Vorráðstefna Jarðfræðafélags Íslands

Ágrip erinda

Haldin í Netheimum,
12. mars 2021

Vorráðstefna
Jarðfræðafélags Íslands

Ágrip erinda

Umsjón

Þorsteinn Sæmundsson, Halldór Geirsson, Ásta Rut Hjartardóttir,
Ingvar A. Sigurðsson, Bjarni Gautason, Lúðvík E. Gústafsson,
Michelle Parks

Dagskrá Vorráðstefnu JFÍ, 12. mars 2021

08:30 Rafræn slóð á fundinn opnar
Fyrirlesarar eru hvattir til að prófa hljóð og deila skjá

Fundarstjóri Þorsteinn Sæmundsson

09:00 – 09:15 Magmatic and tectonic unrest at Reykjanes Peninsula
Halldór Geirsson

09:15 – 09:30 Þyngdarmælingar og landris við Svartsengi
Ólafur Flóvenz

09:30 – 09:45 Bookshelf faulting and conjugate strike-slip faults in the Reykjanes Peninsula oblique rift, Iceland.
Páll Einarsson

09:45 – 10:00 Rift propagation north of Iceland: A case of asymmetric plume dynamics?
Anett Blischke

10:00 – 10:15 Benchmarking the treatment of the atmospheric hydrological cycle in climate models using water vapor isotopes
Árný Erla Sveinbjörnsdóttir

10:15 – 10:30 Ten years of induced earthquakes in the Húsmúli CO2 injection site, Hellisheiði, Iceland
Vala Hjörleifsdóttir

10:30 – 10:45 Magmatic brine assimilation: a new process accompanying rhyolite genesis
Eemu Ranta

10:45 – 11:00 Supercritical and volcanic gases in hydrothermal systems
Andri Stefánsson

11:00 – 13:15 Hlé – Matur – Fyrirlestur á vegum Háskóla Íslands (12:30 – 12:45)
Christopher Hamilton (LPL, University of Arizona, USA; IES, University of Iceland)
Title: Holuhraun as an analog for volcanic terrains on Mars
Slóð:
https://eur02.safelinks.protection.outlook.com/?url=https%3A%2F%2Feu01web.zoom.us%2Fj%2F61411240557&data=04%7C01%7Csteinis%40hi.is%7Caf75391ab7d84a516af908d8e2eb88cc%7C09fa5f0e211846568529677ed8fdbe78%7C0%7C0%7C637508848543656763%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C1000&sdata=X6WCottxc0mLkjS7TaNToaO7C6uPJnSAMDuwiLIld%2BE%3D&reserved=0

Fundarstjóri	**Lúðvík E. Gústafsson**
13:15 – 13:30	Stable isotope constraints on the origin of sulfate in the oceanic crust *Barbara Kleine*
13:30 – 13:45	Including Topography and a 3D-Elastic Structure into a Finite Element Deformation Model of Grímsvötn, Iceland *Sonja Greiner*
13:45 – 14:00	Can recent change of deformation at Krafla caldera, North-Iceland, be attributed to hydrothermal processes? *Chiara Lanzi*
14:00 – 14:15	Morphometry of glaciovolcanic edifices from Iceland: Types and evolution *Gro B.M. Pedersen*
14:15 – 14:30	Ground deformation after a caldera collapse: Contributions of magma inflow and viscoelastic response to the 2015-2018 deformation field around Bárðarbunga, Iceland *Sigi Li*
14:30 – 14:45	Uppspretta jarðskjálftasuðs á Íslandi *Sigríður Kristjánsdóttir*
14:45 – 15:00	The effect of wind on volcanic ash columns and impact on monitoring strategies with wind-affected plume models – demonstrated for Eyjafjallajökull 2010 *Tobias Dürig*
15:00 – 15:15	**Kaffi**
Fundarstjóri	**Halldór Geirsson**
15:15 – 15:30	Environmental conditions of early hominins in NE Asia 1.6 Ma years ago *Elísabet Ásta Eyþórsdóttir*
15:30 – 15:45	Humans in the arid part of central Jordan supported by wetland conditions ca. 70 ka *Steffen Mischke*
15:45 – 16:00	The Nexus of Climate Change and Artificial Intelligence *Thomas Y. Chen*
16:00 – 16:15	Skeiðarárjökull *Oddur Sigurðsson*
16:15 – 16:30	Skriðhraði íslensku jöklanna mældur með Sentinel-1A/B radarmyndum *Tómas Jóhannesson*
16:30 –	**Hressing**

Efnisyfirlit

Ágrip

Supercrtical and volcanic gases in hydrothermal systems

Andri Sefánsson

Institute of Earth Sciences, University of Iceland, Sturlugata 7, 101 Reykjavík

Magma intrusions in the upper Earth's crust drive convection of hydrothermal fluids with typical temperatures of 200-350°C. Recent studies, however, suggest that such hydrothermal fluids may exhibit much higher temperatures (400-600°C) close to the magma to form supercritical fluids. Such fluids have been encountered in active hydrothermal systems worldwide and have the potentials of multiplying power production from geothermal well fields. The conventional subcritical and deeper supercritical hydrothermal fluids are dominated by water of meteoric or seawater origin whereas the gases may be sourced directly from the underlying magma, via rock leaching within the hydrothermal system and from air. Geochemical modeling reveals that supercritical fluids will be characterized by similar volatile element (C, S, B, Cl) abundances to the surrounding subcritical hydrothermal fluids whereas volcanic gas input signatures are very different and depicted by sharp increase of C, S and Cl abundances in the hydrothermal fluids. Among the elements in subcritical and supercritical fluids and volcanic gas are B and Cl. Both these elements are incompatible upon secondary processes occurring at shallow depths within the hydrothermal systems including fluid-rock interaction, have temperature dependent volatility and display variable concentrations in different fluid sources. It follows that their geochemical behavior can be used to trace gas sources and vapor formation temperatures in surface hydrothermal fluid discharges. Near constant B concentration and increased Cl concentration with increased vapor fraction in well fluids at surface imply supercritical fluid input into overlying subcritical hydrothermal fluids while increased concentrations of both B and Cl and decreasing B and Cl abundances with increasing vapor fraction indicate magma gas input and depressurization boiling at subcritical temperatures followed by liquid and vapor separation, respectively. The approach was used to trace vapor formation conditions in selected and exploited hydrothermal systems in Iceland to explore the existence of magma gas input and occurrence of supercritical fluids in active hydrothermal systems.

Benchmarking the treatment of the atmospheric hydrological cycle in climate models using water vapor isotopes

Árný Erla Sveinbjörnsdóttir[1] & Hans Christian Steen Larsen[2]

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Water, through its role of redistributing energy from the equator to the poles, has a crucial role in the stability of the climate system. The World Climate Research Program has identified our understanding of cloud formation as the major source of uncertainty in climate sensitivity. Accordingly a better understanding of simulations of the atmospheric hydrological cycle and its role in cloud formation is of utmost importance to facilitate accurate future climate simulations. The aim of studying atmospheric stable water isotopes is to understand the physical processes involved during evaporation, advection, cloud and precipitation formations, and interactions between the Marine Boundary Layer (MBL) and Free Troposphere (FT).

Water stable isotopes ($^{1}H_{2}{}^{18}O$ and $^{1}H^{2}H^{16}O$) have for several decades been a corner stone in climate research. The water vapor isotopic composition records the history of phase changes in an air parcel and mixing of different air masses with different isotopic composition. Water isotope observations therefore constitute a suitable framework to study the exchanges between the (FT) and the MBL and between the MBL and the ocean. This makes water isotopes a crucial analytical tool for understanding the physical processes linked moisture transport and cloud formation.

Our current knowledge of atmospheric processes responsible of clouds development, moistening/drying of the troposphere remains imprecise [e.g. 1, 2, 3]. Specifically, a better understanding of the mechanisms controlling the marine boundary layer humidity has been identified as an important key for reducing the spread in the climate sensitivity uncertainty [e.g. 3, 4].

We present water isotopes observations measured with cavity ring-down spectrometers from ground-based facilities in the Northern Atlantic Ocean (Bermuda and Iceland) [5] together with δD observations in the free troposphere derived from the Infrared Atmospheric Sounding Interferometer (IASI) [6]. These measurements are analyzed with the aim to improve our understanding of the controls on the isotopic composition of water vapor and with the emphasis on the interactions between the ocean fluxes and the troposphere. We use a framework, which is able to reproduce the isotopic composition of water vapor in the MBL that results of the mixing of the oceanic evaporative flux with the dry tropospheric air [7].

We found a strong relation between water isotopes in the boundary layer and the development of boundary layers across the Northern Atlantic (See for example Figure 1). Deep boundary layers are associated with enriched d-excess values highlighting the role of evaporation in the deepening of the boundary layer through shallow convection. The role of evaporation in controlling the boundary layer dynamic is also diagnosed in the isotopic composition of water vapor in the free troposphere.

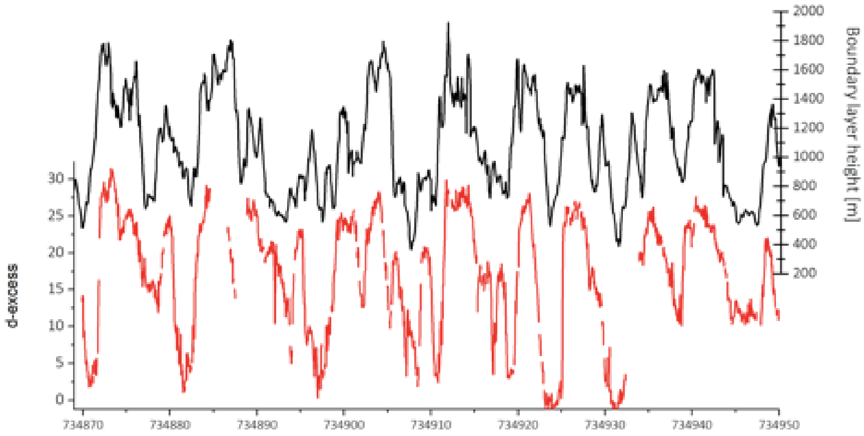

Figure 1 Relation between d-excess hourly variations at Bermuda and variations in the boundary layer heights (ERA5)

We demonstrate the role of shallow convection in the Northern Atlantic in controlling water isotopes and thus humidity. By controlling the amount of dry air involved in the mixing layer, shallow convection has two effects on the boundary layer: (1) increase the mixing contribution from the troposphere and (2) increase the evaporative signal. Our results illustrate the interest of water isotopes observations to investigate the interactions between shallow convection and evaporation.

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Rift propagation north of Iceland: A case of asymmetric plume dynamics?

Anett Blischke[1], Hans Christian Larsen[2], Sæmundur Ari Halldórsson[3], Bryndís Brandsdóttir[3], Charles E. Lesher[4], Clinton Phillips Conrad[5], Eric L. Brown[4], Helen K. Coxall[6], Joost Frieling[7], Juliane Dannberg[8], Ögmundur Erlendsson[9], Anders McCarthy[10], Bernhard Steinberger[11], Bjarni Gautason[2], Carmen Gaina[5], Colin Devey[12], David Peate[13], Garry D. Karner[14], John R. Hopper[1], Sverre Planke[5], et al.

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The nature, origin and impact on the lithosphere by mantle plumes is a key problem in Earth sciences and is central to the IODP science plan themes: Earth Connections, Deep Processes, their Impact on Earth's Surface Environment, and Climate and Ocean Change. The Iceland plume system has quite uniquely been ridge-centered since continental breakup at ~55 Ma through processes of decompression melting within a vertically large melting window and a substantial lateral offset (2000+ km) along the spreading ridges. The impact of a rising mantle plume on continental breakup was the focus of Ocean Drilling Programs ODP Legs 104, 152, and 163 that were fundamental to establish our understanding of volcanic rifted margins. Expanded sampling of igneous crust that formed during breakup will be addressed during IODP Expedition 396 to the Vøring Plateau, and IODP Expedition 395 will further the understanding on the Reykjanes Ridge mantle convection and its climate impact. Both expeditions are scheduled for the offshore drilling platform R/V JOID Resolution during the summer of 2021.

However, sampling by drilling of plume-affected crust generated after breakup has been neglected for four decades. Our IODP proposal 976, together with Expedition 395 examining the V-shaped Ridges along the Reykjanes Ridge south of Iceland targeting samples from Mid-Miocene to present will significantly improve this situation. Our proposal addresses the temporal formation of the Icelandic Plateau Rift that is the poorest understood crust within the Northeast Atlantic and has the potential to constrain fundamental processes related to plume dynamics and origin, and their impact on climate and ocean currents. Six primary drill sites are planned within the Iceland Plateau Rift, penetrating up to 500 m of igneous basement successions, and up to 3000 m of sediment successions. These sites contain paleo-environmental and geochemical records from the Early Eocene breakup of the Northeast Atlantic to the formation of the Kolbeinsey Ridge in Early Miocene. The igneous rock samples will unravel the northward propagating Iceland Plateau Rift system (IPR) which propagated northward from the Greenland-Iceland-Faroe-Ridge, separating the Jan-Mayen microcontinent from East-Greenland. The four segments of the IPR formed by oblique spreading and overlapped with the northward retreating Aegir Ridge. IODP proposal 976 will test conflicting models on the evolution of the Northeast Atlantic mantle, by addressing melting processes and mantle flow at shallower depths, isotopic zonation, possible continental lithospheric contaminants during rift propagation, as well as tectono-magmatic history of the Iceland Plateau Rift by geodynamic modelling with age constrained rock samples. Sediment samples will provide data for modelling the sub-Arctic Oligocene record of the transition into the ice-house world within an important conduit for Atlantic-Arctic oceanic exchange, and the Plio-Pleistocene evolution in sea-surface temperature and ice-cover in a region prone to record these, and a locus of deep-water formation representing the Northern edge of the Atlantic Meridional Overturning Circulation (AMOC).

The Nexus of Climate Change and Artificial Intelligence

Thomas Y. Chen

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As climate change progresses, the world is feeling the devastating effects. From increased frequencies and intensities of natural disasters, such as wildfires and extreme storms, to rising sea levels triggering mass global migrations, the impacts of the earth's warming must be adapted to. Artificial intelligence (AI) and machine learning (ML) are key assets in this fight and can be used in a wide variety of ways in this space. For instance, computer vision for damage assessment after natural disasters (e.g. from satellite imagery) can aid in the allocation of resources and personnel for relief. In this talk, we discuss recent developments at the very interesting nexus between climate change and artificial intelligence and propose future areas of work.

The effect of wind on volcanic ash columns and impact on monitoring strategies with wind-affected plume models – demonstrated for Eyjafjallajökull 2010

Tobias Dürig & Magnús T. Guðmundsson

Institute of Earth Sciences, University of Iceland

When monitoring volcanic ash plumes during explosive eruptions, plume models are applied to constrain the source conditions, in particular the mass eruption rate. To date, modelling volcanic ash plumes in windy conditions is, however, still a major challenge. Wind-affected plume models account for the atmospheric conditions including windspeeds, but require the input of adjusted plume heights, which are not necessarily identical to the plume‘s top elevation detected by the monitoring instruments, e.g., by radar. We discuss two strategies to convert the plume‘s top elevation data into adjusted plume heights, that lead to a significant improvement of the prediction quality of wind-affected plume models. Both strategies were applied to the different phases of the 2010 Eyjafjallajökull eruption, and tested with plume photos and fallout mass.

Environmental conditions of early hominins in NE Asia 1.6 Ma years ago

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[3]Lanzhou University

The Nihewan Basin in China is an intermountain basin located about 140 km north-west of Beijing. It sits in a transitional zone between the North China Plain and the Inner Mongolian Plateau and is a part of the Fen Wei graben system, a NE-SW trending rift system.

The basin is well-known for the Pleistocene mammalian fauna and the lithic relics. Thick sequences of fluviolacustrine and aeolian sediments are exposed at the basin margins. The fossil and artefact sites where first reported in the 1920s and since then, there have been continuous excavation projects in the basin. The sediment layers in the Nihewan Basin have preserved one of the best successions of Palaeolithic archaeological and palaeontological sites in Asia. Oldest stone tools from these excavations have been dated to ~1.66 Ma in the early Pleistocene. Thus, the Nihewan Basin provides an unsurpassed opportunity to gather knowledge and to better understand the environmental background of early hominins and their dispersal in East Asia.

In June 2019, sediment samples were collected from a site called T3 in the Nihewan Basin to examine the environmental characteristics of the Dachangliang archaeological site during the early Pleistocene. Grain-size analysis, measurements of magnetic susceptibility and the identification of calcareous microfossils are used to reconstruct the environmental conditions of early hominins in the area. Was the depositional setting at the section location very variable over time or possibly rather stable? Was freshwater continuously available at or near the section site? The ongoing work addresses these questions in the frame of a MS thesis project.

Including Topography and a 3D-Elastic Structure into a Finite Element Deformation Model of Grímsvötn, Iceland

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Deformation models are an important tool for studying active volcanoes. In order to produce meaningful results, a model needs to incorporate the features of an individual volcanic system, which dominate its deformation. However, in many cases simplifying assumptions are made for the sake of reducing computational cost and time. Assumptions like that of a magma chamber embedded into a homogeneous elastic halfspace neglect topography and possibly complex subsurface structures, but are often necessary, especially for analytical models. This can lead to biased results and potentially unrealistic estimates of model parameters, e.g. the depth or pressure change of the deformation source. The use of numerical models allows for the consideration of irregular features and external datasets when building deformation models.

A Finite Element deformation model was developed for the Icelandic volcano Grímsvötn, which includes real topography and a 3D-elastic structure using a digital elevation model and results from gravity surveys and seismic tomography. For the developed elastic structure, the dynamic elastic moduli, which were derived from seismic velocity- and density-structures, were converted into static elastic moduli, which are relevant for deformation, by assuming a pressure-dependent relation. There is only one continuous GPS-station, GFUM, located on the edge of the Grímsvötn caldera and, so far, the influence of its proximity to a steep 300 m high cliff on deformation has not been studied. Based on GPS-observations at GFUM from Grímsvötn‘s last eruption in 2011, estimates of the depth and pressure change at a shallow magma chamber were found testing different geometries. The influence of the topography alone on the deformation is limited but the elastic structure changed the model parameters significantly. Combining both aspects enhanced the influence of the topography and shifted the source depth to 2-4 km below the caldera, requiring a pressure change of ca. 5-50 MPa for most geometries.

Magmatic and tectonic unrest at Reykjanes Peninsula

Halldór Geirsson et al.

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The Reykjanes Peninsula hosts a part of the Eurasia- North America plate boundary, and also about 4-5 volcanic systems. In 2020, signs of magmatic inflation were observed in Svartsengi, Reykjanes, and Krýsuvík. In 2021, dike propagation and intense seismicity has been ongoing at Fagradalsfjall. In total, the sequence of events may be interpreted as a magma surge under the entire western part of the peninsula. Here, the course of events so far will be covered, from the standpoint of crustal deformation and seismicity.

Stable isotope constraints on the origin of sulfate in the oceanic crust

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At mid-ocean ridges (MORs), seawater carrying dissolved sulfate (SO_4) infiltrates the oceanic crust. However, hydrothermal fluid emissions from such systems predominantly contain H_2S. The absence of SO_4 may be explained by the reduction of seawater SO_4 to H_2S and/ or by the immediate precipitation of anhydrite upon temperature increase. These contrasting hypotheses highlight the need to explore sulfur cycling in the oceanic crust. Here, we utilized the chemical and stable isotope ($\delta^{34}S$, $\delta^{18}O$) systematics in natural anhydrite and pyrite from various locations along the submarine and on-land section of the Mid-Atlantic ridge to quantify the key variables that control anhydrite formation and sulfate recycling in the oceanic crust. Comparison of the natural dataset with results from geochemical isotope modelling revealed that $\delta^{34}S$ and $\delta^{18}O$ values of anhydrite and pyrite were dependent on the isotope composition of the source fluid, extent of water-rock interaction, temperature, and redox conditions. Quantitative formation of anhydrite mainly occurred at temperatures <150°C, whereas at elevated temperatures (>200°C) reduction of seawater-sulfate to H_2S and subsequent pyrite precipitation were found to limit anhydrite formation. Extending our calculations to the oceanic crust revealed that the majority of seawater-sulfate is sequestered into anhydrite in vicinity of MORs at <200°C, with only a small portion discharged by high-temperature hydrothermal vents resulting in similar modal abundance and $\delta^{34}S$ values of anhydrite as a function of depth and degree of rock alteration within the oceanic crust. However, sequestration of sulfur by anhydrite is not long-lasting due to retrograde dissolution of anhydrite.

Can recent change of deformation at Krafla caldera, North-Iceland, be attributed to hydrothermal processes?

Chiara Lanzi[1], Vincent Drouin[2], Freysteinn Sigmundsson[1], Halldor Geirsson[1], Gylfi Pall Hersir[2] & Sigrun Hreinsdottir[3]

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In summer 2018, the Krafla volcanic system shows signs of inflation within the caldera with a rate of 10-14 mm/yr. We evaluate if inflation can possibly relate to about 0.1 MPa/yr pressure increase in the geothermal system, as measurements in monitoring well KG-10 may indicate. We apply the Finite Element Method to consider how deviations from a uniform elastic half-space may affect deformation in the area. We test the influence on the displacement, due to the presence of a local area which envelops the source, with different elastic features. The model enables to reproduce significant features of the observed deformation if the geothermal system is approximate as a sphere with 1.4 km radius undergoing pressure increase of 0.1 MPa/yr. The crust within the Krafla caldera has a local Young's modulus value of *E*~5.50 GPa, and the far-field domain, *E*~30 GPa, in agreement with the average value for Icelandic crust.

Ground deformation after a caldera collapse: Contributions of magma inflow and viscoelastic response to the 2015 - 2018 deformation field around Bárðarbunga, Iceland

Siqi Li[1], Freysteinn Sigmundsson[1], Vincent Drouin[2], Michelle M. Parks[3], Benedikt G. Ófeigsson[3], Kristín Jónsdóttir[3], Ronni Grapenthin[4], Halldór Geirsson[1], Andrew Hooper[5], & Sigrún Hreinsdóttir[6]

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[6]GNS Science, New Zealand

Ground deformation due to viscoelastic relaxation following eruptions is important, as the generated signals can resemble renewed magma inflow. We study post-eruptive unrest at the Bárðarbunga volcano after a caldera collapse and major magma drainage in 2014-2015. Global Navigation Satellite System and Sentinel-1 Interferometric Synthetic Aperture Radar geodesy are applied to evaluate post-eruptive ground deformation from 2015-2018. We explore two end-member models and their combination: 1) viscoelastic relaxation caused by the co-eruptive events, and 2) renewed magma inflow. Our viscoelastic relaxation model, consisting of an elastic layer on top of a viscoelastic layer with a viscosity of 3.0×10^{18} Pa s reproduces broadly the observations. A model of magma inflow into a 10-km deep sill combined with slip on the caldera ring fault also explains the observations well. Our results suggest that the co-eruptive deformation field is likely influenced by viscoelastic relaxation, renewed magma inflow, or a combination of both processes.

Humans in the arid part of central Jordan supported by wetland conditions ca. 70 ka

Steffen Mischke[1], Zhongping Lai[2], Galina Faershtein[3], Naomi Porat[3], Matthias Röhl[4], Paul Braun[5], Johannes Kalbe[6] & Hanan Ginat[7]

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Current conditions in the southern Levant are hyperarid and local communities rely on fossil subsurface water resources. However, the Levantine Corridor provided a pathway for the migration of humans out of Africa and their spread in the Near East and beyond in the Pleistocene, but times of more favourable wetter periods and also their spatial characteristics are not well constrained yet. To improve our understanding of past climate and environmental conditions in the deserts of the Near East, two nearby sedimentary sections including artefact-bearing beds from the Central Jordanian Plateau were investigated using sedimentological and micropalaeontological analysis and OSL dating. Grain-size analysis and structures of the clayey-silty sediments show that they represent reworked loess. Recorded fossils are mostly ostracod valves of the genera Potamocypris, Ilyocypris and Pseudocandona. Additional remains are shells of aquatic and terrestrial gastropods, and charophyte gyrogonites and stem encrustations. OSL dating of the sedimentary sequence suggests that the deposits formed between Marine Isotope Stage (MIS) 5b and the early MIS 2 (ca. 90-25 ka). The organism remains and dating results of an artefact-rich bed suggest that an in-stream wetland existed at the location of Jurf ed Darawish in MIS 5b-4 (ca. 90-60 ka) and supported human activities in a region which is hyperarid and a barren desert today. Consequently, climate conditions must have been significantly wetter in this early part of the Late Pleistocene.

Skeiðarárjökull

Oddur Sigurðsson

Veðurstofa Íslands

Skeiðarárjökull hefur stundum verið kallaður mesti daljökull Evrópu með réttu eða röngu. Fáir jöklar í veröldinni hafa lent í annarri eins áraun og Skeiðarárjökull einkum af eldgosum og margvíslegum jökulhlaupum. Ekki fer á milli mála að hann er mikilfenglegur í sjón og raun.

Skeiðarárjökull er samsettur úr fjórum álmum sem eru aðskildar með þrem miðröndum. Eru það í reynd fjórir allmismunandi jöklar með sitt eðlið hver. Vestasta álman rennur undan austurhlíðum Þórðarhyrnu og endar (endaði) í Grænalóni. Sú næsta kemur frá suðurhlíðum Grímsfjalls. Langstærsta jökulálman hefur ákomusvæði sitt austur af Grímsvötnum og nær það að ísaskilum á Kverkfjallahrygg. Þetta er einn hraðskreiðasti jökull landsins. Austasta álman sópar að sér snjó og ís sem fellur norðan Skaftafellsfjalla. Tvær miðálmurnar eru framhlaups-jöklar en útálmurnar sennilega ekki.

Í miðálmum Skeiðarárjökuls eru áberandi svartir flekkir, sennilega öskulag frá Grímsvatna-gosinu 1873. Samsvarandi flekkir sjást ekki í útálmunum og þarf sérstakrar skýringar við.

Lengst af undanfarnar aldir hafa tvö meginvötn runnið frá jöklinum: Skeiðará austast og Súla vestast. Á undanförnum áratugum hefur sú breyting orðið á að allt leysingarvatn sem frá jöklinum kemur er nú í einum farvegi, Gígjukvísl.

Þyngdarmælingar og landris við Svartsengi

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Landrisið sem hófst á jarðhitasvæðinu við Svartsengi 22. janúar 2020 markaði upphaf mikilla jarðhræringa á Reykjanesskaga sem enn standa yfir. Um viku síðar hófu sérfræðingar ÍSOR þyngdarmælingar á svæðinu í þeirri von að endurteknar mælingar gæfu upplýsingar um eðlismassa þess efnis sem líklega ylli þrýstiaukningunni og er undirrót landrissins. Mælt var í föstum mælipunktum sem flestir eru meðfram hitaveitulögninni frá Svartsengi til Keflavíkur og eftir veginum frá Svartengi að Eldvörpum. Þannig fengust mælingar í nokkrum punktum nánast yfir miðju landrissins og þaðan út frá því þangað sem ætla mátti að áhrifa landrissins gætti lítt eða ekkert. Mælingarnar voru síðan endurteknar þrisvar sinnum, fyrst í apríl 2020, þá í byrjun október 2020 og loks um mánaðamót janúar og febrúar 2021.

Úrvinnsla mælinganna og samanburður við önnur gögn stendur enn yfir. Bráðabirgða-niðurstöður eftir að leiðrétt hefur verið fyrir hæðarmismun milli mæliferða vegna landriss eða sigs („free-air“ leiðrétting) sýna að þyngdarbreytingar eru nálægt áætluðum skekkjumörkum en gefa þó kerfisbundnar niðurstöður sem falla vel að því svæði sem landhæðarbreytingarnar ná yfir og eru því trúverðugar. Þannig mældist um 12 μgal þyngdaraukning yfir miðju landrissins á fyrsta mælingartímabilinu frá lokum janúar til miðs apríl 2020. Eftir það mælist ámóta þyngdarlækkun fram í janúar 2021 sem þýðir að þyngdaraukningin hefur að mestu gengið til baka. Þar kunna þó bakgrunnsbreytingar vegna breytinga í vinnslu í Svartsengi að hafa einhver áhrif en upplýsingar um þær eru höfundum ekki aðgengilegar.

Sameiginlega virðast þyngdarbreytingar og landhæðarbreytingar við Svartsengi benda til þess að einhver massi hafi komist inn í rætur jarðhitakerfisins við upphaf landrissins en afar erfitt er að sjá að þarna hafi verulegt magn kviku getað troðist inn á um 4 km dýpi og horfið svo í kjölfarið. Líklegast er að landrisið stafi að verulegu leyti af vökva- eða gastengdum ferlum þar sem vatn fer í gegnum fasaskipti eða að innstreymi af koltvísýringi úr möttli valdi þrýstiaukningunni. Síðan taka við sveimferli („diffusion“) þar sem gasið eða vatnið síast í burtu með tilheyrandi landsigi og þyngdarlækkun. Ef um er að ræða fasaskipti á vatni er þó ekki útilokað að smávægileg innspýting af kviku hafi komið þeim af stað.

Vísindahópur frá ÍSOR og þýsku jarðfræðirannsóknastofnuninni GFZ-Potsdam vinnur nú að líkangerð af þessum fyrirbærum. Jafnframt er unnið að úrvinnslu á nákvæmum jarðskjálfta-mælingum á ristímabilinu. Þeirra var m.a. var aflað með tækni sem gerði kleift að nota ljósleiðara fjarskiptafyrirtækisins Mílu, sem liggur um Svartsengi, sem háupplausnar skjálftamæla með með fárra metra millibili. Niðurstöður þeirrar vinnu munu væntanlega liggja fyrir með vorinu.

Bookshelf faulting and conjugate strike-slip faults in the Reykjanes Peninsula oblique rift, Iceland

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Oblique and immature plate boundaries are frequently characterized by complicated fault patterns. The structure of the plate boundaries in Iceland is relatively complex. Two of the plate boundary segments are highly oblique to the over-all plate velocity vector between the North America and Eurasia Plates, i.e. the Reykjanes Peninsula and the Grímsey oblique rifts. They contain both volcanic systems and seismogenic strike-slip faults. Oblique spreading leads to extensive volcanism and large earthquakes, a combination that is otherwise uncommon in Iceland. The fissure swarms of individual volcanic systems contain normal faults and fissures, arranged en echelon along the plate boundary. The fissure swarms fade out as they extend into the plates on either side. These volcano-tectonic structures on the Reykjanes Peninsula are overprinted by sets of parallel, N-S striking transcurrent faults that generate the largest earthquakes in the zones, up to M 6.5. Their surface expressions are en echelon fracture arrays and push-up structures. The distance between them varies from 0.3 to 5 km. They occupy the area between the overlapping fissure swarms, and together they form a bookshelf-type fault system taking up the shear component of plate movements across the oblique rift zones.

Both volcanic and seismic activity on the peninsula plate boundary is episodic. The duration of the seismic cycle appears to be of the order of a few decades. The volcanic cycle, on the other hand, is on a time scale of thousand years, the last one ending in 1240 AD. The seismic episode that began in December 2019 is characterized by a series of earthquake swarms along different sections of the plate boundary, west of Lake Kleifarvatn and extending offshore to the Reykjanes Ridge. The maximum magnitude reached so far is 5.7. All teleseismically obtained fault plane solutions are consistent with right-lateral strike-slip faulting on N-S faults. In addition to these bookshelf-type faults, several areas have been identified where earthquakes appear to line up along ENE-WSW-striking, fault-like structures. These structures have so far not been seen at the surface despite thorough search, with one possible exception. Taken together, the N-S and the ENE-WSW faults form a conjugate set of faults. The implied tectonic stress field has a horizontal maximum principal stress with a N45°E orientation, and a minimum principal stress with a N135°E orientation, perpendicular to the fissure swarms on the peninsula.

Similar set of conjugate faults has been seen in the earthquake distribution in the Herðubreið-Herðubreiðartögl area in the Northern Volcanic Zone. There neither set of faults is found at the surface.

It is postulated that bookshelf faulting is one of the characteristics of unstable or immature plate boundaries.

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Morphometry of glaciovolcanic edifices from Iceland: Types and evolution

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The morphology of glaciovolcanoes is considered one of the distinctive characteristics of their ice-confining eruption environment. However, a thorough morphometric analysis of a large number of glaciovolcanic edifices has never been performed. Based on semi-automatic geomorphometric mapping, we present a morphometric database of 155 glaciovolcanic edifices within the Icelandic neovolcanic zones, formed during the last 0.78 Ma (Fig. 1).

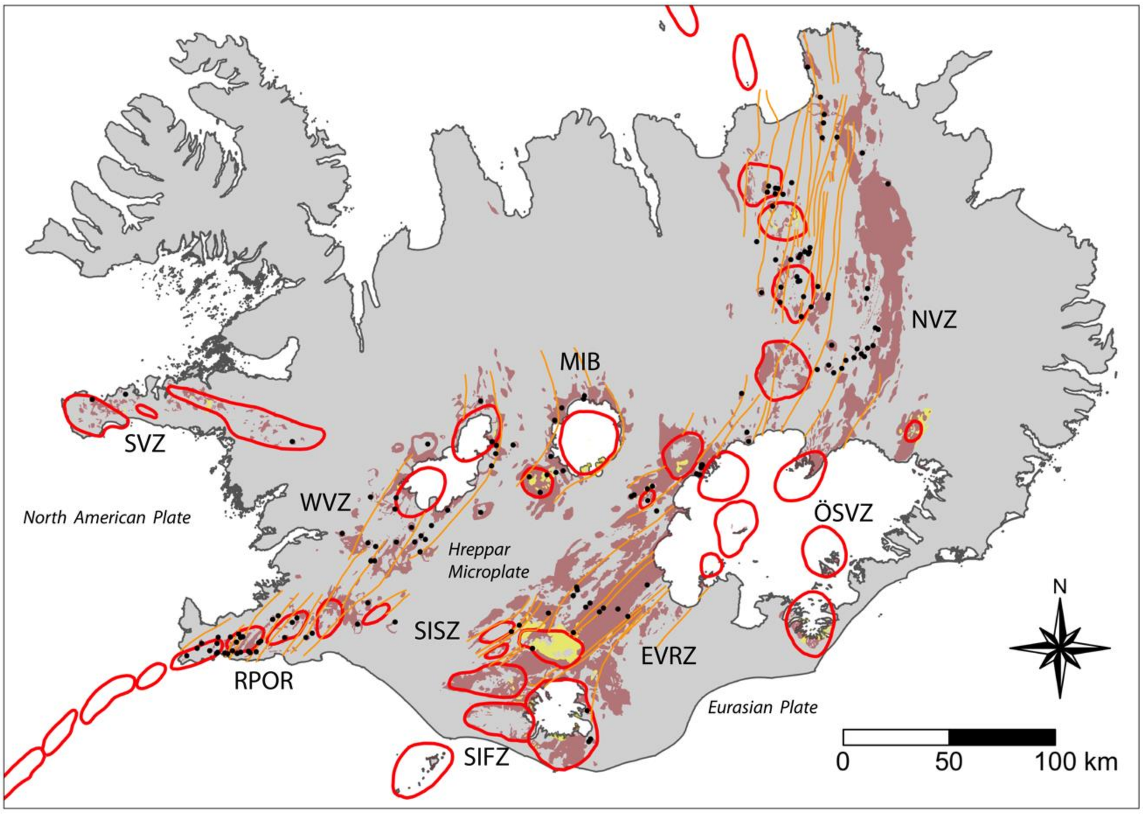

Figure 21. Location of Icelandic glaciovolcanic edifices (black dots) analyzed geomorphometrically. Volcanic systems (fissure swarms in orange, central volcanoes in red) are outlined according to Einarsson and Sæmundsson (1987). The background shows the outline of Iceland in gray and the outline of largest glaciers in white and was provided by the National Land Survey of Iceland. The Móberg Formation is outlined in brown and acid extrusives are in yellow after Jóhanneson and Sæmundsson (1998). The neovolcanic zones are: the Reykjanes Peninsula Oblique Rift (RPOR), the Western Volcanic Zone (WVZ), the Mid-Icelandic Belt (MIB), the South Iceland Seismic Zone (SISZ), the South Iceland Volcanic Flank Zone (SIFZ), the Eastern Volcanic Rift Zone (EVRZ), the Northern Volcanic Zone (NVZ), the Öræfi Snæfell Volcanic Zone (ÖSVZ) and the Snæfellsnes Volcanic Zone (SVZ).

This database enables a comprehensive analysis of the morphometric diversity of a large suite of glaciovolcanic edifices. Sheet-like formations, however, are not considered due to lack of data. Using three planimetric measurements (basal length (L_b), average basal width (W_b) and average summit plateau width(W_p)) and their ratios, three main morphometric groups can be distinguished in a ternary diagram (Fig. 2): 1) conical edifices with no or small summit plateaus, 2) linear ridges and 3) flat-topped edifices (subdivided into equidimensional and elongated). All three groups contain edifices with and without lava caps (Fig. 2).

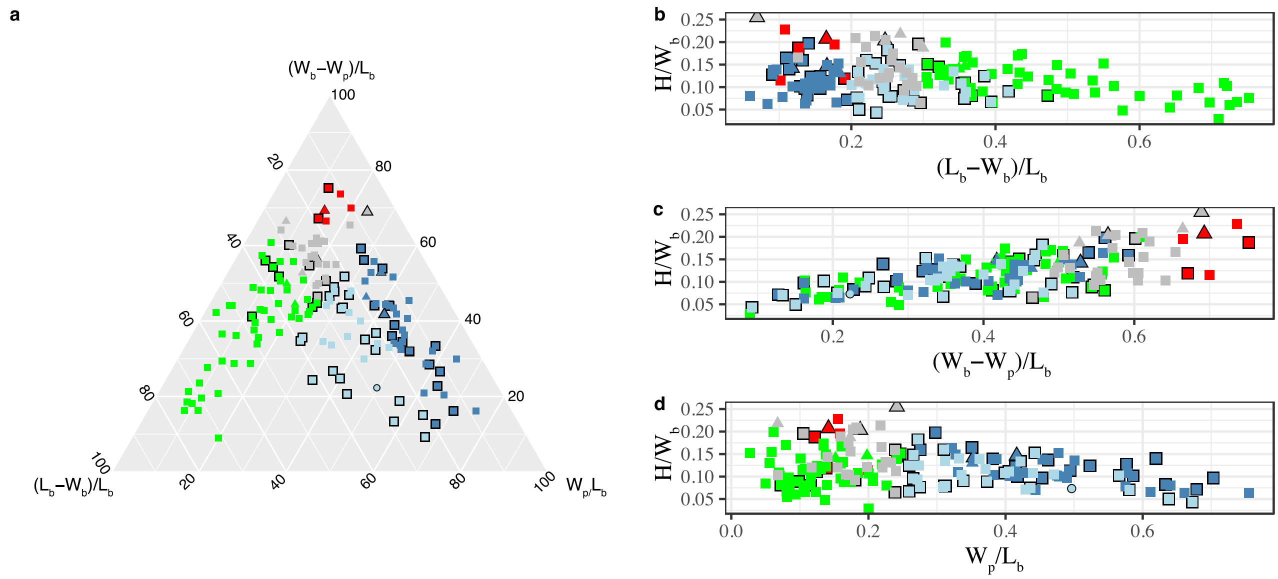

Figure 32. a) Distribution of glaciovolcanic edifices in a ternary diagram considering elongation, flank width and summit plateau ratios. Conical edifices are red, elongated ridges are green, equidimensional flat-topped edifices are blue and elongated flat-topped edifices are light blue. Transitional edifices are gray. Edifices with a lava cap have a black outline. Basaltic edifices are squared and rhyolitic edifices are shown as triangles. b) Height / Basal width (H/W_b) as a function of elongation ratio. c) H/W_b as a function of flank width ratio. d) H/W_b as a function of summit plateau ratio.

These morphometric groups can be fitted to the commonly accepted terminology for cone/mound, tindar and tuya. However, since lava caps occur in all morphometric groups, a grouping based on its existence is not practical. This suggests that by adding the descriptor "lava capped" to any of the three classes may be a useful way to refine the classification. Based on the ternary diagram, ridges are the most morphometrically distinct glaciovolcanic edifice, because of their extreme elongation, followed by flat-topped edifices and finally conical edifices. However, morphometric parameters cannot be used singlehanded to identify glaciovolcanic edifices from other types of volcanic edifices such as composite volcanoes, shields or submarine volcanoes, and should always be complemented with other observations. The glaciovolcanic edifice volumes range from 0.15 · 10−2 km^3 to 32 km^3. Conical edifices are the smallest (< 0.1 km^3) and the group of flat-topped edifices has the largest volumes (> 1 km^3). Overall, with growth three morphological evolutions can be considered: (A) an initial eruptive fissure concentrates into one vent generating an equidimensional edifice, that either can be a conical or a flat-topped edifice; (B) the edifice maintains its elongation, suggesting that a fissure is the dominating vent structure, and during continued eruption develops significant summit plateaus, generating elongated flat-topped edifices; and (C) the edifice increases in elongation because the fissure lengthens during the eruption, and a plateau-building stage does not occur, producing increasingly elongated ridges.

Magmatic brine assimilation: a new process accompanying rhyolite genesis

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Chlorine-rich magmatic fluids are closely linked to the late-stage evolution of silicic intrusions and play a major part during the formation of magmatic-hydrothermal ore deposits. However, how these saline fluids, or brines, interact with melts and affect active volcanic processes is poorly understood. Chlorine isotope ratios in volcanic rocks could potentially keep a record of pre-eruptive melt-fluid interaction, but published $\delta^{37}Cl$ data for silicic rocks is limited.

To bridge this knowledge gap, we present new $\delta^{37}Cl$ and $\delta^{18}O$ data in a sample set (n = 16) that, together with previously published data [1], includes silicic rocks and corresponding intermediate rocks and basalts from 8 volcanic systems in Iceland. The samples cover the alkaline, intermediate and tholeiitic series from rift, propagating rift and off-rift settings. The silicic samples (SiO_2 = 65-77 wt.%) have highly variable Cl contents (280-3990 ppm) and $\delta^{18}O$ values (–0.5 to +6.1 ‰) that are within published values for Icelandic rhyolites. The $\delta^{37}Cl$ values of silicic rocks are negative (–1.9 to –0.6 ‰) except for one positive outlier (+0.9 ‰).

An unexpected result of our study is that the $\delta^{37}Cl$ values of silicic rocks are systematically shifted towards more negative values by up to -2.9 ‰ compared to basalts from corresponding magma suites. These large $\delta^{37}Cl$ shifts are not correlated with eruption type (effusive vs. explosive) and cannot be explained by the usual suspects, i.e., mineral-melt fractionation, degassing or crustal assimilation. Instead, we attribute the observed negative $\delta^{37}Cl$ shifts to assimilation of up to 0.5 wt.% of low-$\delta^{37}Cl$ magmatic brines that have been formed by previous generations of intrusions in long-lived magmatic mushes. This model is compatible with estimated magmatic brine production rates and may explain observations of positive $\delta^{11}B$ signatures in Icelandic rhyolites, negative $\delta^{37}Cl$ values in fluid inclusions from porphyry-copper deposits and negative $\delta^{37}Cl$ in hydrothermal systems associated with volcanic activity at arc volcanoes.

We propose that magmatic brine assimilation is a fundamental, but previously unrecognized process during rhyolite genesis, and should be added to the emerging picture of the silicic magma mush.

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Uppspretta jarðskjálftasuðs á Íslandi

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Í verkefninu IS-NOISE (Rannís) eru suð notað til þess að skoða hraðabreytingar í skorpunni og er uppsprettu suðsins að finna í öldugangi sjávarins. Suð mælt á jarðskjálftamælum á Íslandi sýnir sterk merki um árstíðarbundnar breytingar og er tíðni þess yfirleitt lægra á veturna en á sumrin. Suðið er einnig sterkara (með hærra útslag) á veturna. Gögn frá sjávarduflum sýna að breytingar á tíðni á öldugangi úti fyrir ströndum Íslands helst í hendur við tíðnina í mældu suði á jarðskjálftamælum. Við viljum kanna hvort breyting í uppsprettu suðsins geti komið fram sem hraðabreyting. Til þess að skoða þetta höfum við reiknað aflróf fyrir annars vegar skjálftastöðvar á Hengilssvæðinu 2011-2012 og hins vegar fyrir SIL stöðvar á Reykjanesi á árunum 2015-2020. Til viðbótar við merki frá öldugangi sjávar sjást ýmis önnur merki, bæði náttúruleg og mannleg.

Skriðhraði íslensku jöklanna mældur með Sentinel-1A/B radarmyndum

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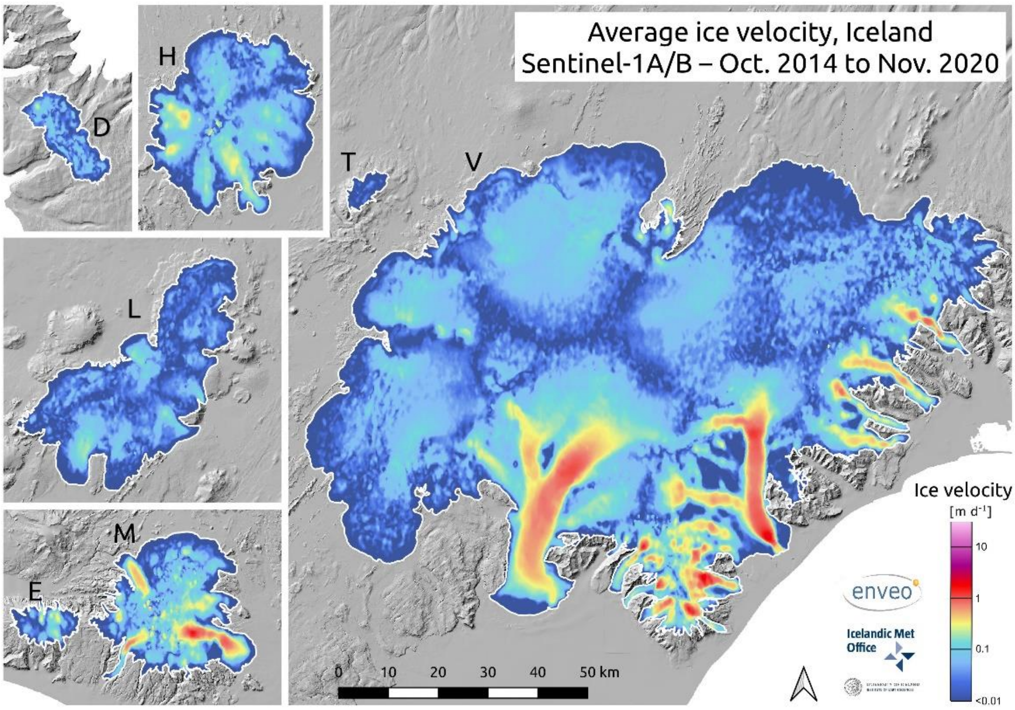
Radarmyndir úr gervihnöttum sýna breytilegt endurkast frá yfirborði jarðar sem endurspeglar óreglur í ýmsum eiginleikum efstu jarðlaga. Þar sem hreyfing er á lausum jarðlögum eða jöklum er unnt er að meta hraða hreyfingarinnar með því greina hliðrun í endurkastsmunstri milli radarmynda frá mismunandi tímum og nefnist aðferðin „speckle-tracking“ á ensku. Nú er unnt að mæla yfirborðshraða ísskriðs á reglulegu neti yfir heilu jöklana með nokkurra daga eða vikna millibili og fylgjast með breytingum ísskriðsins í tíma og rúmi. Íslensku jöklarnir bjóða upp á einstætt tækifæri til þess að beita þessari nýju tækni. Margvísleg gögn eru tiltæk úr fyrri rannsóknum, auðvelt aðgengi er að jöklunum til mælinga, og jökulhlaup og framhlaup, sem reglulega verða í jöklunum, bjóða upp á fjölmörg áhugaverð rannsóknarviðfangsefni. Evrópsku Copernicus Sentinel-1A and Sentinel-1B gervitunglin hafa tekið radarmyndir af Íslandi á 6 eða 12 daga fresti síðan haustið 2014. Hliðrunargreiningu hefur verið beitt til þess að greina skriðhraða jökla hér á landi í íslensk-austurríski rannsóknarverkefni sem stutt er af Rannís. Hliðstæð greining hefur verið unnin fyrir ísbreiður Grænlands og Suðurskautslandsins og ýmsa aðra jökla jarðar á síðustu árum. Meðfylgjandi mynd sýnir meðalskriðhraða íslensku jöklanna samkvæmt frumniðurstöðum þessara rannsókna. Sjá má að hraði íssins er langmestur um miðbik og neðarlega í skriðjöklum sem spanna mikið hæðarbil á landsvæðum þar sem mikil úrkoma fellur. Þar getur hraðinn verið 400–800 metrar á ári þar sem hann er mestur í Skeiðarárjökli, Breiðamerkurjökli og Kötlujökli. Hraðinn er einnig tiltölulega mikill í skrið-jöklum Öræfajökuls og í skriðjöklum í suðaustanverðum Vatnajökli, mun meiri en í stóru skrið-jöklunum í norðanverðum Vatnajökli. Einnig má sjá að jökulísinn skriður mjög hægt í grennd við ísaskil og víðast nærri jöðrum jöklanna. Hliðrunargreiningin er gefur oft ekki fullnægjandi niðurstöður fyrir blautan vetrarsnjó að vor- og sumarlagi eða fyrir jökulís á sprungulitlum leysingarsvæðum að sumri. Greiningin gengur hins vegar oftast vel fyrir kaldan vetrarsnjó og fyrir leysingarsvæði þar sem nokkuð er um sprungur.



Mynd 1: Meðalskriðhraði íslenskra jökla á tímabilinu október 2014 til nóvember 2020 á grundvelli hliðrunargreiningar á radarmyndum Copernicus Sentinel-1A/B gervitunglanna. Jökuljaðrar um árið 2000 eru sýndir með hvítri línu.

Ten years of induced earthquakes in the Húsmúli CO2 injection site, Hellisheiði, Iceland

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The Hellisheiði Power Plant, situated on the south-west side of the Hengill volcanic complex is at a triple junction between 1) Reykjanes Ridge, an obliquely diverging plate boundary that reaches land in the Reykjanes Peninsula 2) the South Iceland Seismic Zone – a transform boundary and 3) the Western Volcanic Rift Zone – a diverging plate boundary.

Reinjection of geothermal brine and condensate into the geothermal reservoir is part of the normal operation of the Hellisheidi power plant, since it was commissioned in 2006. ON has therefore injected fluids on a very large scale for over 15 years now in several injection fields. In most of the fields, there is very little or no induced seismicity. However, when the Húsmúli reinjection area was commissioned in 2011, with injection of over 500 l/s, immediately high levels of induced seismicity were observed, with the largest event reaching magnitude M 4.0.

The injection into Húsmúli was subsequently reduced and is now 200-300 l/s, distributed into five different injection wells. With this level of injection, the seismicity rate has been much lower, with only two larger events occurring, one in 2016, with magnitude M 3.9, and the other in late 2020, with magnitude M 3.7. Currently, both the size of the largest induced events and the seismicity rate are smaller than those of natural seismicity in the neighbouring region.

Here we discuss the seismicity in Húsmúli, focusing on how it relates to the reinjection of geothermal fluids in general, and we look for changes in activity when the co-injection of CO_2 with the geothermal fluid started.