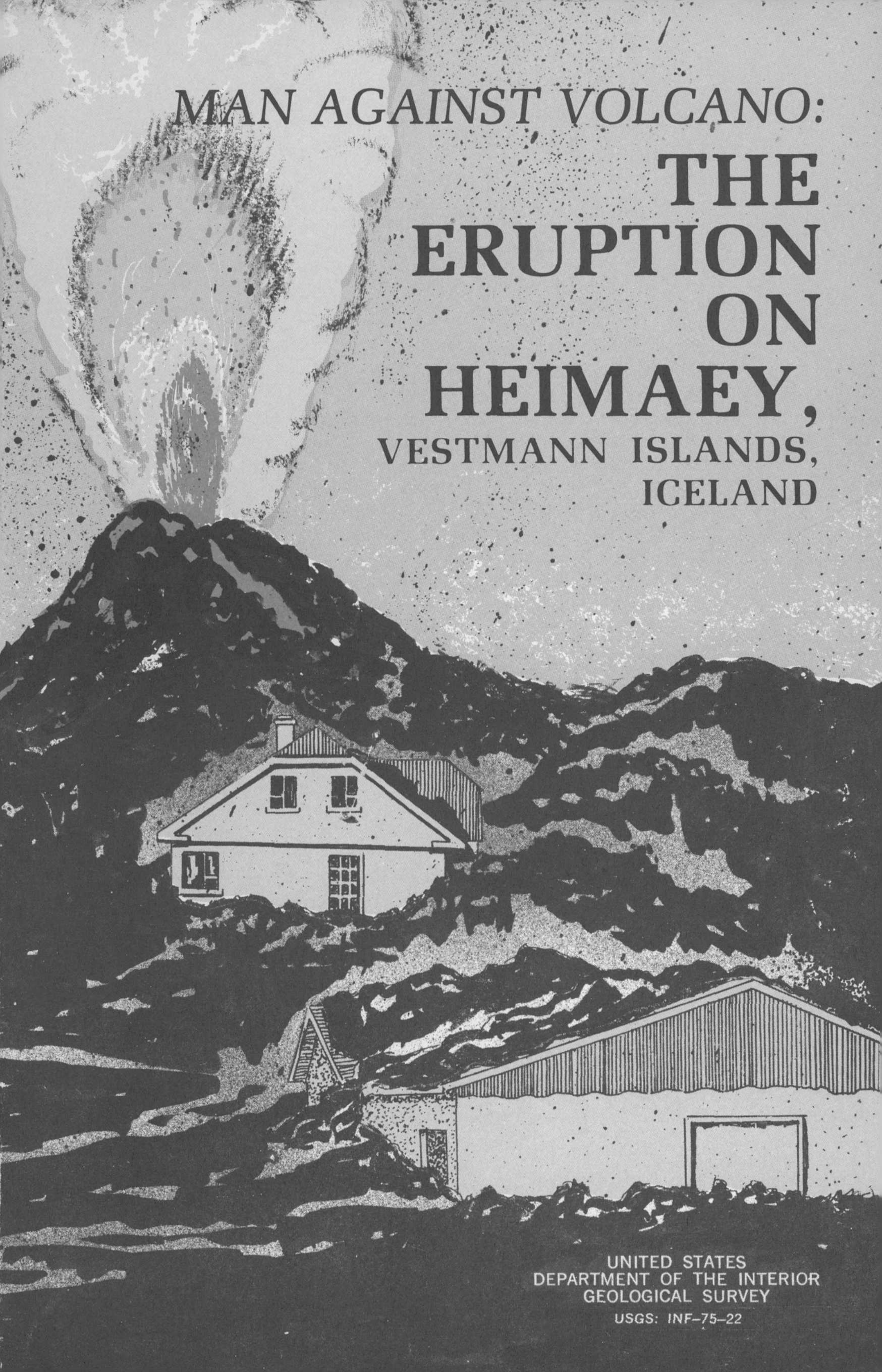
MAN AGAINST VOLCANO: THE ERUPTION ON HEIMAEY, VESTMANN ISLANDS, ICELAND



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
USGS: INF-75-22

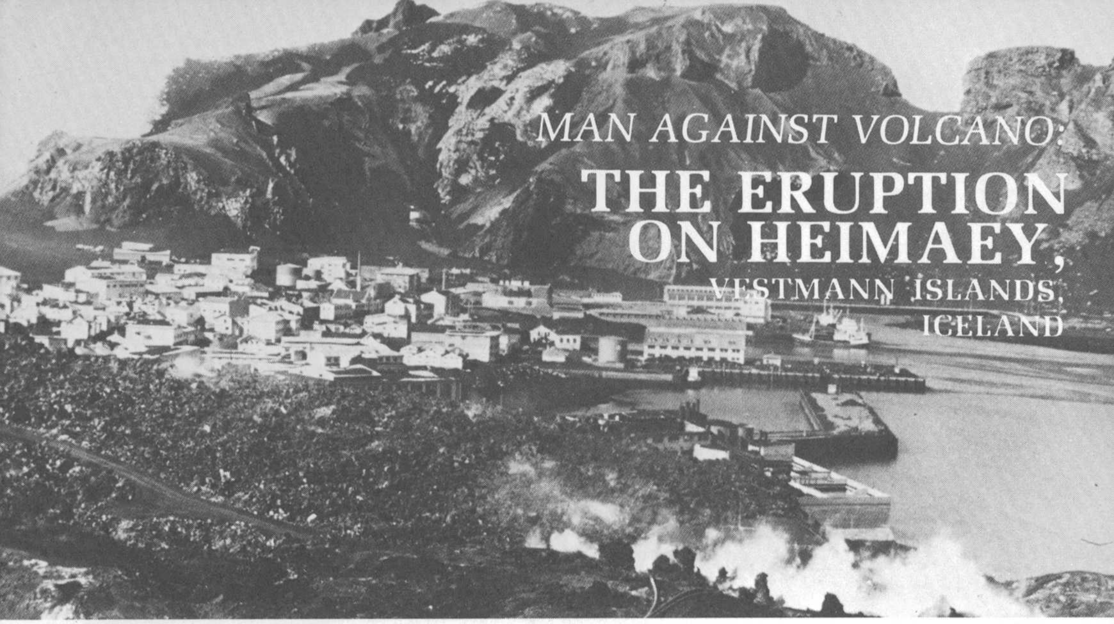
FOREWORD

The U.S. Geological Survey carries out scientific studies in the geological, hydrological, and cartographic sciences generally within the 50 states, but also in cooperation with scientific organizations in many foreign countries for the investigation of unusual earth science phenomena throughout the world.

The following material discusses the impact of the 1973 volcanic eruption of Eldfell on the fishing port of Vestmannaeyjar on the island of Heimaey, Iceland. Before the eruption was over, approximately one-third of the town of Vestmannaeyjar had been obliterated but, more importantly, the potential damage had been reduced markedly by the spraying of seawater onto the advancing lava flows, causing them to be slowed, stopped, or diverted from the undamaged portion of the town.

The Survey's interest and involvement in the Heimaey eruption in Iceland was occasioned by the possibility that the procedures used to control the course of the flowing lava and to reduce the damage in a modern town may some day be needed in Hawaii and possibly even in the continental United States.

This publication is based on the observations of two USGS geologists, Richard S. Williams, Jr. and James G. Moore, as well as on information from the Icelandic Ministry for Foreign Affairs, Icelandic scientists' reports through the Center for Short-Lived Phenomena, and other published scientific reports. A number of Icelandic scientists studied the scientific aspects of the eruption and the engineering aspects of the control of lava flows, in particular, Professors Thorbjörn Sigurgeirsson and Sigurdur Thorarinsson of the University of Iceland Science Institute. Also, Icelandic governmental officials provided logistical and other support, in particular, Mr. Steingrímur Hermannsson, Director, Icelandic National Research Council and Professor Magnús Magnússon, Director, University of Iceland Science Institute.



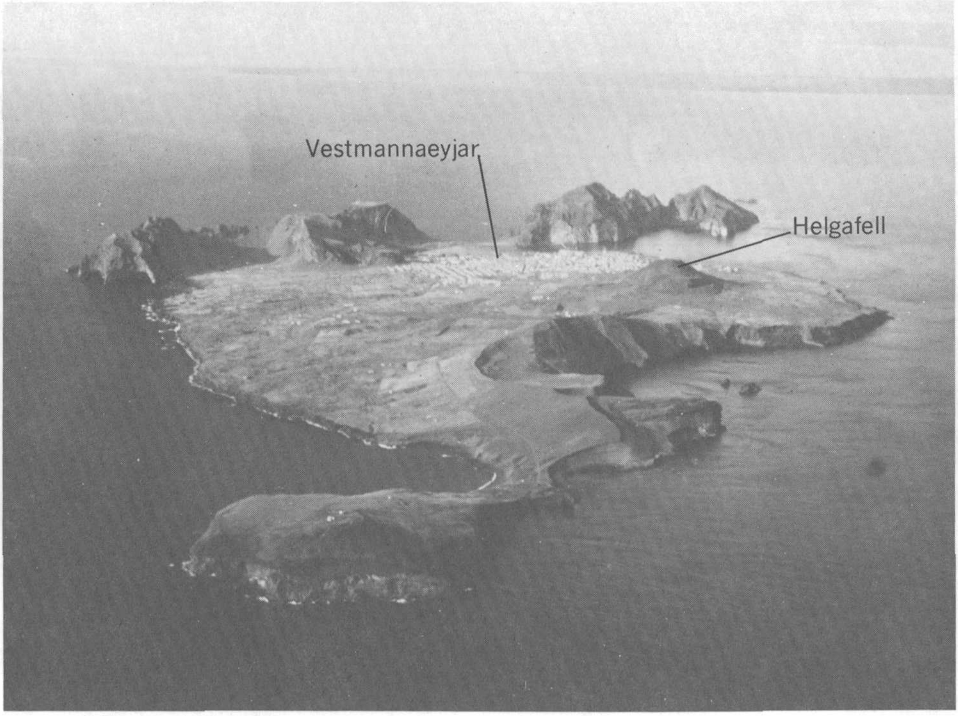
MAN AGAINST VOLCANO: THE ERUPTION ON HEIMAEY, VESTMANN ISLANDS, ICELAND

INTRODUCTION

One of the most destructive volcanic eruptions in the history of Iceland began in the early morning of January 23, 1973, near the nation's premier fishing port, the town of Vestmannaeyjar (Vest-mun-ayar), on Heimaey (Hame-a-ay), the only inhabited isle in the Vestmann Islands volcanic archipelago. This effusive eruption was the fifth in Iceland in a little over a decade. It was also the second major eruption (the other being Surtsey) definitely known to have occurred in the Vestmann Islands since the settlement of Iceland in the ninth century, although there is evidence of a submarine eruption in the archipelago in September 1896. At least 13 offshore (14 including Heimaey) and about 110 onshore eruptions have been documented in Iceland since settlement. Ten of the previous 13 offshore eruptions occurred along the submarine Reykjanes Ridge, an extension of the Reykjanes Peninsula. This Ridge lies along a parallel fracture system approximately 109 miles due west of the northeast-southwest trending Vestmann Islands.

Except for the main island of Heimaey, all of the islets in the archipelago are composed of Holocene (geologically recent) basalts. Except for Surtsey, the islets have near-vertical sides and extend out of the sea as a series of stacks. Surtsey has a sandy point to the north and a narrow boulder and cobble beach fringing the rest of the island, including the steep lava cliffs on its windward side. Older rocks of Pleistocene age (Great Ice Age) crop out on the north and south parts of the island of Heimaey. These are overlain by younger Holocene basalt flows capped by a prominent volcano, Helgafell, which last erupted 6,000 years ago.

The Vestmann Islands follow the same structural trend as the orientation of tectonic fissures (gjár), grabens, and crater rows on the mainland in the eastern volcanic zone in south Iceland. This is a zone of historically active volcanoes, including Hekla, Katla, and the famous Laki fissure eruption of 1783. The Laki eruption produced the largest lava flow observed in historic times, 2.9 cubic miles of lava which inundated 218 square miles. According to Professor Sigurgeirsson, the Reverend Jón Steingrímsson, an Icelandic minister observing the Laki eruption, was probably the first to note the effect of water on the flow of lava.

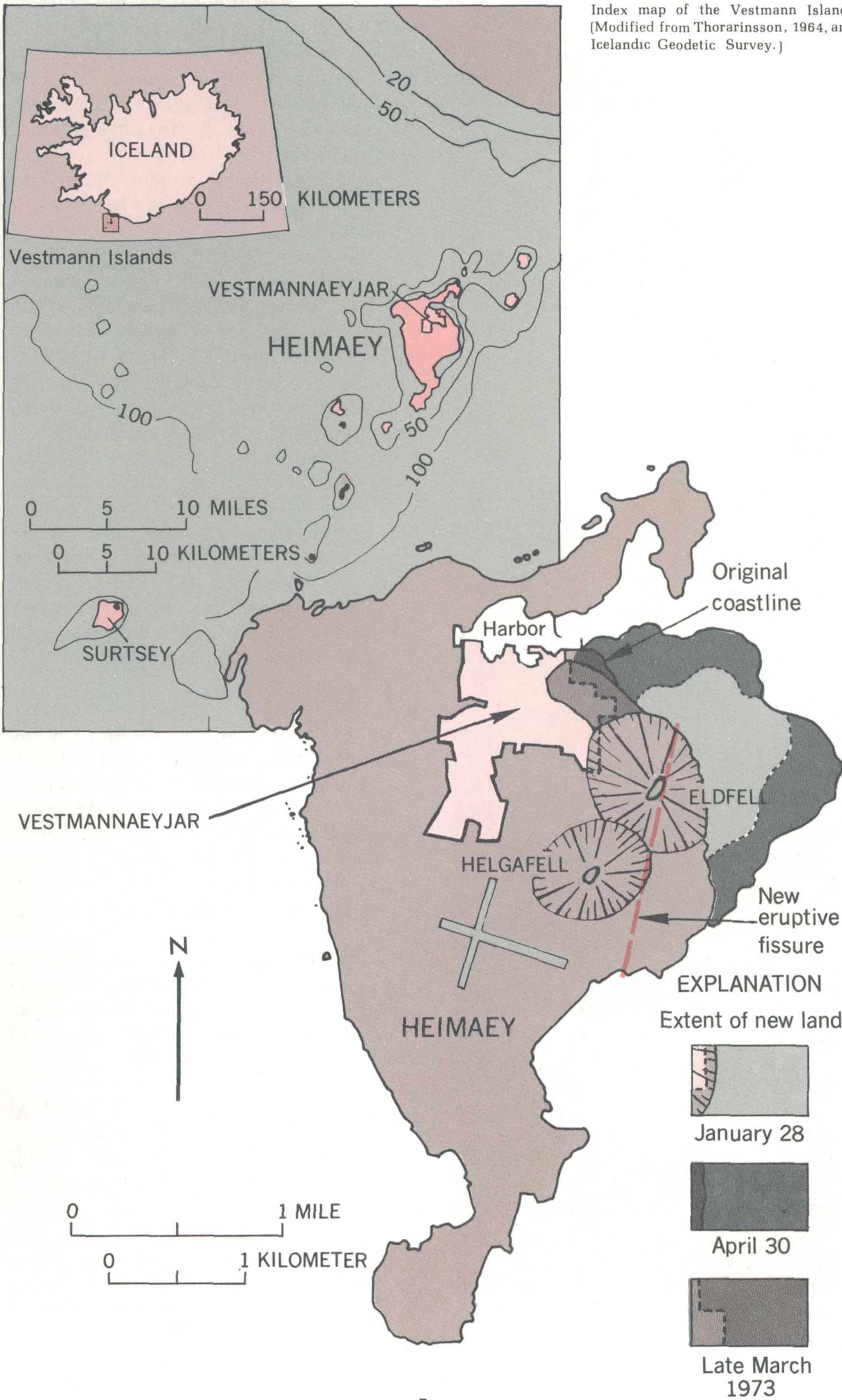


Oblique aerial view north-northwestwards of the island of Heimaey, Vestmann Islands, Iceland, in August 1966, showing the fishing town of Vestmannaeyjar, the east-west trending harbor in the background, and the extinct volcano Helgafell rising to 741 ft in the right center of the island. On January 23, 1974, lava began to pour from a 0.9 mi north-northeast trending fissure to the east (right) of Helgafell. Eldfell eventually grew to be similar in height to Helgafell.

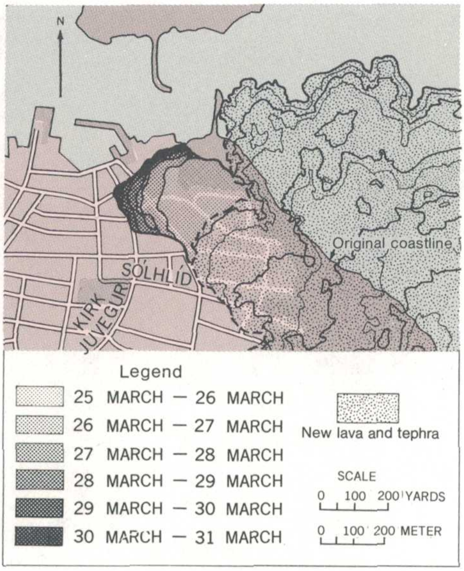
COURSE OF THE ERUPTION

The 1973 eruption began about 2 a.m., January 23, on the eastern side of Heimaey, approximately 1,091 yards from the center of town. A fissure about 1 mile long rapidly opened to a length of about 1¼ miles traversing the island from one shore to the other. Spectacular lava fountains predominated in the initial phase of the eruption, but the activity soon retracted to a small area along the fissure about 0.5 mile north-east of Helgafell. Within 2 days a cinder-spatter cone rose more than 109 yards above sea level and was named Eldfell or "fire mountain" by the official Icelandic place name committee. The output of lava and *tephra* (a collective term for fragmental volcanic materials, such as ash and bombs, which are ejected through the air during the early phase) was estimated to be about 131 cubic yards per second. Within a few days after the eruption, strong easterly winds resulted in a major fall of tephra in the town of Vestmannaeyjar, completely burying homes to the east. By early February the tephra fall slackened markedly, but lava flowed to the edge of the town and threatened to fill in the harbor of Iceland's most important fishing port.

Icelandic geologists and geophysicists monitored the volcano continuously, both from the air and the ground. Foreign scientists also made short-term observations. Satellite studies and imagery of the eruption were acquired by both the NOAA-2 and the Landsat-1 satellites. Post-eruption aerial photographic and thermographic surveys were carried out under a cooperative study by the U.S. Geological Survey and the University of Iceland Science Institute in association with the Icelandic National Research Council.



Index map of the Vestmann Islands. (Modified from Thorarinsson, 1964, and Icelandic Geodetic Survey.)



Daily movement of lava into Vestmannaeyjar in late March 1973. Cooling operations finally halted the flow against the fish-processing plant shown on pages 10 and 11 Dashed lines show former extent of the town under the lava field. (Modified from Jónsson and Matthíasson, 1974.)

View on July 23, 1973, north toward a house engulfed by the March lava flow on the eastern part of Vestmannaeyjar.

By the end of February the spatter-cinder cone was more than 200 yards high. The central crater of Eldfell also fed a massive blocky (aa lava) flow which moved slowly but relentlessly toward the north, northeast, and east. By early May this flow was 33 to 66 feet high at its front, averaged more than 130 feet thick, and was 328 feet thick in places. Its upper surface was littered with *scoria* (cinderlike fragments of dark porous lava) and volcanic bombs, as well as large blocks from the main cone which broke off and were carried along with the flow. The largest block soon was dubbed "Flakkarann" (The Wanderer). Some of these blocks of welded scoria were about 656 feet square and stood 66 feet above the general lava surface. They had been rafted more than 1,000 yards. Preliminary measurements made from a series of aerial photographs taken from the end of March to the end of April indicated that the lava was flowing as a unit about 1,000 yards long by 1,000 yards wide with an average speed of 10 to 26 feet per day.

As the flow advanced to the north and east, large slump blocks from the cone collapsed on February 19 and 20 and moved toward the southeastern part of town. Also, in late March a second large lava flow moved northwest on the west side of the main flow and covered many houses, one fish-processing plant, and the town powerplant.

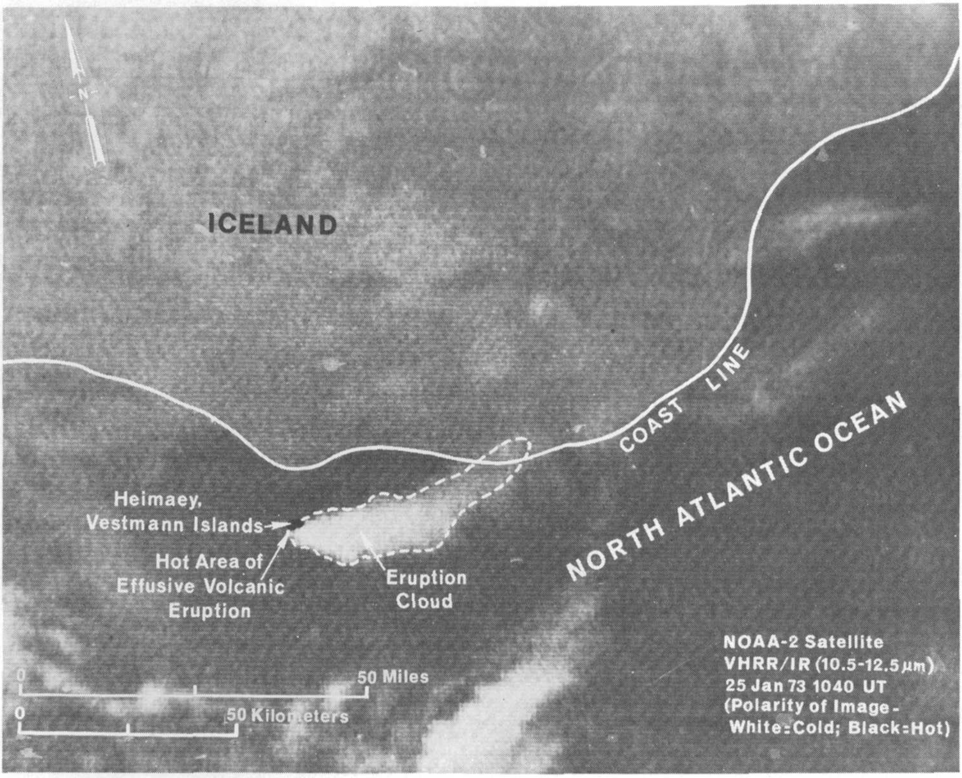
By February 8, lava ejection was estimated to have dropped from 131 cubic yards per second to 78 cubic yards per second; by the middle of

(Top right.)

Eruption of Eldfell Volcano as viewed from the NOAA-2 weather satellite, 33 hours after the eruption began. The plume extends 37 mi downwind to the east, away from the town of Vestmannaeyjar. This thermal infrared image also shows the "hot" area of lava flows at the base of the plume. (National Environmental Satellite Service, NOAA.)

(Bottom right.)

View on July 23, 1973, southeast across homes partially buried by tephra. Vapor-shrouded Eldfell looms in the distance. Pipes which conveyed seawater to the lava flows cross the tephra in the middle ground. Gases rise from the tephra behind the telephone pole.


N
ICELAND
COAST LINE
NORTH ATLANTIC OCEAN
Heimaey,
Vestmann Islands
Hot Area of
Effusive Volcanic
Eruption
Eruption
Cloud
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NOAA-2 Satellite
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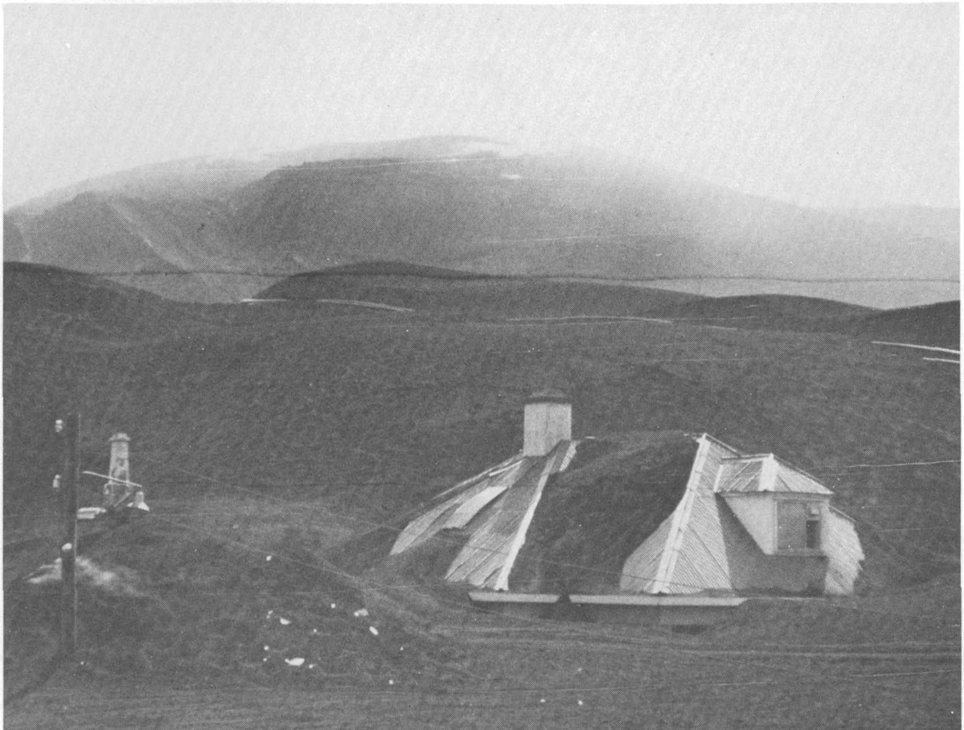
(Polarity of Image -
White=Cold; Black=Hot)



March to 13 cubic yards per second; and by the middle of April to about 6.6 cubic yards per second. As noted before, easterly winds blew tephra over the town during the early stages of the eruption. By January 29, the thickness of tephra varied from 1.1 feet in the northwest part of town to more than 15 feet in the southeast part, and was over 328 feet deep on the outskirts of the town along the flanks of Eldfell.

By the early part of July the eruption had waned; the lava flow was no longer visible, although hidden subsurface flow may have continued for awhile. According to preliminary estimates about 288 million cubic yards of lava and 26.2 million cubic yards of tephra were deposited on and in the waters around Heimaey.

Studies of the volcano's eruptive products by a number of Icelandic scientists have shown that as the eruption progressed, the composition of the material changed until it became similar in composition to the lava comprising the island of Surtsey. This compositional change implies that the lava probably came from a zoned magma chamber enriched in alkalies and silica in its upper part. The chemical changes in the lava were accompanied by mineralogic changes as well as temperature changes. The temperature of the lava also varied

View on July 23, 1973, north across homes partially buried by tephra in the eastern part of Vestmannaeyjar. The lava flow looms in the background. Gases that are moving through the tephra rise from the house on the right. The houses will eventually be exhumed and restored.

from 1,886° to 1,931°F (1,030°-1,055°C) during the first week of the eruption and increased later to as much as 1,976°F (1,080°C).

Volcanic gases of widely varying composition were collected from several locations, which showed that processes of gas fractionation operate effectively over short distances. Gases collected at sea along the submerged part of the active eruptive fissure were dominantly carbon dioxide. Gases collected at sea bubbling up from cooling, submerged lava flows were found to be about 70 percent hydrogen.

Poisonous gas accumulated in low areas within the eastern part of Vestmanneyjar and was particularly concentrated in houses partially buried by ash and scoria. The gas contained 98 percent carbon dioxide and some carbon monoxide and methane. The gas had a faint, subtle, somewhat sour odor. One reported fatality resulted from breathing gas within a building, and several people were partially overcome.

The origin of the carbon dioxide is a matter of some conjecture among geologists familiar with its occurrence on Heimaey. Perhaps it separated from the other volcanic gases (chiefly water and sulfur dioxide) at the volcano's vent, flowed downhill to the town, and collected in low areas. Carbon dioxide concentrations have also been associated with eruptions from Iceland's best known volcano, Hekla; sheep have been found asphyxiated in small dales.

Another possibility is that the volcanic gas moved up and outward from deeper within the volcanic conduit through older volcanic rocks directly into the town. Other gases were removed through condensation or reaction, and the travel path was such that carbon dioxide remained the dominant residual gas. Some scientists believe that it was a combination of both processes. A sizeable tephra wall was constructed by bulldozers between the vent and town to divert the gas; a long trench was also excavated to permit the escape of gases. Neither barrier was completely effective.

DESTRUCTION CAUSED BY THE ERUPTION

The destruction did not occur all at once, but was related to the course of the eruption. The damage was twofold: the highly visible destruction of homes, public buildings and installations, commercial properties, and partial infilling of the harbor by lava flows and tephra falls; and the economic and social impact on the residents of Vestmannaeyjar, local commerce, and the national and international economy of Iceland by the economic disruption of a key fishing port.

Within 6 hours after the eruption began, nearly all of Heimaey's 5,300 residents had been safely evacuated to the mainland. This rapid evacuation was accomplished through the foresight of the Icelandic State Civil Defense Organization, which had a contingency evacuation plan ready for just such a disaster. The fishing fleet in port expedited the evacuation.

Homes and farmsteads close to the rift were soon destroyed by tephra burial or fire from lava bombs and flows. The heavy tephra fall caused severe property damage a few days after the onset of the eruption. Numerous homes, public buildings, and commercial buildings were completely buried by tephra, set afire by glowing lava bombs, or overriden by the advancing front of lava flows. Although many structures collapsed from the weight of the tephra, dozens were saved by crews of volunteers who cleared the roofs of accumulated tephra and tacked corrugated iron "shutters" over the windows.

By early February the lava had begun to fill the harbor, a situation which threatened the future use of Vestmannaeyjar as Iceland's prime fishing port. The harbor on Heimaey is the best along the entire south coast of Iceland and is located in the midst of some of the richest fishing grounds in the North Atlantic.

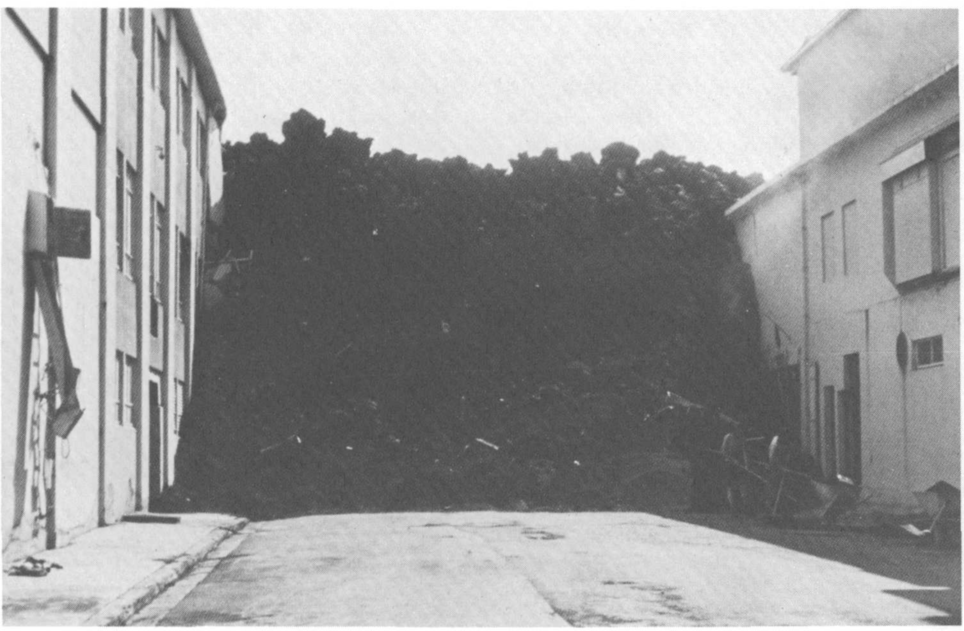
In late March, a new surge of lava into the eastern edge of Vestmannaeyjar destroyed a large fish-freezing plant and damaged 2 others, and destroyed the local power-generating facility and about 60 additional homes. By early May, some 300 buildings had been engulfed by lava flows or gutted by fire, and another 60 to 70 homes had been completely buried by tephra.

The economic and social consequences of the eruption will be felt for many years. The initial social impact was in the total upheaval of a 1,000-year-old island community. A proud and industrious people, with many close bonds of family and friendship, had been involuntarily uprooted, and their livelihoods altered in most cases. Short-term and long-term costs will total many tens of millions of dollars, a very large amount when compared with Iceland's 1971 Gross National Product (GNP) of $500 million. The location of housing and other services for 5,300 people, for example, would be equivalent in national impact to finding emergency housing with overnight notice for 5.3 million Americans.

CONTROL OF THE LAVA FLOWS

Icelanders, from the time of settlement to the present day, have had to contend with the consequences of natural disasters: volcanic eruptions, glacier outburst floods (jökulhlaups), and periods of climatic change (usually caused by the presence of sea ice off the north and east coasts). All of Iceland, either directly or indirectly, has therefore pitched in to lessen the burden on the residents of Heimaey.

View on July 23, 1973, southeast from dock area in the northern part of Vestmannaeyjar toward edge of lava flow where it stopped against and between two fish-factory buildings. Two boys can be seen in the right background sweeping up the tephra. By July 1974 the lava had been completely removed and restoration of the factories had begun.



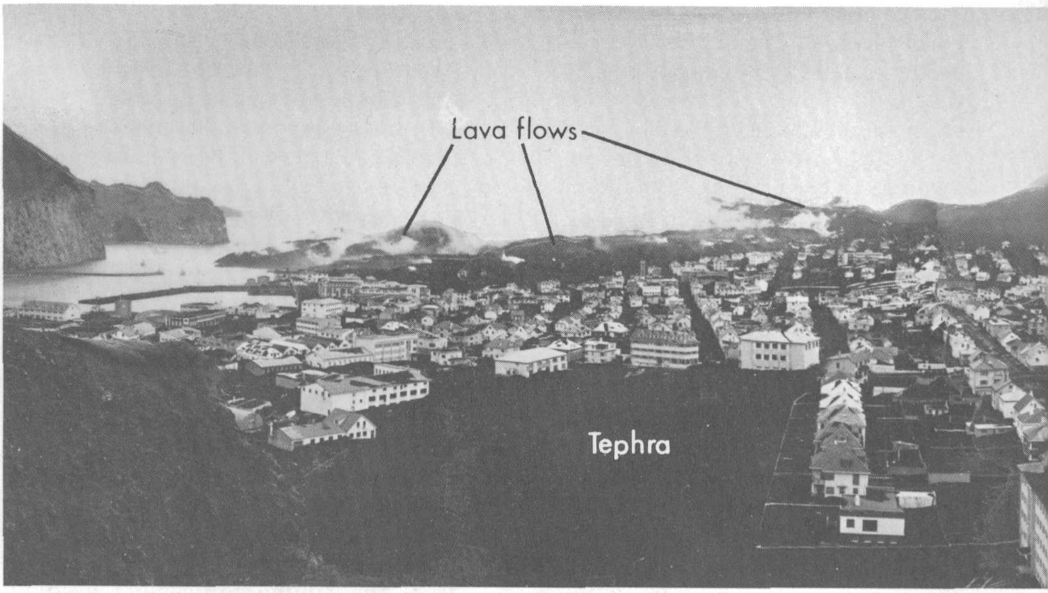
Of great interest was the decision by officials, on the advice of Icelandic geologists and geophysicists, to "fight" the lava flows. Drawing on field observations made on Surtsey, together with theoretical calculations on the cooling effect of water on molten lava, and small experiments on Surtsey and later on Heimaey at the beginning of the eruption, several Icelandic scientists recommended that cooling and hardening of lava by spraying of seawater be used to try to stop the flow of lava on Heimaey. This effort ultimately became the most ambitious program ever attempted by man to control volcanic activity, and to minimize the damage caused by a volcanic eruption. Consequently, it was an experiment of great importance to other communities threatened by damage from volcanoes.

Advance of the main lava flow to the north initially threatened to close the entrance to Vestmannaeyjar harbor. Likewise, advance of the flow to the northwest threatened the town proper and the many fish-processing factories. Accordingly, a twofold program was begun in late February: lava cooling by spraying to increase the lava's viscosity and cause it to slow and thicken, and construction of a lava barrier on the flow's northwest margin to prevent its advance into the town.

A limited cooling operation was first begun on February 7, just 15 days after the eruption began. This use of the city water supply indicated that spraying water on the flow slowed its advance and caused the flow front to thicken and solidify. In early March a pump ship that could deliver a large volume of water was brought into the harbor. In late March and early April, large capacity pumps were acquired from the United States and used to deliver water to the flow front and to selected sites on the surface of the flow.

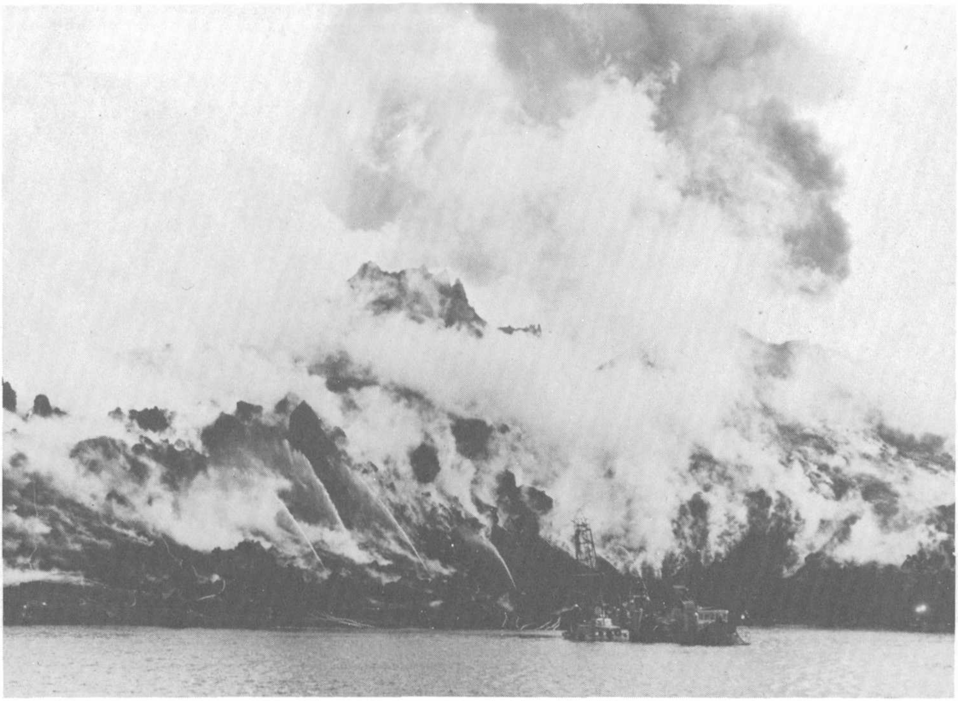
In early April, pumps situated in the harbor area were delivering up to

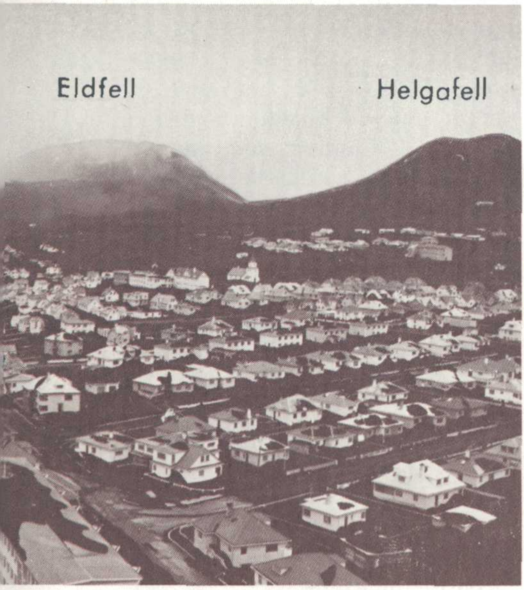
View on July 7, 1974, southeast from dock area in the northern part of Vestmannaeyjar after removal of lava flow which had stopped against and between two fish-factory buildings.



A panoramic view east-southeast across the fishing port of Vestmannaeyjar on May 5, 1973. The 6,000-yr-old Helgafell (Holy Mountain) Volcano is to the right, the new Eldfell (Fire Mountain) Volcano is on the right center. Dark tephra-covered ground is apparent, with lava flows into the town and harbor in the left background.

View to the south from Vestmannaeyjar's outer harbor on May 4, 1975. Seawater is being sprayed directly onto the lava flow front to arrest infilling of the harbor entrance.





Part of northeastern Heimaey and the eastern part of the town of Vestmannaeyjar showing deployment of pipes along northwestern edge of new lava flows on April 15, 1973, and access roads (dashed lines) bulldozed onto and through the lava field. Intake pumps are positioned along two harbor piers. (Modified from Jónsson and Matthíasson, 1974.)

1.3 cubic yards per second of seawater to various parts of the flow. This water cooled about half its volume of lava to 212°F (100°C), substantially below the solidification point of basalt. The fluidity of basalt is at a maximum at 1,832° to 2,192°F (1,000°-1,200°C) and essentially ceases to flow by the time it cools to 1,472°F (800°C).

Water was pumped directly on the flow front at sea level and was also pumped through a number of primary plastic pipes. Each main pipe was branched into a series of smaller pipes. In addition, a large steel pipe was used. More than 19 miles of pipe (75 percent plastic) and 43 pumps were eventually employed in the cooling program.

The most difficult aspect of the cooling program was to deliver large volumes of seawater to the surface of the flow far behind the flow front. The water effectively increased the viscosity, thereby producing internal lava barriers and causing the flow to thicken and ride up over itself.

First, the margin and surface of the flow was cooled with a battery of firehoses. Then a bulldozer track was made up the side of the slow moving flow. The water produced large volumes of steam which markedly reduced visibility and made road building difficult. Then the larger plastic pipes were snaked up onto the flow; they did not melt from the heat as long as water flowed through them. Small holes in the pipes also helped to cool hot spots.

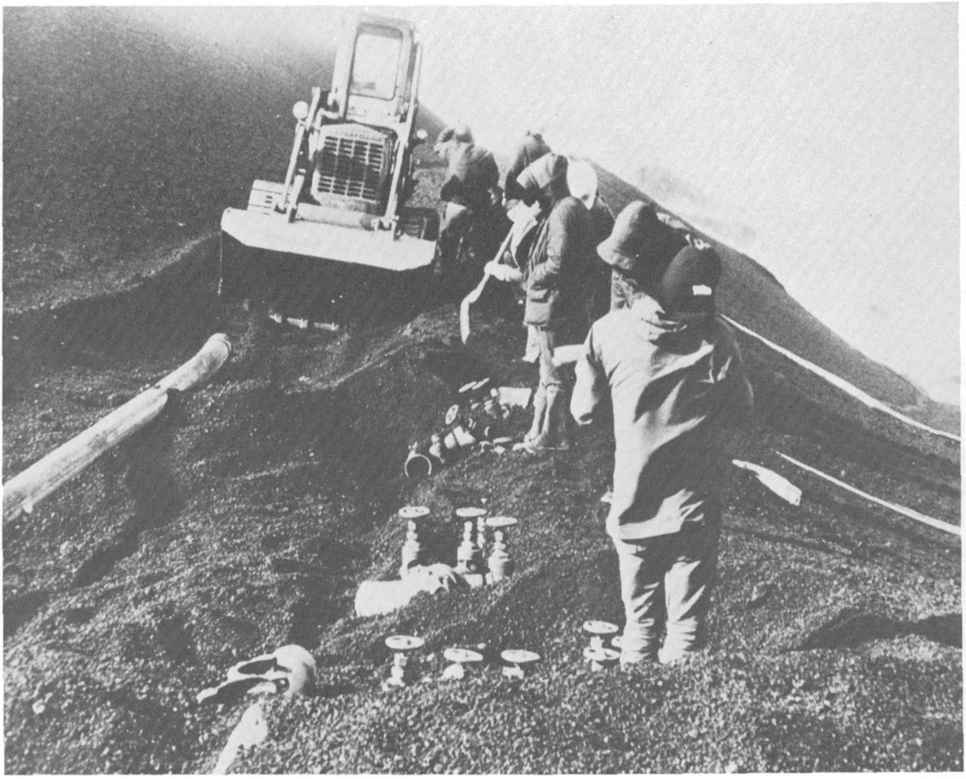
In each general area from 13 to 52 gallons per second of water delivered from the pipe had little effect for about a day. Then the flow began to slow down in that area. At each point, water was poured on for about 2 weeks until steaming stopped near the point of discharge, because much of the flow in a small area had cooled below 212°F. Water was delivered about 55 yards beyond the flow margins and front, so that a thick wall of cool, rubbly lava was created at the margin allowing the flow to thicken behind it.

The cooling of the flow margin was used in conjunction with bulldozed diversion barriers of scoria adjacent to the flow margin. The marginally cooled flow tended to pile up against the barrier rather than burrow under it as would be the case if the flow were more fluid.

The water-cooling program produced a noticeable effect on the main lava flow. The lava was distinctively changed where water had been poured on it. Before watering, the flow surface was blocky and covered with partly welded scoria and volcanic bombs and had a distinct reddish, oxidized color. The general surface had a local relief of 1.1 yards or less, which was the general dimension of many of the blocks. However, large masses of welded scoria which had broken off from the main cone stood 11 to 22 yards above the flow surface. After watering, the general flow surface became much more jagged with a local relief of up to 16 feet and was much more difficult to walk on. Cooling had apparently caused the more plastic interior of the flow to break upward and ride over itself.

The flow surface has turned black to gray. In places closely spaced joints perpendicular to larger joints and shears are similar to joints in pillow basalts. Elsewhere, white incrustations of salt coat fractures that were formerly deeper in the flows, where the cooling seawater was heated and evaporated. The change in surface texture and color can be readily noted on aerial photographs, particularly color aerial photographs.

On May 4, 1973, workmen laid additional pipes to carry seawater up onto the lava flow front and tephra bulwark to cool and harden the still-flowing lava behind the chilled lava margin.

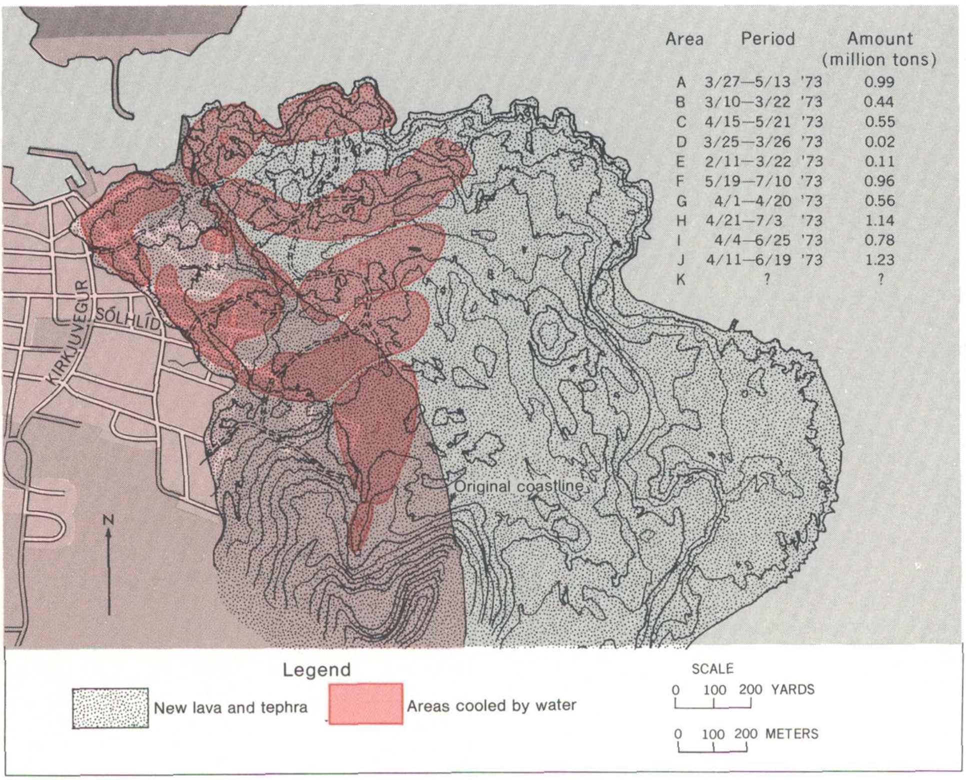


From February 7, 1973, until the lava cooling operation ended on July 10, 1973, approximately 7.3 million cubic yards of seawater were sprayed onto the lava flows. At the peak of the lava cooling, in early April 1973, 75 men were employed around the clock.

Like all volcanic eruptions, the Heimaey eruption was a special case, to which the methods employed to control the lava flows were especially suited. First, the initial eruptive fissure was only 1,093 yards from the center of a large town with an adjacent and economically important harbor, and consequently it was in the national interest to minimize damage. Secondly, the main lava flow was viscous and slow moving, allowing time to plan and carry out the control programs. Thirdly, seawater was readily available in the nearby harbor. And fourthly, transport by sea as well as by a local road system was good, and it was relatively easy to move in pumps, pipe, and heavy construction equipment. Nevertheless, it is likely that some of the lessons learned from the Heimaey experience will be adapted to eruptions in other places.

Scientists and planning authorities also had the benefit at Heimaey of detailed topographic maps rapidly produced from vertical aerial photographs. These maps, in connection with geodetic surveys, permitted measurement of the rate of movement of the main lava flow and an assessment of the best places to build lava diversion barriers. They were also critical in all planning for administrative and scientific purposes.

Area around eastern Vestmannaeyjar showing the parts of the new lava field that were cooled over different periods of time and the amount of seawater pumped. (Modified from Jónsson and Matthíasson, 1974.)



Vertical aerial photograph taken on August 4, 1960, of the island of Heimaey, Vestmann Islands, Iceland, showing the *fishing port of Vestmannaeyjar*, the crater of Helgafell Volcano, and the single airstrip. (U.S. Air Force.)

Vertical aerial photograph taken on September 8, 1973, of the island of Heimaey, Vestmann Islands, Iceland, showing the fishing port of Vestmannaeyjar, the craters of Helgafell and Eldfell Volcanoes, the double airstrip, and the new land on the east. (Icelandic Geodetic Survey.)

The water cooling and construction of lava barriers definitely had a marked effect on the character and course of the lava flows on Heimaey. The 7.8 million cubic yards of water converted 5.5 million cubic yards of molten lava to solid rock. From boreholes drilled into various parts of the lava field north of Eldfell, temperature measurements indicated that the lava cooled 50 to 100 times more rapidly in areas sprayed with seawater than in areas of self-cooling. The placement and measurement of movement of markers (from ground surveys and aerial photographs) on the lava field substantiate the effect of cooling on the speed of lava flow. It has been clearly established that the work on Heimaey represents the greatest effort ever attempted to control lava flows during the course of an eruption; the estimated cost for the lava cooling operations (labor, equipment, transportation, fuel, and others) is $1.5 million.

CONCLUSION

Even after all the devastation and disruption of lives and livelihood, there were some peripheral benefits from the volcanic eruption. On the plus side, the lava and tephra added nearly a square mile to the pre-eruption area of Heimaey, increasing its size by about 20 percent. More than 1.3 million cubic yards of tephra have been cleared away from the town and have been used to extend the runways on the island's only airfield and as landfill for the siting of 200 new homes. The tephra may even become profitable; at least one American firm has expressed interest in using the ash as a light weight aggregate to make construction blocks. Even the remaining heat of the volcano may be tapped.

Town officials have considered running water pipes through the hot lava piles to provide clean, cheap hot water heat for homes and buildings. The tongue of lava that almost blocked the harbor entrance has also turned into an asset and is now acting as a breakwater, temporarily at least helping to protect the harbor from storms. Unfortunately, as this lava breakwater is eroded, the resulting debris may produce shoaling and may ultimately form a baymouth bar at the new outer entrance to the harbor.

Another optimistic aspect to the recovery effort is that by the summer of 1974, after an enormous cleanup effort funded chiefly by all Icelanders, about 2,600 residents or about one-half of the population, had returned and plans were being developed for the construction of 450 new homes within the following 2 to 3 years. By March 1975 the population had grown to 4,300 people, or 80 percent of the pre-eruption population. Vestmannaeyjar has once again become a vigorous fishing community, a new laboratory for geologists, a major tourist attraction, and a testimony to the perseverance and courage of the Vestmann Islanders to turn, with the help of other Icelanders and foreign friends, a seemingly hopeless situation into a bright future.

The success of the islanders in their battle with the volcano has prompted other communities faced with volcanic hazards to look to the lessons learned on Heimaey. The worldwide interest has contributed to making Eldfell one of the most photographed volcanic eruptions in the world. Scientists in Iceland and around the world will be studying the photographs, satellite images, and rock samples for years to come, looking for clues that will contribute to understanding of the nature of volcanoes, as well as looking for ways to at least partially control the destructive effects of future eruptions whether they be in Iceland, in the United States, or in any other inhabited volcanic region of the world.

(From information supplied by R. S. Williams, Jr. and J. G. Moore)

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The measurements used in this publication can be converted to metric equivalents by using the appropriate entries from the following table:

Approximate Conversions

	To convert	to	Multiply by
	inch (in)	centimeter (cm)	2.5
	foot (ft)	cm	30.0
Length	yard (yd)	meter (m)	0.91
	rod	m	5.0
	statute mile (mi)	kilometer (km)	1.61
	nautical mile	km	1.85
	square inch (in^2)	cm^2	6.45
	square foot (ft^2)	m^2	0.093
Area	acre (43,560 ft^2)	hectare (ha)	0.405
	square mile	km^2	2.6
	US:		
	quart (qt)	liter (L)	0.95
	gallon (gal)	L	3.8
Volume	barrel (42 gal)	L	160.0
	cubic foot	m^3	0.028
	cubic yard	m^3	0.76
	ounce (oz)	gram (g)	28.0
Mass	pound (lb avdp)	kilogram (kg)	0.454
	short ton (2,000 lb)	metric ton (t)	0.907

These approximate conversions are derived from the following factors:

1 inch = 2.54 (exact) centimeters

1 pound = 0.4 535 924 kilograms

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

Thomas S. Kleppe, Secretary
U. S. Department of the Interior

V. E. McKelvey, Director
Geological Survey