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Volcanic environment impact on andic properties and carbon dynamics in drained peatlands

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Abstract

The world's soils are the most significant terrestrial C store. They store at least twice the amount of carbon as the atmosphere. Peatlands are the most significant long-term soil C store, even though they only cover about 3% of the terrestrial land surface and thus play a vital role in the global C cycle. Iceland is an island in the North Atlantic characterised by high volcanic activity, with volcanic soils being the most common soil type. As Iceland is an island characterised by high volcanic activity, it is a great setting to investigate how mineral inputs affect soil properties in peatlands. The major contributor to these emissions is attributed to the drainage of organic wetland soils. The aim of this research was to investigate how mineral deposits from tephra and aeolian material from eroding drylands affect soil properties, focusing on andic properties and carbon dynamics in drained peatlands. It also aimed to explore how these properties vary over time and if they are related. Comparing the results of this research with previous similar work on undrained peatlands gives insight into the impact of drainage on the development of pedogenic minerals and C dynamics in peatlands of volcanic regions. Three drained peatlands in NW of Iceland with different degrees of exposure to eolian deposition were examined for this research. Results found that andic properties vary with peatlands depending on their distance from volcanic and barren areas. Compared to their undrained counterparts, andic properties were found to have a slightly higher value in this study which could possibly be attributed to increased oxygenation. Andic soil properties were not found to have the same effect on carbon dynamics as in undrained peatlands where they were found to hamper soil organic matter decomposition. The results presented here point to andic properties having the opposite effect in drained peatlands. While tephra layers have been found to act as barriers, preventing SOM decomposition, this was not found to be the case in this research. Possibly these barrier effects have been counteracted by drainage.

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1 Introduction

The world's soils are the most significant terrestrial carbon (C) store and contain at least twice the amount of C as the atmosphere (Batjes, 2016). The amount stored varies with ecosystems and soil type. Peatlands are waterlogged ecosystems and thus accumulate large amounts of soil organic matter (SOM) due to the anaerobic conditions that slow down the decomposition rates of the SOM. They, therefore, act as a C sink in their natural state (Rydin & Jeglum, 2013). Peatlands are generally of research interest worldwide because of their ability to store large amounts of carbon and the role they can play in climate mitigation.

Wetlands cover about 9000 km² of vegetated areas in Iceland (Arnalds, Gudmundsson, et al., 2016). Roughly 12% of those wetlands are Histosols, the organic soils of peatlands (Arnalds, 2004b). The volcanic activity in Iceland shapes them as they get a steady input of aeolian and tephra material, resulting in high mineral and organic content (Bonatotzky et al., 2019). Due to this, they can develop andic properties (Möckel et al., 2021a), which are the properties of Andosols, the most common soil type in Iceland (Arnalds, 2004a). It has been shown that most Icelandic Histosols exhibit a combination of andic and histic properties (Bonatotzky et al., 2019; Möckel et al., 2021b). Andosols, like Histosols, have a great potential for C storage due to the mineral composition inherent in these soils (Takahashi & Dahlgren, 2016; Wada, 1985).

Peatlands have been of research interest in Iceland (Bjarnadottir et al., 2021; Bonatotzky et al., 2021; Möckel et al., 2021b; Möckel et al., 2020; Óskarsson, 1998) as well as other regions characterised by volcanic activity (Hughes et al., 2013; Ratcliffe et al., 2020; Zhang et al., 2022). However, there is little research on how mineral deposits in the form of tephra and aeolian materials impact peatland soil properties. But those who have concluded that mineral deposits affect the development of soil properties (Bonatotzky et al., 2021; Möckel et al., 2021b; Möckel et al., 2020) and strongly influence the ecology and carbon cycling of these peatlands (Gunnarsson et al., 2015; Ratcliffe et al., 2020). Tephra layers of certain thickness have been shown to alter vegetation in peatlands (Eddudóttir et al., 2017; Hughes et al., 2013; Möckel et al., 2017) due to the disturbance caused by the tephra. Increased C accumulation in peatland has also been linked to tephra input in some cases (Ratcliffe et al., 2020; Zhang et al., 2022). Tephra layers also have the potential to affect C structure, as some research has found them to possibly hamper the decomposition of SOM (De Vleeschouwer et al., 2008; Möckel et al., 2021b). Research on the interaction between C characteristics and andic properties in peatlands has found that SOM of Histosols with andic properties is less decomposed than that of Histosols without notable andic properties (Möckel et al., 2021b).

As Iceland is an island characterised by high volcanic activity (Einarsson, 2008), it is a great setting to investigate how mineral inputs affect soil properties in peatlands. In Iceland, greenhouse gas (GHG) emission patterns show that the emissions between 1990 and 2018 emanate predominantly from land use, land use change, and the forestry sector (LULUCF). The major contributor to these emissions is attributed to the drainage of organic wetland soils (The Environment Agency of Iceland, 2020).

Aim

The aim of this research is to investigate how mineral deposits from tephra and aeolian material from eroding drylands affect soil properties, focusing on andic properties and C dynamics in drained peatlands. It also aims to explore how these properties vary over time and if they are related. This research will advance our knowledge of how volcanic environments shape peatlands and their properties. Also, comparing the results of this research with previous similar work on undrained peatlands (Möckel et al., 2021b, 2023; Möckel et al., 2020) will give insight into the impact of drainage on the development of pedogenic minerals and C dynamics in peatlands of volcanic regions.

To fulfil the aim, the following research questions will be put forward:

- Are andic properties present in the soil layers? Do they vary through time and is there a detectable difference between pre-settlement and post-settlement soils? Palaeoecological research has observed a more stable environment for soil formation before human settlement. After human settlement there has been evidence of more input of aeolian material in soils due to increased erosion (Dugmore et al., 2009; Eddudóttir et al., 2016).
- Can variation in C dynamics be explained by variation in andic properties? Möckel et al. (2021b) found that SOM in Histosols exhibiting andic properties appears to be less decomposed compared to Histosols lacking significant andic characteristics. The presence of andic soil properties appears to influence the C structure by promoting the formation of organo-mineral complexes. These complexes were found to hinder the decomposition of chemically more labile groups.
- Do tephra layers influence C dynamics in drained peatlands of volcanic regions? Blackford et al. (2014) found that tephra layers of certain thickness could alter vegetation in peatlands, and therefore the C dynamics. Tephra layers have also been found to act as a barrier (De Vleeschouwer et al., 2008) preventing input of organic matter (OM) into deeper soil layers, thereby hampering microbial activity.

Three drained peatlands in northern Iceland were investigated in this study. These three peatlands function as drained counterparts of the undrained natural peatlands studied in the PhD project of Susanne C. Möckel (Möckel et al., 2021b, 2023; Möckel et al., 2020).

2 Theoretical background

2.1 Peatlands

Estimations of broad-scale models indicate that the top 1 m of the world's soils contains 1400 to 1600 Pg of soil organic carbon (SOC) (Batjes, 2016). Of those soils, peatlands are the most significant long-term soil C store, even though they only cover about 3% of the terrestrial land surface (Joosten et al., 2016). They thus play an important role in the global C cycle. Majority of peatlands are situated in boreal and the sub-arctic zones (Vitt, 2008) and it is estimated that the C stock in northern peatlands is around 265-621 Pg (Yu et al., 2010). Peatlands worldwide have been drained for land use purposes, such as agriculture, timber production and peat extraction. Several environmental problems have been related to the draining of peatlands (Holden et al., 2004), such as ecosystem destruction and greenhouse gas (GHG) emissions. CO₂ emissions from drained peatlands are estimated to be 2.3 - 3.8% of all anthropogenic GHG emissions (Le Quéré et al., 2018). The Paris Agreement demands to rewet 500.000 km² of drained peatlands worldwide by 2050-2070 (IPCC, 2018), with the aim of reducing GHG emissions.

2.1.1 C dynamics of peatlands

Peatlands can store large amounts of C. Peatlands are waterlogged ecosystems and thus accumulate large quantities of SOM due to the anaerobic conditions that slow down the decomposition rates of the SOM. Consequently, photosynthesis inputs exceed losses through decomposition (Rydin & Jeglum, 2013). The decomposition of SOM to final products, i.e. CO₂ and CH₄ results from microorganism activity, regulated by enzymes, physically controlled transport processes of electron acceptors and nutrients and the quality of the SOM itself (Limpens et al., 2008). The decomposition process under anaerobic conditions operates in the absence of oxygen, which means that alternative electron acceptors are used due to the lack of oxidants. These electron acceptors can be NO₃⁻, Fe³⁺, Mn⁴⁺ and SO₄ and in some cases fermentation products or CO₂ itself. However, these metabolic pathways yield less energy than under aerobic conditions. Moreover, the availability of alternative electron acceptors is often limited, leading to less efficient decomposition and ultimately to the build up of SOM (Schlesinger & Bernhardt, 2020). Environmental changes can influence decomposition processes, which can affect microbial activity by acting on the availability of nutrients and electron acceptors. It can also have an indirect effect through changes in vegetation and soil structure. In peatlands, both heterotrophic respiration and litter degradability exhibit a decreasing trend with depth. More consistent waterlogged conditions are found in the sub soil while there are more fluxes in topsoil (Limpens et al., 2008). Peatland's SOM composition also varies strongly with depth. Recalcitrant compounds usually accumulate in the deeper layers during peat formation as the easily degradable compounds decompose (Leifeld et al., 2012). With drainage, the depth of the oxic peat layer is increased. The previously anoxic layers of the peat are exposed to oxygen and to oxidants as electron acceptors, enhancing the decomposition rate and subsequent increased GHG emissions to the atmosphere (Joosten et al., 2016).

2.2 The volcanic environment of Iceland

Iceland is an island in the North Atlantic Ocean with high volcanic activity (Einarsson, 2008). The island is situated on two tectonic plates with a mantle plume underneath, making earthquakes and volcanic eruptions common (Einarsson, 1991). There are about

30 active volcanic systems in Iceland with an average of 20-25 eruptions per century, but it varies with time periods and years. The four most active volcanic systems are Grímsvötn, Bárðarbunga - Veiðivötn, Hekla and Katla (Thordarson & Larsen, 2007). Explosive eruptions are common in Iceland (Thordarson & Larsen, 2007) and they made up a substantial part of Holocene volcanism on the island. The majority are hydromagmatic basaltic eruptions as the presence of ice and water are common in volcanic areas. Explosive eruptions produce large amounts of tephra that can be buried in soils. Then they form marker horizon in soils, where records of individual eruptions are preserved (Larsen & Eiríksson, 2008). Tephra layers can thus be an invaluable tool in studies of environmental change over time as the age of the tephra layers can be estimated (Eddudóttir et al., 2017, 2020; Eddudóttir et al., 2016). The landscape of the island is shaped by volcanic activity, consisting of mountain terrains and lava fields. Vegetation is characterised by low-growing species, with only a fourth of the island vegetated. More continuous vegetation cover in the lowland areas but is more sparse in the highlands (IINH, n.d.). The weather in Iceland is characterised by mild winters and cool summers (Einarsson, 1984), with frequent precipitation and strong winds.

2.2.1 Environment stability

During the Holocene the climate in Iceland has undergone significant shifts influenced by factors such as the North Atlantic Ocean and atmospheric circulation, as well as volcanism and sea ice/ocean related feedbacks (Geirsdóttir et al., 2020). The Early Holocene followed the Last Glacial Maximum with warmer temperatures and melting glaciers. Iceland became nearly ice-free by ca. 9 ka BP (Larsen et al., 2012). The Holocene Thermal Maximum ca. 8 ka BP to 6 ka BP marks the warmest period in Iceland during the Holocene (Geirsdóttir et al., 2020). *Betula* woodlands are believed to have reached their maximum distribution and elevation during this time period (Eddudóttir et al., 2016). Expansion of the cryosphere commenced during the late Holocene ca. 5 ka BP (Geirsdóttir et al., 2019) with significant decrease in summer temperature. Geirsdóttir et al. (2020) found that ca. 5 ka BP a certain threshold for the Icelandic landscape to recover from cold-events and/or tephra fall was reached. After ca. 5 ka BP two of the largest explosive eruptions of the Holocene in Iceland happened, Hekla 4 ca. 4.25 ka BP (Dugmore et al., 1995) and Hekla 3 ca. 3.06 ka BP (Dugmore et al., 1995) coincide with the start of cooler periods in Iceland and glacier expansion (Geirsdóttir et al., 2019).

2.3 Volcanic soils

Common soils of volcanic regions are called Andosols (Wada, 1985). They are formed in humid environments by rapid weathering of fine-grained, porous parent material containing glass and microlites, in the presence of organic material (Mizota & van Reeuwijk, 1989). The weathering of the volcanic ejecta, Andosols parent material, leads to abundant precipitation of aluminium (Al), iron (Fe) and silicon (Si) and to the formation of short-range order (SRO) minerals such as allophane and imogolite as well as the formation of ferrihydrite and the development of Al/Fe-humus complexes (Bonatotsky et al., 2021; Shoji et al., 1993). Allophane and imogolite are both poorly crystalline aluminosilicates characterized by small particle size (Harsh et al., 2002). Ferrihydrite is an ephemeral mineral and is the most active Fe-hydroxide in soils (Vodyanitskii & Shoba, 2016). Al/Fe-humus complexes are formed through the bond of humic substances to mineral surfaces (Takahashi & Dahlgren, 2016). Andosols can

be divided into nonallophanic – and allophanic Andosols. Allophanic Andosols are dominated by allophane and imogolite and non-allophanic Andosols are dominated by Al-hummu complexes and 2:1 layer silicates (Dahlgren et al., 2004). Layer silicates are silicates that form two-dimensional sheets that stack up, sort of like pages in a book. The sheets of the silicates are very thin, making their surface area very big (Arnalds, 1993).

Andosols have so-called andic properties. According to the World reference base for soil resources (WRB, 2022) and the Keys to soil Taxonomy (2014b) soil material with andic properties must fulfil the criteria of having less than 25% organic C by weight, bulk density of $\leq 0.90 \text{ g/cm}^3$, phosphate retention, which is the soils capacity to absorb phosphate, of 85% or more and $\text{Al}_o + \frac{1}{2} \text{Fe}_o \geq 2\%$ (Al_o and Fe_o = Al and Fe extracted by ammonium oxalate). High contents of SRO mineral such as allophane and ferrihydrite and metal ions like Al and Fe largely give Andosols their distinctive properties (Mizota & van Reeuwijk, 1989). These unique properties include high water-holding capacity, low bulk density, high phosphate retention and stable soil aggregates (Arnalds, 2004a; Dahlgren et al., 2004; Matus et al., 2014; Shoji et al., 1993). Most importantly, Andosols have an unusually high capacity to accumulate SOC. Chemical interaction of SOM with the metal ions Al and Fe and with pedogenic minerals like allophane, imogolite and ferrihydrite (Shoji et al., 1993) facilitate long-term stabilisation of SOC by Al/Fe humus complexes and organo-mineral complexes. In fact, organo-mineral associations are recognized as one of the most important mechanisms for providing long-term SOC stabilization (Kögel-Knabner & Amelung, 2014).

2.3.1 Icelandic Andosols

Soils in Iceland were formed during the Holocene after the glaciers retreated. They are younger than 10.000 years (Arnalds et al., 1995) and could thus be considered young soils. The volcanic environment heavily influences Icelandic soil formation as their parent material is volcanic in origin (Arnalds, 2004b) and most soils in Iceland are classified as Andosols (Arnalds, 2004b). The Icelandic Andosols has low bulk densities, high water retention and high SOC content (Arnalds et al., 1995). P-retention and their effect on P availability in Icelandic soils. The dominant pedogenic minerals are allophane, imogolite and poorly crystalline ferrihydrite (Stefánsson & Gíslason, 2001) while layer silicates are rare or not present (Arnalds, 1993). However, new research on Histosols in Iceland have found them to be present (Bonatutzky et al., 2019). The cool and moist climate of Iceland allows for the rapid formation and build-up of these minerals as they persist in cool environments (Dahlgren et al., 2004).

Large areas are influenced by the continuous flux of aeolian deposits originating from eroded land and volcanic activities (Arnalds, Dagsson-Waldhauserova, et al., 2016). These deposits constantly recharge the soils with new material. Volcanic eruptions can lead to thick tephra deposits in soils, from a couple of millimetres up to more than ten centimetres (Arnalds, Dagsson-Waldhauserova, et al., 2016). These tephra deposits and aeolian material of volcanic origin constantly recharge the surface with new material while the subsoils are preserved and continue to develop after burial (Arnalds et al., 1995).

2.4 The Icelandic peatland environment

Histosols are the organic soils of peatlands. They are high in C as their main parent material is organic remains from local vegetation. (Soil Survey Staff, 2014b).

According to the World Reference Base (WRB, 2022) as well as the Icelandic soil classification system (Arnalds, 2004a) they contain at least 20% of SOC. In Iceland, only about 1.2% of surface soils fulfil this criteria and rarely reach the average of 46% C (Bonatutzky et al., 2019; Möckel et al., 2017) reported for Northern peatlands (Loisel et al., 2014). However, the subsurface distribution of Histosols is greater than 1.2%. Often, in Icelandic wetlands more C rich subsoil can be found below mineral richer surface soil layers (Gísladóttir et al., 2010; Möckel et al., 2017). That indicates that there was once a greater distribution of peatlands in Iceland due to more stable conditions for soil formation before the onset of anthropogenic influence ca. 870 AD. In Iceland, Histosols receive a relatively high amount of aeolian material input of volcanic nature (Arnalds, 2004a) that leads them to have a mixture of histic, andic and vitric properties. Which properties dominate depends on the Histosols location with respect to the major aeolian source areas (Bonatutzky et al., 2019; Möckel et al., 2021b). Even highly organic Histosols in Iceland show andic properties to some degree (Bonatutzky et al., 2019). Ammonium oxalate extractable Al (Al_o) and Fe (Fe_o) in Icelandic Histosols are commonly found to be in the range of 0.7–1.6% for Al_o and 0.5–1.2% for Fe_o , while the Si, extracted by ammonium oxalate (Si_o) content is low (Arnalds, 2004). Approximately 5.5% of surface soil in Iceland is comprised of histic Andosols and they contain between 12% and 20% C (Arnalds, 2004a) which is below the diagnostic criterion of Histosols. While they fulfil the diagnostic criteria of Andosols, they bear strong histic properties such as high C content, low bulk density and only partly decomposed organic material (Arnalds, 2004a). Bulk density in Icelandic Histosols are low, compared to other mineral soils (Arnalds, 2004a) but they are rather high compared to other Histosols in northern countries. Due to that Histosols in Iceland have less C contents than other northern peatlands in non-volcanic regions. However, their C stock is in line or even higher than that of 1.125 t ha⁻¹ reported by Joosten et al. (2016). On average, C stocks in Histosols in Iceland are 1.975 t ha⁻¹, while C stocks of more mineral histic Andosols are around 891 t ha⁻¹ (Óskarsson et al., 2004).

2.4.1 Peatland degradation in Iceland

Like in many other countries in the world, Icelandic peatlands have been drained extensively for agricultural purposes. Approximately 47% of Iceland's inland wetland have been subjected to agriculturally induced drainage (Arnalds, Gudmundsson, et al., 2016). From the middle of the 20th century until the 1990s the Icelandic government financially supported the digging of drainage ditches for agricultural usage (Geirsson, 1998). It was not until the late 1990s (Aradóttir et al., 2013) that there was awakening regarding the value of wetlands, both ecologically and environmentally. Restoration projects were then initiated motivated by nature conservation and mitigation of GHG emissions. However, restoration efforts have been found to be limited (Aradóttir et al., 2013).

2.5 The influence of andic properties on C in peatlands

Andosols, like Histosols, have a great potential of storing C (Takahashi & Dahlgren, 2016; Wada, 1985). Al and Fe are known to stimulate C accumulation by creating bonds with humus (Bonatutzky et al., 2021; Inagaki et al., 2020). The impact of andic properties on soil C dynamics and overall soil properties has been a subject of interest for quite some time (Óskarsson et al., 2004; Wada, 1985). Research about the interplay

between andic and histic properties and its influence on soil development in peatlands is still in its early stages.

Bonatotzky et al. (2019) found that the input of tephra and aeolian matter affected the development of soil properties in Histosols. They found that, in contrast with other previous research on Icelandic soils, layer silicates were present in the soils. Icelandic histosols are known for their lack of layered silicates (Arnalds, 1993). A recent study by Möckel et al. (2021, 2023) found that the interplay between andic and histic properties in some Icelandic peatlands leads to preferential stabilization of labile C compounds such as carbohydrates in organo-mineral complexes. Consequently, the SOM found in Histosols of peatlands, where the development of andic properties is facilitated by mineral deposits of volcanic origin, is less decomposed compared to the SOM in peatlands lacking significant andic soil properties. A study done in Ecuador on histic Andosols also found indication that organo-metal complexes play a role in C accumulation (Buytaert et al., 2007). However, most research done on C dynamics of volcanically affected peatlands does not investigate the effect of andic properties (Hribljan et al., 2016; Zhang et al., 2023).

Thick and compact tephra layers possess the capacity to function as protective barriers, impeding microbial activity and the decomposition of SOM. They can act as capillary barriers thus preventing water infiltration and therefore the infiltration of dissolved organic C (DOC) (De Vleeschouwer et al., 2008). In the short term, this hindrance affects the influx of new organic material into deeper soil layers in the years following tephra deposition. In the long term, these layers act as barriers, preventing the entry of DOC from upper soil layers. DOC is a key control of microbial activity as microbes consume DOC (Bragazza et al., 2012). In peatlands of volcanic regions, when shielded by substantial tephra layers, the subsoil may exhibit similarities to younger surface soils, which may indicate reduced decomposition (Möckel et al., 2021b). Studies have observed increased SOM decomposition adjacent to tephra layers (Broder et al., 2012; Damman, 1988; Mathijssen et al., 2019). In both Patagonia (Broder et al., 2012; Mathijssen et al., 2019) and Japan (Damman, 1988) research on Histosols have found that input of tephra layers tend to increase the decomposition rates by adding nutrients and consequently, stimulate microbial activity and mineralisation. However, a study conducted in Japan by Hotes et al. (2004) provided evidence of decreased decomposition below fine-grained, semi-impermeable tephra layers. Additionally, thick tephra layers have the ability to alter vegetation in peatlands (Blackford et al., 2014; Hotes et al., 2004; Hughes et al., 2013; Möckel et al., 2021b), thereby impacting the chemical composition and stability of their SOC (Kögel-Knabner, 1997). However, even though there is a shift in SOC structure it does not always indicate different stages in decomposition, it can also indicate a shift in vegetation.

Regular inputs of volcanic material can even keep peatlands in an earlier successional state, the so-called tephrotrophic mires of Japan (Wolejko & Ito, 1986) and New Zealand (McGlone et al., 1988), where raised bogs form, but a nutrient demanding fen-like vegetation dominates. Hughes et al. (2013) found that moderate to high tephra deposition could shift plant communities in peatlands, from *Sphagnum* to monocotyledon dominant. They associated that with an initial reduction in C accumulation in peatlands in Japan lasting several hundred years, followed by a rapid rebound in C accumulation that was driven by P inputs and more than compensated for the initial decline in C accumulation. Peatlands in New Zealand however, were found

to have a near instantaneous increase in C accumulation after tephra deposits, attributed to enhanced nutrient availability, particularly P, and a plant community with a wide tolerance for different nutritional conditions (Ratcliffe et al., 2020). Zhang et al. (2022) also found an increase in C accumulation after tephra deposition in a peatland in China that could also be attributed to enhanced P availability, following the same eruption described by Hughes et al. (2013).

3 Methodology

3.1 Research area and sampling approach

The research area is in the Austur-Húnavatnssýsla district in northwest Iceland (Figure 1). Soil samples were collected from three drained peatlands along a north-south transect, Sviðningar (N 66°00.3834' W 020°24.2244') being the furthest north, Hafratjarnarmýri (N 65°34.9751' W 0020°07.7665') and Snæringsstaðir (N 65°28.3547' W 020°04.0158). These peatlands are located in agricultural areas and are characterised by continuous vegetation cover, but erosion and bare spots are common. These sites distances from possible mineral aeolian material deposition sources differ as their source is the active volcanic zones and more sparsely vegetated or barren zones further inland (Figure 1). The main weather characteristics at weather stations within the research areas are shown in table 1.

Table 1. Main weather characteristics from weather stations closest to the research area. Data were available for the following period: Blönduós 1949-2001, Hraun á Skaga 1956-2011 and Nautabú 1949-2004 . Reference: (IMO, n.d.)

	Blönduós	Hraun á Skaga	Nautabú
Elevation m a.s.l.	8	3	111.5
Mean annual temperature (C°)	3.0	2.9	2.7
Mean annual precipitation (mm)	480.7	514.7	470.2
Mean annual wind speed (m/s)	3.8	5.6	4.8

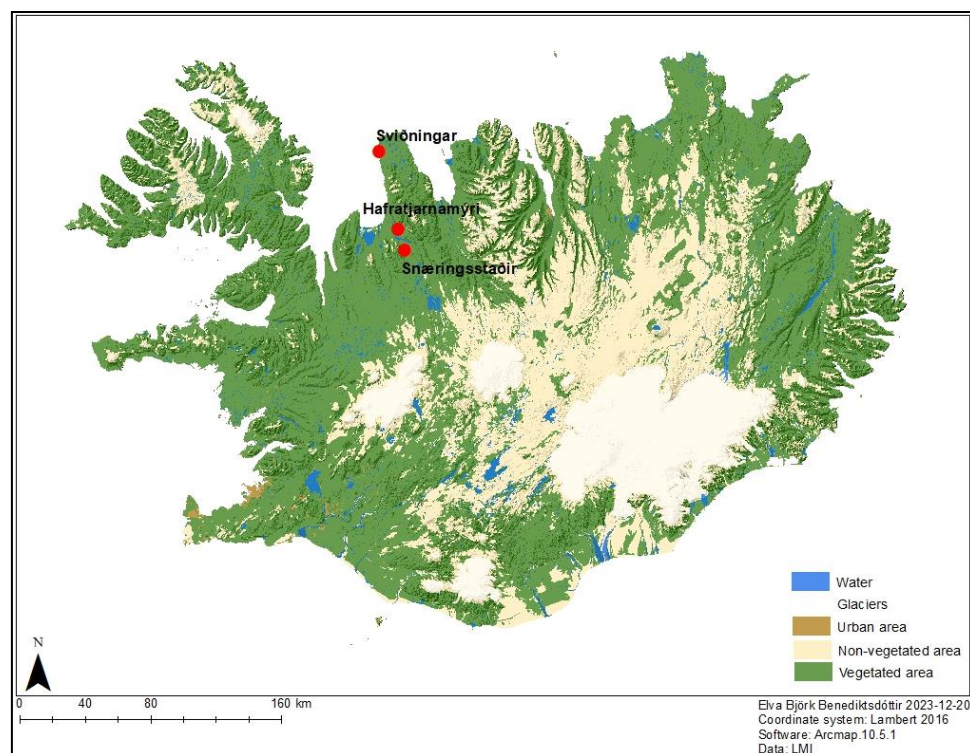


Figure 1. Map of Iceland marked with the placement of the sampling sites.

One soil profile was excavated at each peatland, and bulk soil samples were collected. A soil pit was dug, and bulk soil samples were collected as far as 20 cm below Hekla 4 tephra layer. The samples were collected at 10 cm intervals and 5 cm intervals below and above the tephra layers. (Bonatotzky et al., 2019; Möckel et al., 2021b). A monolith was collected from each peatland used for analysis of dry bulk density (DBD), SOM (SOM) and C/N ratios.

3.2 Laboratory analyses

3.2.1 Selective dissolution of Al, Fe and Si

Selective dissolution data is used in the study of the non-crystalline material content of soils. Active Al and Fe components that are presented in non - crystalline materials are assumed to be dissolved by ammonium oxalate extraction. The method also extracts allophane, imogolite as well as Al/Fe humus complexes (Soil Survey Staff, 2014a). Al and Fe dissolved by sodium pyrophosphate are mainly associated with organic compounds (Al/Fe humus complexes) (Soil Survey Staff, 2014a).

Extraction of Al, Fe and Si with ammonium oxalate was carried out following Soil Survey Staff (2014; method 4G2). For the analysis, 15 ml of ammonium oxalate solution, 0.2 M concentration with a pH of 3.0 was added to tubes with 0.5g of <2 mm of soil. Using a mechanical vacuum extractor, the soil samples were extracted under darkness for 30 minutes. Adding another 35 ml of the ammonium oxalate solution to the soil the samples were extracted again under darkness but this time for 12 hours. The ammonium oxalate extract was then weighed. The extraction of Al, Fe and Si with pyrophosphate followed the Soil survey Staff (2014; method 4G3). Mixed with 30 ml of 0.1 M pyrophosphate solution, 0.5g of <2 mm of soil was shaken for 12 hours. The extract was then allowed to settle overnight, centrifuged and filtered to obtain a clear extract. The Marine and Freshwater Research Institute in Iceland then analysed the ammonium oxalate – and pyrophosphate extracts for Al, Fe and Si by ICP-MS.

The sum of Al and $\frac{1}{2}$ Fe extracted by ammonium oxalate (Al_o and Fe_o) was calculated as it is a diagnostic criterion of andic soil properties (IUSS Working group, 2015). Ferrihydrite was estimated as $\%ferrihydrite = Fe_o \times 1.7$ (Childs, 1985). The equation by Mizota and van Reeuwijk (1989) which is based on Parfitt. and Wilson (1985), was used for allophane calculations where $\%allophane = 100/-5.1*(Al/Si \text{ ratio}) + 23.4 * Si_o$.

3.2.2 Phosphate retention and pH in DiH_2O

Phosphate retention of $\geq 85\%$ is defined as a diagnostic criterion of andic soil properties (IUSS Working group, 2015) and was carried out based on Blakemore et al. (1987). Phosphate retention is not an indication for total phosphorus in the soil. It gives information on the inherent capacity of soils to retain phosphorus (Batjes, 2011). For the analysis, 5g of <2 mm soil was mixed with 25 ml of P-retention solution and shaken for 16 hours. All the samples were then centrifuged and filtered to obtain a clear extract. The extract was then measured by spectrophotometrical absorbance at 466 nm after colour reaction with nitric vanadomolybdate acid reagent. pH in DiH_2O was measured using a soil: water ratio of 1:10 (Blakemore et al., 1987).

3.3 Other data used

This thesis is part of a larger collaborative project called *Peatlands under pressure – The rare interplay of andic and histic soil properties and their implications for C dynamics of organic soils*, which involves the participation of several BSc and MSc students and postdoctoral researchers. Therefore, this thesis also uses some variables determined by colleagues, which are essential to the data I obtained. The following subchapters will introduce the variables obtained by other people.

3.3.1 Dry bulk density, SOM and C/N ratios

Data on dry bulk density (DBD), SOM content and C/N ratios (Arnarsson, 2023) were collected from the monolith at every centimetre. DBD was determined by mass loss after drying a known soil volume. SOM was measured by loss on ignition at 550°C (Heiri et al., 2001). C/N ratios were estimated from total C (%C) and nitrogen (%N). C/N ratios are commonly used for peat decomposition proxy. Peat that is only decomposed a little has larger C/N ratios, whereas the ratio becomes smaller in strongly decomposed peat due to more loss of C over N during microbial decomposition (Krüger et al., 2015; Kuhry & Vitt, 1996). The %C and %N measurements were performed on a Thermo Delta V isotope ratio mass spectrometer (IRMS) interfaced with an NC2500 elemental analyser at the Cornell Isotope laboratory in the USA. Soil organic C (SOC) is equivalent to %C. This can be estimated as carbonate minerals are absent in Icelandic soils (Bonatutzky et al., 2021; Mankasingh & Gísladóttir, 2019; Vilmundardóttir et al., 2014).

3.3.2 Geochemical fingerprint of tephra layers

Tephra layers in Icelandic soils are often visible in the soil profile which makes it easy to determine where they are located. Samples were taken from the visible tephra layers as well as where there was a spike in mineral content (%ASH). The major chemical elements of the tephra layers were analysed using an electron probe microanalysis (EPMA) on a JEOL JXA-8230 Electronic Probe Microanalyzer. The beam diameter and current were set to 5 µm and 5 nA for silica and small-grained tephra. For tephra of basaltic origin and larger-grained tephra particles, the beam diameter was set to 10 µm and the beam current to 10 nA. The accelerating voltage was 15kV. The chemical composition of the tephra layers was used to link the tephra layers to their source volcano by using the database available from Tephabase (n.d.).

3.3.3 SOC structure and C accumulation rate

To analyse the structure of the SOC, ¹³C nuclear magnetic resonance (NMR) spectroscopy was performed at the Agricultural University of Sweden in Umeå (Möckel et al., unpublished data) The structure of SOC contributes to the characteristics of SOM and decomposition processes (Kögel-Knabner, 1997). The different SOC structures resulted from the ¹³C NMR could then be used to calculate two ratios that can be used as decomposition proxies (Bonanomi et al., 2013; Kögel-Knabner, 1997; Tephabase, n.d.). The decomposition proxies, 70-75/52-57 ratio and A:O/N ratio were calculated. The 70-75/52-57 ratios correspond to O-alkyl C (70-75 ppm) and methoxyl C of lignin (52-57 ppm) and correlate with decay rates. As these ratios increase, there is a relatively

higher content of the labile O-alkyl C of carbohydrates than the more recalcitrant methoxyl C of ligning. Which means that higher values mean less decomposed material and lower values mean more decomposed (Bonanomi et al., 2013). The A:O/N are the ratio of alkyl C to O/N-alkyl C. Increased A:O/N ratios indicate more advanced decomposition as there is a relatively greater content of recalcitrant alkyl C than the more labile O/N-alkyl C (Baldock et al., 1997).

Age-depth models for each site were produced. From that C accumulation rates could be calculated by dividing the measured C content of each 1 cm layer by the modelled age difference between the top and bottom of the layers. The final rate was then converted to a per-square metre basis and presented as g C m⁻² yr⁻¹.

3.4 Data analysis

To analyse the difference of andic properties before and after human settlement a Wilcoxon signed-rank test was performed. This test is a non-parametric *t*-test used to assess whether the means of two populations are different (Holmes, 2020). In this case, andic properties before and after settlement. This test was picked as the data does not follow a normal distribution. Soil layers below the settlement tephra layer were grouped as the before settlement and the layers after the settlement layer were considered as after settlement. This was done for each site. Since the settlement tephra layer was not found at Sviðningar, the Hekla 1104 layer was used as the criteria instead. The test was done on P-retention and Al_o+1/2 Fe_o as well as %Allophane %Ferrihydrite and Al_p/Al_o. The results were considered significant if the *p*-value was ≤ 0.05 . The results were displayed by boxplots.

Spearman rank correlations were performed to evaluate if there is a relationship between selected andic properties (P-retention, Al_o+1/2 Fe_o, %Allophane and %Ferrihydrite) and C characteristics (%C, 70-75/52-57, A:O/N, C/N and CAR). Data from all sites was pulled together for this analysis. Same as for the Wilcoxon signed-rank test, results were considered significant if the *p*-value was ≤ 0.05 . The results were displayed in scatterplots.

Principal component analysis (Greenacre et al., 2022) (PCA) was produced to look whether tephra layers influence C dynamics in drained peatlands. The purpose was to see if any soil profile layers group together around tephra layers.

Data analysis, as well as data visualisation, was performed using R Studio version 4.2.2.

4 Results

4.1 Tephra layers

The tephra layers that were found and could be identified at the study sites can be seen in table 2. Full chemical composition of tephra layers found can be seen in appendix 1. More tephra layers and layers of tephra were found but they could not either be identified or were reworked material. The Tephra layers found at all sites were Hekla 1104, Hekla 3 and Hekla 4. Hekla 1766 and the Settlement layer were found at Snæringssstaðir and Hafratjarnamýri but not at Sviðningar. Hekla 5 was only found at Snæringssstaðir as a thin layer (1 cm) and Hekla 3 and 4 formed the thickest layers at that site. At Hafratjarnamýri Hekla 4 was the thickest tephra layer (7 cm) with the rest of the tephra layers being rather thin. At Sviðningar only 3 tephra layers were found with Hekla 4 being the thickest (3 cm).

Table 2. Tephra layers that could be identified

Tephra layer	Year	Reference
Hekla 1766	1766 AD	(Sigmarsson et al., 2022)
Hekla 1104	1104 AD	(Larsen & Þórarinnsson, 1977)
Settlement layer	870 AD	(Schmid, 2018)
Hekla 3	3.06 ka BP	(Dugmore et al., 1995)
Hekla 4	4.25 ka BP	(Dugmore et al., 1995)
Hekla 5	7.05 ka BP	(Larsen & Þórarinnsson, 1977)

4.2 Soil properties

The values for SOM, C and C/N ratios were the highest between Hekla 4 and Hekla 3 at Snæringssstaðir (Figure 2a) and also seemed to be the most stable between those tephra layers. P retention was above the diagnostic threshold for andic properties of 85% at all layers. pH values did increase slightly above tephra layers and $Al_o+1/2Fe_o$ had the highest values between Hekla 3 and the settlement layer. Al_p/Al_o values indicated that the soil is non – allophanic (Figure 3a). The allophane content started to increase after the deposition of Hekla 3. The 70-75/52-57 ratios were the highest at the surface soil layers, pointing to less decomposition in the top layers as expected, while the A/O-A ratios increased with depth pointing to increased decomposition (Figure 4a). There was however a reverse in the values at a greater depth or below Hekla 3.

At Hafratjarnamýri the DBD, SOM, ASH and C (Figure 2b) were more stable in layers between Hekla 3 and Hekla 4 than in the layers above Hekla 3 which is compatible with the other two locations. C/N ratios seemed to be the most stable between Hekla 3 and the Settlement layer. P-retention, $Al_o+1/2Fe_o$, allophane and ferrihydrite (Figure 3b and 4b) all have higher values right below the Hekla 4 tephra layer. P retention was above the diagnostic threshold of 85% for andic properties in all layers except for one. $Al_o+1/2Fe_o$ had stable values between Hekla 4 and Hekla 3 as well as Hekla 3 and the Settlement layer but it was below diagnostic criterion for andic properties between Hekla 4 and Hekla 3 while the opposite was true between Hekla 3 and the Settlement layer. Al_p/Al_o values pointed to non-allophanic soil except for right below or above some tephra layers, a similar pattern was spotted at Sviðningar. Allophane content was

the highest below Hekla 4 while the ferrihydrite content was the highest between Hekla 3 and the Settlement layer. The 70-75/52-57 ratios got lower with depth similar to the other two locations. The A/O-A ratios were quite stable throughout the soil profile with a slight increase after Hekla 3 and Hekla 4 (Figure 4b).

At Sviðningar DBD, SOM, ASH and C (Figure 2c) were the most stable between Hekla 4 and Hekla 3, similar to Snælingsstaðir. P-retention increased with depth (Figure 3c) while pH decreased. $Al_o + 1/2Fe_o$ was under the diagnostics for andic properties and Al_p/Al_o values pointed to non-allophanic soil except for just below Hekla 1104 and Hekla 4 (Figure 3c). In contrast to the other areas, no detectable allophane was found in between Hekla 4 and Hekla 3 or anywhere in the soil layers (Figure 4c). Similar to Snælingsstaðir the 70-75/52-57 ratios decreased with depth and the A/O-A values were the highest right above Hekla 3 (Figure 4c).

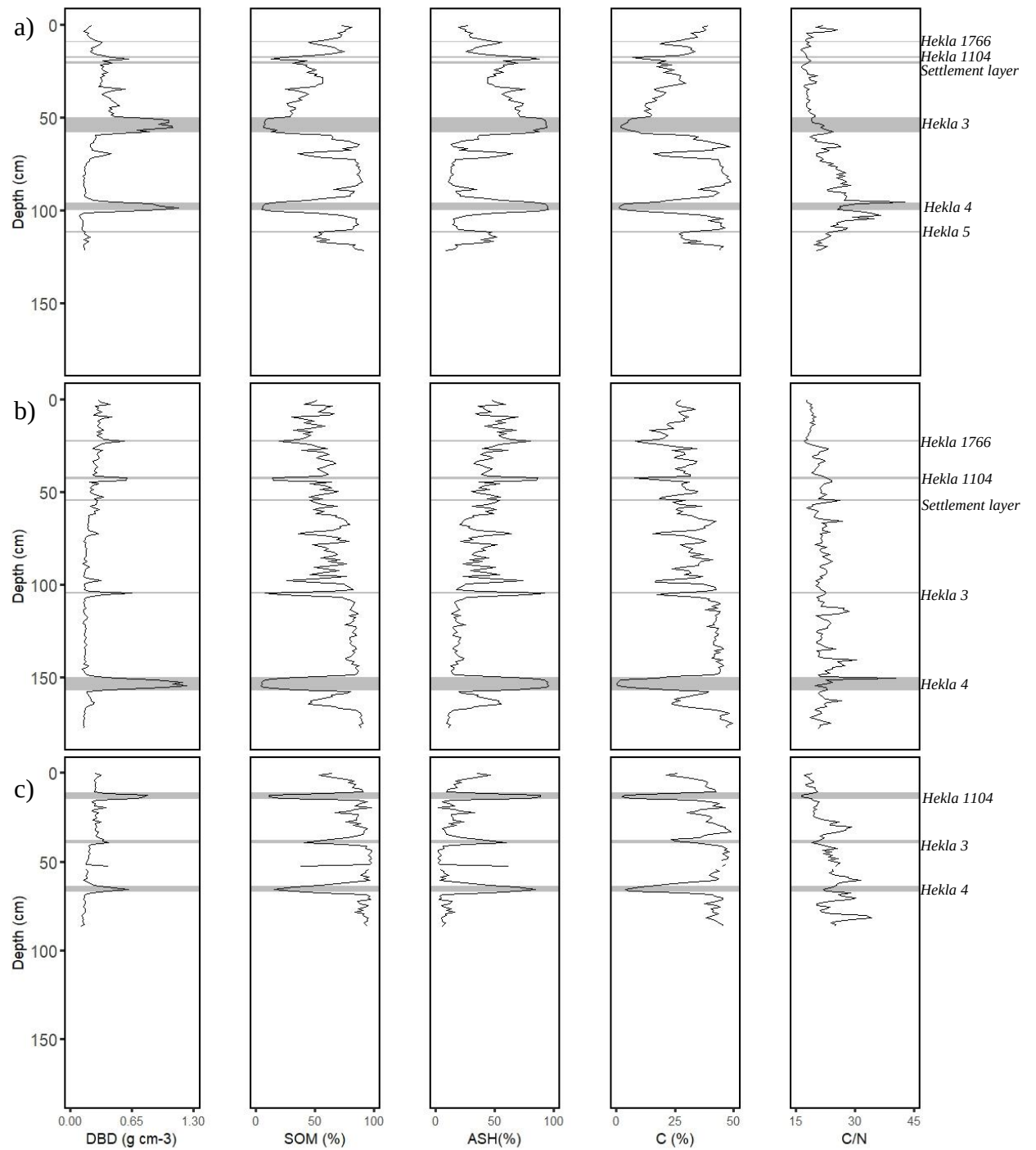


Figure 2. Results of soil properties examined in this study, dry bulk density (DBD), SOM (SOM), mineral content (ASH), and C and C/N molar ratios. Snælingsstaðir (a), Hafratjarnamýri (b) and Sviðningar (c). The grey horizontal lines presented are the tephra layers observed during fieldwork.

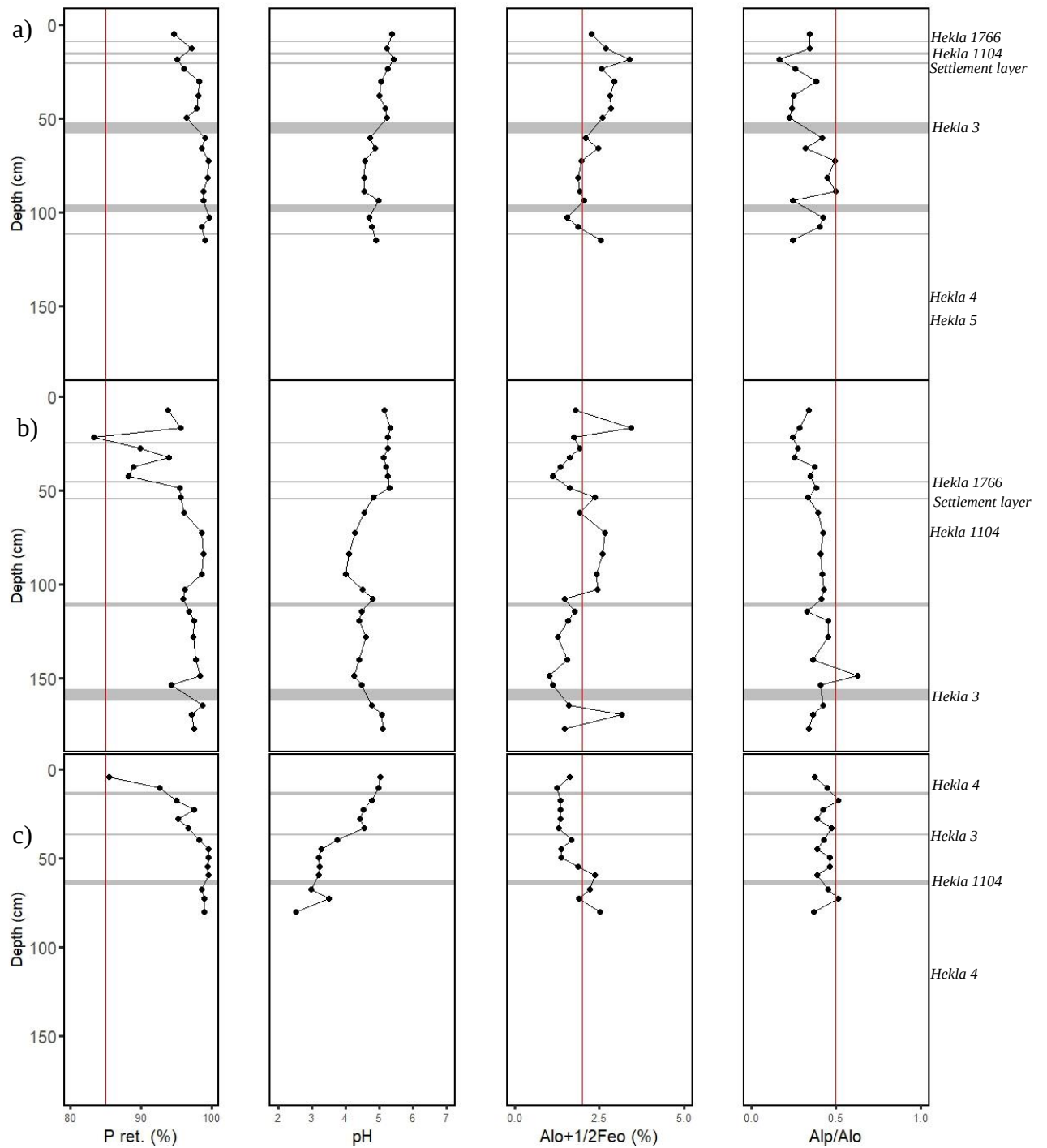


Figure 3. Variables based on P-retention, pH, Alo + $\frac{1}{2}$ Feo and Alp/Alo, from the selective dissolution analysis, from the three peatlands, Snæringstaðir (a), Hafratjarnamýri (b) and Sviðningar (c). P-retention (P-ret.), Alo+1/2 Feo, Allophane and Ferrihydrite are presented in %. The grey horizontal lines presented are the tephra layers that were observed during the fieldwork and the red vertical red lines represent the following thresholds: P-retention $\geq$ as a diagnostic criterion for andic properties, Alo+1/2 Feo $\geq$ 2% as a diagnostic criterion of andic properties, Alp/Alo = 0.5 as the demarcation of allophonic and non-allophonic Andosols (0.1 to <0.5 $\rightarrow$ allophanic Andosols; 0.5-1.0 $\rightarrow$ nonallophanic Andosols).

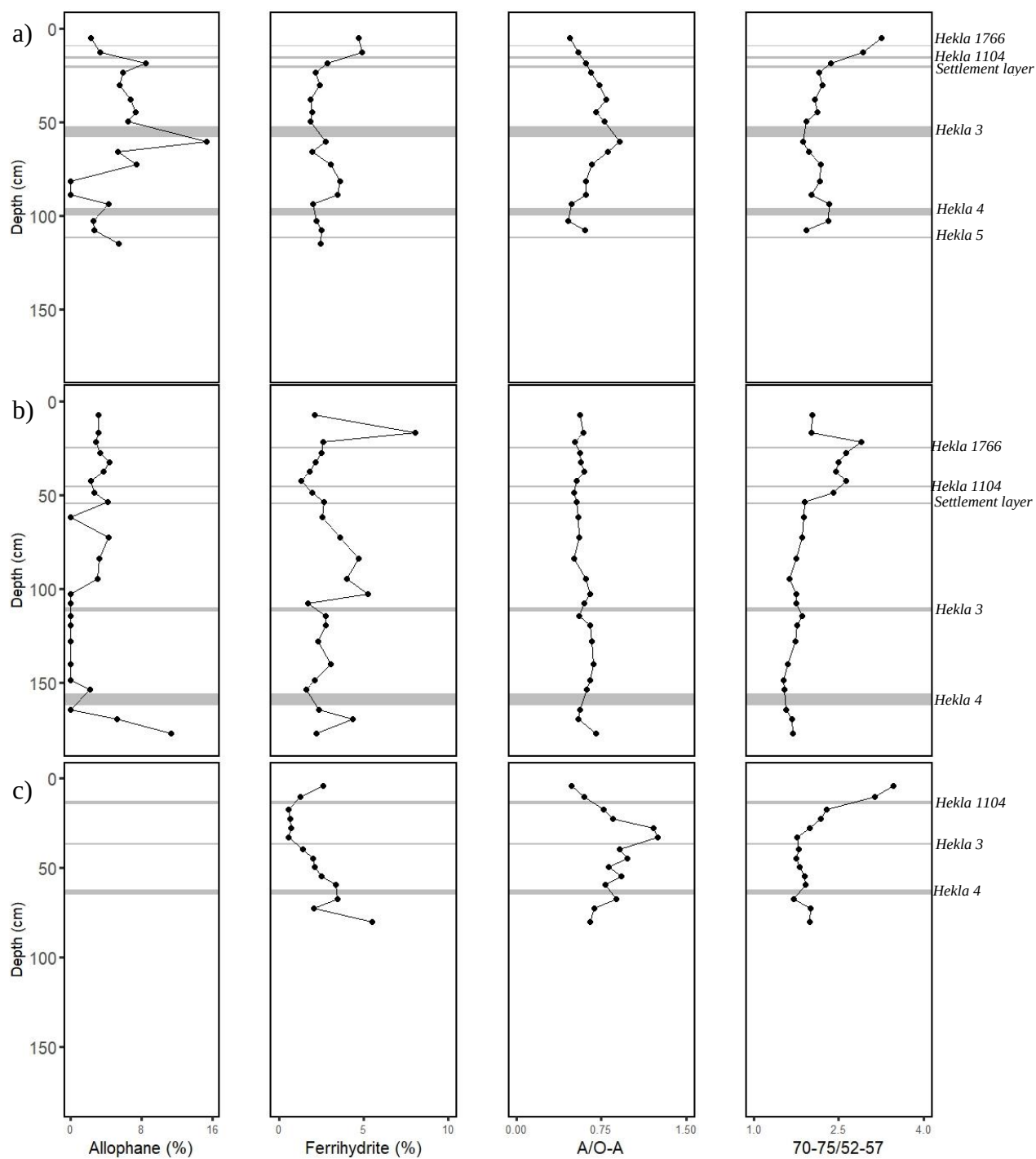


Figure 4. Variables based on Allopahne and Ferrihydrite from the selective dissolution analysis as well as the two ratios from the NMR analysis, A/O-A and 70-75/52-57 from the three peatlands, Snæringstaðir (a), Hafratjarnamýri (b) and Sviðningar (c). Allopahne and Ferrihydrite are presented in %. The grey horizontal lines presented are the tephra layers that were observed during the fieldwork. No measurable amount of Allopahne was found at Sviðningar (c).

The CAR rate at all sites were relatively high from 3 ka BP – 5 ka BP and started to get lower around 3 ka BP. It was the lowest at the surface peat (Figure 5a, 5b and 5c) except for at Hafratjarnamýri, while it increased after Hekla 1766 (Figure 5b). The values were however very sporadic. There was a very noticeable increase in CAR accumulation between Hekla 4 and Hekla 3 at both Snæringstaðir and Hafratjarnamýri (Figure 5a and 5b) that immediately lowered after the deposit of Hekla 3.

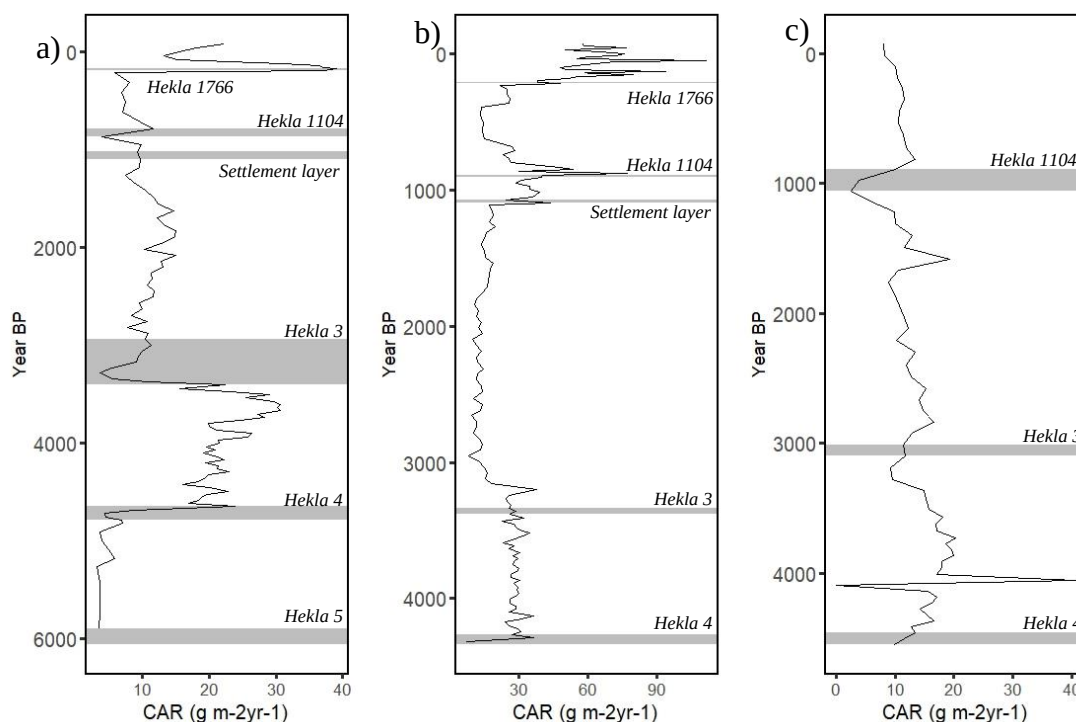


Figure 5. C accumulation rate (CAR) plotted by depth and years for each site, Snæringstaðir (a), Hafratjarnamýri (b) and Sviðningar (c). The grey horizontal lines represent the tephra layers found.

4.3 Andic properties before and after Settlement

At all three sites there was a significant difference in P-retention before and after human settlement. Snæringstaðir p -value = 0.02 (Figure 6a), Hafratjarnamýri p -value <0.001 (Figure 7a) and Sviðningar p -value = 0.3 (Figure 8a). For $A_{10}+1/2Fe_0$ there was no significant difference before and after Settlement in any of the sites (Figure 6b, 7b and 8b) and the same was observed for allophane (Figure 6d and 7d). For Al_p/Al_0 there was only a significant difference at Hafratjarnamýri, p -value =0.004 (Figure 7c) but not at the other two sites (Figure 6c and 8c). The only site that had a significant difference for ferrihydrite was Snæringstaðir, p -value = 0.02 (Figure 6e) while at the other sites no significant difference was found (Figure 7e and 8d).

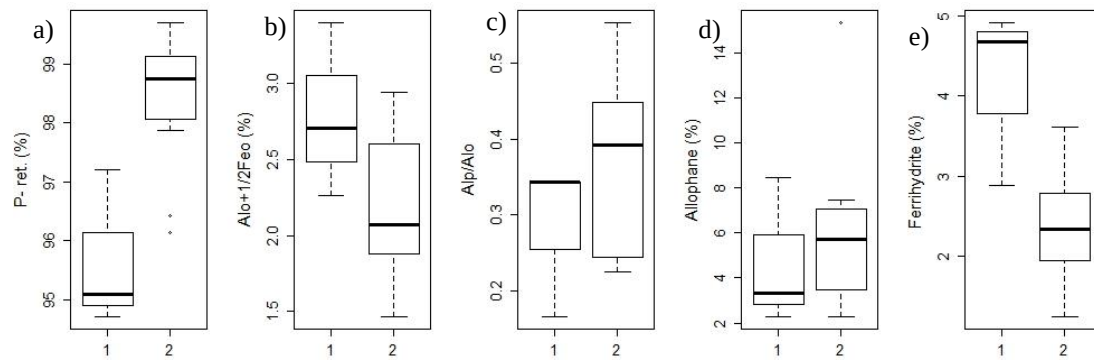


Figure 6. Boxplots of selected andic properties before (1) and after (2) human settlement for Snæringssstaðir. Results from the Wilcoxon signed-rank test resulted in the following p-values: P-retention (a), p-value = 0.02. Alo + 1/2Feo (b), p-value = 0.16. Alp/Alo (c), p-value = 0.3. Allophane (d), p-value = 0.63. Ferrihydrite (e), p-value = 0.02.

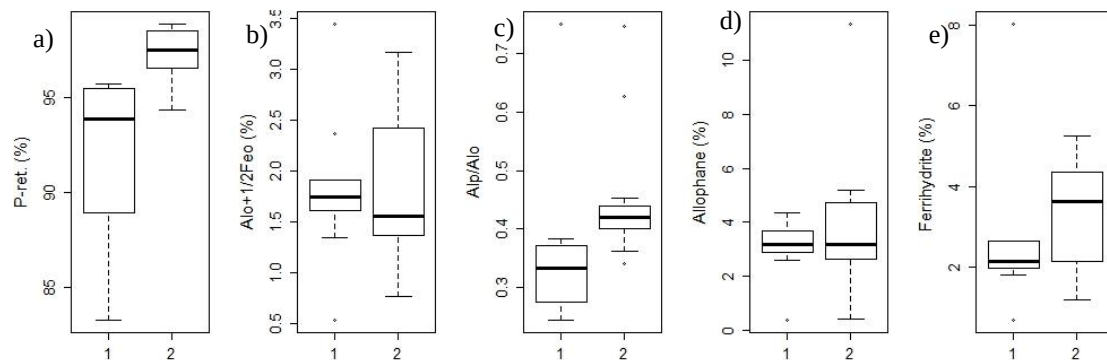


Figure 7. Boxplots of selected andic properties before (1) and after (2) human settlement for Hafratjarnamýri. Results from the Wilcoxon signed-rank test resulted in the following p-values: P-retention (a), p-value < 0.001. Alo + 1/2Feo (b), p-value = 0.68. Alp/Alo (c), p-value = 0.00435. Allophane (d), p-value = 0.68. Ferrihydrite (e), p-value = 0.41.

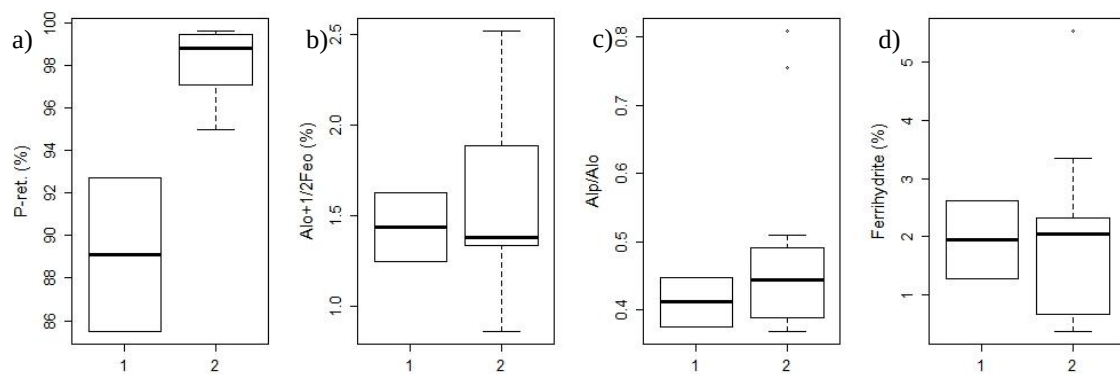


Figure 8. Boxplots of selected andic properties before (1) and after (2) human settlement for Sviðningar. Results from the Wilcoxon signed-rank test resulted in the following p-values: P-retention (a), p-value = 0.03. Alo + 1/2Feo (b), p-value = 0.5. Alp/Alo (c), p-value = 0.95. Ferrihydrite (d), p-value = 0.79. Allophane found at this site was under detection limit.

4.4 Andic properties and C characteristics

The 70-75/52-57 ratio from the NMR measurements did not positively correlate to any of the andic properties. There was however a negative correlation between 70-75/52-57 and P-retention (p -value = 0.0034) (Figure 9b). The A/O-A ratios, also from the NMR measurements, did however positively correlate to P-retention (p -value <0.01) and allophane (p -value = 0.0028) (Figure 9a). There was a negative correlation between A/O-A and ferrihydrite (p -value = 0.0126) (Figure 9a) and a positive correlation was found between P-retention and C/N ratios (p -value = <0.001). C/N ratios are negatively correlated with $Al_0+1/2Fe_0$ (p -value = 0.0134) as well as allophane (p -value = 0.0124) (Figure 10a). P-retention and C had a positive correlation (p -value = 0.005) and there was a negative correlation between C and $Al_0+1/2$ (p -value = 0.0347) (Figure 10b). CAR only positively correlated to allophane (p -value = 0.0061) (Figure 10c).

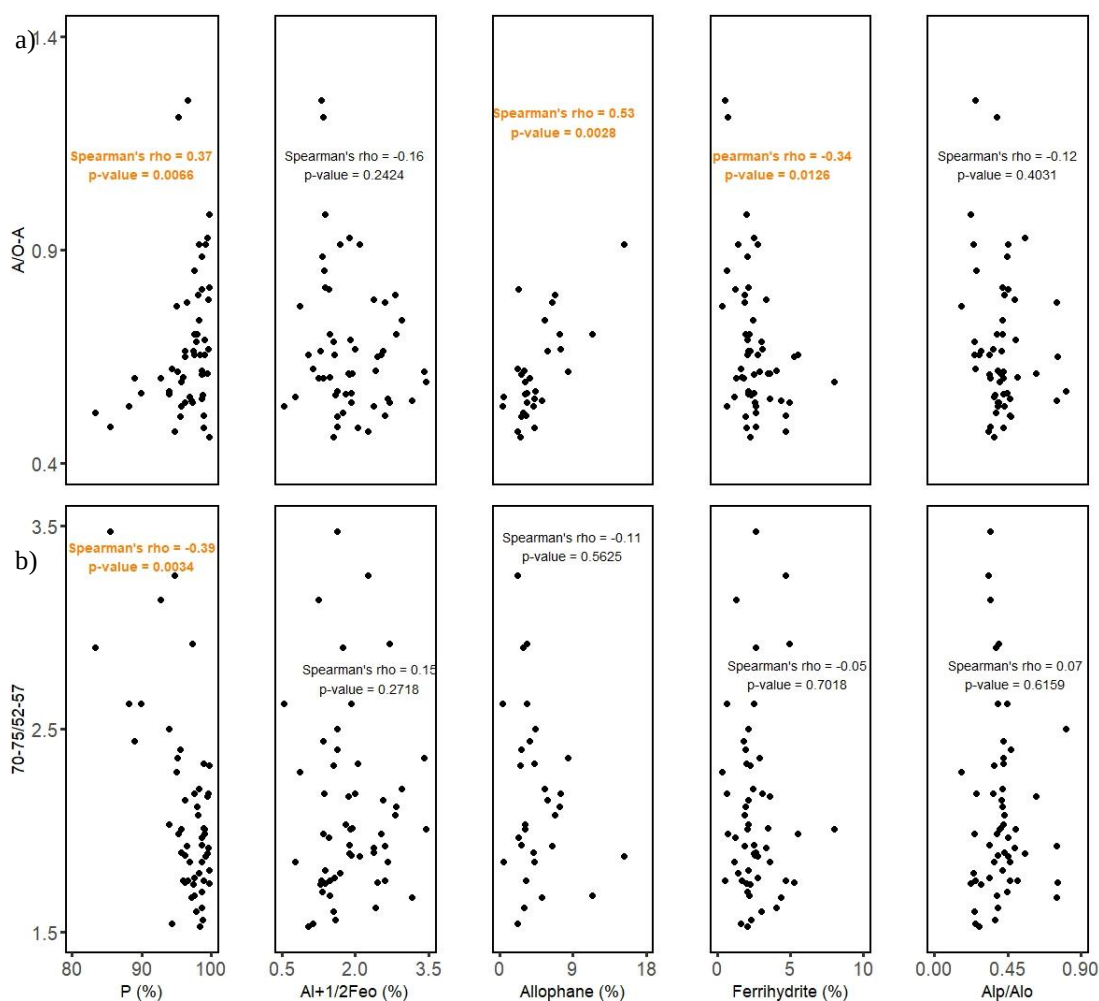


Figure 7. Scatterplots and Spearman rank correlation coefficients (ρ) and probability value (p) between selected andic properties and the SOC structure analysed by NMR, A/O-A (a) and 70-75/52-57.

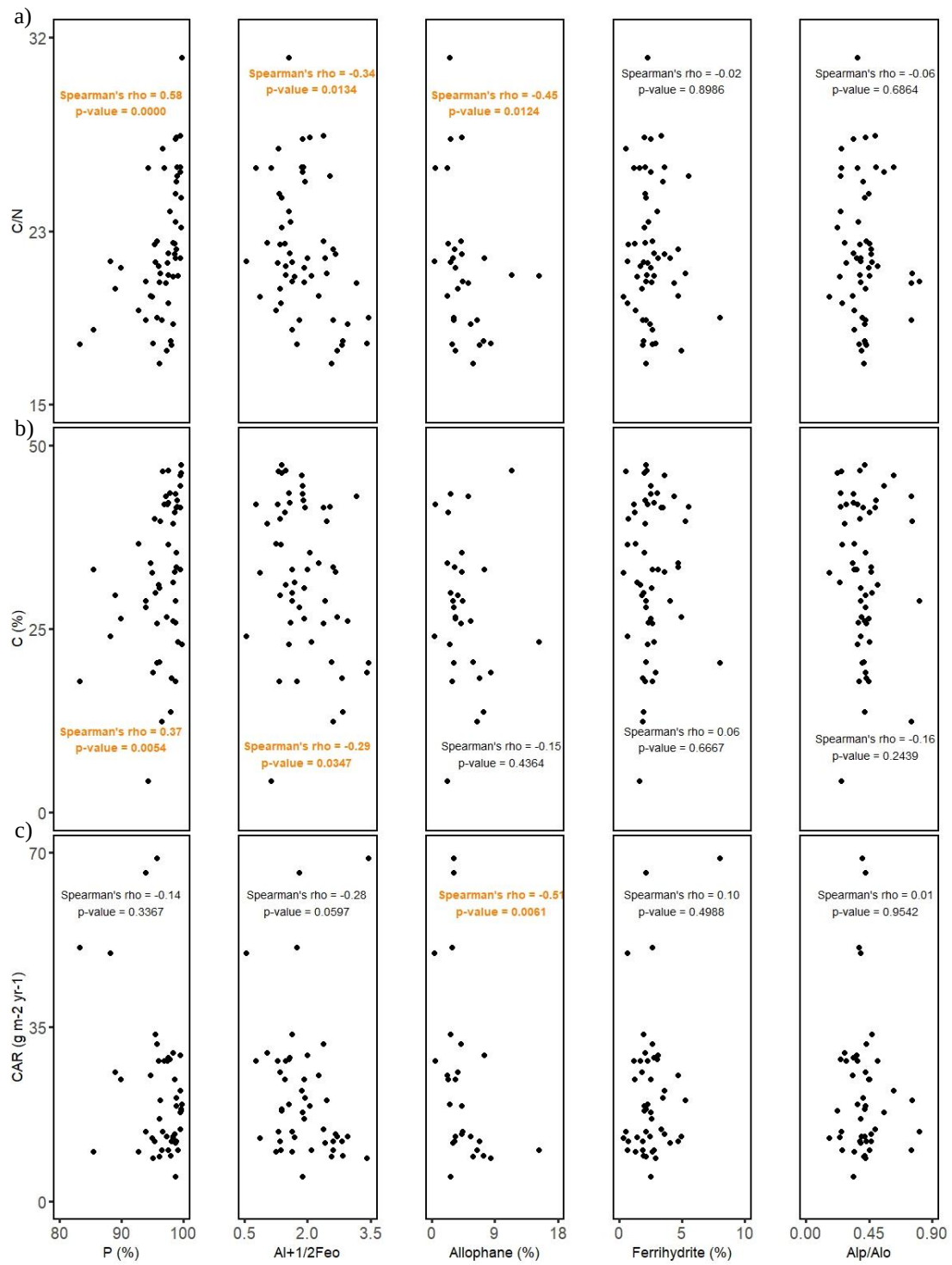


Figure 80. Scatterplots and Spearman rank correlation coefficients (ρ) and probability value (p) between selected andic properties and the C characteristics: C/N ratios (a), C (b) and CAR (c).

4.5 C dynamics and tephra layers

Some clusters could be noted from the biplot of the PCA (Figure 11). At Snæringstaðir soil layers right above Hekla 4 (68-96 cm) grouped together and the same was observed for layers around Hekla 3 (34-63 cm) suggesting similarities of these layers surrounding the tephra.

A notable cluster of layers was spotted at Sviðningar that were between Hekla 3 and Hekla 4 (42-62 cm) indicating more stable C dynamics between these two tephra layers. At Hafratjarnamýri a cluster formed between Hekla 1766 and the Settlement layer (25-51 cm).

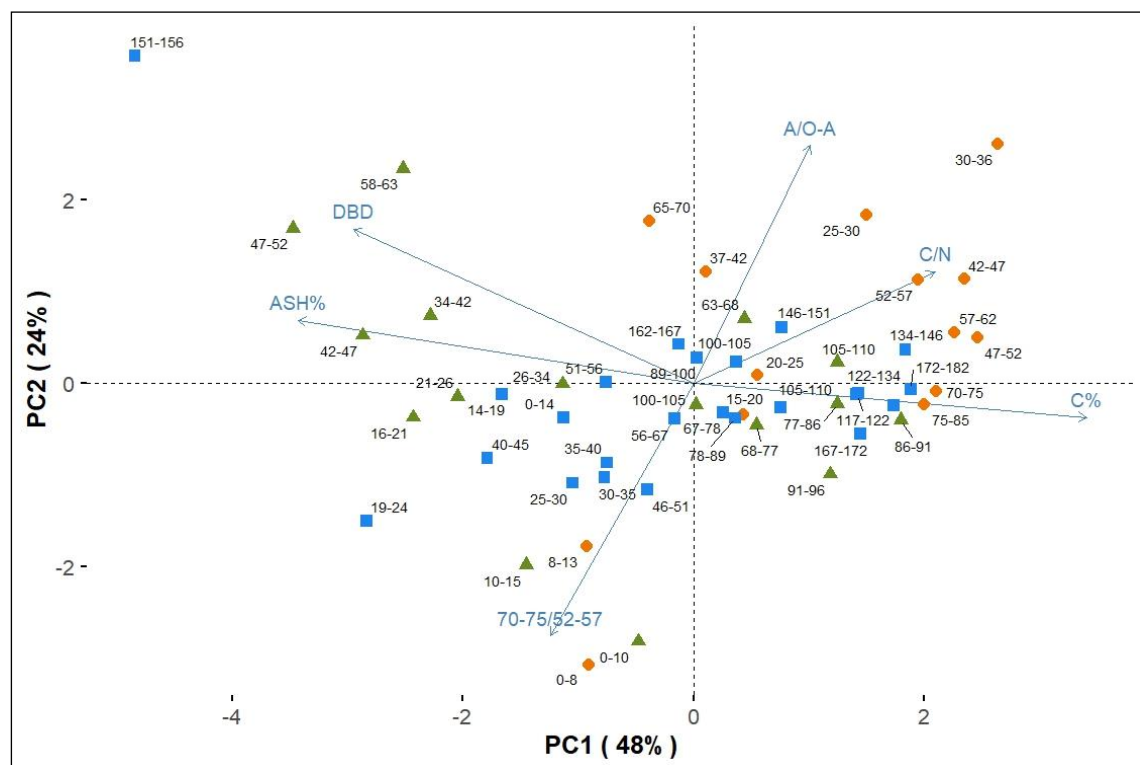


Figure 91. Biplot of the principal component analysis (PCA) on C characteristics/decomposition proxies (C%, C/N, A/O-A and 70-75/52-57) as well as ASH% and DBD. Observations of different sample sites are depicted by shapes and colour (Snæringstaðir: green triangle, Hafratjarnamýri: blue squares and Sviðningar: orange circles). The datapoints are labelled by layer depth.

5 Discussion

5.1 Presence of andic properties

The peatlands presented in this research showed a mixture of andic and histic properties to a certain extent, similar to other research done on this topic in Iceland (Bonatotsky et al., 2019; Möckel et al., 2021b). These peatlands are the drained counterparts of undrained peatlands studied by Möckel et al. (2021b). With drainage more oxygen is available which should lead to an increase in andic properties, particularly higher allophane and ferrihydrite content. Allophane and ferrihydrite formation is facilitated by good oxygenation (Chesworth et al., 2006; Vaughan et al., 2009). Ferrihydrite is also most pronounced when the water table is fluctuating (Vaughan et al., 2009) e.g. in wetland ecosystems. Möckel et al. (2021b) found allophane at all sites, including Sviðningar, which unexpectedly did not have any measurable allophane content in this study, especially as the peatland at Sviðningar is the most effectively drained peatland out of the three as observed during fieldwork. However, there was a higher trend in ferrihydrite than at its undrained counterpart. At both Snælingsstaðir and Hafratjarnamýri the allophane content was generally higher than at their undrained counterparts and at Hafratjarnamýri there was a higher content of ferrihydrite. Snælingsstaðir generally had a lower ferrihydrite content than its undrained counterpart which can be linked to the water table fluctuation (Vaughan et al., 2009). Snælingsstaðir is the least effectively drained peatland out of the three. The content of $Al_o + 1/2 Fe_o$ was higher in the peatlands in this research than reported by Möckel et al. (2021b) but P-retention was similar. Soils at all sites had $Al_p/Al_o < 0.5$ meaning that the soils bear the characteristic of allophanic Andosols rather than non-allophanic. Allophanic Andosols are dominated by allophanic clays (allophane and imogolite) (Dahlgren et al., 2004). Interestingly these peatlands undrained counterparts all had Al_p/Al_o values > 0.5 . Making them non-allophanic, dominated by Al-humus complexes and 2:1 silicates (Dahlgren et al., 2004).

At both Snælingsstaðir and Hafratjarnamýri several layers bear andic properties (Figure 3 and 4) (IUSS Working group, 2015; Soil Survey Staff, 2014b). Generally, andic properties were weakly developed at Sviðningar and most strongly developed at Snælingsstaðir. The difference of how the andic properties are presented between the peatlands can be explained by their difference in distance from volcanic and barren areas (Möckel et al., 2021b). Snælingsstaðir, having the most developed andic properties, is closest to the volcanic and barren areas and thus getting a higher input of volcanic aeolian material than Hafratjarnamýri and Sviðningar.

Sviðningar had no distinct patterns of andic properties that could be detected as well as having no detectable allophane. Allophane formation can be hindered by high SOM content (Arnalds, 2004a; Dahlgren et al., 2004) and low pH levels (Matus et al., 2014; Shoji et al., 1993). That is due to the preferential complexation of Al with humus and therefore unavailability of Al for allophane formation (Nanzoy et al., 1993). However, both Snælingsstaðir and Hafratjarnamýri also had a high SOM content and low pH, but still had detectable allophane. The pH values could possibly be the explanation for the lack of allophane as the formation of allophane is favoured by high pH and hindered by $pH < 5$ (Matus et al., 2014; Shoji et al., 1993). The pH values at Sviðningar are exclusively ≤ 5 except for in the top layer and are in general much lower than at the other two peatlands. However, there is still allophane present in other layers at Snælingsstaðir and Hafratjarnamýri that have $pH \leq 5$. P-retention was above the criteria

for andic properties at all sites (Soil Survey Staff, 2014b; WRB, 2022). Histosols generally have a low P sorption capacities (Batjes, 2011) but the presence of Al and Fe in the soils have led to the high P-retention presented here (Nanzzyo et al., 1993) through the formation of Al/Fe phosphate compounds.

There is a notable consistency in the values of andic properties between Hekla 4 and Hekla 3. The andic properties between these two prominent tephra layers, are the least developed. $Al_o + \frac{1}{2} Fe_o$ are far below the 2% threshold (IUSS Working group, 2015; Soil Survey Staff, 2014b) and allophane is not detected at all at Hafratjarnamýri between those tephra layers. The shift in andic properties after the input of Hekla 3 at both Snæringsstaðir and Hafratjarnamýri is notable. There is an increase in these values after the input of the tephra indicating some kind of shift in the soil formation environment. The increase in the development in andic properties after the deposition of Hekla 3 is most likely due to the increased input of mineral material (Arnalds, Dagsson-Waldhauserova, et al., 2016) of volcanic origin. This is confirmed by looking at the increase in %ASH above Hekla 3 at both Snæringsstaðir and Hafratjarnamýri (Figure 2a and 2b). Eddudóttir et al. (2020) found that the time period between Hekla 4 and Hekla 3 demonstrated a stable depositional environment with decrease in stability after the deposition of Hekla 3. Hekla 3 represented one of the largest explosive eruptions of the Holocene (Larsen & Þórarinnsson, 1977) and it coincided with change to a harsher climate conditions that were colder and lead to ice cap expansions (Geirsdóttir et al., 2013).

5.1.1 Andic properties pre and post settlement

Andic properties did not show a statistical difference pre and post human settlement. Several palaeological studies in Iceland, which focus on environmental changes after the human settlement of the country ca. 870 AD point out that after the settlement of Iceland the environment became more unstable with enhanced vegetation degradation and soil erosion resulting from land use (Dugmore et al., 2009; Eddudóttir et al., 2020; Eddudóttir et al., 2016; Roy et al., 2018). Therefore, it was expected to see changes in peat properties after the settlement, e.g. more pronounced andic properties due to higher inputs of windborne mineral material from barren areas. However, the decrease in depositional stability after the Hekla 3 eruption (Eddudóttir et al., 2020) may have led to the increase of andic properties in these peatlands some time before human settlement, as observed in this study. P-retention was the only criteria that showed significant difference before and after settlement at all sites (Figure 6a, 7a and 8a).

5.2 Andic properties effect on C dynamics

P-retention was found to have a correlation with the decomposition proxies C/N ratio, A/O-A and 70-75/52-57 values. P-retention does not tell us how much available P is in the soil rather the capacity of soils to retain phosphorus. It is also an important criteria for andic soil properties (Soil Survey Staff, 2014b; WRB, 2022), as mentioned before. The positive correlation between P-retention and A/O-A ratios and a negative correlation between P-retention and 70-75/52-57 ratios points to enhanced decomposition with increased P-retention (Baldock et al., 1997; Bonanomi et al., 2013). Allophane was also found to have a positive correlation with A/O-A ratios, also indicating enhanced decomposition. There was negative correlation between C/N ratios and $Al_o + \frac{1}{2} Fe_o$ values on one hand and allophane on the other, indicating a decrease in C/N ratios which indicates a more strongly decomposed peat (Krüger et al., 2015; Kuhry & Vitt, 1996). However, it is worth pointing out that C/N have been found to

have their limits as a proxy for decomposition (Bonanomi et al., 2013; Möckel et al., 2017).

Surprisingly a positive correlation between allophane content and A/O-A was found, as well as a negative correlation between allophane content and CAR, as allophane is known to prevent SOM decomposition (Dahlgren et al., 2004; Wada, 1985) by forming organo-mineral complexes. However, there is a negative correlation between A/O-A and ferrihydrite, pointing to a decrease in decomposition with higher ferrihydrite content. Ferrihydrite also forms organo-mineral complexes with SOM and protects its from decomposition (Dahlgren et al., 2004).

5.2.1 Comparison between undrained and drained peatlands

By comparing the results from this study to findings from their undrained counterparts reported in (Möckel et al., 2021b, 2023), we can determine whether andic properties have a similar effect on C dynamics in undrained peatlands as they do in undisturbed peatlands.

In contrast to the results reported by Möckel et al. (2021b), the findings presented here did not reveal a significant correlation between Al_p/Al_o values and A/O-A ratios. Möckel et al. (2021b) observed a positive correlation, indicating that with increased decomposition there was enhanced formation of metal-humus complexes. The Al_p/Al_o values in the peatlands presented here indicate that the peatlands are dominated by allophane and imogolite rather than metal-humus complexes. Metal-humus complexes have been found to play an important role in C accumulation in organic soils and responsible for the high C content (Buytaert et al., 2007). The influence of drainage could be favouring the formation of allophanic minerals instead of Al-humus complexes. Buytaert et al. (2007) found that in drier organic soils in Ecuador there was a preference for the formation of allophanic minerals over metal-humus complexes. They connected that to less leaching of Si. Also in contrast with Möckel et al. (2021) there was a positive correlation found between allophane content and A/O-A ratios, pointing to increased decomposition with increased amounts of allophane. This is surprising as allophane is known to hamper decomposition (Kögel-Knabner & Amelung, 2014) as it forms organo-mineral complexes with SOM.

Möckel et al. (2021b) found that SOM of Histosols with andic properties was less decomposed than that of Histosols without notable andic properties. This was due to the formation of organo-mineral complexes, which particularly hamper the decomposition of chemically more labile C groups. These results were not reflected in this study. Sviðningar and Hafratjarnamýri display very similar levels of decomposition (Figure 4b and 4c) even though Sviðningar showed no distanced pattern of andic properties. Snæringsstaðir does display, to some extent, less levels of decomposition (Figure 4a), however during fieldwork it was observed that Snæringsstaðir was less effectively drained than the other two peatlands. As mentioned earlier there is rather evidence for enhanced decomposition with increased andic properties.

In general the A/O-N values are higher in these peatlands than in their undrained counterparts (Möckel et al., 2021b), pointing to more advanced decomposition (Baldock et al., 1997). The 70-75/52-57 values presented here are also higher in some

cases, especially in the top soil layers, indicating more available labile C (Bonanomi et al., 2013) than in their undrained counterparts. This is to be expected with drainage as there is more available oxygen (Limpens et al., 2008) and thus enhanced decomposition.

5.3 Tephra layers and their effect on C dynamics

Unsurprisingly, there is a general increase in decomposition with increasing depth at all sites with higher A/O-A ratios and lower 70-75/52-57 ratios toward deeper layers. This indicates more recalcitrant C forms with depth and more labile forms in top soil (Baldock et al., 1997; Bonanomi et al., 2013). Interestingly, there is a shift in the A/O-A ratios at both Snæringsstaðir and Sviðningar below Hekla 3. The ratios start to get lower again and have similar values as the upper layers making them resemble much younger and less decomposed soil (Figure 4a and 4c). These are consistent with previous studies with the initial trend of increased with depth and then a reversal at greater depth (Möckel et al., 2021b; Preston et al., 1987). At Hafratjarnamýri the A/O-A ratios are very consistent throughout the soil profile which is also interesting as we would assume that these ratios would follow similar trends as the other peatlands in this study. This is also in contrast with findings from its undrained counterpart (Möckel et al., 2021b) which followed the same trend as seen at Snæringsstaðir and Sviðningar. The shift to a decreased decomposition below a tephra layer could indicate that the tephra layer acts as a barrier (De Vleeschouwer et al., 2008), preventing fresh organic matter to enter the soil layers below years after the eruption, thus preventing the input of DOC from upper soil layers, hampering microbial activity.

At Hafratjarnamýri the protection these tephra layers can provide against decomposition has perhaps been counteracted by the influence of drainage, but further investigation is needed. With drainage the peat is more oxygenised, decomposition is enhanced and thus the mineralization of C (Loisel et al., 2020). The reason for this only being observed at Hafratjarnamýri could possibly be because of distance from the volcanic and barren areas as well as the level of drainage. During fieldwork it was observed that Snæringsstaðir was the least effectively drained out of the three peatlands. That could possibly be why the effect of the barrier is only counteracted at Hafratjarnamýri and not at Snæringsstaðir. However, Sviðningar was found to be the most effectively drained and there is still evidence of less decomposed material below Hekla 3 at that site. However, this reverse in decomposition rate was not observed at its undrained counterpart (Möckel et al., 2021b). De Vleeschouwer et al. (2008) found that more thick and compact tephra were more effective barriers while the Hekla 3 layer at Sviðningar is rather thin compared to the tephra observed at the other sites. There is the possibility that another factor is affecting the reverse in decomposition at Sviðningar such as increased nutrient availability (Damman, 1988) in the layers above after the deposition of the tephra layer.

More stable SOM and C content is observed in the layers between Hekla 4 and Hekla 3 at both Snæringsstaðir and Hafratjarnamýri. Subclusters in the PCA at both sites between Hekla 3 and Hekla 4 further emphasise that. When Hekla 4 erupted the climate in Iceland was getting cooler after the Holocene thermal maximum, which was the warmest period of the Holocene in Iceland (Geirsdóttir et al., 2013). Research has found more increasing environmental instability after the deposition of the Hekla 4 tephra (Dugmore et al., 1995), which is interesting as well as contradicts the findings of stable

SOM and C between Hekla 4 and Hekla 3. In the peat sections above Hekla 3, SOM and C decrease at both Snæringssstaðir and Hafratjarnamýri. There are other notable shifts in C dynamics after the input of Hekla 3 such as a decrease in SOM and C at both Snæringssstaðir and Hafratjarnamýri. This is also noted in the PCA (Figure 11) where we can see the soil layers above Hekla 3 at Snæringssstaðir form subclusters characterized by increased DBD and %ASH. This indicates an increase in mineral deposits after the input of Hekla 3, which is also noted in the chapter above. Eddudóttir et al. (2020) found that the time before Hekla 3 had a more stable depositional environment, which decreased after the eruption of Hekla 3 and coincided with cooler weather, increased storminess and expanding glaciers.

5.3.1 C accumulation rates

The notable instant increase in C accumulation at Snæringssstaðir after the input of Hekla 4 could possibly be linked to increased nutrient availability after the deposition of the tephra layer. Ratcliffe et al. (2020) found increased C accumulation in peatlands in New Zealand after the input of tephra layers. They found that C accumulation was found to be tightly coupled with N and P accumulation, and highly responsive to changes in the C:P and N:P ratio. Suggesting nutrient inputs have a strong control on rates of peat accumulation, through the effect on plant productivity. Similar findings were reported by Zhang et al. (2022) who found that high carbon accumulation rates were induced through the phosphorus release from tephra layers. The high C accumulation rate between these two tephra layers also matches findings from Hellqvist et al. (2020) who found a high accumulation rate of peat between Hekla 3 and Hekla 4 in a peatland in Northern Iceland. They connected this increase in peat accumulation to higher temperatures than before the deposition of Hekla 4, during the period between ca. 5ka BP and 2.5ka BP. However, Geirsdóttir et al. (2013) found that summertime cooling had already commenced by ca. 5 ka BP. Likewise, Eddudóttir et al. (2016) found that after the Hekla 4 eruption the highland had already started to show evidence of Neoglaciation. There is a notable decrease in C accumulation after the input of Hekla 3 at both Snæringssstaðir and Hafratjarnamýri. That coincides with the notable increase in mineral content and in andic properties at this site after the deposition of Hekla 3, pointing towards a more unstable depositional environment than before the input of the tephra. Hughes et al. (2013) found that moderate to thick tephra layers could alter peatland plant communities from Sphagnum to monocotyledon dominant which led to decrease in C accumulation. However it was only temporary, with a rebound linked to increase in nutrients. It is well conceivable that vegetation changes following volcanic eruptions play a role in changes in C accumulation rates at the two sites. Hekla 3, like Hekla 4, was one of the largest explosive volcanic eruption during the Holocene in Iceland (Larsen & Þórarinnsson, 1977) and vegetation changes after the eruption have been reported (Eddudóttir et al., 2016; Hellqvist et al., 2020).

6 Conclusions

The aim of this study was to advance the understanding of how volcanic environments shape peatlands and their properties with a focus on how mineral deposits from tephra and aeolian material affect andic properties and C dynamics in drained peatlands. Based on the analysis of data sets of C characteristics, andic soil properties and decomposition proxies the following conclusions were drawn:

- Andic soil properties vary with peatlands depending on their distance from volcanic and barren areas. They do vary with time, depending on changes in the environment and climate. Higher values of Ferrihydrite and Allophane were found in the peatlands presented here compared to their undrained counterparts which can be attribute to enhanced oxygenation.
- There was no definite proof of immediate change in andic properties after human settlement. Rather an increase in the deposit of aeolian material was found leading to enhanced andic properties, a couple of centuries before or after the deposit of Hekla 3.
- Andic properties were not found to have the same effect on C dynamics in drained peatlands as they did in undrained peatlands. Evidence presented here implies that they can enhance decomposition rates rather than decrease them as presented in their undrained counterparts. There is a possible effect of drainage on the decrease of metal-humus complexes, but they have been found to play an important role in peatland C accumulation.
- Tephra layers can act as a barrier, protecting SOM in deeper layers from decomposition. Some evidence found here points to the fact that this can be counteracted by drainage. However, further evidence is needed.
- Tephra layers can both increase and decrease decomposition rates by affecting nutrient availability as well as lead to vegetation changes. This can happen at different rates and over different timescales.

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Appendix 1

Tables for the total tephra chemical composition measured using EPMA.

Snæringssstaðir

Reworked material, 4-5 cm

SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
56.91	1.37	14.91	10.09	0.29	2.13	5.44	4.17	1.53	0.71	97.56
72.16	0.21	14.18	3.19	0.07	0.12	1.89	4.53	2.83	0.01	99.19
73.13	0.08	12.88	2.00	0.10	0.00	1.20	4.63	2.88	0.00	96.91
59.65	1.29	15.21	9.53	0.25	1.68	5.07	4.25	1.61	0.50	99.04
57.95	1.39	15.15	10.11	0.28	2.08	5.50	3.92	1.56	0.72	98.66
69.13	0.22	15.09	3.04	0.12	0.09	1.15	5.46	4.73	0.02	99.05
72.56	0.10	12.83	1.98	0.10	0.03	1.26	4.80	2.83	0.00	96.50
60.02	1.31	15.22	9.41	0.23	1.60	5.04	4.20	1.64	0.49	99.17
74.35	0.14	13.46	2.12	0.10	0.04	1.30	4.72	2.92	0.01	99.15
57.22	1.43	15.00	10.26	0.26	2.18	5.57	3.92	1.49	0.66	98.00

Hekla 1766, 9-10 cm

SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
58.29	1.41	15.09	9.95	0.27	2.04	5.44	4.23	1.54	0.71	98.97
69.37	0.76	13.80	4.79	0.12	0.55	1.91	5.16	3.20	0.17	99.83
51.11	1.72	13.85	11.26	0.22	6.80	11.41	2.13	0.23	0.13	98.87
65.12	1.09	12.73	8.07	0.20	1.32	4.58	4.00	1.87	0.24	99.22
49.82	3.17	12.36	14.54	0.26	4.97	8.98	2.64	0.61	0.61	97.96
51.72	0.72	3.22	6.49	0.20	16.49	20.43	0.24	0.00	0.00	99.50
60.04	1.86	12.93	10.43	0.24	2.05	5.87	3.28	1.55	0.84	99.09
59.86	1.14	15.46	9.17	0.29	1.62	4.99	4.39	1.68	0.46	99.07
60.65	1.11	15.36	9.26	0.30	1.60	4.89	4.34	1.63	0.38	99.51
72.57	0.16	14.28	3.11	0.08	0.11	1.93	4.60	2.59	0.05	99.49
58.34	1.47	15.36	9.98	0.26	2.16	5.58	4.29	1.47	0.61	99.52
58.09	1.45	15.17	9.78	0.26	1.98	5.57	4.16	1.50	0.67	98.63
57.66	1.48	15.17	10.54	0.26	2.17	5.59	3.92	1.45	0.79	99.03

Hekla 1104, 17-18 cm

SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
72.31	0.23	14.04	3.15	0.13	0.10	1.85	4.40	2.74	0.03	98.97
72.01	0.18	14.15	3.33	0.10	0.11	1.81	4.49	2.73	0.00	98.91
71.74	0.18	14.11	3.08	0.07	0.12	1.82	5.09	2.80	0.02	99.04
72.52	0.18	14.05	3.09	0.13	0.13	1.82	4.75	2.81	0.04	99.51
72.88	0.16	14.26	3.29	0.09	0.10	1.85	4.49	2.77	0.04	99.93
71.75	0.24	14.10	3.25	0.13	0.12	1.86	4.53	2.72	0.01	98.70
72.14	0.19	14.29	3.19	0.08	0.13	1.83	4.47	2.79	0.02	99.15
72.53	0.23	14.34	3.16	0.15	0.12	1.87	4.67	2.79	0.01	99.87
72.14	0.22	14.40	3.27	0.13	0.11	1.94	4.82	2.77	0.03	99.84
71.85	0.19	14.21	3.19	0.13	0.11	1.81	4.85	2.76	0.04	99.14

Reworked material, 18-19 cm

SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
49.91	1.73	13.89	12.66	0.22	6.87	11.39	2.43	0.22	0.18	99.50

49.92	1.83	13.76	12.96	0.24	6.59	11.08	2.55	0.23	0.18	99.35
49.78	1.69	13.77	12.48	0.22	6.90	11.35	2.68	0.22	0.14	99.22
50.14	1.81	13.59	12.84	0.22	6.68	11.11	2.52	0.24	0.15	99.30
49.86	1.88	13.64	13.05	0.22	6.58	11.01	2.56	0.23	0.18	99.21
49.71	1.66	13.78	12.72	0.21	6.83	11.48	2.51	0.20	0.14	99.24
50.28	1.84	13.78	12.91	0.23	6.67	11.26	2.53	0.23	0.17	99.90
50.03	1.75	13.91	12.48	0.24	6.81	11.55	2.47	0.22	0.17	99.62
50.02	1.80	13.83	12.70	0.20	6.74	11.06	2.50	0.23	0.16	99.25
50.33	1.80	13.75	12.77	0.22	6.57	11.15	2.55	0.21	0.18	99.53

Settlement layer, 20-21 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
50.60	1.92	13.79	13.05	0.22	6.13	10.46	2.64	0.31	0.23	99.35
49.73	1.94	14.36	11.29	0.20	7.42	11.87	2.55	0.30	0.19	99.85
49.57	1.93	14.37	11.25	0.19	7.27	11.95	2.54	0.27	0.21	99.56
49.81	1.90	13.70	12.70	0.23	6.64	11.24	2.57	0.23	0.18	99.20
49.57	2.08	14.04	11.98	0.23	6.87	11.48	2.65	0.33	0.21	99.43
49.82	1.90	14.44	11.31	0.20	7.10	11.78	2.54	0.28	0.22	99.58
50.16	1.80	13.77	12.79	0.24	6.62	11.32	2.57	0.23	0.17	99.67
50.01	1.98	14.48	11.28	0.18	7.28	11.75	2.46	0.29	0.17	99.88
49.40	2.00	14.24	11.27	0.19	7.27	11.81	2.51	0.31	0.18	99.18
49.34	2.00	14.34	11.29	0.21	7.23	11.85	2.36	0.29	0.19	99.10

Reworked material, various origin, 25-26 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
66.26	0.53	15.94	4.92	0.19	0.45	2.07	5.29	4.03	0.05	99.72
67.71	0.46	15.86	4.41	0.18	0.29	1.81	5.28	4.28	0.09	100.36
65.76	0.50	15.89	5.00	0.21	0.41	2.13	5.58	4.02	0.12	99.61
66.15	0.47	16.00	4.93	0.19	0.41	2.16	5.26	3.91	0.06	99.54
66.23	1.19	14.37	6.24	0.23	1.09	2.97	5.02	2.77	0.29	100.40
65.83	0.52	16.18	4.97	0.19	0.44	2.14	5.47	3.95	0.08	99.78
66.81	0.45	15.52	4.57	0.19	0.39	2.00	5.68	4.10	0.08	99.78
66.42	0.46	15.97	4.64	0.14	0.39	2.01	5.34	3.94	0.05	99.36
67.82	0.44	15.93	4.42	0.19	0.30	1.70	5.06	4.22	0.10	100.19
65.74	0.53	15.79	4.72	0.21	0.45	2.06	5.46	3.97	0.12	99.05
50.38	2.51	13.53	13.37	0.23	5.63	9.92	2.95	0.43	0.28	99.23
50.30	1.97	13.51	13.09	0.22	6.14	10.38	2.76	0.28	0.21	98.86
50.41	1.94	13.66	13.03	0.22	6.19	10.47	2.67	0.29	0.20	99.08
50.54	2.61	13.47	13.52	0.22	5.63	9.93	2.93	0.41	0.29	99.55
50.75	1.97	13.62	13.08	0.25	6.00	10.21	2.81	0.32	0.20	99.21
50.55	2.53	13.68	13.38	0.25	5.56	9.99	2.83	0.41	0.29	99.47
50.66	2.61	13.62	13.44	0.20	5.58	9.96	3.05	0.43	0.24	99.80
50.21	1.73	13.88	12.33	0.20	7.02	11.38	2.54	0.23	0.17	99.69
50.80	1.93	13.77	13.27	0.23	6.18	10.61	2.77	0.31	0.22	100.09
50.25	2.62	13.51	13.24	0.24	5.67	9.97	3.03	0.42	0.26	99.21

Reworked material, various origin, 27-28 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
49.30	0.07	31.88	0.63	0.02	0.15	14.99	2.71	0.06	0.01	99.82
63.12	0.75	15.36	8.35	0.21	0.97	4.24	4.08	1.74	0.30	99.11
67.04	1.09	13.98	5.33	0.15	0.98	2.68	4.96	2.93	0.29	99.43
66.95	0.48	15.88	4.74	0.19	0.37	1.89	5.25	4.31	0.04	100.11
67.77	0.42	15.08	5.60	0.15	0.38	3.08	4.33	2.10	0.10	99.01

48.89	0.06	31.96	0.70	0.00	0.13	14.68	2.93	0.05	0.04	99.44
66.83	0.53	15.91	4.63	0.20	0.36	1.92	5.22	4.05	0.03	99.68
71.62	0.20	14.14	3.07	0.08	0.12	1.91	4.74	2.36	0.05	98.29
51.06	1.99	13.71	13.05	0.23	5.98	10.31	2.79	0.30	0.20	99.62
50.80	1.93	13.74	12.96	0.18	6.22	10.53	2.60	0.29	0.19	99.43
49.92	1.77	14.02	12.15	0.20	6.98	11.61	2.43	0.22	0.13	99.44
50.01	2.37	13.68	13.14	0.23	6.13	10.52	2.86	0.37	0.23	99.55
50.45	1.90	13.71	13.14	0.22	6.29	10.71	2.65	0.27	0.18	99.52
49.55	2.62	13.40	13.34	0.20	6.09	10.46	2.85	0.36	0.24	99.11
49.90	1.66	14.10	11.87	0.21	7.33	12.11	2.26	0.17	0.18	99.80
50.00	3.20	12.57	15.05	0.26	4.89	9.37	3.10	0.46	0.36	99.26
50.60	1.92	13.76	13.15	0.21	6.13	10.53	2.69	0.32	0.19	99.49
52.04	2.71	13.67	15.74	0.25	5.49	4.59	3.89	0.49	0.29	99.16

Veidivötn, 34-35 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
50.17	1.84	13.66	12.30	0.21	6.85	11.34	2.52	0.22	0.18	99.29
49.94	1.69	13.93	11.94	0.19	7.49	11.90	2.45	0.18	0.12	99.84
49.86	1.72	13.90	12.20	0.20	7.11	11.71	2.50	0.20	0.16	99.56
49.95	1.75	13.88	12.33	0.24	7.09	11.65	2.59	0.22	0.17	99.86
63.86	0.89	15.67	7.44	0.17	1.37	4.69	4.43	1.67	0.33	100.52
49.60	1.67	14.07	11.87	0.21	7.44	12.11	2.42	0.19	0.16	99.73
50.16	1.76	14.05	12.19	0.22	7.29	11.89	2.54	0.21	0.16	100.47
49.83	1.77	14.10	12.20	0.22	7.12	11.68	2.45	0.21	0.17	99.76

Veidivötn, ca. 2500 ka BP, 42-43 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
49.52	1.67	14.02	12.07	0.23	7.47	12.04	2.26	0.18	0.14	99.60
49.55	1.65	13.96	11.97	0.23	7.46	11.95	2.43	0.17	0.17	99.54
49.36	1.71	14.04	12.17	0.23	7.50	11.94	2.31	0.19	0.15	99.60
49.69	1.69	14.03	11.83	0.21	7.56	11.90	2.43	0.18	0.13	99.66
49.78	1.70	13.78	12.10	0.22	7.24	11.74	2.39	0.20	0.16	99.31
49.78	1.69	13.83	12.00	0.19	7.37	11.78	2.39	0.19	0.15	99.37
49.28	1.69	13.89	11.87	0.20	7.41	11.99	2.42	0.18	0.14	99.07
62.20	0.78	15.04	8.57	0.23	1.09	4.39	4.54	1.74	0.25	98.83
49.52	1.69	13.96	12.21	0.20	7.41	11.93	2.36	0.18	0.14	99.60

Hekla 3, 50-58 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
74.17	0.12	13.17	1.98	0.09	0.02	1.23	4.57	2.86	0.00	98.21
74.94	0.12	13.39	2.01	0.10	0.03	1.25	4.60	2.95	0.00	99.38
74.78	0.11	13.17	2.02	0.09	0.04	1.32	5.08	2.92	0.00	99.53
74.96	0.09	13.21	2.00	0.09	0.02	1.24	4.84	2.81	0.01	99.26
75.14	0.10	13.37	2.06	0.07	0.02	1.28	4.55	2.95	0.01	99.55
74.59	0.07	13.38	2.01	0.11	0.02	1.25	4.54	2.93	0.00	98.89
75.10	0.09	13.20	1.92	0.10	0.02	1.23	4.76	2.96	0.00	99.39
75.34	0.13	13.28	1.99	0.05	0.01	1.31	4.68	2.95	0.00	99.74
73.67	0.13	13.06	1.97	0.07	0.03	1.32	4.60	2.87	0.02	97.73
75.31	0.14	13.38	2.02	0.11	0.03	1.32	4.60	2.88	0.04	99.83

Veidivötn 88-89 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
49.50	1.43	14.37	11.32	0.21	7.80	12.77	2.29	0.13	0.14	99.97
49.43	1.38	14.40	11.21	0.20	7.89	12.54	2.22	0.14	0.14	99.54
49.68	1.42	14.46	11.26	0.19	7.76	12.54	2.03	0.14	0.12	99.61
49.52	1.47	14.38	11.16	0.22	7.77	12.61	2.20	0.16	0.09	99.58
49.40	1.41	14.19	11.08	0.16	7.91	12.74	2.25	0.14	0.13	99.41
49.44	1.42	14.35	11.16	0.23	7.84	12.67	2.14	0.12	0.14	99.51
50.15	1.38	14.27	10.99	0.23	8.01	12.53	2.22	0.14	0.13	100.05
49.96	1.48	14.46	11.31	0.20	7.93	12.95	1.93	0.15	0.15	100.52
49.67	1.40	14.30	11.20	0.22	8.08	12.68	2.26	0.14	0.15	100.10
49.33	1.43	14.28	11.16	0.20	7.80	12.87	2.27	0.15	0.11	99.60

Hekla 4, 96-100 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
74.68	0.12	13.30	2.05	0.09	0.02	1.31	4.47	2.90	0.04	98.97
74.72	0.14	13.35	1.94	0.11	0.01	1.32	4.78	2.92	0.01	99.30
74.83	0.10	13.24	1.96	0.07	0.02	1.19	4.50	2.89	0.00	98.79
74.95	0.07	13.28	2.05	0.11	0.02	1.32	4.67	2.94	0.00	99.40
74.49	0.13	13.10	2.07	0.09	0.03	1.29	4.83	2.78	0.00	98.81
73.85	0.10	13.31	1.97	0.11	0.04	1.30	5.04	2.82	0.00	98.54
74.59	0.11	13.33	1.99	0.07	0.03	1.22	4.89	2.84	0.00	99.07
75.16	0.11	13.18	1.96	0.12	0.03	1.33	4.43	2.93	0.00	99.25
73.94	0.11	13.13	1.95	0.08	0.02	1.30	4.62	2.88	0.00	98.03
73.88	0.08	13.12	1.92	0.10	0.04	1.27	4.62	2.80	0.00	97.83

Hekla 5, 111-112 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
74.68	0.12	13.30	2.05	0.09	0.02	1.31	4.47	2.90	0.04	98.97
74.72	0.14	13.35	1.94	0.11	0.01	1.32	4.78	2.92	0.01	99.30
74.83	0.10	13.24	1.96	0.07	0.02	1.19	4.50	2.89	0.00	98.79
74.95	0.07	13.28	2.05	0.11	0.02	1.32	4.67	2.94	0.00	99.40
74.49	0.13	13.10	2.07	0.09	0.03	1.29	4.83	2.78	0.00	98.81
73.85	0.10	13.31	1.97	0.11	0.04	1.30	5.04	2.82	0.00	98.54
74.59	0.11	13.33	1.99	0.07	0.03	1.22	4.89	2.84	0.00	99.07
75.16	0.11	13.18	1.96	0.12	0.03	1.33	4.43	2.93	0.00	99.25
73.94	0.11	13.13	1.95	0.08	0.02	1.30	4.62	2.88	0.00	98.03
73.88	0.08	13.12	1.92	0.10	0.04	1.27	4.62	2.80	0.00	97.83

Katla, 114-115 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
48.26	4.23	12.88	14.87	0.22	4.75	9.34	3.29	0.89	0.54	99.26
48.73	4.00	12.98	14.29	0.21	4.72	9.09	3.42	0.91	0.51	98.86
49.08	4.04	13.12	14.19	0.18	4.68	9.17	3.39	0.94	0.52	99.31
49.02	4.09	13.26	14.15	0.23	4.55	9.17	3.23	0.93	0.51	99.14
50.49	3.78	13.14	13.43	0.22	4.49	8.53	3.44	1.09	0.50	99.11
71.09	0.31	13.69	3.96	0.14	0.21	1.25	5.38	3.91	0.06	100.00
49.32	3.94	13.35	14.16	0.19	4.58	9.07	3.35	0.96	0.45	99.36
48.52	4.37	12.64	14.88	0.24	4.39	8.92	3.41	0.97	0.51	98.85
49.54	4.07	13.00	14.21	0.24	4.50	8.94	3.29	0.97	0.46	99.22

49.40	4.06	13.31	14.42	0.22	4.57	8.97	3.30	0.94	0.52	99.71
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Mainly Veidivötn, 116-117 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
49.41	1.95	14.41	11.11	0.21	7.33	12.19	2.52	0.25	0.18	99.56
50.30	1.68	14.20	12.14	0.24	6.97	11.22	2.49	0.32	0.17	99.73
49.41	1.90	14.18	11.03	0.19	7.52	12.09	2.47	0.27	0.20	99.27
49.21	1.84	14.18	11.27	0.15	7.40	12.16	2.45	0.26	0.16	99.08
49.56	1.94	14.40	11.38	0.20	7.47	12.02	2.56	0.26	0.20	99.99
49.00	1.96	14.36	11.15	0.19	7.52	12.11	2.47	0.26	0.21	99.23
49.45	1.92	14.19	11.16	0.20	7.60	12.23	2.46	0.25	0.19	99.65
49.48	2.49	13.86	13.04	0.24	6.89	11.24	2.17	0.65	0.23	100.30
73.34	0.21	13.38	2.46	0.10	0.24	1.68	4.48	2.84	0.01	98.74

Hafratjarnamýri

Reworked material, 2-3 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
65.53	0.50	15.14	6.36	0.22	0.49	3.44	4.61	1.97	0.15	98.41
66.69	0.50	15.26	6.45	0.20	0.55	3.58	4.30	1.95	0.14	99.62
68.36	0.46	15.16	5.72	0.18	0.41	3.09	4.54	2.10	0.03	100.05
74.44	0.12	13.38	2.04	0.08	0.01	1.43	4.59	2.93	0.01	99.03
50.95	2.02	13.72	13.18	0.24	5.87	10.17	2.54	0.32	0.16	99.18
74.58	0.10	13.20	2.04	0.06	0.01	1.28	4.63	2.89	0.00	98.80
72.60	0.22	14.64	3.27	0.13	0.10	1.91	4.31	2.87	0.00	100.05
65.20	0.63	15.31	7.31	0.25	0.70	3.97	4.37	1.80	0.22	99.77
74.48	0.13	13.23	1.98	0.10	0.02	1.29	4.52	2.82	0.00	98.57
66.02	0.55	15.11	6.63	0.21	0.54	3.58	4.52	1.97	0.18	99.31
74.34	0.14	13.12	2.04	0.08	0.01	1.31	4.73	2.96	0.01	98.73

Reworked material, 6-7 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
50.05	2.54	12.90	15.31	0.25	5.45	9.84	2.63	0.37	0.31	99.65
48.74	4.45	13.45	15.19	0.23	4.69	9.40	3.27	0.84	0.52	100.77
49.73	3.30	12.69	16.02	0.27	4.77	9.05	2.80	0.53	0.37	99.52
50.68	3.11	13.07	14.99	0.20	4.74	9.25	2.89	0.49	0.39	99.81
50.20	2.82	13.46	13.99	0.24	5.43	9.81	2.94	0.45	0.33	99.67
49.97	2.00	14.21	11.65	0.18	7.03	11.80	2.50	0.28	0.19	99.82
50.73	1.90	13.85	13.50	0.22	6.39	10.85	2.68	0.25	0.21	100.58
50.60	2.76	13.35	13.75	0.23	5.41	9.81	2.84	0.44	0.29	99.47
48.34	4.33	13.04	14.87	0.23	4.74	9.33	3.33	0.86	0.49	99.56
50.88	2.59	13.61	13.79	0.20	5.45	9.93	2.95	0.43	0.28	100.11
65.59	0.52	16.14	5.01	0.19	0.48	2.20	5.54	3.53	0.08	99.29
74.81	0.10	13.32	1.97	0.04	0.01	1.29	4.65	2.89	0.03	99.11
74.00	0.09	13.13	2.17	0.08	0.04	1.30	4.40	2.83	0.04	98.08
71.85	0.20	14.52	3.20	0.14	0.13	1.99	4.71	2.59	0.03	99.35
64.53	0.62	15.22	7.60	0.20	0.73	3.99	4.44	1.82	0.21	99.36
74.16	0.12	13.15	1.98	0.07	0.01	1.25	4.74	2.85	0.00	98.33
67.33	0.45	15.01	5.56	0.19	0.37	3.30	4.64	2.08	0.08	99.00
67.22	0.41	15.80	4.32	0.18	0.26	1.64	5.34	4.39	0.05	99.61
65.73	0.59	16.38	5.05	0.23	0.47	2.30	5.41	3.91	0.08	100.15

71.71	0.19	14.26	3.32	0.11	0.11	1.80	4.88	2.75	0.00	99.12
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Reworked material, 9-10 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
64.24	0.66	15.11	7.44	0.22	0.74	3.92	4.76	1.85	0.24	99.18
62.70	0.73	15.32	8.08	0.19	0.88	4.42	4.49	1.75	0.23	98.79
71.95	0.14	13.89	2.97	0.10	0.12	1.96	4.81	2.45	0.01	98.40
71.93	0.22	14.22	3.15	0.15	0.12	1.98	4.85	2.48	0.00	99.09
75.57	0.08	13.36	1.84	0.07	0.01	1.30	4.44	2.80	0.02	99.49
63.43	0.74	15.26	8.35	0.26	0.90	3.93	4.25	2.00	0.25	99.37
72.78	0.17	14.66	3.10	0.10	0.13	1.96	4.72	2.48	0.00	100.09
72.92	0.21	14.43	3.01	0.08	0.12	2.01	4.85	2.59	0.03	100.25
64.40	0.67	15.43	7.65	0.25	0.73	4.13	4.63	1.77	0.24	99.91
72.52	0.24	14.17	3.21	0.12	0.10	1.88	4.84	2.73	0.01	99.82

Reworked material, 12-13 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
67.55	0.35	15.10	5.20	0.19	0.33	3.06	4.54	2.15	0.08	98.56
71.89	0.28	14.51	3.60	0.14	0.16	2.28	4.72	2.46	0.00	100.04
72.15	0.16	14.37	3.13	0.13	0.12	1.99	4.80	2.46	0.09	99.40
49.69	1.89	13.77	12.64	0.24	6.46	11.16	2.20	0.23	0.14	98.42
71.67	0.16	14.53	3.15	0.10	0.14	1.91	4.84	2.53	0.04	99.06
67.59	0.38	15.30	5.67	0.20	0.36	3.16	4.29	2.09	0.12	99.16
65.04	0.63	15.55	7.41	0.21	0.72	3.96	4.14	1.81	0.24	99.71
72.19	0.22	14.33	3.13	0.13	0.14	2.05	4.54	2.51	0.00	99.24
65.60	0.49	15.21	6.41	0.19	0.53	3.55	4.63	1.97	0.07	98.66
63.98	0.62	15.20	7.37	0.27	0.69	3.98	4.43	1.84	0.18	98.56

Reworked material, 16-17 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
60.52	0.97	13.48	9.92	0.23	1.08	4.55	3.45	1.65	0.31	96.16
49.49	2.66	13.44	13.58	0.22	5.65	10.18	2.79	0.37	0.26	98.65
49.90	1.80	13.80	12.60	0.23	6.47	10.84	2.60	0.25	0.20	98.69
61.55	1.08	13.89	9.03	0.18	2.69	6.03	3.61	1.28	0.22	99.57
60.88	0.99	13.59	10.51	0.22	1.19	4.74	3.31	1.61	0.35	97.39
72.11	0.22	14.18	3.36	0.11	0.14	1.78	4.91	2.51	0.02	99.34

Reworked material, various origin, 18-19 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
50.70	1.76	14.12	12.85	0.22	6.66	11.60	2.30	0.21	0.18	100.60
49.60	2.80	13.21	14.48	0.25	5.65	10.27	2.51	0.43	0.35	99.54
49.97	2.10	13.41	14.21	0.24	6.25	11.03	2.65	0.21	0.19	100.26
51.51	3.27	12.78	15.18	0.25	3.64	7.90	3.16	0.74	0.67	99.10
58.83	1.41	15.62	10.37	0.26	2.11	5.73	3.90	1.46	0.67	100.36
49.84	3.01	13.20	14.84	0.22	5.28	9.65	2.73	0.49	0.33	99.60
49.87	1.99	13.52	14.12	0.25	6.12	10.98	2.60	0.24	0.20	99.89
49.87	1.76	14.09	12.18	0.18	7.26	11.96	2.35	0.20	0.14	99.99
52.50	3.27	12.89	15.15	0.33	3.53	7.81	3.03	0.74	0.69	99.94

Hekla 1766, 22-23 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
60.78	1.24	15.45	9.47	0.25	1.54	4.96	4.51	1.65	0.36	100.22
60.00	1.14	15.37	9.68	0.24	1.63	5.14	4.34	1.60	0.45	99.59
59.07	1.45	15.64	9.69	0.26	2.00	5.40	4.03	1.51	0.58	99.63
57.57	1.39	15.26	10.40	0.27	2.13	5.83	3.57	1.42	0.76	98.59
60.28	1.14	15.22	9.34	0.26	1.55	4.91	4.19	1.68	0.39	98.96
60.58	1.20	15.57	9.30	0.28	1.57	4.95	4.23	1.60	0.36	99.64
60.46	1.16	15.49	9.31	0.26	1.56	4.86	4.58	1.65	0.44	99.77
72.48	0.24	14.40	3.32	0.08	0.13	1.92	4.77	2.70	0.02	100.06
60.22	1.16	15.47	9.56	0.29	1.51	5.09	4.46	1.60	0.42	99.78
58.16	1.47	15.42	10.06	0.29	2.08	5.58	4.20	1.48	0.65	99.39

Reworked material, various origin 27-28 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
48.63	1.98	14.55	12.03	0.20	7.27	11.48	2.23	0.26	0.17	98.80
72.72	0.25	14.47	3.28	0.11	0.11	1.91	4.04	2.81	0.02	99.72
49.11	3.40	12.39	15.92	0.27	4.50	9.02	2.92	0.54	0.49	98.57
49.63	3.32	12.18	16.77	0.28	4.48	8.70	2.83	0.52	0.41	99.13
74.79	0.11	13.06	1.77	0.07	0.03	1.24	3.98	2.82	0.00	97.87
47.05	4.47	12.95	14.97	0.22	4.79	9.66	3.21	0.79	0.59	98.70
49.21	2.70	13.41	14.04	0.24	5.68	10.06	2.55	0.42	0.28	98.59
72.94	0.21	14.57	3.39	0.11	0.11	1.91	4.49	2.69	0.00	100.41
46.55	2.87	15.53	13.06	0.19	6.97	10.73	2.56	0.40	0.30	99.16
75.69	0.14	13.86	2.23	0.12	0.01	1.36	4.28	2.89	0.00	100.58
49.62	1.47	14.18	11.27	0.20	7.82	12.81	2.25	0.15	0.13	99.90
76.62	0.28	12.81	2.70	0.12	0.25	1.62	3.70	2.62	0.03	100.75
50.69	3.21	12.65	14.88	0.28	4.28	8.46	2.89	0.68	0.54	98.56
50.13	1.96	13.63	13.29	0.24	6.16	10.87	2.71	0.27	0.17	99.42
75.73	0.11	13.46	2.06	0.09	0.02	1.35	4.25	2.89	0.00	99.96

Reworked material, various origin, 31-32 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
72.31	0.21	14.15	3.08	0.07	0.12	1.84	4.55	2.78	0.02	99.12
71.94	0.21	14.10	3.21	0.12	0.09	1.85	4.74	2.76	0.03	99.06
71.55	0.24	14.18	3.24	0.12	0.11	1.89	4.89	2.73	0.03	98.97
70.82	0.19	14.19	3.36	0.11	0.10	1.91	4.86	2.81	0.00	98.35
73.79	0.08	13.00	1.96	0.12	0.01	1.29	4.82	2.75	0.00	97.82
71.60	0.18	13.94	3.42	0.08	0.11	1.86	4.60	3.15	0.00	98.95
74.00	0.07	13.13	2.05	0.12	0.02	1.31	4.58	2.84	0.00	98.12
63.93	0.59	14.97	7.38	0.24	0.73	3.91	4.57	1.86	0.19	98.37
66.56	0.43	14.94	5.77	0.21	0.42	3.26	4.74	2.10	0.11	98.54
50.27	1.99	13.56	13.27	0.25	6.14	10.78	2.71	0.26	0.17	99.40
49.62	2.57	12.68	15.30	0.27	5.45	9.83	2.89	0.37	0.29	99.27
49.95	3.24	12.78	15.05	0.27	4.60	8.94	2.84	0.62	0.42	98.72
50.06	1.93	13.54	13.42	0.26	6.22	10.71	2.70	0.26	0.17	99.27
49.90	1.86	13.77	12.72	0.21	6.50	11.07	2.55	0.22	0.18	98.98
57.14	2.05	12.62	13.34	0.26	2.09	6.33	3.36	1.25	0.92	99.36
48.91	2.63	13.34	14.19	0.26	6.03	10.21	2.57	0.40	0.31	98.86
48.46	2.47	13.63	13.45	0.21	6.31	11.20	2.58	0.30	0.30	98.92
49.66	1.64	13.99	12.11	0.22	7.26	12.04	2.40	0.19	0.12	99.64

49.65	2.96	12.94	14.73	0.27	5.24	9.47	2.69	0.57	0.47	98.98
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Reworked material, various origin, 37-38 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
66.89	0.38	15.31	5.41	0.14	0.34	3.50	5.02	1.84	0.12	98.94
71.03	0.20	14.19	3.06	0.13	0.11	1.77	4.88	2.79	0.02	98.18
46.38	2.76	15.51	13.71	0.25	7.05	10.54	0.42	0.44	0.27	97.33
72.18	0.18	14.30	3.28	0.11	0.12	1.91	4.84	2.63	0.02	99.57
55.78	1.92	14.67	10.84	0.26	2.67	5.95	3.91	1.40	1.00	98.40
50.81	2.70	12.29	15.38	0.33	3.11	7.49	3.24	0.77	1.04	97.16
73.48	0.06	13.34	2.08	0.09	0.02	1.30	4.53	2.93	0.02	97.85
72.27	0.21	14.18	3.30	0.17	0.12	1.94	4.79	2.81	0.02	99.81
66.48	0.70	13.52	6.98	0.18	0.59	3.05	4.44	2.43	0.21	98.58
71.72	0.24	14.20	3.27	0.13	0.11	1.97	4.90	2.78	0.00	99.32
45.90	2.53	15.98	12.73	0.18	7.10	10.68	2.59	0.43	0.21	98.33
61.75	0.90	14.96	9.13	0.28	1.20	4.27	5.27	1.16	0.30	99.22
49.61	1.87	13.52	12.21	0.22	6.71	11.13	2.11	0.26	0.15	97.79
68.78	0.34	14.85	4.86	0.16	0.31	2.65	4.51	2.27	0.08	98.81

Hekla 1104, 42-43 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
71.56	0.24	14.19	3.28	0.10	0.14	1.90	4.58	2.75	0.04	98.78
71.54	0.25	13.96	3.23	0.10	0.11	1.90	4.81	2.70	0.02	98.62
71.68	0.16	14.14	3.24	0.13	0.11	1.89	5.00	2.70	0.03	99.08
71.37	0.23	14.17	3.19	0.09	0.10	1.87	4.69	2.83	0.04	98.58
71.62	0.24	13.80	3.33	0.16	0.10	1.78	4.63	3.01	0.04	98.70
71.71	0.22	14.03	3.12	0.11	0.09	1.96	4.86	2.80	0.04	98.95
71.37	0.22	13.95	3.25	0.06	0.13	1.86	4.60	2.67	0.04	98.15
72.39	0.20	14.11	3.18	0.13	0.11	1.78	4.95	2.75	0.08	99.67
72.07	0.21	14.03	3.26	0.09	0.13	1.84	4.76	2.80	0.03	99.22
71.67	0.19	14.23	3.24	0.08	0.12	1.88	4.85	2.77	0.05	99.08

Grímsvötn, 48-49 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
49.06	2.63	13.37	14.15	0.24	5.89	10.16	2.58	0.42	0.29	98.80
49.54	2.70	13.26	13.48	0.24	5.77	10.07	2.83	0.42	0.29	98.59
50.15	3.14	12.72	15.07	0.26	4.86	9.08	2.95	0.58	0.43	99.25
49.60	2.79	13.24	13.92	0.23	5.47	9.87	2.96	0.45	0.30	98.83
49.91	1.90	13.65	13.19	0.23	6.26	10.82	2.73	0.27	0.16	99.12
50.05	1.99	13.78	13.46	0.22	6.15	10.48	2.75	0.27	0.19	99.34
49.56	2.73	13.45	13.65	0.22	5.66	10.15	2.83	0.40	0.31	98.96
50.09	2.83	13.44	13.86	0.22	5.53	9.89	2.81	0.44	0.36	99.47
49.78	2.71	13.37	13.42	0.24	5.74	10.10	2.78	0.40	0.32	98.86
50.23	2.83	13.45	13.31	0.23	5.71	10.18	2.87	0.40	0.30	99.51

Landnám (Veidivötn) and Katla 920, 54-55 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
49.87	1.93	13.72	13.29	0.19	6.47	11.04	2.57	0.24	0.16	99.49
47.38	4.48	13.01	15.16	0.21	4.89	9.50	3.03	0.77	0.54	98.97

47.32	4.48	12.96	15.11	0.21	4.96	9.52	3.01	0.77	0.57	98.91
50.17	1.79	13.75	13.06	0.21	6.43	11.24	2.56	0.21	0.20	99.62
47.31	4.55	12.91	15.20	0.21	4.92	9.57	3.24	0.76	0.57	99.24
50.08	1.88	13.74	13.32	0.23	6.54	11.30	2.49	0.22	0.20	100.00
47.45	4.41	12.95	15.12	0.23	4.85	9.53	3.25	0.79	0.55	99.13
47.19	4.45	12.83	15.08	0.25	4.85	9.52	3.16	0.78	0.54	98.65
49.97	1.83	13.72	12.99	0.23	6.44	11.26	2.44	0.25	0.19	99.32
49.97	1.80	13.87	13.20	0.22	6.47	11.38	2.45	0.22	0.18	99.76

Reworked material, 97-98 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
73.56	0.14	12.33	1.71	0.10	0.03	1.30	4.19	2.78	0.00	96.14
61.36	1.00	15.40	7.68	0.24	1.54	4.83	4.02	1.56	0.35	97.99
64.04	0.89	15.36	6.34	0.19	1.19	4.07	4.31	1.79	0.31	98.50
77.93	0.10	12.95	0.19	0.01	0.00	2.17	5.34	0.74	0.01	99.43
63.06	0.83	15.44	6.74	0.19	1.29	4.51	4.42	1.68	0.23	98.39
74.34	0.11	13.43	1.98	0.05	0.05	1.26	4.60	2.90	0.00	98.72
62.24	0.87	16.38	5.89	0.19	1.10	5.10	4.74	1.43	0.27	98.22
74.12	0.08	13.30	1.96	0.09	0.03	1.31	4.87	2.96	0.00	98.73
63.45	0.89	15.47	6.43	0.18	1.24	4.20	4.42	1.85	0.34	98.47
73.74	0.10	13.18	2.02	0.08	0.01	1.25	4.71	2.87	0.03	97.99

Hekla 4, 150-157 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
74.99	0.08	13.28	2.01	0.09	0.02	1.27	4.67	2.93	0.01	99.35
74.68	0.09	13.24	2.05	0.07	0.01	1.35	4.80	2.87	0.00	99.16
73.64	0.12	13.03	2.03	0.08	0.01	1.23	4.58	2.87	0.00	97.59
75.67	0.09	12.79	1.73	0.07	0.03	1.16	4.44	2.87	0.02	98.87
74.64	0.07	13.43	2.00	0.10	0.02	1.31	4.71	2.94	0.00	99.21
74.92	0.11	13.35	2.01	0.06	0.01	1.26	4.75	2.93	0.02	99.43
74.55	0.09	13.40	1.97	0.11	0.03	1.27	4.79	2.90	0.03	99.14
74.76	0.12	13.26	2.03	0.09	0.02	1.25	4.52	2.84	0.04	98.93
74.49	0.14	13.48	2.18	0.08	0.01	1.33	4.56	2.77	0.01	99.05
74.05	0.11	13.09	2.01	0.05	0.01	1.25	4.86	2.92	0.01	98.36

Reworked material, various origin 164-165 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
49.05	1.86	14.20	11.13	0.20	7.45	11.99	2.66	0.27	0.20	99.01
50.78	3.11	12.68	14.56	0.24	4.46	8.39	3.16	0.75	0.55	98.67
63.19	0.94	16.84	6.51	0.22	1.15	3.53	5.00	3.15	0.27	100.80
48.66	4.09	13.08	14.33	0.21	4.79	9.24	3.24	0.92	0.50	99.06
49.66	1.94	14.20	11.20	0.20	7.43	12.10	2.49	0.25	0.18	99.66
49.04	1.88	14.30	11.11	0.22	7.53	12.12	2.48	0.27	0.21	99.16
47.87	4.39	13.12	15.21	0.22	5.06	9.81	3.03	0.81	0.52	100.04
46.86	3.61	13.71	13.84	0.18	6.12	11.14	2.86	0.58	0.40	99.30
47.83	4.23	13.19	15.25	0.22	5.21	9.85	3.22	0.79	0.45	100.24
49.51	2.95	13.20	14.28	0.22	5.53	9.73	2.81	0.45	0.36	99.04
65.82	0.57	16.20	4.88	0.18	0.52	2.34	4.93	3.69	0.10	99.23
67.20	0.38	16.06	4.05	0.18	0.33	1.63	5.38	4.24	0.06	99.51
64.38	0.64	15.89	5.70	0.19	0.67	2.62	5.07	3.54	0.18	98.88
67.03	0.39	15.78	3.94	0.17	0.29	1.75	5.13	4.28	0.02	98.78

66.81	0.38	15.78	3.99	0.19	0.27	1.64	5.53	4.31	0.02	98.93
67.19	0.40	15.95	4.18	0.16	0.30	1.81	5.49	4.20	0.03	99.72
67.08	0.31	15.68	3.95	0.17	0.32	1.74	5.85	4.31	0.05	99.46
67.25	0.38	15.93	4.02	0.20	0.28	1.62	5.63	4.26	0.11	99.67
66.65	0.36	15.57	4.05	0.13	0.31	1.64	5.79	4.31	0.05	98.87
67.18	0.38	15.80	3.97	0.13	0.29	1.67	5.65	4.32	0.00	99.40

Sviðningar

Grímsvötn and reworked material from other origin, 1-2 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
74.46	0.14	13.36	2.03	0.10	0.01	1.29	4.54	2.95	0.02	98.90
66.87	0.39	14.87	5.63	0.21	0.34	3.20	4.75	2.17	0.11	98.55
58.91	1.25	15.14	9.61	0.30	1.88	5.25	4.20	1.58	0.64	98.76
69.82	0.20	13.41	3.24	0.10	0.13	1.85	5.03	2.75	0.00	96.53
73.51	0.17	13.94	2.65	0.09	0.03	1.59	4.69	2.87	0.01	99.55
59.35	1.16	15.50	9.64	0.29	1.58	5.07	4.17	1.63	0.52	98.90
67.32	0.45	15.08	5.56	0.17	0.35	3.14	4.49	2.16	0.14	98.84
58.44	1.48	15.08	9.98	0.28	2.07	5.65	3.93	1.45	0.70	99.05
71.19	0.21	14.18	3.34	0.11	0.13	1.92	4.88	2.78	0.00	98.73
59.83	1.21	15.32	9.24	0.27	1.53	4.92	4.53	1.58	0.48	98.91
48.66	2.60	13.22	13.84	0.22	6.05	10.31	2.69	0.39	0.31	98.29
49.14	3.01	12.95	14.54	0.24	5.60	9.77	2.83	0.45	0.32	98.84
49.49	2.88	13.24	14.25	0.23	5.57	9.76	2.80	0.46	0.30	98.99
49.54	2.96	13.23	14.68	0.24	5.44	9.72	2.76	0.44	0.37	99.38
49.33	2.86	13.00	14.43	0.24	5.54	9.84	2.76	0.44	0.31	98.74
49.50	2.91	13.16	14.71	0.25	5.44	9.80	2.69	0.46	0.29	99.21
49.30	2.85	13.17	14.52	0.26	5.52	9.65	2.86	0.46	0.32	98.91
49.34	2.92	13.17	14.59	0.21	5.50	9.72	2.69	0.44	0.32	98.91
49.20	2.90	13.16	14.52	0.21	5.51	9.76	2.74	0.46	0.32	98.79
49.47	2.80	13.21	14.54	0.25	5.57	9.73	2.86	0.44	0.26	99.13

Reworked material from Hekla, 8-9 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
71.93	0.21	14.23	3.20	0.11	0.11	1.86	4.82	2.77	0.04	99.28
72.60	0.22	13.39	3.22	0.13	0.02	0.97	5.14	3.57	0.01	99.28
70.40	0.24	13.72	3.10	0.10	0.10	1.88	4.65	2.70	0.05	96.95
74.38	0.12	12.63	1.64	0.07	0.04	1.17	4.23	2.82	0.02	97.10
71.73	0.21	13.74	3.22	0.14	0.10	1.78	5.19	2.75	0.04	98.91
71.19	0.20	13.85	3.32	0.14	0.11	1.76	4.79	2.75	0.03	98.14
72.90	0.24	13.35	3.25	0.10	0.02	0.97	5.20	3.61	0.00	99.64
71.37	0.22	14.02	3.27	0.12	0.11	1.91	4.93	2.79	0.05	98.78
71.56	0.25	14.07	3.24	0.11	0.09	1.87	4.55	2.72	0.04	98.50
72.01	0.25	14.38	3.07	0.10	0.10	1.83	4.66	2.77	0.04	99.21

Hekla 1104, 11-15 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
71.57	0.23	14.07	3.30	0.08	0.09	1.95	4.79	2.76	0.04	98.89
71.70	0.24	13.96	3.22	0.11	0.13	1.85	5.01	2.77	0.01	99.00
71.64	0.21	13.93	3.15	0.08	0.13	1.96	5.04	2.91	0.01	99.06

71.29	0.18	13.80	3.14	0.11	0.12	1.88	5.07	2.72	0.01	98.33
71.57	0.18	14.00	3.16	0.13	0.11	1.87	4.75	2.75	0.00	98.53
71.24	0.22	14.06	3.21	0.11	0.11	1.89	4.69	2.76	0.02	98.31
71.36	0.19	14.12	3.16	0.11	0.11	1.93	4.51	2.74	0.07	98.29
71.90	0.19	14.34	3.12	0.12	0.13	1.91	5.08	2.81	0.02	99.62
71.19	0.23	14.08	3.25	0.11	0.13	1.92	4.92	2.76	0.00	98.59
71.21	0.20	14.13	3.13	0.15	0.11	1.90	4.91	2.73	0.01	98.47

Hekla 3, 38-40 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
66.18	0.45	14.98	5.84	0.22	0.44	3.24	4.67	2.07	0.08	98.17
62.11	0.78	14.79	8.28	0.27	0.94	4.17	4.17	2.12	0.23	97.85
65.57	0.47	14.80	5.70	0.18	0.40	3.32	4.64	2.10	0.08	97.26
66.38	0.39	14.85	5.98	0.16	0.44	3.18	4.80	2.08	0.13	98.38
63.28	0.63	15.14	7.72	0.24	0.81	4.09	4.48	1.73	0.20	98.33
65.93	0.47	14.98	6.23	0.23	0.49	3.35	4.78	2.03	0.15	98.64
64.34	0.62	14.92	7.14	0.19	0.71	4.20	4.87	1.44	0.20	98.63
65.10	0.52	15.28	6.46	0.20	0.53	3.49	4.77	1.99	0.17	98.51
66.80	0.39	14.87	5.73	0.20	0.41	3.14	4.68	2.13	0.15	98.50
63.18	0.67	15.04	7.89	0.26	0.85	4.01	4.45	1.77	0.22	98.34

Veiðivötn, 59-60 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
49.69	1.45	14.16	11.39	0.19	7.49	12.60	2.23	0.14	0.11	99.45
49.40	1.49	14.34	11.32	0.20	7.69	12.62	2.11	0.14	0.12	99.42
49.44	1.48	14.42	11.45	0.22	7.56	12.56	2.24	0.14	0.14	99.65
49.34	1.43	14.34	11.46	0.20	7.77	12.45	2.16	0.16	0.12	99.43
49.60	1.49	14.32	11.45	0.17	7.68	12.64	2.21	0.14	0.14	99.84
48.97	1.36	14.18	11.38	0.20	7.81	12.56	2.27	0.15	0.10	98.98
49.56	1.42	14.21	11.46	0.18	7.54	12.52	2.28	0.13	0.12	99.42
49.44	1.41	14.33	11.43	0.19	7.80	12.53	2.10	0.14	0.12	99.50
49.51	1.46	14.17	11.50	0.18	7.53	12.63	2.27	0.14	0.12	99.51
49.60	1.47	14.22	11.47	0.20	7.75	12.54	2.21	0.14	0.14	99.73

Hekla 4, 64-67 cm

SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total
73.87	0.08	13.08	1.98	0.12	0.02	1.28	4.79	2.95	0.00	98.17
74.31	0.11	13.34	2.20	0.11	0.09	1.48	4.87	2.87	0.02	99.40
74.74	0.10	13.35	1.97	0.12	0.03	1.35	4.59	2.87	0.00	99.12
73.68	0.10	13.23	1.99	0.05	0.01	1.28	4.90	2.82	0.02	98.07
72.77	0.12	13.13	1.98	0.10	0.02	1.31	4.53	2.93	0.05	96.94
73.35	0.07	13.03	1.95	0.09	0.02	1.38	4.66	2.90	0.01	97.46
74.35	0.12	13.13	2.05	0.08	0.03	1.27	4.84	2.98	0.05	98.91
74.54	0.12	13.33	1.99	0.09	0.02	1.26	4.47	2.96	0.01	98.79
73.82	0.13	13.33	1.95	0.08	0.02	1.28	4.91	2.91	0.00	98.44
75.01	0.14	13.36	1.97	0.09	0.01	1.26	4.93	2.86	0.01	99.63