Title: The story told by volcanoes about our past geological history

Author: Birgir V. Óskarsson

Abstract

Modern developments in the field of volcanology are revealing a geological record dominated by volcanic products formed in very large eruptions. The scale of these eruptions supersedes modern activity by several orders of magnitude. The implication of this volcanism is that geological activity in the past has not been uniform and that large-scale catastrophic events have played a significant role in shaping our earth. This fact is leading scientists to better constrain the origin and effects of this volcanism and to formulate models to better explain our past. These developments represent a shift in paradigm in geosciences which is significant for Christians exploring models of origins.

Introduction

Volcanology is an exciting field, and truly does involve scientists chasing volcanoes and sometimes literally running from hot glowing lava as portrayed in Hollywood movies. It is a field that studies volcanoes as the name indicates, both past and present, and involves many disciplines such as geology, geophysics, and geochemistry. Volcanology's objectives are to collect knowledge about the size and scale of volcanic eruptions, the types of volcanic activity, how volcanoes change with time, why they erupt, where they erupt and their impact. This information then helps us understand how our earth works and helps protect people from the hazard's volcanoes impose. Volcanic eruptions are in most cases catastrophic events, and thus have the potential of bringing about large environmental changes rapidly, but they can also be very efficient in 'freeze-framing history. Volcanic eruptions can bury habitats and environments in an instant, preserving that moment in history when these events took place. Advancements in the field of volcanology are interestingly imposing a challenge on two tenets of the conventional geological paradigm, *uniformitarianism,* and the *age of the earth*. Uniformitarianism is the concept that the geological record is primarily built by processes that resemble present processes. This paradigm is linked with *deep time*, or the concept that the geological record is very old and represents gradual development of earth and life. Christians on the other hand question aspects of these two tenets, for one if God exists, then miracles are possible and God could have created things rapidly and at His time, whenever that was. On the other hand, the biblical story contains a catastrophic event on a global scale named Noah's flood, and indeed many cultures around the world have records of a similar story. Such a catastrophe, if global, would involve processes that are not seen today, and many Christians hold to *catastrophism*, which is the concept that earth has been largely shaped by high-energy, large-scale catastrophic events. Because volcanoes are linked to catastrophes, and large-scale volcanism to catastrophism, volcanoes have drawn the attention of Christian geologists wanting to learn about how catastrophes happen and what catastrophic deposits look like, because of their implications for these big questions of origins.

How and where do volcanoes erupt?

In 1950's and 60's, scientists noticed that volcanic and earthquake activity were confined to specific areas and lineaments on earth's crust that delineated what would be known as plate boundaries, showing earth's crust was broken into several plates. With further mapping and measurements, it became evident that some plate boundaries that had grabens and volcanic ridges were moving apart from each other while boundaries with buckled and folded mountains along with volcanoes were colliding against each other and sometimes with parts subducting into the mantle. These movements and fractures appeared to generate the conditions for magma from below to rise and erupt at the surface. With additional constraints on the physical nature of the layers within earth's interior being worked out from geophysical measurements showing properties that could sustain these movements, the mechanisms necessary for plate movements were outlined, and the theory of plate tectonics was born (e.g. Frisch et al, 2022).

What do we know about the size of past volcanic activity?

In the conventional uniformitarian view, plate tectonic movements are always slow and steady and volcanic activity is restrained to the fractures created by these small movements. However, geological mapping in every continent has revealed large volcanic provinces or so-called Large Igneous Provinces (LIPs, Fig 1) with lava-flows and ash deposits covering enormous areas indicating volcanic eruptions that supersede modern activity by several orders of magnitude (Coffin et al, 2019; Ernst, 2014). This colossal type of volcanism is today well described in the scientific literature and large-scale lava outpourings are termed flood basalts (literally meaning lava flows that flooded large areas) and large-volume explosive eruptions expelling humongous volumes of ash are named supervolcanoes. The evidence that these were very large events is unambiguous from the scale of the lava flows. Single lava flows have been mapped to cover 100´s of kilometers and some ash deposits blanketing areas thousands of square kilometers with volumes in the order of hundreds to even thousands of cubic kilometers (Fig 2, e.g. Reidel et al, 2013). Modern volcanic activity typically results in lava flows and ash deposits with lengths in the order of only kilometers and volumes usually well below a cubic kilometer (Fig 2). The architecture of many flood basalt sequences can also be readily differentiated from small eruptions, showcasing stacks of widespread flat tabular sheets opposed to the thin and lobate layers created by small eruptions (Fig 3, e.g. Óskarsson and Riishuus, 2014). The implication of this volcanism is that they seem to suggest that conditions on earth generating magma have not always been uniform.

Although some of these LIPs coincide with plate boundaries, others are found in the middle of the plates not fitting the general pattern of conditions for generating volcanism by plate tectonic activity. Thus, studies on LIPs have revealed another mechanism for volcanism which is associated with narrow stems of hot mantle, or mantle plumes, and their chemistry suggests they originated from deep below even as far as the core-mantle boundary. Today models are showing that these plumes also fit into the story of plate tectonics and are interpreted to be related to “graveyards” of oceanic crusts that sank into the mantle from subduction zones and accumulate at the core-mantle boundary (Fig 4). These piles gave rise to pools of hotter and less dense mantle that can rise by buoyancy in these narrow stems or plumes and create volcanic anomalies on the surface (Tronnes, 2010). Some plume activity is still seen today as in Iceland, Hawaii and the Reunion islands, but notably, many of these plumes when they first reached the surface, erupted colossal volumes of lava, forming the LIPs.

What do volcanoes teach us about rates of geological processes?

Volcanic products are treasure troves of information about the environment from which they erupted. Different types of volcanic products and edifices indicate whether they erupted under water, glacier or dry air andthe minerology and composition of lava flows and ash give us information about the journey the magma took through the crust, the inner composition of the earth and thus shedding light on how our earth operates.

Volcanic eruptions are complex events that have within them a range of processes, both constructive and destructive. Constructive processes accumulate piles of volcanic material in relatively short time spans, the volume reflecting the scale and magnitude of the eruptions. Destructive would be the erosive processes that follow explosions, earthquakes and collapsing ash plumes. Moreover, rapidly emplaced volcanic ash and lava fragments forms unstable landforms that are easily reshaped by gravity, wind and water shortly after deposition. Magma intrusions into the volcanic piles activate geothermal activity which can transform areas into hard rock and fill cavities with secondary minerals rapidly. If the eruption takes place in water bodies or under glaciers, cooling rates are enhanced. In addition water can mobilize and rework the volcanic products rapidly and form sedimentary layers along with the piles of lava and ash. Water can also escape catastrophically and erode canyons and gullies rapidly. Even ash deposited into the sea has been observed to trigger algae blooms. This diversity of processes, landforms and products arising from volcanic eruptions has opened the eyes of many scientists to the fact that several formations in the geological record previously thought to have formed separately, can be linked to the same catastrophic events with short duration.

One exceptional place to see this diversity of processes in one volcanic eruption is Surtsey island, on the south coast of Iceland. Surtsey formed in a volcanic eruption in 1963-67 and built an island of ash and lava flows with an initial area of 2.6 km^2 and subaerial volume of 0.1 km^3. The island, despite a young age, looks very much like an old island. The coastal areas are marked by high and steep cliffs, geothermal activity has altered the core of the ash mounds into hard rock, reworked sediments drape the sides of the mounds, the boulders on the coast are rounded, numerous gullies cut the sides of the hills, old tree trunks that weredriftwood, stick out of the eroded ash mounds, and even human boot tracks from early visitors are hardened into the rocks (Esperante and Óskarsson, 2023). With intense coastal erosion and wind erosion the island has decreased significantly in size and today its area is only 1.2 km^2 with volume of 0.07 km^3 which is about half its initial size(see Óskarsson et al, 2020).

Where is time in the old volcanic sequences?

Volcanoes issue lava flows and ash that bury the surrounding environments. When this happens, the local environment is captured in the state it was. It is well known that rocks on the surface degrade quickly, with the development of soils and vegetation and if buried quickly would preserve this past evidence of the passage of time. Volcanic rocks also have unstable radiogenic elements that decay with time and are used by scientists as clocks to date the rocks. Scientists are noticing that in between lava flows in LIPs, where radiometric ages place hiatuses of tens or even hundreds of thousands of years, the surface of the lava flows are pristine showing little or no signs of degradation, lacking evidence of prolonged periods of time. Even fragile and porous components of the crust are perfectly preserved (e.g. Óskarsson and Riishuus, 2014). Sediments in between lava flows are sometimes interpreted as soils, however under scrutiny many show evidence of having formed in the very same events that produced the lava flows as described above. Vegetation found in these layers are only incidental and could have easily been transported in place from other localities during these same catastrophic events and do not have to have grown in situ. This relative assessment of time that contradicts the ages that are derived from dating the rocks, is a convincing argument for geologists to not rely on radiometric ages as absolute ages, but rather only relative ages when the ages give an order. Hence, Christian geologists think that rigorous scientific work needs to be conducted to resolve this apparent contradiction between relative and absolute ages.

Making sense of the past

In the geologic record, volcanic activity on the scales of flood basalt volcanism is more a rule rather than an exception. We all know the difference between a small wound that bleeds after a cut and a hemorrhagic state after a serious accident. In the same way, if evidence of colossal volcanism is persistent throughout the geological record, that would indicate the earth has undergone a serious hemorrhagic state in the past. Our understanding of large-scale volcanism is challenging the uniformitarian paradigm and shifting it to a catastrophic paradigm. Knowing that diverse processes are triggered by volcanism, large-scale events are expected to have impacted other systems in catastrophic ways. However, the current paradigm still relies heavily on dating methods that separate these catastrophic events by eons of time. With evidence now availble that seems to indicate that many of these events may be interconnected and that there is something wrong with the radiometric dating system, Christians (and possibly others) are seeking for a unifying theory that explains this colossal volcanism and other geological phenomena in the context of a shorter timeframe. One model being explored is named Catastrophic plate tectonics (Austin et al, 1994; Baumgardner 1994; 2016). This model incorporates the components of the traditional model of plate tectonics but postulate that the plate movements occurred catastrophically and therefore rapidly. The idea of rapid movements of the continents had interestingly been mentioned in 1858 by a French geographer and scientist named Antonio Snider-Pellegrini, being one of the first proponents of continental drift (Snider-Pellegrini, 1858). In his model he suggested that the rapid movements of the continents happened during Noah's flood. This is also the consensus of many Christians, and in the modern synthesis of catastrophic plate tectonics, besides these rapid movements, colossal volumes of magma would have been released forming the ocean floors. Mountain ranges would have formed rapidly by colliding plates, oceanic crusts sank rapidly into the mantle and down to the core generating plumes that rose to erupt at the surface forming the LIPs, tectonic movements eroded the continents and sediments were mobilized by tsunamis upland destroying the animals and plants that were potentially distributed after well defined paleoecological habitats burying them sequentially as the lands were being inundated,explaining the order of the fossil record. Massive amounts of greenhouse gases were emitted polluting the air and the oceans. All of these events greatly impacted earth and life in multiple ways including setting in motion environmental challenges resulting in a great mass extinction. The aftermath was a prolonged period of post-cataclysmic adaptation that encompassed periods of climactic instabilities that culminated in the Ice age, and minor and more local catastrophes.

Conclusion (Learning from catastrophes)

Despite the fact that a geological model like 'catastrophic plate tectonics' may have good explanatory power, much remains to be explored and further research is needed. Nonetheless the Biblical paradigm of catastrophism is paving the way for predictions that are in line with the direction where earth sciences seem to be heading. A correct understanding of the catastrophic past is of extreme importance for understanding current challenges involving geological phenomena, not to mention how hazards are assessed and mitigated. One of the consequences of the uniformitarian view is that people tend not to see the true scale of these past events, and thus their effects are diluted within the massive time spans believed to be associated with them. However, our experience with rates of geologic phenomena is that they are usually much more rapid than anticipated. This perception should be even more valued now as human populations have increased across the globe and in particular in areas of natural risks (e.g. around active volcanoes or seismic areas) and the effect of human habitation and activity on earth's vital systems are becoming more evident. Thus, studies on catastrophes and our catastrophic past can be a major contribution of Christianity to the modern science enterprise, providing a framework that more closely reflects the geological past. This improved understandingwill enable society to better mitigate future catastrophes, both natural and anthropogenic. Importantly together with conducting cutting edge scientific discoveries, the Christian can bring a message of hope in a Creator that will one day make all things new. Despite our tectonically broken world and our dreadful catastrophic past, we can rest assured that God is our refuge and strength, therefore we will not fear, the Lord is with us, He is our fortress (Psalm 46:1-2; 7).

Figures:

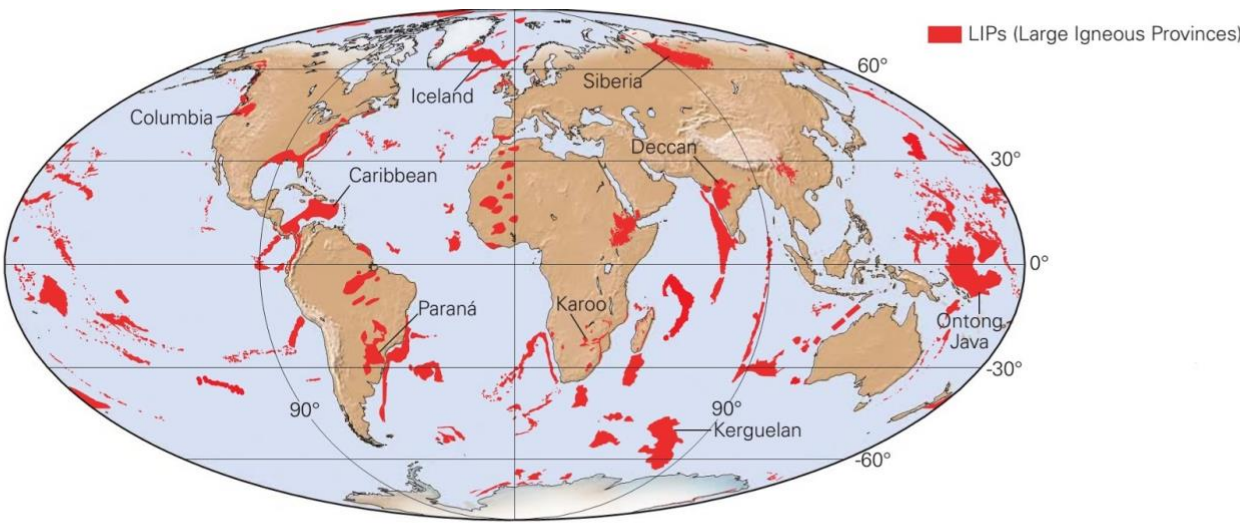

Figure 1 Map showing the locations of the Large Igneous Provinces (LIPs, red fields). Courtesy: NEED to find reference

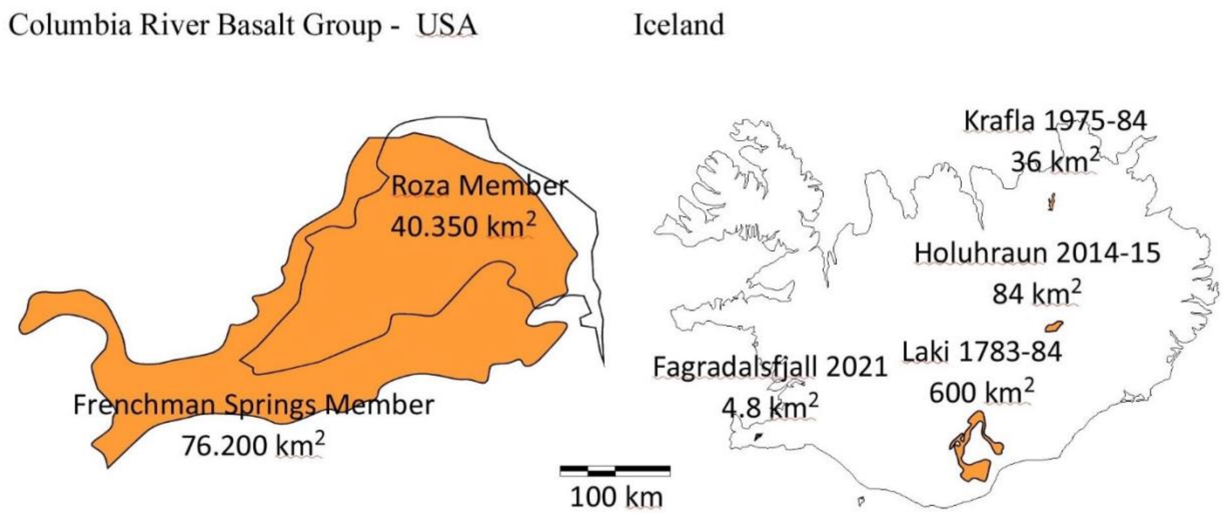

Figure 2 Comparison between pre-historic lava flows within one of the smallest LIPs in the world, the Columbia River Basalt Group, USA (see Fig 1), and four historical lava flows in Iceland. The Laki 1783-84 eruption is considered one of the largest eruptions on earth in modern times, yet it is dwarfed by the lava flows of the Columbia River Basalt.

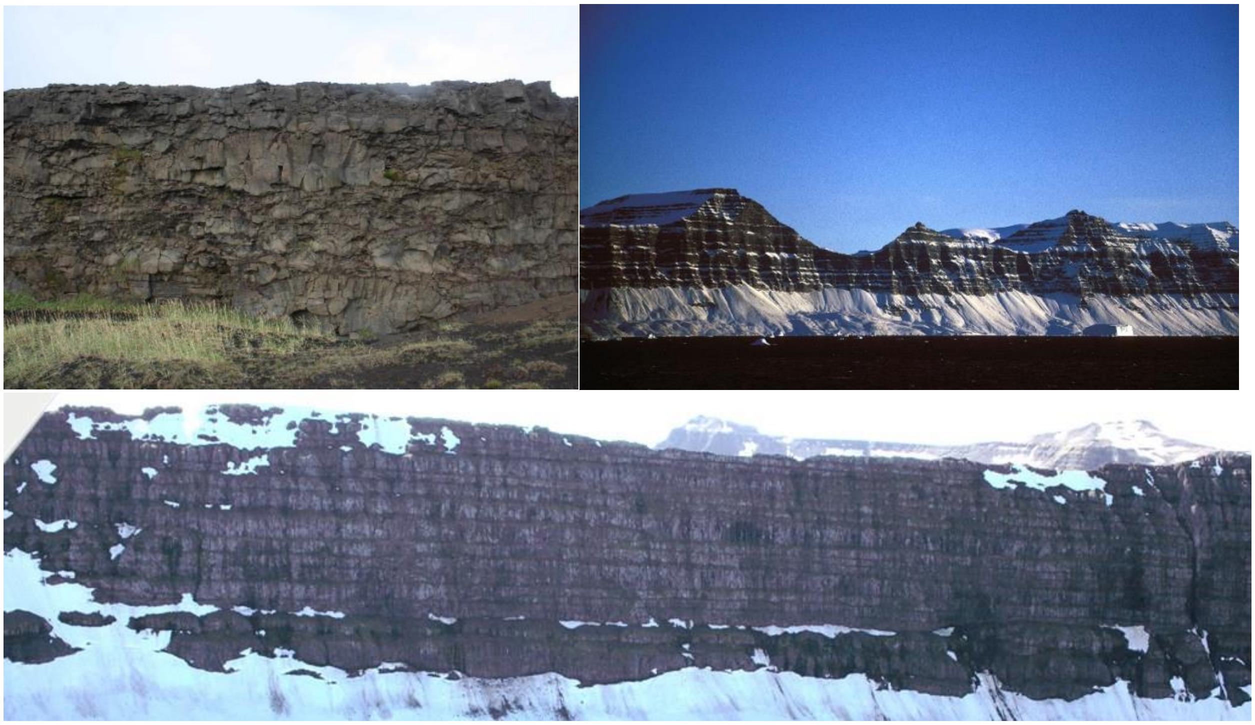

Figure 3 (Upper left) Wall of meter-size lava lobes formed in small eruptions in Iceland. (Upper right) Stacks of km-long pre-historic lava sheets in east Greenland from very large flood basalt volcanism. (Bottom) Pre-historic km-long lava sheets formed in flood basalt volcanism in Iceland.

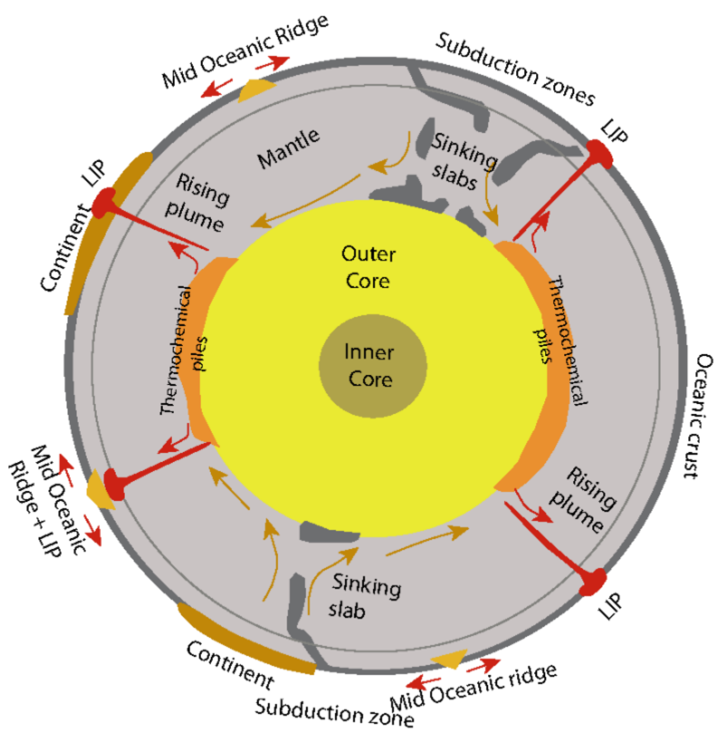

Figure 4 Schematic illustration of the structure of the earth and its relation to plate tectonics. Note how oceanic plates at subduction zones can sink to the core-mantle boundary and give birth to mantle plumes that rise to the surface pinching the crust and forming volcanic anomalies that are associated with LIPs. The origin of thermochemical piles at the core-mantle boundary is not entirely understood but some think they may be graveyards or oceanic slabs. Adapted from Tronnes, 2010.

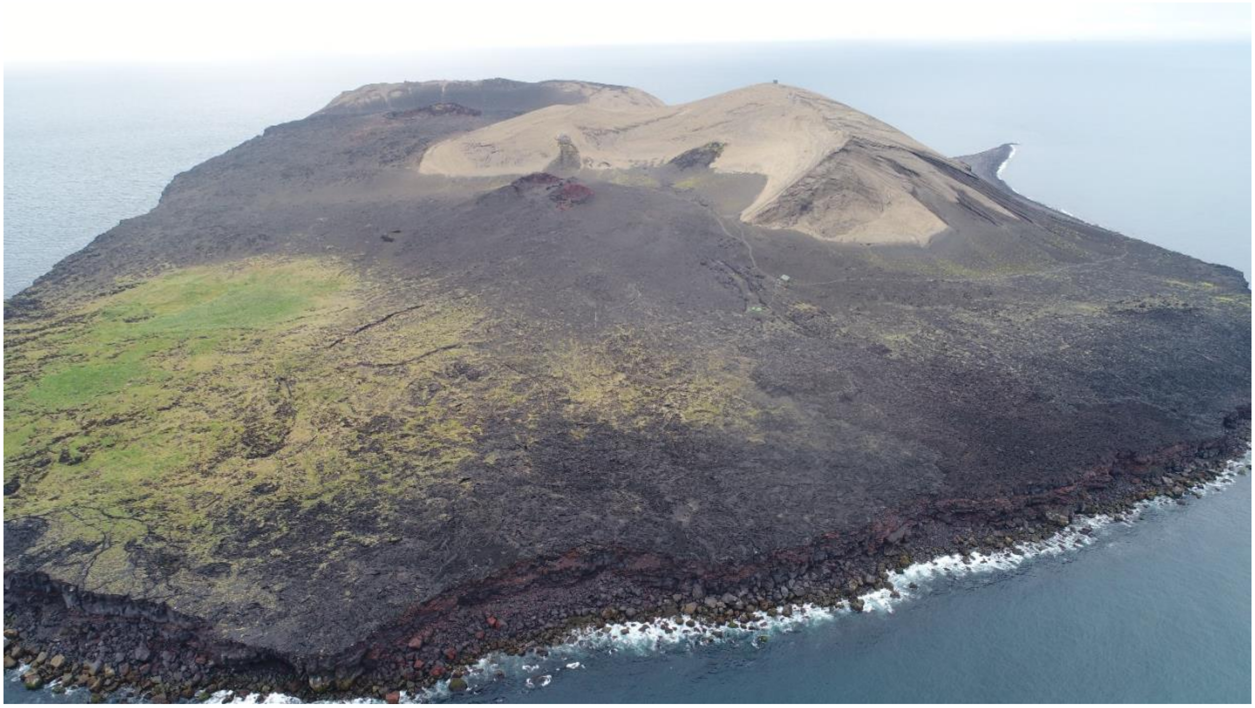

Figure 5 Surtsey Island in south Iceland. The island formed in a volcanic eruption in 1963 to 1967. Despite a young age many features in it make it look like an old island.

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Image Fig 3 flood basalts in Greenland: https://commons.wikimedia.org/wiki/File:Greenland-plateau-basalt_hg.jpg