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Investigating effects of climate change on glaciers and proglacial landscapes in southeast Iceland: Fluvioglacial Behavior of Sólheimajökull and Seljavallajökull

Roberta B.C. Miller
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Investigating effects of climate change on glaciers and proglacial landscapes in southeast Iceland: Fluvioglacial Behavior of Sólheimajökull and Seljavallajökull

Roberta B. C. Miller
Williams College

Individual Study Project, School for International Training, Iceland and Greenland: Climate Change and the Arctic, Fall 2016

Advisor: Oddur Sigurðsson
Academic Director: Ragnar Honeth

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Abstract:

The Seljavallajökull glacier, part of the Eyjafjallajökull glacier system, and Sólheimajökull, part of the Mýrdalsjökull glacier system, are two glaciers that extend into valleys in the southeast part of Iceland. Due to climate warming, both of these glaciers are part of a melting ice cap. They are located nearby to one another, and Sólheimajökull has been extensively studied for its outwash plain sedimentology, retreat history, pro-glacial geomorphology and has been steadily monitored by the Glaciological Society of Iceland. Seljavallajökull has also been monitored by this group, but it has not been studied for sediment profiles and landscape chronology as Sólheimajökull has. The goal of this paper is to synthesize information on fluvio-glacial dynamics and glacial retreat in Iceland to better understand future outcomes of climate change in correlation with local sedimentology in glacial outwash zones. This will describe what kind of geomorphological outcomes and risks are possible in a presently warming global climate in glacial and volcanic environments. Using the wealth of data existing for Sólheimajökull as well as field observations at Seljavallajökull, this localized study will provide measured examples of patterns and behaviors of retreating glaciers, and will possibly provide evidence of the kind of sediment depositing and fluvial events that happen due to melting glacial ice. A hypothesis for sedimentary studies of these outwash zones is that their sediment profiles will have layered sediments, perhaps of similar types between the two glacial sites, with interruptions and differences based on local fluvio-glacial events, volcanic history, and retreating sediment outwash. Since there has been more recent flooding at Sólheimajökull, there will be more disruption in sediment layers. Both glaciers are retreating, and this paper aims to thoroughly describe and catalog sediment outputs, glacial processes, and climate responses that occur in Iceland and at a larger scale in a warming climate.

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List of Common Abbreviations:

GIS - Geographic Information Systems
GPS - Global Positioning System
DEM - Digital Elevation Map
LiDAR - Light Detection and Ranging

1. Introduction:

1.1. Climate Change in Iceland

Climate change, and the myriad ways in which it impacts and drives the future of this planet, manifests itself across scientific fields with urgency and relevance embedded in the consequences. In Iceland specifically, climate change has had a multifaceted role both in how it presents itself due to the country’s unique location as well as the effects it has on the country. Iceland, which lies just outside of the arctic circle, has feels = the effects of arctic amplification as well, a process which results in even more prominent and rapid warming in the poles due to ocean circulation, the fluctuation and presence of sea ice, and greenhouse radiation behavior differences due to the global position (Lainé, A., 2016). The status of the arctic as well as total surface and sea ice cover has an enormous on albedo and ocean circulation, and therefore holds an enormous impact on global systems and climate. Iceland finds itself in a particularly unique position in that alongside this amplified state, Iceland has its own jet

stream that helps temper North Atlantic ocean temperatures and in turn contributes to the downward distribution of cold water through a sea gyre down the deep western boundary current (Lippsett, L., 2012). The Icelandic Irminger current brings warm water up, where it cools above the country, and is then propelled down by the north Icelandic jet stream (see Appendix Figure A). This makes Iceland, and the monitoring of climate change in and around Iceland, a certain priority. With this information, the monitoring of ice dynamics in and around Iceland comes to mind. Iceland, a country known for its glaciers and ice caps as well as its role in impacting sea ice abundance and coverage, provides a wealth of opportunity to monitor and study ice dynamics and to better understand how local and smaller systems will function and affect the future.

1.2. The relevance of this project

1.2.1. Retreat of Icelandic glaciers

As a student beginning a career in climate science, it was clear that a good place to start would be to comprehend local systems and behaviors on a small scale in order to better understand their global context as well as how, especially with an issue as large as climate change, small manifestations of feedback loops and landscape behavior plays a role in the greater narrative of this planet. With this in mind, I chose to learn everything I could about the behavior of retreating glaciers in Iceland, as well as to spread this knowledge and therefore perhaps contribute in our overall understanding of climate warming. In order to do this, I aim to work from the ground up. By understanding more about glacial behavior and how a retreating glacier (or even the presence of a glacier) can affect a landscape, the more context we have to understand the role and impact of this ice loss in a rapidly warming future. Despite the two subjects, while perhaps distantly related, will tell us a great deal as these glaciers retreat faster, and by more fully comprehending the patterns of these two glaciers and providing a base knowledge, future changes will have a greater context for students such as myself. While landlocked glaciers may not directly affect something such as the ocean currents, the loss of albedo they provide as well as gas storage, temperature increase, and the impact melting glaciers have on the land surrounding is certainly important. This project aims to “get to know” these glaciers, so we can better predict and prepare for what’s going to happen with them specifically in a warming climate, leading to a more complete knowledge and familiarity with ice loss in Iceland and global effects of climate change.

1.2.2. Sedimentary evidence and relevance

Fluvioglacial and depository processes are heavily affected and caused by the environment of the glacier. For this project, I have chosen to focus on Sólheimajökull and Seljavallajökull, two outlet glaciers in southeast Iceland. By getting to know what kind of processes happen that are noticeable and trackable at the small scale at these outlet glaciers as well as recounting what events have indeed already happened through soil profiles to the water table, we can understand the relative timeline and activity log so to speak of these glaciers, and therefore possibly predict with more depth what their behavior will be in the future as things get warmer and melting increases. Using simple methods, we can look at and study the sediment deposits in the outwash plains of these two glaciers as well as do extensive research about their behavior and history to create a portrait of the landscape chronology of each. In learning about their past behavior and effect on the land, while paying attention to the historical climate

data, I will be creating a starting point and set up to use these two sites as reference points to track and comprehend our warming future. Glaciers often work over landscapes like enormous bulldozers, expelling sediment and boulders and carving up the earth. Looking through the layers of earth in their wake tells the stories of the fluvio-glacial events that have happened locally, when they happened, and what their role is in shaping the land of Iceland.

1.3. ISP Objective

For this project, there are two goals. One is to create a comprehensive review synthesizing the behaviors of glacial retreat as well as fluvio-glacial sediment deposits, tying them into the context of global climate change. The second is to go out into the field and use field observations and data as well as this literature synthesis to profile two specific outlet glaciers, Sólheimajökull and Seljavallajökull, as well as their landscape chronology and patterns. The on site data collected uses GPS trackers as well as digging soil pits in front of these glaciers, which are then mapped as waypoints, to create detailed maps of the areas as well as use the profiles to understand their local deposit history. The clasts and types of soil around glaciers can provide information about the history of the glacier (including outburst floods, glacial till, volcanic activity etc.). Both Sólheimajökull (in great depth) and Seljavallajökull have been monitored and studied by the Glaciological Society of Iceland, but the two sites are very different. The outwash plain site of Seljavallajökull is a deposit site that the glacier never extended to before the last Ice Age¹, whereas the data from Sólheimajökull describes a recently active glacial landscape. The contrast and comparison between the two will be useful in understanding the variety and range of a retreating glacier's impact. This approach is contemporary and useful towards educating other young scientists and creating a baseline of knowledge of glacier dynamics and climate change. Björnsson, H. et al. in a 2008 study endorses this relevance explaining, "scientifically speaking, the following fields of glaciological studies are probably the most significant regarding Iceland: a) the hydrology of temperate icecaps, b) interactions between glacial and volcanic phenomena, c) glacier hazards due to jökulhlaups, d) surges and the stability of ice masses, and e) the future evolution of glaciers and their role as indicators of climate change, based on the location of the island in the North Atlantic Ocean, just under the Arctic Circle". This indicates that having accessible syntheses of information is not only useful, but significant to science conducted in Iceland. He goes on to say that "the study of all these fields is supported by unusually detailed data, easily accessible on maps of glacier surface and bedrock topography (using... GPS measurements and satellite observations), along with a wide range of glacier mass balance and glacio-meteorological and hydrological observations. The whole of this basic information has been applied towards increasing the overall understanding of Icelandic glaciers and developing and revising numerical models to simulate the growth and decay of present and former glaciers and to simulate the impact of climate change on glacial runoff" (Björnsson, H. et al., 2008). In an attempt to emulate and create a synthesis using these kinds of data sources as well as field observations and techniques that are possible and

¹ Sigurðsson, Oddur, 2016., Personal communication.

available, this synthesis also creates a literature review for a more complete picture of the relevance of glaciers to climate change.

1.4. Study Area

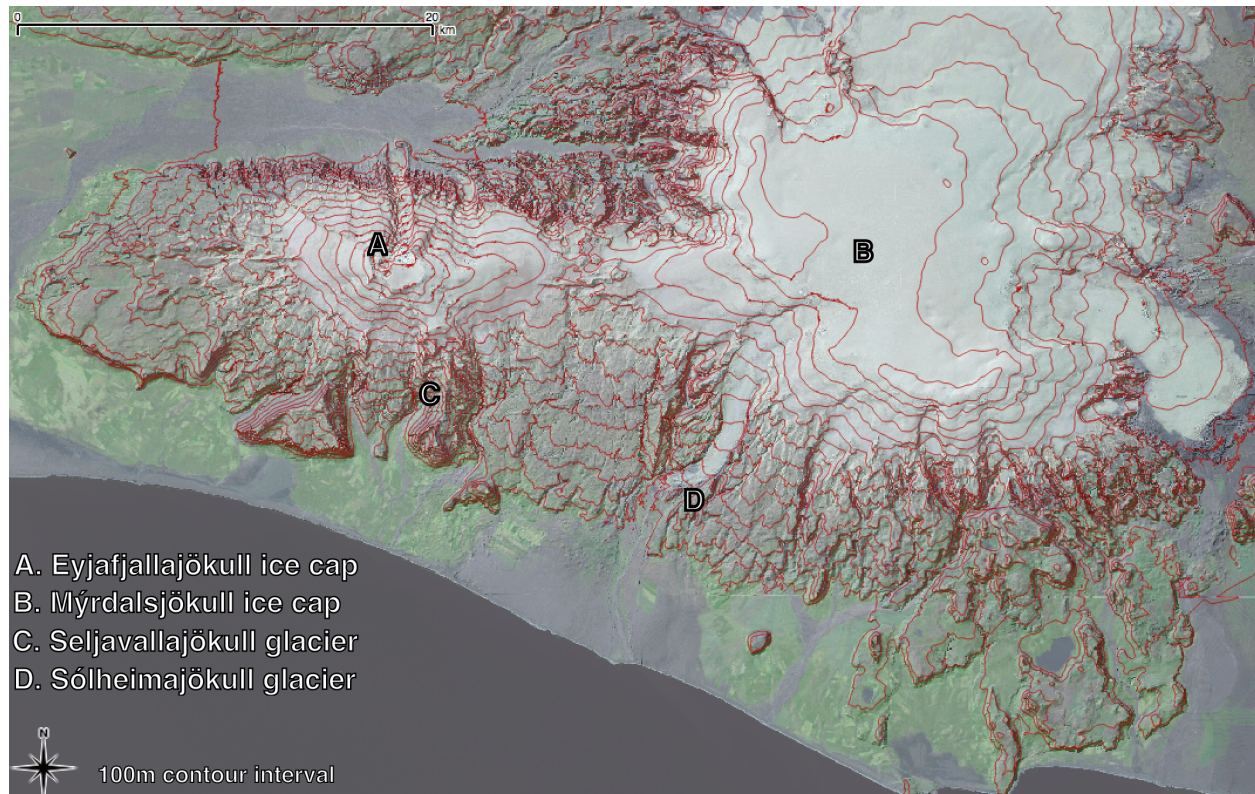


Figure 1. Map of site area, Mýrdalsjökull and Eyjafjallajökull, made with clipped DEMs, hillshade, Landsat8 and aerial photograph layers retrieved from Landmælingar Íslands using QGIS 2.16.3.

The chosen sites are Sólheimajökull and Seljavallajökull. Seljavallajökull is a south running outlet glacier off the ice cap of Eyjafjallajökull, while Sólheimajökull is a south running outlet glacier off the Mýrdalsjökull ice cap. These two ice caps cover central volcanos, both of which have recorded eruption history. In addition, Mýrdalsjökull and Eyjafjallajökull used to be joined as a single ice cap which separated in the mid 20th century. (Friis, B., 2011). Sólheimajökull has not behaved or fluctuated in the same way a great deal of the outlet glaciers have from Mýrdalsjökull, but “is compatible with other outlet glaciers of Eyjafjallajökull and Mýrdalsjökull, e.g. Seljavallajökull, Steinholtsjökull and Klifurárjökull” (Friis, B., 2011). These two connecting factors as well as the in depth history of study around Sólheimajökull were reasons these two sites were chosen. Their sedimentary deposits and outwash plain features have certainly enough differences for contrasts and distinctions in predictable behavior, but the glaciers themselves have mirrored each other both in their shared ice cap and in retreat history.

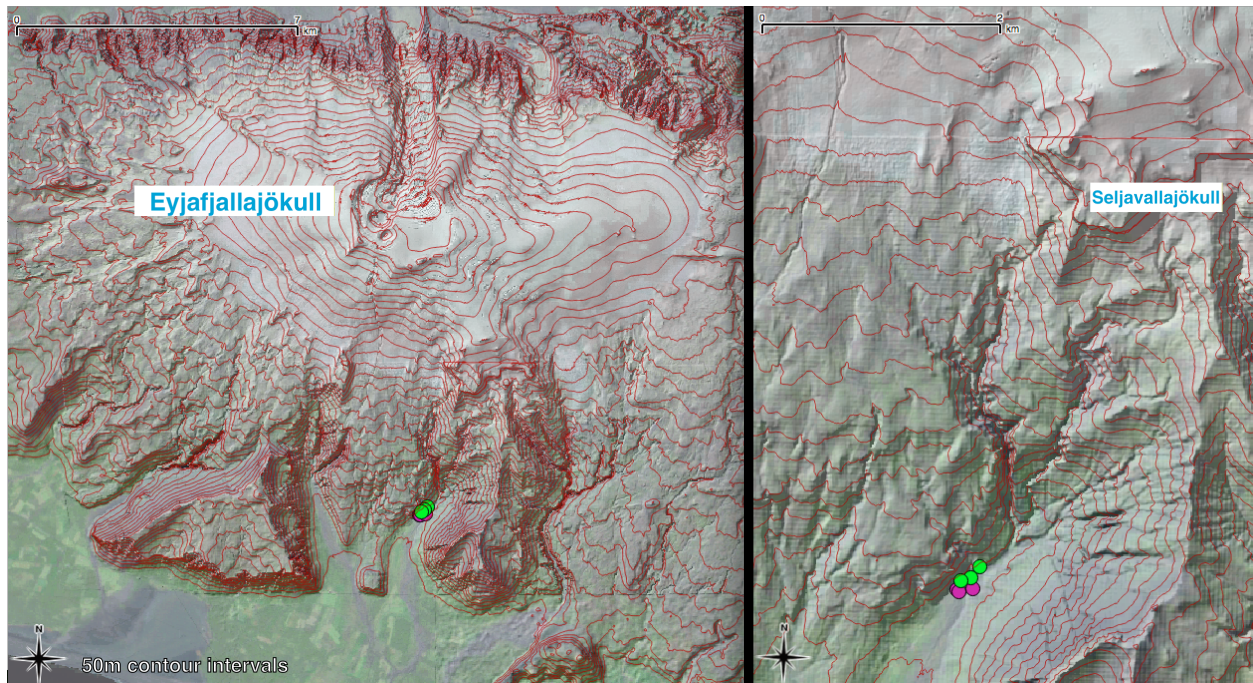


Figure 2. Map of site area for Seljavallajökull, including site context, made with clipped DEMs, hillshade, Landsat8 and aerial photograph layers retrieved from Landmælingar Íslands using QGIS 2.16.3. Points marked represent waypoints of soil pit profiles.

Seljavallajökull reaches its end before entering the valley, but the drainage area leads right to the outwash plain where we did our field work. While the river running down from Seljavallajökull joins another from Eyjafjallajökull before entering the outwash plain, this second source has a wealth of other drainage sites and is also farther away from the plain than the terminus of Seljavallajökull. There is another very small feeder that comes in from the east, but it has no glacial or ice cover source and therefore will probably have a much lower impact on overall sediment deposit than Seljavallajökull, which appears to play a weighty role in drainage to the valley. (See Appendix Figure B for map and diagram of site and drainage sources). Seljavallajökull is 0.55 km in width on average, and 1.33 km in length (manually measured through aerial maps from the National Land Survey of Iceland). It is comparatively a much smaller glacier than Sólheimajökull, but therefore has a terminus much closer to the greater ice cap it feeds from.

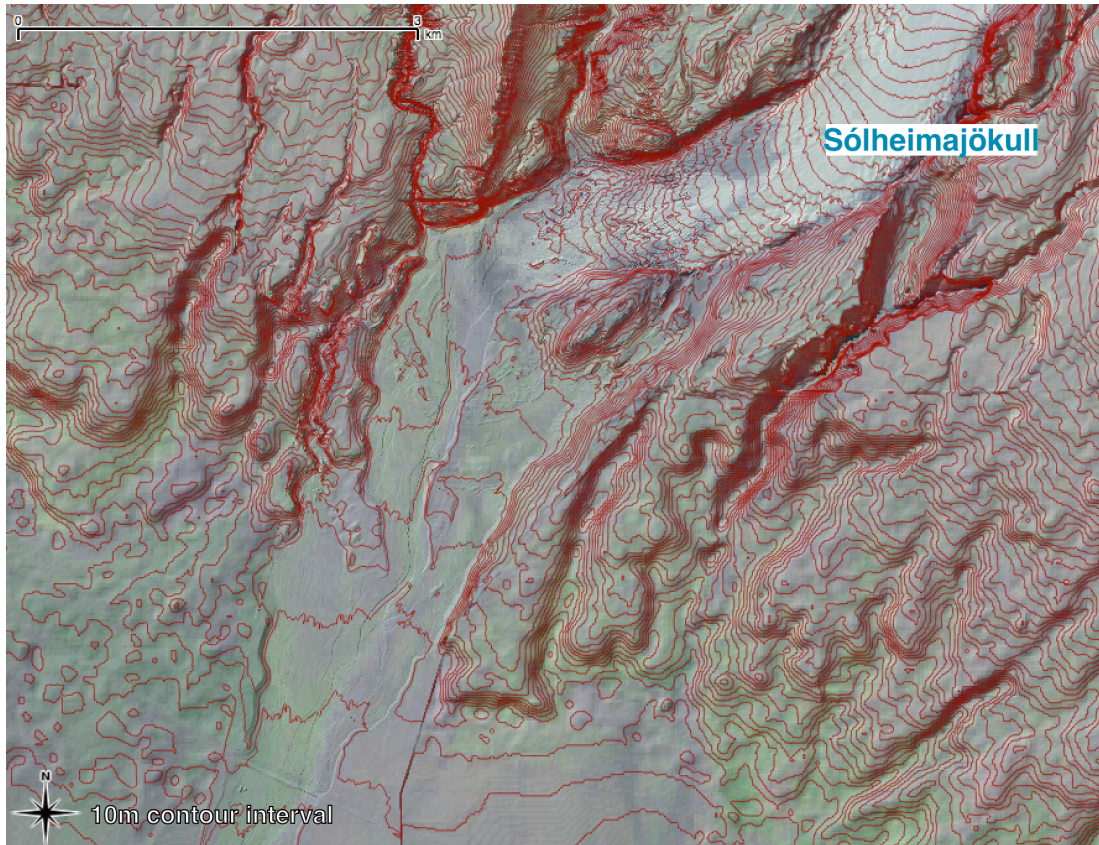


Figure 3. Map of site area for Sólheimajökull, made with clipped DEMs, hillshade, Landsat8 and aerial photograph layers retrieved from Landmælingar Íslands as well as LiDAR footprints from Ragnar Heiðar Þrastarson of the IMO, using QGIS 2.16.3.

Sólheimajökull extends out into the u-shaped valley, thus it has a fairly direct path of outwash and sediment deposit into the plain. In this site, due to limited resources and time, field measurements and observations from the Friis, B., 2011 master's thesis, after which we modeled our methods and approach at Seljavallajökull, are used instead collecting the data in person. However, site visits and qualitative observations were made. By far, the clearest source of drainage comes from the glacier (see Appendix Figure C), and this area has been well monitored for fluvio-glacial activity and events. Sólheimajökull is 15 km long and 1-2 km wide on average (Friis, B., 2011). The volcano, Katla, which the ice cap covers, is fairly active and therefore plays a large role in the sediment deposit and melt rate of the glaciers and ice covering it.

2. Materials/Methods:

2.1. Location and Resources

Bjarki Friis's master thesis from 2011, Late Holocene glacial history of Sólheimajökull, southern Iceland (Faculty of Earth Sciences, University of Iceland), is a large source of inspiration for the validity and idea behind the methods as well as location selection, point of reference for context, and comparable example of maps and data interpretation. For the locations, I based the selection off of similarity to

Sólheimajökull, which has by far the most literature surrounding sediment deposition and glacial history in the area, and is also the focus of Friis's thesis. In his thesis, Friis writes that Seljavallajökull in particular is a glacier that has had similar retreat patterns to Sólheimajökull. Since these fluctuations and behaviors are grouped together and are also geographically close, it will be interesting to compare whatever extent of observations we are able to make at Seljavallajökull with Friis's at Sólheimajökull. Friis also describes in detail his method of analyzing the soil samples in order to describe what sediment is where and what could have possibly deposited it there. From pages 35-45, he details what sediment is found where, its stratigraphy, as well as its origin for sections of the Sólheimajökull outwash plain, including cross section figures and the direction of glacier movement. I intent to use his sediment analysis as a reference guide for other in addition to other literature on sediment behavior and deposition in pro-glacial zones in Iceland.

The greater focus of the paper, which aims to create a synthesis of understanding of fluvio-glacial behavior in relation to climate change, can be done with extensive research and literature review, which intend to connect meaningfully on a local level with the chosen two glacier sites. This requires a review of glacial retreat in Iceland, pro-glacial sediment dynamics, volcanic activity in Iceland, and climate change in Iceland.

2.2. Data Collection & Analysis

To dig the soil pits, a garden shovel and trowel were used to create pits that extend in depth until the water table, with dimensions of equal depth to width. We then took photos of the profiles and recorded them. When we did this, I created waypoints on a Garmin Dakota 10 GPS tracker to denote various spots where a pit existed. To analyze these profiles to determine soil type and possible deposit origin, literature on the landscape chronology of nearby Sólheimajökull were used as a point of comparison.

DEMs and landsat data of the area from overlaid with satellite imagery and manipulated in QGIS were then used for detailed maps of the glacial areas and data collection sites. It is possible to geo-reference this satellite imagery, and in doing this, one can create a detailed base map on which to display our soil pit points and water runoff and sediment discharge direction to describe the fluvio-glacial activity of the outwash zone. By creating hillshades and contours, the maps are visually compelling, informative, and an interesting way of visualizing the area/data.

In my analysis of the local sediments, I will use Friis's master thesis as a template for diagnosing and describing soil profiles as well as conferring with other literature on glacial processes and sediment discharge in Iceland. I will also use historical climate data on ice and glaciers as well as temperature to put these locations into context with future glaciological changes and events regarding current climate change. The chosen methods, modeled after Friis's master thesis, are supported in other literature as well. According to another paper by Staines, K.E., "Current understanding of jökulhlaup processes and products is... largely based on qualitative conceptual models developed from sedimentary studies... geomorphological evidence either from field measurements... or from remote sensing" (Staines, K. E. H., and Carrivick, J. L., 2015). Similarly, this research will use sedimentary studies, geomorphological evidence from field measurements, GPS trackers, and remote

sensing in QGIS. Therefore these are reliable ways to understand sediment flows and floods in pro-glacial zones.

3. Synthesis Review:

3.1. *Effect of climate change on glaciers*

As the climate changes and overall surface temperatures increase, there is a strong indication that glaciers will be heavily affected by this change. Glaciers in turn contribute to more broad reaching effects of climate change both in local environments and in more global ones such as sea level rise. According to the Icelandic Meteorological Office as well as the University of Iceland, “climate change will have a substantial effect on glaciers and runoff from glaciated areas in the Nordic countries”, and that in “many glaciers and ice caps are expected to essentially disappear over the next 100–200 years and runoff from glaciated areas in the period 30–100 years from now has been projected to increase by 25–50% of the present runoff from these areas for typical glaciated watersheds in Iceland” (Jóhannesson, T. et al., 2004). This increase in runoff and disappearance of glaciers is urgently imminent and would have multifaceted impacts. While one could consider a positive outcome in the increase of hydropower technology from glacial discharge and water runoff, the domino effect and diversity of outcomes due to rapid glacial retreat are far more alarming than promising. Around 11% of Iceland is covered by glaciers, containing a total of 3,600 km³ of water, which would raise global sea level by 1 cm if melted. (To see a visual of Icelandic glacier distribution as well as corresponding volcanically active zones, see Appendix Figure D.) In addition, ice loss and glacial retreat has accelerated from the 19th century onward, and 2.7% has been lost during the last ten years alone from total icecap volumes in the country (Björnsson, H. et al., 2008). Looking into the future, based on climate models, glacier dynamics models, and other studies, main icecaps will lose up to 35% of their current volume in the next 50 years, resulting in a peak of glacier meltwater runoff and discharge (Björnsson, H. et al., 2008).

3.2. *Climate change and glacier runoff*

The glacial runoff mentioned by Jóhannesson et al., and its imminent rise, is not insignificant to Iceland’s watershed. In fact, they “currently provide at least one-third of its total runoff” and these glaciers even “constitute long-lasting reservoirs of ice that turns to meltwater and feeds the country’s main rivers, some of which have been harnessed for hydropower” (Björnsson, H. et al., 2008). Glacial runoff typically has annual cycles and fluctuations due to seasonal accumulation and ablation, but these regular patterns can be disrupted and influenced based on seismic and volcanic activity as well as longer term climate warming. Glacial runoff in general means that there is an increase of unfrozen water in the earth system, which contributes to sea level rise, but also has impacts locally that result in flooding, river re-routing, and changes to the land. In a developed landscape, this can have consequences for road building, location of habitation centers, farms, and more. This leads to their outwash plains to be an interesting and dynamic place to observe. If “climate change and accelerated glacier melt lead to an increase in suspended sediment discharge from proglacial zones”, then “glacierized alpine catchments and the proglacial zones therein are amongst the most dynamic geomorphic systems. Glacial erosion produces large amounts of sediment

temporarily stored in... potentially unstable landforms” (Geilhausen et al., 2013). As such, monitoring and understanding fluvio-glacial systems and dynamics through sediment deposits makes sense.

3.3. Climate change and volcanic activity with glaciers

Climate fluctuations and changes have a strong influence on glacial response dynamics, but so does their surrounding location. In proglacial zones, sediment output and deposits have multiple origins. While a great deal of geomorphological formations and sedimentary composition are due to glacial till, movement, and runoff, in Iceland in particular volcanic activity plays a key role. Many glaciers, particularly the two in focus in this synthesis, branch out from ice caps that cover active volcanoes. Volcanic activity contributes to the size and frequency and even induces jökulhlaups, or glacial outburst floods, which can devastate land, communities, and roads, and 60% of Iceland’s glacial cover is underlain by active volcanoes. (Björnsson, H. et al., 2008). The eruption and general seismic activity concerning these volcanoes has a large impact in the sediment output and responses in fluvio-glacial systems. Geothermal activity under glaciers and icecaps due to magma leads to melted glacier ice wherever there is exposure to the heat. This not only creates a depression in the glacial surface due to the internal structural change of the glacier, but also rapidly melts a large portion of the ice in a concentrated area at once. Under these spots where geothermal exposure occurs, even more of the melt water in the surrounding area congregates due to low basal pressure potential at the depressions. Eventually, it will be so unstable that the water will burst out in the form of a jökulhlaup (Björnsson, H. et al., 2008). Areas in Iceland that have been monitored for a long time for volcanic activity as well as glacier dynamics, such as Vatnajökull, have been an example of how the presence of geothermal activity can heavily influence the discharge and runoff in any given year, especially in the presence of jökulhlaups. It can be simplified to the idea that if there is more heat, there will be more melting and therefore greater runoff (sometimes presenting as large sudden events such as the jökulhlaups). However, it can be difficult to see how increased temperature volcanically connects to climate change. It turns out that as climate warming progresses, volcanic activity may actually become more frequent in a glacial setting.

The relationship between glaciers and the volcanoes they overlay is dynamic. The weight exerted by ice when it covers a landscape is enormous, which is why when ice and glacial covers move through landscapes they have the ability to sculpt and shape the earth. This effect is seen all over the globe, creating mountains and valleys and all sorts of geomorphological outcomes. However, when the immense weight of ice is covering a geothermally active area, the relationship can result in much faster rates of landscape change than a retreating glacier sculpting a valley over thousands of years. When a glacier overlays the earth, the crust is compressed and a lot of pressure is exerted on the area below. In Iceland, which coincides with the mid-atlantic ridge, often the area below the glacier is an active volcano, and this pressure pushes down on magma chambers. As glaciers melt in size, there is a corresponding loss of that compression. With less compression, more magma can be melted and formed due to the release of pressure on the rock. With an increase in magma, there is a possibility of an increase of local volcanic activity. This relationship has been observed in Iceland at

Vatnajökull, where “researchers found that the glacier’s thinning and retreating caused approximately 0.014 cubic kilometers of magma to form each year. As a result of this magma growth, the researchers predicted an increase in volcanic activity under the ice cap” (Handler, E., 2015). In a system that includes global warming, there could be a future study of the relationship between climate data and magma formation in Iceland.

This relationship not only means a potential increase in volcanic activity, which could result in the increased deposit of volcanic sediments in the area, but also an increase in fluvio-glacial events and therefore more sediment transport and discharge in proglacial zones.

3.4. *Jökulhlaups and glacial sediment deposits*

As mentioned, jökulhlaups play a significant role in the sediment output in sander (outwash plain) deltas alongside discharge and runoff deposits. Glacial erosion and consequent sediment transport, either by jökulhlaup or otherwise, affects the environment. This relationship and its historical presence, especially in Iceland, can be summarized by the following: “during Pleistocene and post-glacial times, the island and its surrounding sea-floor topography have been significantly shaped by glacial erosion and glacial or fluvio-glacial deposits. Glaciers have carved alpine landscapes characterized by cirques, sharp mountain peaks, broad lowlands, and long, steep u-shaped valleys or narrow fjords. The largest agricultural regions in the south and west were created by glacial and fluvio-glacial sediments in late glacial and early Holocene periods. In addition, the topography and sediments of near-shore marine environments have been heavily influenced by glacial erosion and deposition. The impact of glacial rivers is evidenced by deeply eroded canyons and sediments transported onto sandur deltas. Iceland’s specially-named Palagonite Formation is largely the product of subglacial volcanic activity that was later subjected to erosion” (Björnsson, H. et al., 2008). This writing refers to much larger glaciers than the two outlet glaciers in focus, but it goes to show that fluvio-glacial sediments play a major role in the future status of Iceland. Even on a smaller scale, runoff and flooding events can have smaller scale local impacts within an immediate timeline.

Jökulhlaups especially drive this, as they “may profoundly alter landscapes, devastate vegetation, and threaten lives as well as the roads, bridges and hydroelectric plants along glacier-fed rivers. The effects of jökulhlaups on the landscape appear in massively eroded canyons and in sediment deposits on outwash plains” (Björnsson, H. et al., 2008). Sólheimajökull is an outlet glacier of Mýrdalsjökull, an ice cap which hosts jökulhlaups that are some of “Earth’s largest contemporary floods, rivaled only by floods associated with the end of the last glaciation 11,500 years ago” (Björnsson, H. et al., 2008). Generally, it is understood that “climate change and accelerated glacier melt lead to an increase in suspended sediment discharge from proglacial zones”, and that due to accelerated glacial retreat, “sediment delivery from glacial valleys will most likely be significantly altered in the near future, leading to changes in sediment flux”, as has been studied in detail in the Alps (Geilhausen et al., 2013). This includes sediment delivery resulting from jökulhlaups, which lead “to significant net erosion of the riverbed, producing an increase in flow conveyance capacity of the river channel... This implies that flood propagation becomes ‘smoother’ or ‘easier’ due to rapid river channel adjustment” (Guan M., et al., 2015). This creates a feedback loop where flooding

becomes easier as there is an increase in runoff outbursts. The reason why this feedback loop is significant is that “a major implication... is the verification of the significant impacts of geomorphological changes on hydraulics required for flood risk assessment during an event where erosion and deposition is severe” (Guan M., et al., 2015). Another study strengthens this point, explaining, “The frequency and potentially the magnitude of jökulhlaups is predicted to increase with climate change and glacier retreat... thereby placing more persons and infrastructure at risk from outburst floods. Understanding when, how and why proglacial erosion and deposition occurs during jökulhlaups is therefore crucial for hazard mitigation and landscape management” (Staines, K. E. H., and Carrivick, J. L., 2015).

4. Sólheimajökull and Seljavallajökull:

4.1 Reasons for locations

The two outwash glaciers chosen behave very similarly to one another (Friis, B., 2011). Sólheimajökull and its sediment flows have been extensively studied and monitored, as “the snout bifurcates and has been measured at three locations since 1930 by members of the Iceland Glaciological Society... For six centuries all major jökulhlaups from Mýrdalsjökull have issued from this main outlet glacier of the ice cap” (Sigurðsson, O., 1998.) Not only this, but “Sólheimajökull and its proglacial area have been repeatedly photographed from the air since the mid-20th Century and consequently repeat aerial photographs exist covering ~ 60 years... Sólheimajökull has one of the longest and most studied glacier fluctuation records in Iceland, extending back to the mid-Holocene... a jökulhlaup occurred in July 1999 at Sólheimajökull, offering the opportunity to examine not only the impact of that event in comparison to ~30 years of preceding ice ablation-fed river flow, but also the landscape response in the ~ 15 years afterwards.” (Staines, K.E., et al., 2015). This makes the area chosen especially reliable, and since these two glaciers behave very similarly and are located in the same region, they are promising choices. While a lot more is known and there is a much greater expanse of sedimentary and fluvio-glacial activity at Sólheimajökull, a site visit to Seljavallajökull to dig soil pits and make observations serves as an attempt to expand the study of these glaciers for a longer term future study of their behavior. The future of fluvio-glacial behavior Sólheimajökull could affect the now popular tour visits to the area as well as the road and settlements near it, and the outwash zones of Seljavallajökull include farmland and hiking paths. While a lot more information can be gathered from Sólheimajökull, Seljavallajökull’s outwash zone is worth visiting because it is readily accessible for monitoring and has an ultimately quite different position and proximity to the studied deposition zone compared to Sólheimajökull. Seljavallajökull never extended to the sampled area, but indeed all of the runoff and sediment load discharge from the glacier is collected in this single valley. In addition, the terminus of Seljavallajökull is much more proximate to the main ice cap than at Sólheimajökull. These differences don’t allow for me to make any kind of conclusion about the results of these differences, but instead open a window of opportunity to understand how glacial retreat and sediment output manifests in a variety of pro-glacial zones.

4.2. Sólheimajökull field observations

4.2.1. Soil profiles

One of the most major differences that will manifest in the comparison between these sites is the recent fluvioglacial history at Sólheimajökull, especially in regard to the 1999 jökulhlaup that occurred there. Where regular river and sediment flows might deposit finer grain sediment at a smaller magnitude, this is disrupted by events such as jökulhlaups. Using soil pit profiles from Bjarki Friis's master thesis, we get a better view of what kind of deposits are being made and what their origin is. (See Appendix Figure E for map of area and soil profile logs).

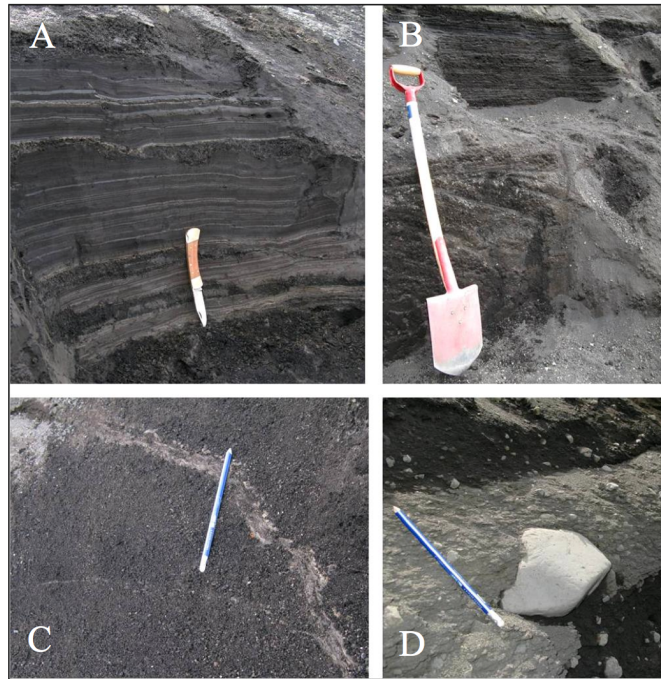


Figure 4. Soil pit profiles at the Sólheimajökull sandur adapted from Friis, B., 2011. Objects included for scale reference.

In this first soil pit profile, laminations between silt and courser dark sand are apparent. These layers as well as their horizontal orientation and dipping indicates a fluvial origin (Friis, B., 2011). These sandy layers are all dark in color and rough in texture. They are relatively tightly packed. According to Friis, it is likely that this area was fed by glacial meltwater and the origin of these sediments is mainly from drainage river and glacial discharge. While the jökulhlaup increases bed turbidity by a large extent, these uninterrupted layers suggest that in the chronology of this deposit area, these layers have remained relatively undisturbed and were therefore perhaps dammed from larger outbursts or perhaps occurred more recently.



Figure 5. Second set of soil profiles at the Sólheimajökull sandur adapted from Friis, B., 2011. Objects included for scale reference.

At this second profile, we see both a fine dark sediment present as well as a layer of a vast mix of sediments. This profile is not nearly as neatly deposited as the first. In fact, there is a clear layer of much larger clast, churned up, mixed type sediment overlying the entire profile. Section A shows a dyke running from the coarse and mixed layer into the finer material and D shows a profile of the entire section. Friis interprets the origin of the dark finer sediment as perhaps resulting from ash from an eruption mixed with water to become pumice. On the surface of the pumice are what can be determined as jökulhlaup sediments, deposited in the same event as the pumice, but rather than volcanic origin, these rocks appear to have a glacial origin, transported by a large fluvial force such as the jökulhlaup. The largest clasts present would only have been moved by ice, therefore qualifying the surface as glacial till rather than solely fluvial deposits. (Friis, B., 2011).

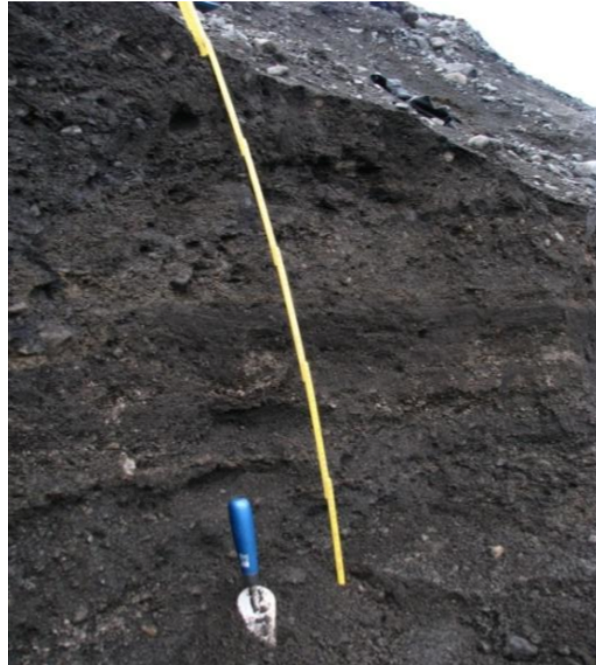


Figure 6. Third soil pit profile at the Sólheimajökull sandur adapted from Friis, B., 2011. Objects included for scale reference.

In this third sample, the top layer can be classified as glacial till, meaning the origin is movement by ice, due to the extent of clast size found. However, the sand and silt layers that are slightly laminated appear to be of fluvial origin, old enough that these layers could be tilted and deformed by some larger landscape movement. The soil pit changes toward the bottom to a larger gravel last which would also have a fluvial origin, but due to their difference from the layers above and lack of horizontal layering probably came and filled in channels and changed flow of the fluvial source (Friis, B., 2011).



Figure 7. Fourth soil pit profile at the Sólheimajökull sandur adapted from Friis, B., 2011. Objects included for scale reference.

In the next soil profile, The heterogenous deposit appearance, varying clasts and coarse texture, as well as the types of sediments suggest the origin of these sediments as mudflow or regiment discharge during glacial retreat from the ice surface, a process that is common during rainfall or days with a lot of ice melt. The larger clast boulders farther down in the pit suggest a larger moving force, but due to the overlying layers is most likely still flow till rather than jökulhlaup sediments. (Friis, B., 2011).

Regarding sediment in the area in general, any brown silty clay found either farther down in the pits or mixed within is most likely sourced from pools of stagnant water in abandoned channels. When this happens, sediment that would have otherwise been suspended can settle and deposit. (Friis, B., 2011). The finer the grain of sediment, the less force and lower flow the depositing factor had. These layers can be laminated, but this requires a period of sediment deposit that doesn't too severely disrupt the layers as a jökulhlaup would. Gravel and sand layers will probably have come from a fluvio-glacial origin. Larger rocks and gravels will probably have a glacial origin as well, but depending on the size and context could have been deposited with fluvial origins, glacial till origins, or jökulhlaups.

4.2.2. Landscape chronology

There was a variety of types of events and origins represented in these soil profile logs. There was a variety or regular fluvio-glacial processes indicated, such as mudslides, till, stagnant water, and fluvial deposits influenced by river runoff and

discharge distribution. According to Guan, et al., 2015, “In proglacial areas, the riverbed generally comprises of poorly sorted sediment materials from coarse particles to fine sand particles”. These deposits were mixed in and represented as well as an example of completely unsorted mixed grain layers from the 1999 jökulhlaup. This jökulhlaup had by far the largest scale impact on the Sólheimajökull sandur, but the profiles give a more complete view of the landscape chronology. They show a history of glacial retreat through the till in the third sample, fluvio-glacial river sediment transports, melt water and mudslides, volcanic ash, as well. This illustrates the huge amount of landscape change that can occur in regular daily and annual cycles, longer term retreat cycles, as well as these sudden more catastrophic events.

4.2.3. Fluvio-glacial history

The largest and most influential force in recent landscape change at Sólheimajökull was the 1999 outburst flood. Regarding a climate change context, this is perhaps the most recent event that is correlated with global warming in several contexts that shows results and change that carry a higher risk and impact. There historically were eight other major jökulhlaups at Sólheimajökull between 4.5 ka BP and the mid-14th Century before the eruption center of Katla, the volcano, migrated. (Staines, K. E. H., and Carrivick, J. L., 2015). Subglacial volcanic activity from Katla induced the 1999 jökulhlaup, and even drained a previously ice-dammed lake that had been previously sequestered (Staines, K. E. H., and Carrivick, J. L., 2015). During this event, “the flooding process was sudden, short-lived and had high discharge, lasting approximately 6 h. The flood burst initially from the western margin of Sólheimajökull and drained into a former ice-dammed lake basin, approximately 3.7 km from the glacier snout thereby filling it” (Guan, et al. 2015). Though the sandur was not the only burst location for the jökulhlaup, in the proglacial zone “the jökulhlaup was predominantly confined to the main river channel although over-bank flow led to the reactivation of some ice-proximal paleo-channels” (Staines, K. E. H., and Carrivick, J. L., 2015). The geomorphological impact overall can be summarized to be that “deposition occurred in supraglacial, ice-marginal and proglacial locations... with the greatest impact in the ice-proximal zone” (Staines, K. E. H., and Carrivick, J. L., 2015). Aside from this overall impact, “in the proglacial area, up to 6m of sediment were deposited, the source of which was predominantly subglacial excavation” and a “1,200 m boulder fan was deposited in front of the western side of the glacier terminus with boulders > 10 m in diameter” (Staines, K. E. H., and Carrivick, J. L., 2015). This 6m increase is significant, and while the bulk of the effects were limited to the ice-proximal area, this huge addition of sediment will impact future sediment transport and bed load movement by pro-glacial rivers and flows for a quite some time to come. The addition of a boulder fan meant that suddenly rocks greater than 10 meters in diameter suddenly flooded into the valley, and had there been and structures or roads in that area, they surely would have been destroyed.

In the wake of this event, the main impact on the landscape and on fluvial discharge has sourced from glacial retreat. Since the event, the boulder fan has not been heavily affected. Other landscape change and difference has been a result of channel flow changes and sediment movement from these proglacial water flows. In fact, “Between 2001 and 2010 there was a progressive increase in downstream channel

braiding, suggesting that sediment deposited by the jökulhlaup is moving through the proglacial channel system, being re-distributed by non-jökulhlaup flow” (Staines, K. E. H., and Carrivick, J. L., 2015). This illustrates that the effects of a jökulhlaup are simultaneously long lasting, such as the boulder fan, while also readily responded to by the other fluvio-glacial processes in the proglacial environment, changing the channel direction and braiding as well as sediment transport in these water flows.

4.3. Seljavallajökull data analysis

4.3.1. Soil profiles

The soil profiles taken at Seljavallajökull extend down to the water table so that our samples extend as far as it possible to dig. To identify the origin and type of soil layers, I use comparable soil samples from similar pits at Sólheimajökull observed by Friis. I have selected profiles from our field data that show a range of similarity and contrast between them. (See Appendix Figure F for a map of area and soil profile waypoints).



Figure 8. Soil pit profile at the Seljavallir catchment valley. Tape included for scale reference.

In this profile, there is a top layer of sandy coarse sediment that overlays a slightly finer grain layer that has vegetation mixed in. This vegetative layer is not evenly nor consistently deposited, and sits on top of a thicker band of that same coarser sand. At about .1m from the bottom, a layer with larger lasts of rock begins and the

composition is no longer homogenous. In a qualitative analysis, it is possible that from the bottom up, the following origin events occurred. For the bottom layer, which has a mixture of large rocks and sand, there must have been some larger flooding or flow even than the usual discharge from the glacier covered mountains above. Perhaps fluvioglacial activity from either Seljavallajökull or Eyjafjallajökull, or perhaps heavy weather patterns, caused an increase in runoff and river discharge. The gritty sand layer on top of this appears to be sediment deposited from pro-glacial riverbed flows, as it fits Staine's description of proglacial fluvial sand deposits in runoff zones. Above this, the vegetative finer layer suggests turbidity and quick overturn in this area. There was most likely some kind of sudden disruption of the area, although the source was not related to an event considering the effect is so tightly concentrated and is surrounded by the regular sandy deposits, which extend to the surface. The surrounding area has been bulldozed in the past and sculpted from human activity, and it is unclear exactly where the boundaries are of the affected zones, so it is impossible to claim with confidence the cause of this quick disruption of sediment².



Figure 9. Second soil pit profile at the Seljavellir catchment valley. Tape included for scale reference.

In the second soil profile pit, we reached the water table much faster. The top layer is poorly sorted and has a mix of coarse sandy sediment and quickly (about .3m deep) starts to include larger clasts of rocks. This unsorted mix of rock and coarse sand

² Oddur Sigurðsson, 2016, personal communication.

extends to the base of the pit to the water table. The inclusion of these rocks at a much shallower depth indicate either than the sand on top in the first pit was deposited in that site but not this or that this mixed layer was deposited more recently than the mixed layer at the first site. The sandy layer is slightly courser in grain size than the sand at the first layer, and appears to be slightly less homogenous in color and texture. It is possible that this sediment's fluvial origin had a higher discharge and therefore brought courser grain deposits. The rocks would have been moved by a higher flow event, similar to the possible cause of those found at the first profile.



Figure 10. Third soil pit profile at the Seljavellir catchment valley. Tape included for scale reference.

The third soil profile was the deepest one of our samples (1.1m). The top layer was the same dark sandy sediment that appears to match the description of proglacial fluvial deposits. This layer is fairly thick and homogenous. Under this, there is a clear contact to a much lighter sediment that is browner and more clay-like. Considering Staine's analysis of sediment at Sólheimajökull, this brown sediment that is slightly finer grain perhaps is from a time of relative stagnation when suspended clay sediment could settle. Alternatively, the sediment comes from a different location than the dark sandy sediment. Under this layer, and in fact the brown sediment permeates the next to a large extent, we once again find the mixed grain larger clast deposit. As this similar layer appears consistently between the various pits and have very similar qualitative qualities as well as rock diameters, it is possible that they are all from the same event. It is possible that due to the greater distance from the river channel in this valley, there

has been a greater opportunity for sediment to collect and remain on top of this larger clast layer, explaining the greater thickness on top of it. However, as mentioned, none of these temporal estimates can be certain due to the human intervention in the area and therefore all explanations are estimates based solely on current positioning and cannot indicate exact time or reason.

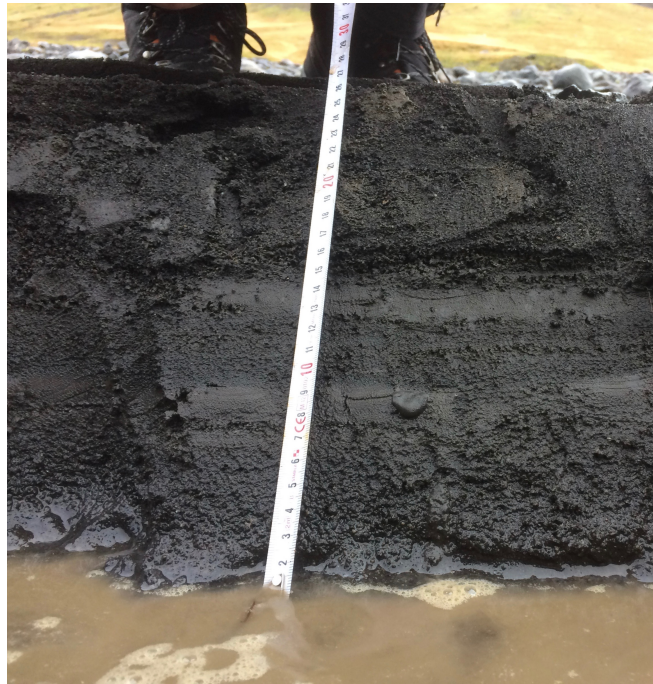


Figure 11. Fourth soil pit profile at the Seljavellir catchment valley. Tape included for scale reference.

In the fourth profile, we chose a location that was very near to the river, which resulted in a sample that reached the water table almost immediately (.27m). In this profile, layers of homogenous black sandy sediment can be seen. The proximity to the river and singular sediment type could possibly strengthen the idea that this indeed is the type of sediment transported and deposited by the river channel most commonly. Interrupting these layers are two bands of similar but slightly finer grain deposits, which could have a similar origin but perhaps during a time when flow discharge velocity was different in the fluvial source and therefore transported slightly different sediment sizes. The sediment layers are tightly packed and are evenly and horizontally distributed around the entire pit. The sedimentary origin of this black sandy sediment is igneous, but I hypothesize that the way it was deposited is fluvial due to its location and abundance in the drainage valley and fine gritty grain.



Figure 12. Final soil pit profile at the Seljavellir catchment valley. Tape included for scale reference.

In this last profile (.7m deep), there is the familiar black sandy sediment for the first .13m down, but right after that there is a loose and poorly sorted mix of sediments that goes to the base. This mix has much larger rocks varying all the way to a fine grain base, and is loosely packed. The color is a lighter brown, but there are a plethora of differently colored sediments mixed in. In this loose layer, there is some evidence of vegetation as well. This layer is highly diverse and unlike any of the other layers that included larger clast size rocks in our other profiles. With no direct comparison to the logs at Sólheimajökull, it is unclear what might have caused this much turbidity without manifesting in a large portion of other areas in the valley (as an event as large as a jökulhlaup might do). While it may appear to be a matrix supported type diamict in some ways, it is highly unlikely that the cause is from an outburst flood considering the geomorphology in the rest of the valley which lacks evidence. Rather it is possible that this is a result of landscape bulldozing, or some other fluvial process that is not identifiable with the information at hand.

4.3.2. Landscape chronology

There is massive uncertainty due to the human intervention influencing the sediment deposit and location in this area, but regardless a great deal of the sediment types were very similar to the kinds of sediments found in the sandur of Sólheimajökull. This is optimistic for the idea that the sediments being brought down by the water

channels and drainage paths at Seljavallajökull are from similar environments and conditions as those at Sólheimajökull. That said, there is a lack of any of the depositions that would indicate jökulhlaups, which might indicate that this specific type of drainage catchment that is at the foot of ice caps (ones where the glacial terminus does not extend into the valley) generally tend to have less turbulent and dramatic activity due to the distance.

5. Discussion:

5.1. Sediment deposits and volcanic influence

Overall, the two sites exhibited quite different scenarios of pro-glacial landscapes. While both extend from systems that are volcanic, the volcanic activity at Katla seems to have had a more obvious influence on the sandur at Sólheimajökull than Eyjafjallajökull has on the Seljavellir valley extending from Seljavallajökull. This is evidenced by the logged jökulhlaups that have occurred there, and while the majority of major jökulhlaups occurred before Katla's crater center migrated in the 20th century, the 1999 jökulhlaup suggests that volcanic activity still has a heavy impact on this landscape. It changed the courses and directions of pro-glacial rivers, created a huge boulder fan of large sized rocks, and caused massive flooding in the landscape with a heavy discharge. The landscapes in front of glaciers and fluvio-glacial systems are always changing, as seen by the myriad other types of sediment output exhibited in the landscape, and the retreat alone of a glacier can have a heavy influence in dragging glacial till. In the Seljavellir valley, however, the landscape studied for sediment output was not so much a plain as a valley where the sediments would drain from Seljavallajökull and the Eyjafjallajökull ice cap. This resulted in a lot of the sediments found at the site to seem quite similar in composition (as both would be originated in similar environments), as well as sharing some similarity in the more regular fluvial deposits found at Sólheimajökull. However, it was clear that the impact of Seljavallajökull's retreat and runoff could not be as strongly correlated with the sediments deposited due to fewer fluvio-glacial records and human intervention. The valley had two other feeder rivers into the main one that cut through the center, and given the overall fine sediment grain in comparison, fluvial events at the Seljavellir valley appear to have a lower discharge rate than those at the Sólheimajökull sandur. This is possibly because of the distance between the glacier terminus and the valley, the intervening topography between the two, or perhaps that the Seljavellir valley may not be one of the main drainage sites for the runoff and water output from the Eyjafjallajökull ice cap. The underlying volcano at Eyjafjallajökull is quite active, and last erupted in 2010, indeed causing two jökulhlaups to occur. However, according to maps created by the IMO, the path of these floods did not pass through this valley, but rather a neighboring outlet (See Appendix Figure G for map) (Sigurðsson, O., 2011).

In comparing volcanic unrest and threat between the two locations, it is important to note the history and location of the two studied areas. The valley chosen for Seljavallajökull, near the farm, "is interpreted to be the oldest part of the Eyjafjallajökull volcano, with a suggested age of more than 0.78 Myr", and in the area around Seljavellir includes "the most pronounced expression of geothermal activity at Eyjafjallajökull" which "is confined to its south flank" (Sturkell, E., et al., 2010). Despite

this activity in the area of the valley, the sediment drainage does not always direct into the specific chosen valley in front of Seljavallajökull (see Appendix G for path of recent jökulhlaups). This would explain that while there is recent volcanic activity and jökulhlaups, there isn't as clear evidence of major flooding as there is at Sólheimajökull. Keeping in mind the human intervention in the area, there is considerable doubt about the origin and mechanism by which the larger clast rocks found in the profiles were deposited. However, when one analyzes the structure of the Katla caldera, "the caldera rim is breached in three places, to the south-east, north-west and south-west. These gaps in the caldera rim provide outflow paths for ice in the caldera to feed the main outflow glaciers, Kötlujökull, Entujökull and Sólheimajökull" (Sturkell, E., et al., 2010), which indicates as does the flow path in 1999, that this sandur would be a predictable path for floods to take from Mýrdalsjökull. Not only this, but the magnitude of geothermal and volcanic activity at Katla has the potential to be a lot greater than that at Eyjafjallajökull (The Economist, 2010).

In terms of non-jökulhlaup related sediments and volcanic events, both glaciers are indeed retreating, which means that there will be a longer period of ablation than accumulation every year, so monitoring the sediment output of these glacial systems could still be an interesting endeavor even aside from larger flow events.

5.2. Climate change, sediments, and volcanic activity

As mentioned earlier, the retreat and melting of glaciers and ice caps can cause a greater risk for volcanic eruption due to the heightened production of magma and release of pressure on the craters. Both Katla and Eyjafjallajökull are active volcanoes with a very recent history of activity. As the climate changes and global warming progresses, both craters could experience a release of pressure and an increase in magma volume in their respective underlying chambers. This could lead to an increase in geothermal activity, resulting in more frequent jökulhlaups or smaller floods and therefore more frequent bouts of high sudden sediment discharge events. Jökulhlaups and lahars (massive debris flows) are potential risks in such a future. Based on the volcanic and sedimentary history and landscape chronologies of the two studied outwash zones, however, it appears that the Sólheimajökull sandur is at greater risk for massive landscape change and significant sediment displacement than the valley by the farm at Seljavellir, despite both locations being near particularly active geothermal zones. It was not possible to accurately or sufficiently describe potential origins for larger clast diamicts in the Seljavellir valley both due to human machine intervention with uncertain boundaries (although we tried to sample randomly within areas that were far away from the farm) as well as the distance from the Seljavallajökull glacier and the multiple feeder rivers into the valley. However, recent flooding activity appears to be directed mainly into neighboring valleys rather than the one studied. This implies that while major sediment moving events may become more frequent as the climate warms, this valley in particular may not be at as high of a risk as others in the area (which is good news for the farm). Even so, this is speculative and given all the uncertainties in volcanic activity, may not remain the case. Still, the sediment profile pits we were able to analyze showed a valley with relatively lower discharge rates and periods of stagnation. This leaves the pro-glacial landscape at Sólheimajökull to seem to be at a greater risk as the climate warms for more drastic change. Not only is it one of the main drainage

routes of Mýrdalsjökull's outbursts due to the structure of Katla's caldera, but Katla has more potential for larger scale volcanic activity as well as a greater accumulation and weight of ice overlaying the caldera. In cataloging and monitoring the recent changes as well as patterns of these two areas, we can more fully understand what kind of changes might occur in the future to the landscape.

As Sólheimajökull and Seljavallajökull continue to retreat and their ice caps lose mass, and as overall melt increases yearly, more fine sediment will drain out with runoff and the risk of larger fluvial events will increase. Monitoring these fluxes will provide more information about the land system and glacier dynamics with the environment as a whole as ice cover changes in Iceland. While soil profiles alone cannot tell us much about the climate at any given time, in context with climate data, fluvio-glacial event history, retreat data, and volcanic activity, they provide some evidence and concrete documentation of the affects of the glaciers on their landscape.

5.3. *Conclusions*

Glaciers in Iceland are rapidly retreating, and as this process continues, the effect of ice loss is multifaceted and has an impact on on albedo, volcanic activity, river discharge velocity, lahar or jökulgaup risk, flooding, till movement, river redirection and more. According to a paper at the ACIA International Symposium on Climate Change in the Arctic, "changes in glacier runoff are one of the most important consequences of future climate changes in Iceland, Greenland and some glaciated watersheds in Scandinavia... Rapid retreat of glaciers also has other implications, for example changes in fluvial erosion from currently glaciated areas, changes in the courses of glacier rivers, which may affect roads and other communication lines, and changes that affect travelers in highland areas and the tourist industry. In addition, glacier changes are of international interest due to the contribution of glaciers and small ice caps to rising sea level" (Jóhannesson, T., et al., 2004). Climate change is such a vast and powerful phenomenon that in order to be able to respond and prepare for future changes, we must try to gather as much information and familiarity with the contributing and affected earth systems as possible. Since humans play such a large role in driving global warming, it is our responsibility to act. One of the things Icelanders must prepare for is the inevitable amount of change that will occur in their area as a result. If ocean circulation and Iceland's jet streams are affected and local ocean temperatures change, it changes the ecology and conditions of the surrounding ocean. As glacial retreat contributes to global sea level rise and Iceland loses some of its reflective albedo on land and though loss of sea ice, local systems and processes in this country will play key roles in global climate systems. While this project serves as a starting point for base knowledge and understanding of how glacier retreat plays a role in all of this as well as its geomorphological impact on a smaller local scale, it hopefully contributes to the body of scientific knowledge we have and can use to be better informed actors in response to climate change. The two chosen sites differ from each other both in types of fluvio-glacial processes apparent in the landscape, scale of volcanic potential, and size, but both are relatively near civilization, are part of active climate responsive systems, and are retreating similarly to one another. However, in understanding the recent chronology of local events as well as the extent of their role in larger climate responsive systems,

Iceland can begin to use geoscientific studies from these regions to inform their policy decisions, take action, and move forward toward a more globally responsive relationship with the earth and our impact on it.

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Contacts/Advisors:

Advisor

Oddur Sigurðsson

oddur@vedur.is

Glaciological research (jarðfræðingur geologist)

Veðurstofu Íslands

Bústaðavegi 9

108 Reykjavík

sími:522 6116

farsími:863 9979

Icelandic Meteorological Office

Bústaðavegi 9

IS-108 Reykjavík

telephone:+354-522 6116

cell phone:+354-863 9979

Other Contacts

Ragnar Heiðar Þrastarson

rhth@vedur.is

Land information systems program director and analyst with avalanches hazard.

Veðurstofu Íslands

Bústaðavegi 9

108 Reykjavík

Icelandic Meteorological Office

Bústaðavegi 9

IS-108 Reykjavík

7. Appendix:

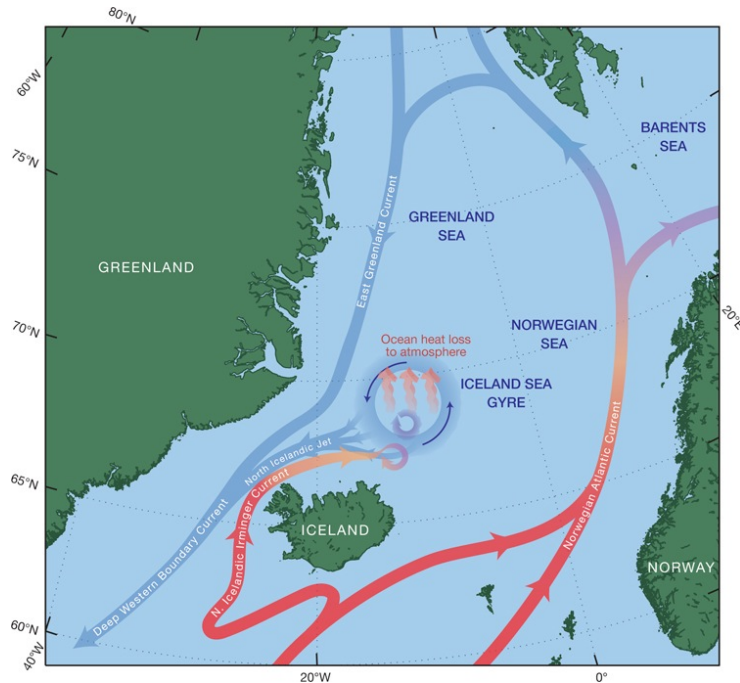


Figure A. Icelandic ocean currents, demonstrating its global influence in the cooling and circulation of warm water entering the arctic. Graphic adapted from Lippsett, L., 2016.

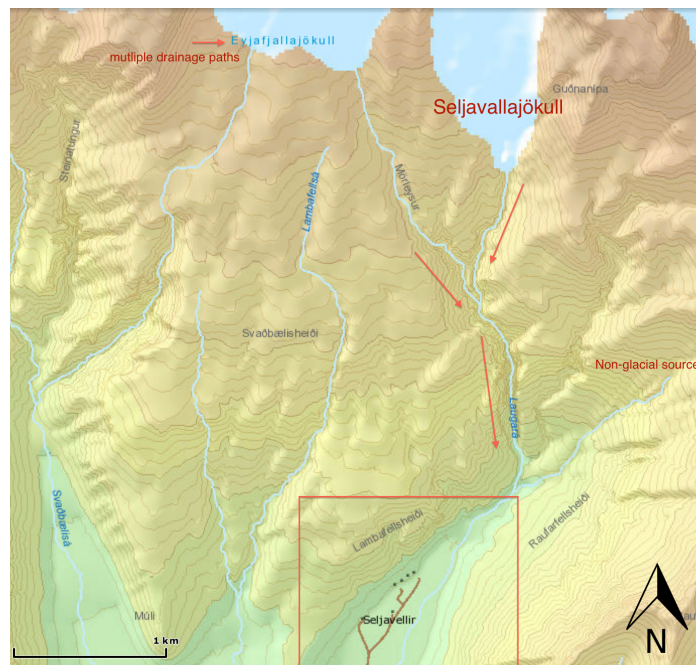


Figure B. Drainage and site map of Seljavallajökull and the Seljavellir outwash plain. Map created by Bertie Miller, edited and made using imagery from the National Land Survey of Iceland's web map navigator.

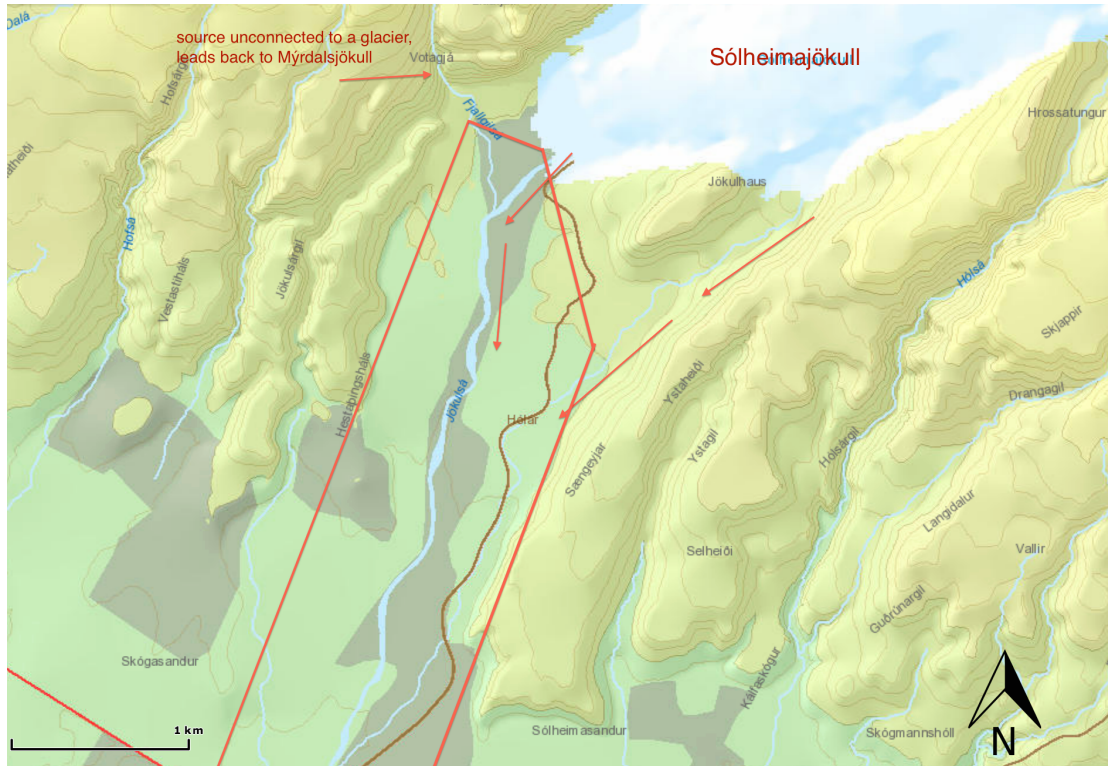


Figure C. Drainage and site map of Sólheimajökull and the Sólheimajökull outwash plain. Map created by Bertie Miller, edited and made using imagery from the National Land Survey of Iceland's web map navigator.

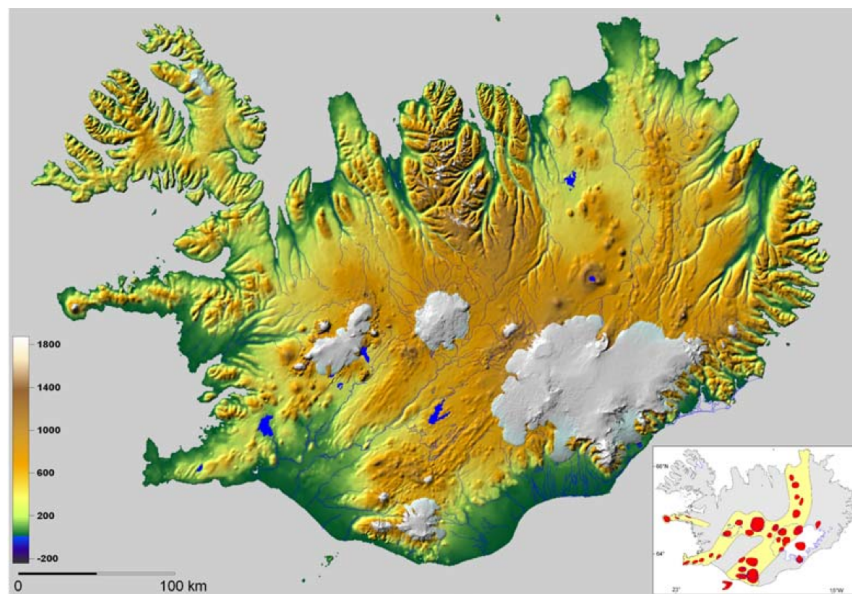


Figure D. Topography of Iceland, with glacier distribution. The main icecaps are bordered by smaller glaciers. The inserted geological map shows the active volcanic zone and the central volcanoes. – Íslandskort sem sýnir legu helstu jökla. (Björnsson, H. et al., 2008)

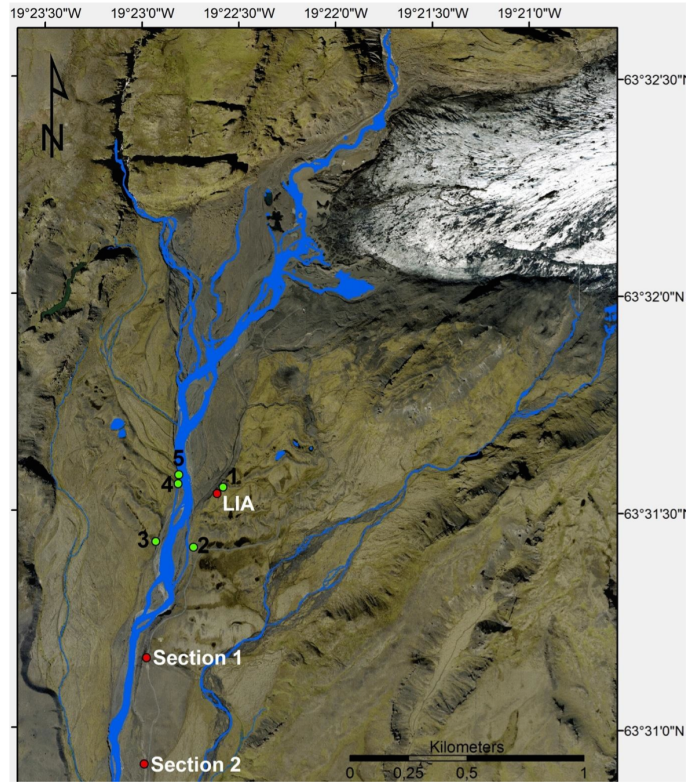


Figure E. Map of the proglacial zone of Sólheimajökull. Green dots indicate where soil profile logs are taken. Adapted from Friis, B. 2011.



Figure F. Map of the proglacial valley in front of Seljavallajökull and the Seljavellir outwash zone, with marked spots for waypoint locations of soil profiles. Created using Garmin Dakota 10 GPS technology as well as Google Earth. Sites 4/5 should be a single point rather than two.

Jökulhlaup 14.-15. apríl 2010 vegna eldsumbrota undir Eyjafjallajökli

Glacial bursts triggered on April 14-15 2010 by central eruption of Eyjafjallajökull volcano

- Flood area
- Asphalt road
- Gravel road
- Building
- River body (linear), ditch
- River body (areal), lake

Projection: Lambert Conformal Conic
 Datum: WGS 1984
 Roads, buildings, and water bodies are from LM18SSGV.
 DTM is from ISOR.
 Flood mapping: EPI/BBB
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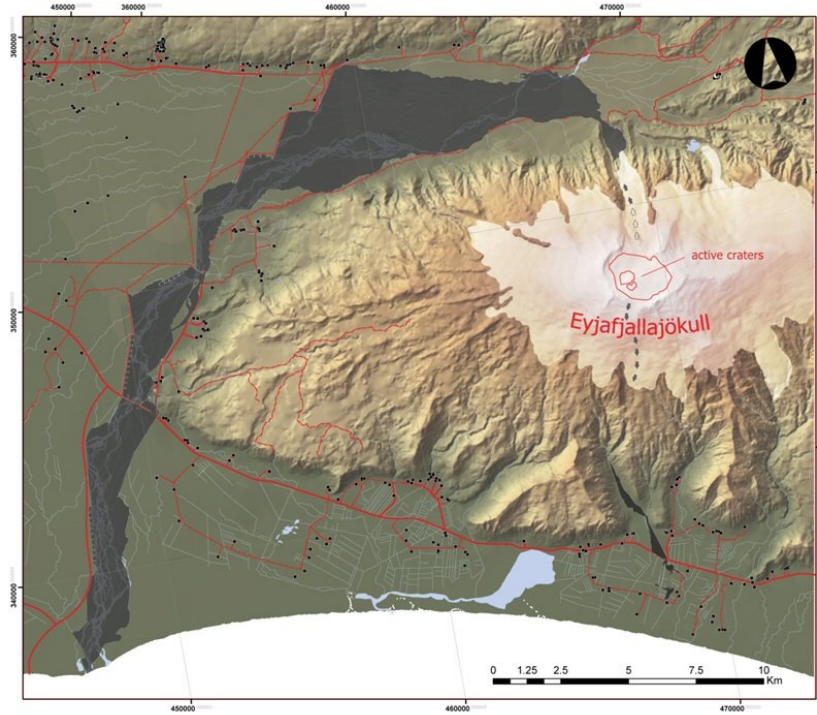


Figure G. IMO map tracking the path of the 2010 jökulhlaups caused by the eruption of Eyjafjallajökull in April, 2010. (Sigurðsson, O., 2011)