maintained local assemblies. It is believed that a number of these chieftains proposed to establish an assembly for the whole country, forming the Althing (Karlsson, 1996).

The period from the formation of the Althing in AD 930 until the loss of independence to Norway in AD 1262 is known as the Commonwealth. During this period, Iceland was under a common law, the country was divided into quarters and the General Assembly met once a year. Leadership was in the hands of local chieftains who were called *goði* (pl. *goðar*). The *goðar* participated in the legislative body, *logrétta,* nominated members for the courts, had to represent the farmers and were expected to solve disputes by bringing cases to the courts on behalf of the men they represented (Þorláksson, 2004). About three dozen *goðar* existed in Iceland at some point, but the number was gradually reduced by conquest or marriage alliances and by AD 1220 there were five families controlling all the country (Sawyer *et al*., 1993). During this period, Iceland converted into Christianity. This happened peacefully but with pressure from the king of Norway, Olav Tryggvesson, who retained Icelandic hostages in Norway. In the year AD 1000, the Althing by influence of its Lawman decided to adopt Christianity to avoid the prospect of civil war and/or Norwegian intervention. However, the right to carry out some practices such as the offering of heathen sacrifice in private and the exposure of unwanted children continued for about twenty years more before they were completely abolished (Derry, 1979; Þorláksson, 2004).

The first bishop of Iceland, Ísleifur, was consecrated in AD 1056 and although there was no Episcopal see he settled at Skálholt in the south of the country, which had been his family farm. This farm formally became the Episcopal see later, when his son Gissur became bishop after his death. Under Gissur's bishopric the tithe was introduced in AD 1097, before than in other Scandinavian countries. This was the first general and proportionate tax introduced in the country, consisting of 10% on income and 1% on property (Hjálmarsson, 1993). The tithe was divided into four parts and distributed for the bishop (later the Crown), for priest services, for the upkeep of the church building and for poor-relief (Lárusson, 1967; Byock, 1993). This tax led to the Church becoming wealthy and powerful. Also, many chieftains built churches on their estates in order to collect a quarter of the tithe, or two quarters if a family member or a servant was ordained as a priest (Byock, 1993). By the beginning of the 12th century there were two bishops in Iceland, one with jurisdiction over the western, southern and eastern quarters (Skálholt) and one with jurisdiction over the north (Hólar) (Byock, 1993). By this time the rural communities were already organised in *hreppar* (sing. *hreppur)*. The *hreppur* might have originated in the need for cooperation amongst farmers for the "round-up" of the sheep from communal grazing areas (Lárusson, 1967). *Grágás,* the book where the laws were compiled, required that all communities had their *hreppur*, formed by at least 20 adjacent good farms. The *hreppar* was required by law to collect the tithe and maintain the poor, as expressed in *Grágás* and later in *Jónsbók* (Eggertsson, 1992). In 1237, the Archbishop of Nidaros refused the Icelandic nominations for the then vacant bishoprics and consecrated instead two Norwegians (Hjálmarsson, 1993). Quarrels between the *goðar*, deteriorating economic conditions and pressure from the Norwegian bishops in Iceland, led to the surrender of power to Norway. This occurred by the approval in 1262 of an agreement, known as the Ancient Covenant, by an incomplete gathering of the Althing. The fact that Icelanders had no timber for shipbuilding had led them to depend on Norwegian merchants for trade. The agreement required that a tribute of 40 ells of wadmal (a coarse woollen fabric) was paid annually by every taxpayer. In return, the king would maintain the peace and law in Iceland, and would send six ships in each of the following two summers and thereafter as many as was thought necessary. Royal officials replaced the *goðar* and the legal functions of the Althing were adjusted to follow the Norwegian judiciary system (Derry, 1979).

In 1269 a dispute began when the bishop of Skálholt proposed that the Church should rule over all estates where churches had been built. Eventually he succeeded and freeholders who had previously lived on these farms became tenants of the Church (Hjálmarsson, 1993). By 1303 the Althing was complaining that exports from Iceland were not matched by imports. Norway had developed a royal monopoly amongst its dependencies by concentrating trade at Bergen and imposing excessive tolls. Iceland still depended on Norwegian shipping for trade but this was also decaying due to the rise of a rival commercial power on the north coast of Germany, the Hanseatic League. The Hanseatic League was a great association of merchants formed by German towns, which by 1397 had the monopoly of all trade and fishing rights in the northern waters of Europe (Cramer, 1949). The year 1397 also saw the union of the Scandinavian kingdoms: Sweden, Denmark and Norway, known as the union of Kalmar. Denmark was the strongest partner in this union (Carus-Wilson, 1966). Both Iceland and Norway had become part of Denmark before in 1380, when King Hákon of Norway died (Hjálmarsson, 1993).

The fifteenth century saw probably the worst catastrophe in Icelandic history when in 1402-1404 the Black Death, probably in the form of Pneumonic Plague[1], killed about two-thirds of the population (Tomasson, 1977). A large number of farms were abandoned or came under the Church as gifts from dying people. During this century, the Icelandic stockfish took over from the wadmal as the country's main export product. English ships began to fish in the Icelandic waters and carried trade, which generated some battles between English and the Danish king and the Hanseatic League (Hjálmarsson, 1993). Trading conditions further deteriorated when the over-wintering of foreign trading vessels was banned in 1490 (Vasey, 1996). Another outbreak of the plague (Black Death or pneumonic plague) took place in 1494-1495 killing between 30-50% of the population (Karlsson, 1996).

[1] It has been suggested that, as Iceland was not colonized by rats at the time, the plague was the pneumonic and not the bubonic form as is frequently believed (1974).

Table 2- Main social-political events that occurred in Iceland from settlement till the 15th century.

Scale	Time period		Important events		Sources	
Iceland	*c*. 870-930 (*Landnám*)		Introduction of Scandinavian livestock and land management systems. Formation of the General Assembly		(Thorsteinsson *et al.*, 1971; Amorosi *et al.*, 1997)	
Iceland	930-1280 (Commonwealth)	1000	Common law, *goðar's* leadership, rural communities organised in *hreppar*. Increased wealth and power of the Church. Increase of tenancies.	Conversion to Christianity	(Byock, 1993; Hjálmarsson, 1993)	(Derry, 1979; Þorláksson, 2004)
		1097		Introduction of the tithe		(Hjálmarsson, 1993)
		1237		Consecration of Norwegian bishops		(Hjálmarsson, 1993)
Iceland /Europe	13th/14th century	1280-1380	Foreign control, economic decline, isolation, Norwegian trade monopoly and later influence of Hanseatic league. Increase of Church's land properties, increase in tenancies.	Norwegian control	(Carus-Wilson, 1966; Derry, 1979; Vasey, 1996)	(Vasey, 1996)
		1347-1350		Black death		
		1380		Danish control		(Vasey, 1996)
		1397		Union of Kalmar		(Carus-Wilson, 1966; Derry, 1979)
Iceland	15th century	1402-1404	Influence of Hanseatic league and English merchants, disputes over trade, stockfish main export product.	Black death, pneumonic plague?	(Hjálmarsson, 1993)	(Derry, 1979), (Karlsson, 1996), (Tomasson, 1977) (Tomasson, 1977; Derry, 1979; Karlsson, 1996)
		1490		Ban on over-wintering of foreign trading vessels.		(Vasey, 1996)
		1494-1495		Black death, pneumonic plague?		(Karlsson, 1996)

In the 16th century the union of the Scandinavian kingdoms was finally dissolved when, after many conflicts and disputes, Sweden became independent. However, Norway remained a Danish province till 1814 and Iceland did not get its independence till much later (acknowledged as a sovereign and independent state but under the king of Denmark in 1918, and finally proclaimed a republic in 1944) (Sawyer *et al.*, 1993; Hjálmarsson, 1993). The religion of the island changed once more, this time in a less peaceful way when the king, Christian III of Denmark, sent a governor with two warships in 1541 to enforce Lutheranism. Skálholt submitted and was given a new bishop; whereas Jón Arason, the bishop of Hólar, refused to submit the diocese. He took the Lutheran bishop of Skálholt prisoner, expelled the king's representative, and restored the monasteries. However, Arason and his sons were captured by a rival chieftain and beheaded in November 1550 under orders from Denmark. At this time the crown became the biggest landowner on the island after seizing all the lands owned by monasteries (Derry, 1979; Hjálmarsson, 1993). In 1602 a decree gave trade monopoly to a few Danish companies operating on terms set by the crown. These merchants had also to abide by the ban on over-wintering. People often could not sell goods to these merchants and tried to sell to foreigners, for which they were occasionally prosecuted (Vasey, 1996). During the time of the Danish trade monopoly, mutton and beef, compared with fish, were bought and sold on the foreign market at a lower price than on the home market (Lárusson, 1967). The trade monopoly partly ended with the opening of trade to all crown subjects in 1787 (Vasey, 1996).

The 18th century has been described as the "worst century of Icelandic history" (Tomasson, 1977). The last decades of the 17th century had also been hard due to cold weather leading to people dying of starvation. This led King Frederick IV to answer to

Icelandic delegates' petitions by sending two commissioners, Árni Magnússon and Páll Vídalín, to investigate the situation and make proposals for improvements. To this end a nationwide census was carried out in 1703 and a land registry was completed in 1712 (*Jarðabók*). During the data collection, in 1707-1709, a smallpox epidemic struck the population killing about one third of it. Another smallpox epidemic occurred in 1785-1787 (Hjálmarsson, 1993). To the epidemics were added many volcanic eruptions such as the "Mývatn fires" caused by the Krafla in 1724-1729, and whose lava flow reached Lake Mývatn (Gardarsson, 2006), the Katla in 1756, the Hekla in 1766 and the Laki in 1783-1784. The worst of these was the Laki eruption which led to the poisoning of vegetation and animals, leading to the consequent death by starvation of *c.* ten thousand people and which affected the weather in all Europe (Hjálmarsson, 1993; Demarée *et al.*, 2001).

The unequal distribution of land and wealth in the 18th century added to these hardships. A few families had the ownership of most private lands and were additionally the fief-holders of most Crown and Church farms which were of better quality (Sigurjonsson *et al.*, 1999). Although in 1802 most church farms were expropriated by the Danish crown, many of them ended up subsequently in the hands of the private elite (Magnússon, 1985; Jónsson, 1993; Bolender, 2006). Other occupations in the higher classes of society during this period included district officers (*hreppstjórar*), sheriffs (*sýslumenn*), other civil officials and Lutheran pastors and bishops; many lesser officials were tenants. In the lower classes were several categories of householders, such as freeholders, tenant farmers, and dependent cottagers. Further down were servants who accounted for more than a quarter of the population during the second half of the 19th century. Servants were usually employed for a year by any of the above categories, including the lower classes, and lived in their master's farm-house (Jónsson, 1993).

Non-householders' classes were formed by paupers and *lausamenn* (literally, free men), who lodged in farm households and sold their labour for short periods. *Lausamenn* obtained better wages and terms than did servants, but were never numerous since in order to be allowed to take on temporary work and not have a permanent residence they were required to have considerable goods (Jónsson, 1993; Vasey, 1996; Sigurjonsson *et al.,* 1999). Church and State cared for the helpless and indigent; by the law code of *c*. 1280, *Jónsbók*, the commune had to support poor farm households by giving them help if they were under temporary difficulties or by distributing their members to other households if they were considered unable to maintain themselves (Vasey, 1996). To avoid the burden of the poor, people were legally tied to the commune of their birth or where a settlement had been acquired. The movements of labour were regulated by obliging people who did not live independently as farmers to hire themselves out as servants to those in independent positions. The only exception to this was the *lausamenn*, until this class was outlawed in 1783. However, certain seasonal movement of people usually occurred during the summer when farmers recruited casual labour for the hay harvest from the poorer sectors of the fishing population and during the winter when a large part of the rural male population went to work in the fishing stations in the south and west of the country (Jónsson, 1993).

In the 19th century important political changes took place. In 1814 the Union of Norway and Denmark dissolved, leaving Iceland, the Faroe Islands and Greenland as part of Denmark (Hjálmarsson, 1993). In 1845 the Althing was restored and in 1863 the *lausamenn* were given legal status again although under strict conditions. This harsh law was a major reason for the large servant class during the 19th century. After years of debate in the Althing labour bondage was relaxed by a law in 1894 which established that everyone 22 years or older could be free from labour service provided he or she obtained a licence from the police authorities for a small fee, had a fixed address and registered with the local authorities every year. Another law in 1907 allowed everyone over 20 years of age with an annual income of over 200 kr to be free from service (Jónsson, 1993).

In Denmark the King renounced absolute power in 1849 and a constitution was established. After these political reforms a constitution was introduced in Iceland in 1874 which decreed legislative and financial power to the Althing. However, for laws to take effect they still had to be signed by the King (Jónsson, 1993; Hjálmarsson, 1993). Iceland obtained home rule in 1904, was recognised as a sovereign and independent state in 1918 and declared a republic in 1944 (Hjálmarsson, 1993).

Table 3- Main social and political aspects taking place in Iceland during the 16th-19th century.

	Time period		**Important events**		**Sources**	
Scale	**Century**	**Specific years**	**General events in the century**	**Events in specific years**	**For general events in the century**	**For specific years**
Scandinavia	16^{th} century	Until 1523	Introduction of Lutheranism. Crown becomes bigger land owner	Internal wars in the union and final dissolution	(Derry, 1979)	(Sawyer *et al*., 1993)
		1536		Lutheranism established in Denmark		(Derry, 1979; Hjálmarsson, 1993)
		c. 1550		Lutheranism established in Iceland, Crown seizes lands from monasteries.		(Derry, 1979; Hjálmarsson, 1993)
		1563-1570		7 years of war between Sweden and Denmark		(Derry, 1979)
Iceland	17^{th} century	1602-1787	Trade monopoly, low prices of meat products	Trade monopoly to a few Danish companies	(Lárusson, 1967; Vasey, 1996)	(Vasey, 1996)
		1693		Hekla eruption		(Lárusson, 1967)
Iceland/Mývatn	18^{th} century	1707-1709	The "worst century of Icelandic history"	Smallpox	(Tomasson, 1977)	(Vasey, 1991)
		1703-1712		Nationwide census and land register		(Hjálmarsson, 1993)
		1724-1729		Mývatn fires		(Gardarsson, 2006)
		1756		Katla eruption		(Vasey, 1991)
		1762-1763		Smallpox		(Vasey, 1996)
		1766		Hekla eruption		(Hjálmarsson, 1993)
		1783		Free labourer class outlawed		(Jónsson, 1993)
		1783-1784		Laki eruption		(Vasey, 1991; Demarée *et al*., 2001)
		1785-1787		Smallpox		(Vasey, 1991)
		1787		Opening of trade		(Vasey, 1996)
Iceland	19^{th} century	1802	Althing restored, improvement of labour laws	Expropriation of most bishoprics' farms by the Danish crown	(Jónsson, 1993)	(Magnússon, 1985; Jónsson, 1993; Bolender, 2006)
		1845		Parliament (Althing) restored		(Jónsson, 1993)
		1863		Free labourers are given free status but under strict conditions		(Jónsson, 1993)
		1874		Althing gains legislative power conjointly with the Crown		(Jónsson, 1993)

2.4 The Icelandic historical farming system

From the colonization of Iceland in the late 9th century until the 19th century the economy of the island was based on livestock farming. At the end of the 19th century, even though fishing was the main national income, farming still provided a livelihood for almost two-thirds of the population (Jónsson, 1993). During the *Landnám* period Norse settlers introduced the first large herbivores in Iceland. Zooarchaeological evidence suggests that livestock was initially dominated by cattle and pigs, with caprines[2] being relatively scarce in the south of the country, and in a proportion of 1 cattle to 2 caprine in the north. In the 11th, 12th centuries and later periods, pigs seem to become very rare and livestock is predominantly caprine (Vésteinsson *et al.,* 2002). Cereal cultivation was also introduced to Iceland in the 9th century although limited to the south of the country and abandoned by the 1500's. It is widely believed that cessation of grain cultivation was the result of climatic deterioration (Sveinbjarnardóttir, 1992; Byock, 1993; Smith, 1995); although more recent research suggests that instead of climate, soil quality and management was the critical limiting factor to early grain production (Simpson *et al*., 2002).

The first settlers also introduced livestock management systems from Scandinavia. Three grazing regimes were in place from early times, summer grazing of communal grazing areas (*affrétir*), summer grazing of private shielings (*sel*) and winter grazing of farm estates (Simpson *et al*., 2001; Simpson *et al*., 2004). During the summer months milking livestock were taken to shielings to graze from the middle of June until the latter half of September (*Jónsbok*). At the shielings animals were milked and dairy

[2] The term "caprine" in Vésteinsson *et al*. (2002) seems to be used to signify sheep as well as goats. The correct term for sheep would be ovine.

products such as butter, *skyr* (a yoghurt-type product) and cheese were manufactured (Sveinbjarnardóttir, 1992). The rest of the livestock were taken to the *affrétir*; the law demanded that farmers took their flocks there in a given week in June and round them up and drive them back before a specific week in September. However, in 1281, when the law codes of the *Grágás* were replaced by the *Jónsbók*, the Althing approved a modification to allow each district to set its own dates on the basis of local circumstances. In late autumn was the round-up, which consisted of driving the sheep from the *affrétir* to a public fold, called a *rétt*, where they were identified by marks on the ears and handed out to their owners (Eggertsson, 1992). Once back in the farm it was decided how many sheep were to be slaughtered and how many were to be kept through the winter depending on the amount of hay available. The animals to slaughter could include some lambs, old ewes, barren ewes and wethers (adult castrated males). The remaining livestock from the *affrétir* and horses were then taken to winter grazing areas. These were within the boundaries of individual farms, although they were occasionally shared. Rams were taken indoors from early November, before the start of the breeding season. Lambs would be housed during the nights if there was snow and adult ewes and wethers were kept outdoors as much as possible until heavy snow or ice covered the ground. This served to maintain sheep numbers and to conserve hay, which was given mainly to cows (Adalsteinsson, 1991).

The production of hay during the summer to supply livestock through the winter was critical for maintaining livestock numbers (Friðriksson, 1972; Adalsteinsson, 1991; Amorosi *et al*., 1998). There were two categories of hay production: 1) grass harvesting from outfield areas (*úthey*), including wet meadows (*engi*) and 2) cultivated home-fields surrounding the main domestic buildings of the farmstead which produced high quality grass (*tún*). Cattle were given the best quality hay while sheep would graze longer the summer pastures and were given poorer quality hay from the outfield areas when needed (Ashwell, 1963; Friðriksson, 1972; Vasey, 1991).

The main changes in this agricultural system took place during the 1950's. These included changes in haymaking from manured home-fields and meadows to fields fertilised with chemical fertilisers and the disappearance of the traditional winter grazing and shieling systems. The communal grazing system is still in practice, although to a lesser extent (Friðriksson, 1972; Gardarsson, 2006).

2.5 Farm success and failure in Iceland

The Norse expansion into the North Atlantic during the 9th and 10th centuries provides contrasting examples of success and failure of rural societies. Viking-age Scandinavian populations had colonized the already occupied islands of Shetland, Orkney, northern Hebrides and the Scottish mainland by *c*. AD 825 and the "pristine" islands of Faeroe, Iceland and Greenland between AD 860 and 1000. These populations depended mainly on agriculture for their subsistence but developed different adaptive strategies and had different outcomes. In this way, by the late Middle Ages the population in the first group of colonized islands and in the Faeroes had increased or stabilized and relatively prospered, whereas in Greenland the population became extinct (*c*. AD 1450-1500). Iceland on the other hand, underwent a major loss of population and extensive land degradation, which continued into later periods (McGovern *et al*., 1988).

The existence of early farms that failed and others that have been successful to the present day, within small geographical areas in Iceland, makes it an ideal place to investigate the causes for historical farm success and failure in the context of environmental change. Furthermore, the extensive archive of historical written records together with detailed tephrochronological, archaeological and climatic data, makes it possible to combine a range of historical data not easily accessible for other places. This type of study in Iceland is however not without problems. An aspect to take into account is the use of the term "abandonment" or "desertion". These terms are used in many studies; however they need to be used with caution given that unsuccessful farms in Iceland were in most cases absorbed by successful farms and continued to be used, an issue also recognized by Dugmore *et al*. (2007). The term "failure" or "unsuccessful" is preferred here and refers to the failure of a farm to keep functioning independently. The definition of an "independent" farm is then another consideration; the presence in the landscape of many old structures in disuse might be considered evidence of "abandoned" independent farms. This issue has been discussed previously, for example, Lárusson (1967) points out that Ólafur Lárusson in his classical work "*Byggð og Saga*", argues that most "deserted farms" (his apostrophes) described from the late medieval period are in reality cottages (dependent farms) and that these grew from the fourteenth to the nineteenth century as a reflection of the rise and fall in the population. These cottages were often temporarily occupied, appearing in good periods and disappearing in bad times (Magnússon, 1985). Abandoned shielings (summer grazing areas) might have also been previously wrongly interpreted as abandoned farms (Sveinbjarnardóttir, 1992). It has been suggested that the abandonment of dependent or small farms was in many cases a successful management strategy to conserve land resources such as woodlands (e.g. Mairs *et al*., 2006; Vésteinsson, 2006; Dugmore *et al*., 2007).

The causes of farm failure in Iceland have been a source of controversy for a long time and although the first studies considering the issue date from the 1700's, few have directly analysed the causes and processes of farm failure. Ólafsson (1943) (cited in:

Sveinbjarnardóttir, 1992) listed the main reasons for farm abandonment as: epidemics, indifference of government and landowners in improving the farms, and the emigration from country to sea-shore. However, more commonly, abandonment has been associated with climatic deterioration and land degradation induced by sheep grazing (e.g. Sveinbjarnardóttir, 1992).

Studies supporting human induced land degradation in Iceland are characterised by pollen-based evidence of woodland deforestation and grassland expansion (e.g. Hallsdóttir, 1987), and tephrochronological based soil erosion analyses showing considerable increase in sediment accumulation rates soon after *Landnám* (See Thorarinsson, 1961b; Arnalds, 1984; Dugmore and Buckland, 1991; Guðmundsson and Ólafsdóttir, 2002 for examples). Although these studies analyse the causes for land degradation, most of them see humans as passive receptors of external stresses. Other researchers raised the idea of the lack of adaptation to environmental change, as the cause of land degradation. Amongst these explanations for failure to adapt are the less favourable climate of Iceland together with the absence of a native population denying the opportunity for the settlers to learn from people that had previously adapted to the local conditions (Thorarinsson, 1961a). Another explanation is the failure to perceive environmental change due to short-term but wide fluctuation in climatic conditions with several years of mild conditions followed by several years of severe conditions masking a long-term decline of temperature (Simpson *et al*., 2001). Recent studies have analysed human-environment interactions in more detail. Simpson *et al*. (2004) used tephrochronology to assess soil erosion in two winter grazing areas in northeast Iceland, and concluded that adaptive management practices were a key factor in contributing to the success of farms. In a related piece of research, Brown *et al*. (2006) argue that the shieling system served to a certain extent, to prevent soil erosion in northeast Iceland.

Farm “abandonment” in relation to environmental change continues to be a topic of debate in Iceland; at the same time the assessment of the different degrees and levels of impacts associated with long term continuous human occupation has been proposed as the next key level of investigation (Mairs *et al.,* 2006). In this respect, this thesis will assess long term dynamics of human responses to environmental change in Iceland by estimating and comparing the relative adaptive and coping capacities of successful and failed farms.

Chapter 3 -Study area and research design

3.1 Research design summary

Recapitulating on the theoretical framework outlined in Chapter 1, the resilience or vulnerability of a system is determined by the exposure and sensitivity of the system to external stresses and by its capacity of response (including its coping and adaptive capacity). This basic model presented in Chapter 1 (Figure 4) has been expanded in Figure 6 for its application to the study area and the main time period explored in this thesis (the 18th century). The grey box in the diagram is labelled as "uniform" and refers to the assumptions made regarding the exposure and sensitivity components of the framework and the institutional factors influencing the study area: Mývatnssveit. Exposure and sensitivity refer to the main climatic aspects and topographic factors affecting them, which will be described for Mývatnssveit in Section 3.2. Uniformity in this sense does not imply that the climate does not vary in time, but that these variations affect the study area uniformly. Institutional factors include land tenure characteristics and the rules regulated by the hreppar (such as grazing regulations). These institutional factors can directly influence the adaptive capacity of the system in a positive or a negative way. An example of negative influence could be insecure tenancy conditions which discourage land improvements. In this example, the institutional factor can reduce the adaptive capacity of the system (illustrated by the "-" sign in the diagram) generating maladaptive strategies resulting in farm failure.

The human capacity of response is considered "diverse" because it varies according to the relative influence of different factors such as: the availability of resources, learning and knowledge transfer and individual perceptions of the significance of the source of exposure. The resources considered in this thesis have been classified as: productive, human and natural. Productive resources include those directly involved in farming production such as livestock, home-fields, meadows, outfields and shielings. Human resources include labour, learning and knowledge transfer. In the diagram, productive and natural resources are connected to human resources because labour is needed in order to take advantage of them. The relative availability of these resources constitutes the coping capacity of the farm which leads to short term success (Section 1.2.3). The resources are also linked to "learning", because the capacity to learn how to manage resources in a changing environment and the transmission of this knowledge in space and time contributes to the adaptive capacity of the farm. People's perceptions of the nature and significance of environmental stresses and of their ability to respond directly influence their capacity to learn.

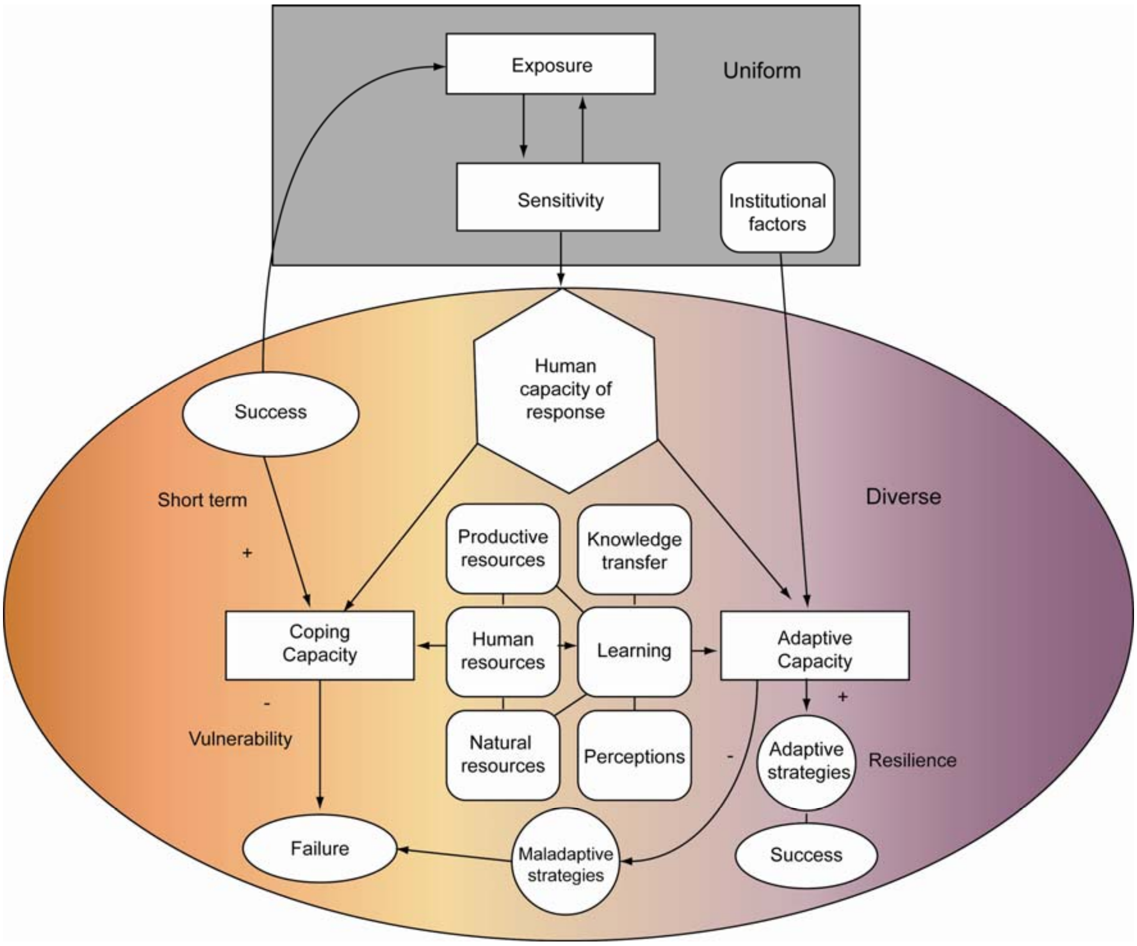

Figure 6- Theoretical framework applied to Mývatnssveit, see text for details.

Indicators of the different components of the framework were derived from three data sources: soil and sediments records, historical records and ethnography. Table 4 summarises the data sources and indicators used in this study, explains their connection with the theoretical framework and presents a brief description of the nature and availability of the indicators. The exposure and sensitivity of the farms to environmental stresses will be, to a certain degree, controlled for with soil and sediments derived indicators. However, the focus of this thesis is on the human capacity of response, so most of the indicators reflect the past availability of resources of the farms. The indicators "livestock rent" and "number of children per farm" are considered to be possible constraints on the capacity of response of the farm. This is because they are assumed not to be linked to the productivity of the farms. However, this will be examined by looking at the differences between successful and failed farms. The hypothesis tested in this case are: that failed farms have in average higher livestock rents than successful farms, and that failed farms have in average higher number of children (defined as people under 15 years) than successful farms.

Table 4- Data sources and description of derived indicators.

Data sources		Derived indicators	Theoretical framework component	Description
Soil records		SAR in winter grazing areas	Indicator of sensitivity/exposure to erosion and deposition	Quantitative. Available for different time periods defined by tephrochronology and radiocarbon dating.
		Total P content in home-field soils	Proxy for hay productivity (productive resource). Coping and adaptive capacity indicator.	Quantitative. Available for different time periods defined by tephrochronology and radiocarbon dating.
		Micromorphologic characteristics in home-field soils	Can reveal evidences of deposition of eroded materials and of management aspects. Indicator of sensitivity/exposure and of adaptive capacity.	Semi-quantitative. Available for different time periods defined by tephrochronology and radiocarbon dating.
Historical records	Land registers	Tax value	Productive resource. Coping and adaptive capacity indicator.	Quantitative. Available for the years 1686, 1696, 1712 and 1847.
		Land rent	Productive resource. Coping and adaptive capacity indicator.	Quantitative Available for the years 1686, 1696, 1712 and 1847.
		Livestock rent	Coping and adaptive capacity indicator (constraint ?).	Quantitative Available for the years 1686, 1696, 1712 and 1847.
		Livestock numbers	Productive resource. Coping and adaptive capacity indicator.	Quantitative. Available for 1712.
		Natural resources	Coping and adaptive capacity indicator.	Quantitative/Qualitative. Available for 1712.
	Census	Total number of people/farm	Human resource. Coping and adaptive capacity indicator.	Quantitative. Available for 1703 and 1835.
		N° of children (under 16)/farm	Coping and adaptive capacity (constraint).	Quantitative. Available for 1703 and 1835.
		N° of servants/farm	Human resource. Coping and adaptive capacity indicator.	Quantitative Available for 1703 and 1835.
Ethnography		Management aspects	Management aspects reflect learning and knowledge transfer. Adaptive capacity indicators.	Qualitative. Retrospective information on Icelandic agriculture before 1950.
		Perceptions	Adaptive capacity indicator or constraint. Perceptions on farm success and failure and on the nature of environmental stresses.	Qualitative. Based on opinions of farmers at present.

3.2 Study area: Mývatnssveit

The Mývatn region (Mývatnssveit), situated in north-east Iceland (Figure 7), is the furthest inland permanently settled region of the country. It surrounds Lake Mývatn, a large shallow lake fed by underground water and springs rich in phosphate and silica. These attributes lead to a complex food chain characterised by an abundance of diatoms, cyanobacteria, chironomids and simuliid flies, fish and waterfowl. The name of the lake (translated: Midge Lake) derives from the abundance of flies.

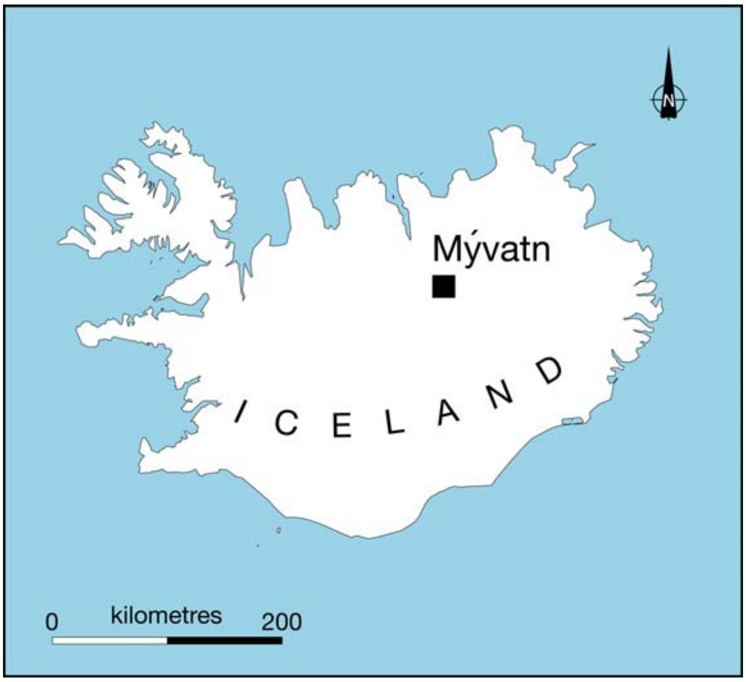

Figure 7- Location of the Mývatn area, northeast Iceland.

The present boundaries of the district extend south to the edge of the glacier Vatnajökull, covering an area of 4,900 km^2. At the beginning of the 18^{th} century Iceland was divided into districts (*sýsla*) which had a number of communes (*hreppr*). Each district comprised a number of parishes which consisted of those farms that paid tithes to the same church

(Lárusson, 1961). The study area belongs to the district of Þingeyjarsýsla, the commune is referred to in historical sources as Mývatn hreppur (Simpson *et al*., 2001), Haganeshreppur (1696), Skútustaðahreppur (1754) and Skútustaðaþingsókn (Lárusson, 1967).

Mývatnssveit was selected as a study area because of the largely uniform topographical conditions of the farmable land and the extensive record of archaeological research in the area. A topographical assessment of the *c*. 500 km^2 of farmland in the district reveals that more than 90% of the area is lying at elevations of between 250 and 400 m.a.s.l and that 95% of the area has slopes of less than 5˚. These attributes contribute to a fairly uniform influence of solar radiation, with *c*. 80% of the area receiving between 380,000-400,000 WM^{-2} in the summer months (Brown *et al*., 2006). These characteristics support the assumption that the farms in the area must have been exposed in a similar way to climatic factors. Another aspect taken into account was that in the 18th century Mývatnssveit seemed to have had a more even distribution of wealth amongst farms when compared to other districts (McGovern *et al*., 2007). Additionally, the majority of the farms in the area were tenancies (Lárusson, 1967), this adds to the uniformity of topographical conditions and exposure to climate another level of consistency, given by the institutional arrangements.

In general, the climate around Lake Mývatn is more continental than maritime. The annual mean temperature in Mývatnssveit is low compared with most other parts of the country and also more variable (Bergthórsson, 1985). Eirnarsson (1979) summarises the main climatic characteristics of Mývatnssveit based on the meteorological conditions in the period 1931-1960 from the weather stations of Reykjahlið, Stadarhóll and Grímsstaðir. Based on this study, the average annual mean temperature in the area is *c*. 2º C with the warmest month of the year, July having a mean of over 10ºC and the coldest one, February having a mean of -4.2ºC. Frost is frequent in Iceland, but does not normally last for very long periods and winter thaws are common. In the Mývatn area the annual number of frost days (i.e. days during which the minimum temperature at 2 m height was below freezing) is around or above 150. Mývatnssveit is in the rain shadow of the south-easterly winds created by the glacier Vatnajökull. As a consequence, the precipitation in the area is low compared with other parts of the country, the annual precipitation being *c*. 400 mm compared with 1000-4000 mm in southern Iceland. The maximum precipitation occurs in July-August and the driest month of the year is May. Despite the abundant climatic reconstructions of Iceland, no palaeoclimatic records specific to the Mývatn area have been published. The implication of this is that assumptions need to be made based on climatic reconstructions for the country, but climatic changes are not always spatially congruent, particularly on annual to century time scales (Dawson *et al*., 2003; Jackson *et al*., 2005).

The main aspects of the geology of the Mývatn area are Pleistocene basalt ridges to the west and south west of the lake, smoothed by glacial erosion. These are now mostly covered by soil and heath vegetation. Lake Mývatn is situated on the edge of the Krafla volcanic system, to the south of the lake, extensive lava fields stretch into the almost desert interior (Ólafsson, 1979; Thorarinsson, 1979). In terms of erosion, the Þingeyjarsýsla district has very contrasting areas of soil erosion; some areas have erosion levels that are among the lowest found in Iceland, but there are also areas of severe and extremely severe soil erosion. Figure 8 shows an erosion map of northeast Iceland, constructed by the Agricultural Research Institute of Iceland (RALA) and the Soil Conservation Service (LR). The construction of the map was based on satellite images to determine boundaries between wasteland and vegetated land, and visual inspections in the field to assess type and severity of erosion. A comprehensive description of the erosion types and severety classes can be found in Arnalds *et al*. (2001b).

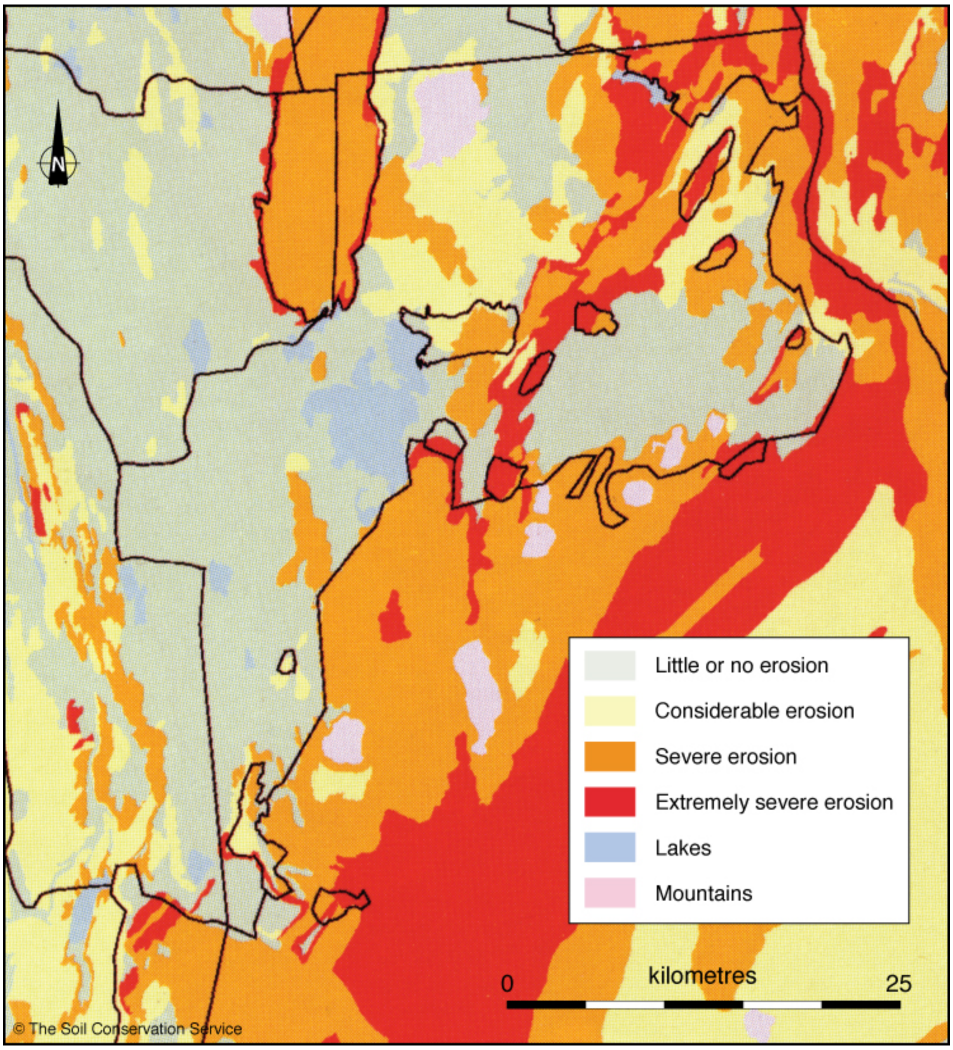

Figure 8- Soil erosion clasess in Northeast Iceland according to severity. The district of Þingeyjarsýsla is marked in the top centre of the figure, within which Lake Mývatn can be seen. The Mývatn region has areas of very contrasting erosion, from little or no erosion to severe and extremely severe erosion. Adapted from Arnalds *et al*. (2001b).

3.3 Selection of farms and time periods of study

The selection of farms to include in the study followed two main criteria: that they were early-settled independent farms and that they had a recognizable and accessible ancient home-field. Figure 9 shows the spatial distribution of early settled farms in Mývatnssveit.

The boundaries shown in the map represent 19th century delimitation and were reconstructed by Orri Vésteinsson from the Institute of Archaeology of Iceland (*Fornleifastofnun Íslands*). They are based on written descriptions collected by the sheriffs following legislation in 1882. For the boundaries of the farms Reykjalíð, Grænavatn and Baldursheimur, medieval documents were also taken into account. This information was then complemented with a field survey also carried out by the Institute of Archaeology of Iceland in Mývatnssveit during 1996-1999. In this survey, boundaries were corrected by checking what could be observed in the field, adding information obtained from landowners and deleting 20th century changes (Vésteinsson, pers. comm.).

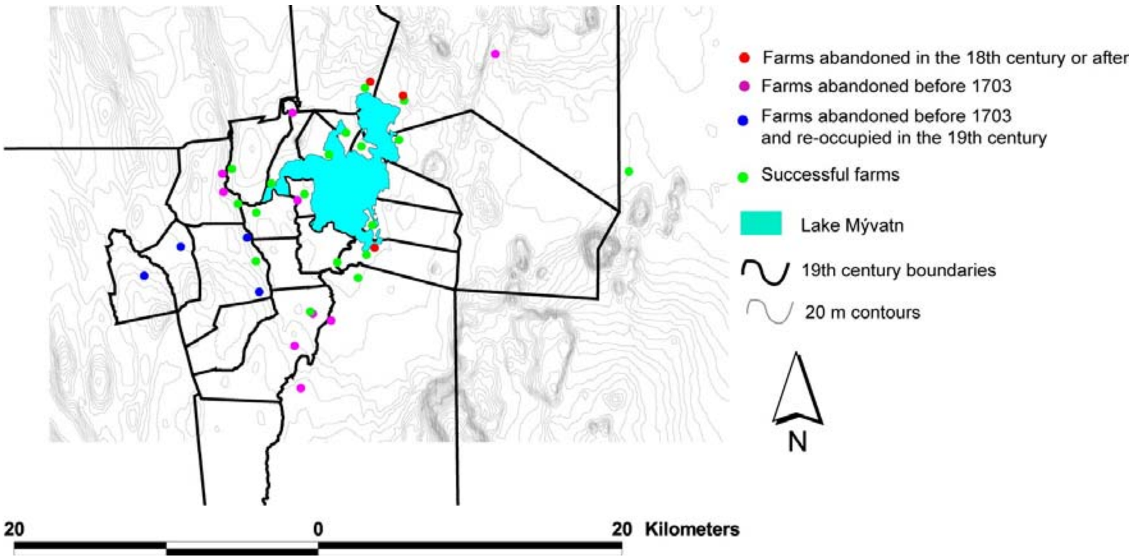

Figure 9- Distribution of early settled farms in Mývatnssveit, northern Iceland.

It is evident from Figure 9 that farms which failed were often in close proximity to successful farms, which has called into question the paradigm of climate induced abandonment. So far, studies involving successful and failed farms in the Mývatnssveit area have focussed on comparing extreme outcomes of early settled farms. For example, high status successful farms such as Hofstaðir, associated with an early large hall-building, an early small church and with the highest valuation in the area by 1712; and catastrophic failures such as Sveigakot and Oddastaðir, now both sub-arctic desert (Simpson *et al*., 2004; Adderley *et al*., 2008). Another common element has been that the unsuccessful farms studied were abandoned before the 1300's. This is not surprising, given that the majority of early failed farms in Mývatn were abandoned during this time period. In Table 5, early settled unsuccessful farms in Mývatnssveit are grouped in: i) farms abandoned in the 18th century, for which historical information from land registers is available; ii) pre-Arnamagnæan[3] farms (i.e. abandoned before 1712), and iii) pre-Arnamagnæan farms reoccupied in the 19th century. Other unsuccessful farms not included in Table 5 are farms established in the 19th century and abandoned in the 19th or 20th century (Krákárbakki and Hlíðarhagi), and sites where historical documents attest to short time occupation but ruins are either faint or non-existent (Þorlákskot, Þuríðarnes, Hrútvíðirsel, Kirkjubær/Rófugerði, Arnarbæli and Hraunás/Mýnesás) (Vésteinsson, pers. comm.).

[3] Arnamagnæan derives from Árni Magnússon (Arnas Magnæus in Latinised form) and refers here to the time period in which he collected the information for the *Jarðabók*.

Table 5- Unsuccessful farms in Mývatnssveit, northern Iceland. Data collected from Vésteinsson (2008) and Vésteinsson (Pers. Comm.).

Farm name	Date of settlement	Date of abandonment
Old farms, *lögbýli*[4] (abandoned in the 18th century or after)		
Gröf	?	1720
Fagranes	First documented ref. 1446	1728
Brjánsnes	First documented 1560	1804
Pre-Arnamagnæan farms (abandoned before 1703)		
Sveigakot	*c.* 871	*c.* 1100
Hrísheimar	9th century	Pre-1104
Selhagi	Pre-1300	?
Steinbogi	10th century	13th century
Oddastaðir	Pre-1158	Re-occupied for 4-5 years in 1680's
Brenna	Pre-1158	?
Stöng	Pre-1477	?
Hali	Pre-1158	?
Beinistaðir	?	Pre-1300
Þóleifsstaðir	Pre-940	Pre-1300
Selholt	Post-940	Pre-1300 with short re-occupation in the 14th or 15th century
Pre-Arnamagnæan farms (abandoned before 1703) and re-occupied in 19th century		
Hörgsdalur	?	?
Bjarnastaðir	?	?
Litlu-Gautlönd	?	?
Stöng	?	Pre-1477, re-occupied in 1920's

Excluding the re-occupied farms, two phases of "abandonment" of early farms can be seen on Table 5, an early phase (pre AD 1300) and a later phase (18th century and after). The fact that the majority of farms belong to the early, and not the later phase, is particularly interesting, considering that the 18th century has been regarded as the "worst period of Icelandic history" due to epidemics, volcanic eruptions and adverse weather conditions (Tomasson, 1977). It is thus interesting to study the few farms that have failed in this later period; however, it is perhaps of more significance to look at the successful

[4] Independent farm

farms during the same period to gain an insight into the factors that have made these farms resilient.

From the later period of abandonment, Gröf was discarded from the general analyses as it was considered a cottage of Reykjalíð in 1712, there is no indication of a possible date of settlement and it is not mentioned in the 1686 or the 1696 land registers. Gröf and Fagranes are said to have been abandoned due to the volcanic eruptions of 1720's in Mývatnssveit, known as the "Mývatn fires". It is argued here that although these settlements were abandoned after the volcanic eruption, it was ultimately their vulnerability which caused this impact to result in permanent abandonment. For example, other high status farms affected by the Mývatn fires, such as Reykjalíð and Grimstaðir were not abandoned. Moreover, Grimstaðir's farm building had to be relocated due to the lava flow. Brjánsnes is said to have been abandoned in 1804 due to erosion. However, its neighbouring farms Garður and Kálfaströnd are still in operation. Moreover, Brjánsnes belongs now to Garður and its home-field is still in use. From the early phase of abandonment, data is more limited as there are no early historical records including information for all the farms. Furthermore, many of these farms such as Hrísheimar and Sveigakot are so eroded that their home-field's soils have been completely lost. In other farms, soils are present but home-field boundaries have been lost or are not clearly visible. Based on this and the accessibility of the site Þóleifsstaðir was selected from this group. Þorleifsstaðir is at present part of Baldursheimur, and is 2.4 km southwest from it and 2.3 km from Hrísheimar. From the group of farms abandoned before 1703 and re-occupied in the 19th century, Bjarnastaðir was selected. The farm was recorded as an abandoned farm within the boundaries of Gautlönd in the 1712 land register. It was re-settled in 1850 although formal land division began in the years 1920-1925 (Vésteinsson, 1996).

Table 6 shows early farms in Mývatnssveit which have been occupied since they were first settled, and for which there is available historical information from land registries. Of these successful farms, five were selected: Baldursheimur, Gautlönd, Geirastaðir, Grímsstaðir and Grænavatn. From these, Baldursheimur, Gautlönd and Grímsstaðir are associated with pagan burials and so are assumed to have been occupied in the 10th century. The presence of a chapel or a church on a farm has also been suggested as an indicative of early settlement. Geirastaðir and Grænavatn are considered early-settled on these grounds (Vésteinsson, 2008). Apart from their early and continuous occupation, other factors considered in their selection were their close proximity to failed farms, the availability of archaeological reports, and the presence of people who have been living in the farm from before 1950 and who could be interviewed. Figure 10 shows the location of the nine farms selected for this study with 19th century farm boundaries.

Table 6- Successful, early and long-term occupied farms in Mývatnssveit, northern Iceland.

Farm name	Date of settlement
Reykjahlið	1st documented 13th c. Landnámabók
Geirastaðir	1st documented 13th c. Landnámabók
Arnarvatn	1st documented 1394
Gautlönd	1st documented 13th c. saga, presence of pagan burial
Baldursheimur	1st documented 1544, presence of pagan burial
Grænavatn	1st documented 13th c. Landnámabók
Skútustaðir	1st documented 13th c. saga
Haganes	1449
Vogar	1437
Grímsstaðir	1548, presence of pagan burial
Helluvað	1468
Garður	1st documented 1510
Kálfaströnd	1st documented 1449
Neslönd	1st documented 1447
Vindbelgur	1st documented 1431
Hofstaðir	1st documented 1477
Geiteyjarströnd	1st documented 1446

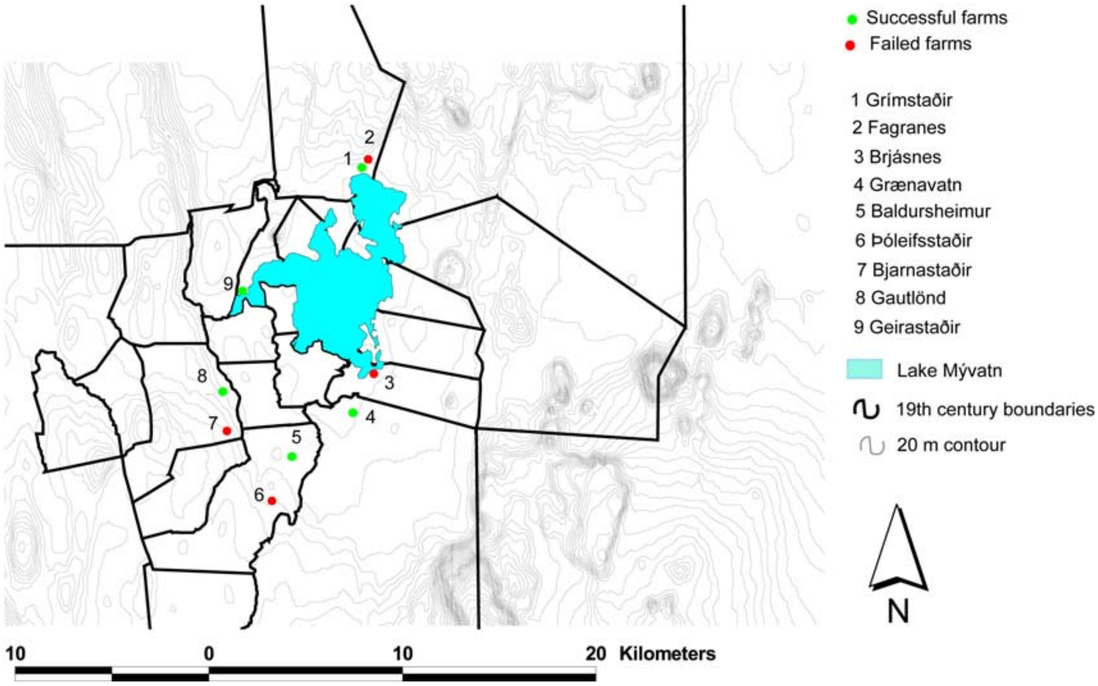

Figure 10- Location of study farms in Mývatnssveit, northern Iceland.

3.4 Dating techniques

The chronology of soils derived data will be established by stratigraphic relations and the use of tephrochronology and radiocarbon measurements. It is important to take into account that although the main focus of this study is on the two periods of abandonment (i.e. pre-1300 and post-1700); it is meaningless to look at the data in isolation from previous time periods. This is especially true for soils derived data where the significance of human impacts can only be appreciated in the light of pre-settlement conditions. For this reason pre-*Landnám* contexts are considered where possible.

3.4.1 Tephrochronology

The deposition of tephra (ash) on top of soils during volcanic eruptions has allowed the development of tephrochronology. This technique, developed in Iceland by Thorarinsson (1961b), consists of the identification and dating of tephra layers to be used as chronological markers. The timing of eruptions or tephra falls may be recorded in historical sources (e.g. Thorarinsson, 1967), correlated to annually laminated ice core records (e.g. Grönvold *et al*., 1995) or dated using radiocarbon measurements on associated organic material (e.g. Kjartansson *et al*., 1964). With tephrochronology it is possible to link tephra deposits with associated archaeological or environmental signals in an unambiguous manner (Hunt, 1999; Shane, 2000). One of the most important tephra layers for the study of human related environmental impacts in Iceland is the so called *Landnám* layer. This layer is thought to have originated in the Vatnaöldur-Hrafntinnuhraun crater row close to the time of settlement (Einarsson, 1963; Thorarinsson, 1967), and, therefore, can be use to separate pre-settlement from post-settlement soil processes. There are a large number of pre and post settlement tephras in Icelandic soils; however, the complete sequence is very rarely encountered in a particular region (Gerrard, 1985).

Figure 11 shows the tephra horizons that have been identified in Mývatnssveit.

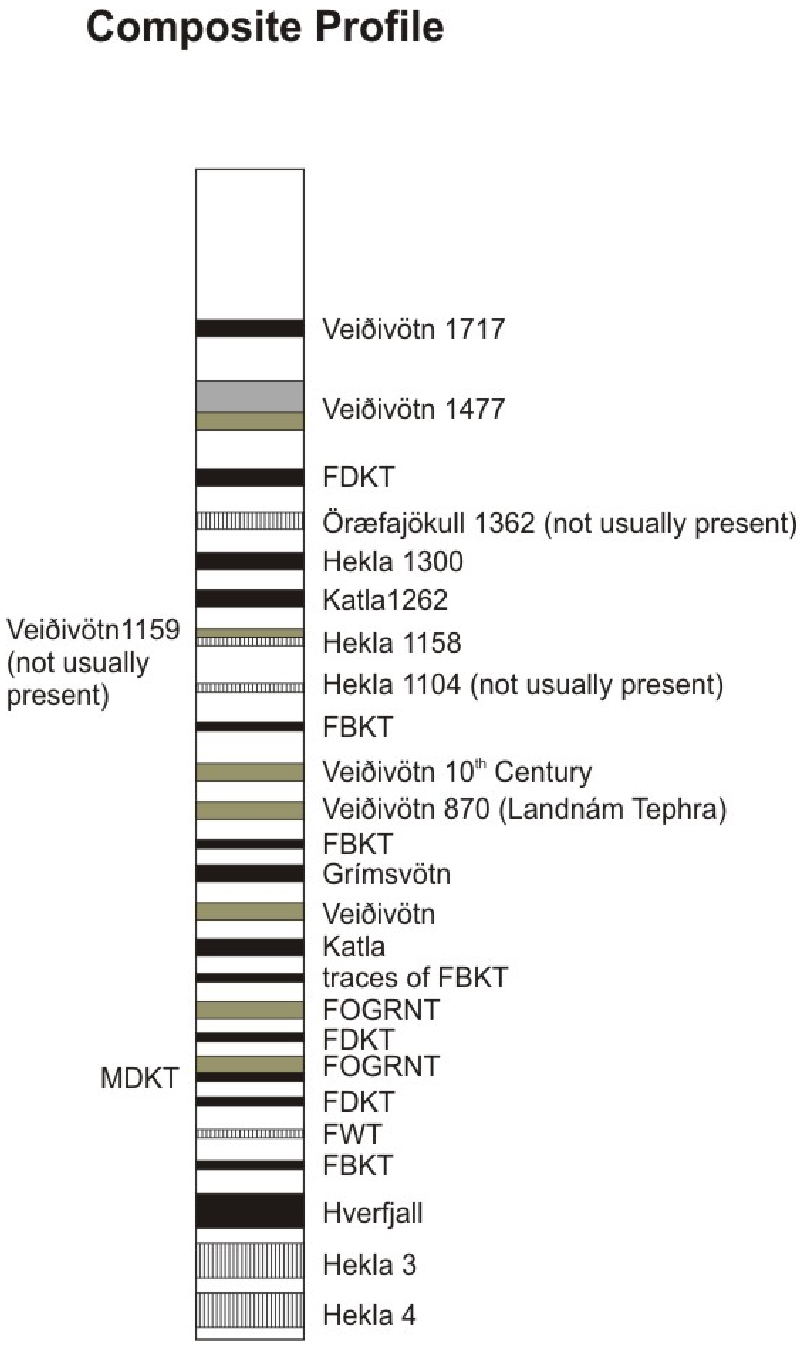

Figure 11- Tephrochronology found in Mývatnssveit (After Newton et al., 2003).

The most constant or widely distributed tephras in the area are *Hekla* 4 (*c*. 4,000 BP), *Hekla* 3 (*c*. 2,800 BP), *Hverfjall* (2,500 BP), *Landnám* (AD 871 ± 2), *Veiðivötn* 1477 (AD 1477) and *Veiðivötn* 1717 (AD 1717) (Simpson *et al.,* 2004; Brown *et al*., 2006). These tephras will be used here as isochrones, they are identified in the field by their colour, thickness, texture and stratigraphic relationships and can be verified with micromorphological descriptions. Table 7 summarises the main characteristics of the tephras used in this study.

Table 7- Summary of characteristics associated with tephra (Ólafsdóttir *et al*., 2002; Simpson *et al*., 2004).

Tephra	Origin	Age	Type	Field colour and texture	Micromorphology description
Veiðivötn 1717	Veiðivötn	AD 1717	Basic	Coarse sand	Black sandy
Veiðivötn 1477 or "a"	Veiðivötn	AD 1477	Basic	10YR 3/2; fine sand	Brown and black; fine sand; isotropic, glass; smooth, angular and subangular; common vesicular; common 1° of irregular line alteration and few 3° of pellicular core alteration
Landnám	Veiðivötn	AD 871 ± 2	Basic/Acid	2.5YR 3/3; silt loam	Brown; fine sand; isotropic glass; smooth angular; rodlike to blocky
b/c	uncertain	*c*. AD 600 and AD 700	Basic	7.5YR N2/0-7.5YR N3/0; fine sand	Black; fine sand; isotropic; smooth subangular
Hverfjall or h	Hverfjall	*c*. 2500 BP	Basic	7.5YR N2/0; coarse sand	Pale brown; coarse sand; anisotropic speckled with rodlike and tabular inclusions; smooth subangular blocky; common vesicular; few 1° of linear alteration
Hekla 3 or H_3	Hekla	*c*. 2800 BP	Acid	10YR 5/5; silt loam	Yellow; silt; isotropic glass; smooth angular leticellular, few fibrous; 1° of pellicular alteration
Hekla 4 or H_4	Hekla	4000 BP	Basic/Acid	10YR 5/5; silt loam	Black fine-grained upper part and white fine-grained lower part

3.4.2 Radiocarbon measurements

Radiocarbon dating is a technique based on the radioactive decay of the isotope carbon-14 (^{14}C) in organic materials (Libby, 1955). This isotope is produced in the upper atmosphere by the bombardment of nitrogen atoms by cosmic rays (Greene, 1983; Rapp *et al*., 1998). The atmospheric concentration of radiocarbon is incorporated into living organisms via carbon dioxide. When an organism dies, the uptake of ^{14}C ceases and its concentration begins to decline through radioactive decay (Renfrew *et al*., 1996). The conventional technique for calculating the date of death is by determining the amount of radioactivity (in a sample of any organic matter) and comparing it with the known half-life of ^{14}C (the length of time that it takes for half of the radioactivity of an element to decay) (Greene, 1983). Another method of calculation is the Accelerator Mass Spectrometry (AMS) which measures directly, by high-energy mass spectrometry, the concentration of ^{14}C relative to the amount of ^{12}C and ^{13}C present in a sample (Hester, 1987; Rapp *et al*., 1998). The AMS method has the advantages of requiring smaller samples, having a faster speed of counting and the ^{14}C range can be extended to between 60,000 and 100,000 years (Taylor *et al*., 1984; Hester, 1987).

Because home-fields in Iceland were traditionally enriched using household waste, including fuel residues from the hearth, charcoal is commonly found in home-field soils. It was anticipated that where tephras were not present in a soil profile, charcoal samples would be taken for radiocarbon dating. It is acknowledged that the dates obtained in this way will correspond to the time of death of the plant where the charcoal came from. Therefore, the dates obtained from charcoal may be earlier than the date of its use for fuel and of its incorporation to the soil. Charcoal samples were identified at the Glasgow University Archaeological Research Division (GUARD) and ^{14}C measured at the AMS facility of the Scottish Universities Environmental Research Centre (SUERC).

3.5 Data sources

Three types of data sources will be used in this study: historical records, soil and sediments records, and ethnographic data. Table 8 shows the data sources available for each study farm. These data sources are used to derive indicators of exposure/sensitivity and of human capacity of response. The following sections provide a description of the data sources and the derived indicators, while at the end of the chapter a summary with a rationalization of what the indicators represent in relation to the theoretical framework is presented.

Table 8- Data sources available per study farm (X indicates availability).

		Soils records			Historical records						Ethnography
	Farms	**SAR in winter grazing areas**	**Total P in home-field areas**	**Micro morph ology**	**1686 land register**	**1696 land register**	**1712 land register (Jarðabók)**	**1847 land register**	**1703 census**	**1835 census**	**Interviews**
Successful	Baldursheimur	X	X	X	X	X	X	X	X	X	X
	Gautlönd	X	X	X	X	X	X	X	X	X	X
	Geirastaðir	X	X	X	X	X	X	X	X	X	X
	Grimstaðir	X	X	X	X	X	X	X	X	X	
	Grænavatn	X	X	X	X	X	X	X	X	X	X
Unsuccessful	Brjánsnes	X	X	X	X	X	X		X		
	Fagranes	X	X	X	X	X	X		X		
	Þórleifsstaðir		X	X							
	Bjarnastaðir	X	X								

SAR= Soil accumulation rates; Total P= Total phosphorus content.

3.5.1 Soil and sediments records

A variety of definitions for the term soil can be found according to the discipline and context in which it is used. Holliday (1990) defines it as a natural body formed by the interaction of different factors such as climate, flora, fauna and landscape position on rock parent material and sediments over time and which acts as a medium for plant growth. To this definition an important aspect can be added: soil properties reflect the environment in which they have been formed (Jenny, 1980). From the first part of the definition it follows that soils are the basis for agriculture and as such physical and chemical characteristics of relict and fossil soils should reflect their quality and provide an indication of past crop productivity. From the second aspect it can then be assumed that these characteristics will also reflect the management practices and environmental conditions that contributed to their formation. Soil characteristics will be examined here in relation to two key management units of the historical Icelandic farming system: winter grazing areas and home-field areas. An assessment of soil erosion in the winter grazing areas in Mývatnssveit by Simpson *et al.* (2004) suggested that the management of winter grazing areas in addition to landscape position was a key factor contributing to the success or failure of early settlements. Following this, the assessment of temporal patterns of soil erosion (through the measurement of soil accumulation rates) in winter grazing areas of successful and failed farms can be used as an indicator of farm vulnerability.

The productivity of home-field areas has been considered an important factor contributing to the initial success and long-term sustainability of early settlements throughout the North Atlantic region (Simpson *et al*., 2002; Adderley and Simpson, 2005; Adderley and Simpson, 2006; Adderley *et al.,* 2008). The amount of livestock, in particular milking cows, that could be maintained during the winter in Iceland was dependent on the amount of hay produced during the summer. Manure and household waste were incorporated into home-fields to increase hay productivity. These amendments have a high phosphorus (P) content and given that Icelandic soils have a strong phosphate fixation capacity (Wada *et al*., 1992; Arnalds *et al*., 1995; Arnalds, 2004; Arnalds, 2005) the concentration of total P measured in discrete soil layers in home-field soils can be considered an indicator of past home-field productivity. Total P values and other evidence of home-field management of successful farms relative to failed farms can be used as indicators of farm resilience or vulnerability. The different techniques employed to derive the soil data are explained below.

3.5.1.1 Measurement of Soil Accumulation Rates

Soil Accumulation Rate (SAR) is the term used to describe sediment or soil thickness between dated tephra layers which can be measured and used as a proxy for past soil erosion (Dugmore and Buckland, 1991; Simpson *et al.,* 2004). The basic idea is that the amount of material deposited at a certain point in the landscape must relate to the amount of erosion going on elsewhere (Gerrard, 1991). In this respect, two important assumptions have been generally made; firstly that the rates of sediment accumulation are directly proportional to rates of local wind erosion, and secondly that the intensity of this erosion reflects the overall intensity of soil erosion in the surrounding area (Dugmore and Erskine, 1994). In the first assumption it is implicit that the accumulated material corresponds to sediment and not organic material accumulated in situ, which would imply the influence of pedogenic processes and landscape stability.

SARs have been used in Iceland to study spatial and temporal patterns of land degradation. In the first tephrochronological studies in Iceland, Thorarinsson (1961b;

1981) highlighted the dramatic acceleration of aeolian sediment accumulation rates following Norse settlement. He argued that sheep grazing was the main cause for post-*Landnám* soil erosion. However, much of Thorarinsson's work and that of others following the same methodology (e.g. Dugmore and Erskine, 1994) was obtained from rofabard sections (eroded remnants of vegetation). Studies of this type may overestimate average sediment accumulation as rofabards are much thicker than the soil cover was before deflation started (Gerrard, 1985). Other studies have measured SAR in soil profiles in vegetated areas at points along transects covering different terrain elevations (e.g. Ólafsdóttir and Guðmundsson, 2002; Simpson *et al.,* 2004). These studies give a better spatial representation of aeolian soil erosion. Furthermore, the Ólafsdóttir and Guðmundsson (2002) study provides a regional and temporal baseline against which evidence of land degradation at specific locations of the Mývatnssveit area can be assessed. In this manner, the assessment of SARs in the winter grazing areas of a successful and a failed farm highlighted differences in inherent susceptibility of soils to erosion, initial impacts of settlement and the influence of land management practices in the ultimate success or failure of the farms (Simpson *et al.,* 2004). The same approach used in shieling areas, revealed that they presented lower SARs than regional post-*Landnám* values suggesting these areas were successfully managed to prevent landscape degradation (Brown *et al*., 2006).

In this study it is proposed that SARs of winter grazing areas can be used as indicators of farm vulnerability to climatic and landscape change. To assess this, a soil profile was dug at a random location in the winter grazing area of each of the study farms and the sediment accumulated between tephra layers was measured to a resolution of 0.5 cm. All the soil profiles were located at altitudes ranging from 274 m to 368 m (sd=30). The data was analysed applying a General Linear Model (GLM) using the statistical software Minitab 15. The model included SAR as the response variable, whereas time periods, defined by tephrochronology, and outcome (success or failure of the farm) were factors.

SAR data is further supported by micromorphology to verify the assumption that the measured accumulation reflects erosion and not soil formation processes e.g. accumulation of organic matter. Additionally, two soil erosion experiments were conducted with the aim of determining present day rates of erosion in the study area as a control for SAR.

3.5.1.1.1 Soil erosion experiments

The assessment of soil erosion in Iceland is based on the classification of erosion forms that can be identified in the landscape (Arnalds *et al*., 2001b). These comprise six erosion forms associated with vegetated areas and seven to describe barren deserts (Table 9). Additionally, each erosion form has an erosion severity scale from 1-5, 1 being the lowest level of erosion and 5 the most severe (Arnalds *et al*., 2001a). Present day rates of erosion have been measured in Iceland in association with some of these erosion forms. For example, by monitoring the retreat of rofabards (e.g. Friðriksson, 1995; Arnalds, 2000) and on sandy deserts by measuring mass flux by saltation using dust traps (Sigurjonsson *et al*., 1999). However, erosion rates of isolated spots have not been assessed and research in general on erosion spots is limited. Although isolated spots are assigned low erosion grades (1-3), they are extremely widespread (Arnalds *et al*., 2001b). Moreover, the degradation process is often initiated by isolated spots that expose the soil to erosion by water and wind and progress to higher erosion grades or other erosion forms such as deserts (Ólafsdóttir, 2001).

Table 9- Icelandic erosion classification system (Arnalds, 2000).

Erosion forms associated with vegetated areas	Types of deserts
Rofabards	Melar (lag gravel, till surfaces)
Advancing erosion fronts (sand encroachment)	Lavas
Isolated spots	Sandur (bare sand, sand sources)
Isolated spots and solifluction features on slopes	Sandy lavas
Water channels	Sandy melar (sandy lag gravel)
Landslides	Scree slopes
	Andosol remnants

Aeolian eroded sediments can be transported in three different ways: through creep, saltation and in suspension (Bagnold, 1973; Sigurjonsson *et al.,* 1999). The mode of transportation depends on wind speed, particle density and the texture of the topsoil (Sterk and Raats, 1996). Particles transported by creep are too heavy to be lifted from the soil surface so they roll or slide along the ground. Saltation refers to grains moved with a bouncing motion, while suspension refers to the movement of small particles which can be carried at great heights and be subject to long range transport (Sterk and Raats, 1996; Sigurjonsson *et al.,* 1999). It has been suggested that, in general, particle sizes of 0.5 to 2 mm are transported by creep, 0.05 to 0.5 mm by saltation, while particles smaller than 0.1 mm are carried in suspension (Hudson, 1973). Some particles may move both by saltation and suspension as indicated by the overlapping particle sizes.

Present day rates of erosion were measured here in two different erosion forms and using two different techniques. The first was particle tracing on sandy melar, and the second involved the use of a sediment trap on erosion spots.

Particle tracing: The use of tracers in erosion studies is known as “particle tracing”, “sediment tracing” or “particle tracking”. It involves the deliberate marking of natural or artificial sediments with an identifiable signature and the use of the spatial and temporal distribution of these marked sediments to provide some insight into the transport pathways of the sediment (Black *et al*., 2007). Particle tracking has been used predominantly in the determination of sediment flux in aquatic systems (FAO, 1998) and wind erosion studies generally of sandy soils (e.g. Sear *et al*., 2000). The tracking of silt (< 63 μm) is more difficult to achieve and has not received much scientific attention (Black, 2006). Two dual signature tracers (fluorescent and magnetic) were used in this study. The tracers differed in their grain size and colour, one being silt sized (20-40 μm) and green and the other one fine sand sized (60-100 μm) and pink. Three kilograms of silt size tracer and two kilograms of sand size tracer were mixed in order to simulate natural soil composition (i.e. approximately 60% silt and 40% sand).

Five random soil samples were taken in the area prior to tracer introduction to determine magnetic susceptibility (MS) background levels. The tracer was introduced in the summer of 2007 in a 2 m by 2 m quadrat and dispersed using a sieve at a rate of 2.5 kg/m^2 (Figure 12a). This concentration was selected following Black (2006) who used 500 Kg in an area of 200 m^2 in a sand transport experiment in the Dee estuary in Wales. Additionally, an 11,000 gauss permanent magnet with an exposed length of *c*. 16.5 cm was placed 5 m to the south of the quadrat. South was the predominant wind direction at the time of the introduction of the tracer. The purpose of the magnet was to indicate the height of sediment transport above the soil surface. A wind screen was used during the process of tracer introduction due to the wind increasing in speed. Green tracer particles and, interestingly, soil particles were being caught by the magnet even before completing this process.

Five samples were taken in the injection area immediately after tracer introduction by pushing a 7.5 cm x 5.5 cm x 2 cm tin box into the ground and lifting it with the help of a trowel (Figure 12b). The samples were transferred to re-sealable plastic bags after collection. The same numbers of samples were taken in the injection area at two days, seven days and after a year of tracer introduction. Additionally, two transects of five metres long each were set in the predominant wind directions, north east and south west in order to evaluate the dispersal of the tracer in the area surrounding the quadrat. Samples were taken along these transects at 0.2, 1, 2, 3, 4 and 5 m from the introduction area immediately after tracer introduction and two and seven days following introduction.

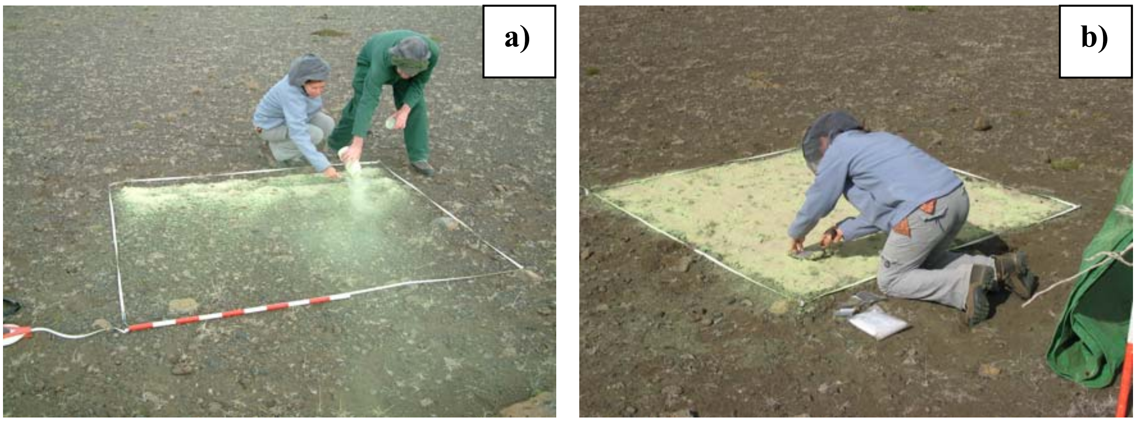

Figure 12- Tracer introduction (a) and sample collection (b).

In the lab, soil samples were air dried and sieved to 2 mm. Plastic pots of 10 cm^3 were filled with the samples and low field susceptibility was measured using a Bartington

MS2 meter and a MS2B single sample dual frequency sensor. Mass specific susceptibility was calculated with the equation:

$$\chi_{lf} = \kappa_{lf}/mass_i/10$$

Where χ_{lf} is the mass specific low frequency susceptibility, κ_{lf} is the low frequency reading, mass is the sample mass expressed in g and the volume of the sample is $10cm^3$. This calculation gives values in 10^{-6} m^3kg^{-1} (Dearing, 1999).

Sediment traps: a modified Wilson and Cooke sediment trap (MWAC) was used to measure sediment transported by saltation and suspension processes (Sterk and Raats, 1996). The MWAC trap has been used in many soil erosion studies in the past (e.g. Sterk and Raats, 1996; Goossens and Gross, 2002; Sterk *et al.*, 2004). The MWAC consists of a central pole with a series of sample bottles attached at different elevations. A vane keeps the sediment trap oriented into the wind. The sample bottles consist of 100 ml plastic bottles with two glass tubes, an inlet and an outlet, entering the bottle through the cap. The tubes are bent 90º in opposite directions on the outside. In this way, particles carried by the wind enter through the inlet, the air escapes through the outlet, and the particles are trapped in the bottles. Further modifications of the trap used in this experiment are an internal diameter of the inlet and outlet tubes of 7 mm, and 5 sample bottles per trap at elevations of: 0.05 m, 0.12 m, 0.19 m, 0.26 m and 0.5 m (Figure 13). Data from wind traps are usually quoted as weight of sediment collected per unit width over a given time, e.g. g $cm^{-1}year^{-1}$ (Hornung, 1990).

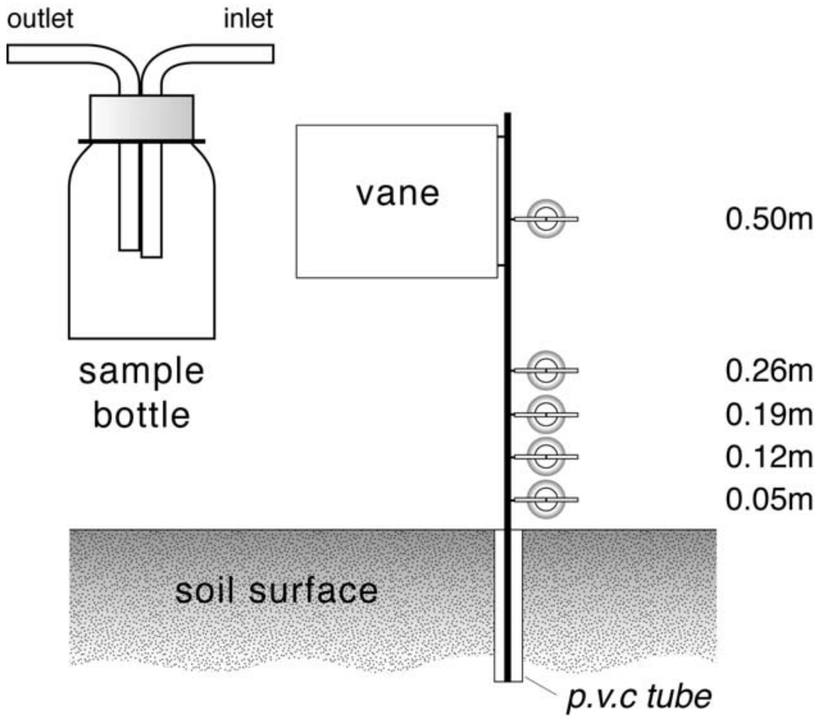

Figure 13- Modified Wilson and Cooke sediment catcher and sample bottle.

Two sediment traps were installed at the edge of vegetated areas, next to erosion spots, in the winter grazing areas of the study farms Gautlönd (28W 0397036, 7271651) and Baldursheimur (28W 0403884, 7266492). Additionally, the level of the soil surface was measured with a dumpy level at 32 points in two 5 by 5 m quadrats in the erosion spots. After a year, the sediments deposited in each of the sample bottles were collected separately. The sediments were air dried, weighed and analysed for particle size distribution by the Coulter principle (see Appendix 1). The soil level at the 32 points of the quadrats was measured after a year and the difference between this and the initial set of measurements was determined.

3.5.1.2 Field descriptions and micromorphology

A randomly located soil pit was excavated in each old home-field of the study farms. Additionally, a reference soil pit was excavated in the winter grazing area of the farm Baldursheimur. The thickness of soil layers was measured to ± 1 cm and the Munsell colour and field texture of each layer was recorded. Representative undisturbed soil samples were collected in Kubiena tins (dimensions approximately: 7.5 cm x 5.5 cm x 2) from between tephra horizons for micromorphological analysis.

Micromorphology is the microscopic study of undisturbed soils and sediments in thin-sections and is a distinctive and well-established approach for addressing a wide range of questions in archaeology and environmental history (Courty *et al.*, 1989; Davidson *et al.*, 2001). Micromorphology will be used in here to examine soils from winter grazing areas and home-fields. In winter grazing areas, this technique will be applied to verify the assumption that SARs reflect sediment accumulation (as opposed to organic accumulation) and to distinguish the erosion processes involved, e.g. water versus wind erosion. This technique has only been applied in combination to SARs in two studies in the past (Simpson *et al.,* 2004; Brown *et al*., 2006). These studies stress the contribution of materials of different origins to SAR in different points of the landscape. For example in a study by Simpson *et al*. (2004), micromorphological evidence indicated that erosion both by wind and water took place in winter grazing areas. This study suggests that good vegetation cover and landscape stability immediately pre-*Landnám* in the failed farm Sveigakot might have masked the evidence of earlier erosion in that inherently more unstable site. In shieling areas, micromorphological data indicated vegetation cover and landscape stability in pre-*Landnám* soils with different levels of post-*Landnám* instability at two different sites (Brown *et al*., 2006).

Micromorphology has been applied more frequently in the reconstruction of past cultivation practices (Davidson and Carter, 1998; Simpson and Bryant, 1998; Simpson *et al.,* 2002; Guttmann *et al*., 2006; Adderley *et al.,* 2008). In these studies, micromorphology has permitted the identification of different types of materials used as amendments and has provided information on aspects of the environment of formation of various types of cultivated fields. This technique is often supported by other analyses such as phosphate content, particle size and ethnographic studies (Davidson and Carter, 1998).

Thin sections were prepared following standard procedures at the University of Stirling Thin Section Micromorphology Laboratory. These included acetone exchange of water, resin impregnation under vacuum, cutting and precision lapping to 30 µm. The thin sections were analysed by dividing the analytical area in micro-strata, defined by the colour and structure observed under a magnifying glass and using a light box. They were subsequently described using an Olympus BH-2 petrological microscope and following terminology in the internationally accepted terminology in the Handbook for Soil Thin Section Description (Bullock *et al*., 1985) and the Guidelines for Analysis and Description of Soil and Regolith Thin Sections (Stoops, 2003).

3.5.1.3 Phosphorus content analysis

The chemical elements most commonly affected by human activity in soils are carbon, nitrogen, sodium, phosphorus and calcium. Of these, phosphorus (P) is the most adequate for use in studies of the past because it is an ecologically deficient element and it has low mobility in most soil systems (Tiessen, 1995). In areas where there have been considerable inputs of organic matter in the past, P can remain detectable in the soil for periods of 10^2-10^3 years (Crowther, 1997). Furthermore, P in its common form as phosphate, is less susceptible than most of these elements to leaching, oxidation, reduction or plant uptake. Losses of phosphorus can occur, but are generally very small compared to the total cultural input (Holliday and Gartner, 2007).

P exists in the soil in many forms; in terms of its chemistry is referred to as: organic P, inorganic P or total P (Holliday and Gartner, 2007). According to its availability to plants it can be considered as non-available or fixed, potentially available or immediately available. As organic matter decomposes within soils, the phosphorus it contains becomes mineralized and tends to become fixed within the inorganic fraction (Brady, 1990). In acid soils phosphorus is fixed mainly by aluminium and iron and in alkaline soils by calcium (Hesse, 1971). In Andosols (most of Icelandic soils), the presence of colloidal constituents such as allophone, imogolite and ferrihydrite clay minerals are responsible for its high P retention. This P retention is generally more than 90% (Wada *et al.,* 1992; Arnalds, 2004; Arnalds, 2005). P analysis is often referred to as phosphate analysis; however this term is incorrect when referring to total soil P because some organic P compounds are not phosphates (Bethell *et al*., 1989; Holliday and Gartner, 2007). The advantage of total P determination compared with that of inorganic P, which is used in some surveys, is that it provides a measure of the overall P concentration irrespective of the stage of mineralization (Crowther, 1997). The measurement of total P may be the best indicator of human inputs of P when comparisons are made with natural soils (Bethell *et al*., 1989).

Bulk soil samples were taken between identified tephra layers in the excavated soil profiles from the study farms home-fields. Total P was determined in the samples using a modified Sodium hydroxide fusion method (Smith and Bain, 1982) followed by spectrophotometric measurement. Replicate samples and blanks were also processed to test the precision of the method and for possible contamination, respectively (for detailed methods see Appendix 1). High levels of phosphorus are associated with high vegetation productivity. Therefore the concentration of total P in discrete soil layers (defined by tephrochronology) of home-field soils can be considered an indicator of its past productivity. The total P concentration of an area can only be considered high or low when compared with a background sample of "natural soil". Because there are no areas in Mývatnssveit which can be considered to have been completely devoid of human activity, background samples will be taken from winter grazing areas. These areas are subjected to extensive grazing; therefore it is assumed that their phosphorus concentration will be relatively low. Two hypotheses are considered here; the first is that total P content of home-field soils will not be statistically different between successful and failed farms in the soils representing the pre-*Landnám* period. Additionally, it is expected that this pre- *Landnám* content will be similar to background samples. This would indicate an initial, pre-settlement, uniform soil quality in all the study farms. The second hypothesis is that successful farms will have significant greater total P content than failed farms in the soils from post-settlement periods. This would suggest that the home-fields of the successful farms were more intensively fertilized than those of the farms that failed and that their improvement was crucial to the success of farming systems in the study area.

Additional lab analyses carried out on the bulk soil samples included: pH in water solution (1:2.5), determination of organic matter content by loss on ignition (LOI) at a temperature of 425 ºC, and particle size analysis. Detailed methods can be found in Appendix 1).

3.5.2 Historical records

Land registers and census data from the late 17th and the early 18th century are considered in this thesis. The 1712 land register (*Jarðabók*) and the 1703 census (*Manntalið* 1703) are the most complete and important documents from this time. They were both compiled by Árni Magnússon and Páll Vídalín who were commissioned by the Danish king to investigate the situation in the country, after the hardships faced by the Icelandic population in the last decades of the 17th century, and to make proposals for improvements (Hjálmarsson, 1993). Statistical analyses were carried out on the data extracted from the historical records to assess differences between successful and failed farms. These analyses were conducted using the statistical software Minitab 15 and Microsoft Office Excel 2003.

3.5.2.1 Land registers

Four land registers, corresponding to the years 1686, 1696, 1712 and 1847, are considered in this study. Land registers convey information on tax value, land rent and livestock rent (also called cattle hire). Additionally, the *Jarðabók* includes information on livestock numbers, natural resources and other farm's characteristics. The data from the 1686 and 1696 land registers were extracted from the reconstruction and analysis of the manuscripts made by Lárusson (1967). The manuscript called the 1686 land register is referred to sometimes as the 1681 manuscript. It was compiled by the Capitaneus's representative in Iceland, Johan Klein, but edited by his successor, Christopher Heidemann. This land register was ordered by the Crown with the aim of establishing a tax necessitated by Danish-Swedish war. The Crown required that the tax value was calculated based on the land rent following the ratio 20:1. This register was completed and delivered to the Treasury Office in 1687 and it was the first one in Iceland to incorporate all owner categories, including private property. The information referred to as the 1696 land register comes from manuscripts compiled from 1695 to 1697 (the revision of the compilation started in 1686). This compilation, in contrast to the 1686 register, reverted to older tax values according to "custom and usage" which reflected market values (Lárusson, 1967). The 1847 land register is known as *Jarðatal á Íslandi* and was written by Johnsen (1847) based on contemporary data.

According to owner category, farms from the mid-sixteenth century could be owned privately, by the Church or by the Crown. These independent farms were called *lögbýli* and were often partly or completely rented out to tenants as independent or as dependent farms, the latter called *hjáleigur*. Tenant farms were legally in the same category as owner-occupied ones but had to pay land rent and had insecure tenure, with short-term leases for one or two years or, more commonly, as tenancies at will (Jónsson, 1993). Dependent farms or cottages could not be sold separately and usually had restricted or negotiated access to basic farm resources such as meadows, pastureland, fuel and turf (Bolender, 2006). Another distinction made was between *heimaland* and *heimajörð,* if one farm was another farm's *heimaland,* it meant the farms were one operational unit, even if they were far from each other. *Heimajörð* was the farm in which various cottages were included as parts.

According to the *Jónsbók* a tenant could not legally lease out any part of the farm on his own accord. However, in practise many tenants did lease part of the farm for building cottages for which they collected rent. In these cases, the tenant lived cheaply because the cottars paid the larger part of the land rent determined for the farm. In other cases, the owner through a representative collected land rent from each tenant living on the farm, including cottars. It appears from the *Jarðabók* that cottages could also sometimes pay a tax value that reduced the one on the *heimajörðin*. Due to these variations in a farm's rights and duties it can sometimes be difficult to determine whether a farm was independent or not. In the *Jarðabók* a farm was considered independent if on its own account it provided food, lodgings, and conveyance for the poor even if it had a common pasture with other farms (Lárusson, 1967).

Although there is no evidence of what factors were taken into account for the historical valuation of farms in Iceland, it has been associated with the quality of the land (Lárusson, 1961; Lárusdóttir, 2006). For example, records of a farm called Galtafell in 1565 state that the land was valued according to how many cattle the farm could feed (Lárusson, 1967). With respect to the land rent, the *Jónsbók* stated that it should be determined by free negotiation between the parties. However, during the last decades of the 15th century it was common to set the land rent at 1/20 of the farm value (Lárusson, 1961). The land rent was usually paid in kind with cattle, cattle derived products, homespun and knitted articles, fish, 2-3 days' work and in exceptional cases, in coins (Lárusson, 1967). The land rent unlike the tax value seems to have fluctuated in response to difficult times such as low market prices and disease, the later probably as a consequence of a reduction in the demand for land (Eggertsson, 1998). The relative lack of variation in tax values compared to land rents might be explained by the difficulties involved in reducing the tithe. The tithe was a property tax, it was calculated at one per cent of the total value of debt-free property which had a value of at least 5 hundreds. The collected tithe was divided into four equal parts to be assigned for poor-relief, to the priest, to the Church and to the bishop (Lárusson, 1961). According to a decree of the National Assembly in 1671, the tithe could only be reduced after a valuation carried out by the district judge and 12 men from the jurisdictional district appointed by him (Lárusson, 1961). Therefore, it can be assumed that the tax value could only be reduced after this type of valuation. For this reason, it is generally believed that land rent reflected more accurately the productivity of the farms than the tax value (Lárusson, 1967; Eggertsson, 1998).

Most farmers rented not only the land but also some of their livestock. The *Jónsbók* established that the person who owned more cattle than he needed should let cattle at a reasonable price to those who were in need of them. At the beginning, tenants apparently were not required to rent livestock from their landlords, but towards the 15th century many landowners tied the provision of land and livestock (Eggertsson, 1998). This practice contributed to over-exploitation with farm owners demanding increasing numbers of livestock to be hired by the tenant, which meant sometimes that the tenant could not even feed one lamb of his own. The *Jónsbók* established that the livestock rent should be no higher than the value of two quarters of butter or the value of the fodder necessary to feed four lambs during winter. If butter or hay were not available, the hire could be paid with twelve ells of homespun (Lárusson, 1961). Given that a cow had a value of 120 ells, this indicates the livestock rent was 10%. However, examples from the *Jarðabók* seem to suggest the livestock rent was 20 ells per cow value or 16.7%, whereas Jónsson (1993) reports livestock rents of between 12-20% in the 18th and 19th century. In this thesis the livestock rent will be calculated according to the *Jarðabók* reported value of 20 ells.

All expressions of value in the 1686 and 1696 land registers were unified by Lárusson to hundreds (*hundrað* = h) and ells (*alin* sing. *Álnir* plur. = *ál*) as are reported in the older registers. The words hundreds and ells should be interpreted as abstract money of account. The units were based on a duodecimal system in which a hundred or long hundred meant 120 ells or 1 cow value (or cow equivalent) (i.e. the value of one 4-8 year old cow that had calved at least twice) (Lárusson, 1967).

3.5.2.2 Census

The socio-economic structure regulating the number and size of households in pre-modern Iceland and the existence of one of the earliest complete national census in the world (Þjóðskjalasafn Íslands (National Archives of Iceland), 2009), makes it possible to test demographic data as indicators of past farm productivity. Social and legal constraints on marriage and household formation effectively controlled, more than mortality rates, the size of the population (Vasey, 1996). For example, married servants generally could not find employment in the same farm, making access to enough land to sustain a family a prerequisite for marrying (Eggertsson, 1998). Later, a law established in 1824, forbade the marriage of people who received poor relief by the hreppur. Moreover, the hreppur had the right to separate families if they were not able to support themselves (Vasey, 1996). These regulations led to the peculiar characteristics of the Icelandic demographics of the pre-modern era. These included: low percentage of marriages, particularly in the servant sector (in 1703 44% of all Icelandic women 50 years and older had never been married and only 1% of the work servants were married); late marriage (mean age at marriage of woman 28.9) and low birth rate (Vasey, 1996; Eggertsson, 1998).

A household was formed by husband and wife, their children, possibly foster children, relatives and servants; who lived with the family (Magnússon, 1985). From the early eighteenth until the late nineteenth century, it was a common practice for tenant families to send their children to work as servants in other farms and hire other young people as workers for their own farms. This arrangement made the household flexible in size, so that it could increase or decrease according to its changing fortunes (Pinson, 1992). Changes in fortune could also induce changes in the actual farm size. Insecure leases and the fact that the law did not guarantee the tenant any compensation for improvements made on the farm, meant that any investments were made on mobile assets instead. In this way, in a good year a farmer would buy more livestock or move with the household to a larger farm, whereas in a bad year he would move to a smaller farm (Jónsson, 1993).

Given this household size flexibility and the fact that the number of farms in the country remained relatively stable through most of the pre-modern era (Eggertsson, 1996; Eggertsson, 1998), it is reasonable to assume that more productive farms had also more household members in the working age group than less productive ones. The minimum age of the working group, or the economically active population, is considered to be 15 years (Jónsson, 1993). The 1703 census was analyzed and used to support the data from the land registry of 1712. The 1703 census was the first one in Iceland which reported for every person name, age, household position and relation to head of household; and is probably the first census covering a whole country (Thorarinsson, 1961a; Tomasson, 1977).

3.5.3 Ethnography

Qualitative research is based on trying to understand, describe and explain social phenomena "from the inside" (Gibbs, 2007). Four primary methods, used alone or in combination, are generally applied in qualitative research: observation, textual analysis, interviews and audio/video recording (Silverman, 2006). These methods are often used in local knowledge and perceptions studies, such as those dealing with past and present land management practices and landscape degradation, aiming at influencing policy formulation (e.g. Ólafsdóttir and Júlíusson, 2000; Dahlberg, 2000; Calvo-Iglesias *et al*., 2006). In the Mývatn area the only study of this type was carried out by Ólafsdóttir and

Júlíusson (2000), covering the counties of Norður and Suður-Þingeyjarsýsla. This research examined farmers' perceptions in relation to land degradation in Iceland, highlighting differences between stakeholders and the need to include farmers' views in successful conservation plans.

Cultural theory, also known as the theory of socio-cultural viability can be used as a tool for analysing perceptions and behaviour. Cultural theory was developed by Douglas (1970) and is based on the assumptions that human behaviour is culturally biased, that there are a limited number of cultural types and that the typology of viable combinations is universal (Mamadouh, 1999). The typology produced is based on two dimensions of sociality named grid and group. Grid refers to the degree to which an individual's life is restricted by externally imposed prescriptions. Group stands for incorporation into a bounded group (Douglas, 1970; Thompson *et al*., 1990). The combination of these two dimensions of sociality produces four cultural types (according to the original model): hierarchy, egalitarianism, fatalism and individualism. Thompson *et al*. (1990) added a fifth type called autonomy. These dimensions of sociality and related cultural types have been represented in many ways (see Mamadouh, 1999 for a review). The "map" developed by Thompson is one of the most frequently used (Figure 14). The figure depicts individualism with both low group and low grip. Individualists believe they are free of control by others but that they have the ability to control other people's lives. Fatalism is characterised by high grid and low group, for these individuals fate organises their life. The hierarchy is a social environment characterised by strong group boundaries and imposed prescriptions (high group and high grid). These prescriptions or regulations are justified by the importance of the collective over the individuals. Egalitarianism maintains strong group with few regulations (high group and low grid). In this social environment there is minimum role differentiation. The fifth group is characterised by people who do not control others and are not controlled (Thompson *et al*., 1990; Mamadouh, 1999; Billgren and Holmén, 2008).

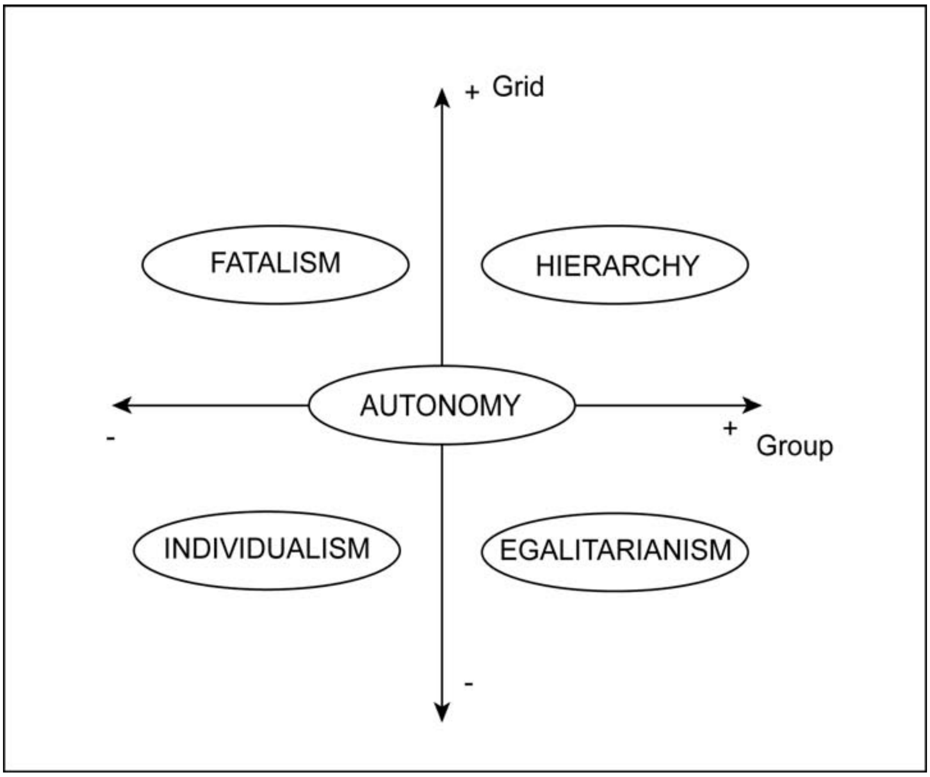

Figure 14- Cultural types. Adapted from Thompson (1990).

Thompson (1990) combined the basic cultural types described above with ecological insights from Holling (1986) to explain the "myths of nature". The myths of nature refer not to fictions but to stories representing truths which underlie our assumptions about reality (Thompson *et al*., 1988); in this sense they are "partial truths" (Holling *et al*., 2002b). Figure 15 illustrates the combined myths of nature and dimensions of sociality. According to this model, individualists view nature as being benign or robust. This view encourages a trial and error management style. Fatalists perceive nature as capricious or unpredictable. This myth is associated with lack of management because people who held this view believe that it will make no difference. Hierarchists consider that nature is sometimes "perverse" and sometimes "tolerant". This position assumes that with appropriate management the state of equilibrium can be maintained. Egalitarians are associated with viewing nature as ephemeral. This myth supports a very cautious approach to management since it is based on the perception that any manipulation of nature can lead to disaster (Thompson *et al*., 1988; Thompson *et al*., 1990; Billgren and Holmén, 2008). It is not clear what view of nature is associated with the autonomists in Thompson's cultural types. Holling *et al*. (2002b) add a fifth view of nature which they call "evolving". They associate this view with shifting stability of landscapes and self-organisation and recognise the difficulties in representing this view in a simple diagram.

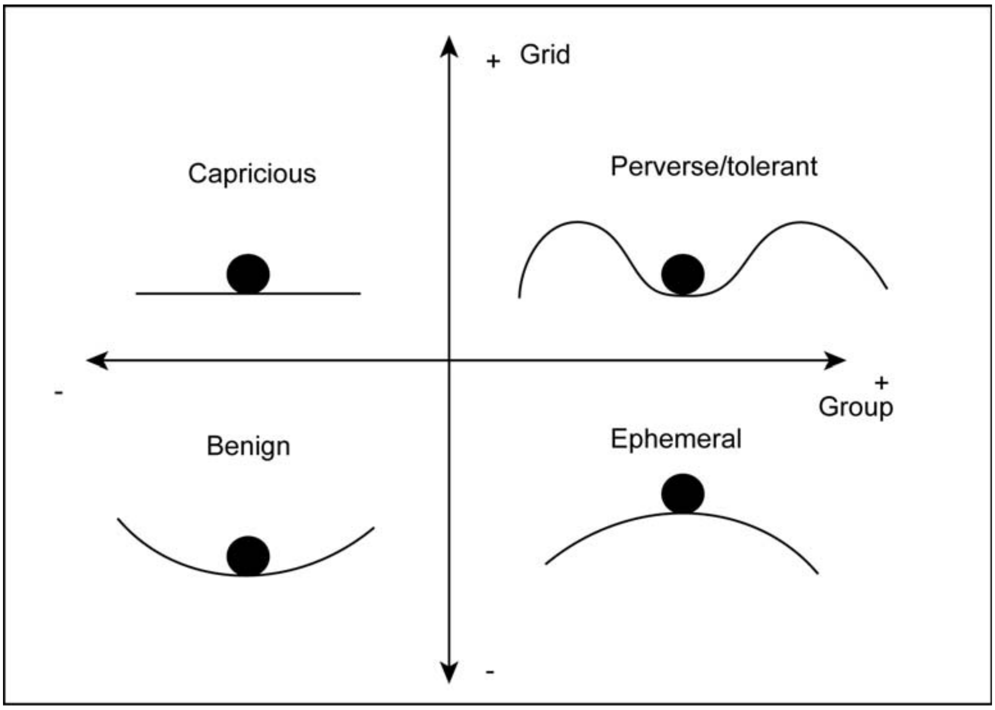

Figure 15- Myths of nature adapted from Thompson (1990).

In the real world people rarely express their beliefs in ways as simple as those depicted in the myths of nature (Janssen, 2002). Cultural theory was employed in this thesis to illustrate how perceptions may have an influence on management approaches.

Interviews and audio recording were used to gather information on past land management practices and natural resources and to explore farmers' perceptions on land degradation and the causes for past farm success and failure in Mývatnssveit. Interviews were of the semi-directive or semi-structured type, being this a standard ethnographic method for gathering information using an open-ended format (Briggs, 1986). With this method participants are guided in the discussion by the interviewer, but the direction and scope of the interview are allowed to follow the participants' train of thought. A list of topics and proposed questions was developed to be used as a guide by the interviewer (see

Table 10). Eight people in total were selected to be interviewed. These were the heads of household from the successful study farms: Gautlönd, Grænavatn, Baldursheimur, Geirastaðir and Grimstaðir; the farmer from Garður (to which Brjánsnes now belongs); and the heads of household from the farms Skutustaðir and Narfastaðir, considered potential key informants. In some cases other family members contributed in the answers of the main interviewee.

Table 10- Semi-directive interview outline.

Theme	Suggested questions
Carrying capacity and livestock composition	How many livestock did the farm have and what was the livestock mix (i.e. how many cows, horses, milking ewes, etc)?
Spatial and temporal movement of livestock	How was the livestock moved around the landscape? i.e. if summer shielings were used, which livestock were taken there and when? When were they brought back to the farm? Which livestock were taken to communal grazing areas and when?
	When was the round up of the livestock done and where?
	How many livestock were slaughtered? What did this depend on?
Vegetation type and distribution	How were different vegetation categories distributed across the farm? (Draw on map specific areas of meadows, woodland, etc.)
Home-field	Was the home-field fertilized? What with (e.g. manure, ash)? How was it managed (e.g. when was it fertilized, harvest, etc)?
Natural resources	What natural resources did the farm have access to (e.g. fishing, wood, meadows, etc)?
Constraints	What were the main environmental problems of the farm (e.g. sand blow, flooding?)
Innovation and adaptations	Can you recall any innovations in management that were applied in the past?
	What? When? Why were they applied and were they successful?
Farm success and failure	What factors were more likely to influence farm productivity?
	What management decisions were more important in determining the success or failure of farms?
	What do you think farm success or failure in Mývatn depended on?
Networks of support and public institutions	What kind of support was available in case of natural disasters or when facing economic problems?
Commercialisation	How and to whom were farming products sold?
Climate and environmental change	Do you remember any significant changes in weather patterns in the past? Have there been changes in erosion/vegetation?

At the beginning of the interviews the name and age of the participants were recorded and they were asked to state how long they and their family had been living in the farm. Each participant was given a map of their farm and asked to draw its boundaries and management areas in the past (e.g. shielings, communal grazing areas, home-field, etc.). The interviews were carried out in Icelandic by Astrid Ogilvie, from the Institute of Arctic and Alpine Research (INSTAAR) and by Brynjar Asgeisson, from the

Stefansson Arctic Institute. They were recorded using a digital voice recorder and later translated and transcribed into English. The transcription of interviews normally introduces issues of accuracy, fidelity and interpretation because it involves a change of medium (Gibbs, 2007). Another aspect that has an influence in these issues is the fact that the interviews were carried out by a translator and not by the researcher.

The interviews were analysed following the methods described in Gibbs (2007). These included thematic coding, organizing codes hierarchically and making comparisons using qualitative tables. Coding is a way of categorizing the text in themes to facilitate the analysis of the data. The codes were derived initially from the interview's questions, with more codes added when common themes appeared in the respondents' answers. The codes were then grouped together and labelled by farm name. Codes that were about the same thing were gathered together under a same branch to form a "hierarchy", formed by a parent and its children[5]. Comparative qualitative tables, containing a summary of the respondents' answers linked to the codes, were then derived from each hierarchy.

[5] The hierarchies are arranged downwards with the most general items at the top and the more specific lower down. Sub-hierarchies are referred to as branches. The most general code is referred to as the parent and those lower down the hierarchy are its children. Codes in the hierarchy that share the same parent are called siblings.

Chapter 4 -Results and discussions: Soil records

Soil and sediment data are related to two key management areas of the historical Icelandic farm: winter grazing areas and home-field areas. Soil accumulation rates (SARs) are used to assess the degree of exposure and sensitivity to soil erosion in winter grazing areas. The analysis of phosphorus content in home-field soils provides an indication of the use of amendments and related productivity. Micromorphology, on the other hand, is used to identify the nature of the amendments and provides information on the environment of formation of both areas to complement the analyses.

4.1 Soil accumulation rates in winter grazing areas

Table 11 shows the SAR measured in the winter grazing areas of the study farms. They are presented by time period as defined in the field by tephrochronology. The only tephra that appeared consistently in all the soil profiles was the *Landnám* tephra. The prehistoric tephras H_4 and H_3 only appeared in three and two profiles respectively, and for this reason were not considered for statistical analyses. The time periods statistically analysed were: 500 BC - AD 871, AD 871 -1477, AD 1477 -1717 and AD 1717 -2007. Additionally, because in some soil profiles the AD 1717 tephra could not be identified to allow a separation of the latter two periods, an analysis of the combined period AD 1477 -2007 was also made (samples where the AD 1717 tephra was present were also included in this group).

Table 11- Soil accumulation rates (SAR) by time period in the study farms.

	SAR (mm/yr)						
Farm	**2000-800 BC (H_4-H_3)**	**800-500 BC (H_3-Hv)**	**500 BC - AD 871 (Hv-*Landnám*)**	**AD 871 (*Landnám*)-1477**	**AD 1477 - 2007 (present)**	**AD 1477 -1717**	**AD 1717 - 2007 (present)**
Baldursheimur	0.067	0.067	0.131	0.099		0.292	1.069
Bjarnastaðir			0.066	0.198	0.264		
Brjánsnes				0.363	1.208		
Fagranes	0.050		0.109	0.099		0.375	0.138
Gautlönd	0.042	0.300	0.131	0.165	0.208		
Geirastaðir				0.165		0.250	0.138
Grænavatn				0.297		0.458	1.000
Þórleifsstaðir			0.124	0.165		0.125	0.276
Mean	**0.053**	**0.184**	**0.112**	**0.194**	**0.560**	**0.300**	**0.524**
Sd	**0.013**	**0.165**	**0.027**	**0.092**	**0.562**	**0.126**	**0.470**

Figure 16 shows the mean SAR through time in the winter grazing areas of the study farms. A continual increase in SAR is evident after settlement, with the greatest increase in the time period post- AD 1717. The error bars show that the variability in the SARs between farms is also greater in this time period. Other studies in Iceland have also reported an increase in SARs after AD 1717 (Gerrard, 1985; Ólafsdóttir and Guðmundsson, 2002). Dugmore and Erskine (1994) found an increased SAR and variability of erosion and deposition after AD 1510 and concluded that the high variability was due to local factors affecting the deposition while the more uniform accumulation previous to AD 1510 was the result of transporting mechanisms operating on a scale of hundreds of thousands of metres.

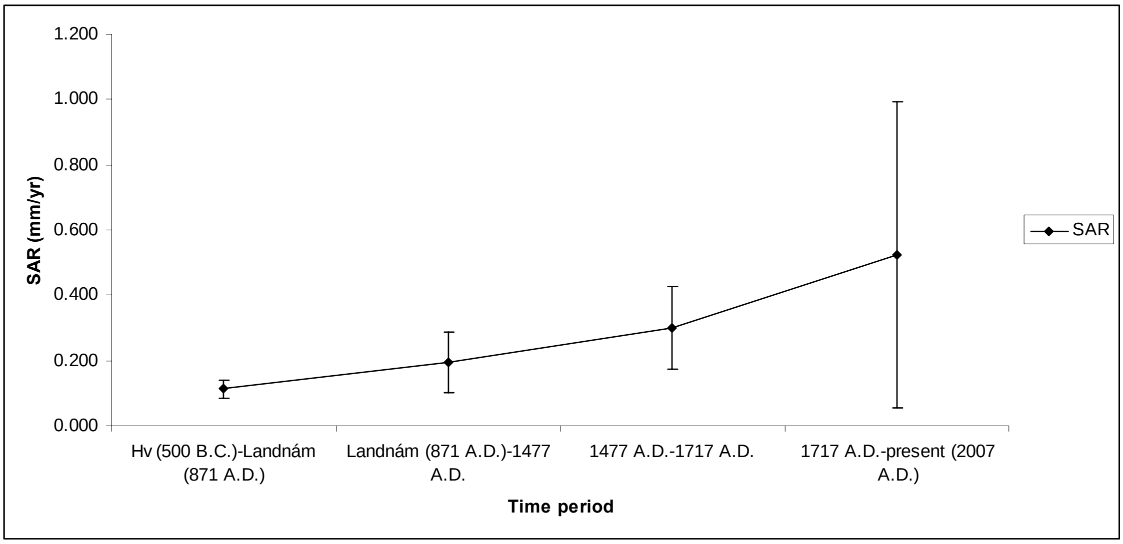

Figure 16- Soil Accumulation Rates per time period in all the study farms. Error bars show the standard deviation.

The data was further classified according to the farm “outcome” (whether the farm was successful or not), and a General Linear Model (GLM) using SARs as the response variable and time period and outcomes as factors was carried out. Because the data did not meet the assumption of equal variance the test was repeated transforming the data with natural logarithm (ln). The results showed significant differences in the mean SAR in the different time periods (df=4, 21; F=3.11; P=0.037) but no significant differences between successful and failed farms (df=1, 21; F=1.83; P=0.190) and nor was the interaction between time period and outcome (df=4, 21; F=0.57; P=0.685). Tukey’s method was used to compare all possible pairs of level means for the specified factors (time period and outcome). The adjusted P-values and confidence intervals showed that SAR in the AD 1477-present period were greater than in the pre-*Landnám* period (see Appendix 2). The fact that statistical differences were only found in the combined time period “AD 1477-present” reflects the high variability in the 1717-present data. Figure 17 shows that this variability was greater in the successful farms.

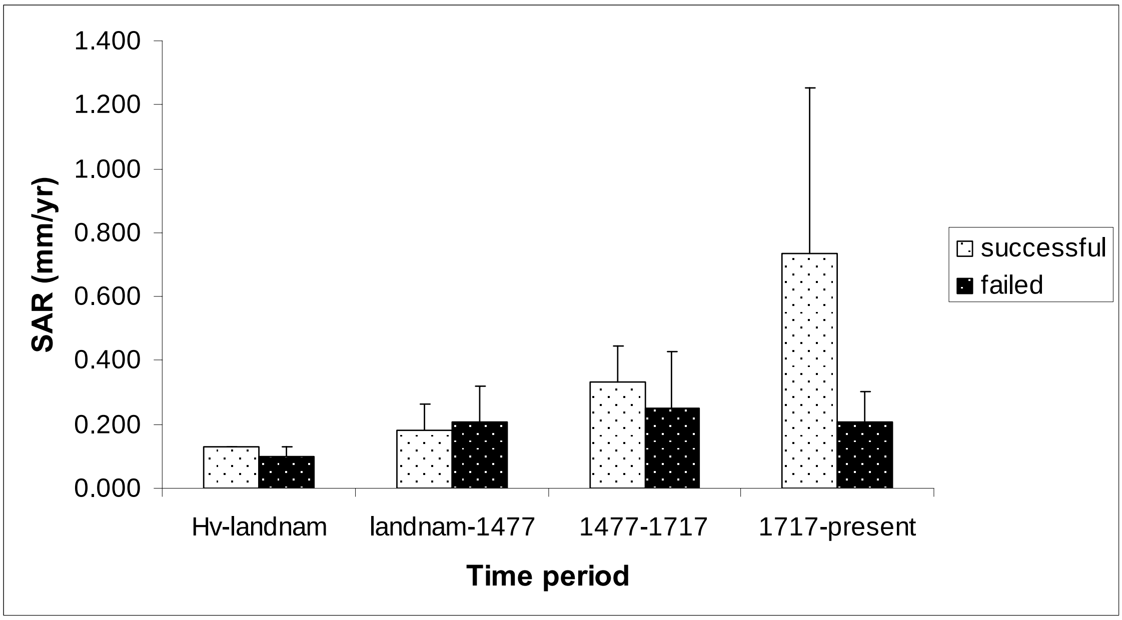

Figure 17- Soil Accumulation Rates in winter grazing areas of successful and failed study farms in Mývatnssveit. Error bars are based on the standard deviation.

The analysis of the data suggests that deposition in Mývatnssveit only surpassed prehistoric levels after AD 1477, with the bigger increase and variability post- AD 1717. The nature of the accumulated material is of key importance in the interpretation of past erosion and has been overlooked in studies based on SAR. Accumulated material can be composed of organic matter, mineral material eroded by water and mineral material eroded by wind. Furthermore, if the eroded material represents aeolian erosion then this can correspond to local sediment sources, sediments kilometres away from the deposition area or a mixture of both. SAR at a particular point might also vary through time just as the result of its location relative to the areas of erosion. That is to say that SAR in an area could increase if an eroding slope is moving closer (Dugmore and Buckland, 1991).

The nature of the accumulated sediment in the winter grazing areas of the study farms was assessed by micromorphological analysis of a representative soil profile and is reported below. Determining whether the sediment may have come from local sources is more complicated. Two experiments, one using particle tracing and the other one involving the use of sediment traps were carried out to explore this issue.

4.1.1 Soil erosion experiments

This section presents the results and discussions from two soil erosion experiments referred to as: particle tracing and sediment traps. These experiments represent pilot studies and were conducted with the aim of determining present day rates of soil erosion in the study area and of assessing the assumption that SARs are associated with local erosion (see Section 3.4.1.1).

4.1.1.1 Particle tracing

The conditions during the first week of the experiment were of "very slow wind" according to the Icelandic Met Office (2010). The windspeed at the time of tracer introduction measured at the automated Mývatnsheiði weather station was between 3.5-4.1 m/s. The maximum windspeed during the first seven days of the experiment was 5.2 m/s and the maximum gust 6.6 m/s (Gísladóttir, 2007). Table 12 shows the low frequency mass specific susceptibility values at five points in the injection zone on the day of injection (0 days), and 7 days and a year after tracer injection. Additionally, background levels of low frequency mass specific magnetic susceptibility are provided, these were obtained at five points in the area before the introduction of the tracer.

Table 12- Low frequency mass specific susceptibility in the tracer injection zone at 0 days, 7 days and 1 year after the injection together with natural background levels.

Injection zone sample	Low frequency mass specific susceptibility ($10^{-6}m^3kg^{-1}$)			
	0 days	**7 days**	**1 year**	**background**
1	3.34	5.42	2.64	2.06
2	3.90	3.04	2.34	2.08
3	3.47	6.49	2.12	1.98
4	3.06	3.85	2.20	2.11
5	2.26	3.60	2.23	2.07
mean	**3.21**	**4.48**	**2.31**	**2.06**
sd	**0.61**	**1.43**	**0.20**	**0.05**

A one-way analysis of variance (ANOVA) of the MS data versus time after tracer injection was carried out to test for significant differences in the means. Figure 18-a shows the residuals plots of the ANOVA test. The residuals in the normal probability plot do not follow a straight line, showing that the data did not meet the assumption of normal distribution. The fanning of the residuals across the fitted values in the residuals versus fits plot shows that the data did not meet the assumption of equal variance. Johnson's transformation (Johnson, 1978) was used to normalise the data (AD= 0.284; P= 0.592) and an ANOVA was carried out again on the transformed data. Figure 18-b shows the residual plots of the ANOVA test with the transformed data. The normal probability plot of the residuals follows roughly a straight line and the plot of residuals versus fitted values shows residuals scattered randomly about zero. These plots confirmed the transformed data met the assumptions of the test.

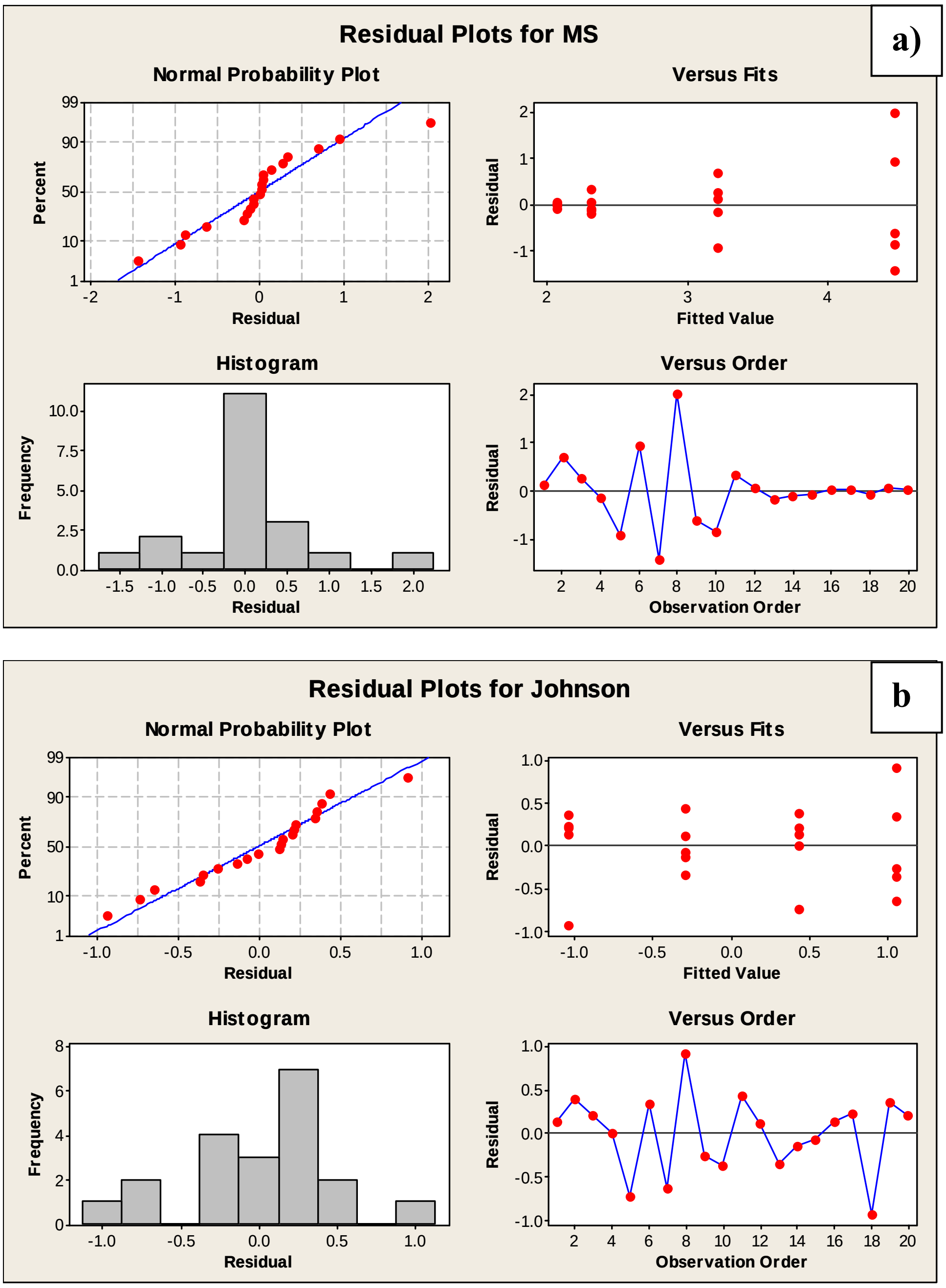

Figure 18-Residual plots from ANOVA tests of Magnetic susceptibility versus time, a) shows the data does not meet the assumptions of normal distribution and equal variance; b) residual plots of the data after Johnson's transformation.

The results of the ANOVA on the transformed data indicated that the level means are significantly different from each other (df= 3; F= 17.30; P< 0.001). The significant differences were specifically between the means of the MS at: 0 days after tracer introduction versus background levels, 7 days versus 1 year after tracer introduction, and 7 days after tracer introduction versus background levels. The results, however, do not show a difference between the MS on the day of introduction versus 1 year after it, or between background levels versus 1 year after tracer introduction. The results need to be interpreted with caution taking into account: the high MS background levels of the natural soil, the uneven distribution of the tracer in the injection area and the use of a destructive method of MS determination. The uneven distribution of the tracer is evident in the error bars (based on the standard deviation) of the graph of MS in the injection area after tracer introduction and background levels seen in Figure 19. The greater variability seen in the samples taken 7 days after tracer introduction could be the result of tracer re-distribution. The difficulties in achieving a uniform distribution of the tracer in the injection area have been reported before. Black (2006), in a particle tracking experiment in the Dee estuary, reported that the use of a disperser did not introduce a uniform concentration onto the sand bed of the injection area. He obtained χ_{lf} values ranging from 50-225 m^3kg^{-1}. However, because a portable field sensor was used in that study, it was possible to take many measurements to get a more representative mean. By taking many measurements on the injection area it would also be possible to eliminate extreme values (outliers) in the calculation of the mean. The use of a sieve was useful in this experiment in avoiding the introduction of lumps of tracer, formed in the fine green material, but did not help in achieving a uniform distribution.

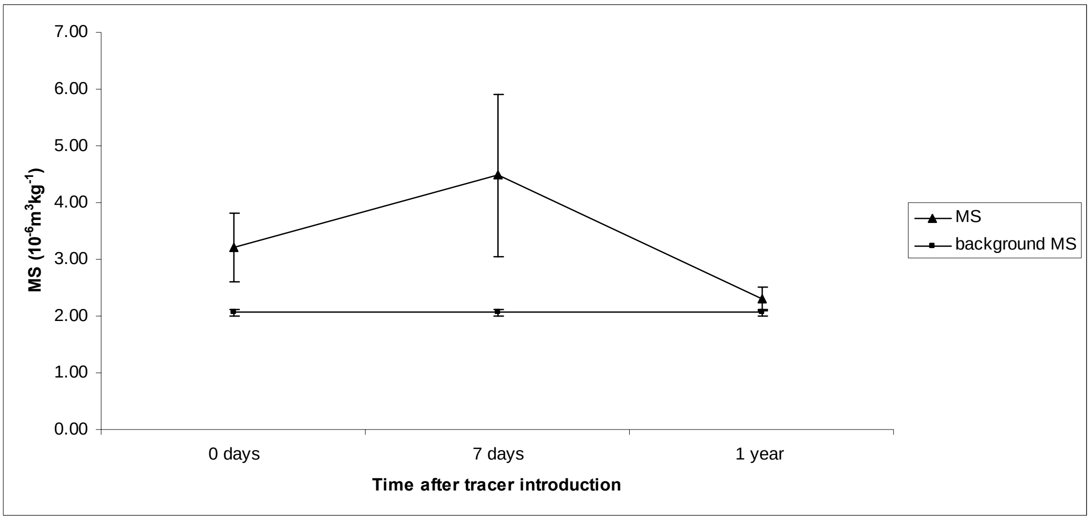

Figure 19- MS background level and MS in the injection area at the time of tracer introduction (0 days), 7 days and 1 year after tracer introduction. Error bars are based on the standard deviation.

Regarding the soil natural MS levels, the χlf of the native soil (mean of five samples) was 2.06 x 10^{-6} m^3kg^{-1} (sd = 0.05) compared with 21.19 x 10^{-6} m^3kg^{-1} for the tracer. Although these values indicate that the tracer is around 10 times more easily magnetised than the native soil, this is not a big difference in tracing studies. For example, Black (2006) used a tracer 400 times more easily magnetised than the natural sand studied. The fact that the measurements were not taken with a field sensor makes this problem more significant. Because the measurements taken in the lab represent a mixture of the deposited tracer in 82.5 cm^3 of soil (given the dimensions of the collecting box), this implies a bigger proportion of soil than in measurements taken with a field sensor which measures *c*. 0.6 cm of the soil surface. Furthermore, because of the high MS level of the natural soil, it is not possible to assess the mass of tracer eroded through the magnetic separation of the tracer from the samples. However, an estimated value of the rate of tracer eroded in a year can be calculated by linear interpolation with the equation:

$$Y_2 = \frac{(X_2 - X_1)(Y_3 - Y_1)}{(X_3 - X_1)} + Y1;$$

Where:

X_1= MS before introduction (background level)	Y_1= amount of tracer before introduction
X_2= MS a year after tracer introduction	Y_2= amount of tracer a year after introduction
X_3= MS tracer introduction day	Y_3= amount of tracer on introduction day

$$Y2 = \frac{(2.31 - 2.06)(2.5 - 0)}{(3.21 - 2.06)} + 0 = 0.54 Kg / m2$$

If 0.54 Kg/m^2 is the amount of tracer left after a year of its introduction and 2.5 Kg/m^2 the original amount introduced then 1.96 Kg/m^2 of tracer was eroded in a year.

The visual assessment of the experiment provides an insight into the eroding behaviour of the different particle sizes. Because the tracer mixture had a higher proportion of silt sized particles, the quadrat appeared green after the introduction of the tracer (Figure 20-a). Two days after tracer introduction the quadrat was pink in appearance, suggesting the green particles had been blown away (Figure 20-b). However, during the process of taking soil samples, it was appreciated that the pink particles were forming a “crust” and that green particles were still present under the surface (Figure 21-a). Seven days after the tracer was introduced, the quadrat had been reduced by approximately 2 cm from the borders. After a year of tracer introduction most of the tracer had disappear, but some remnants were seen in particular in the holes left by previous samples (Figure 20-c and Figure 21-b).

Figure 20- Injection area on the day of tracer introduction (a), seven days after (b) and a year after tracer introduction (c).

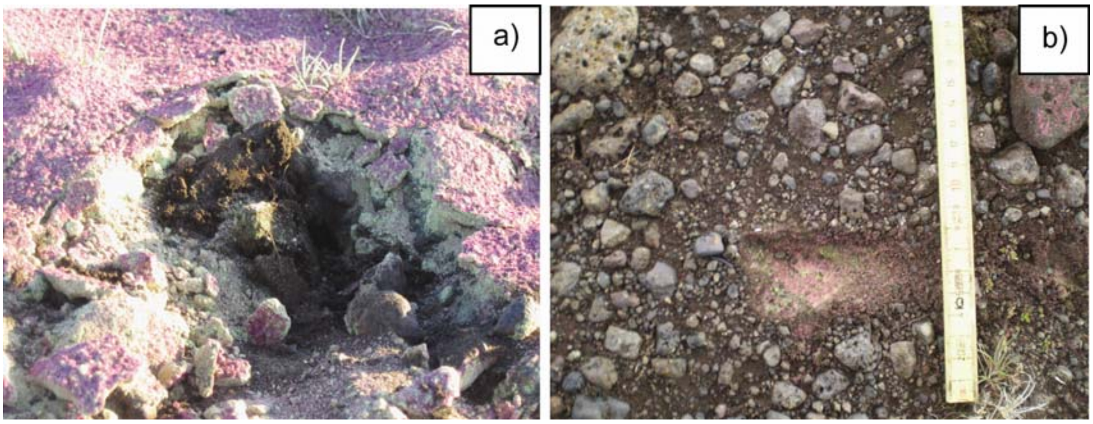

Figure 21- a) sand sized particles (pink) are forming a "crust" on the surface; b) remnants of tracer in a quadrat after a year of introduction.

The spatial dispersion of the tracer was assessed by taking samples along two transects orientated in the main wind directions (northwest and southeast) at 2 and 7 days after tracer introduction. Table 13 shows the low frequency magnetic susceptibility of the soil samples at different distances from the introduction area. Most of the values were within background levels, the points with higher susceptibility (2.14 x 10^{-6} m^3kg^{-1}, at 1 and 4 m from the injection area in the NW transect) were only 0.03 x 10^{-6} m^3kg^{-1} above the highest background level (2.11 x 10^{-6} m^3kg^{-1}), and thus cannot be considered with confidence to have a higher susceptibility due to tracer content. The purpose of the samples along transects was to "trace" particles spatially, in this respect ANOVA tests showed the two transects were indistinguishable either from each other or from background estimates (F=0.41, P=0.80). GLM analysis showed no significant effect of orientation (factor: SE vs. NW, P= 0.217) or distance from source (P= 0.533). Furthermore, there was no evidence of a temporal component in tracer distribution (factor: 2 vs 7 days, P= 0.839). Nevertheless, a few green and pink particles were seen in the field when the samples were taken, indicating that visual inspection of coloured particles was a more sensitive measure than the MS analysis in these soils. This is due to the small amount of particles present, the high magnetic susceptibility of background levels and the fact that the measurements were not taken with a field sensor. The fact that not many tracer particles were seen in the proximity of the introduction area might indicate that the prevailing mode of transport is suspension, with particles travelling relatively long distances. However, the "dilution" of the particles in the landscape makes it difficult to assess this.

Table 13- Low frequency magnetic susceptibility (MS) along two transects 2 and 7 days after tracer introduction. SE= southeast orientation, NW= northwest orientation.

Distance from introduction area (m)	MS 2 days after tracer introduction (10^{-6} m^3kg^{-1})		MS 7 days after tracer introduction (10^{-6} m^3kg^{-1})	
	SE	NW	SE	NW
0.2	2.09	2.00	2.04	2.01
1	2.07	2.13	2.04	2.14
2	2.06	2.08	1.98	2.01
3	2.04	2.11	2.01	2.02
4	2.04	2.04	2.06	2.14
5	1.99	2.08	2.13	2.10
Mean	**2.05**	**2.07**	**2.04**	**2.07**
Sd	**0.03**	**0.05**	**0.05**	**0.06**

The use of a field magnet served to provide an initial appreciation of the magnetizability of the soil and of the height of transport of silt and sand sized particles. On the day of tracer introduction, the green (silt sized) particles were caught by the magnet through all its length (*c.* 16.5 cm), while pink (sand sized) particles were scarcely seen and were mainly distributed in the first 6.5 cm from the soil surface (Figure 22-a). Particles of soil were also caught by the magnet and were irregularly distributed through out its length. On the seventh day after tracer introduction rain washed away most of the particles caught by the magnet (Figure 22-b). These observations suggested that silt sized particles erode more easily and transport is by saltation or suspension compared to sand sized particles.

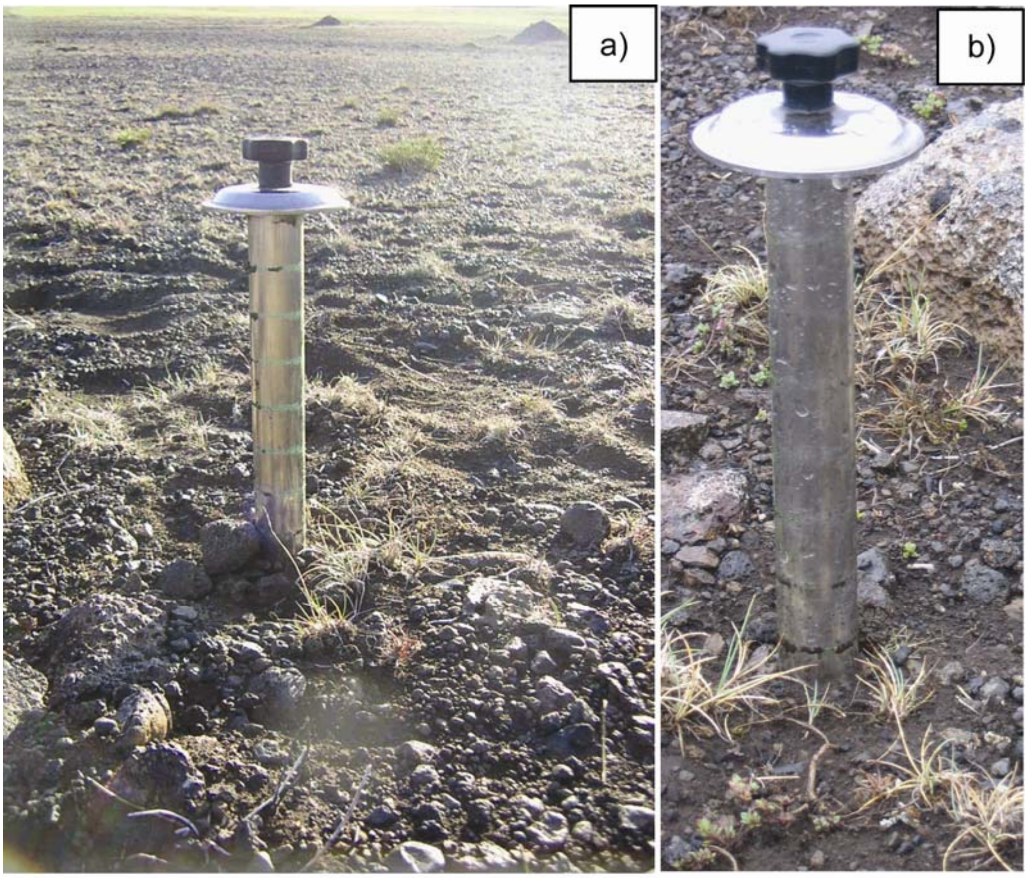

Figure 22- 11,000 Gauss field magnet in a sandy melar in Grænavatn, a) green tracer and soil particles can be seen attached to the magnet; b) after 7 days of tracer introduction the particles on the magnet were washed out by rain.

4.1.1.2 Sediment traps

Sediment traps were used to improve on the data collected with the particle tracing experiment and to make comparisons between the rates of erosion recorded with the two methods. The sediment trap presents the advantage over the use of a magnet that results are not affected by rain and that rates of deposition can be directly measured by weighing the sediments collected by the trap. Figure 23 shows a sediment trap and sediment collected in a sample bottle after a year in the field.

Figure 23- Sediment trap and insert a sample bottle showing the sediments collected by the sediment trap at Baldursheimur after a year.

Table 14 shows the mass flux of sediment trapped in a year at different heights with two sediment catchers in the farms Baldursheimur and Gautlönd. The mass flux, expressed in g/m^2, is obtained by dividing the mass of trapped sediment by the area of the inlet tube opening (38.5 mm^2).

Table 14- Mass flux of sediment trapped in a year at different heights with two sediment catchers in the farms Baldursheimur and Gautlönd.

Height (m)	Mass of trapped sediment (g)	Mass flux (g/m^2)
Baldursheimur		
0.05	0.05	1298.701
0.12	0.14	3636.364
0.19	0.24	6233.766
0.26	0.34	8831.169
0.50	0.22	5714.286
total	**0.99**	**25714.286**
sd	**0.11**	**2835.81**
Gautlönd		
0.05	0.00	0.000
0.12	0.00	0.000
0.19	0.01	259.740
0.26	0.04	1038.961
0.50	0.06	1558.442
total	**0.11**	**2857.143**
sd	**0.03**	**696.96**

An estimation of the total mass flux rate between 0.05 m and 0.5 m at each point sampled can be calculated by integrating the appropriate regression equation across height. Regression analyses of Mass flux versus height were carried out using linear, quadratic and cubic regression models. Model testing was carried out to assess which model fitted the data better. The regression models and the model testing calculations and results can be found in Appendix 3. A quadratic model fitted better the data for the Baldursheimur trap (R^2= 92.2) (Figure 24 a) whereas a linear model fitted better the data for the Gautlönd trap (R^2= 87.3) (Figure 24 b).

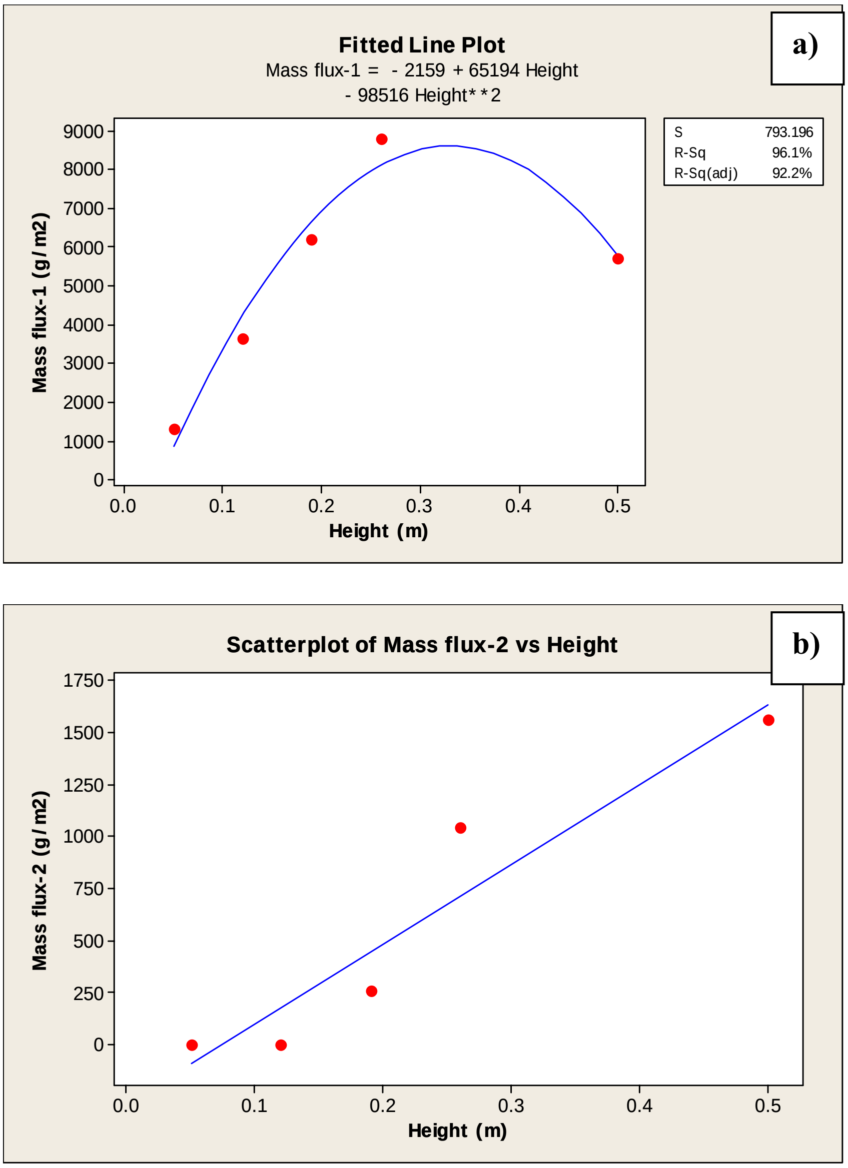

Figure 24- Fitted line plot and regression equation of a quadratic relationship between height and mass flux for trap-1 in Baldursheimur

The definite integral of the quadratic equation for the Baldursheimur trap, with height limits (0.05, 0.5) is:

Mass flux= -2159 + 65194X -98516X^2= 2995.479 g/m^2, or 0.002995 g/mm^2

Where X= height (m)

The definite integral of the linear equation for the Gautlönd trap, with height limits (0.05, 0.5) is:

$$\text{Mass flux} = -287 + 3831X = 344.936 \text{ g/m}^2, \text{ or } 0.000345 \text{ g/mm}^2$$

Where X= height (m)

The most striking feature of these results is the great difference in mass flux between the two farm sites, approaching an order of magnitude. This underlines the importance of local variation in any understanding of landscape historical processes. The fitted mass flux profiles seen in Figure 24 show an unexpected tendency of increasing mass flux values with height (although decreasing again at 0.5 m in the Baldursheimur trap). This does not correspond to other studies where the opposite is true (e.g. Sterk and Raats, 1996) and might be explained by the low density of Icelandic soils.

The small amount of sediments collected per bottle made it difficult to analyse particle size. This was achieved only for four of the samples, all from the Baldursheimur trap; the results are presented in Table 15 along with mean values from soils in the area used as reference material.

Table 15- Particle size distribution of sediments captured at different heights with a sediment trap in Baldursheimur.

	Concentration of particles (%)				
Height (m)	**Clay (<2 µm)**	**Silt (2-63 µm)**	**Fine sand (63-212 µm)**	**Medium sand (212-630 µm)**	**Coarse sand (630-2000 µm)**
0.12	0.75	37.25	55.20	6.80	0.00
0.19	0.00	48.80	48.60	2.60	0.00
0.26	1.11	44.49	48.50	5.20	0.70
0.50	0.59	35.61	48.10	14.20	1.50
Mean	**0.61**	**41.54**	**50.10**	**7.20**	**0.55**
Reference values	**1.2**	**36.6**	**50.8**	**10.0**	**1.2**
Sd of reference values	**0.9**	**12.1**	**7.5**	**8.1**	**2.2**

The particle size distribution is within the normal mean distribution of the reference soils. It is interesting to note that the highest bottle had a greater percentage of medium and coarse sand size particles than the rest; however these are still within the reference mean values. Assuming Icelandic soils conform to Hudson's (1973) estimations of mode of transport according to particle size, approximately 42 to 90 % (particles smaller than 100 µm) of the transported particles might be travelling by suspension. This implies that a significant proportion of wind transported particles travel a long distance.

Differences in soil surface level were measured at 64 points in two 5 m^2 quadrats (32 points/quadrat) after a year in two erosion spots located in the proximities of each of the sediment traps. The measurements per point can be found in Appendix 4. The differences in soil surface level in most of the points after a year show a difference of 1 cm. Taking into account a precision of 1 cm, the differences in soil surface level in Baldursheimur are insignificant. Points 5, 17 and 23 of Gautlönd quadrant show differences in soil surface level of more than 10 cm after a year. These differences are unlikely to have been caused by erosion or deposition and are attributed to errors in the measurement. The results seem to indicate these spots are not actively eroding. However, erosion might be active at the margins of the spots where measurements were not made. The measurement of the perimeter of the erosion spots with a more precise instrument would make it possible to assess this.

4.1.1.3 Soil accumulation rates and present day rates of mass flux

Table 16 shows the SARs measured in the winter grazing areas of the study farms expressed in $g/mm^2/yr$. Converting the units from mm/yr to $g/mm^2/yr$ was achieved by multiplying measured SAR by reference soil bulk density values. These bulk densities were mean values from field measurements in the winter grazing area of the farm Hofstaðir, and were 0.8 g/cm^3 for soils above the 1477 tephra layer and 0.9 g/cm^3 for soils below it (Simpson, pers. comm.). These values can then be compared to the mass transport rates calculated with the tracer experiment and the sediment traps.

Table 16- Soil accumulation rates (SAR) in the winter grazing areas of the study farms expressed in $g/mm^2/yr$.

	SAR ($g/mm^2/yr$)				
Farm	**Hv-*Landnám***	***Landnám*-1477**	**1477-1717**	**1717-present**	**1477-present**
Baldursheimur	0.118	0.089	0.234	0.855	0.574
Bjarnastaðir	0.059	0.178			0.211
Brjánsnes		0.327			0.966
Fagranes	0.098	0.089	0.300	0.110	0.196
Gautlönd	0.118	0.149			0.166
Geirastaðir		0.149	0.200	0.110	0.151
Grænavatn		0.267	0.366	0.800	0.604
Þórleifsstaðir	0.112	0.149	0.100	0.221	0.166
Mean	**0.101**	**0.174**	**0.240**	**0.419**	**0.379**
Sd	**0.025**	**0.083**	**0.101**	**0.376**	**0.302**

The mean soil accumulation rates in each of the study farms are greater by more than 1 order of magnitude in all the time periods than the mass transport rates measured with sediment traps (0.000345 and 0.002995 g/mm^2) and with particle tracing 0.00196 g/mm^2. The obvious implication of this is that the transported sediment is not deposited uniformly in the landscape. However, the rates of transport measured with the sediment traps may represent an underestimate because the transport of particles above 0.5 m is ignored. The relationship between sediment transport and deposition is not well understood. Another issue to consider is the possibility that only a small portion of measured SARs is derived from deposition of eroded material, and that the bulk of SARs derives from endogenous soil processes (e.g. accumulation of organic matter). If this was the case then SARs cannot be reliably used as an indicator of local erosion rates.

4.2 Field descriptions and micromorphology

In this section field and micromorphological descriptions are presented for soil profiles from the old home-fields of the study farms and from a reference winter grazing area profile. Micromorphological descriptions are summarised in tables and a key for the abbreviations used can be found in Appendix 5. The micromorphological analysis of thin sections from the study farms' winter grazing area and from home-fields showed four basic sedimentary types representing different accumulation processes:

1. Biogenic silica: this includes the accumulation of diatoms and phytoliths, both inorganic residues of biological origin. Diatoms are unicellular algae with an external siliceous skeleton. They are optically isotropic, have negative relief and can assume different shapes (Bullock *et al.*, 1985). Diatoms are abundant in lake sediments and wet soils, and therefore, their presence in the micromorphological record is considered an indication of wet environments (FitzPatrick, 1993). Phytoliths, also known as plant opals, are especially abundant in grasses and horsetails, although they occur in a wide range of other plant groups (Clarke, 2003). Because many wetlands are composed by high phytolith production plant taxa such as grasses and sedges (Clark *et al.*, 1992), poor drainage is often associated with high levels of silica in general (Clarke, 2003). Phytolith morphology can be use for the identification of plant families and even species. However, an adequate phytolith micromorphological analysis would require the use of very high

magnifications. The micromorphological analysis in this thesis was conducted with a maximum objective of 40 X and in limited random areas in each thin section. Photos and descriptions of the phytolith types found in the thin sections can be found in Appendix 6.

2. Organic matter: includes coarse organic material such as parenchymatic and fungal sclerotia, and fine organic material like cell residues and amorphous brown and black material. The type of organic material present in a thin section gives an indication of the degree of decomposition. For example plant material where the cell structure is recognizable (i.e. parenchymatic and cell residues) are fresh or have not undergone strong decomposition. Amorphous material, on the other hand is associated with advance decomposition. The degree of organic accumulation is important in the inference of past vegetation cover associated with standstill phases of landscape stability.

3. Coarse mineral material: composed mainly of wind blown coarse mineral material derived from tephra. The coarse mineral material in the thin sections was dominated by pale brown (volcanic glass) and black particles of different sizes. Pumice fragments (grey particles) were also abundant in some micro-strata. Volcanic glass includes particles with vesicles and phenocrysts, typical of igneous rocks. The size of particles can give an indication of the energy involved in the transportation of the material.

4. Cultural material: This type is only present in the home-field thin sections, this was expected as only soils from these areas have been cultivated and improved. This sedimentary type is formed by household waste which includes fuel residues, charcoal and bone fragments. These materials were

commonly used as fertilizers and so can give an indication of the intensity of home-field management.

4.2.1 Winter-grazing areas

The winter grazing areas of the study farms have an altitude range of *c*. 280 to 370 m. The vegetation in these areas can be described in general as dwarf shrub heath, dominated by *Vaccinium sp*. and *Empetrum nigrum* with different degrees of vegetation cover corresponding to the degree of erosion (Figure 25-a and b). The soils are typically sandy silt loam in texture in the pre-*Landnám* horizons and fine sandy silt loams in the post-*Landnám* horizons. An exception to this general description is the winter grazing area of the farm Brjánsnes which is composed of black sand dunes and lava fields with vegetation ranging from sparsely vegetated land (Figure 25-d) to birch woodland and dwarf shrub heath (Figure 25-e and f). The lavas are classified according to the Geological Map of Iceland as basic and intermediate, and are older than 1100 years (Jóhannesson and Saemundsson, 1998). Parts of the sandy areas have been planted with Lyme grass (*Leymus arenarius* L.) and metallic meshes have been placed in the farm Brjánsnes in an effort to constrain the movement of the dunes (Figure 25-c). Lyme grass is a natural dune grass which has been used for erosion control on dunes and other sandy soils in many parts of the world (SNH, 2000). In Iceland, Lyme grass tends to accumulate sand in small dunes 1-4 m heigh, which are common throughout the country (Arnalds *et al.,* 2001a). The soil profiles and field descriptions of the winter grazing areas of all the study farms can be found in Appendix 7.

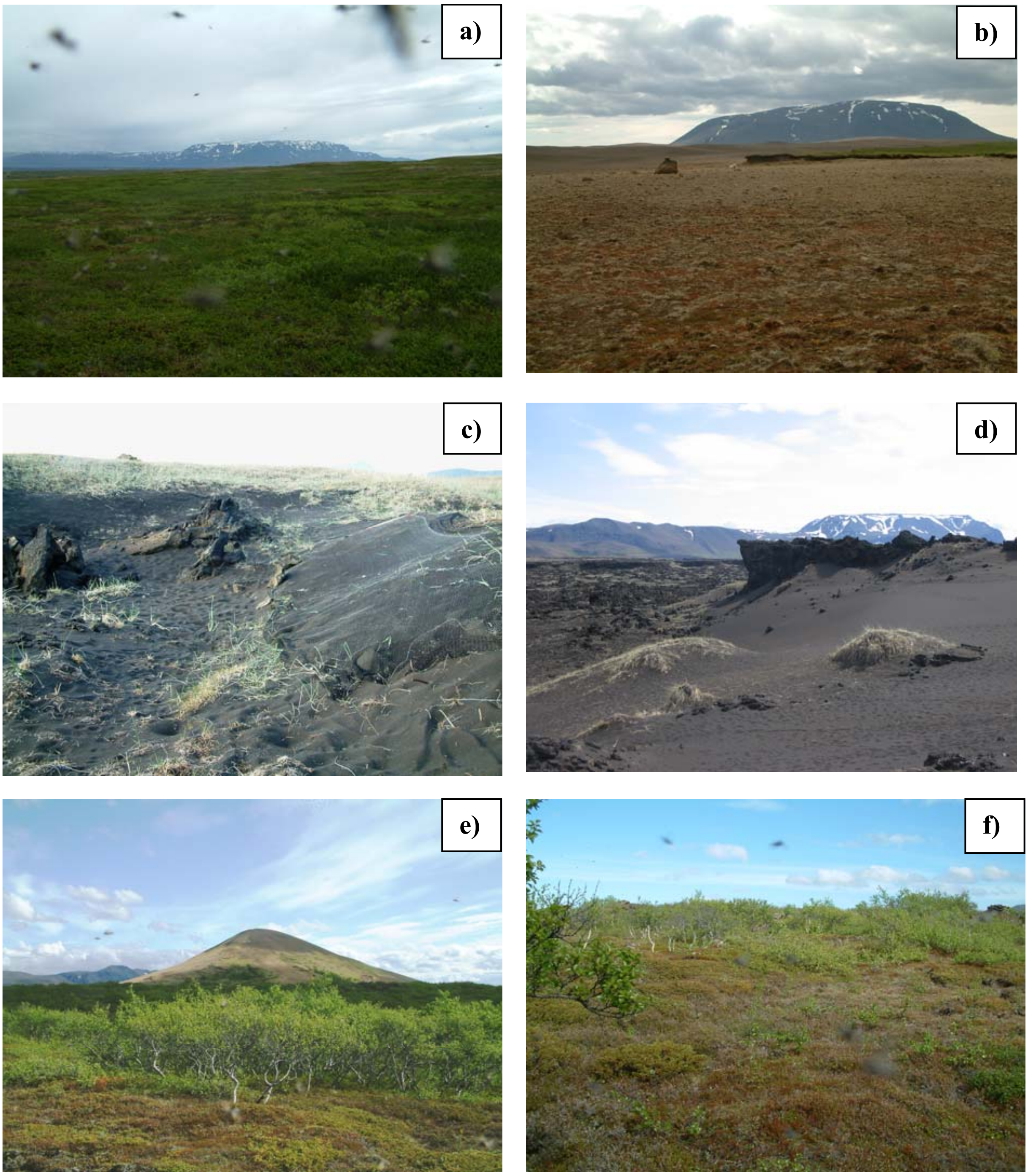

Figure 25- Winter grazing areas: a) dwarf shrub heath vegetation, Grænavatn; b) sparsely vegetated land with rofabards; Grænavatn; c) sandy area with planted Lyme grass and metallic mesh as erosion control measurements, Brjánsnes; d) sparsely vegetated sand-lava field, Brjánsnes; e) birch woodland-dwarf shrub heath mosaic, Brjánsnes; f) mosaic dominated by dwarf shrub heath; Brjánsnes.

A representative winter grazing area, belonging to the farm Baldursheimur, was selected for micromorphological analysis. A soil pit was dug at an elevation of 320 m.a.s.l. Figure 26 shows the soil stratigraphy and field description of the soil profile. The micromorphological descriptions of the four samples taken from the soil profile can be seen in Table 17.

The predominant sedimentary type in all thin sections was type 3 (coarse mineral material), composed by few pale brown and black particles. Black particles were in general of silt and fine sand size, whereas pale brown particles included silt, fine and medium sand size grains. Two micro-strata in different thin sections differed from this general coarse mineral composition. Micro-stratum 1 of thin section C was composed by dominant/very dominant pale brown particles ranging in size from silt to coarse sand (Figure 27-a). These particles are formed by volcanic glass and the almost complete absence of organic material in this micro-stratum indicates that it was formed by rapid tephra fallout. Micro-stratum 1 of thin section D included very few grey particles formed by pumice fragments ranging in size from medium to coarse sand (Figure 27-b). These pumice fragments are rounded and have coatings of fine material, and have been reported previously in samples from the Icelandic northern highlands by Stoops (2008). In Stoop's study the coatings are explained as being formed by the reworking of sediments and "abrasion" by wind erosion. The term "abrasion" is wrongly used in this sense since by definition it would involved the wearing down of the fragments by friction. The view that the coatings are formed by the aeolian transportation of the sediments is shared in this thesis.

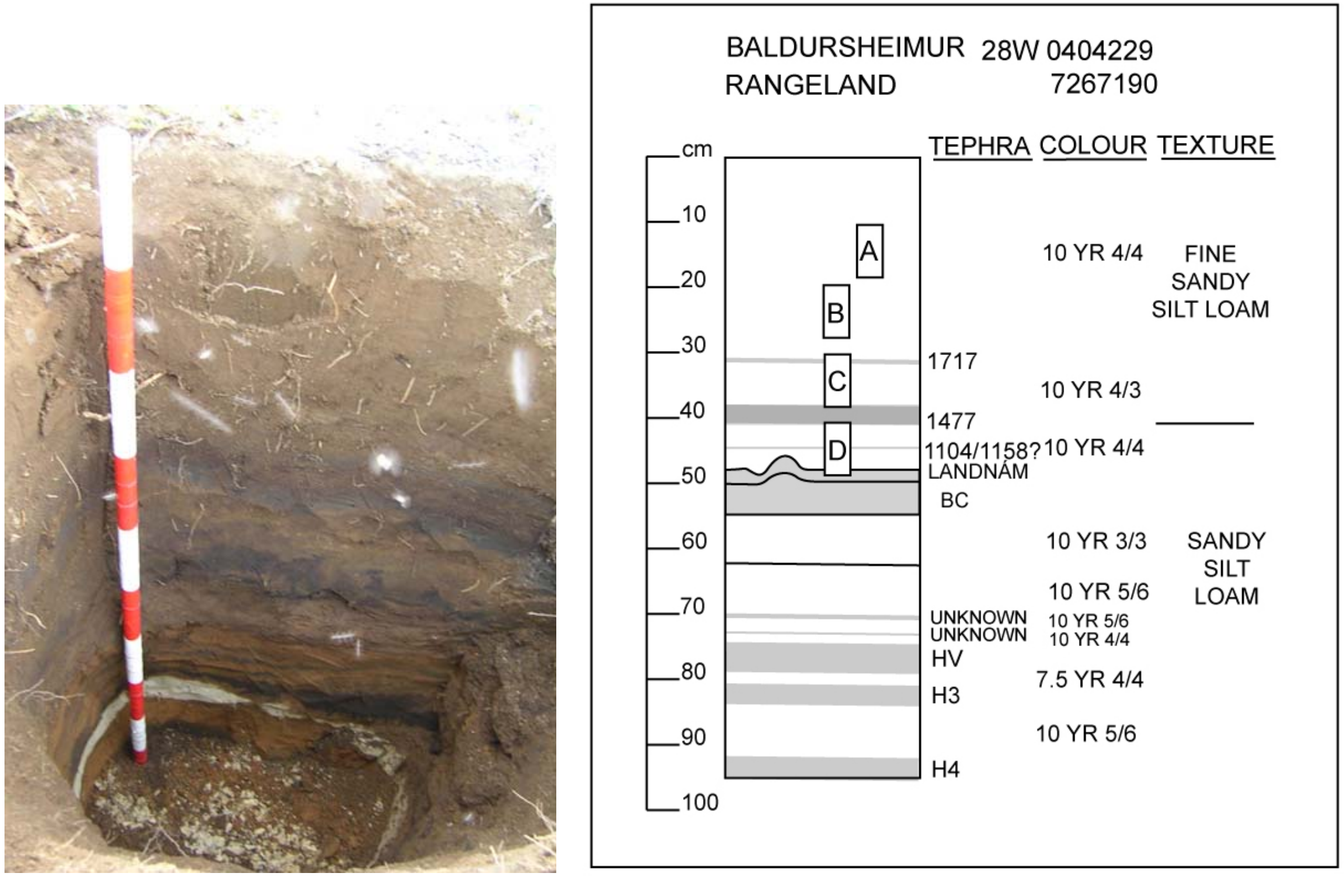

Figure 26- Soil profile and field description in Baldursheimur's winter grazing area with thin section sample locations (A, B, C and D).

Despite the dominance of sedimentary type 3, sedimentary type 2 is also present. The organic material presents different stages of decomposition. In thin sections C and D it is dominated by advanced decomposition as evident in the abundance of fine organic amorphous brown material. Thin section B presents well preserved organ residues, predominantly of leaf, and fungal sclerotia (Figure 27-c). The organ residues present a parallel, linear arrangement in some cases, but are more commonly inclined or arranged randomly (Figure 27-c and 27-d). The parallel arrangement of well preserved organs has been described previously in Iceland and has been explained by slow deposition and rapid burial of the organic matter before humification takes place (Stoops *et al*., 2008). Sedimentary type 1 is represented only by traces of phytoliths, mostly serrated and rectangular, and diatoms with bilateral symmetry.

The occurrence of sedimentary types 3 and 2 along the profile is interpreted as evidence of episodes of wind deposition of different intensities with alternated organic accumulation. The episodes with greater energy involved in the transportation, inferred from the bigger particle sizes, occur between the *Landnám* and AD 1477 tephras and between the AD 1477 and the AD 1717 tephras. The greater amount of organic accumulation occurs above the AD 1717 tephra. Soils above this tephra have also the greater SAR measured in mm per year for this soil profile (

Table 16). These results suggest that the interpretation of SAR as indicative of local soil erosion needs to be taken with caution.

Table 17- Micromorphological descriptions of thin sections from soils at Baldursheimur's winter-grazing area.

		COARSE MINERAL MATERIAL									COARSE ORGANIC MATERIAL		FINE ORGANIC MATERIAL			PEDOFEATURES						
		TEPHRA					BIOLOGICAL ORIGEN															
Thin section sample	Micro-stratum	Brown	Pale brown	Gray	Black	White	Phytoliths	Diatoms	Fine mineral material	Groundmass b Fabric	Parenchymatic	Fungal sclerotia	Cell residue	Amorphous (black)	Amorphous (brown)	Textural (silt (coatings)	Amorphous crypto-crystaline	Excremental (spheroidal)	Microstructure	Sorting	Coarse material arrangement	Related distribution
A	1	*t*	••	*t*	••	*t*	*t*	*t*	••• Br; O/m	Ss	*t*	*t*	*t*	•	•	*t*	*t*	*t*	Co: Ma/Pl	M	Ra	C-Po
B	1	*t*	••	*t*	••	*t*	*t*	*t*	••• Br; O/m	Ss	••	•	*t*	*t*	•	*t*			Co: Ma/In mi	M	Ra/Li	C-Po/Ds-e-En
C	1		••••		••				• Br; O/m	Ss	*t*	*t*	*t*						Sg	P	Ra	Co-Mo
	2	*t*	••		••	*t*	*t*	*t*	••• Br; O/m	Ss	*t*	*t*	*t*	*t*	••	*t*			Co: Ma/Chn	P	Ra	C-Po/S-s f En
D	1	*t*	••	•	••	*t*	*t*	*t*	••• Br; O/m	Ss	*t*	*t*	*t*	*t*	•	*t*			Ma	P	Ra	C-Po/Ds-f-En
	2	*t*	••	*t*	••	*t*	*t*	*t*	••• Br; O/m	Ss	*t*	*t*	*t*		•	*t*			Co: Ma/Pl/ Chn	P	Ra	C-Po

Frequency class refers to the appropriate area of section (Bullock *et al*., 1985): t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%) •••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al*., 1985): *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

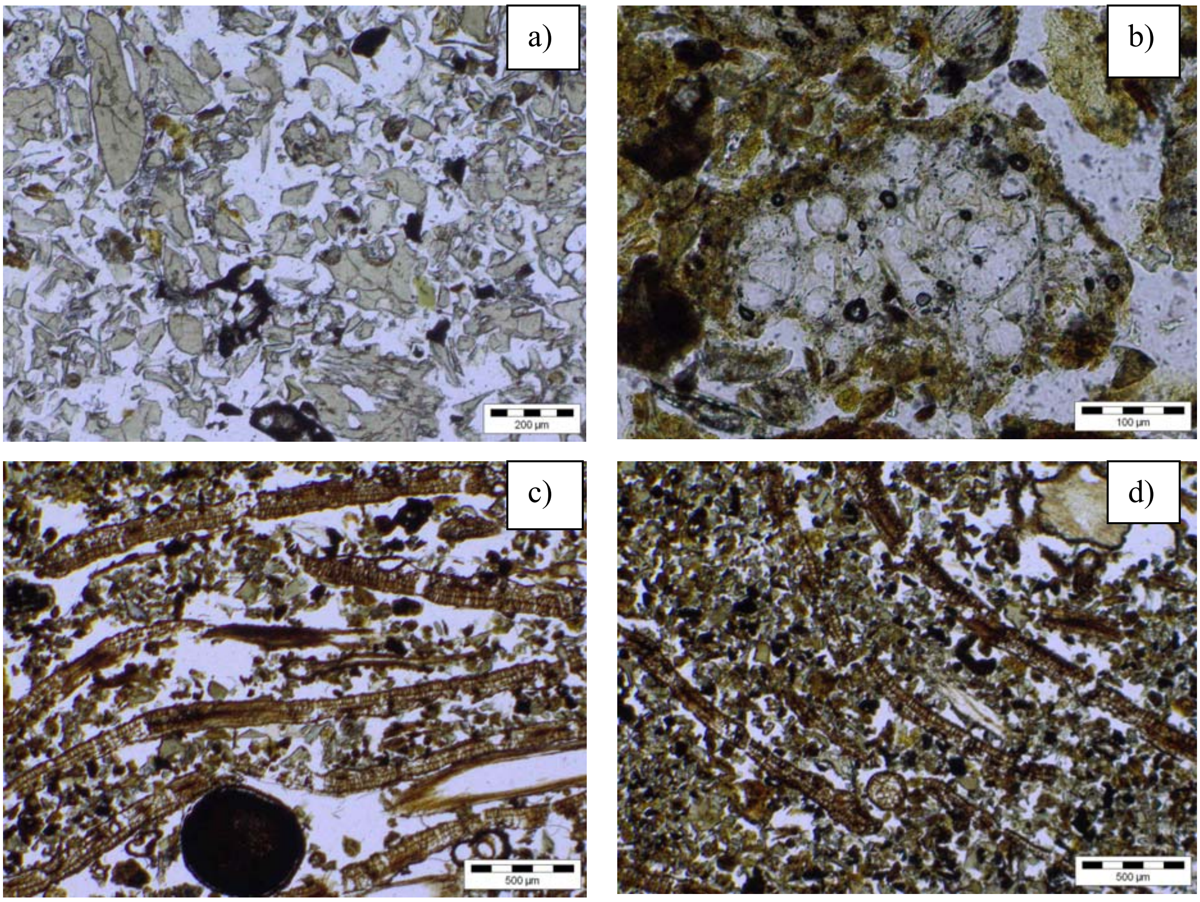

Figure 27- Micromorphological features in Baldursheimur's winter grazing area: a) volcanic glass in coarse monic related distribution; b) pumice fragment with coating of fine material; c) well preserved organ (leaf) residues in parallel arrangement and fungal sclerotia in the bottom of photograph; d) tilted leaf organ residues.

4.2.2 Home-fields

In 1919 the home-field sizes in Mývatnssveit ranged from 1 to 7.7 ha (Jónsson, 1919). The old home-fields of the study farms are similar in their general characteristics, located as was customary, around the farm house and in close proximity of a lake, stream or river. The exception to this is Þórleifsstaðir which is 1.3 km away from the Kráká river, the closest water source being bog-water (Vésteinsson, 2008). The following sections describe and discuss the field and micromorphological characteristics of the study farms home-field soils.

4.2.2.1 Baldursheimur

By 1919 the home-field of Baldursheimur was 4.3 ha (Jónsson, 1919). The soil profile and field description of the soil pit dug in the home-field can be seen in Figure 28. The soil profile presented mottles of dark colours (i.e. 10 YR 3/3: dark brown, 10 YR 2.5/1: black and 2.5 YR 3/4: dark-olive brown), indicating water-logged conditions. Tephra layers were not seen in the profile and charcoal was collected for dating purposes. However, these samples were later identified as peat and were not dated.

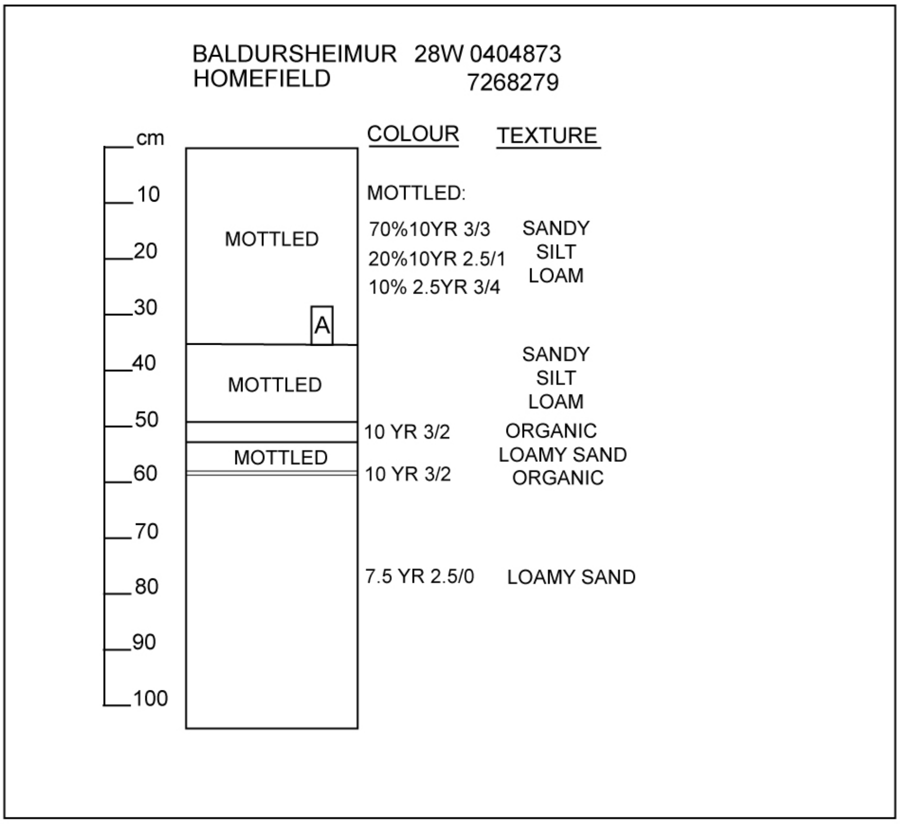

Figure 28- Soil profile, field description and location of thin section sample (A) at Baldursheimur's home-field.

The micromorphological description of the thin section from Baldursheimur's home-field profile is presented in Table 18 (BaldA). Two micro-strata were distinguished, in both of them there is a dominance of sedimentary type 3 and some evidence of type 4, although the latter was more frequent in micro-stratum 1. The coarse mineral material forming sedimentary type 3 is characterised by frequent to common pale brown particles and few black tephra particles. Both pale brown and black particles range in size from silt to coarse sand, however the largest black particles are up to 750 μm long whereas pale brown particles reach 2 mm long. Sedimentary type 4 comprises two types of fuel ash residues and charcoal. One of the fuel ash residues appears only as a trace in micro-stratum 1, where is mineral-based, grey under PPL and red under OIL (Figure 29-a and b). The most abundant fuel ash residue is organic-based, grey under PPL and light grey under OIL, it is associated with phytoliths, a little charcoal and rubified material (Figure 29-c and d). Yellowish faintly anisotropic features with well-developed radial crystallization were identified infilling the voids or coating coarse mineral material and, in many cases, associated with amorphous brown organic material (Figure 29-e and f). These yellow anisotropic features are recorded as iron-phosphate features (Table 18).

The general abundance and the variation in particle sizes (silt to coarse sand) of the coarse mineral material in the thin section indicate continual wind-blown events of different intensities with episodes of high energy aeolian deposition. This is in accordance with data derived from interviews to the farmers where they highlighted the problems they have had in the past with sand storms (see Chapter 6). The evidence of the use of household waste as amendments (fuel resources) also corresponds with the accounts of the farmers who explained how the home-field was almost completely lost to erosion and was recovered by adding soil amendments. These amendments, as seen in the thin section, included different types of fuel residues. The mineral-based fuel residue is interpreted to be mineral-based turf combusted at low temperature (*c.*

400 °C), based on the abundance of rubified coarse mineral material and following the descriptions of Simpson *et al*. (2003). The other fuel ash residue, described as light grey under OIL, could not be identified. The distinctive crystallitic groundmass b fabric of wood ash is not present; nor does it has the abundance of rubified coarse mineral material characteristic of mineral based turf or the frequent phytoliths and few diatoms seen in peat ash (Simpson *et al*., 2003).

Table 18- Micromorphology descriptions of thin sections from Brjánsnes (BrjA) and Baldursheimur's (BaldA) home-field soils.

		COARSE MINERAL MATERIAL										COARSE ORGANIC MATERIAL			FINE ORGANIC MATERIAL			PEDOFEATURES								
		TEPHRA																								
Thin section sample	Micro-stratum	Brown	Pale brown	Gray	Black	White	Phytoliths	Diatoms	Bone	Fine mineral material	Groundmass b Fabric	Charcoal	Parenchymatic	Fungal sclerotia	Cell residue	Amorphous (black)	Amorphous (brown)	Textural (silt (coatings)	Fe-phosphate	Amorphous crypto-crystaline	Excremental (mamillate)	Excremental (spheroidal)	Microstructure	Sorting	Coarse material arrangement	Related distribution
BrjA	1	*t*	••	*t*	••	*t*	*t*	*t*		••• Yb; O/m	Ss		•	*t*	*t*	••	••			*t*	*t*	*	Ma	P	Ra	C/Si-s-Po
	2	*t*	••	*t*	••	*t*	*t*	*t*		••• Yb; O/m	Ss		*t*		*t*	•	••			*t*		***	Ma	P	Ra	C/Si-s-Po
BaldA	1	*t*	•••	*t*	••	*t*	*t*	*t*		•• Yb; O/m	Ss	•		*t*		•	•	*t*	***			*t*	Co: In mi/Ma /Chm	P	Ra	Si-s-F En
										•• Gry (PPL), L-Gry (OIL); O/m	Ss															
										t Gry (PPL), R (OIL); O/m	Ss															
	2	*t*	•••	*t*	••	*t*	*t*	*t*		•• Yb; O/m	Ss	*t*		*t*		•	•	*t*	**		*t*		Co: In mi/Ma	P	Ra	Si-s-F En
										t Gry (PPL), L-Gry (OIL); O/m	Ss															

Frequency class refers to the appropriate area of section (Bullock *et al*., 1985) t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%) •••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al*., 1985) *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

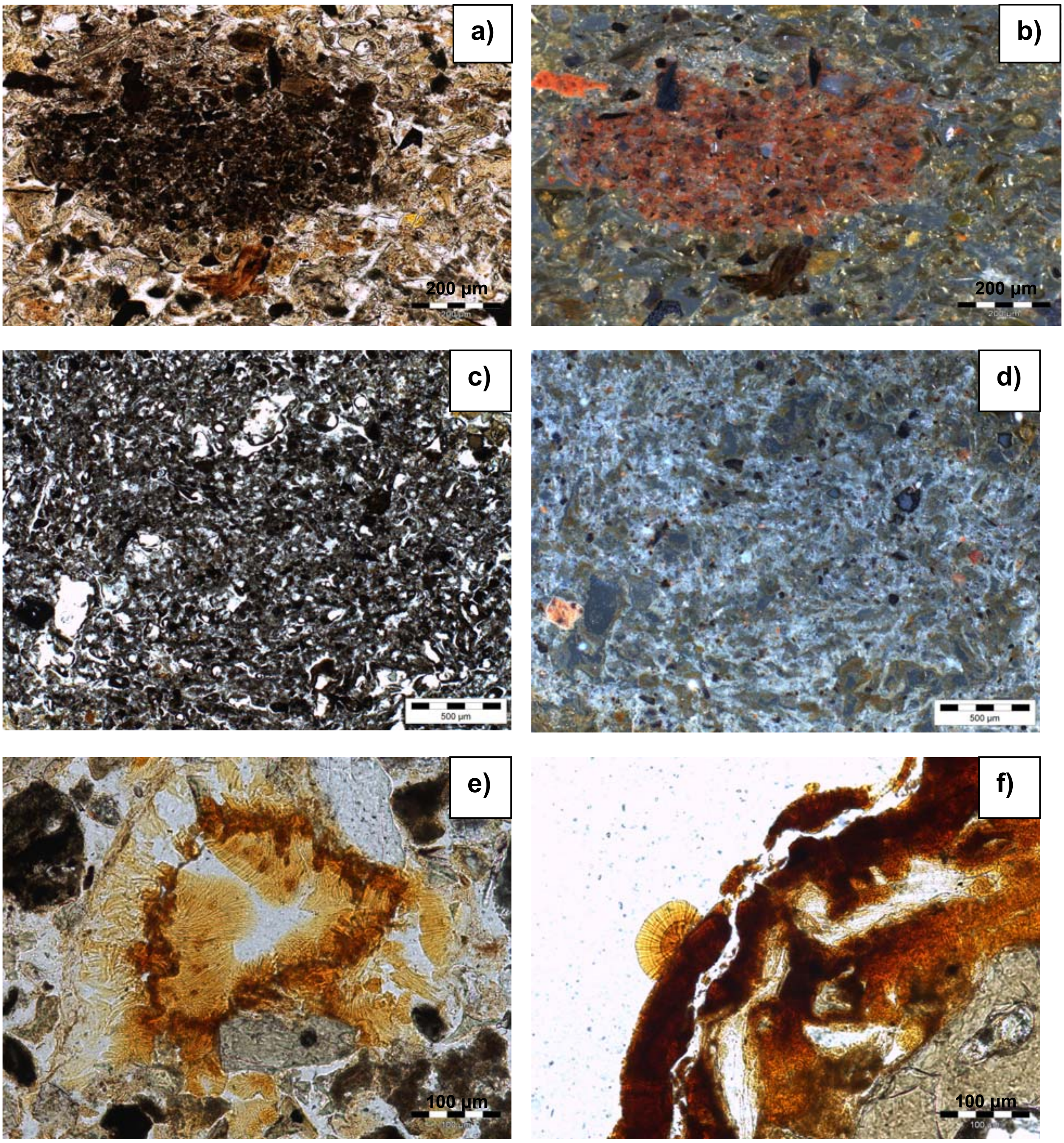

Figure 29- Micromorphological features observed in Baldursheimur's homefield: a) fuel ash residue under PPL; b) same feature under OIL, the rubified coarse mineral material is interpreted as residues of mineral-based turf material combusted at low temperature. c) and d) are indicative of another type of fuel ash residue (unidentified) under PPL and OIL, respectively. e) and f) are yellowish faintly anisotropic features with radial crystallisation interpreted as iron-phosphate features.

Iron-phosphate features of the type seen here have been recorded as different compounds according to their origin and composition. The possibilities considered are: *i*) the features represent various stages of alteration of the mineral vivianite originated in reduced conditions (Landuydt, 1990; Gebhardt and Langohr, 1999), *ii*) they represent the mineral goethite formed in oxidized conditions (Stoops *et al*., 1990; Kaczorek and Sommer, 2003; Kaczorek *et al*., 2004), or *iii*) they represent the mineral calcioferrite, formed by the release of P and Ca from bone hydroxyl-apatite (Jenkins, 1994; Simpson *et al*., 2000). Both vivianite and goethite are found in bog iron ores. Vivianite ($Fe_3(PO_4)_2.8H_2O$) is a hydrated iron phosphate mineral (Gaines *et al*., 1997) which can occur as an amorphous mass or as small encrustations or radiations of monoclinic crystals (McGowan and Prangnell, 2006). It can be found in different forms; fresh and un-oxidized it is colourless or faintly whitish or greyish, when exposed to air it is oxidized and it changes in colour to bluish and greenish, as oxidation progresses it transforms into minerals varying in colour from brown to yellow to red-brown (McGowan and Prangnell, 2006). Teodorovich (1961) proposed that only the pure unoxidized form of the mineral should be called vivianite, whereas the blue-greenish oxidized form should be called kerchenite and the further oxidation products (brown, yellow and red-brown) bosphorite and oxykerchenite. The formula of the mineral goethite can be expressed as Fe(O,CO3)OH (Yapp, 2001). Stoops and Delvigne (1990), describe the crystallization of goethite in soils saturated during long periods as "*multilayered coatings composed of fanlike aggregates of fine needles, consisting of a parallel stacking of very fine crystallites*". This description and the accompanying figure of a compound coating of needle-shaped goethite crystallites in a bog ore from Belgium reported in Stoops and Delvigne (1990) closely resembles the feature seen in Figure 29-f. Based on this, two hypotheses regarding the origin of these features are proposed. The first is that the features are bog iron ore compounds (vivianite oxidized products or goethite), and the second is that the features are derived from the decomposition of bone into calcioferrite. These hypotheses could be tested by examination of chemical composition and structural characteristics through X-ray analysis using a Scanning Electron Microscope (SEM).

If the material was derived from bone decomposition, a compositional analysis would reveal high concentrations of Ca, Fe and P (Jenkins, 1994). Furthermore, if this hypothesis was supported, the concentration of Manganese (Mn) might be used to discern between fish or mammal bone. The content of Mn in cattle, swine and fowl bone ash has been reported to be as low as one tenth of that from fish, compared with other elements (Hamada *et al*., 1995). The concentration of strontium (Sr) can further indicate in the case of fish bones if they came from a marine environment or not (Simpson *et al.,* 2000). Strontium is the most abundant trace element in ocean water, reaching values of up to 8 mg/l compared to 0.021 to 0.375 mg/l in fresh water sources (Rosenthal *et al*., 1970; Babaluk *et al*., 1997; Cabrera *et al*., 1999). If the features are bog iron ore compounds high concentrations of Fe, P and even Mn would be expected (Kaczorek *et al.,* 2004) but low concentrations of Ca. With the X-ray technique, the nature of the iron-phosphate features can be assessed by analysing nano-scale properties (such as size and crystal form in the features), and comparing them with fish bone reference materials (Adderley *et al*., 2004).

4.2.2.2 Brjánsnes

Brjánsnes old home-field is a wet meadow by the shores of Lake Mývatn now used by the farm Garður. Two pits were dug in the home-field (field description in Figure 30). In the first pit the water table was within the first 30 cm. No tephra layers were seen in the profiles and no charcoal was recovered so there is no chronology for this site. Micromorphological descriptions can be found in Table 18.

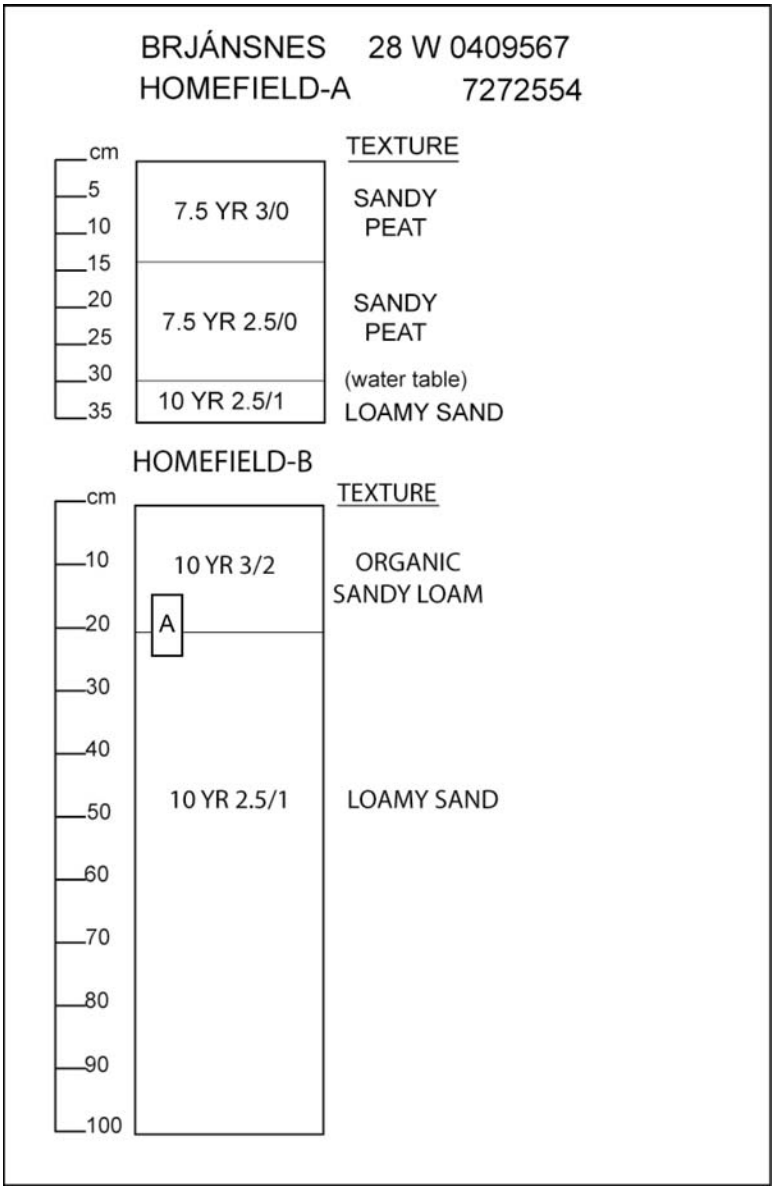

Figure 30- Soil profile and field descriptions at Brjánsnes home-field.

Brjánsnes thin section is formed by a mixture of sedimentary types 2 and 3. The thin section was divided into two micro-strata based on the concentration of spheroidal excremental pedofeatures. Although these pedofeatures can not be distinguished by the naked eye it was deemed an important factor and thus was used as the criteria for the separation of the micro-strata. Key features in this thin section are the abundance of spheroidal excremental pedofeatures in micro-stratum 2 (Figure 31 and Table 18) and the mixture of coarse mineral with brown amorphous fine organic material. The excremental pedofeatures are approximately 10 µm in diameter and occur in the groundmass and not inside plant tissues as is observed with mite excrements similar to these.

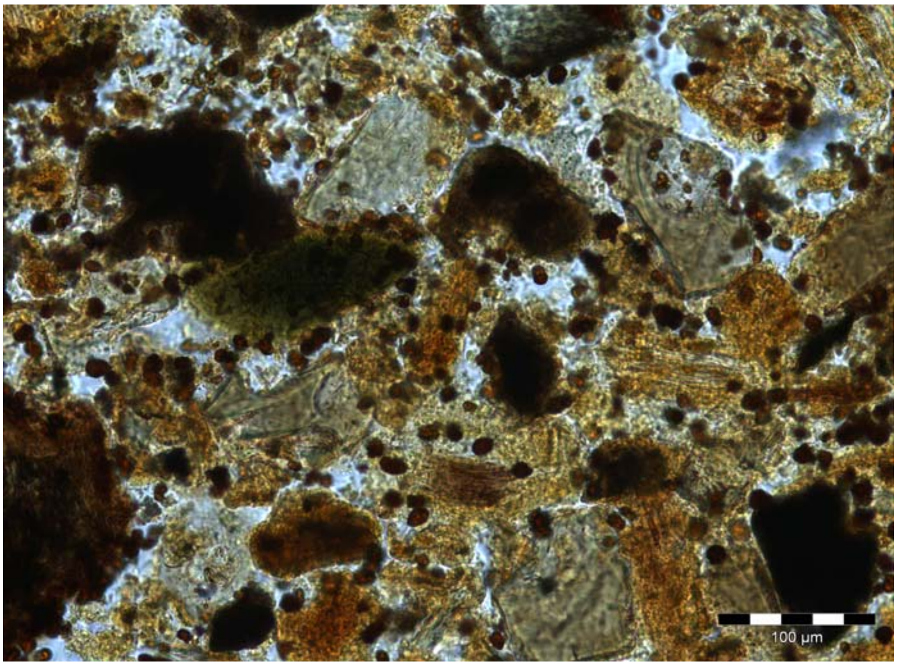

Figure 31- Spheroidal excremental pedofeatures in Brjánsnes home-field soil.

The coarse mineral material in both micro-strata is composed by few pale brown and black tephra grains ranging in size from 20-350 µm (includes silt, fine sand and medium sand). The abundance of excremental pedofeatures in the top soil of Brjánsnes home-field shows a stratum very active biologically. There is also evidence of disturbance due to modern agricultural activity seen in the mixture of organic and inorganic material. The size of the coarse mineral material shows low energy involved in the deposition.

4.2.2.3 Gautlönd

By 1919 Gautlönd's home-field was 5.1 ha (Jónsson, 1919). Figure 32 shows the soil profile and field description at Gautlönd's home-field. Heavy mottling was evident in the soil profile between the AD 1477 and the AD 1717 tephras, indicative of periodic wet and drying. The micromorphological descriptions of the two samples taken from the profile are presented in Table 19.

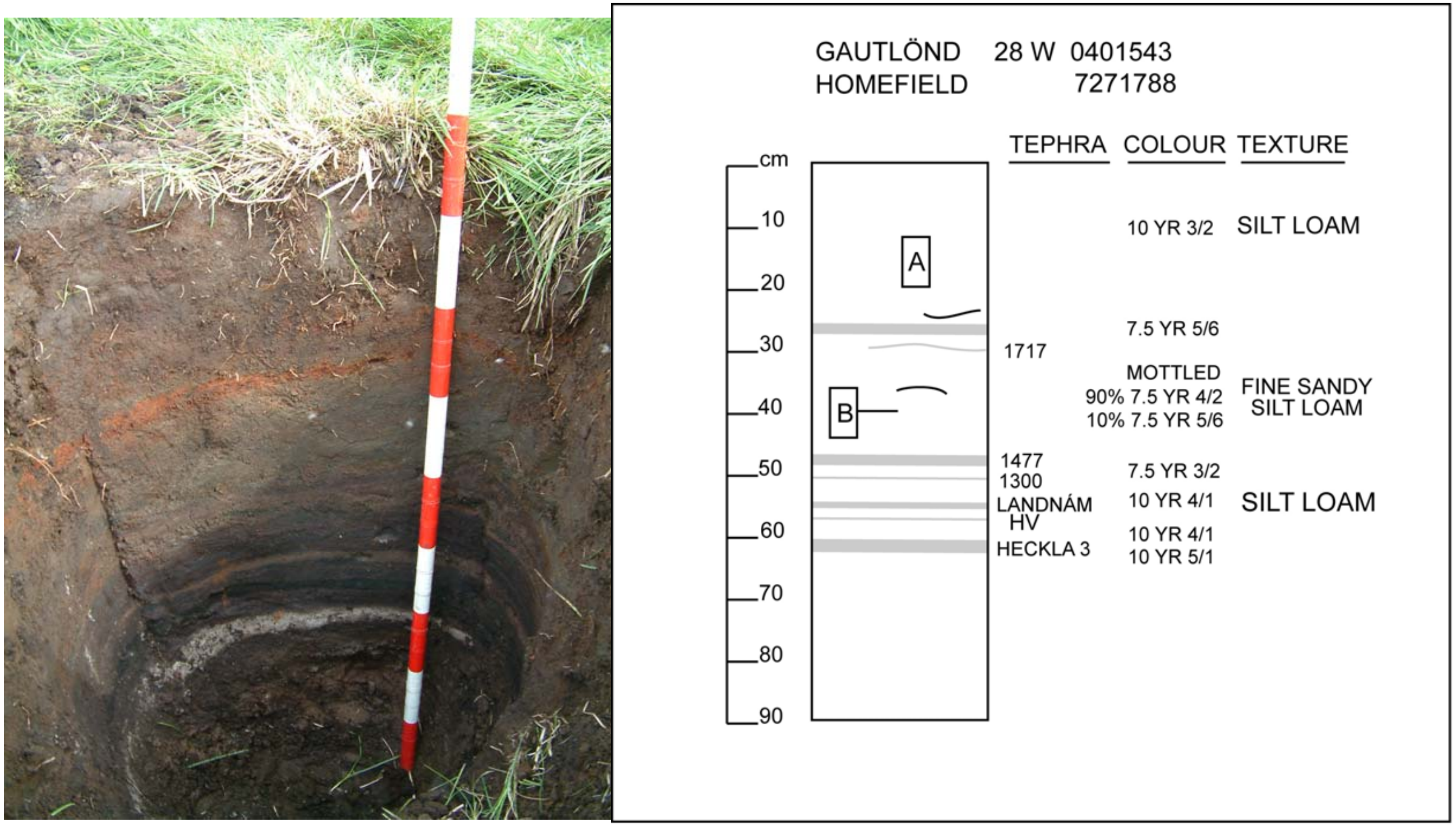

Figure 32- Soil profile and field description at Gautlönd home-field, showing the location of Kubiena samples A and B.

Thin section A in Gautlönd's profile was taken above the AD 1717 tephra. Four micro-strata are distinguishable in this section. All the sedimentary types are present in different degrees in the micro-strata. The bottom layer, micro-stratum 4, is formed by micro-bands of coarser and finer mineral material. In the coarser bands the length of the particles is 100 to 1250 µm (fine to coarse sand) and they are arranged in a coarse monic related distribution. The coarse minerals of the finer bands are 20-100 µm (silt and fine sand) in length and occur in a dense groundmass of fine mineral material in a double-spaced porphyric related distribution pattern. Very few diatoms and phytoliths occur in the groundmass. Many of the phytoliths are, according to Pearsal *et al*. (1992) type 10-I: epidermal quadrilaterals rectilinear long (see Appendix 6). Amorphous crypto-crystalline pedofeatures are occasional and traces of bones and charcoal are visible. Micro-stratum 3 is characterised by sedimentary type 4, dominated by fuel residues with traces of bone. Fuel residues are few and are recorded as grey fine mineral material white under oblique incident light (OIL). Amorphous crypto-crystaline features are very abundant. The coarse mineral material is also arranged into coarser and finer micro-bands in micro-stratum 2. This micro-stratum shows traces of charcoal and bone. Micro-stratum 1 has greater amount of phytoliths and diatoms than the previous micro-stratum. It also includes traces of bone, charcoal and other fuel residues.

Thin section B represents the soil between the AD 1477 and the AD 1717 tephras. The coarse mineral material is formed by black (few) and pale brown (very few) particles ranging in size from 20 to 200 µm (silt to fine sand) and arranged randomly. Key features seen in thin section B include: diatoms (very few), phytoliths (very few), abundant amorphous crypto-crystalline pedofeatures, often with concentric rings (Figure 33-a). Other features present are iron-phosphate features (rare), found associated with brown amorphous organic matter (Figure 33-b) and traces of charcoal and ash.

Table 19- Micromorphology descriptions of thin sections from Gautlönd home-field soils.

Thin section sample	Micro-stratum	COARSE MINERAL MATERIAL: TEPHRA: Brown	Pale brown	Gray	Black	White	Phytoliths	Diatoms	Bone	Fine mineral material	Groundmass b Fabric	COARSE ORGANIC MATERIAL: Charcoal/lignified	Charcoal	Parenchymatic	Fungal sclerotia	FINE ORGANIC MATERIAL: Cell residue	Amorphous (black)	Amorphous (brown)	PEDOFEATURES: Textural (silt (coatings)	Fe-phosphate	Amorphous crypto-crystalline	Excremental (spheroidal)	Microstructure	Sorting	Coarse material arrangement	Related distribution
A	1	*t*	•	*t*	••	*t*	••	••	*t*	••• Yb; O/m *t* Gry (PPL), Wh (OIL); O/m	Ss	*t*	*t*	*t*	*t*	*t*	•	•		*t*	**		Co: Ma/ Pl	M	Ra/Ba	Si/Ds Po
	2	*t*	••	*t*	••		•	•	*t*	••• Yb; O/m	Ss	*t*	*t*		*t*		•	•	*t*		**		Ma	P	Ra/Ba	Si-s Po
	3	*t*	•	•	••	*t*	*t*	*t*	*t*	•• Yb; O/m •• Gry (PPL), Wh (OIL); O/m	Ss Ss						•	*t*	*t*		*****		Ma	P	Ra	Si-s Po
	4	*t*	•••	•	•••		•	•	*t*	•• Yb; O/m	Ss		*t*		*t*	*t*	•	•	*t*		**		Co: Sg/ Ma/ Gr	P	Ba	C-Mo/Ds Po
B	1	*t*	•	*t*	••		•	•		••• Yb; O/m *t* Gry (PPL), Wh (OIL); O/m	Ss	*t*	•	*t*	•	*t*		••		*	****		Co: Ma/ Pl	M	Ra	Si/Ds Po

Frequency class refers to the appropriate area of section (Bullock *et al*., 1985) t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%) •••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al*., 1985) *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

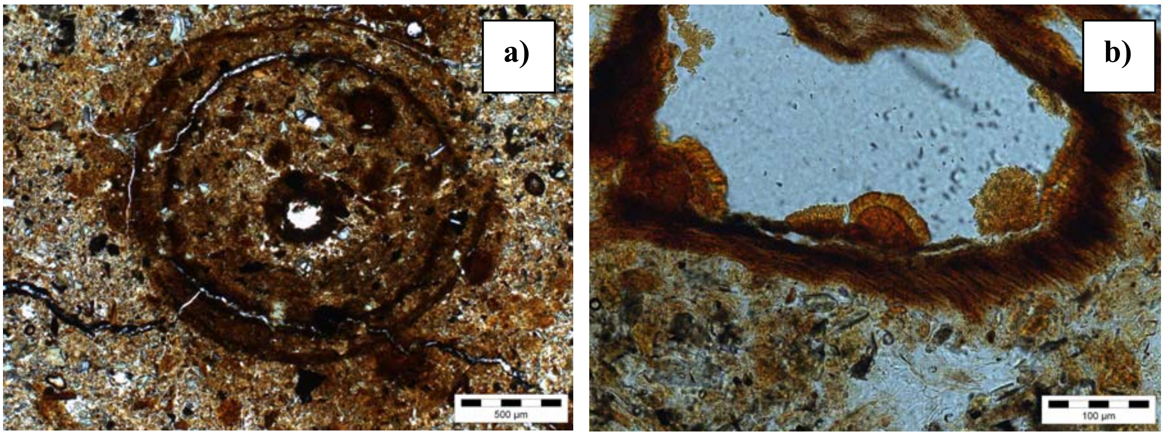

Figure 33- Pedofeatures seen in thin sections from Gautlönd: a) amorphous crypto-crystalline pedofeature with concentric rings, indicative of periodic wet and drying; b) Iron-phosphate features.

Between AD 1477 and 1717 the evidence from diatoms and amorphous crypto-crystalline pedofeatures with concentric rings, together with the presence of mottles seen in the field, indicate that the area was subjected to periods of wet and drying. The presence of amorphous cryptocrystalline features is related to iron oxidation and has been previously described as a typical characteristic of Icelandic silt loam andisols in thin section (Romans and Robertson, 1980; Arnalds *et al*., 1995). The presence of organic material with reddish brown colours further supports this, since it has been associated before with slow humification of peat deposits (Stoops *et al*., 2008). The presence of fuel residues indicates that household waste was used as an amendment. After AD 1717, the presence of bands of coarser mineral material (fine to coarse sand) intercalated with bands of finer material (silt to fine sand), suggests increased deposition of sediments transported by wind with varying energy. At the same time that the coarse mineral material increases in the profile so does the cultural input. This might be interpreted as efforts to try to maintain the home-field from damage caused by sand storms. The reduction in the abundance of amorphous crypto-crystalline pedofeatures in the soils above the AD 1717 tephra layer suggests dryer conditions at this time period. This could be the direct result of a reduction in the overall precipitation but it could also be due to improved drainage conditions in the soils due to the sand inputs.

4.2.2.4 Geirastaðir

The home-field of Geirastaðir was 2.2 ha in extent according to Jónsson's (1919) map. Two soil pits were dug in the home-field (Figure 34 and Figure 35).

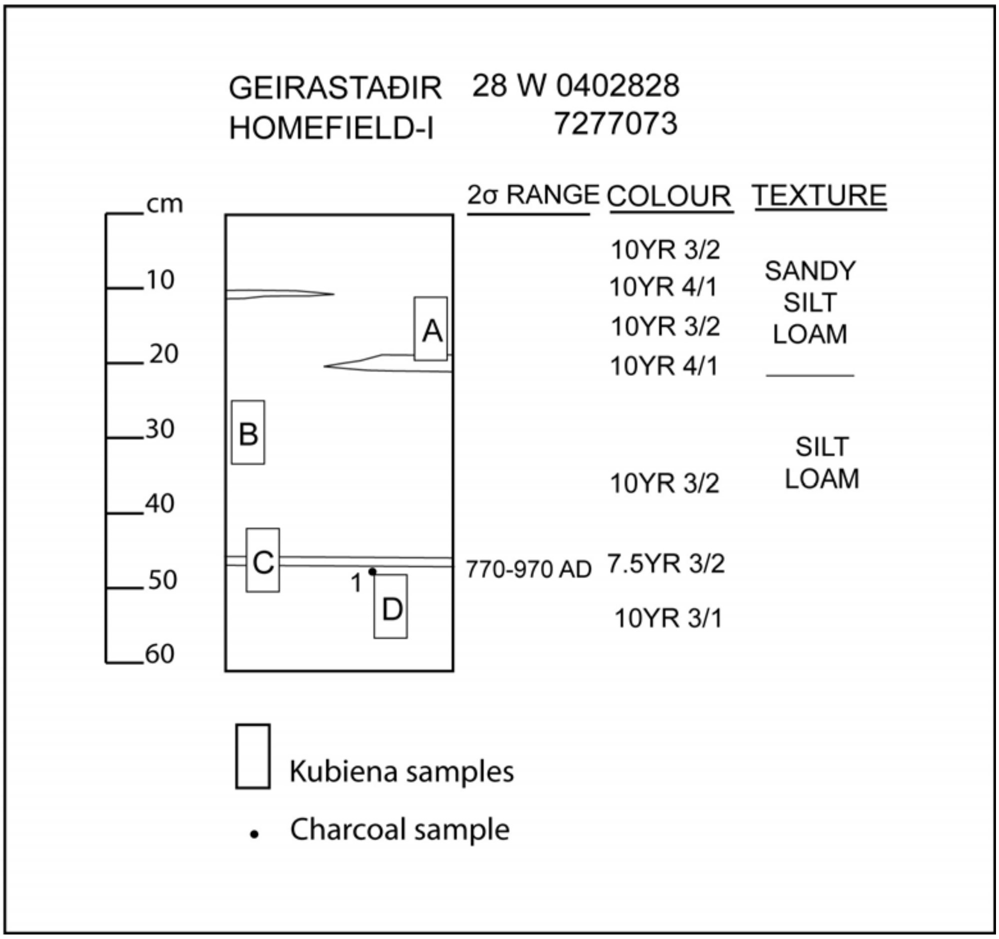

Figure 34- Soil profile and field description at Geirastaðir's home-field, profile I showing the locations of Kubiena and charcoal samples.

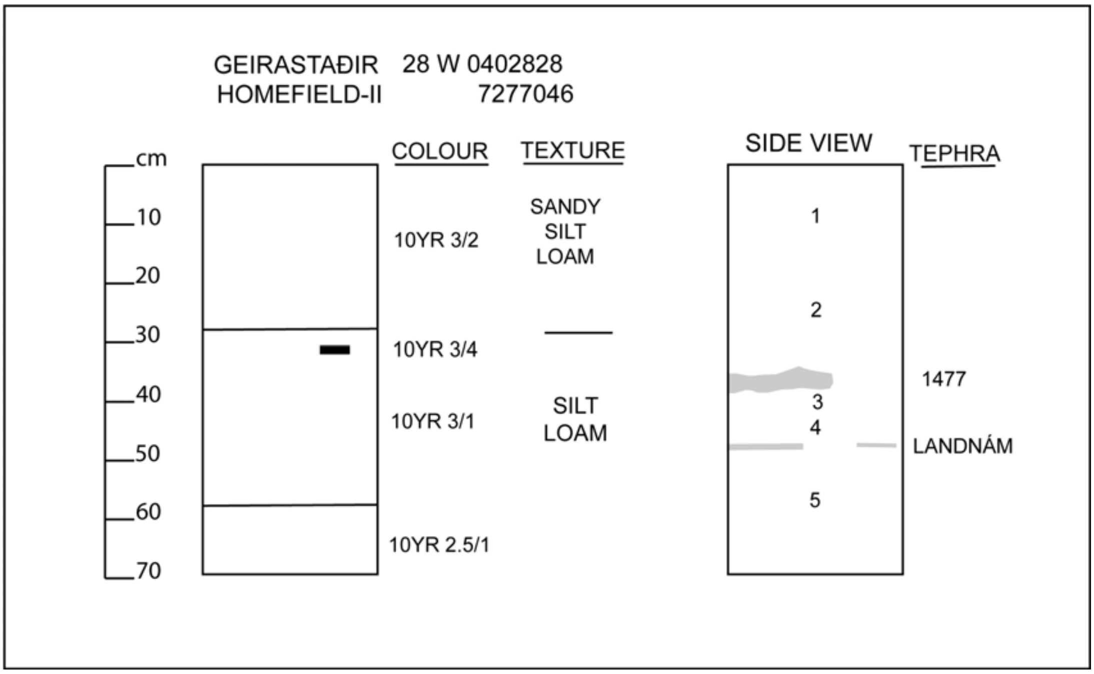

Figure 35- Soil profile and field description of Geirastaðir's home-field, profile II.

No tephra layers were found in the first profile and charcoal samples were collected for dating purposes. Only one charcoal sample, derived from birch (*Betula sp.*) could be analysed and provided a date of AD 770-970 (Table 20).

Table 20- Radiocarbon dated samples from Mývatn, northeast Iceland (samples were identified by Dr Susan Ramsay at GUARD and dated at SUERC).

Site	Lab code	Depth in the profile (cm)	Species	14C years BP	δ13 (‰)	2 σ range (years AD)
Geirastaðir	GU-16824	48	*Betula sp.*	1165±30	-25.1	770-970
Grænavatn	GU-16823	75	*Salix sp.*	395±30	-25.8	1430-1630
Grænavatn	GU-16825	173	*Betula sp.*	855±30	-26.1	1050-1260

Table 21 includes descriptions for thin sections A and B of Geirastadir's home-field. Thin section A, is formed by three vertically arranged micro-strata dominated by sediments type 4 and 2. Sedimentary type 4 in micro-stratum 1 comprises fuel ash residues which differ in colour when examined under OIL. The most abundant ash fuel residue is light grey under OIL, other types are white and dark grey under OIL, and all of them present some rubification and carbonized particles. The different ash fuel residues under PPL and OIL can be seen in Figure 36. Associated with these fuel ash residues are also traces of charred bone and charcoal (few). Micro-stratum 2 is dominated by a groundmass composed of a light yellowish-brown fine mineral material with no ash fuel residues. In micro-stratum 3 fuel ash residues appear again but less abundantly than in the first micro-stratum. Other key features observed in all the micro-strata of this thin section are very few diatoms, occasional/many crypto-crystalline pedofeatures some with concentric rings, mammilliate and spheroidal excremental pedofeatures and amorphous brown fine organic material (abundance: few). The coarse mineral material in the three micro-strata is dominated by pale brown and black particles with size ranges of 30-500 μm and 10-300 μm, respectively.

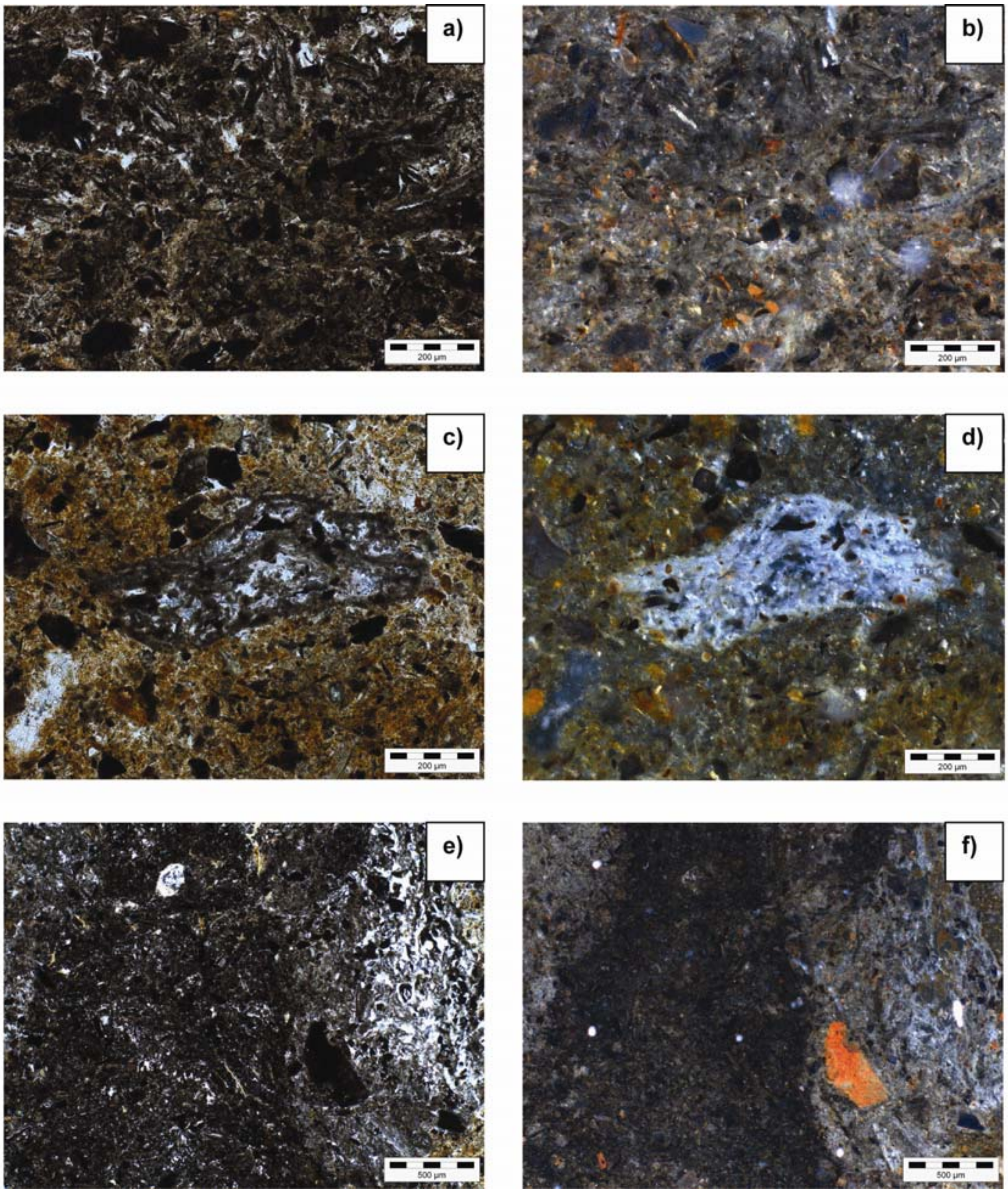

Figure 36- Fuel ash residues in thin sections from Geirastaðir's home-field: a) grey in PPL, b) light grey in OIL, c) grey PPL, d) white OIL, e) grey PPL, f) dark grey OIL and rubification.

Table 21- Micromorphology descriptions of thin sections from Geirastaðir home-field soils.

Thin section sample	Micro-stratum	COARSE MINERAL MATERIAL: TEPHRA: Brown	Pale brown	Gray	Black	White	Phytoliths	Diatoms	Bone	Fine mineral material	Groundmass b Fabric	COARSE ORGANIC MATERIAL: Charcoal	Parenchymatic	Fungal sclerotia	FINE ORGANIC MATERIAL: Cell residue	Amorphous (black)	Amorphous (brown)	PEDOFEATURES: Textural (silt (coatings)	Fe-Phosphate	Amorphous crypto-crystaline	Excremental (mamillate)	Excremental (spheroidal)	Microstructure	Sorting	Coarse material arrangement	Related distribution
A	1	•	••		••		*t*	•	*t*	•• Yb; O/m	Ss	••	*t*	*t*		•	••			***	*t*	*t*	Co: Ma/Pl	P	Ra	O-Po
										•• Gry (PPL), L-Gry (OIL);O/m	Ss															
										• Gry (PPL), Wh (OIL); O/m	Ss															
										• Gry (PPL); D-Gry (OIL); O/m	Ss															
	2	*t*	••	*t*	••	*t*	•	•		•••• L-Yb; O/m	Ss	•		*t*	*t*	•	••			**	*t*		Co: Ma/Pl	P	Ra	O-Po
	3	*t*	••	*t*	••	*t*	*t*	•		••• Yb; O/m	Ss	•	*t*	*t*	*t*	•	••			***	*	*	Co: Ma/Pl	P	Ra	O-Po
										• Gry (PPL), L-Gry (OIL); O/m																
										• Gry (PPL), Wh (OIL); O/m																
B	1	*t*	•	*t*	••	*t*	•	•	*t*	••• Yb; O/m	Ss	••	*t*	*t*	*t*	•	•••	*t*		**		*t*	Ma	P	Ra	O-Po
										• Gry (PPL), Wh (OIL); O/m																
	2	•	••	•••	••					•• Yb; O/m	Ss							**					Pg	W	Ra	Ch/C-Po
	3	•	•	*t*	••	*t*	•	•	*t*	••• Yb; O/m	Ss	•	*t*	*t*	*t*	••	•••			**	*t*	*t*	Ma	P	Ra	O-Po

Frequency class refers to the appropriate area of section (Bullock *et al.*, 1985) t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%) •••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al.*, 1985) *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

In thin section B, three micro-strata are recognized. The first micro-stratum is, like thin section A, dominated by sedimentary types 4 and 2. However, the cultural sediments forming type 4 in this micro-stratum are less diverse, with very few fuel ash residues, only of the form that appears white under OIL, few charcoal and traces of bone, some of it charred. Low concentrations of phytoliths and diatoms are seen (Figure 37-a). Most of the coarse mineral material ranges in size from 10-125 µm, although some pale brown particles reach up to 4 mm. Micro-stratum 2 is dominated by sedimentary type 3 formed by coarse mineral material of a bigger size range (100-1250 µm) and associated with textural silt coating (Figure 37-d). The grey particles of this micro-stratum are rounded. Micro-stratum 3 is very similar to micro-stratum 1 but presents less charcoal. In thin section C key features are fuel ash residues of the type light-grey under OIL in micro-strata 1 and 3, many crypto-crystalline pedofeatures and rare iron-phosphate features in micro-stratum 2, and banded coarse material arrangement in all the micro-strata. Also noticeable is the lenticular microstructure in thin sections B and C.

Thin section D is formed of five micro-strata. Micro-stratum 1 is dominated by sedimentary type 3, with particles with a size range of 10-250 µm. Micro-strata 2 and 3 are formed by micro-bands of silica and mineral accumulation (types 1 and 3). The silica micro-bands are composed by frequent/common diatoms and very few phytoliths (Figure 37-b and c). Micro-strata 4 and 5 are formed by micro-bands of organic and mineral accumulation. Micro-stratum 4 differs from 5 in the greater abundance of amorphous brown fine organic material. Micro-stratum 5 is composed of two bands defined by the size of the coarse mineral material, in one band most of the mineral has a size range of 10-200 µm while the other band is composed by coarser particles (100-500 µm).

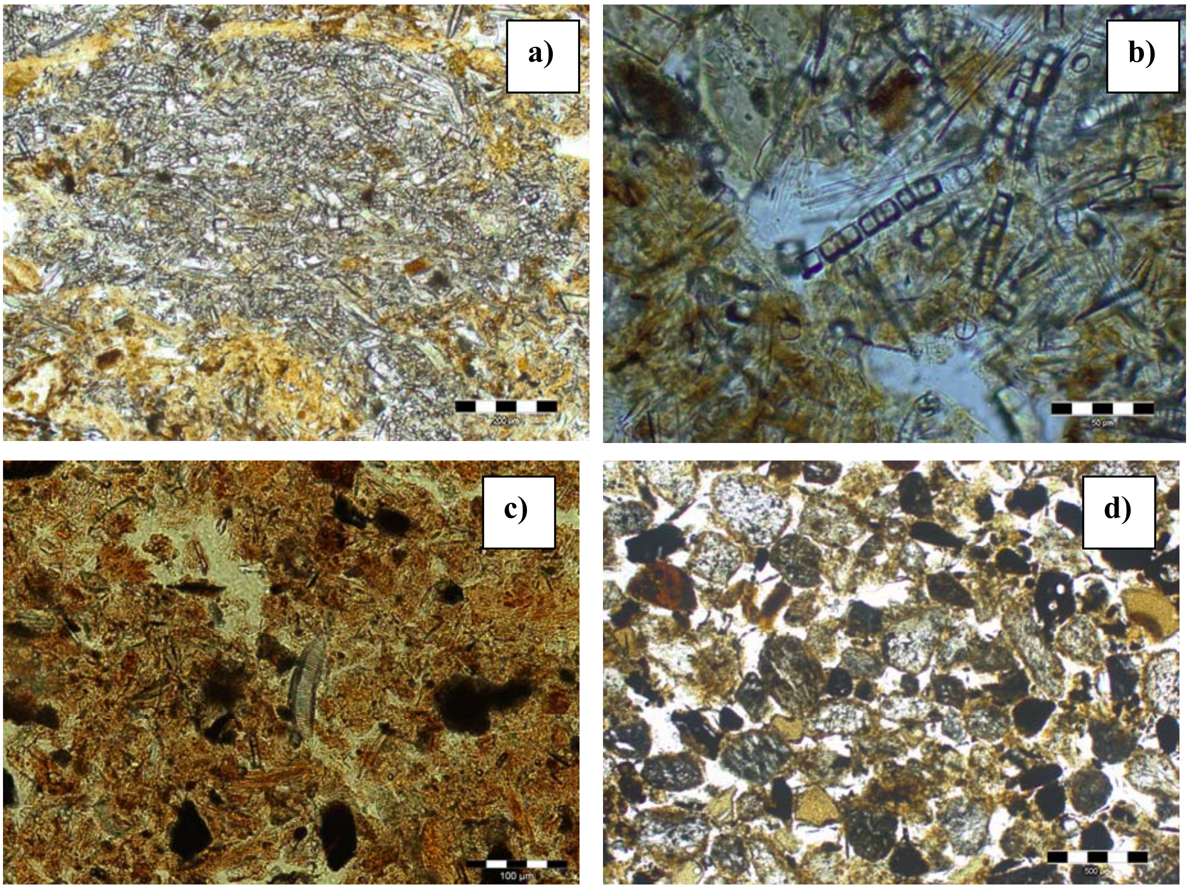

Figure 37- Features seen in soils thin sections from Geirastaðir's home-field: a) accumulation of diatoms and phytoliths, b) diatoms, c) diatom and d) accumulation of coarse sand size particles.

In thin section C key features are fuel ash residues of the type light-grey under OIL in micro-strata 1 and 3, many crypto-crystalline pedofeatures and rare iron-phosphate features in micro-stratum 2, and banded coarse material arrangement in all the micro-strata. Also noticeable is the lenticular microstructure in thin sections B and C. Thin section D is formed by five micro-strata. Micro-stratum 1 is dominated by sedimentary type 3, with particles with a size range of 10-250 µm. Micro-strata 2 and 3 are formed by micro-bands of silica and mineral accumulation (types 1 and 3). The silica micro-bands are composed by frequent/common diatoms (Figure 37- b and c) and very few phytoliths. Micro-strata 4 and 5 are formed by micro-bands of organic and mineral accumulation. Micro-stratum 4 differs from 5 in the greater abundance of amorphous brown fine organic material. Micro-stratum 5 is composed by two bands defined by the size of the coarse mineral material, in one band most of the mineral has a size range of 10-200 μm while the other band is composed by coarser particles (100-500 μm).

Table 22- Micromorphology descriptions of thin sections from Geirastaðir home-field soils.

		COARSE MINERAL MATERIAL										COARSE ORGANIC MATERIAL			FINE ORGANIC MATERIAL			PEDOFEATURES								
		TEPHRA																								
Thin section sample	Micro-stratum	Brown	Pale brown	Gray	Black	White	Phytoliths	Diatoms	Bone	Fine mineral material	Groundmass b Fabric	Charcoal	Parenchymatic	Fungal sclerotia	Cell residue	Amorphous (black)	Amorphous (brown)	Textural (silt (coatings)	Fe-Phosphate	Amorphous crypto-crystaline	Excremental (mamillate)	Excremental (spheroidal)	Microstructure	Sorting	Coarse material arrangement	Related distribution
C	1	•	•	*t*	••	*t*	•	•	*t*	••• Gry (PPL), L-Gry (OIL); O/m	Ss	•			*t*	••	•			*			Co: Ma/Vu	P	Ba	Ds-Po
	2	*t*	•	*t*	••	*t*	•	•	*t*	••• Or; O/m	Ss	•	*t*	*t*	*t*	••	•		*	***	*t*	*t*	Co: Le/Gr	P	Ra/Ba	Ds-Po
										••• Gry (PPL), L-Gry (OIL); O/m	Ss															
										• L-Ye	Ss															
	3	*t*	•	*t*	••	*t*	•	•	*t*	••• Yb; O/m	Ss	•	*t*	•	*t*	••	••			**	*t*		Co: Le/Pl/ Vu	P	Ba	Ds/O-Po
										••• Gry (PPL), L-Gry (OIL); O/m																
D	1	*t*	•••	*t*	•••	*t*	*t*	*t*		••• Gry; O/m	Ss			*t*		*t*	•						Chm	P	Ra	Ds-Po
										• Yb; O/m	Ss															
	2	•	••		••		•	•••		•• Yb; O/m	Ss		*t*	•	*t*	*t*	••			*t*			Co: Chn/Ch m/Sg/Pl	P	Ra/Ba	O-Po/C Mo
	3	*t*	•		•	*t*	•	•••		•• Yb; O/m	Ss		*t*	•	*t*	•	••			**	*t*		Co:Chn /Ve	P	Ra/Ba	C-Po
	4		••		*t*	*t*	•	•		•• Yb; O/m	Ss		*t*	•	*t*	••	•••			*t*			Co: Chm/Pl/ Ve	P	Ra/Ba	O-Po
	5	*t*	••	•	••	*t*	*t*	*t*		••• Yb; O/m m	Ss			*t*	*t*	•	•	*t*		*t*			Co: Ma/Chn	P	Ra/Ba	O/Ds-Po

Frequency class refers to the appropriate area of section (Bullock et al., 1985) t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%) •••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al.*, 1985) *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

From the micromorphological descriptions it is evident that the uppermost sample from Geirastaðir's profile, thin section A, presents more signs of cultural activity than the rest of the profile. The vertical arrangement of the micro-strata is a sign of disturbance by agricultural work, possibly related to the incorporation of amendments to the soil. These soil amendments are formed by charcoal, bone fragments and ash fuel residues, which indicates use of household waste. The differences in colour under OIL in the ash residues described above may represent different materials combusted at different temperatures, although the sources could not be identified. The amorphous crypto-crystalline pedofeatures in this sample include iron-stained roots, iron nodules, concentric iron rings and other iron concentrations. The iron concentric rings imply different phases of wet and drying.

The bigger particles sizes in the coarse mineral material of thin section B, micro-stratum 2, are indicative of higher energies involved in transportation. The grey particles in this micro-stratum are pumice grains and their rounded shape indicates reworking and abrasion by wind, although water deposition can not be discounted. The lack of organic matter in this micro-stratum indicates an unstable soil environment. The other two micro-strata in the thin section exhibit cultural features but in less abundance and diversity than in thin section A. The micro-bands of angular coarse mineral material and organic matter and silica features in micro-strata C and D suggest windblown accumulation and phases of standstill. The differences in the mineral material size range of the micro-bands imply differences in the energy involved for their transportation.

The only chronology in profile I in Geirastaðir is provided by a charcoal sample collected just above thin section D (Figure 34). This sample was identified at the

Glasgow University Archaeological Research Division (GUARD) as birch (*Betula sp.*) and gave a calibrated date of AD 770-970 (95.4% probability, see Table 20). This and the fact that there was no charcoal or other cultural indicators in thin section D suggest that this sample represents pre-*Landnám* conditions. The increase in the abundance of amorphous crypto-crystalline pedofeatures above this thin section suggests that conditions in the area got wetter once human activities started in the site. However, the greater abundance of diatoms in thin section D compared to the rest of the thin sections (frequent/common to very few), seems to contradict this. The downward movement of diatoms in the soil profile due to bioturbation and percolation of soil water has been reported previously (Simons *et al*., 2000) and might explain this apparent discrepancy. If the concentration of diatoms in thin section D is then considered to be the result of downward movement from more superficial strata, this would support the hypothesis of wetter condition after settlement. Wetter conditions might have been artificially created by irrigation or the clearance of trees to establish a wet meadow/home-field.

4.2.2.5 Grænavatn

The home-field was 5.6 ha in 1919 (Jónsson, 1919). The profile exposed in Grænavatn's home-field was the deepest of all the home-fields excavated, being composed by more than 2 metres of soils and sediments. The soil stratigraphy and field description of the profile can be seen in Figure 38. The profile was formed by alternating layers of sand and layers of organic and cultural material. The layers of sand were in general very dark grey (10 YR 3/1) and very dark greyish brown (10 YR 3/2) in colour. The cultural layers were predominantly brown (10 YR 4/3) and dark brown (10 YR 3/3), although with some reddish brown colours (5 YR 3/2 and 5 YR 4/4) deep in the profile. Given that the *Landnám* tephra was not found in the profile, a charcoal sample was collected at *c*. 180 cm. Another charcoal sample was collected between the thick accumulation of the 1477 and the 1717 tephras. These samples were identified at the Glasgow University Archaeological Research Division (GUARD) as birch (*Betula sp*.) and willow (*Salix sp*.), respectively. They gave calibrated dates of AD 1050-1260 and AD 1430-1630 (95.4% probability, see Table 20 and Figure 38).

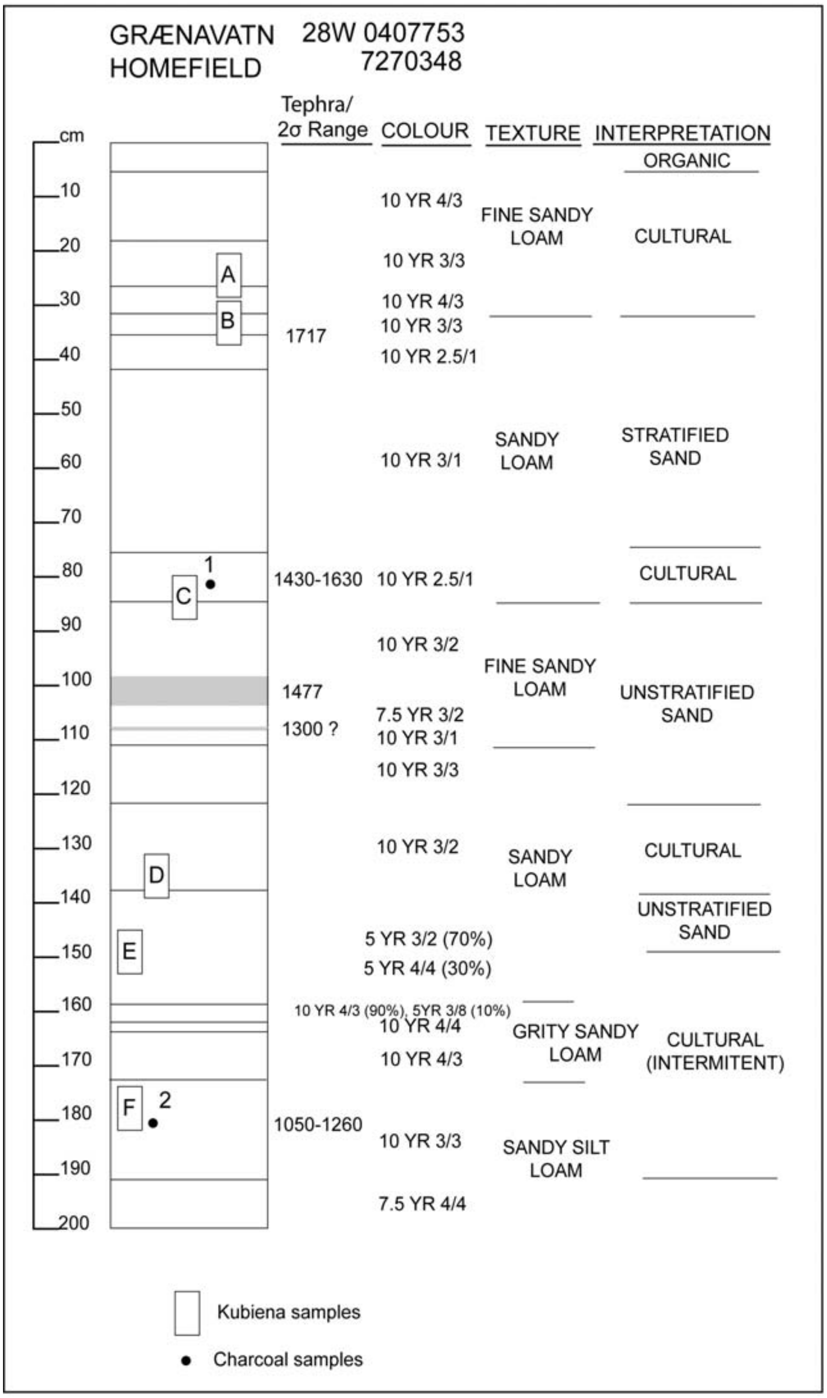

Figure 38- Soil stratigraphy and field description of Grænavatn home-field.

Six kubiena samples were taken from this profile. Micromorphological descriptions can be found in Table 23 and Table 24. Thin section A is formed by sedimentary types 2, 3 and 4. Sedimentary type 3 is the most dominant type and is formed by coarse mineral material ranging in size from 50 to 250 µm. Sedimentary type 2 is characterised by fuel ash residues of white/light yellow appearance under OIL and traces of charcoal. Thin section B is formed by micro-sequences of coarse mineral material and vegetation accumulation occurring at the same time. Micro-stratum 2, is formed by dominant/very dominant pale brown and very few black particles ranging in size from 100-600 µm and 30-150 µm, respectively. The key characteristic of thin section C is the alternation of micro-strata formed by sedimentary types 2 and 3. Sedimentary type 3 is predominant in micro-strata 1 and 3 where it is composed of well sorted and moderately sorted grains, respectively. Micro-stratum 2 is a "cut micro-stratum" and is dominated by sedimentary type 2, whereas in micro-stratum 3 both sedimentary types (2 and 3) are equally dominant.

Table 23- Micromorphology descriptions of thin section samples A, B and C from Grænavatn home-field soils.

		COARSE MINERAL MATERIAL										COARSE ORGANIC MATERIAL			FINE ORGANIC MATERIAL			PEDOFEATURES							
		TEPHRA																							
Thin section sample	Micro-stratum	Brown	Pale brown	Gray	Black	White	Phytoliths	Diatoms	Bone	Fine mineral material	Groundmass b Fabric	Charcoal	Parenchymatic	Fungal sclerotia	Cell residue	Amorphous (black)	Amorphous (brown and red)	Textural (silt (coatings)	Amorphous crypto-crystaline	Excremental (mamillate)	Excremental (spheroidal)	Microstrocture	Sorting	Coarse material arrangement	Related distribution
A	1	*t*	••	*t*	••	*t*				••• Yb; O/m, • Gry; O/m, Wh /L-Ye(OIL); O/m	Ss	*t*	*t*			•	••	*t*	*t*			Chn	P	Ra	Ds-po
B	1	*t*	••	*t*	••				*t*	•• Yb; O/m	Ss	*t*	*t*	*t*		••	•••	**	*t*		*t*	In mi	P	Ra	Si-s- F-En
	2	*t*	••••	*t*	•	*t*				• Yb; O/m	Ss					*t*	•	*t*				In mi	W	Ra	C-F-En
	3	*t*	•••	*t*	•••	*t*				•• Yb; O/m	Ss	*t*	*t*	*t*		•	••	**				In mi	M	Ra/Ba	Ds-F-En
C	1	•	•••	•	•••	*t*				•• Br; O/m *t* Gry (PPL), Wh (OIL)	Ss Ss	*t*				*t*	•	*t*				In mi	W	Ra	C-F-En
	2	•	••	*t*	••	*t*			*t*	••• D Br; O/m •• Gry (PPL), Wh (OIL); O/m	Ss Ss	••				•	•	*t*				In mi	P	Ra	Si-s-Po
	3	•	•••	*t*	•••	*t*			*t*	•• Br; O/m *t* Gry (PPL), Wh (OIL); O/m	Ss Ss	•			*t*	•	•	*t*	*t*			In mi	M	Ra	C-F-En
	4	•	••	*t*	••	*t*			•	••• D Br; O/m	Ss	••				•	•	*t*	*t*			In mi	P	Ra	Si-s-Po

Frequency class refers to the appropriate area of section (Bullock et al., 1985) t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%) •••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al.*, 1985) *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

Two micro-strata where seen in thin section D, both formed by a combination of sedimentary types 2 and 3. Micro-stratum 1 is dominated by frequent/common pale brown particles of silt to medium sand size grains. Micro-stratum 2 is a cut micro-stratum the key features of which are frequent/common grey rounded particles and very few bone fragments. Some of the bone fragments found in both micro-strata are dark red in colour. Thin section E is formed by two micro-strata. The microstructure of both micro-strata is complex. Micro-stratum 1 is dominated by sedimentary type 2 formed by reddish/brown amorphous and parenchymatic organic material. Occasional amorphous crypto-crystalline pedofeatures are also present. Key characteristics of micro-stratum 2 are big voids forming channel and chamber microstructures. The micro-stratum is dominated by sedimentary type 3 with pale brown particles of silt to coarse sand size and black particles of silt to medium sand size. Thin section F was subdivided into two micro-strata. The microstructure of this thin section, as in the previous sample, is complex. Key characteristics of both micro-strata are the orange colour of the fine mineral material (abundance: very few in micro-stratum 1 and dominant/very dominant in micro-stratum 2) and the many amorphous crypto-crystalline pedofeatures. Another aspect of interest is the reddish-brown colour associated with the organic matter which has a parallel arrangement.

Table 24- Micromorphology descriptions of thin section samples D, E and F from Grænavatn home-field soils.

		COARSE MINERAL MATERIAL										COARSE ORGANIC MATERIAL			FINE ORGANIC MATERIAL			PEDOFEATURES							
		TEPHRA																							
Thin section sample	Micro-stratum	Brown	Pale brown	Gray	Black	White	Phytoliths	Diatoms	Bone	Fine mineral material	Groundmass b Fabric	Charcoal	Parenchymatic	Fungal sclerotia	Cell residue	Amorphous (black)	Amorphous (brown and red)	Textural (silt (coatings)	Amorphous crypto-crystaline	Excremental (mamillate)	Excremental (spheroidal)	Microstrocture	Sorting	Coarse material arrangement	Related distribution
D	1	*t*	•••	•	••	*t*			*t*	••• Yb; O/m	Ss	*t*				•	•	*t*	*t*			In mi	M	Ra	Si-s F/E En
	2	*t*	••	•••	••	*t*			•	•• Yb; O/m	Ss	•		*t*		•	*t*	*t*	*t*			In mi	P	Ra	Si-s F/E En
										•• Br; O/m	Ss														
E	1	•	••	*t*	••	*t*		•	*t*	••• Yb; O/m	Ss	*t*	•	*t*	*t*	•	••		**			Co: Ma/Chn /Cr	P	Ra	Si-s-Po
										• D Gry (PPL), L Gry (OIL); O/m															
	2	•	••	*t*	••	*t*	*t*	*t*		•• Yb; O/m	Ss			•	*t*	*t*	•	*t*	*		*t*	Co: Chn/Ch m/In mi	P	Ra	C/Si-s-Po/Si-s-En
										•• D Gry (PPL), L Gry (OIL); O/m • L Ye															
F	1	•	••	*t*	••	*t*	*t*	*t*		••• Yb; O/m	Ss			*t*		••	•	*t*	***		*t*	Co: Gr/le/C hn	P	Ra	C/Si-s-Po
										• Or; O/m • L-Ye	Ss														
	2	*t*	••	*t*	••	*t*	*t*	*t*	*t*	•••• Or; O/m	Ss			*t*		••	*t*		***			Co: Ma/Chn /Pl	P	Ra	C/Si-s-Po

Frequency class refers to the appropriate area of section (1999) t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%) •••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al.*, 1985) *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

The charcoal samples identified in Grænavatn's home-field indicate that willow and birch were used as fuel resources. The light yellow colour in the fuel ash residues of thin section A, might be the result of peat combusted at high temperatures (Simpson *et al.,* 2003). Micro-stratum 2 of thin section B is interpreted to be the AD 1717 tephra. The stratified sand strata observed in the field represent recurring episodes of wind-blown sand deposition while the un-stratified strata (C and E) might represent one higher-energy event. The predominance of intergrain microaggregate microstructures and enaulic distribution patterns from thin sections D to B are the result of the high content of sand-sized grains. This evidence suggests increased wind erosion and deposition at some point after AD 1050. The cultural evidence suggests substantial management efforts were made to maintain the home-field. These characteristics, although more marked in this soil profile, are similar to the alternation of coarse mineral and cultural material seen in Baldursheimur and Gautlönd. However, this seems to happen a lot earlier in Grænavatn (before AD 1477). The field soil colour, the abundance of amorphous crypto-crytalline pedofeatures and reddish-brown colour of the organic matter in deeper samples from the profile (E and F) also indicate wetter conditions before AD 1477.

4.2.2.6 Grimstaðir

The soil profile and field description of Grimstaðir's home-field can be seen in Figure 39. Micromorphological descriptions are detailed in Table 25.

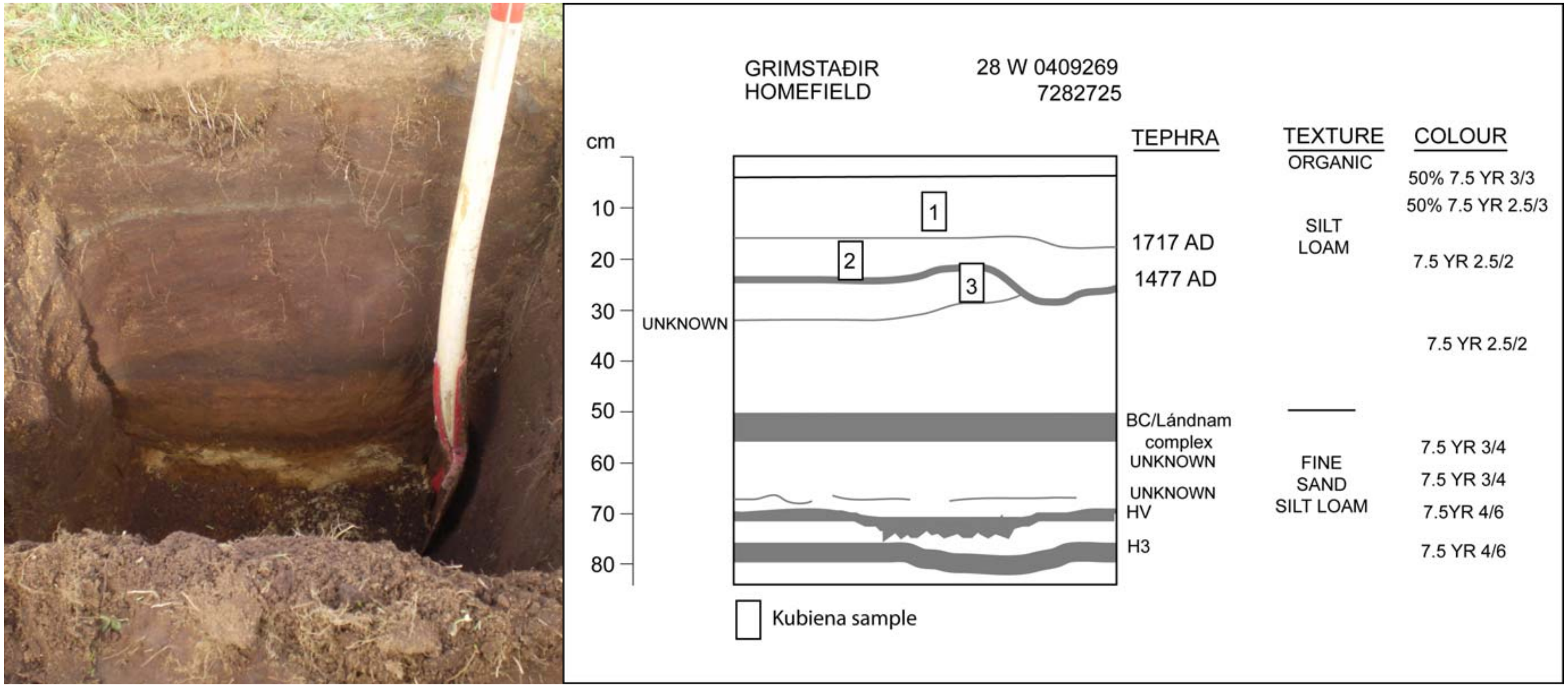

Figure 39- Soil profile and field description of Grimstaðir's home-field, showing locations of thin sections 1, 2 and 3.

Three thin section samples were collected in the profile. Thin section 1 was collected above the AD 1717 tephra and two micro-strata were distinguished. Micro-stratum 1 was dominated by sedimentary type 2, formed mainly by cell residues and amorphous reddish-brown organic material. Sedimentary type 4 was also evident with ash, charcoal and bone fragments. The mineral component was dominated by black particles of silt and fine sand- size (size range 10- 100 µm). Some pale brown particles presented an orange-reddish hypo-coating. The pale brown particles in micro-stratum 2 are more abundant and of bigger size, ranging from 30-400 µm. The organic material is sometimes arranged sub-horizontally. Thin section 2 was collected between the AD 1477 and the AD 1717 tephras. This thin section was divided into six micro-strata, most of them dominated by sedimentary type 2. This sedimentary type in the thin section had a predominance of amorphous black and brown organic material. Exceptions to this were micro-strata 4 and 6 which were formed predominantly of black coarse mineral particles of silt and fine sand-size. Thin section 3 was taken between the AD 1300 and 1477 tephras. Seven micro-strata of alternating organic and mineral material were distinguished in this thin section. Micro-stratum 1 was dominated by sedimentary type 3 formed by frequent/common pale brown and black particles of silt to medium sand-size. Micro-stratum 2 was formed mainly by sedimentary type 2, characterised by amorphous black and brown organic material orientated often in parallel (sub-horizontally). Micro-stratum 3 was formed by both organic and wind blown accumulation with particle size ranging from silt to medium sand. Micro-strata 4 and 5 were dominated by sedimentary type 2. Both micro-strata presented inter-connected phytoliths (see Appendix 6) and diatoms with bilateral symmetry. Diatoms however were more abundant in micro-stratum 4. Micro-stratum 6 is formed by sedimentary type 3 with dominant/very dominant grey particles.

Micro-stratum 7 is dominated by organic material, predominantly fine amorphous reddish/brown.

Table 25- Micromorphology descriptions of thin sections from Grimstaðir home-field soils

		COARSE MINERAL MATERIAL										COARSE ORGANIC MATERIAL			FINE ORGANIC MATERIAL			PEDOFEATURES							
		TEPHRA					BIOLOGICAL ORIGIN																		
Thin section sample	Micro-stratum	Brown	Pale brown	Grey	Black	White	Phytoliths	Diatoms	Bone	Fine mineral material	Groundmass b Fabric	Charcoal	Parenchymatic	Fungal sclerotia	Cell residue	Amorphous (black)	Amorphous (reddish, brown)	Textural (silt (coatings)	Amorphous crypto-crystaline	Excremental (mamillate)	Excremental (spheroidal)	Microstrocture	Sorting	Coarse material arrangement	Related distribution
1	1		•	*t*	••		*t*	*t*	*t*	••• Rb; O/m • Gry (PPL), Wh (OIL); O/m	Ss	*t*	*t*	*t*	•	•	••	*t*	*	•		Co: Ma/Pl/Gr	M	Ra	Ds-Po
	2		••	*t*	•		*t*	•		•••• Rb; O/m	Ss	*t*	*t*	•	*t*	•	•••	*t*	*			Co: Ma/Pl/La	M	Ra/Ba	Ds-Po
2	1	*t*	•	*t*	•		*t*	•		••• Yb; O/m	Ss		*t*	*t*		•	•••	*t*	*t*			Co: Ma/La/Pl	M	Ra/Ba	Ds/O-Po
	2	*t*	•		•			*t*		••• Rb; O/m	Ss	*t*	*t*	*t*		••	••		**			Co: Ma/La	M	Ra/Ba	O-Po
	3	*t*		*t*	•	*t*		*t*		•••• Rb; O/m	Ss		*t*	•		•	•	*t*	*t*			Co: Ma/La	M	Ra/Ba	Ds-Po
	4		••		•••			*t*		••• Yb; O/m • Rb; O/m	Ss		*t*	*t*		*t*	•		*	*t*		Co: Ma/Ch	M	Ra	Si-s Po
	5	*t*	•		••			*t*	*t*	••• Rb; O/m • Gry (PPL), Wh (OIL); O/m	Ss		*t*	*t*	•	•	•••		*			Ma	M	Ra/Int	Si-s Po
	6	*t*	••		•••					••• Gry (PPL), L-Gry (OIL); O/m	Ss		*t*			•	••		*			Co: Ma/La/Sg	P	Ra	Si-s Po/C-Mo
3	1	*t*	•• •		•••	*t*				• Gry; O/m • Rb; O/m	Ss Ss						*t*		*t*			Co: Sg/Ma	P	Ra	C-Mo/C-Po
	2		•	*t*	••	*t*	*t*	•		••• Rb; O/m	Ss	*t*	*t*	*t*	*t*	•	••	*t*	*			Co: Gr/La	M	Ra/Ba	Ds-Po
	3	*t*	••	•	••	*t*	*t*	*t*		••• Gry; O/m • Rb; O/m	Ss Ss		*t*			*t*	•		*t*		*t*	Ma	P	Ra	C-Po
	4	*t*	•	*t*	•	*t*	*t*	••	*t*	••• Yb; O/m	Ss	*t*	*t*	*t*	*t*	•	••	*t*	*t*			Co: Gr/La	P	Ra/Ba	Ds-C-En/Si-s Po/Ds-Po
	5	*t*	••	*t*	••		•	•		••• Rb; O/m	Ss	*t*	*t*	*t*	*t*	•	••	*t*	*	*t*		Co: Gr/La	P	Ra/Ba	Si/Ds-Po
	6	*t*	•	••••	•					•• Rb; O/m	Ss			*t*	*t*	*t*	•		*t*			Sg	M	Ra	C-Mo
	7	*t*	•	•	•	*t*	*t*	•		••• Rb; O/m	Ss	*t*		•	*t*	•	•••	*t*	*			Co:Gr/La	P	Ra/Ba	Ds/O-Po

Frequency class refers to the appropriate area of section (Bullock et al., 1985) t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%) •••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al*., 1985) *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

All the thin sections from Grimstaðir home-field were dominated by sedimentary type 2, formed by organic matter in an advance stage of decomposition as indicated by the predominant amorphous black and reddish-brown organic material. The micro-strata where coarse mineral material was dominant were interpreted as tephra layers. For example, micro-stratum 6 of thin section 2 was interpreted as the AD 1477 tephra. Micro-stratum 4 of the same thin section might be a redistribution of the 1477 tephra. Micro-stratum 1 of thin section 3 was interpreted as the 1477 tephra. Micro-stratum 6 of thin section 3 was formed by pumice (grey particles) with no coatings of fine material as has been seen in other farms and so it was interpreted as a primary tephra fall. This tephra possibly corresponds to the AD 1300 tephra. The mixture of: inorganic, organic and cultural material in an apparently random pattern, together with the cut-shapes of the micro-strata, indicate agricultural work. The laminar microstructures were formed of organic matter in sub-horizontal parallel arrangement. This characteristic of organic matter deposition in Icelandic soils has also been reported by Simpson *et al*. (1999) and by Stoops *et al*. (2008). Both studies explained this sub-horizontal parallel arrangement as being produced by slow deposition and rapid burial of the organic matter before humification takes place. The small amount of anthropogenic evidence seen in the profile could be due to the area being in the margins of the original home-field. The main farm building was moved in the 1720's due to the Mývatn fires lava flow and the old main home-field area may now be under lava rock. Limited cultural deposits were also reported after an archaeological survey of the area (Vésteinsson, 2008).

4.2.2.7 Fagranes

Two soil pits were dug in Fagranes home-field. Soil profiles and field descriptions are presented in Figure 40 and Figure 41. Micromorphological descriptions are included in Table 26.

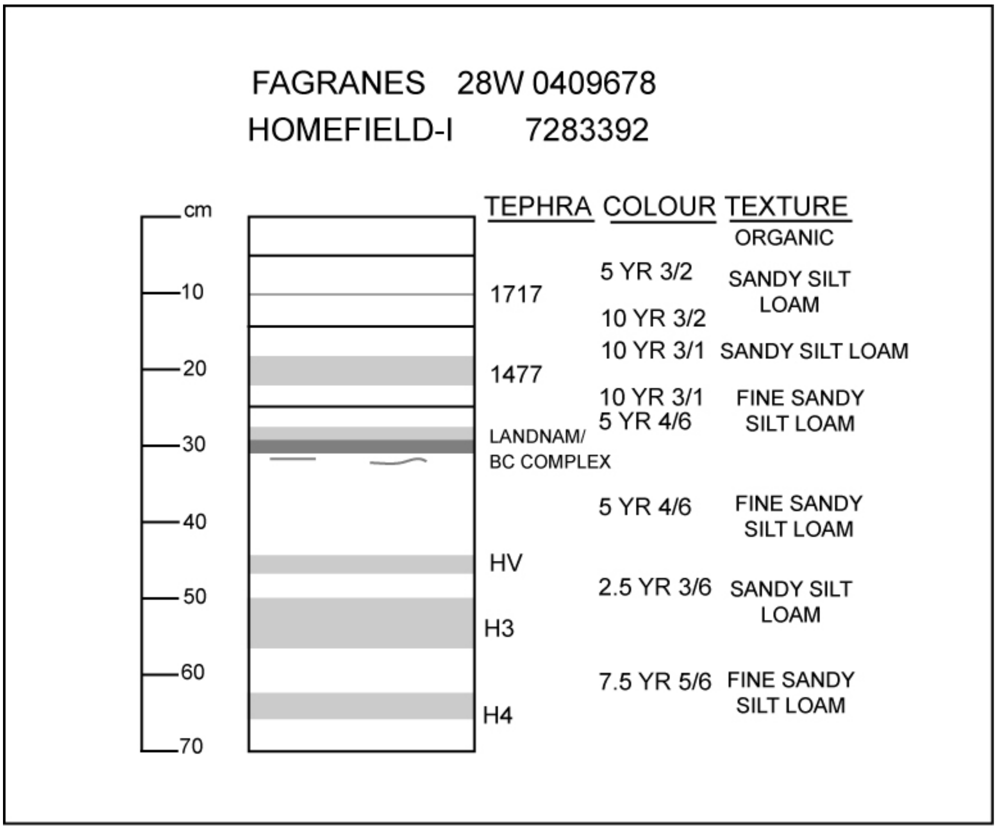

Figure 40- Soil stratigraphy and field description of profile I at Fagranes home-field.

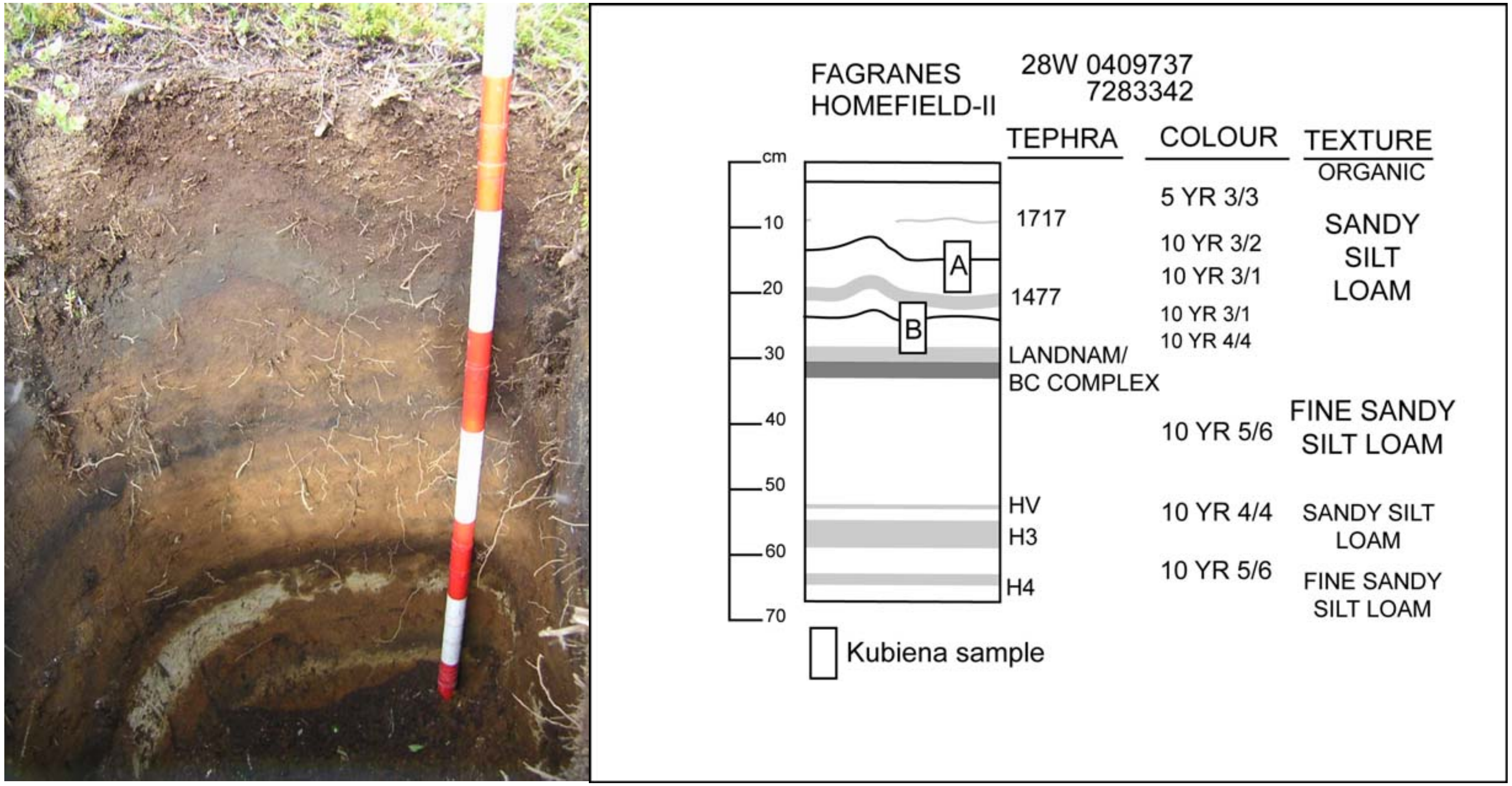

Figure 41- Soil stratigraphy and field description of profile II at Fagranes home-field showing location of thin sections A and B. The undulation of the 1477 tephra and the soil layers immediately below and above it is an indication of past frost heave formation.

Thin section A was taken between the AD 1477 and the AD 1717 tephras (Figure 41). Two micro-strata were distinguished in this thin section. Micro-stratum 2 was formed of sedimentary type 2, composed of frequent/common pale brown and black particles of silt to fine sand-size. This micro-stratum exhibited a random coarse material arrangement and intergrain microagregate and lenticular microstructures. Micro-stratum 1 was formed of a mixture of sedimentary types 2 and 3. Here the same type of aeolian material as in the previous micro-stratum was present but less abundant (few) and mixed with frequent/common fine amorphous brown organic material. Other important aspects of this micro-stratum were the very few fungal sclerotia and rare spheroidal excremental pedofeatures.

Thin section B was taken above the *Landnám*/BC tephra complex. This sample was dominated by a mixture of sedimentary types 2 and 3. There were differences in the aeolian accumulation with coarser and finer particles. The coarser particles were grey and ranged in size from 200-900 µm, while the finer particles were pale brown and black and range in size between 50-400 µm. Sedimentary type 2 was characterized by very few fungal sclerotia, rare spheroidal excremental pedofeatures, few amorphous brown and very few amorphous black fine organic materials.

Table 26- Micromorphology descriptions of thin sections from Fagranes home-field soils.

Thin section sample	Micro-stratum	COARSE MINERAL MATERIAL – TEPHRA: Brown	TEPHRA: Pale brown	TEPHRA: Gray	TEPHRA: Black	TEPHRA: White	Phytoliths	Diatoms	Bone	Fine mineral material	Groundmass b Fabric	COARSE ORGANIC MATERIAL: Charcoal/ lignified	Charcoal	Parenchymatic	Fungal sclerotia	FINE ORGANIC MATERIAL: Cell residue	Amorphous (black)	Amorphous (brown)	PEDOFEATURES: Textural (silt (coatings)	Fe-phosphate	Amorphous crypto-crystalline	Excremental (spheroidal)	Microstructure	Sorting	Coarse material arrangement	Related distribution
2-A	1	*t*	••	*t*	••	*t*				••• Yb; O/m	Ss	*t*		*t*	•	*t*	•	•••			*t*	*	Co: Pl/Cr/ Gr	P	Ra	Si-s-Po/Ds-E En
	2	•	•••		•••	*t*				••• Gry (PPL), O/m • Yb; O/m	Ss Ss			*t*	*t*		*t*	*t*					Co: In mi/Le	P	Ra	CMo/C-F En
2-B	1	*t*	••	•	••	*t*		*t*		••• Yb; O/m	Ss			*t*	•		•	••	*t*		*t*	*	Co: Ma/Pl /Cr/Le	P	Ra	Si-Ds Po

Frequency class refers to the appropriate area of section (Bullock *et al*., 1985) t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%) •••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al*., 1985) *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

There were no signs of amendment or any anthropogenic evidence in either of the thin sections from Fagranes' home-field. The mixture of sedimentary types 2 and 3 in both thin sections indicated that aeolian accumulation had taken place but not at a sufficiently rapid rate to prevent organic accumulation. Biological activity was also marked in both thin sections evident with very few fungal sclerotia and rare spheroidal excremental pedofeatures from beetle larvae. Between AD 1477 and AD 1717, there was a random coarse material arrangement of silt and fine sand-size particles in an intergrain microaggregate microstructure indicating aeolian deposition. The lenticular microstructure indicates freeze-thaw conditions (FitzPatrick, 1993). The thin section representing the soils between *Landnám* and AD 1477 showed the same random arrangement of the coarse mineral material. However, the particles were of silt to coarse sand size implying higher energy involved in their transportation.

4.2.2.8 Þórleifsstaðir

The home-field of Þórleifsstaðir consists of an elongated enclosure of 4.5 ha with an extension making a total of *c*. 9 ha (Vésteinsson, 2008), making it the largest home-field of all the study farms. A soil pit was dug in the first enclosure near archaeological remains. Þórleifsstaðir's soil profile and field description can be seen in Figure 42.

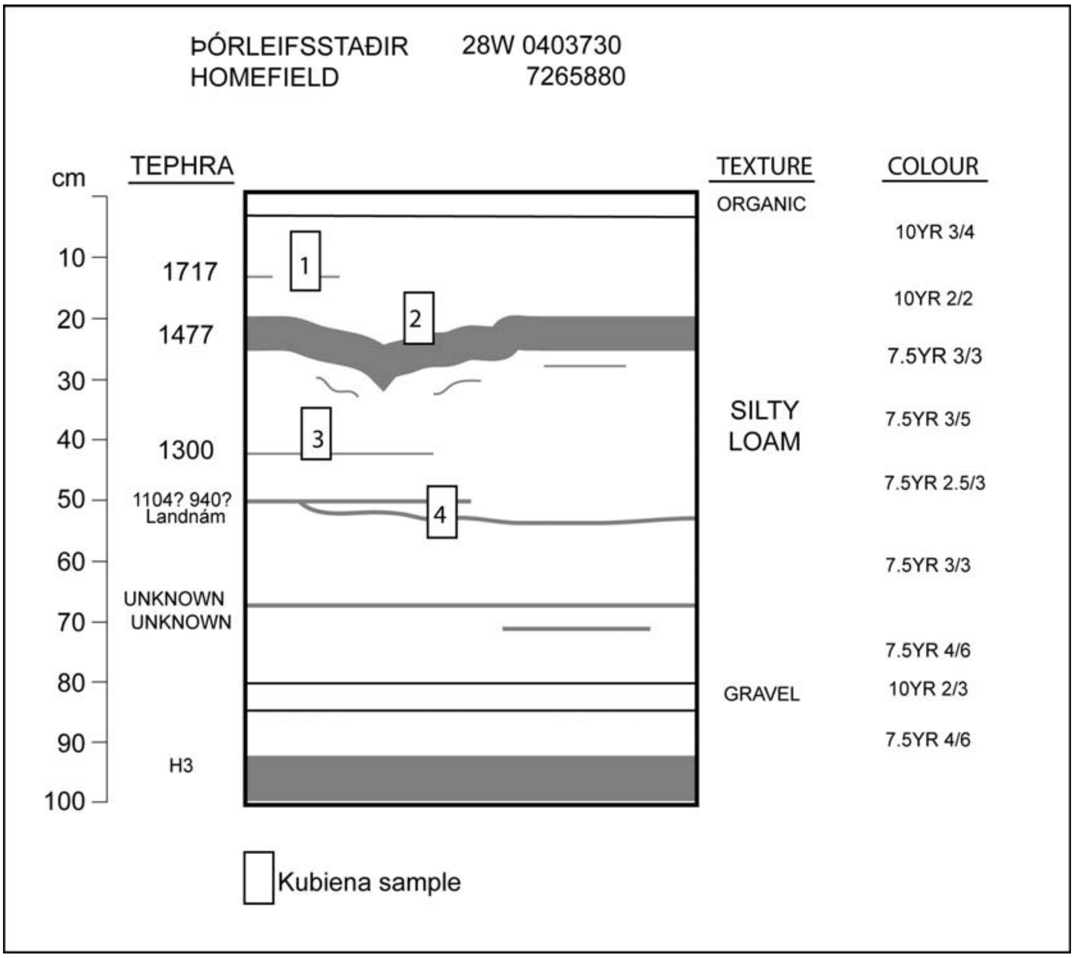

Figure 42- Soil profile and field description of Þórleifsstaðir home-field, showing the location of thin sections 1, 2, 3 and 4.

Four Kubiena samples were taken from the profile, their micromorphological description can be found in Table 27. The deepest thin section (4) was divided into four micro-strata. Key features in this thin section included many amorphous crypto-crystalline pedofeatures in micro-strata 1 and 4, very abundant in micro-stratum 3 and traces in micro-stratum 2; charcoal found in micro-strata 1, 2 and 3; and the presence of lenticular microstructure in all the micro-strata. Micro-stratum 2 is notably different from the rest in that it lacked the light yellow and yellowish brown colours of the fine mineral material present in the rest of the thin section, and also in the almost complete absence of amorphous crypto-crystalline pedofeatures and fine organic matter. It is comprised of frequent/common pale brown and black coarse tephra mineral material; most of these particles were about 30-150 μm long although some pale brown particles were as large as 450 μm.

Thin section 3 was divided into two micro-strata. Points of interest in this sample were the composition of micro-stratum 2, which was formed almost entirely by sedimentary type 4 and the greater amount of diatoms in both micro-strata compared to the other thin sections from this profile. Micro-stratum 2 contained few bone fragments, some of which were associated with Fe-Phosphate features. Micro-stratum 1 of this thin section was formed by sedimentary types 1 and 4 and had many amorphous crypto-crystalline pedofeatures.

Thin section 2 was divided in two micro-strata. Micro-stratum 2 was formed almost entirely by tephra, composed of frequent/common pale brown and black and few brown coarse mineral particles with a size range of 20-200 μm. Key features in thin section 1 were excremental spheroidal and mamillate pedofeatures (Figure 43-a and b, respectively), fungal sclerotia and the occurrence of both coarse and fine organic material.

Table 27- Micromorphological descriptions of thin sections from Þórleifsstaðir home-field soils.

		COARSE MINERAL MATERIAL (>50 µm)										COARSE ORGANIC MATERIAL			FINE ORGANIC MATERIAL			PEDOFEATURES								
		TEPHRA																								
Thin section sample	Micro-stratum	Brown	Pale brown	Grey	Black	White	Phytoliths	Diatoms	Bone	Fine mineral material	Groundmass b Fabric	Charcoal	Parenchymatic	Fungal sclerotia	Cell residue	Amorphous (black)	Amorphous (brown)	Textural (silt (coatings)	Ca-Fe-P	Amorphous crypto-crystaline	Excremental (mamillate)	Excremental (spheroidal)	Microstructure	Sorting	Coarse material arrangement	Related distribution
1	1	*t*	••		••	*t*	*t*	*t*		••• Yb; O/m	Ss		•	*t*	*t*	•	•			*t*	*t*	•	Gr/Chn	P	Ra	C-Si-s Po
2	1	*t*	••	*t*	••	*t*		*t*		••• Yb; O/m	Ss		*t*	*t*	*t*	•	•	*t*		*t*			Chn/Pl	P	Ra	C-Si-s Po
	2	••	•••		•••					• Yb; O/m	Ss		*t*			••	*t*	*t*		*t*			Sg/Pl	M	Ra	C-Mo
3	1	*t*	••		••		*t*	•	*t*	•• Yb; O/m • L Ye; O/m	Ss	•		*t*		*t*	•	*t*		***			Chn/Pl/Le/Gr	P	Ra	C-Si-s Po
	2	*t*	•		•		*t*	•	••	• Yb; O/m	Ss	•••	*t*		*t*	•	*t*	*t*	*t*	*			Ma	P	Ra	C-Si-s Po
4	1		••		••		*t*	*t*	•	•• Yb; O/m •• L Ye; O/m	Ss Ss	•				•	••	*t*		***			Le/Chn	P		C-Si-s Po
	2	*t*	•••		•••					•• Gry; O/m • Yb; O/m	Ss Ss	•					*t*			*t*			Le/Sg	M	Ra	C-Mo/ C-Si-s Po
	3	*t*	••	*t*	••		*t*	*t*		•• Yb; O/m • L Ye; O/m	Ss Ss	•	*t*	*t*		•	•			*****			Le/Chn/Sg	P	Ra	C-Si-s Po/C-Mo
	4	*t*	••	*t*	••		*t*	*t*		••• Yb; O/m • Gry; O/m	Ss			*t*	*t*	•	•	*t*		***			Le/Vu/Pl	P	Ra/Ba	C-Si-s Po

Frequency class refers to the appropriate area of section (Bullock *et al*., 1985) t Trace • Very few (<5%) •• Few (5-15%) ••• Frequent/common (15-50%)•••• Dominant/very dominant (>50%). Frequency class for textural pedofeatures (Bullock *et al*., 1985) *t* trace * Rare (<2%) ** Occasional (2-5%) * Many (5-10%) ****Abundant (10-20%) ***** very abundant > 20%.**

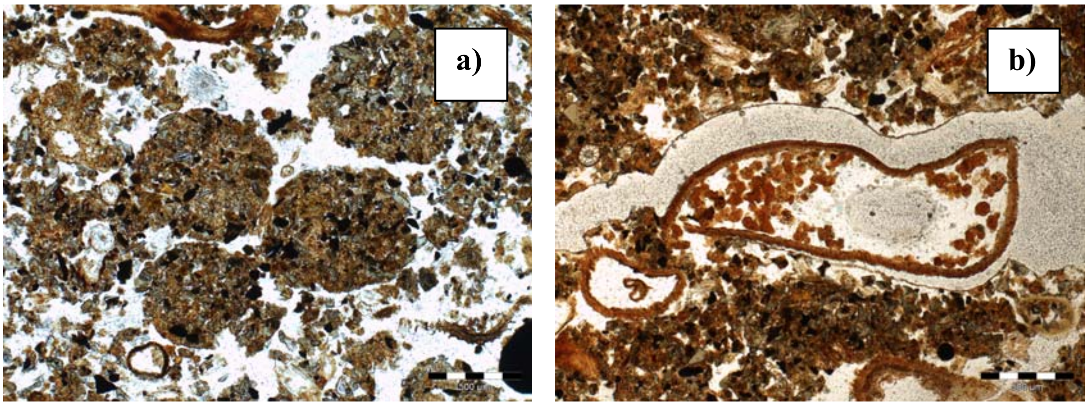

Figure 43- Excremental pedofeatures observed in soils thin sections from Grimstaðir's home-field: a) spheroidal excrements from beetle larvae; b) mamillate excrements from mites.

Two tephra bands were present in the thin sections from Þórleifsstaðir, micro-stratum 2 of thin section 4, being possibly the *Landnám* or the AD 980 tephra, and micro-stratum 2 of thin section 2, interpreted as the AD 1477 tephra. Micro-stratum 4 of thin section 4 probably represents conditions before settlement. In this layer, the random/banded arrangement is evidence of the two accumulation processes taking place, aeolian deposition and standstill phases of organic accumulation. The lenticular microstructure seen in the micro-strata below the AD 1477 tephra are indicative of freeze-thaw conditions (FitzPatrick, 1993). Evidence of use of household waste as soil amendment were seen in the micro-strata above *Landnám* and below the AD 1477 tephra. An archaeological survey reported that anthropogenic deposits were capped by the AD 1300 tephra and so it is believed that the farm was abandoned before this time (Vésteinsson, 2008). According to the family living now in Baldursheimur, there were more people living on this farm by 1703 than in Baldursheimur and it was abandoned around 1712. However, the farm is reported in Jarðabók as "*an old and ruined homestead standing in front of the farm of Baldurs and there are large ruins from the ancient fence and structures. The place is occasionally used to keep the cattle/livestock but it has not happened for many years. It is not possible to inhabit it again since the home-field is mostly overgrown*." For the home-field to be overgrown by vegetation and to be described as an "old and ruined homestead" it is likely that the place had been abandoned many years before the information for the Jarðabók was collected in 1712. Most likely the people from Baldursheimur were referring to the farm Hrútavíðasel not far from this site which had four people living there in 1703 (Þjóðskjalasafn Íslands (National Archives of Iceland), 2009). Hrútavíðasel was possibly initially a shieling of Baldursheimur, as the suffix "sel" indicates. It is now also abandoned. Another change noticeable in the soil layers above the AD 1477 tephra is the decline in the abundance of amorphous crypto-crystalline features from "very abundant" and "many" in previous layers to just traces in the layers above. This together with the reduction in the abundance of diatoms ("very few" to "traces"), suggests that conditions in the area became drier after AD 1477 Thin section 1, is more biologically active, as it is expected from samples closer to the surface. This was evident in the mamilliate and spheroidal excremental pedofeatures. Spheroidal excremental pedofeatures are typical of beetle larvae (Figure 43-a) and mamilliate of mites (Figure 43-b). The thin section also presented more organic matter in different stages of decomposition, evident in the abundance of parenchymatic coarse organic material and amorphous black and brown fine organic material.

4.2.2.9 Home-field soils formation processes in Mývatnssveit

A summary of the key sedimentary types and features seen in the soils' thin sections from the studied home-fields and their related interpretation is presented in Table 28. It can be seen from the table that sedimentary type 3 is a common element in all the home-fields. The coarse mineral material composing this type appears sometimes in a banded pattern forming strata of different particle size (e.g. Gautlönd thin section A, micro-stratum 4), mixed with organic matter (e.g. Fagranes thin sections A and B) or mixed with both organic matter and cultural material (e.g. Baldursheimur, Grænavatn A, B and C). In some micro-strata the coarse mineral material appears devoid of organic or fine mineral material, forming single grain or intergrain microaggregate microstructures and coarse monic or enaulic c/f-related distribution patterns (e.g. Grimstaðir thin section 2 micro-strata 4 and 6). This has been associated in Icelandic soils with rapid tephra fallout or wind erosion of tephra deposits (Simpson *et al*., 1999; Stoops *et al*., 2008). The particle size of the mineral material gives an indication of the energy involved in their transportation. Coarse sand size particles (630-2000 µm) will need higher energy for their transportation.

In the soil profiles with contrasting soil water regimes, drier conditions are associated with an increase of wind blown sand deposition (e.g. Gautlönd, thin section A; Grænavatn, thin sections A, B and C). These evidences of drier conditions could be the result of a reduction in precipitation, a change in the water retention capacity of the soils due to a reduction in the soil organic content/increase of the mineral content, or both. The change to drier conditions is not reflected in all the profiles and where it occurs, it appears in different time periods. For example, Gautlönd profile reflects drier conditions after AD 1717, Grænavatn and Þórleifsstaðir after AD 1477 whereas in Geirastaðir drier conditions seem to have occurred pre-settlement. Soil water regime changes are explained by local conditions such as increased sand deposition, influenced by landscape position, and changes in management, such as irrigation/flooding and additions of organic matter. Wet soil conditions seem to have been of great importance historically for hay productivity in Iceland. For example, the home-field of a high-status farm (Hofstaðir), as opposed to lower status home-fields, is located predominantly on imperfectly drained soils, which are suggested to encourage grass productivity in Iceland (Lawson *et al*., 2009).

The evidence of increased cultural material associated with increased mineral material or above layers of sand accumulation might indicate that household waste was used not only with the purpose of improving the fertility of the soils but also of improving their physical characteristics. This evidence was seen in the farms south of Lake Mývatn (i.e. Grænavatn, Baldursheimur), where encroaching sand is still a problem. The predominant direction of sand movement is north-east as a result of dry south-westerly winds (Arnalds *et al.,* 2001a). No evidence of animal manures, such as calcium spherulites, was seen in the thin sections. However, the absence of faecal spherulites could be due to low spherulite production in the gut of animals due to low soil pH or due to their degradation after deposition in the soil. It has been reported that spherulite dissolution occours generally at pH values below 7.7 and sometimes even at values as high as pH 8 (Canti, 1999). The pH values of the home-field soils ranged from 5.1 to 8.4, with a median of 6.6 (see Appendix 8).

Table 28- Summary of key sedimentary types and features seen in soils' thin sections from home-fields of the study farms and their interpretation.

Farm	Type	Key sedimentary types and features	Interpretation
Baldursheimur	Successful	Sedimentary types 3 & 4. Fe-phosphate features, fuel residues, silt to coarse sand size particles.	Use of different types of fuel combusted at different temperatures and household waste as soil amendment. Continual wind blown sand deposition of varying intensities.
Gautlönd	Successful	All sedimentary types. More abundant amorphous crypto-crystalline pedofeatures pre- AD 1717. More abundant mineral material of silt to coarse sand size particles post- AD 1717.	Increased sediment deposition of wind blown sand and drier conditions after AD 1717. Use of household waste as soil amendment.
Geirastaðir	Successful	Sedimentary types: 2, 3 & 4 post-*Landnám*; 1, 2 & 3 pre-*Landnám*. More abundant amorphous crypto-crystalline pedofeatures pre-*Landnám* Fuel residues and bone fragments post-*Landnám*.	Wetter conditions and use of household waste as soil amendment post-settlement. Wind deposition of varying intensities.
Grænavatn	Successful	Sedimentary types 3 & 4. Sedimentary types occur in alternating layers. More abundant amorphous crypto-crystalline pedofeatures pre- AD 1477	Wind blown sand deposition of varying intensities. Use of household waste as soil amendment. Drier conditions after AD 1477
Grimstaðir	Successful	Sedimentary types 2, 3& 4. Amorphous black and reddish-brown organic material.	Mostly stable landscape with organic soils. Use of household waste as soil amendment. Some events of low energy wind-deposition of sand.
Brjánsnes	Failed	Sedimentary types 2 & 3. Mineral material of silt to medium sand size mixed with organic material. Excremental pedofeatures.	Bio-turbation and modern agricultural activity.
Fagranes	Failed	Sedimentary types 2 & 3. Mineral material of silt to fine sand size pre- AD 1717 and silt to coarse sand size pre- AD 1477. Lenticular microstructure.	Aeolian deposition of higher energy involved in the period landnám- AD 1477. Freeze-thaw conditions. Soil amendments not used.
Þórleifsstaðir	Failed	Sedimentary types 2 & 3 above AD 1477; 1, 2, 3 & 4 *Landnám*-AD 1477. Fuel residues, bone fragments and more abundant amorphous crypto-crystalline pedofeatures from *Landnám*- AD 1477.	Use of household waste as soil amendment and wetter conditions from early settlement to AD 1477.

4.3 Phosphorus content and other bulk sample analyses

Results of total P, pH and Loss on Ignition (LOI) analyses can be found in Appendix 7. Total P values were grouped according to time period, as defined in the field by tephrochronology and by sample type (successful farm, failed farm or background). A GLM was carried out with “total P” as the response variable and “time period” and “type” as factors. The data did not meet the assumptions of normality and equal variance so it was transformed using natural logarithm. The results showed no significant differences in total P content between the different time periods (df=2, 42; F=0.32; P=0.731), but significant differences according to the type (df=2, 42; F=8.77; P<0.001). The interaction between time and outcome was not statistically significant (df=4; F=0.26; P=0.902). Tukey’s multiple comparisons test showed that successful farms had a significant greater total P content than both failed farms and background levels (P= 0.0122 and P= 0.0016, respectively). Furthermore, the total P content in failed farms was not significantly different from background levels (P= 0.6339). Figure 44 shows the phosphorus content (total P) in successful, failed farms and background levels in all the time periods considered. The figure shows not only greater mean values of phosphorus content on successful farms but also, in general, greater variance.

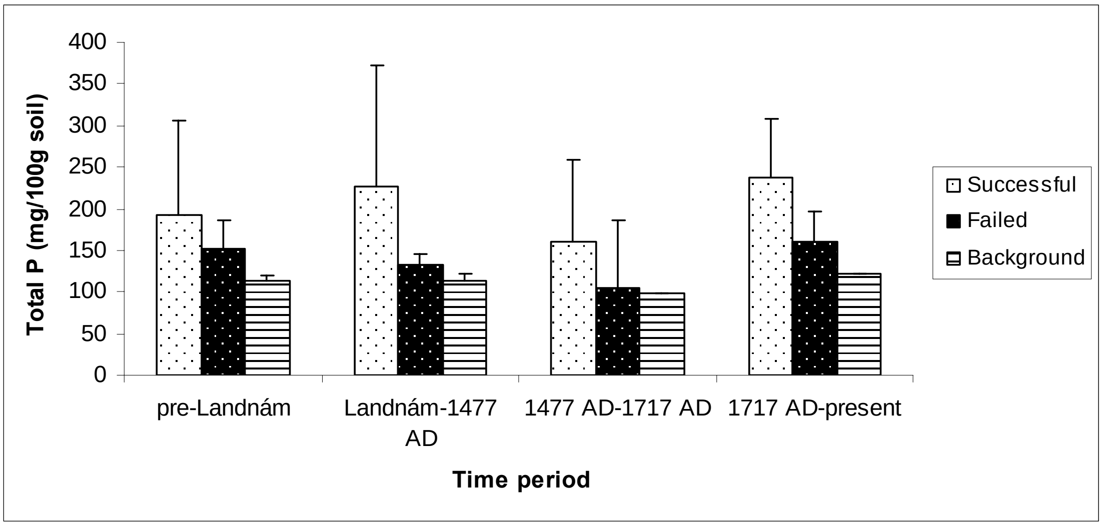

Figure 44- Total P in successful and failed study farms by time period, together with background levels. Error bars show the standard deviation.

Soil organic matter, measured by LOI, showed also greater variation in successful farms (Figure 45). Although the mean LOI in successful farms seems to be greater than in failed farms these differences were not statistically significant (p=0.346). LOI was not correlated with total P (P=0.061) as other studies of anthropogenic soils in NW Europe have reported (Crowther, 1997; Dercon *et al*., 2005; McKenzie, 2006).

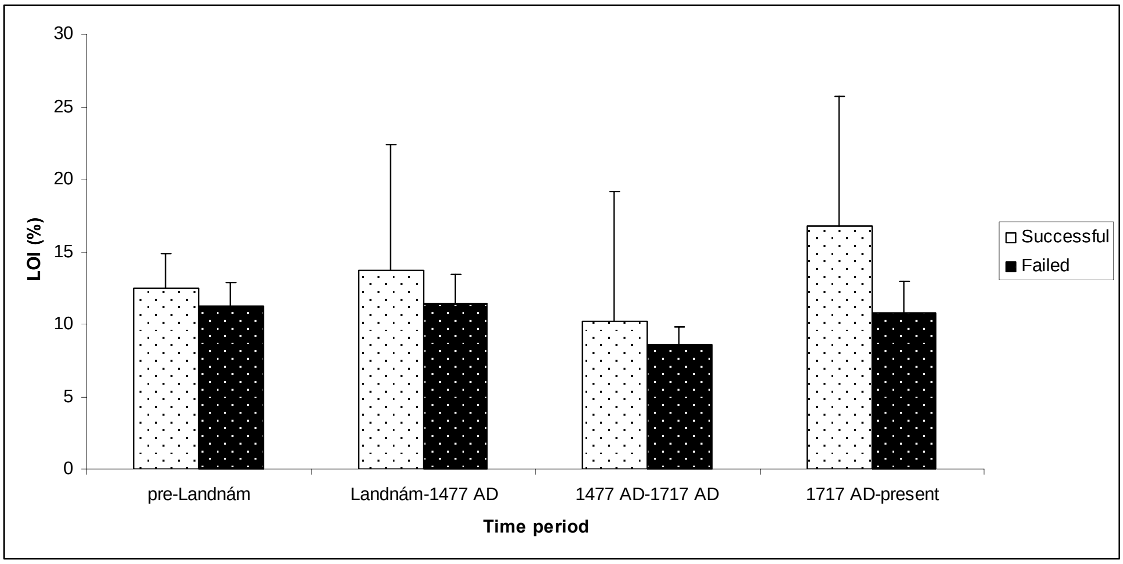

Figure 45- Organic matter measured as loss on ignition (LOI) in successful and failed study farms by time period. Error bars show the standard deviation.

The greater variability in Total P content and LOI in successful farms is the result of both intra and inter site variability. For example, Total P values from the two profiles analysed in Geirastaðir suggest that the home-field of this farm is more fertile than the mean (of both successful and failed farms) in all time periods (Figure 46). Moreover, total P values in Geirastaðir's home-field almost doubled after settlement. Grænavatn, on the other hand, presents great intra-site variability in both Total P and LOI (See Appendix 8). In this case, the variability seems to be associated with the alternation of cultural and sand layers throughout the soil profile (Figure 38). Sand layers, as would be expected, showed lower Total P and LOI values.

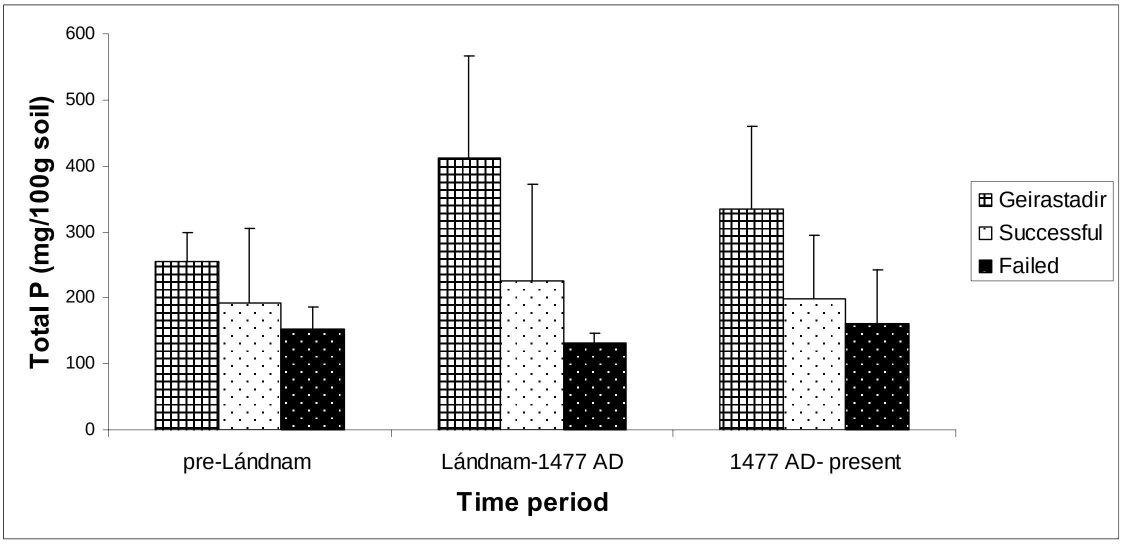

Figure 46- Total P in the home-field of Geirastaðir compared to mean values for successful and failed farms.

Three important points can be summarized from the total P analyses: *i*) successful farms seem to have been established in areas that were inherently more fertile than failed farms; *ii*) the only farms that show a significant enhancement in total P values after settlement are successful farms; and *iii*) there is great intra and inter site variability in successful farms. Previous studies have suggested the significance of inherent soil properties, soil variability and initial choice of field location in Iceland (Simpson *et al*., 2002; Adderley *et al*., 2008). Simpson *et al*. (2002) modelling the grain production of two sites in south-west Iceland concluded that inherent soil quality was more important than weather in determining the level of grain production. They also highlighted that initial soil conditions were critical in determining the trajectory of soil organic matter carbon and nitrogen levels under similar land management strategies. Although they did not include phosphorus in their model, initial soil conditions might affect this element in a similar way.

Chapter 5 -Results and discussions: Historical records

The total number of farms in the district of Þingeyjarsýsla in the land registers of 1686 and 1696 was 74. From these, 66 were private, 2 belonged to the Church, 5 to the Crown and 1 to the Bishop. Within the district, the commune of Mývatn had 21 registered farms at this time, 19 of which were private property. The private property was, in most cases, farmed by tenants who paid land rent to the owners. All of the study farms in 1686 and 1696 were private property occupied by tenants, although Geirastaðir had been Cathedral property of the Hólar see in 1550 (Lárusson, 1967). In 1712 half of the property of Baldursheimur was owned by a priest, Rev. Bjarni Ormsson (Magnússon *et al*., 1913). By 1835, owner farm-occupancy had increased and Geirastaðir, Gautlönd and Grímsstaðir are recorded as being occupied by their owners (Þjóðskjalasafn Íslands (National Archives of Iceland), 2009). The tax value, land rent and livestock rent of all the farms in the commune of Mývatn in the years 1686, 1696, 1712 and 1847 can be found in Appendix 9.

5.1 Tax value

The highest valuation in the area in 1686 is reported for the farm Reykjalíð, later Church property, at 80 hundreds. For the years 1696 and 1712 the highest valuation was 40 hundreds (Hofstaðir) and for 1847 it was 30 hundreds (Skutustaðir) (see Appendix 9). The frequency of different tax value ranges in Mývatn in the four land registers considered can be seen in Figure 47. The figure shows in general higher tax values in the year 1686 compared to 1696, 1712 and 1847. This is because the 1686 land register was constructed on the principle that the tax value is linked to the land rent in the proportion 20:1. In contrast, the 1696 land register gives the value of the properties according to "custom and usage"; reverting to older tax values which reflected market values (Lárusson, 1967). Figure 47 also illustrates a decline in the most frequent tax value in the area from12 hundreds in the years 1696 and 1712 to 10 hundreds in 1847. Although there is also an increase in the frequency of farms taxed at 20 hundreds.

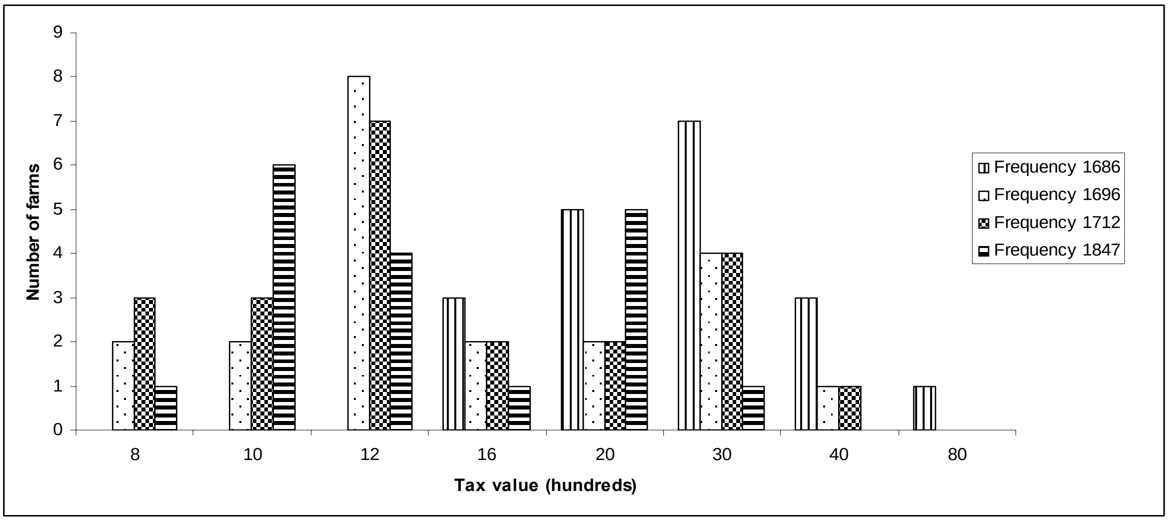

Figure 47- Frequency of different taxation values in Mývatn in the land registers of 1686, 1696, 1712 and 1847.

Figure 48 shows the tax value of the study farms in the four land registers considered. In 1686 the highest tax value reported amongst the study farms was 23.67 hundreds for Baldursheimur, Gautlönd and Grimstaðir. It is not known why the farm Grænavatn does not appear in the 1686 land register, however it is recorded with a tax value of 30 hundreds in the year 1562 (Hreiðarsdóttir *et al.*, 1998). In the land registers of 1696 and 1712, Grænavatn is recorded with the same tax value which is the highest amongst the study farms for these years. In 1847, the highest valuation among the study farms was 20 hundreds, assigned to Grænavatn and Grimstaðir. The lowest tax value registered in 1686 for Mývatn was 13.67 hundreds for Geirastaðir. In the later land registers, the lowest valuation was 8 hundreds, recorded for Garður and Fagranes in 1696 and 1712, and only for Garður in 1847 (Fagranes had been abandoned by then). The tax value of the failed farms, Fagranes and Brjánsnes, is below the regional mean in all the land registers. This suggests that both farms were always below the average productivity of the Mývatn area. The reason for the low productivity could have been due either to lower land quality or the size of the farm. Low tax value and land rent have been associated with small farms in other Nordic countries in the late middle ages (Österberg, 1981). However, this cannot be taken as the sole reason for abandonment as Garður, the only other farm in the area with the same valuation in 1696 and 1712, survived to the present.

In both successful and failed study farms, with the exception of Grænavatn, the tax value remains constant after 1696. This stability is consistent with Lárusson's (1967) analysis of tax value records of privately owned farms in 1446 and 1695 taken from the Diplomatarium Islandicum[6]. He reports a combined tax value from 123 privately owned farms of 2085 hundreds in 1446 and 2077 hundreds in 1695. Although the general tendency in the study farms is of stability through time, the only decline is on the highest valuation, which coincides with the tendency described above for the whole area. Lárusson (1961) claims that a reduction of taxes was permitted only exceptionally and usually in connection with the deterioration of the home-field. He cites an example found in Jarðabók where a farm (Fagribær) in Þingeyjarsýsla had it tax value reduced from 30 to 20 hundreds. The reason for the reduction is reported as the destruction of part of the home-field and meadows due to a landslide. The land rent of that farm had also been reduced to amount to 5% of the tax value. However, Lárusson concludes from his analysis that it was more common to reduce only the land rent when land deterioration occurred. The reason for this might have been the direct connection

[6] The first voulume of the Diplomatarium was published in 1857. The editors collected archives an edited them to provide a collection made up of 15 volumes. The first volume was edited by Jón Sigurðsson.

between the tax value and the tithe (i.e. the tithe was calculated as 1% of the property value in every property valued at 5 hundreds or more) and the difficulties involved in reducing it. According to a decree of the National Assembly in 1671, a reduction of the tithe could only be made after a valuation had been carried out by the district judge and 12 men from the jurisdictional district appointed by him. Moreover, the maintenance of the tithe value was in the interest of the commune, since ¼ of it was used to support the poor. At the end of the 15th century, the existence of the communes was threatened in some districts because many farms were taken over by the Church and so they no longer paid the tithe. When the tithe plus the land rent became too burdensome for the farmer to pay, the tithe was given priority (and indirectly the tax value), resulting in a reduction of the land rent (Lárusson, 1961). Bad harvests and famine are reported to have caused a depreciation of the land rent, but in such cases it was again increased after a few years. It seems, therefore, that reductions in the tax value generally occurred when the land productivity was affected permanently or for a long term, whereas the land rent fluctuated more often in response to difficult times. It has been claimed, from research in other Nordic countries, that land rents reflected both production and market conditions, although it is difficult to assert which was the dominant influence (Gissel *et al.*, 1981).

The tax value could also be reduced due to land division, often of inherited property, or increased by acquisition of new land. The expansion of a farm often involved the purchase of an abandoned farm. A resolution of the National Assembly in 1604 established the depreciation of deserted farms to one-third of their original value. When an abandoned farm became part of another farm, the new tax value became two-thirds of the total original value of both farms. An example is given from Jarðabók of the farm Steig and the abandoned farm Kallstaðir, both valued at 6 hundreds. When Kallstaðir was abandoned the taxation value was reduce to one-third and Steig's valued increased to 8 hundreds by assimilating Kallstaðir (Lárusson, 1961). Excluding the 1686 land register, because of the way in which the tax value was calculated, as explained above, Grænavatn is the only study farm showing a change in tax value through time. This change is a reduction of the tax value in 1847 compared to the previous land registers. The Jarðabók (Magnússon *et al.*, 1913) describes the deterioration of the winter grazing area of Grænavatn by sand-blowing and of the home-field by landslides into Grænavatn lake. Other signs of deterioration mentioned in Jarðabók are descriptions of the lake getting shallower due to the sand-blowing, the decline in trout catching and the reduction of the forest. However, it was stated that the forest was still extensive enough for charcoal making. These factors could have led to the later devaluation of the land.

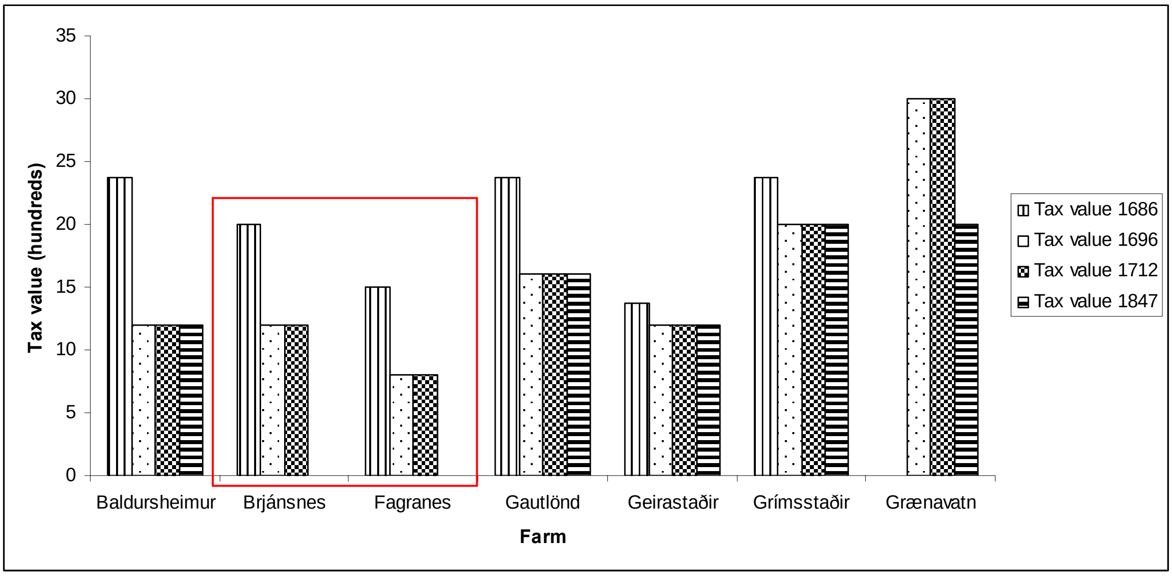

Figure 48- Tax value in the study farms according to the 1686, 1696, 1712 and 1847 land registers. Failed farms framed in red.

5.2 Land rent

The first reference with respect to the calculation of the land rent appears in Grágás, where is it established that it should not exceed 10% of the capital. Later, the *Jónsbók* stated that the land rent should be determined by free negotiation between the parties (Lárusson, 1967). The land rent unlike the tax value fluctuated in response to difficult times, such as low market prices and disease, the latter probably as a consequence of a reduction in the demand for land (Eggertsson, 1998).

In Mývatn, the highest land rent in 1686 was 480 ells registered for the farm Reykjalíð, which had also the highest tax. In 1696 the highest land rent was 580 ells, paid for Skutustaðir. In 1712 it was 300 ells, paid by both Reykjalíð and Skutustaðir. In 1847 Skutustaðir still had the highest land rent in the area, which had increased to 330 ells (Appendix 9). Figure 49 shows the frequency of land rent values in Mývatn in the land registers of the years 1686, 1696, 1712 and 1847. The most frequent land rent values in the area were 120 and 140 ells in 1686 and 120 ells in 1712 and 1847. In 1696 there was a more even distribution of different land rent values. Among the study farms the highest land rent in 1686 was 140 ells paid by Baldursheimur, Gautlönd and Grimstaðir. In 1696 Grænavatn had the highest land rent of the study farms at 240 ells. In 1712 it was 150 ells in Gautlönd and in 1847 170 ells in Grimstaðir. The lowest land rent in Mývatn in 1686 was 80 ells paid for the farms Helluvað and Geirastaðir. In 1696 it was 60 ells for Helluvað, Ytri Neslönd and Syðry Neslönd. The latter two farms came from a division of the farm Neslönd which had previously a land rent of 140 ells. In 1712 the lowest land rent was 50 ells for the cottage Littlaströnd and in 1847 40 ells for the same cottage. The lowest land rent among the study farms in 1686 was 80 ells, registered for Geirastaðir. In 1696 the lowest land rent of the study farms was 62 ells paid for the later abandoned farm Brjánsnes. In 1712 the two failed farms, Brjánsnes and Fagranes, had the lowest land rent of the study farms, which was 60 ells. The land rent of both failed farms, was well below the regional mean in all the years. This, in agreement with the tax value, seems to indicate that these farms were of below average productivity.

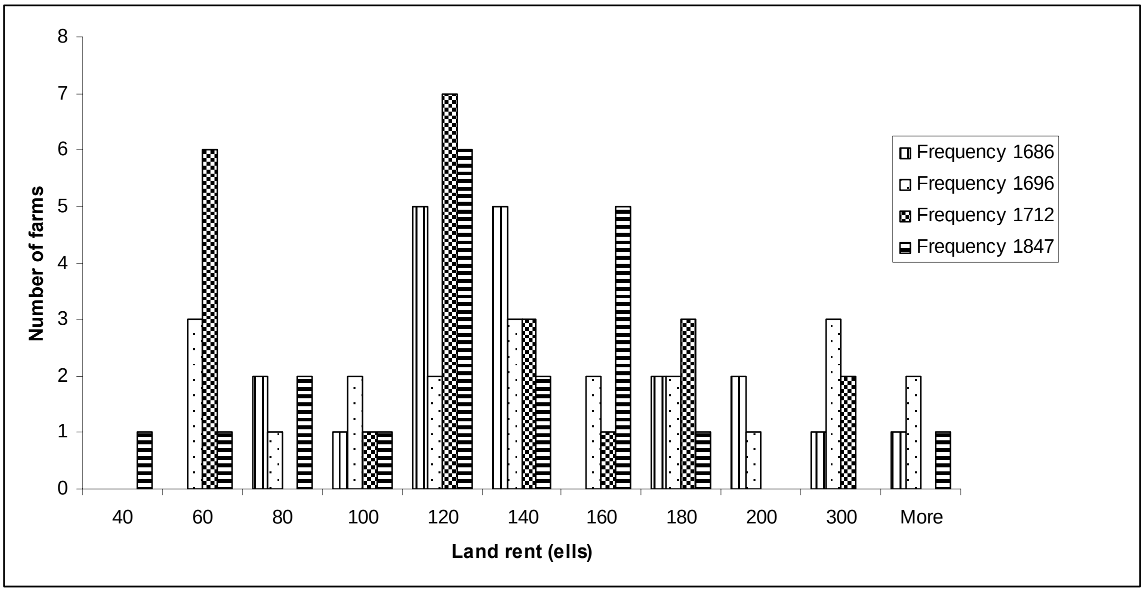

Figure 49- Frequency of different land rent values in Mývatn in the land registers of 1686, 1696, 1712 and 1847.

Figure 50 shows the land rent fluctuations through time for the successful and failed study farms. In both successful and failed farms there is a decline in the land rent from 1696 to 1712; this decline being more marked for the successful farms. This decline has been explained by the smallpox epidemic which occurred during the course of the 1712 land register compilation (Lárusson, 1967). Lárusson, analysing the farms from the Hólar diocese, reported a continuous decline in the land rent and cattle hire from 1446/7 to 1710/13 in farms owned by the Crown and from 1388 to 1710 of Church property. He explains this continued decline by the low prices of mutton and beef during the Danish trade monopoly and the big decline from 1696 to 1712 in particular as a result of the smallpox epidemic. However, in the study farms, all of which are private property, the continued decline is only evident for the failed farms.

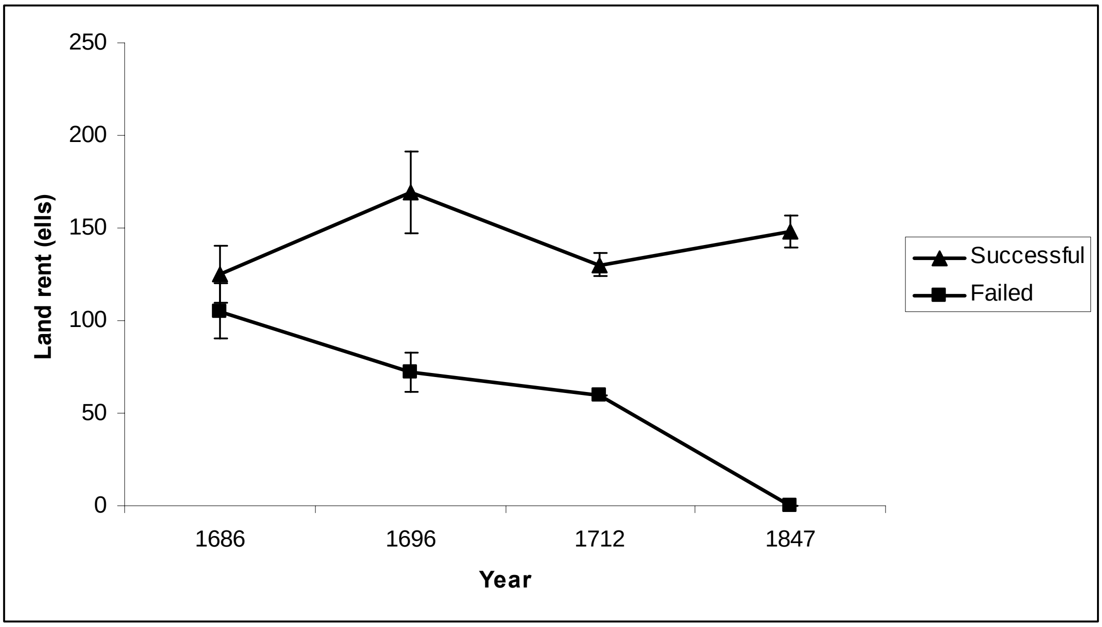

Figure 50- Land rent in successful and failed study farms in the land registers of the years 1686, 1696, 1712 and 1847. The land rent of the failed farms in 1847 has been assigned a value of zero, since having been abandoned by then did not pay land rent. The error bars are based on the standard error.

Looking at the land rent fluctuations in each of the study farms, the pattern is more variable (Figure 51). Nevertheless, the failed farms are the only ones showing a consistent decline in the land rent in all the land registers. Land rent reductions have been previously regarded as either a precursory or a parallel phenomenon to farm desertion in Scandinavian countries. Explanations for this connection have bee the source of debate and have included: the lack of manpower connected to population decline, decline in productivity, variable political trends and changes in cultivation practices (Gissel *et al.,* 1981).

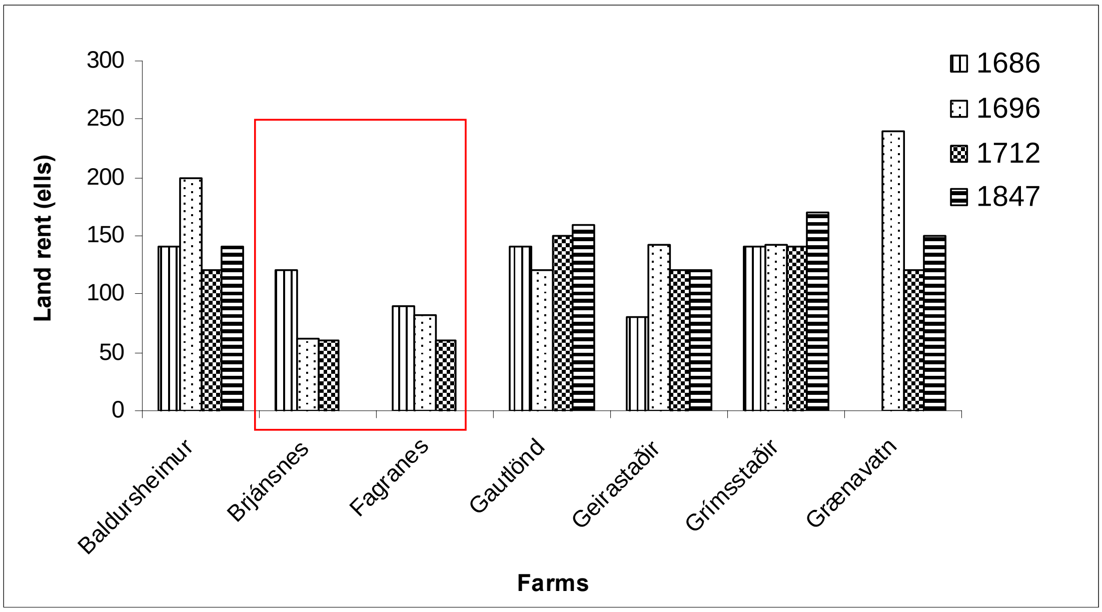

Figure 51- Land rent in the study farms in the land registers of the years 1686, 1696, 1712 and 1847. Failed farms framed in red.

5.3 Livestock rent

Another burden for the tenants was the lease of animals, which the majority was required to rent with the farm at an annual interest of 12-20 per cent (Jónsson, 1993). The tenant had the responsibility of renewing the leased livestock and in some cases he was forced to pay rent irrespective of whether the animals were alive or not (Lárusson, 1961). In Mývatn the highest rent paid for livestock in 1686 was 280 ells in Reykjalíð. This farm continued having the greatest livestock hire in the area in 1696 and 1712, being equivalent to 260 and 160 ells respectively. In 1847 the highest livestock rent was 140 ells in Skutustaðir. The lowest rent paid for livestock in the area was 60 ells in 1686. In the subsequent land registers the lower livestock rent was 20 ells, or 1 cow equivalent, paid in Vindbelgur in 1696, Gautlönd and Vindbelgur in 1712 and Syðri Neslönd in 1847. Figure 52 shows the frequency of livestock rent values, expressed in ells, in Mývatn in 1686, 1696, 1712 and 1847. The most common livestock rent paid in 1686 ranged between 101 and 120 ells. In 1696 the most common livestock rent paid ranged between 61-80 and 101-120 ells. In 1712 and 1847 the most common livestock rent amounts paid in the area were in the range of 21-40 and 61-80 ells.

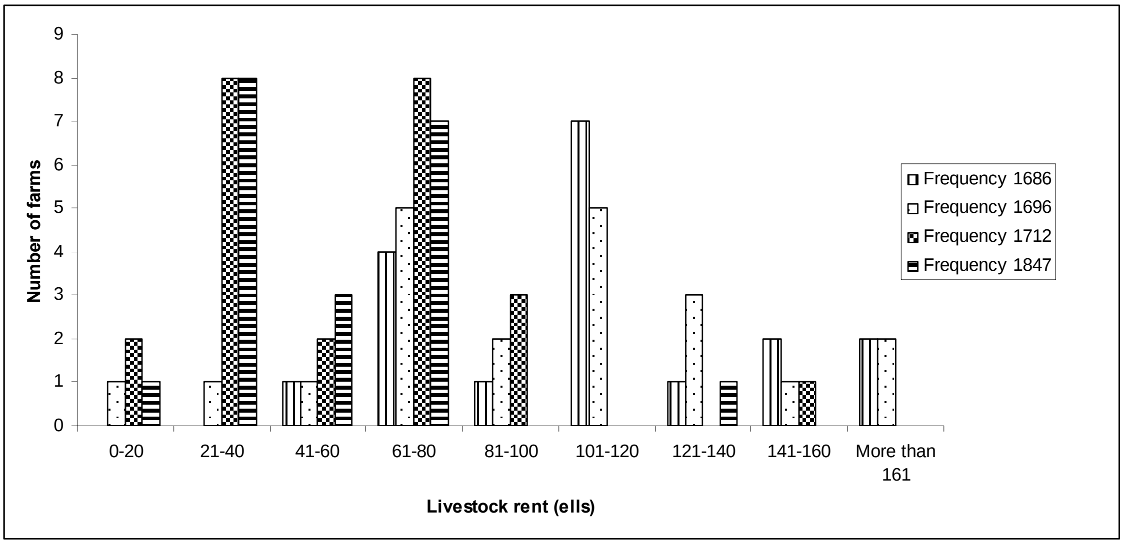

Figure 52- Frequency of livestock rent values (ells) in the Mývatn area in the years 1686, 1696, 1712 and 1847.

Figure 53 shows the livestock rent in ells in the study farms in the years 1686, 1696, 1712 and 1847. In 1686 the livestock rent in all the study farms was either 80 or 110 ells, equivalent to 4 and 5.5 cow values, respectively. In 1696 there was more variability, with the highest value paid for livestock being 140 ells in Grænavatn and Baldursheimur. In 1712 it was 120 ells in Grímsstaðir and in 1847 80 ells in Baldursheimur, Grímsstaðir and Grænavatn. The lowest figure paid for livestock in 1696 and 1712 in the study farms was 40 ells in Geirastaðir. In 1847 it was 30 ells in Gautlönd. These figures show a decline in both the highest and lowest livestock rent values in the study farms from 1696 to 1847. The overall pattern in the region is a decline of more than 50% in the livestock rents from 1696 to 1712. However, the study farms do not follow a clear trend. Árni Magnússon stated in the Jarðabók that both the livestock rents and the land rents were in general reduced due to the epidemic and that it would take 8 to 10 years for things to improve (Lárusson, 1967). However, by 1847 the livestock rents in the region not only did not increase but showed a further decline.

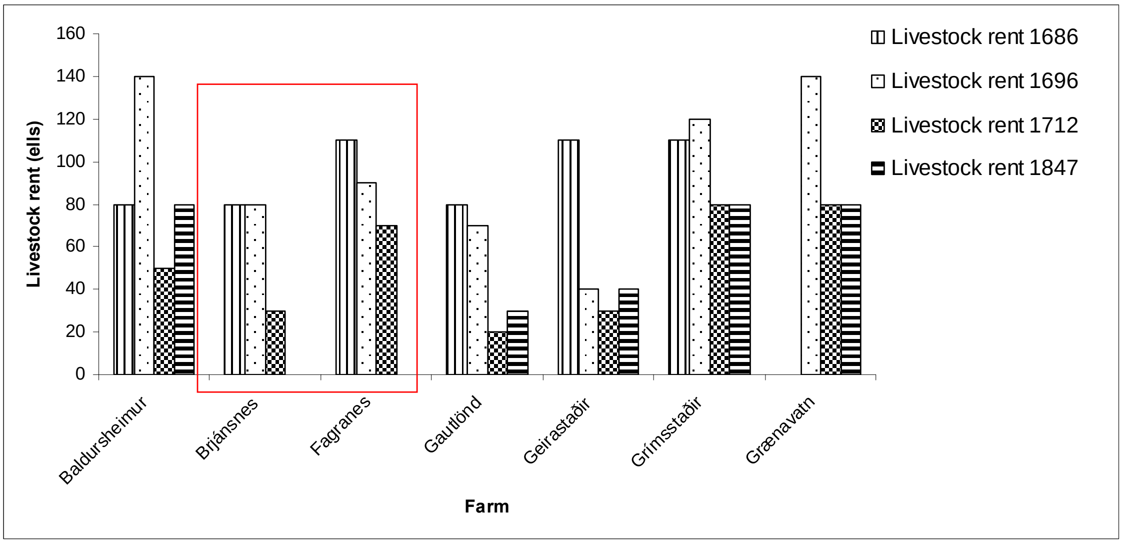

Figure 53- Livestock rent expressed in ells in the study farms in the years 1686, 1696, 1712 and 1847. Failed farms framed in red.

Figure 54 shows the land and livestock rent of successful and failed study farms in the yeas 1686, 1696, 1712 and 1847. Three interesting points can be discerned in the figure: i) the land rent is lower in failed farms than in successful farms in all the years considered, ii) the land rent of successful farms is greater than their livestock rent in all the years considered and iii) the livestock rent in the failed farms is greater than their land rent in 1696. The fact that the livestock rent was greater than the land rent in the failed farms in 1696 was due, in Brjánsnes case, to a decrease in the land rent with no change in the livestock rent. In Fagranes, the livestock rent was higher than the land rent also in 1686. In 1696 both the land and the livestock rents of Fagranes were reduced, and although the land rent was reduced in a higher proportion than the livestock rent, this remained higher. Livestock rent consisted in most cases of cattle, which was very expensive to maintain. If the reduction in the tax value and land rent recorded in the failed farms reflects a deterioration of the land, the unchanged livestock rent in Brjánsnes would mean that the farmer would have had to reduce his own livestock in order to keep the hired one. In Fagranes, the permanently higher livestock rent would mean this farm had either less livestock of its own compared to successful farms or less productive land per unit of livestock. Unfortunately, these assumptions cannot be tested as livestock numbers were only reported in the 1712 register. However, a comparison of livestock numbers in successful and failed farms in 1712 can shed light on the relative wealth of these farms as well as their productivity. Further indication of the relative productivity of the farms can be obtained from a demographic analysis of the AD 1703 census data.

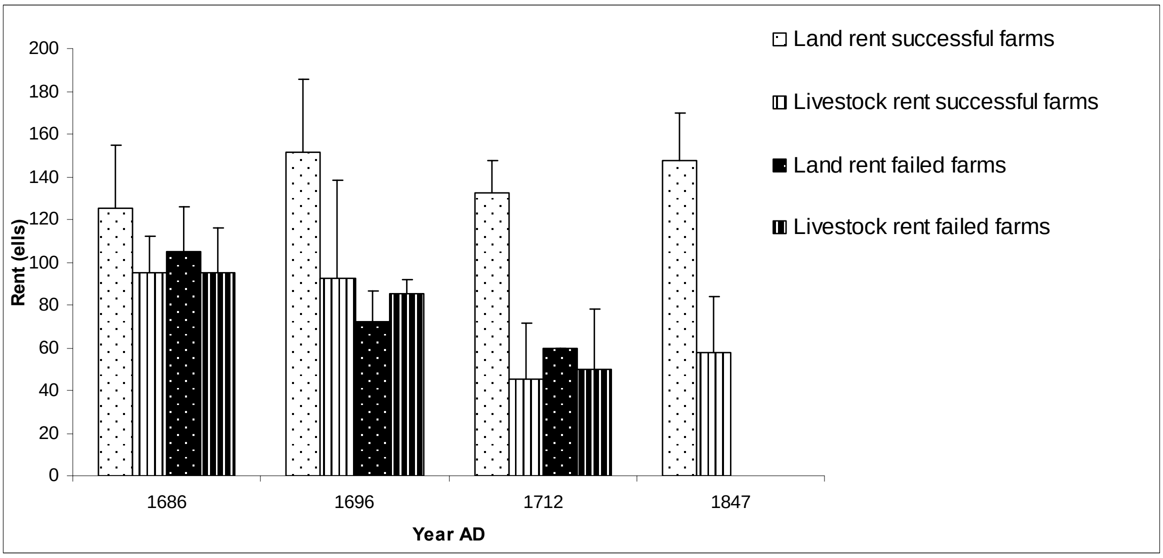

Figure 54- Land and livestock rent in successful and failed farms in Mývatn in the years 1686, 1696, 1712 and 1847.

5.4 Livestock numbers and natural resources

Figure 55 shows the mean number of livestock in livestock units (LU), and the mean LU: livestock rent ratio in successful and failed study farms in 1712. The successful farms have in average more LU than failed farms (14.7 compared to 5.6, respectively). Furthermore, the LU: livestock rent ratio shows that in 1712 for each LU of hire livestock the successful farms had in average 7.9 LU of their own, while failed farms had in average 2.4 LU of their own.

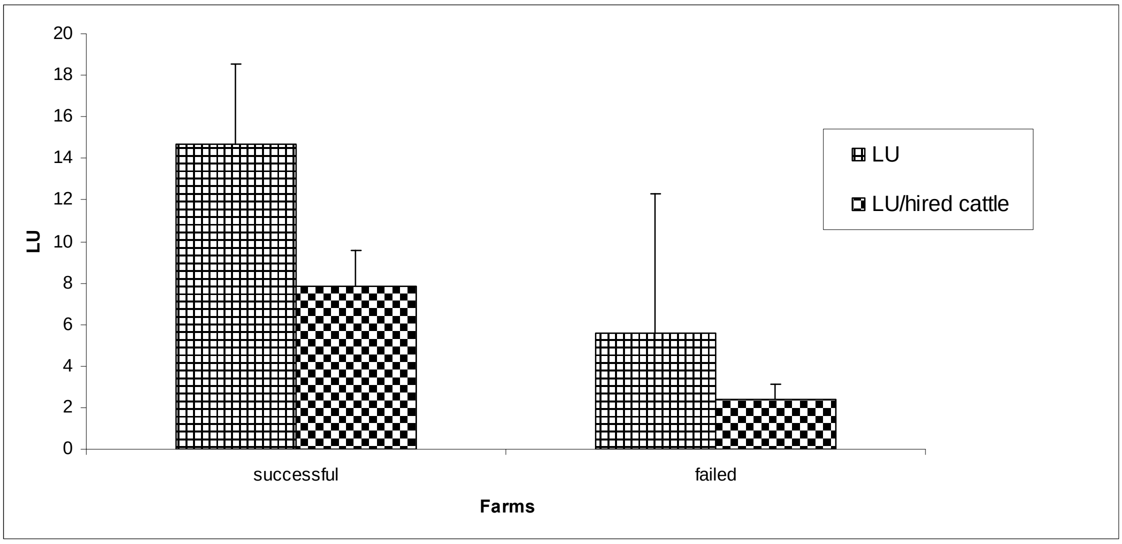

Figure 55- Mean livestock units in successful and failed study farms in 1712.

In addition to the taxes, rents and livestock information, the 1712 land register describes the availability of natural resources and the main constraints in each of the farms. Table 29 summarizes the study farms' natural resources and constraints registered in the *Jarðabók,* the farms Garður and Skutustaðir are also included for later comparisons with interview data. All the farms surrounding Lake Mývatn are reported to have good fishing. From the farms with no access to Mývatn, towards the south of the lake, the *Jarðabók* reports no fishing for Baldursheimur, little fishing in Grænavatn and good fishing in Gautlönd. With respect to egg collecting, it is interesting that the *Jarðabók* reports no eggs for the failed farms Brjánsnes and Fagranes. Both farms are on the shores of Lake Mývatn, furthermore Brjánsnes was next to Garður which reports egg collecting. This points out to regulation on egg collecting rather than an absence of this resource in these farms, although it is not clear how egg-collecting rights were attributed. The *Jarðabók* reports egg-collecting on eleven farms in Mývatn, the largest egg harvest reported for Grimstaðir (900 eggs) and the lowest for Garður and Skutustaðir (120 eggs each). Gudmundsson (1979), compares this figures with records from 1941 which register 11,091 eggs for Grimstaðir, 900 eggs for Garður and 1700 eggs for Skutustaðir. He explains the discrepancy with the *Jarðabók* values as understates from the farmers to evade taxes and overexploitation due to famine in preceding years. However, even the lower numbers reported would have meant an important contribution to farmers sustenance in difficult times. Gudmundsson (1979) also cites descriptions from visitors to Mývatn in the years 1747 and 1786, who refer to egg harvesting as a “contributory source of livelihood” for the farmers of the area.

The constraints more often mentioned in the *Jarðabók* are landslides and flooding of the home-fields or meadows, dangerous outfields (winter grazing areas) due to lava rock, and damage to the home-field and outfields due to sand deposition.

Table 29- Farm natural resources and constraints by farm according to Jarðabók (Magnússon and Vídalíns, 1913).

Farm	Fishing	Egg collecting	Turf	Other fuel resources	Other resources	Constraints
Baldursheimur	No	No	Sandy	Little firewood	Large outfields	Damage to the home-field by sand deposition, flooding of meadows, snow in the outfield.
Brjánsnes	Good	No	Stony and sandy	firewood, peat	Enough outfields	Damage to the home-field by landslides and sand deposition, no meadows, dry and sandy soils in outfields, dangerous lava fields.
Garður	Good	Good	Stony	No	Not mentioned	Damage to the home-field by sand deposition, flooding of meadows, small outfields.
Fagranes	Good	No	No good	firewood, peat	Not mentioned	Damage to the home-field by landslides, bog in the outfields dangerous. Has to pay 3 days of meadow cutting.
Gautlönd	Good	No	Stony	firewood	Good outfields	Irregular and scattered meadows.
Geirastaðir	Good	Good	Good	little firewood + dung	Good outfield for sheep	Lava fields in the outfield dangerous for cows and horses, small meadows.
Grímsstaðir	Good	Good	Stony	Firewood, peat	Angelica	Damage to the home-field by landslides, dangerous lava fields in the outfield
Grænavatn	Little	Little	Not mentioned	Firewood good but decreasing	Little Angelica	Damage to the outfield by sand deposition, landslides in the home-field, flooding in the meadows.
Skutustaðir	Good	Good but decreasing	Good	Firewood	Not mentioned	Snow in the outfield, outfield small and stony, dangerous lava fields, difficult collection of grass in wet meadows.

5.5 Census data

Figure 56 shows the mean number of people (total), mean number of servants and mean number of children (under 16) per farm in successful and failed study farms in 1703. As discussed previously, the ability to make enough hay during the summer was dependent not only on the size and quality of the home-field and meadows but also on the availability of labour during these months (Magnússon, 1985). Thus the number of people, and in particular servants, can be considered an indirect indicator of the productivity of the farms. This is confirmed by a correlation analysis of the census data of 1703 and the land tax and rent data from 1712. The Pearson's correlation analysis reveals a positive correlation between the number of servants per farm and the tax value (df=7; r = 0.811; P = 0.008) and between the number of servants per farm and the land rent (df= 7; r = 0.702; P = 0.035). The size of the farm household in Iceland in 1703 had a median of five people (Pinson, 1992). The study farms exhibit a greater median than the national values with a median of 12 and a mean of 10.83 in successful farms, and a median and mean of 7 in failed farms. The results demonstrate that the successful farms had a greater number of people per farm on average, and in particular of servants, than the failed farms in 1703. More than 50% of the people in successful farms were servants, whereas in the failed farms servants accounted for less than 40%. The number of children per farm was similar in successful and failed farms with a mean of 2.5 and 2.3, respectively.

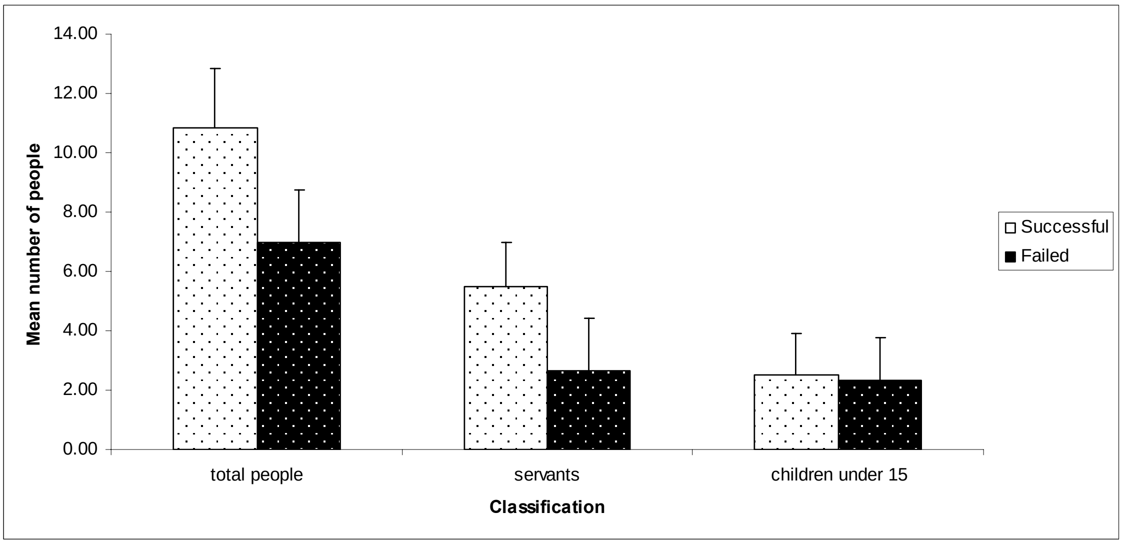

Figure 56- Number of people in successful and failed study farms in Mývatn (total, servants and children under 15), according to data from the 1703 census (Þjóðskjalasafn Íslands (National Archives of Iceland), 2009).

To summarize, both the low tax value and land rent of failed farms with respect to the regional mean in the four land registers considered, suggests that these farms were historically smaller and less productive than average. Furthermore, the sustained decline in the land rents through time suggests a continued decline in productivity. This productivity decline could have been the result of the progressive deterioration of the land, or possibly the effects of difficult times (e.g. epidemics, market prices) having a greater impact in these more vulnerable farms. Despite being less productive, failed farms do not generally show smaller livestock rents than successful farms. This disparity in the proportions of livestock rent/land rent between successful and failed farms would have led the latter to have proportionally less livestock of their own. This is reflected in the lower LU reported in failed farms in 1712. Finally, a smaller, less productive farm would have also required fewer servants, who were essentially employed to work in the production of hay.

Chapter 6 -Results and discussions: Ethnography

The interviews with the farmers of Mývatnssveit were analysed following the methods described in Gibbs (2007). The transcriptions from the interviews after thematic coding are presented in Appendix 10. Related codes were gathered into hierarchies and a summary of the respondents' answers linked to the codes of each hierarchy are summarized in the following sections in comparative qualitative tables.

6.1 Farm characteristics and farmers' perceptions

Figure 57 shows a hierarchy developed with "Farm characteristics" as parent and "Natural resources" and "Perceptions" as siblings. The code "Natural resources" refers to the natural resources the farmers had access to before the 1950's. The code "Perceptions" was divided into farmers' perceptions of their own farm (in terms of advantages and constraints) and in their perceptions of farms in the Mývatn district in general (what factors they think have influenced farm success and failure).

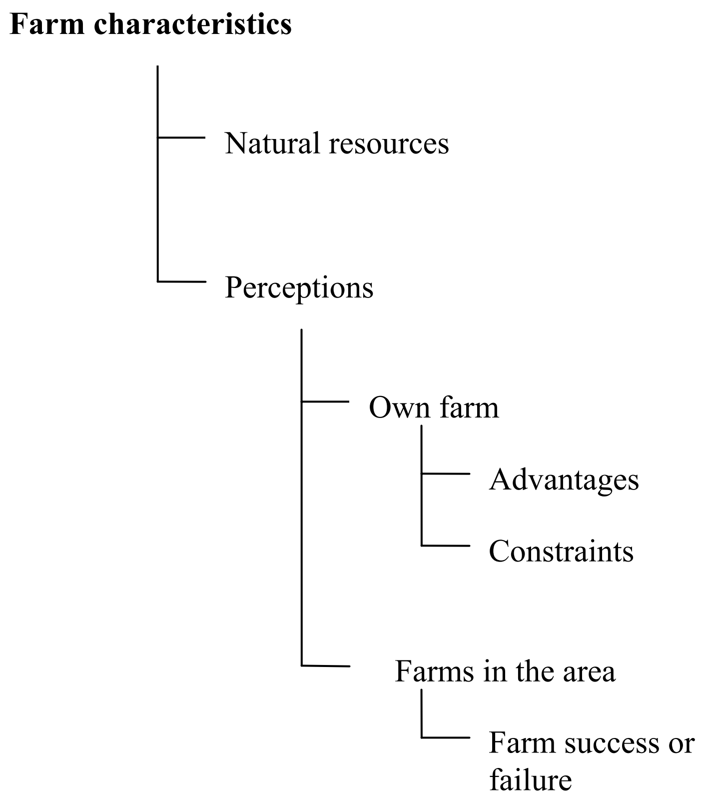

Figure 57- Hierarchy of farm characteristics and farmers' perceptions.

Table 30 presents a summary of respondents' answers on farm characteristics and farmers' perceptions. The first column in table 1 lists general characteristics of the farms in terms of their general size and accessibility to Lake Mývatn. This is not based on questions presented to the farmers but rather on observations made by the researcher that are considered to be relevant to the analysis of the topics discussed in this section. Looking at the columns "General characteristics" and "Natural resources" in Table 30, it can be seen that when the farmers were asked about what natural resources they had available in their farms, those with no access to Lake Mývatn (from Gautlönd, Grænavatn and Baldursheimur) listed some resources using most of the times the words "little" or "not many". From these three farms only one of the respondents emphasized a natural resource. This was the farmer from Gautlönd, who emphasized that most of their land is vegetated and could be used. He later mentions the vegetated area again when asked about the advantages of the farm. It is interesting that in Grænavatn, Iceland moss was mentioned among the natural resources. Iceland moss (*Cetaria islandica*), *Fjallagrös* in Icelandic, is considered by some people as a "famine food", however it is still commonly eaten boiled in milk. The three farms that have access to Mývatn (Geirastaðir, Garður and Skutustaðir), emphasised fishing as their main natural resource. Of these, only Skutustaðir specified Trout. Egg collecting was mentioned in Geirastaðir and Garður, although the latter one does not collect any more. The farmer at Garður associates the decrease in eggs with the diatomite factory established in Mývatn in the late sixties and dismantled in the seventies. Ptarmigan is only mentioned as a resource in Geirastaðir.

Although the farmers' perception on the advantages of their farms was not addressed in all the cases, of the three farms where it was, two listed the vegetation as an advantage. However, in one of them (Gautlönd) emphasis was given on the extent of land covered by vegetation, whereas in the other one the emphasis was on the quality of the vegetation and its availability all year round (Geirastaðir). Fishing was mentioned in the two farms with access to Mývatn (Geirastaðir and Garður). Additionally, one of these three farms listed having hard working people in the farm as an advantage. The second column of the perceptions group refers to what factors in their own farm were considered as constraints on farming. This topic was addressed in five farms, which listed as constraints: the weather (three farms: Gautlönd, Grænavatn and Geirastaðir), having a small home-field (three farms: Grænavatn, Baldursheimur and Skutustaðir), blowing sand (two farms: Grænavatn and Baldursheimur) and transportation (Geirastaðir).

In their perceptions of factors influencing farm success and failure in the area, five of six farmers considered “people” to be an important factor. For three of them, “people” was seen as a positive factor. Two different positive qualities of people were mentioned: willingness to work or being hard-working (Gautlönd, Grænavatn and Geirastaðir) and “cleverness” (Grænavatn and Geirastaðir). The farmer at Geirastaðir highlighted how important it was to make the most of the resources they had. The farmers at Garður and Skutustaðir however, considered the amount of people in a farm to be a negative factor, causing the division of farms and increased pressure on the land, making it difficult for the farms to sustain the amount of people in them. The vegetation was mentioned directly in three farms (hay in two of them) and the weather in two. However, these two factors are linked, as specified by the respondent in Baldursheimur “weather, affecting the possibilities of winter grazing and making hay”. Even if the factors “weather” and “vegetation” are grouped together, the social factor still gets mentioned more as influencing farm success and failure than the weather. In addition to the aspects listed above, Gautlönd also cited the size of the farm, the amount of livestock and access to technology.

Table 30- Interviews' results on farm characteristics and farmers perceptions.

Farms	General characteristics	Natural resources	Perceptions		
			Advantages	Constraints	Success and failure
Gautlönd	Big farm, no access to Mývatn	Vegetation, "all of our land has vegetation so there are not big areas that can't be use". Little trout, not many birds or eggs.	Size, "...we could lease to others", vegetated area.	Bad winters (frost and snow).	Size of farm, vegetation, amount of livestock, people: "willingness to work", access to technology.
Grænavatn	Big farm, No access to Mývatn	Iceland moss, little trout, little egg collecting.	Not addressed	Small home-field, weather (making it difficult to make hay), blowing sand.	People: "having hard-working and clever people"; amount of hay.
Baldursheimur	Big farm, no access to Mývatn	Not much fishing, a little egg collecting.	Not addressed	Blowing sand, erosion, small home-field	"Weather affecting the possibilities of winter grazing and making hay".
Geirastaðir	Small farm, on Mývatn shores	Good fishing (even in winter), ptarmigan, a lot of eggs "there are two islands in Sandvatn and every year we maybe took 1500 eggs. In each nest they would be 20-30 eggs".	Vegetation available all year round, quality of vegetation "close by the lakes the grazing is very good because the midges make the soil more fertile", good fishing "lakes near never frozen".	Transportation, weather.	Weather, People: use of available resources "a big factor is how clever you are as a farmer to use what you have and make the most of good weather when you have it".
Garður	On Mývatn shores	Good fishing, egg collecting "but nowadays we can't because of the factory that destroyed the lake, killed all the flies and all of the nutrition's that the lake provided the area with".	Good fishing, hard-working people in the farm.	Not addressed	Division of the farms, amount of people on the same farm.
Skutustaðir	Near Mývatn with fishing rights.	Trout "it had a lot of impact in many people…for many people it was more important than farming."	Not addressed	Small home-field.	Amount of people on the farm "some farms had about 25 people in each house so maybe the farms couldn't sustain them".

The importance of wild food resources becomes apparent in the responses' summary in Table 30. This is especially true for the farms with access to Lake Mývatn that had access to good fishing and egg collecting. Mývatn is fed with groundwater, rich in phosphate and silica, which makes the lake more productive than other smaller lakes in the area (McGovern *et al*., 2007). The importance of wild food sources in Iceland in the past has been generally underestimated (e.g. Friðriksson, 1972; Tomasson, 1977). Vasey (1996) argues that wild food resources must have played an important role after the Laki eruption, given that vegetation and fisheries recovered more quickly than livestock and based on the relative loss of animals compare to humans (two to three times more). Vasey considers that taking into account that nine ewes were needed to support a person; the livestock left in 1785 would have supported fewer than 19,000 people when in fact the population was 39,251. The most important wild food source was fish, thus farms with access to good fishing grounds were best able to withstand agricultural failures (Vasey, 1991). In a zoo-archaeological study of five farms in the Mývatn area by McGovern *et al*. (2006), fish and bird bones were found to make a substantial proportion of the total bone collection of each site. Bird's bones were dominated by ptarmigan even though the middens were rich in waterfowl egg shells. Fish bones were predominantly of freshwater fish although cured marine fish and even seal and cetacean bones were found. The study concluded that waterfowl egg harvesting has been controlled for more than a thousand years to guarantee the sustainability of this natural resource in the area.

Similarities and differences between the natural resources reported in the 1712 land register (Section 5.1.1.4) and the interviewees' responses can be found. The *Jarðabók* accounts on fish availability correspond almost exactly to the farmers responses, with all the farms with access to Mývatn reporting good fishing. An exception to this is Gautlönd which is reported to have good fishing in the *Jarðabók* but little fishing according to the interview. The accounts on eggs' availability also correspond to the information gather from the interviews. However, it is interesting that the *Jarðabók* reports no eggs for the failed farms Brjánsnes and Fagranes. Both farms are on the shores of Lake Mývatn, furthermore Brjánsnes was next to Garður which reports egg collecting. This points out to regulation on egg collecting rather than an absence of this resource in these farms. However, it is not clear how egg-collecting rights were attributed. The *Jarðabók* reports egg-collecting on eleven farms in Mývatn; the largest egg harvest is reported for Grimstaðir (900 eggs) and the lowest for Garður and Skutustaðir (120 eggs each). Gudmundsson (1979), compares this figures with records from 1941 which register 11,091 eggs for Grimstaðir, 900 eggs for Garður and 1700 eggs for Skutustaðir. He explains the discrepancy with the *Jarðabók* values as understatements from the farmers to evade taxes and overexploitation due to famine in preceding years. However, even the lower numbers reported would have meant an important contribution to farmers sustenance in difficult times. Gudmundsson (1979) also cites descriptions from visitors to Mývatn in the years 1747 and 1786, who refer to egg harvesting as a "contributory source of livelihood" for the farmers of the area. The constraints more often mentioned in the *Jarðabók* are landslides and flooding to the home-fields or meadows, dangerous outfields (winter grazing areas) due to lava rock and damage to the home-field and outfields due to sand deposition. The damages due to sand deposition coincide with the responses from the farmers from Baldursheimur and Grænavatn. However, neither flooding nor dangerous outfields were mentioned in the interviews as constraints.

With respect to the factors contributing to farm failure in the past, it was seen that two farms considered excess of people in a farm and farm divisions as possible causes. In earlier time periods farms were rarely divided among children. Instead, the oldest son usually took the farmstead property while younger males received a portion of the moveable property, especially livestock. With this mechanism farmsteads of a set size and productive capacity consistently produced the same amount relative to their neighbours (Bolender, 2006).

6.2 Farm management

Figure 58 represents a hierarchy based on farm management. In this hierarchy, hay production, shielings and communal grazing areas are siblings. Hay production was subdivided in the codes Home-field and Meadows, reflecting the information gathered in the interviews. This division shows that hay was produced from the two areas but that they were managed very differently.

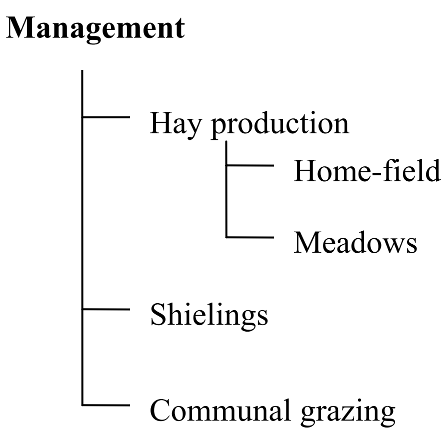

Figure 58-Hierarchy on farm management.

To compare the codes in this hierarchy two qualitative tables are presented. Table 31 presents a summary of the respondents’ answers on hay production in home-fields and in meadows. The Icelandic terms, *tún* for home-field and *engi* for meadow, are not translated in the respondents’ extractions presented on the table. Looking at the Home-fields column it is noticeable that in five of the six farms interviewed farmers said they had a very small home-field or no home-field at all. Three of them highlighted this as a constraint (see Table 30). One important aspect of home-field management is the manuring. Four of the six farms said they manured only with cow and horse manure. Three of the farms specified that they could not use sheep manure as fertilizer because it was used for fuel, one farm said it was used for smoking trout. The farmer at Geirastaðir said they did not need to save the sheep manure because they had a generator. However, he stressed that most of the farms in the area used sheep dung for fuel prior to the arrival of the electricity. In one of the farms (Baldursheimur), the respondent uses a narrative to emphasize the importance of hay making:

> “Having hay was very important, I remember on the day of my 12th birthday, the 12th of June of 1949, I was living in the east and there was no more hay. I went with my mother and we cut some little twigs to give to the livestock”.

Another issue stressed in Baldursheimur when discussing home-field management, was the efforts put into restoring the home-field when it was damaged by blowing sand (Table 33). From this section of the interviews it can be inferred that at least in five of the six farms most of they hay produced came from the meadows. This seems to have been common in Iceland, Vasey (1996) maintains that as late as 1880 a third or less of the hay crop came from home-fields. The meadows were located in naturally wet areas, or areas that were flooded. Two of the farmers (from Gautlönd and Baldursheimur) describe how they inundated the areas. In Gautlönd, many ditches and damns were built. The meadows were flooded from the 17th of June for a month. In Baldursheimur, on the other hand, the meadows were flooded for two or three months during the spring. The farmer from Gautlönd described an *engi* they used called Nautey (bull pasture) and how his grandfather (Jon Sigurdsson, born in 1828) managed it:

> "The reason why the meadows were good is because they were flooded, it used to be a swamp before and after flooding it a lot of sand came from the river and made the area better for the growing of grass. The area had natural fences, a ditch, a small mountain, the river and we only needed to put a small fence between the lake and the river, we kept bulls and sheep during the summer there. The area was divided into two, one area was used for grazing and the other one for making hay and the following year we would swap it to maintain the fertility. They had also 2 other *engi* for hay making. Almost all the areas that were wet were used for making hay".

The farmer also described how his grandfather constructed dams and channels by hand to bring water from a stream nearer to his land and home-field. The respondent from Skutustaðir however mentions the construction of ditches in the meadows with the purpose of drying the area. The role of water in hay production in Iceland is not clear; there are some indications of productivity of meadows related to flooding. For example, Lárusdóttir (2006) reports that "late in the nineteenth century, a hard-working farmer from Laxamýri in north-east Iceland, had an impressive irrigation system built, damming the river so its rich nutrients fertilized the meadow, increasing its productivity". High quality meadows in Mývatnssveit are associated with periodically flooded marshland, for example around Reykjalíð in the northeast corner of the lake and in a delta created by the Kraka river, called Framengjgar (McGovern *et al.,* 2007). On the other hand, others stress the lack of drainage systems in the past as one of the reasons for the low productivity of grass in the marshes (Vasey, 1996). This seemly disparity in opinions may reflect a management of alternating drainage-irrigation. Preusser (1976) believes that an alternate and seasonal cycle of drainage and irrigation gives the best results for the productivity of meadows. The inundation of the meadows during the spring, which is the greatest period of freeze-thaw, protects the vegetation and prevents the formation of thúfur. The drainage of water during the summer, on the other hand, increases the soil temperature accelerating the rate of growth of the vegetation. Differences in the responses related to the management of meadows can also be related to the type of meadow. There seems to be at least two types of wet meadows in Iceland according to their water content: *mýri* (pl. *myrar*) and *flói* (pl. *flóar*). In the *myrar* the soil is saturated with ground water whereas in the *flóar* the soil is over-saturated and the water reaches or surpasses the soil surface. The vegetation of the *myrar* is denser, more continuous and more species rich than in the *flóar* (Thoroddsen, 1912).

Table 31- Comparative table of hay production management in the study farms.

Farm	Hay production	
	Home-fields	Meadows
Gautlönd	Used manure in home-field.	Had 3 areas of wet meadows used for hay making. “Almost all the areas that were wet were used for making hay”. They flooded these areas on the 17^{th} of June and close the dam a month later. “It was my grandfather who built all the dams and a ditch hand made from the river…he made a lot of ditches from the small river to make the water come nearer into his land”.
Grænavatn	Very small home-field, used horse and cow manure “as the sheep manure was so valuable for fuel”.	Made hay from wet meadows.
Baldursheimur	Very small home-field, fertilized with cow and horse manure, sheep manure used for fuel. Management efforts to restore areas damaged by erosion (refer to Table 33). Importance, “Having hay was very important, I remember on the day of my 12^{th} birthday, the 12^{th} of June of 1949 I was living in the east and there was no more hay. I went with my mother and we cut some little twigs to give to the livestock”.	Most of the hay obtained from meadows. “It was quite wet in these areas so it was difficult to cut the hay, sometimes it was kept wet and brought back to be dried at the farm…we would flood the meadows and it was done for 2 or 3 months in the spring…Framengi was an important area where several farms owned meadows. Some farmers rented their part or section of their part and the hay was paid in trout”.
Geirastaðir	Small home-field, fertilized with manure “not many people would use dung to fertilize because they needed it for fuel but in our house we had a power station so we could use it”.	Many meadows “we had an *engi* in the island of Helgey…we never rented or bought (hay) from anyone else. They were two meadows near home so we never had to go too far away. There are so many small lakes around that a lot of rich grazes grow there”.
Garður	No home-field. “ sometimes we would put cow manure on the hills around the farm because we had no real *tún*, the sheep manure was dried and used for fire”	Made hay in many meadows, including meadows in Skutustaðir. “My grandfather owned Skutustaðir and many of the farms in Mývatnssveit used the *engi* around Skutustaðir because a lot of the home-fields could not hay because of lack of grass. They would maybe pay for it somehow, not with money”.
Skutustaðir	Very small home-field, did not fertilize much “we didn’t have many cows and most of the manure was used to smoke trout”.	Most hay came from meadows. “We would dig ditches to dry the area, which worked very well, now the ditches are filled in”.

Table 32 presents information on shielings and communal grazing areas. The Icelandic terms for these areas are *sel* for shielings and *affrett* for communal grazing areas. One of the farms (Gautlönd) speaks of having 4 shielings at one time, of which one was leased. This farm had mentioned in a previous question that the size of the farm was an advantage because it meant they could lease to others. The lease of shielings and pastures is also reported in *Jarðabók*. For example, Brjánsnes is reported to have rights to the meadows in Skutustaðir, although it is highlighted that it is very far and hard for the people to go there to collect the meadows. The price they paid for this right is not specified. The farm is also reported to rent a shieling from Grænavatn for 10 ells. Geirastaðir is reported to use it neighbours meadows to feed cows and horses, which could not be taken to the winter grazing areas, the price is not specified. An unexpected response from the shielings theme was that from the farmers from Baldursheimur who said they used the shieling all year round "to keep the sheep that were sold to England". This would have happened in the 1940's or 1950's when many farms in the area started to sell livestock to England, these sheep were one year old or older (see Table 34). It is likely that an increase in the meat demand, combined with a decrease in the demand for milk products, lead to the change in the traditional use of the shieling during the summer only. Another unusual response about the shielings was that from the farmer in Garður who claimed that their shieling was in the communal grazing area, by the small lake Syðra-Hólavatn. This is especially strange because shielings in communal grazing areas were forbidden by law. In the *Grágás* (Dennis *et al*., 2000) it is stated that "Men have no right to build shielings in communal pasture. The men who own communal pasture there have the right to break up any shieling. And the man who built a shieling or had it built is fined at the suit of all who own the communal pasture, with the fine payable to each of them". However, a section on the *Jarðabók* about Garður says: "The land for winter grazing is small and the owner takes the livestock to Hólavatnsheiði and keeps it at a place called Garðssel, and it was there where the men from either Skútustaða or Baldursheims estates took theirs, when there was one landowner for the three estates". The name Garðssel does not appear in the current map of the area but it is marked simply as "sel" (Landmælingar Íslands (National Land Survey of Iceland), 2004). It is possible then that if one landowner had many farms he controlled a communal grazing area too, allowing the building of a shieling. The respondent at Skutustaðir could not offer any information on shielings because they stopped being used before she and her husband were born. From all the interviews it seems that most of the shielings stopped being used at the beginning of the 1900's. With respect to the communal grazing areas, three of the five farms where this topic was discussed, mentioned serious soil erosion in the south *affrett*.

Table 32- Comparative table of shielings and communal grazing areas management in the study farm.

Farm	Shieling	Communal grazing
Gautlönd	4 shielings, 1 was leased (Sandarsel), 1 was sold in 1857 and converted into a farm (Stöng). "The *sel* was as big as the quality of the land around".	They used Sudurafett; "By law you needed to use the *affrett* to preserve the grazing around the farm" sheep were taken around the 10th of June and rounded up 13th-15th September "when the weather was good they were release in mid May". "About 15-20 years ago the *afrett* was reduced and fenced off…the area that was cut off was because of serious erosion due to overgrazing and climatic conditions".
Grænavatn	They had 1 shieling and 1 *kvíjar*.	They used the south communal. Livestock was taken there in spring and rounded up in early September.
Baldursheimur	1 (Hrutavidarsell), was used all year round "especially to keep the sheep that were sold to England. Someone was paid to stay there."	They used the south communal. "Stengjarett was abandoned because of sand erosion, the sand filled Strengjarett."
Geirastaðir	1 in Vagnbrekka.	They used the south communal at the beginning and changed to the east one in 1942-43 because of the sheep disease. Sheep were taken at the end of May-beginning of June and rounded up middle of September. "some farmers would gather the sheep, slaughtered what they needed and then put the sheep back in the *affrett*…sometimes they would put the livestock out in March and collect them before they had offspring, but we wouldn't do that (in his farm)".
Garður	The shieling was in the communal grazing (Holavatnsas) "Garður stopped using *kviar* and *sel* around 1800-1900".	They used the east communal. "Most people in the old days used the south affrettir. However, nowadays people mostly use the east communal because of erosion, overgrazing as well as the disease".
Skutustaðir	Unknown "my husband was born in 1912 and there was no *sel* here at that time".	Not addressed.

6.3 Climatic and environmental changes

Under this hierarchy are included the farmers' perceptions on historical changes in the weather, vegetation and erosion in Mývatnssveit (Figure 59).

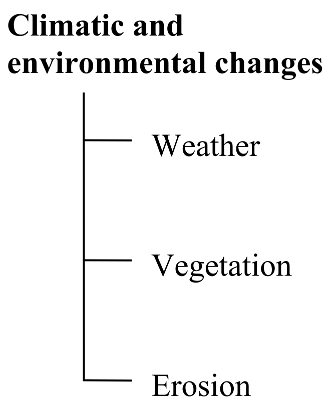

Figure 59- Hierarchy on climatic and environmental changes perceived by the farmers of the study farms.

Table 33 presents a summary of the climatic and environmental historical changes perceived by the respondents of the study farms in terms of weather, vegetation and erosion. In most of the farms the weather was considered to be more variable and unpredictable at present. In general the winters are perceived to be milder. Two respondents considered the vegetation to be better now than in the past. One of them associates the improvement of the vegetation with the closure of the diatomite factory, while the other one associates this improvement with a reduction in grazing pressures. The farmer at Gautlönd however, considers that the vegetation in general has decreased since the 1940's. Erosion was discussed in five of the farms, from which only one of the respondents (from Gautlönd) associated erosion with overgrazing, together with climatic conditions. The rest of the people interviewed only talked about the weather when discussing erosion, blowing sand being specified in three farms (Baldursheimur, Geirastaðir and Garður). Erosion control measures were mentioned in four of the farms (Gautlönd, Grænavatn, Baldursheimur and Garður). Two of them (Gautlönd and Garður), described the control measures applied by the government to control erosion. These consist of fencing off the most affected areas to avoid grazing and applying fertilizer and seeds. In this scheme the government provides seeds and fertilizer and the farmers the labour and manure. Other measures have been applied by the farms on their own initiative, for example in Grænavatn they deal with eroded areas by applying old hay and manure on them. A similar technique is described in Baldursheimur where damages in the home-field by blowing sand have successfully been repaired by cutting turf and placing it in the affected areas. An unsuccessful measure was also mentioned, the farmer at Garður has used nets in the past to contain sand movement but with no good results.

Table 33- Comparative table of perceived environmental and climatic changes by the farmers.

Farm	Weather	Vegetation	Erosion
Gautlönd	Improved "The last 20 years have been very warm and with more moisture in the air".	"Since the 1940's everything has been decreasing, trees and grass".	Erosion in the communal areas due to overgrazing and climatic conditions, control measures: "the government is seeding grass in the highlands to control the erosion".
Grænavatn	Very good, no great changes only minor variations.	"There were different kinds of willow (*gráviðri, gullviðri, fjalldrapi*), birch (*birki*), *Melgrasi* grew in the sand".	Ongoing problem, control measures: "our son Haraldur has been today about 20-30 km to the south to apply old hay and animal manure".
Baldursheimur	Variable "the year 1939 had a very bad spring, one of the worst… all of a sudden the summer came and the weather changed from being very bad to be all of a sudden 20 degrees and very warm".	"There have been some changes in the grass species, not so much. The home-field is much bigger now than in the old days, it was about 5 ha and now it is about 70 ha".	Blowing sand was a big problem "my mother in law had twins in 1919 and there was so much blowing sand that we needed to hang things on the window so the sand would not get to the babies". Control measures: damages in the home-field by blowing sand were addressed by cutting turf and placing it in the areas where the vegetation was gone.
Geirastaðir	More unpredictable with milder winters "in the old days it was quite usual to be -20˚C in February whereas now it happens but it lasts only one day".	Changes depend on the weather. It is better now "since they close the factory in 2005 the vegetation has been getting better and better".	Sheep are not responsible but make recovery slower "the glacial rivers are responsible, the sand that the glacial rivers bring and the wind takes it".
Garður	Variable "is getting worse, however the winters are milder, there used to be much more ice around the sea. Some winters are hard and some are mild, summers are also very different".	"The vegetation has been and will keep on changing because of volcanoes, sand and strong winds".	The effect of men on erosion is very small "it is mostly nature, erosion used to be worse, today the sand is blowing less". Control measures: "now we are doing land improvements together with the government, we get some funding but mostly fertilizer and seed, the farmers supply the work and the natural fertilizer…we have tried in the past to use nets to cover areas that had bad sand erosion but that didn't work".
Skutustaðir	"There's not a big difference between winter and summer any more, colder in the summer and no so cold in the winter".	Improved since animals are kept inside "before they tried to graze outside as much as they could".	Not addressed.

A perception study of land-cover changes in northeast Iceland has been carried out by Ólafsdóttir and Júlíusson (2000). Not all the themes treated in their study have been explored here. However, a thing in common is the farmers' perception that erosion is mainly of climatic origin. The occurrence of south and southwest winds was highlighted although sand encroachment was not seen as a present day problem. The old practice of distribution of manure and old hay on bare patches was also emphasized in their study.

6.4 Networks of support and commercialization

Figure 60 illustrates the hierarchy named: networks, sub-divided into two siblings: support and commercialization.

Networks

- Support
- Commercialization

Figure 60- Hierarchy on networks.

In Table 34 a summary of the respondents' discussions on networks of support and commercialization is presented. When asked what kind of aid they would or could have received in hard times, five of the six respondents listed "the community". This could be further divided into two types of community support, one that the community was obliged to offer and one offered by solidarity. The farmer at Gautlönd said that: "if you were poor the whole community by law had to help you". The farmer at Garður described how this help was implemented:

> “Farmers could offer to take on a poor person and instead they received money from the municipality or the government. The one that put the lowest bid would get the rights to take care of the poor person. Mostly these were old people and others who had ailments or were without hope”.

Examples of solidarity among the community are found in the answers given by the farmers at Geirastaðir and Skutustaðir. The farmer at Geirastaðir said that in hard times people would come to his farm to graze or to fish. The farmer at Skutustaðir said that when a farmer lost sheep other farmers would donate one of theirs to help. Eggertsson (1998) considers that the family was the main institution of support in pre-modern Iceland. When the family failed, then the hreppur acted as a social safety net. An important function of the hreppur was to help the poor by assigning indigent people to households if they did not have relatives or they could not support them. The commune also subsidised households that were in temporary difficulties and provided insurance against disease in livestock. By law a farmer could seek compensation from the commune if one fourth of his stock or more died. The commune-based social safety net partly substituted private insurance arrangements.

Four of the six farms considered Lake Mývatn to be an important support in difficult times by providing fish and eggs. Two of the respondents mentioned the cooperative as an important support. All livestock and dairy products are now sold through agricultural cooperatives at prices which are set by a committee of six persons, three form the cooperatives and three from the business community in Iceland; these subsidised prices for agricultural produce were first established in 1947 (Pinson, 1992).

Table 34- Comparison of support and commercialization networks in the study farms.

Farm	Support	Commercialization
Gautlönd	Community and lake. "If you were poor the whole community by law had to help you. Around the 1880-90 there was a big famine, the government had to use a lot of money to help the farmers"…"No one would go hungry because of the lake"	"Around 1950 there were lots of changes and we started selling livestock to England, there were 1 year old or older, younger than this weren't sold. We only sold about 10-15 per year".
Grænavatn	Community. "People had to manage themselves, but would help each other in dire need…once a woman's husband died; she had 10 children and no means of supporting them so they were farmed out, one here, one there, to different families".	Not addressed.
Baldursheimur	Lake. "The lake supported a bigger area than Mývatn in times of hardship because they wouldn't stop people from outside coming to fish. Later on organizations were formed to monitor people's food supply… they would ensure that poor people got help from the wealthiest farms"	Sheep to England, excess wool and other products were taken to Husavik where they got exchanged by dried and salted fish. "Around 1940 we stopped milking the sheep, after that it was emphasis in the meat and the wool".
Geirastaðir	Cooperative, community and lake. "It was very hard to found this cooperative because it was after the famine". "In 1930 when farmers didn't have enough hay they would come to graze his land in the spring. A lot of people from far away would come here to fish for trout".	Around 1950 they started selling milk to Husavik and they sold a lot of smoke trout. "He remembers salting trout and salmon in barrels when he was young to take to France and they would salt it in France".
Garður	Community. "Farmers could offer to take on a poor person and instead they received money from the municipality or the government. The one that bid the lowest would get the rights to take care of the poor person. Mostly these were old people and others who had ailments or were without hope".	In 1940-50 they only sold fish "people would often not even be able to pay for the fish" and occasionally livestock to England "that was the first money the farmers in Iceland ever saw, the sheep gold. The reason for Iceland fishing success was because Icelanders finally had money to invest in ships"
Skutustaðir	Lake, community and cooperative. "You could always get by because there were lots of eggs and fishing. If farmers lost sheep the other farmers would give him one sheep each, there is a lot of good people here. There is an old poem that says that the people in Mývatn would be like any other if they didn't have the trout, the melgrass and John in Gautlönd. John did a lot of things for the community, unselfish work; he was one of the founders of the cooperative".	They sold some trout overseas and to stores in the last 20 years or so.

With respect to commercialization, most of the respondents (four of five), consider the main changes in this aspect to have occurred in the 1940-50's. One of the commercialized products emphasized was 1 year old sheep sold to England, mentioned in three farms. Fish was also mentioned in three farms. One farm mentioned the sale of excess wool to Húsavík and another one the sale of milk.

6.5 Myths of nature in Mývatnssveit

A way of analysing how human's perceptions of nature might shape their management strategies is by using cultural theory and the basic cultural types developed by Douglas (1970) and described in Section 3.4.3. The society of Iceland, from the Viking to the modern period, has been described by some as egalitarian due to having had less class distinctions than other Nordic societies (e.g. Tomasson, 1980). Although this romantic view of the Icelandic society is debatable and has been criticised (e.g. Fridjónsdóttir, 1981), certain aspects of the hreppur organisation can be considered egalitarian. An example of this is given by the past management of communal grazing areas, where grazing quotas were assessed by members of the community. This aspect of the commune organisation meets the criteria of egalitarian social relations, described by Thompson (1990, p. 6) as: "no individuals are granted the authority to exercise control over others by virtue of their position". Other aspects of the Icelandic social organisation in the past resemble the hierarchic point of view. The hierarchy is a social environment characterised by strong group boundaries and binding prescriptions (Thompson *et al*., 1990). Examples of strong binding prescriptions are found in the restrictions on trade during the Danish trade monopoly in the 17th and 18th century and on the strict linked labour contracts which continued until the 19th century (see Section 2.3).

However, looking at the individual responses in the interviews and using the combined cultural perspectives/myths of nature typology of Thompson (1990), other "ways of life" become apparent. For example, the respondents from the farms Geirastaðir and Garður can be described according to the typology as fatalists in their perception of nature as "capricious". This can be illustrated by the accounts detailed in section 6.3, where the respondent from Geirastaðir explains his view on erosion and landscape degradation: "Sheep are not responsible but make the recovery slower… (Vegetation) changes depend on the weather". The respondent from Garður provided a similar explanation: "the effect of men on erosion is very small…the vegetation has been and will keep on changing because of volcanoes, sand and strong winds". This perception of nature supposes that the state of ecosystems is determined by fate and that nature acts at random. It is common for people who depend directly upon nature for their living, to perceive nature as highly variable and unpredictable (Marten, 2001). Thompson and Rayner (1988) consider that people with this view of nature do not engage in management because they think of natural resources as unmanageable. However, Holling *et al*. (2002b) consider that people in this typology think of nature as "infinitely malleable and amenable to human control only if the right values and timing are chosen". An example of this can be found in the response from the farmer at Geirastaðir with respect to farm success and failure where he links success to "making the most of good weather when it comes" (section 6.1).

Other perspectives are more difficult to characterise by a single label from the typology. For example, the respondent from Gautlönd could be said to view nature as "perverse/tolerant" or "resilient", using the terminology in Holling *et al*. (2002b). This view acknowledges a certain degree of uncertainty as being inherent in the system, generating management approaches that are adaptive (Thompson *et al*., 1988; Holling *et al*., 2002b). This is reflected in the participant's response on communal grazing areas where he revealed that the sheep were released in mid May when the weather was good or in June when the weather was bad (Section 6.2). On erosion and land degradation he considered erosion in the communal grazing areas to be a consequence of both overgrazing and climatic conditions.

It is not the purpose of this brief analysis on perceptions to squeeze people into rigid categories, nor to declare that any particular view is right or wrong. Each myth is a partial representation of reality (Mamadouh, 1999; Holling *et al*., 2002b), and each individual holds a mixture of perspectives which changes over time (Janssen, 2002). Nevertheless, this framework captures the idea that the way how people perceive nature influences their management strategies and that these are related (Janssen and de Vries, 1998; Janssen, 2002). The perspectives captured in this thesis cannot be directly extrapolated to different people in a different time period, but they are used to exemplify how social organisation and individual perceptions of nature might have influenced the adaptive capacity of farms in the past.

Chapter 7 -Synthesis

This thesis sets out to investigate the resilience of historical north European farming systems using Mývatnssveit as a case study. The research questions and objectives of the study parted from the premise that the changes in climatic factors experienced during the Little Ice Age would have uniformly affected the area. This led to the question that if climatic change is a major contributor to farm abandonment, why have some farms in the same geographical area survived and remained productive from settlement till present day while others suffered extensive land degradation and failed? A resilience/vulnerability framework was then proposed to answer this question. The following sections relate to the specific objectives of the thesis. Thus, Section 7.1 deals with the selection of suitable indicators of farm resilience/vulnerability based on the results from this research; and section 7.2 explores two methods for the integration of indicators and discusses this synthesis in relation to the theoretical framework.

7.1 Suitable indicators of historical farm resilience

The assumption that the main environmental changes i.e. climate would have affected in the same way a small geographical area such as Mývatnssveit led to the questions: were the failed farms inherently more vulnerable to environmental change? And if so, what factors made these farms more vulnerable and successful farms more resilient? To address these questions this study set to assess and compare the resilience/vulnerability of successful and failed farms in Mývatnssveit. To achieve this it was first necessary to identify appropriate indicators of historical resilience/vulnerability. Quantitative variables from soils and historical records were tested and semi-quantitative (i.e.

micromorphology) and qualitative (i.e. interviews) data sources explored to select the indicators.

To determine which of the variables reflected the resilience or vulnerability of a farm, it was necessary to assess if they showed differences between successful and failed farms. Ideally, these differences should be statistically significant and consistent through different time periods; however the nature of some datasets made this not always possible and different criteria were considered. The possibility of taking many samples and measurements from each soil profile (at least one between tephra layers), made it possible to analyse statistically the soils' quantitative data using a General Linear Model (GLM) or analysis of variance with fixed factors. As opposed to this, the limited amount of past written records available and the small number of failed farms, made the use of the GLM inappropriate to analyse these data. In this case, the indicators were considered by comparing their value in failed farms with the general mean or the mean of the successful farms. Finally, the assessment of semi-quantitative and qualitative data was achieved by observing aspects that consistently differed between successful and failed farms.

The GLM results of the SAR measurements in winter grazing areas showed no significant differences between successful and failed farms in any of the time periods considered and therefore cannot be considered a good indicator of resilience/vulnerability in this analysis. These results could be interpreted in many ways; one explanation would be that erosion in the winter grazing areas was not an important factor in determining farm success or failure. It could also be argued that one soil profile might not be representative of the whole winter grazing area of a farm, or that the necessarily small sample sizes (number of farms analysed) did not give sufficient statistical power to detect differences in SARs. Moreover, SARs might be an overestimation of erosion since without a micromorphological or LOI analysis of all the sites sampled it cannot be ascertained that the accumulated material is, in its totality, aeolian transported sediments. The measured quantity of transported material (assessed by two different methods here) was around 2 orders of magnitude less than the measured SAR values, suggesting that the bulk of accumulated material may not be composed of eroded sediments. Even if the accumulated material is entirely composed by aeolian sediments, the assumption that SARs reflect local soil erosion could be erroneous. In this case, SAR would only be appropriate as a proxy of erosion at a wider scale. It has also been suggested that SARs at a particular point may vary through time according to the location relative to the areas of erosion. Thus, the SARs in an area could increase if an eroding slope is moving closer (Dugmore and Buckland, 1991). The micromorphological evidence presented here from the reference profile of Baldursheimur indicates that organic material may be a significant part of the accumulated material in the winter grazing areas of Mývatnssveit. The assessment of sediment type has commonly been achieved by field observations of organic and gravel layers (e.g. Gerrard, 1985; Dugmore and Erskine, 1994). However, soil layers of mixed mineral and organic material are difficult to assess in the field with the naked eye. In these cases, SAR studies combined with LOI analysis and micromorphology would permit a more accurate estimation of past erosion. The determination of the sediments origin is more difficult to achieve due to the variety of possible sources. Sediment sources in Iceland include: sandy areas of glacial and glacio-fluvial origin, sandy sedimentary rock, volcanic ash deposits, unstable sandy deserts, erosion spots and bare soil remnants (Sigurjonsson *et al.,* 1999; Arnalds, 2000; Arnalds *et al.,* 2001a; Arnalds, 2004). The accumulated material at any particular point is thus likely to come from a combination of different sediment sources. While SARs remain a useful tool for reconstructing past landscape change at the scale of the whole country, their use for reconstructing local scale erosion should be regarded with caution. In this study the amount of silt sized particles collected in sediment traps suggest that the transported sediments in the area have the potential to travel great distances. Further research on sediment sources and patterns of erosion might make possible the use SARs as indicators of farm resilience in the future.

From the bulk soil analyses, only Total P content in the home-field soils presented significant differences between successful and failed farms. Total P content has been commonly used as an indicator of past human presence and manuring intensity (e.g. Simpson, 1997; Guttmann *et al*., 2006), but it has not been applied to date as an indicator of farm resilience. The potential of using Total P content as an indicator of farm resilience in other geographical contexts will be constrained by the retention characteristics of the soil, the similarity of the underlying geology in the sites studied and by the possibility of obtaining background or control samples. The results obtained here suggest that two aspects of the home-field fertility were of importance in contributing to the resilience of farms systems in Iceland: *i*) the initial fertility of the soil and *ii*) the maintenance through time of this fertility. A study by Adderley *et al*. (2008) based on an integrated agro-ecosystem model supports these results. Using climate and soils data to model the hay productivity in home-fields encompassing the Mývatn area and the Laxá valley in northeast Iceland, they concluded that both inherent soil characteristics and fixed continuous manure inputs influenced the sustainability of the home-field.

The analysis of indicators extracted from historical records showed that both the tax value and the land rent of the failed farms (Fagranes and Brjánsnes) are below the general mean. In the case of land rent, the results suggest that is not only the low value in a particular year that is associated with farm failure but also its continual reduction through time. It is believed that this reduction indicates a decline in land productivity due to land degradation. However, other explanations that have been proposed in the debate on the connection between the reduction of land rent and farm abandonment in Scandinavian countries cannot be discarded. These explanations have included lack of manpower (connected to population decline), fall in market prices, farm division and changes in agricultural practices (Lárusson, 1967; Gissel *et al.,* 1981). Ultimately, the land rent seems to reflect the income of a farm and as such it is a valid indicator of vulnerability regardless of the direct reason for the reduction of value. The livestock rent does not show a distinctive pattern between successful and failed farms. The significance of the livestock rent is however, relative to the productivity of the farm. For example, in all the successful farms the land rent is always greater than the livestock rent, whereas in Brjánsnes the livestock rent is greater than the land rent in 1696 and in Fagranes this is the case in 1686 and 1696. If we consider land rent a proxy for farm size or productivity, this would have meant that the failed farms had to keep more livestock per area of productive land than successful farms or have considerably less livestock of their own. This is further supported by looking at the relation between LU and livestock rent (in cow equivalents) in successful and failed farms reported in 1712. This relation shows that successful farms had on average 7.85 LU of their own per unit of rented livestock, while failed farms had on average 2.41 LU. Therefore, even though livestock rent cannot be used in isolation as an indicator of farm vulnerability, the two ratios of land rent: livestock rent and LU: livestock rent (in cow equivalents) can be used. Added to these, the mean number of livestock per farm, excluding hired livestock and expressed in LU, is also greater in successful than in failed farms. From the census data of 1703, the means of the variables “number of people” and “number of servants per farm" were greater in successful than abandoned farms. The average number of children and of adults (excluding servants) per farm was very similar in successful and failed farms. Thus, from the census data only the number of servants per farm will be considered as a resilience indicator.

The analysis of natural resources and constraints per farm recorded in the *Jarðabók*, does not allow an obvious distinction between successful and failed farms. However, there are two points of interest: on one hand the failed farms, Brjánsnes and Fagranes, are the only ones situated on the shores of Lake Mývatn that do not record egg collection. On the other hand, Brjánsnes is the only farm that appears as having no meadows and Fagranes is the only one that records having to pay for meadow cutting. The information gathered in interviews of the older generation of farmers in Mývatn showed that most of the farmers considered Lake Mývatn, due to the possibilities of fishing and egg collecting, a basis for support in difficult times. The interviews also suggest that most farms had a very small home-field or no home-field at all, and that most of the hay produced came from meadows. The difficulty in using natural resources as indicators of farm resilience lies in that, apart from eggs numbers, their abundance per farm has only been recorded qualitatively (e.g. good or bad fishing, large outfields, etc). Moreover, the relative importance of each resource type compared with others is not known. In this analysis fishing and egg collecting have been considered as suitable indicators because their importance was highlighted in the interviews and because they have been cited by many sources as a contributory source of livelihood for farmers in Mývatn in the 18th century (e.g. Gudmundsson, 1979; Vasey, 1991; McGovern *et al.*, 2006).

The contribution of management aspects to the resilience of the study farms is more difficult to assess. Two aspects of the management of the home-fields, based on the interviews and on the micromorphological analysis of soil samples, are considered here: *i*) the use of household waste as soil amendment and *ii*) the flooding and draining of the home-fields and meadows. The household waste identified in the soil samples included bone fragments and fuel residues (i.e. charcoal and ashes). Manure was not identified, but this could reflect the poor preservation conditions due to the low pH of the soils rather than a lack of manuring. Based on information from the interviews, it is likely that the manure input was not very high in most farms because they used sheep manure as fuel and most farms did not have many cows and horses.

The only farms, in which no household waste was identified either in field observations or under the microscope, were Brjánsnes and Fagranes. In Brjánsnes only a sample, close to the soil surface, could be taken and given the evident disturbances caused by modern agriculture and biological activity it cannot be said that this farm had no household waste inputs in the past. The soil of Fagranes on the other hand, showed no signs of agricultural disturbance and two samples representing the soils from AD 1477-1717 and AD 1717 to present day were obtained. In this case, both the lack of signs of household waste in the soil thin sections and the low values of Total P indicate that the home-field was either not fertilized at all or that the inputs were very low. Interviews of the farmers revealed that household waste was used not only for the purpose of fertilization but also for erosion control. Two farms located to the south of Lake Mývatn, Grænavatn and Baldursheimur, still apply waste organic materials both in the home-fields and out-fields (winter grazing areas in the past) to restore areas damaged by erosion and sand deposition.

The micromorphological evidence suggests that not all farms faced the same degree of wind blown sand deposition. The blown sand in the Mývatn area travels principally north-east carried by dry south-westerly winds. Therefore, the degree of exposure to sand accumulation is related to the position of the farm in the landscape. The incidence of blown sand seems to have varied through time. Studies carried out by Ashwell (1966) in central Iceland have shown that atmospheric pressure and winds are markedly affected by the influence of long term changes in icecap conditions. Thus, it is possible that different circulation patterns during the Little Ice Age may have created different patterns of soil erosion. Furthermore, sand deposition not only affected soils but also lakes and wetlands; many small lakes in the *Framengjgar,* located to the south of Lake Mývatn, must have become smaller and shallower, or even disappeared entirely, due to sedimentation (Lawson *et al*., 2009). The *Framengjgar* is mentioned in the interviews as an important wet meadow which was shared by several farms.

Given the different functions of the use of household waste (i.e. as a fertilizer and as a technique for soil erosion control), and the differences in exposure of the farms, it is difficult to use the micromorphological evidence of household waste as an indicator to compare the resilience/vulnerability between farms. Alternatively, Total P values are used to provide an indication of fertility, while the amount of coarse mineral material assessed with micromorphology, or the position in the landscape relative to the influence of south-westerly winds could be used as indicators of exposure.

The second management aspect of consideration, the flooding and draining of the home-field and meadows seems also to have had a two-fold function. On one hand it might have served to prevent the formation of *thúfur* due to freeze-thaw conditions and on the other, to enrich the soil with nutrients from the rivers. It is also possible that the sand input caused by flooding served to improve the physical conditions of the soil. Evidence of flooding of the home-fields can be obtained from the micromorphology, inferred from the presence of amorphous crypto-crystalline pedofeatures (AC-CP features), and from the interviews by descriptions of past management. However, AC-CP features appear both in successful and abandoned farms in different forms. The only farms with no AC-CP features recorded or with only traces are: Brjánsnes, Baldursheimur and Fagranes. From these farms, Brjánsnes cannot be considered because, as explained before only a superficial sample was taken. In Baldursheimur no AC-CP features were seen, but many iron-phosphate features were recorded. Iron-phosphate features also form under wet conditions and so may also be taken as indicators of flooding. In Fagranes however, no features associated with wet conditions were identified. Furthermore, Fagranes had the only home-field in which a *thúfur* feature was identified in the soil profile (seen in Figure 41). Given the small number of profiles per farm considered, the presence of *thúfur* cannot be ruled out in the other home-fields. Nonetheless, its occurrence in Fagranes suggests a lack of flooding which would have prevented freeze-thaw conditions. Unfortunately there is no evidence available on the management of failed farms from interviews. Due to this incomplete evidence from micromorphology and interviews, the differences in the use of flooding in successful and failed farms cannot be fully assessed.

Table 35 summarises the data sources explored, the indicators derived from them and their suitability for characterising the resilience/vulnerability of farms. In the table, indicators are defined as primary or secondary. Primary indicators are those which were initially considered, while secondary indicators have arisen after the analysis of the data or from the analysis of primary indicators. This leaves a selection of quantitative, qualitative and semi-quantitative indicators that are deemed relevant to the characterisation of the vulnerability/resilience of the study farms. The secondary indicators derived from micromorphology and interviews are interrelated. Thus, the information gathered in the interviews on the use of amendments in the home-fields is supported in the micromorphology analysis by the identification of household waste; the use of flooding described by farmers is supported by amorphous crypto-crystalline and iron-phosphate pedofeatures and the incidence of blown sand mentioned by interviewees in attested to by the coarse mineral material content of soil samples. The indicators identified as suitable need to be integrated in order to obtain a comprehensive representation of the resilience or vulnerability of each farm.

Table 35- Summary of data sources and assessment of derived primary and secondary indicators.

Data sources	Derived primary indicators	Quantitative	Qualitative	Semi-quantitative	Suitable	Not suitable	Derived secondary indicators	Quantitative	Qualitative	Semi-quantitative
Soils records	Total P post-*Landnám*	X			X					
	Total P pre-*Landnám*	X			X					
	LOI	X				X				
	Particle size	X				X				
	Micromorphology			X		X	Household waste			X
							Pedofeatures			X
							Coarse mineral material			X
Historical records	Tax value	X			X					
	Land rent	X			X					
	Livestock rent	X				X	Land rent: livestock rent	X		
							LU: livestock rent	X		
	Livestock units	X			X					
	Natural resources			X			Egg collecting			X
							Fishing		X	
	Number of people	X			X					
	Number of servants	X			X					
	Number of children under 15	X				X				
	Number of adults (excluding servants)	X				X				
Interviews			X			X	Use of soil amendments		X	
							Home-field flooding		X	
							Blown sand		X	

7.2 The integration of indicators

Having identified suitable indicators of farm resilience/vulnerability, it is necessary to integrate them in a way that permits conclusions to be drawn about common factors in successful and failed farms. In the literature on socio-ecological systems, resilience/vulnerability has been assessed either quantitatively by the calculation of composite indices or qualitatively by means of discussions, historic accounts and testimonials/interviews. The selection of the method for integration depends on the type of data used, indices being employed when the data used is entirely quantifiable, whereas when the data is entirely qualitative or a combination of both the integration seems to be done solely by discussions. In both cases the integration is used in order to test a theoretical model to explain the situation studied. In this study, a wide range of indicators were used including several numerical data sets and therefore both approaches are explored.

7.2.1 Quantitative integration of indicators: a vulnerability/resilience index

The calculation of a composite index involves the standardization and weighting of variables before adding them into an index. The standardization procedure is necessary in order to integrate indicators that are measured in different units. Different methods are used for the standardization of variables. Here the standardization used follows the equation used by Briguglio (1995):

$$V_{ij} = \frac{\left(X_{ij} - MinX_i\right)}{\left(MaxX_i - MinX_i\right)} \qquad \text{Equation 1}$$

Where:

V_{ij}: is the degree of vulnerability.

X_{ij}: is the value of the $_i$th variable included in the index.

Max X_i and Min X_i: are the maximum and minimum values of the $_i$th variable for all the farms considered in the index.

In this manner, the equation produces a value between zero and one for each of the indicators considered. The value calculated like this for each indicator is a “sub-index”, where zero corresponds to the minimum value of vulnerability with respect to all the study farms. All the primary and secondary quantitative indicators identified as suitable were used to calculate composite index-1. Indices are usually calculated with contemporary data and are used either to predict outcomes of possible future events or to explain disasters based on data from the time period immediately preceding it. Here, the tax and rent data used was that for 1712 because it is the closest land register to the time of abandonment of the farms Brjánsnes and Fagranes. However, pre-settlement Total P values were also included because the initial fertility of the farms was considered an important factor in their subsequent history. For the farms abandoned before 1712 (Bjarnastaðir and Þórleifsstaðir) Total P values at the time period of abandonment were used.

A second composite index was calculated by adding secondary indicators of natural resources (i.e. fishing and egg collecting). Fishing is described qualitatively in the *Jarðabók* as good, little or no fishing. The standardisation for this resource was done by assigning a value of one to the farms that report good fishing, a value of zero to the farms with no fishing and 0.1 to the ones with little fishing (i.e. Grænavatn). Egg collecting is described as a semi-quantitative resource in Table 35 because although the

Jarðabók provides numbers of eggs collected for most of the farms, for Grænavatn it does not provide numbers but mentions that it has a little egg collecting. For this resource, the farms with no egg collecting were assigned a value of zero, Grænavatn was arbitrarily assigned a value of 0.1 to account for its "little" collecting and equation 1 was used to standardise the rest. Standardising the indicators derived from micromorphology would have implied more subjectivity due to the complexity of the data. For example, pedofeatures indicating periodically wet conditions were only recorded as amorphous crypto-crystalline or iron-phosphates, however different types were observed (e.g. typic nodules, double ring concentric nodules, coatings, etc.). The presence or predominance of one type or other might relate to differences in soil saturation periods, iron content or organic matter content but this is not fully understood. Indicators of blown sand exposure are also complex, with sand seen in the soil profile as stratified or un-stratified thick layers and coarse mineral material seen under the microscope arranged in micro-bands or mixed with the groundmass and with different size ranges. Therefore, the indicators derived from micromorphology and interviews were not included in the calculation of the composite indices. The composite indices were achieved by calculating the mean of the sub-indices, producing in this way equally weighted indices. An alternative is to use different weights for each indicator, on the assumption that they have a different impact on vulnerability. However, it is not possible to establish such weights on statistical grounds. Table 36 shows the sub-indices and composite indices per farm.

Table 36- Resilience/vulnerability sub-indices and composite indices.

Farms	Total P pre-*Landnám*	Total P (at abandonment or 1717 A.D)	Tax value	Land rent	LU/ Livestock rent	LU	Number of servants	Composite index-1	Fishing	Egg collecting	Composite index-2
Successful											
Baldursheimur		0.18	0.18	0.25	0.26	0.77	0	**0.27**	0	0	**0.21**
Geirastaðir	0.38	0.55	0.18	0.25	0.23	0.31	0.22	**0.30**	1	0.4	**0.39**
Grænavatn		0.33	0.55	0.25	0.11	0.72	0.78	**0.46**	0.1	0.1	**0.37**
Grimstaðir	0	0.20	0.55	0.33	0.08	0.59	0.89	**0.38**	1	1	**0.52**
Gautlönd		0.41	0.36	0.38	1	1	0.78	**0.66**	1	0	**0.62**
Failed											
Bjarnastaðir	0.13	0.16						**0.15**			
Brjánsnes		0.17	0.18	0	0.05	0	0.22	**0.10**	1	0	**0.20**
Fagranes		0.08	0	0	0	0.16	0	**0.04**	1	0	**0.16**
Þórleifsstaðir	0.22	0.11						**0.17**			

Considering the composite index-1 values per farm, they can be arranged in decreasing order of vulnerability like this: Fagranes, Brjánsnes, Bjarnastaðir, Þórleifsstaðir, Baldursheimur, Geirastaðir, Grimstaðir, Grænavatn and Gautlönd (the latter being the least vulnerable or more resilient farm). The incorporation of the sub-indices for fishing and egg collecting only changes slightly the positions, leaving Fagranes and Brjánsnes with the lowest scores, followed by Baldursheimur, Grænavatn, Geirastaðir, Grimstaðir, and Gautlönd (Þórleifsstaðir and Bjarnastaðir were not considered for the calculation of composite index 2 because they were abandoned before the *Jarðabók* compilation of natural resources). Because the composite indices are retrospective and are based on the farms' outcomes (i.e. whether they were successful or not), the failed farms are naturally expected have the lower scores. What is interesting is that the indices allow the integration of many variables into a single-value measure of vulnerability based on meaningful data. This facilitates the evaluation of many factors that made failed farms weaker than successful ones. However, it can be argued that the calculation of the indices is subjective and there are a number of aspects that need to be considered if any conclusions are to be drawn based upon them. Firstly, caution is required when comparing farms which do not have the same number of sub-indices. This is especially problematic for the farms Bjarnastaðir and Þórleifsstaðir, for which composite indices are formed only by 2 sub-indices. Another issue is that the post-settlement Total P values represent different time periods for these two farms because they were abandoned before the 18th century. Additionally, the analysis of the composite indices in isolation from the sub-indices can hide the effect of individual variables. For example, Baldursheimur had a low Total P content compared to Geirastaðir but their composite indices are similar because its effect is cancelled by a higher score in LU. With the addition of the sub-indices "fishing" and "egg collecting", to form composite index-2, Baldursheimur's vulnerability index is more similar to Brjánsnes. This is the case because equal weights were assigned to each sub-index, while in reality the relative importance of each indicator is not known. It can also be argued that some of the indicators are related and in this case their importance may be over-emphasised. For example, the tax value, land rent and the number of servants per farm can be all considered as indicators of productivity. Furthermore, the difficulties in assigning a meaningful score to other indicators (such as the flooding and use of amendments in the home-fields, the exposure to sand storms and the significance of other farm resources such as large outfields); meant that important factors were omitted. Finally, it is difficult to relate these indices to the theoretical framework because the exposure and sensitivity components of resilience could not be captured numerically. Thus, although the sub-indices work well for comparisons of the numerical variables, the indicator approach does not provide an adequate way to examine all the data available. This approach would be more useful in comparing a large numbers of sites, which have the same number of quantitative variables available. For the small number of sites considered here, a structure which permits the recognition of common features in the farm groups (i.e. successful vs. failed farms), while at the same time allowing the appreciation of the individual characteristics of the farms is needed. It is also necessary that this structure allows the incorporation of both quantitative and qualitative variables.

7.2.2 Qualitative integration of indicators and relation with the theoretical framework

In order to facilitate comparisons of the numerical variables between the farms and discuss them in association with the qualitative data, they were transformed into qualitative measures. Based on the scoring method used by Brooks *et al*. (2005) for the standardisation of indicators, the range of data for each numerical variable was divided into quintiles. In this manner, each numerical data set was divided into five classes, each containing a fifth or 20% of the data. The quintiles were used to describe the data, thus the lower quintile, representing 1/5 of the frequency distribution of the particular data set, is considered very low and the subsequent fractions are described as low, moderate, high and very high (Table 37). Summary qualitative tables were then built, encompassing the indicators identified as suitable and other important characteristics of the farms. These are presented in Table 38 for the successful study farms and in Table 39 for the failed study farms. The information on these tables will be subsequently discussed in the context of the theoretical framework.

Table 37- Standardisation of indicators into qualitative values, based on the quintiles scoring system by Brooks *et al*. (2005).

		Indicator									
Quintile	**Quality**	**SAR**	**Land rent/ LR**	**LU/LR**	**Livestock rent**	**Total P**	**Tax**	**Land rent**	**Livestock rent**	**Servants**	**LU**
1/5	Very low	0.099	1.13	2.98	40	124.04	12.00	90	40	1.2	7.21
2/5	Low	0.131	1.63	3.54	80	149.55	12.33	120	80	2.8	10.76
3/5	Moderate	0.172	1.75	5.13	80	184.28	16.80	140	80	6.8	14.51
4/5	High	0.299	2.52	6.37	110	246.90	22.94	150	110	7.4	15.96
5/5	Very high	1.069	7.5	19.6	140	563.21	30	300	140	9	19.6

The integration of the indicators allows the assessment of the differences between successful and failed farms in terms of their history and characteristics. From Table 38 the common features of successful farms in Mývatnssveit can be summarized as follows:

- The home-field had high to very high fertility. Exceptions to this are Grænavatn, in which the Total P content varied in relation to layers of wind blown sand, and Grimstaðir; the home-field of which is likely to have been moved in the 1720's due to a volcanic eruption. The initial fertility of the home-field might have also been important.

- They had access to many meadows either in their own land or rights to meadows outside it.

- Tax and rents were variable but they had a high land rent: livestock rent ratio.

- They had moderate, high or very high LU and LU: livestock rent ratio. Exceptions to this are Geirastaðir which had a low LU but high LU: LR ratio and Grimstaðir which had low LU: LR ratio but moderate LU.

- High or very high number of servants. Exceptions to this are Baldursheimur which had no servants and Geirastaðir which had a low number of servants.

Table 38- Summary of indicators and relevant characteristics in successful study farms. LR=livestock rent, LU= livestock units.

	Characteristics									
Farm	**P content in home-field**	**Home-field and meadows**	**Winter grazing areas**	**Tax value**	**Land rent**	**Livestock rent**	**LU**	**Resources**	**No. of servants**	**Constraints**
Baldursheimur	Moderate from AD 1717 to present day, no data on previous periods.	Use of household waste + possibly flooding of home-field. Flooding of meadows, access to *Framengjgar*	Dwarf-shrub heath vegetation, abundant rofabards and sparsely vegetated areas. V low/low SAR pre-*Landnám* to 1477, high in 1477-1717 and v. high in 1717 - present.	High in 1686; low after	Moderate in 1686; very high in 1696; low in 1712; moderate in 1847. Low Land rent/LR in 1696 but high thereafter	Low in 1686; very high in 1696; very low in 1712; low in 1847	Very high (16.14) very high LU/LR ratio	Large outfields. Fuel: little firewood, turf	Very low (0)	Damage to the home-field by sand deposition, flooding of meadows, snow in the outfield. No fishing or egg collecting.
Gautlönd	High from AD 1477-1717; very high from AD 1717 to present	4.3 Ha. Increased sand deposition and drier conditions after AD 1717. Use of household waste. Access to many meadows, flooding of home-field and meadows	Extensive, dwarf-shrub heath vegetation. Variable SAR pre-*Landnám* (v. low/high/low), moderate thereafter.	Very high in 1686; moderate in 1696-1847	Moderate in 1686; low in 1696; high in 1712 and 1847. Moderate Land rent/LR in 1712 but very high thereafter.	Moderate in 1686, low in 1696 and very low in 1712 and 1847	Very high (19.6) very high LU/ livestock rent ratio	Good fishing by AD 1712, firewood, good outfields	High (7)	Irregular and scattered meadows.
Geirastaðir	High/very high pre-*Landnám*; very high from *Landnám*- AD 1477; high/very high from AD 1477 to present.	Wetter conditions and use of household waste. Good meadows in Helgey	Dwarf-shrub heath vegetation, moderate SAR from *Landnám* to present day	Low from 1686-1847	Very low in 1686; high in 1696; low in 1712 and 1847. Very high land rent/LR from 1696 onwards	High and higher than land rent in 1686; very low from 1696-1847	Low (9.02) but high LU/ livestock rent ratio	Good fishing, egg collecting and turf, little firewood, good outfields for sheep	Low (2)	Dangerous lava rock in outfield, small meadows.

Table 38- Continuation

Grænavatn	High/moderate/low in alternating layers related to bands of wind deposited sand and household waste from *Landnám*-1477; low/very low from 1477-1717; moderate/high 1717-present.	5.6 ha, Intense wind blown sand deposition of different energies and use of household waste. Drier conditions after 1477. Access to *Framengjgar*.	Dwarf shrub heath vegetation, high SAR *Landnám*-1477 and v. high thereafter.	Very high in 1696 and 1712; high in 1847	Very high in 1696; low in 1712; very high in 1847. Moderate Land rent/LR in 1696, low in 1712 and high in 1847.	Very high in 1696; low in 1712 and 1847	High (15.26) moderate LU/ livestock rent ratio	Little fishing, egg collecting and angelica, good firewood but decreasing	High (7)	Damage to outfields by sand deposition, landslides in home-field, flooding of meadows.
Grímsstaðir	Very low pre-*Landnám*, low/ moderate *Landnám*-1477, very low 1477-1717, moderate 1717 to present	Stable landscape, low energy sand deposition	Dwarf-shrub heath vegetation	Very high in 1686 and high thereafter	High from 1686-1712; very high in 1847. Low Land rent/LR in 1696, high in 1712 and very high in 1847.	High in 1686; very high in 1696; low in 1712 and 1847	Moderate (13.38) low LU/ livestock rent ratio	Good fishing and egg collecting, firewood, peat, angelica.	Very high (8)	Damage to home-field by landslides, dangerous lava rock in outfields.

Table 39 shows the common characteristics of the failed study farms, the key points are:

- The fertility of the home-fields was low to very low. Amendments were not used or were used at a low level, keeping the fertility low. The initial fertility of the home-field was low or it was moderate but decreased to very low after settlement.

- They had no meadows or else these were small or decreasing in size. They may have had to pay to have access to meadows.

- They had low or very low tax value in 1696 and 1712.

- They had very low land rent and this decreased through time.

- They had very low LU and LU: livestock rent ratio.

- They had no servants or else the number of servants was low.

Table 39- Summary of indicators and relevant characteristics in failed study farms. LR=livestock rent, LU=livestock units.

	Characteristics									
Farm	**P content in home-field**	**Home-field & meadows**	**Winter grazing areas**	**Tax value**	**Land rent**	**Livestock rent**	**LU**	**Resources**	**No. of servants**	**Constraints**
Bjarnastaðir	Low pre-*Landnám;* moderate/very low from *Landnám*-1477; low from 1477-1717; very high from 1717 to present.	Possible flooding or natural wet conditions	Dwarf shrub heath vegetation, v. low SAR pre-*Landnám*, moderate from *Landnám*-1477 and high from 1477-present day.	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Brjánsnes	Low from 1477 to present, no data on previous periods.	Bio-turbation, modern agriculture, no meadows	Sparsely vegetated sand dunes and lava fields; birch-woodland/dwarf shrub mosaic. high SAR *Landnám*-1477 and v. high 1477-present	High in 1686 and low in 1696 and 1712.	Low in 1686 and very low in 1696 and 1712. Decreasing through time. Very low Land rent/LR in 1696 and high in 1712	Low and stable from 1686 to 1712 but always higher than land rent	Very low (4.34) very low LU/ livestock rent ratio	Good fishing, enough outfields. Fuel resources: firewood, peat.	Low (2)	Damage to home-field by landslides and sand deposition, no meadows, dry and sandy soils in outfields, dangerous lava fields.
Fagranes	Low from *Landnám*-1477; very low from 1477-present	Aeolian deposition of high energy from *Landnám*-1477; freeze-thaw conditions pre-1477. No evidence of household waste.	Dwarf-shrub heath vegetation, partially covered by lava from 1720's eruptions. Low/v. low SAR pre-*Landnám*, v. high at 1477-1717, moderate from 1717-present.	Moderate in 1686 and very low afterwards	Very low and decreasing from 1686 to 1712. Very low Land rent/LR in all years.	Very high in 1686, high in 1696 and moderate in 1712. decreasing but always higher than land rent	Very low (6.76) very low LU/ livestock rent ratio	Good fishing, firewood, peat.	Very low (0)	Damage to home-field by landslides, bog in outfields dangerous. Has to pay 3 days of meadow cutting.
Þórleifsstaðir	Moderate pre-*Landnám*; very low post-*Landnám* to present	9 ha, wetter conditions and use of household waste from early settlement until before 1477, meadows reduced.	Dwarf-shrub heath vegetation, abundant rofabards. Low pre-*Landnám* SAR, moderate landnám-1477, low 1477-1717, high 1717-present day	N/A	N/A	N/A	N/A	N/A	N/A	N/A

7.2.3 The resilience framework applied to farm success and failure in Mývatnssveit

In the theoretical framework it was argued that the resilience or vulnerability of a system was a function of its exposure, sensitivity and ability to cope and/or adapt to external stresses. The purpose of the following sections is to relate the theory to the empirical evidence collected in this study and assess the usefulness of this framework to explain farm success and failure.

7.2.3.1 Exposure and sensitivity

The premise of this thesis was that all the farms in the Mývatnssveit area were exposed to the prevailing climate conditions in essentially the same manner. However, evidence of differences in coarse mineral material in soils obtained via micromorphology, SARs measured in winter grazing areas, information gathered from interviews with farmers and historical records together with evidence of erosion rates in the present day suggest that there were local differences in the exposure of farms to winds and aeolian sediments. The farms to the south of Lake Mývatn are more exposed to the prevailing south-westerly winds which cause aeolian sediments to move in north–east direction. Part of these sediments may be of glacial origin which may have been transported over long distances in sand and dust storms, known in Icelandic as *mistur* (Ashwell, 1986). It has been suggested that the advance of glaciers during the Little Ice Age may have increased the tephra production from volcanoes and therefore the availability of material prone to being eroded by wind (Dugmore *et al*., 2000). This increase in tephra would have resulted from the formation of glacial caps on volcanoes causing rapid cooling of magma which otherwise would have been ejected mainly as lava. On the other hand, atmospheric pressure and winds in Iceland are markedly affected by the presence of icecaps (Ashwell, 1966). Therefore, fluctuations in the icecaps during the Little Ice Age could have also created differences in the patterns and intensity of wind circulation in the past. The evidence from SARs in winter grazing areas suggests exposure was higher after AD 1717 and that the most exposed farms were Baldursheimur, Grænavatn, Brjánsnes (with very high SARs), Bjarnastaðir and Þórleifsstaðir (with high SARs). However, sediments may have also come from local sources instigated by high grazing pressures and high soil sensitivity levels. The abundance of rofabards (erosion escarpments) in the farms mentioned above suggests that they were not only more exposed but also more sensitive to erosion. This is because rofabard erosion is more intense in unstable Andosols that have formed in thick aeolian deposits, since thick rofabards have more surface area for lateral wind and rain impact and longer slopes causing more water erosion and saltation (Arnalds, 2000). Although, environmental exposure and sensitivity are closely related and may be impossible to distinguish, it was expected that pre-*Landnám* SARs could be used as proxies for the relative exposure and sensitivity of the soils to climate without human influence. However, the small number of samples obtained corresponding to the pre-*Landnám* periods meant this could not be fully examined. Most pre-*Landnám* SAR measurements taken were classified as very low or low. The exception to this was the measurement corresponding to the period 800-500 BC in Gautlönd, classified as high.

It is also possible that the study farms experienced somewhat different microclimates produced by small scale differences in landscape attributes such as altitude, slope and aspect. The altitude in the winter grazing areas assessed here ranged from 274 to 368 m.a.s.l, however it is difficult to evaluate how these differences would have affected the farms. Moreover, the assessment of the landscape attributes of the totality of each farm is problematic because old farm boundaries are not known.

7.2.3.2 Adaptive and coping capacity

As defined in the theoretical framework, adaptation refers to long term sustained adjustments in a system and as such is associated with learning, cultural knowledge and management. The main adaptive strategy adopted by farmers in Iceland in the past was probably the change in the initial mix of domestic animals. This mix consisted of cattle, sheep, goats, horses and pigs, at settlement and changed to a reduction in the number of goats and the complete eradication of pigs by the 10th century, followed by a shift from an emphasis on cattle to sheep production (McGovern *et al*., 2007).

Other evidence of the development of adaptive strategies in Iceland through history can be found in the existence of grazing regulations in the early law codes (*Grágás* and *Jónsbók*) and research findings on different farm management aspects such as winter grazing areas (Simpson *et al*., 2004) and shieling areas (Brown *et al*., 2006). For later periods, it has been suggested that the insecure and short term tenancy system in place in Iceland in the 18th and early 19th century discouraged farmers from making any improvements or innovations on the farms (Jónsson, 1993). These harsh tenancy conditions, together with the restrictions imposed on labour mobility can be described by the "rigidity trap" concept. The rigidity trap refers to the ability of a system to persist "even beyond the point where it is adaptive and creative" (Holling *et al*., 2002d, p.96). A rigid state is characterised by a high degree of connectivity and the suppression of innovation, usually by methods of social control (Holling *et al*., 2002d; Hegmon *et al*., 2008). The rigid state described above would have constrained innovations which required a great deal of short-term effort, but from which benefits would only have accrued in the longer term. However, it is possible that small adaptive strategies could have taken place. For example, two management aspects identified in this study (i.e. the use of household waste and organic matter to control erosion and the flooding of the home-fields and meadows), were strategies which required continuous efforts but the effects of which would have been felt within a year as well as in the longer term. The proximity to water sources apart from being important for household use would have influenced the possibilities of flooding. An examination of the water sources of the study farms shows that four of them are on the shores of Lake Mývatn (Fagranes, Brjánsnes, Grimstaðir and Geirastaðir), two on the shores of smaller lakes (Grænavatn and Baldursheimur), two near streams (Gautlönd and Bjarnastaðir) and Þórleifsstaðir is the only farm which nearest water source (other than bog water) is the river Kráká 1.3 km away. Moreover, the wetland adjacent to its home-field is thought to have reduced in size, possibly both as a consequence of wind blown sand and sediments carried by the Kráká river from the southern highlands (McGovern *et al.,* 2007). The flooding-draining systems and other aspects of the home-fields and meadows were further developed in the 19th century when the land tenure conditions improved. For example, the farmer from Gautlönd pointed out that the irrigation channels and dams in his farm were made by his grandfather who was born in 1828 and died in 1888. Most of the farmers interviewed indicated their families have been living in the farm from the late 18th or the early 19th century. Another important aspect which stimulated farm improvements was the development in commercialisation derived from the opening of trade and the formation of cooperatives. In Mývatn the cooperative was founded in the late 19th century.

Coping capacity refers to short term responses to abnormal periods of stress. The access to natural resources, in particular wild food sources (i.e. eggs and fish), has been identified here as an indicator of coping capacity. Most of the farmers interviewed in this study recognized the possibilities of fishing and egg collecting in Lake Mývatn as an important source of support in difficult times. Although the importance of wild food sources in Iceland in the past has been often underestimated (e.g. Friðriksson, 1972; Tomasson, 1977), other researchers have explored their significance in the context of external stresses. For example, Vasey (1996) considers that wild food resources must have played an important role after the Laki eruption, given that vegetation and fisheries tend to recover more quickly than livestock. Vasey considers that taking into account that nine ewes were needed to support a person; the livestock left in 1785 would have supported fewer than 19,000 people when in fact the population at that time was 39,251 people. In another study Gudmundsson (1979), comparing egg counts from the *Jarðabók* with records from 1941, noticed that *Jarðabók* values were considerably lower. He suggested this discrepancy with the values could be due to understatements from the farmers to evade taxes, but also considers possible that the low counts were genuine and the result of overexploitation due to famine in preceding years. Thus, in general farms with access to wild food sources could respond to environmental stress by temporarily increasing their exploitation and, therefore, would be best able to withstand agricultural failures.

Resources directly involved in the livestock production system such as home-field, meadows, winter grazing areas and shieling areas, can also be considered components of its coping capacity. This is because a farm with a surplus of such resources could produce an immediate response to stress by renting or selling the resource to others. Thus, people with fewer resources are more likely to be affected by natural stresses than people with greater resources (Yohe and Tol, 2002). The quality of the productive resources was assessed in this thesis qualitatively by information extracted from the *Jarðabók* and from interviews to farmers. Additionally, other indirect indicators of productivity were assessed quantitatively, such as tax value and land rent records, number of servants and home-field Total P content. All these indicators are of course interrelated because the productivity of a farm was dependent on the quality of all of these resources and the tax value and land rent reflected this productivity. For example, the tax value and the land rent in many Scandinavian countries reflected the age and size of the farms. Thus, in Norway in the late middle ages the older and best farms had a high land rent and in general, younger farms with lower land rents became deserted before the larger ones (Gissel *et al.,* 1981). In this study all the successful farms are considered old due to either the presence of pagan burials or of a church or a chapel; however their tax value and land rent are not high in every case. These individual differences and the particular factors that contributed to the resilience or vulnerability in each of the study farms are discussed next.

Baldursheimur: the evidence from interviews, *Jarðabók*, SARs and micromorphology indicates this farm was very exposed and sensitive to sand storms and erosion. The presence of a pagan burial site indicates this farm was probably occupied by the 10th century. However, there are no signs of Baldursheimur being a particular productive farm. Its tax value from 1696 to 1847 is considered low compared to the other successful farms, although the most frequent valuation in Mývatnssveit. Despite its erosion and sediment deposition problems, the *Jarðabók* highlights its large outfields as an important resource. Thus, the reductions in the land and the livestock rent in 1712 are more likely to reflect a temporally reduction in productivity possibly due to a lack of manpower rather than land degradation. This is supported by the lack of servants recorded in 1703, very unusual for a big farm with high numbers of livestock and particularly so considering that there were only two people living on the farm by then. In a later census in 1835 the farm has still no servants but eight adults living in it. While there are signs of amendments used in the home-field Total P values are moderate, possibly reflecting low input of amendments combined with large inputs of wind blown sand. Although according to the *Jarðabók* this farm had problems of flooding of meadows, the interview to the farmer revealed they had access to the *Framengjgar* meadows. This was an important resource which could be partially or completely rented to others if necessary. In summary, although this farm was highly exposed and sensitive to sand storms and erosion, its resilience was given by its coping and adaptive capacity. The coping capacity relied on large outfields and access to good meadows and accordingly its adaptive capacity is reflected in the efforts to ameliorate the effects of sand deposition and to improve the productivity of meadows.

Gautlönd: this farm seems not to have been very exposed to sand storms, given that sand deposition is not mentioned in the *Jarðabók* and coarse mineral material content in the home-field is not as abundant as in Grænavatn or Baldursheimur. Although Gautlönd is located to the south of Lake Mývatn its more westerly position seems to be outside the influence of prevailing winds. The presence of a pagan burial site indicates this farm was probably occupied in the 10^{th} century. Indications of this farm's high productivity are given by its high Total P content in the home-field, reportedly good outfields, high LU, high number of servants and its high land rent in 1712. However, Gautlönd's tax value was moderate compared to the other successful study farms and its land rent was low in 1696. The increase in the land rent could have been produced by the farm absorbing or making temporal use of the then abandoned farms Litlu-Gautlönd and Bjarnastaðir. However, because the dates of abandonment of these farms are not known this cannot be confirmed. Other contributors of the coping capacity of the farm would have been the good fishing, although reported to be decreasing in 1712, and the possibility of renting shielings and meadows. Signs of adaptive management in this farm are the many irrigation channels and dams, which were made in the 19^{th} century by the current farmer's grandfather: Jon Sigurdsson. Jon Sigurdsson was also identified by other farmers in the area as one of the founders of the cooperative and someone who made many improvements in the community in general. In summary, this farm had a moderate exposure and sensitivity. It resilience was based on very high coping and adapting capacity. Its coping capacity was given by large outfields, abundance of meadows, good fishing and many shieling areas. Its adaptive management efforts are reflected in the irrigation channels and dam systems.

Geirastaðir: this farm had a comparatively low exposure and sensitivity to sand storms and erosion. The presence of a chapel indicates its ancient origins; however there is contradictory information about its productivity. On one hand, its low values of tax, land rent, livestock numbers and numbers of servants suggest it was probably a small or perhaps just an average farm. On the other hand, the high and very high Total P content in the home-field from pre-*Landnám* to present day suggests its home-field was the most productive of the study farms. Furthermore, the farm had access to good meadows, fishing and egg collecting. It is possible that the low valuation was carried over from older values, since the farm belonged to the Hólar see until 1550 and Church properties were usually taxed lower than private properties (Lárusson, 1967; Gissel *et al.,* 1981). Nevertheless, even assuming that the farm was small, this would have been offset by its low exposure and sensitivity and a still high coping capacity conferred by good meadows, fishing and egg collecting.

Grænavatn: this farm was very exposed and sensitive to sand storms and erosion. The presence of a chapel and the fact that it is mentioned in the book of settlements (Icelandic: *Landnámabók*) indicates this farm's ancient origins. Signs of high productivity are given by its very high tax value in 1696 and 1712 and very high land rent in 1696. The reduction in land and livestock rent in 1712 may have been a response to the smallpox epidemic. Other signs of high productivity are its high LU and number of servants. The Total P content in the home-field is very variable due to the influence of sand deposition but there are signs of intense management. Although the *Jarðabók* only reports a little fishing and egg collecting for this farm, the access to good firewood sources and to the *Framengjgar* meadows would have contributed to its coping capacity. A sign of adaptive management in this farm is the technique of applying organic matter to areas of sand deposition, still in practiced at present. To summarize, although this farm was very exposed and sensitive to erosion and deposition, its resilience was high due to its high coping and adaptive capacity. The resources constituting its coping capacity were conferred by its size and accessibility to firewood and meadows.

Grimstaðir: this farm had a comparatively low exposure and sensitivity to sand storms and erosion but high exposure to lava flow. The presence of a pagan burial indicates its ancient origins which is confirmed by its very high/high tax value and land rent. Other indicators of high productivity are the very high number of servants and moderate LU. Total P values are very low to moderate but may not be reliable measures of the main old home-field area as this was moved due to a lava flow. Apart from its large size, as indicated by its valuation, other contributors to the farm's coping capacity were the access to firewood, peat, meadows, angelica, fishing and especially egg collecting, the highest in the area even at present. In summary, Grimstaðir was a resilient farm due to a combination of a generally low exposure and sensitivity (although high exposure to lava flow) and high coping capacity.

Bjarnastaðir: this farm was probably very exposed to sand storms, although like the other farms surveyed in the area, very low SARs in the period immediately pre-*Landnám* show that the landscape was stable at the time of settlement. The area is also sensitive to erosion and rofabard formation. Total P analyses suggest its home-field had an inherently low fertility and did not achieve high productivity until after AD 1717. However, its location near the stream Gautlandalækur/Bjarnastaðalækur suggests this farm would have had access to natural and/or created meadows. This is supported by field observations of the home-field soil characteristics and by the accounts in the *Jarðabók* about the area being used by Gautlönd for hay making after its abandonment.

Brjánsnes: the presence of a sand dune system in Brjánsnes outfields confirmed its high exposure to sand and dust storms. Additionally, this farm might have been particularly sensitive to sand storms due to the presence of lava rock which would have reduced wind speeds and encourage sand deposition. Its low tax value and very low land rent suggests this was a small or not very productive farm. Other indicators of low productivity are its very low LU and low number of servants. The farm did have some important resources such as fishing, firewood and peat but the absence of meadows would have been a significant constraint.

Fagranes: this farm had low exposure to sand storms but was exposed instead to lava flows. However, research on historical volcanic eruptions in Iceland suggests that their impact was rarely fatal to settlements (Dugmore *et al*., 2007). Its very low tax value and land rent suggests it was a small/unproductive farm. Other indicators of low productivity are the low and very low Total P content in the home-field, very low LU and no servants. The farm had access to some resources, such as fishing, firewood and peat; however a major constraint was the lack of sufficient meadows, making necessary an extra payment for access to a sufficient quantity of this resource. Although this farm can be compared to Grímsstaðir in its level of exposure and sensitivity to environmental factors it was vulnerable due to its low coping capacity given by limited resources.

Þórleifsstaðir: based on SAR it can be inferred that this farm was very exposed to sand storms after AD 1717, but probably only moderately exposed while the farm was actually occupied. The area is also sensitive to erosion and rofabard formation. The productivity of this farm can only be analysed based on its home-field since the farm boundaries are not known. Total P analyses suggest the home-field had an initially moderate fertility but that it became impoverished soon after settlement. This reduction in productivity/fertility may have been compensated by extending the home-field. An archaeological survey indicates the initial home-field was 4.5 ha and that an extension was added to make it approximately 9 ha in total (Vésteinsson, 2008). The only source of water near the home-field is a wetland which is thought to have reduced considerably in size although the period of this reduction is unknown. The archaeological survey also shows there was some consumption of bird eggs on the farm. The reduction of the wetland would have affected the farm's hay production and probably the availability of eggs. Additionally, the distance to the river would have made the building of channels to flood the home-field and meadows very difficult. However, it is unknown whether the reduction of the wetland occurred during the occupation of the farm.

From this analysis it can be seen that the study farms, although in the same geographical area, had small scale differences in their exposure and sensitivity to environmental stresses. However, the case studies demonstrate that similar levels of exposure and sensitivity could result in different outcomes (i.e. success and failure). For example, Þórleifsstaðir and Baldursheimur, both located to the south of Lake Mývatn, had the same or a similar degree of exposure to sand storms and sensitivity to erosion. However, the failure to maintain the fertility of the home-field and the long distance of the home-field from water sources might have contributed to the greater vulnerability of Þórleifsstaðir. Another example is Grimstaðir and Fagranes which were both exposed to the lava flow from the volcanic eruption known as the Mývatn fires. However, Grimstaðir relocated its farm house and home-field and continued functioning whereas Fagranes was abandoned. The indicators analysed suggest that Fagranes had a very low coping capacity due to its low productivity and lack of natural resources and was thus more vulnerable to the lava flow. Other studies in Iceland have concluded that the abandonment of farms was not entirely a reaction to environmental degradation (e.g. Mairs *et al*., 2006).

In Fagranes case, its low tax value might have been associated with small size as has been suggested for farms in Norway by Gissel *et al*. (1981). If this is the case, it is possible that a minimum size for farm survival existed and that Fagranes was below the threshold. However, Brjánsnes, the only other failed farm for which tax values are available had the most frequent tax value in Mývatn, twelve hundred. Farms with this valuation level show a large variability in the indicators of productivity and availability of natural resources. It is not possible to test the association of tax value with farm size in Mývatnssveit because the original farm boundaries are not known. The valuation of farms could have included different criteria such as the availability of natural resources and whether the farm belonged to the Church or not.

7.3 Synthesis summary

Following the analysis and synthesis of the indicators, a model specific to Mývatnssveit of the factors generating resilience or vulnerability and ultimately contributing to the success or failure of farms in the past can be produced (Figure 61). In the model, the grey box represents factors to which the farms in Mývatn were exposed in a uniform way. Given the extension and the topographic characteristics of the study area, climatic factors are assumed to have been fairly homogeneous in the area (Chapter 3). Small scales differences in the exposure and sensitivity of farms to erosion and sand accumulation were found, but they were found not to be associated with success or failure and, therefore, are not included in the model (Chapter 4). Institutional factors contributed in some cases to the coping capacity of farms. An example of this is the subsidies the commune could give to farms with temporary difficulties (Chapter 6). However, institutional factors could also reduce or constrain the adaptive capacity of farms (symbolised by a triangle in the model). An example is given by the insecure tenancy conditions which discouraged the farmers from making land improvements (Section 7.2.3.2).

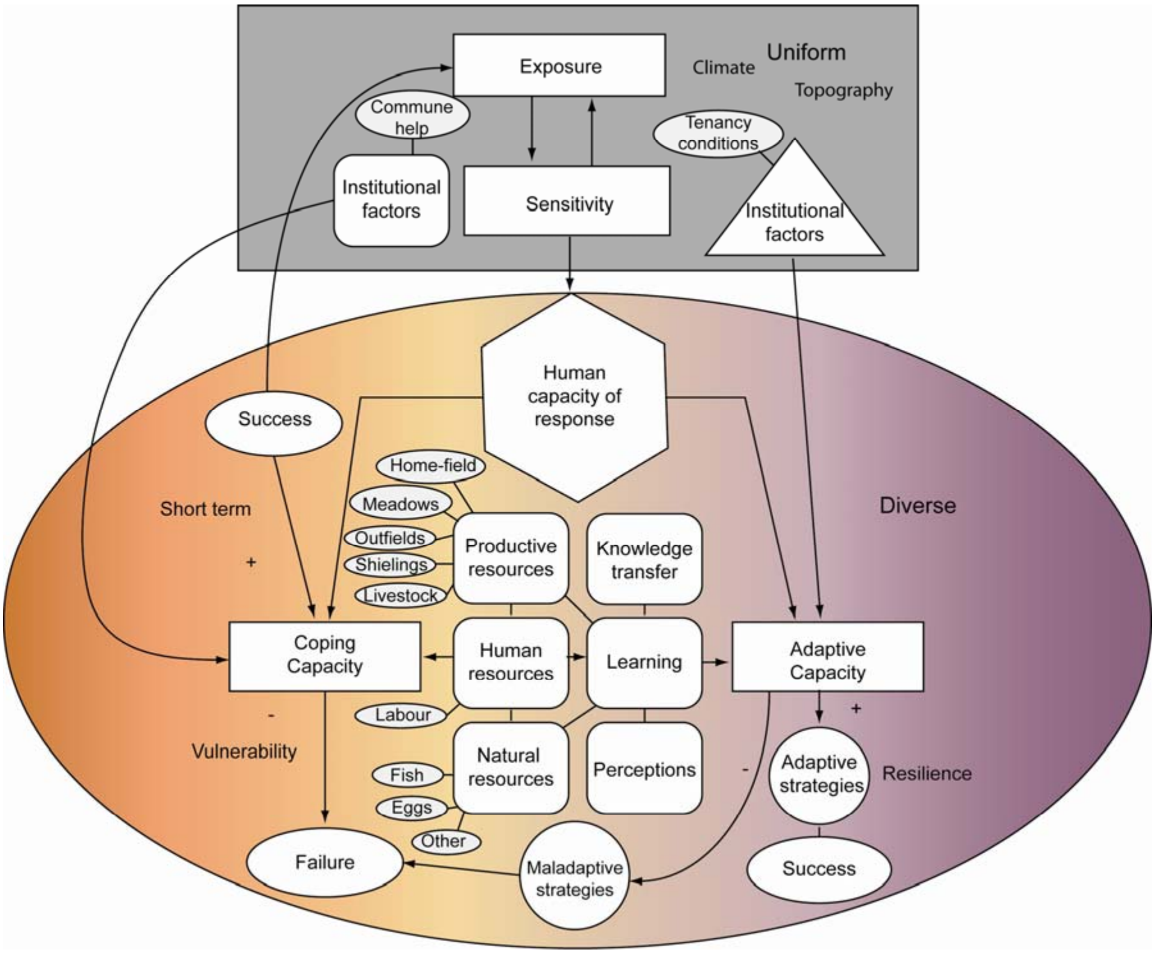

Figure 61- Model of factors influencing historical farm success and failure in Myvatnssveit, northern Iceland. See text for details.

The diversity of human responses to exposure comes from the combination of different factors in different degrees. The seeming uniformity of the farms in Mývatnssveit given by their shared production system and topographic characteristics masks a considerable diversity which emerges when the individual farms are considered in detail. The greater availability of natural resources of the farms with access to Lake Mývatn shaped their coping and adaptive capacity. Farms further away from the lake relied more on productive resources such as bigger outfields, or more shielings and meadows which could be rented out (Sections 5.4 and 6.1). Differences in the intensity of management, especially of the home-field, would have depended on factors such as the availability of labour, the amount and types of livestock in the farm (and as a consequence, the amount of manure), learning, knowledge transfer and perceptions (Chapters 4, 5 and 6). In many farms the lack or insufficiency of one resource was compensated by another, but failed farms had in general fewer resources (productive, human and natural) than successful farms. This lack of resources limited their capacity of response to environmental stresses increasing their vulnerability and leading to farm failure.

7.4 Theoretical framework vs. perceptions

The factors that farmers cited as influencing the historical success and failure of farms in Mývatnssveit are compared in Table 40 with the results reached through the integrative framework applied in this thesis. The order of the factors in the table follows the frequency in which they were named in the interviews. Thus, as reported in the ethnography results (Chapter 6), the factor “people” was mentioned most often among the farmers as influencing success and failure followed by vegetation, weather, farm size and amount of livestock. Although the methodology applied does not rank the factors considered in the integration of the data sets, points in common with farmers’ perceptions can be distinguished. The main point of agreement is the consideration of the human component as the principal factor influencing farm success and failure. The factor termed in the table “people” involves different aspects. In the interviews, certain people’s attributes were seen, by some respondents, as positive factors leading to success. These attributes were: “willingness to work” and “cleverness”, the latter described by a farmer as the ability to take advantage of available resources and of periods of good weather. The “cleverness” aspect can be matched in the theoretical framework with the learning and knowledge transfer components, which are reflected in the results in the evidence of successful management, such as the use of soil amendments in the home-fields, irrigation and soil erosion control. People’s willingness to work cannot be directly measured, especially in the past, but the number of workers per farm, in particular servants, used in the framework can be used as an equivalent, in that, in general, it should reflect the amount of available labour for farm work.

Table 40- Comparison of farmers' perceptions of the factors that have influenced farms success and failure in Mývatnssveit and the results from the integration of data.

Factor influencing success and failure	Perceptions	Theoretical framework and results
People	Willingness to work, use of available resources, cleverness.	Learning and knowledge transfer. Reflected in management aspects.
	Amount of people (negative)	Human resources. Amount of people, in particular servants (positive)
Vegetation	Possibilities of making hay and amount produced.	Productive resources. Reflected in the fertility of the home-field. Damage to home-fields and meadows highlighted in *Jarðabók* as main constraints.
	Vegetated area (connected with farm size).	Reflected in tax value and land rent. Quality of vegetated areas reported in *Jarðabók*
Weather	Affecting winter grazing and haymaking. General.	Assumption of changes in weather affecting the farms in a uniform way. Local scale differences in wind erosion but unrelated to successful/failure.
Farm size	Possibility of leasing areas.	Farm size reflected in the tax value and land rent, higher in successful than failed farms.
Livestock	Amount of livestock	LU reported in *Jarðabók*, very low in failed farms

A point of discrepancy between farmers' perceptions and the framework results was the consideration, by two of the respondents, that the amount of people per farm was a cause for farm failure. This can be explained by the changes in owner occupancy of farms and in household arrangements which occurred in Iceland in the late 19th and early 20th century. During this time period the opportunities for wage work, previously illegal, allowed farmers to obtain the capital to buy their farms. This triggered the emergence of large families and multiple households with kin replacing servants (Pinson, 1992). Therefore; the effects of the number of people per farm in farm success and failure may have differed between the 20th and the 18th century.

The factors: vegetation, farm size and livestock, also identified by the respondents as influencing farm success and failure in the past, are considered to be productive resources in the human capacity of response component of the theoretical framework (Figure 61). The only factor from the model not directly mentioned by the respondents as influencing farm success and failure in the past was “natural resources”, although it was implicit in the response regarding the ability of making use of available resources. Furthermore, the role of natural resources (i.e. fish and eggs) was emphasised in the interviews when the majority of the respondents identified Lake Mývatn as a support “institution” in times of need (see Chapter 6).

Two respondents cited weather as a cause for farm failure, but only one of these mentioned it as the only factor; half of the respondents identified multiple factors. It is interesting that none of the respondents mentioned erosion among the factors contributing to farm failure, even though the farmer at Garður had indicated that Brjánsnes was said to have been abandoned due to blown sand. This is in agreement with the lack of statistical differences found in SAR between successful and failed farms in Chapter 4.

Chapter 8 - The importance and limitations of the resilience framework in the assessment of historical vulnerabilities

Many theoretical frameworks and indicators have been used in the study of human and environmental interactions. This study used a theoretical framework devised from the integration of key concepts from climate change research to answer questions of farm success and failure. The following sections discuss the suitability of the indicators, spatial and temporal scales and of the theoretical framework used in this thesis for the study of historical dynamics and their potential for application to wider contexts.

8.1 The selection of resilience indicators and their application in the study of farm success and failure

The selection of indicators to use in any resilience research will depend on the system studied. In order to select indicators which adequately explain the resilience of a system it is necessary to define and characterise that system. Carpenter *et al*. (2001) highlight the importance of answering the question: resilience of what to what? In this research the resilience of north European livestock farming systems to environmental change was explored. Environmental change encompasses a wide array of factors including climate, soils and vegetation and it was out of the scope of this research to define all the environmental changes which have occurred in the history of Iceland. Instead, based on a review of historical climate change research, the study was based on the assumption that the main changes would have been general to the geographical area studied. Additionally, the main local differences in exposure and sensitivity to environmental factors were identified. It is suggested in this study that the differences in farm outcome (i.e. success vs. failure) are the result of differences in human responses defined by the farms' adaptive and coping capacities. Most of the indicators used in this research reflect the historical farms' relative ability to respond to environmental change and were grouped into those derived from historical records and those derived from soils records.

The indicators derived from historical sources revealed the human, natural and economic resources that were available to the farms and which were the main factors determining their coping and adapting capacities. Whether a resource denotes the coping or adaptive capacity of a system is context specific, an indicator of coping capacity in a particular system may be an indicator of adaptive capacity in another one. Moreover, the same indicator in a system can influence both its coping and adaptive capacity. For example, egg collecting in Mývatnssveit can be considered an adaptive strategy considering the evidence of its sustainable management from the 9th century to present day (Gudmundsson, 1979; McGovern *et al*., 2006; McGovern *et al*., 2007). However, it is also considered a coping strategy because given a short-lived period of stress (e.g. volcanic eruption, bad winter) farmers could have increased the collection of eggs in the short term (e.g. for a season) to cope with temporary food shortages. In the analysis of the adaptive capacity of a system, it is important not only to identify the resources available to carry out adaptations, or the particular cultural practices/adaptations that have been employed in response to a particular stress, but also to explore the factors that have constrained the implementation of other adaptation strategies. Some studies have highlighted that often factors beyond the individual level, such as social and political aspects, can limit the adaptive capacity of a SES (Smithers and Smit, 1997; Smit and Wandel, 2006; Cumming *et al*., 2006). For example, the main limitation for adaptation in Icelandic agriculture in the pre-modern period seems to have been the short-term and insecure nature of land tenancy contracts. Land tenure and restrictive lease conditions have been identified in other contexts as important limitations to adaptations and in consequence a factor reducing the resilience of farming systems (Scheffer *et al*., 2000; Carpenter *et al*., 2001). The legal restrictions on labour to participate in fishing activities and on free commercialization were additional limitations to the adaptive capacity of farmers. Due to these limitations most farms' resilience in pre-modern Iceland depended on their coping capacity rather than the longer term adaptive capacity.

Indicators derived from soils records in general have a wider application than historical records, both geographically and temporarily, as long as a chronology can be established. They can be derived from bulk soil samples and from micromorphological samples and the range of possible indicators goes from the relative content of different chemical elements to features observed in micromorphology. The most commonly used soil-derived indicators are chemical elements that can be associated with specific cultural activities and those which indicate relative levels of soil fertility. From the indicators derived from soil records, SARs were used to test the exposure/sensitivity in the farms. Total P content and micromorphology analyses on the other hand, provided information on the past productivity and management of the farms and therefore are also indicators of coping and adaptive capacity. The interviews with the older generation of farmers conducted in this study provided insights into local knowledge and perceptions. Although it is not possible to evaluate the differences in knowledge transfer and perceptions from people in successful and failed farms in the past, the interviews permitted an exploration of how these aspects might have influenced their adaptive capacity.

The theoretical framework used here can be extrapolated to other socio-ecological systems; however the indicators selected need to be case specific. For example, the indicators derived from historical records used here might only be available or applicable to Iceland and other Scandinavian countries for a particular time period. For example, Gissel *et al*. (1981) also used land rents and taxes in Scandinavia as part of their study on desertion and colonisation of Nordic countries in the Middle Ages. Other indicators of productivity or economic status such as market prices might be appropriate and available in other studies. In this sense soils present the advantage of being widely available. A limitation in the use of soil records however, is where a large number of sites need to be studied, due to the time and effort involved in the collection and analysis of the samples. Moreover, soils records should not be analysed in isolation of historical context and where possible the two types of records should be combined.

8.2 Spatial and temporal scales of study

The spatial scale of study in this research was defined by the farm units, based on 19th century boundaries. This delimitation together with local knowledge of old management areas (e.g. home-fields and winter grazing areas) allowed for comparisons on management and soil quality to be made between farms. However, the assessment of erosion in winter grazing areas and the erosion experiments carried out showed that erosion acts on a wider spatial scale. Although the SARs were inadequate as indicators of farm past erosion they served to assess the relative exposure and sensitivity of each farm to blown sand and deposition. The spatial scale of the erosion/accumulation process would have also created a management problem in the past for the farmers, if the main source of aeolian sediments came from outside the farm and the hreppur boundaries. This is reflected in management efforts in the past orientated towards restoring damaged areas but not to the stabilization of aeolian sediment sources. This difference in the spatial scale at which management and ecosystem processes function has been termed “spatial mismatch” and has been identified as a limitation to the adaptive capacity of systems in other contexts (Cumming *et al.,* 2006). Local knowledge also revealed that some farms had rights to resources outside their boundaries and that some leased areas (e.g. shielings) or resources (e.g. meadows) to other farms. This means that the Icelandic farm of the past cannot be defined only by physical boundaries but also by its accessibility to resources.

Resilience was analysed in this study at the scale of the individual farm and was linked to the notions of farm success and failure. However, if the scale of study was expanded to the level of the district, region or the whole country could farm abandonment be described as failure? New perspectives are increasingly being explored in studies of societal failure or collapse linked to environmental degradation. McAnany and Yoffee (2010) argue that societal collapse seldom occurs and that abandonment can be seen as the flexibility of people to seize opportunities in a different place. This point of view is also considered by Gissel *et al.* (1981) who highlight that desertion should be studied alongside with colonization; although in most cases it is difficult to match one with the other. In relation to degradation in southern Iceland, Dugmore (2007) argues that although the dramatic reduction in the extent of woodland can be seen as an ecological disaster, given that sufficient scattered woodland did survive to provide essential supplies of charcoal, it is more appropriate to consider it as a “landscape fit to purpose”. Most of the failed farms in this study were not re-occupied but became part of other farms. Only Bjarnastaðir was later re-occupied but while “abandoned” its land continue to be use by Gautlönd. This suggests that the failure of these farms increased the resilience (in the short or long term) of other farms and contributed to their success and of the hreppar in general.

With respect to time scales, it is important to consider what the indicators represent in the short and in the longer term. For example, the indicator "LU" has been used here in its economic sense as a positive factor decreasing the vulnerability of the farm systems when its value is high. However, high numbers of LU can also be considered a factor that increases vulnerability when is related to overgrazing and erosion problems. In this sense, Carpenter *et al*. (2001) stress that the time scale of the resilience needs to be considered since resilience in one time period can be gained at the expense of a succeeding period. In this manner, high numbers of LU per unit of land could contribute to the resilience of a farm by providing more food and income at a certain time but also generate vulnerability in a later period due to land degradation. The analysis made in this thesis considered total LU instead of LU/area because historical farm boundaries are not known for all the study farms. A further consideration to make with respect to time scales is that rather than the static value of an indicator at a specific time, in many circumstances it is the change of the indicator through time which makes it relevant. For example, the continual reduction in the land rent in the failed farms may be more significant than their particular value in AD 1712. The evolution in time of the indicators derived from soils was also important because the possibility of comparing pre-*Landnám* levels of soil accumulation and soil fertility with post-settlement levels permitted the teasing out of the influence of management from inherent soil characteristics.

In general, there is a marked contrast in the time scales considered in the resilience/vulnerability research arena according to whether the study aims at predicting human responses to future environmental stresses or at explaining historical situations. Studies aiming at predicting social responses to future stresses commonly include only present day data or a short time series. For example, although Luers *et al*. (2005)

recognise that the vulnerability of people and places is a complex phenomenon defined by a long history of human and environmental interactions, they consider for their assessment of vulnerability of wheat-based agricultural systems yield estimates for only four years. This is because they based their study on fast-changing variables (e.g. management) and treated slow-changing variables (e.g. soil quality) as constants. They recognise, however, that in the longer term some constants become variables that can lead to a change in sensitivity. These differences in the rate of change make difficult the integration of fast and slow changing variables.

Vulnerability studies, which aim at explaining historical situations such as the effects of natural disasters on SES, often examine longer time scales. The length of time considered varies in every case study but is usually connected with the identification of major changes in the system of production studied. For example, Fraser (2003) traces the Irish potato famine of 1845-1850 back to changes in grain prices in 1815 and to the collapse of the Irish industry in 1825 and 1840. These changes lead to the decline of the economic diversity of the system resulting in most of the Irish population relying on potato cultivation for their subsistence by 1845 and in the increased vulnerability of the country. The study of historical situations suggests that it is important to consider the long-term history of human-environmental interactions in any particular system when assessing its vulnerability at any point in time. This includes studies aiming at predicting human responses that look at present and future vulnerabilities. The question is how far back in history should vulnerability studies look? This is of course context dependent and should be determined by taking into consideration the different rates of change of the most important variables influencing the system. In reconstructing historical situations, it is also important to recognise points in time of significant external stresses and of major changes in the functioning of the system.

8.3 The resilience framework in the study of historical farm success and failure in Mývatnssveit and wider applications

It is clear that the study of social-ecological systems requires an interdisciplinary approach in order to avoid simplistic explanations of complex phenomena. However, there is continual debate on the appropriate theoretical framework or model to use for the integration of social and environmental data. Cumming and Collier (2005) highlight that there is no single correct model of complex systems and that "the choice of which model to use becomes a pragmatic issue rather than a philosophical one". The theoretical framework used here integrates the main concepts currently used in the resilience to climate change research. It is recognised that the terms resilience, vulnerability, adaptive capacity and sustainability have multiple levels of meaning ranging from the metaphorical to the specific (Carpenter *et al.,* 2001; Klein *et al*., 2003). Different levels of meaning are valid as long as these are clearly defined for the specific study. The point of view expressed by Carpenter *et al*. (2001) highlights the usefulness of these concepts in terms of their ability to influence research topics and stimulate productive hypotheses is shared here. Many models and frameworks might only be adequate for certain systems or situations. The model used here was useful for the local scale of the analysis and for the integration of quantitative and qualitative data. The general theoretical framework can be extrapolated to other social-ecological systems even if different indicators are selected. The concepts of resilience and adaptive capacity have been typically used in current climate change research, only recently have these aspects been considered in the study of long term dynamics (e.g. Redman, 2005;

Fraser, 2006; Fraser, 2007; Hegmon *et al*., 2008). The use of a research framework compatible with that of present climate change research in the study of historical situations can not only provide a better understanding of human responses to environmental change and of the sustainability of SES, but can also facilitate the transfer of this knowledge to inform policy makers.

Although the importance of different geographical and temporal scales of analysis is recognised care must be taken when aggregating data. Local scale analyses of resilience allow appreciation of the diversity and range of adaptive human responses which, if aggregated within a particular population, can be lost in average (Adger and Kelly, 1999). For this reason it was considered important to present the data both in terms of type of farm (i.e. successful vs. failed) and individually. This approach showed that the resilience and adaptive capacity of the farms relied on a combination of factors rather than individual variables.

8.4 Future research and concluding remarks

Throughout this study the potential for future research in different areas has been identified. For example, the information derived from micromorphology analysis combined with that from local knowledge suggests that wet meadows played an important role in farm survival. Research on the importance of hay production in historical farm systems in Iceland has typically focussed on the home-field, underestimating the importance of wet meadows. However, it has been estimated that up to the end of the 19th century about two thirds of the hay crop in Iceland came from wet meadows (Vasey, 1996). Although due to modern agriculture wet meadows have lost their economic value in Mývatnssveit, they are still important for their ecological and cultural heritage value. A more complete understanding of historical hay production and meadow management in Iceland can be obtained by assessing the cultural classification of wet meadows (e.g. *myrar* and *flóar*) and by comparing their past and present extension, management, quality and productivity. The assessment of past hay production can be achieved by reconstructing the areas of wet meadows in the past using historical maps and by determining productivity through vegetation surveys. Identification of different types of pedofeatures associated with wet meadows and home-field' soils (e.g. Ca-Fe-phosphate, Fe nodules) using micromorphology, combined with local knowledge on management aspects and element analysis using a scanning electron microscope (SEM) can be used to assess under what circumstances certain pedofeatures are formed. This information could facilitate the reconstruction of past management for time periods and areas in which local knowledge cannot be obtained.

Another opportunity for research combining local knowledge with micromorphology, is the investigation of areas that have been restored from erosion using traditional methods such as the use of old hay and manure. The identification of micromorphological signatures associated with such management practices would make it possible to apply this knowledge in the reconstruction of past management in areas where no living memory exists.

A different aspect which has not been fully explored in Iceland is the modelling of whole farm systems. Landscape pressures have been explored using a grazing simulation model developed by Thomson (2006). The model, named Búmodel, was developed based on Icelandic climate and vegetation to predict patterns of vegetation production and utilisation. Búmodel has so far been used for the assessment of winter grazing areas and shielings areas in Iceland and extrapolated to rangelands in the Faroe

Islands (Brown *et al*., 2006; McGovern *et al.,* 2007). However, it is difficult to apply the model to whole farm systems in Mývatnssveit not only because early farm boundaries are not known but also because of the uncertainties involved in the historical access to resources. Historical farm boundaries may be reconstructed by building on the work of Orri Vésteinsson on 19th century boundaries and patterns of settlement (Vésteinsson, pers. comm.; Vésteinsson, 1998; Vésteinsson, 2006). A key aspect of the boundaries' reconstruction would be to include the different management areas such as shielings, winter grazing areas, home-fields and wet meadows. This could be done by combining some of the information gathered here in interviews with the farmers with a landscape survey. Nonetheless, the lack of informants for every farm (e.g. failed farms) and of early land registers means that is not possible to reconstruct all the farms in the area in different time periods with the same degree of certainty. Another shortcoming in modelling long term productivity in the farms, is that Búmodel does not take into account the impact that vegetation over-utilisation outside the growing season has on vegetation growth in subsequent seasons (Thomson and Simpson, 2006). The reconstruction of a farm's access to resources is difficult to achieve in many cases and should be based on landscape analysis, historical records and local knowledge.

When considered at the level of the community, the story of Mývatnssveit is one of resilience. The 18th century has been called the "worst period of history" in Iceland (Tomasson, 1977) due to an increased exposure to variable and severe climate conditions and to other adverse factors such as the Danish trade monopoly, epidemics and volcanic eruptions. However, in this period only three early settled farms in Mývatnssveit were abandoned. This study suggests that these farms had a lower coping and adaptive capacity due to a limited accessibility to resources and having a lower home-field soil quality. Although the same amount of data was not available for the earlier abandoned farms (i.e. Bjarnastaðir and Þórleifsstaðir), soil-derived indicators suggest these farms had inherently lower home-field fertility or had an initially moderate fertility which was not maintained through time.

The analysis in this thesis has shown many aspects in common among the study farms, but has also highlighted their individuality. The farms, although located in the same geographical area and having the same production system, were variable in their level of management, their accessibility to natural resources and ultimately their productivity level. Success and failure has been analysed at the local level, however it is recognised that the failure of individual farms might have been connected to the success of other farms and of the community as a whole. All the deserted farms considered in this thesis became part of surviving farms and continued to produce resources. In this sense, farm abandonment can be seen as the re-organization of the community (*hreppar*) to enhance its overall resilience. Adger *et al*. (1999) convey this point maintaining that every social and economic change involves both "winners" and "losers" and that vulnerability at the population and at the individual levels can move in opposite directions. Other studies in Iceland have supported this association between success and failure. For example, Mairs *et al*. (2006) proposed that the abandonment of subsidiary farms was a sign of effective management strategy of the large complex settlement at Dalur to buffer environmental impacts across a larger area. Another example, is the study by Dugmore *et al*. (2006) which suggested that the clearance of farms from Þórsmörk in south Iceland might have had the purpose of protecting surviving woodland for charcoal production.

To learn lessons from the past, it is necessary not only to look at examples of failure but also at the successes. After all, as McAnany and Yoffe (2010) have expressed, in history human resilience has been the rule rather than the exception. Moreover, people can learn not only from their mistakes but also from their achievements. This thesis has provided an insight into the factors that influence the capacity of humans to respond to environmental stress and of ways in which this capacity of response can be evaluated. The basic theoretical framework and the methodologies developed in the thesis can be applied to a variety of geographical contexts and to studies of the past as well as present day situations.

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Appendix 1. Lab methodologies for soil bulk samples

All soil bulk samples were air dried and sieved to 2 mm previous to lab analyses.

Soil pH determination

Soil pH was determined using the standard method of Bascomb (1974). For this, 10g of soil was weighted into a beaker and 25 ml of distilled water was added. This was stirred and allowed to stand for 30 minutes. The metre was calibrated using buffer solutions of pH 7 and 4. The soil suspensions were stirred again before introducing the meter electrode. The pH was recorded to 1 decimal place when the reading was stable. The pH was measured again after adding 2 ml of 0.01M Calcium Chloride ($CaCl_2$).

Soil organic matter determination by Loss on Ignition (LOI)

A small quantity of soil from each sample was placed into a crucible and weighted. The crucibles were then placed into a muffle furnace and left overnight (approximately 16 h) at a temperature of 425 ˚C (Ball, 1964). They were placed into a dessicator to cool for 45 minutes before re-weighting. LOI was calculated by the equation:

$$\% LOI = \frac{W2 - W3}{W2 - W1} * 100 \;;$$

Where:

W1= weigh of empty crucible
W2 = weight of crucible with air dry soil
W3 = weight of crucible with furnace sample

Soil Total P determination by sodium hydroxide fusion

This procedure was carried out for all of the bulk soil samples from the home-fields including three replicates. In addition to this, three "blank" samples were processed to test for possible contamination. For this procedure soil samples were sieved to 90 µm. To eliminate its calcareous content, 2g of soil per sample were weighted into beakers and 0.5M chloridric acid (HCl) added to cover the soils. After stirring, the suspensions were left standing overnight at room temperature. The suspensions were then filtered using a Buchner flask and GF/C filters. The filters were then rinsed with distilled water to remove any traces of acid. The filters containing the samples were left in the oven to dry overnight at a temperature of 105˚C.

Total P was determined on these samples using the sodium hydroxide fusion method of Smith and Bain (1982), followed by colorimetric measurement in solution. To this end, 0.1 g of soil per sample was weighed into nickel crucibles. A 1g pellet of Sodium Hydroxide (NaOH) was added to each crucible. The crucibles were heated over a Bunsen burner until the pellets were liquid and mixed with the soil. The crucibles were left to cool down for a few minutes and then placed into 50 ml beakers. 25 ml of distilled water were poured into the beakers and these were covered and left overnight. Water and sample were stirred and poured into 50 ml cylinders and made up to 45 ml with distilled water. The samples were transferred into centrifuge tubes and centrifuge at 3000 rpm for 10 minutes. The supernatant liquid was transferred into plastic bottles using a pipette.

For the colorimetric determination the following solutions were prepared before hand: stock ammonium molybdate, stock phosphorus standard and diluted phosphorus standard solutions of 0, 2, 4, 6, 8 and 10 µm of P. The preparation of these solutions was as follow:

1.2% stock Ammonium Molybdate reagent: 6 g of Ammonium Molybdate Tetrahydrate and 0.150g of Antimony Potassium Tartrate were dissolved in 300 ml of distilled water. 74 ml of concentrated Sulphuric acid was added. This was allowed to cool before transferring to a 500 ml volumetric flask and made to volume with distilled water.

Phosphorus stock solution (0.1 mg P/ml): 0.4393 g of Potassium dihydrogen orthophosphate (KH_2PO_4) dried at 105˚C were dissolved in 500 ml of distilled water and 1 ml of HCl was added. This was then transferred into a 1000 ml volumetric flask and made to volume with distilled water. A drop of Toluene was added.

Dilute Phosphorus standard (2 µm/ml): 1 ml of the Phosphorus stock solution was made to volume in a 50 ml volumetric flask with 2.5% Acetic acid.

Standard 0 µm P: made by adding 5 ml of distilled water, 20 ml of 1.2% stock Ammonium Molybdate and 5 ml of Ascorbic acid.

Standard 2 µm P: made by adding 1 ml of dilute P-standard, 4 ml of distilled water, 20 ml of stock Ammonium Molybdate and 5 ml of 1.5% Ascorbic acid.

Standard 4 µm P: made by adding 2 ml dilute of P-standard, 3 ml of distilled water, 20 ml of stock Ammonium Molybdate and 5 ml of Ascorbic acid.

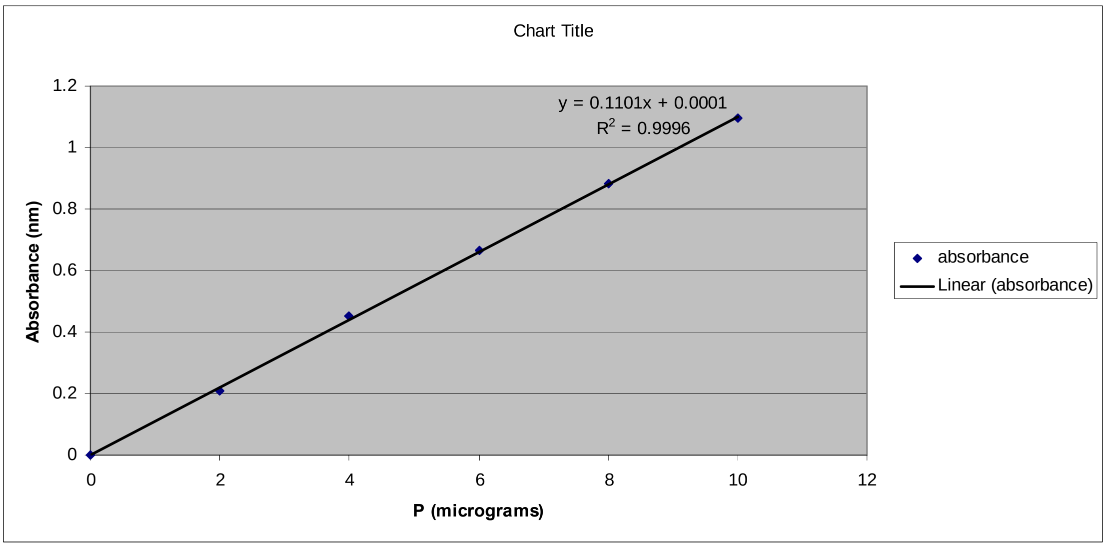
Standard 6 µm P: made by adding 3 ml of dilute P-standard, 2 ml of distilled water, 20 ml of stock Ammonium Molybdate and 5 ml of Ascorbic acid.

Standard 8 µm P: made by adding 4 ml of dilute P-standard, 1 ml of distilled water, 20 ml of stock Ammonium Molybdate and 5 ml of Ascorbic acid.

Standard 10 µm P: made by adding 5 ml of dilute P-standard, 20 ml of stock Ammonium Molybdate and 5 ml of Ascorbic acid.

In 50 ml volumetric flasks the samples were prepared by adding 5 ml of sample solution, 20 ml of dilute ammonium molybdate reagent and 5 ml of ascorbic acid. Because the sample solutions were developing darker than the standards dilutions were made with 1 ml of the soil sample supernatant in 4ml of distilled water per sample, and in some cases with 0.5 ml of soil sample supernatant in 4.5 ml of distilled water. These were again prepared into solutions adding 20 ml of stock Ammonium Molybdate and 5 ml of Ascorbic acid. All the samples and standards were allowed at least 30 minutes for colour development.

The absorbance of the standards and samples was measured in a 40 mm cell at 880 mm using distilled water to zero the colorimeter. These standards were used to plot a graph of absorbance against relative concentration of P.



L

inear regression of P standard solutions.

The equation of the trend line was then used to calculate the concentrations of total P in the samples. This concentration was then transformed into expressions of mg of soil in 100g of soil by multiplying the μg of P in the samples by 45 (for the 1 in 4 ml dilutions) or by 90 (for the 0.5 in 4.5 ml dilutions).

Particle size analysis

Particle size analysis was carried out using Coulter Counter equipment. For samples with an organic matter content of more than 10%, particle size analysis was determined using soils which had undergone LOI.

Each soil sample was spooned out to a clean 60ml wide neck plastic bottle to fill approximately 2-3 cm of the bottle. The soil was covered with approximately the same amount of distilled water. 2 ml of Calgon were added to the bottle. The bottles were shook manually first and then using an automatic shaker for at least an hour. One sample at a time was analysed in the Coulter Counter, which was set to Optical Module. For this, the sample bottle was placed on a magnetic stirrer machine. Sample solution was taken from the bottle using a Pasteur pipette and added, drop-wise, to the funnel of the Coulter Counter. The machine, connected to a PC indicates how much sample to add. The analysis are done automatically and saved in the computer. This procedure was repeated for each sample.

Appendix 2- Results of the Tukey method of multiple comparisons for the factors "time period" and "outcome"

```
Tukey 95.0% Simultaneous Confidence Intervals
Response Variable ln-sar
All Pairwise Comparisons among Levels of time-period
time-period = 1  subtracted from:
time-period    Lower  Center  Upper    -+---------+---------+---------+-----
2            -0.6840  0.4519  1.588        (-----------*----------)
3            -0.4148  0.8552  2.125           (------------*-----------)
4            -0.2193  1.0507  2.321             (------------*-----------)
5             0.0545  1.1904  2.326                (----------*----------)
                                       -+---------+---------+---------+-----
                                     -1.0       0.0       1.0       2.0
time-period = 2  subtracted from:
time-period    Lower  Center  Upper    -+---------+---------+---------+-----
3            -0.7327  0.4033  1.539        (----------*----------)
4            -0.5372  0.5988  1.735          (----------*----------)
5            -0.2452  0.7385  1.722             (--------*---------)
                                       -+---------+---------+---------+-----
                                     -1.0       0.0       1.0       2.0
time-period = 3  subtracted from:
time-period   Lower  Center  Upper    -+---------+---------+---------+-----
4            -1.075  0.1955  1.466    (------------*------------)
5            -0.801  0.3352  1.471       (----------*-----------)
                                      -+---------+---------+---------+-----
                                    -1.0       0.0       1.0       2.0
time-period = 4  subtracted from:
time-period    Lower  Center  Upper    -+---------+---------+---------+-----
5            -0.9962  0.1397  1.276     (----------*-----------)
                                       -+---------+---------+---------+-----
                                     -1.0       0.0       1.0       2.0
```

```
Tukey Simultaneous Tests
Response Variable ln-sar
All Pairwise Comparisons among Levels of time-period
time-period = 1  subtracted from:
             Difference       SE of            Adjusted
time-period    of Means  Difference  T-Value    P-Value
2                0.4519      0.3816    1.184     0.7600
3                0.8552      0.4266    2.005     0.2980
4                1.0507      0.4266    2.463     0.1377
5                1.1904      0.3816    3.120     0.0372
time-period = 2  subtracted from:
             Difference       SE of            Adjusted
time-period    of Means  Difference  T-Value    P-Value
3                0.4033      0.3816    1.057     0.8260
4                0.5988      0.3816    1.569     0.5319
5                0.7385      0.3305    2.235     0.2059
time-period = 3  subtracted from:
             Difference       SE of            Adjusted
time-period    of Means  Difference  T-Value    P-Value
4                0.1955      0.4266   0.4583     0.9902
5                0.3352      0.3816   0.8786     0.9016
time-period = 4  subtracted from:
             Difference       SE of            Adjusted
time-period    of Means  Difference  T-Value    P-Value
5                0.1397      0.3816   0.3662     0.9959
```

```
Tukey 95.0% Simultaneous Confidence Intervals
Response Variable ln-sar
All Pairwise Comparisons among Levels of outcome-1
outcome-1 = 1  subtracted from:
outcome-1     Lower   Center   Upper   --------+---------+---------+--------
2           -0.8489  -0.3346  0.1796   (----------------*----------------)
```

```
                                            --------+---------+---------+--------
                                                -0.60     -0.30      0.00
Tukey Simultaneous Tests
Response Variable ln-sar
All Pairwise Comparisons among Levels of outcome-1
outcome-1 = 1  subtracted from:
           Difference       SE of           Adjusted
outcome-1    of Means  Difference  T-Value   P-Value
2             -0.3346      0.2473   -1.353    0.1904
```

Key:

Time periods:

1= pre-*Landnám*

2= *Landnám*- AD 1477

3= AD 1477-1717

4= AD 1717- present

5= AD 1477- present

Outcomes:

1= Success

2= Failure

The highlighted confidence interval and adjusted P-value above shows that SARs in the AD 1477-present period were greater than in the pre-*Landnám* period.

Appendix 3- Model testing

Model testing (Mass flux vs. height)

F test/general test

$H_{\emptyset}$: $y = \alpha + \beta x$

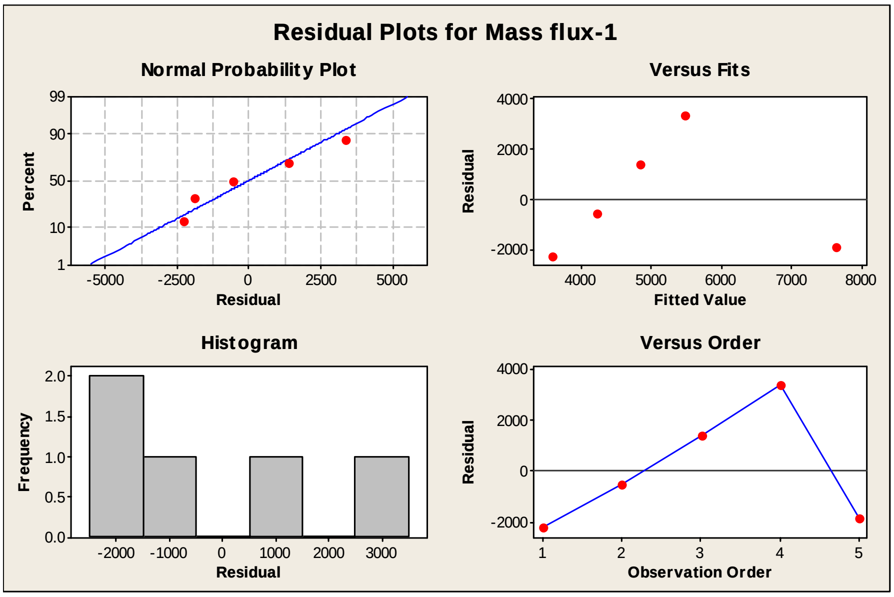
H_1: $y = \alpha + \beta_1 x + \beta_2 x^2$

Linear model

Trap 1-Baldursheimur

Regression Analysis: Mass flux-1 versus Height

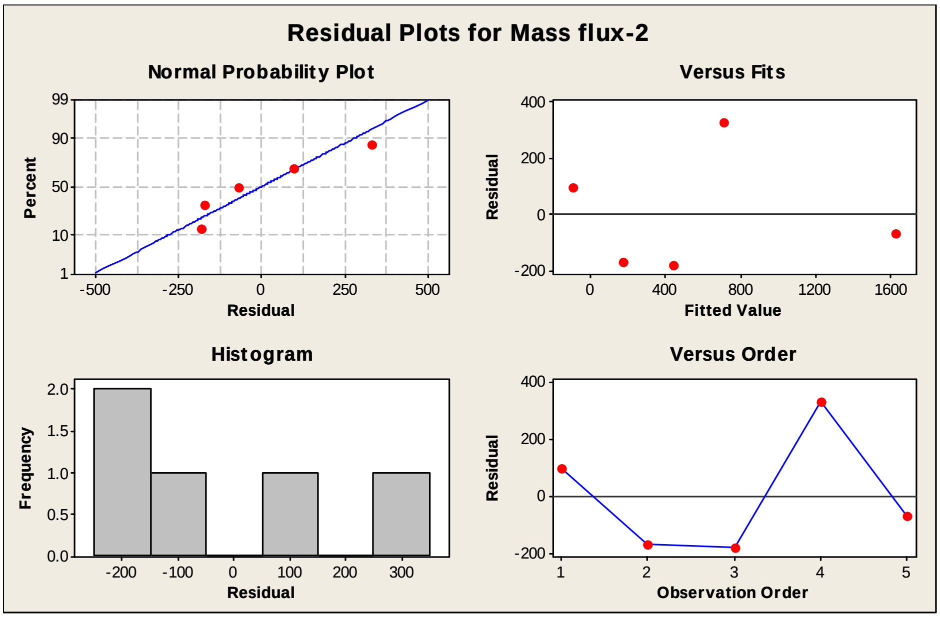
```
The regression equation is
Mass flux-1 = 3124 + 9012 Height


Predictor  Coef  SE Coef     T      P
Constant   3124     2152  1.45  0.243
Height     9012     7905  1.14  0.337


S = 2735.16   R-Sq = 30.2%   R-Sq(adj) = 7.0%


Analysis of Variance

Source          DF        SS       MS     F      P
Regression       1   9723999  9723999  1.30  0.337
Residual Error   3  22443317  7481106
Total            4  32167315
```



Trap 2-Gautlond

Regression Analysis: Mass flux-2 versus Height

```
The regression equation is
Mass flux-2 = - 287 + 3831 Height


Predictor     Coef  SE Coef      T      P
Constant    -286.8    195.7  -1.47  0.239
Height      3831.5    718.7   5.33  0.013


S = 248.663   R-Sq = 90.5%   R-Sq(adj) = 87.3%


Analysis of Variance

Source          DF       SS       MS      F      P
Regression       1  1757492  1757492  28.42  0.013
Residual Error   3   185501    61834
Total            4  1942993
```

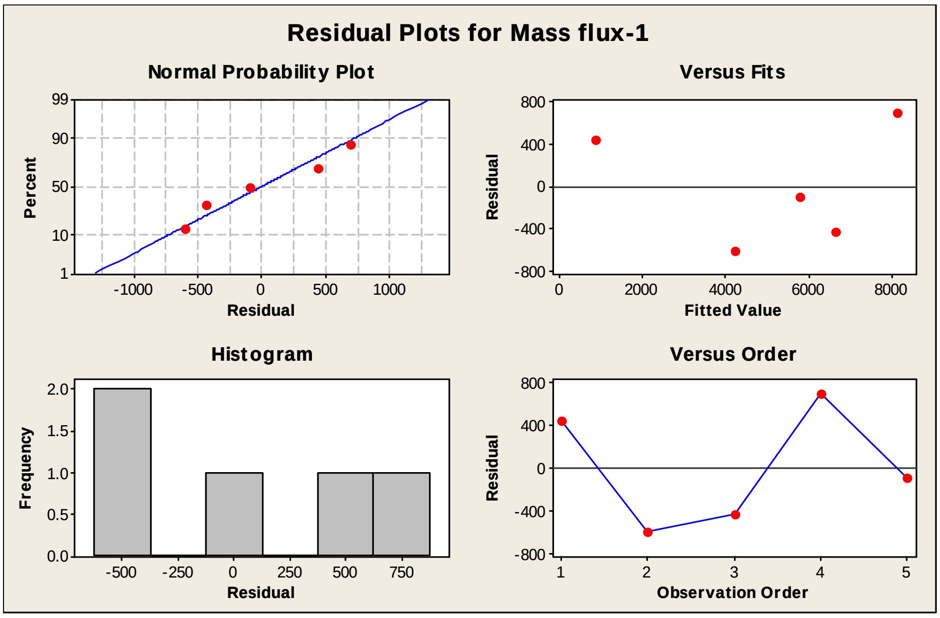


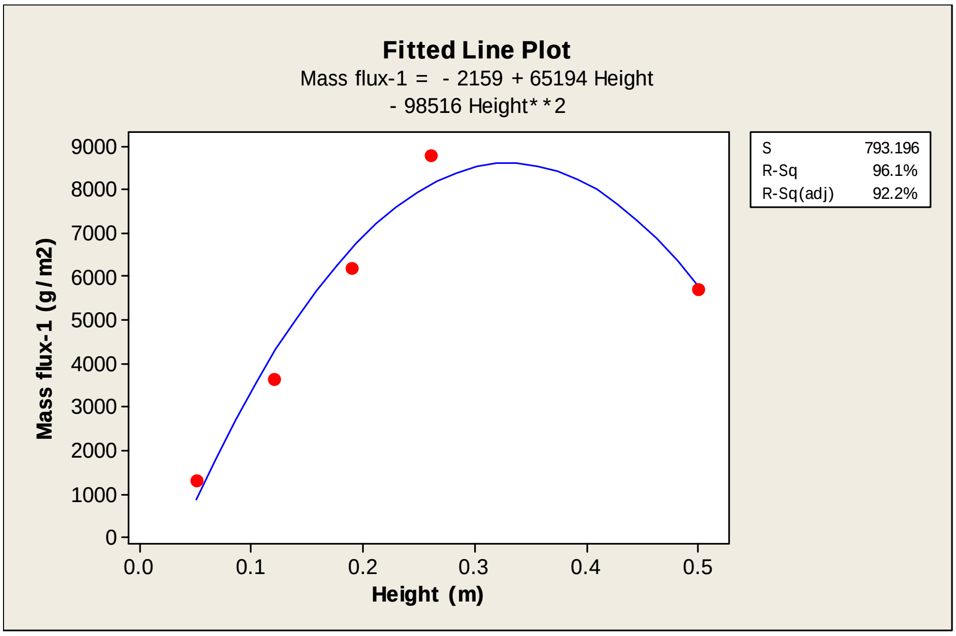
Quadratic model

Trap 1-Baldursheimur

Polynomial Regression Analysis: Mass flux-1 versus Height

```
The regression equation is
Mass flux-1 = - 2159 + 65194 Height - 98516 Height**2


S = 793.196   R-Sq = 96.1%   R-Sq(adj) = 92.2%


Analysis of Variance

Source      DF        SS        MS      F      P
Regression   2  30908995  15454498  24.56  0.039
Error        2   1258320    629160
Total        4  32167315


Sequential Analysis of Variance

Source     DF        SS      F      P
Linear      1   9723999   1.30  0.337
Quadratic   1  21184996  33.67  0.028
```


Residual Plots for Mass flux-1
Normal Probability Plot
Percent
Residual
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
Residual
Observation Order


Fitted Line Plot
Mass flux-1 = - 2159 + 65194 Height
- 98516 Height**2
S 793.196
R-Sq 96.1%
R-Sq(adj) 92.2%
Mass flux-1 (g/m2)
Height (m)

Trap 2- Gautlönd

Polynomial Regression Analysis: Mass flux-2 versus Height

The regression equation is
Mass flux-2 = - 388.5 + 4912 Height - 1896 Height**2

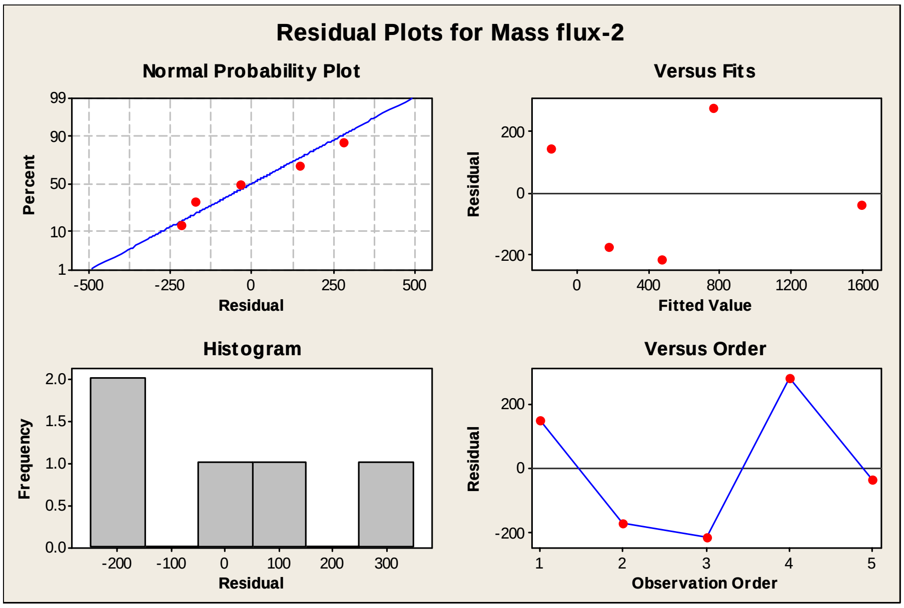
S = 298.042   R-Sq = 90.9%   R-Sq(adj) = 81.7%

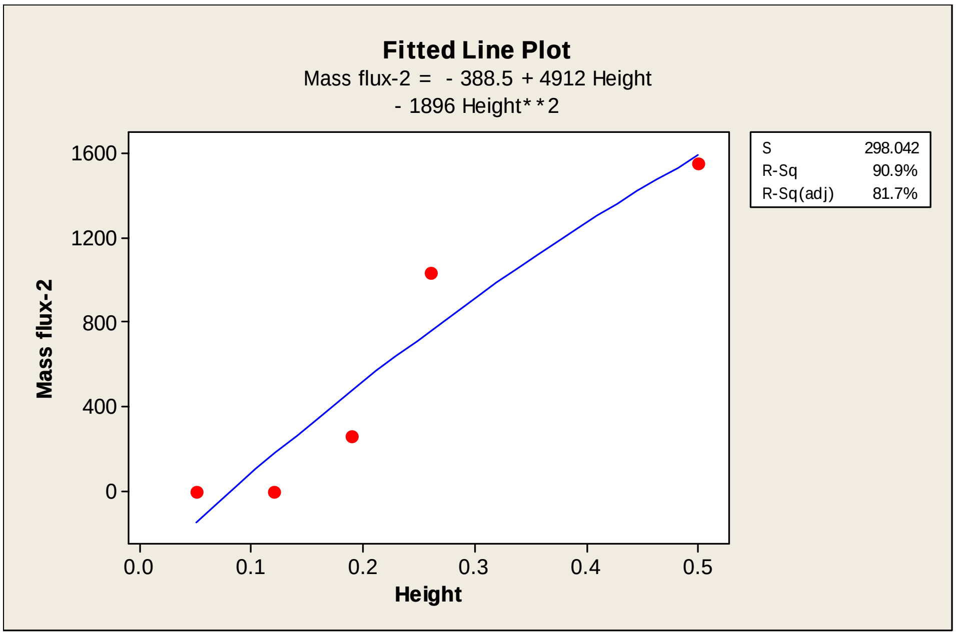
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	1765335	882668	9.94	0.091
Error	2	177658	88829		
Total	4	1942993			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	1757492	28.42	0.013
Quadratic	1	7843	0.09	0.794





Testing linear vs. quadratic regressions

Sediment Trap 1-Baldursheimur

$$F = \frac{(22443317 - 1258320)/(3-2)}{1258320/2} = 33.68$$

Table F= 18.51

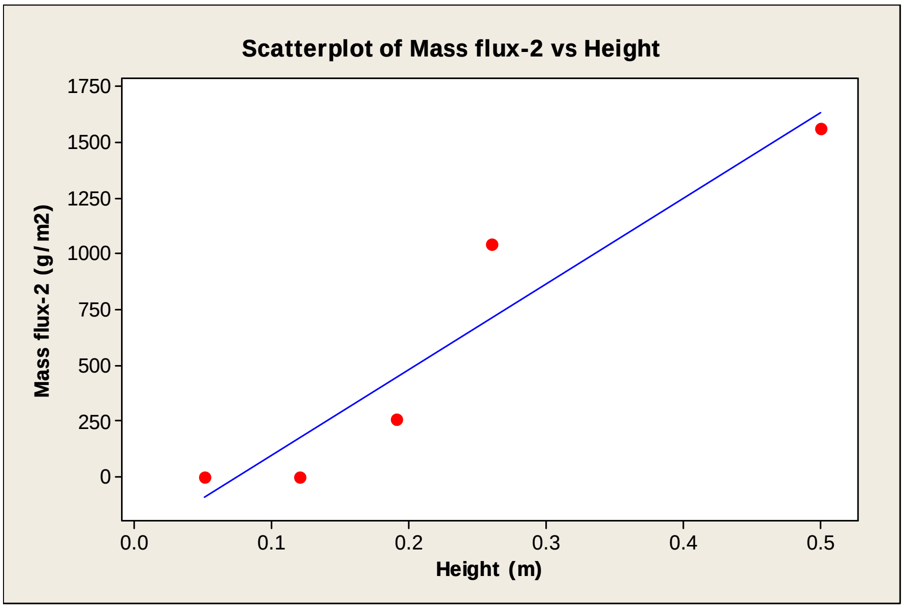
The calculated F value is bigger than the tabulated value so the HØ is rejected (quadratic equation fits better).

Sediment Trap 2-Gautlönd

F= 185501 – 177658/3-2 = 0.088

177658/2

The calculated F value is smaller than the tabulated value so the HØ is accepted (linear equation fits better).



Testing quadratic vs. cubic regression (for Baldursheimur)

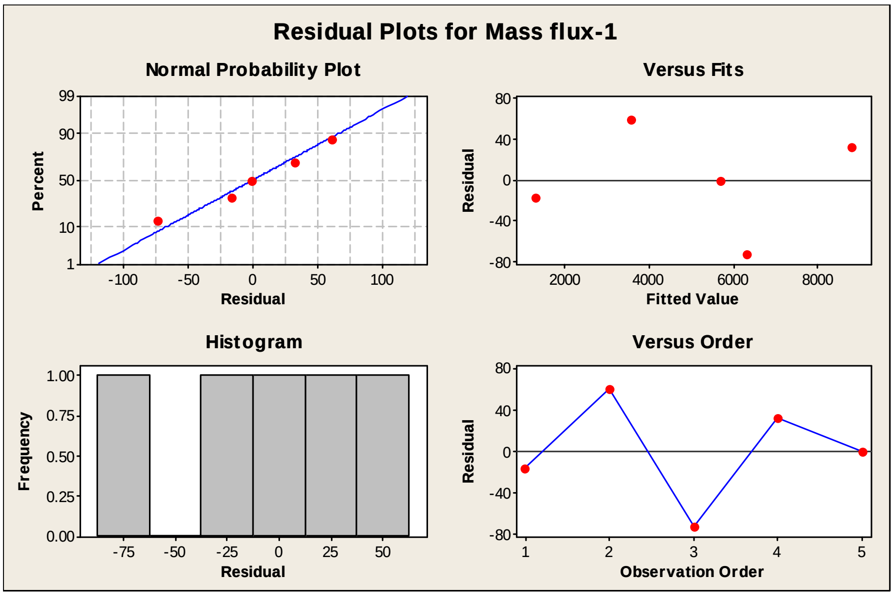
Polynomial Regression Analysis: Mass flux-1 versus Height

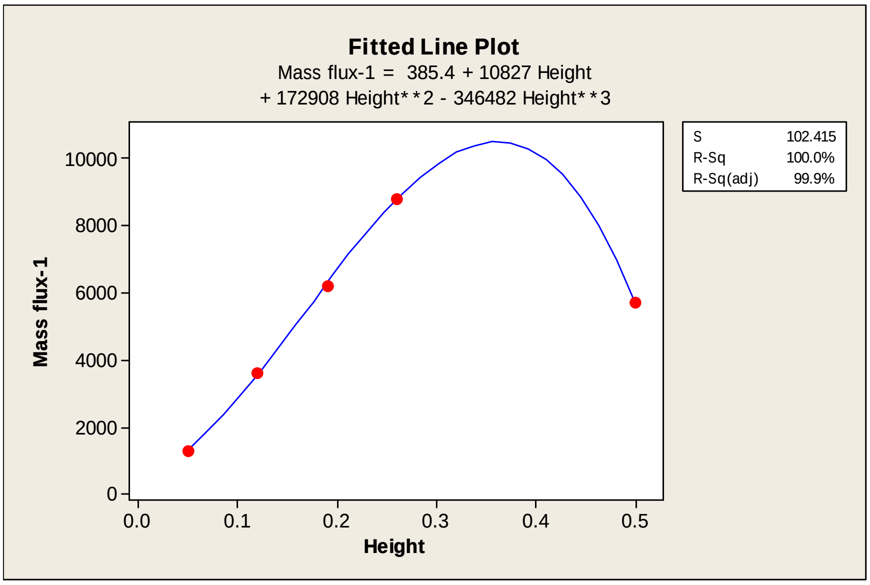
```
The regression equation is
Mass flux-1 = 385.4 + 10827 Height + 172908 Height**2 - 346482 Height**3


S = 102.415   R-Sq = 100.0%   R-Sq(adj) = 99.9%


Analysis of Variance
```

Source	DF	SS	MS	F	P
Regression	3	32156827	10718942	1021.95	0.023
Error	1	10489	10489		
Total	4	32167315			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	9723999	1.30	0.337
Quadratic	1	21184996	33.67	0.028
Cubic	1	1247832	118.97	0.058





$$F = \frac{1258320 \quad - 10489 \quad / \, 2 - 1}{10489 \quad / 1} = 118.97$$

Tabulated F = 161.448

The calculated F value is smaller than the tabulated value so the HØ is accepted (quadratic equation fits better).

Appendix-4- Measurements of soil surface level over a year in erosion spots

Sediment trap at Baldursheimur

Point	01 July 2008	01 July 2009	Measure1-ref1	measure1-ref2	Measure2-ref1	Measure2-ref2	Difference 1	Difference 2
1	233	273	17	169	17	170	0	-1
2	234	274	18	170	18	171	0	-1
3	235	275	19	171	19	172	0	-1
4	236	275	20	172	19	172	1	0
5	220	261	4	156	5	158	-1	-2
6	220	260	4	156	4	157	0	-1
7	220	260	4	156	4	157	0	-1
8	225	263	9	161	7	160	2	1
9	224	265	8	160	9	162	-1	-2
10	226	266	10	162	10	163	0	-1
11	211	251	-5	147	-5	148	0	-1
12	210	249	-6	146	-7	146	1	0
13	210	248	-6	146	-8	145	2	1
14	208	248	-8	144	-8	145	0	-1
15	213	253	-3	149	-3	150	0	-1
16	216	256	0	152	0	153	0	-1
17	199	238	-17	135	-18	135	1	0
18	199	239	-17	135	-17	136	0	-1
19	200	240	-16	136	-16	137	0	-1
20	199	238	-17	135	-18	135	1	0
21	205	244	-11	141	-12	141	1	0
22	206	246	-10	142	-10	143	0	-1
23	187	226	-29	123	-30	123	1	0
24	186	226	-30	122	-30	123	0	-1
25	186	228	-30	122	-28	125	-2	-3

26	189	229	-27	125	-27	126	0	-1
27	193	233	-23	129	-23	130	0	-1
28	195	235	-21	131	-21	132	0	-1
29	178	220	-38	114	-36	117	-2	-3
30	178	220	-38	114	-36	117	-2	-3
31	180	219	-36	116	-37	116	1	0
32	180	217	-36	116	-39	114	3	2

Key: Measure1: measurement taken in 2008
Measure2: measurement taken in 2009

Sediment trap at Gautlönd

Point	01 July 2008	01 July 2009	Measure1-ref1	Measure1-ref2	Measure2-ref1	Measure2-ref2	Difference 1	Difference 2
1	149	179	109	-12	108	-12	1	0
2	150	181	110	-11	110	-10	0	-1
3	154	185	114	-7	114	-6	0	-1
4	154	187	114	-7	116	-4	-2	-3
5	156	208	116	-5	137	17	-21	-22
6	155	187	115	-6	116	-4	-1	-2
7	156	187	116	-5	116	-4	0	-1
8	159	190	119	-2	119	-1	0	-1
9	162	193	122	1	122	2	0	-1
10	169	200	129	8	129	9	0	-1
11	164	201	124	3	130	10	-6	-7
12	163	193	123	2	122	2	1	0
13	163	194	123	2	123	3	0	-1
14	166	197	126	5	126	6	0	-1
15	168	200	128	7	129	9	-1	-2
16	177	207	137	16	136	16	1	0
17	172	191	132	11	120	0	12	11
18	170	201	130	9	130	10	0	-1
19	170	202	130	9	131	11	-1	-2
20	173	205	133	12	134	14	-1	-2
21	177	209	137	16	138	18	-1	-2

22	182	213	142	21	142	22	0	-1
23	181	185	141	20	114	-6	27	26
24	179	210	139	18	139	19	0	-1
25	179	210	139	18	139	19	0	-1
26	181	212	141	20	141	21	0	-1
27	183	215	143	22	144	24	-1	-2
28	188	218	148	27	147	27	1	0
29	187	222	147	26	151	31	-4	-5
30	186	219	146	25	148	28	-2	-3
31	189	217	149	28	146	26	3	2
32	191	218	151	30	147	27	4	3

Key: Measure1: measurement taken in 2008
Measure2: measurement taken in 2009

Appendix-5 Key to micromorphological descriptions

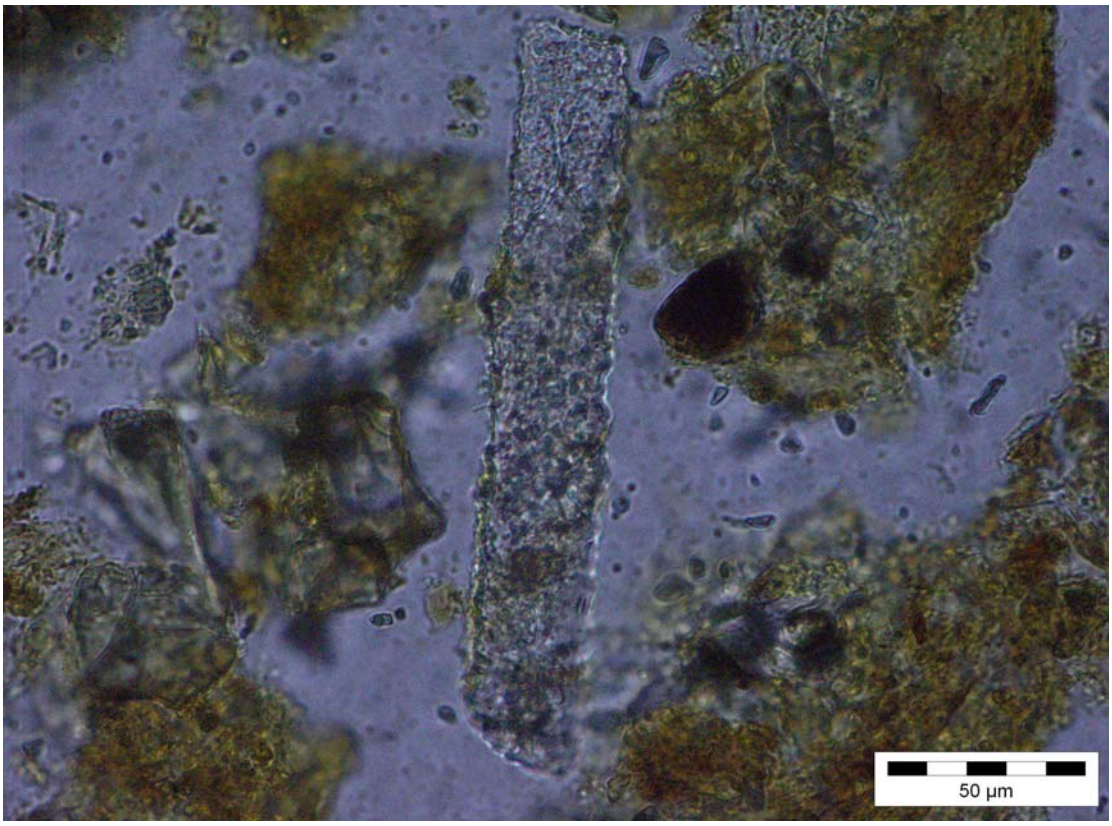
Abbreviation	Micromorphological component
	Fine mineral material
Br	Brown
D-Br	Dark brown
D-Gry	Dark grey
Gry	Grey
L-Gry	Light grey
L-Yb	Light yellowish brown
L-Ye	Light yellow
OIL	Oblique incident light
O/m	Organo-mineral
Or	Orange
PPL	Plain polarized light
R	Red
Rb	Reddish brown
Wh	White
XPL	Crossed polars
Yb	Yellowish brown
	Groundmass b Fabric
Ss	Stipple-speckled
	Microstrocture
Chn	Chanel
Chm	Chamber
Co	Complex
Cr	Crumb
Gr	Granular
In mi	Integrate microagregate
La	Laminar

Le	Lenticular
Ma	Massive
Pg	Pellicular grain
Pl	Platy
Sg	Singular grain
Ve	Vesicular
Vu	Vughy
	Sorting
M	Moderately sorted
P	Poorly sorted
W	Well sorted

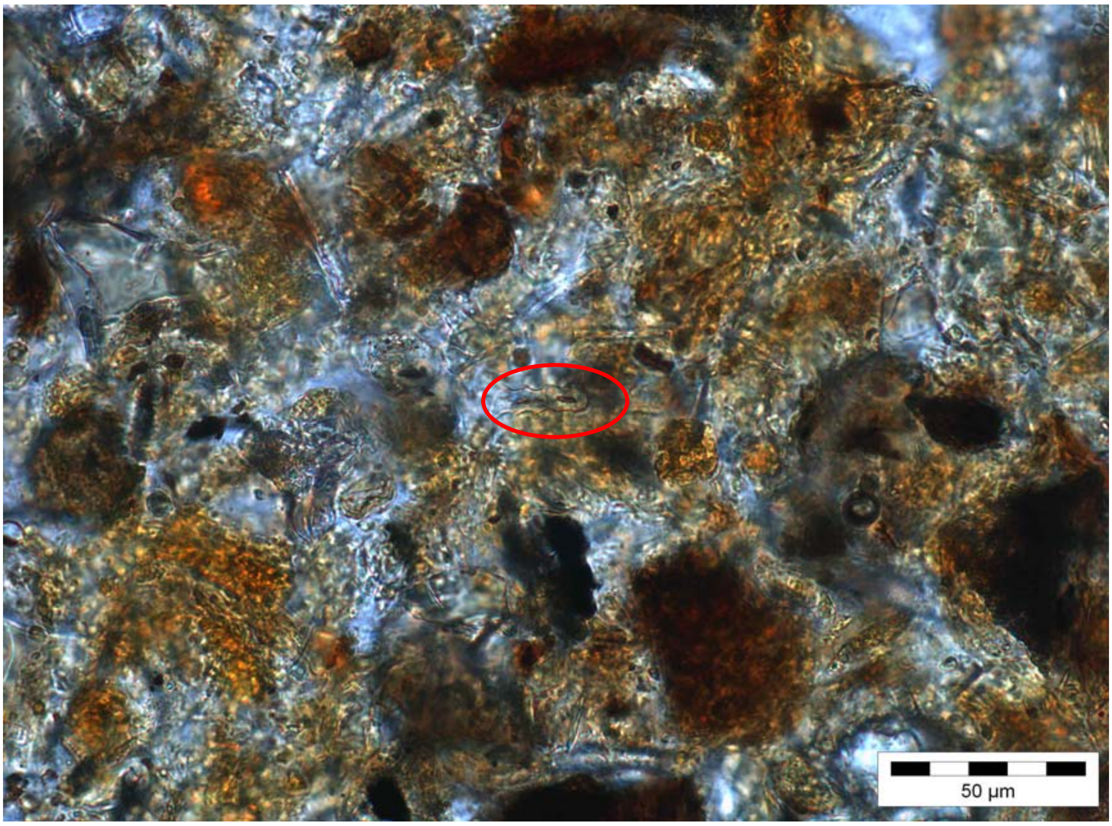
Coarse material arrangement

Ba	Banded
Int	Interlaced
Li	Linear
Ra	Random
	Related distribution
Ch	Chitonic
C-F-En	Close fine enaulic
C-Mo	Coarse monic
C-Po	Close porphyric
C/Si-s-Po	Close single-spaced porphyric
Ds-C-En	Double-spaced coarse enaulic
Ds-e-En	Double-spaced equal enaulic
Ds-f-En	Double-spaced fine enaulic
Ds-Po	Double-spaced porphyric
O-Po	Open porphyric
Si-s-F-En	Single-spaced fine enaulic
Si-s F/E En	Single-spaced fine/equal enaulic
Si-s Po	Single-spaced porphyric

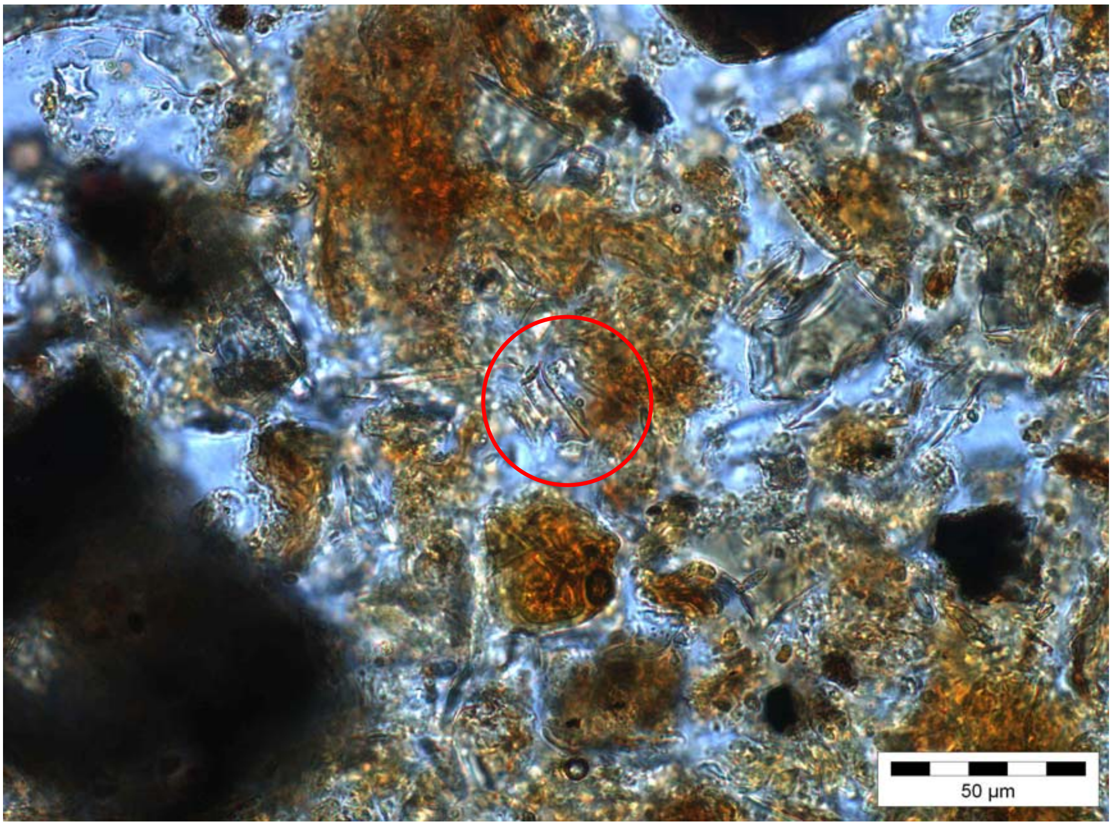
Appendix 6- Photos and descriptions of the most commonly observed phytoliths in the micromorphological samples



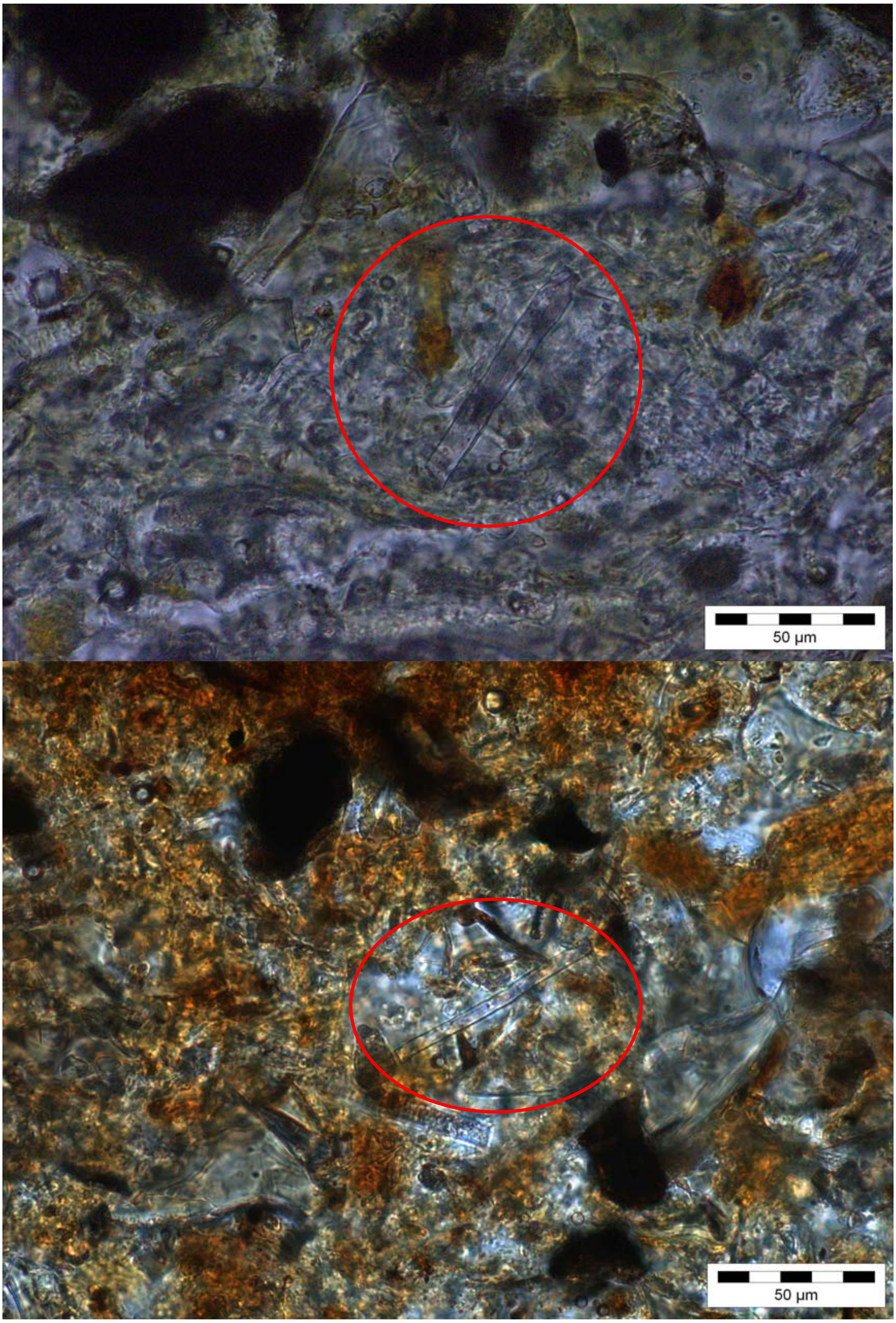
A rectangular serrated phytolith (PPL). Found in the soil samples from Baldursheimur winter grazing area.



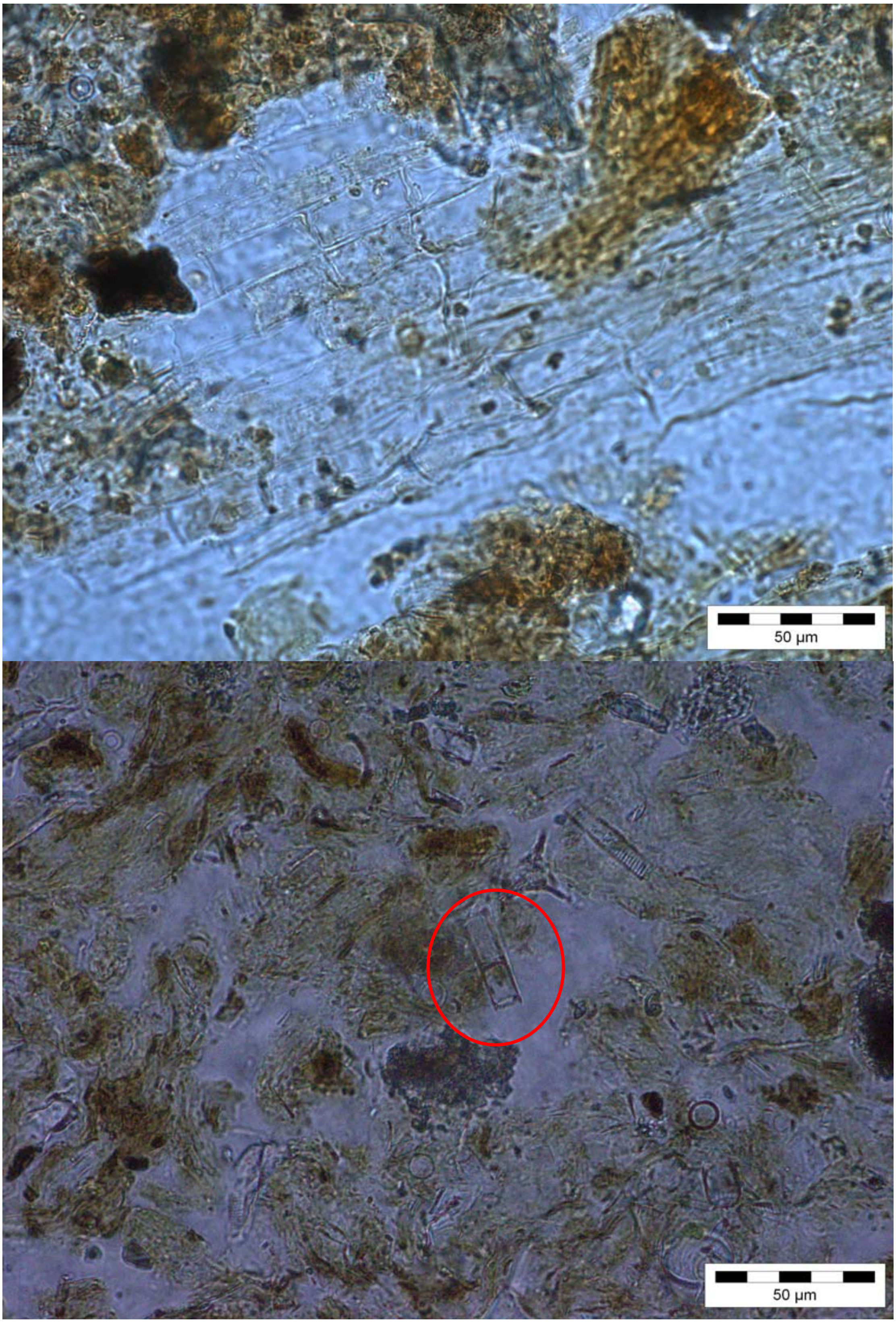
A spiny rod according to Madella (1999) or cylindrical polylobate according to Madella *et al.* (2005). Found in Geirastaðir's home-field soil samples.



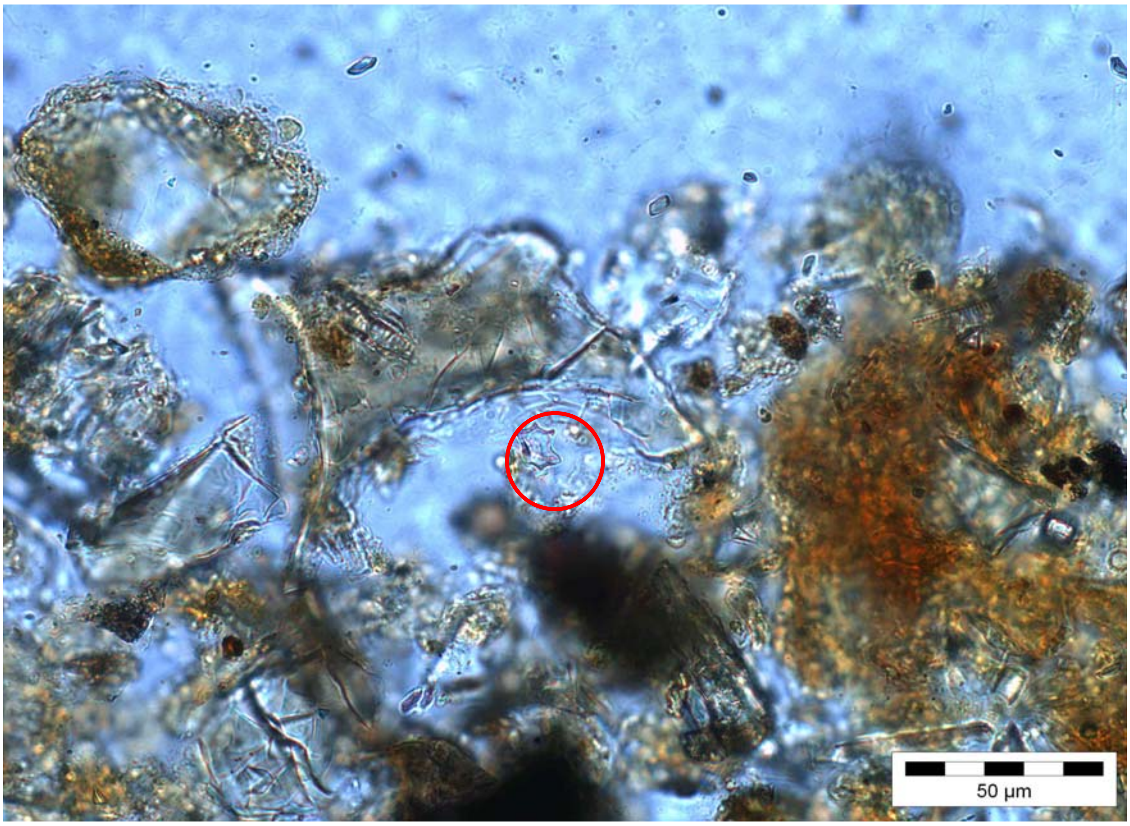
Round-trapezoid short cell phytolith (PPL). This type of phytolith is typically produced by festucoid grasses (Ball *et al*., 2007). Found in Geirastaðir's home-field soil samples.



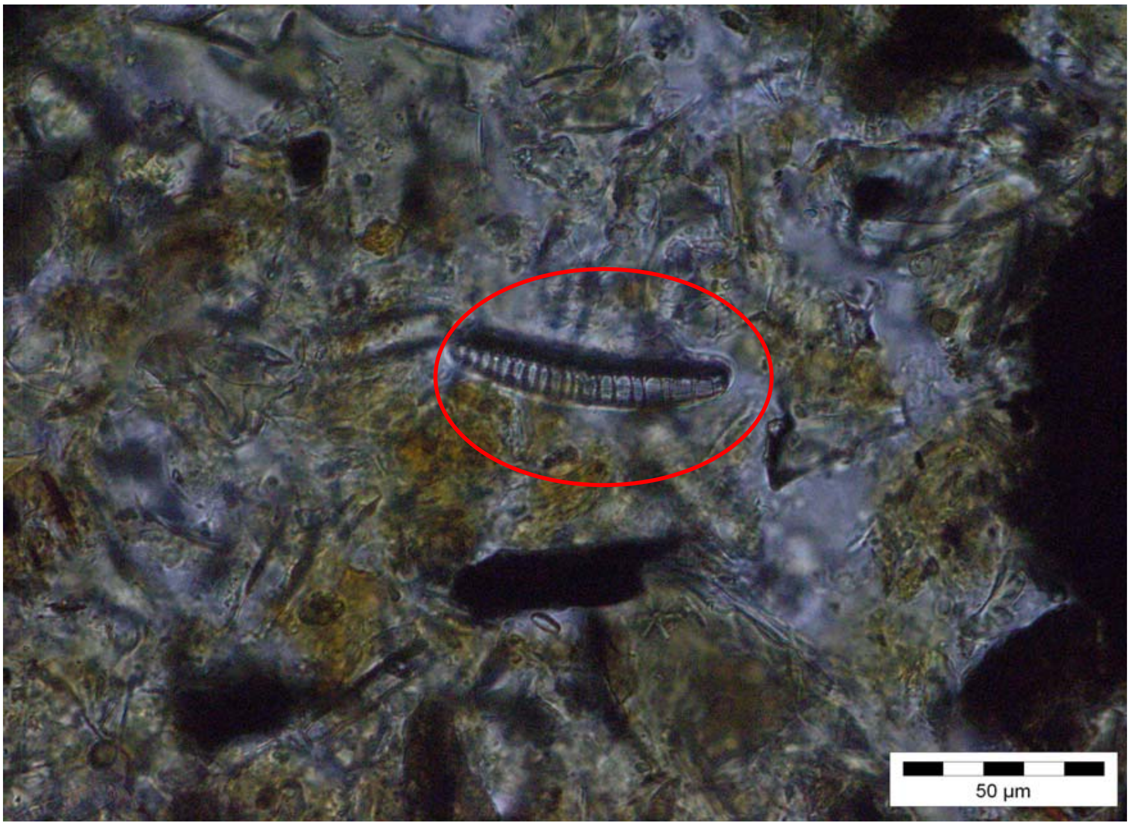
Two examples of epidermal quadrilateral rectilinear long phytoliths, type 10-I according to Pearsall and Dinan (1992) or long smooth rod according to Madella (1999). Found in Gautlönd's home-field soil samples.



Two samples of articulated medium smooth rod phytoliths. Found in Geirastaðir's home-field soil samples, respectively.



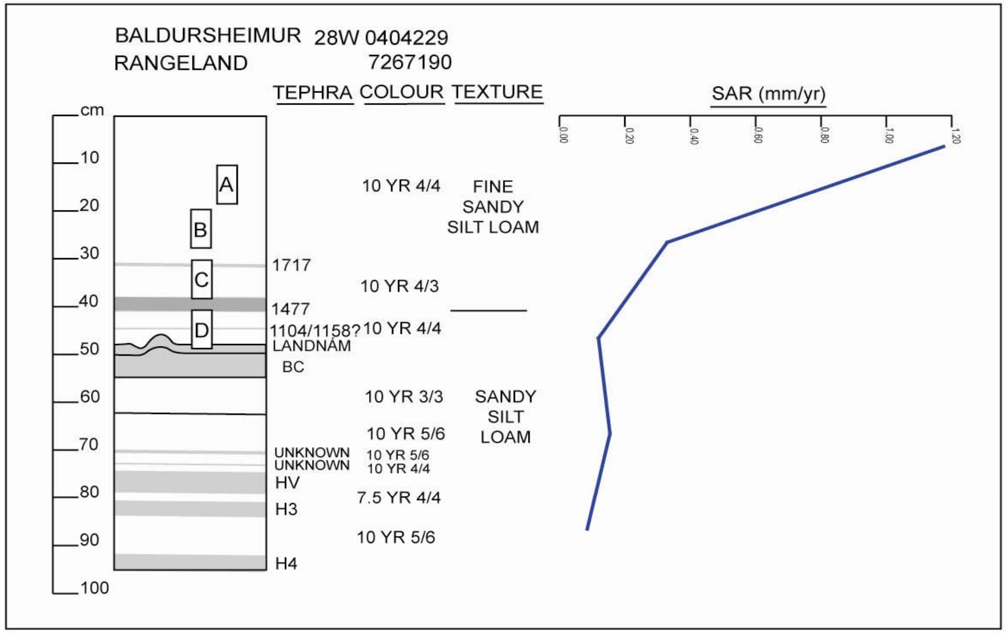
Found in Geirastaðir's home-field soil samples.



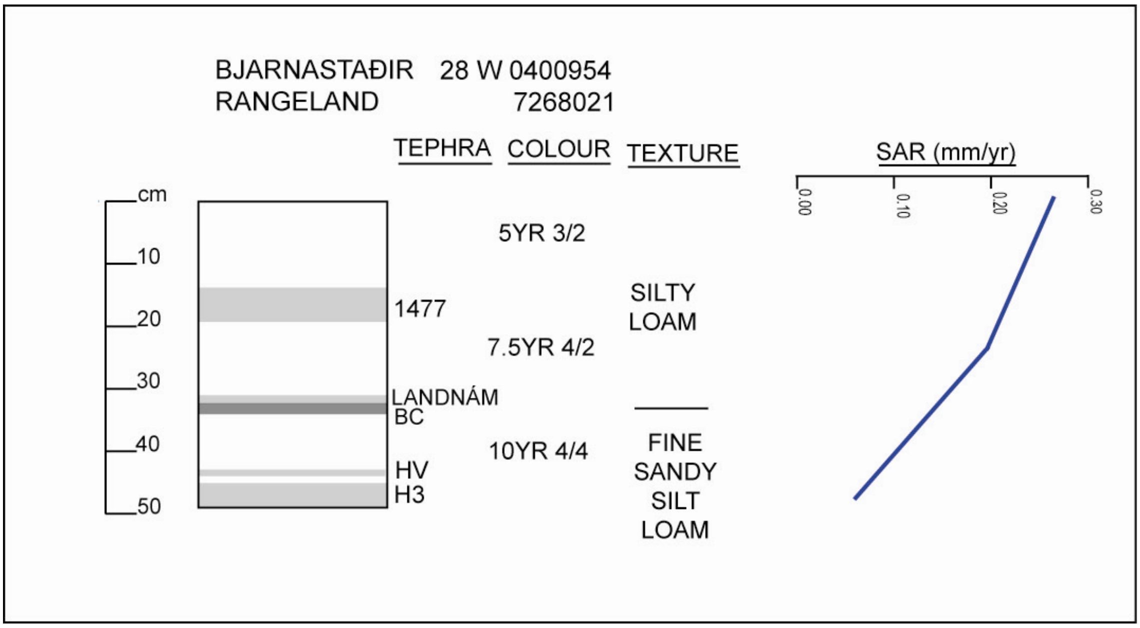
Possibly a tracheid phytolith (Madella, 1999) found in Gautlönd's home-field soil samples.

Appendix 7-Winter grazing areas profiles, field descriptions and SARs per study farm

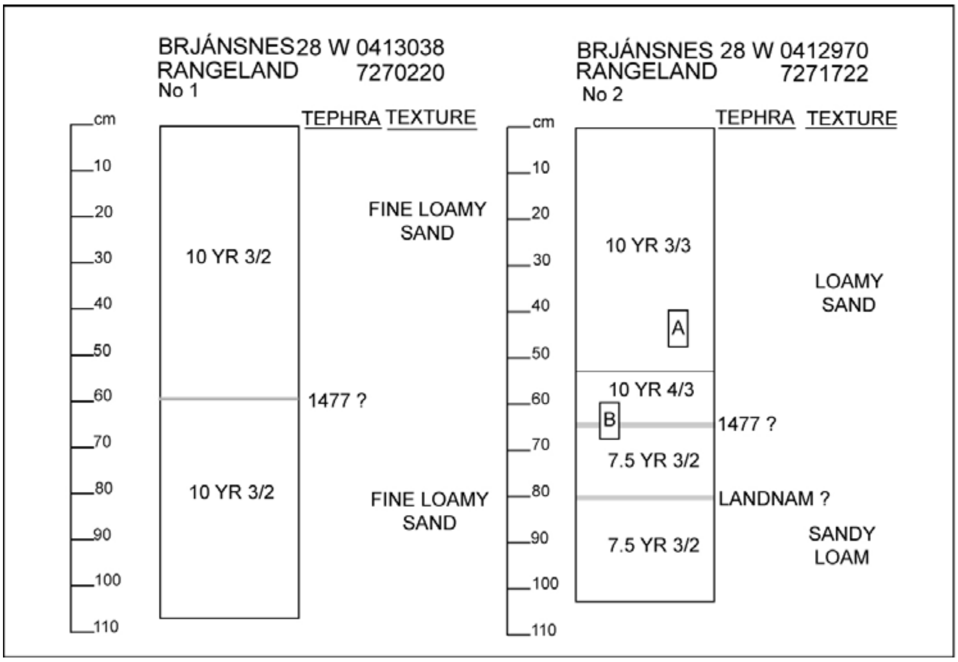
Farm: Baludursheimur
Elevation: 320 m.a.s.l
Vegetation: grassy heath



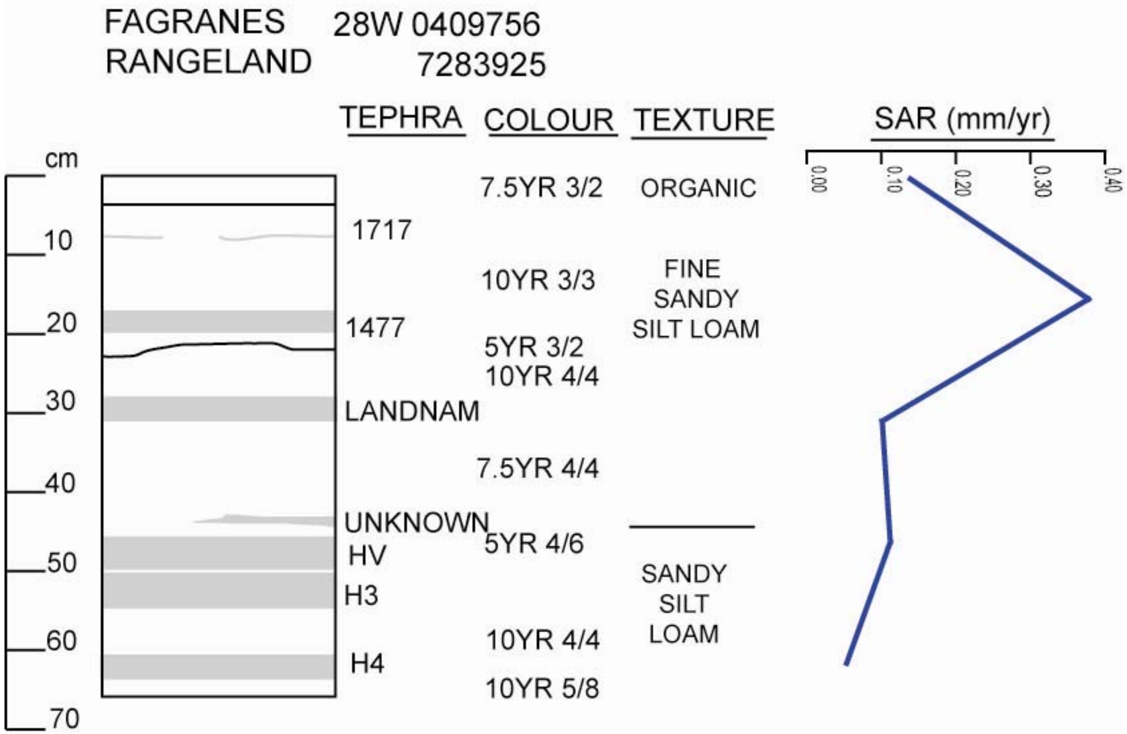
Farm: Bjarnastaðir
Elevation: 368 m.a.s.l
Vegetation:



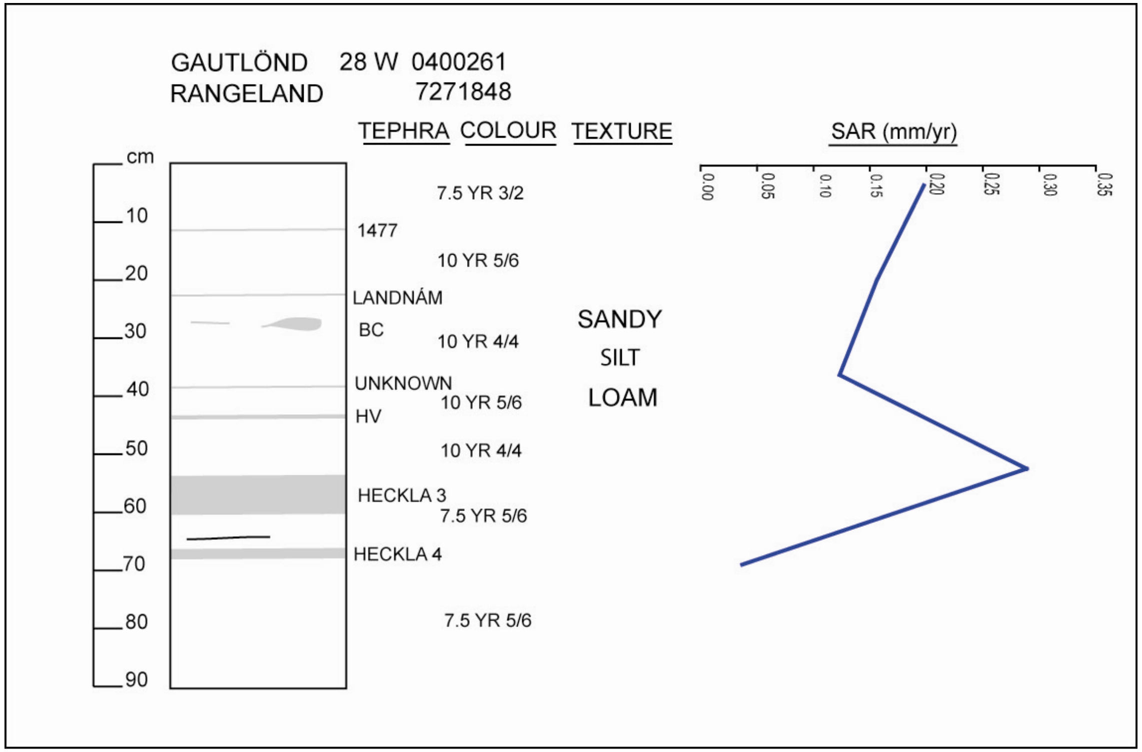
Farm: Brjánsnes
Elevation: 1= 274 m.a.s.l; 2= 307 m.a.s.l
Vegetation: 1= birch woodland 50%-bare ground 50%; 2= mosaic dwarf shrub heath-birch woodland



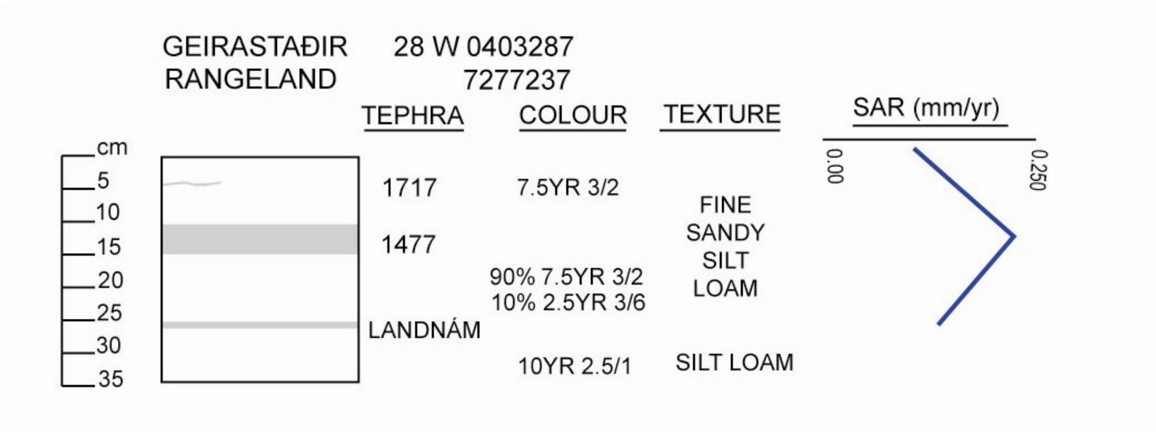
Farm: Fagranes
Elevation: 318 m.a.s.l
Vegetation: grassy heath

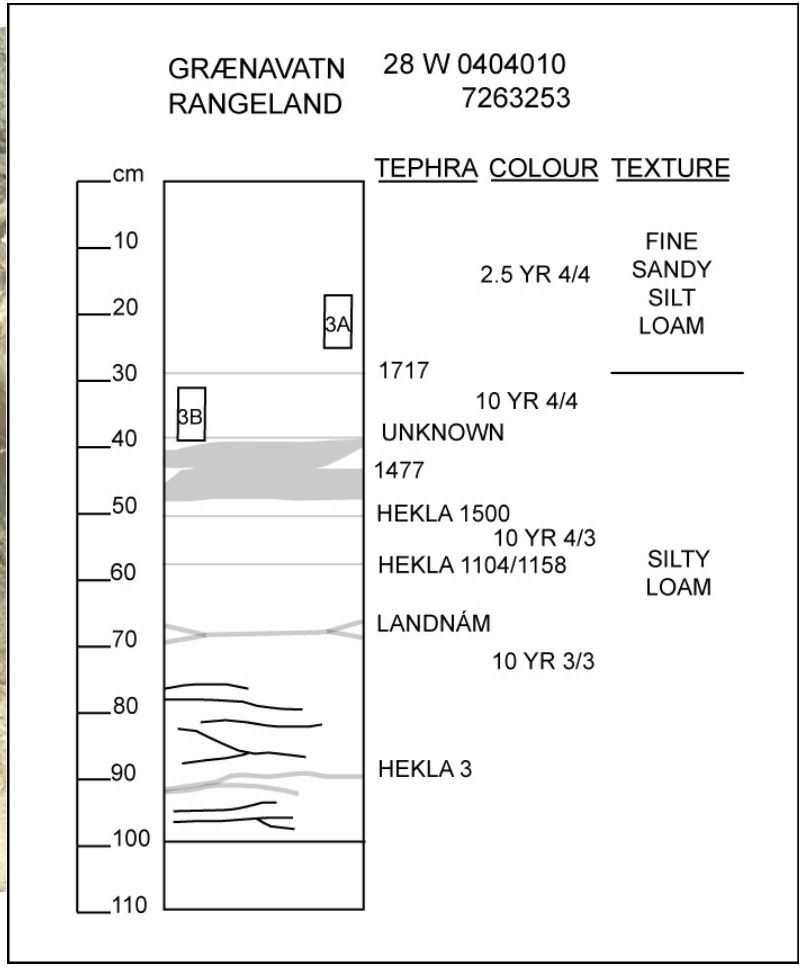


Farm: Gautlönd
Elevation: 318 m.a.s.l
Vegetation: grassy heath

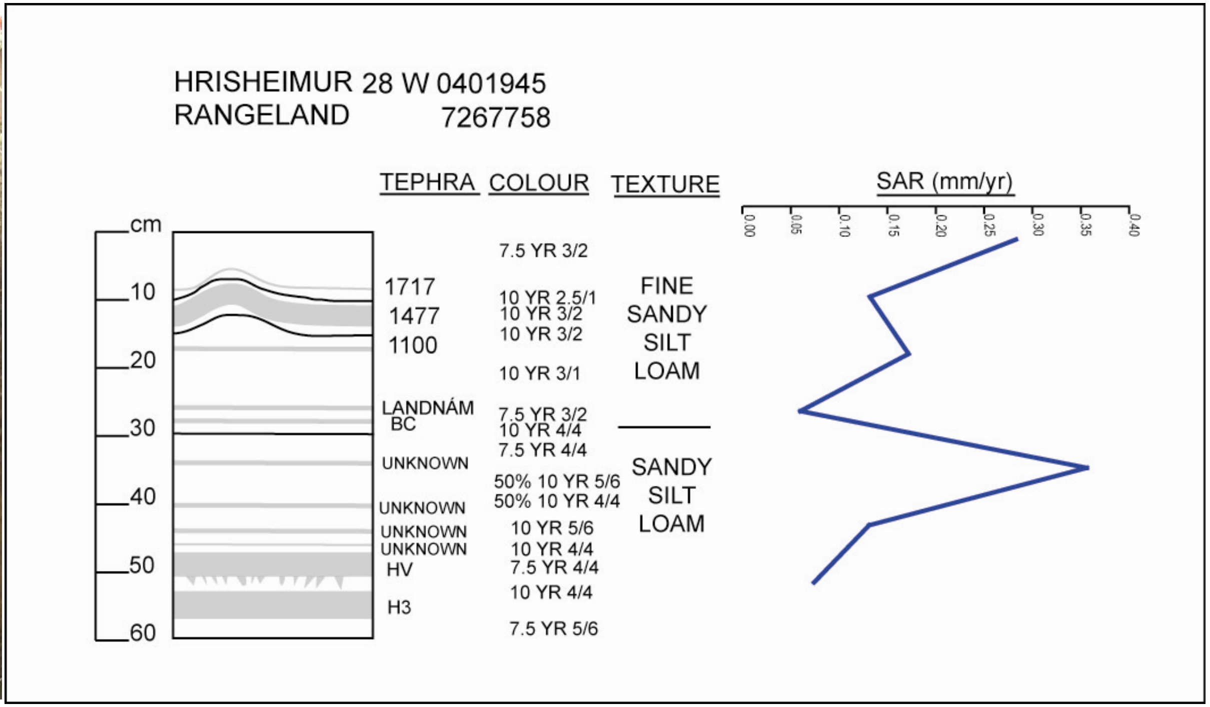


Farm: Geirastaðir
Elevation: 287 m.a.s.l
Vegetation: grassy heath




GRÆNAVATN
RANGELAND
28 W 0404010
7263253
cm
TEPHRA
COLOUR
TEXTURE
10
20
30
40
50
60
70
80
90
100
110
3A
3B
2.5 YR 4/4
FINE SANDY SILT LOAM
1717
10 YR 4/4
UNKNOWN
1477
HEKLA 1500
10 YR 4/3
HEKLA 1104/1158
SILTY LOAM
LANDNÁM
10 YR 3/3
HEKLA 3

Farm: Þorlafstadir
Elevation: 353 m.a.s.l
Vegetation: grassy heath



Appendix-8 Results from bulk soil analyses

Sample	pH	pH (CaCl2)	LOI (%)	Total P (mg/100g soil)
Baldursheimur home-field A	5.8	4.5	4.29	154.86
Bjarnastaðir home-field 1	6.6	5.6	16.93	263.99
Bjarnastaðir home-field 2	6.2	5.8	16.34	143.42
Bjarnastaðir home-field 3	7.0	5.8	9.27	122.98
Bjarnastaðir home-field 4	7.0	6.0	13.18	151.59
Bjarnastaðir home-field 5	6.5	6.0	10.11	128.29
Brjánsnes home-field 1	5.8	4.4	9.14	148.73
Fagranes home-field II-A	7.0	6.0	7.65	105.00
Fagranes home-field II-B	7.4	6.0	10.28	133.20
Gautlönd home-field 1	6.6	5.4	24.05	267.67
Gautlönd home-field 2	6.7	5.6	14.97	227.20
Geirastaðir home-field I-A	6.4	5.0	15.30	423.42
Geirastaðir home-field I-B	6.4	5.2	18.68	542.77
Geirastaðir home-field I-C	6.4	5.4	18.48	420.15
Geirastaðir home-field I-D	6.6	5.6	15.21	225.16
Geirastaðir home-field II-1	6.4	5.0	20.26	247.64
Geirastaðir home-field II-2	5.9	4.8	22.76	243.96
Geirastaðir home-field II-3	5.9	4.8	17.49	252.95
Geirastaðir home-field II-4	5.4	4.6	18.71	563.21
Geirastaðir home-field II-5	5.1	4.8	11.53	286.06
Grænavatn home-field A	7.1	5.8	11.07	231.29
Grænavatn home-field B	7.6	6.3	11.57	178.16
Grænavatn home-field stratified sand	7.8	6.3	1.71	102.13
Grænavatn home-field C	7.8	6.4	3.65	143.01
Grænavatn home-field un-stratified A	8.2	6.9	4.94	129.93
Grænavatn home-field D	8.3	7.0	7.03	188.37
Grænavatn home-field un-stratified B	8.1	7.1	10.14	150.77
Grænavatn home-field E	8.4	7.0	5.77	231.29
Grænavatn home-field F	8.3	7.0	6.58	206.36
Grimstaðir 1 (1717-pres)	5.6	5.2	30.89	166.41
Grimstaðir 2 (1477-1717)	6.4	5.8	20.30	91.14
Grimstaðir 3 (1300-1477)	6.6	6	30.62	166.41

Grimstaðir 4 (lnam-1300)	7.0	6.2	26.99	142.98
Grimstaðir 5 (Hv-unknown)	7.2	6.4	10.74	66.99
Þórleifsstaðir 1 (1717-present)	6.4	5.4	12.31	65.57
Þórleifsstaðir 2 (1477-1717)	6.8	5.6	9.45	67.46
Þórleifsstaðir 3 (1300-1477)	7.2	6	13.01	118.83
Þórleifsstaðir 4 (pre-*Landnám*)	7.0	6	12.42	175.41

Total P replicates and blanks

Sample	Total P (mg/100g soil)	Sample	Total P (mg/100g soil)	Sample	Total P (mg/100g soil)	Sample	Total P (mg/100g soil)
Geirastaðir 3	252.96	**Fagranes 2B**	133.20	**Geirastaðir 2**	243.96	**Blank 1**	8.23
Replicate 1	276.25	**Replicate 1**	144.65	**Replicate 1**	229.25	**Blank 2**	4.47
Replicate 2	275.43	**Replicate 2**	130.34	**Replicate 2**	204.32	**Blank 3**	5.41
Mean	**268.21**		**136.06**		**225.84**		**6.03**
Median	**275.43**		**133.20**		**229.25**		**5.41**
SD	**13.22**		**7.57**		**20.04**		**1.96**
SE	**7.63**		**4.37**		**11.57**		**1.13**

Appendix-9- Tax value, Land rent and Livestock rent in Mývatnssveit according to the land registers of the years 1686, 1696, 1712 and 1847

	Tax value (Hundreds)			
Farm	**1686**	**1696**	**1712**	**1847**
Helluvað	13.66	12	12	10
Gautlönd	23.66	16	16	16
Baldursheimur	23.66	12	12	12
Sveinsströnd			9	10
Litlaströnd	33.66	12	3	
Arnarvatn	20	16	15	
Haganes	30	20	20	10
Skútustaðir	30	30	30	30
Álftagerði				
Grænavatn		30	30	20
Garður	20	8	8	8
Brjánsnes	20	12	12	
Kálfaströnd	23.66	12	12	12
Geiteyjarstr	20	12	12	10
Vogar	40	30	30	20
Reykjahlíð	80	30	30	20
Fagranes	15	8	8	
Grímsstaðir	23.66	20	20	20
Neslönd	23.66			
S. Neslönd		10	10	10
Y. Neslönd		10	10	10
Vindbelgur	20	12	12	12
Geirastaðir	13.66	12	12	12
Hofstaðir	33.66	40	40	20
Mean	**26.73**	**17.33**	**16.50**	**14.56**
Median	**23.66**	**12.00**	**12.00**	**12.00**
Sd	**14.69**	**9.17**	**9.56**	**5.85**
Se	**3.37**	**2.00**	**2.04**	**1.38**

Study farms are highlighted

	Land rent (Ells)			
Farm	**1686**	**1696**	**1712**	**1847**

Helluvað	80	60	60	80
Gautlönd	140	120	150	160
Baldursheimur	140	202.5	120	140
Sveinsströnd			120	80
Litlaströnd	200	180	50	40
Arnarvatn	120	140	140	
Haganes	180	202.5	180	140
Skútustaðir	180	580	300	330
Álftagerði			120	120
Grænavatn		240	120	150
Garður	120	110	100	60
Brjánsnes	120	62	60	
Kálfaströnd	140	140	140	120
Geiteyjarstr	120	140	120	120
Vogar	240	200	180	160
Reykjahlíð	480	400	300	150
Fagranes	90	82.5	60	
Grímsstaðir	140	144.5	140	170
Neslönd	140			
S. Neslönd		60	60	90
Y. Neslönd		60	60	120
Vindbelgur	120	100	120	120
Geirastaðir	80	142.5	120	120
Hofstaðir	200	180	180	160
Mean	**159.5**	**168.9**	**130.4**	**131.5**
Median	**140**	**140**	**120**	**120**
Sd	**88.35**	**122.44**	**66.91**	**58.69**
Se	**20.27**	**26.72**	**13.95**	**13.12**

Study farms highlighted

	Livestock rent			
Farm	**1686**	**1696**	**1712**	**1847**

	Cow value	Ells	Cow value	Ells	Cow value	Ells	Cow value	Ells
Helluvað	5	100	4	80	2	40	2	40
Gautlönd	4	80	3.5	70	1	20	1.5	30
Baldursheimur	4	80	7	140	2.5	50	4	80
Litlaströnd	8	160	8	160	1.5	30	2	40
Arnarvatn	6	120	4.5	90	4	80		
Haganes	8	160	6	120	4	80	3	60
Skútustaðir			12	240	5	100	7	140
Grænavatn			7	140	4	80	4	80
Garður	4	80	4	80	2	40	2	40
Brjánsnes	4	80	4	80	1.5	30		
Kálfaströnd	6	120	6	120	4	80	3	60
Geiteyjarstr	6	120	6	120	4	80	3	60
Vogar	7	140	7	140	3	60	4	80
Reykjahlíð	14	280	13	260	8	160	4	80
Fagranes	5.5	110	4.5	90	3.5	70		
Grímsstaðir	6	120	6	120	4	80	4	80
Neslönd	6	120						
S. Neslönd			3	60	2	40	1	20
Y. Neslönd			3.5	70	2	40	2	40
Vindbelgur	3	60	1	20	1	20	2	40
Geirastaðir	5.5	110	2	40	1.5	30	2	40
Hofstaðir	9	180	6	120	5	100	4	80
Mean	**6.2**	**123.3**	**5.6**	**112.4**	**3.1**	**62.4**	**3.0**	**60.6**
Median	**6**	**120**	**6**		**3**		**3**	**60**
Sd	**2.5**		**2.9**		**1.7**		**1.4**	**28.38**
Se	**0.58**		**0.66**		**0.39**		**0.33**	**6.51**

Study farms highlighted

Appendix-10 Thematic coding of interview's data

Themes were derived from the interview's outline and by identifying common issues in the respondents' answers. Themes are presented below in bold with respondents' answers by farm name.

Livestock

GEIRASTAÐIR

3 cows, 1 bull, around 100-110 sheep, 2 horses sometimes 3.

BALDURSHEIMUR

When she was here they had: 4 horses, 4 or 5 cows, 120 sheep.

GARDUR

Around 1850 the farm had around 400 sheep. Around 1930 the sheep disease came and killed many sheep. Around 1900 it was thought to be good if farmers had 100 sheep, many farms then had two or three farms on the farm. Maybe each farm had 100 sheep, so maybe 200 sheep at Garður around 1900. There would be 1-2 horses and 1-2 cows.

Today they have about 1200 sheep.

GAUTLÖND

Livestock around 1940: 4 cows, 8-10 horses, 150 sheep: 118 were ewes (when he was young).

Weaning pens (*Kviar*)

GAUTLÖND

They were structures very close to the house. The sheep were milked and the milk processed here, it was near the new house, which is called now Kviholt. In 1930 they stop using Kviar.

GEIRASTAÐIR

To the right of the house, from arriving there was the kviar, he doesn't know when it stopped being used.

GARDUR

The sheep were in Kviar until the beginning of July, then the lambs were moved into the grazing areas and the ewes were kept in the Kviar.

Shielings (*Sel*)

GAUTLÖND

One of the shielings was Stong, another one was Nollsel. They could not define how big the sel was: "it was as big as the quality of the land around." The sels were always very far from the farms. There was Gautlöndsel, used by the farm, they also used Nollsel. The sel near Sandvatn was called Sandarsel and it was leased. The sel at Stong was used until 1857, after that it was sold and changed into a farm (they called it Lögbyli or place of residence).

There used to be a woman who came to milk the ewes, it was very difficult to milk them all in one day.

GEIRASTAÐIR

The shieling was in Vagnbrekka (see map).

BALDURSHEIMUR

The shieling was used all year round, especially to keep the sheep that were sold to England. They would pay someone to stay in the sel (Hrutavidarsell). Somebody lived at the sel.

GARDUR

The shieling was in the communal grazing (see map).

Gardur stopped using Kviar and Sel sometime between 1800-1900. The Sel was at Holavatnsas, in a communal grazing area, that sel was only used during the summer. Today that sel belongs to SKÚTUSTAÐIR, how and why they claim to own that area at Holavatnsas, Arni does not know.

After 1900 there where no more sel.

SKÚTUSTAÐIR

Her husband was born in 1912 there was no sel here at that time.

Communal grazing areas (*afréttir*)

GAUTLÖND

The one they use is called Sudurafrett, it starts behind Baldursheimur and it is around the Kraka and Sudura (another river) and Sellandafjall. "By law you needed to use the communal grazing to preserve the grazing around the farm." They don't use it anymore because they do not need to. "The sheep were taken there on June and the round up was about the 13th-15th of September. Until 15-20 years ago all the farms used the area (Grænavatn, Skutustaðir, Littlastrond, Baldursheimur, Gautlönd) but Gautlönd no so much", they would take about 3 days for to gather all the livestock. By about this time the communal area was reduced and fenced off (see map). "The government is seeding grass in the highlands to control the erosion. The area that it was cut off from the communal grazing is because of serious erosion due to over-grazing and climatic conditions (too many droughts). Also today there are a lot fewer sheep than before so they don't need the area so much. In 1975 there were 22.000 sheep grazing the communal areas of the whole district. Around this time Gautlönd fenced off their area and just used its land. Today they have around 7,000-8,000 sheep."

They used horses to bring them back. The sheep was taken out around the 10th of June, the farmer would walk with them to the communal areas.

GEIRASTAÐIR

He talks about east and south communal grazing, when he was young the livestock was taken to the south (same communal as Gautlönd) but in 1942-43 this changed and they were taken to the east communal, this was because the sheep disease. Because they are north of the river they decided to put them in the east. In 1930 the sheep sickness started and they were importing rams. What he calls east communal grazing is east from Skjalfandafljot river. He thinks Gautlönd used this area for their horses and Skutustaðir used to use it when they had sheep. He seems to mix the names of the communal grazing areas.

He used to collect the sheep in the horses and he never got lost. They would take the livestock to the communal grazing areas at the end of May beginning of June. Some farmers would gather the sheep, slaughtered what they needed and then put the sheep back in the communal, but they wouldn't do that (in his farm).

Prior to 1956-57 animals were grazing outside but after they would mainly stay inside. Middle of September was the round up. Sometimes they could put the animals earlier, in early or middle may, when it was warmer. It never happened in Geirastaðir but sometimes other farmers would put the livestock out in March and collect them before they had offspring. He never participated in putting the animals out because he was so young.

GARDUR

The sheep were in Kviar until the beginning of July, then the lambs were moved into the grazing areas and the ewes were kept in the Kivar. They usually fetched them around the middle of September. They would fetch them all the way to Tungnafellsjokull.

The south and the east communal grazing areas were divided with a fence. Most people in the old days used the south communal grazing areas however now days people mostly use the east communal grazing area, mostly because of erosion, over grazing as well as the disease. Often farmers would use it a specific grazing area due to tradition. Some farms claimed to own communal grazing areas. There are no documents about these lands and so they farmers at Reykjalíð, Skutustaðir and Grænavatn try to claim and own as much land as they could and can.

Garður uses the east afrett. Today they have about 1200 sheep. Garður and another farm (Reykjalíð) supply around 30% of the fertilizer for the communal grazing areas because they have so much sheep. Reykjalíð claims to own almost all of the eastern afrett, but Arni says that the church owns that land.

GRÆNAVATN

Livestock were sent south to the communal pastures in spring. They did not need to be taken there – they found their own way. Were taken around end May (check) and rounded up in early September.

GRÍMSSTAÐIR

They use to do the round up on the 15th of September (from the heimalandi). But the sheep were always released again because they didn't have a place to keep them. When it started to freeze some sheep would die because the ice in the lake would break. They put the sheep in near Christmas or in January depending on the weather. They would always graze the animals as much as they could to save hay. They would fodder the animals depending on how much there was to graze. The animals were released in the spring as soon as the vegetation was out.

Structures for gathering of sheep (*rett*)

GAUTLÖND

"Strengajarrett (see map) was used until 1905 and then they built GAUTLÖNDrrett about 1909-1911 to bring it closer to the settlements and everyone used that one from then on. Sellandarrett was used first."

BALDURSHEIMUR

Baldursheimarrettur is still in use. Each farm has its on area within the Rett. Some farms are big and some are small, it all depended on the amount of sheep they had. Some areas within the Rett were for different municipality (not Mývatnssveit) sometimes sheep would walk long distances and into other afréttir. Strengjarett was abandoned because of sand erosion, the sand filled Strengjarett. Reykjahlidarrett is much older. Gautlandarett used for about 20 years until 1933, it was too wet. Strengjarett not used for many years, was before Gautlandarett and Baldursheimarrett took over Gautlandarrett and is used still today. The reason for Gautlandarett was built on Swamps was so that the sheep could rest well, rest their feet. When it would rain Gautlandarrett would just turn into a major swamp and it was hopeless to use. Baldursheimarett was the first rett that was built in a new building style, the first of its kind in Iceland. They used concrete to strengthen the walls of it. They were built in a circle and many other communities in Iceland found the circle shape of the Baldurheimarett to be better than the old square rettir, easier to collect the sheep.

Around 1932 they built sheep houses at Baldursheimar, two sheep houses that were built using concrete. These two sheep houses housed around 90 sheep. The material was expensive for the houses, concrete was expensive so they would mix it and that made the concrete weaker.

GRÆNAVATN

They were not taken to a specific rétt but to a fence area Seljaland (check) and then the next day home to Grænavatn. Usually there were very few sheep belonging to others mixed up with theirs.

Slaughter

GAUTLÖND

Around 100 lambs were slaughtered, around 19th they were lots of changes and they started selling livestock to England, these ones were 1 year old or older, younger than this weren't sold. They only sold about 10-15 per year (to England). The number of animals slaughtered depended entirely upon the amount of hay they had. If they had a lot of hay fewer animals were slaughtered.

GARDUR

Garður slaughtered most of the lambs if not all, sometimes they kept a few to bring them up and sell to England. That was the first money the farmers in Iceland ever saw, the sheep gold. Arni says the reason for the Iceland fishing success is because Icelanders finally had money to invest in ships and more.

GRÍMSSTAÐIR

They drove the animals to slaughtered to Breidimyri until 1930 when they built the slaughter house in Husavik.

Home-field and meadows (*tun* and *engi*):

GAUTLÖND

The home-field was around the house. They used manure to fertilize the home-field. In Gautlönd there was an *engi* used called Nautey (bull pasture), his grandfather (of Bodvar, called Jon Sigurdsson) used the river to flood the area. See map near Sveinstrandartjorn Lake. The reason why the meadows are good is because it was flooded, it used to be a swamp before and after flooding it a lot of sand came from the river and made the area better for the growing of grass. The area had natural fences, a ditch, a small mountain, the river and they only needed to put a small fence between the lake and the river, they kept bulls and sheep during the summer there. The area was divided into two, one area was used for grazing and the other one for making hay and the following year they would swap it to maintain the fertility. They had also 2 other *engi* (see map) for making hay. Almost all the areas that were wet were used for making hay. Bodvar's grandfather was born in 1828 and died when he was 60. He was the one who built all the dams and a channel hand made from the river and the bridge. He made a lot of channels from the small river to make the water come nearer into his land. They used to inundate the area on the 17th of June and close the damn a month later.

GEIRASTAÐIR

The tun was close by, *engi* was in the island Helgey (see map) were they make hay, they never rented or bought from anyone else. They were two meadows near home so they never had to go too far away. There are so many small lakes around that a lot of rich grazes grow there, near Sandvatn.

They didn't fertilize much until 1940's when they started using chemical fertilizers, no many people would use dung to fertilize because they needed for fuel but in his house they had electricity (power station) so they could use it. They used to drive the dung to the home-field when they had a tractor.

BALDURSHEIMUR

The home-field was not very big so they got most of the hay from the medows.

It was quite wet in these areas so it was difficult to cut the hay, sometimes it was kept wet and brought back to be dried at the farm. This varied with the years. The grass did not grow so well around the house, that is why the home-field was small.

Around 1940 they stopped milking the sheep, after that it was emphasis in the meat and the wool. There have been some changes in the grass species, not so much. The home-field is much bigger now than in the old days, it was about 5 ha and now it is about 70 ha. In the past the home-field was damaged by erosion and they put animal manure and hay that was rotten or was not good to recover it. They were always dealing with erosion, it was a continue problem. The home-field was fertilized only with cow and horse manure as they needed the sheep dung for fuel. They talk about how important the home-field was. People by the sea could take drift wood but people living inland it was all they had. On the day of her 12th birthday in June of 1949 she was living in the east and there was no more hay. She went with her mother and they cut some little twigs to give to the livestock.

They would flood the meadows and it was done for 2 or 3 months in the spring. They tried to do it when it was not raining because otherwise it would get muddy.

Several farms owned the particular meadows they showed in the map and they were also rented out to other people, the hay was covered with turf and they went to get it in the winter with a horse and a sledge on the ice. The farmers could also rent their part, or part of their part and the hay was paid in trout. The farms that owned the engi were: Baldursheimur, Grænavatn, Litlastrond, Alftagerdi and Skutustaðir. The boundaries were marked by natural landmarks (streams, etc). These Engi were called **Framengi.** See in the map the area between Nautey and Grænavatn, to the south of Skutustaðir. Around 1900 Einar Benediktsson (famous Icelandic Poet) was Syslumadur (like a governor/sheriff till 1980 they did both) at around Mývatn and he would go on a horse and mark many farms and land and had farmers sign documents regarding land ownership and land rights.

GARDUR

His grandfather was the owner of Skutustaðir so they used some or their meadows.

Engi, was all around, the farm collected hey in the Engi, Arnis Grandfather owned Skutustaðir and many of the farms in Mývatnssveit used the Engi around Skutustaðir because a lot of the home-fields could not hey because of lack of grass. They would maybe pay for it somehow, not with money.

Sometimes we put cow manure on the Tun and the dung was dried and used for fire. We would put the manure on the hills around the farm because we had no real tun.

SKÚTUSTAÐIR

They didn't have much of a home-field just engi. They would dig canals to dry the area that worked very well, now the canals are filled in. they tried to use manure when they could but they didn't have many cows, and most of the manure they used to smoke trout.

GRÆNAVATN

Very small home-field therefore also did haymaking on outlying meadows.

Yes, used animal manure, but mainly of horses and cows as the sheep manure was so valuable for fuel.

GRÍMSSTAÐIR

Each spring they use to fertilize the tun they did it each day if they had enough animals. But they needed to plough first (stinga ut). They used cow and horse manure and they would carried it in …..drag by horses. The manure that was left unbroken in the field was collected for fuel, also they used sheep dung and sometimes they collected wood (in the fall they would collected).

They used a scythe to cut hay, and they collected from wet meadows, swamps and wet areas. If they could they would dry the hay where they cut it but if they couldn't they would bring it to the home-field and dry it there. They had a special scythe with something to collect the grass to use it in ponds so it woudn't get wet. Sometimes they would keep the hay where they cut it and collected in the winter. They would rake the hay together tied it up and carry it in their backs. The islands in Mývatn were also used to collect hay. They would go in a boat must of the time they would live it there and fetch it in the winter in a sledge when it was frozen. The island is called slutnes (see map).

Vegetation changes

GAUTLÖND

Since 1940's: everything has been decreasing, trees and grass. The shepherds used to brush the snow off the trees and vegetation to let the sheep graze.

GEIRASTAÐIR

Depended on the weather. After 1970 there were bad years for midges (with no many midges), the vegetation gets a lot of minerals from the midges. When there's an early spring there are lots of midges. Since they close the factory in 2005 the vegetation have been getting better and better. A lot of grazing areas like Helgey got bad because of the factory. He says that prior to 1970 there use to be a lot more midges and he thinks that they are going to increase more in the future. They just started measuring midges populations after the 1970 when they were decreasing. No one has used the land since 1995 so it's changing.

The vegetation is a lot better now that what it used to be. He thinks sheep are not responsible for erosion. The glacier rivers are responsible, the sand that the glacier rivers bring and the wind takes it. He says the sheep can have an effect but it is mainly the rivers and the though winters that come and freezes everything and kills the grass. After the vegetation is killed like that it just blows away. He talks about areas that are filled with sand. The sheep just make the recovery much slower (he says that is just his theory). Volcanic ashes and eruptions help as well.

GARDUR

"Changes in vegetation have been and will keep on changing, because of volcanoes, sand and strong winds".

SKÚTUSTAÐIR

"There's been great improvements in the vegetation because the animals are mostly kept inside now so the vegetation gets rested". Before they tried to graze outside as much as they could.

GRÆNAVATN

"Different kinds of willow (*gráviðri, gullviðri, fjalldrapi*), birch (*birki*). *Melgrasi* grew in the sand. Grass of course".

Resources

GAUTLÖND

A little bit of trout. Not a lot of birds or eggs. A few ducks when they started flooding the meadows so they could take a few eggs.

GEIRASTAÐIR

A lot of fishing, but in Sandvatn it would freeze because it's so shallow and it takes about 10 years for the lake to be fishable again. They used to dig a hole in the ice in Mývatn to fish and they used nets in the 1950's. They hunted ptarmigan and take a lot of eggs. There are two islands in sandvatn and every year they maybe take 1500 eggs. In each nest they would be 20-30 eggs and they would leave about 4-5, they had to because the birds wouldn't be able to sit on 30 eggs. He still collects.

BALDURSHEIMUR

Not much fishing, a little bit in Kraka, a bit of egg collecting. No angelica.

GARDUR

The most valuable natural resource that Gardur had was their fishing grounds. They would sell some of it but hardly ever they received much for it. Sometimes men would come and buy fish and promised to pay the next time they would come and buy but they hardly ever brought anything when they returned.

… The once used to pick eggs but now days they can not because of the factory that destroyed the lake. Killed all the flies and all of the nutrition's that the lake provided the area, many of the Engi that were full of vegetation in the beginning and until the middle of the 1900 century are now almost dead and do not yield much hey.

SKÚTUSTAÐIR

There used to be a lot more of trout before, she doesn't know if it is because of the factory or the tourists if they have an effect on the water. The trout had a lot of impact in many people, they would have food from that. For many people it was more important than farming. They had fishing rights in Mývatn. It was forbidden to fish from September to February.

People that didn't have access to water would come here to fish, many people from many places came to fish. In this farm they didn't do a lot of fishing but in another farm near here they would have two people just for fishing during the summer and they would sell smoked trout. Egg collecting: in Grimstaðir they would collect thousands each summer, they were the bigger egg collecting farm and they used to trade with eggs.

GRÆNAVATN

Fjallagrös (*Lichen islandicus* or Iceland moss).

Trout to some extent (NB not much trout in Grænavatn as conditions in the lake not so favourable – better in Mývatn).

Eggs taken to some extent – not emphasised except re. the duck species called Húsönd ("House duck") which they said often attaches itself to human dwellings. They put boxes by an old outhouse and these ducks would nest there and some eggs would be taken. Could get 20-30 eggs (not sure over which time period).

GRÍMSSTAÐIR

Egg collecting: they would collect during the spring every 4 days, they would never leave less than 4 eggs in a nest. They would collect 7,000 to 8,000 eggs a year. If they collected 6,000 it was a poor years, in good years they would collect up to 9,000. during the wars there were more eggs 15,000 and 16,000, they sold few during this years.

Advantages

GAUTLÖND

The size of the land so they could lease to others. All of their land has vegetation so there are not big areas that can't be use.

GEIRASTAÐIR

Was thought to have been a very good farm for sheep, one of the best in the areas, because there was access to grass all year round because of the lava, the lava devours the snow. His parents leave there from 1900's, they had 6 offspring, he's the second youngest and the only one left. In 1930 when farmers didn't have enough hay farmers would come to graze his land in the spring (he heard it from other people), even from Gautlönd. The lakes near the house were never frozen. Close by the lakes the grazing is very good because the midges make the soil more fertile. With the factory he saw a change in the productivity of the grazing areas because of the water was providing less nutrients and there were less midges. It's the force of nature that makes Mývatn so hospitable. A lot of people from far away would come here to fish for trout.

Geirastaðir it's lucky because is so big compare to others. They use to go there to graze a lot.

Constraints

GAUTLÖND

Frost and bad winters. A lot of snow. But the years from 1920-1960 were relatively warm.

GEIRASTAÐIR

Transportation was hard. Was mainly using horses and there was no roads. The first bridge was built in 1950. The weather of course will always be a big factor. Mývatn recycles itself every 28-29 days so they never had problems of floodings.

BALDURSHEIMUR

Blowing sand was a big problem, her mother in law had twins in 1919 and there was so much blowing sand that they needed to hang things on the window so the sand would not get to the babies. This problem happened mainly in the early in the summer because of southerly winds. It is very different now, it is much better now. It was a very big problem and they used to deal with it by cutting turf and replacing the areas where the vegetation was gone.

"Being high up snow could be a bit of a problem".

The erosion was particularly bad when it was dry. This area of the country has the least precipitation so it is very susceptible to this problem. Around 1940 they started to cordoned off to do something about it. They hardly have soil here, is mainly sand.

Here they had the difficulty that the hay was taken from the meadows and not from the home-field.

SKÚTUSTAÐIR

There weren't many tuns here so getting hay was a difficulty, with the tractors it became easier.

GRÆNAVATN

Limited land (home-field small – had to gather hay elsewhere).

Livestock wandered far.

Haymaking could be difficult (e.g. due to weather).

Weather generally.

Blowing sand.

1950s, 1960s began. There have been tremendous changes. When Steingerður came here 50 or so years ago there were lots of people – the house was full of people. Now the district is being emptied. Young people go to school and then to University and then to Reykjavik or elsewhere. The farming tradition seems less attractive to people. Their son, Haraldur is farming here and lives in a new timber house adjacent. He has a wife (a teacher at a small children's playgroup) and 4 children – two have left and it is uncertain if one of the others will take over when he grows up.

Innovations

GAUTLÖND

They tried to make innovations in the tun but the frost would destroy a lot of their work. Technology around 1850: ploughs, a couple of farms would buy them together, technology to flatten the meadows so it would be easier to collect them.

GEIRASTAÐIR

In the 1930 they built a small power plant or generator that made life a lot easier for them, it produced 7.2 Gigawatts, and this was powered by water and was in used until 1969. In the 1970's the municipality was building dams so they cut the water supply to his.

Power plant. They would make a lot of products at home like milk products. They had a big home, and they made all they needed, his father would weave a lot during the winter.

Most changes were from 1950-1960. Because of technology, bulldozers, heavy machinery.

BALDURSHEIMUR

There were not any big innovations before 1950. Then they started getting tools, tractors, etc…

In 1943 they started skimming the milk once a week. And later on they created the milk industry in Husavik and they started selling milk to them. In times of the sheep disease (around 1930?) people could only keep about 25 out of their 100 or so sheep stock. Farmers could retain 25 lambs and had to re grow their sheep stock from those 25 lambs. Farmers started to grow cows in order to sell milk to the milk industry at Husavik.

GARDUR

Farmers tried to use new technology if they could. Tried to make some land improvements. Now they are doing land improvements together with the government, they get some funding, but mostly fertilizer and seed. The farmers supply the work and the natural fertilizer, Melgrass. They have tried to use nets to cover areas that have bad sand erosion.

GRÆNAVATN

Laid emphasis on coming of electricity (1962). Noted especially how much easier life became after got washing machine.

Success/failure

GAUTLÖND

The size of it, the vegetation, how much livestock the farm could support and how much the farmer was willing to work on the farm and how much it was able to access the technology.

GEIRASTAÐIR

Weather but a big factor is how clever you are as a farmer to use what you have and make the most of good weather when you have it.

BALDURSHEIMUR

The weather was the most important thing. If you could make hay or not. The weather was unpredictable, it could change from year to year. The weather during the winter was also important because some farmers would try to graze during the winter. In Baldursheimur a shepherd would take them far from the house to graze and stayed with them during the day to make sure they didn't return until night.

GARDUR

In the beginning of the 20th century the farms were divided into many small pieces, many relatives living on the same farm. This made the demand for resources to be higher, more. The people at Garður were tough farmers, they worked very hard and everyone had to work hard to be able to survive.

SKÚTUSTAÐIR

Nowadays especially Grænavatn and Grænavatn they had about 25 people in each house so maybe the farms couldn't sustain so many people.

GRÆNAVATN

Emphasis on having many hard-working and clever people.

Also the importance of never having too little hay.

Support

GAUTLÖND

The county always supported the poor. Many people had a hard time. If you were poor the whole community by law had to help you. Around the 1880-90 there was a big famine the government had to use a lot of money to help the farmers.

No one would go hungry because of the lake (Mývatn).

GEIRASTAÐIR

He mentions the cooperative which was founded around 1882 (he’s not sure). It was very hard to fund this cooperative because it was after the famine but farmers used to read a lot and this cooperative was created after the one in Denmark.

BALDURSHEIMUR

There wasn’t much. Mývatn help a lot of farms that were close to it by providing fish. During hardships people also would come in horses to get fish from the lake. The lake supported a bigger area than Mývatn in times of hardship because they wouldn’t stop people from outside coming to fish. Later on organizations were formed to monitor people food supply. They would check how much hay the farms had for the sheep and they would teach the farmers about how much hay they needed. They would ensure that poor people got help from the wealthiest farms. Documents of this can be found in Husavik.

GARDUR

Farmers support, farmers could offer to take on poor people and instead they received money from the municipality or the government. The one that bid the lowest would get the rights to take care of the poor person. Mostly these were old people and others who had ailments or were without hope.

SKÚTUSTAÐIR

Assistance during hardship: you could always get by because there were lots of eggs and fishing. If farmers lost sheep the other farmers would give him one sheep each, there is a lot of good people here. They sold some trout oversees, and to stores in the last 20 years or so. She talks about an old poem that a congress man said that says the people in Mývatn would be like any other if they didn't have the trout, the melgrass and John in Gautlönd. John did a lot of things for the community, unselfish work, he was one of the founders of the cooperative.

GRÆNAVATN

People had to manage themselves, but would help each other in dire need. Mentioned a case where a woman's husband died. She had 10 children and no means of supporting them so they were farmed out, one here, one there, to different families.

Weather

GAUTLÖND

He was born in 1925 and that was a very mild year. 1925-1950 they would release the sheep in mid may because the weather was so good, when it was bad they released them on June. Prior to 1920 the weather was bad, very cold, the winters of 1916 and 1918 the weather was very bad. In 1858 almost all the sheep died. He's reading a book of a person that wrote it from his diary were it says that near Reykjalíð 1880-81 there were only two sunny days in the whole summer. The last 20 years have been very warm, more moisture in the air.

GEIRASTAÐIR

After 1940 and until 2000 it was colder but with mild weather in between.

… in the old days it was quite usual to be -20 C in February whereas now it happens but it lasts only one day. The weather is changing more often now, more unpredictable. In the old days the blizzards could last for a week but today it doesn't happen. Because of this the average temperature is rising and the winters are milder.

BALDURSHEIMUR

The weather has always been sporadic, the years from 1930-145 were good; the year 1939 had a very bad spring, one of the worst. Many people had it hard that spring, all of a sudden the summer came and the weather changed from being very bad to be all of a sudden 20 degrees and very warm.

GARDUR

The weather has been changing a lot, if it had not been for the technology many people and animals would have died. The weather is getting worse, however the winters are milder, there used to be much more ice around the sea. Some winters are hard and some are mild, summers are also very different.

GRÆNAVATN

Helgi thinks the weather at Grænavatn is pretty good! He does not think there have been any great climate changes other than some minor variations.

Abandoned farms

GEIRASTAÐIR

Brenna is probably the oldest settlement in all Mývatn. He thinks they might have pigs because the remains of the structure are so big. The walls of the structure are about 4 m thick and about 1.5 m high. He talks about Hofstaðir and that Orri said that Brenna is probably older that Hofstaðir. There's another farm that it is older, it is close to Kleif. Both farms belong now to Geirastaðir. In the 1400's all the livestock at Brenna were used to be moved to Geirastaðir to graze as the winter conditions were much harder in Brenna. There are no evidence of livestock ever been grazed in Kleif so he thinks it was a fishing farm. Right now farms own not only the land but also the waters.

BALDURSHEIMUR

In 1703 in the census there were 6 people living at Þórleifsstaðir (more people that in Baldursheimur). The woman says it was abandoned in 1712. Before 1700's a lot of farmers in the south owned land in Mývatnssveit. Only one person had like 3 or 4 farms here. Only about 3 to 4 farms were owned by farmers.

GARDUR

There was someone living in Brjánsnes when his family first came. He thinks the farm was abandoned because of sand blown.

Brjánsnes or Brjánsnes, it becomes abandoned just when Marteinn the first farmer at Garður arrives around 1700, either Marteinn or Jon the son of Marteinn bought the farm Brjánsnes. The area was all covered in Swamps, Marshes and small rivers and lakes. Today the area is more filled with sand and has turned into land that is used today. Brjánsnes was thought to be a very good farm around 1700, good fishing grounds, not many people know about the area, no written documentation. Garður was a small farm in the beginning until they bought Brjánsnes then Garður became a lot bigger. Erosion could have destroyed the settlement at Brjánsnes, not really certain why Brjánsnes became abandoned.

SKÚTUSTAÐIR

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Food

GAUTLÖND

They eat mostly cod and haddock now, half of the time.

GEIRASTAÐIR

Around 1950 they started selling milk to Húsavík and they sold a lot of smoke trout. He remembers salting trout and salmon in barrels when he was young to take to France and they would smoke it in France. They sold quite a lot to France, but they also eat a lot of it. They would eat fresh but also rotten (they leave it hanging out) but you had to be careful because of the flies. He eats trout twice a week now.

GARDUR

They mostly consumed dried trout.

SKÚTUSTAÐIR

There wasn't much difference in what they eat in the summer and the winter.

GRÍMSSTAÐIR

They would smoke or salt meat at home. When they smoke the meet they would hang the meat in the kitchen and smoke it there, as well as the trout. Although the trout was eat a lot fresh. During the winter they hang the trout outside and live it to rot. Some farmers had goats to milk but most farmers had cows. The milk that wasn't used directly was made into skyr and the skyr allowed to sour.

Commercialization

BALDURSHEIMUR

Excess wool was sold. Sometime people would take products to Húsavík and get fish in return. Most of times they wouldn't get money. They would get dried fish and salted fish.

GARDUR

Until 1940-1950 they only sold fish and occasionally sheep to England, put people would often not even be able to pay for the fish.

… Today their sheep is mostly for meet productions, the government pays a small amount of money for the wool. Most of the value that used to be in the sheep is thrown away today, all the fat and most of the organs.

GRÍMSSTAÐIR

Sometimes Haupnersverslunin in Akureyri would buy live animals. In Húsavík all the meat was salted and exported to Norway and England but the intestines were brought back home to eat.

During the winter they would order some products through the cooperative (such as corn). In January this products would arrive to Húsavík by ship. People would go to get the products in a sledge in groups of about 30 people depending on the snow and there would always do more than one trip. They would sell some wool in Húsavík and they would keep some. The wool was treated with urine and then was clean in the lake and dried out. The meat and wool products that they processed at home were taken in the autumn to Húsavík and they would get products in return (like coffee, etc). But the non-processed wool was sold in the spring. They would transport that on horses. The wool was spinned and knit in the winter.

Erosion

GEIRASTAÐIR

He thinks sheep are not responsible for erosion. The glacial rivers are responsible, the sand that the glacial rivers bring and the wind takes it. He says the sheep can have an effect but it is mainly the rivers and the though winters that come and freezes everything and kills the grass. After the vegetation is killed like that it just blows away. He talks about areas that are filled with sand. The sheep just make the recovery much slower (he says that is just his theory). Volcanic ashes and eruptions help as well.

BALDURSHEIMUR

There has been many good work done regarding erosion, farmers along with the government have been working very well. Farmers get seed and fertilizer from the government and apply it to their farms. The natural fertilizer is however a lot better than the chemical fertilizer because it is more effective, the animal fertilizer creates dirt. It is very hard to say if erosion is becoming worse or is improving because of all the work that is being done.

GARDUR

Erosion used to be worse, today the sand is blowing less and the land is growing. The affect that men have on erosion is very small. It is mostly nature, the earth needs more nutrition's to be able to sustain grass growth.

GRÆNAVATN

Erosion is an ongoing problem which they continually try to do something about. Their son Haraldur had been today about 20-30 km to the south to apply old hay and animal manure (a remedy mentioned by others, especially at Baldursheimur).