Iceland's Volatile Landscape

Iceland's inhabitants have cohabitated with volcanoes, glaciers and earthquakes since the settlement circa 871 CE. The recent eruption in Geldingadalir is the latest chapter in a centuries-long tug-of-war between humans and forces of nature—as melting ice caps hint at an even more dynamic volcanic future.

By Tenley J. Banik

PHOTO: TOBY ELLIOT/UNSPLASH

ICELAND IS A LAND OF CONSTANT—and often dramatic—change. When inhabitants of Reykjanes, the peninsula that juts into the Atlantic Ocean on the southwestern corner of Iceland, began feeling earthquakes in February 2021, few people were surprised. After all, the region occupies one of Iceland's main rift zones, where tectonic plates are slowly spreading apart and new crust is created through volcanism. What followed was unusual: a month of seismic activity strong and disruptive enough to cause some residents to temporarily relocate to other areas of Iceland simply to be able to stand on solid ground or sleep through the night. Over 600 earthquakes of magnitude 3 or greater, which are easily felt by people, registered in Reykjanes during those weeks. Roads perched on mountainsides became unstable and dangerous to traverse, and geologists increased the amount of monitoring to better understand the local subsurface geology. The reason for the increased earthquake activity quickly became apparent: over several weeks, geologists were able to seismically track the movement of magma upward through the subsurface, culminating in Iceland's newest volcanic eruption on the evening of March 19 in an area called Geldingadalir.

Scientists, emergency personnel, and tourists swarmed the site. Unlike the penultimate Icelandic eruption at remote Holuhraun in 2014–15, the Geldingadalir (aka Fagradalsfjall) eruption was less than an hour's drive from the Reykjavík area and the international airport in Keflavík, and easily accessible to the public via an hour-long hike. In addition to being accessible, the eruption was characterized by a combination of mildly explosive, crater-building activity and basalt lava flows—evoking a sense of safety for people approaching the eruption site. This approachability, however, belies the omnipresent potential for hazardous conditions such as high concentrations of toxic gases and fast-moving lava flows.

Having now recently concluded (or nearly so), what can we take from this eruption and what it means for Iceland's landscape? In short, it serves as a reminder that Iceland is geologically alive, and that increases in earthquakes and volcanic activity can occur at any time—and that the forces that lead to Iceland's volatile landscape are always at work.

A HISTORY OF UNPREDICTABILITY

ICELAND EXISTS BECAUSE THE MID-ATLANTIC RIDGE—A tectonic plate boundary that stretches down the middle of the ocean basin where the North American and Eurasian plates are rifting apart—and a mantle hot spot are coupled, meaning that together they produce a much larger volume of magma than either feature alone. The nation is therefore the result of about 20 million years of higher-than-normal magma

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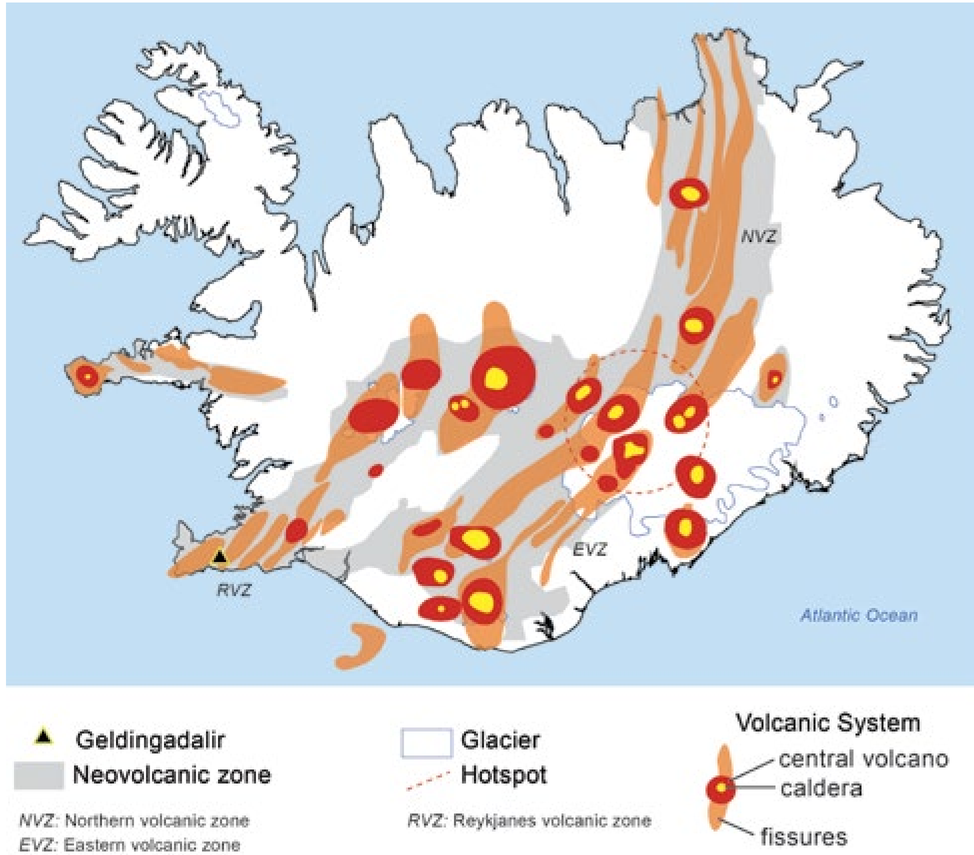

Iceland is the result of a combination of the Mid-Atlantic Ridge and a hot spot, which produces widespread active volcanism concentrated in volcanic zones.

production and volcanism. As Iceland continues to spread, continued volcanism ensures the creation of new crust in the areas surrounding the active rifts in the west, east, and north of the country.

Icelanders have lived with and in this dynamic environment since the Settlement approximately 1,150 years ago. Even the date of the Settlement itself is determined in part by the remnants of an eruption. Accounts written several hundred years later suggest Iceland's first permanent settler, Ingólfur Arnarson, arrived in the year 874; however, the presence of the Vatnaöldur ash layer (also called the Settlement or landnám layer), produced by a large eruption in circa 871-2, was found just below the oldest remains of a settlement in south Iceland. This hints that Norse settlers perhaps arrived on the heels of an eruption that dispersed ash across Iceland and even to continental Europe.

Icelanders have always paid close attention to volcanism and earthquakes; their survival depended on it. Since the Settlement, Iceland averages more than 20 eruptions per century. Roughly 75 percent of historical

Tephra horizons in south-central Iceland. The thick and light-colored layer at the center of the photo is rhyolitic tephra from Hekla.

PHOTO: DENTREN/WIKIMEDIA

eruptions have at least some explosive activity producing tephra—a catch-all term for bits of volcanic rock that result from explosive eruptions, which includes everything from tiny ash particles to pumices of all sizes. Tephra can have devastating effects on crop and livestock survival, which has led to many historical occasions of farm abandonment and regional agriculture devastation resulting from its deposition. In south-central Iceland, for example, homesteads throughout the valley of Þjórsárdalur were abandoned in 1104 after an eruption of Hekla deposited 10–30

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centimeters (about 5–12 inches) of pumice over the landscape.

SIMILARLY, A 1362 ERUPTION of Öræfajökull buried the surrounding region in the southeast in tens of centimeter of pumice; as a result the region was renamed 'Öræfi', which means 'wasteland' in Icelandic. Before that eruption, the Öræfi district had been one of the most productive agricultural areas in Iceland, and at least 30 farms were destroyed and abandoned for decades after the eruption; rural settlements as far as 70 kilometers east of Öræfajökull were damaged by the tephra fall, and many were abandoned for several years. More recently, tephra from the 2010 Eyjafjallajökull eruption notably forced the grounding of airplanes, wreaked havoc on air traffic patterns for over a week, and ultimately led to more than $1.5 billion dollars in economic loss.

The scale of the effects of these impactful eruptions pales in comparison to those associated with the other, approximately 25 percent of Iceland's historical eruptions—the effusive basalt eruptions that blanket the landscape in seemingly endless lava flows forming much of Iceland's modern, unique landscape. On the extreme end, the Laki eruption of 1783–84 in southeastern Iceland produced basalt lava flows and craters that emanated from an erupting gash-like fissure in the ground. The lavas took advantage of pre-existing river valleys to travel more than 60 kilometers (35 miles) from the fissures; at one point, the flow speeds reached approximately 140 meters an hour (about 450 feet an hour).

Before Geldingadalir, the RVZ last experienced an eruption in the 1200s.

That eruption continued intermittently for 10 months, watched carefully by the inhabitants of the Síða district and the local Reverend, Jón Steingrímsson, who diligently recorded his observations on the eruption and the effects it had on the local people. When it was over, over 15 cubic kilometers (or about 3.6 cubic miles) of new lava covered more than 600 square kilometers (or about 230 square miles) of the landscape. The lavas that rushed out of the fissure also contained high levels of sulfur and fluorine. As the winds carried Laki's noxious fumes across Iceland in every direction, fluorine coated the grass, curbing its growth and poisoning the livestock that grazed on it. At the time, Icelanders were highly dependent upon the meager crops they could raise in the short summer months and their livestock; without them, approximately 20 percent of the population starved to death. The sulfur was distributed throughout the atmosphere and ultimately was responsible for lowering average temperature in the Northern Hemisphere by 1–3 degrees Celsius over the next few years.

Another flood basalt eruption in the same region, that of Eldgjá from 934–40, erupted similarly large volumes of lava (about 18 cubic kilometers), tephra (about 1.4 cubic kilometers), and almost twice the sulfur volume as observed from Laki. The few written records that mention this time in Iceland's history indicate that the lava covered productive farmland, forced families to relocate, and even changed the course of the local river. Records from Europe and the Middle East also indicate significant changes in weather patterns that have been modeled to be strongly linked to the sulfur erupted from Eldgjá.

How do more recent flood basalt eruptions compare to these giants? The six-month-long Holuhraun (2014–15) eruption produced a mere 1.21 cubic kilometers of lava, and while gas emissions had effects regionally, they ultimately did not impact even the entirety of Iceland or elsewhere in Europe. Similarly, the Geldingadalir eruption, which has likely ceased after roughly seven months of activity, produced a comparatively paltry (about 4.5-square-kilometer) lava field containing a volume of 0.142 cubic kilometers of lava.

MANAGING PRESENT PHENOMENA

GELDINGADALIR LIES IN THE ACTIVE REYKJANES VOLCANIC zone (RVZ). The RVZ landscape is a hodge-podge of volcanic landscapes that tell of the region's dynamic past—this area of Iceland was glaciated during the most recent Ice Age, which ended around 10,000 years ago. A blanket of ice could not stop the volcanic forces at work in the subsurface, so volcanism continued despite the ice cover.

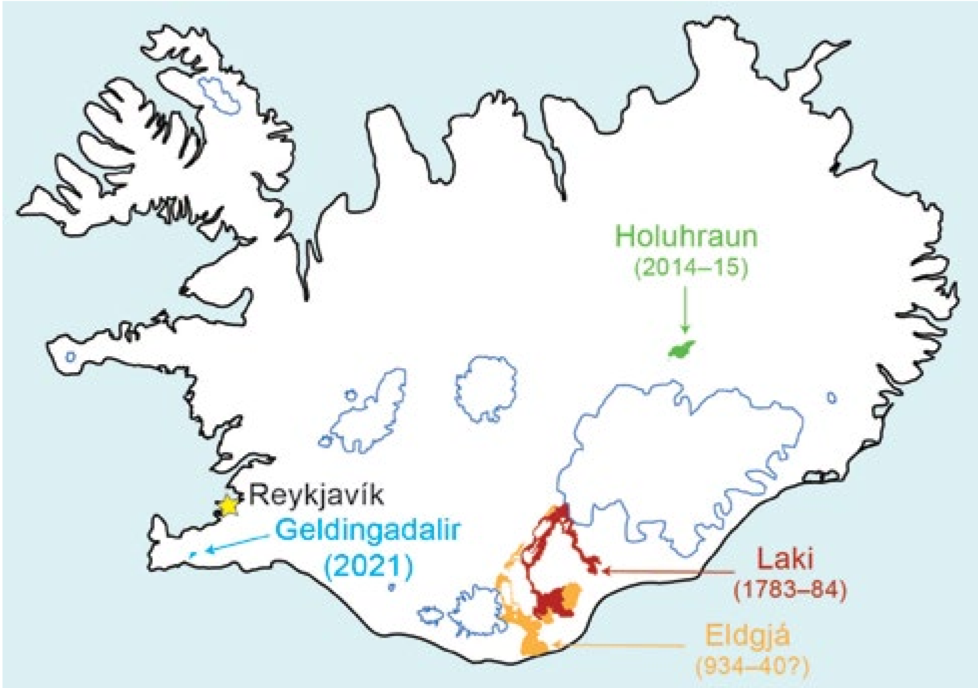

IMAGE COURTESY TENLEY BANIK

The Geldingadalir lava flow is tiny compared to several of Iceland's prior basalt lava eruptions, such as Eldgjá, Laki, and Holuhraun.

As a result, the RVZ is marked by unique landforms that only manifest when eruptions occur under and are confined by ice. These scattered subglacially erupted mountains consist of lava and glass that forms when magma erupts against ice or water—the rapid temperature change shatters the magma and quickly cools it into glass. This same process can produce violent, explosive eruptions when not constrained by a glacier (for example, Eyjafjallajökull in 2010), but when the explosivity is suppressed by ice, the erupted material piles up, leaving behind mountains and ridges when the ice melts. Younger lava flows, and their low craters erupted after the ice melted, fill in the topographic lows and leave a stark, sparsely vegetated landscape between the older mountains. Before Geldingadalir, the RVZ last experienced an eruption in the 1200s, and dating of eruptive material indicates that, on average, the RVZ erupts approximately every 700–800 years since the last major ice sheets in the area melted. At least with respect to timing, Geldingadalir is considered a very average eruption. Earlier historical RVZ eruptions were also similar in style to the Geldingadalir eruption, with basaltic lava flows, crater rows, and establishment of a flow field.

But one way this eruption is markedly different from previous eruptions has been in the monitoring and communication surrounding all aspects of the eruption. Icelanders have decades of experience in managing human interaction with a wide range of natural phenomena—ranging from avalanches, to

An effusive fissure eruption, the activity at Geldingadalir produced a steady outflow of basaltic lava while releasing volcanic gases.

PHOTO: TOBY ELLIOT/UNSPLASH

Steam rises where lava burns through glacier ice at Eyjafjallajökull in 2010.

PHOTO: CLEFTY/FLICKR

blizzards, to hurricane-strength winds, volcanic eruptions, and floods. Many view Geldingadalir as a monitoring and communication success. By the time the eruption started, the Icelandic Met Office, Civil Protection, University of Iceland, local police and rescue squads, and many other entities had been carefully tracking an uptick in regional earthquakes since the previous autumn, including installing more seismic stations to detect changes in earthquake patterns and magma movement. These groups then acted quickly once earthquakes intensified and the eruption started, working to ensure safety and scientific understanding at the site. Each new advance in the scientific understanding of the situation was published on social media and websites; police and other emergency personnel regularly communicated to the public about site conditions, closures, and new access routes; and the widespread use of social media sites and mobile phone coverage at the site allowed communication between locals and tourists. Determining the best parking location or sharing stories of expeditions to the volcano were ever-popular topics of conversation.

Earthquakes upended the daily lives of hundreds.

DESPITE THIS, THE Geldingadalir eruption was not without challenges. Due to the ongoing COVID-19 pandemic restrictions coinciding with its duration, hikers were encouraged to remain spaced apart while hiking—difficult to do with hundreds of other people also on the same narrow path. Iceland experienced an increase in tourism around the same time as the eruption started, and stories filtered through social media of foreign tourists foregoing testing and quarantine requirements in order to get to the volcano, thereby potentially putting others' health at risk. There were several instances of hikers not following posted health and safety precautions, including venturing into unsafe areas, being ill-prepared for weather conditions, getting lost at the site, or getting injured. The local environment was certainly impacted by the sudden arrival of humans wandering in nature; mountains that previously had little trace of humans teemed with people, machines plowing hiking trails, and noise. Local inhabitants dealt with hundreds of vehicles and thousands of people inundating an area that previously had no parking or other infrastructure or established hiking trails, in addition to the added concern about the eruption. The air quality was frequently degraded due to volcanic gasses, and the aforementioned earthquakes upended the daily lives of the hundreds of people living nearby.

PHOTO: JONATAN PIE/UNSPLASH

PHOTO: LEX MALONEY/UNSPLASH

ABOVE: **Hikers look out** at the lava field created by Fagradalsfjall.
LEFT: **On day 51 of the eruption,** visitors sit to observe an active fissure.

TRACKING THE FUTURE TO COME

THE GELDINGADALIR ERUPTION MIGHT BE ABOUT FINISHED, but Iceland is still volcanically active and will erupt again. Of particular interest now are the volcanic systems that lurk under Iceland's icecaps. Climate change is leading to accelerated ice melting—which has the potential to trigger more volcanic eruptions, as large ice masses press down on the surface, increasing the pressure on the underlying crust and mantle. When the ice later melts and the pressure on the subsurface releases, magma production intensifies. The last time Iceland experienced a deglaciation like the present one, approximately 10,000 years ago, the eruption rate increased tens of times higher than the current eruption rate due to this enhanced magma production.

Is this what awaits Iceland over the next few hundred years as the ice caps recede? If so, the resulting eruptions will impact the lives of Icelanders—and potentially people on a regional or global scale—for centuries to come.

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