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Résumé de l'article

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The Eldfell Eruption, Heimaey, Iceland: A 25-Year Retrospective

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SUMMARY

The Eldfell eruption commenced on 23 January 1973 as a 1.5 km fissure crossing the island of Heimaey. Many houses close to the main vent were destroyed by pyroclasts before a flank collapse of the volcano in February allowed lava to move into the town. The Icelanders responded by spraying seawater on the lava, finally stopping the advance less than 100 m from the port quaysides. During the eruption period, which lasted until early June, more than 400 establishments were destroyed by tephra fall and lava. The residents of Vestmannaeyjar (~5300 persons at the start of the eruption) were safely evacuated by trawlers and an airlift. Today (1999) the town has approximately 4800 inhabitants, and a thriving post-eruption economy.

RÉSUMÉ

La première manifestation de l'éruption du volcan Eldfell a été l'apparition d'une fissure de 1,5 km de longueur en travers de l'île de Heimaey. De nombreuses maisons situées à proximité du principal évent ont été détruites par des projections de pyroclastes avant que l'effondrement d'un flanc du volcan en février ne permette à la lave d'envahir la ville. En arrosant le front de laves avec de l'eau de mer, les Islandais ont réussi à stopper la poussée de lave à moins de 100 m des quais. Durant la période d'éruption qui a duré jusqu'en juin 1973, plus de 400 bâtiments ont été détruits par des laves et des projections volcaniques. Les résidents de Vestmannaeyjar (environ 5 300 personnes au début de l'éruption) ont été évacués par chalutiers et par pont aérien. Aujourd'hui (1999), la ville compte 4 800 habitants et son économie est florissante.

INTRODUCTION

This article is a synopsis of a lecture presented as part of the E.R. Ward Neale Tour for the Geological Association of Canada during the fall of 1998 and the winter of 1999. It summarizes the principal geological factors and some sociological elements of the Eldfell eruption in Iceland between January 1973 and July 1998.

My interaction with the Westmann Islands commenced in 1960, when, as a high school student, I sailed through the archipelago and first saw Heimaey. Ten years elapsed before I returned in 1970, participating in observations on the uninhabited island of Surtsey. Over the course of the next 25 years I returned to Heimaey many times; three visits in 1973, and one each in 1974, 1983, 1990 and 1998. During these various visits I had the opportunity of documenting the changes on the island. These commenced with the production of a short documentary film "The Heimaey Eruption: Iceland 1973" for the CBC program *The Nature of Things* (October 1974), and continue today.

Many volcanoes have affected the populace of Iceland since the days of the first Viking settlers *ca.* 874, but with a few exceptions, the damage was usually confined to individual farmsteads or small settlements. The Heimaey eruption was the first in almost 100 years that necessitated the evacuation of large numbers of people.

The 1875 Plinian eruption that initiated the Öskjuvatn collapse within the Askja caldera (Fig. 1), and that culminated in the phreatic eruption of Víti (Hell), was the last major eruption that adversely affected the Icelandic populace. It forced, perhaps, several thousands of citizens away from Iceland and directly forged a special bond between Iceland and Canada, since many of the emigrants settled in Manitoba. Earlier outpourings of basalts in Sveinagjá on the 100 km-long Dyngjufjöll fissure region north of Askja preceded the main eruption within the Askja caldera and heralded the last century of activity in the eastern sector of the neovolcanic zone.

The easternmost volcanic belt of Iceland has been far more active than the westernmost belt (Fig. 1) from post-glacial time to the present. In historic and recent times eastern belt eruptions have averaged approximately once every 5 years. The most active volcano is Grímsvötn under the Vatnajökull ice-sheet. There was a relatively long pause in volcanic activity in Iceland between the eruption of Grímsvötn in 1934 and of Hekla in 1947, and again between 1947 and 1961 when Askja erupted. In the 12 years between 1961 and 1973, eruptions centred principally on the Westmann islands off the south coast.

The Westmann archipelago, consisting of the remains of nearly 30 volcanic centres, saw the birth of four volcanoes in an almost unbroken decade of activity — Surtsey 1963, Jólnir and Syrtlingur 1965, the re-eruption of Surtsey (1966-1967), and Eldfell in 1973. Hekla (1970), a mainland exception, also erupted in this same time frame. Activity since 1975 has been in the region between Hekla (1980, 1990, 1991), Krafla 1975-84 (a total of nine short volcanic outbreaks), and Grímsvötn. Recent, spectacular, sub-glacial eruptions beneath the Vatnajökull have been provided by Grímsvötn (1983 and 1998), and Gjálp (north of Grímsvötn) in 1996 (Fig. 1).

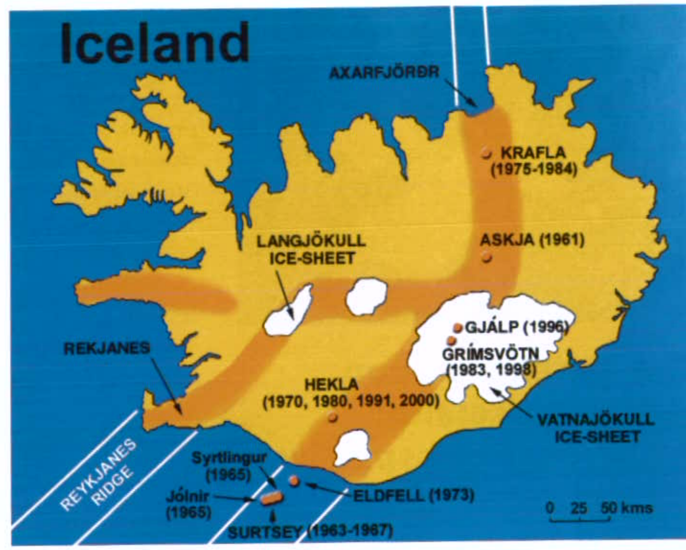
The Start of the Eldfell Eruption: 1973

The eruption of Eldfell was unexpected, and there were no obvious advance warnings. It is possible that a cluster of small earthquakes (focus *ca.* 20 km) nearly beneath Heimaey two days prior to the eruption may have marked the initial movement of magma toward the surface. However, this conclusion is contested by others who cite the two recording seismometers as alternatively giving a solution beneath Torfajökull, a seismically active area on the south coast of Iceland.

A fissure approximately 1500 m long split the eastern half of Heimaey at about 1:55 a.m. on the morning of 23

Figure 1 (at right) Location and dates of Icelandic Eruptions 1970-2000. The Westmann Archipelago is situated about 10 km south of Iceland. The volcano Eldfell is on Heimaey, the largest northern-most island of the group. Surtsey is 20 km south of Heimaey and is the southernmost island in the Archipelago. The straight white lines approximate the position of the spreading ridge. The south-western ridge axis is the Reykjanes Ridge. The Northern Ridge extends from the north coast near Tjornes into the Atlantic from Axarfjörðr.

The orange areas on the mainland indicate active volcanic regions (the neovolcanic belts of Iceland). The western belt runs from Reykjanes north to Langjökull ice-sheet. The eastern belt runs from the Westmann Islands, north through Askja and Krafla. The principal eruption centres are indicated as red spots. White areas represent the various ice-sheets of central Iceland.



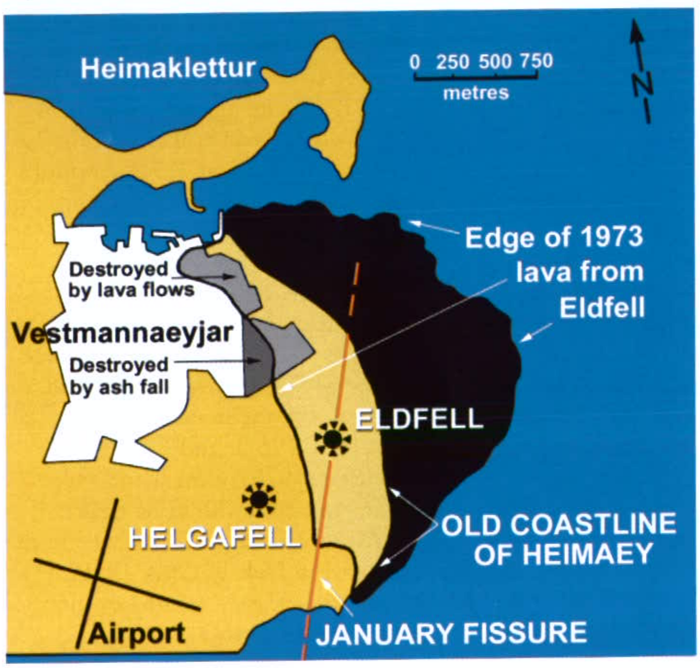


Figure 2 The initial fissure, the position of the new volcano Eldfell and the old volcano, Helgafell; the 1973 lava field from Eldfell and damaged areas of Vestmannaeyjar.

Figure 3 Clearing ash from flat rooftops was a priority for rescue workers. Individuals or small groups of people helped to clear rooftops closest to the volcano.

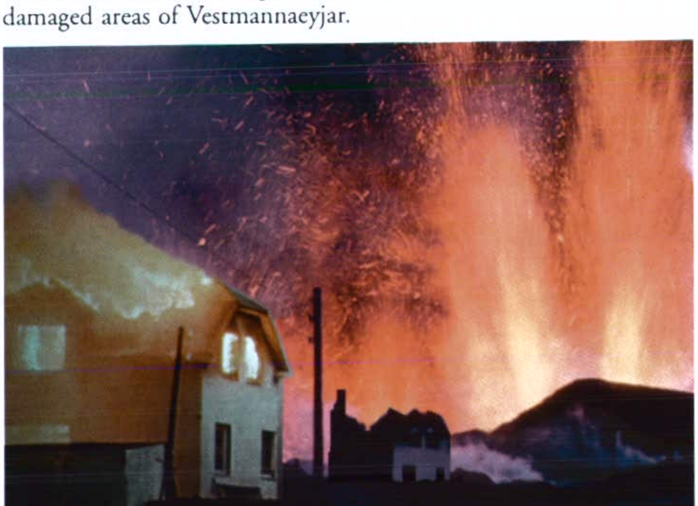


Figure 4 Houses closest to the vents were destroyed by fires created from hot volcanic bombs breaking through windows or roofs.

Figure 5 The lava advance into the town destroyed several hundred buildings including reinforced concrete structures in the harbour area. Cooling hoses can be seen on the lava front in the centre of the photograph.

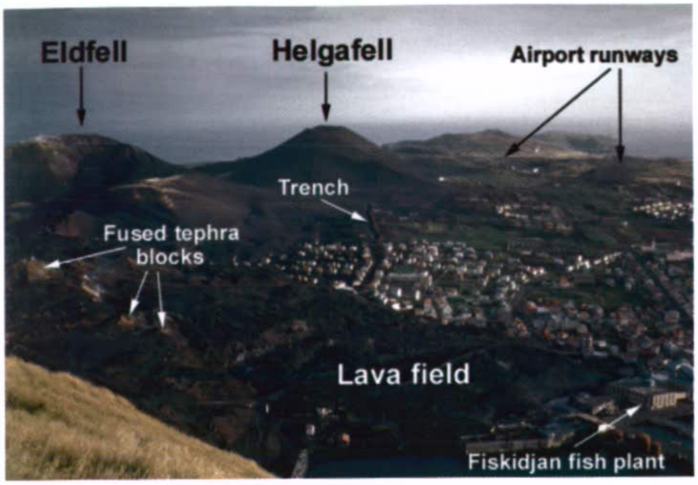
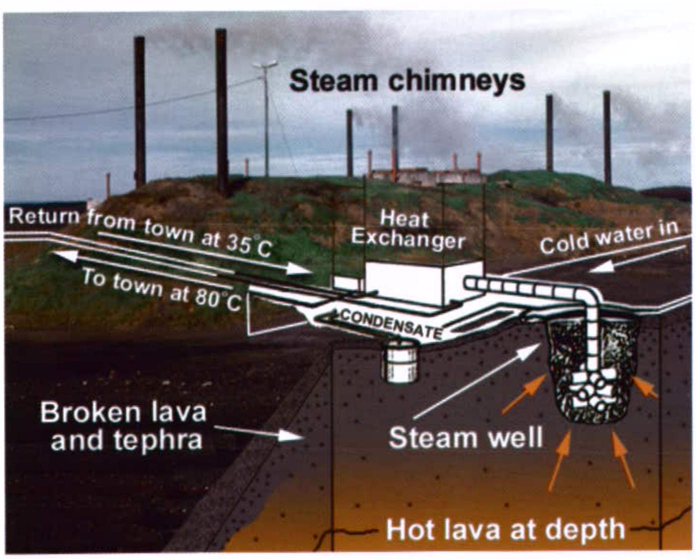


Figure 6 View from Heimaklettur into Vestmannaeyjar illustrating the extent of the lava field, the Fiskidjan plant and the trench cut to divert gas from the town.

Figure 7 Temporary housing in west Vesmannaeyjar, August 1974.



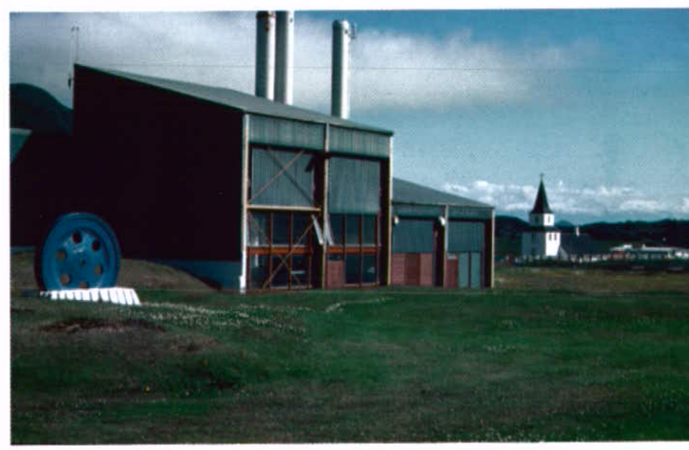


Figure 8 (**at left**) Photo/diagram schematic through one of the Vestmannaeyjar heating units.
Figure 9 (**above**) The geothermal water distribution plant in central Vestmannaeyjar.

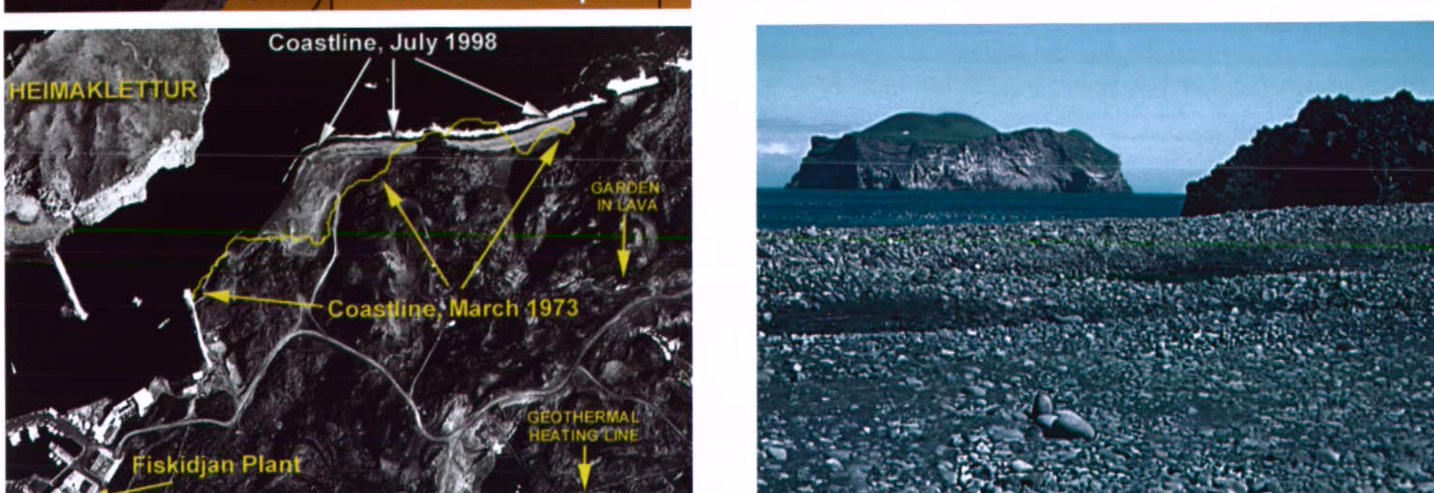


Figure 10 Broad beaches now project beyond the lava front east of the harbour entrance. The aerial photograph (**left**) illustrates the coastline in March 1973 and in July 1998. Substantial new beaches (arrowed) are now present and the photograph (**right**) is taken in the position of the central arrow in "Coastline, July 1998"). The aerial view also illustrates the position of the Fiskidjan Plant, the garden in the lava field, and part of the geothermal heating line running into the town. Figure 10 (left) is courtesy of Landmælingar Íslands.

January 1973. S. Thorarinsson (personal communication, 1973) reported that the initial fissure could have been as long as 3.5 km when submarine extensions both north and south of the sub-aerial fissure were taken into consideration (Fig. 2). The opening fissure did not cause any earthquakes, and the population of Vestmannaeyjar was unaware of the eruption until woken by police or neighbours. In the first hours of activity approximately 30-40 vents were ejecting pyroclastic materials to a height of about 150 m. Nearly 5000 inhabitants left Vestmannaeyjar on the Westmann trawler fleet between 3 a.m. and 7 a.m.

Twelve hours after the start of the eruption the fissure had shortened to approximately 600 m, and this contraction process continued during the first week until only three vents were active. After three days, approximately 35 million m^3 of lava had covered about 1.35 km^2. In the first seven days about 50 million m^3 of lava were extruded. Flow rates were estimated from 100 $m^3 \cdot sec^{-1}$ at the start of the eruption, falling to $80m^3 \cdot sec^{-1}$ after the first day (Thorarinsson *et al.*, 1973). Lava temperatures were measured at 1050°C. Most recently, Th. Einarsson has provided estimates of initial flow rates as high as $500m^3 \cdot sec^{-1}$, falling to about $5m \cdot sec^{-1}$ in the last days of the eruption in late June (Th. Einarsson, personal communication, 1998).

The initial basalt lava had a composition between Hawaiite and Mugearite, with occasional xenoliths of gabbro presumably reamed off the conduit at depth beneath the volcano. The "fire fountains" along much of the fissure in the first few days reached heights of several hundred metres. These terminated as the main vent centred on Eldfell. More violent explosive activity at the main vent led to the production of large quantities of tephra, and a pyroclastic cone *ca.* 150 m high in the first 10 days of the eruption. A large block lava field was extruded on both sides of the northern two-thirds of the fissure (Fig. 2). Fine ash in the eruption cloud reached 9 km above the island, and at the end of the first week approximately 2.5 million m^3 of tephra had fallen on the town. Ash thicknesses were up to 6 m close to the volcano and 0.5 m in west-central Vestmannaeyjar, about 1.5 km from the main vent.

From an engineering viewpoint the town was threatened in three ways. The first was tephra that fell onto roofs, which had not been constructed to take heavy loads. Most rooftops that collapsed did so after the ash (S.G. 1.0-1.3) had reached depths of 75-100 cm. The highly vesicular ash was able to take up large quantities of rainwater, and under the adverse winter weather this quickly became a serious concern. Roof collapse occurred when ash amounted to *ca.* 1000 $kg \cdot m^{-3}$ (*ca.* 250 $lbs \cdot ft^{-2}$). The response was to shovel rooftops and provide interior roofing supports before the ash became too heavy. High sloping roofs were able to shed ash by themselves; the more contemporary low-angled rooftops of private housing and the large-area flat roofs in the fish plants and factories provided the greatest problem. Groups of workers, sometimes using small tractors, removed most of the rooftop ash within the first two weeks.

Considerable damage came from large bombs (up to 250 kg) thrown through the windows and rooftops of the houses closest to the vents. Bombs up to 25 kg were hurled more than 1 km from the volcano into the town under prevailing winds. The pyroclastic fragments often set fire to the interior of the houses, when they broke open after impact. This threat was compounded by tephra fall covering the fire hydrants in the streets of Vestmannaeyjar. The Icelanders responded by barricading all the windows and doorways in the town facing the volcano. Using galvanized steel sheeting, 14,000 sheets were placed in position within the first 10 days of the eruption.

The hazard that ultimately caused the most damage was the lava advance. By the end of the first week, ramparts of ash were under construction to divert the lava flows from the eastern section of the town (Fig. 2). Unfortunately, the flows either pushed the barricades in front of them or overrode them. Cooling attempts from fire hoses were made at the end of the first week of February. Although not very effective, these initial efforts were continued on a larger scale, and by late February and early March there were teams involved in cooling various sectors of the lava front. The technique involved the solidification of the lava forming a dam, thus preventing the movement of the liquid lava behind. Fluid lava that overrode the dam was in turn cooled, adding to the barrier.

Efforts made to halt the lava advance were essential because of the danger to the town, and more particularly, the harbour entrance. On 19 February, the north-west part of the volcanic cone began to collapse. The following day a landslip of partially solidified tephra and lava destroyed houses in the easternmost section of the town (Fig. 2). The collapse of the cone produced several large masses of fused tephra that floated on the lava. The largest of these was approximately 200 m x 200 m x 45 m (above the surface of the lava flow) with the exposed portion weighing nearly 2 million tons. These rock masses moved distances of up to 30 m per day until they finally grounded more than a kilometre from their original position (Fig. 6). The principal effect of the cone collapse was to allow lava streams to move toward the northwest.

Later Developments in the Eruption

The Icelanders were fortunate in the location of the initial fissure. The lava streams emerging from 23-24 January to 4 February principally flowed east and north. Between 4 and 9 February the flows moved to the northwest with a maximum advance on 6 February. This advance ruptured a submarine electrical power cable and a 15-cm water pipeline from the mainland. An older 10-cm water pipeline survived, and diesel generators on the island took over electricity production. Because Heimaey has no ground water supplies the local government laid water pipelines from the mainland in 1966-1968 and also in 1971. From 9-19 February the flows were again directed to the northeast, but from 19 February to 4 April, the flows reverted to the northwest. A second major advance lasting from 22-26 March demolished a large section of the northeastern part of the town and came close to destroying the port facilities. This lava advance destroyed more than 200 buildings in the town before it was finally stopped less than 100 m from the quayside (Fig. 6). During the eruption period more than 400 establishments were destroyed by the tephra fall and the lava advance, including one fish processing plant. Two other processing plants were damaged. The lava advance into the town ceased on 4 April 1973.

Pumping large quantities of seawater onto the leading edge of the lava field appears to have been successful in diverting and/or halting the lava advance in many areas. From the inception of pumping in early February the number of pumps was increased to combat specific advances. On 6 March the south breakwater was almost over-ridden. The town fire brigade together with water pumped from the vessels Sandey and Loðsinn succeeded in stopping this advance. In late March, 38 large pumps arrived from the United States and these were used to cool the lava front from the extreme northwest advance position near the Fiskidjan fish plant, eastward along the northern edge of the lava field. Th. Einarsson (personal communication, 1998) reports that more than 6 million tons of seawater were pumped onto the lava flow.

Another major problem created for the rescue workers occurred when noxious gas concentrations began to build up in the town. There were high concentrations of volcanic-derived CO_2 (90-98%), CO (1%) and hydrogen, methane, oxygen, nitrogen and argon. Gases were first noticed in mid-February in low-lying areas. By March, concentrations began to rise, particularly in the basements and cellars of buildings. In early April the lower sections of the town were sealed off, and health authorities continuously monitored gas levels in case the evacuation of rescue teams became a necessity. The only fatality during the eruption was a person overcome by gas in a basement. The gas was probably derived from the crater of Eldfell from which the gas seems to have made its way into the town by flowing over and/or through the lava field and tephra-covered areas. Large quantities of steam flowing out of the old Helgafell lava flow damaged many houses. In order to minimize steam damage and to prevent the danger of gravity flow of gas into the town, a trench was dug running from the lower northern slopes of Helgafell toward the westernmost margin of the lava front in the centre of the town (Fig. 6).

The Heimaey eruption stopped 5 months and 5 days after it started. The island grew by approximately 2.2 km^2, and the output of volcanic products was calculated at approximately 250 million m^3. Probably about 20-25 million m^3 was ash, the remainder being lava. The last activity in Eldfell was on June 28 and the last lava flow was observed on 28 June 1973.

Social and Economic Effects of the Eruption

Although the Heimaey eruption was a financial disaster of the first magnitude for Iceland, it could have been considerably worse in monetary terms and particularly in loss of life. If the fissure had opened up several hundred metres further west, the number of people killed would have been in tens or possibly hundreds. Had the eruption started in the middle of the day, or if the wind had been blowing from the east, there could have been more casualties. As it was, families were together at home, the whole of the Westmann fleet was in port and winds were confined to a slight breeze. The population of Vestmannaeyjar was evacuated from Heimaey within 6 hours of the start of the eruption by the fishing fleet and by Icelandic civil and American military aircraft from Keflavík. The boats landed at Þorlákshofn (Thorlakshofn) in south Iceland and the refugees were transported to Reykjavík by busses. Five schools in the capital acted as reception centres and later that day the 5000 evacuees (about 2.5% of the Icelandic population) had been placed with relatives or friends in the region. There were no casualties or injuries in this phase of the operation.

The 200-300 people who elected to stay on the island of Heimaey began evacuating the belongings of islanders whose homes were situated close to the vents. This same group rotated with volunteers from Almannavarnir Rikisins (the Icelandic civil defense force) and other groups from the mainland during the 5-month eruption period.

Throughout the eruption there was a tremendous sense of determination not to "give in" to the volcano, almost as though it had become a human adversary. As early as the fifth day of the eruption, people were talking of selling the ash (as a light-weight construction aggregate) to European and/or North American companies. This never happened, but the ash was evaluated and finally used as fill in different parts of Heimaey. There was also conjecture as to whether the harbour would be better because of the new lava field. To a degree this proved correct, but later marine erosion and sediment transportation created a different type of problem as outlined below.

Aid came to Iceland from many countries, but particularly the Scandinavian bloc (approximately US$15 million). Prefabricated houses (550) were bought from Scandinavia and Canada and erected in southwest Iceland to house the evacuees. Almost $25 million was spent on Heimaey paying for the rescue work, road construction, new houses, apartments and businesses. The total cost of the eruption was close to US$100 million. When one considers the population of Iceland (210,000) the cost per family was quite considerable.

The last lava flowed into the town on 4 April. Within days a roadway was graded onto the surface of the flow and the water pipes were laid to cool this northwestern sector of the lava field. The tephra clearing operations started in April. By October more than 1.5 million m^3 had been removed. The ash was used in extending the Vestmannaeyjar airport runways (Fig. 6), and providing new roads and the bases of new houses in the western section of the town. Fertilizer and grass seed were dropped onto ash areas from aircraft in May and June. By July, 40 families had returned and by November more than 2000 people were again living on Heimaey. More than 3500 had returned to the island by July 1974.

By late 1974 the new housing areas were nearing completion (Fig. 7) and many of the streets in the town blocked by the lava advance had been cleared. The harbour entrance had acquired a large natural breakwater from the lava field and the port approaches (especially treacherous during winter gales) had been fortuitously improved. The cone of the new volcano and the high lava front averaging 40 m to a maximum thickness of more than 100 m, provided shelter to the town from the predominant southeasterly winds. In summary, the islanders made a remarkable and rapid recovery, largely due to their own persistence and tenacity in the

Figure 11 Comparative general views from the summit of Helgafell toward the harbour area. The July 1973 view (**left**) shows the still-venting gas and steam trench and the generally black, tephra-strewn landscape. In the July 1998 photograph (**right**) Helgafellsbraut and new housing occupy the lower slopes of Helgafell.

Figure 12 Intersection at the main bank. Note that the chimneys used in 1973 (**left**) for oil heating had vanished well before 1998 (**right**). A pub has replaced the grocery store. The lava front visibly blocking the street in 1973 has been removed and graded.

Figure 13 The garden in the lava field. This illustrates that even the most inhospitable parts of the lava flow can be converted into pleasant surroundings.

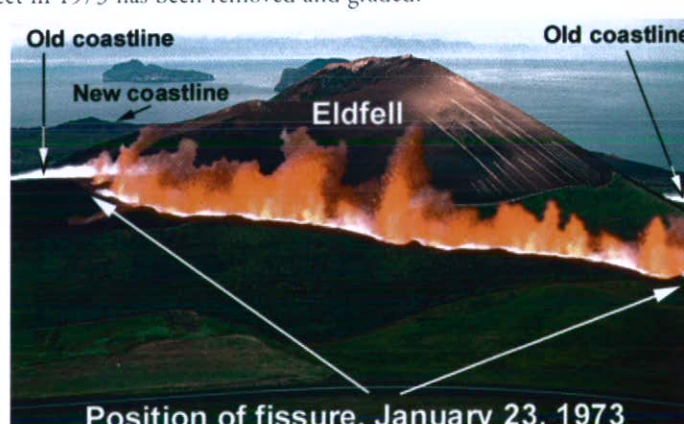


Figure 14 Comparisons of Eldfell in January 1973 and July 1998. The 1973 fissure is shown inserted "within" the 1998 profile of Eldfell. The 1973 coastline is marked as "Old coastline" and the "New coastline" (of 1998) is also shown. Both photographs are taken from the summit of Helgafell with the two distant islands used as registration points to "anchor" the respective images. The lines running toward the summit of Helgafell are the windbreak fences mentioned in the text.

face of what must be one of the most frightening natural phenomena on Earth.

Heimaey and Vestmannaeyjar Post-eruption

Following the eruption in 1974 S. Jónsson and H. Johnsen from Orkustofnun, the Icelandic National Energy Authority, began an evaluation of the new lava field from Eldfell for hot-water heating of homes in Vestmannaeyjar. By mid-summer of 1975 a proposal to establish a test facility was submitted and eight homes were placed on a small hot water loop. By 1976 a small pilot facility was constructed equivalent to a 0.5MW heating plant, and late that same year an additional 25 houses were added to the heating loop.

A larger proposal to develop the lava field for geothermal energy came in 1978. Between 1979 and 1982 approximately 19MW of heating was added in four phases of construction. The projections for the geothermal field suggested a minimal useful lifetime of about 12 years (lasting until about 1989).

Figure 8 illustrates a typical heat exchange unit on the lava field north and east of Eldfell. A number of wells were excavated to the surface of the hot lava, about 6-8 m below ground level. A typical well was filled with concrete tubing and tephra and capped with plastic sheeting. Steam generated in the well passed to a heat exchanger where fresh water was heated to 80°C. The hot water was then pumped to the central station in the town (Fig. 9) for distribution to homes and businesses. The return water in the loop arrived back at the geothermal field at 35°C. A cold water feed allowed condensate to form and this, together with some fresh water, was allowed to penetrate the ash to provide new steam generation.

The geothermal field lasted almost as predicted, and technically ceased significant input to the town in the summer of 1989. Heating of the town has continued to a minor extent from the lava field, supplemented by electrical heating of the water (there is lots of cheap hydro-electricity in Iceland) and a partial addition from "waste" heat from the town incinerator placed in the lava field. The eruption assisted the residents of Vestmannaeyjar in breaking away from the conventional oil-fired, individual home, heating systems to a central water-heating system. Although this used the surplus heat generated from the lava field it was an easy transition to adapt to a hot-water system heated by cheap electricity from the mainland.

It is possible, however, that the history of geothermal power on Heimaey might change again. The latest thoughts on the potential geothermal power on the island is that a deep borehole, perhaps to 1.5 km or 2 km in depth might provide a renewed and more permanent heat source for the town.

Like the geothermal field, other features on Heimaey have gradually changed with age. Some of these changes are subtle and not easily noticed. The summit height of Eldfell for example, is about 18-20 m lower than it was at the close of the eruption. This has presumably been caused by physical compaction of the summit tephras, probably combined with slumping inside the crater and a degree of mass movement on the outer crater walls. The Icelanders have done a great deal to stabilize the cone. This stabilization effort started with grass seeding in the summer of 1973, and has continued up the flanks of Eldfell, now carpeted in areas of plastic, some wooden retaining walls, and lots of luxuriant growth of vetches and grasses. Only the exposed summit area remains in a natural state, although wooden windbreaks and patches of sown *Spartina* grass probably will help to cover the last few tens of metres to the summit over the next half-century (Fig. 14).

As earth scientists perhaps we think of geological processes as being very slow, and not readily observable in a lifetime. Heimaey is one of the exceptions to that rule, and nowhere is this better seen than in the battle of the two elements of fire and water. As a 30-year-old I was aghast at the amount of change created by vast quantities of lava extruded from a very small vent. This had expanded into the sea, building up the island by 2.2 km^2. As a 55-year-old I was equally surprised at the erosion of the lava front and the development of beaches. In 25 years, about 0.2 km^2 of the new lava had been removed by storm erosion and converted to 0.1 km^2 of new beaches (Th. Einarsson, personal communication, 1998). These stretched away in great rounded masses of basaltic boulders along the lava front from the breakwater that had originally guarded the port (Fig. 10).

The principal battle with the volcano had been to prevent the lava flows from closing the entrance to the harbour. This battle had been won by the use of seawater sprayed onto the advancing lava front from boats in the channel between Heimaklettur and the lava front. Today the conflict between humans and nature continues by dredging, and marker buoys indicate the safe passage for shipping into the port.

Other changes have been equally fascinating. Helgafellsbraut now runs from the base of Helgafell to the town centre. Back in the ill-fated days of the eruption the line of this street was a trench created to divert gas away from the town (Fig. 11). The lava front that had come so close to destroying the town and infilling the harbour, has been graded and planted with grass and flowers. A number of roads run across the top of the lava, and tourist buses now wind from the town into the centre of the lava field and right to the base of Eldfell. Oxidation of the summit basaltic tephras commenced immediately following the eruption and has continued at a rapid pace with the abundant rainfall and a hot pile of basalts allowing hydrothermal alteration to take place. The crater of Eldfell is now completely rusty brown, with a few wisps of steam emerging from cracks. In the harbour area the Fiskidjan fish plant is closed: the result of rationalization and consolidation of the fish processing facilities on the island. I reflect on the tremendous efforts made by so many people to save this one building from the onslaught of lava in March and April of 1973. To me this plant had been the symbolic centre of the struggle to save the port.

My other effort was to document changes by repeating photographs at exactly the same places that they were taken in 1973, an excercise that I had also undertaken in 1983. Two comparative sets are illustrated in Figures 11 and 12.

Tourism has been one of the indirect benefits that the volcano brought to Heimaey. Many Icelanders visit the island for the festival that takes place in early August, and many non-Icelandic people come to the island to watch the bird life. Having a home-grown volcano has added to the tourist potential, and close to the town incinerator a small technical exhibit commemorates the battle with Eldfell. A series of poster boards in a small pull-off beside the road provides a concise and accurate account of the eruption. Photographs illustrate some of the major events, and beside the display is one of the 38 diesel pumps that had been used to take seawater to the lava front.

I have already mentioned the seeding application that was conducted shortly after the end of the eruption. At that time the lava field retained too much residual heat for seed germination. However, in the decades that have passed, various areas of the flow have cooled sufficiently to allow successful plant recolonization. Much of the lava surface is covered with mosses, and in a number of places grasses and flowers, both native and introduced, have re-established themselves. Perhaps the most striking example of the potential of the lava field is a garden about 40 by 10 m created by an elderly couple in 1988. This is a small oasis that confirms the belief that the lava field can be "cultivated" with time and a lot of loving care.

The Heimaey eruption has been a fascinating development for Iceland. The nature of the eruption provided invaluable geological and sociological information about potential activity associated with eruptions in a mid-ocean ridge setting.

Fortunately, post-glacial volcanic activity has been very limited in the western (Reykjanes-Langjökull) volcanic belt when compared to the eastern belt (Fig. 1), and there have only been a few historic eruptions on Reykjanes. Seemingly, settlements at Grindavík, Hafnarfjörður, Kopavogur and even Reykjavík have some volcanic risk, but potential activity at Keflavík is very low. Perhaps the techniques and lessons used and learned on Heimaey might be able to assist other Icelandic communities when and if the need ever arises.

One last piece of news should be added as we reach the transition to 2000. Icelandic geologists and geophysicists are watching the volcano Katla that lies beneath Myrdalsjökull Ice Sheet immediately north and east of the Westmann Islands. Meltwater rivers from both Myrdalsjökull and the more westerly and smaller Eyjafjallajökull Ice Sheet indicate that the region is becoming geothermally active, suggesting the possibility of an eruption at Katla or perhaps beneath Eyjafjallajökull. Should this happen, the water supply to the Westmann Islands could be threatened in at least two ways. The water could be contaminated by trace elements such as fluorine in ejecta, and the 22-km pipeline from the glacier to the coast might be broken by a jökulhlaup or by seismic or volcanic activity. Time will tell!

ACKNOWLEDGMENTS

I would like to dedicate this summary paper to Ward Neale. Ward is a constant inspiration to all of us who attempt syntheses of geological research topics to present them in an easily digestible form to the general public, and particularly to schoolchildren. It is only fair to point out that without Ward there would be no E.R.W. Neale Medal awarded by GAC, hence no E.R.W. Neale lecture tour and likely no summary paper!

I would like to express my thanks to Catherine Hickson and Roger Macqueen for their helpful comments in preparing this paper. All of the colour photographs, with the exception of Figure 4, are by the author. Figure 4 is a composite digital image with the base photograph by S. Arnórsson. I could not have completed this summary without the help provided by Icelandic colleagues. They gathered almost all of the factual information furnished in this account. Sincere thanks are expressed to the late Thorleifur Einarsson who graciously provided summaries and statistics from the start of the eruption to 1998. The late Sigurdur Thórarinsson and Svein Jakobsson helped with results in the early days of the eruption, members of Orkustofnun assisted with data on the geothermal field, and Armann Hoskuldsson provided some useful comments to the manuscript. However, I am especially grateful to Stefán Arnórsson, who encouraged me to go to Iceland in January 1973 and who obtained the initial research permits for me to travel to Heimaey. We have enjoyed many geological discussions about Iceland during the past 40 years, and he provided some timely corrections to my misconceptions in this paper! Stefán, together with his wife Edda Árnadóttir, have always made me welcome in their fascinating country. Hjartanlegar kveðjur til ykkar beggja.

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Note added in press

Even as the paper was being proofread, news arrived from Iceland that another eruption has just commenced, this time at Hekla (not Katla). A 6- to 7-km fissure opened up across the summit, ash has reached 15-km elevation and is falling as far as the north coast. Lava flows have extended up to 4 km from the fissure. In retrospect this is not too surprising. Hekla (Fig. 1) has erupted at an almost exact interval of 120 months (plus or minus a few) from 1960 to present. It is unlikely that this eruption will be that long lived and it probably will not have any adverse affects on the Westmann Islands, although the source of water for Heimaey (see the concluding paragraphy prior to the Acknowledgments) might be adversely affected for short periods of time.