Volcanic hazards and risk management in Iceland

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Introduction

Iceland is very sparsely populated with about 380,000 people living in a country of just over 100 thousand km^2. One consequence of this is that despite frequent volcanic eruptions, fatalities are not common. Only two deaths can be traced directly to volcanic activity (scientist hit by a falling lava block in 1947 and gas poisoning in 1973) in the last 100 years.

Volcanic activity is common in Iceland and eruptions, usually lasting days to weeks, happen on average once every three years. Even though some eruptions cause substantial damage, most eruptions do not. This is mainly because Iceland is very sparsely populated with on average only 3-4 people per square kilometer and most live in SW-Iceland, just outside the boundary of the volcanically active zone. However, the threat from volcanic eruptions is ever present in Iceland where authorities and monitoring institutions need to be on constant alert. This level of alertness, and the fact that locals in general are well-aware of the potential dangers posed by volcanoes, is the key to successful co-existence of people and volcanoes in Iceland. In this article the background and the main characteristics of volcanism in Iceland are explained. Recent examples of volcanic crises are presented, the monitoring outlined, damage and losses discussed and some lessons from the volcanic activity in the last several decades are given.

Geological setting

The geological setting of Iceland is highly unusual (Einarsson, 2008). It is located on a mid-oceanic ridge where two of the large tectonic plates that make up the earth's surface drift apart from one another with an average rate of opening of 2 cm per year (Figure 1). The western part belongs to the North American Plate while the eastern part belongs to the Eurasian Plate, the plate that includes Europe and the largest part of Asia. In addition, a mantle plume beneath Iceland rises from deep within the Earth's mantle. This combination of a tectonic plate boundary and a mantle plume is the reason for the existence of Iceland. It also explains why volcanic activity in Iceland produces about four times as much magma as does a comparable section of the Mid-Atlantic Ridge outside Iceland.

The oldest rocks in Iceland are 16-18 million years old (Figure 1), found in the northwest and eastern parts on the island. The plate boundary is manifested as a 40-80 km wide volcanic zone that cuts across Iceland from the southwest to the northeast. Volcanic activity is confined to these zones. In South Iceland the plate spreading is distributed on two near-parallel zones. In the southwest is the Western Volcanic Zone, merging with the Mid-Atlantic Ridge offshore. From the center of Iceland lies the Eastern Volcanic Zone, extending beyond the coast in South Iceland. The plate boundary in North Iceland is represented by the Northern Volcanic Zone.

Within the volcanic zones volcanic features are arranged into volcanic systems (Figure 1). Each system is elongated along the volcanic zone and is 30-190 km long and 10-30 km wide. Most volcanic systems have a central volcano in the middle and fissure swarms extending along the volcanic zones in both directions. The central volcanoes are typically 20-30 km in diameter, rise 500-1000 m above their surroundings with a caldera in the centre. Most volcanic eruptions occur within the central volcanoes, where the erupted magma ranges from basalts through intermediate compositions to rhyolites. Volcanic activity is less frequent on the fissure swarms and the erupted magma is all basaltic.

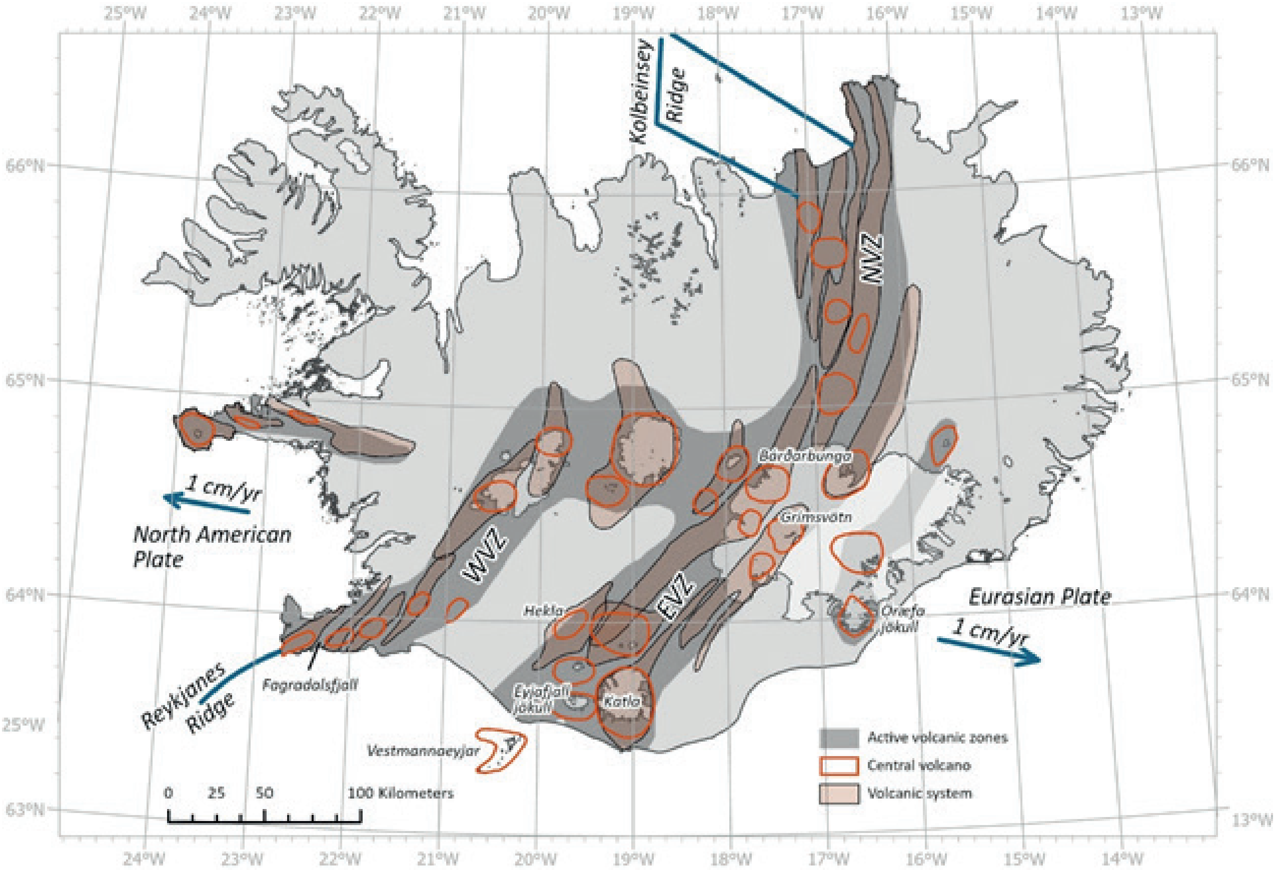

Figure 1. Plate boundaries, volcanic zones, volcanic systems and central volcanoes in Iceland.

Iceland is located at about 65°N and has a cool temperate maritime climate with relatively high precipitation. About 10 % of the island is covered with glaciers. This includes substantial parts of the volcanic zones. Consequently, about 50 % of all volcanic eruptions in Iceland take place within the glaciers or on high volcanoes with considerable ice cover (Larsen, 2002). This combination implies that volcano-ice interaction is very common, with volcanic eruptions or geothermal activity in glaciated areas, melting ice and causing volcanogenic floods.

The combination of volcanic activity associated with rifting along the plate boundary, the existence of large central volcanoes where magma can evolve in the crust, and the highly variable environmental conditions between ice-covered and ice-free areas, implies that volcanic activity in Iceland covers a very broad spectrum. Basaltic, mostly effusive fissure eruptions occur on the fissure swarms, but high groundwater levels and ice cover can result in highly explosive hydromagmatic activity in some parts of the country and offshore. Within the central volcanoes, activity can range from frequent, relatively small basaltic eruptions, to occasional large-volume explosive eruptions.

According to a recent estimate by Thordarson and Larsen (2007) 79 % of all magma is erupted as basalt, 16 % is of intermediate composition and 5% is silicic. Some eruptions are mixed, produce both lava and tephra and some produce only lava. About 80 % of eruptions in Iceland are mostly explosive. This contrasts sharply with e.g. Hawaii and most other places where basalts are dominant. This importance of basaltic explosive activity is mostly due to the widespread occurrence of magma-water interaction, within the glaciers, in parts of the rift zones where groundwater levels are very high and lakes are common. Moreover, occasionally eruptions occur in the shallow ocean off the coast of Iceland.

Magnitude and frequency of volcanic eruptions in Iceland

The most common type of activity are explosive or effusive eruptions within central volcanoes, with the four volcanic systems of Hekla, Katla, Grímsvötn and Bárðarbunga being the most active. The majority of eruptions are of moderate size, but they include some large explosive eruptions. Less common are large eruptions on the fissure swarms like the one that occurred in Holuhraun in central Iceland in 2014-2015 (Pedersen et al., 2017).

Apart from the largest events, estimates of erupted volume are uncertain for eruptions that occurred more than 100 years ago. Table 1 provides numbers on the 22 confirmed eruptions of the last 50 years; the average interval between eruptions in this period is 2.3 years. Out of these, less than 0.1 km^3 of magma was erupted in 10 eruptions, nine produced between 0.1 and 0.25 km^3, with the largest events producing respectively 0.45 km^3 and 1.4 km^3. It is possible that the number of the smallest events is not complete, as a few very minor events may have occurred beneath the glaciers in this period. A more general overview of recurrence times of events, based on the known eruption history in the last 1,100 years, is given in Table 2. Estimates of production rate indicate that on average 7-8 km^3 of magma is erupted every 100 years (Thordarson and Larsen, 2007). The largest eruptions have recurrence times of 250-1000 years. They are principally of two types: (1) Major flood basalt eruptions producing up to 20 km^3 of lava, and (2) very large explosive eruptions that may produce up to 10 km^3 of tephra.

Since the settlement of Iceland, over 1,100 years ago, only four lava flows are responsible for up to half of the total magma erupted in this period. This includes the large Laki lava. It was formed in 1783-1784, during a major rifting event in the Eastern Volcanic Zone, covering 600 km^2. This eruption caused great hardship at the time and the associated high volcanic gas concentrations and disturbance to weather patterns caused widespread disruption in many parts of the northern hemisphere (Thordarson and Self, 2003).

Volcano	Year	Deposits	Magma composition	Eruption type	Lava area (km^2)	Lava bulk volume km^3	Tephra volume (DRE) km^3	VEI	Insured loss - Present day value (million EUR)
Fagradalsfjall (1)	2021	lava	basalt	Effusive	4.85	0.15		1	
Holuhraun 2014-2015 (2)	2014	lava	basalt	Effusive	84	1.44		1	
Grímsvötn (3)	2011	tefra	basalt	Explosive	0		0.27	4	2.1
Fimmvörðuháls (4)	2010	lava	basalt	Effusive	1.3	0.02		1	
Eyjafjallajökull (5)	2010	tefra/lava	intermediate	Explosive	0,6	0.02	0.18	3	2.5
Grímsvötn (6)	2004	tefra	basalt	Explosive	0		0.05	3	
Hekla (7)	2000	lava/tefra	intermediate	Mixed	15	0.095		2	
Grímsvötn (8)	1998	tephra	basalt	Explosive	0		0.05	3	
Gjálp (9)	1996	tefra	intermediate	Sub-Glacial	0		0.45	2	9.6
Hekla (7)	1991	lava/tefra	intermediate	Mixed	25	0.24	0.01	3	
Krafla, September (10, 11)	1984	lava	basalt	Effusive	24	0.13		1	
Grímsvötn (8)	1983	tefra	basalt	Explosive	0		0.01	2	
Krafla, November (10, 11)	1981	lava	basalt	Effusive	17	0.05		1	
Krafla, January-February (10, 11)	1981	lava	basalt	Effusive	6.3	0.032		1	
Krafla, October (10, 11)	1980	lava	basalt	Effusive	11.5	0.035		1	
Krafla, Jully (10, 11)	1980	lava	basalt	Effusive	6	0.025		1	
Krafla, March (10, 11)	1980	lava	basalt	Effusive	~1	0.003		1	
Hekla 1980-1981 (7)	1980	lava	intermediate	Mixed	25	0.17	0.026	3	
Krafla, September (10, 11)	1977	lava	basalt	Effusive	<1	0.002		1	
Krafla, April (10, 11)	1977	lava	basalt	Effusive	~1			1	
Krafla, December (10, 11)	1975	lava	basalt	Effusive	<1	<0.001		1	
Vestmannaeyjar (12)	1973	lava/tefra	basalt	Mixed	3.2	0.23	0.02	2	260-330*

(1) Pedersen et al. 2021, (2) Pedersen et al. 2017, (3) Hreinsdóttir et al. 2013, (4) Edwards et al. 2012, (5) Gudmundsson et al. 2012, (6) Oddsson et al. 2012, (7) Pedersen et al. 2018, (8) Gudmundsson 2005, (9) Gudmundsson et al. 2004, (10) Einarsson 1991, (11) Sæmundsson 1991, (12) Einarsson, 1974.
* The Vestmannaeyjar eruption occurred prior to the establishment of NTI. The loss has been estimated based on the existing coverage, provide by NTI as today.

Table 1. Volcanic eruptions in Iceland 1973-2021.

All eruptions - volume erupted (lava and tephra)		Explosive eruptions (Volcanic Explosivity Index)	
Volume (DRE) km^3	Years	VEI	Years
<0.03	5-10	1	5-10
0.03 - 0.1	10	2	10-20
0.1- 0.3	10	3	10
0.3 - 1.0	20-40	4	30-50
1-3	~250	5	100-200
3-10	~500	6	~1000
>10	~1000	7	no known eruptions

DRE: Dense rock equivalent = total material erupted compacted to the density of solid rock.
VEI: Volcanic Explosivity Index, based on plume height and bulk (total) volume of airborne material (tephra) erupted:
VEI 1 < 0.001 km^3 < VEI 2 < 0.01 km^3 < VEI 3 < 0.1 km^3 < VEI 4 < 1 km^3 < VEI 5 < 10 km^3 < VEI 6 < 10 km^3.
The bulk volume of tephra is often about ~three times the DRE volume, as tephra has high porosity.
(Table modified from Gudmundsson et al. 2008).

Table 2. Recurrence times of eruptions in Iceland.

Volcanic hazards in Iceland

Iceland is very sparsely populated with about 380,000 people living in a country of just over 100 thousand km2. One consequence of this is that despite frequent volcanic eruptions, fatalities are not common. Only two deaths can be traced directly to volcanic activity (scientist hit by a falling lava block in 1947 and gas poisoning in 1973) in the last 100 years. The principal hazards (Figure 2) are: (1) Tephra fallout, (2) lava flows, (3) jokulhlaups (flooding caused by volcanic or geothermal activity under glaciers), (4) gas pollution, (5) Pyroclastic density currents, and (6) lightning.

Tephra fallout

The majority of explosive eruptions in Iceland are basaltic and take place within the glaciers, most frequently in the Grímsvötn volcano (Larsen 2002, Thordarson and Larsen, 2007; Gudmundsson et al., 2008). Most of these eruptions are of modest size (<0.1 km3, Volcanic Explosivity Index = 3 – see Table 2), with magma-water interaction being an important driver of magma fragmentation resulting in eruption plumes and the spread of ash layers. Most of these eruptions have relatively little effect in inhabited areas due to the remote location of the source volcano. Substantial explosive eruptions, (VEI 4) occur approximately once every 30-50 years. Larger eruptions (VEI 5) occur once every 100-200 years.

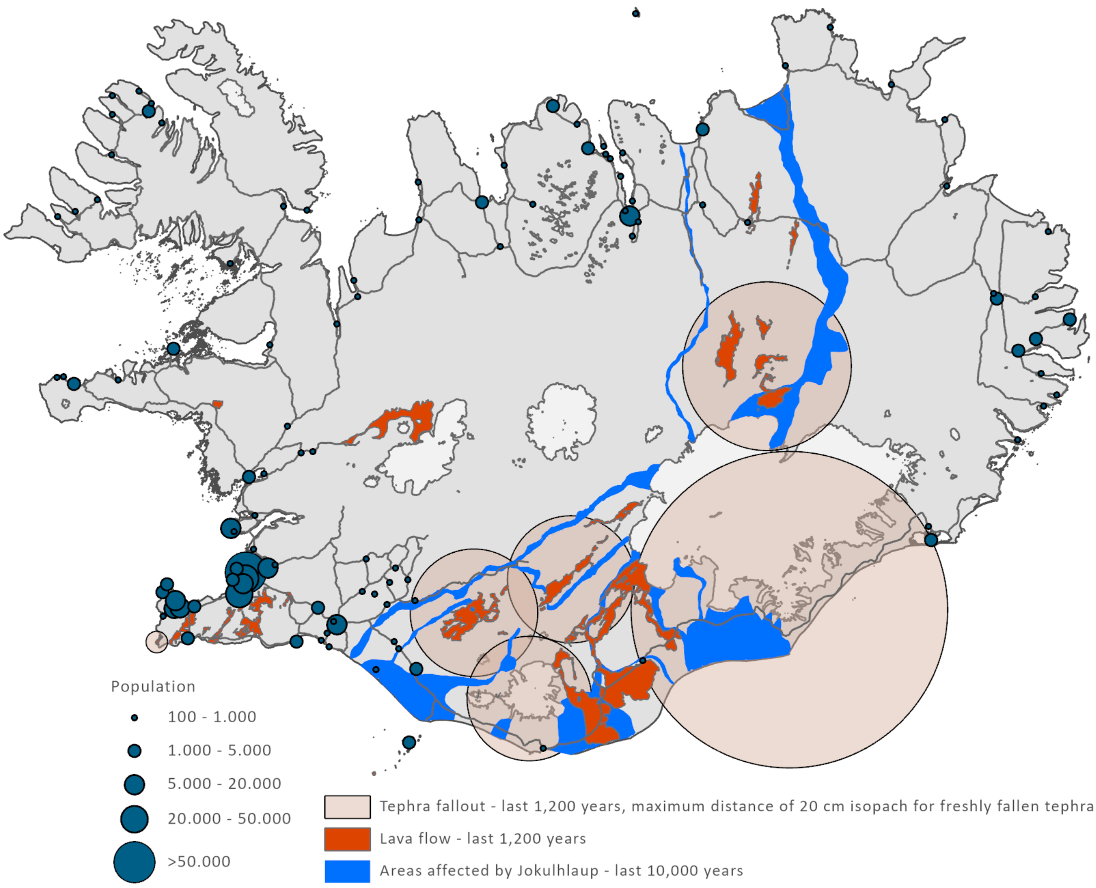

Figure 2. Population centres, main roads and areas that can be seriously affected by explosive eruptions and jokulhlaups according historical and geological records (after Gudmundsson et al., 2008).

Lava flows

Lava flows formed in the last 100 years cover more than 200 km^2 of land. However, most of this lava is formed in the highlands or in uninhabited regions and therefore do not cause damage. There are exceptions to this, notably the eruption on the island of Heimaey in Vestmannaeyjar. No casualties or injuries occurred, and the inhabitants were successfully evacuated from the island. However, during the five months of the eruption, about 400 buildings were destroyed and there was extensive damage to infrastructure and disruption to the local economy. The most recent eruption on the Reykjanes Peninsula in March-September 2021 occurred only 8 km from the nearest town. However, there was no damage to buildings or infrastructure.

Jokulhlaups

Jokulhlaups (floods) caused by release of meltwater from glaciers in Iceland are mainly of two types: (a) release of meltwater that accumulates beneath the glacier due to melting by geothermal activity, (b) large scale events caused by melting during eruptions. Type (a) is much more common, with such events occurring on average every 1-2 years. Damage is usually minor. However, frequent geothermally induced jokulhlaups can change vegetated land to wasteland susceptible to sandstorms as observed in one region in SE-Iceland. Type (b) is less common but may result in major flooding, as occurred in the catastrophic jokulhlaup during the eruption of the ice-covered Katla volcano in 1918 (peak discharge estimated as high as 300,000 m^3/s). Other examples include a major jokulhlaup in SE-Iceland caused by the Gjálp eruption in 1996 and several much smaller floods during the eruption of Eyjafjallajökull in 2010. These floods may destroy bridges, roads, and other infrastructure, but usually occur in uninhabited floodplains.

Gas pollution

During large effusive eruptions large amounts of volcanic gasses may be released into the atmosphere. This is principally Sulphur dioxide (SO_2) which in high concentrations is harmful to people. Gas pollution is therefore monitored, and warnings given depending on concentrations during eruptions (Barsotti et al., 2020). During the large eruption of Holuhraun in 2014-2015, high concentrations occurred occasionally in towns up to 100 km away from the eruption site, causing temporary halt to outdoor work.

Pyroclastic density currents

During large explosive eruptions, pyroclastic density currents (PDCs) are a major hazard in some volcanic regions around the world. They form when eruption plumes collapse and the hot volcanic tephra and gasses flow outwards away from the volcano, devastating everything in their path. PDCs occur in Iceland but most are small and do not reach much beyond the area close to the vents. However, in the very large but infrequent VEI 5-6 eruptions PDCs may reach inhabited areas. The latest eruption where PDCs reached inhabited farmland was in the eruption of Öræfajökull in 1362. However, with increased tourism the danger from PDCs to hikers on Hekla volcano is increasing, as precursors to eruptions on Hekla are very short (~1 hour or less).

Lightning

During explosive eruptions lightning may be a serious hazard to people. This especially applies where the magma interacts with water. Notable examples are eruptions in Katla volcano, which happen on average once every 50 years. Lightning may also damage power lines and other such infrastructure. Two people were killed by lightning during the eruption of Katla in 1755, but no other fatalities due to this hazard are known in Iceland.

Volcanic monitoring and response

Networks of seismometers and GPS stations monitor volcanic regions around Iceland. These are mainly operated by the Icelandic Meteorological Office (IMO), providing real-time data (seismic), and same-day updates on the status of deformation at selected volcanoes (the GPS-station network). A network of real-time gauging stations in glacial rivers monitor discharge and geothermal signals in the rivers. These networks are publicly accessible on the web-page of IMO (https://vedur.is). The IMO also has C- and X-band radars to track eruption plumes. Air quality and gas concentrations are monitored by the Environment Agency of Iceland. During unrest and volcanic activity, response is coordinated by the Civil Protection Department of the Icelandic Police Commissioner. During volcanic unrest and activity, expertise is sought widely and active collaboration on monitoring and assessment exists between the IMO and the Nordic Volcanological Center at the Institute of Earth Sciences, University of Iceland. An informal Science Advisory Board of the Civil Protection Department holds frequent meetings during unrest, over the last two years exclusively as online meetings.

Case stories – last 50 years

Vestmannaeyjar (1973)

On the 23rd of January 1973 a 1,600 m long volcanic fissure opened only 300 m from the nearest houses in the town of 5,000 inhabitants on this island off the south coast (Einarsson, 1974). A battle was fought between man and the lava in order to protect the harbour and the houses in town. Both cooling of the lava with seawater as well as diversion dikes and retention dams were used. The combination was a success even though a part of the town was lost.

Dams and dikes were made from the available material that was mainly of low density, including tephra from the eruption. The diversion dikes held to the end of the eruption but the retention dam (with lava flow perpendicular to the structure) broke on 18th of March at which time the lava front had risen up to twofold the height of the dam that was about 25 m high at its highest point (Jónsson, 2013).

The cooling of the lava started along the same line as the diversion dike at the lava edge using firehoses. As the lava started to threaten the entrance to the harbour, seawater was also pumped from ships onto the lava front especially the northwesternmost part of the lava nearest to the harbour. In order to cool not only the lava front but also its interior, a pipe was placed on top of the still moving lava allowing the water to reach some further 200 m inside the lava margin. Bulldozers and similar heavy machinery had to be used to place the pipe, but as this was slowly advancing a'a lava[1], it was possible to operate such machines on the cool uppermost rubble covering the hot interior. This risky operation seemed to slow down the progression of the lava. Based on the first successes using available pumps, 32 large pumps were acquired from the USA and a cooling of the lava field on a major scale started. During this latter cooling phase some 5,7 million tons of seawater was pumped onto about 0,45 km^2 of lava surface, i.e. the part of the lava closest to town and the entrance to the harbour (Jónsson & Matthíasson, 1974).

The highly fractured surface of the slow-moving a'a lava resulted in a relatively large cooling area and thus efficient cooling. Additionally, this type of lava is in many cases easier to control with dikes and dams as the high viscosity and yield stress allows the lava to raise high above obstructions without overtopping them.

Gjálp (1996)

This eruption took place under an initially 600-750 m thick ice and lasted 13 days in October 1996 (Gudmundsson et al, 2004). It broke through the ice cover after 31 hours of eruption. However, the resulting explosive eruption was relatively minor causing no damage, as the eruption site is more than 60 km away from the nearest inhabited area. The subglacial eruption on the other hand was large, producing 400-500 m high mountain beneath the ice. The eruption melted more than 3 cubic kilometers of ice and all this meltwater was stored for five weeks in the subglacial lake within the Grímsvötn caldera, 10 km to the south.

All this meltwater was then released in a major jokulhlaup that reached peak discharge of approximately 50,000 m^3/s. The jokulhlaup swept away one of the main bridges (Figure 3) and caused additional extensive damage to the main ring road, closing it for some weeks afterwards. No farms or towns were in danger as the flood plain has been uninhabited for hundreds of years.

(1) 'A'ā (also spelled aa) is one of three basic types of flow lava. 'A'ā is basaltic lava characterized by a rough or rubbly surface composed of broken lava blocks called clinker.

Figure 3. The jokulhlaup resulting from the eruption in Gjálp in 1996. The bridge was destroyed by the large icebergs carried with the floodwater.
Source: Photo by Magnús T. Gudmundsson.

Eyjafjallajökull (2010)

The infamous explosive eruption of Eyjafjallajökull in 2010 began on the 14th of April, following a smaller effusive flank eruption at Fimmvörðuháls (Gudmundsson et al, 2012). The continuous eruption lasted 39 days, with minor occasional activity in the following two weeks.

The eruption (Figure 4) occurred during a period when the prevailing wind direction was towards Europe. Ash clouds were blown towards Europe resulting in this moderate-sized eruption becoming a global event, causing the cancellation of over 100,000 passenger flights in Europe and across the North Atlantic. Jokulhlaups occurred repeatedly in the first 2-3 days. However, existing flood barriers withstood the impact, and by cutting flow paths for

Figure 4. The Eyjafjallajökull eruption in May 2010.
Source: Photo by Magnús T. Gudmundsson.

the floodwaters through the main highway, damage to the bridge on the ring-road was avoided. Recently adapted response plans for volcanic eruptions in the area were applied, including three short-duration evacuations. Locally, ash fall caused minor losses to nearby farms.

Grímsvötn (2011)

On the 21st of May 2011 the largest explosive eruption in Iceland for several decades began in Grímsvötn, the ice-covered volcano in the western central part of the Vatnajökull ice cap. An area to the south of the volcano was heavily influenced by temporary ash cover. Most of the economic losses were suffered by farmers and were uninsured. Insured losses at farms were for the most part only minor, such as damage to metal cladding, windowpanes, external walls and floor finishing. Despite being much larger, the overall impact of Grímsvötn 2011 was much less than that of the Eyjafjallajökull eruption a year earlier. The main reasons for this were firstly more favourable wind patterns, resulting in only minor distribution of tephra towards Europe, and secondly, the duration of the explosive eruption in Grímsvötn was only a few days, short compared to the 39 days of Eyjafjallajökull.

Bárðarbunga-Holuhraun (2014 - 2015)

The largest eruption in Iceland since the large Laki eruption in 1783-84 took place in the central highlands over six months between September 2014 and February 2015. The volume of lava erupted was 1.4 km^3, covering 84 km^2 (Pedersen et al., 2017). This eruption was a consequence of a major rifting event when a 40 km long segment of the volcanic zone rifted apart by 2 m. The magma came from underneath the central volcano Bárðarbunga where the caldera subsided by 65 meters. Such caldera collapses are not common but may happen once every 100-200 years in Iceland. The last major rifting episode prior to Holuhraun occurred in 1975-1984, the Krafla fires in North Iceland, with major rifting, dike intrusions and repeated eruptions. However, the eruptions at Krafla were an order of magnitude smaller than the eruption at Holuhraun.

Due to the remote location of the Holuhraun in the highlands at the northern margin of Vatnajökull ice cap, no damage to houses or infrastructure occurred. The danger of the eruptive fissure extending towards south and beneath the glacier was taken seriously, and large parts of the highlands were closed for travel due to the possibility of major flooding. Sulphur dioxide emission was very high, making a large area around the eruption dangerous. The remote location and the timing of the eruption in autumn/winter with higher winds than in summer contributed to making the effects of this eruption smaller than it could have been. Nevertheless, high gas concentrations caused disruption at times. On a few occasions people in towns more than 100 km away from the eruption site were instructed to stay indoors.

Fagradalsfjall (2021)

On the evening of 19th of March 2021, a volcanic eruption started in a small valley in the Fagradalsfjall Mountain on the Reykjanes Peninsula in SW-Iceland, only 8 km from the nearest town, close to various important infrastructure and with more than 75 % of the total population of Iceland living less than 40 km away from the site.

The eruption was preceded by an intense earthquake swarm (thousands of earthquakes, the largest of magnitude 5.7) starting 23 days before the onset of the eruption accompanying intense ground deformation as a 9 km long dyke intrusion formed in the crust.

By all standards it was of low intensity producing only lava (Figure 5). The most recent surface measurements of the lava, from the 30th of September 2021, show that the lava has covered about 4,85 km^2 of land and the volume of the lava is about 0,15 km^3 (Pedersen et al. 2021; Institute of Earth Sciences, University of Iceland, 2021). Currently (1st of December 2021), no activity has been detected since the 18th of September.

Figure 5. The lava flow in Fagradalsfjall on the 15th of September 2021, view towards north. The town of Reykjavík can be seen in the distance. On the left is the diversion dike built to prevent the lava flowing westwards.
Source: Photo by Björn Oddsson.

Extensive work took place in the days preceding the eruption on possible measures to minimize damage to infrastructure and populated areas in the event of an effusive eruption as an explosive eruption was considered improbable in this area. This work included mapping of infrastructure and available machinery for possible protection work through e.g. the possible construction of protection dams and diversion dykes; this work was aided by the use of computer modelling of possible direction and extent of lava flows. As things turned out, the eruption occurred at favorable location. Considerable volumes would need to erupt and fill valleys in the vicinity of the eruption site before the lava would advance sufficiently to cause damage.

Computer modeling of lava flow evolution to help predict the evolution of the lava field was done from the start, with simulations adjusted to observed effusion rates (Figure 6). Lava viscosity and yield strength had to be adjusted from time to time as the eruption evolved. For example, around 19th of May the flow shifted from being dominantly a'a to pahoehoe[2] resulting in changes to modeling parameters. As different software have different strengths and weaknesses, using more than one lava modeling software proved to be beneficial.

Five protection works were constructed: Three retention dams and two diversion dikes. Additionally, three Work Site Protection Barriers (WSPB) were made to protect the site where the actual dam or dike was being built.

The first two WSPB (1.5 to 2 m high) delayed the advance of the a'a lava, allowing the lava front to rise some 2 to 4 m above the barriers. After the lava changed to pahoehoe (Figure 7), the more fluid lava advanced as soon as it overtopped the barriers.

(2) Pāhoehoe (from Hawaiian [paːˈhoweˈhowe], meaning "smooth, unbroken lava"), also spelled pahoehoe, is basaltic lava that has a smooth, billowy, undulating, or ropy surface.

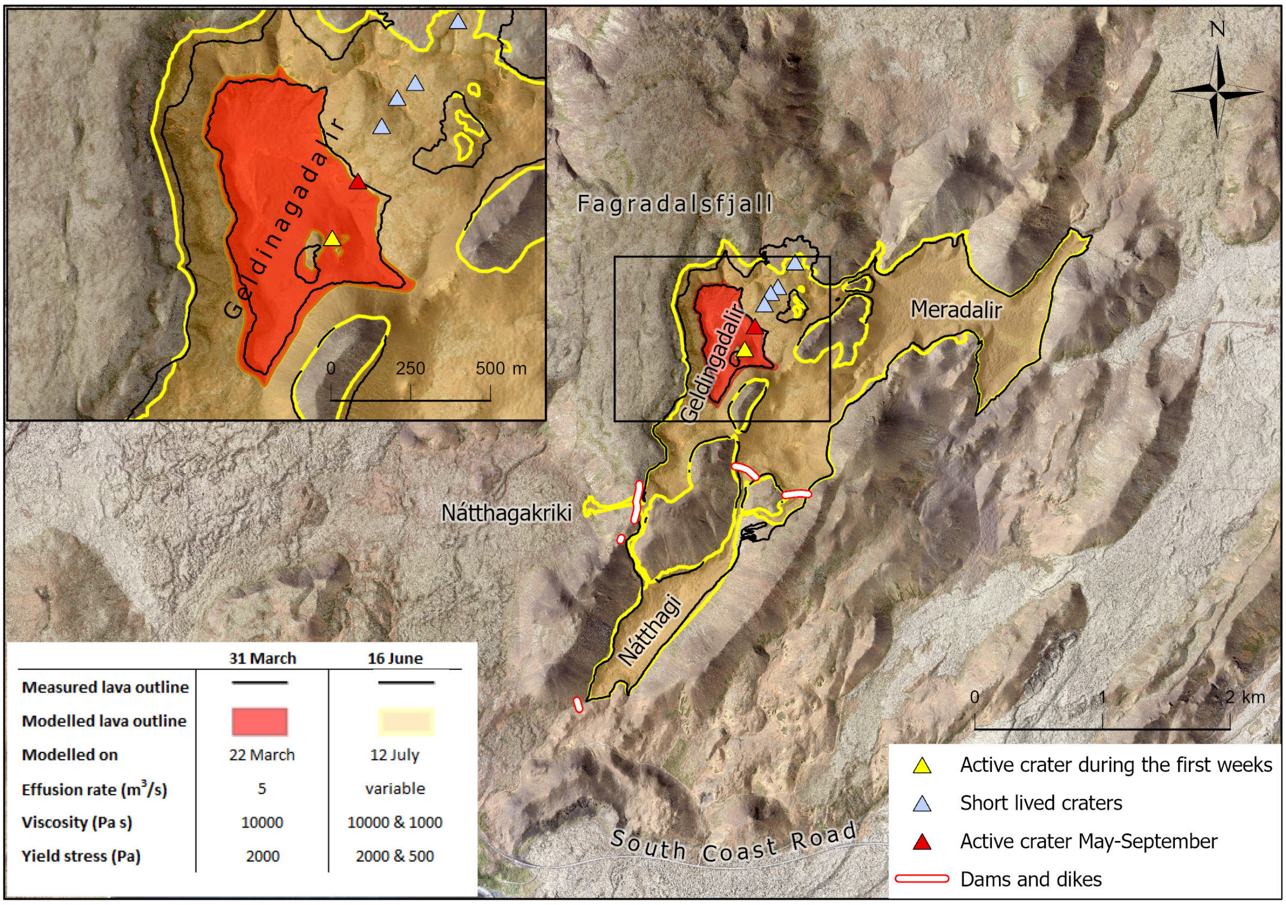

Figure 6. Comparison of measured and simulated lava extent for the eruption in Fagradalsfjall in 2021. Simulated lava extent from Verkís Consulting Engineers, simulated in HEC-RAS. The measured lava outline is based on data from Icelandic Institute of Natural History, Institute of Earth Sciences, University of Iceland, and National Land Survey of Iceland.

The diversion dikes are located along a ridge aimed at preventing the lava to flow towards west. The dikes did prevent such overspill on three occasions but by that time the lava was so high that they might not have withstood a fourth one.

The experience of these efforts shows that the progression of lava can be influenced by dams and diversion dikes. The dams delay the advance and are much more effective against the more viscous a'a flows while diversion dikes can have an important effect on the direction of propagation, e.g. where lava flows down from a topographic high.

Insurance against volcanic risk

Following the volcanic eruption in Vestmannaeyjar, the Icelandic government established the National Relief fund to compensate building owners for their loss. Three years later the fund was replaced by the Natural Catastrophe Insurance of Iceland (NTI), which was founded as a public undertaking by a special Act of the Alþingi (parliament) of Iceland. NTI functions as an insurance company collecting premiums for insurance cover. The purchase of catastrophe insurance for earthquake, volcanic eruption, snow avalanches, landslides and floods is compulsory for all buildings; as well as for contents that have been insured against fire. Buildings are insured according to their valuation for fire as assessed by the Property Registry Office and contents are insured according to their owners' self-assessment. Since fire insurance of buildings is compulsory in Iceland, all buildings are likewise insured against natural perils covered by the programme. The catastrophe cover is a stand-alone policy; the fire insurance companies collect the premiums alongside fire premiums in exchange for a collection fee. There is a single premium of 0.25 ‰.

Figure 7. Emergency heightening of the eastern dam, one day before overtopping.
Source: Photo by Ari Guðmundsson.

Infrastructure i.e. waterworks, geothermal heating systems, sewage systems, electric installations, bridges, harbour installations, and ski-lifts, which are not normally insured against fire, are separately insured (premium 0.2 ‰) with the institution.

The policy only insures against direct losses resulting from the above-mentioned catastrophes. There is a deductible of 2 % for each loss as well as a minimum deductible.

A special resource fund (Bjargráðasjóður) was initially founded in the early 20th century. The fund is an independent institution, owned equally by the Icelandic government and the Farmers Association of Iceland. The fund obtains its resources from the government budget. One of the main functions of the fund is to financially support farmers who have suffered losses related to natural catastrophes (including volcanic eruptions). The scheme includes properties, fences, grass-fields, and powerlines, related to the agricultural industry. The fund does not support losses which are insurable, e.g., by the NTI.

Even though there is a compulsory insurance against volcanic eruption provided by the NTI, and a special resource fund in place, protection is not complete. As an example, business interruption is not covered by the private insurance companies nor the NTI. The comprehensive car insurance policy, provided by the private insurance companies likewise does not include volcanic eruptions.

Concluding remarks

Volcanic activity in Iceland is both frequent and sometimes causes high magnitude events. Sizeable parts of the country are affected in some events, notably by fallout of ash in explosive eruptions. The co-existence of glaciers and volcanoes creates flooding hazards when ice is melted by geothermal activity or during eruptions. Population density is very low and the highlands, where most of the activity takes place, is unpopulated. As a result, most small to moderate-sized events cause little or no damage. However, there are occasions where eruptions take place near or almost within populated areas as the example from Vestmannaeyjar in 1973 vividly shows.

One of the main lessons from the last 50 years is that preparedness is all important. Response plans need to be ready beforehand, to be used in the event of a volcanic eruption. The basis of response plans has to be sound scientific knowledge of the hazards. This includes detailed studies of the characteristics of previous eruptions, recurrence times, types and magnitudes of events expected for each volcano.

The following points summarize some of the elements that form the basis for preparedness and response in Iceland:

1. Rigorous basic and applied research of the volcanoes and their products provides the vital information on which any response is based.
2. Response plans, including any mitigating measures possible to reduce the impacts of events that for Iceland can range from lava flows to floods of glacial meltwater.
3. Active dialogue with local inhabitants, informing them of scientific results and ensuring their involvement in response plans.
4. Effective and effortless collaboration between researchers, engineers and both local and national civil protection authorities is all important when it comes to minimizing material and economic losses.
5. A sound insurance system for natural disasters enhances resilience in society to such events.

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