SURTSEY RESEARCH

PROGRESS REPORT

I.

The Surtsey Research Committee
Reykjavik - Iceland

February 1965

I N D E X

INTRODUCTION

On the 14th of November, 1963, a submarine eruption began approximately 20 miles off the south coast of Iceland, and 12 miles southwest of the Vestmann Islands. The next day an island appeared, which has grown steadily ever since, and has now reached the height of approximately 170 meters and the size of about 2,3 sq. km. To begin with, the material, ejected by the volcano, consisted of tephra and steam, but in April, 1964, the volcano changed to lava eruption. Then the permanency of at least a part of the island was secured. The island was named Surtsey.

The new island immediately aroused the interest of Icelandic and foreign scientists. The Surtsey Research Committee, consisting of scientists from Iceland and abroad, was formed to co-ordinate and strengthen research work in the earth sciences and biology in connection with Surtsey and the surrounding areas. An intensive research program was written, covering the various scientific fields of interest.

The following reports by Icelandic scientists, engaged in the Surtsey research project, are not intended to show scientific conclusions, but only to indicate the work that has been done during the year 1964. Much data has been collected, which has not been thoroughly studied yet. The program will be continued, and will, we hope, lead to the publications of interesting scientific papers.

Several foreign scientists have participated in the Surtsey research program. Furthermore, important assistance has been given to us by individuals and institutions abroad for which we wish to express our thanks. Especially would I like to mention Professor Paul S. Bauer of the American University, Washington, D.C., The Office of Naval Research in Washington, D.C., the Duke University in North Carolina and the U.S. Navy, Keflavik, Iceland.

Reykjavik, February 23rd, 1965

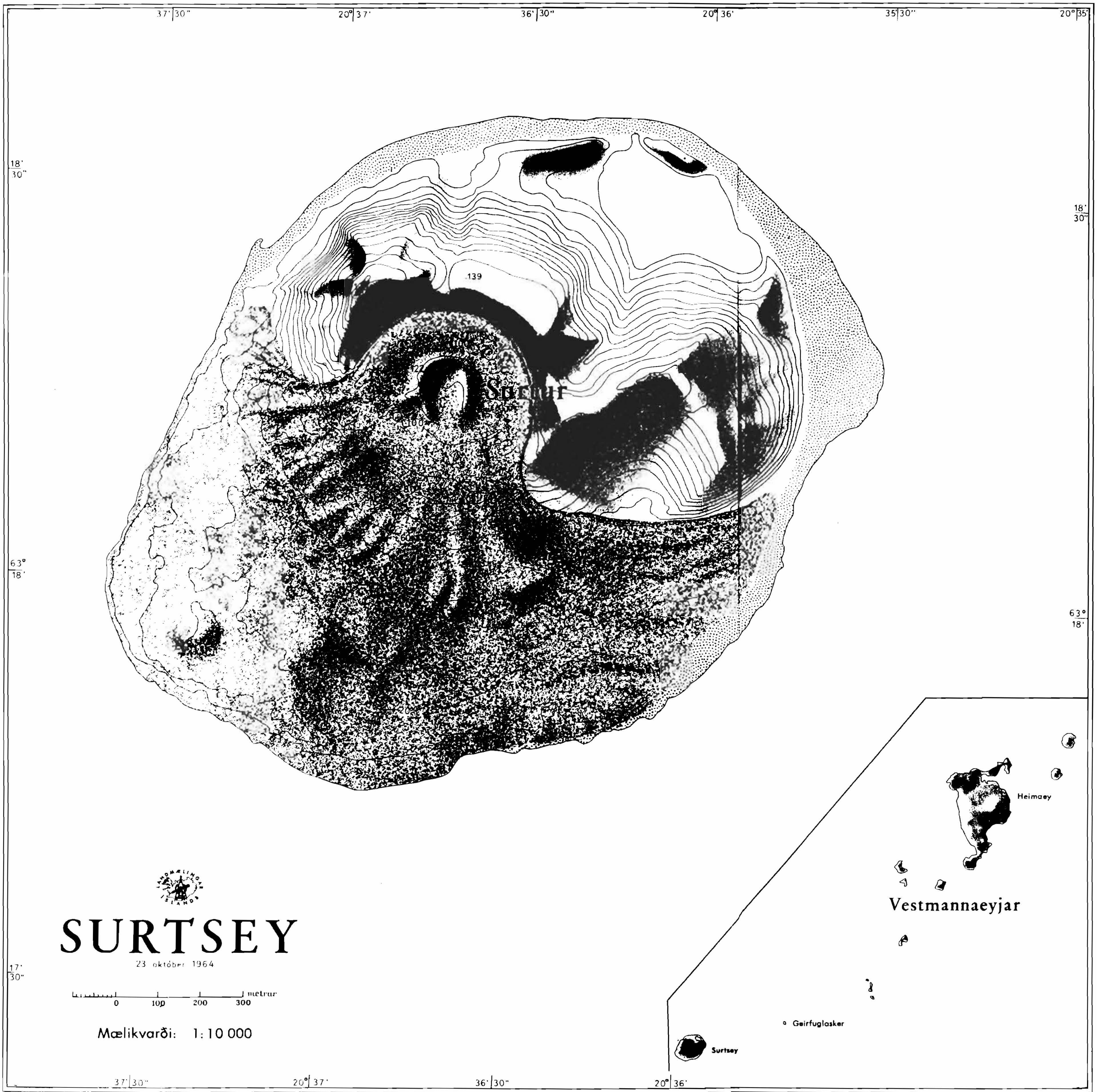
Steingrimur Hermannsson
Chairman

The Iceland Survey Department

MAP OF SURTSEY

drawn after aerial photographs
from Oct. 23rd, 1964

For the history of the eruption and explanation of the Map, see Dr. Sigurdur Thorarinsson, this report p. 51.


37' 30"
20° 37'
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139
Surtur
Heimaey
Vestmannaeyjar
Geirfuglasker
Surtsey
SURTSEY
23 október 1964
0 100 200 300 metrar
Mælikvarði: 1:10 000

O C E A N O G R A P H Y

A REPORT ON THE TEMPERATURE EFFECT OF THE SURTSEY ERUPTION ON THE SEA WATER

by

Svend Aage Malmberg
University Research Institute
Department of Fisheries

A. Material and Methods.

Nine surveys were carried out in the waters around Surtsey during the one year period November 1963 - November 1964 (Table 1).

Table 1. Hydrographic Work in the Waters around Surtsey (Nov. 1963 - Nov. 1964).

	Ship	Cruise	Date	No. of stations	No. of obs. $t^{o}C$	No. of obs. S o/oo
1	Albert	Albert	15.-16.XI	20	88	87
2	María Júlía	P-63	1.-3.XII	21	100	98
3	Ægir	A-64	21.-24.I	37	159	156
4	Þorst.þorskab.	K-64	31.III-3.IV	43	198	198
5	"	L-64	10.IV	20	88	87
6	Fanney	P-64	29.-30.V	21	111	112
7	Ægir	R-64	22.-23.VI	9	48	48
8	Albert	Q-64	5.-7.VIII	28	176	177
9	Flókaklettur	RII-64	16.-17.XI	21	83	83
			Total	220	1051	1046

The hydrographic observations consisted of temperature measurements and collection of water samples for salinity determinations and other chemical analyses. The temperature measurements were made with the common reversing thermometer ($\Delta t^{o}C = \pm 0.02$), the water sampling with Knudsen water bottles, and the salinity determinations with the conductivity method

(Auto-Lab Salinometer; $\triangle S$ o/oo = $\pm$ 0.003). A continuous sea surface temperature recorder was also operated during some of the cruises.

The observations were made on one N-S going and on one E-W going section, with Surtsey in the middle, and with stations from 12 miles distance up to 300 m distance off the island. During some of the cruises, observations were also made on sections farther to the west, across the shelf area (Selvogsbanki).

All these observations are valuable in connection with detailed oceanographic observations in this very productive area off Iceland.

In addition to data from the surveys in the sea area around Surtsey, some temperature observations and water samplings were made from the shore of Surtsey and also by fishermen in the surrounding waters.

B. Observations and Results.

On November 13, 1963, a day before the visible eruption, a ship conducting herring search in the area (M/T Þorsteinn þorskabítur) recorded a distinct temperature maximum of 9.4°C about 2 miles southwest from the eruption center, while temperature in other parts of the region was about 7°C. This indicated that some underwater volcanic activity had already started at this time.

In the next morning, the visible eruption was first noticed by the crew of a fishing boat (Ísleifur II), a couple of miles away. At a distance of about 0.4 miles from the eruption center the boat's engineer measured a sea surface temperature of about 11°C, which was at least 3-3.5°C higher than elsewhere in the nearby coastal area. On the other hand, no increase in sea temperature due to the eruption was noticed the day after, during the first oceanographic survey to the area (November 15-16, 1963), not even in 300 m distance from the eruption center.

During the surveys made in December 1963, January and the beginning of April, 1964, again no increase in sea temperature could be found at short distances from Surtsey. On the contrary, the temperature was slightly lower (about 0.2°C) at the stations worked near Surtsey than farther away, probably as a result of cooling on a shallow water during winter time.

On April 3, 1964, a lava eruption began, but up to that date the main eruption material consisted of a tephra-laden mass. On April 10, 1964, during a continuous flow of lava from the island into the sea, a sea surface temperature of 8.3°C was recorded 0.4 miles east of Surtsey, which was 0.5°C higher than farther away.

It would be difficult to trace a slight increase in sea surface temperature during the summer months (May, June, July, August), because of the seasonal warming-up due in the surface layer, but at least no unusual intense warming-up due to the eruption was observed on the cruises in May and June, 1964.

On July 6, 1964, fishermen reported a sea surface temperature of 30-40°C in 50 m distance from the lava-sea interface at the shore of Surtsey. This high temperature was supported by temperature measurements made by a group from the Physics Laboratory of the University of Iceland on September 12, 1964, in a creek at the shores of Surtsey. The weather condition was very favourable. The results are given in Table 2.

Table 2. Sea Temperature and Salinity Measurements on Surtsey on September 12, 1964.

	Depth m	Distance from the lava-sea interface	t°C	S o/loo
1.	0	30-50 m	33.2	38.13
2.	0	"	27.6 22.8	36.77
3.	0	"	25.6	36.51
4.	0	2-3 m	38.0	38.70
5.	0.3-0.4	2-50 m	$\ll$20.0	

On October 10, 1964, measurements were again made on Surtsey. The temperature on the SE-coast in about 3 m distance from the lava-sea interface was 16-17°C, and the salinity was 34.98 o/oo S. At this time there was a considerable swell which made observations difficult. Observations were also made in a lagoon on Surtsey during that trip. The temperature there was 6.2°C and the salinity 34.03 o/oo S.

On the cruises in September and November, 1964, again no increase in sea temperature due to the eruption was observed.

Thus it may be concluded that the heating effect of the eruption upon the sea water has been very little, especially after the island was born. The sea water, first in close contact with the crater, and later with the lava mass, must of course have been heated up locally, but owing to the intense mixing with the vast quantity of surrounding ocean water, this effect could not be traced in as short a distance from Surtsey as 0.5-1.0 miles, and only on one occasion in about 0.4 miles distance from Surtsey.

CHEMICAL-OCEANOGRAPHIC EFFECTS OF THE SURTSEY ERUPTION

by

Unnsteinn Stefánsson
University Research Institute
Department of Fisheries

I. Observational Data.

1. Oceanographic Surveys in the Surrounding Coastal Area.

During the period November 15, 1963, to November 17, 1964, a total of nine cruises were conducted to the sea area surrounding Surtsey. The number of stations worked as well as the type of data collected are listed in Table 1. During all of these cruises except one, observations were made along four sections directed east-west and north-south from Surtsey. On each section collections were made at 5 stations, located between 0.2 and 12 nautical miles off the island. On four occasions additional sections were worked farther west in the Selvogsbanki region, and on one occasion (June 1964) only 9 stations on two sections could be worked due to adverse weather conditions.

Table 1

Chemical Observations around Surtsey and in the Selvogsbanki Region.

Cruise	Date	No. of stations	No. of observations				
			Sal.	Oxygen	Phosph.	Silicate	Nitrate
Albert	15-16/11 ´63	20	87	61		87	
P-63	1-3/12 ´63	21	98			46	
A-64	21-24/1 ´64	37	156		73	88	
K-64	31/3-3/4 ´64	43	198		97	113	
L-64	10/4 ´64	20	87		41	42	

Cruise	Date	No. of stations	No. of observations				
			Sal.	Oxygen	Phosph.	Silicate	Nitrate
P-64	29-30/5 ´64	21	112		95	95	93
R-64	22-23/6 ´64	9	48		33	33	
Q-64	5-7/9 ´64	28	177		172	172	164
R2-64	16-17/11´64	21	83		75	81	75
		220	1046	61	586	757	332

Nutrient samples were collected in polyethylene bottles, frozen aboard the ships and analyzed sprectrophotometrically ashore. Facilities for freezing samples were poor on some of the ships and this limited the number of samples taken.

2. Collection of Water Samples from the Island.

Samples were procured by landing parties on four occasions:

a) May 31, 1964. Two samples were taken at the southwest and southeast shores of Surtsey where lava was flowing into the sea. Samples were also taken from a lagoon formed on the northern part of the island.

b) September 9, 1964. Four samples were taken on the southwest shore in a small creek formed by the lava flow.

c) October 15, 1964. A sample was collected at the south shore of the island at the edge of the lava and also from the lagoon at the north coast of the island.

d) November 25, 1964. A sample was taken at the southeast coast. At the same time an experiment was carried out extracting hot lava with sea water. The sample so obtained was partly analyzed at the oceanographical laboratory of the Icelandic Fisheries Research Institute, and the remaining part sent to the National Institute of Oceanography, England, for detailed analyses of macro- and micro-constituents.

3. <u>Experiments on Dissolution of Nutrients from Erupting Materials.</u>

The effect of temperature on the process of dissolving nutrients from tephra was investigated experimentally in the laboratory. Five gram portions of tephra from a sample collected from the deck of a patrol vessel sailing under the ash cloud, were added to polyethylene bottles containing 200 ml of synthetic sea water and the bottles kept at different temperatures for two hours, with occasional shaking. The samples were then filtered and the filtrates analyzed for reactive silicates, phosphates and nitrates.

II. Results.

A paper based on the results obtained so far is in preparation and will be ready for publication within a few months. In the present report only a few of the main findings will be briefly touched upon.

1. <u>Salinity, Dissolved Oxygen and Fluorides.</u>

In all instances the salinity in the surrounding sea area was found to be normal for the season in question, ranging from 34.90 to 35.20 oo/oo. However, the salinity of samples taken at the shores of the island showed abnormally high values. Thus the four samples taken on September 9th in a small creek at the southwest shore ranged from 36.51 to 38.70 o/oo. These high values must be attributed to intense evaporation as the corresponding sea temperatures ranged from 26^{o} to 38^{o}C. But this local heating could only be traced a small distance from the shore, and the effects on the surrounding sea area must have been negligible.

Oxygen concentrations were determined at a number of stations during the first cruise. The results did not reveal abnormal concentrations for that season.

The fluoride concentration was determined on 8 samples that gave extreme values of dissolved nutrients. The fluorides ranged from 0.060 to 0.070 mg-at/litre with a mean value of 0.065 mg-at/litre. This value is practically identical with that given in the literature for sea water of the salinity in question. Thus no additional fluoride concentrations due to the eruption could be detected in the surrounding area, but considering the great dilution of sea water that comes in contact with eruption materials, this result does not exclude the possibility of fluoride enrichment.

2. Nutrients.

Laboratory experiments on the extraction of nutrients from tephra ejecta as well as glowing lava, revealed that significant quantities of silicates and phosphates were dissolved. At temperatures above 80^{o} the amounts of dissolved silicates in normal sea water increased by a factor of 4-6, the dissolved phosphates by a factor of 2-3. No significant amounts of nitrates dissolved from the eruption materials.

Horizontal distribution of reactive silicates in the study area during the first four cruises revealed a significant increase in concentrations within a small area surrounding the island. At the stations closest to the island (0.2 nautical miles or less) concentrations as high as 20 μg-at/litre were found, decreasing to 8 μg-at/litre or less 15 miles away from the eruption centre. The normal winter values in the Selvogsbanki area are about 6-7 μg-at/litre. Increased silicate concentrations were found both at the sea surface and near the bottom. It is believed that these resulted partly from sea water coming in contact with hot eruption material, and partly from dissolution of tephra fallout sinking through the sea as well as material lost from the island by marine erosion. Dissolved phosphates also increased because of the volcanic activity, but to a lesser degree than the silicates.

Results from the investigations made during the last five cruises indicate that after eruption of lava began in early April, the Surtsey eruption has had very little direct effect on the nutrient concentration in the surrounding area. An analysis of the available material suggests that although higher nutrient concentrations were found near the island than farther away during the summer; these can in most cases be attributed to reduced biological uptake associated with greater turbulence near the island.

B I O L O G Y

REPORT
ON DISPERSAL OF PLANTS TO SURTSEY

by

Eythor Einarsson
Museum of Natural History
Department of Botany

The present author visited Surtsey two times during 1964 for the purpose of investigating dispersal of plants to the island. The first visit was made on May 21st, the second on October 15th. During both visits a thorough search for macroscopic plants, or parts of plants, was made on the sandy shores of the east, north and north west coasts of the island and on the shores of the Lagoon, into which the sea is reaching during heavy south east and east wind at high water. Because of surf during both visits it was impossible to search for plants on the lava shores of the west, south and south east coasts of the island.

During both visits plant parts were found drifted ashore, just as can be found on the shore almost everywhere in Iceland, but no macroscopic plants were found growing on the coast with the single exception of some filamentous Chlorophyceae species, which were found forming little mats on ashore drifted piece of wood. Most of these plant parts were found on the shore east of the Lagoon.

Parts of the following plant species were found on the island:

On May 21st:

Vascular plants:

Cochlearia officinalis L. Some few fresh green basal leaves, 1 inflorescence and stem with stem leaves and inflorescence.

Elymus arenarius L. 1 old seed.

Ligusticum scoticum L. 3 fresh green basal leaves.

Matricaria maritima L. Ca. 25 fresh green basal leaves and 1 fresh young plant with basal leaves and the uppermost part of the root. This young plant was brought to Reykjavik and potted, but did not survive.

Poa pratensis L. Some few fresh green leaves and stolons.

Sedum rosea (L.) Scop. Some few fresh green leaves and 3 fresh green stems with leaves.

Algae:

Ascophyllum nodosum (L.) Le. Jol. Some 40 thallus fragments, one of them with an epiphytic growing Monostroma sp. near the base.

Fucus inflatus L. and Fucus vesiculosus L. 20-30 thallus fragments of each species.

A species of filamentous green algae, probably belonging to Chlorophyceae, found growing on ashore drifted piece of wood.

On October 15th:

Vascular plants:

Alopecurus pratensis L. 1 panicle with few seeds. Collected for germination ability control.

Angelica archangelica L. 1 old stem with leave bases.

Anthoxanthum odoratum L. 1 panicle with few seeds. Collected for germination ability control.

Euphrasia sp. 1 inflorescence with open and empty capsules.

Festuca rubra L. 2 stems with leaves, one of them with a panicle without any seeds.

Galium boreale L. A part of a stem with two leave whorls.

Mertensia maritima (L.) S.F. Gray. A part of stem with fresh leaves.

<u>Sedum rosea</u> (L.) Scop. A stem with empty follicles.

<u>Silene maritima</u> With. A calyx with fragments of a capsule.

<u>A root</u>, probably of some grass species. Collected, potted in Reykjavik. Seems to be dead now.

<u>Algae</u>:

<u>Chorda</u> sp. 20-30 thallus fragments.

<u>Ascophyllum nodosum</u> (L.) Le.Jol. 40-50 thallus fragments.

<u>Fucus inflatus</u> L. Some few thallus fragments.

<u>Fucus vesiculosus</u> L. ca. 20 thallus fragments.

<u>Odonthalia dentata</u> (L.) Lyngb. 1 thallus fragment.

BIOLOGICAL RECORDS ON SURTSEY

by

Sturla Friðriksson
The University Research Institute
Reykjavik, Iceland

The recording of the colonization of the dryland biota on the island of Surtsey has been performed at approximately monthly intervals, since it was foreseen, in the spring of 1964, that the island would survive the distructive forces of the sea.

The study was considered of value in order to furnish information on the successive order in which living organisms colonize a virgin island in the North-Atlantic, as well as it was believed to throw light on the spreading potential of various life forms and their means of transport over an ocean body.

Living organisms can either reach the island by their own mobility or can be supported by other agents. Undoubtedly man will play his part as a carrier, but steps are being taken in restricting unnecessary visits of people to the island.

Birds invade the island on their own wing support and so do possibly also some of the flying insects.

The dispersal of other living forms are by birds, by air and by ocean currents.

The immigration to the island will most likely take place from the neighbouring islands and the mainland of Iceland. The dryland closest to Surtsey is a rock at a distance of 5.5 km, where a few species of higher plants are to be found.

At the distance of 20 km is the largest among the Vestmann Islands with a flourishing fauna and flora. The distance from Surtsey to the mainland extends to over 30 km.

The various members of the Vestmann Islands differ in number of plant species and similarly the islands differ in that respect from the mainland.

The variation in distribution of plant species enables the determination of the possible minimal distance a given species has travelled, in order to reach the new island. This may give valuable information as to the different spreading potentiality of various plants. Although the immigrating biota is most likely to derive from Iceland, there is still the possibility of a long distance dispersal from other European countries.

Surtsey is by now the southernmost part of Iceland, and it is quite possible that the migrating birds from the continent of Europe may land on the island, after the flight across the ocean. On Surtsey it might be possible to detect whether these birds do carry plants and lower animals, and thus to what extent birds take part in the transport of the biota across the Atlantic Ocean.

The air currents carry bacteria, spores, light seeds and insects and by a study of air currents in the Atlantic it may be possible to trace the most likely route of dispersal.

Various floating objects drift ashore carried by ocean currents.

Among the debris are found plant parts and a few lower animals that sometimes have been carried attached to floats or drift wood.

Although the distance between the island of Surtsey and the nearest islands is short compared to the distance between Iceland and the continent of Europe, the study of the colonization of the new island may give some indication as to the way the biota does disperse in the North Atlantic and it may explain some facts regarding the dispersal of plants to Iceland in post-glacial time.

Previously, records have been kept on some biological events taking place on the island. The first records have been published (S. Fridriksson, Náttúrufrædingurinn 1964). Further data have been collected and other problems are under study.

Undoubtedly, microbes and airborn spores were the first to land on the surface of the volcanic island, which must have been completely devoid of life after the constant shower of hot falling tephra.

When the first attempt was made to estimate the number and kinds of microbes at two different sites on the island as well as in the lagoon, formed on the north east coast, it was noted that the microbial flora was extremely sparse and scanty in strains.

Fungi were sought at sea level and further up, and found to be rather rare, especially at the higher levels.

Algae and various forms of plankton may have been washed upon the shores of the newborn island at an early date as quite a few forms of these were collected when the first investigation was made on May 14th, 1964.

There have as yet been no signs of mosses or lichens, and no vascular plants have so far grown on the island. Various living plant parts, however, are constantly being washed ashore and germinable seed have been found. These plant parts have been mostly of coastal species found growing on the neighbouring islands, such as sea rockets, lyme grass, bistort, wild chamomile, roseroot and angelica.

These various plant parts have been collected and a study made of their vividness after their apparent immersion in salt water. In comparison fresh plant parts and seed have been immersed in salt water for different length of time and their vividness and germination ability measured following such treatment.

Surface samples of tephra from different sites have been collected for a possible study of its content of lower organisms and their part played in formation of soil.

The occurrence of two flying insects has been recorded and a note made of the presence of various birds and seals that have been found visiting the island.

REPORT

ON THE MARINE BIOLOGICAL SURVEY AROUND AND ON SURTSEY

by

Adalsteinn Sigurdsson
The University Research Institute
Department of Fisheries

Plankton and bottom samples were taken around Surtsey on December 1-2, 1963, 1-12 nautical miles off the island. A trawling station was also taken 5½ nautical miles W of the island, where the catch consisted of 8 species of fish besides Norway lobster.

The result from this survey supported the general view that life was normal around Surtsey.

On January 23rd, 1964, zooplankton samples were taken around Surtsey. They have not been worked up yet.

Phyto- and zooplankton, as well as bottom animals, were sampled around Surtsey April 2-3, 1964. On April 3rd a trawling station was also taken 2½-6 nautical miles SE of Surtsey, where we obtained 11 species of fish.

The samples already worked up did not show anything extraordinary. However, at the stations located 1 nautical mile off the island, there was a layer of volcanic sand over the mud, and fewer animals were obtained there than at the stations further away. We could not measure the thickness of that layer.

Phyto- and zooplankton were taken around Surtsey on the 10th of April, 1964. The composition of plankton was similar to that found about one week earlier.

On May 29-30, 1964, phyto-and zooplankton and bottom samples were taken around Surtsey. The bottom samplings were unsuccessful because of technical difficulties.

The samples, which have been worked up, have not shown anything extraordinary.

The same can be said about plankton samples from June 22-23, and plankton and bottom samples from September 5-7, 1964.

On November 16-17, 1964, plankton samples were taken to collect larvae of fish and bottom animals. As was to be expected at this time of year, very few larvae were found.

Bottom samples were also taken and there were living animals in all of them. The material from one station only has been worked up as yet. This station was clearly over the new lava on the sea floor, 0.2 nautical miles W of the island, off a place where lava was flowing into the sea and where the depth was 70 m. The sample was taken by a scraper. As could be expected, it got caught at once. However, the sample obtained contained some fragments of new lava and 8 animals listed below:

Name	Number
Pectenaria koreni	2
Portunus holaster	4
Pandalus montagui	1
Crangon allmani	1

This sample shows an early immigration to the lava on the sea floor and, especially as regards the Polychaeta, a rather surprising one.

Every other week in summer and every third week in winter m/s Gullfoss has taken samples with Continuous Plankton Recorder on her route passing Surtsey. The samples obtained after the beginning of the eruption were in good accordance with the samples from previous years.

All the marine biological surveys seem to indicate that the eruption has not had any effect on the life in the sea, except for the bottom animals in the area covered by a thick layer of volcanic material.

Scientists who have worked up the samples:

Ingvar Hallgrímsson	Zooplankton
Jutta Magnússon	Zooplankton
Aðalsteinn Sigurðsson	Bottom animals and their larvae
Unnur Skúladóttir	Bottom animals
Þórunn Þórðardóttir	Phytoplankton

The shore at the north coast of Surtsey was examined for marine animals November 25th, 1964.

The animals which had drifted ashore were:

Euphausiacea	in great numbers
Amphipoda	"
Cirripedia (Lepas sp.)	some few on debris drifted ashore
Chaetognatha	a few animals
Scopelidae	few animals
Scyphozoa	"

None of these animals have interest as immigrants.

G E O C H E M I S T R Y

Measurements on the D/H-ratio in H_2-gas and water vapour collected at the volcanic island Surtsey during the year 1964.

by

Bragi Árnason,
University of Iceland, Physical Laboratory,
Reykjavik, Iceland

Introduction:

During the year 1964 four visits were made to the volcanic island Surtsey.

The reason for these visits was to attempt to collect samples of volcanic gases and water vapour, escaping from the molten lava, for D/H-measurements.

The visits were made on May 21st, August 19th, October 15th and November 25th.

On the first visit, May 21st, it was impossible to approach the crater, but both water and gas samples were collected from fissures in the lava field. The temperature in the bottom of the fissures was about 840°C.

The gas analysis showed almost atmospheric gas containing no hydrogen[1)] and the condensed water vapour measured for its D/H-ratio showed almost the same deuterium content as oceanic water.

On the visit on August 19th it was again impossible to approach the crater and only samples of gas from a fissure in the lava field were collected.

These showed almost the same results as previously[1)].

On October 15th it was possible to get much closer to the crater and a chimney was found from which the gas was escaping with great force.

Chemical analysis of this gas indicated that it was mostly magmatic gas, which contained about 23% hydrogen and about 1% nitrogen + inert gases[1].

On November 25th it was also possible to come quite close to the crater, but the conditions had changed, so that it was impossible to collect as good gas samples as on the previous occasion. The gas samples contained so much atmospheric oxygen that the hydrogen was completely burned to water[1].

Despite this, the D/H analysis on the water gave a D/H-ratio that was not far from the D/H-ratio in the water collected on October 15th (see tab. 1).

<u>Method of collection:</u>

A stainless steel tube of about 8 mm diameter was put in the fissure and connected to a trap, which was used to condense the water vapour. 250 ml gas sample tubes made from pyrex glass were connected to the trap.

On October 15th the stainless steel tube acted as a condenser but on November 25th and all other occasions a trap of pyrex glass cooled to $-80^{o}C$ was used. (See fig. 1).

<u>Analysis:</u>

The water was converted to hydrogen gas as described by Friedman[2], and analysed for its D/H-ratio in a specially constructed mass spectrometer[2].

The results are expressed as deuterium enrichment (plus δ value) or depletion (negative δ value) relative to SMOW (Standard Mean Ocean Water, having a D/H-ratio of about 158.10^{-6})[3].

The gas analysis was made as follows: The gas was first passed through a liquid air cooled trap, to condense the heavy components. The residual gas containing nitrogen, hydrogen and inert gases was then passed through a copper oxide oven at about

500°C, where the hydrogen was completely burned to water. The resulting water vapour was then allowed to pass into a liquid air cooled trap, whereby it was frozen out.

The residual gas, now containing nitrogen and inert gases, was then pumped away and the condensed water allowed to reevaporate and passed through a uranium oven in the usual way, as described by Friedman[2].

The hydrogen gas was then analysed in the same mass spectrometer as the water samples.

The accuracy of the measurements is within 0.2%. Tab. 1 shows the results.

Discussion:

Although the number of measurements is limited, they may give some indications.

For example, if we use the values from October 15th, $\delta_{H_2O} = -5.0\%$ and $\delta_{H_2} = -14.38\%$, and say that the hydrogen and water is in equilibrium at t°C, we can calculate the equilibrium constant, K = 1.11^{xx} and use the theoretically estimated equilibrium constants for various temperatures[4]. Then we will obtain t = 1010°C, which is not far from the measured gas temperature (ca. 1140°C)[5].

Fig. 2 shows the theoretically calculated equilibrium constant for the reaction $H_2O + HD \rightarrow HDO + H_2$ (vapour phase)[4].

$$^{xx}\ K = \frac{(H_2)/(HD)}{(H_2O)/(HDO)_{vapour}}$$

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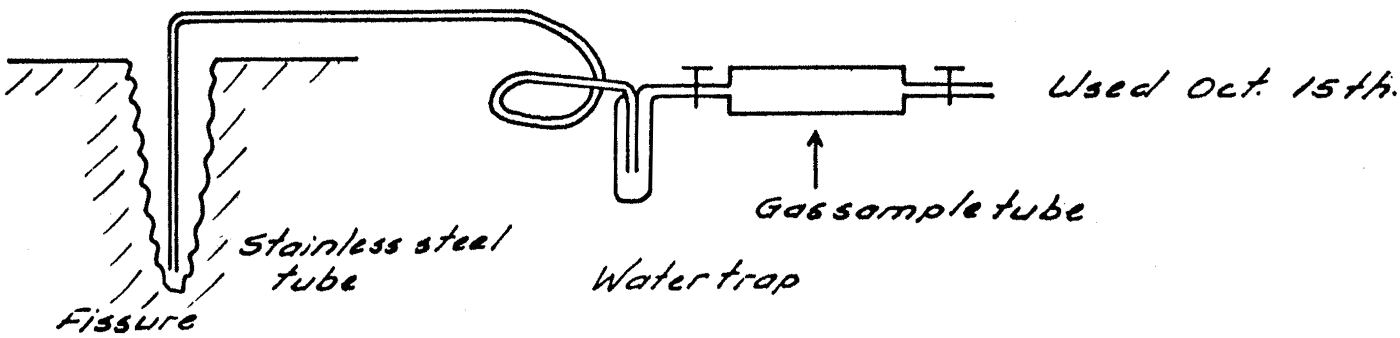
TABLE 1

Measurements on the D/H-ratio in H_2-gas and water vapour collected at Surtsey during 1964.

Date of sampling	Sample no.	Water % δ	H_2- gas % δ
May 21st	1	+ 2.18	
"	2	+ 1.73	
"	3	+ 1.90	
"	4	+ 1.90	
"	5	+ 1.90	
"	6	+ 1.76	
"	7	+ 1.31	
"	8	+ 2.22	
"	9	+ 1.90	
"	10	+ 1.68	
October 15th	11	- 5.00	- 14.38
"	12	- 5.07	
November 25th	13	- 5.59	
"	14	- 5.57	
"	15	- 6.06	

FIG I

Gas and water collecting apparatus.



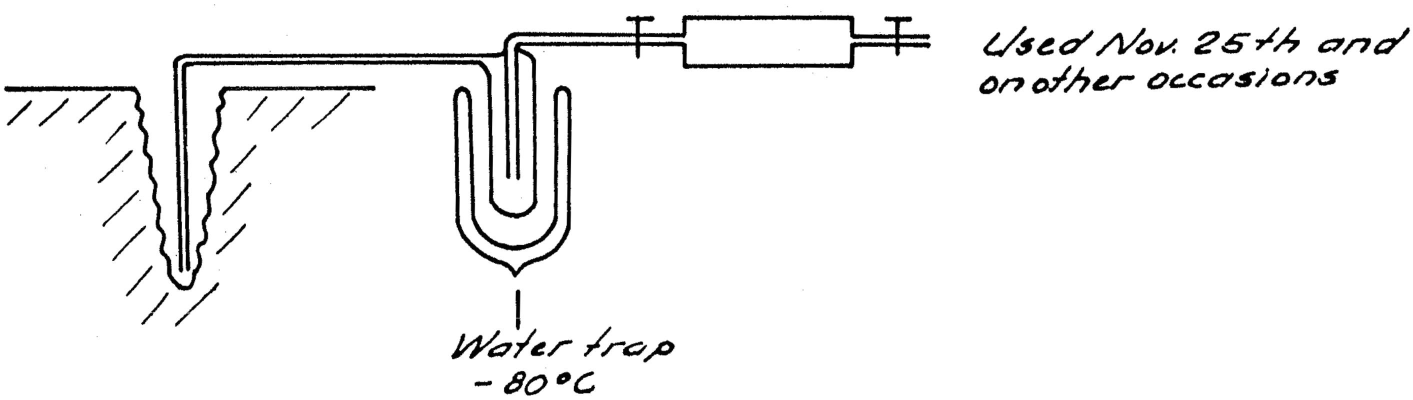
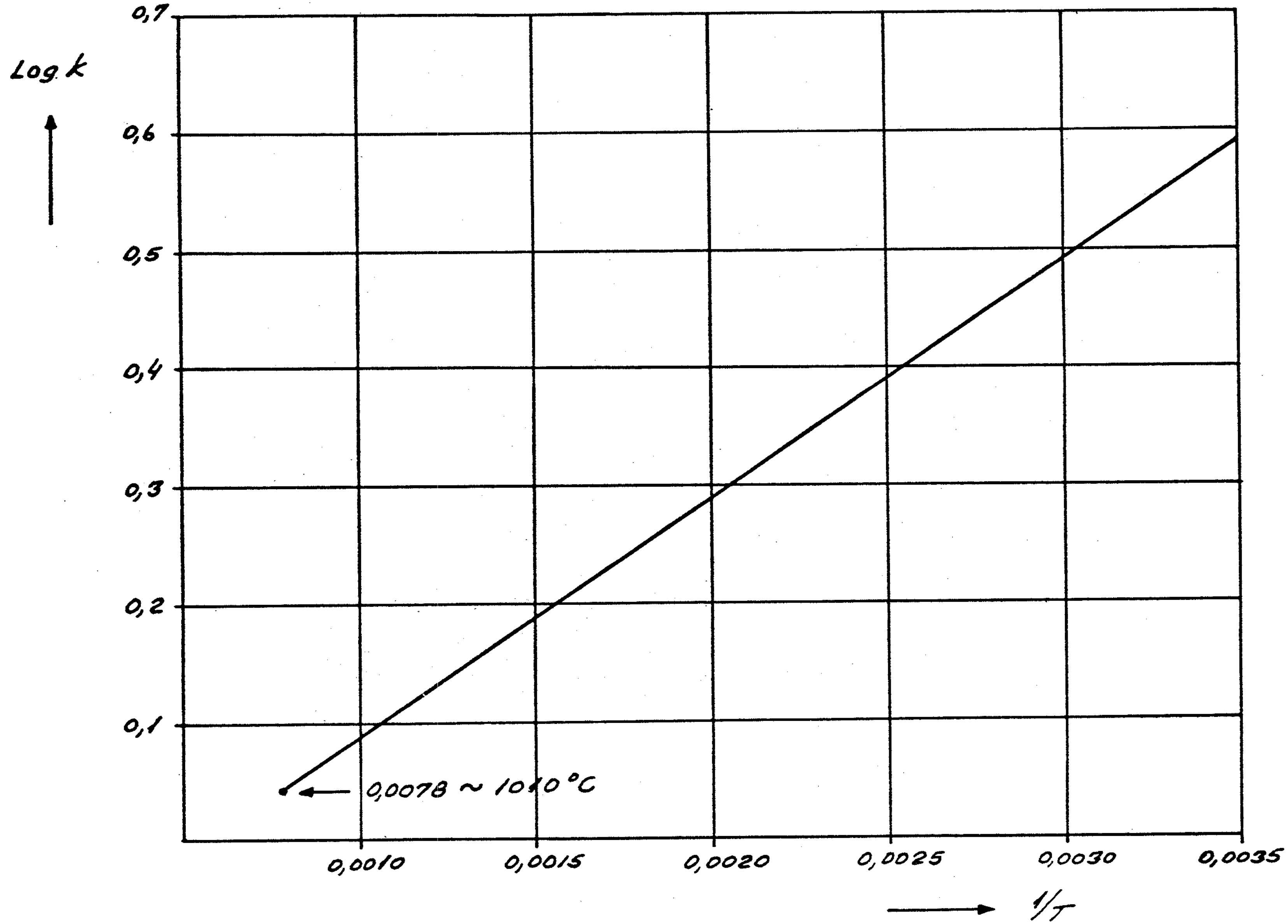


FIG. 2.



Log k
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0078 ~ 1010 °C
0,0010
0,0015
0,0020
0,0025
0,0030
0,0035
1/T

PRELIMINARY REPORT ON COLLECTION AND ANALYSIS OF VOLCANIC GASES FROM SURTSEY

by

Guðmundur E. Sigvaldason and Gunnlaugur Elísson,
The University Research Institute, Reykjavík.

Considerable effort has been exercised in connection with sampling and analysis of volcanic gases from Surtsey. Relatively little information is available on the chemistry of volcanic gases from Iceland and other parts of the Mid-Atlantic Ridge. On the other hand considerable information on volcanic gases from the Pacific area has been accumulated during the past few years, and it will be of major interest to compare the chemistry of volcanic gases from the Atlantic and Pacific areas.

Shortly after the Surtsey eruption changed over to a quiet outpouring of lava, attempts were made to collect escaping gases. During 1964 four such attempts were made on May 21st, August 19th, October 15th and November 25th. On each of these occasions different conditions of sampling were met with since conditions at the crater changed rapidly.

May 21st. Samples were taken from a lava fissure away from the main stream of lava. One meter below the surface the lava was still glowing, temperature measurements with an optical pyrometer indicated 840^{o}C. Copper tubing was used to draw the gas into a dewer bottle,cooled in air, where water was condensed and from there the gas was pumped into the gas sampling tubes.

August 19th. On this sampling trip conditions were similar as during the first trip. Copper tubing proved, however, fully inadequate, because of drastical corrosion of tubes and too low melting point.

October 15th. Conditions at the crater had now changed in such a way, that the main bulk of lava escaped by closed channels after remaining for a short while in the open crater.

At a few places along the channel roof gases escaped. Sampling was performed at one such exit, a narrow opening where gases were emitted at high velocity. At 10 cm high torch like sodium coloured flame was formed as the gases burned with atmospheric oxygen.

Temperature measurements were attempted with thermocouples mounted on the end of an iron tube. This tube melted in the flame. Fortunately the copper tubing used for previous sampling attempts had now been replaced with a tube of stainless steel, which was lowered below the base of the flame. The gas instantly filled the sampling tubes and since pressure was considerably above atmospheric all along the sampling train, contamination was effectively prevented. Because of rapid reaction between sulphur dioxide and hydrogen sulphide under these conditions, the presence of H_2S was checked with lead acetate paper at the end of the stainless steel tube. The test was not indicative of any appreciable amount of H_2S, a faint brownish colour developed on the paper. In the condensate, however, considerable amount of elementary sulphur was precipitated resulting either from the reaction $2H_2S + SO_2 \rightleftharpoons 2H_2O + 3S$ or condensation of sulphur gas.

Because of the large amount of gas flowing through the sampling train, condensation of steam was probably not fully effective resulting in low steam to gas ratio.

<u>November 25th</u>. Conditions at the crater were similar as on the October trip. Samples were taken from an opening on the lava tunnel close to the crater wall. This opening was, however, 2-3 meter wide and a relatively quiet but large flame was developed. The stainless steel tube was lowered into this opening, and the gas drawn through the sampling train with an aspirator bottle.

Discussion.

With an exception of the gas sample of Oct. 15th all samples were heavily contaminated with air. This contamination results from convective air currents within the lava. On May 21st and August 19th reaction with the copper tubing resulted in low oxygen. No active volcanic gases were detected in those two samples except CO_2.

As shown by the H/D analysis of the condensate from May 21st (Árnason, this report), the steam probably resulted from evaporation of sea water from the wet ash underlying the lava. During this early period of lavaproduction, large amounts of incrustations were formed on the lava surface, giving it a peculiar green colour. The principal component of these salts is aphthitalit ($K_3Na(SO_4)_2$).

The gas samples of Oct. 15th are unique with regard to low, if any, atmospheric contamination. Maximal amount of air, which could have been introduced into this sample, is 1 percent if all nitrogen is considered atmospheric. Nitrogen and rare gases are however undoubtedly present in volcanic gases and a valuable upper limit for the concentration of these components in the gases from Surtsey is established with this analysis.

The Oct. 15th sample contains 3.4. percent CO in the non-condensible components and 45.9 percent CO_2. In all other samples carbon is just found as CO_2. Methan was not detected in any of the analysed samples. (Limit of detection of the analytical method is 0.01 percent CH_4).

Sulphur is present as SO_2 in all samples where sulphur was found. H_2S has not been detected in the gas samples, but strong smell of H_2S from the beginning period of lavaproduction has been reported. In the case of the Oct. 15th sample, H_2S, if present, was converted completely to elementary sulphur.

Equilibrium calculations by Heald, Naughton and Barnes (1962, 1963) show that at 1500°K and variable partial pressure of oxygen, there are regions where in each oxydation reduction couple, such as H_2S - SO_2 or H_2- H_2O, the reduced or the oxydized gas is dominant. In the case of our Oct. 15th cample, the oxydized gas components are clearly dominant. The partial pressure of oxygen in a gassystem containing all sulphur as SO_2 is, according to Heald et alii, greater than 10^{-4} atm at 1500°K. The calculated equilibria given by these authors is found on the basis of a sample with atomic ratios, hydrogen : oxygen : carbon : sulphur - 275.5 : 142.2 : 2.680 : 1.000. The atomic ratios for our Oct. 15th sample are respectively 20.3 : 31.3 : 1.82 : 1.000, the difference between these two samples depending principally on higher water content in the sample from Hawaii. If we, however, use the calculated equilibrium curves of Heald et al., a minimum partial pressure of oxygen would be 10^{-9} atm if the detection limit for H_2S of our analytical method is 0.1 percent of the noncondensible components.

Based on the concentration of components in the Oct. 15th sample, the equilibrium temperature for this mixture can be calculated

$$CO_2 + H_2 \rightleftharpoons CO + H_2O$$

$$\frac{[CO] \quad [H_2O]}{[CO_2] \quad [H_2]} = K$$

Fig. 1 shows the change in K with temperature according to values taken from Critical Tables and from Ellis (1957). For the Oct. 15th sample K = 1.30 indicating a temperature of 1190°K and 1157°K respectively (885 and 920°C).

This calculated equilibrium temperature is considerably below the measured temperature at the vent 1100 - 1200°C (Sigurgeirsson, this report), and 100° lower than the temperature obtained by Árnason (this report) by means of isotope fractionation studies. These results are in accordance with the findings of Heald et al., which found an equilibrium composition of volcanic gases from Hawaii to correspond to a lower temperature than actually measured at the sampling site.

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TABLE I

Chemical analysis of volcanic gases.

	1. 21.5.64	2. 19.8.64	3. 15.10.64	4. 25.11.64	5. 25.11.64	6.
H_2O	62.83	11.74	80.00	76.94	76.94	18
O_2	6.73	15.09	0.00	3.69	3.39	14
H_2	0.00	0.00	4.56	0.00	0.00	0.022
CO_2	0.07	0.44	9.18	0.99	2.05	0.37
SO_2	0.00	0.00	5.40	0.90		0.057
CO	0.00	0.00	0.68	0.00	0.00	Tr.
CH_4			0.00			
N_2+A	30.37	72.73	0.18	17.48	17.62	68
TOTAL	100.00	100.00	100.00	100.00	100.00	
TEMP. °C	840	840	1100	1100	1100	750

1-5. Surtsey.

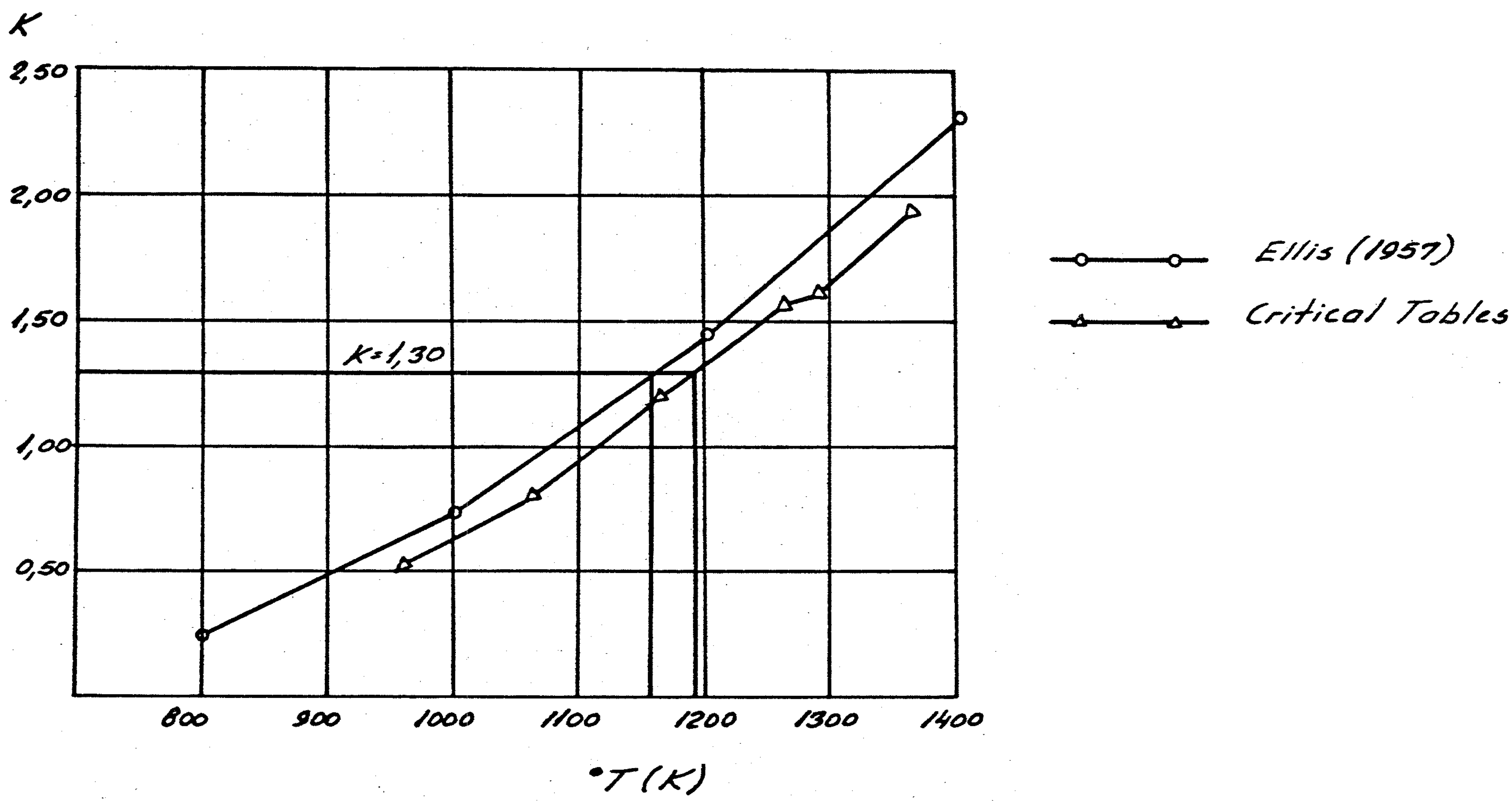
6. Puu Puai, Hawaii 30.11.59 (KI-F) (HEALD, NAUGHTON, BARNES 1963).

H_2S : 0.12%

TABLE II

Chemical analysis of noncondensible component of volcanic gases from Surtsey.

	21.5.64	19.8.64	15.10.64	25.11.64	25.11.64
O_2	18.1	17.1	0.00	16.0	14.7
H_2	0.00	0.00	22.8	0.00	0.00
CO_2	0.2	0.5	45.9	4.3	8.9
SO_2	0.0	0.0	27.0	3.9	
CO	0.0	0.0	3.4	0.0	0.0
CH_4			0.00		
N_2+A	81.7	82.4	0.9	75.8	76.4
TOTAL	100.0	100.0	100.0	100.0	100.0


K
2,50
2,00
1,50
1,00
0,50
K=1,30
800
900
1000
1100
1200
1300
1400
°T (K)
Ellis (1957)
Critical Tables

SURTSEY:

PETROLOGY AND CHEMISTRY

by

Sigurdur Steinthorsson
The University Research Institute
Reykjavik - Iceland

Summary

A petrological survey is made of material collected at various times during the history of the Surtsey island, which has now been erupting for fourteen months. The mineralogy is that of basaltic lava and tephra, with the composition of the plagioclase changing with time towards more albitic varieties (An 60 - An 53), but the composition of the olivines (Fo 80) and the pyroxenes (augite) remaining constant.

One chemical analysis is included, showing rather low SiO_2 content (46.5%) for recent Icelandic basalts, and a norm, which does not agree very well with the modes. Finally the abundances of a few trace elements are listed.

(i) Introduction

Since the beginning of the Surtsey eruption in November 1963, rock samples have been collected at various times for inspection and analysis. As yet only a preliminary survey has been made of these samples, but further research will be forthcoming in due course.

The nature of the eruption has changed several times during its history: The initial explosive phase lasted until the 4th of April 1964, when quiet outpouring of lava took over for a month. Then lava-fountain activity ensued until the 9th of July, when the lava started to flow again. To begin with, the lava flowed straight out of the vent to build up the area around, but towards the end of August 1964 it changed habit, and has since then escaped from the crater in tunnels to emerge at sea level some 800 m away. Specimens are at hand representing the various phases, and from their comparison one may deduce certain facts in connection with the course of crystallization, even with reference to the temperature, and the circumstances of the formation of the textures.

In the early days of the eruption, samples were obtained from the ash-cloud by sailing the coast guard vessels under the falling ejecta and then collecting from the deck. Later, when ascension on the island became less hazardous, specimens of bombs and lava were gathered in the usual way by landing parties.

(ii) Petrography

The tuff (slide A, cf. footnote on Table I) represents the chilled magma, which has lost most of its gases. The mineral assemblage may then presumably be regarded as that of the magma in the crater. The liquid is represented by the brown, translucent sideromelane glass (73%) in which olivine (7.7%) and plagioclase (7.3%) crystals occur quite abundantly. The olivines (about Fo 80) appear to be in the process of rapid growth. They are often quite large, but almost invariably skeletal; olivine microlites are common as well. A few, somewhat zoned phenocrysts of plagioclase are present, but the majority occur as tiny needles or microlites with sutured ends. Their composition is that of high temperature labradorite (An 60). Neither pyroxene nor iron ore has crystallized yet, but the ore is present as irregular clots in the glass, frequently fringing gas bubbles, which occupy 15-20% of the rock volume.

In a bomb taken on the island in December 1963, the crystallization has proceeded somewhat further, as pyroxene comes in, and olivine and plagioclase have increased in amount (Table I, B). The modal volumes are, however, inaccurate, because the rock is too fine-grained for exact optical analysis.

During the first months of the eruption large phenocrysts of feldspar, up to 5 cm across, were quite commonly to be found in the eruption products. They were present from the beginning in November 1963 and throughout the winter, but by mid May 1964 they had disappeared. These phenocrysts have been analysed by prof. Wenk of the University of Basel, and were found to be high temperature labradorite (An 66). Their disappearance is thought to be due to the fact that the feldspars, forming from the liquid in the spring 1964, were more albitic (probably about An 56) than the basic phenocrysts, which resulted in the resorption of the latter.

Probable relicts of these basic feldspars are seen in section C, where two large phenocrysts (2-3 mm across) show reversed zoning: The core, which is clear and fresh (An 53), is rimmed with a cloudy zone, crammed with "inclusions", which in turn is followed by the outest zone, fresh again, which is much more basic in composition than the core (An 67). It seems possible that the phenocrysts are being recrystallized by diffusion to gain stability in the environment, the recrystallization starting in the centre of the crystal and proceeding outwards. The composition of the groundmass-plagioclase is An 53.

The two remaining specimens are similar in age, and were collected in approximately the same distance from the crater. One is a dolerite, well crystallized, with ophitic pyroxene and crystals of iron ore. The other is glassy; the magma liquid flowed out of a tunnel straight into the sea. From the modes (D and E, Table I) we see that some of the olivine and pyroxene are still to be crystallized, most of the ore, and all of the pyroxene, but the ore present in section E occurs as crystals inside the olivine phenocrysts. The pyroxene in the dolerite is somewhat purple in colour, which might indicate titaniferous nature (cf. analysis and norm in Tables II and III). Neither the olivines nor the feldspars are skeletal here, which is not surprising, considering the fact that they have had much better time to develop than those in sections A–C, because the magma must lose much gases and heat on its way along the tunnels from the crater down to sea (about 800 m), which of course results in the continuous crystallization of the liquid.

(iii) Chemistry

A complete chemical analysis has been made of only one sample yet, (sample A), which is tabulated with a norm in Tables II and III. In Table II, three other analyses of recent Icelandic lavas are quoted for comparison. The Surtsey material is amongst the most basic lavas erupted in Iceland in recent years, comparable in that respect only with a lava stream (Lambafitjarhraun)erupted in 1913 in the neighbourhood of Mt. Hekla (SiO_2 46.21%), but is somewhat higher in alkalies.

The norm, Table III, is not comparable with either mode A or D, because the mineralogy of A is immature, and the chemistry of D most likely different from that of A. Section D is, however, the only one with a reasonably mature mineralogy. Some of the discrepancies in pyroxene and iron ore may be attributed to the fact that coloured and dark minerals assume greater volumes in modal analyses than the colourless ones. Some of the titanium forming the ilmenite may be present in the pyroxene, but as we understand that the role of Ti in pyroxene is somewhat in the dark, we shall let the matter rest there.

A few trace elements have been evaluated in Surtsey material. They are quoted in Table IV with the corresponding values of the standards W-1 and G-I against which they were measured.

More analyses are forthcoming of Surtsey material, major components as well as trace elements. This report is to be looked upon as an outline sketch of the problem in which certain features, such as the xenoliths, have been omitted completely.

Acknowledgements

Thanks are due to Dr. Sigvaldason, who did some of the trace element and U-stage determinations, and to Dr. Tryggvason for a few U-stage analyses.

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TABLE I

Modal analyses of five thin sections.

	A	B	C	D	E
Glass	72.9	21	54.9-x	-	53.5
Feldspar	7.3	32	33.5	48.0	31.7
Olivine	7.7	13	11.6	16.4	12.3
Pyroxene	0.8	15	-	25.8	-
Opaque	11.3	19	x	9.8	2.5
	100.0	100	100.0	100.0	100.0

A. Thin section no. 944. Tuff gathered 1.12.63. The opaque assumes more volume than is correct, because it is disseminated in the sideromelane giving colour to a "stolen" volume of glass.

B. Thin section no. 945. Bomb taken ashore the island 6.12.63.

C. Thin section no. 1089. Surface of pahoehoe lava, flowed in August 1964.

D. Thin section no. 1088. Taken in sea-cliffs from lava frozen in a tunnel. Probably flowed in Nov. or Dec. 1964.

E. Thin section no. 1090. A molten piece of lava flowed into the sea out of a tunnel, and was rescued instantly (24.1.65).

TABLE II

Chemical analyses from four Icelandic volcanoes, which have erupted in the 20th century.

	1. Katla 1918	2. Hekla 1948	3. Askja 1961	4. Surtsey 1963
SiO_2	47.68	54.25	50.33	46.50
TiO_2	5.01	1.54	2.94	2.28
Al_2O_3	12.54	16.34	12.23	16.80
Fe_2O_3	3.44	2.24	2.37	1.65
FeO	12.34	10.05	13.89	10.80
MnO	n.d.	0.26	0.27	0.20
MgO	5.25	3.39	4.99	7.62
CaO	9.58	7.09	8.95	9.45
Na_2O	2.43	3.41	2.81	3.32
K_2O	0.88	0.95	0.68	0.57
P_2O_5	0.23	0.35	0.28	0.33
H_2O^+	0.44	0.42	0.27	0.02
H_2O^-	0.15	0.08	0.05	0.03
	99.97	100.37	100.06	99.57

The analyses are cited after Thorarinsson *et al.* (1964)

TABLE III

A norm of the chemical analysis of sample A
(analysis 4, Table II)

	Norm A.			Mode D
Orthoclase	3.34			
Albite	24.10	58.90	Feldspar	48.0
Anorthite	29.47			
Nepheline	1.99			
	6.61			
Diopside	3.60	12.98	Pyroxene	25.8
	2.77			
Olivine	10.78	20.37	Olivine	16.4
	9.59			
Magnetite	2.32	6.58	Ore	9.8
Ilmenite	4.26			
Apatite	0.67	0.67	Apatite	-
Water	0.05			
	99.55	99.50		100.0

TABLE IV

Trace elements in Surtsey rock collected 1.12.63.

	Surtsey	W-I	G-I
Co	53 p.p.m.	50 p.p.m.	2.4 p.p.m
Cu	65 -	120 -	14 -
Ni	110 -	75 -	nd.
Rb	20 -	10 -	220 -
Sr	295 -	160 -	250 -
V	195 -	240 -	15 -
Y	13 -	24 -	13 -

Elements Co, Cu, Ni and V are measured by emission spectrography; the remaining ones with an X-ray fluorescence spectrograph.

GEOLOGY

THE SURTSEY ERUPTION

COURSE OF EVENTS AND THE DEVELOPMENT OF THE NEW ISLAND

by

Sigurdur Thorarinsson
Museum of Natural History
Reykjavik, Iceland

Collecting of information.

From the very beginning of the Surtsey eruption my main contribution to the research work connected with this eruption has been to try to follow by all available means the course of events in order to facilitate the reconstruction of a more or less continuous and reliable picture of the eruption, and to time its different phases and changing habits.

This has been accomplished partly by own observations, partly by collecting information from eye witnesses such as pilots flying over Surtsey, visitors to the island, the staff of the Vestmann Islands Air Control Tower, who have Surtsey in view every clear day, passengers on ships passing Surtsey, a.s.o. I have also tried to collect everything written in newspapers about the eruption.

During the winter 1963/64 my observations from ships were supplemented mainly by Dr. Thorleifur Einarsson. We went out repeatedly on coast guard vessels together or by turns. The Director of the Coast Guard Service, Pétur Sigurdsson, and the crews on his vessels were most helpful to us.

Thanks to the helpfulness of Agnar Kofoed Hansen, Director General of Aviation, I have been able to do many more reconnoitring flights than otherwise would have been possible. Febr. 23, 1965, I made my 62nd reconnoitring flight over Surtsey. I had then visited the island 16 times by boat and landed there 11 times, thereof 4 times by air. My first landing was Dec. 16, 1963. I had taken about 2000 photographs of the island, whereof 1300 in colour. With the aid of these photos and verical photos taken about every second month by the Geodetic Survey of Iceland, and with frequent measurements from coast guard vessels, it ought to be possible to reconstruct with tolerable exactness and continuity both the building up and the breaking down of Surtsey, as well as to illustrate most of the various phases of this spectacular eruption, Only two maps based on aerial photos have been worked out yet, and some of the areal figures given below are preliminary.

Mr. Ósvaldur Knudsen has taken a long 16 mm cinemafilm in colour of the Surtsey eruption, and I have tried to be of assistance to him in making the film documentary valuable.

Course of events.

The Surtsey eruption started visibly at 07 h 15 m Iceland mean time Nov. 14, 1963. This was witnessed by the crew of the fishing vessel Ísleifur II of the Vestmann Islands. The position of the volcanic activity was 63°18'N and 20°36'.5 W, three naut. miles WSW of Geirfuglasker, the southernmost island of Iceland. At 11 o'clock, when first seen by the writer, there were active eruptions in at least two separate places on a line running N 35° E to S 35° W, and the length of the fissure, about 500 m in length. The following night the island was born. In the morning of Nov. 15 it had reached a height of 10 m, and during the next few days it grew rapidly, as the eruption was more or less continuous. Nov. 19 the island was 60 m high and 600 m long. Then it was still an oblong ridge, split by a fissure which was flooded by the sea, and on this fissure two to four separate vents were erupting, shifting from one part of the fissure to another. Gradually the form of the island changed to hoof shape, which after Nov. 26 was usually open to the soutwest. Sometimes a reef blocked the opening, but it never lasted long until the reef was broken by the surf, or blown away by explosions. After the middle of December only one crater was active most of the time, and the island became nearly circular. In spite of the very effective marine abrasion, which at times cut broad platforms into the outer walls of the volcanic cone, the island on the whole grew in area and height. Dec. 30, the height was 145 m and the diam. about 1100 m.

Towards the end of January the activity in the crater ceased altogether. The island has then reached a height of 174 m, or 300 m from the former sea floor. Its max. length was then 1300 m. Febr. 2 at 11 p.m. a new vent started at sea level on the NW flank of the cone, and the following day the new eruption increased rapidly. Between Febr. 2 and 7 two vents were usually playing at the new eruption site, the innermost erupting lava fountains as the outer one, which was tephra producing, barred the sea from access to it. After Febr. 7 only the outer vent, Surtur II, was active, behaving on the whole in similar way as Surtur I had done until its extinction at the end of February. The eruption was wholly explosive, either with intermittent "wet" explosions, when the sea flooded the vent, or with a more or less continuous uprush of tephra and vapour, when the access of water was blocked by a tephra reef. The explosive activity went on until April 4 at noon, when so thick a tephra wall blacked the gap in the crater wall that the sea had no longer access to the vent. Then the eruption changed to a wholly effusive one with lava in the crater, and so it has been since then.

When the explosive activity ceased the eruption had, roughly estimated, produced 400/500 million cub.meters of tephra, equivalent to an average production of 40 cub.m per second. The area of the island at the end of the explosive phase was about 1.05 km^2.

The effusive phase.

Since the effusive eruption started on April 4, 1964, a lava lake has nearly continuously boiled in the crater, and except for a lull in the lava production between the end of April and June 9, 1964, there has been no stop in the flow of lava from the crater. At times the lake rose so high that the lava welled over the rims of the vent and flooded the slopes of the lava dome with speeds up to at least 10 m per second. More often, however, the lava found outlets through channels high in the lava dome flowing down the slopes in many rivulets. Gradually their routes were extended along closed tunnels, and during the winter 1964/65 these rivulets usually did not come to the surface until they had almost reached sea level. The lava has mainly flowed towards south and built up a semicircular lava dome with the result that Surtsey may now be regarded as a tablemountain, vix. a basalt shield volcano resting on a tephra socle. The height of the lava dome above sea level was about 95 m at the end of August, 1964; Oct. 23 it was 100 m, and has not changed much since then. The area of the new island, which was about 1.7 km^2 at the end of August, 1964, was 2.3 km^2 according to an aerial photogrammetric measurement of Feb. 23, 1965. Bathymetric maps are needed before the total amount of lava can be calculated, but it seems that the production of lava per month is about the same, calculated in weight, as that of tephra during the explosive phase of the eruption. The chemical composition of the lava is the same as that of the tephra. Thus the change from explosive to effusive activity was due entirely to change in the external conditions.

What happens, when the lava enters the sea.

From the very beginning of the lava eruption it has been striking, how much of the lava becomes fragmented when coming in contact with the sea water. Explosive pseudoeruptions on a small scale could frequently be observed. A great amount of coarse, more or less glassy sand was formed because of fragmentation of the pahoe-hoe lava surface by rapid cooling, and also by the crushing effect of the breakers and the grinding of blocks by the surf. The sand thus formed builds up a collar of sand in front of the lava flow so that at low tide one can walk on a sandy beach in front of the advancing lava. The lava is thus constantly advancing over a layer of wet sand at sea level. How thick this layer is we do not know yet, but it may be assumed that from sea level and down to the former sea-floor at 130/140 m depth, there is some mixture of coarse sand, intrusive lava and pillow lava, which also may be intruded into the water soaked sand to some extent. Only by drilling through the new lava can we get a definite knowledge of the submarine structure of the lava flow, and such a drilling is highly desirable, as it may throw light on the formation of pillow lava and other features of submarine flows.

Where the lava has ceased to flow it takes only few weeks for the marine abrasion to form vertical cliffs up to 40 feet at the lava front. Above high water level these cliffs are mainly built up of thin lava sheets, in places intercalated by layers of sand. Below high water level there is in places a clear tendency towards the formation of pillow lava. Occasionally a few, rather well developed pillows have been observed; typical pillow lava has not been observed, but one may expect it to be formed below low water level.

Geomorphological studies.

Surtsey is a true Paradise for geomorphologists. The fight between the constructive and destructive forces is fascinating, but also, when the eruption has come to an end, it will be interesting to follow the work of the exogenic forces: marine abrasion, the erosion of wind and running water, landsliding, frost action, etc., which will continue to change the shape of the island. Most of these forces work there with nearly incredible speed and efficiency, and illustrate how relative the time factor is in geomorphological processes.

Morphoscopic studies, which started in April, 1964, reveal that the rounding of blocks and gravel on the shores is an extremely fast process, and on the whole it is astonishing how fast various landscape forms are created on the new island.

GEOPHYSICS

Some Geophysical Observations at Surtsey in 1964.

by

Sveinbjörn Björnsson
The State Electricity Authority,
Department of Natural Heat

A. Observations of atmospheric electric disturbances at the volcano cloud.

In the beginning of the submarine Surtsey eruption, there were frequent lightning discharges in the volcano cloud and this lightning activity continued with varying intensity until April 4th 1964, when the formation of a wall of scoria prevented the ready access of sea water into the crater and it filled with molten lava.

First attempts to investigate these electric disturbances were undertaken by Prof. Thorbjörn Sigurgeirsson, University of Iceland, in November-December of 1963 and January of 1964. These investigations were greatly advanced when U.S. scientists began their observations of the electrical phenomena in February of 1964.

On February 5th Bernard Vonnegut, Arthur D. Little, Inc., Barrie McLean, American Meteorological Society and the writer went on M.V. Haraldur to Surtsey and made observations of the potential gradient of the electric field with a portable electrometer. Motion pictures of the volcano cloud were taken from the boat. Time lapse motion pictures were also taken from the airport on Vestmannaeyjar 23 km distant from the volcano.

On February 16th Charles B. Moore, Arthur D. Little, Inc., Duncan C. Blanchard, Woods Hole Oceanographic Institution and James Hughes, Office of Naval Research, sailed to Surtsey on M.V. Haraldur and recorded the potential gradient and point discharge near the volcano cloud.

On February 11th, 12th, 15th and 16th Robert Anderson and Stuart Gathman, Naval Research Laboratory and Henry I. Survilas, Arthur D. Little, Inc., made flights near the volcano in a

Constellation airplane equipped by the Naval Research Laboratory with electric field meters in the wing tips.

These observations have been continued by the writer. On March 22nd further potential gradient observations were made near the volcano and under the volcano cloud aboard an Icelandic Coast Guard ship.

A report on all these observations and the obtained results has been written and is being published in "Science" under the title "Atmospheric Electric Disturbances Produced by the Volcano Surtsey, Iceland".

B. Observations of charge separation at the contact of molten lava with sea water.

As lava flowed into the sea, dense, white steam clouds evolved. It was soon suspected that these clouds might be electrically charged. D.C. Blanchard (Nature, 201, 1164, (1964)) found in his laboratory experiments that if drops of salt water fell on molten lava, positively charged clouds of sea salt particles evolved. The charge concentration in these laboratory-created clouds was estimated to be as high as 10^8 elementary charges per cubic centimeter. This is about two million times as great as the positive space charge that is normally found in the atmosphere.

In order to verify, if this kind of charge separation was working in Surtsey, the writer went on July 24th aboard an Iceland Coast Guard vessel to Surtsey and waited for a flow of lava into the sea. It was not possible to go ashore because of surf, but when the ship sailed under the steam plume, evolving from the contact of lava and sea, a strong increase in the potential gradient was observed. From the recorded observations it may be deduced that the charge concentration in the cloud at its source must have been about 10^6 elementary charges per cubic centimeter.

On August 19th an U.S. Navy helicopter brought a group of scientists to Surtsey. This was the first opportunity to observe the charge separation directly at its source, where the lava flowed into the sea. The lava flow was covered with a thin black crust and its contact with the sea was relatively quiet. Dense, white steam clouds evolved there. By means of potential gradient measurements the charge concentration in these clouds was estimated to be of the order of 10^6 elementary positive charges per cubic centimeter.

At some places the thin crust broke and molten lava was squeezed out. Explosions occurred as this very hot lava came into contact with the sea. Fragments of lava were thrown up to several meters height along with fountains of waterdrops. These waterdrops evaporated and formed clouds of steam. The charge concentration in these clouds was estimated to be $10^7 - 3 \cdot 10^8$ elementary positive charges per cubic centimeter.

Further observations of the charge separation were made on January 18th. This time the space charge was measured directly with a Faraday cage. Steam clouds evolving from the quiet contact of lava and sea contained positive charge up to 1.1×10^6 elementary charges per cubic centimeter. No negative space charge was observed.

According to the potential gradient measurements made near the volcanic crater in February and March 1964, the volcano cloud carried a net positive charge as it was ejected from the crater. It is tempting to attribute the positive electricity in the volcano cloud to the contact of sea water with magma in the crater. However, caution must be used here, for the conditions during the eruption are exceedingly complex, and other charge separation mechanisms undoubtedly play a rôle. It would be of great interest to investigate the similar intense lightning activity, which accompanies the frequent subglacial eruptions in Iceland. In these eruptions the water plays the rôle of the sea at Surtsey.

C. Measurements of the radon content of magmatic gas.

Radon is the decay product of radium. If the radium concentration in magma is determined, the radon concentration in the magmatic reservoir can be calculated. As the magma ascends and pressure is released, the magmatic gases escape.

A determination of the ratio of the radon concentration in the magmatic gases and the radon concentration in the magmatic reservoir would give an estimate of the content of volatile gases in the reservoir.

One attempt has been made to determine the radon content in the magmatic gases. A value of 100 pC per liter of magmatic gas was obtained. Further measurements are necessary. Measurements of the radium content of the lava are in preparation.

SOME GEOPHYSICAL STUDIES IN SURTSEY IN 1964.

by

Gudmundur Pálmason
State Electricity Authority
Department of Natural Heat

1) A provisional seismograph was operated in the Vestmann Islands from Jan. 23 to April 11. It was assembled from parts obtained from the Department of Natural Heat and the Meteorological Office, Reykjavik. The seismograms have been read, but no comparison has been made yet with other data on the eruption. Due to excessive use of recording paper its operation had to be discontinued in April. At present it would be possible to operate it again for some time.

2) In the expedition of Nov. 25 I made an attempt to measure the electrical conductivity of the flowing lava near the sea. The result was somewhat uncertain, but a resistivity of 2 to 8 ohmmeters was indicated. The measurement was made with a four electrode arrangement and an ordinary earth resistivity apparatus. The temperature of the flowing lava was estimated at 1150^{o}C according to measurements by Prof. Thorbjörn Sigurgeirsson.

The experiment was repeated on Jan. 18, 1965. Although this work was not done in 1964, the results will be given here. A two electrode arrangement was used instead of four. Readings were easily obtained and gave a resistivity of aoubt 4 ohmmeters in good agreement with the former result. In view of the agreement between these two experiments, the results are considered fairly reliable.

3) Gravity measurements in Surtsey were planned in 1964, but due to reparation of the Worden Gravity Meter of the Department of Natural Heat, these could not be carried out. The Gravity Meter was repaired in November, and has been taken

to Surtsey twice in January 1965. The results are not yet available. It would be desirable to take gravity readings on all neighbouring islands where a helicopter could land. Such measurements would only take a few hours.

SOME GEOPHYSICAL MEASUREMENTS AND OBSERVATIONS IN SURTSEY 1963-1964.

by

Thorbjörn Sigurgeirsson
University of Iceland, Physical Laboratory

1. Time-lapse photographs of volcanic cloud.

During the early stages of the eruption, photographs were taken of the upper part of the volcanic cloud at 10 sec. intervals from the Physical Laboratory in Reykjavik, 114 km from the volcano. The photographs were taken on an 8 mm movie camera. The periods covered by these photographs are:

1963	Nov.	16,	7:30 - 16:05	Icel.	Mean	Time
"	"	17,	7:30 - 12:55	"	"	"
"	"	18,	11:20 - 15:35	"	"	"
"	"	22,	8:45 - 14:30	"	"	"
"	"	23,	9:50 - 16:05	"	"	"
"	Dec.	1,	9:35 - 15:45	"	"	"

From these photographs it is possible to follow the height of the cloud. These measurements have not yet been completed, but the maximum height shown on these photographs occurred on Nov. 23rd at 10:10 o'clock. Between 7 and 9 km height the top of this cloud rose at a speed of 12 m/sec. Fig. 1 shows samples of how the height of the volcanic cloud varies with time.

2. Geomagnetic field measurements.

On Aug. 19th field intensity measurements were carried out with a proton precession magnetometer in collaboration with Mr. Gudmundur Gudmundsson. Measurements were made on profiles totalling 5 km as shown on the map in fig. 2. The results have been reduced to mean field intensity at Leirvogur Magnetic Observatory, and profiles A and B are shown on fig. 3.

Profile A reaches from the east coast of the island up a steep slope to the 155 m peak and from there along the ridge to the 173 m high top close to the west coast.

The magnetic profile shows a clear correlation to the landscape. All peaks give increased field intensity, but the variations in intensity are remarkably small. Along the entire length of profile A the island is made of volcanic ashes or sand, formed during the first phase of the eruption. The results show that this formation is only weakly magnetized.

Profile B runs from the end of the lava field in the southeast part of the island along the sandy beaches in east and north and ends at the end of the lava field in northwest.

A strong magnetic disturbance from the lava shows up at both ends of the profile. Otherwise the magnetic field is homogeneous. The two small maxima in the magnetic profile might indicate the location of craters which were active during the early stages of the eruption.

On Sept. 12th complete field determinations were made at two points on the island (marked by I and II in fig. 2). The D and H components were measured with a QHM-magnetometer and the total field F with a proton precession magnetometer. Reduced to mean field values at Leirvogur the results were:

Surtsey I (20°36'30"W, 63°18'22"N):
$D = 336^{\circ}18'$ $H = 12800\gamma$ $F = 51455\gamma$

Surtsey II (20°36'30"W, 63°18'32"N):
$D = 336^{\circ}44'$ $H = 12847\gamma$ $F = 51456\gamma$

3. Temperature measurements.

On September 15th, 1964, an attempt was made to measure the temperature in flowing lava at its advancing edge close to the shore in the southeast part of the island.

The thermometer was a 2 m long iron-constantan thermocouple enclosed in a steel pipe 0,5" in diameter. The electromotive force is measured with a microammeter having an internal resistance of 2500 Ω and a full scale deflection of 50 μA.

Temperature measurements in two different places gave the following results:

Emf	Cold junction temperature
64,5mV	25°C
63,0mV	30°C

Standard tables of Emf for iron-constantan thermocouples only extend to 1000°C, but a linear extrapolation would give as a result of the two temperature measurements 1130°C and 1110°C respectively. For such high temperatures an iron-constantan thermocouple is, however, not a reliable thermometer.

Subsequently an attempt was made to measure the temperature in a flame of gas emerging from a small opening in the top of a lava cone about 100 m from the crater. The opening was only about 10 cm long and 1 cm wide, but the gas emerged from it with a great force, apparently with supersonic speed, creating a loud whistling sound. Samples of this gas were collected by Gudmundur Sigvaldason and Gunnlaugur Elísson for chemical and isotopic analysis.

When the thermometer was inserted in the flame, the steel pipe melted or burned, and the thermocouple was destroyed. A tube of stainless steel used for collecting gas samples was, however, not affected by the flame.

On November 25th, 1964, temperature measurements were made with a 10 m long Chromel-Alumel thermocouple enclosed in a chromium-nickel steel tube, 0.25" in diameter. The resistance of the thermocouple is 5 Ω. The Emf was measured with the same instrument as previously. Measurements in an advancing lava front at the coast due south of the crater gave the following results:

	Emf	Cold junction temperature	T
Location 1	47,9mV	$\sim 15^oC$	1193^oC
" 2	47,9mV	$\sim 15^oC$	1193^oC

The thermometer intended for measuring the temperature of the cold junction was broken so these temperatures are only estimated.

Near to the crater the thermometer was sunk about 5 m into a large opening in a lava tunnel. A temperature of about 1140^oC was reached,but the thermometer did not reach the fluid lava. This same opening was being used for gas sampling by Gudmundur Sigvaldason, Gunnlaugur Elísson and Bragi Árnason.

In another opening at the edge of the crater a temperature of about 1170^oC was measured, but also here the thermometer does not appear to have reached the fluid lava, (visual observation was made impossible by the heat).

On January 18th, 1965, an attempt was made to measure the temperature in the crater itself. The thermometer was hanging about 8 m vertically down from a cliff forming the bank of the crater lake, the cold junction was only 2 m from the edge. A visual observation of the thermometer was not possible and apparently it did not reach to the surface of the lava lake as the temperature only rose to between 1000 and 1100^oC. When the thermometer was pulled out, about 50 kg of solidified lava was sticking to its end. Most likely this came from lumps of partly solidified lava which were thrown up from the surface of the lava lake. In an attempt to free the end of the thermometer from the solidified lava, the thermometer was broken and had to be brought home for repair.

On January 31st, the temperature was measured in lava about 800 m SSW of the crater and 100 m from the sea. The lava came welling up through cracks in the consolidated lava field and had formed a low dome-shaped hill. At the edges of this hill the molten lava emerged through small openings (20-40 cm in diam.) in the partly solidified crust. Frequently the flow through one opening stopped and was covered by a solid crust in a few minutes, but new outlets were formed elsewhere.

The end of the thermometer was pushed to a depth of 10-20 cm into the lava and allowed to follow its flow for about half a meter. This takes a few minutes and meanwhile a solid crust starts to form on the surface, so that the thermometer has to be pulled out to avoid its freezing in.

Both a potentiometer and the previously mentioned micro-ammeter (AVO-Meter) were used to measure the Emf of the thermocouple, which had been repaired by welding together the ends of the wires and the shield tube with stainless steel.

The microammeter was calibrated against the potentiometer on November 26, 1964, and again on February 2md, 1965, with the same result.

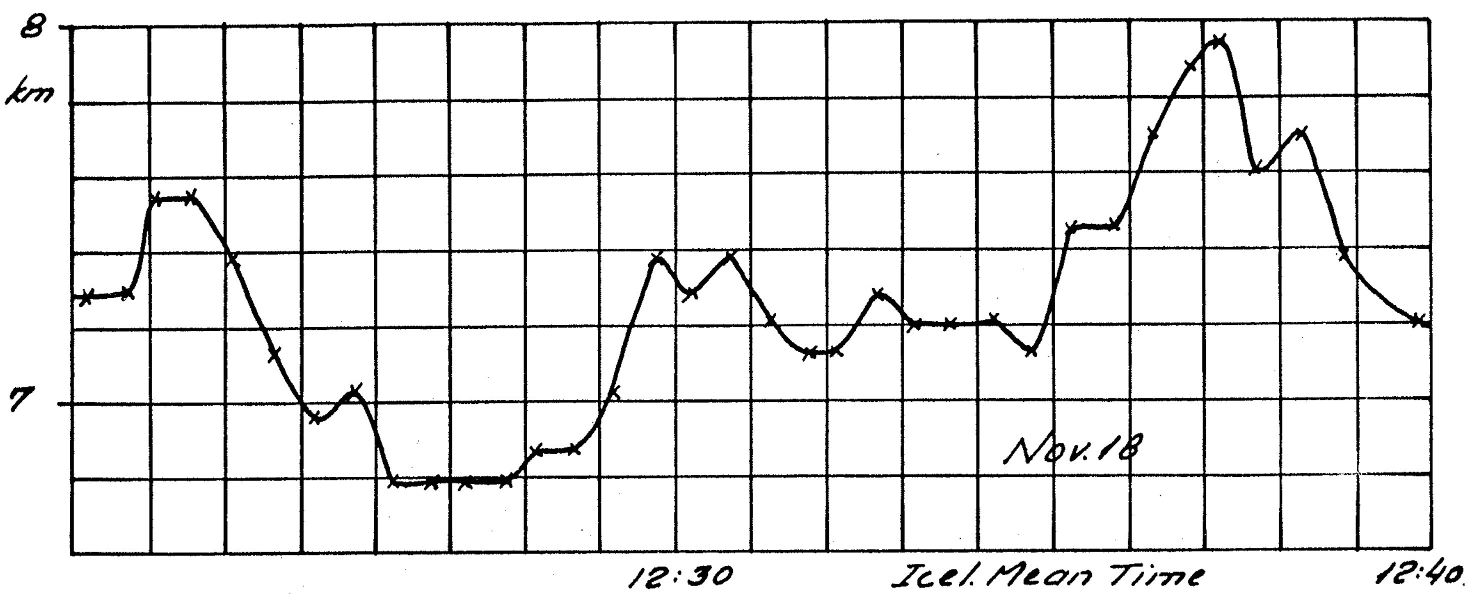
The following 9 temperature determinations were made:

Meter	Emf mV	C.j.temp. °C	T °C
AVO	47,4	21	1182
Pot.	45,21	22	1125
AVO	46,5	24	1164
"	44,8	44	1138
"	46,0	21	1144
Pot.	45,77	20	1138
"	45,81	20	1139
"	45,85	20	1140
"	45,81	19	1138

The results show that the temperature varies a great deal from place to place, and most likely the entire mass of lava welling up in this place has been cooled down to some extent. The four last measurements are made in two openings only a few meters apart, and give consistent results.

FIG 1.

Height of volcanic Cloud.



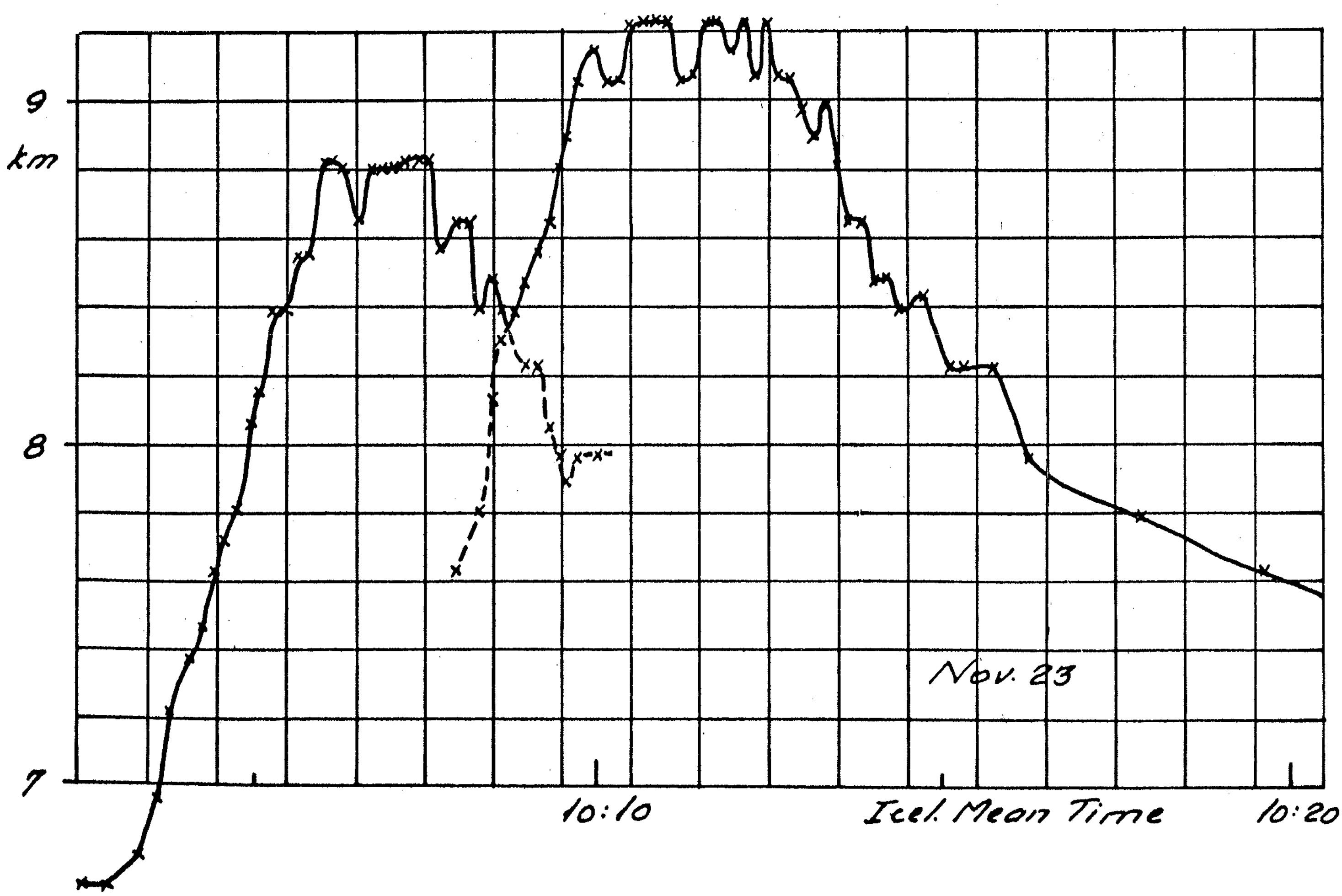


FIG 2.

SURTSEY

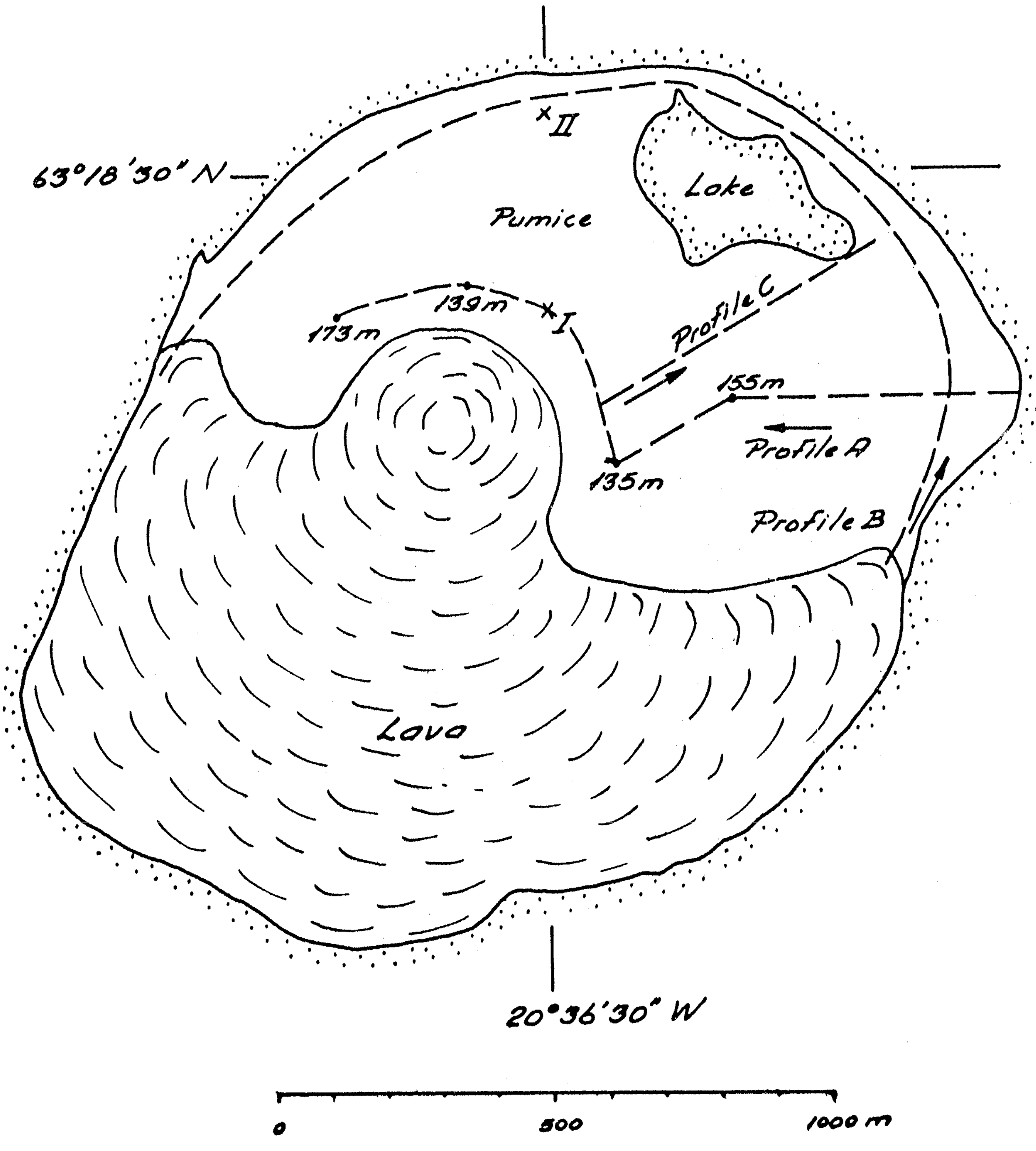


FIG 3

Magnetic Field Intensity