Haustráðstefna
Jarðfræðafélags Íslands

Ágrip erinda

Haldin í Netheimum,

19. nóvember 2021

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Autumn conference of The Geoscience Society of Iceland

Abstracts

Held online,

November 19, 2021

Umsjón/Organisation:

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

Dagskrá Haustráðstefnu JFÍ, 19. nóvember 2021

Program of JFÍ fall meeting, November 19, 2021

11:45	Ráðstefnan opnar / Meeting link opens	
12:25	Þorsteinn Sæmundsson	Setning / Opening address

Fundarstjóri/session chair: Þorsteinn Sæmundsson

12:30-12:45	*Anett Blischke*	Jarðhitakerfið við Ytri-Vík: Strúktúrjarðfræðikönnun
12:45-13:00	*Vala Hjörleifsdóttir*	Hengill – the most extensively monitored seismic region in Iceland
13:00-13:15	*Knútur Árnason*	The deep crustal conductor under Iceland: Almost a half century old unresolved enigma confusing geosciences !!
13:15-13:30	*Gunnar Gunnarsson*	Að stækka jarðhitaauðlindina niður á við: Staða djúpborunarverkefnisins og framtíðarsýn
13:30-13:45	*Andri Stefánsson*	Fingerprinting superhot geothermal resources using boron and chlorine systematics
13:45-14:00	*Barbara I. Kleine*	Tracing the fate of seawater-sulfate in the oceanic crust using stable isotopes
14:00-14:15	*KAFFI / COFFEE BREAK*	

Fundarstjóri/session chair: Sigríður Kristjánsdóttir

14:15-14:30	*Greta H. Wells*	Holocene jökulhlaups along the Hvítá River, Iceland: geomorphology, hydrology, and implications for Icelandic Ice Sheet reconstruction
14:30-14:45	*Angel Ruiz-Angulo*	Impact of Ocean Warming and Natural Variability on the Stratification and Mixed Layer Depth around Iceland
14:45-15:00	*Stefan T.M. Peters*	Evaporite-derived oxygen in iron oxide-apatite deposits
15:00-15:15	*Chica Mendoza Joseline Jamileth*	Emplacement temperatures of the ~ 3580 BC Chachimbiro pyroclastic blast deposits (Ecuador) through paleomagnetism
15:15-15:30	*Michael R. Hudak*	Conduit formation and crustal microxenolith entrainment in a monogenetic basaltic eruption: Observations from the 3.5 ka eruption of Þríhnúkagígur Volcano, Iceland
15:30-15:45	*Samuel Scott*	Shallow magma degassing drives short-period lava fountaining at Fagradalsfjall, Iceland

15:45-16:00	*KAFFI / COFFEE BREAK*	

Fundarstjóri/session chair: Nína Aradóttir

16:00-16:15	*Edward W. Marshall*	Rapid geochemical evolution of the mantle-sourced Fagradalsfjall eruption
16:15-16:30	*Gro B. M. Pedersen*	Volume, Discharge Rate and lava transport at the Fagradalsfjall eruption 2021: Results from near real-time photogrammetric monitoring
16:30-16:45	*Oliver D. Lamb*	Turbulence and bubbles: acoustic observations of fire fountains during the 2021 Fagradalsfjall eruption, Iceland
16:45-17:00	*Ásta Rut Hjartardóttir*	Recent activity of the Tungnafellsjökull fissure swarm and its link with the Bárðarbunga volcanic system
17:00-17:15	*Michelle Parks*	Recent deformation observations and geodetic modelling at Askja volcano
17:15-17:30	*Eyjólfur Magnússon*	Grímsvötn halda í sér í tilefni 25 ára afmælis Gjálpargossins
17:30-19:00	Spjall og sprútt í rafheimum	Discussions and drinks in virtual breakout rooms

Efnisyfirlit

Ágrip

Abstracts

Fingerprinting superhot geothermal resources using boron and chlorine systematics

Andri Stefánsson

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Superhot geothermal fluids with temperatures of~400-600°C have been encountered in many active geothermal systems worldwide. Although utilization of such fluids may potentially multiply power production, the presence and location of superhot reservoirs is unclear at present. Many geothermal well fluid discharges display excess enthalpy behavior, i.e. too high vapor to liquid ratio relative to liquid reservoirs and adiabatic boiling to surface. The cause of such excess enthalpy behavior may be depressurization boiling and phase separation or alternatively boiling of subcritical geothermal fluids by conductive heat transfer from a magmatic body possibly producing superhot geothermal fluids in the vicinity of the intrusion. Here, boron and chlorine is used to assess the vapor formation temperatures and weather excess fluid enthalpies in conventional geothermal wells is caused by subcritical boiling or deep superhot fluid input from below into the utilized geothermal reservoir. Boron and chlorine are non-reactive elements in geothermal fluids. At low temperatures (<300-350°C) both elements are non-volatile but become increasingly volatile at higher temperatures (>400°C). It follows that vapor formation temperatures may be estimated using B and Cl systematics. Elevated B/Cl ratios relative to the subcritical geothermal reservoir fluids at near constant B concentration with increasing enthalpy are indicative of superhot reservoirs whereas high enthalpy fluid discharges with low B concentrations and B/Cl ratios indicate depressurization boiling at temperatures below 300°C followed by liquid and vapor separation. The newly developed approach has been applied to fingerprint possible superhot geothermal fluids within the Hellisheiði, Nesjavellir and Krafla geothermal systems. The results indicate widespread occurs of superhot fluids at depth at Krafla, as well in some parts of the Nesjavellir geothermal system, a potential location of future IDDP-3 drilling activities.

Impact of Ocean Warming and Natural Variability on the Stratification and Mixed Layer Depth around Iceland

Angel Ruiz-Angulo[1], M. Dolores Pérez-Hernández[2], Esther Portela[5,6], Solveig R. Ólafsdóttir[3], Andreas Macrander[3], Thomas Meunier[4], Steingrímur Jónsson[7]

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The ocean around Iceland witnesses some of the most important transformations of water masses that drive the Global Ocean Circulation. The variability of these water masses and their transformations contribute to the global meridional circulation, MOC, which is extremely important for the global climate variability. Over the past 50 years, the Arctic climate has changed significantly, involving the ocean, land, atmosphere and cryosphere. These changes have given birth to the Arctic amplification, which is a complex feedback phenomenon resulting from excessive atmospheric heating and simultaneous ocean freshening. The consequences of these changes are already affecting ecosystems and human activities. Those changes in temperature and salinity modify the stratification of the upper ocean, which partially controls the Mixed Layer Depth (MLD). The physical processes taking place within this layer influence biogeochemical processes like phytoplankton blooms and carbon or oxygen sequestration. From the latest IPCC report, it has been observed with high confidence that the depth of this layer is changing. Here, we analyze about 30 years of continuous four-yearly (from 1990 to present) sections around Iceland carried out by the Icelandic Marine and Freshwater Institute and other databases including Argo float data (from 2002 onwards) and glider sections. The present study provides an unprecedented description of the seasonal to decadal variability of stratification and MLD, and their link with the changing North Atlantic under Global Warming.

Jarðhitakerfið við Ytri-Vík: Strúktúrjarðfræðikönnun

Anett Blischke[1], Arnar Már Vilhjálmsson[1], Sigurveig Árnadóttir[1], Unnur Þorsteinsdóttir[1], Albert Þorbergsson[2,3] og Bjarni Gautason[1]

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Markmið þessa verkefnis var að tengja strúktúrjarðfræðigreiningar á yfirborði við jarðeðlisfræðileg gögn frá Ytri-Vík í þeim tilgangi að varpa ljósi á samhengið milli jarðhitakerfisins og berggangasyrpunnar sem liggur þar meðfram ströndinni. Nýrra fjarkönnunargagna var aflað með dróna áður en farið var á staðinn til kortlagningar. Unnið var í mörkinni á fimm rannsóknastöðvum og voru mælingar á berggangaflötum (e. dyke planes), sprungubeltum (e. fracture zones), misgengjum (e. faults), bergsprungum (e. fractures), bergbrestum (e. joints), steindaæðum (e. mineral veins) og skriðrákaförum teknar saman í þeim tilgangi að lýsa heildarmynd svæðisins. Niðurstöðum þessarar vinnu var svo lýst í tengslum við jarðhita- og grunnvatnskerfi svæðisins. Berggangakerfi stefna N-S og NNA-SSV og tengjast aðalmisgengjakerfi með NNA-SSV strikstefnu sem hallar til vesturs. Misgengja- og berggangakerfið við Ytri-Vík nær hugsanlega lengra í átt að NA-hlíðum Kötlufjalls. Þau strúktúrjarðfræðilegu gögn sem safnað var í verkefninu koma vel heim og saman við þekkt gögn um jarðfræði og skjálftavirkni, og einkum segulmælingar sem gerðar hafa verið í nágrenninu. Þær sýna einnig tvær megingangastefnur; N-S og NNA-SSV. Jarðhitakerfið við Ytri-Vík situr í berggangasyrpu sem kemur fram í segulgögnum sem há frávik. Kerfið virðist hins vegar ekki tengjast gangaþyrpingu sem kemur fram sem lág segulfrávik. Stefnur misgengja og bergganga sem valda hæstu segulfrávikunum virðast vera örlítið frábrugðnar stefnum utan segulfrávikanna. Því er þeirri tilgátu varpað fram að um tvískipt gangakerfi sé að ræða, sem myndað er á mismunandi tímum. Með þessari rannsókn hefur verið sýnt fram á hvernig sameina má segulmælingar, drónagögn í háupplausn og nákvæma strúktúrjarðfræðilega rannsókn í þeim tilgangi að auka skilning á sprungukerfum jarðhitasvæða. Jafnframt er bent á að aldursgreiningar og upplýsingar um bergfræðilega samsetningu bergganga væru gagnleg viðbót við rannsóknina sem myndi stuðla að auknum skilningi á jarðhitakerfunum við Eyjafjörð og á tertíersvæðum á Íslandi almennt.

Recent activity of the Tungnafellsjökull fissure swarm and its link with the Bárðarbunga volcanic system

Ásta Rut Hjartardóttir and Páll Einarsson

Institute of Earth Sciences, University of Iceland

The Tungnafellsjökull volcanic system is located in central Iceland, at the triple junction between the Eastern Volcanic Zone, the Northern Volcanic Zone, and the Central Iceland Volcanic Zone. It is about 40 km long and up to 10 km wide, and includes two calderas, one beneath the Tungnafellsjökull glacier and the other one in the Vonarskarð valley, and two fissure swarms extending to the north and south of the Tungnafellsjökull central volcano. The surface formations within the fissure swarms are mainly loose sediments and two postglacial lava flows. The fissure swarms consist of normal faults and a few open fractures. The normal faults and fractures in the N fissure swarm have more variable trends than is often seen along other fissure swarms. The most common trend is towards the north-northeast, but east-northeasterly trends can also be seen, including the Dvergar eruptive fissure. The faults in the southern fissure swarmhave a very strong WSW trend. While many of the normal faults do not show any evidence of recent movements, some of them do, especially along some faults in the northern fissure swarm. There, sink holes can be found in the sediment along the faults, some new and others slightly older. The formation and erosion of these sink holes has been observed during repeated field trips in the years from 2009 to 2021. Other sink holes have also been mapped from aerial photographs. This work has revealed that the sink holes are consistently found along some faults but not others, and are for example especially common along the boundary faults of one of the grabens in the northern fissure swarm. Erosion rate of the sinkholes is quite variable, depending on topography and surface conditions. Sinkholes have been observed that formed and were almost obliterated by erosion within our observation period. Many older holes were rejuvenated during the last years. The recent activity of the Tungnafellsjökull volcanic system is correlated in time with the unrest of the Bárðarbunga volcanic system. InSAR images spanning the 1996 Bárðarbunga unrest showed deformation along the graben with the numerous sink holes. In addition, seismicity increased significantly in the Tungnafellsjökull volcanic system during the 1996 and 2014 unrest in Bárðarbunga, which was linked with the Gjálp and Holuhraun eruptions, respectively.

Tracing the fate of seawater-sulfate in the oceanic crust using stable isotopes

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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.

Emplacement temperatures of the ~ 3580 BC Chachimbiro pyroclastic blast deposits (Ecuador) through paleo-magnetism

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Paleomagnetic methods can be used to determine the emplacement temperature of pyroclastic deposits. This can be done by looking at the unblocking temperature spectra of the thermoremanent magnetization (TRM). Chachimbiro volcanic complex is an andesitic-dacitic stratovolcano located at the northern zone of the Ecuadorian volcanic arc. The lateral blast eruption that occurred at 3640-3510 BC originated from a ~650 m wide and ~225 m high rhyodacite dome. This satellite lava dome, located ~6 km to the east of the main vent, erupted, resulting in a large pyroclastic density current (PDC). PDCs are hot mixtures of lithic fragments, gas and pumice, varying in size from fine ash up to metric blocks that descend the flanks of a volcano at great speeds, being the primary cause of death during explosive eruptions. The resulting PDC from this violent laterally directed explosion covered an area of 62 km^2, with the thickest parts of the deposit displaying as much as 15 m. We collected >80 oriented block samples from 8 locations; their distances varying between 1.8 km to 6.7 km away from the source. Here we present the emplacement temperatures of the Chachimbiro pyroclastic deposits and the potential factors controlling them. Our rock-magnetic results indicate low titanium Ti-magnetite as the main magnetization carrier; maghemite being present in trace amounts. We have recognized that, based on the unblocking analysis of the TRM, the overall temperatures vary from 250°C to 450°C depending on the clast size and type. In general, our results suggest a minimum temperature of ~250°C, with a large portion of the juvenile clasts having temperatures up to about ~450°C. This work highlights the usefulness of paleomagnetism to evaluate the emplacement temperatures of PDCs, thereby allowing to better assess the associated risk.

Rapid geochemical evolution of the mantle-sourced Fagradalsfjall eruption

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Upwelling heterogeneous mantle beneath mid-ocean ridges and hot spots undergoes progressive decompression melting that gives rise to an enormous spectrum of instantaneous primary melt compositions. However, primary basaltic melts or even their incomplete mixtures are rarely erupted as lavas, as they are almost always homogenized prior to eruption within crustal magma reservoirs.

The recent eruption of the Fagradalsfjall complex in the Reykjanes Peninsula of Iceland represents basaltic magma directly erupted from a sub-crustal storage region (Bali et al., 2021). Over the course of the eruption, the lavas have changed significantly in composition with time. The first erupted lavas were more depleted (K_2O of 0.14 wt% and La/Sm of 2.04). Later, the lavas became increasingly enriched and were most enriched in early May (K_2O of 0.31 wt% and La/Sm of 3.05). After early May, the lava composition began to shift towards depleted compositions at a slower rate.

The compositional shift of the lava is mirrored by changes in radiogenic isotope composition. As the erupted lavas became more enriched, they became increasingly radiogenic in terms of their $^{87}Sr/^{86}Sr$ (0.703094 to 0.703168) and $^{206}Pb/^{204}Pb$ (18.730 to 18.839) ratios and increasingly unradiogenic in terms of their $^{143}Nd/^{144}Nd$ ratios (0.513010 to 0.512949). These shifts in isotopic composition are consistent with increasing proportions of enriched melt in the erupted lava over the course of the eruption.

The range of lava compositions forms an array that lies along binary mixing lines. The enriched endmember of the binary mixing line leads away from the majority of Icelandic lavas, and towards highly-enriched melt compositions. This is consistent with mixing between a larger mass of depleted melt and a smaller mass of highly enriched melt.

Melt inclusions measured in olivine and plagioclase from the first few days of the eruption show a wide range of depleted and enriched compositions that encompass the lava compositions. Some enriched melt inclusions have compositions that are consistent with the enriched compositions inferred from the binary mixing curves. Thus, the Fagradalsfjall lava represents a rare window into the timescales and processes occurring within sub-crustal melt reservoirs.

References: Bali et al. 2021, AGU FM 2021 abstract

Grímsvötn halda í sér í tilefni 25 ára afmælis Gjálpargossins

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Dagana 5. –6. þessa mánaðar voru 25 ár liðin frá því að bræðsluvatn Gjálpargossins sem safnaðist fyrir í Grímsvötnum skilaði sér niður á Skeiðarársand í mikilfenglegu jökulhlaupi. Þá brutust um 3,6 km^3 af vatni undan jöklinum en hámarksrennslið á sandinum var áætlað nærri 50.000 m^3/sek. Hlaupvatnið, um 8°C heitt, bræddi skarð í ísstíflu Grímsvatna. Af þeim sökum og vegna aukinnar jarðhitavirkni við austurenda Grímsfjalls eftir Grímsvatnagosið 1998 hefur ísstífla vatnanna verið mun veikari en áður og því hefur vatnssöfnun Grímsvatna og Grímsvatnahlaup verið með mjög ólík því sem var fyrir nóvember 1996. Ef horft er til 50 ára tímabils fyrir Gjálpargosið þá liðu oft 4–6 ár á milli hlaupa sem skiluðu yfirleitt 1–3 km^3 af vatni í Skeiðará. Sem betur fer voru þetta hægvaxandi hlaup sem tóku oftast 2-3 vikur og því var hámarksrennsli þeirra yfirleitt á bilinu 2.000–10.000 m^3/sek, það er mun minna en í nóvember 1996 þó svo stundum hafi heildarvatnsmagnið verið litlu minna. Eftir að ísstíflan laskaðist hafa jökulhlaup verið mun minni og tíðari, stundum árlega eða oftar. Stærstu hlaup þessa tímabils, haustin 2004 og 2010, voru hvort um sig um 0,6 km^3 að heildarrúmmáli en önnur hlaup þessa tímabils hafa verið talsvert minni. Hlaupin 2004 og 2010 uxu hins vegar úr óverulegu rennsli við jökulsporð í hámarksrennsli á aðeins 5 dögum og náðu því bæði um 3.000 m^3/sek hámarksrennsli sem er sambærilegt við hámarksrennsli margra hlaupa fyrir Gjálpargos. Á undanförnum árum hefur náið verið fylgst með Grímsvötnum, vatnsborð þeirra vaktað, yfirborð þeirra kortlagt reglubundið út frá fjarkönnunargögnum og GPS hæðarsniðmælingum. Auk þess hafa jökulbotn og ísþykkt í grennd við ísstíflu Grímsvatna verið betur kortlögð með íssjá. Nú ber svo við að ekki hefur komið hlaup úr Grímsvötnum í 3 ár. Frá 2018 hefur safnast í Vötnin nærri 1,0 km^3 af vatni sem er það mesta í 25 ár. Í erindinu verður farið yfir þær breytingar sem orðið hafa Grímsvötnum og ísstíflu þeirra frá Gjálpargosi og hvað gæti orsakað þessa nýju hegðun Grímsvatna sem svipar meira til þess sem var fyrir Gjálpargos. Einnig eru leiddar líkur að því að hlaup sé yfirvofandi og að hámarksrennsli þess geti farið yfir 5.000 m^3/sek.

Holocene jökulhlaups along the Hvítá River, Iceland: geomorphology, hydrology, and implications for Icelandic Ice Sheet reconstruction

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Glacial outburst floods (jökulhlaups) have significantly modified landscapes across Earth throughout the Quaternary and are a contemporary geohazard in glaciated regions worldwide. Iceland experiences more frequent jökulhlaups than nearly anywhere on Earth, though research has focused on floods triggered by subglacial volcanic eruptions. However, floods from ice-marginal lakes may be a better analogue for most global jökulhlaups. As the Icelandic Ice Sheet retreated in the early Holocene, meltwater lakes accumulated at ice margins and periodically drained in jökulhlaups. One such lake formed in the Kjölur highlands and drained along the Hvítá River in southwestern Iceland, leaving behind abundant geomorphologic evidence including 50-meter-deep canyons, bedrock channels, and boulder deposits. Yet, only one publication has investigated these floods (Tómasson, 1993).

This project uses a suite of field mapping, geochronological, paleohydraulic, and modeling techniques to better constrain flood routing, timing, and dynamics. It presents new lines of geomorphologic evidence, revises drainage route maps, provides estimates of flood magnitude, and discusses ongoing cosmogenic nuclide dating analysis to establish flood chronology. These findings situate the Hvítá jökulhlaups within the context of Icelandic deglaciation and paleoenvironmental change during the transition from glacial Pleistocene to warmer Holocene conditions. These events are also an excellent case study for jökulhlaup geomorphology in bedrock terrain, landscape impacts of extreme floods, and drainage dynamics from ice-marginal lakes, helping to close a research gap in Iceland and advance understanding of links between climate, ice response, and hydrology in other Arctic and alpine regions.

Volume, Discharge Rate and lava transport at the Fagradalsfjall eruption 2021: Results from near real-time photogrammetric monitoring

Gro B. M. Pedersen[1*], Joaquin M. C. Belart[2,3], Magnús Tumi Gudmundsson[1], Birgir Vilhelm Óskarsson[4], Nils Gies[4,5], Thórdís Högnadóttir[1], Ásta Rut Hjartardóttir[1] Virginie Pinel[6], Etienne Berthier[7], Tobias Dürig[1], Hannah Iona Reynolds[1], Christopher W. Hamilton[1,8], Guðmundur Valsson[3], Páll Einarsson[1] , Daniel Ben-Yehosua[9], Andri Gunnarsson[10], Björn Oddsson[11]

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The effusive eruption at Fagradalsfjall on the Reykjanes Peninsula, Iceland, began on March 19, 2021.To monitor key eruption parameters (i.e. effusion rate and volume), near real-time photogrammetric monitoring was performed using a combination of satellite and airborne stereo images. This monitoring started ~11 hours after the eruption began. On September 30, 2021, 32 surveys had been performed providing an unprecedented temporal data set (including volume and discharge rate estimates, orthophotos, thickness maps and thickness change maps) delivering information and maps necessary for evaluating hazards. Currently, the lava-flow field covers 4.8 km^2 and the estimated bulk (including vesicles and macroscale porosity) volume is 150 million m^3, giving an average discharge rate (from the start of the eruption) of 9.5 ± 0.2 m^3/s. In phase 1, the mean TADR was 4.9 ± 0.1 m^3/s and increased slightly to a mean of 6.3 ± 0.4 m^3/s in phase 2. The TADR increased to a mean of 11.4 ± 0.5 m^3/s in phase 3 and 11.0 ± 0.4 m^3/s in phase 4, while in phase 5 the mean TADR dropped to 5.6 ± 0.6 m^3/s.

Compared to recent Icelandic eruptions, the evolution of the discharge rate of Fagradalsfjall is very unusual, having a low, fairly stable discharge in phases 1–2 and increasing in phase 3. We consider this conduit-controlled flow a plausible model for Fagradalsfjall because it explains the sharp contrast with the behavior to other Icelandic eruptions (e.g., Hekla, Grímsvötn and Bárðarbunga) where pressure in a magma chamber is considered the main control of flow.

Að stækka jarðhitaauðlindina niður á við: Staða djúpborunarverkefnisins og framtíðarsýn

Gunnar Gunnarsson

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Rætur djúpborunarverkefnisins má rekja allt aftur til ofanverðrar síðustu aldar. Það var árið 1985 þegar hola NJ-11 á Nesjavöllum var boruð nokkuð óvænt í mjög heit jarðlög á um 2.100 m dýpi. Hitinn í neðsta kafla holunnar mældist 380°C en þess ber að geta að það voru efri mörk mælisviðs mælitækisins sem notað var. Gera má ráð fyrir að hitinn hafi í raun verið eitthvað hærri. Hola þessi var hönnuð miðað við fengna reynslu af borunum á Nesjavöllum. T.a.m. náði vinnslufóðring einungis niður á 565 m dýpi en skammt neðan fóðringarenda voru lekar æðar. Í ljós kom að mikið millistreymi var í holunni. Heitur vökvi streymdi inn í hana úr æðum á miklu dýpi og út úr henni inn í æðar skammt neðan fóðringarenda. Ekki reyndist unnt að kæfa þetta millirennsli og ómögulegt reyndist að hafa stjórn á aðstæðum með þeim búnaði sem var til staðar. Var því brugðið á það ráð að fylla með möl í neðsta hluta holunnar. Töldu menn sig með naumindum hafa borgið fjörvi sínu og hétu því að gera svona nokkuð aldrei aftur… og þó…

Þó það hafi verið óskrifuð regla lengi á eftir að ekki skyldi borað dýpra en 2000 m á Nesjavöllum gleymdist ekki svo glatt vitneskjan um heitu jarðlögin við holu NJ-11. Höfðu margir kitlandi löngun til að prófa að bora í þau aftur og vera þá viðbúnir þeim aðstæðum sem upp gætu komið. Segja má að þarna hafi kviknað hugmyndin að Íslenska Djúpborunarverkefninu (Iceland Deep Drilling Project – IDDP). Þrjú stóru orkufyrirtækin; HS-Orka (þá Hitaveita Suðurnesja), Landsvirkjun og Orkuveitusamstæðan ákváðu upp úr síðustu aldamótum að hvert fyrirtæki um sig myndi bora djúpa holu á sínu svæði. Hugmyndin var að fara ofan í ofurheitar rætur jarðhitakerfanna og vinna þaðan mjög heitan vökva – jafnvel í yfirmarksástandi.

Svo fóru leikar að fyrsta hola verkefnisins; IDDP-1, var boruð í Kröflu. Var hún óvænt boruð í kviku á um 2,1 km dýpi en áætlað dýpi hennar fyrirfram var um 4,5 km. Þrátt fyrir þessa óvæntu uppákomu söfnuðust mjög merkilegar niðurstöður úr IDDP-1. Hægt var að hleypa henni upp og blés hún við háan þrýsting og hita – hiti gufunnar var 430-450°C. Efnafræði gufunnar var nokkuð krefjandi og áraun á mannvirkið mikil. Þegar tilraunum var lokið kom í ljós að vinnslufóðringin var ónýt. Næsta hola verkefnisins IDDP-2 var boruð niður á ríflega 4,6 km á Reykjanesi. Náðust merkileg kjarnasýni úr dýpstu hlutum hennar. Hæstu gildi á hita og þrýstingi sem mældust voru 426°C og 340 bar skömmu eftir borun. Svo óheppilega vildi til að fóðringin eyðilagðist skömmu síðar og ekki hefur verið unnt að komast niður fyrir skemmdina.

Nú stendur til að bora næstu holu í Djúpborunarverkefninu á Hengilssvæðinu. Áhugaverðustu jarðlögin til að bora slíka holu í eru auðvitað þau sem NJ-11 var boruð í á sínum tíma. Má því segja að hringnum sé lokað. En áður en hægt verður að ráðast í það verkefni að bora holuna þarf að leysa nokkrar tæknilega áskoranir sem lúta að holutækni. Unnið er að því hörðum höndum að finna viðeigandi lausn á þessum tæknilegu vandamálum svo hægt sé að heimsækja jarðlögin við NJ-11 aftur. Markmiðið er að reyna að stækka vinnsluna niður á við með þeim aðferðum sem duga.

The deep crustal conductor under Iceland. Almost a half century old unresolved enigma !! Confusing geosciences !!

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MT resistivity soundings in the late 1970'ies and early 1980'ies revealed a Deep Conductive Layer (DCL) under most of Iceland. When first observed, the DCL was interpreted as partial melt below a thin and hot crust. In contrast, seismic and gravity studies indicate a thick, dense and relatively cold crust, with the DCL as an intra-crustal layer below the brittle/ductile transition. The DCL has, however, not been accounted for in the thick crustal model. The nature of the thick cold crust under Iceland and the GIFR ridge has been disputed for a long time. Is it due to a mantle plume or does it contain stretched fragments of continental crust ("Icelandia")? A fundamental question is: What is the DCL and what can it tell us about the origin and nature of the Icelandic crust? Recent findings indicate that the DCL is electrically and seismically anisotropic, suggesting ductile flow in the middle to lower crust. The DCL domes up beneath central volcanos with high temperature geothermal systems and the only low temperature area in Iceland studied by MT to date. ÍSOR has, in cooperation with HÍ and five universities in Europe and Canada, applied to RANNÍS for funds to study the DCL under NE Iceland. We will use MT-soundings, gravity, magnetics, petrological laboratory studies and modelling of magma development to narrow down possible causes of the DCL and its role in the evolution of Iceland. The commonly assumed model of eastward migrating/stepping of spreading zones in Iceland cannot account for the ~15 Ma rocks in the far west and east Iceland without a spreading rate about twice that measure. Can we, by mapping the DCL, detect ancient/buried volcanic/spreading zone(s) and resolve the internal paradox in the eastward-migrating rift model?

Conduit formation and crustal microxenolith entrainment in a monogenetic basaltic eruption: Observations from the 3.5 ka eruption of Þríhnúkagígur Volcano, Iceland

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Þríhnúkagígur volcano, a part of the Brennisteinsfjöll volcanic system in southwest Iceland, is a 3.5 ka basaltic fissure eruption with a composite spatter cone and lava field, characteristic of this style of eruption on the surface. However, its uppermost conduit is evacuated, extending ~120 meters down from the vent into a 4×10^4 m^3 lung-shaped cave allowing for direct observation of field relationships of – and from *within* – the shallow plumbing system. It provides unique three-dimensional insight to conduit formation in fissure systems. Additionally, this allows for crustal contamination of magmas to be evaluated geochemically. During the eruption, unconsolidated tephra was intruded and entrained by the ascending magma, comprising up to 10% of the eruptive volume. Residual tephra exposed in the cave wall is geochemically distinct from both the dike that fed the Þríhnúkagígur fissure and the erupted lavas. This allows for mixing models of the dike and tephra compositions to geochemically evaluate cryptic contamination of the lavas by microxenoliths of the fine, glassy tephra. Yet even with these external constraints on crustal contributions to the Þríhnúkagígur lavas, trace element and Sr-Nd isotope mixing models cannot reproduce consistent values for the relative proportions of the dike and tephra components in the lavas. This suggests that multiple batches of magma were involved in this small volume eruption. Although the tephra cannot be identified as a component of the lavas on the basis of whole rock geochemistry, it likely played an important role in the Þríhnúkagígur eruption, and more speculatively in the eruption of Miðhnúkur, an older co-located spatter cone that also has microxenoliths of tephra in its lavas. We infer that as a mechanically weak pre-existing structure, the tephra acted as a preferential pathway for magma ascent and influenced vent location during the eruption of Þríhnúkagígur and possibly in other eruptions.

Recent deformation observations and geodetic modelling at Askja volcano

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At the beginning of August 2021, inflation was detected at Askja volcano, on a continuous GNSS station located to the west of Öskjuvatn and on interferograms generated using data from four separate Sentinel-1 tracks. Ground deformation measurements at Askja commenced in 1966 with levelling observations and since this time additional ground monitoring techniques have been employed, including GNSS and Satellite interferometry (InSAR) to detect long-term changes. Ground levelling measurements undertaken between 1966-1972 revealed alternating periods of deflation and inflation. Measurements from 1983-2020 detailed persistent subsidence of the Askja caldera, initially at an inferred rate of 7 cm/yr, decaying in an exponential manner. Suggested explanations for the long-term subsidence include magma cooling and contraction, or withdrawal of magma – eventually facilitated by an extensive magma-rich plumbing system, with an open conduit between the uppermost and the deeper parts of the magmatic system. This presentation will focus on the recent period of uplift and provide an overview of the GNSS and InSAR observations to date and present the latest geodetic modelling results which describe the best-fit source for the observed deformation.

Turbulence and bubbles: acoustic observations of fire fountains during the 2021 Fagradalsfjall eruption, Iceland

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The 2021 eruption within the Fagradalsfjall volcanic system in south-west Iceland provided a rare opportunity to observe and describe eruptive activity from a persistent fissure event. The eruption, which began on 19th March, was characterised by persistent effusive activity punctuated by explosive fire fountaining events and produced lava flows covering an area of 4.85 km^2. On 21st April, a four-element infrasound microphone array was installed approximately 800 m north-west of the eruption site to track activity that was occurring across five active vents at that time. After 1st May, activity became focused at one vent which displayed remarkable rhythmic fire fountain eruptions throughout the rest of the month and into June. Here we detail the key observations derived from acoustic data recorded during this phase of activity, including complementary insights from seismic and observational data. Least-squares estimates for back-azimuths and apparent velocities from data recorded by the infrasound array provides a high-resolution time-series of activity occurring within the vent. Each fire fountain event can be divided into at least three key phases depending on their frequency of the recorded acoustics which correlate strongly with visual observations of activity. Two phases are defined by the peak lava fountaining followed by turbulent lava bubbling which can be distinguished using a quantitative comparison to jet noise spectra. The third phase is characterized by sequences of high amplitude acoustics generated by large, distinct bubble bursts within the vent. These sequences sometimes exhibit an upward 'gliding' of frequencies which may be linked to downward draining of lava after each fire fountain and can be used to constrain the cross-sectional shape of the vent. Such close and almost continuous acoustic recordings of basaltic fissure eruptions are rare and provide a unique insight into the dynamics of high-velocity multiphase volcanic eruptions.

Shallow magma degassing drives short-period lava fountaining at Fagradalsfjall, Iceland

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During the recent eruptive episode at Fagradalsfjall, fire-fountaining occurred with astonishing regularity (every 7-8 minutes) throughout May and June. Previous studies of fire fountaining at Kilauea and Etna have suggested that fountaining results from collapse of a bubble-melt foam layer accumulated on top of a magma reservoir. We performed high-temporal resolution open-path Fourier Transform Infrared Spectroscopy (OP-FTIR) measurements on several days during the fountaining period, recording dynamic changes in the gas composition throughout the fountaining cycle. In addition, we utilize visual (camera) and acoustic data to place constraints on the magnitude and duration of gas release. Our observations show that the length of fountaining cycle increased between May 5th and May 18th, with the paroxysmal stage of fountaining becoming shorter and the repose period between fountaining events increasing. While the abundance of all measured volcanic gas components increased by roughly an order of magnitude during the fountaining events, the measurements reveal that the gas driving the fountaining is characterized by lower H_2O/CO_2 and H_2O/SO_2 and higher SO_2/HCl. Since H_2O and halogens (HCl and HF) only degas at low pressures close to atmospheric pressure, while SO_2 and particularly CO_2 degas at higher pressures, these observations place constraints on the depth of foam layer generation, the area of the magma chamber roof feeding the conduit, and deep magma fluxes into the system.

Evaporite-derived oxygen in iron oxide-apatite deposits

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How magnetite-apatite ore deposits form is one of the longest standing question in geosciences, with various formation models having been put forward. In this contribution, we show for the first time that magnetite-apatite rocks from the type locality at Kiruna, Central Sweden, contain up to tens of atom percent oxygen that were derived from evaporitic sulfate, as is indicated by their anomalously low $\Delta'^{17}O$ values down to -363 ppm. The evaporite-derived oxygen component is best explained if the magnetite-apatite rocks formed from late-stage magmatic fluids that had interacted with evaporites, and possibly also from anatectic sulfate melts. An inventory study shows that several other Proterozoic and Cambrian magnetite-apatite deposits have anomalously low $\Delta'^{17}O$ values similar to Kiruna, whereas post-Cambrian magnetite-apatite deposits, in contrast, have more moderate $\Delta'^{17}O$ values. We therefore suggest that magnetite-apatite deposits may ubiquitously contain evaporite-derived oxygen, with variations in the lowermost $\Delta'^{17}O$ values of the deposits reflecting the changing isotope composition of atmospheric O_2 through time.

Hengill – the most extensively monitored seismic region in Iceland

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The volcano Hengill has recently become the most seismically instrumented region in Iceland. Hengill is situated at the triple junction between the Reykjanes oblique rift, the western volcanic zone and the South Iceland seismic zone, about 30 km from downtown Reykjavík. On the flanks of the volcano there are two geothermal power plants, Nesjavellir and Hellisheiði, providing 423 MWe and 540 MWth combined.

Many types of seismicity are observed in the region, including volcano seismicity, tectonic events, as well as induced seismicity from injection and production in the geothermal fields. ON Power (Orka Náttúrunnar) has operated a 10 station, short-period seismic network around the volcano since 2016, through a contract with Iceland Geosurvey (ISOR). As part of three projects, funded by ERA-NETS Geothermica: DEEPEN and COSEISMIQ and ACT: SUCCEED, seismic monitoring has increased substantially in the region. COSEISMIQ operated 21 broad-band seismic stations, as well as a small aperture seismic array, from 2018-2021 with the goal of understanding the induced seismicity. As part of the SUCCEED project a helically wound fibre optic cable was installed in the CO_2 injection area Húsmúli, aimed at monitoring the mineralization of CO_2. Furthermore, in the summer of 2021 a 500-station network, consisting of seismic nodes (small, transportable and self-sustained short-period seismometers) was installed both in Nesjavellir and on Hellisheiði, together with continuous operation of distributed acoustic sensing (DAS) on two dark fibre optic cables crossing Nesjavellir. Finally, in the summer of 2021 a vibrating truck generated signals to be recorded on fibre optic cables and nodes of the SUCCEED and DEEPEN projects.

In this presentation we give an overview of the seismic monitoring and what we hope to learn from the data.