SURTSEY RESEARCH PROGRESS REPORT

IV.

The Surtsey Research Society
Reykjavik - Iceland

June 1968

I N D E X

Introduction

The Surtsey eruption has ceased. It stopped in early June 1967, after having lasted for three years and seven months. The main island, which was formed, Surtsey, does, on the other hand, remain, and the scientific work has continued with full strength under the administration of the Surtsey Research Society.

At the end of June 1968 the second Surtsey Scientific Conference was held in Reykjavik. It covered both geological and biological sciences and was attended by a great number of scientists from Iceland and from abroad. The scientific work in 1968, which is reported in this progress report, the fourth one in the series, reflects in several ways the conclusions of the Conference. Although many studies in the fields of earth sciences have continued and new ones been added, it will be seen that the main emphasis has shifted from volcanology to biology. This is to be expected, as the invasion of life onto Surtsey and its coast has increased greatly after the volcanic activities ceased.

Several scientific papers are now being published on the Surtsey research work, especially in the fields of geosciences. Much of the work will, though, continue for many years to come, and as a matter of fact, this is of great importance. Only by continued scientific studies on Surtsey for several years will a complete picture of its development be discovered. The Surtsey Research Society will do its utmost to make this possible.

The Surtsey Research Society wishes to acknowledge most important support and assistance from several sources, such as the Icelandic Government, the National Research Council of Iceland, the Icelandic Coast Guard, and various Icelandic research institutes. Also, vital financial support from various foreign agencies, especially the U.S. Office of Naval Research, the U.S. Atomic Energy Commission and the Bauer Scientific Trust is highly appreciated. Finally, excellent co-operation by Icelandic scientists from various

institutions and many foreign scientists should be emphasized. Their fine work has made the Surtsey research program possible.

For the Surtsey Research Society,

Steingrimur Hermannsson
Chairman

B I O L O G Y

Comparative Ecology of Colonizing Species of Vascular Plants

by
Eythor Einarsson
Museum of Natural History, Reykjavik

During the summer of 1967 two trips were made to Surtsey and one trip to the nunatak areas Braedrasker and Kárasker in Vatnajökull.

On the 20th of June when the author investigated particularly the northern part of Surtsey no trace at all could be seen of about 15 small specimens of Cakile edentula (Bigel) Hook. and a single specimen of Elymus arenarius L. which had been found growing in the sand on the south bank of the coast a month earlier (Thorarinsson, pers. comm.). They must therefore either have been washed away by the sea or covered by the loose sand which the wind blows to and fro on the coast now and then. The same day, however, 6 specimens of Cakile edentula, 5 of them tiny seedlings only, and the 6th rather small, were observed near the high tide mark on the north-east coast of Surtsey in a straight easterly direction from the little lake and about midways between this lake and the nearest shore. These plants were growing where a layer of sand had nearly covered heaps of ashore drifted seaweeds, mainly Ascophyllum nodosum. No plants had been observed in this area before. Besides that two additional small specimens of Cakile were found near the north-west corner of the little lake.

On June 26th it was observed that one of these Cakile specimens had flowered (Thorarinsson, pers. comm.), the first plant specimen ever to flower on Surtsey.

During the summer of 1967 some mosses also started to grow on Surtsey. At first mosses were observed on sand near the north-west corner of the lagoon on the north coast. On September 9th two separate clusters of mosses were observed in this locality, one of them being about 70 cm in diameter. These mosses could have been dispersed to the island by man. On this same day the author observed some moss clusters near the central part of the island (see map) where, at least, no macroscopic plants have been observed growing before and this locality is situated more than 500 m from the shore at an altitude of about 60 m. The mosses were growing in four separated clusters on a thin sand or tephra layer covering the edge of a lava field where the lava is still lukewarm. These mosses have been identified by the bryologist B. Jóhannsson, Department of Botany, Museum of Natural History, Reykjavik, and the names are published here with his kind permission. The species are Funaria hygrometrica Hedw. and Bryum argenteum Hedw. Both these species are common on Heimaey and elsewhere in Iceland (Jóhannsson pers. comm.) and are very often dispersed by man. The locality where they grow on Surtsey is situated just along a footpath commonly used by scientists working on the island and, as mentioned before, more than 500 m from the shore. It is therefore most likely that these two additional species have been dispersed by man, although various measures have been taken to prevent human disturbance and dispersal of biota to the island.

On the same day a tiny plant was observed growing in a mixture of sand and tephra on the south-east coast of Surtsey by the amateur algologist S. Hallsson. This locality is very much alike most of the localities on the north-northeast coast area where all the cormophytes known to grow in Surtsey had been found until this very day, i.e. situated at the high tide mark on the relatively flat coast, but at a distance of about 1 km farther south. This plant was investigated by the author the next day and identified as Honkenya peploides (L.) Ehrh, and it has without doubt been dispersed by the sea from Heimaey as the other Honkenya specimens found in Surtsey.

During the days September 9 to 11 a thorough study of all the specimens of vascular plants found on Surtsey was carried out. It then became evident that a small grass specimen, which was at first thought to belong to Elymus arenarius L. could hardly be correctly identified. It was considered, because of the shape of the base of the blade, the ligula and the sheath, to be more alike Festuca rubra L. Later microscopical investigation of a transverse section of a blade in a laboratory confirmed this identification. Festuca rubra L. is a very common species in the Vestman islands (Fridriksson and Johnsen 1967) and for instance found on Súlnasker, about 10 km east-north-east of Surtsey. As easterly winds are common here, Festuca rubra might have been dispersed by sea this short distance to Surtsey. At least the transport of seeds by sea could have taken so short a time that the seeds might have survived such an immersion in salt water. The fact that Festuca rubra was found on Surtsey, growing near the high tide mark on the coast, supports the suggestion of dispersal by sea. This species could though also have been dispersed by birds this short distance as numerous birds have been observed on Surtsey (Gudmundsson, 1966 and 1967) and very often seen on the coast of the island. The total number of specimens observed growing on the island at this time was 46 cf. fig. 1, but some of them were very small and other almost covered by sand. These specimens belonged to five species:

Honkenya peploides (L.) Ehrh. 26 specimens were observed. None of the specimens had flowered and no buds were observed.

Cakile edentula (Bigel) Hook. 14 specimens were observed, most of them vigorous and healthy looking. Far the biggest specimen was about 70 cm long and 40 cm broad. All 14 specimens had flowered and were with fruits, 5 of them were also still with a few flowers.

Elymus arenarius L. 4 specimens were observed. None of them had flowered.

Mertensia maritima (L.) S.F. Gray. A single small specimen with only one leaf of a normal size was observed. No sign of buds could be seen.

Festuca rubra L. A single small specimen was observed. No sign of flowering could be seen.

Most of these specimens are growing in loose sand at the high tide mark on the relatively flat coast and the sea will without doubt wash many of them away during the winter. Two or three of the Cakile specimens, the westernmost growing Honkenya and the Mertensia, however, have a slight chance of escaping being washed away. But as the winter storms are heavy and the sand is very loose they are in great danger of being covered by sand-drifts or simply blown away.

Dispersal

Of the five species of vascular plants which have been observed growing on the island Surtsey up to the present day, four are halophilous species and have without doubt been dispersed to the island from the Vestman Islands. The seeds of both Cakile and Honkenya are of a large size and well adapted to floating (Löve, D. 1963) and they are known to be able to stand immersion in salt water. Seeds of Mertensia and Elymus are also relatively large and able to float. The fifth species, Festuca rubra, might also have been dispersed by sea this short distance from the Vestman Islands to Surtsey, but it is also quite possible that this species has been dispersed by birds. Other species of coastal plants might as well be dispersed to Surtsey in the near future by the sea and they will probably be able to grow in the uniform sand habitat of the coast. Seeds and parts of other plant species will probably also continue to drift ashore on Surtsey, but it is rather unlikely that the seeds will germinate or that the plants will be able to grow in this coastal habitat. More non-coastal species common in the Vestman Islands might occasionally be dispersed to Surtsey from the nearest islands, or even the Icelandic mainland which is only about 32 km away from Surtsey, by birds, and some of such species may succeed in surviving. Dispersal of species with light seeds by wind should also be possible over these short distances mentioned before. Mosses seem to have been dispersed to Surtsey already by man and even some species of vascular plants might be dispersed in the same way in spite of every attempt made to prevent such dispersal.

- - - - - - - - -

In August 1967 an expedition was made to the nunataks Braedrasker and Kárasker in Vatnajökull's big southern outlet Breidamerkurjökull. Braedrasker was investigated earlier in 1963, 1965 and 1966. In 1965 seven plots of the size of 1 m^2 each were marked in the oldest part of the nunatak for making it possible to study the plant succession on the nunatak (Einarsson 1967 and 1968) and vegetation analyses carried out in these plots in 1965, 1966 and 1967. The results of the analyses are found in table 1. The Hult-Sernander scale was used for cover estimation. Still in 1967 the cover in all plots was far less than 1/16 of the surface. Some changes have been observed to have taken place in these plots during the years 1965 - 1967. Some of the first observed specimens in the plots have not survived and others have invaded. In plots nos. 3 and 6 specimens found in 1965 were dead in 1966, and in plots nos. 2 and 7 specimens found in 1966 had disappeared in 1967. In both 1966 and 1967, however, new colonizing species were found in many of the plots, for instance nos. 1, 2 and 3, and the number of specimens of some of the species has also increased in some of the plots. In each of plots nos. 2 and 5 for instance, one specimen of Poa alpina L. was found growing in 1965, and in 1966 several small specimens of the same species were observed growing around the old ones and in 1967 most of them were still about. In plot no. 7 one specimen of Cerastium alpinum L. was found growing in 1965; in 1966 several seedlings of the same species were observed around the old specimens and in 1967 the old one was dead but three of its descendants had survived and were healthy looking.

The total number of species of vascular plants found in Braedrasker is 23, cf. table 1, but some of the species have only been observed once and not found again. The most common vascular plant in 1967 was Saxifraga caespitosa L. closely followed by Poa alpina. Then come Poa flexuosa Sm., Cerastium cerastoides (L.) Britton and Cerastium alpinum. The mosses on Braedrasker are becoming more prominent than before, but the most common species are still Philonotis tomentella Mol. and Rhacomitrium canescens (Hedw.) Brid.

Just after 1940 the Björnsson brothers at the farm Kvísker, the nearest farm west of Breidamerkurjökull observed that a small area in the middle of Breidamerkurjökull, situated about 13 km from the margin of the glacier, had become free of ice. According to their opinion the ice most likely retreated from this area in the late thirties, i.e. about 30 years ago (Björnsson, S. 1958), and in 1957 and 1958 they made expeditions to the area which they named Kárasker and found 33 species of vascular plants growing scattered in the area (Björnsson, H. 1958). Kárasker which is built up of basalt and rhyolite (Einarsson, Th., pers. comm.) and almost completely covered by basalt-rhyolite morains, is a mountain slope, sloping 5^{o} to 20^{o} to the east-north-east. In early September 1965 it was about 500 m broad and 1 200 m long, the altitude being from 580 to 760 m.

Hálfdán Björnsson from Kvísker (1958) describes the vegetation of Kárasker as being pretty luxuriant in some sheltered depressions and rivulet beds and dominated by grasses and other vascular plants. In the more exposed gravel flats between the depressions Björnsson, however, reports the vegetation to be very sparse and scattered but mostly dominated by the same species. This means that in Kárasker there was already then, about 20 years after it became free of ice, a distinct difference between the vegetation in the sheltered depressions with a favorable snow cover and soil moisture and the vegetation of the more exposed and dry gravel flats between the depressions. In the six years old Braedrasker no such difference can as yet be observed, on the contrary, the plants seem to be growing there completely accidentally scattered over the oldest part of the nunatak. Thirty three species of vascular plants were then found in Kárasker, cf. table 2. The most common ones were Cerastium cerastoides and Poa alpina. Three species of mosses not identified are reported, but the mosses were found in few places only and were much less prominent than the vascular plants. No lichens or fungi were observed. In a small rivulet, however, some filamentous algae were observed.

During the 1961 expedition five additional species of vascular plants and five species of mosses were found cf. table 2. No lichens or fungi were observed. The vegetation was still dominated by grasses, but mosses seemed to be a little more prominent than before. Far the most common species were Poa alpina and Cerastium cerastoides, but Arabis alpina L., Deschampsia alpina (L.) R. et S., Oxyria digyna (L.) Hill, Poa flexuosa and Trisetum spicatum (L.) Richt. were also common.

In 1963 three additional species of vascular plants were observed in Kárasker, cf. table 2. The mosses were obviously more prominent than in 1961. One fungus, Russula alpina (Blytt) Möll. et Schaeff., was observed. On flat rocks in the central part of the nunatak some thalli of a crustaceous lichen were found together with

Rhacomitrium canescens, the biggest of them being 5 to 8 mm in diameter, but without any apothecia and as a whole so immature that it was not possible to identify them although they all seemed to belong to the same species. The vegetation of the most sheltered depressions was getting still more luxuriant and in most places dominated by Poa alpina, which is the most common plant species of the nunatak. Other common species of vascular plants were Cerastium cerastoides, Arabis alpina, Deschampsia alpina and Poa flexuosa. On the more exposed gravel flats the vegetation was much more sparse and scattered, but also dominated by Poa alpina, especially in the central and the southern part of the nunatak, other common species being Poa flexuosa, Saxifraga caespitosa, Saxifraga oppositifolia L., Trisetum spicatum and Rhacomitrium canescens. On a few gravel flats in the northern part even Arabia alpina was dominating. Most of the plant specimens in Kárasker were observed to be very healthy looking and seemed to be doing well.

In 1965 still two additional species of vascular plants were observed in Kárasker, cf. table 2, and some species of mosses. Vegetation analyses were carried out in eight plots which were clearly marked for future studies of the plant succession. As a whole the vegetation of the sheltered depressions had not changed much, although mosses are still becoming more prominent. The same species of vascular plants are dominating, i.e. Poa alpina and other grasses, but Cerastium cerastoides and Arabis alpina were not as common as before, at least not relatively. On the gravel flats the vegetation was somewhat more prominent, the dominating species being Poa alpina, Deschampsia alpina, Poa flexuosa, Poa glauca, Vahl., Oxyria digyna, Saxifraga caespitosa, Trisetum spicatum and Phleum commutatum Gaud.

In 1967 three new species of vascular plants were found in Kárasker. The total number of vascular plants found in this 30 year old nunatak is therefore 46 and 38 of them have been observed during two or more separate trips to the nunatak. In 1967 identifiable lichens were found in Kárasker for the first time, i.e. Peltigera apthosa (L.) Willd. and Stereocaulon sp. In the eight plots there had been some changes since 1965, new species had colonized many of the plots and others passed away, and in half of the plots the vegetation cover had increased. Especially the cover has increased in plots nos. 7 and 8, cf. table 2, which are both found in a favourably sheltered depression in the oldest part of the nunatak. In plots nos. 3 and 5, which are found on gravel flats, the vegetation was also covering a higher percentage of the surface than in 1965, and in plot no. 5 mosses were found for the first time in 1967.

At the present time it is difficult to make any comparison between the plant succession and vegetation of the nunataks and the colonization of Surtsey by higher plants. So far no vascular plants have succeeded to survive during the winter on Surtsey, as they have been covered by sand or washed away by the sea, and therefore no permanent vegetation has as yet been established there. As already mentioned some of the plant specimens observed growing on Surtsey have a fair chance to survive this winter, at least the mosses in the central part of the island.

The vegetation of the two nunatak areas has, however, been compared with the vegetation of the third nunatak area in Breidamerkurjökull. The name of this area is Esjufjöll, and it is much bigger than the other two. Esjufjöll are composed of four mountain ridges, the biggest ranging about 500 m above the surrounding ice. This area has a flora of 96 species of vascular plants and has without doubt been free of ice during the whole postglacial period, and as its vegetation is untouched by man and sheep, it is probably very close to a climax vegetation. The Kvísker brothers, mentioned earlier, have investigated this area and the present author studied it in 1961. As the area, however, is very big, it needs a much more intensive investigation. But so far it can be stated that the grass species, which dominate the vegetation of Kárasker and Braedrasker, are without doubt pioneer species which do not play any important role in the vegetation of Esjufjöll.

Most of the species of vascular plants found in Braedrasker and Kárasker are considered to have been dispersed to these nunataks by wind and they have probably been blown along the surface of the ice to the nunataks from the nearest mountains, a distance of 5 - 7 km. Some of the species, however, might have been dispersed by birds;

Vaccinium uliginosum L., which was found growing in Kárasker for the first time in 1967, has thus without doubt been dispersed to the nunatak by birds.

References

Björnsson, H. 1958: Gróður og dýralíf í Káraskeri. *Jökull* 8. 19-20.

Björnsson, S. 1958: Könnunarferð í Kárasker. *Jökull* 8. 15-17.

Einarsson, E. 1967: Comparative Ecology of Colonizing Species of Vascular Plants. *Surtsey Research Progress Report III*, 13-16.

" 1967: The Colonization of Surtsey the New Volcanic Island by Vascular Plants. *Aquila*. In press.

" 1968: Vegetationen på nogle nunatakker i Vatnajökull. *Naturens Verden*. In press.

Fridriksson, S. and Johnsen, Björn, 1967: On the vegetation of the Outer Westman Isles, 1966. *Surtsey Research Progress Report III*, 20-36.

Gudmundsson, F. 1966: Birds observed on Surtsey. *Surtsey Research Progress Report* II, 23-28.

" 1967: Bird Observations on Surtsey in 1966. *Surtsey Research Progress Report* III, 37-41.

Löve, D. 1963: Dispersal and Survival of Plants. *North Atlantic Biota and their History*, 189-205. Oxford.

Acknowledgements

This work has in part been sponsored by the Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Biology Branch, under contract No. AT(30-1)3549.

TABLE I

All species of vascular plants and the most prominent moss species found in Braedrasker. The numbers 63, 65, 66 and 67 in the column marked Year mean that the species were found for the first time in 1963, 1965, 1966 and 1967 respectively. The results from the vegetation analysis carried out in 1965, 1966 and 1967 in seven plots marked 1 to 7 are found in columns 1 to 7 respectively. For cover estimation the Hult-Sernander scale was used.

Species		1			2			3			4			5			6			7		
		65	66	67	65	66	67	65	66	67	65	66	67	65	66	67	65	66	67	65	66	67
Arabis alpina	65							1														
Cardaminopsis petraea	66																					
Cerastium alpinum	65																			1	1	1
Cerastium cerastoides	65																					
Draba norvegica	67																					
Epilobium lactiflorum	65																1					
Festuca vivipara	67																					
Luzula spicata	65																					
Minuartia rubella	65																					
Oxyria digyna	65					1																
Phleum commutatum	66																					
Poa alpina	65	1	1	1	1	1	1							1	1	1					1	
Poa flexuosa	65										1	1	1									
Poa glauca	65																					
Sagina intermedia	65																1	1	1			1
Sagina procumbens	65																1	1	1	1	1	
Saxifraga caespitosa	65		1	1		1	1													1		
Saxifraga oppositifolia	66		1	1																		
Saxifraga rivularis	67																					
Silene maritima	66																					
Sedum annuum	65																1					
Trisetum spicatum	63																					
Veronica fruticans	66																	1				
Ceratodon purpureus	63					1	1															
Philonotis tomentella	65	1	1	1	1	1	1		1	1					1	1			1			
Pogonatum urnigerum	66					1																
Pohlia wahlenbergii	63								1	1								1	1		1	1
Polytricum juniperinum	66		1	1																	1	1
Rhacomitrium canescens	63					1			1	1	1	1	1		1	1					1	1

TABLE II

All species of vascular plants, fungi, lichens and the most common moss species found in Kårasker

The numbers 58, 61, 63, 65 and 67 in the column marked Year mean that the species were found for the first time in 1958, 1961, 1963, 1965 and 1967 respectively. The results from the vegetation analysis carried out in 1965 and 1967 in eight plots marked 1 - 8 are found in columns 1 - 8 respectively. The numbers found in the second line from above mean the estimated percentage of the vegetation cover in each plot. For cover estimation the Hult-Sernander scale was used. In some of the plots the mosses were not identified to the species.

Species	Years	1		2		3		4		5		6		7		8	
		35		25		15	20	20		1	5	30		25	40	60	70
		65	67	65	67	65	67	65	67	65	67	65	67	65	67	65	67
Arabis alpina	58			1	1	1						1	1	1	1	1	1
Armeria maritima	58																
Cardaminopsis petraea	58																
Cerastium alpinum	58			1													
Cerastium arcticum	61																
Cerastium cerastoides	58	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Deschampsia alpina	58	1	1													4	4
Draba norvegica	58																
Epilobium anagallidifolium	58														1		
Epilobium lactiflorum	58			1								1	1			1	1
Erigon boreale	67																
Festuca rubra var.mutica	58																
Festuca vivipara	58																
Galium normanicii	58																
Gnaphalium supinum	61																
Luzula spicata	58																
Minuartia rubella	61																
Oxyria digyna	58	2	2			1		1	1			1	1			1	1
Phleum commutatum	58			2	2			1	1								
Poa alpina	58	1	1	1	1		1	1	1	1	1	1	1	1	2	1	1
Poa flexuosa	58	1	1	2	2			1	2		1						
Poa glauca	58	1	1														
Ranunculus glacialis	58																
Rhodicia rosea	58																
Sagina intermedia	58																
Sagina procumbens	63																
Sagina saginoides	65																
Salix herbacea	61																
Salix callicarpaea	63					2	3										

Species	Years	1		2		3		4		5		6		7		8	
		35		25		15	20	20		1	5	30		25	40	60	7
		65	67	65	67	65	67	65	67	65	67	65	67	65	67	65	6
Saxifraga caespitosa	58						1									1	
Saxifraga cernua	58																
Saxifraga nivalis	58																
Saxifraga oppositifolia	58																
Saxifraga rivularis	58																
Sedum annuum	65																
Sedum villosum	58																
Sibbaldia procumbens	67																
Silene acaulis	61																
Silene maritima	63																
Taraxacum sp.	58																
Thymus drucei	58																
Trisetum spicatum	58	1	1			1	1	1	1			1	1	1	1	1	
Vaccinium uliginosum	67																
Veronica alpina	58																
Veronica fruticans	58																
Viscaria alpina	61																
Brachythecium rivulare	65																
Bryum affine	61																
Ceratodon purpureus	65															1	
Hygrohypnum sp.	65											1	1				
Philonotis tomentella	61	2	2									1	1	1	2		
Pohlia annotina	61																
Pohlia proligera	61																
Pohlia wahlenbergii	61							1	1			1	1			4	
Polytrichum alpinum	61													2	2		
Polytrichum juniperinum	61																
Rhacomitrium canescens	61	1	1					1	1							1	
Mosses (not identified)				2	2	1	2				1						
Russula alpina	63													1	1		
Peltigera apthosa	67														1		
Stereocaulon sp.	67																

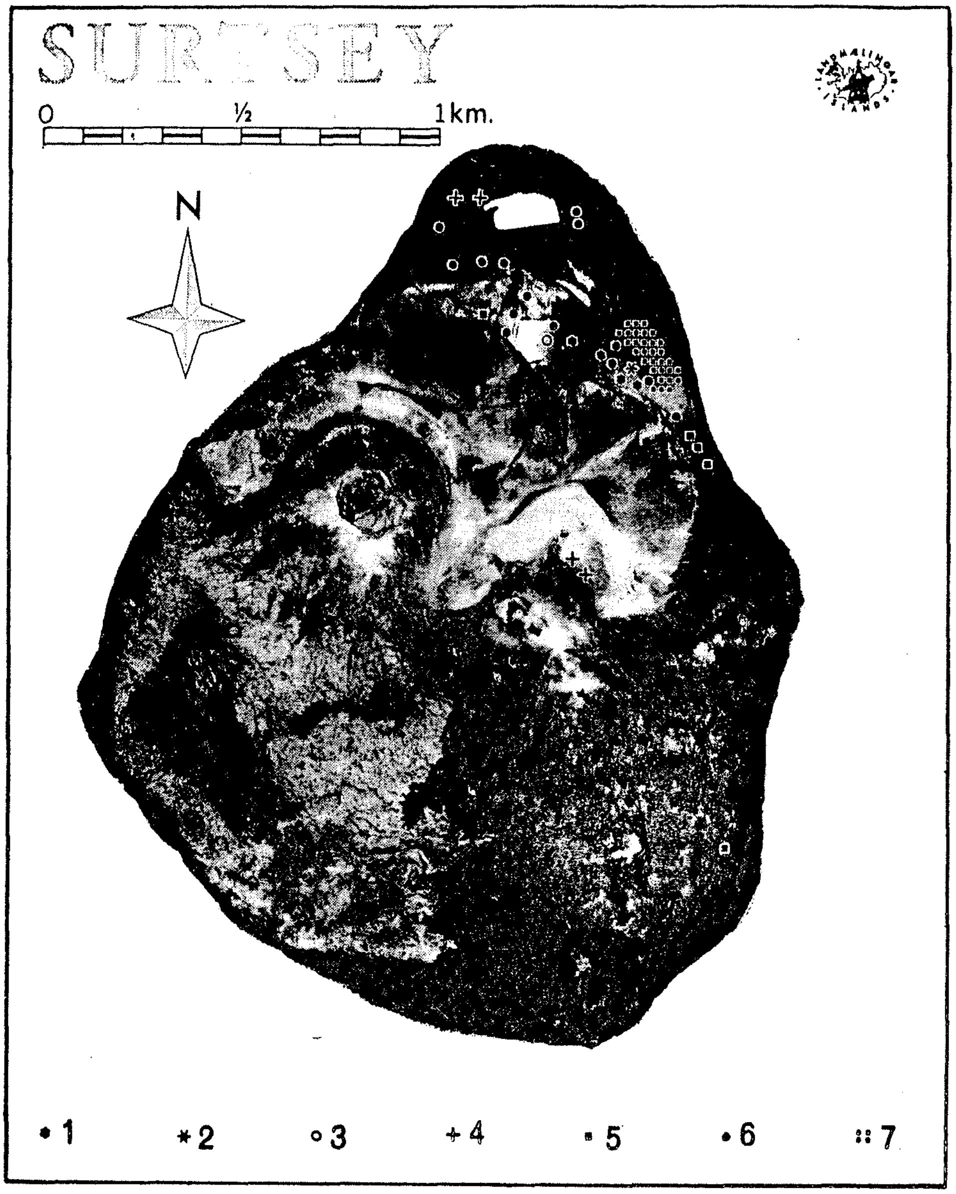


Figure 1. Air photograph of Surtsey 13 July 1967. Landmælingar Íslands (Icelandic Survey Department). All the plant localities mentioned in the paper as they were on 11 September 1967 are marked on the photograph. Each of the bigger marks shows the locality of one specimen. 1: *Elymus arenarius*, 2: *Festuca rubra*, 3: *Mertensia maritima*, 4: Mosses, 5: *Honkenya peploides*, 6: *Cakile edentula*, 7: 21 specimens of *Honkenya peploides* scattered over a small area.

Possible formation of amino acids when molten lava comes in contact with water

by
Sturla Fridriksson
Agricultural Research Institute, Reykjavik

Introduction

During volcanic eruptions metallic carbides are exposed to the atmosphere and water where they react to form simple carbon compounds. These can be the first steps in further reactions towards amino acids and more complex organic compounds.

The experiment described was performed in order to test whether simple organic compounds might be synthesized from inorganic during the volcanic activities at Surtsey.

While the present experiment was being prepared, a group of scientists from National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California, U.S.A., visited Iceland on Oct. 4th, 1966. They were assisted in collecting samples of

a) dry and wet surface dust from Surtsey sand and a crater fumarole with temperatures ranging from 120°C to at least 150°C.

b) ash from the crater island "Syrtlingur" before and after it touched the surface of Surtsey.

These samples were analyzed by C. Ponnamperuma et. al. and are reported on in Surtsey Research Progress Report III (1967)

The water extract of the sample of "the Surtsey ash" contained 0.003 uM each of aspartic acid and alanine as well as 0.004 uM each of glycine and aerine. The HCl extract contained traces of glycine, serine and alanine. The freshly collected ash was found to contain 100 parts per million of organic matter and that from the fumaroles 50 parts per million. As stated by Ponnamperuma (1967) there were, however, a number of possible sources of contamination, such as the sea water which constantly rushed into the crater, and organic matter in the air.

The following experiment described here, however, was carried out under aseptic measures where contamination with natural ocean water and air was prevented, and where the natural phenomena of contact between molten lava and water was directed under controlled conditions.

Methods

The experiment was performed as follows. Three different kinds of liquids were prepared:

1. Destillated water D.W.
2. Filtrated sea water S.W.
   This sea water was collected off the Reykjanes peninsula.
3. Artificial sea water A.S.W.
   This was prepared by dissolving in destillated water the various inorganic salts as listed in formula 1.

Liquid no. 1 was sterilized in an autoclave. Liquids nos. 2 and 3 were filtrated through Zeiss filters.

The solutions were stored in sterile containers in a cool storage. Three gallons of each sample were used in the experiment, but one gallon of each kept as a control.

Three new aluminium vessels of 20 liters capacity with lids were obtained. After thorough cleaning with destillated water they were sterilized in an autoclave for 45 minutes, then they were placed into sterile polyethylen bags and closed tightly. Three extra glass jars were also provided for and prepared as above, later to be filled with cinder.

In the course of experiment two ladles with long shafts were also used.

On Oct. 14th 1966 an expedition was made to Surtsey, the new volcanic island, where it was possible to get access to molten lava in an isolated opening approximately 500 m from the crater, where the lava of 1100°C temperature flooded from the crater in subterraneous veins or closed tunnels from under the solidified surface of somewhat older lava. The solid lava surrounding the open spot was free of any vegetation as Surtsey was almost devoid of life and the atmosphere over the surface of Surtsey is furthermore very clean with quite a low bacterial count. This was tested on several occasions previously and during the summer 1966 (Fridriksson 1965, Fridriksson and Kolbeinsson 1965, and Kolbeinsson and Fridriksson 1967).

The liquids of each sample previously prepared as indicated in item 1, 2 and 3 had been carried to the island in nine gallon containers, three gallons of each sample. The aluminium vessels were then opened and each filled with one sample of liquid. Three gallons of liquid respectively being poured into each vessel. Then molten lava was scoped up with a ladle from the lava stream and poured into the vessels, an approximately six lbs. portion of lava into each vessel. When the molten lava came in contact with the liquid an explosive boiling occurred with steam being evolved for ca. 5 minutes. Then the solutions were again transferred from the aluminium vessels to the sterile 1 gallon glass containers, three containers for each solution.

The cinder from each lot was separated and transferred to three sterile glass jars The samples were transported to Reykjavik and stored in a cool storage.

On Febr. 4th 1967 liquid samples were drawn from the glass flasks under sterile conditions for bacteriological investigation. Liquid no. 2 and control turned out to be contaminated with a flagellated bacterium, but the remaining samples were sterile. The contamination of the liquid no. 2 is most likely due to failure in the filtration process.

Results and Analysis

a) Rock samples of each treatment (1, 2 and 3) were sent to Dr. C. Ponnamperuma of N.A.S.A., California. Two samples of No. 1 and one sample of No. 2 and No. 3. Two of the containers broke during the transport and when the remaining two were tested, No. 1 and No. 2 were both contaminated.

b) A rock sample of treatment 1 (rock from distilled water) was shipped in the sterilized containers to Dr. Sidney W. Fox, Institute of Molecular Evolution, University of Main, Coral Gables, Florida, U.S.A. When this sample was tested for contamination, both before shipping from Iceland and in Florida, it proved to be free of organisms. It arrived in good condition and was tested for amino acids by analyses of the extract as well as of the crushed sample.

Amino acids were found present in both cases as indicated in attached list. On the whole the values were higher than in ash samples collected by Ponnamperuma et.al. except for the two sulfur-containing amino acids, methenine and cystine. The sample also contained a high NH_3 value 1.243 uM indicating a possible contribution from the geochemical environment.

All precautionary measures had been taken to prevent the samples ever coming in contact with any organic matter. Sample No. 1 was always kept in the clean sterile jar or distilled water. All implements used were washed thoroughly with distilled water and sterilized. And the test for contamination was performed in a sterilizing chamber at the Pathological Institute, Reykjavik. It would furthermore have to be considered highly unlikely that the sample of distilled water and cinder from Surtsey would serve as a favourable medium for growth if incidentally contaminated by bacteria.

As contamination must be regarded improbable it must be considered extremely likely that an amino acid synthesis did take place when molten basaltic lava of temperatures at 1100°C came in contact with the distilled water.

It should be accepted that abiogenesis does not necessarily have to be confined to the primordial conditions on primitive earth, but rather that it can take place wherever conditions may be similar to the conditions then present. Such conditions may be produced during submarine volcanic activities. And these conditions may just have been present during the Surtsey eruption. There the basic compounds required for the synthesis were available in solution or gases whereas the energy necessary for bringing it about was available in forms of lightnings and temperatures of over 1100°C (Fridriksson 1966). Absence of oxygen is furthermore considered a necessity for the synthesis. It is regarded to have been almost, if not entirely, absent from the primitive atmosphere. In comparison analysis of volcanic gases from Surtsey as collected by Sigvaldason et.al. (1967) did similarly not show any free oxygen. Should these have been the conditions necessary for the primordial formation of life, the much similar conditions at Surtsey may have been providing conditions causing synthesis of primitive organic compounds.

Acknowledgements

I am indebted to Dr. Sidney W. Fox, Institute of Molecular Evolution, University of Main, Florida, U.S.A., for his kind assistance and criticism and to Mr. C.R. Windsor for analyzing the amino acids of the rock sample from Surtsey. This work has been sponsored by the Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Biology Branch, under contract No. AT(30-1)3549.

Formula [1] Artificial Sea Water

$NaCl$	18.014	g/l
$MgCl_2$	3.812	g/l
$MgSO_4$	1.752	g/l
$CaSO_4$	1.283	g/l
K_2SO_4	0.8163	g/l
$CaCO_3$	0.1221	g/l
KBr	0.1013	g/l
$SrSO_4$	0.0282	g/l
H_3BO_3	0.0277	g/l

ANALYSIS FOR AMINO ACIDS,

analyzed from a rock sample from Surtsey

Amino Acids	u Moles A	u Moles B
Lys	0.064	0.015
His	0.017	0.005
NH_3	0.694	1.243
Arg	0.048	0.010
Asp	0.096	0.037
Thr	0.055	0.010
Ser	0.056	0.027
Glu	0.082	0.068
Pro	0.037	0.033
Gly	0.136	0.150
Ala	0.136	0.027
Val	0.062	0.021
Met	0.014	
Ileu	0.045	0.018
Leu	0.073	0.026
Tyr	0.021	0.005
Phe	0.032	0.014

A - Extract of Surtsey Rock

B - Crushed Surtsey Rock

The Colonization of Vascular Plants on Surtsey in 1967

by

Sturla Fridriksson and Björn Johnsen
Agricultural Research Institute, Reykjavik

This report describes the records made on the colonization of vascular plants on Surtsey during the summer of 1967, as well as the planning of fixed quadrates on the four major substrates of the island. The study was financed by the U.S. Atomic Energy Commission under grant No. AT(30-1)3549.

Method of investigation

During the summer the investigation on the island was almost continuous from 31st March to 24th September. The island was visited occasionally during the winter months. Throughout this period the development of vegetation on Surtsey was observed regularly. For this purpose, among other things, the student Sigurdur Richter was stationed on the island. The authors made shorter visits. Daily tours of inspection were made, and the northern part of the island examined with special care. The location and stage of growth of new individual plants were recorded as they were found, and their progress followed during the summer. Every plant was marked with a stake bearing its number, and the position of all plants plotted on an air-photograph. Photographs were taken of the plants for record purposes. About the middle of July the island was visited by a team of surveyors who proceeded to map a grid over the island and select quadrates representing four typical substrates. For this purpose, fixed points were measured throughout the island. These were later marked by conspicuous marks(sandbags) for aerial photography. The island was photographed from the air on 18th July during excellent weather conditions, calm weather and sunshine. From coordinates 05 and 42 in the national grid system a grid was laid over the island. The squares are each one hectare in area and identified by a letter and number, e.g. A 1, B 2, etc. The north shore was closely surveyed according to this system and the corners of the squares marked with iron pipes. After this, the location of the plants within the squares was determined and plotted on the aerial photograph, from which the accompanying map is drawn. Four fixed quadrates were chosen and specially marked for future more detailed examination. Two were in the northern part of the island, D 11 and F 15, while two were on the lava in the south, K 18 and J 3.

Substrates

One of the vital conditions for the effective colonization of plants is the existence of a favourable soil in which plants can take root and grow.

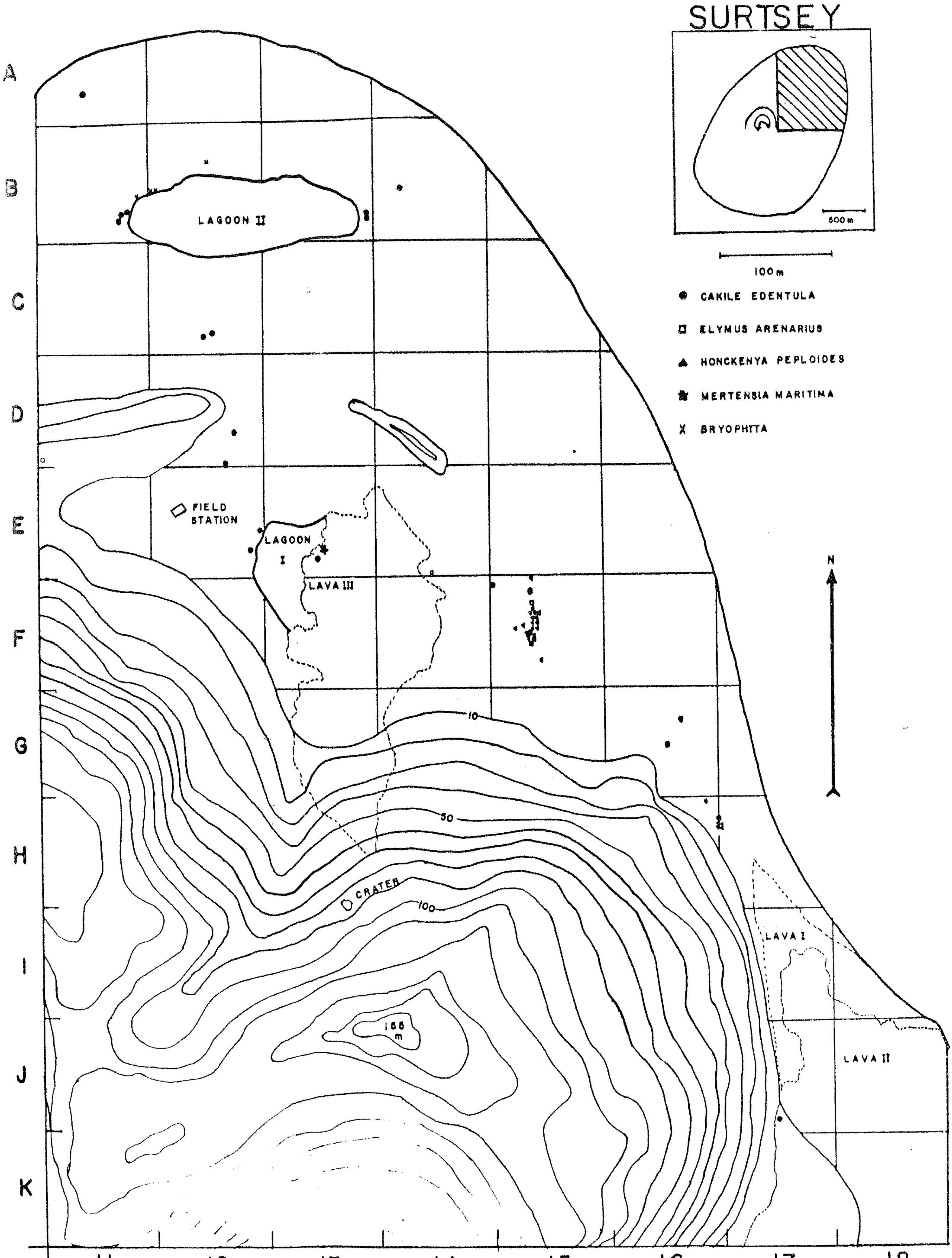
Since Surtsey first emerged from the sea, many changes have taken place from year to year, with an alternation between building up and breaking down, all of which have gone to form the landscape and topography of the island. At present there have been formed four major types of substrates on Surtsey: tuff, old lava, new lava and beach sand.

a) A great deal of the central part of the island was formed during the first phase of the eruption providing a tuff substrate, which is gradually hardening. It was continuously mixed with ocean water and has still a high salt content.

b) Lava from the first outbrake, mostly overlaid with cinder from the eruption of the small islands. Covers a great deal of the southern part of Surtsey.

c) New bare lava was formed after a certain pause in the volcanic activity on the island, starting on 19th August 1966 and continuing without a break for nearly 9½ months, coming to an end on 4th June 1967. During this period the island grew a certain amount towards the south-east owing to this new lava flow; an increase roughly estimated at 0.6 sq.km.

d) The beach at the beginning of the eruption, beaches of cinder, pumice and loose lava fragments started to form at the northern side of the island. During the winter 1966-67 this process continued and a considerable quantity


SURTSEY
600 m
100 m
CAKILE EDENTULA
ELYMUS ARENARIUS
HONCKENYA PEPLOIDES
MERTENSIA MARITIMA
BRYOPHYTA
N
LAGOON II
FIELD STATION
LAGOON I
LAVA III
CRATER
10
50
100
156 m
LAVA I
LAVA II
A
B
C
D
E
F
G
H
I
J
K
11
12
13
14
15
16
17
18

of loose tephra from the south of the island was heaped up on the northern side. In this way about 0.13 - 0.15 sq.km. were added to the north beach. This increase of beach area on the north side created conditions much more favourable to plant colonization in the following summer than had existed in the previous one. Under normal circumstances the formation of soil on Icelandic lava is a relatively slow process. On the shore, however, conditions favourable to plant growth can develop rapidly. On Surtsey various forms of organic material are washed ashore, e.g. a considerable amount of seaweed and driftwood, as well as the remains of various marine organisms, such as fish and plankton. This organic matter mixes with the sand, which is washed out volcanic cinders, and as soon as the air temperature rises, begins to disintegrate. Large numbers of seabirds (various species of gull) frequent the shore, supplementing the organic content of the sand with their excreta. This initial step in formation of soil on the beach, however, is not stable. The heavy seas of the winter cause considerable disturbance of the order in which the material may be deposited churning up whatever arrangement there might have been. The most soluble nutrients are washed away, while other organic matter is buried by the sand and shingle. However, though a great deal of organic matter is thus lost, the sea compensates with a fresh supply of drift material. This cycle is repeated annually, so there is no question of a really stable formation of soil on the shore. However, some organic matter may be carried up the beach beyond the highest tide mark, and thus supply the basis for a more consistent soil formation, and such conditions now exist on the northern shore of Surtsey.

Description of fixed quadrates

Following the surveying of the island, four quadrates were selected for a more detailed study. These are according to the map identified by letters and figures as D 11, F 15, K 18 and J 3.

D 11 lies to the north-west of the hut and extends over a low ridge, Bólfell, ca. 10-20 m above sealevel, where meteorological instruments have been installed. The substratum is cinders, similar to that found in the neighbouring hills and formed in the earliest phase of the eruption.

F 15 is east of the southern lagoon. Within the quadrate is an area once covered by the older lagoon, though the greater part of this has since been filled up by sand and lava. The quadrate is on a level platform of sand about 6 m above sealevel. The substratum is washed out beach sand mixed with various kinds of drift material. Almost half the number of plants recorded during the period of investigation, i.e. 24 individuals, which all are coastal species, were found in this area.

K 18 lies on the eastern margins of the new lava, which is bare and has not been overlaid with cinder. This may be regarded as a likely area for the colonization of the first lower plant life, such as mosses and lichens, thus preparing the way for higher species.

J 3 is in the northwestern area of the older lava, about 150 m from the sea and 16 m above sealevel. An automatic meteorological station has been installed here. The quadrate is level for the most part, though with a slight slope towards the west. The basis is ropey-type lava with a 10-15 cm overlay of ash. The ash, deriving from the eruption of the smaller islands Syrtlingur and Jólnir, fills all hollows and crevices in the lava and may therefore accelerate the formation of soil.

These quadrates were selected to provide as wide a variety of growth conditions as possible on the four types of substratum, i.e. washed out beach sand; loose tephra and ash, which hardens to tuff; bare, recent lava; and older lava with a surface-layer of ash. It will be interesting to trace the changes in the substrata which will be a necessary prelude to any plant colonization there.

Description of vegetation

In Surtsey Reports II and III an account was given of the colonization of plants on Surtsey 1965-66. In the first year about 30 plants of the species Cakile edentula were found in E 14. In the second year 4 seedlings of Elymus arenarius and one plant of Cakile edentula were found in C 11. These plants lasted only a very short time in both years, and they were not to develop beyond the seedling stage. However, the summer of 1967 has been more favourable on Surtsey, and 52 individuals of 4 species of vascular plants have been recorded, beside two species of Bryophyta. One of these mosses was in a small patch on the northern shore of the lagoon, and the other just by the old crater (see Bergthor Jóhannsson's and Eythor Einarsson's reports). In the early summer 15 individuals of Cakile edentula had been observed, the first plant being discovered on 18th May. Most of these were defeated later by unfavourable conditions, especially wind erosion. Later during the summer altogether 21 individuals were recorded of which 15 flowered and 6 bore matured pods. The species is annual. Of Honckenya peploides 26 individuals were recorded, a number of which produced considerable vegetating growth, though none flowered during the summer. This species is perennial. The third species was Elymus arenarius, which is a perennial grass species and of which 4 individuals were found. These only set a few leaves and did not flower. The most developed individual of these was 41 cm in height. The fourth species was Mertensia maritima, a perennial of which only one specimen was found on the "New Year" lava by the lagoon, in E 13. It was trodden on and only one leaf remained when last examined. See Table 1 and accompanying map.

Almost half the recorded specimens were on a single strip of drift-layer in F 15, about 150 m from the shore. It may be assumed that this layer was formed by an exceptionally high tide, reaching a point to which the sea has not yet since attained, and for this reason the seed carried up with the drift was able to germinate undisturbed. It is conceivable that some of the perennials which were there may manage to survive the winter, provided that the quadrate F 15 is not disturbed unduly by the sea. As may be seen from Table 1, the various specimens of Cakile edentula began to germinate at different times and grew under varying conditions. Some plants barely got beyond the seedling stage, while others achieved normal growth and bore flowers and mature pods.

The first plant to flower on Surtsey was Cakile edentula no. 3 in F 15. We observed it in flowers during an expedition on 26th June. It later set mature pods. Since then 15 individuals of this species flowered and 6 produced matured pods. The total number of pods formed were approximately 300 with almost twice as many seeds.

It is noteworthy that individual plants have succeeded in multiplying in their new habitat, and thus laid the foundation of a new generation.

Acknowledgements

This work has been sponsored by the Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Biology Branch, under contract No. AT(30-1)3549.

List of plants found on Surtsey 1967

No.	Species	Location	Date of discovery	Maximum stage of growth	Flowering time	No. of pods developed
1.	Honckenya peploides	F 15	24/6	8 leaves on a branch		
2.	Honckenya peploides	F 15	24/6	10 leaves on a branch		
3.	Cakile edentula	F 15	2/6	10 branches with leaves, flowers and pods	26/6	more than 50 pods
4.	Wilted grass seedling					
5.	Honckenya peploides	G 16	24/6	one stalk and 6 leaves		
6.	Cakile edentula	G 16	2/6	15 branches with leaves flowers and mature pods	6/7	40 pods
7.	Cakile edentula	C 12	2/6	cotyledonous		
8.	Cakile edentula	C 12	2/6	cotyledonous		
9.	Cakile edentula	D 12	2/6	6 leaves and flowerbuds		
10.	Honckenya peploides	F 15	24/6	2 branches with 12 leaves		
11.	Honckenya peploides	F 15	25/6	3 branches with 24 leaves		
12.	Honckenya peploides	F 15	25/6	1 branch with 6 leaves		
13.	Honckenya peploides	F 15	25/6	1 branch with 10 leaves		
14.	Honckenya peploides	F 15	25/6	1 branch with 14 leaves		
15.	Honckenya peploides	F 15	25/6	2 branches with 19 leaves		
16.	Honckenya peploides	F 15	25/6	5 branches with 50 leaves		
17.	Honckenya peploides	F 15	25/6	1 branch with 14 leaves		
18.	Cakile edentula	C 12	27/6	1 branch with flowers	3/8	
19.	Cakile edentula	F 15	29/6	1 branch with 3 leaves 8 flower stalks	3/8	
20.	Cakile edentula	D 12	30/6	1 branch with 6 leaves and 12 flower stalks	14/7	
21.	Honckenya peploides	F 15	6/7	1 branch with 11 leaves		
22.	Honckenya peploides	F 15	6/7	2 branches with 14 leaves		
23.	Elymus arenarius	F 15	12/7	2 leaves 12 cm		
24.	Elymus arenarius	F 15	12/7	3 stolons 25 cm, 20 cm, 40 cm		
25.	Honckenya peploides	F 15	12/7	1 stem with 8 leaves		
26.	Honckenya peploides	F 15	12/7	1 stem with 7 leaves		
27.	Cakile edentula	F 15	12/7	6 branches with leaves and flowers		30 mature pods
28.	Cakile edentula	B 13	13/7	1 stem with 4 leaves		

No.	Species	Location	Date of discovery	Maximum stage of growth	Flowering time	No. of pods developed
29.	Cakile edentula	B 13	13/7	1 stem with 4 leaves		
30.	Honckenya peploides	H 16	14/7	4 leaves		
31.	Cakile edentula	B 14	14/7	stem and leaves, flowers	3/8	
32.	Cakile edentula	B 11	14/7	2 branches with 9 leaves 2 stands of flowers	3/8	
33.	Cakile edentula	B 11	14/7	stem with 8 leaves and flowers	3/8	
34.	Cakile edentula	B 11	14/7	4 branches with 16 leaves, flowers	3/8	
35.	Cakile edentula	E 12	15/7	6 branches with 8 flower stalks	3/8	more than 50 pods
36.	Cakile edentula	E 12	15/7	big plant with number of branches and flower stalks	5/7	more than 50 pods
37.	Elymus arenarius	E 14	18/7	3 leaves, 15 cm		
38.	Cakile edentula	J 17	17/7	dwarf plant, 1 stem with 2 leaves and flower buds		
39.	Honckenya peploides	F 15	18/7	stem with 12 leaves		
40.	Elymus arenarius	F 15	19/7	2 leaves		
41.	Cakile edentula	F 15	18/7	1 stem 4 leaves 1/2 cm		
42.	Honckenya peploides	F 15	20/7	stem with 4 leaves		
43.	Honckenya peploides	F 15	20/7	1 stem with 14 leaves		
44.	Honckenya peploides	H 17	28/7	seedling		
45.	Honckenya peploides	H 17	28/7	1 stem with 7 leaves		
46.	Honckenya peploides	H 17	28/7	1 stem with 6 leaves		
47.	Cakile edentula	H 17	28/7	1 stem with 4 leaves and flowers	3/8	
48.	Cakile edentula	A 1	3/8	1 stem with 7 leaves and 2 flower stalks	3/8	
49.	Honckenya peploides	H 17	3/8	1 stem with 4 leaves		
50.	Honckenya peploides	F 15	3/8	1 stem with 7 leaves		
51.	Mertensia maritima	E 13	11/8	1 cotyledon and 2 leaves		
52.	Cakile edentula	E 13	11/8	5 branches with flowers and pods	11/8	more than 50 pods
53.	Funaria hygrometrica	B 12	11/8			
54.	Funaria hygrometrica	K 10	9/9			
55.	Bryum argenteum	K 10	9/9			

Records of Drifted Plant Parts on Surtsey 1967

by

Sturla Fridriksson and Björn Johnsen
The Agricultural Research Institute, Reykjavik

All the vascular plants colonizing Surtsey up to the year 1967 have grown from drifted seed. It may, however, be considered possible that plant parts other than seed can drift to Surtsey and take roots on the shore if conditions are favourable. An investigation of the plant material drifting to the island would reveal what species might have a chance to establish in this way. The shores of Surtsey were thus inspected regularily during the research period in the summer 1967. Records were made of drifted plant material which is constantly being washed ashore, and from this material samples were taken for further study.

In the table plant parts of various species found drifted ashore in Surtsey during the year 1967 are recorded. The total number found are 16 species of vascular plants and one lichen sp., Zanthoria paretalis. It is difficult to state from where these plant parts have derived, as they are of rather common occurrence in Iceland. Thirteen of these species are found in the neighbouring islands and it is most likely that they have derived from there, this being the shortest distance from the living colonies of these species. These species are marked with a star in the table.

The remaining species have most likely been carried from the largest island, Heimaey, or from the mainland of Iceland. One of the species, Carex maritima, does not occur on Heimaey, so it must have drifted from other localities, most likely from the mainland.

Empetrum nigrum has limited distribution on Heimaey and besides this it is there isolated from the sea. Therefore it has most likely derived from the mainland where it might have been washed to the sea by rivers.

The species Elymus arenarius and Honckenya peploides have a wide distribution on the south coast of Iceland. They are also found on Heimaey, but to a much minor extent. It is therefore more likely that plant parts of these species also drifted from the mainland. From the total amount of the drifted material, parts of Festuca rubra are most abundant, being found in 12 instances out of 14 observations times.

Cochlearia officinalis is the second in abundance as it is found 8 times out of 14, and Matricaria maritima the third, found 6 times out of 14. The high proportion of these species in the drifted plant material is due to the fact that they are the dominant and most frequent species of the neighbouring islands. This observation points out the rather obvious fact that the abundance of the drifted material is mostly influenced by the distance from the source of plant material.

Acknowledgements

This work has been sponsored by the Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Biology Branch, under contract No. AT(30-1)3549.

SPECIES AND PLANT PARTS RECORDED DRIFTED ASHORE ON SURTSEY 1967

Species	June 27th	June 28th	June 29th	June 30th	July 1st	July 7th	July 8th	July 11th	July 20th	July 21st	July 26th	July 27th	Aug. 1st	Aug. 3rd
* AGROSTIS TENUIS										S.I			S.I	S.I
* ARMERIA VULGARIS			I	I	I									
* ATRIPLEX PATULA		L.S												L.S.I
CAREX MARITIMA									L.S.I.R					
* COCHLERIA OFFICINALIS	S.I	L.S		L	S.I						S.I	S.I		L.S.I
EMPETRUM NIGRUM									L.S	L.S	L.S			L.S
ELYMUS ARENARIUS									S.I	S.I	I			
* FESTUCA RUBRA	L.S.I	L.S.I	L.S.I	L.I	L.S.I	L.S.I	L.S.I	I	S.I	L.S.I	L.I	L.I		
HONCKENYA PEPLOIDES						L.S			L.S	L.S	L.S		L.S	
* MATRICARIA MARITIMA			L.S.I		S.I	S.I	L						L.S	L.S
* POA PRATENSIS			I	L.I	I	L.S.I				I			S.I	S.I
* POA TRIVALIS							L.I						S.I	
* PUCCINELLIA MARITIMA														S.I
* SILENE MARITIMA													L.S.I	L.S
* TARAXACUM OFFICINALIS			I	I			I							
* SEDUM ROSEUM		S												
* ZANTORIA PARETALIS				Th										

I = INFLORESCENCE

L = LEAVES

S = STEMS

R = ROOTS

Th = THALLUS

Dispersal of Seed by Snow Buntings to Surtsey in 1967

by

Sturla Fridriksson
The Agricultural Research Institute

and

Haraldur Sigurdsson
The Industrial Research and Development Institute

Distant islands must to a great extent owe their plant and animal life to long distance dispersal of living material. The role played by birds in such a transport has been a matter of some dispute among biologists.

It was suggested that the almost sterile habitat of the new volcanic island of Surtsey might offer an unique opportunity for studying the possible role birds play in transporting plants and lower animals across wide stretches of ocean.

Surtsey being the southernmost dryland of Iceland might become the first landing place for migratory birds arriving in the spring from other European countries. As the island is almost void of life there would be a minimal possibility for such migratory birds to consume any amount of food from terrestrial plants or animals on Surtsey. If such birds were to be captured on the island and shown to carry living organisms it would be extremely reasonable to conclude that such organisms had been transported by the birds to Surtsey over the ocean.

For this reason two assistants were given the task of recording migration of birds to the island and to collect a variety of birds on Surtsey as they arrived during the period March 31 to May 12 1967. The ornithological work was supervised by Dr. Finnur Gudmundsson who will report separately on the migration of the birds.

The birds caught by the assistants were identified, sexed, and weighed. They were then closely searched for any possible seeds or other organisms which might be attached to the exterior of the body, after which the birds were dissected and their alimentary tract cleaned of content. This content was then measured by volume and weight and inspected for organisms' if there were seeds present they might be identified and tested for germination Finally, the grit from the gizzard was inspected as its minerals or rocktypes might reveal its origin and thus the location where the last intake of food had occurred

Results

From the total number of 97 birds of 14 different species, none of the birds carried seed or other organisms on their exterior. A few birds, however, carried nematodes or other parasites which are not of direct interest in the transport of colonizing organisms.

Two waders had when shot, obviously been feeding on Euphausids which are regularly being washed upon the shore. In three birds dead insects were found in upper parts of the alimentary tract. Most bird stomachs were practically empty, in others there was only some grit in gizzards.

Of the 32 snow buntings caught, ten individuals of the nominate race had, in addition to grit, seeds in their gizzards. In Table I these snow buntings are listed with information on measurements of birds and content of their alimentary tract. The ten birds carried with them 87 seeds Most of these had hard seed coats and were berry kernels, but two which were soft had burst open and were partly digested The majority of the seeds seemed viable and when few were tested three of these germinated, two of which were grown to maturity The plants grown were that of Polygonium persicaria L. and Carex nigra All. (C. Goodenowii Gay). See Table III.

Grit from the ten snow buntings was examined under the petrographic microscope. Each grit sample weighed 0.2-0.5 grams Half of each sample was used for the preparation of a thin section and each grain identified as a mineral or rocktype. The number of grains identified in each thin section ranged from 97 to 511. Table II shows that the number of mineral or rocktypes is high (18 types and 2 additional unidentified species), but the grit grains can, however, be divided into three clearly separated groups: basaltic ash from

Surtsey, metamorphic rocktypes and younger sediments.

The ash from Surtsey stands out clearly in the microscope as angular and lightbrown glass with a large number of gas bubbles and sparse crystals of plagioclase and olivine.

In the table the minerals quartz, plagioclase and alkali-feldspar are the most conspicuous constituents, but these are the principal rock forming minerals of granite and gneiss. The alkali-feldspar is mostly a microcline which is characteristic of metamorphic rocks. One of the birds carried garnet, but this mineral is common on the metamorphic rocks of the Scottish Highlands and northwestern Ireland. High grade metamorphic rocks occur in the cores of ancient continents. Large areas composed of metamorphic rocks are to be found in Scotland, Hebrides, North and Northwest Ireland, Shetland Islands, Scandinavia and Greenland. In Iceland metamorphic rocks of this kind have never been found, since Iceland is geologically a very young country.

Concluding remarks

The records indicate that of the 14 species of birds caught on the island only the snow buntings were seed carriers. It must be regarded as highly doubtful that the birds could have collected seeds of this size and kind on the island. As the seeds were in the gizzard and none in the stomach, it proves that the birds had not been caught feeding, but apparently consumed the seeds at an earlier time. The accompanying rocks and minerals definitely show that the birds had not been on the mainland of Iceland, i.e. there was no old Icelandic basalt in the gizzards. On the other hand, there were grains of cinder picked up in Surtsey and mostly metamorphic rocktypes and younger sediments, which must have been collected by the birds outside Iceland.

It is interesting to note that the birds were not of Icelandic race. It is, however, unlikely that they were arriving from Greenland at this time of the year, and without stopping on the mainland of Iceland. More logical explanation is that the birds migrate for the winter to the British Islands or the Continent of Europe. The collection of rocks in the grit indicate that the birds had been feeding lately in the Scottish Highlands.

Most of the seed species identified are rather common both to Iceland and the British Islands, such as the Empetrum, Scirpus, Spergula and Carex nigra and the occurrence of these in the gizzards does not allow for any further speculation about their origin. Polygonum persicaria, however, can be regarded as a European species which only survives in Iceland around cultivated areas and hot springs. It is not a common species and it may be considered rather unlikely that seed of this plant would have been picked up in Iceland with the other seeds or that it had been carried by ocean to Surtsey and picked up there.

One of the two seeds in sample no. 5 was identified by Dr A. Melderis of the British Museum as Andromeda polifolia L. This plant is definitely not found growing in Iceland, but is native to Greenland as well as the British Islands where it is found in bogs from Somerset to the Hebrides.

Finally the occurrence of Medicago sativa seed in four samples (det. Melderis) eliminates both Greenland and Iceland from being the place of origin of the seeds. Medicago is not found in those countries, it is not used in seed mixtures in Iceland and does not produce seed when sown. On the other hand, it grows in the British Islands, and all the plant species are also to be found in Scandinavia, but the possibility of snow bunting coming from there is more unlikely. To explain the occurrence of these particular seeds in the gizzards of the snow bunting it would be logical to conclude that they were together with the grit picked up by the birds in the British Islands and carried by them over the ocean to Surtsey on their migration to Greenland via Iceland. After this transportation some of the seed at least still retained their germination ability. The incidence is thus a rather definite proof of a long distance dispersal of seed by birds.

Acknowledgements

This work has been sponsored by the Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Biology Branch, under contract No. AT(30-1)3549.

TABLE I

Records of snow buntings caught on Surtsey during March 31 to May 12, 1967

Sampling No.	Bird No.	Date of capture	Wind direction	Birds			Content of gizzard		
				Sex	Age	Weight in grams	Total volume in ml.	Total weight in grams	No. of seeds
1	3	April 4	NE			26.0	0.12		1
2	22	April 24	S-SW	female		25.8	0.25		18
3	25	April 24	S-SW	male	adult	28.6	0.1	0.3	1
4	26	April 24	S-SW	male	adult	36.5	0.2	0.5	2
5	27	April 24	S-SW	female	adult	24.7	0.1	0.3	2
6	34	April 24	S-SW	male	adult	28.8	0.2	0.6	1
7	37	April 24	S-SW	male	adult	27.3	0.1	0.3	19
8	38	April 24	S-SW	female	adult	24.8	0.1	0.35	20
9	39	April 24	S-SW	male	adult	27.95	0.1	0.25	20
10	47	April 24	S-SW	male	adult	30.6	0.1	0.55	2
							TOTAL		87

TABLE II

Sample No.	1	2	3	4	5	6	7	8	9	10
Total weight	0.6	0.3	0.2	0.5	0.2	0.4	0.3	0.2	0.1	0.2
Number of identified grains	511	371	173	440	97	387	97	417	177	383
Minerals and rocktypes, excluding ash from Surtsey, %										
Quartz	37.2	54.5	46.5	68.3	76.7	27.0	33.3	15.6	19.5	6.7
Plagioclase	7.4	9.6	18.2	1.9	3.3	46.8	20.8	9.8	9.7	6.7
Alkalifeldspar	43.9	14.6	11.8	5.6	13.4	2.1	15.3	69.8	26.4	2.2
Magnetite			0.9	1.9				0.4		
Garnet		1.8								
Hornblende						2.8		1.0		2.2
Granite	11.5	5.9	4.5	5.6	3.3	7.1	20.8	1.4	20.9	4.4
Hornfels					3.3				1.4	2.2
Sandstone		2.2	0.9				1.4	2.0	6.9	
Quartzite		7.4	11.8			7.8	4.2		8.3	15.6
Clay			5.4	1.9		1.4				
Arkose		4.0								4.4
Limestone				11.1						
Dolerite				3.7						
Gneiss						5.0	4.2		6.9	48.9
Unidentified minerals										6.7
Rockgroups in %										
Ash from Surtsey	77.1	85.5	36.4	90.1	38.1	63.6	25.8	50.8	59.3	88.3
Metamorphic rocks	22.9	14.2	59.5	7.4	61.9	35.0	73.2	48.2	37.9	11.7
Sediments		0.3	4.1	2.5		1.4	1.0	1.0	2.8	

TABLE III

Number of seeds of various species
found in samples from snow bunting caught on Surtsey 1967

Species of seed	Sampling No										Total per species
	1	2	3	4	5	6	7	8	9	10	
Polygonum persicaria					1						1
Carex nigra All			1								1
Empetrum		12		2			19	19	18		70
Andromeda polifolia L					1						1
Spergularia		3									3
Medicago sativa		2				1		1	2		6
Scirpus	1	1									2
Unidentified										3	3
Total seeds per bird	1	18	1	2	2	1	19	20	20	3	87

Ornithological Work on Surtsey in 1967

by

Finnur Gudmundsson
Museum of Natural History, Reykjavik

A great majority of the land birds of Iceland are migratory. In autumn most of them proceed in a southeasterly direction and many winter in the British Isles, which is the first land they reach after crossing a wide stretch of ocean. However, some species continue to France and the Iberian peninsula, and some even to West Africa. In spring the direction is reversed, as migrants of Icelandic origin now proceed in a northwesterly direction and reach Iceland by way of or coming from the British Isles. Bird banding has furnished much of the existing information about winter quarters and migration routes of Icelandic migrants. Much information also exists about arrival dates of various species in spring and about their exodus in autumn. On the other hand, direct observational methods for the study of bird migration have been badly neglected in Iceland.

In view of this fact it appeared highly desirable to test the potentialities of Surtsey for such studies. It has long been known that islands lying in the path of important migrations furnish ideal conditions for the study of visible migration, and, as the southernmost part of Iceland, Surtsey appeared to fulfil these requirements. To be sure, the almost lifeless habitat of a new volcanic island could not be expected to tempt many land birds to stop on the island, but on the other hand the very sterility of the island could be expected to offer unique opportunities for studying the possible role of birds in transporting viable seeds or other organisms across ecological barriers such as wide stretches of ocean. On Surtsey there would be a fair chance that migrants could be collected on arrival before intake of food from local food resources was likely to obscure the results.

These were the main considerations that led to the decision to have Surtsey manned during the period of spring migration in 1967.

Mr. Árni Waag stayed on the island from March 31 to May 11. His work on the island was shared by Mr. Völundur Hermóðsson from March 31 to April 17, by Mr. Páll Steingrímsson from April 17 to April 20, and by Mr. Jón Baldur Sigurdsson from April 22 to May 6.

Besides 13 species of resident sea-birds which were regularly seen around the island, 28 species of migratory birds were observed on or near the island during the above period. Individuals of many migrants settled on the island in greater numbers than had been expected and 97 birds were collected. The collected birds belonged to the following species:

1.	Pink-footed Goose (Anser brachyrhynchus)	1
2.	Ringed Plover (Charadrius hiaticula)	1
3.	Golden Plover (Pluvialis apricaria)	2
4.	Turnstone (Arenaria interpres)	6
5.	Whimbrel (Numenius phaeopus)	4
6.	Redshank (Tringa totanus)	9
7.	Purple Sandpiper (Calidris maritima)	1
8.	Dunlin (Calidris alpina)	3
9.	Long-eared Owl (Asio otus)	1
10.	Redwing (Turdus iliacus)	17
11.	Wheatear (Oenanthe oenanthe)	5
12.	Meadow Pipit (Anthus pratensis)	9
13.	White Wagtail (Motacilla alba)	6
14.	Snow Bunting (Plectrophenax nivalis)	32
	Total	97

All collected birds were weighed and sexed, and a close search for seeds in their alimentary tract was made. All birds may distribute seeds, either directly or indirectly. Direct distribution is done by defecating viable seeds. This occurs less among seed-eating birds than among fruit and berry eating birds because seed-eating birds mostly crush the seeds by the bill and consume grit to ensure a final digestion in the gizzard. Indirect distribution takes place through seeds becoming embedded in mud on a bird's feet or bill, or seeds that attach themselves to the feathers of birds. The effectiveness of birds as dispersal agents varies greatly, as does the distance the seeds are carried. Although it is a well known fact that many species of birds play some part in seed dispersal, very little is known about the possibility of long-distance dispersal of plants by birds. But this aspect of the work on Surtsey in 1967 will be dealt with by Dr. Sturla Fridriksson. Here merely the results of the ornithological observations will be discussed.

Early migrants like the redwing (Turdus iliacus), the golden plover (Pluvialis apricaria) and the common snipe (Gallinago gallinago) did not turn up on Surtsey in any numbers, but the reason for this may have been special weather conditions at the time of their arrival. Under normal conditions the main stream of spring migrants appears to reach the southeastern part of Iceland, and this is apparently more pronounced when the migrants experience westerly winds during their passage from the British Isles. Surtsey may thus lie at the western fringe of the main migration path.

On the whole there was never a pronounced passage of waders through Surtsey, the only exception being a considerable passage of redshanks (Tringa totanus) on April 17 when about 350 - 400 redshanks made a stop-over on the island. Oystercatchers (Haematopus ostralegus) and turnstones (Arenaria interpres) stayed on the island in small numbers throughout the study period, but although their numbers varied slightly from day to day there were no signs of a pronounced passage. However, in early April groups of oystercatchers of 5 - 10 birds were repeatedly seen approaching the island from the southeast. When on the island both oystercatchers and turnstones fed exclusively on euphausids washed upon the shore. This was also the main if not the only food source for most other land birds visiting the island.

Throughout April the weather was unfavourable, cold and changeable, but during the first days of May it improved although it continued cold. On May 3 there was a light northeasterly breeze and clear skies. In the afternoon of that day a stream of migrants passed Surtsey and individuals of some species settled on the island in considerable numbers. Already at 1100 hrs. a flock of about 50 geese passed the island and from about 1300 hrs. until it became dark flocks of geese passed Surtsey on their way towards the mainland of Iceland.

Among the geese seen, greylags (Anser anser), pinkfeet (Anser brachyrhynchus), and barnacle geese (Branta leucopsis) could be identified, but geese in many flocks could not be identified because of the distance from the island. During the afternoon small flocks of barnacle geese settled twice on the north shore of the island.

In addition to geese, passerines passed the island in large numbers on May 3 and many stopped on the island. The passage of meadow pipits (Anthus pratensis) was particularly impressive, but white wagtails (Motacilla alba), redwings (Turdus iliacus), wheatears (Oenanthe oeanthe), and snow buntings (Plectrophenax nivalis) also passed through in some numbers. The passage of passerines was, however, perhaps still more pronounced the next day (May 4), whereas the passage of geese was almost confined to May 3.

On May 3 one merlin was present on the island and the next day two or more merlins were seen. They were preying upon various passerines.

Although waders were not conspicuously involved in the migratory movements described above, it may be mentioned that two whimbrels were collected on the island on May 3 and on the same day two large and very compact flocks of birds were seen heading for the mainland of Iceland. These were probably waders and most likely knots (Calidris canutus), although identification could not be established with certainty.

If we assume that the migrants reaching Surtsey on the afternoon of May 3 had come from Scotland and Ireland they probably set out on the evening of May 2 or during the following night. An examination of the weather conditions in the eastern North Atlantic shows that throughout the week before May 2 the weather on the west coast of Scotland and the north coast of Ireland was not conducive to the inception of migratory movements. The wind was westerly and the sky mainly overcast, with occasional drizzle or rain from April 25 to April 29. On April 30 and May 1 the wind was northerly and northwesterly, force 4-8, with showery weather. However, on May 2 the north wind decreased gradually and by midnight there was almost calm weather and mainly clear skies on the western seaboard of the British Isles.

Birds that had started about midnight that day heading for Iceland would have had light easterly or southeasterly winds for the first few hours. Then the easterly wind increased, and for the last two thirds of the way at the altitude of the birds it was between 25 and 35 knots. It is therefore almost certain that the birds drifted to the west. And possibly the wind was so strong that some of the birds may never have managed to reach Iceland This westward drift may explain the "rush" of migrants reaching Surtsey and even heading for Iceland west of Surtsey.

During the entire study period on Surtsey a few snow buntings, usually 1 - 4, were almost daily encountered on the island, but a pronounced passage was not observed except on April 24 and on May 4. On April 24 about 30 snow buntings appeared suddenly on the island. Of these 21 (16 males and 5 females) were collected. All the collected birds proved to belong to the nominate race *Plectrophenax nivalis nivalis* and not to the Iceland race *Plectrophenax nivalis insulae*. It is therefore almost certain that the birds in question were of Greenland origin and that they were on migration from the British Isles to Greenland.

Acknowledgements

This work has been sponsored by the Surtsey Research Society with a grant from the U S. Atomic Energy Commission, Biology Branch, under contract No. AT(30-1)3549.

ABSTRACT

Goose Barnacles (Lepas spp.) on Surtsey Pumice

by

Finnur Gudmundsson and Agnar Ingólfsson
Museum of Natural History, Reykjavik

Article published in: Náttúrufrædingurinn, Vol 37, no. 3-4, 1967

During the years 1964-1966 one of us (A.I.) was engaged in a comparative study of the food and feeding habits of Icelandic gulls. In the course of this study it was found quite unexpectedly that goose barnacles (Lepas spp.) were an important food item in gulls collected in October/November 1965, at Sandvik on the Reykjanes Peninsula in S.W. Iceland. This was unexpected because at high latitudes goose barnacles rarely occur in sufficient abundance to become a likely food source of any importance for sea-birds. The percentage of gulls (all species lumped together) which had fed on goose barnacles increased until October 18, when it reaches the maximum of 70%, but after that the percentage quickly decreases. Although goose barnacles were among the chief foods taken by the gulls in the Sandvik area during the above period, they by no means confined themselves to this food item as they sometimes do when some foods (e.g. capelin (Mallotus villosus) or sandeel (Ammodytes lancea)) are present on a very large scale. In only 40% of the gulls that had fed on goose barnacles did they amount to half or more of the stomach contents.

The explanation of the unexpected quantity of goose barnacles in many of the gulls collected at Sandvik was not far to seek. The beaches on the South and West of the Reykjanes Peninsula were dotted with heaps of Surtsey pumice covered by vast quantities of goose barnacles. Their presence there can be accounted for as follows:

On November 14, 1963, a submarine volcanic eruption began off the Westman Islands, about 120 km (75 miles) to the southeast of Sandvik, and this gave rise to a new permanent island, Surtsey. In late May 1965 a second eruption began close to Surtsey, and soon another island of tephra rose from the sea (Syrtlingur). Later on a third island (Jólnir) was formed, but these two subsidiary crater islands disappeared again (see Thorarinsson, 1966, for an exact

chronology of events). The term "Surtsey pumice" is used here and elsewhere in this report for pumice produced during this whole period of submarine eruptions.

On October 27, 1965, we collected samples of pumice with goose barnacles that had been washed upon the shores of the Reykjanes Peninsula. Collections were made at four stations on the south side of the peninsula (Herdisarvik, Thorkötlustadabot, Arfadalsvik and Sandvik), and at one station on the west side (Stora-Sandvik). Three species of Lepas were found on the pumice samples. Lepas fascicularis was by far the most common species. Next in abundance was Lepas anatifera, while the third species, Lepas pectinata, was rare compared with the other two. This species had not previously been recorded in Iceland, but was now found at three of the five stations where collections were made. The material collected at Herdisarvik contained 7 specimens of L. pectinata, the material from Thorkötlustadabot contained 15 specimens, and the material from Arfavik 33 specimens of this species.

Unfortunately it is not known when pumice with goose barnacles began to drift onto the beaches of the Reykjanes Peninsula. No gulls were collected there during the summer and autumn of 1965 before October 8. And during the same period no search for pumice with goose barnacles was made along the shores of the peninsula. It may be mentioned, however, that during the winter of 1964-1965 no traces of goose barnacles were found in 87 gulls collected in the Sandvik area during the period October 5, 1964 - February 2, 1965. Neither were any traces of goose barnacles on pumice found on the shores of Stóra-Sandvik on March 9, 1966. However this may be, it is obvious that the great abundance of goose barnacles found on pumice in various parts of Reykjanes in the autumn of 1965 could not have reached maturity unless certain conditions were present simultaneously: Vast numbers of larvae of the species in question must have reached the waters off South Iceland at a time when very large quantities of floating pumice were available and when the temperature of the sea was exceptionally high. All these requirements were apparently fulfilled during the summer of 1965. The temperature of the sea off South Iceland was then well above the average, which means that there must have been a strong influx of Atlantic water, probably carrying vast numbers of viable Lepas larvae into the areas of floating pumice off South Iceland. And in April, 1965, the Syrtlingur eruption began and throughout the summer this crater island produced ash and pumice at an average rate of 4 - 5 cubic yards per second.

The case of the pumice that was produced during the first months of the Surtsey eruption that began in the November of 1963 was quite different. This eruption occurred in the winter when the sea off the South coast of Iceland was not warm enough to enable Lepas larvae to survive and make use of the pumice that was available then. And at the beginning of April, 1964, or before the temperature of the sea off the Icelandic coasts had begun to rise again to any appreciable degree, the Surtsey eruption ceased to produce pumice. And as the summer of 1964 advanced the greater part of this pumice had either been washed upon the mainland shores or drifted away from the land to the open sea. Besides, the sea temperature was never as high in the summer of 1964 as in the summer of 1965. This must be the reason why no traces of goose barnacles were found in the stomachs of 87 gulls that were shot at Sandvik in the autumn of 1964 and the winter of 1964-1965.

The same is most likely true of the pumice that was produced by the Jólnir eruption that began at Christmas of 1965. This eruption, which produced a similar quantity of material as the Syrtlingur eruption, admittedly lasted until August 10, 1966, and therefore growth of goose barnacles on the pumice might have taken place that summer, too. Unfortunately, however, other work prevented us from making a study of this question then.

We can assume that every year larvae of the three Lepas species that were found on the Surtsey pumice in 1965 are carried to the South coast of Iceland, but their quantities most likely vary a great deal from one year to another. Normally, the greater part of this larva mass probably perishes owing to the absence of requisite living conditions. This is a good example of the enormous wastage of life which is characteristic of many invertebrates, their reproductive rate therefore being high to the same degree. Such species can with impunity stand enormous setbacks and sacrifice countless millions of individuals in their search of favourable living conditions. It is because of these relatively aimless volleys of organisms that the Lepas larvae were able to make use of the Syrtlingur pumice in 1965 to the large extent indicated above. Then a volley of organisms scored a direct hit, a relatively rare occurrence. But in a direct connection with this fact the question arises if and to what extent volcanic eruptions and pumice production in past geological epochs may have contributed to the development and diversity of marine organisms depending on floating objects for their survival.

Bryological Observation on Surtsey

by

Bergthor Jóhannsson
Museum of Natural History, Reykjavik

The biological students stationed on the island for the summer reported in early August finding a mat of moss plants growing on the island.

I, therefore, visited the island in August 17th, 1967, and investigated the location, which was on the northern and north-western border of the New-lagoon, on a sand bank at the edge of the water. There were several patches in a row on the edge of the bank. All the moss plants were at a young state of growth with no indication of sex organs. They were all of the same species, Funaria hygrometrica Hedw.

On the 12th of September a second location of moss growth was discovered on the island. In this case the botanist, Eythor Einarsson, discovered patches of moss at the edge of a lava crater in the central part of the island. I identified samples of these as being of two species, the previously found Funaria hygrometrica Hedw. and a second species Bryum argenteum Hedw. These are the first two species of bryophytes known to start growth on the new volcanic island.

Mycological Investigations in Iceland, IV

by

T. W. Johnson, Jr.
Department of Botany, Duke University
Durham, North Carolina, U.S.A.

and

A. R. Cavaliere
Department of Biology, Gettysburg College
Gettysburg, Pennsylvania, U.S.A.

In four years (March, 1964-March, 1968) of study on the aquatic fungi of Iceland and Surtsey over two thousand collections have been made with a total yield of approximately two hundred and seventy-five species identified. Two hundred and ninety samples were taken in the period from March, 1967 - March, 1968. For the most part, sampling and trapping stations were located in southern Iceland, the Vestmannaeyjar and on Surtsey. Following past practices, fungi were collected on baits (hempseed, pollen, snakeskin, and cellophane), on submerged wood panels, apples, and twigs, and on marine and freshwater algae.

The total aquatic mycoflora of Iceland and its coastal waters is of course unknown, but the segments thus far uncovered present some unique mycological problems. Accordingly, recent emphasis has been on (1) exploration of particular systematic or developmental problems, and (2) identification of fungi on marine algae. Compilation of a species list continues, but is not an effort of first priority.

The developmental morphology of *Mycosphaerella ascophylli* has been worked out in its entirety. This fungus occurs on *Ascophyllum nodosum*, but its role in the reduction of populations of this alga remains obscure. Several chytridiaceous fungi have been collected on other marine algae. Among these is a *Phlyctochytrium* of the ornamented series, the first such fungus found in a marine habitat. *Petersenia lobata* and *P. pollagaster* occur in moribund *Ceramium rubrum* on the south coast of the Reykjanes Peninsula and on Heimaey. In *Polysiphonia violacea* from the shoreline of Heimaey, and near Keflavik, a fungus resembling *Pleotrachelus inhabilis* (?) has been collected. Its complete morphology is unknown since the material is sparse, but in terms of spore discharge pattern, it suggests a species of *Petersenia*. Other fungi occurring in marine algae include *Olpidiopsis feldmanni*, and a form of *O. andreei* (on *Acrosiphonia* and *Trailliella*), and *Chytridium polysiphoniae* on *Pylaiella litoralis*. The latter fungus is one of a species complex, and studies are under way to determine justifiable limits to the species.

In addition to the foregoing species, collections of fresh-water algae from the southwestern and southern portions of Iceland have harbored several aquatic fungi. Notable in the collections are *Ancylistes closterii* (in *Closterium*), *Chytridium lagenaria* (on *Cladophora*), *C. versatile* (on *Fragilaria*), *Diplophlyctis intestina* (endobiotic in *Chara*), *Myzocytium proliferum* (in *Spirogyra*), *Olpidium endogenum* and *O. entophytum* (in *Closterium* and *Spirogyra*, respectively), and *Podochytrium clavatum* (on *Pinnularia*). *Chytridium versatile* var. *podochytrioides* is shown to be a *Podochytrium* with affinities to *P. cornutum*. These are, of course, all new records for Iceland.

As is common in survey studies on aquatic fungi, specimens are found which, because of paucity of material, cannot be identified with confidence. Material thus far collected from southwestern Iceland and Heimaey include representatives of *Micromyces*, *Phlyctidium*, *Phlyctochytrium*, *Blyttiomyces*, *Chytridium* and *Rhizophydium*.

From baited cultures (soil and water) nineteen species of aquatic fungi have been collected and identified, but well over fifty additional species have been recovered. Among the fungi on marine algae are *Ectrogella perforans*, *Pontisma lagenidioides* and *Sirolpidium bryopsidis*. The freshwater species show rather remarkable distributional patterns. Two examples are illustrative. *Phlyctochytrium punctatum* and *P. irregulare*, known only from the U.S., occur also in lava soils below moss tussocks in southwestern Iceland. The watermold *Achlya spiracaulis* has a known distribution in Louisiana, Michigan, and Iceland.

Marine Fungi Imperfecti have not been found in abundance in Icelandic coastal waters. Nine species have been identified, and a host of unidentified forms in the genus *Phoma* have been recovered.

from submerged wood. Several collections of imperfects in the *Helicoma-Zalerion-Dictyosporium* complex await comparative studies for identification. In the colder waters of Iceland *Dictyosporium*-like fungi with morphological affinities to *Helicoma* are common, and should be useful in delimiting generic limits.

Among the marine lignicolous Ascomycetes of Icelandic coastal waters, *Ceriosporopsis halima* is ubiquitous. Five species of *Halosphaeria* (including two which seem only to inhabit colder waters), four of *Remispora*, and one or two species in *Sphaerulina*, *Amphisphaeria*, *Corollospora* and *Leptosphaeria*, also occur. Of unusual systematic and morphological interest are the recovered species of *Zignoella* and *Haloguignardia*. The latter genus, in particular, is very poorly known and needs considerable morphological study.

Following is a list of aquatic fungi found on driftwood or on marine algae cast ashore on Surtsey or floating off-shore:

Oömycetes: *Pythium* spp. (possibly *P. monospermum* and *P. torulosum*)
Aphanomycopsis bacillariacearum (in *Pinnularia*)
Sirolpidium bryopsidis (in floating *Bryopsis*)

Deuteromycetes: *Phoma* spp.
Dinemasporium marinum

Ascomycetes: *Ceriosporopsis halima*
Amphisphaeria maritima
Lulworthia medusa

No soil- or freshwater-inhabiting aquatic fungi have been isolated from Surtsey, although such organisms are abundant on Heimaey.

These studies are supported by the U.S. Atomic Energy Commission, Contract AT-(40-1)-3556.

Survey on the Intertidal and Subtidal Algae on Surtsey in 1967

by
Sigurdur Jónsson
Laboratoire de Botanique de la Sorbonne
and
Laboratoire de Biologie Végétale Marine
Faculté des Sciences, Paris

Previous to the lava flow which started on Surtsey on August 19th 1966, 14 marine algal species had been found growing on the rocky shore (1). This growth exhibited two conspicuous belts in the littoral zone bordering the lava delta, an upper one of green algae, dominated by *Urospora penicilliformis*, and a lower one of film forming Diatoms, belonging mainly to *Navicula mollis*. The other species encountered were only occasionally found and then mainly confined to tide pools.

This vegetation was seriously affected by the eruption. On the east coast it was totally destroyed by the lava flow advancing into the sea. Elsewhere, especially on the west coast, it was damaged by the scouring action of sand and sea, but presumably it was not completely wiped out.

In the course of the year 1967 intermittent algological surveys were carried out on Surtsey during a period extending from spring to autumn. The littoral zone was studied by means of direct observations, and the sublittoral zone, down to 20 m depth, was investigated by means of SCUBA-diving techniques.

A. Survey of the intertidal zone

After the 1966 eruption had ceased in 1967 the lava delta of Surtsey was surrounded by two types of coastlines: the old west coast formed in 1964-1965 and the new east coast.

Projecting rocks, boulders, promontories and vertical cliffs characterized the intertidal zone of the old coast, as the new coast consisted mainly of vast beaches of sand, gravel and shingle. On the north-east part of the new shore large rocks broken from the lava front occupied, however, the upper part of the intertidal zone.

Most of the coast was accessible at low tides. However, serious problems of access were encountered along the vertical cliffs on the south-west coast, which could be safely descended in few places only. This applied also to the south-east point where the intertidal zone was too narrow to be explored on foot.

In the first surveys carried out in May and June along the old coast the conspicuous belts of Urospora and Diatoms previously observed were lacking. Only a few tufts of Urospora were found on the rocks, intermingled with sparsely represented Diatoms. This situation markedly changed in the course of the following weeks. In the beginning of August when this coastline was prospected again, Urospora and Diatoms had spread out widely on the rocks, thus forming, once more, the two characteristic belts. Moreover, analyses of field collections made in this survey lead, rather surprisingly, to the identification of all the algal species met with on this shore in 1966 prior to the eruption, except Pylaiella littoralis and Enteromorpha species (1). These species, confined to the Urospora-belt or its vicinity, on rocks and in tide pools, played, however, only a subordinated role in the general physiognomy of the algal vegetation. In addition the occurrence of Acrosiphonia albescens Kjellm. on rocks and in rock-pools of the mid-littoral zone of this shore represents a new record for Surtsey. Like other algal invaders so far settled on Surtsey, this species is also found to occur in the Vestmannaeyjar-archipelago, mainly as epiphyte on Gigartina stellata in the lowest part of the eulittoral zone. Another new record of great biological importance is the presence of a single barnacle found in this survey, in a small hole of the rock, in the lower part of the littoral zone.

As to the new shore it was entirely devoid of algal growth, except its rocky north-eastern part where the Urospora-belt was already growing up. Diatoms in branched gelatinous sheaths, belonging to Navicula mollis occurred in rock-pools, but did not form a continuous belt as on the west coast, presumably because of the still intensive scouring action prevailing in the lower part of the shore. Other algal settlers occasionally encountered on the new coast were a few young thalli of Porphyra umbilicalis, Petalonia zosterifolia, Ectocarpus confervoides and a single tuft of Acrosiphonia albescens species concurrently occurring on the west coast.

During investigations carried out towards the end of the survey in September and October in the same areas as previously studied, no major changes of the marine algal vegetation was noted. In addition to species already met with, two new indigenous species were, however, found. One of these was an immature specimen of Enteromorpha linza (L.) J.Ag., 6 cm high and the other resembles somewhat Enteromorpha compressa (L.) Grev., as described by Bliding (2. p. 132). Both of these species, which grew in rock-pools on the west coast, occur elsewhere in the archipelago. Moreover, it was noted in October, that Codiolum gregorium, sometimes in fruiting conditions, was locally abundant on the west coast, often mixed with decaying filaments of Urospora.

B. Survey of the subtidal zone.

Investigations on the submarine algal colonization of Surtsey were carried out on August 15th by means of a transect made by SCUBA-divings, off the western rocky shore of the island. This area was, because of its location on the lee-side of the eruption, the most likely place to offer a rocky bottom favourable for algal settlement.

The position of the transect was determined by taking sextant readings on to accurately fixed points on the shore. Depths were measured both by echo-sounding and with wrist depth-gauges and were corrected to depth below mean lower low water. A deep-to-shallow transect sampling method was employed. Occasionally hydrophone was used by divers to communicate directly with the boat. The survey of the bottom was limited to a maximum depth of 20 meters. This depth was located 90 meters offshore.

The area explored by divers was found to be covered with rocks, 2-4 meters in diameter, and not dissimilar to those found in the intertidal zone. The rocks were surrounded by sand and dust which was easily stirred up by the divers when swimming over the sea bed. At 20 meters depth, where the depth increased abruptly, the rock was covered with asperities.

Sampling was done along the transect towards the shore at various depths, namely 20 m, 17-13 m, 13-6 m and 6-0 m.

At 20 m depth benthic animals, mainly hydrozoids, were dominating on the rocks. Diatoms also occurred at this depth, but no macroscopic algae were found. In the depth range of 17-13 m, the rocks were covered with young plants of Alaria esculenta, only 6-18 cm long spaced approximately at 0.5 intervals. Very young hairy Desmarestia viridis, about 4,5 cm long, grew among the Alaria plants, and one specimen of Giffordia hincksiae with plurilocular sporocysts was brought up from this depth. The presence of Diatoms in gelatinous sheaths on the rock surfaces was also asserted. In the segment of the transect at 13-6 m depth, Alaria was again the dominating species and was accompanied by Desmarestia and Diatoms. The largest specimen of Desmarestia found was 40 cm long and came from the depth of 10 m. The longest Alaria plant observed was 1,10 m long and was found at 6 m depth. This vegetation was immature and without epiphytes. The 6-0 m depth range was very difficult to explore owing to the excessive surge and strong currents prevailing at this depth. The divers succeeded, however, in surveying the bottom at up to 3 m depth. At this depth no vegetation occurred and the rock was clean and did not offer the slippery coating observed at greater depths.

Reconnaissance dives undertaken some 270 m north of the transect revealed, at 10 m depth, the same kind of bottom and an important Alaria-vegetation covering it.

Desmarestia viridis and Giffordia hincksiae are new immigrants on Surtsey. They are obligate sublittoral species which have been found in the archipelago before, either by dredgings or SCUBA-divings. D. viridis has been brought up from 5-25 m depth in various localities off the shores of Heimaey (Eidid, Urdarviti, Bótin, Ofanleitishamrar), Brandur and Hellisey and G. hincksiae has been found to occur as epiphyte on the stipe of Laminaria hyperborea and Alaria esculenta on 6-18 m depth, in the vicinity of Heimaey and Brandur. As to Alaria esculenta, a very young specimen had alreday been found in 1966 on the south-east coast of Surtsey (1, p. 49) the day before the shore was submerged in the new lava.

C. Remarks on the marine algal settlement.

Although seriously affected by the last lava flow on Surtsey, the marine algal settlement has continued and 5 new invading species were detected in 1967 in addition to those previously found and which were all rediscovered with two exceptions. This totalizes 17 species of benthic algae so far identified on Surtsey, Diatoms not included.

The relative paucity of the algal vegetation on the west coast in the beginning of the survey could indicate that the algal growth previously observed was destroyed during the eruption and that re-population took place later on. This is not necessarily the case. It must be borne in mind that most of the intertidal colonizers, if not all, appear to be annual forms, which pass the wintertime as micro-scopic plants easily overseen in nature. This might, therefore, have been the situation of the algal growth, when investigations started in the spring. On the other hand, it is obvious that repopulation took place on the north-east coast, where all life was buried under the lava flow. The occurrence on this coast of initial algal populations, similar to that observed before the destruction, is significant and suggests that the algal settlement is the subject of invariable principles. The presence, however, of colonizers, such as *Acrosiphonia albescens*, which had not been encountered before on Surtsey, seems to indicate that the order of arrival and settlement of certain species might also be accidental.

At present there is no absolute delimitation between the littoral fringe and the eulittoral zone of Surtsey. For this reason it is difficult to appreciate the real extension of the species. This inconvenience will now be surmounted by increasing settlement of barnacles, which have already appeared on the coast. Their occurrence will serve as a precious biological indicator for the establishment of the littoral zonation and the estimation of the degree of exposure of the coast. Their upper limit, in quantity, will eventually mark the boundary between the eulittoral zone and the littoral fringe and this limit will facilitate the study of the variations in the vertical distribution of the benthic algae as their settlement proceeds.

The occurrence of Alaria esculenta as probable pioneer species of the subtidal zone was not surprising, as it had already been met with in 1966. It was unexpected, however, to find Alaria so wide spread, exhibiting a noticeable sublittoral belt, of up to 60-70 meters broad. In adjacent waters this species grows most luxuriantly in the uppermost part of the sublittoral zone extending downwards to 6-10 m depth. In the vicinity of Álsey, divers brought Alaria up from 20 m depth, but this was exceptional. The distributional range of Alaria observed on Surtsey, where it grows at 6-17 m depth, is therefore somewhat exceptional. On the other hand, the largest specimens of Alaria were on Surtsey found at 6 m depth, which appears to be the optimal depth for the growth of this species elsewhere in the archipelago. As to Desmarestia viridis, its vertical distribution on Surtsey coincides fairly well with that observed elsewhere, for example off Eidid, on Heimaey, where it was found last summer at 6-25 m depth.

Actually the lower limit of the vegetation on Surtsey is located at about 20 m depth. This limit is approximately the same as observed elsewhere in the archipelago, where SCUBA-diving studies have been carried out (Geirfuglasker, Hellisey, Álsey and in different localities at Heimaey). The upper limit of the sublittoral vegetation on Surtsey is, on the other hand, abnormally characterized by a barren belt, which corresponds on adjacent shores to the position of the Laminaria digitata and/or Alaria esculenta belt.

According to the type of life history exhibited by Alaria and Desmarestia, involving an alternation between a large and structurally complex sporophyte and an exceedingly minute gametophyte, it is obligated that these plants grew up from eggs which settled on the bottom of Surtsey. As to the Desmarestia plants it is obvious, because of their juvenile characters, that they grew up during the summer season. It seems likely that the same applies to the Alaria plants despite their presence on Surtsey the year before. The size of these plants compare favourably with the size of the Alaria plants found in Aug. near Heimaey, growing on artificial substrate (aircraft wreck), which had been immerged in the sea, at 6 m depth, for 3 months. This observation shows, moreover, that the growth of Alaria in Icelandic waters is not restricted to the wintermonths as seems to be the case, for example, on the Norwegian coast (3).

Acknowledgements

Field work was carried out from the Surtsey Biological Laboratory in Vestmannaeyjar and the principal investigator was efficiently assisted by Sigurdur V. Hallsson. SCUBA-divings were successfully assumed by Captain Halldór Dagsson and his diving companions of M/S "SÆÖR".

This research has been sponsored in part by the Oceanic Biology Program Branch, Office of Naval Research, Washington, D.C., under contract F61052 67 C 0087 and the Surtsey Research Society. This is highly appreciated.

References

1. Jónsson, S.: Further settlement of marine benthic algae on the rocky shore of Surtsey. Surtsey Res. Progr. Rep. III, p. 46, 1967.
2. Bliding, C.: A critical survey of European taxa in Ulvales. Opera Botanica, 8, 1963.
3. Sundene, O.: The implications of transplant and culture experiments on the growth and distribution of Alaria esculenta. Nytt Mag. Bot. 9, 155, 1962.

Report on Studies of Microorganisms on Surtsey, 1967

by

Arinbjörn Kolbeinsson, M.D. and Sturla Fridriksson

The aim of the studies was to estimate the relative bacterial content of the air over the island as well as that of the surface of the tephra. The study in 1967 was a continuation of observations performed on Surtsey in the previous years (1964-1966). They had shown that the microbial flora in the air and the surface tephra at Surtsey was scanty and presumably influenced by weather conditions and dependent on elevation above sea level. Fewer bacteria were found at the higher elevation than at sea level, and it was also shown, that a high wind, with sea water spray over the island, increased the bacterial counts.

Air sampling

A study was performed on August the 3rd, 1967, during a calm day with light overcast. The methods used for investigating the bacterial content of the air were those described in the Proceedings of the Surtsey Research Conference, Reykjavik, June 25th - 28th 1967. The counts were performed from samples taken at three sites at different elevations: "Eiði" 1 meter above sea level, "Sandur" about 20 meters above sea level and "Bólfell" about 30 meters above sea level. The observation time was five and a half hour and media used were the same as described earlier.

Results did not differ substantially from the previous findings. The bacterial counts were as follows: At "Sandur" 0,0 colonies pr. plate pr. hour, at "Bólfell" 0,2 colonies pr. plate pr. hour and at "Eiði" 1,8 colonies pr. plate pr. hour. The types of microorganisms which were isolated were of the same general kinds as described in earlier studies, saprophytic bacteria and a few species of moulds.

Tephra sampling

On the 21st of July thirteen samples of surface tephra were collected at various sites and different elevation. Five of the sampling sites were located on a transect from the lagoon across the ridge (Háls) 120 meters above sea level and down to the southwest coast. Samples had been collected from these same sites, in the years 1965 and 1966. Several samples were taken on the northern coast, where a few individuals of higher plants had already colonized, and in addition one sample was taken close to the hut (Pálsbær). The tephra samples were collected asceptically in sterile plastic containers each sample weighing 100-200 gr. They have been stored at - 22°C since the 23rd of July 1967. The samples will be kept for later investigations for autotrophic bacteria as well as saprophytic species.

Acknowledgements

This work has been sponsored by the Surtsey Research Society with a grant from the U.S. Atomic Energy Commission, Biology Branch, under contract No. AT(30-1)3549.

Preliminary Report on the Surtsey Investigation in 1967

Terrestrial Invertebrates

by

Carl H. Lindroth, Hugo Anderson, Högni Bödvarsson
and Sigurdur H. Richter, Department of Entomology,
Zoological Institute, University, Lund, Sweden

The team, consisting of C.H. Lindroth, H. Anderson, H. Bödvarsson and S. Richter, was the same as in 1966.

Surtsey was visited by all four members on August 20 to 21, by Lindroth also on June 26, and Richter stayed on the island from June 24 to August 11, with brief interruptions.

The smaller Westman Islands were visited by helicopter on August 18, but, due to suddenly deteriorating weather conditions, only Geirfuglasker and Súlnasker could be investigated.

The investigators stayed on the main island of the group, Heimaey, during the period August 16 to 22.

Thereafter, exploration were started of the southern coastland of the mainland of Iceland, between Seljaland and Vík, which must be regarded as the most important source area of the Surtsey immigrants. Collecting was performed there August 23 to 30.

The vast material collected is being worked up by many specialists in different countries and the final results are not yet available.

1. Surtsey

The following list is restricted to species of terrestrial invertebrates discovered on Surtsey in 1967 and previously unknown on the island.

New records of Terrestrial Arthropods found on Surtsey in 1967

37 species.

I N S E C T A

D i p t e r a, 19 species.

Fam. Chironomidae (det. D.R. Oliver)

Chironomus sp. 6.VII., ♂ in glue trap.

Nanocladius minor Edw. VII., ♂.

Fam. Tipulidae (det. B. Tjeder)

Prionocera turcica F. 12-14. VII., 3 ♀

Fam. Bibionidae (det. H. Andersson)

Dilophus femoratus Meig. 12.VII., ♀; 13.VII. ♂♀; 12.VIII., 2 ♂, ♀.

Fam. Sciaridae (det. R. Tuomikoski)

Lycorella conspicua Winn. 21.VIII. ♂.

Bradysia sp. (cf. nitidicollis Meig.) 13.VII., ♀.

Fam. Syrphidae (det. H. Andersson)

Platycheirus albimanus F. 13.VII., ♀.

Fam. Heleomyzidae (det. H. Andersson)

Leria Serrata L. 5.V. (2); 6.V. (1); 8.V. (80); 9.V. (1); 10.V. (24); 5.VI. (2); 7.VII. (1); 25.VII.(1).

Fam. Sphaeroceridae (det. H. Andersson)

Copromyza ecuina L. 8.V. (1).

C. similis Coll. 21.VIII. 1 ex. in glue trap.

Fam. Scatophagidae (det. H. Andersson)

Scatophaga litorea Fall. 30. VI., ♀.

Fam. Sepsididae (det. H. Andersson)

Themira damfi Beck. 21.VIII., 1 ex. in glue trap.

Fam. Piophilidae (det. H. Andersson)

Piophila vulgaris Fall. 12.VII., ♂ in glue trap.

Fam. Calliphoridae (det. H. Andersson)

Calliphora uralensis Vill. 12. VII., ♂.

Cynomyia mortuorum L. 16.VII., ♀ in glue trap.

Fam. Muscidae s.l. (det. L. Lyneborg)

Myospila meditabunda F. 25.VII., 1 ex. in the house.

Spilogona (?) micans Ringd. 12.VII., ♀ in glue trap.

Coenosia pumila Fall. 13.VII., ♀ in glue trap.

Fam. Hippoboscidae (det. H. Andersson)

Ornithomyia chloropus Bergr. 28.VII., ♂♀ in the house; ♂, 2 ♀ on bird (Sterna).

H y m e n o p t e r a, 4 species.

Fam. Ichneumonidae (det. G.J. Kerrich)

Pimpla sodalis Ruthe. 12.VII., ♂; 12.VIII., ♀.

Fam. Braconidae.

Meteorus leviventris Wesm. (det. R.D. Eady). 12.VII., ♀ in the house.

Chorebus (?) cytherea Nix. (det. G.C.D. Griffiths). 13.VII., 1 ex.

Fam. Proctotrupidae (det. A. Sundholm).

Platygaster splendidulus Ruthe. 13.VII., ♀.

C o l e o p t e r a, 2 species.

Fam. Carabidae (det. C.H. Lindroth).

Amara quenseli Schnh. 12.VII., macropterous ♀.

Pätrobus septentrionis Dej. 12.VII., ♀ (probably washed ashore dead).

L e p i d o p t e r a, 5 species (det. P. Douwes).

Fam. Noctuidae.

Rhyacia festiva Schiff. 20. VIII., ♂ (probably washed ashore dead).

Fam. Geometridae.

Cidaria munitata Hb. 1.VIII. (1).

Fam. Pyralidae.

Crambus pascuellus L. 11.VII. (1).

Nomophila noctuella Schiff. 20.VIII. (2).

Fam. Tineidae.

Bryotropha similis Stt. 14.VII. (1).

Plutella maculipennis Curt. 8.VIII. (2). Already found in 1964 and 1966 but not recorded by us.

H e m i p t e r a, 1 species.

Fam. Aphidae (det. F. Ossiannilsson).

Brachycaudus helichrysi Klt. 12.VIII., Winged ♀.

M a l l o p h a g a, 1 species.

Gen. Sp. 14.VII. (1), from unknown bird.

C o l l e m b o l a, 1 species.

Fam. Isotomidae (det. H. Bödvarsson).

Archisotoma besselsi Pack. 20-21.VIII., 2 ex. under drift-wood.

A R A C H N O I D E A

A r a n e i d a, 2 species (det. Å. Holm).

Fam. Linyphiidae.

Lepthyphantes mengei Kulcz. 21.VII., ♀; 21.VIII., ♀.

Meioneta nigries Sim. 20.VIII., ♂♀.

A c a r i, 1 species.

Fam. Ixodidae.

Gen. sp. 5.V., on bird (Anthus).

Including previously recorded species, the number of terrestrial Arthropods found on Surtsey are divided into taxonomic groups, as follows:

Insecta: 56 spp.			
Diptera	36	Neyroptera	1
Siphonaptera	1	Mallophaga	1
Hymenoptera	5	Collembola	1
Coleoptera	3	Arachnoidea: 7 spp.	
Lepidoptera	7	Araneida	3
Hemiptera	1	Acari	4

A total number of 63 species. This means that, through the collecting made in 1967, the terrestrial invertebrates known from Surtsey have more than doubled. It should be realized, however, that the vast majority of them are casual visitors only. Permanent inhabitants of the island are only certain flies breeding in carcasses on the shore, first and foremost Leria modesta Meig., the most abundant of all insects.

2. Coleoptera of the small Westman Islands (Table 1).

A careful investigation of the fauna of all islands of the Westman group is a necessary prerequisite for understanding the development of the Surtsey fauna itself. The fauna of the main island, Heimaey, is now fairly well known but almost all of the smaller islands were visited also, most of which are situated closer to Surtsey. Coleoptera, the best known order of insects, has been selected, to illustrate the distribution of insects on the small islands; species found on Heimaey only are not considered.

3. As described in the report for 1966, it was planned to release a great number of small (3-4 mm) bright yellow plastic grains into the sea in order to find out how easy hydrochorous transport could take place between Heimaey and Surtsey. On June 22nd, Sigurdur Richter released more than 10 millions of these grains at the mouth of the bay Klauf in the SW part of Heimaey. Exactly one week later, in spite of unfavourable weather (western winds), most of the time, he found more than 1000 of these grains washed ashore on Surtsey. The distance is about 20 km. The result has application to botanists as well: Klauf seems to be the only place on the Westman Islands where Cakile edentula, Elymus arenarius, Honckenya peploides, and Mertensia maritima, that is, the first four plants species appearing on Surtsey, grow abundantly together on the shore. Therefore, this is most likely the place from where they emanated.

The plans for the summer of 1968, in the later part of June, include visits to all the small Westman Islands by means of helicopter, continued survey of the fauna of the southern mainland of Iceland and, of course, investigations on Surtsey itself.

After the results of the field-work in 1968 are available, it is intended to publish a detailed report of the entire investigations.

Acknowledgements

This work has been sponsored by the Surtsey Research Society under an U.S. Atomic Energy Commission grant.

TABLE I

Distribution of Coleoptera on the small Westman Islands.

	Heimaey	Ellida-ey	Bjarn-arey	Álfsey	Brandur	Hellis-ey	Súlna-sker	Geirf.-sker	Surtsey
CARABIDAE									
Amara quenseli Schnh.	+	-	-	-	11	2	1	-	1
Calathus melanocephalus L.	+	14	7	16	34	16	9	-	-
Nebria gyllenhali Schnh.	+	17	13	32	2	2	1	-	-
Notiophilus biguttatus F.	+	4	-	6	-	-	-	-	-
Patrobus septentrionis Dej.	+	3	2	3	1	-	6	-	(1)
DYTISCIDAE									
Hydroporus nigrita F.	+	-	-	1	-	-	-	-	-
STAPHYLINIDAE									
Atheta amicula Steph.	+	-	-	1	-	-	-	-	-
A. atramentaria Gyll.	+	3	1	1	-	-	-	-	4
A. excellens Kr.	+	8	1	-	5	-	4	-	-
A. fungi Gr.	+	1	-	-	-	-	-	-	-
A. islandica Kr.	+	-	-	1	-	-	-	-	-
A. vestita Gr.	+	-	-	4	-	6	15	74	-
Lesteva longelytrata Gze.	+	2	-	-	-	-	1	-	-
Micralymma marinum Ström	+	-	-	-	-	-	-	5	-
Omalium excavatum Steph.	+	3	-	-	1	-	-	-	-
Othius melanocephalus Gr.	+	15	4	2	1	-	-	-	-
Oxypoda islandica Kr.	+	1	-	-	-	-	-	-	-
Philonthus trossulus Nordm.	+	-	-	1	-	-	-	-	-
Quedius mesomelinus Mrsh.	+	-	1	-	-	-	-	-	-
BYRRHIDAE									
Byrrhus fasciatus Forst.	+	2	1	-	-	-	-	-	-
ELATERIDAE									
Hypnoidus riparius F.	+	4	1	4	-	-	-	-	-
LATHRIDIIDAE									
Enicmus minutus L.	+	-	4	-	-	-	-	-	-
CRYPTOPHAGIDAE									
Atomaria analis Er.	+	1	-	-	-	-	-	-	-
CURCULIONIDAE									
Barynotus squamosus Germ.	+	3	1	-	-	-	-	-	-
Otiorrhynchus arcticus O.Fbr.	+	10	2	6	14	21	31	-	-
O. dubius Ström	+	-	-	1	-	-	-	-	-
SCARABAEIDAE									
Aphodius lapponum Gyll.	+	7	1	-	-	-	-	-	-

The Early Development of Freshwater Biota on Surtsey

by

Bassett Maguire, Jr.
The University of Texas at Austin
Austin, Texas

On June 1 and 2, 1967, 11 aquatic organism traps were sterilized with 50% ethanol (denatured with methyl violet and pyridine) and placed in various locations on the lava fields of Surtsey. These traps were made of polyethylene and are about 80 cm long, 50 cm wide and 30 cm deep (they were sold as laundry tubs). Pieces of lava were placed over the edges of the traps so that the winds would not blow them away. It is anticipated that these traps will fill with rain water and provide 11 isolated habitats in which the process of colonization by fresh water algae, protozoa, and micro-metazoa can be followed.

On June 1, 3 and 5 air was sampled by holding up petri plates containing sterile agar (made with Bold's Basal Medium), and on the 3rd air samples were taken with a rotorod sampler (some rods were covered with agar and others with silicone stopcock grease as adhesive). These sampling techniques have been shown to be effective in the capture of airborn dissemules of the freshwater and soil algae (Brown, Larson and Bold, 1964). Wind velocities were about 55 knots on June 1, 15 knots on June 3, and 5 knots on June 5; intermittant rain fell during the days on which the samples were taken, but only on June 5 was any rain caught on the agar surface (and then only a little from the leading edge of a shower).

On June 4, a series of ash samples were taken from 8 points in a transect on the NNE side of the island, from just above the beach to the highest point of the ash. Samples of these were cultured in artificial lake water (Maguire, 1963), Bold's Basal Medium, sea water culture medium, and millipore filtered pond water. Some of the cultures were fed a few drops of an autoclaved suspension of dried, pulverized wheat leaf (Cerophyll) in distilled water. A similar series of ash samples were taken on August 13; they were cultured as outlined above.

In June, a depression in the ash of the east side of the island was deepened and lined with a sheet of polyethylene, a 5-8 cm layer of ash was spread on this sheet, a second sheet was added, and in turn covered with an ash layer. It was hoped that water would collect in this depression to produce a pond of about 2 by 4 m. At one time there was water in the depression, but it did not last long, either because capillarity permitted the water to drain out through the ash or because the bottom was punctured even though it had been made of double layer construction.

Collections were made from each of the 11 traps during the second week of August. At this time only 4 of the traps contained water (the summer had been unusually dry and the traps had not been put on Surtsey in time to take advantage of the winter rains). Water samples were examined immediately after collection and then divided into subsamples, some of which were fed with Cerophyll suspension. Ash samples were taken from the dry traps, all of which had had water in them at some time between early June and mid August. Subsamples of ash and water were given to Dr. Harold C. Bold, a phycologist, and to Dr. Stuart S. Bamforth, a protozoologist; I have others cultured (as outlined above) and have examined them periodically. Soil samples were kindly obtained by Mr. Sigurdur H. Richter from islands between Surtsey and Iceland (Geirfuglasker - nearest Surtsey, and Dyrhólaey (Portland) an island very near to mainland and now connected to it by a wide beach). These samples were subdivided and treated as outlined above.

Results

More data and more detailed information on the species of small aquatic organisms in the ash and the traps (excluding bacteria and protozoa) will be available when culture studies are complete. Information obtained to this date is summarized below:

1. Except for bacteria and fungi (of which there were many colonies), no freshwater organisms grew from the cultures of air and rain samples.

2. Cultures from the ash transect extending from slightly above sea level (1) to the top of the ash hill (8) contained the following:

Samples of June 4, 1967: nothing except for moss protonema in 2, 3, 4 and 8.

Samples of August 13, 1967:

1. Stichococcus (in fresh water and salt media)
   Dunaliella
2. Chlamydomonas
3. Chlorococcum
   Stichococcus
   Dunaliella
4. Chlorella like
5. Chlamydomonas (2 spp)
6. none
7. none
8. none

3. From the traps (no. 3, 4, 5 and 10 contained water):

Samples of August 14, 1967:

1. none (salty?)*
2. none*
3. Anabaena
   Fasciculochloris
   Chlamydomonas
   Oicomonas
   Bodo
   Cercobodo
   Mayorella
   Hartmannellidae or Vahlkampfiidae
   Small filose Rhizopod
   Euchelys (?)

   Contained bird feathers, faeces, pieces of marine crustacea brought in by birds.

4. _Chlamydomonas_
   Chlorococcalian alga
   Monas
   Bodo
   Amphimonas (?)
   Cercomastax (?)

5. _Nannochloris_
   Chlorococcalian alga
   Monas
   Bodo
   Oicomonas
   Amphimonas

6. none

7. _Bodo_
   Colpoda

8. none

9. none

10. _Chlamydomonas_
    Chlorella like alga
    Cercobodo (?)
    Oicomonas

11. none*

4. The cultures from soil samples from intermediate islands contained:

Geirfuglasker (top): _Tetracystis_
Chlorococcum
moss
Monas
Bodo no. 1
Bodo no. 2
Cercomastix
sm. zooflagellate
v. small Actinopod

---

* Cultures have not yet been completely examined (Dr. Bamforth is now working on them).

Holotrich no. 1

Holotrich no. 2

Oxytrichidae

Rhabdostyla

Nematode

Dyrhólaey (top and bottom combined):

Nodularia

Chlamydomonas

Tetracystis

Chlorococcum

Chlorella

Bumillaria

Spongiochloris

Hormidium

Entocladia (in marine medium)

Pinnularia

Monas

Gymnostome

Colpoda

Hypotrichina

Discussion

There was an average of 6.75 different species in the samples from traps which contained water, and an average of only 0.5 species in those were dry. The higher number in the wet traps could be caused by differential efficiency in the trapping of dissemules of aquatic organisms by traps which contained water for different lengths of time and/or by a high mortality which might have occurred as evaporation proceeded in the drying traps with the result that they became highly saline as the amount of water decreased toward zero.

The early development of freshwater communities in the traps has been very rapid considering their isolation and their unnatural character. This high colonization rate is additional support for the conclusion that many small aquatic organisms have very efficient dispersal mechanisms. It is too early to see developmental patterns of these communities; within the next few years, however, a fascinating story should unfold.

Marine Biological Studies of the Sublittoral Bottoms Around Surtsey

by

Willy Nicolaisen
Marine Biological Laboratory, Helsingör, Danmark

In order to follow the invasion of bottom animals onto the newly formed bottom around Surtsey, the author collected bottom samples at the end of August 1966 and the end of May 1967.

Most of the samples were obtained by means of a 0,1 m^2 Smith-MacIntyre quantitative bottom sampler but the "Mouse trap" bottom sampler was used in some cases.

The sampling stations were located by means of an echosounder and a radar.

In August 1966 sampling was carried out on the Surtsey cross (i.e. at distances 1, 3, 7 and 12 nautical miles N, E, W and S of the island). Furthermore, the slope from the island down to the old bottom was sampled. In most cases 3 samples were taken at each station. A total of about 100 samples was obtained.

Since the effect of the eruptions seemed to have been neglible at the stations at larger distance from the island, the majority of the samples obtained in May 1967 were taken on the slope. A few samples were though taken at a distance of 1 and 2 nautical miles from Surtsey. Also, a transect at right angles to the coast of Iceland N.E. of Surtsey was sampled in order to get material from an unaffected area. Altogether about 140 grab hauls were made.

The Bottom

From the shore of Surtsey the bottom slopes rather steeply down to a depth of about one hundred meters.

The samples from August 1966 showed that to the north this slope was covered with a thick layer of gravel of volcanic origin which contained many calcareous fragments of serpulid tubes. To the east, south and west of the island the slope was rocky down to a depth of 90-100 m. On many stations on the slope the bottom was covered by a layer of fine volcanic ash. Outside a depth of 100 m the bottom material was fine sand or mud.

In May 1967 the picture had altered completely. The samples showed that the new eruption on Surtsey which started in August 1966 had caused considerable changes on the slope. At some stations on the slope especially off the southern coast of Surtsey the bottom was rocky but elsewhere it had been covered by a layer of volcanic gravel very much like that which was found off the north coast in the previous survey. The new gravel, in contrast to that of August 1966, contained no tube fragments.

The Animals

The following list shows the bottom animals that have been found in the samples from August 1966 which have been worked up so far.

ANTHOZOA:

Some species of soft bottom Actinians have been found in the samples from depths larger than 100 m.

NEMERTINI:

One species has been found in the samples from outside 100 m depth.

POLYCHAETA:

Harmothoe sp. One individual was found in a grab sample taken at a depth of 34 m north of Surtsey.

Pholoe minuta. A few individuals have been found outside 100 m depth.

Sthenelais filamentosus. Two individuals of this species, which so far is only known from Islandic waters, were found in a sample from 125 m depth.

Anaitides groenlandica. A few individuals of this species have been found both inside and outside 100 m depth.

Kefersteinia cirrata. One individual has been found in a grab sample from the slope north of Surtsey (68 m depth).

Goniada maculata has been found both inside and outside 100 m depth.

Nephthys hombergi. Three individuals were found in a grab sample from 125 m depth, east of Surtsey.

Scoloplos armiger. This species was common on the bottom outside 100 m depth. Inside 100 m depth, an individual has been found at 16 m depth north of Surtsey.

Spio filicornis. Two individuals were found in a sample from 16 m depth, north of Surtsey. One specimen has been found in a sample from 100 m depth.

Spiophanes bombyx. Three individuals have been found in a grab sample from the slope (68 m depth).

Spionidae sp. A yet unidentified spionid was common on the slope south-west of Surtsey.

Diplocirrus glaucus. Some individuals have been found outside 100 m depth.

Ammotrypane aulogaster. This species was frequently found outside 100 m depth. One individual has been found in a grab sample from 90 m depth east of Surtsey.

Capitella capitata has been found both inside and outside 100 m depth. One individual had the gut filled with fine volcanic ash.

Owenia fusiformis. Of this species which seems to be very common outside 100 m depth, one individual has been found on the slope (68 m depth, north of Surtsey).

Pectinaria koreni was common inside and outside 100 m depth. The length of the individuals varied between 8 and 14 mm. The gut of several of the specimens contained fine volcanic ash.

Ditrupa arietina. This species was common at depths larger than 100 m.

CRUSTACEA:

Eurynome aspera. This crab has been found in a sample from the northern slope of Surtsey.

Some Crustaceans have been found in the samples from depths larger than 100 m.

BIVALVIA:

Cardium echinatum. This species has been found at depths larger than 100 m.

Cyprina islandica has been found outside 100 m depth.

Spisula elliptica. One individual has been found in the samples from depths larger than 100 m.

Macoma calcarea. This species is rather frequent outside 100 m depth.

Abra nitida. The species was common in the samples from outside 100 m depth. It was also rather frequent inside 100 m depth.

Abra prismatica has only been found in the samples from depths larger than 100 m.

ECHINODERMATA:

Amphiura filiformis. Some individuals have been found in the samples from depths larger than 100 m.

Ophiura affinis. Small individuals of this species were common in the samples from the slope. The species was also found outside 100 m depth.

The grab samples taken in August 1966 show that several species of bottom invertebrates had already invaded the slope.

In the sediment from the slope off the west coast of Surtsey animal life was sparse; the only common species being a small spionid polychaete. The sediment in this area most likely derives from the Jólnir eruption which started in December 1965 i.e. a little more than half a year before these samples were collected. In contrast to this, the grab samples from other parts of the slope where the sediment seems to have been deposited earlier than that of the west coast, contained several species of bottom invertebrates. The most common species were the Polychaetes Pectinaria koreni, Scoloplos armiger and Capitella capitata, the Bivalve Abra nitida and the Echinoderm Ophiura affinis

The latest eruption which started in August 1966 had a disastrous effect on the fauna of the slope. The samples from May 1967 showed that the new eruption had killed all animal life on the slope. Neither the samples from the newly deposited gravel, nor those from the rocky bottom contained any animals. Evidently the fauna had not been able to survive the deposition of gravel on the bottom. On the old bottom outside the slope, life seemed to be normal.

Discussion

The bottom animals that invade the slope can either be migrating adults or pelagic larvae. The first type cannot be of great importance. The most important group of invaders must be the pelagic larvae.

Dispersal by pelagic larvae is very dependant on change factors. The larger the distance is between the new substrate and a potential parent population, the smaller is the chance that the currents will carry a larval swarm to this new environment. It is therefore not surprising that the species of the unaffected bottom areas close to Surtsey were the first to invade the slope of the island.

Many of the species found on the slope are known to be very tolerant of variations in factors such as temperature, salinity, bottom texture and depth.

It was to be expected that the first invaders of the sediment on the slope would be species that feed on particles suspended in the water. It was therefore surprising that the most common polychaetes were Pectinaria koreni, Scoloplos armiger and Capitella capitata. These species are known to feed by ingesting the bottom material in order to utilize the organic content. In fact the intestine of these animals is very often filled with the volcanic bottom substrate.

Acknowledgements

This research has been sponsored by the Surtsey Research Society with a grant from the Oceanic Biology Program Branch, Office of Naval Research, Washington, D.C., under contract F61052 67 C 0087.

The Coastal Invertebrate Fauna of Surtsey and Vestmannaeyjar

by

Adalsteinn Sigurdsson
The Marine Research Institute
Reykjavik

Introduction

As soon as an island arose above the sealevel SW off Vestmannaeyjar in 1963, zoologists began to think of how and when the coastal fauna would be transported to the shore of the island. Already in 1964 zoologists began to survey the littoral zone of Surtsey, but no settling of animals was observed until the summer 1967.

In the beginning of August 1967 Dr. Sigurdur Jónsson and Mr. Sigurdur Hallsson found Balanus and Hydrozoa on the west coast of Surtsey, but did not collect them.

Some few days later a collection of the coastal fauna of Surtsey and Vestmannaeyjar was initiated.

The Icelandic coastal fauna is only sparsely known and it is therefore of great importance to carry out intensive surveying of the coastlines in the vicinity of Surtsey. This will give a valid background for comparison between the faunistic components there and the new coastal fauna of Surtsey.

The sampling

In August 1967 intensive sampling of the fauna and flora of Vestmannaeyjar was carried out partly from the splash-spray zone down to the low water mark and partly from 0-30 m depth using the technique of SCUBA-diving. On two occasions samples were collected by dredging. Bad weather conditions prevented landings on Surtsey in August, but the epifauna on the hard bottom at the west coast of the island was collected by the divers.

As both an algologist and a zoologist were sampling at the same time, the divers collected both algae and animals. The samples were put into plastic buckets closed by lids. A cross was cut in the center of the lids so the material could be pressed through the slits, which, however, prevented the material from escaping. Other important sampling equipment consisted of knives, chisels and hammers.

At the laboratory in Vestmannaeyjar the samples were sorted out and the algae and animals were preserved separately. However, some of the algae, which can shelter small animals, were preserved with their tiny inhabitants so the sorting out could be performed more safely later under the microscope.

The seawater in which the samples were brought up was passed through a fine plastic filter to catch the small invertebrates. The Protozoa and Ostracoda were neglected.

The animals were preserved in alcohol except the samples from six localities in the littoral zone of Heimaey, which were preserved in 4% formalin.

In the intertidal zone quantitative samples were taken wherever possible.

On the 21st of September and 20th of October 1967 samples were taken in the littoral zone of Surtsey.

Fig. 1 shows the approximate location of the sections which were worked last summer, as well as those from where the samples have been identified.

On the sandy shore of the northern part of the island the only animals found were those washed ashore and which are not going to become a part of the future population of the beach as they actually are planktonic or living on floating objects in the sea. The only exception was a dead mussel, Mytilus edulis, which was found in the sand far from the coast.

Under most of the cliffs forming the rest of the coastline, sand mixes with seawater in the surf which thus scours the rocks making animal life impossible there.

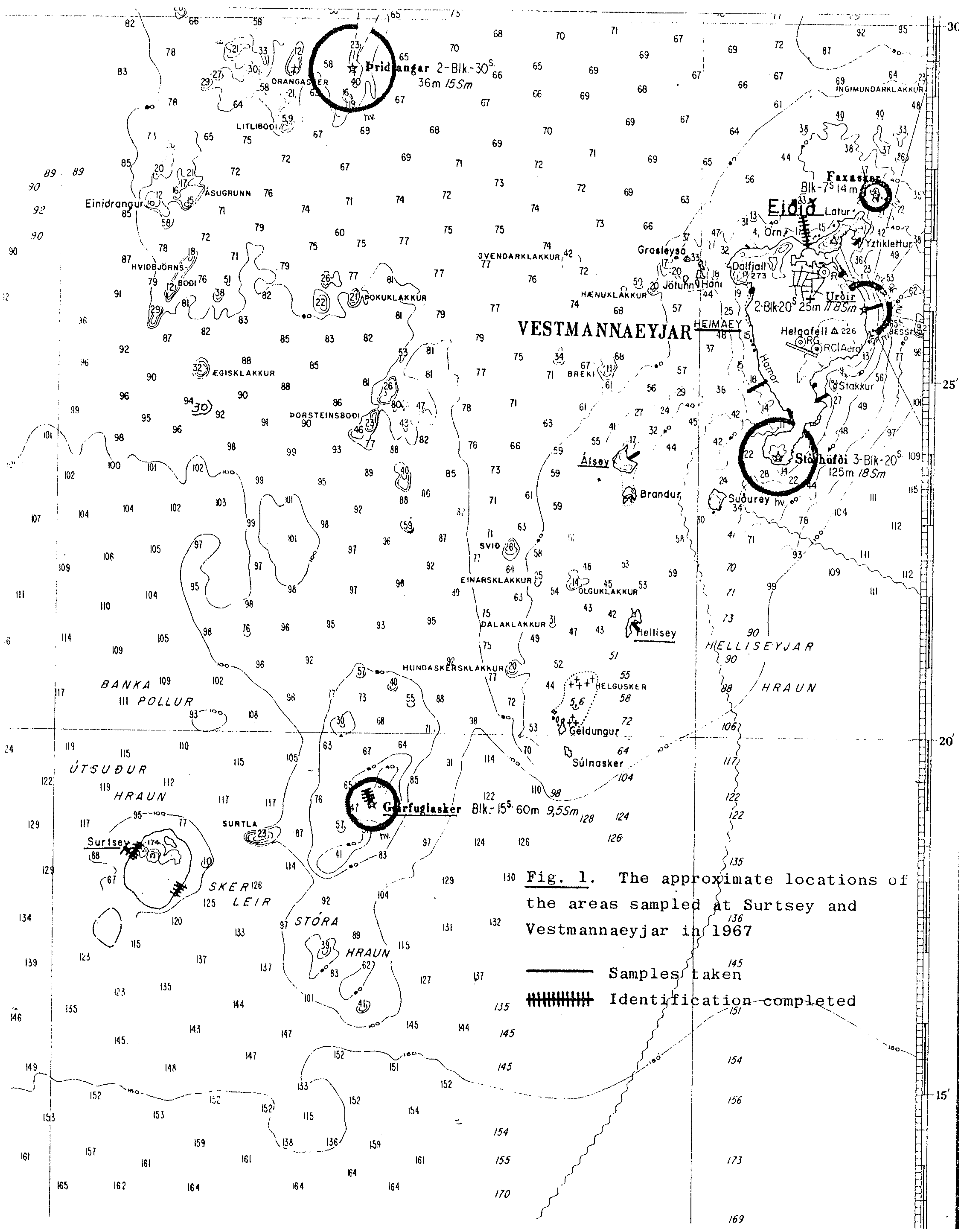


Fig. 1. The approximate locations of the areas sampled at Surtsey and Vestmannaeyjar in 1967

—— Samples taken

‡‡‡‡‡ Identification completed

On the west coast, however, a stretch of the littoral and sub-littoral zones, at least down to 20 m depth, is formed by large blocks of rocks. Therefore, the scouring effect of the sand occurring elsewhere on the rocky shore is absent.

The littoral zone was carefully surveyed for marine animals on the above mentioned dates and 13-15 species were found (see below).

In September gravel and shingles covered a very short stretch of the east coast, but the only animals found there had been washed ashore. In October small rocks and shingles had accumulated to a greater extend and 4-6 species of marine bottom animals were collected. Sampling was made difficult by the surf and some of the existing species may have escaped attention.

The material from 1967 is now being worked up and although only a small part of the work is finished 22 new species have been found for Vestmannaeyjar of which 8 species are new for Iceland.

Samples from the Littoral Zone of Surtsey

Table I shows the animals found in the littoral zone of Surtsey on September 21st and October 20th 1967 (see above). The number of specimens taken are listed wherever possible.

TABLE I

Animals from the intertidal zone of Surtsey on September 21st and October 20th 1967.

	West Coast		East coast
	21st Sept	20th Oct.	20th Oct.
Hydrozoa (not identified)	x	x	x
Nematoda (not identified)		x	
Polychaeta (not identified)	x	x	x
Bryozoa:			
1) Membranipora membranacea (L.)	x	x	
2) Celloporella hyalina (L.)	x		
Copepoda (Rock pools) (not identified)	x	Not sampled	Not sampled
Cirripedia:			
1) Verruca stroemia (O.Fr.Müller) Schumacher	2	18	
1) Balanus balanoides (L.)	4		
Nudibranchia:			
Acanthodoris pilosa (Abildgaard)	3	2	
Lamellibranchia:			
1) Mytilus edulis L.	3	17	11
1) Anomia squamula (L.)	30	68	46
1) Saxicava arctica (L.)	15	51	

1) Pelagic larvae

2) No pelagic larval stage

Most of the animals listed in Table I were on stones or rocks which might have been thrown up from the sublittoral zone by the surf.

Samples from 10-20 m Depth West of Surtsey

On the 16th of August 1967 sampling was carried out at the west coast of Surtsey on rocky bottom down to 20 m depth. Animals were only found in the samples from 10-20 m (see Table II). In addition the SCUBA-divers observed many small crabs at a depth of 20 m together with 3 or 4 species of fish, but were unable to catch any of them.

TABLE II

Animals from the West Coast of Surtsey on August 16th 1967 at 10 - 20 m Depth

	10 m	20 m
Hydrozoa 2 or 3 species (not identified)		x
Polychaeta 3 or 4 species (not identified)		x
Bryozoa 1 species (not identified)		x
Copepoda (not identified)	x	x
Amphipoda 3 species (not identified)		x
Decapoda:		
Spirontocaris pusiola (Krøyer)		3
Hyas coarctatus Leach, juv.		3
Portunus holsatus I.C. Fabricius, juv.	2	
Nudibranchia 2-4 species		x
Lamellibranchia:		
Mytilus edulis L., juv.		50
Anomia squamula (L.), juv.		15
Saxicava arctica (L.), juv.		2
Bivalve juv.		1

Samples from Geirfuglasker and Heimaey

In this section the number of species in each systematic group will be given and also the names of all species new for the waters around Vestmannaeyjar.

As the larval development plays an important role in the possible transport of littoral invertebrates from Vestmannaeyjar to Surtsey, this aspect will as far as possible be taken into consideration. In this connection it should be mentioned that the distance from Geirfuglasker to Surtsey is approximately 2.5 nautical miles, while the distance between Heimaey and Surtsey is approximately 10 nautical miles. The prevailing surface current in this region is westwardly and pelagic larvae may therefore easily be transported from Vestmannaeyjar to Surtsey.

PORIFERA:

The few species found have not yet been identified.

COELENTERATA:

A. Hydrozoa:

Some species were collected, but they have not been identified yet and the results can not therefore be included in this report.

B. Anthozoa:

a. Octocorallia:

One common species was found.

b. Hexacorallia:

One or two species were found, but it has not been possible to have them identified.

VERMES:

A. Nemertina:

One specimen was found, but it has not been identified.

B. Nematoda:

They are very common, but it has not been possible to have them identified.

C. Annelida:

Polychaeta:

Only one species has been identified so far.

Spinter miniaceus Grube.

One specimen was found at Eidid at 20-27 m depth. It had only been found once in Icelandic waters 5 nautical miles east of Seydisfjördur and is thus new for the south coast.

TENTACULATA:

A. Bryozoa:

They are brood-protecting and the larvae are usually only few hours in the plankton although both non-pelagic and long-lasting pelagic stages are known. The material is now being worked up and so far 34 species have been identified of which 2 species have not been found earlier at Iceland. These records will be included in the Bryozoa of The Zoology of Iceland, which will soon be published.

B. Brachiopoda:

Only one specimen has been found and that was in the intertidal zone in Geirfuglasker. It has not been identified.

ARTHROPODA:

A. Crustacea:

a. Copepoda:

They have not been identified.

b. Cirripedia:

3 species, all with pelagic larvae, have been found. One of them, Balanus balanus (L.) da Costa, is new for Vestmannaeyjar. This species was taken in the samples from Geirfuglasker at 0-24 m (9 spec.) and in the intertidal zone (some shells) and also two shells from 32 m depth at Eidid.

The other two species have been found in Surtsey (see above).

c. Isopoda:

The non-parasitic Isopoda have brood-protection and no pelagic larval stage. 8 species of them were in the samples from Geirfuglasker and Heimaey, and 3 of these are new for the region around Vestmannaeyjar.

Ianiropsis breviremis Sars, is new for Iceland. It was found at Geirfuglasker at 0-24 m (15 spec.) and Eidid at 10 m (2 spec.) and 0-5 m depth (8 spec.).

Ianira maculosa Leach, is new for Vestmannaeyjar. Previously it has only been found 6 times at Iceland at 40-326 m depth. This time it was found at Geirfuglasker at 0-24 m (10 spec.), at Eidid at 15 m (3 spec.) and 32 m (1 spec.).

Idothea pelagica Leach. Earlier Icelandic records are only from Grindavík (S.W.) and Snæfellsjökull (W.). It is now common in the intertidal zone of Geirfuglasker and Heimaey.

Of parasitic Isopoda one male was found, but has not been identified.

d. Amphipoda:

The Amphipoda have brood-protection and direct development. 18 species have been found of which 3 seem to be new for Iceland and one of them might be a new species.

Amphilocus manudens Bates is, however, new for Iceland. It was found at Eidid at 20-27 m, but only one specimen.

Additional 4 species are new for the south coast of Iceland and therefore also for Vestmannaeyjar. They are:

Metopa alderi Bates, 2 specimens from Geirfuglasker at 0-24 m.

Sympleustes glaber (Boeck.). 20 spec. from Geirfuglasker at 0-24 m and 2 spec. from Eidid at 6-10 m.

Parapleustes monocuspis (G.O. Sars). 17 spec. from Geirfuglasker at 0-24 m and 1 spec. from Eidid at 32 m.

Eurysteus melanops (G.O. Sars). Found at Eidid. Two spec. at 32 m, 6 spec. at 15 m and 1 spec. at 6-10 m.

e. Decapoda:

9 species were found, all with pelagic larvae. They are all recorded earlier from or close to Vestmannaeyjar.

B. Insecta:

Some insects, mostly larvae, were in the intertidal zone at Eidid. They have not been identified.

C. Arachnida:

Acarina:

3 or 4 species have been found at Vestmannaeyjar, but they have not been identified as yet.

D. Pycnogonida:

3 species were found and only one of them was previously recorded from Vestmannaeyjar.

Ammothea laevis (Hodge) was for the first time found at Vestmannaeyjar. It was found at Geirfuglasker at 0-24 m (15 spec.). Earlier records from Iceland are few and all from N.E. to S.E.

Cordylochele sp. is new for the Vestmannaeyjar and perhaps also for Iceland.

MOLLUSCA:

A. Polyplacophora:

Few spec. were found, but they have not been identified.

B. Gastropoda:

a. Prosobranchia:

17 species are in the samples which have been worked up from which 4 or 5 have pelagic larvae, 9 have non-pelagic larvae or direct development, but the development of the rest is unknown. All 17 species have been found earlier at or near Vestmannaeyjar.

b. Opisthobranchia:

Nudibranchia:

Two species have been identified so far, but 2 or 3 are waiting for identification and one of these seems to be new for Iceland.

Tergipes tergipes (syn.: T. despectus (Johnston)). One specimen from Eidid at 20-27 m. Earlier Icelandic records are from Reykjavik and Grímsey and it is therefore new for the south coast.

Limapontia capitata (Müller). 7 spec. were found at Eidid in the littoral zone. It has only once been recorded from Icelandic waters and then from Reykjavik. It is thus new for Vestmannaeyjar.

C. Lamellibranchia:

11 species were found at Vestmannaeyjar, 9 of which have pelagic larvae, one has non-pelagic larval development and the development of one is not known. All the species have been recorded earlier from the region around Vestmannaeyjar. 3 of the species with pelagic larvae have already been found in the intertidal zone of Surtsey (see above).

ECHINODERMA:

A. Asteroidea:

2 species were found at Vestmannaeyjar, one with pelagic larvae, but the other brood-protecting with direct development. Both are recorded earlier from Vestmannaeyjar.

B. Ophiuroidea:

2 species were found at Vestmannaeyjar both with pelagic larvae and are earlier known from the area.

C. Echinoidea:

One common species with pelagic larvae was found.

D. Holothurioidea:

One species was found at Vestmannaeyjar. It has earlier been found there. The larval development is unknown.

TUNICATA:

A. Ascidiacea:

The larval stage is very short or sometimes missing. Usually it lasts only few hours and not more than 24 hours.

4 species were found. One of them has been recorded earlier from the area, but one is new for Iceland.

Molgula lanceplanei is a new species for Iceland. One spec. was found at Geirfuglasker at 0-24 m.

Boltenia echinata (L.) is a new species for the south coast of Iceland. It was found at Geirfuglasker at 0-24 m (8 spec.) and Eidid at 32 m depth (6 spec.).

Polycarpa pomaria (Savigny). Earlier Icelandic records are only from Faxaflói and the species is therefore new for Vestmannaeyjar.

Acknowledgements

I owe my sincere thanks to all who have contributed to the research of the coastal fauna of Surtsey and adjacent regions.

This research has been sponsored in part by the Oceanic Biology Program Branch, Office of Naval Research, Washington, D.C., under contract F61052 67 C 0087, and the Surtsey Research Society, for which I want to express my special thanks. Also, do I want to thank those who have identified whole groups of animals. They are:

Mrs. K. Bille-Hansen (Bryozoa)
Mr. Jean Just (Amphipoda)
Dr. Henning Lemache (Nudibranchia)
Mr. Jörgen Lützen (Ascidiacea)

References

1. Einarsson, H., 1948: Echinoderma. Zool. of Iceland, Vol. IV, Part 70.

2. Huus, Johan and Jörgen Knudsen, 1950: Tunicata. The Zoology of Iceland, Vol. IV, Part 71b.

3. Jörgensen, C. Barker, 1946: Reproduction and Larval Development of Danish Marine Bottom Invertebrates, with Special Reference to the Planktonic Larvae in the Sound (Öresund). 9. Lamellibranchia. Medd. Komm. Danm. Fisk.-Havunders. Ser.: Plankton, Bd. IV, Nr. 1.

4. Kramp, P.L., 1939: Octocorallia. Zool. of Iceland, Vol. II, Part 7.

5. Lebour, Marie V., 1928: The Larval Stages of the Plymouth Brachynra. Proc. Zool. Soc. London, Part 2.

6. Lemche, Henning, 1938: Gastropoda Opisthobranchiata. The Zool. of Iceland, Vol. IV, Part 61.

7. Madsen, F.J., 1949: Marine Bivalvia. Zool. of Iceland, Vol. IV, Part 63.

8. Marcus, Ernst, 1940: Mosdyr. Danmarks Fauna, 46.

9. Óskarsson, Ingimar, 1952: Skeldýrafána Íslands. I. Samlokur í sjó. (Lamellibranchia).

10. Óskarsson, Ingimar, 1962: Skeldýrafána Íslands. II. Sæsniglar með skel (Gastropoda Prosobranchia & Tectibranchia).

11. Rees, C.B., 1950: The Identification and Classification of Lamellibranch Larvae. Hull Bull. Mar. Ecol., Vol. III, No. 19.

12. Stephensen, K., 1910: Skjoldkrebs (Storkrebs I). Danmarks Fauna, 9.

13. Stephensen, K., 1928: Storkrebs II. Ringkrebs. 1. Tanglopper (Amfipoder). Danmarks Fauna, 32.

14. Stephensen, K., 1933: Havedderkopper og Rankefödder. Danmarks Fauna, 38.

15. Stephensen, K., 1937: Marine Isopoda and Tanaidacea. Zoology of Iceland, Vol. III, Part 27.

16. Stephensen, K., 1937: Pycnogonida. The Zoology of Iceland, Vol. III, Part 58.

17. Stephensen, K., 1938: Cirripedia (incl. Rhizocephala). The Zoology of Iceland, Vol. III, Part 30-31.

18. Stephensen, K., 1939: Crustacea Decapoda. Zoology of Iceland, Vol. III, Part 25.

19. Stephensen, K., 1940: Marine Amphipoda. Zoology of Iceland, Vol. III, Part 26.

20. Stephensen, K., 1948: Storkrebs IV, Ringkrebs. Danmarks Fauna, 53.

21. Sæmundsson, B., 1937: Icelandic Malacostraca in the Museum of Reykjavik. Vísindafélag Íslendinga (Soc. Scient. Islandica) XX.

22. Thorson, Gunnar, 1936: The Larval Development, Growth and Metabolism of Arctic Marine Bottom Invertebrates Compared with those of other Seas. Meddelelser om Grönland, Bd. 100.

23. Thorson, G., 1941: Marine Gastropoda Prosobranchiata. Zool. of Iceland, Vol. IV, Part 60.

24. Thorson, G., 1946: Reproduction and Larval Development of Danish Marine Bottom Invertebrates, with Special Reference to the Planctonic Larvae in the Sound (Öresund). Medd. Komm. Danm. Fisk.- Havunders. Serie: Plankton, Bd. IV.

25. Wesenberg-Lund, Elise, 1951: Polychaeta. Zoology of Iceland, Vol. II, Part 19.

G E O L O G Y

ABSTRACT

Measurement of Horizontal Ground Surface Deformation in Iceland

by

R. W. Decker
Dartmouth College, Hanover,
New Hampshire

Paper published in: Transactions of the American Geophysical Union, vol. 49, no. 1, p. 114, March, 1968.

Fifty-five survey lines averaging 2.7 km in length were established and measured with a Geodimeter in southern Iceland during the summer of 1967. The lines are joined to form two segmented profiles across the rift zones, and are primarily designed to detect horizontal movements perpendicular to the rift axes. Some stations were also established to measure possible strike slip movement along the open fractures (gjá). Experimental accuracies from repeated observations and calibration checks are within the stated instrumental standard deviation of $\pm$ (10 mm $\pm$ 2 X 10^{-6} X distance). If extensional movements of 20 mm per year take place entirely within a 2 to 3 km line segment, they should be detectable at better than a 99% confidence level in two years. More homogeneous strains across the entire 50 to 100 km wide rift zones will require a much longer wait for their detection. In either case the large number of line segments will allow statistical evaluation of the measurement errors versus possible deformation.

The Geology and Petrography of the Vestmann Islands

A Preliminary Report

by

Sveinn Jakobsson
Mineralogical-Geological Institute
University of Copenhagen

Introduction

Following the Surtsey eruption it was thought desirable to carry out a comparative study of the geology and petrology of the Vestmann Islands along with the youngest member of this group of islands, Surtsey.

This investigation is based on fieldwork by the author in the summers of 1966 and 1967. Laboratory work was carried out in the Geological and Mineralogical Institute of the University of Copenhagen. The work is still in progress; this report only being a summary at the present stage of the study.

Summary

The Vestmann Islands were formed in submarine eruptions by the same mechanism as seen in the Surtsey eruption. An exception is the northern part of Heimaey, which in part might be subglacial. The age of the three biggest islands, Heimaey (except the northern part), Ellidaey and Bjarnarey is 5-6000 y.b.p. The numerous steep peaks on the sea-bottom west of the islands are probably all recent craters.

Both the chemistry and the mineralogy of the rocks show, that the Vestmann Islands, including Surtsey, are made up of typical alkalne olivine basalts, comparable to the alkaline basalts of Hawaii. The analyses of the lavas fall into two distinct but closely related groups. In the Helgafell lava small nepheline-bearing residual pockets are common. The Klifid intrusion has developed segregation veins of basanitic composition.

General geology

The stratigraphy of the Vestmann Islands is rather straight-forward with the exception of the northernmost part of Heimaey (Heimaklettur formation, cf. the geological map Fig. 1). The islands were built up by the same mechanism of submarine eruptions as seen in the Surtsey eruptions 1963-67. The eruptions were explosive in the beginning due to the presence of seawater, but where the eruptions lasted long enough a lavaphase did follow as for example on Heimaey, Ellidaey and Bjarnarey. Álsey, Hellisey and Geirfuglasker are examples of craters where the lavaphase did not develop. In the younger islands the material is everywhere the same, finely bedded tuffs and thin lavabeds which bear a close resemblance to those of Surtsey.

In most cases each island or skerry is a remnant of a crater. In Fig. 2 and 3 sections through the principal islands are shown compared to Surtsey as it was in the summer 1967. The largest eruptions have been in Sæfell-Helgafell. The tuffcrater of Sæfell has a diameter of approx. 1 km. Shortly after the cessation of the Sæfell eruption a lava eruption started on the northern flank of the crater forming the mountain Helgafell.

A new bathymetric map of the sea bottom west of the islands made by the Icelandic Hydrographic Survey has revealed numerous steep peaks on a relatively flat shelf. With the Surtla, Syrtlingur and Jólnir eruptions in mind it seems highly probable that these peaks have been built up in submarine eruptions of short duration. On the Vestmann Island area (Fig. 1), which covers nearly 700 km^2, about 55-60 submarine craters can be located.

The Heimaklettur formation is different from the rest of the archipelago, as tuffbreccias and hyalobasalts are more common here. At least five eruption sites can be located of which only the cores are left. These rise as prominent cliffs up to a height of 270-280 m. The oldest part of this formation, Háin, is formed by submarine eruptions with a following lava phase similar to that of Surtsey, and with the sealevel close to what it is at the present time. After Háin had been eroded to a considerable extent, the rest of the Heimaklettur formation was built up, apparently under different conditions. The lowest part of these cliffs are generally made up of finely bedded tuffs with variable dips; higher up, coarse tuff-breccias follow, intercalated with basalt intrusions in all forms. On the top of each cliff there is a thin pile of lava layers. The base of the lava piles lies at about 180-260 m a.s.l.; lowest in Yztiklettur and highest in Heimaklettur. Pillow lava has not been observed.

The general picture of the Heimaklettur formation (except for Háin) seems to indicate that the water level was considerably higher at the time of formation, possibly indicating the presence of a glacier.

Various kinds of xenoliths, especially of sedimentary origin, are found in the clastic ejacamenta of Sæfell and Surtsey. Some of these contain fossils and Mrs. E. Nordmann of the University of Copenhagen kindly undertook the determination of the fossils from Sæfell (the fossils from Surtsey were too fragmentary for identification). It was possible to identify ten species of pelecypods, one gastropod and one foraminifer. All these species are found in the sea around Iceland today and at a depth similar to that found around the Vestmann Islands at the present time.

Tectonics

Where the direction of eruption fissures can be measured as in Ellidaey, Bjarnarey and Surtsey, it is seen to vary between N 12°- 45°E. The average value is close to N 40°E and this is also the trend of the main volcanic zone, which includes Heimaey and Surtsey. An interesting feature is the en echelon arrangement of the Surtur II-Surtla eruption fissures and the probable orientation of the fissures of the Heimaklettur formation (Dalfjall-Yztiklettur). This can be interpreted as zones striking N 75°E with en echelon tension gashes having an angle of 40° to that of the zones (Fig. 4).

Age

At Gardsendi on the southern part of Heimaey a thin layer of peat is found resting on the Stórhöfdi lava and overlain by the Sæfell tuff. This peat has been dated by the C^{14}-method (Kjartansson 1967). Three datings gave an average of 5400 B.P. The Stórhöfdi volcano is probably slightly older and Sæfell-Helgafell slightly younger.

It is possible to estimate the age of both Ellidaey and Bjarnarey by comparing soil profiles from these islands to profiles on southern Heimaey, the age of which is known. In Fig. 5 soil profiles from various parts of Heimaey, Ellidaey and Bjarnarey are drawn showing the main tephra layers. From these profiles it can be suggested that the southern part of Heimaey, Ellidaey and Bjarnarey are of similar age. It should be noted that it is not possible to distinguish between the age of Sæfell-Helgafell and Stórhöfdi on basis of the soil profiles.

On Klifid the thickness of the soil layer was found to be 3.10 m at a height of 220 m. The top of the profile has been disturbed by eolian erosion (as the Ellidaey profile), but the rest of the profile seems to be undisturbed. At a depth of 1.5 m the three distinctive tephra layers E, F and G are recognized. The thick and coarse tephra layer at 2.0 m depth was possibly derived from the big Sæfell eruption. Below this depth the soil gradually gets more and more mixed with tephra until the Klifid tuff is reached. It seems reasonable to suggest from this profile that Klifid and hence the whole Heimaklettur formation, is at least several thousand years older than the southern part of Heimaey. A sample taken at the bottom of the Klifid profile did not contain sufficient humus for C^{14}-dating.

Other islands proved not to be dateable by means of tephrocronology as the soil layers had suffered from heavy eolian erosion at times, or were simply absent.

Petrography

The Vestmann Islands are made up of tuffs and lavas in about equal amounts. Both tuff and lava has been developed from the same vent in the majority of the eruption sites.

The tuffs consist mainly of more or less palagonitizated brown sideromelane glass and opaque tachylitic glass. Phenocrysts of olivine and plagioclase are present in variable amounts. The tuff-breccias of the Heimaklettur formation contain appreciable amounts of hyalobasaltic fragments. Common amygdoidal minerals are calcite and natrolite. The palagonitization is generally most advanced in the tuffs and tuff-breccias of the Heimaklettur formation.

The lavas are medium to fine grained and generally have an intergranular texture. Some of the lavas contain phenocrysts to some extent. This is especially true of Helgafell lava (and Sæfell tuff) with 6-8% of plagioclase phenocrysts and Stórhöfdi lava, which contains 10% of olivine phenocrysts.

The rocks of the Vestmann Islands, including Surtsey, are classified as alkaline olivine basalts, (see chemical analyses in Tables 1 and 2). The lavas fall into two groups called VE I and VE II. Háin, Brandur, Stórhöfdi, Geirfuglasker and Surtsey belong to the first group, VE I, while the second group, VE II, includes the Heimaklettur formation except Háin; Helgafell-Sæfell and Ellidaey. The segregation veins of the Klifid intrusion (Heimaklettur formation) are called VE III for convenience.

The mineralogy of the lavas has the general characteristics of alkaline basalts. The groundmass feldspar is labradorite to andesine (VE I) and andesine (VE II); titanaugite is intergranular, it is often distinctly purplish and has a weak pleochroism. The olivine occurs both as phenocrysts, especially in the VE I type, and as a constituent of the groundmass. The composition of the olivine is Fa 8-27, the phenocrysts being the most Mg-rich. Ores form up to 12% of the lavas. In reflected light the ore is shown to be magnetite often with ilmenite-exsolutions and Cr-spinel (picotite). The magnetite is either acicular and often interstitial (VE I) or more euhedral and always homogeneous at great magnifications (VE II). Of special interest is the Cr-spinel which with certainty only has been found in the VE I rock-type. It is usually included in the olivine phenocrysts as tiny dark-brown cubes (0.01 -0.03 mm). It is also occasionally found in the groundmass and is then always heavily zoned to magnetite. A preliminary microprobe analysis of the Cr-spinel reveals that it is made up of 60-65% chromite and 40-35% hercynite. Apatite is present in minor amounts, but is more common in the VE II lavas. A few microprobe analyses of the plagioclase and pyroxene in the groundmass of Helgafell lava and the Klifid segregation vein are given in Table 5.

Both lava types can contain big phenocrysts of plagioclase up to 5 cm across, comparable to those found in Surtsey. A few of these have been analysed and are listed in Table 4 along with an analysis of a phenocryst from Surtsey (Wenk et al. 1965). The available analyses of the phenocrysts fall into two groups, one at An 50 and another at An 65. It is of interest to note, that the An-content of the big phenocrysts is about the same (Ræningjatangi lava VE 18) or lower (Háin lava VE 72) than the average An-content of the groundmass plagioclase of these lavas.

The olivine analysis in Table 4 shows the average composition of the olivine phenocrysts of the Jólnir tuff. The phenocrysts contain about 0.5 vol% of Cr-spinel inclusion. The olivine fraction also contains impurities (5%) in form of glass which proved impossible to avoid (thus accounting for the high CaO-content).

In the Helgafell lava, small residual pockets (5x5 mm) were developed, where the grain-size is two-three times that of the surrounding groundmass. Here the plagioclase is oligoclase to andesine. The purple titanaugite is pleochroic and often zoned to ægirine-augite. The Mg-content of the olivine falls to Fo 40-50. Apatite is present in appreciable amounts as minute strings. Interstitially, between plagioclase laths, nepheline is found typically as small hexagonal prisms along with light-brown residual glass.

The segregation vein of the Klifid intrusion (chemical anal. in Table 1) shows a further stage in this differentiation. The vein is coarse and porous with oligoclase to albite as the feldspar. The titanaugite is strongly zoned to ægirine-augite, free crystals of the latter mineral are also present.

The early-formed magnetite is often found as skeletons. Apatite is evenly distributed as long needles. The olivine is only found in minor amounts and has the composition Fo 60-80. Nepheline forms about 1% of the rock. A clear, isotropic mineral with low refractive index and trapezoidal habit is probably analcite. Residual glass is present interstitially.

Chemistry

Chemical data of both major and trace elements of the rocks are given in Tables 1 and 2. The two Surtsey analyses in Table 1 are quoted from Steinthórsson 1966 and Tilley et al. 1967.

The chemistry as well as the mineralogy of the rocks of the Vestmann Islands and Surtsey reveal that they are typical alkaline olivine basalts. All have normative nepheline except the lavas of Brandur and Heimaklettur, but they show late stage oxidation of iron and hence give normative hypersthene. The Geirfuglasker tuff is palagonitized and weathered to some degree*. The analyses of the lavas fall naturally into two groups and the average values of these two types are given in Table 3 along with the composition of the Klifid segregation vein. The VE I-type, which includes Surtsey, is close in composition to the average alkaline olivine basalts of Hawaii (Macdonald & Katsura 1964 p. 124); although TiO_2 and K_2O of the VE rocks is slightly lower and Al_2O_3 and MgO slightly higher. VE II is transitional to Hawaiite. A comparison with the alkaline olivine basalts of the Mid-Atlantic Ridge is more difficult because of meagre data, but the average composition of the VE lavas compares fairly well with the average of alkaline olivine basalts from volcanic islands along the Atlantic Ridge (Engel & Engel 1964).

The AFM diagram, Fig. 6, shows the plots of the VE lavas. New AFM data from Surtsey (Steinthórsson 1967) is included. The lavas lie close to the Hawaiian alkali line. The position of the Klifid segregation vein and the Jólnir olivine is also shown.

---

* Analyses of tuffs and tephras have been omitted when the overall chemistry of the rocks is considered, as they only approximately represent the magma from which they are cooled, because of eolian differentiation of phenocrysts (esp. olivine) and glass shards of different weight.

Fig. 7 is an alkali/silica diagram (on waterfree basis) of 37 selected analyses of Icelandic postglacial lavas including the VE rocks. The line drawn is the Hawaiian division line. All the VE lavas, two alkalic lavas from Snæfellsnes, and all available analyses of lavas from the "Katla area" (Katla, Eldgjá, Raudubjallar and Lambafit) fall above this line. The VE lavas and the lavas from Snæfellsnes can be labelled as typical alkali basalts, although the Snæfellsnes lavas have no normative nepheline. The lavas of the "Katla area" are more transitional types. It can be added here, that an uncompleted analysis of the Hamragardar lava in Eyjafjöll just NE of the Vestmann Islands, indicates hawaiite. Probably it is appropriate to talk about an alkaline zone of postglacial lavas which includes the Vestmann Islands and the "Katla area", but with falling alkalinity towards the northeast. This is in contrast with the "oceanic" tholeiites of the Reykjanes volcanic zone. Chemical data from Snæfellsnes, although few, suggest that this is an alkaline volcanic zone, comparable to the Vestmann Islands-Katla area zone. The bilateral symmetry of these two alkaline zones against the tholeiitic Reykjanes zone is interesting.

A full chemical analysis of the host rock of the Klifid segregation vein is not yet available, but an uncompleted analysis indicates a composition close to Ellidaey lava (i.e. VE II type). The fractionation trend of the segregation vein is most marked in the iron enrichment, but titanium and alkalies also increase, while silica is constant and magnesium and aluminium decrease. This is similar to the segregation trends of the high-alumina basalts and tholeiites listed by Kuno (1965). Fig. 8 shows the VE II - VE III trend in a total iron-silica diagram (Kuno op.cit. p. 312).

The trace element analyses of the VE rocks (Table 2 and 3) shows, that they are notably lower in Sr, Ba, and probably Zr, than corresponding rocks of Hawaii (Nockolds & Allen 1954). Table 6 gives trace element data on some of the plagioclase and olivine phenocrysts (cf. chemical analysis in Table 5). An analysis of the pyroxene-fraction of Klifid segregation vein (VE 81) is included. The high Cr-content of the olivines if due to the presence of Cr-spinel inclusions.

Fig. 8 shows that Ni and Co, respectively, rise linearily with increasing content of Mg from the Klifid segregation vein through the VE II and VE I lavas towards the olivine position. On the same diagram data of a partial analysis of the Stórhöfdi lava is included (VE I-type). Fig. 10 shows that the Co : Ni ratio increases rapidly from the VE I-type through VE II towards the segregation vein (VE III).

The difference in chemical composition between the VE I and VE II rock-types, although small, is thought to be significant. These two types never occur together, each eruption site produces only one of the two types. The differentiation within a single eruption site is insignificant. There seems also to be a difference between these two types with respect to the nature of the eruption. Of the five lava craters preserved, Surtur II, Surtur III and the Stórhöfdi craters (VE I-type) are of the shield-volcano type. The Helgafell, Bjarnarey and Ellidaey craters (VE II-type) have, on the contrary, developed spatter cones.

Methods

The chemical analyses were made by the author on samples dried for two hours at 110°C, using a rapid silicate analysis method established by Borgen (1967, with modifications by I. Sörensen). The microprobe analyses were carried out on a ARL electron microprobe at the Royal Technical University of Copenhagen; minerals, analysed by the author served as standards, only corrections for background were performed. The trace-element analyses were done on a Hilger large quartz spectrograph. Mineral separations were made on a Franz isodynamic magnetic separator and by heavy liquids.

The CIPW molecular norms were calculated after the modified rules of Kelsey (1965).

Acknowledgements

Thanks are due to Professor A. Noe-Nygaard for advice and many helpful suggestions.

Mrs. H. Bollingberg made the trace element analyses, Mr. I. Sörensen did two mineral analyses, Mr. F. Lerche-Nielsen ran the microprobe analyses, and Mrs. R. Larsen drew the geological map and one profile. To all these I am deeply grateful.

This work was supported by the Icelandic Scientific Fund and the Surtsey Research Society.

References

Borgen, B.E. 1967: Analytical procedures used in the geochemical laboratory of the Survey. Geol. Surv. Greenland Report no. 10:1-44.

Einarsson, Tr. 1948: Bergmyndanasaga Vestmannaeyja. Árbók Ferðafél. Íslands 1948:131-157.

Engel, A.E.J. and Engel, C.G. 1964: Composition of basalts from the Mid-Atlantic Ridge. Science 144:1330-1333.

Kelsey, C.H. 1965: Calculation of the CIPW norm. Mineral. Mag. 34:276-282.

Kjartansson, G. 1967: Nokkrar nýjar C^{14} aldursákvarðanir. Nátt.fr. 36, 3:126-141.

Kuno, H. 1965: Fractionation trends of basalt magmas in lava flows. Journ. Petrol. 6, 2:302-321.

Macdonald, G.A. and Katsura, T. 1964: Chemical composition of Hawaiian lavas. Journ. Petrol. 5, 1:82-133.

Nockolds, S.R. and Allen, R. 1954: The geochemistry of some igneous rock series: Part II. Geochim. Cosmochim. Acta 5: 245-285.

Pálmason, G., Tómasson, J., Jónsson, J. and Jónsson, I. 1965: Djúpborun í Vestmannaeyjum. State Electr. Authority (mimeogr.) :1-43.

Sigvaldason, G. 1967: Chemistry of basalts from the Icelandic rift zone. Vís.fél. Ísl. 38:50-52. Report of a symposium.

Steinthórsson, S. 1966: Surtsey: Petrography and Chemistry. Surtsey Research Progr. Rep II:77-86.

" 1967: Petrography and Chemistry of the Surtsey Rocks. Proceed. Surtsey Research Conference: 62-64.

Thórarinsson, S. 1949: Some tephrocronological contributions to the volcanology and glaciology of Iceland. Geogr. Ann. 31:237-256.

Tilley, C.E., Yoder, H.S. and Schairer, G.F. 1967: Melting relations of volcanic rock series. Carn. Inst. Annual Report 1965-66: 260-269.

Wenk, E. Schwander, H. and Wenk, H.-R. 1965: Labradorit from Surtsey. Acta nat. isl. II, 15:1-29

TABLE 1

Chemical analyses

	VE I			VE II			VE III	SU (VE 1)	
	Häin lava VE 72	Brandur lava VE 43	Geirfugl-asker tuff VE 32	Heima-klettur lava VE 58	Helga-fell lava VE 67	Elli-daey lava VE 24	Klifid segr. vein VE 81	Surtsey lava Apr.1964 I	Surtsey lava Apr.1964 S-2
SiO_2	46.90	46.49	43.55	47.54	47.27	46.80	46.83	46.56	46.71
TiO_2	2.36	2.17	1.86	2.30	2.36	2.62	4.12	2.02	1.72
Al_2O_3	15.35	15.55	14.45	16.35	16.98	15.85	12.21	15.93	16.68
Fe_2O_3	2.26	5.73	7.85	5.64	2.66	4.65	3.88	1.61	1.61
FeO	9.20	6.15	4.64	6.28	9.10	8.40	12.00	10.32	10.00
MnO	0.19	0.20	0.19	0.17	0.15	0.17	0.26	0.20	0.20
MgO	8.67	9.05	10.00	6.27	5.38	6.07	3.79	9.00	9.46
CaO	11.08	10.88	4.44	9.96	10.43	9.88	8.92	10.51	9.62
Na_2O	2.76	2.67	3.60	3.54	3.63	3.66	5.05	3.21	2.97
K_2O	0.54	0.38	0.98	0.68	0.70	0.67	1.07	0.51	0.55
P_2O_5	0.34	0.28	0.39	0.36	0.37	0.34	0.78	0.26	0.27
H_2O^+	0.50	0.38	8.14	0.35	0.48	0.45	0.62	0.02	0.03
H_2O^-								-	0.07
	100.15	99.93	100.09	99.44	99.51	99.56	99.53	100.21 x)	99.89
Anal.:	S.Jak.	S.Jak.	S.Jak.	S.Jak.	S.Jak.	S.Jak.	S.Jak.	J.H.Scoon	S.Stein.
CIPW norm.									
Or	3.2	2.2	5.8	4.0	4.1	4.0	6.3	3.0	3.3
Ab	22.4	22.6	30.4	29.9	26.2	28.4	30.0	19.6	22.3
An	27.9	29.3	19.5	26.7	28.0	24.8	7.5	27.5	30.5
Ne	0.5				2.4	1.4	6.9	4.1	1.5
Ap	0.8	0.7	0.9	0.9	0.9	0.8		0.6	0.6
C			0.3						
Hy		6.5	9.8	2.6					
Di	20.1	18.0		16.1	17.5	17.7	26.4	18.6	12.5
Ol	17.0	7.8	10.6	6.3	11.5	10.3	6.5	20.5	23.4
Mt	3.3	8.3	10.2	8.2	3.9	6.8	5.6	2.3	2.3
Hm			0.8						
Il	4.5	4.1	3.5	4.4	4.5	5.0	7.8	3.8	3.3

x) Includes Cr_2O_3: 0.06 %

TABLE 2

Trace elements ppm

Vestmannaeyjar

	VE I				VE II						VE III
	Háin	Brandur	Stór-höfdi	Geir-fugl.sk.	Ræn.-tangi	Helli-sey	Heima-klettur	Elli-daey	Helga-fell	Bjar-narey	Klifid
	VE 72	VE 43	VE 61	VE 32	VE 18	VE 48	VE 58	VE 24	VE 67	VE 54	VE 81
Cr	310	285	440	355	90	75	110	80	55	40	-
V	310	315	340	165	250	270	235	315	235	260	170
Ni	200	195	285	285	60	60	75	65	50	50	20
Co	50	60	65	60	35	40	40	45	35	40	30
Zr	230	155	175	170	150	175	205	215	185	200	330
Cu	100	70	120	20	45	50	45	40	35	45	90
Sr	190	190	160	230	170	220	200	220	200	200	140
Ba	60	60	40	60	60	65	70	80	80	70	100

Surtsey

SU (VE I)

	Surtsey lava Jun.-Aug.'64 SU 42	Jólnir tephra Jul.-Aug. '66 SU 20	Surtsey lava Aug. '66 SU 18	Surtsey lava Dec. '66 SU 24
Cr	300	800	370	325
V	310	300	245	260
Ni	215	460	270	250
Co	60	70	50	50
Zr	190	165	120	145
Cu	80	100	85	85
Sr	210	140	125	170
Ba	65	40	30	40

Anal.: H. Bollingberg

TABLE 3

Average chemical values of lavas

Major element wt. % (on waterfree basis)

	VE I	VE II	Segregat. vein (VE III)
SiO_2	46.8	47.6	47.4
TiO_2	2.1	2.5	4.2
Al_2O_3	15.9	16.6	12.3
Fe_2O_3	2.8	4.4	3.9
FeO	8.9	8.0	12.1
MnO	0.20	0.17	0.26
MgO	9.1	6.0	3.8
CaO	10.6	10.2	9.0
Na_2O	2.9	3.6	5.1
K_2O	0.50	0.69	1.07
P_2O_5	0.29	0.36	0.79
Number of analyses	(4)	(3)	(1)
Trace elements ppm.			
Cr	360	75	-
V	300	260	170
Ni	235	60	20
Co	55	40	30
Zr	165	190	330
Cu	85	45	90
Sr	175	200	140
Ba	50	70	100
Number of analyses	(6)	(6)	(1)

TABLE 4

Microprobe analyses of groundmass minerals

	Plagioclase					Cl. pyroxene				
	Helgafell lava		Klifid segr.vein			Helgafell lava			Klifid segr. vein	
	VE 67		VE 81			VE 67			VE 81	
	I	II	I core	I border		I	II	III	I core	I border
SiO_2	55.0	55.4	61.5	63.3		49.8	49.6	51.7	50.7	51.1
TiO_2						2.0	1.6			
Al_2O_3	27.1		22.5	21.8		3.1	2.8	1.7	1.4	1.3
FeO						11.7	13.6	14.7	13.5	15.3
MgO						12.8	12.2	11.0	10.9	10.2
CaO	10.1	10.1	5.4	4.4		20.1	19.8	19.4	19.6	18.9
Na_2O	5.3	5.7	7.9	8.6		0.3	0.5	0.3		
K_2O	0.5		1.3	1.8						
	98.0		98.6	99.9		99.8	100.1	98.8	96.1	96.6
An	49.0	49	25.7	20.0	Ca	42.8	41.8	42.0	43.3	42.6
Ab	46.7	51	67.7	70.4	Mg	38.0	35.9	33.1	33.5	32.0
Or	4.3		6.6	9.6	Fe	19.2	22.3	24.9	23.2	25.4

TABLE 5

Chemical analyses of phenocrysts

	Plagioclases					Olivine
	Ræn. tangi lava VE 18	Háin lava VE 72	Helgafell lava VE 19	Surtsey*) lava Wenk et al. (1965)		Jólnir tephra SU 20
SiO_2	55.78		50.68	53.3		
TiO_2	0.06		0.08			0.14
Al_2O_3	27.54	28.30	31.00	29.9		
Fe_2O_3	0.11					0.49
(Fe_2O_3 + FeO)		0.40	0.52	0.3		
FeO	0.16					14.80
MgO	0.00		0.00			40.09
CaO	10.54	10.52	13.32	12.5		1.29
Na_2O	5.48	5.52	3.70	3.6		
K_2O	0.36	0.30	0.08	0.2		
H_2O^+	0.23					
	100.26					
An	50.5	50.5	63.6	65.0	Fo	83
Ab	47.4	47.8	35.9	33.8	Fa	17
Or	2.1	1.7	0.5	1.2		
d($\pm$0.005):	2.685	2.683	2.711	2.715		
Anal.:	S.Jak.	S.Jak.	I.Sör.	H.Schw.		I.Sör.

*) Microprobe analysis

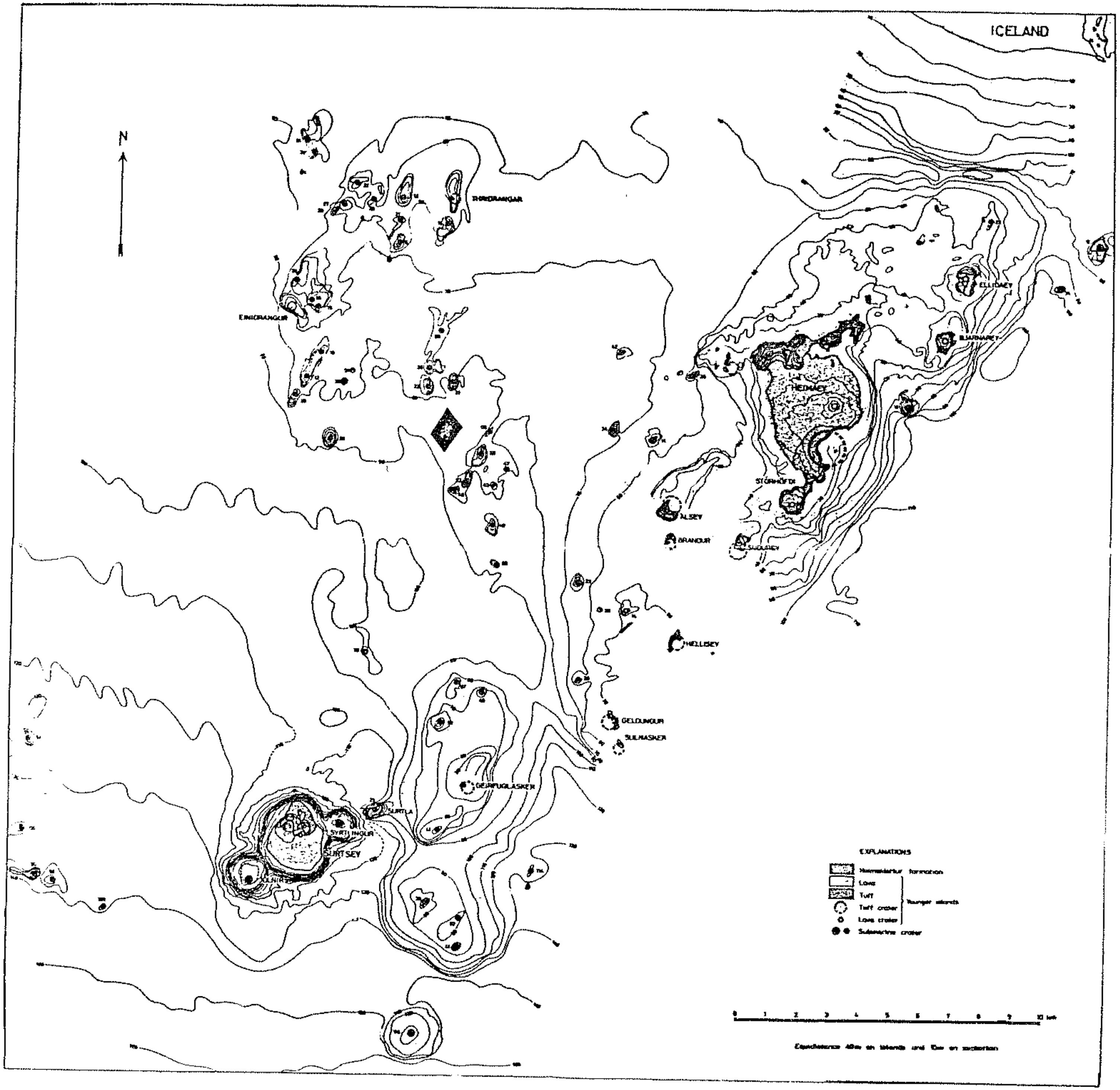
TABLE 6

Trace elements in minerals

	Plagioclase phenocrysts			Olivine phenocrysts			Pyroxene
	VE 18	VE 72	VE 19	VE 18	VE 72	SU 20	VE 81
Ti	300	315	240	100	105	1900	1.1600
Cr	< 10	< 10	< 10	160	60	1230	< 10
V	< 10	< 10	< 10	< 10	< 10	< 10	285
Ni	< 10	< 10	-	615	805	3000	35
Co	-	-	-	165	140	160	40
Zr	-	-	-	20	35	50	245
Mn	-	-	-	2550	1800	2030	3300
Cu	< 10	< 10	< 10	< 10	15	40	30
Sr	570	575	375	-	-	-	35
Ba	60	50	< 10	-	-	-	< 10
	(one crystal)	(one crystal)	(one crystal)	(av. of phenocr.)	(av. of phenocr.)	(av. of phenocr.)	(average of rock)
An	50.5	50.5	64.8			Ca	(43)
AB	47.4	47.8	32.4	Fa	83	Mg	(33)
Or	2.1	1.7	2.8	Fa	17	Fe	(24)

Anal.: H. Bollingberg

Fig. 1


ICELAND
N
ELLIDAEY
BJARNAREY
HEIMAEY
STORHÖFDI
ALSEY
BRANDUR
SUDUREY
HELLISEY
GELDUNGUR
SULNASKER
GEIRFUGLASKER
SURTLA
SYRTLINGUR
SURTSEY
JOLNIR
THRIDRANGAR
EINIDRANGUR
EXPLANATIONS
Heimaklettur formation
Lava
Tuff
Tuff crater
Lava crater
Submarine crater
Younger islands
0 1 2 3 4 5 6 7 8 9 10 km
Equidistance 40m on islands and 10m on seabottom

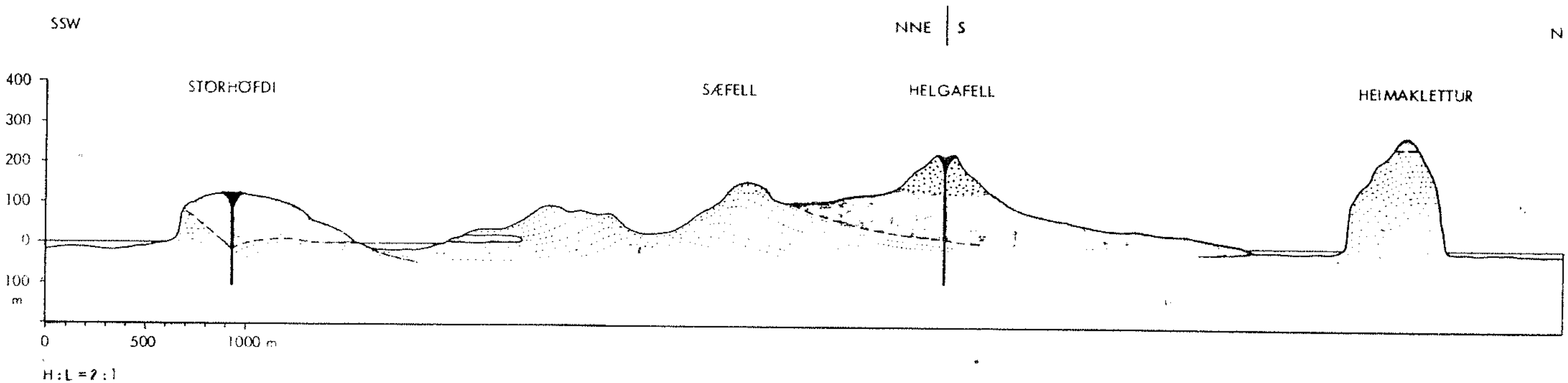


Fig. 2 Cross section through Heimaey from south to north. Lavas are shaded, scoriae with heavy dots and tuffs with light dots indicating layering.

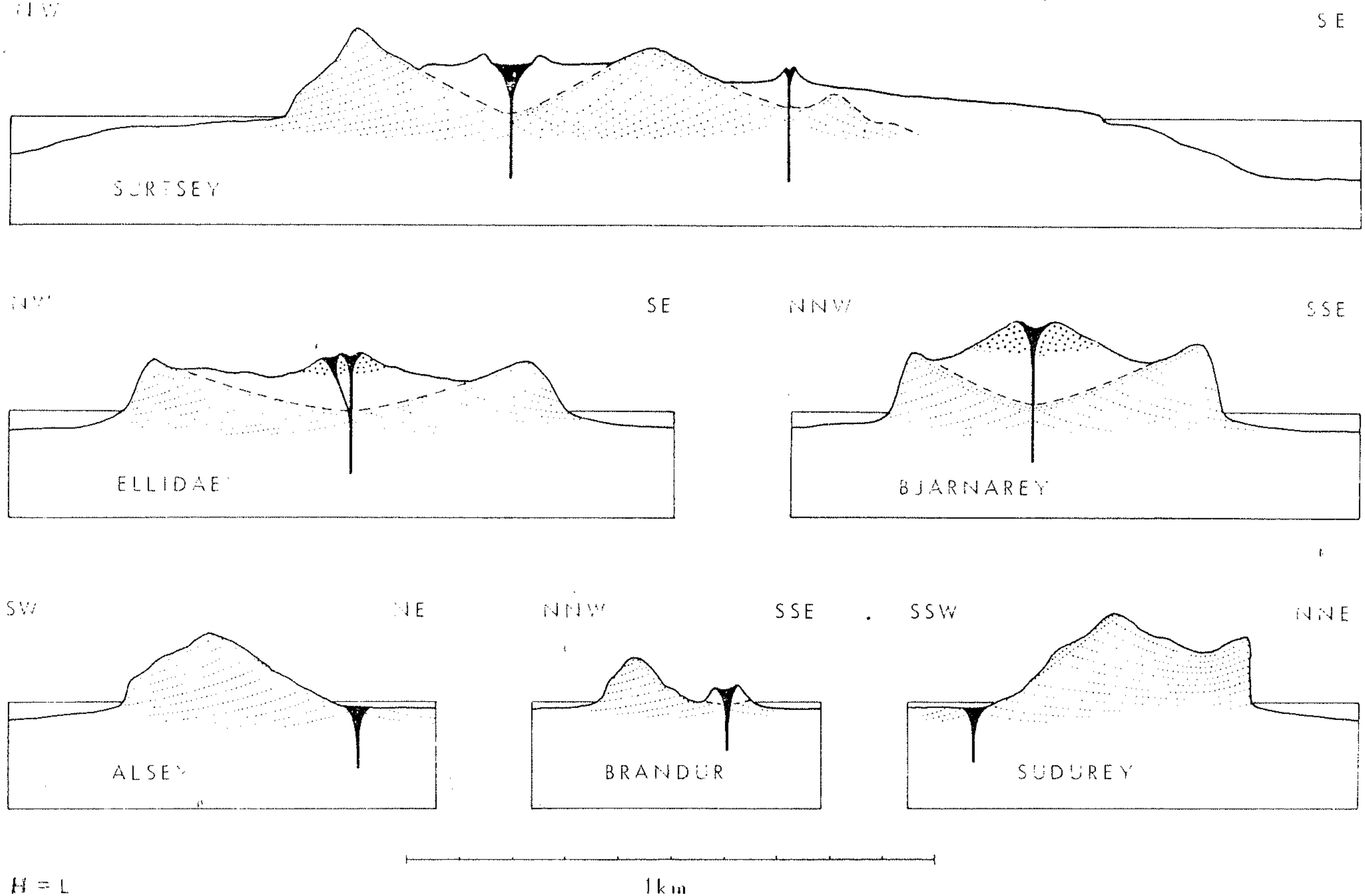


Fig. 3 Section through Surtsey (summer 1967) and, for comparison, five of the other islands. Same legend as in Fig. 2.

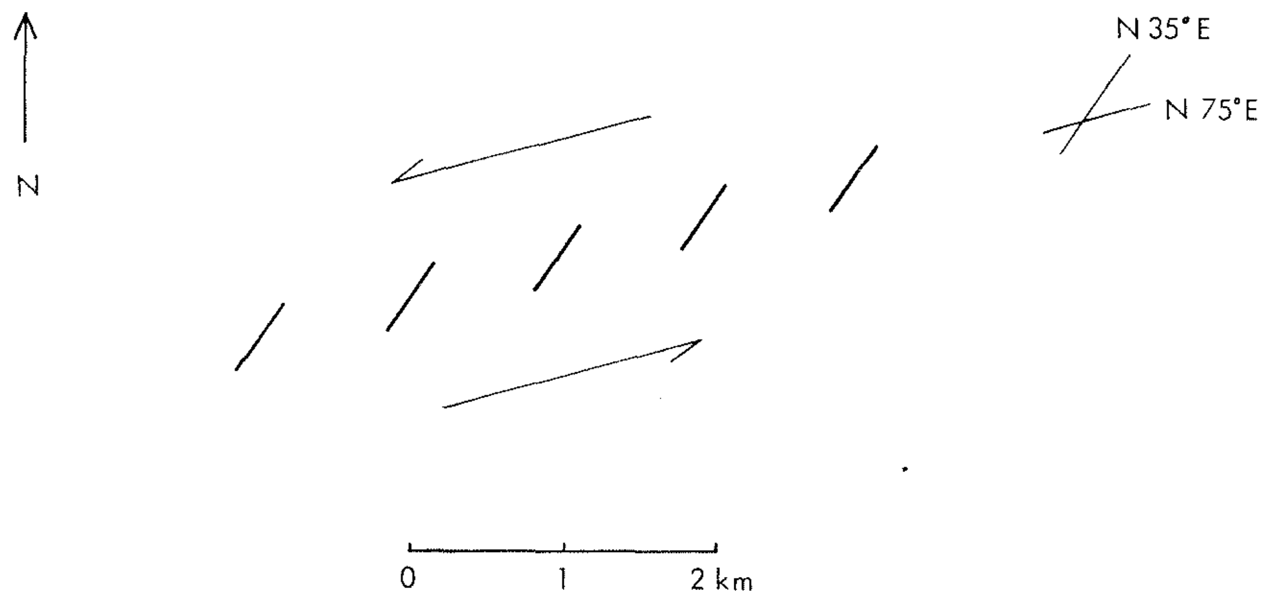


Fig. 4 An idealized representation of the en-echelon eruption fissures of Surtur II - Surtla and Dalfjall - Yztiklettur.

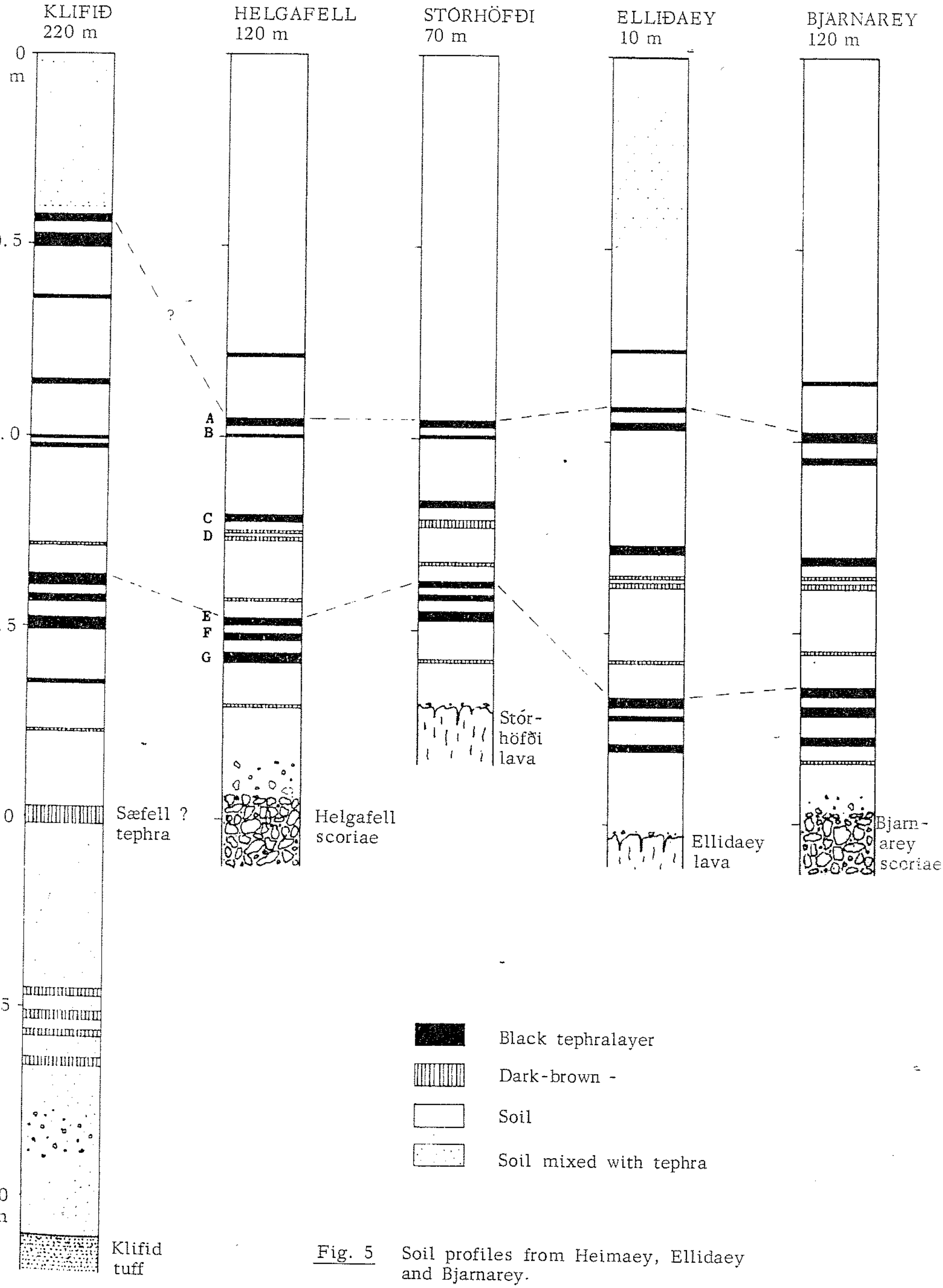


Fig. 5 Soil profiles from Heimaey, Ellidaey and Bjarnarey.

Fig. 6 A F M - diagram (F = total iron as FeO) showing the plot of the VE rocks and Jólnir olivine compared with the average tholeiitic trend (solid line) and alkalic trend (dashed line) of Hawaii Is. Shaded area indicates distribution of Icelandic postglacial lavas.

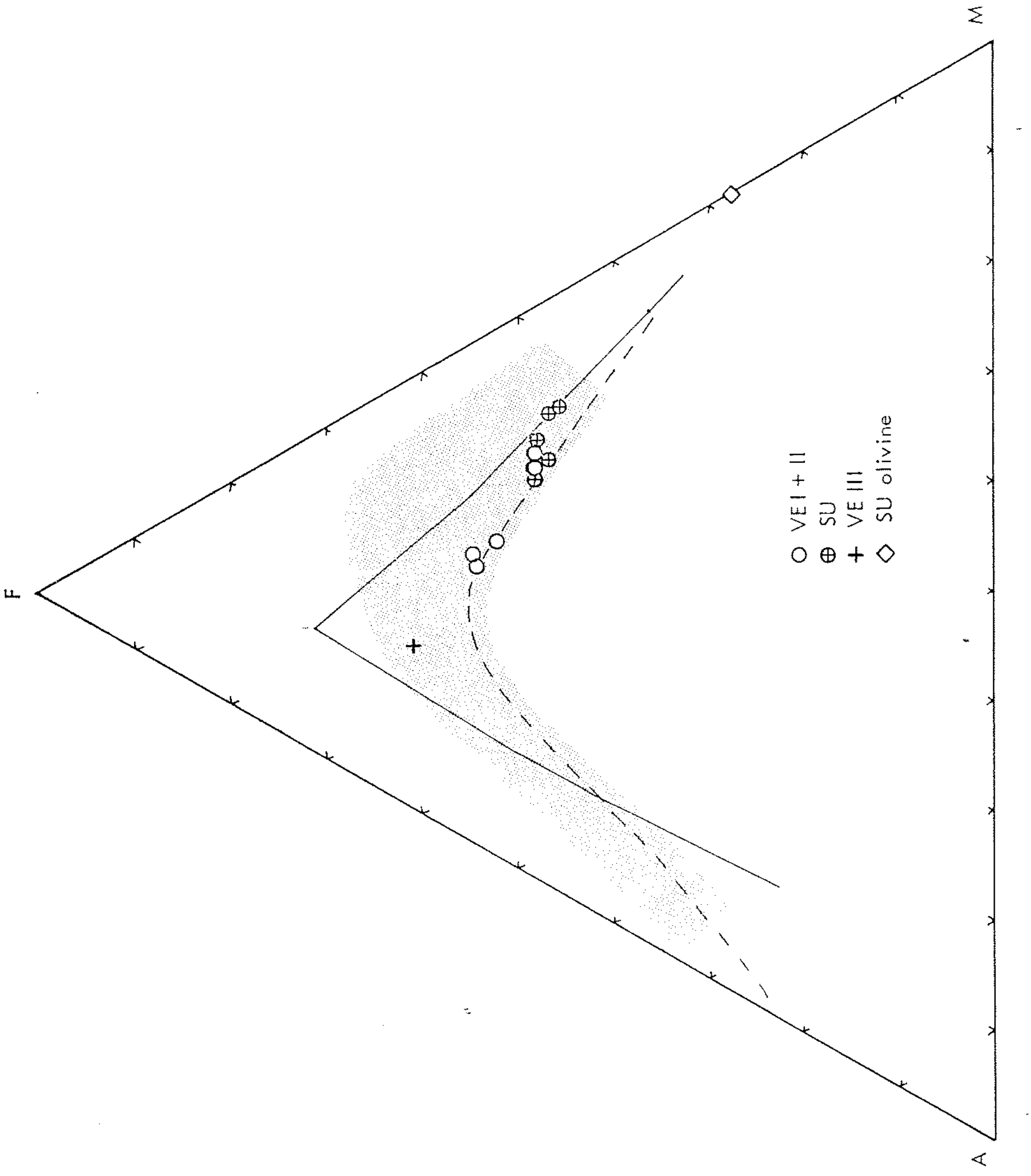
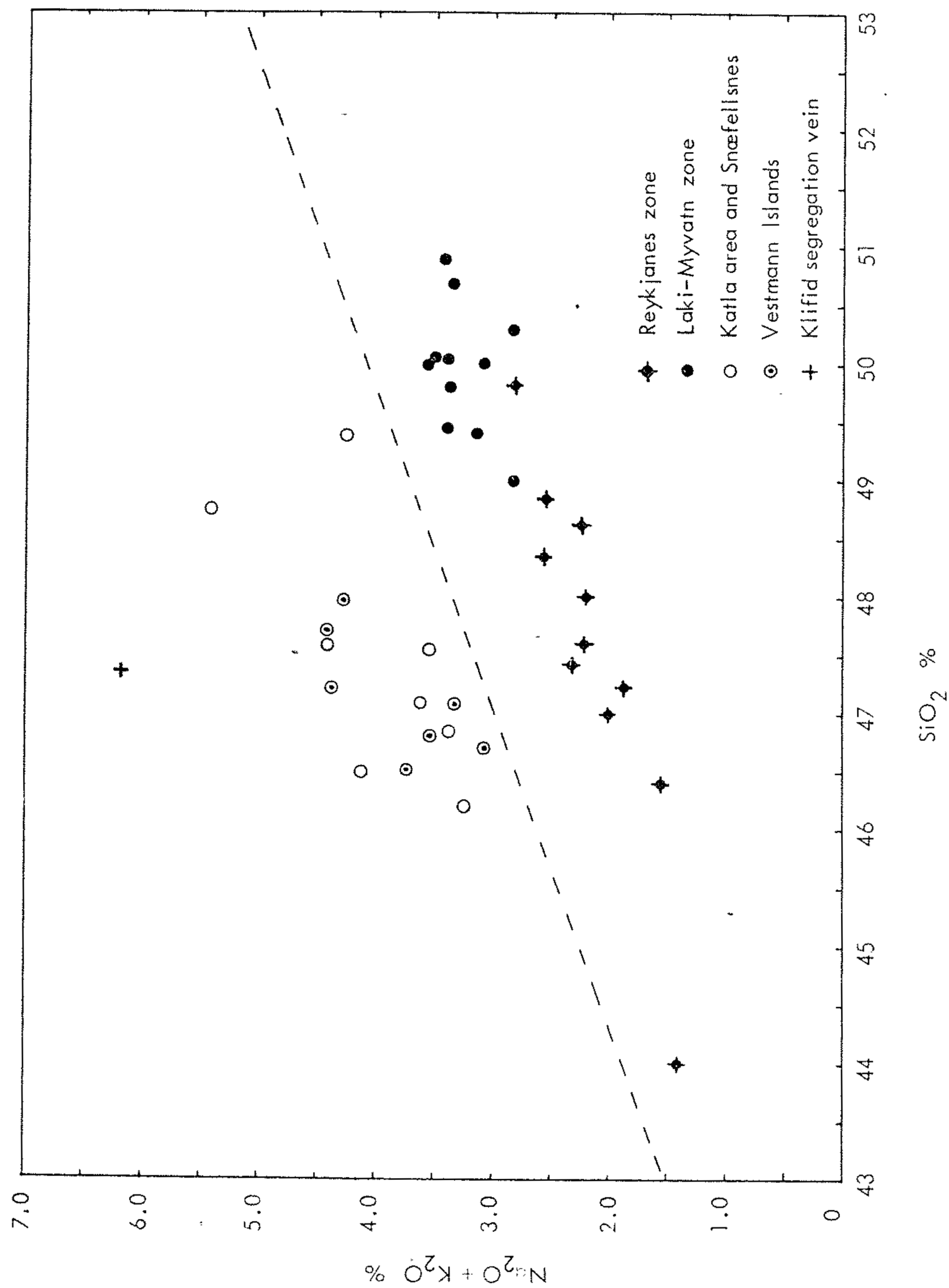
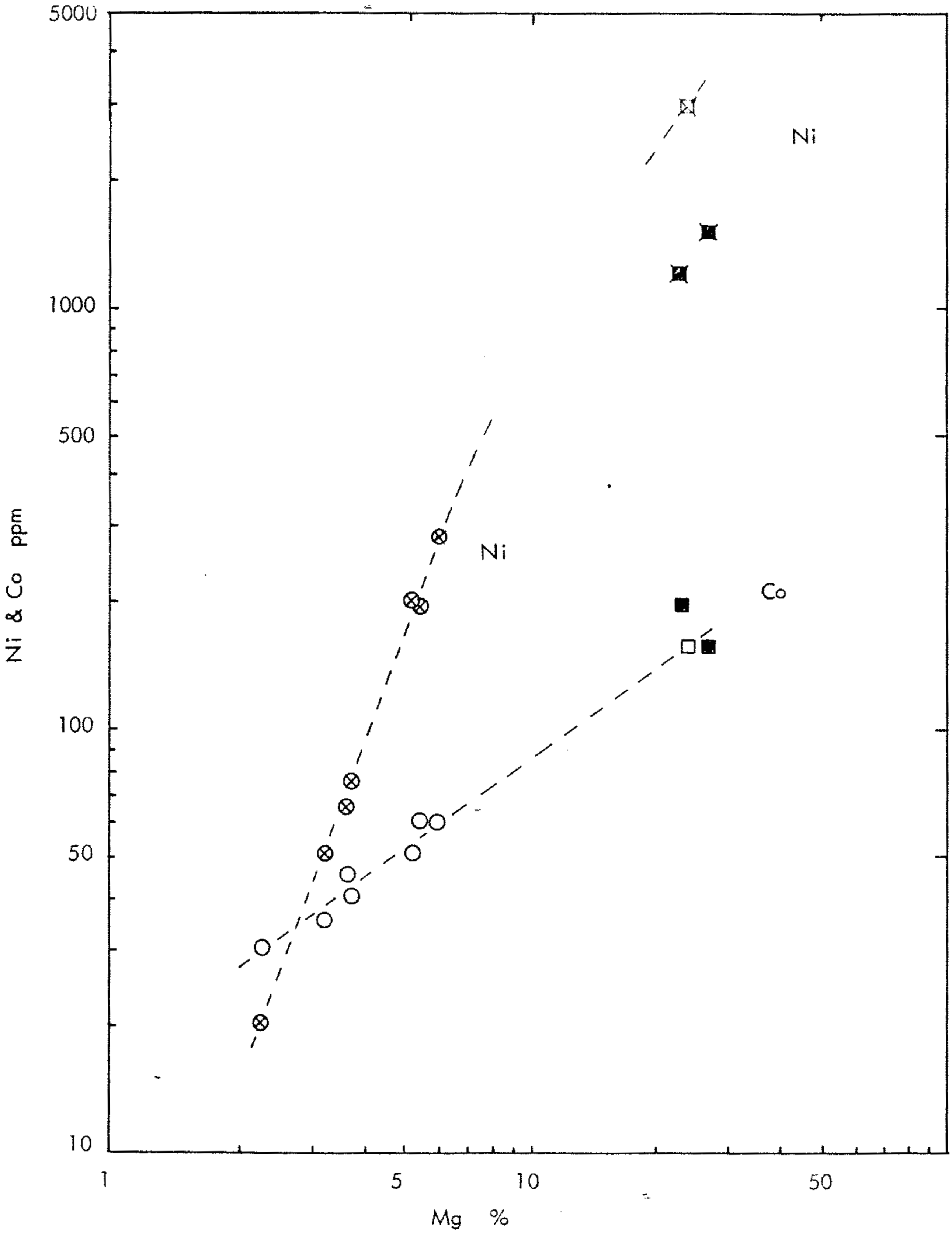


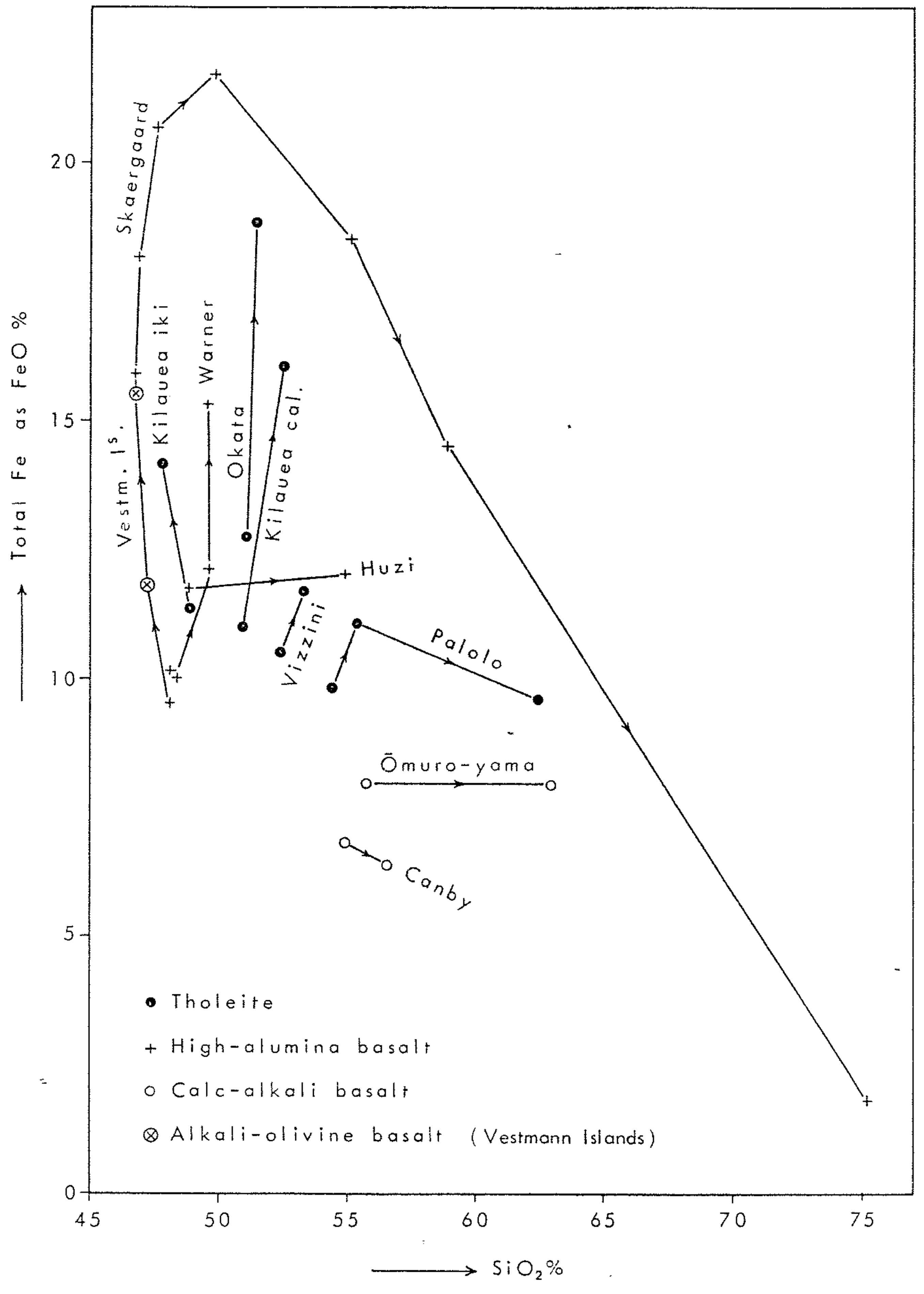
Fig. 7 Alkali:silica diagram of 37 selected postglacial lavas of Iceland, including VE rocks. The dashed line is the Hawaiian division line.

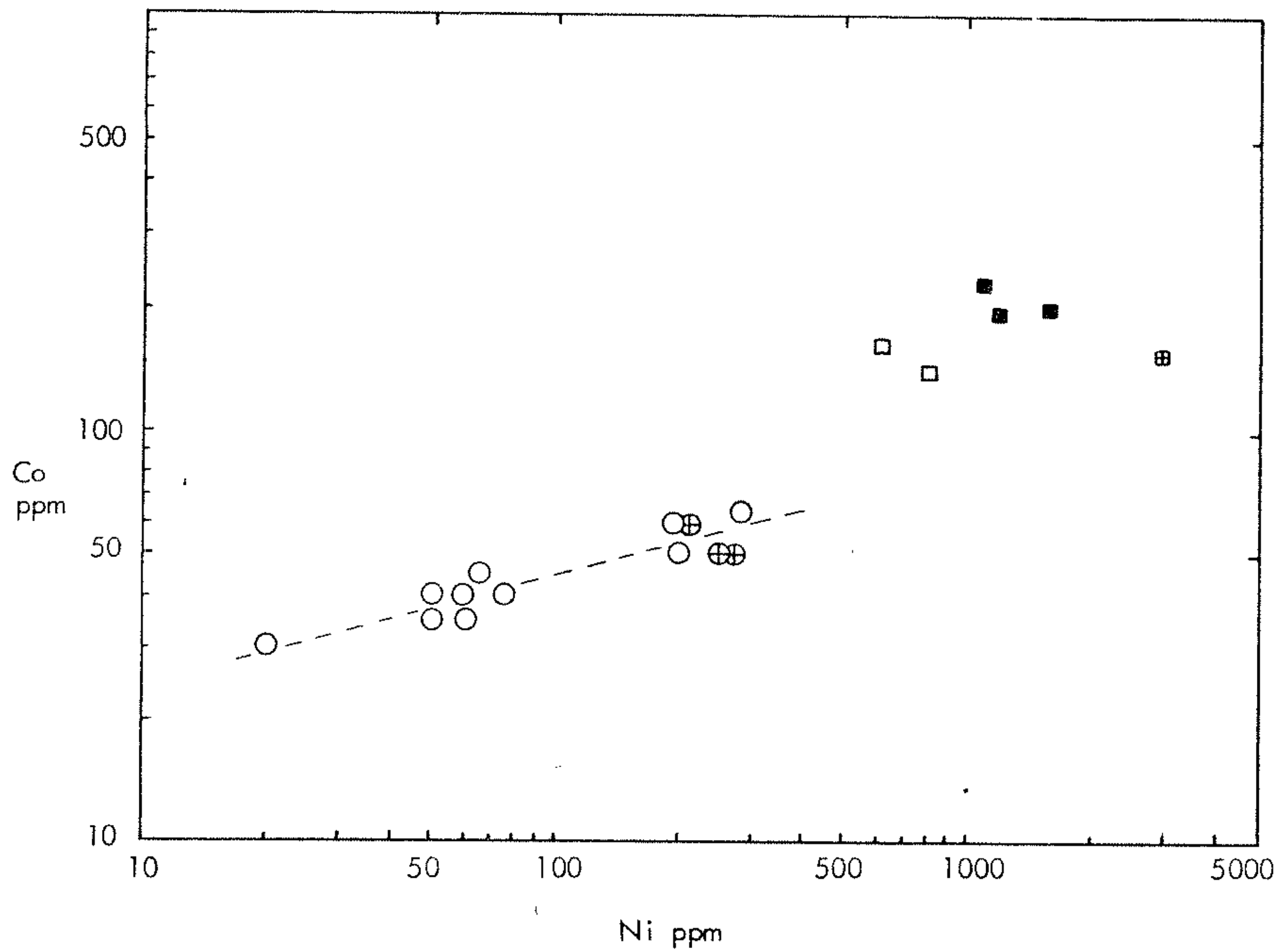




<u>Fig. 8</u> Plot of log Mg against log Ni and Co respectively. Circles: VE-lavas; open squares: Jólnir olivine; solid squares: tholeiitic olivines.

Fig. 9 Total iron - silica diagram from Kuno (1965 p. 312), into which is plotted trend of VE II - segregation vein (VE III).





<u>Fig. 11</u> Log Ni against log Co (ppm). Open circles: **VE**-lavas; open circles with crosses: Surtsey lavas; open squares: **VE** olivine phenocrysts; open square with cross: Jólnir olivine; solid squares: olivines from tholeiites.

Shore and Offshore Morphology of Surtsey, Report on Preliminary Studies in 1967

by
John O. Norrman
Department of Physical Geography
Uppsala University, Sweden

This report is based on field studies in September 1967 and information from previous investigations kindly offered by Dr. S. Thorarinsson. The purpose of the 1967 studies was to gather enough information for planning a detailed quantitative study in 1968. Aerial photographs on an approximate scale of 1:10.000 from August 1967 were available and used when mapping general characteristics of the shores. 28 monuments distributed on the lava plateau on top of the cliffs were fixed and the distance to the cliff edge was measured. These monuments will be used for repeated surveys. The northern ness formed by beach deposition was surveyed in a square grid system of sections marked by steel rods. Samples were collected from the swash zone.

General description

The main parts of the coasts facing E, SSW and WNW is presently characterized by a vertical cliff abraded in lava beds. The height of the cliff wall varies from about 5 to 12 m. There is only a narrow section on the WNW coast with direct wave attack on tephra material. In this section the cliff cut in the cone of Surtur II (the Younger Surtur Crater) extends to the rim of the crater at about 160 m a.s.l.

The tephra slopes of Surtur I and Surtur II facing N and NE are sheltered by a ness built up by beach material transported along the shore, with sizes ranging from boulders to sands. Two lagoons are found on the ness. The inner one is partly sheltered by tephra ridges. The outer one is entirely encircled by beach material.

Along the SSW and WNW coasts the abrasion platform below the cliffs is strewn with huge blocks and boulders, in some places piled up at the cliff wall. Closely W of the southern end of the island there is a pocket beach with shingle.

From just S of the Surtur II cone a high bench of blocks and boulders has been built up The crest of the bench slopes towards the ness, where most of the coarse material is hidden by beach sand. In the same direction there is a rapid increase in roundness of the boulder material.

Off the cliffs of the southern part of the E coast the shore line bulges out because of a beach accumulation up to about 60 m in width. There is a series of distinct cobble ridges running closely parallel to the shore line The upper part of the beach is made up of blown sand which also covers a low cliff Between this beach and the northern ness a fan-formed lava flow from Surtur I projects into the sea with a vertical cliff, which at its base has a cover of block talus.

Cliff development in the lava

The cliff walls demonstrate sequences of lava flow partly intercalated by layers of scoracieous material. The lava beds generally vary in thickness from about 0.5 to 1.5 m, occasionally they are several metres thick. There is a pronounced weakness in the more or less horizontal boundaries between the beds, and a structural weakness along planes at right angle to the bed surface. Thus, when only a shallow notch is formed by abrasion, the mass above it will fall down leaving a vertical wall. The open exposition to Atlantic waves approaching the steep submarine slopes in waters of more than 130 m depth makes possible movement of any block sizes present; that means volumes of several cubic metres.

The coarse material forming the bench on the northern part of the WNW coast emanates from the area SW of Surtur II where the cliff is high and the beds are comparatively thin, which has resulted in a swift production of transportable material.

In several places along the WNW and SSW coasts a tendency to change in character of the lava at about sea level was found. There the lava forms more irregular masses of pillow-like shape.

These parts seem to be more resistant to abrasion because of locking joint systems.

As yet little is known about the submarine morphology of the abrasion platform. According to preliminary comparisons between the 1965 and 1967 coast lines, the 10-m depth contour of July 1967 on the SSW coast roughly corresponds to the shore line of August 1965.

Sources of beach material

In the early stages of the development of the island, waves rapidly cut into the tephra. Except on the sheltered N coast no beach deposition of any permanency took place. The fine-grained tephra was brought in suspension by the swash and was lost offshore. Even close to the area on the WNW coast, where tephra is still supplied, it makes up an insignificant part of the beach material.

The formation of coarse beach material from cliff falls has previously been mentioned. Boulders are rapidly abraded to a rounded form and fragmented parts are transported along the shore. As the abrasion platform is still comparatively narrow and steep, it seems most probable that a considerable amount of eroded material is surged off the platform and slips down the submarine slope.

The latest outflow of lava reaching the sea started on August 19th 1966 and the activity ended in early June 1967. The molten lava poured down high cliffs and splashed into shallow water. At contact with the water vast quantities of this lava were instantly fragmented into pieces of granule size, that could easily be transported by the breakers. In my opinion the effect of this spontaneous source is reflected in a rapid growth of the northern ness. From the autumn of 1966 to August 1967 the northern spit advanced about 80 m, and the shoreline had been built out in an area where the water depth was about 30 m 12 months earlier.

During the large outflows of 1964 and 1965 fragmented lava did not produce directly available beach material in the same effective way because the lava front was rapidly built out into deep water, and the particles went down the submarine slopes.

The northern ness

Cliffs cut in the tephra cones of Surtur I and II facing NE and N respectively form the inner margin of the large ness built out towards N. The ness may be divided into an outer and inner zone roughly divided by the outer lagoon. The depression marked by this lagoon continues to the SW end of the ness. Its surface has to some extent been lowered by deflation.

In the outer zone more or less rounded fragments of lava almost entirely constitute the beach material. Grain sizes within the range of coarse sand to granules dominate. In the inner zone there is a mixture of tephra and lava material. In the innermost part lava particles only form an incomplete windblown cover.

The beach profile has a well developed plunge step. Along the eastern beach the step is made up of material of pebble and cobble size. As previously mentioned, very coarse material forming the bench of the WNW coast can be traced into the western beach of the ness. The detailed configuration of the ness swiftly changes with direction of wave approach. It was found that at erosional stages of the western beach with wave approach from W, large cusps were formed with very coarse material in the horns. Boulders 0.5 to 1.0 m in size were seen actively rolling at the step by swash action. At time of observation the wave period was 10.5 sec and the significant wave height was estimated at about 2 m.

On September 12th the mean inclination of the shoreface within the present swash action above the temporary mean water level was measured in 24 equally spaced sections. On the eastern beach the average inclination was 5° (range 4° to 6°). According to Inman and Shepard (1963) and Wiegel (1964) this should be expected with a median grain size of about 0.5 mm, which at least qualitatively agrees with the present conditions. During the erosion on the western beach the slope varied from 6° to 10°. In the area of rapid deposition at the northern point of the ness the inclination of the shoreface varied from 2° to 4°.

Changes in shore line configuration

During the short life of Surtsey the position of its shore line has changed considerably due to lava flows and wave attack. Maps of area changes from February 17th 1964 to August 24th 1965 and from this date to January 3rd 1967 have been published by Thorarinsson (1966 and 1967). During the first of these periods the configuration changed from an almost circular form to a rectangular shape, with rather straight coasts facing SW, NW, NE and SE, chiefly by outflows of lava from Surtur II towards S to SW.

The lava flows from Surtur I that lasted from August 1966 to June 1967 were directed in a sector from E to S and resulted in heads projecting E and SE. During the first 6 months of 1967 these heads were severely abraded and in the section between them on the E coast a wide beach has been built out. In the western part of the island abrasion has continued without significant change in orientation of the coast. Including the northwards projecting triangular ness, this means that the configuration has changed from a rectangular shape oriented in NE-SW to a pear shape oriented in N-S. As can be judged from the depositional part this reflects an adjustment to the directional distribution of wave force. (Cf. discussions on Anholt island by Schou (1945) and Norrman (1964)).

Submarine morphology

A depth contour map covering the bottom to a distance of 600 m from the shore has been published by Rist (1967). This map is based on 33 radial sections echo-sounded in August 1966. A detailed survey was carried out in July 1967 by Sub.lieut. B.E T. Humphrey, R.N., covering a circular zone out to 2 km from the shore. Recordings within the 10-m contour are incomplete. A provisional map in the scale of 1:10.000 based on these soundings readily reveals irregular morphological features of the Surtur I lava flow to a depth of 70 m on the southernmost part of the E coast

Of great interest are the submarine platforms formed at the shoal of Surtla and the totally abraded islands of Syrtlingur and Jólnir. Surtla is situated 1.5 km ENE of Surtsey. The cone elongated in ENE-WSW is planed off at a depth of 31 to 34 m. A submarine eruption was noticed on December 28th 1963, and the shoal seems to have been built up close to the sea surface.

Syrtlingur linked to the ENE submarine slope of Surtsey was seen above sea level on May 28th 1965 and disappeared by abrasion on October 24th the same year. When largest it had a diameter at sea level of about 650 m. It now forms a platform at a depth of 22 to 23 m, with some minor ridges at 20 m.

Jólnir, that had its centre about 1.0 km WSW of Surtsey, came above sea level for the first time on December 28th 1965 and finally disappeared in September 1966. When largest, its diameter at sea level was about 600 m. It now forms a platform at a depth of 13 to 16 m. (All data on the history of the islands is according to information from S. Thorarinsson).

It is presently not known to what an extent the levels of the platforms are entirely due to an abrasion and if abrasion is still active at a depth of 30 m. The relation between age and depth is striking. One of the main objects of the diving operations planned for 1968 is a study of the morphology and sediments of these platforms.

Acknowledgements

The studies reported were supported by the Surtsey Research Society and the Swedish Natural Science Research Council (contract 2160-3). During parts of the field work the author was accompanied by Dr. S. Thorarinsson and Mr. G. Sigbjarnarson.

References

Norrman, J.O., 1964: Lake Vättern, investigations on shore and bottom morphology. Geogr. Ann. Vol. 46.

Rist, S., 1967: Echographic soundings around Surtsey. Surtsey Research Progress Report III.

Schou, A., 1945: Det marine Forland. Folia Geogr. Danica. Tom. IV.

Shepard, F.P., 1963: Submarine Geology. 2nd ed. Harper & Row.

Thorarinsson, S., 1966: The Surtsey eruption, course of events and the development of Surtsey and other new islands. Surtsey Research Progress Report II.

Thorarinsson, S., 1967: The Surtsey eruption, course of events during the year 1966. Surtsey Research Progress Report III.

Wiegel, R.L., 1964: Oceanographic Engineering. Prentice-Hall.

ABSTRACT

The Petrology of Acid Xenoliths from Surtsey

by

Haraldur Sigurdsson
Industrial Research and Development Institute
Reykjavik, Iceland

Will be published in: The Geological Magazine, London

A number of acid plutonic xenoliths from the volcano Surtsey are described, along with fine grained rock-fragments, consisting chiefly of anorthitic plagioclase and tridymite. The chemistry of the xenoliths indicates a compositional pattern from tonalitic to pyrometamorphic types. A hypothesis is put forward that the tonalitic xenoliths have undergone partial fusion during transport to the surface in the basaltic magma and the removal of a salic liquid from granitic xenolith into the magma has resulted in the formation of a residue of anorthitic plagioclase and tridymite. Granitic xenoliths from other parts of Iceland, and their fusion products, are also described.

ABSTRACT

Structure and Products of Subaquatic Volcanoes in Iceland

by
Gudmundur E. Sigvaldason
Industrial Research and Development Institute
Reykjavik, Iceland

Published in: Contr. Mineral. and Petrol. 18, 1-16 (1968)

Iceland provides a unique opportunity to study the mechanism of subaquatic eruptions. The Neovolcanic zone dissecting the country from NE to SW has been volcanically active since the end of the Tertiary, and a large number of eruptions have occurred under glaciers where melt water provided a subaquatic environment.

The subaquatic volcanic piles have a regular structural sequence consisting of pillow lavas at the base covered by pillow breccias and glassy tuffs. This regularity is believed to result from external conditions rather than changes caused by variations in endogenic forces. The effective chilling of the lava surface as it enters the water prevents the natural degassing of the material under the prevailing hydrostatic pressure. The interior parts of a pillow continue to degass, however, creating gas pressures within each unit representing the amount of exsolved gases at magmatic temperature. The amount of exsolved gases is ultimately controlled by the hydrostatic pressure and pillow stability is thus a function of water depth above the volcanic vent. As the volcanic vent comes closer to the surface, a larger part of the dissolved gases will exsolve and pressures will be created within each glass encrusted unit which eventually are capable of exploding the material into fine-grained tuffs.

A subaquatic lavaflow tends to form a thick pile instead of spreading out because of the effective chilling of flow fronts. This pile, consisting to a large extent of pillows, is eventually covered with layers of glassy tuffs. These tuffs are characteristically altered into palagonite. The alteration process neither can be related to immediate reactions between the hot melt and water,

nor can this large-scale alteration be explained as a continuous weathering process under prevailing climatic conditions. It is suggested that a subaquatic volcanic structure is somewhat similar to a geothermal field during the period of cooling, where the pillow pile serves as a heat source and the tuffs provide the confining walls and cover. The palagonitization is thus considered to represent mild hydrothermal alteration in a short-lived thermal system.

The Surtsey Eruption
Course of events during the year 1967

by
Sigurdur Thorarinsson
Department of Geology and Geography
Museum of Natural History, Reykjavik

Introduction

My contribution to the Surtsey Research work in 1967 was to follow the course of events of the eruption and the morphological changes of Surtsey. In the latter I was assisted by Guttormur Sigbjarnarson, cand.real., The National Energy Authority. In Aug. 1967 Dr. John O. Norrman from the Department of Physical Geology, University of Uppsala, was on my proposal appointed Principal investigator of the littoral morphology of Surtsey and its changes. Dr. Norrman started his field work on Surtsey on Sept. 9, 1967, and spent about 10 days on the island.

During 1967 I made 17 reconnoitring flights over Surtsey. Six times the aircraft landed on the island and two times I landed there by boat. My stays on the island varied from a few hours to four days. Like in previous years I have enjoyed the helpfulness of the Director General of Aviation, Agnar Kofoed Hansen, and the director of the Coast Guard Service, Pétur Sigurdsson. The trips to Surtsey with the aim of landing have been paid by the Surtsey Research Society. I am indebted to the pilots Sigurjón Einarsson and Thórólfur Magnússon for valuable information from their many flights over Surtsey.

Aerial mapping

Using the Coast Guard Service's aircraft SIF the Icelandic Survey Department aerial-photographed Surtsey three times in 1967, viz. on January 3rd, March 29th and July 17th. The photographs of July 17th came closest to picturing the island as it was when the eruption ended and will be used for the preparation of a topographical map, scale 1:5000 with 5 m contour intervals.

The Surtsey eruption Dec 1966 - June 5 1967

In the Surtsey Research Progress Report III I gave a short description of the beginning and first months of the effusive activity that began when a 220 m long fissure opened up on the floor of the Older Surtur Crater (Surtur I) on Aug 19. 1966 From the beginning of December the lava flowed almost exclusively in small tunnels which opened up at or a short distance inside the sea-shore.

On December 12 it was observed that vapour was rising from a fissure on the inner slope of the Older Surtur Crater Examination of Sigurjón Einarsson's pictures showed that the fissure is faintly discernible on a photo taken Oct. 2. On Dec 15 I observed the fissure from the air It stretched from the lava floor of the crater up the slope to about 105 m height above sea level and its direction was W20^{o}N. A very small amount of lava had been poured out from its lower half, and from the upper half vapour was rising Dec. 17 Sigurjón Einarsson observed glowing lava in the lower half of the fissure, but there was no outpouring at that time, and this was the only time lava was observed glowing in that fissure. The lava produced by this fissure formed a small apron of a-a lava on top of the ropy lava floor in the Older Surtur Crater.

In the morning of Jan 1, 1967 it was observed from the Westman Islands that a fissure had opened up on the north slope of the Older Surtur Crater and lava flowed down the slope towards the lagoon. At 11 a.m. the following day, when I flew over Surtsey, the lava had filled half of the lagoon and was advancing westwards, seriously threatening the scientists' hut, Pálsbær (named after professor Paul Bauer, the benefactor of the Surtsey Research Society) situated on the west side of the lagoon (cf. the map, fig. 1).

The following morning I landed on Surtsey and studied the new eruption closer The production of lava had slowed up, and lava flowed then only from the lower one of two small craters that had been formed on the north slope of the Older Surtur Crater. The higher one of these small craters was about 110 m above sea level, the lower one about 20 m farther down on the slope, and from the higher crater the fissure stretched upwards to about 120 m height above sea level (All the height figures may have to be corrected a little when the photogrammetric map has been worked out). From this part of the fissure some sand had been blown out, but no lava had been extruded. On the south (viz. the inner) slope of the Older Surtur Crater a fissure had opened up - probably on Jan. 1 and certainly before the morning of Jan. 2 - to an elevation of about 100 m and poured out lava although on a smaller scale than the fissure on the north side. Two small craters were active on this fissure. By this new activity the nearly N - S running system of fissures pouring out lava had reached a total length of about 0.5 km. The lava level had now been raised to about the same height as it had reached in the Younger Surtur Crater during the autumn and winter 1964/65.

On Jan. 2, shortly after noon, a miniature fissure opened up on the NE side of the Older Surtur Crater in about 60 m height and lava was seen glowing there for some hours, but practically no lava was poured out there.

Fortunately enough, the lava front that advanced over the lagoon stopped on Jan. 4 at a distance of 120 m from the scientists' hut. In the crater on the north slope the lava was last seen glowing Jan. 6, while on the south slope the lavaflow ceased two days later. It had by then formed a narrow stream of a-a lava which had flowed about 150 m towards SE along the foot of the slope.

When landing on Surtsey Jan. 7, 1967, I observed on the inner side of the Older Surtur Crater two parallel curved fault scarps - the downthrow about 1 m - and some lava had been squeezed out along the lower one. The lava filling such a fissure has actually formed a cone sheet.

From the fissures that had opened up on Aug. 19, 1966, lava flowed incessantly, but on the whole on a gradually diminishing scale, during the entire winter and spring of 1967. The average rate of lava production was about 2 m^3/sec. On June 5 it was last seen glowing at the south shore of Surtsey, but now and then some vapour was observed rising from the south coast of Surtsey until the middle of October 1967.

As mentioned before the lava flowed mainly in tunnels In the craters on the Aug. 19-fissure the height of the lava level varied a lot, and the small lava lake boiling there gradually diminished in area. One of the last things to happen in the craters was a building up of a nearly 10 m high hornito on the floor of the northern crater during the first half of May 1967. The map, fig. 1, shows the craters as they were when the eruption ended.

At the end of the year 1967 the emission of vapour from the Aug. 19-fissure and its craters had nearly ceased, but there was still some vapour rising from the fissures that opened up in early October and on Jan. 1 on the inner side of the Older Surtur Crater and also from the upper crater on the north slope. The emission of vapour around the lava crater of 1964 seemed rather to increase during the autumn and early winter, especially on the west side of that crater.

The lava from the 1966/67 effusive phase of the Surtsey eruption covers about 250 acres, whereof 10 on the north side of the island. Of these 250 acres 125 are outside the shore as it was when the lava flow began. The area of Surtsey when the eruption ended was 2.8 km^2 (280 ha).

Although it is a question of definition when an eruption really ends, the author regards the 1966/67 lava phase of the Surtsey eruption as having come to an end on June 5, 1967, when lava was last seen glowing and showing signs of being still moving, and so long a time has now elapsed since then that a renewed activity in Surtsey or adjacent area will probably be regarded as a new eruption - this is also a question of definition.

On June 5, 1967, the Surtsey eruption had lasted 3 years and 7 months and been visible for 3 years and 4 1/2 month. It is the second longest eruption in Iceland since its settlement began 1100 years ago, and only a few months shorter than the longest one, the "Mývatn Fires" 1725 - 1729, which were in many ways a similar eruption except for the difference caused by different environment in which the eruptions took place; one in the sea, the other on dry land The total production also was on a similar scale.

In the previous reports on the Surtsey eruption as well as in other papers published on the eruption I have tried to calculate approximately the average lava and tephra production in m^3/sec for the various phases of the eruption. According to these calculations the total production of lava and tephra should amount to about 1.1 km^3. A bethymetric map 1:10 000 based on measurements carried out by an English research vessel in cooperation with the Icelandic Hydrographic Service on July 12 - 25, 1967, is now available. According to a hypsographic curve based on that map the total volume of Jólnir, Surtsey, Syrtlingur and Surtla above 120 m depth is about 0.94 km^3, and above 125 m depth it is about 1.02 km^3. The average depth in the area before the Surtsey eruption started did probably not exceed 125 m.

Taking into consideration the distribution of Surtsey tephra on the Westman Islands and the isopach maps of the Syrtlingur and Jólnir tephra on Surtsey I have roughly calculated that the volume of tephra deposited outside the area covered by the hypsographic curve to be 115 $\pm$ 25 million m^3. Consequently the total amount of tephra and lava produced by the Surtsey eruption is 1.1 to 1.2 x $10^9 m^3$, whereof about 70% is tephra. Only about 9% of this material is now above sea level.

Text to pictures

Figure 1: The outlines of Surtsey, Syrtlingur and Jólnir at different times.

I. The Older Surtur Crater as it was on July 17, 1967.

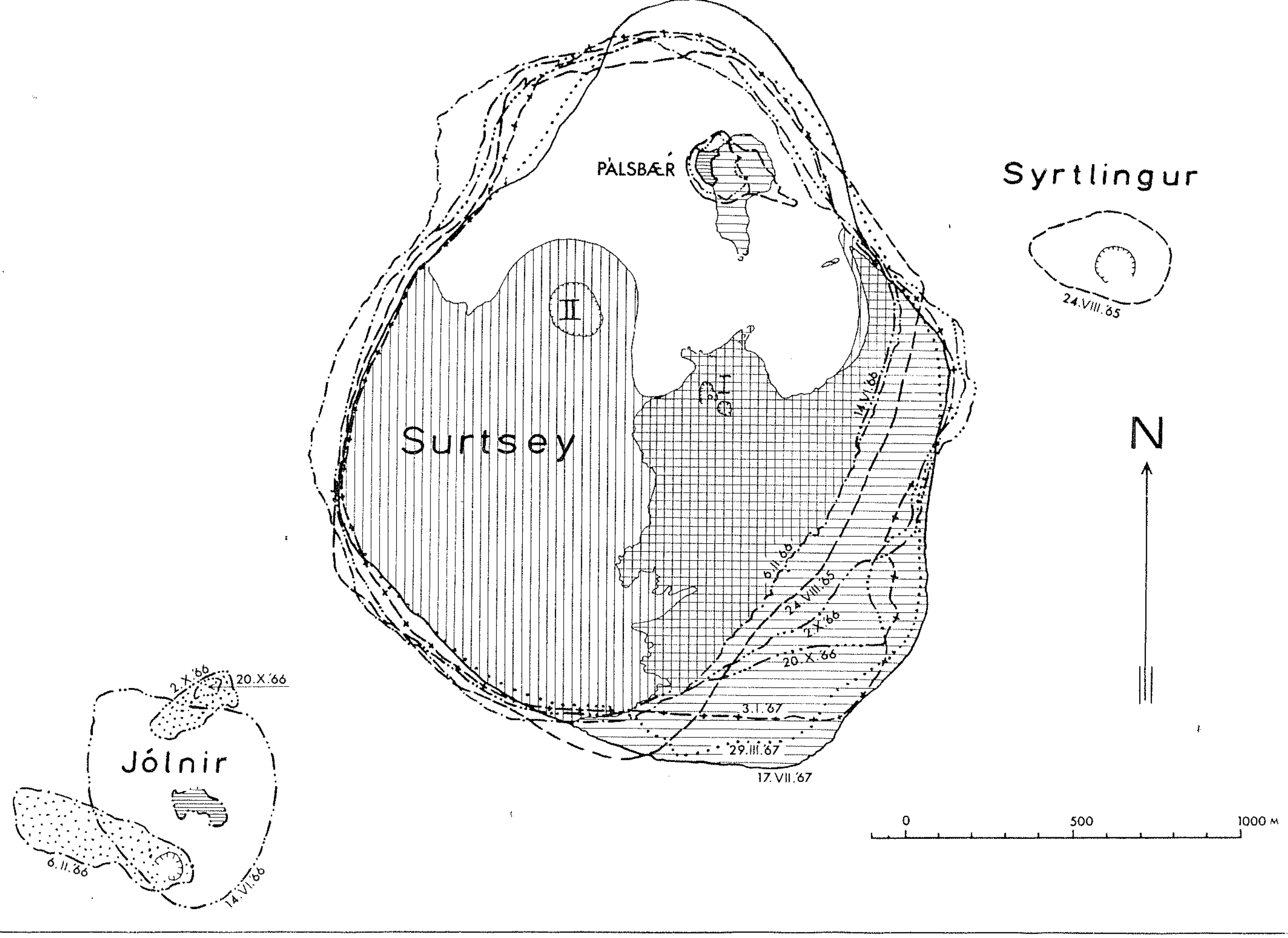
II. The Younger Surtur Crater.

Vertical and cross striation: areas covered by the 1964/65 lava.

Horizontal and cross striation: areas covered by the 1966/67 lava.

Dense striation: lagoon.

Dotted areas (Jólnir): shoals more or less visible at low tide.



Syrtlingur
24.VIII.'65
PÁLSBÆR
II
I
Surtsey
14.VI.'66
6.II.'66
24.VIII.'65
2.X.'66
20.X.'66
3.I.'67
29.III.'67
17.VII.'67
N
Jólnir
2.X.'66
20.X.'66
6.II.'66
14.VI.'66
0
500
1000 M

Result of Precision Levelling in Surtsey

by

Eysteinn Tryggvason, Associate Professor
The University of Tulsa, Tulsa, Oklahoma

Introduction

On June 20 a levelling profile across the Surtsey lava was marked by 42 benchmarks consisting of small brass pins. These pins were inserted into the lava surface in a permanent position and a number (601 to 642) was stamped on each pin (Figure 1). This profile was levelled from east to west on June 21 to 22. A second levelling was made on August 9 to 10, also from east to west, and the third levelling on August 11-12 from west to east.

In addition, levellings from the east end of the profile (601) to the pond east of the research hut (Pálsbær) and to the doorstep of the hut were made on June 23 and again on August 12. Measurements of the surface elevation of a pond near the north shore of the island were made on August 9 to 12, and these were tied to the levelling profile.

Levelling across the Surtsey lava

The main result of the levelling is shown in Table 1 and Figure 2. In Table 1 all elevations are based on the elevation of benchmark 601 at the east end of the profile. As this work is primarily a study of the deformation of the Surtsey lava by comparing levellings made at different times, the accuracy of these levellings are of utmost importance.

The levelling of June 21-22 was less accurate than the later levellings due to limited time and experience. However, the probable error in relative elevation of the benchmarks is less than 0.5 millimeters over a distance of one kilometer. The levellings of August 9 to 12 are more accurate, with probable error about 0.25 millimeter per kilometer of profile. Thus the variation of observed elevation

(Table 1) is very much greater than the error of observation

The change in observed elevation of the benchmarks is shown in Table 1, and the average daily change is shown on Figures 3 and 4. The whole profile subsided relative to benchmark 601 with the possible exception of benchmark 642 on the west coast of Surtsey. Greatest subsidence between June 21-22 and August 9-10 was observed for benchmarks 619 (7.7 centimeters), 617 (5.6 centimeters), 625 (4.5 centimeters), 608 (3.4 centimeters), and 626 (3.3 centimeters). Other benchmarks subsided less than three centimeters. The probable error of the observed subsidence is about one millimeter on the western part of the profile and less on the eastern portion, making the probable error in the average daily rate of subsidence approximately 0.02 millimeters for the period June 21-22 to August 9-10 (Figure 3). Estimated errors in Figure 4 increase from left to right due to decreased time between levellings and are roughly 0.2 millimeters at benchmark 620 and 0.5 millimeters at 642. When Figures 3 and 4 are compared, it is clear that the rate of deformation is similar for the roughly 50 days period covered in Figure 3 and for the one to three day period covered in Figure 4. However, there are some significant changes. The movement of benchmarks 616, 617, 618, 619 and 620, relative to each other, is greater for the later period. The increase in average relative rate of movement in this area from the first to the second period amounts to about 20 percent. These benchmarks are in the area of the latest lava flows of Surtsey and the lava of this area was quite hot during the summer of 1967. The irregular movement of this area is probably caused by slow plastic flow of the still hot lava. Contraction due to cooling of the lava may account for a fraction of this subsidence.

The portion of the profile lying between benchmarks 621 and 640 was subsiding rapidly in August 1967 while a quite slow subsidence was observed over the much longer period between the first and second levelling. The rate of vertical movements of benchmarks 624 through 638, relative to each other, is, however, very similar for the two periods, while the whole area where the benchmarks are located, has started to subside rapidly in August of 1967.

The change in rate of deformation from the first to the second period is shown on Figure 5. This graph shows very clearly the increased rate of subsidence in the western part of the island. A subsidence of benchmarks 624 to 638 at the rate observed in August 1967 would in one week account for the total subsidence of this area between June 22 and August 10.

Levelling near the north coast of Surtsey

On June 22 the surface of the pond east of the research hut was tied by levelling to benchmark 601 and to the doorstep of the hut. It was assumed that the surface elevation of this pond was very close to mean sea level. On August 13 levelling was performed from benchmark 601 to several points on northern Surtsey, including the average elevation of the pond near the coast north of the research hut. Table 2 shows the result of these levellings.

The elevation of the northern pond was observed around high-and-low tide during a four day period, August 9 to 12, so the average elevation of this pond was obtained with an accuracy of roughly 5 centimeters. The amplitude of the tides in this pond was 1.52 meters on August 9 but decreased during the period of observation due to decreasing ocean tide (Table 3). The pond tide was delayed more than two hours relative to predicted ocean tide in Heimaey. The difference in time of ocean tide at Surtsey and Heimaey is not known but assumed to be insignificant. The average delay of the low tide is 2 hours 52 minutes, while the high tide is delayed an average of 2 hours 24 minutes. Furthermore, the delay is greater for large tidal amplitude than for small amplitude.

There is certainly some difference between the mean elevations in the pond and in the ocean, the pond being somewhat higher. How much this amounts to is not exactly known, but a mathematical solution of the problem seems possible and will be attempted. Preliminary study indicates that the average surface elevation of the pond may be about 10 centimeters above mean sea level.

The southern pond was about 12 centimeters lower on August 12 than on June 22, relative to 601 and the research hut. On August 12, this pond was about 10 centimeters above the mean elevation of the northern pond and it is highly unlikely that the difference between the two ponds varies much. It is assumed that heavy rain may temporarily raise the level of the southern pond but the high permeability of the coarse sand between the pond and the ocean will allow a fast recovery of normal pond level. The elevation of the southern pond decreased about one centimeter per day during August 9-12, 1967. This was probably due to decreasing ocean tide during that period.

The water level in beach sand is normally somewhat higher than the mean sea level, the difference being proportional to the amplitude of the tide. The tidal amplitude of the northern pond decreased about 10 percent per day during August 9-12. Therefore, it may be assumed that the elevation of the southern pond above mean sea level has decreased about 10 percent per day during the same period. This reasoning places the elevation of the southern pond only 10 centimeters above mean sea level and the average elevation of the northern pond very close to mean sea level.

It is probable that the elevation of the southern pond is always nearly the same, relative to sea level except during periods of heavy rain and that the observed decrease in its elevation relative to the hut and 601 during the summer of 1967 is in fact due to an uplift of the northern part of Surtsey.

Conclusion

The Surtsey lava was deforming quite rapidly during the summer of 1967. Most of it subsided relative to benchmark 601 which is located near the northern edge of the lava, east of the tuff mountain formed during the first phase of the Surtsey eruption in 1963-64. Certain portions of the lava (benchmarks 608, 617, 619, 625) subsided more rapidly than other areas, probably due to slow plastic flow of the hot lava, and the subsidence rate of the lava was mostly higher in early August than earlier in the summer.

A large area in the western part of the lava where benchmarks 622 through 640 lie, appears to have started to subside as one block in early August 1967. These benchmarks are all within 500 meters distance from the lava crater of 1964-65 while all other benchmarks on the levelling profile are farther away from this crater. This might indicate a beginning of the formation of a caldera-like depression of roughly 500 meters radius, centered near the crater.

Levelling on the northern part of Surtsey indicates that benchmark 601 was uplifted relative to sea level during the 50 days between the first and last levelling. This uplift may amount to about 10 centimeters.

Acknowledgements

This research was partly supported by the National Science Foundation grant GP-5365 and partly by the Surtsey Research Society.

TABLE I

ELEVATION OF THE SURTSEY PROFILE AND CHANGES IN MEASURED ELEVATION

Benchmark	Elevation* meters	DH (1)** millimeters	DH (2)*** millimeters	Average daily rate of elevation changes in millimeters A***	B***
601	0.0000	0.000	0.000	0.000	0.000
602	2.1116	-5.085	-0.076	-0.103	-0.026
603	3.7015	-7.103	-0.244	-0.144	-0.083
604	6.6902	-11.668	-0.525	-0.237	-0.180
605	9.9526	-14.248	-0.818	-0.289	-0.282
606	12.2598	-14.386	-0.844	-0.292	-0.291
607	14.9332	-24.443	-1.121	-0.497	-0.389
608	14.5701	-34.310	-1.398	-0.698	-0.488
609	15.5663	-22.545	-0.671	-0.459	-0.227
610	16.9093	-12.085	-0.397	-0.246	-0.128
611	19.8787	- 8.928	-0.380	-0.182	-0.122
612	22.1399	- 9.893	-0.155	-0.202	-0.039
613	24.4769	-18.145	-0.532	-0.370	-0.180
614	25.3169	-11.335	-0.276	-0.231	-0.084
615	26.3514	-11.138	-0.316	-0.277	-0.099
616	33.5863	-23.459	-0.827	-0.478	-0.293
617	35.1862	-55.622	-2.428	-1.134	-1.087
618	38.3812	-22.520	-0.872	-0.459	-0.307
619	40.0789	-77.015	-3.691	-1.571	-1.735
620	42.5310	- 8.921	-1.582	-0.197	-0.174
621	42.3529	-23.402	-2.198	-0.492	-0.646
622	43.4024	-17.345	-2.619	-0.368	-0.975
623	43.6928	-23.200	-3.138	-0.487	-1.389
624	44.8529	-29.603	-3.255	-0.618	-1.484
625	47.5836	-44.779	-3.811	-0.928	-1.944
626	46.3979	-33.215	-3.352	-0.692	-1.554
627	38.1017	-19.533	-3.051	-0.413	-1.282
628	30.1553	-11.671	-2.969	-0.253	-1.204
629	23.4799	- 7.434	-2.712	-0.167	-0.945

TABLE I -- Continued

ELEVATION OF THE SURTSEY PROFILE AND CHANGES IN MEASURED ELEVATION

Benchmark	Elevation* meters	DH (1)** millimeters	DH (2)** millimeters	Average daily rate of elevation changes in millimeters A***	B***
630	22.1249	- 6.091	-2.716	-0.133	-0.949
631	21.8859	- 6.078	-2.952	-0.133	-1.231
632	23.3125	- 6.990	-2.528	-0.152	-0.763
633	24.6109	- 6.592	-2.842	-0.144	-1.118
634	24.4854	- 7.879	-2.715	-0.170	-0.971
635	28.4475	- 8.576	-3.019	-0.184	-1.334
636	24.4872	-10.444	-2.916	-0.222	-1.205
637	23.0009	-10.301	-3.006	-0.219	-1.321
638	21.5758	- 9.051	-2.919	-0.193	-1.206
639	17.9631	- 7.930	-2.563	-0.160	-0.716
640	13.5802	- 6.695	-2.317	-0.135	-0.367
641	11.8132	- 5.653	-2.164	-0.114	-0.135
642	7.0888	- 0.498	-1.834	-0.009	+0.376

* Elevation as measured June 21 to 22, 1967, above benchmark 601.

** DH (1) is the change of measured elevation from June 21 - 26 to August 9 - 10 assuming no movement of 601.
DH (2) is the change from August 9 - 10 to August 10 - 11.
Minus sign means subsidence relative to 601.

*** A covers the period June 21 - 22 to August 9 - 10
B covers period August 9 - 10 to August 11 - 12.

TABLE 2

DIFFERENCE IN ELEVATIONS ON NORTHERN SURTSEY

	June 23, 1967 cm	August 13, 1967 cm
H (601) - H(S - Pond)	878.42	890.63
H (Doorstep) - H (S - Pond)	728.42	740.32
H (S - Pond) - H (N - Pond)		9.73
H (000) - H (N - Pond)		406.21
H (Doorstep) - H (N - Pond)		750.06
H (601) - H (N - Pond)		900.36
H (Marker - 0) - H (N - Pond)		153.62
H (601) - H (Doorstep)	150.00	150.31
H (601) - H (Marker - 0)		746.74
H (Marker - 0) - H (S - Pond)		143.88
H (Doorstep) - H (Marker - 0)		596.44

H (601) is the elevation of benchmark numbered 601

H (S - Pond) is the surface elevation of the southern pond (Dropi)

H (N - Pond) is the average surface elevation of a tidal pond near the north coast of Surtsey

H (Doorstep) is the elevation of the doorstep of the research hut

H (000) is the elevation of top of galvanized pipe marking the zero point of triangulation grid in Surtsey

H (Marker - 0) is the elevation of a brass nail placed in lava about one meter east of north end of the southern pond

TABLE 3

TIDAL OBSERVATIONS IN THE NORTHERN POND ON SURTSEY

August 9 - 12, 1967

Time of high or low tide		Height of tide in pond	Delay of pond tide	
In pond	In Ocean			
d h m	d h m	cm	h	m
9-16-51	9-13-56	-69.9	2	55
9-22-39	9-20-09	80.6	2	30
(10-05-13)	10-02-27	(-67)	(2	46)
10-10-58	10-08-33	64.1	2	25
10-17-35	10-14-40	-64.8	2	55
10-23-19	10-20-52	74.9	2	27
11-06-11	11-03-10	-66.0	3	01
11-11-41	11-09-19	54.5	2	22
11-18-16	11-15-26	-63.4	2	50
11-23-58	11-21-40	61.1	2	18
12-06-45	12-03-56	-57.5	2	49
12-12-30	12-10-11	55.7	2	19
12-19-08	12-16-20	-41.5	2	48

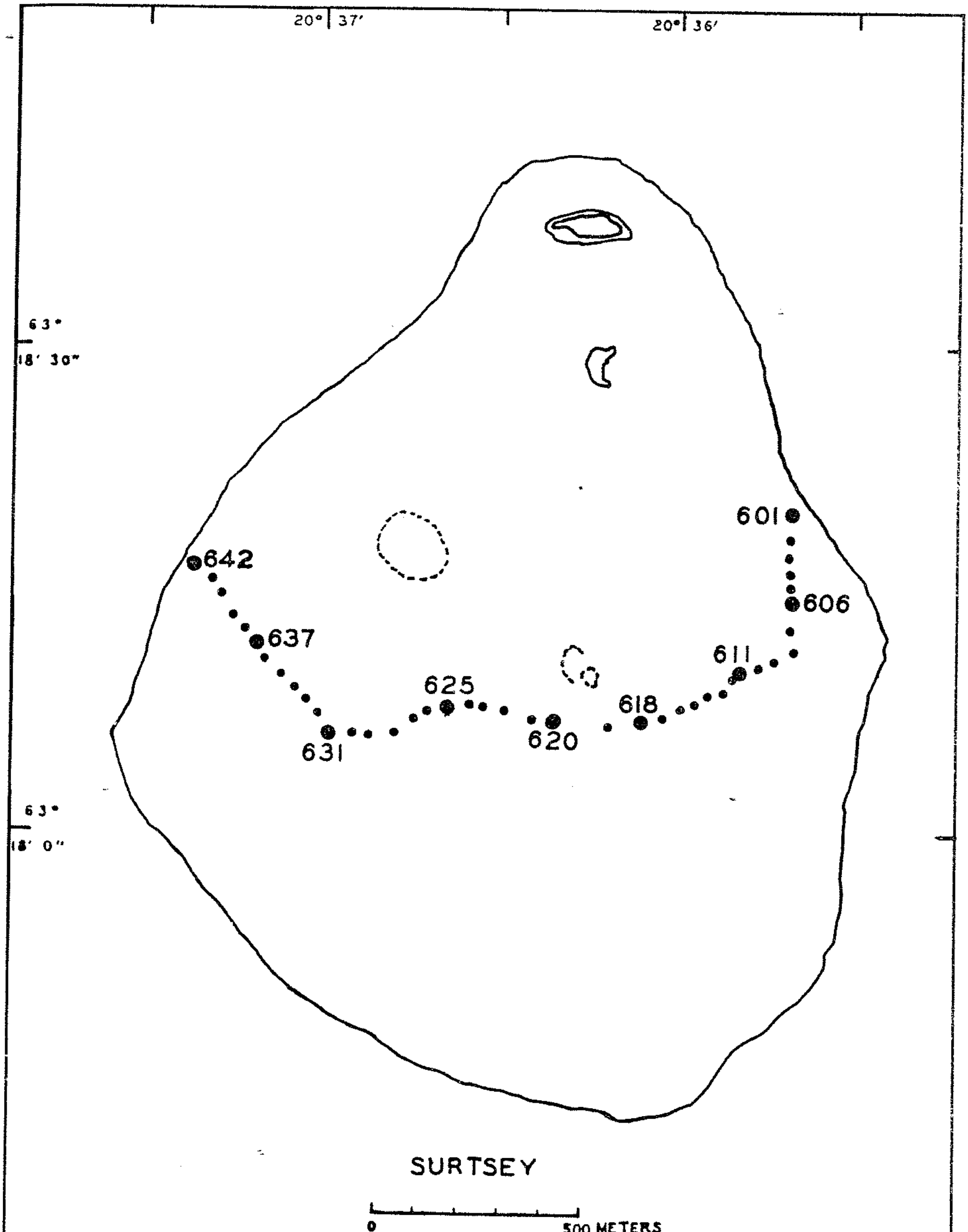


FIGURE 1. MAP SHOWING LOCATION OF BENCHMARKS ON THE LEVELLING PROFILE IN SURTSEY.

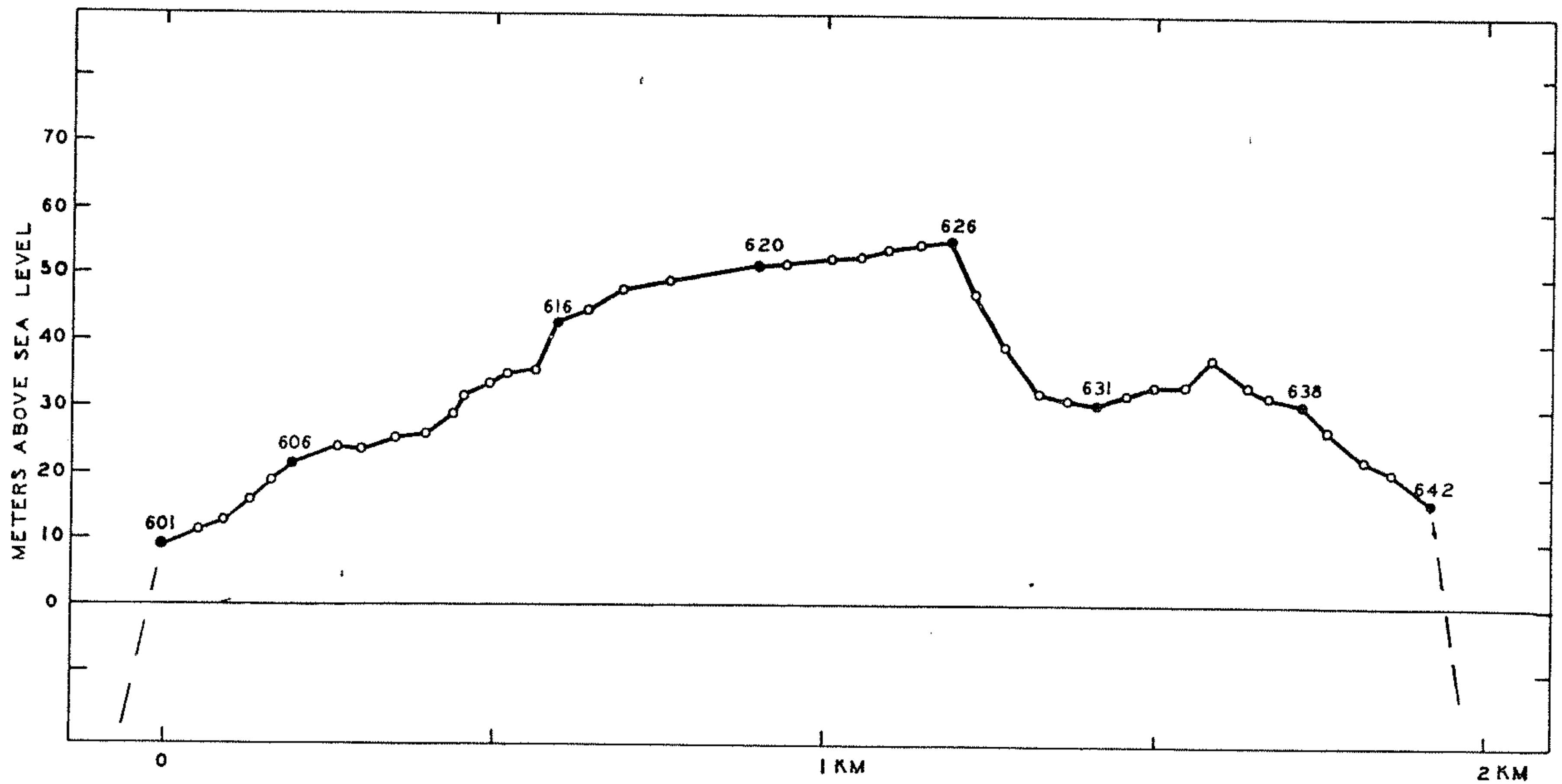


FIGURE 2. ELEVATION OF THE LEVELLING PROFILE IN SURTSEY IN JUNE 1967
VERSUS DISTANCE ALONG THE PROFILE

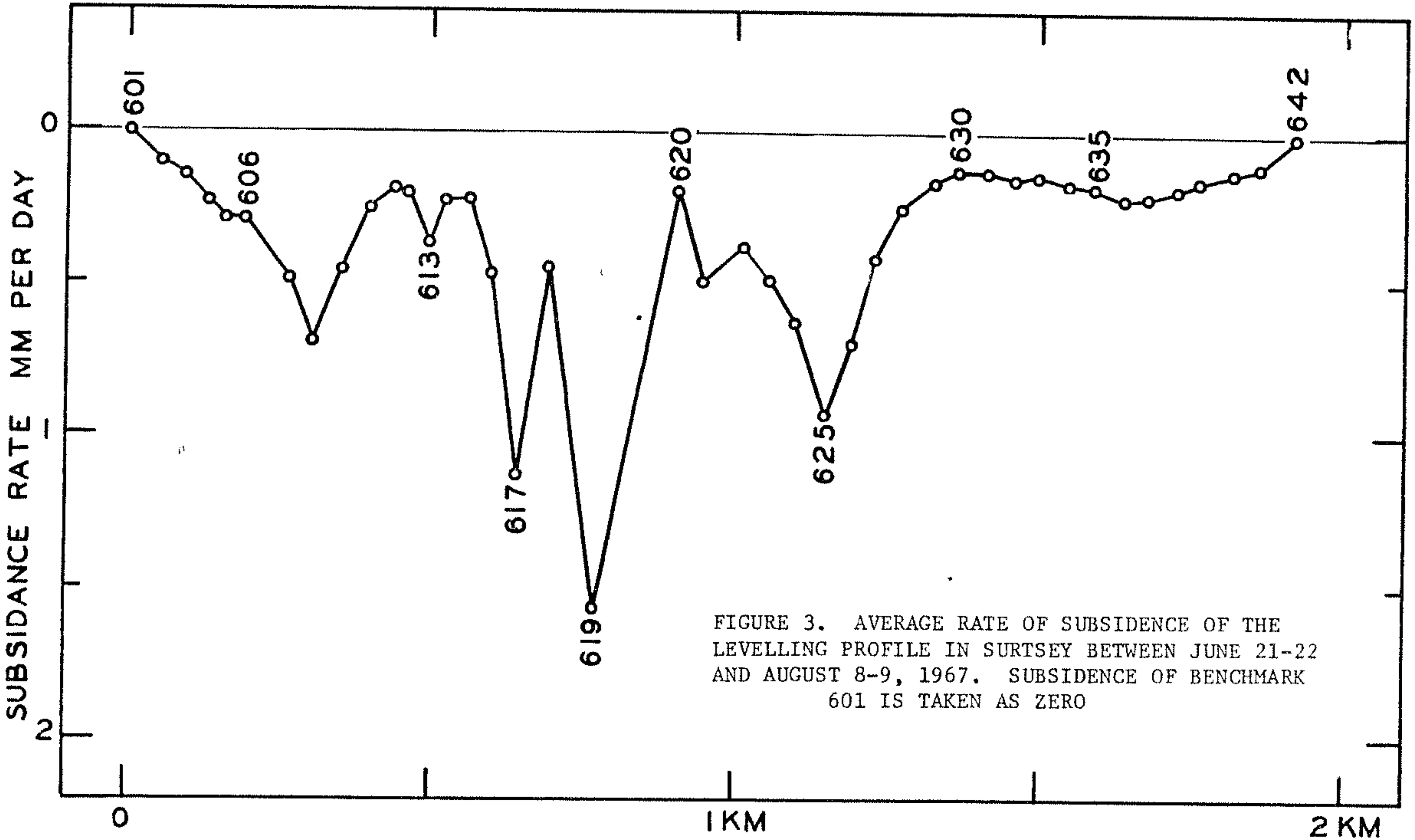


FIGURE 3. AVERAGE RATE OF SUBSIDENCE OF THE LEVELLING PROFILE IN SURTSEY BETWEEN JUNE 21-22 AND AUGUST 8-9, 1967. SUBSIDENCE OF BENCHMARK 601 IS TAKEN AS ZERO

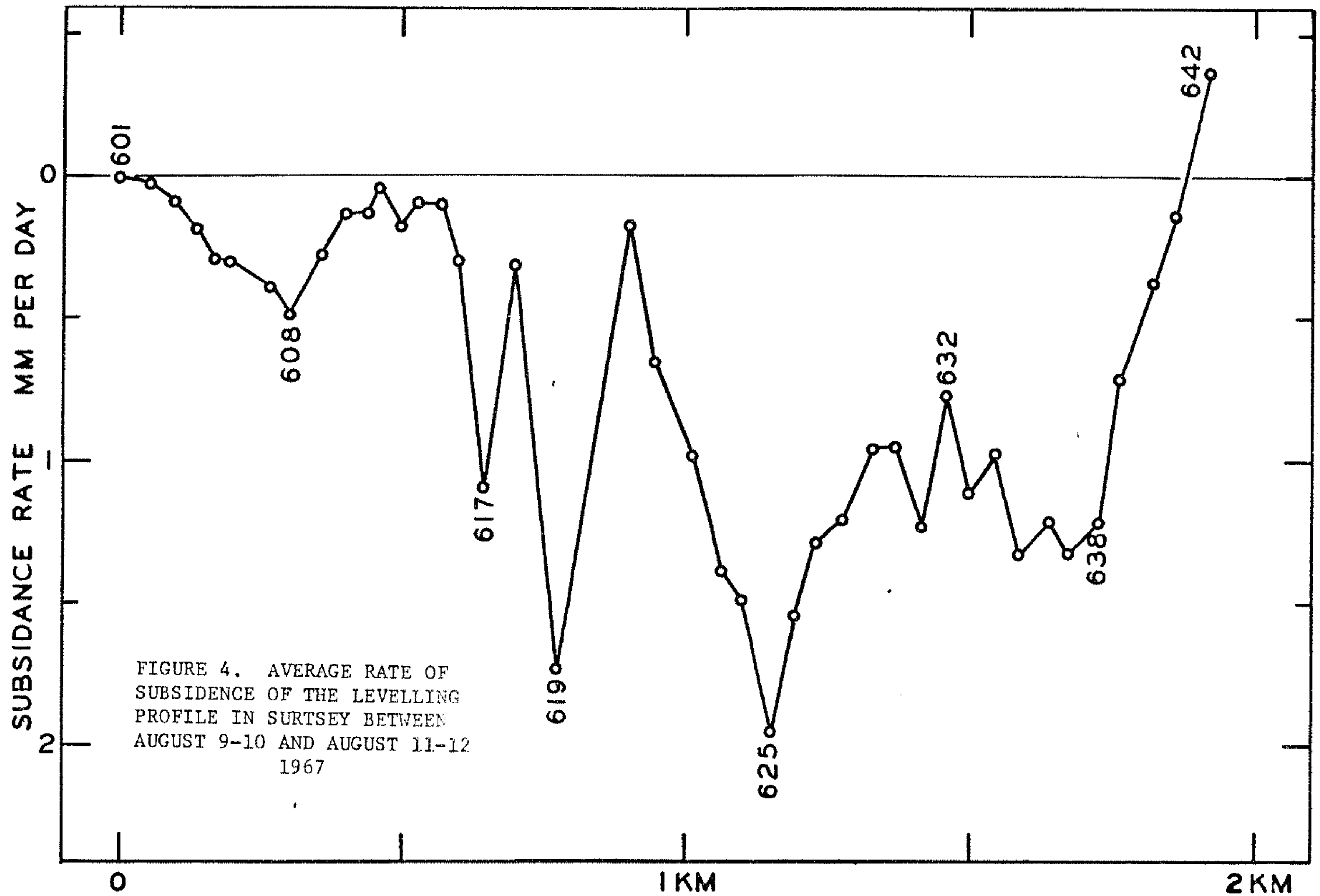


FIGURE 4. AVERAGE RATE OF SUBSIDENCE OF THE LEVELLING PROFILE IN SURTSEY BETWEEN AUGUST 9-10 AND AUGUST 11-12 1967

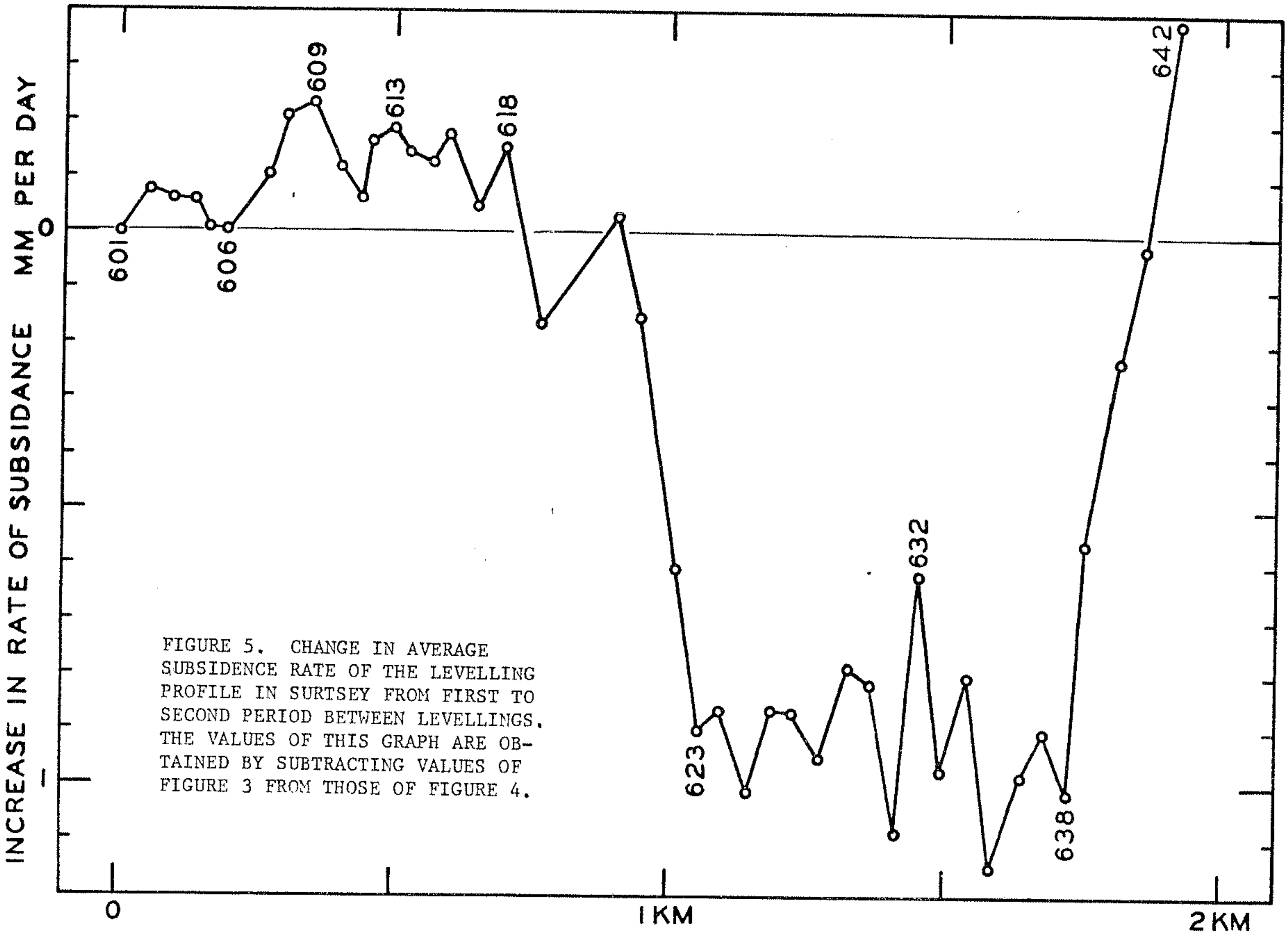


FIGURE 5. CHANGE IN AVERAGE SUBSIDENCE RATE OF THE LEVELLING PROFILE IN SURTSEY FROM FIRST TO SECOND PERIOD BETWEEN LEVELLINGS. THE VALUES OF THIS GRAPH ARE OBTAINED BY SUBTRACTING VALUES OF FIGURE 3 FROM THOSE OF FIGURE 4.

GEOCHEMISTRY

ABSTRACT

Collection and Analysis of Volcanic Gases at Surtsey

by

Gudmundur E. Sigvaldason and Gunnlaugur Elísson
Industrial Research and Development Institute
Reykjavik, Iceland

Will be published in: Geochimica et Cosmochimica Acta, 1968

The results of sampling and analysis of volcanic gases emitted during the recent eruption of Surtsey are reported. On several occasions natural conditions provided the possibility of sampling gases without detectable atmospheric contamination. Samples collected within the erupting crater or in its immediate vicinity are believed to represent the initial degassing stage of the magma. Later degassing stages are represented by samples collected at various distances from the crater. It is concluded that hydrogen, water and carbon components are released preferentially during the initial degassing stage but sulphur components show a relative increase as degassing proceeds.

The average atomic ratios of the three least contaminated samples is as follows: H:O:Cl:S:S:N: 176:100:0.40:2.58:5.85:0.135.

Water Soluble Leachate of Volcanic Ash from Surtsey

by
Gudmundur Sigvaldason
The Industrial Research and Development Institute
and
Sturla Fridriksson
The Agricultural Research Institute

Loose cinder and ash covers a great part of the central area and the northern slopes of Surtsey. This substrate was formed during the first phase of the eruption when tephra was erupted from the submarine crater and piled up in a cone shaped island. This substrate was therefore continuously mixed with ocean water as it was being formed, and in 1966, when tested for soluble mineral content, it still had a high salt content.

No growth has so far started on this substrate, possibly due partly to the high salinity (0.7 g NaCl/1 kg) and the large amount of $CaSO_4$.

A sample of 6 kg was collected from a 20 cm thick surface layer approximately 80 m above sealevel on the northern slope of the island.

The total sample was leached thoroughly with distilled water. Altogether 7.29 g of dissolved salt were found in the leachate. An analysis of the leachate is presented in Table I.

The balance between cations (124.5 eqv.) and anions (116.5 eqv.) is fair.

Assuming that the reactions between the tuffaceous material and sea water does not involve chloride, the gain or loss of chemical elements in the leachate relative to sea water can be calculated (Table I).

TABLE I

Analysis of leachate of ash from Surtsey compared with sea water

Element	Leachate of Surtsey ash mg/l	Sea water mg/l	Relative gain on equal Cl-basis	
			El. $\frac{Cl\ ocean}{Cl\ Surtsey}$	%
Ca	535	410	3563	24 14
Mg	252	1280	1678	3.05
Na	1710	10470	11389	7.04
K	106	380	706	2.50
Cl	2850	18970	18970	
SO_4	1642	2650	10936	63.27
HCO_3	3,7	140		
F	0,6			
PO_4	4,5			
SiO_2	52,0			

Large amount of $CaSO_4$ in excess of $CaSO_4$ in normal sea water indicates that sea has been sprayed repeatedly over the ash. This sea water has evaporated and precipitated $CaSO_4$ which has not been leached out again to the same extent as other components during rainy weather. A slight but probably significant increase relative to sea water is found in other components such as Na, K and Mg. A part of this material as well as silica has probably been leached out of the rocks.

G E O P H Y S I C S

Preliminary Report on Meteorological Observations in Surtsey 1967

by

Hlynur Sigtryggsson
The Icelandic Meteorological Office, Reykjavik

Observations of temperature, wind and general weather conditions were begun on April 1st and continued until September. They were far from continuous, however, and averages can not be based on them, but they may serve as a basis for comparison between weather conditions on Surtsey and on Stórhöfdi, and to make some inference regarding the climate of Surtsey.

On June 30th the following instruments were installed:

1. Automatic Registering Station, which registered wind direction and speed, temperature and rainfall. The station was installed on the western part of the island south of Bóndi. The station was operative through July.

2. Thermo - Hygrograph was installed in a special shelter above the hut. It was operative until September 20th.

3. Soil thermograph was installed near the hut. Measuring elements were at 5 and 20 cm depths. It was operated until September 20th.

4. Barograph was installed in the hut. It was intended that it should register explosions from the eruption, but it did not fulfil this purpose, since the eruption stopped before the installation. The barograph was not well suited for this purpose anyway, since it had an effective damping device.

Preliminary survey of the observation material shows that the general climate of Surtsey is very similar to Stórhöfdi. The mean temperature difference amounts to 0.9°C in April and 0.5 - 0.6°C in June and July, which is roughly what could be expected from difference in elevation of the two stations; the temperature being generally warmer in Surtsey.

Using observations on Surtsey and Stórhöfdi the mean temperature for the spring and summer months of 1967 is as follows in Surtsey:

April	3.1°C
May	6.0 "
June	8.3 "
July	9.8 "
August	10.3 "
September	9.1 "

The main characteristics of the air temperature is the small daily amplitude, 3 - 4°C being a characteristic amplitude on sunny days, and 1 - 2°C on overcast days. This is clearly caused by the proximity of the sea.

Precipitation values at Surtsey suffer from the same shortcomings as other observations, they are not continuous, except for July, when the automatic station was operating. The station had the inherent defect, however, of collecting blowing sand and registering that as precipitation. During July it was not difficult to distinguish the lithometeor from the hydrometeors, but it might prove troublesome on other occasions.

In July the automatic station registered a total rainfall of 43.0 millimeters. In the same month Stórhöfdi registered a rainfall of 54.9 mm. With few exceptions the various intervals of observations in April through June in Surtsey showed the same general tendency, i.e. considerably less precipitation in Surtsey than on Stórhöfdi, most of the Surtsey values ranging from 60 to 80% of the corresponding values at Stórhöfdi. This general trend was reversed, however, on a small minority of the individual values.

The precipitation at Stórhöfdi in 1967 is as follows:

Month	mm.
April	106.2
May	44.7
June	149.8
July	54.9
August	84.3
September	97.4

During July, when the automatic station was in operation, the mean wind speed was measured 4.1 m/sec. at two meters above the ground. The corresponding figure at Stórhöfdi is 6.9 m/sec. at 9 meters above the ground.

If it is assumed that the wind speed at 2 meters has to be increased by 25% to get a figure comparable to the speed at 9 meters, the wind speed at Surtsey would be 5.1 m/sec. which is only slightly higher than the wind observed in the same month at some stations on the south coast of Iceland (Mýrar 4.6, Eyrarbakki 4.8 m/sec.).

In marked contrast with the air temperature the soil thermometers show a very pronounced daily amplitude, a 10-12°C difference being typical on a sunny day in July at 5 cm depth and 2.5 - 3.0°C at 20 cm depth. The corresponding figures on a cloudy day are 4°C and 1°C or less. The mean temperature of the soil in July is considerably higher than of the air, the mean temperature at 5 cm depth is 14.2°C but 12.7°C at 20 cm.

The corresponding figures at Reykjavik are 11.2°C and 9.9°C, in a plot without vegetation. The vertical temperature gradient is therefore greater at Surtsey than at Reykjavik, and one may therefore assume that the volcanic heat in Surtsey is quite insignificant at the spot where the soil measurements were made.

Soil temperature and its daily amplitude decreases slowly in August and early September. When the observations were discontinued late in September, the mean temperature at 5 cm depth was close to 9°C and the daily range 1 to 2 degrees. At 20 cm depth the corresponding figures were 8°C and 1/2°C.

Although the above findings are based on discontinuous observations, it seems clear that the general climatic conditions in Surtsey do not deviate much from those of Stórhöfdi, and deviation can be inferred from well known principles. (Precipitation is a possible exception to this). The microclimate of the island seems to be quite different, however, especially the temperature conditions over the sand where new vegetation is most likely to appear.

In the future it is therefore intended to continue some observations of the general climate, but to place increased emphasis on microclimatic observations.

Acknowledgements

This work has been sponsored by the Surtsey Research Society under an U.S. Atomic Energy Commission grant.

Report on Hydrographic Surveys at Surtsey 1967

by

Pétur Sigurdsson
Icelandic Coast Guard, Reykjavik

By an agreement between the Icelandic Hydrographer and the Commanding Officer of H.M. Surveying Ship HECLA, Captain G.P.D. Hall, R.N. D.S.C., one survey boat and crew were detached from HECLA to carry out hydrographic surveys around Surtsey from the 12th to the 25th of July 1967, while HECLA was carrying out oceanographic surveys south óf Iceland.

Sub-lieutenant B.E.T. Humphrey, R.N., was in charge of the survey party from HECLA. Accommodation for the survey party were arranged in the Westman Islands and costs involved were born by the Icelandic Hydrographic Service.

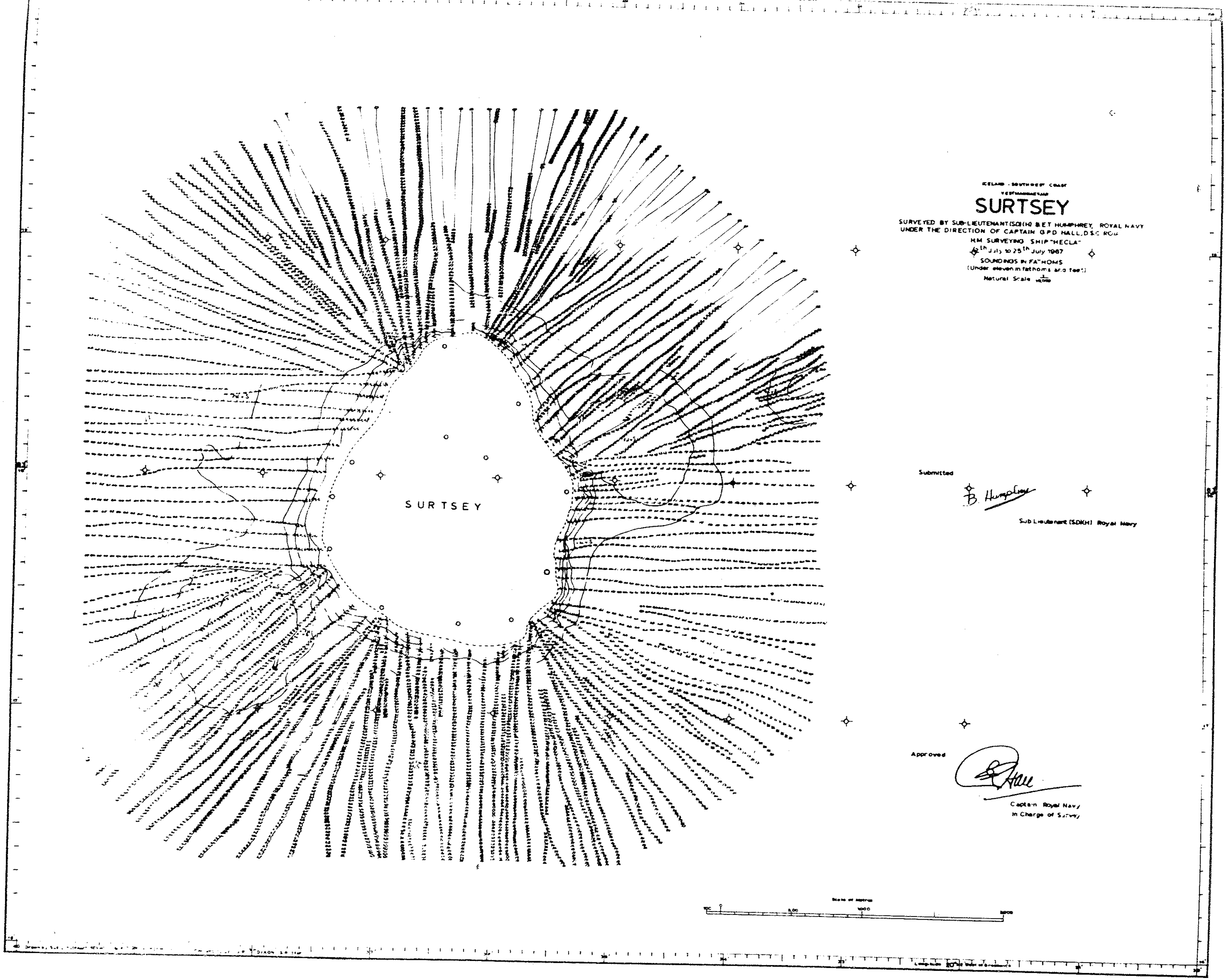
Scale and extent of survey was specified by the Icelandic Hydrographic Service while the execution of the work was wholly the responsibility of the officer in charge, - using conventional British hydrographic techniques.

The survey work was carried out in close cooperation with the Icelandic Coast Guard vessel THOR, which was at the same time engaged in hydrographic work west of the Westman Island.

Some preliminary work had been carried out by the Icelandic Hydrographic Service, i.e. location of survey marks on Surtsey and installment of a tide gauge in Heimaey harbour.

Scale of survey was 1:10000. Soundings in fathoms and feet reduced to mean low water springs.

Area covered was approximately 6 square nautical miles or a belt of ca 1 nautical mile in width around the island from close inshore out to a depth of about 70 fathoms.



SURTSEY
SURVEYED BY SUB-LIEUTENANT(SD)(H) B.E.T. HUMPHREY, ROYAL NAVY
UNDER THE DIRECTION OF CAPTAIN G.P.D. HALL, D.S.C. R.N.
HM SURVEYING SHIP "HECLA"
6th July to 25th July 1967
SOUNDINGS IN FATHOMS
(Under eleven in fathoms and feet)
Natural Scale
SURTSEY
Submitted
B. Humphrey
Sub Lieutenant (SD)(H) Royal Navy
Approved
Captain Royal Navy
In Charge of Survey

Continued Geomagnetic and Seismic Measurements on Surtsey

by
Thorbjörn Sigurgeirsson
University of Iceland, Science Institute

Geomagnetic measurements

Magnetic field measurements were continued at the stations Surtsey I, II and III. Field intensity measurements were carried out with the same proton precession magnetometer as before and the results are listed in Table I. (Field intensity in gammas).

Table I

Station	Date	U.T.	F	F (Leirv.)	ΔF
Surtsey I	1967 July 1	10:24	51328	51042	286
Surtsey I	1968 March 19	16:30	51411	51191	220
Surtsey II	1968 March 19	15:47	51609	51172	437
Surtsey III[1)]	1967 July 1	09:30	48767	50982	-2215

1) 1.28 m above ground.

The Horizontal component and declination were measured at Surtsey II with a QHM magnetometer. The results are given in Table II.

Table II

Surtsey II, 1967 July 1, 11:30 U.T.

H	D	H (Leirv.)	D (Leirv.)	ΔH	ΔD
12953	337°04ʹ.4	12124	337°05ʹ.1	829	-0ʹ.7

Field intensity measurements were also made at Surtsey II on June 30, 1967, but the geomagnetic field was too disturbed for a reliable determination.

The ΔH and ΔD values of Surtsey II measured on July 1 are the same as those measured on Sept. 12, 1964.

Total field intensity, on the other hand, is decreasing at all stations. Fig. 1 shows ΔF values for Surtsey I and Surtsey II since 1964. The plot for Surtsey I shows that the field is still decreasing and probably will go on decreasing for some years to come. This means that the magnetic anomalies caused by the lava in Surtsey have not yet reached their full strength and will still be increasing for some time.

Fig. 2 is a total field intensity map from the aeromagnetic survey which was carried out from a helicopter on August 31, 1965 at an altitude of 200 m. The readings have been corrected for time variations in the geomagnetic field by using recordings from Leirvogur Geomagnetic Observatory and refer to mean values for the field intensity. The magnetic map shows positive anomaly over the southern part of the island closely related to the basaltic lavapile.

Seismic measurements

The magnetic tape seismometer was operated on Surtsey from July 7th to September 29th with some interruptions. Three detectors were situated at one station near the hut in the northern part of the island, one detector was in the western part of the island and one in the southeastern part. Distance between these stations was about 1 km. Time signals were received from the British station MSF on 60 kHz.

From Oct. 20th, 1967, to March 10, 1968, a single component seismometer was operated on Surtsey connected to a 0.1 W UHF transmitter which transmits the signal over a distance of 20 km to a receiver in the Westman Islands. The battery powered seismometer and transmitter have operated unattended for 10 weeks. From the Westman Islands the frequency modulated signal goes to Reykjavik via a VHF telephone channel which the Icelandic Telephone Authority has put at our disposal for this purpose. In Reykjavik the signal is recorded on a conventional seismic recorder at the seismic observatory operated by the Meteorological Office.

Through the kind invitation of the University of Cambridge, England, we have been able to use their magnetic tape equipment to reproduce on paper the magnetic tape records from 1966. Fil.lic.

Ragnar Stefánsson has conducted the playback reproduction and is engaged in evaluating the result. These records contain a large number of earthquakes which seem to come from a depth of 4-5 km. Periodic tremors are also frequent, and seem to reflect pulsations in the eruptive activity. The investigation of these records has not been completed.

The magnetic tape records from 1967 have not yet been reproduced on paper, but this will soon be done as we are acquiring magnetic tape equipment for this purpose.

The telemetered seismograms only show very weak earthquakes on Surtsey last winter. Some tremors are present, but it is not yet clear if these originate underground or are due to wind and waves.

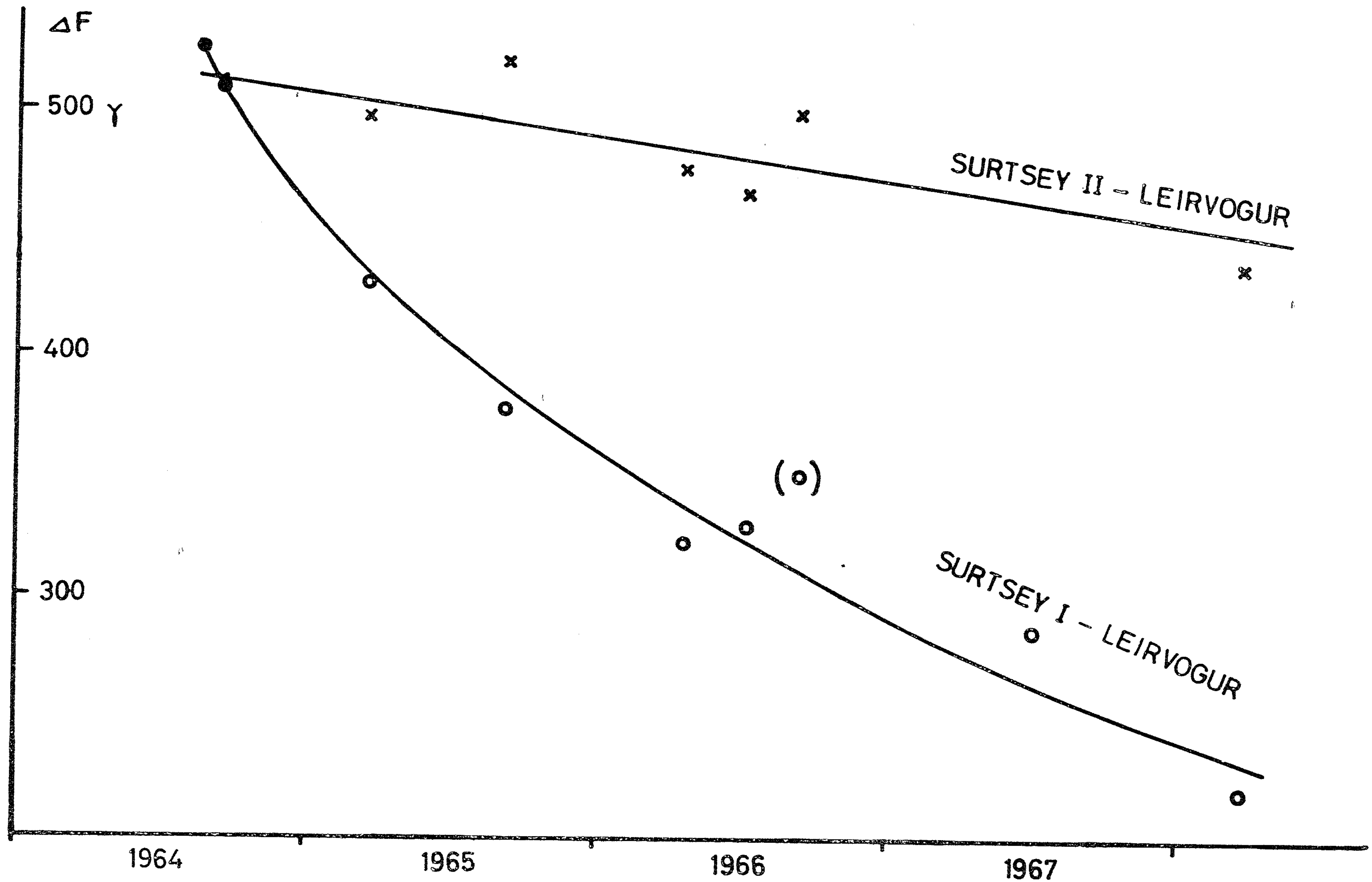
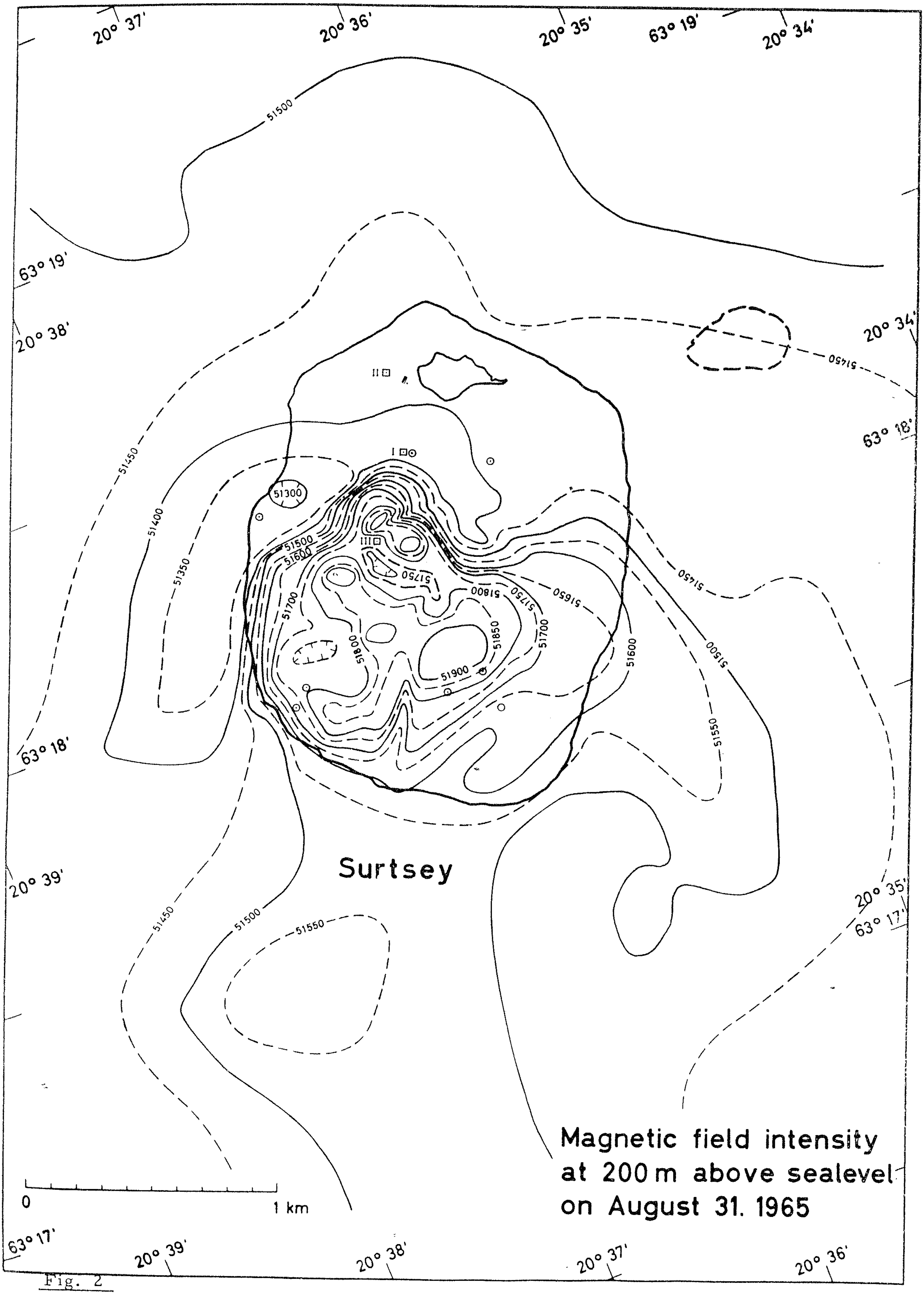

ΔF
500 γ
400
300
1964
1965
1966
1967
SURTSEY II - LEIRVOGUR
SURTSEY I - LEIRVOGUR

Fig. 1


20° 37'
20° 36'
20° 35'
63° 19'
20° 34'
63° 19'
20° 38'
20° 34'
63° 18'
63° 18'
20° 39'
20° 35'
63° 17'
63° 17'
20° 39'
20° 38'
20° 37'
20° 36'
51500
51450
51400
51350
51300
51500
51600
51700
51750
51800
51850
51900
51750
51700
51650
51600
51450
51500
51550
51450
51500
51550
I
II
III
Surtsey
0
1 km
Magnetic field intensity
at 200 m above sealevel
on August 31. 1965
Fig. 2

Analysis of 1966 Infrared Imagery of Surtsey, Iceland x)

by

Richard S. Williams, Jr., Air Force Cambridge Research Labs., Bedford, Massachusetts
Jules D. Friedman, U.S. Geological Survey, Washington, D.C.
Sigurdur Thorarinsson, Museum of Natural History, Reykjavik
Thorbjörn Sigurgeirsson, University of Iceland, Science Institute, Reykjavik
Gudmundur Pálmason, National Energy Authority, Reykjavik

In August 1966 the Air Force Cambridge Research Laboratories, in cooperation with the U.S. Geological Survey, the National Energy Authority and the Infrared Physics Laboratory of the University of Michigan, undertook thermal infrared imagery surveys of selected sites in Iceland (Figure 1). Friedman, et al (1967) described the instrumentation used during these surveys and presented some preliminary results of these surveys.

This report summarizes the most important results of the study of the thermal regime of Surtsey. Included in this summary are a discussion of surface temperature and radiometric temperature observations based on ground and airborne measurements and an analysis of the effective radiance recorded by the Nimbus II satellite.

1. Ground and Airborne Surface Temperature and Radiometric Temperature Observations

Measurements of ground- and sea-surface temperatures during the Surtur I effusive eruption were made on 27 August 1966. The sea-surface temperature traverse was made from the Icelandic ship LÓÐSINN between Geirfuglasker and Surtsey (refer to Index map of Vestmannaeyjar Archipelago, Figure 2) with a Barnes IT-3 fixed-

x) This report forms a part of a paper presented at the XIVTH Gen. Assembly of the IUGG (IAV Section) in Zürich, Switzerland in October 1967 and contains excerpts from a forthcoming paper entitled, "Infrared Survey of Surtsey, Iceland", by the same authors.

field radiometer sensitive to emitted radiation in the 8-13μ wavelength region. A mean radiometric temperature of 12°C was obtained between 2 and 4 p.m. with some fluctuation during periods of rough sea. This temperature level is moderately consistent with mean sea-surface temperature records for August of 11.5°C for the Vestmannaeyjar Archipelago (Figure 3) and with the radiometric temperature range of 7-17°C derived from the Nimbus II HRIR scan-line profiles of effective radiance (Figure 10).

A diurnal maximum surface-temperature of 13°C was registered by the IT-3 for tephra surfaces (ashfall materials forming the rims of Surtur I and II). A radiometric temperature of 30°C was obtained by the same instrument integrating a trapezoidal area of several hundred square meters across the congealed lava lake and crater walls of Surtur II from a distance of more than a hundred meters. This temperature probably resulted from the integration of high temperatures due to convective venting from several large fractures and fumaroles noted on photographs and infrared images of Surtur II and lower surface temperatures of basalt scoria and lava crust. Infrared image-density variations indicate that surface temperatures within the Surtur II crater area varied from place to place during the eruptive activity in Surtur I in August 1966. A temperature of 1130-1140°C was registered for highly fluid incandescent olivine basalt lava 19-22 August, 1966 by Sigurgeirsson (1967) using a 10-m NiCr/NiAl Pyrotenax thermocouple.

Several days after the last reported explosive pulse from Jólnir's crater on 10 August 1966, Thorarinsson estimated the water temperature at the edge of the Jólnir crater lake to be 40-50°C.

These temperature points, associated with features identifiable on the infrared images, are useful in establishing a general correlation (Figure 4) relating image emulsion density and surface temperature as given in Table 1. Because of the sparse distribution of known temperature points, film processing and instrumental variations, and differences in emissivity of surface features, such a correlation can be only semiquantitative. A nonlinear relationship between the image density scale and radiometric surface temperature is indicated. There is greater image density variation per degree temperature difference at the lower end of the scale and, hence, greater reliability at the lower end of the scale. The theoretical relationship between radiant flux and radiometric surface temperature based on the Stefan-Boltzman function (Fulk and Reynolds, 1957) is given in Figure 5. These two correlation curves used with isodensity scans (Figure 6) of the imagery provide a means to estimate the areal distribution of surface temperatures useful for approximating the total hemispherical emission (Table 3) to verify the effective radiance recorded by the Nimbus II HRIR system on 22 August 1966 (Figure 10 and Table 3). Figure 9 is an isoradiance map, derived from an aerial thermal infrared image, which shows approximate radiometric surface temperatures over the entire surface of the lava flow in Surtur I on 29 August 1966. The solid black pattern indicates underflowing incandescent lava issuing from lava tubes where the irregular, lobate front of the flow has reached the sea. Of great interest are the areas of greatest cooling - at the margins of the flow and in a linear pattern in the central portion of the flow area. Decker and Peck (1967) also report that the coolest areas at Alae Lava Lake, Hawaii, were at the cooled thin margins. The cool linear central features are believed to be thick coherent slabs of helluhraun (pahoehoe) flow.

On 21 July 1967, additional surface-temperature measurements were undertaken on the surface of the 1966 flow which issued from Surtur I. YSI telethermometer and Atkins thermistor probe systems (range $< 120^{\circ}C$) were utilized as well as a Rototherm thermocouple probe (range = $100-550^{\circ}C$) in measuring temperatures in venting fumaroles and fractures. Surface temperatures ranged from ambient levels ($10-14^{\circ}C$) for tephra surfaces to more than $550^{\circ}C$ in one fracture in the floor of the Surtur I crater. This last measurement indicates that near-incandescent lava was present (July 1967) within a meter of the apalhraun flow surface.

In the area of the last sizable surface exposure of lava from Surtur II in April and May 1965 fractures parallel to the that a $\pm 2^{\circ}$ K to $\pm 4^{\circ}$ K variation in ocean surface temperature in the comparison of satellite data with actual surface temperature measurement can be expected. The approximate least-squares fit of a horizontal line on the analog scan-line trace suggests that the average ocean surface temperature of 285°K, based on effective radiance, is fairly accurate. Confirmation of the ocean surface temperature reading from Nimbus II records is provided in Figure 3. Figure 3 is admittedly a highly generalized sea surface map, but the average August sea surface temperature gives additional support to the Nimbus II data. Also most of the field of view of the HRIR detector is filled by ocean surface, hence it is contributing most of the radiant emission (see Table 2).

In conversion from radiometric temperature to true surface temperature, variations in surface emissivity of 1% can lead to an error of approximately 0.7° K (Gayevskiy, 1963). Kern (1965), in his TIROS work, found that water has an emissivity of 0.99 at ambient-temperature levels in the 8-13 micron spectral band. Daniels (1967) reported that average emissivities of basalt and tephra are on the order of 0.96 ± 0.02 for the 8-13 micron spectral band. Moreover, it is known that deviation from a plane surface in the form of surface roughness (as on the ocean surface or a lava flow) causes a higher apparent emissivity than the true emissivity of the material. Emissivities in the 3.45 to 4.07 spectral band, the 50% response points of the Nimbus II HRIR detector, are not as well known. The detector of the Nimbus HRIR system sensed radiation from a 64 km^2 segment of the earth's surface in the vicinity of Iceland. Table 2 indicates that over 96% of this transected area is ocean surface possibly having an emissivity of 0.99. Emissivity variations in the Surtsey case are thus assumed to be within the limit of observational error but are a valid subject for future investigation and could cause a reassessment of the energy values reported in this paper.

period was the time of greatest thermal emission from Surtsey in 1966. Although the pyroclastic satellite volcano, Jólnir, erupted explosively repeatedly between the time Nimbus II was placed in orbit (May, 1966) and 10 August, the thermal yield of these pyroclastic eruptions was probably not great enough for the infrared emission to rise above background levels, and no record of Jólnir's eruptive history was found on the Nimbus II infrared imagery.

The Nimbus II oscillograph record of Orbit 1315 indicates that a maximum effective radiance (N) = $10^{0.75}$ watts/m^2 · steradian^{-1} (equivalent to a radiation of 7.13×10^{14} ergs/sec from an area of 64 km^2) was redorded by the HRIR detector, taking into account the spectral response of the system. This is equivalent to 2.94×10^{17} ergs/sec total blackbody radiation, the total energy radiated from a 64 km^2 segment of the earth's surface integrated by the Nimbus II HRIR detector assuming an emissivity of unity.

Although the spectral response and internal calibration corrections of the HRIR system are taken into account in determining the effective radiance indicated by the spike, several factors affect the accuracy of this portion of the analog profile of effective radiance: 1) sensor scan angle, 2) atmospheric absorption, emission and scattering and 3) emissivity variations of the terrestrial and ocean surface.

Order of Magnitude of Required Corrections

The nadir angle of the sensor on Orbit 1315, as the sub-satellite trace passed within 275 km of Surtsey, was approximately 14° (Jack Conway, written communication 1967). This corresponds to an increase in transmission path length of 3% for a total of 1148 km instead of the orbital altitude of 1114 km. An atmospheric path increase of 3% would have little effect.

The correction for atmospheric influence would also be slight within the error of measuring the amplitude of the positive spike. Kunde (1964), Kern (1965), and Allison and Kennedy (1967) have discussed the atmospheric attenuation error and conclude flanks of serpentine pressure ridges and collapse features were convecting vapors to the atmosphere at temperatures of 40-60°C. The previous year (August 1966) these same fractures were associated with infrared image-saturation anomalies indicating convective temperatures above 100°C (Figure 6). Figure 6 does not fit the planimetric configuration of Surtsey and Jólnir due to distortion caused by an incorrect setting of the M1A1 scanner with respect to apparent ground motion.

Figures 7 and 8 are radiance profiles, lines AB and AC, showing radiant flux from different geologic (volcanologic) features. These profiles graphically portray the dynamic thermal regime of the active volcano, Surtsey, and its satellite volcano, Jólnir, at a specific point in time.

2. <u>Effective Radiance as Recorded by the Nimbus II High Resolution Infrared Radiometer (HRIR)</u>

Radiant emission from the Surtur I eruptive area (August-October, 1966) was of sufficient magnitude to be recorded by the HRIR system of the Nimbus II meteorological satellite. The anomaly detected by this system is visible as a minute black spot in the correct geographic position for Surtsey on the photographic record of the infrared imagery and as a sharp positive spike on Visicorder oscillograph analog profiles (showing variations in effective radiance along individual scan lines) made from records of the original spacecraft interrogation (Figure 10).

The Surtsey anomaly was first recorded on Orbit 1288, 20 August, the first orbital overpass of Iceland after the eruption began the previous morning. The anomaly is not present on imagery of previous orbits although openings in the cloud cover permitted identification of parts of southern Iceland during the nights immediately prior to 20 August. The anomaly was also identified on the following dates and orbits: 22 August, Orbit 1315; 8 September, Orbit 1546; 16 September, Orbit 1648; 20 September, Orbit 1701; and 21 September, Orbit 1774. The anomaly is definitely identifiable as late as 3 October (Orbit 1874) but becomes questionable during the latter part of October. It is significant that this

Total Hemispherical Emission Estimates from Ground Observations and Airborne Infrared Imagery

The maximum effective radiance, 7.13×10^{14} ergs/sec, as determined from the Nimbus II HRIR oscillograph record, taking into account the spectral response of the HRIR detector, is equivalent to 2.94×10^{17} ergs/sec total blackbody radiation based on the Stefan-Boltzmann function (Fulk and Reynolds, 1957). These Nimbus radiation estimates may be compared with estimates made from field observations supplemented by isodensitracer scans of airborne infrared imagery (Figure 6). The total hemispherical emission from a comparable area on the earth's surface can be estimated by dividing the resolution element of the HRIR detector (64 km^2, the area on the earth's surface transected by the cone representing the solid angle viewed by the HRIR system), into unit areas of roughly equal temperature (Figure 6). Using this method, the radiance contribution of each part may be estimated and integrated with the other parts. Temperature measurements, volcanologic observations on the island and isodensitometric analysis of the airborne imagery suggest the map units and temperatures as shown in Table 2. The area of Surtsey was 2.35 km^2 when the 19 August 1966 fissure eruption began (Thorarinsson, 1967, p. 575).

The radiation values for each map unit given in Table 2 were estimated using the following method devised by A.E. Stoddard (written communication, 1967):

If each temperature unit is assumed to radiate as a blackbody, and the HRIR detection response is taken into account, the response function ϕ_λ, may be approximated by a function which is everywhere zero except within the interval 3.45 to 4.07μ when it assumes the value one. These wavelengths are the 50% response points of the Nimbus II detector. The following approximation for each of the four temperature units is then valid:

$$\bar{N}(AT) = AT\int_{3.45}^{4.07} B(\lambda,T)d\lambda$$

where A_T = the area at temperature T

$B(\lambda, T)$ = the Planck function (the amount of energy radiated in all directions from one cm^2 blackbody surface at temperature T per second and per unit wavelength interval).

$\overline{N}$ = maximum effective radiance.

Given this integral as a function of temperature and the area of each surface-temperature unit, the total energy radiated by each part within the response window of the Nimbus II detector may be calculated.

To calculate the total energy radiated from each map unit, we may substitute a function which is unity over the entire range of wavelengths

$$E_T = A_T \int_0^{\infty} B(\lambda, T) d\lambda$$

The advantage of using the above equation is that it gives us total radiation estimates for the eruptive volcanic area, which then can be compared to the calculated rate of thermal energy yield.

Thermal Yield of Effusive Eruption from Volumetric Outflow Observations

To give an indication of the thermal energy yield of the August 1966 fissure eruptions, we may apply the methods of Hédervári (1963) and Yokoyama (1956-57), which relate the volcanic energy to the volume of the products erupted, according to the following equation:

$$E_{th} = V \rho (TC + B) J$$

where E_{th} = thermal energy yield in ergs/sec. (assuming cooling to ambient temperature level)

V = volume of effusive lavas in cm^3/sec.

ρ = mean density of effusive lavas in g/cm^3

T = maximum temperature of the lava in $^{\circ}C$

C = specific heat of basalt lava in cal/g $^{\circ}C$

B = latent heat of lava in cal/g

J = 4.186×10^7 ergs/cal.

Field observations reported by Thorarinsson (1967b) and Sigurgeirsson (1967) provide us with values for V and T. Thorarinsson estimated the volumetric yield of lava to have been between 5 and 10 m^3/sec for several days after 20 August. If we assume the rate of outflow to have been 7 m^3/sec early in the morning of 22 August (02:28 UMT) at the time the subsatellite point of Nimbus II, Orbit 1315, passed almost directly across Surtsey (nadir angle of 14°) we may compare the effective radiance from Surtsey, as detected by the Nimbus HRIR 1114 km above the earth's surface, with the rate of thermal energy output of the volcano.

Thermocouple measurements of fresh incandescent flows by Sigurgeirsson yielded a temperature of 1140°C for the lava. Other values for the parameters in the Eth equation for basalt are: ρ, 2.8 g/cm^3; C, 0.25 cal/g °C (at 800°C), and B, 50 cal/g. Then the total thermal yield would be:

$$Eth = 2.67 \times 10^{17} \text{ ergs/sec (or } 6370 \times 10^{6} \text{ cal/sec).}$$

Table 3 presents a summary and comparison of the thermal energy output and radiant emission from Surtsey on 22 August 1966 based on field observations, and estimates from the airborne infrared imagery and Nimbus II HRIR satellite data.

Conclusions

It may be estimated in conclusion that approximately 3.3% of the total thermal yield of the Surtur I effusive eruption was radiated into space on 22 August 1966, and that the bulk of the remaining thermal yield was dissipated by non-radiant heat transfer mechanisms to the ocean, the atmosphere, and to the terrestrial sub-surface of the island.

Acknowledgements

We wish to thank Steingrimur Hermannsson, Director, National Research Council, for his competent and generous support towards our research efforts in 1966 and 1967. We are also grateful to members of the Surtsey Research Society for organizing and financially supporting the round trip to Surtsey in 1966; to Professor Paul S. Bauer, American University, Washington, D.C., for friendly encouragement, support, and interest during the study; to the U.S. Naval Air Station, Keflavík, for helicopter support in 1967; to Jón Jónsson, Sveinbjörn Björnsson, and other scientists of Orkustofnun for able field support; to Árni Johnsen for invaluable assistance during the 1966 and 1967 field surveys; and to Dr. Alonzo E. Stoddard, Prof. of Physics, Pomona College, Claremont, California, for technical advice of radiant emittance calculations.

References

Allison, L.J. and Kennedy, J.S., 1967, An evaluation of sea Surface Temperature as Measured by the Nimbus I High-resolution Infrared Radiometer: NASA Tech. Note, TN-4078.

Daniels, D.L., 1967, Additional infrared spectral emittance measurements of rocks from the Mono Craters region, California: Interagency Rpt. 90, U.S. Geological Survey.

Decker, R.W. and Peck, D.L., 1967, Infrared radiation from Alae Lava Lake, Hawaii: in Geological Survey Research 1967, U.S. Geol. Surv. Prof. Paper 575D, p. 169-175.

Friedman, J.D., Williams, R.S., Jr., Miller, D.C., and Pálmason, G., 1967, Infrared surveys in Iceland in 1966: in Surtsey Research Progress Rpt., The Surtsey Research Society, Reykjavik, Iceland, v. III, p. 99-103.

Fulk, M.M., and Reynolds, M.M., 1957, Radiometry: in Amer. Inst. of Physics Handbook, Sect. 6g, p. 6-64-6-86, McGraw-Hill Book Co., New York.

Gayevskiy, V.L., 1963, Measurement of surface temperature by the radiation method: Main Geophysical Observatory, Trudy Vsesoyuznogo Nauchnogo Meteorologicheskogo Soveshchnaya, v. 9, p. 386-394.

Hédervári, P., 1963, On the energy and magnitude of volcanic eruptions: Bull. Volcanologique, v. 25, p. 373-385.

Kern, C.D., 1965, Evaluation of infrared emission of clouds and ground as measured by weather satellites: Air Force Cambridge Research Laboratories Environmental Research Papers, no. 155, 112 p.

Kunde, V.G., 1964, Theoretical relationships between equivalent blackbody temperatures and surface temperatures measured by the Nimbus HRIR in observations from the Nimbus I meteorological satellite: NASA Spec. Paper SP-89, p. 23-36.

Sigurgeirsson, Th., 1967, Continued geophysical measurements in Surtsey: in Surtsey Research Progress Rpt., The Surtsey Research Society, Reykjavik, Iceland, v. III, p. 104-105.

Thorarinsson, S., 1967a, The Surtsey eruption and related scientific work: The Polar Record, v. 13, no. 86, p. 571-578.

Thorarinsson, S., 1967b, The Surtsey eruption: course of events during the year 1966: in Surtsey Research Progress Rpt., The Surtsey Research Society, Reykjavik, Iceland, v. III, p. 84-91.

Yokoyama, I., 1956-57, Energetics and active volcanoes: in Bull. Earthquake Res. Inst., v. 35, Pt. I, p. 75-97.

Table 1

EXPLANATION

ISORADIANCE MAP ANALYSIS OF SURTSEY AND JOLNIR M1A1 INFRARED IMAGE, 19 AUGUST 1966, 1745 UMT, 4.5-5.5 MICRONS

Geologic Interpretation	*Δd and Map Unit	Anomaly Category	Radiometric Surface Temp. Range (°C)	Original Image Characteristics: Tone	Original Image Characteristics: Form
Sea surface; Basalt flow surface - Cool (1964-1965 flows) Tephra rims of Surtur I and II and Jólnir	0.114 - 0.456	Ambient level	10-12	Dark gray	Large areas; A few subtle gradations discernible.
Basalt flow surface of 1964-1965 flows; Jólnir lagoon water; basalt flows of 1964-1965 (Surtsey) adjacent to anomalously warm surfaces. Jólnir crater lake; basalt crust over cooling lava and subsurface lava courses of 1964-1965 flows where high conductive heat flow is associated with convective heat flow; Warm periphery of features emitting gases and steam.	0.456 - 1.368	Low and intermediate level anomalies	12-64	Medium gray to Light gray to Gray	Subtle gradations; Faint curvilinear features; Generalized diffuse areas; Many sublinear bands
Three areas: 1) area of predominately convective heat transfer from secondary fumaroles, fractures along pressure ridges and circular collapse features in area of 1965 flows, 2) primary fumaroles and gas and steam emission from scoriaceous walls of Surtur II crater and in general area of roof of northern part of subsurface lava course (1965), and 3) peripheral to image-saturation anomalies of Surtur I.	1.368 - 1.596 1.596 - 1.938	High temperature anomalies	64-78 78-100	Very light gray White	Specific small areas; Punctuate and bleb-like features; bead-like alignments; sharp curvilinear features concentrated in three general areas.
Image saturation in general area of effusive incandescent flows, lava fountains and cauldron activity; intense fumarole emission and image saturation adjacent to fumaroles.	>1.938	Image saturation anomalies	100 - 1100	Bright White	Ellipsoidal area; saturation after-effect along some scan lines; blooming around some curvilinear and point sources.

*Δd: image density increment

TABLE 2

Radiant Emission of Surtsey and Surrounding Ocean surface
Based on Surface Temperature
22 August 1966

	AT	T°	$\bar{N}$ (AT)	ET (AT)
Map Unit (geologic feature)	Area (km^2)	T°K (average)	$AT \int_{3.45}^{4.07} B(\lambda,T)d\lambda$ ergs/sec	$AT \int_{0}^{\infty} B(\lambda,T)d\lambda$ ergs/sec
1. Incandescent lava Surtur I	.01	1120°	$10.00x10^{14}$	$0.09x10^{17}$
2. Other volcanic anomalies	.20	300°	$0.02x10^{14}$	$0.01x10^{17}$
3. Ambient Terrain (cool basalt and tephra)	2.14	286°	$0.11x10^{14}$	$0.08x10^{17}$
4. Ocean surface	61.65	248.5°	$3.08x10^{14}$	$2.30x10^{17}$
TOTAL	64.00	- 300°	$13.21x10^{14}$	* $2.48x10^{17}$
				** $2.94x10^{17}$

* Cumulative total based on T° map units.

** Based on Stefan-Boltzmann function for black-body radiation and blackbody equivalent temperature (300°K) derived from Nimbus data.

TABLE 3

COMPARISON OF THERMAL ENERGY OUTPUT AND RADIANT EMISSION FROM SURTSEY, 22 AUGUST 1966 AS ESTIMATED BY TWO SENSING SYSTEMS

	ENERGY UNIT ESTIMATED		REMOTE SENSING SYSTEM	ENERGY (ERGS/SEC) FROM $64KM^2$ ELLIPTICAL AREA, INCLUDING SURTSEY, INTEGRATED BY NIMBUS HRIR DETECTOR	ENERGY FROM ACTIVE VOLCANO	
					ERGS/SEC	PER CENT OF TOTAL
RADIATION	(1) Effective Radiance (N), (that portion of the radiance of the $64Km^2$ target which passes the equivalent detector filter) of the HRIR radiometer per second $\bar{N}=\int A(T)\left\{\int_{3.45}^{4.07} B(\lambda, T_{BB})d\lambda\right\}dT$ Where A(T)=area at temperature T $B(\lambda, T_{BB})$=Planck function	A	Nimbus II HRIR. Scan-line oscillograph record, orbit 1315, 22 August 1966 02:27:29 UMT $63^{o}15'$N, $20^{o}45'$W center point of terrestrial sweep.	7.13×10^{14}	Volcano emission alone not resolvable from Nimbus record. See below.	N/A
		B	M1A1 infrared scanner (Airborne, 5,000 feet) isodensitometric scan of imagery and surface temperature points. Emission estimated from spectral band comparable to Nimbus II HRIR system.	13.21×10^{14}	10.02×10^{14}	N/A
	(2) Total hemispherical emission ($\mathcal{E}$) (radiation emitted per second in all wavelengths assuming emissivity=1) $\mathcal{E}=\int A(T)\left\{\int_{0}^{\infty} B(\lambda,T)d\lambda\right\}dT$ $\cong \sigma \int A(T)T^4 dT$ Where A(T)=area of temperature T $B(\lambda,T)$=Planck function σ=Stefan-Boltzmann constant (1.354×10^{-12} cal cm^{-2} $^{o}K^{-4}$ sec^{-1})	A	Nimbus II HRIR. Scan-line oscillograph record equivalent blackbody radiation using Stefan-Boltzmann constant.	2.94×10^{17}	Volcano emission alone not resolvable from Nimbus record. See below.	N/A
		B	M1A1 infrared scanner (Airborne) isodensitometric scan of imagery and surface temperature points. Emission in all wavelengths estimated.	2.48×10^{17}	0.09×10^{17}	3.26

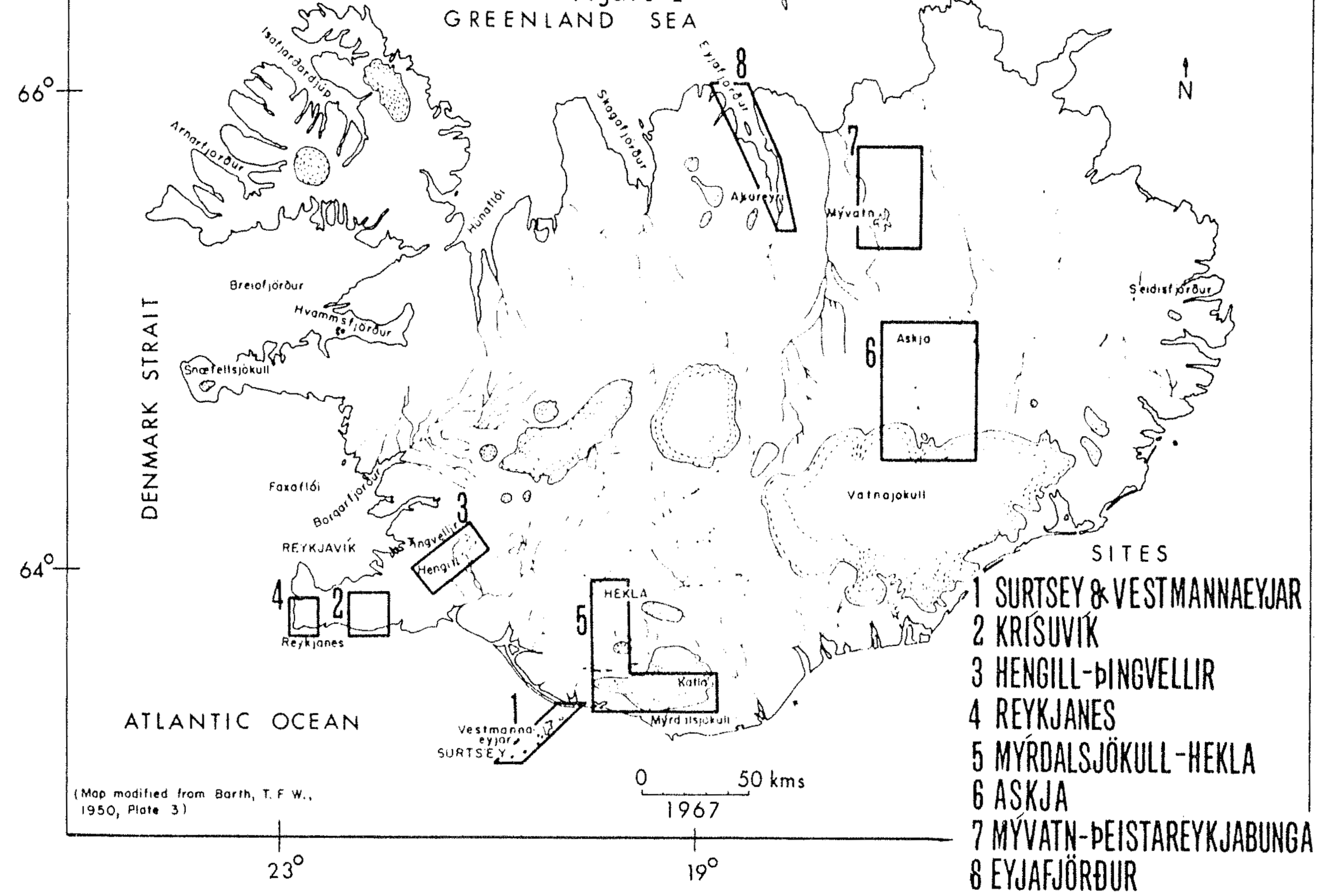
TABLE 3. (Cont.)

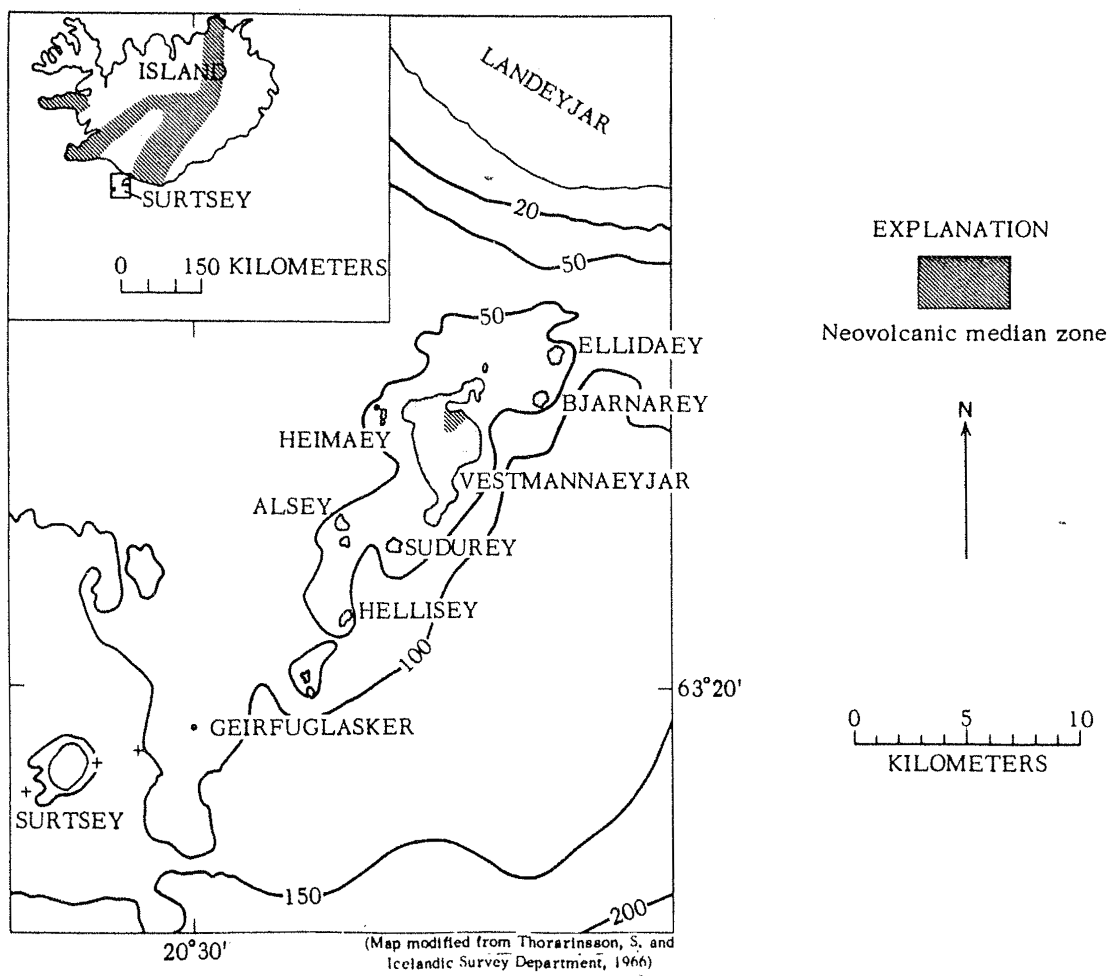
COMPARISON OF THERMAL ENERGY OUTPUT AND RADIANT EMISSION FROM SURTSEY, 22 AUGUST 1966 AS ESTIMATED BY TWO SENSING SYSTEMS

	ENERGY UNIT ESTIMATED	REMOTE SENSING SYSTEM	ENERGY (ERGS/SEC) FROM $64 KM^2$ ELLIPTICAL AREA, INCLUDING SURTSEY, INTEGRATED BY NIMBUS HRIR DETECTOR	ENERGY FROM ACTIVE VOLCANO ERGS/SEC	ENERGY FROM ACTIVE VOLCANO PER CENT OF TOTAL
TOTAL THERMAL ENERGY YIELD	Thermal energy yield (Eth) Eth=VP (TC+B) J Where V= Volumetric outflow of lava per second P= Mean density of olivine basalt lava T= Maximum temperature (^{o}K) above ambient C= Specific heat of basalt (at $800^{o}C$) B= Latent heat of lava J= Equivalent work of heat	Volcanologic ground observations of max. temperature (by thermocouple) of incandescent lava and volumetric rate of outflow. Also temperature of ocean and tephra surface.	N/A	$2.67 x 10^{17}$	97

SITES OF THERMAL INFRARED SURVEYS IN ICELAND—AUGUST 1966

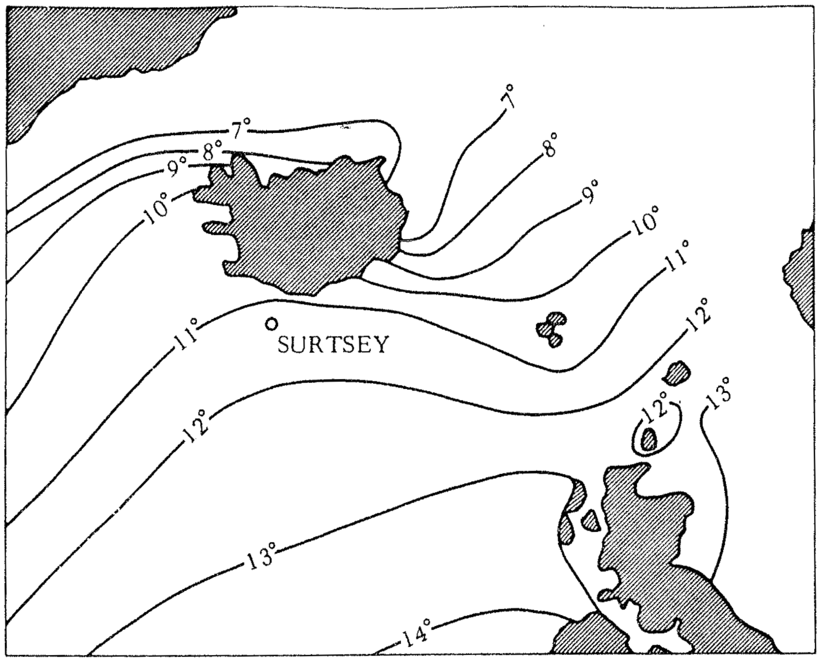
Figure 1





INDEX MAP OF VESTMANNAEYJAR ARCHIPELAGO, ICELAND

Figure 2



SOURCES
(1) Nautisk- Meteorologisk Aabog (Copenhagen, 1898-1939)
(2) H. Thomsen, 1938, Zoology of Iceland, vol. 1, pt. 4, pp. 6-8, Copenhagen

CONFIRM 11.5° C SEA SURFACE TEMPERATURE NEAR SURTSEY AUGUST, 1966
(3) S. A. Malmberg, unpublished, Sea surface temperature in Vestmannaeyjar Archipelago, August 1966; records of Marine Research Institute, Reykjavik
(4) Radiometric temperature traverse from Icelandic vessel Lodsinn between Geirfuglasker and Surtsey, August 23, 1966

Figure 3
AVERAGE SURFACE TEMPERATURE OF THE SEA (°C) FOR AUGUST, 1898-1939

Figure 4
INFRARED IMAGE TONAL DENSITY VS RADIOMETRIC SURFACE TEMPERATURE
SURTSEY, 8/19/66, 1745 UMT, $\lambda = 4.5-5.5\mu$

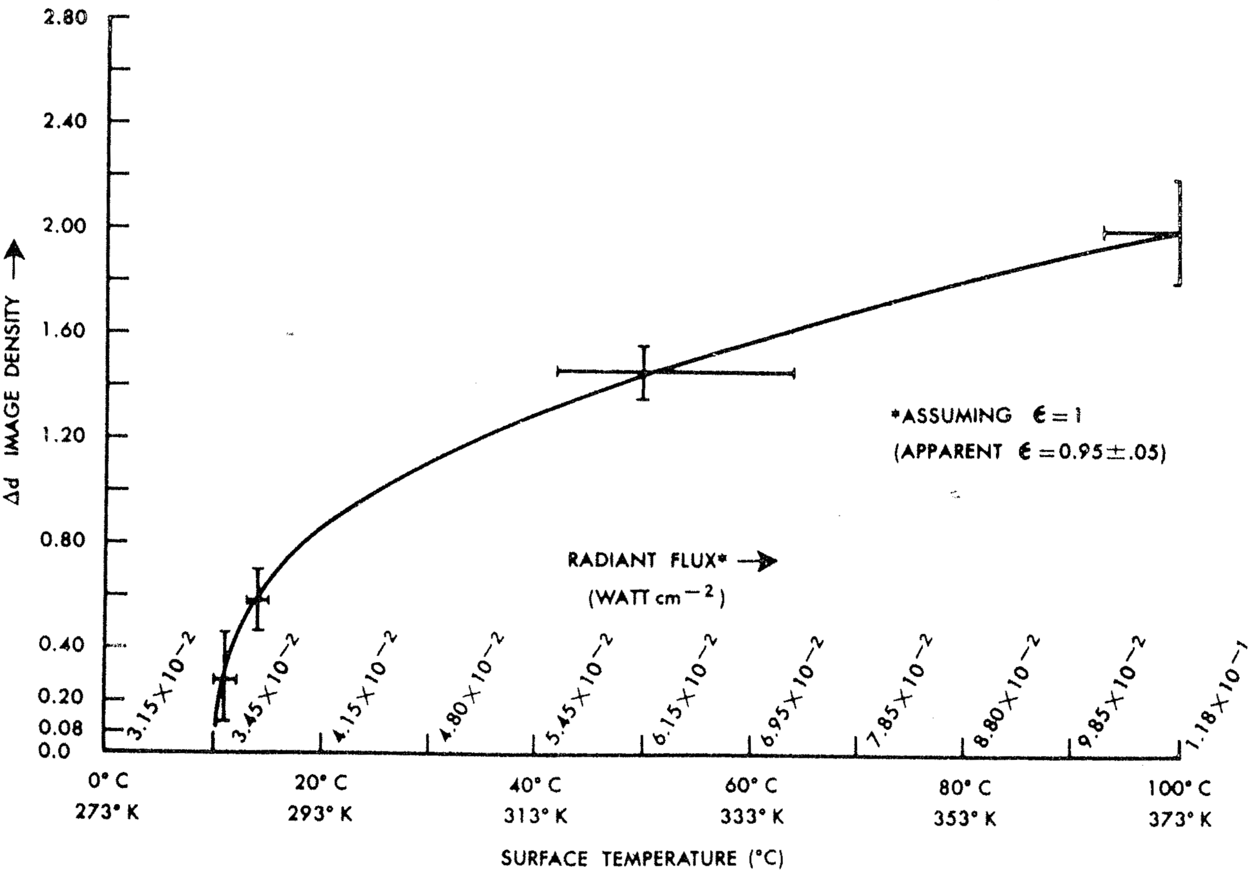
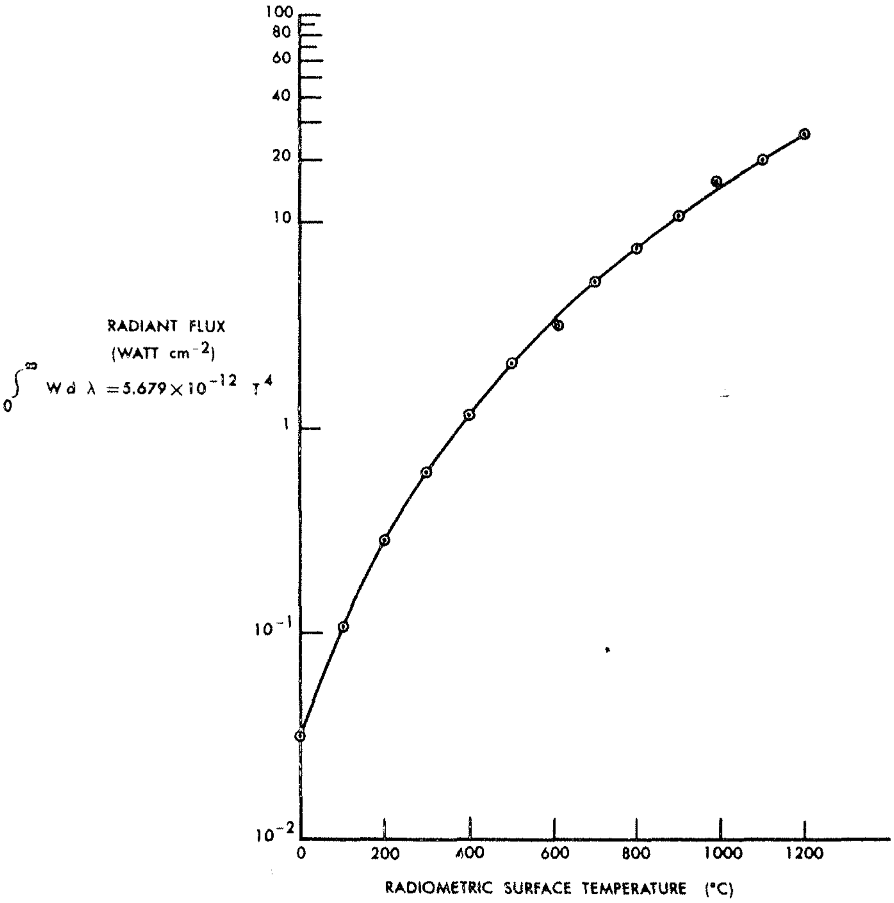


Figure 5

RADIANT FLUX VS RADIOMETRIC SURFACE TEMPERATURE



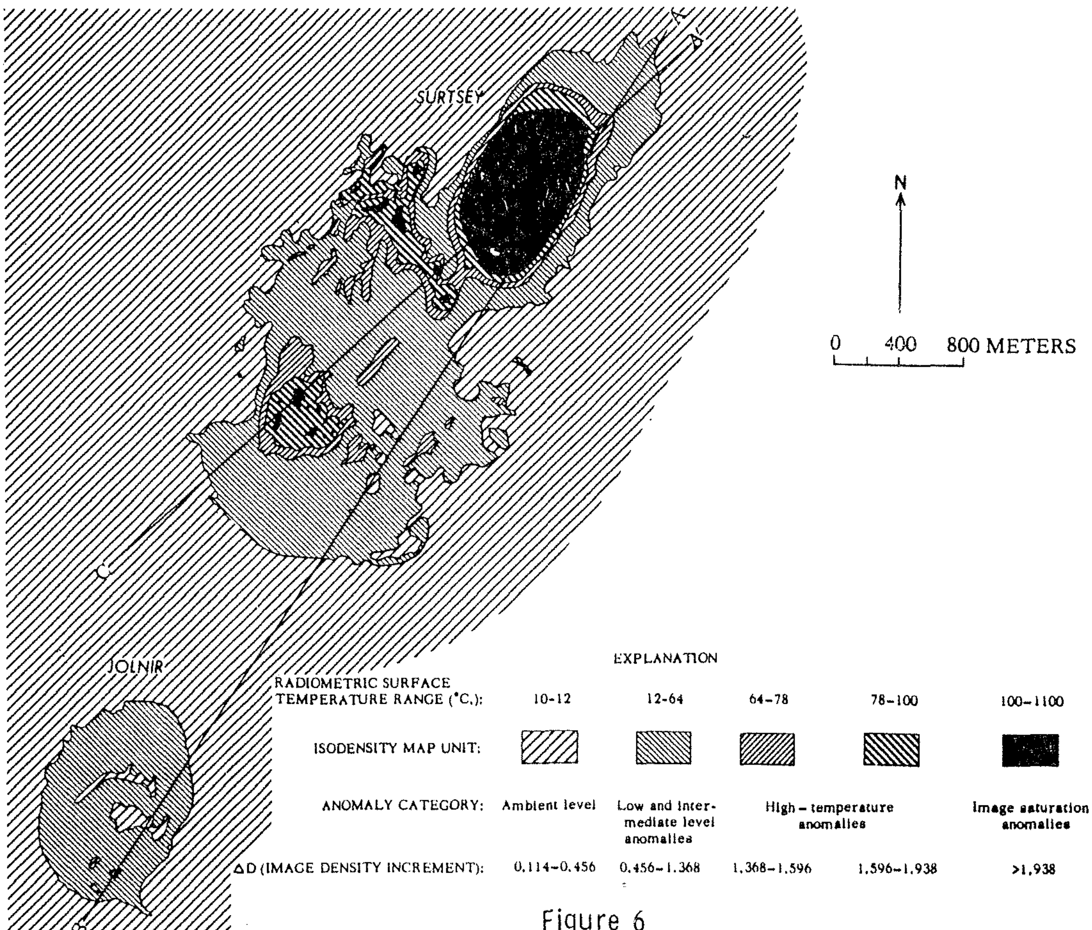


Figure 6

ISORADIANCE MAP OF SURTSEY & JOLNIR, VESTMANNAEYJAR, ICELAND
(From MIAI infrared image, 19 August 1966, 1745 UMT, 5000 Feet, 4.5-5.5 μ)

Figure 7

RADIANCE, LINE A–B SURTSEY AND JÓLNIR 8/19/66, 1745 UMT

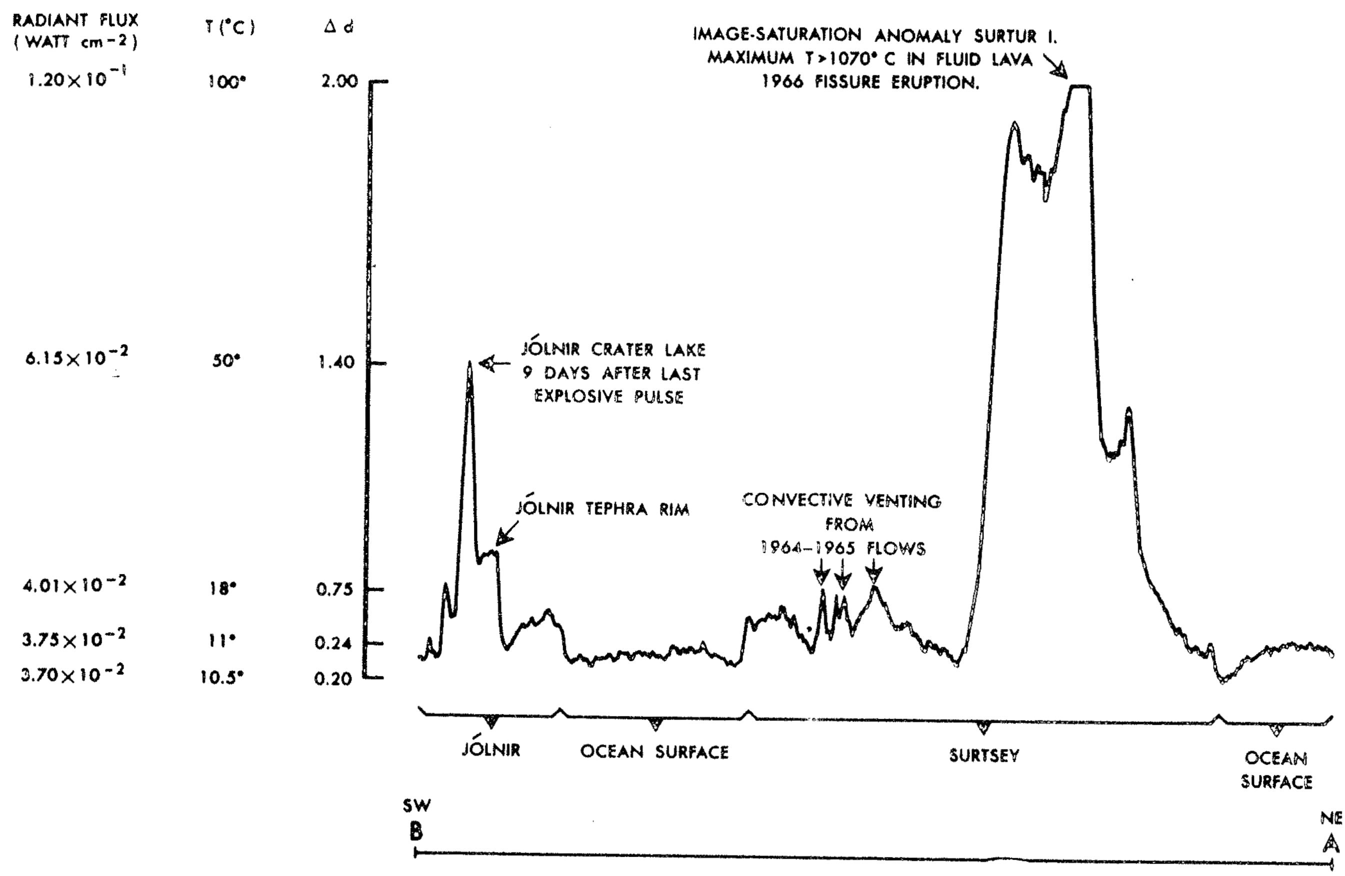
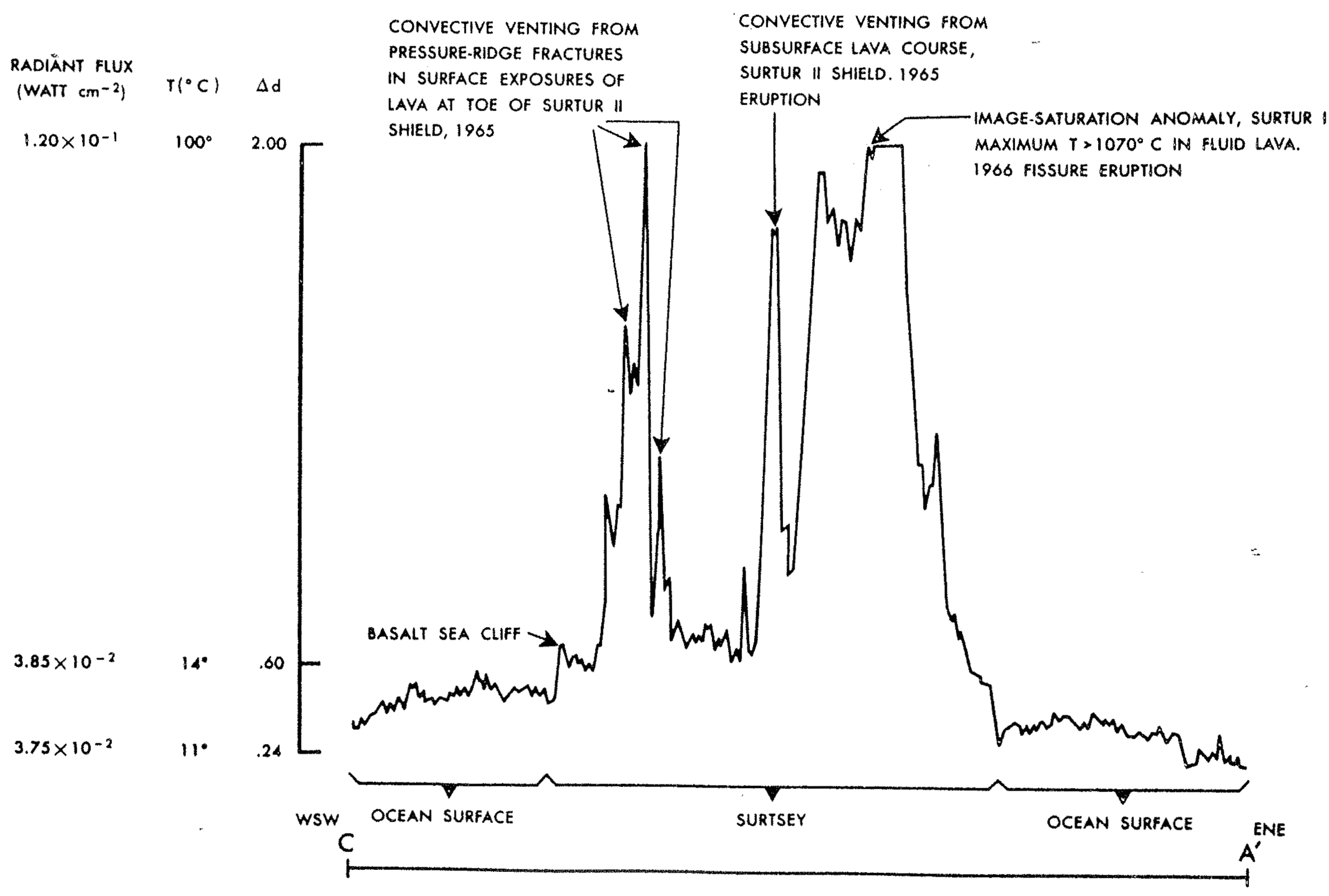


Figure 8

RADIANCE, LINE A'–C SURTSEY 8/19/66, 1745 UMT



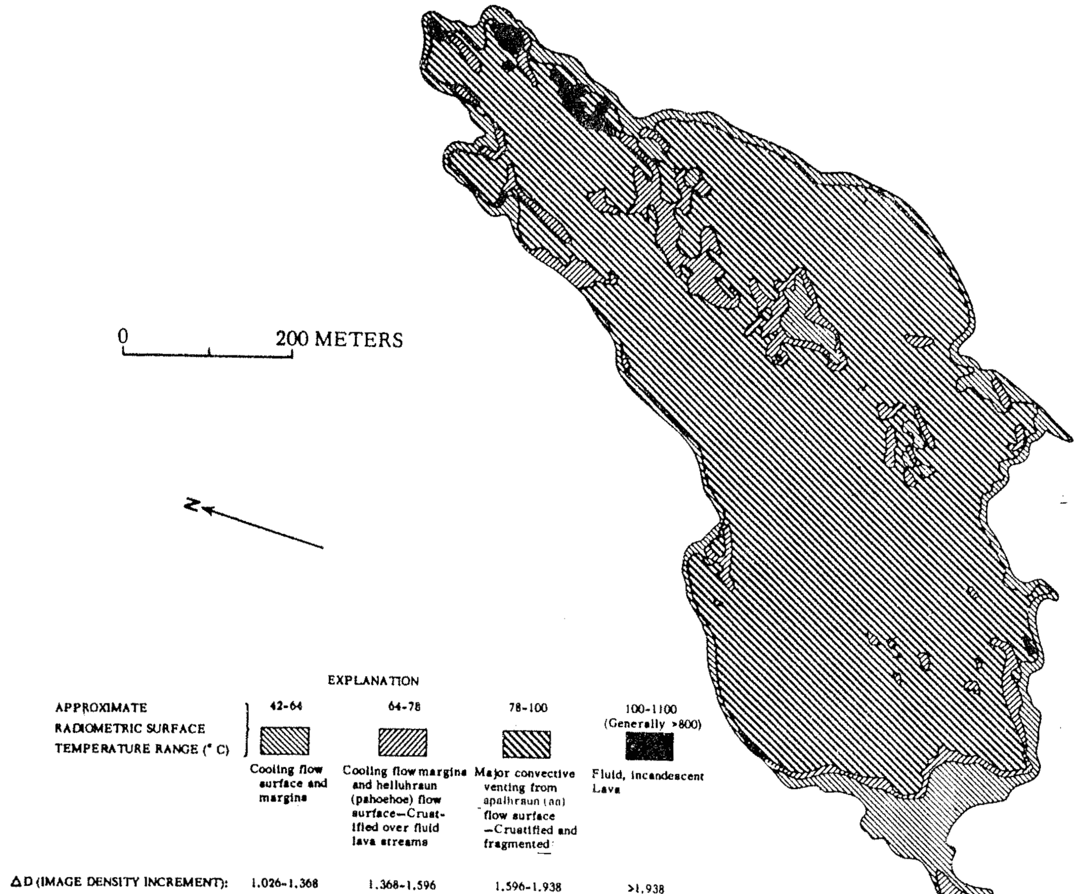


Figure 9

ISORADIANCE MAP OF LAVA FLOW FROM SURTUR I, SURTSEY, ICELAND
(From MIAI infrared image, 29 August 1966, 1721 UMT, 2500 Feet, 4.5-5.5 μ)

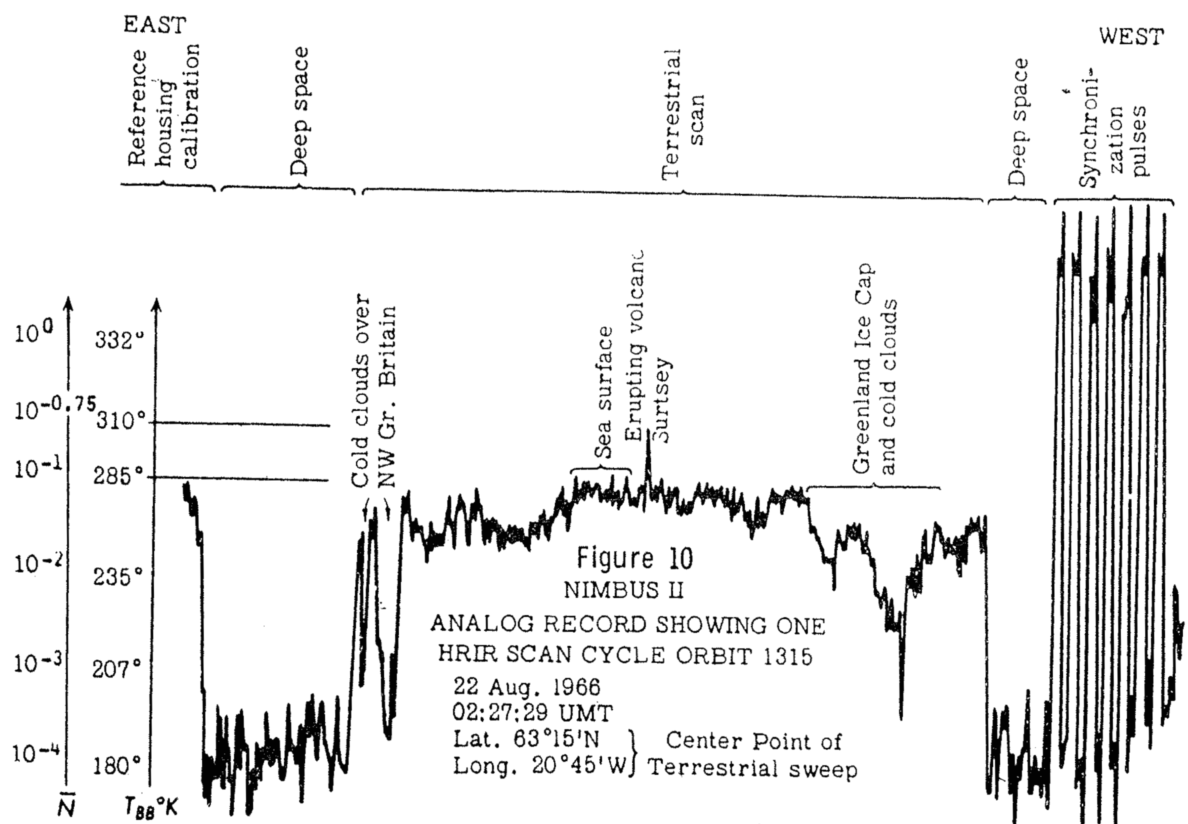


Figure 10
NIMBUS II
ANALOG RECORD SHOWING ONE HRIR SCAN CYCLE ORBIT 1315
22 Aug. 1966
02:27:29 UMT
Lat. 63°15'N } Center Point of
Long. 20°45'W } Terrestrial sweep

$$\text{Effective radiance, } \bar{N}\ (\text{watts}/m^2 \cdot \text{ster}) = \int_0^\infty B_\lambda\,(T_{BB})\,\phi_\lambda\, d_\lambda$$

Where B_λ = Planck function T_{BB} = Equivalent blackbody Temperature in °K ϕ_λ = Effective spectral response (about 3.4 to 4.1 μ)

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

Beam Transmittance Measurements carried out in the Waters around Surtsey 1-2 August 1966

by

Svend-Aage Malmberg
Marine Research Institute, Reykjavik

Summary

Beam transmittance measurements were carried out in the waters around Surtsey and Jólnir at two spectral intervals, in the red and in the blue, and temperature recordings as well, during 1-2 August (Fig. 1; Table 1). All measurements were made continuously from sea surface to bottom. During the observations Surtsey was inactive, but Jólnir active. The object of the investigations was mainly to determine the attenuation coefficients in the sea water and their connection with the vertical stratification and to obtain data for studies on suspended and dissolved matter in the sea water for comparison with other areas.

Table 1. Beam Transmittance Measurements in the Waters around Surtsey and Jólnir 1-2 August 1966.

Stat. No.	Pos.		Depth
No.	N	W	m
30	63°30,5´	20°37,1´	78
31	63°26,0´	20°37,3´	85
32	63°22,0´	20°37,3´	102
33	63°19,0´	20°37,5´	85
34	63°16,3´	20°39,0´	65
35	63°18,0´	20°45,0´	134
36	63°18,0´	20°53,0´	138
37	63°18,0´	21°04,0´	155
38	63°09,0´	20°40,0´	218
39	63°11,3´	20°37,8´	185
40	63°15,0´	20°37,0´	148
41	63°16,5´	20°37,0´	125
42	63°17,0´	20°37,5´	85
43	63°17,6´	20°33,1´	120
44	63°17,9´	20°30,0´	103
45	63°18,0´	20°21,0´	136
46	63°18,0´	20°10,0´	136

The main results are as follows:

1) A distinct intermediate maximum of attenuation was observed at ca. 50 m depth on four stations (33, 34, 42, 43), all located over the submarine slope of the volcanic islands. On the other stations farther offshore it was not observed (Figs. 2-3). At the four above mentioned stations the vertical temperature distribution was similar as elsewhere in the study area. Thus the maximum attenuation found does not seem directly connected with the stratification but more likely related to the existence of the volcanic islands. Primarily, it may be due to some change in the building-up of Surtsey and/or other elevations in the area, and secondly due to currents. A noteworthy feature is the distribution of the scattering layer at about 30-60 m depth observed by means of echo soundings in the last week of July 1966 in the area around Surtsey (Figs. 4-7). The scattering layer occurs mostly only on one side of the submarine elevations, thus probably indicating a transport of particulate matter by currents in special directions and patterns. It may be of interest to repeat beam transmittance measurements in the area and collect water samples for filtering according to the observed distribution of attenuation.

2) The relation between the attenuation coefficients in the blue ($\Delta a(B)$) and in the red ($\Delta a(R)$) obtained around Surtsey at all depths and shown in Fig. 8 indicated one linear characteristic. Surface data all around Iceland (Fig. 9) show the same characteristic (Fig. 10), as well as most subsurface data, with few exceptions in the near surface layer at river outlets as e.g. at Þjórsá and Ölfusá (Fig. 11). According to Figs. 8 and 10 the coastal water all around Iceland is in optical view characterized by the equation

$$\Delta a(B) = 1.2 \cdot \Delta a(R)$$

However, salinity observations in connection with beam transmittance measurements could possibly distinguish between the run-off from the various rivers.

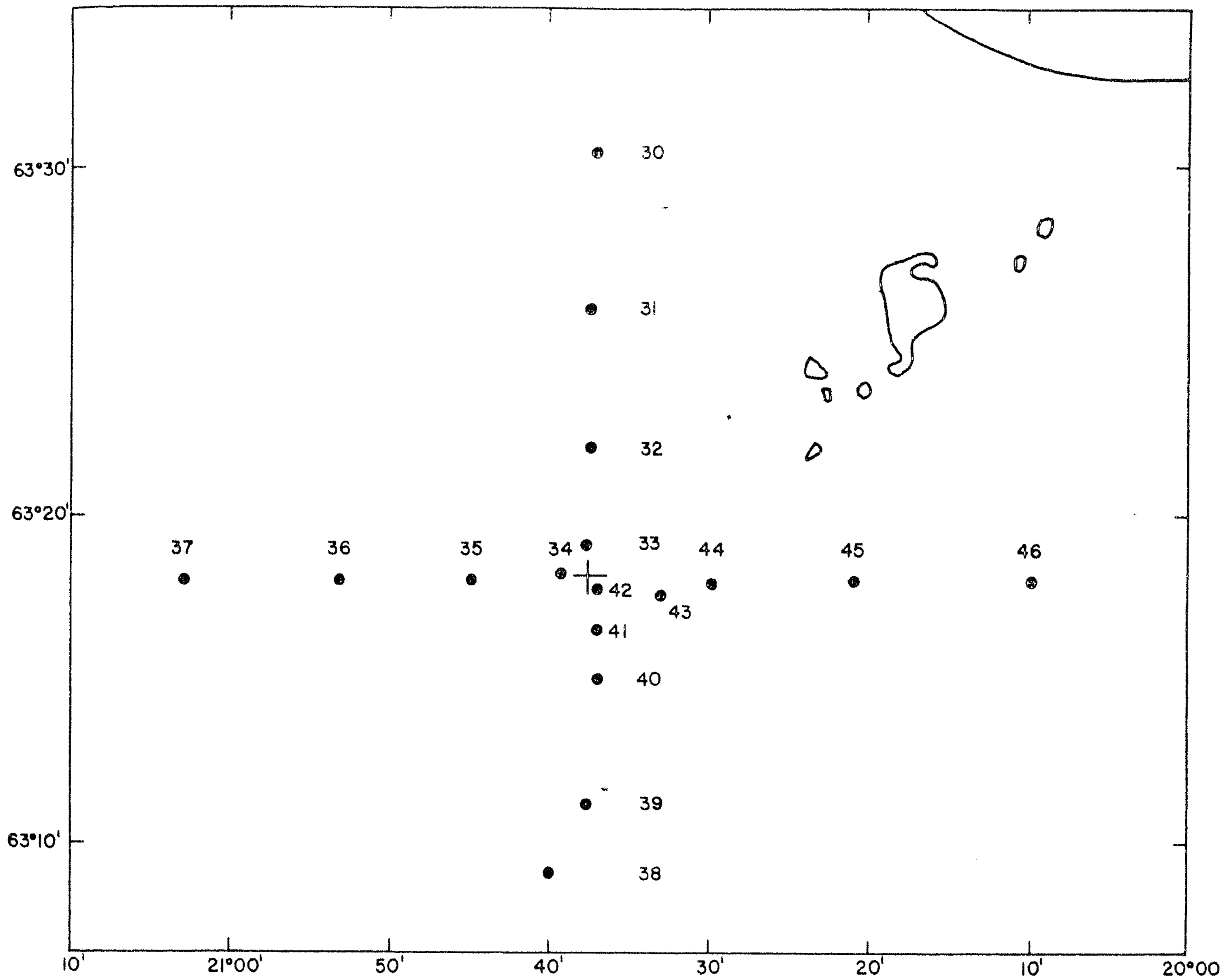


Fig. 1 Location of beam transmittance measurements in the area around Surtsey and Jólnir on 1-2 August 1966.

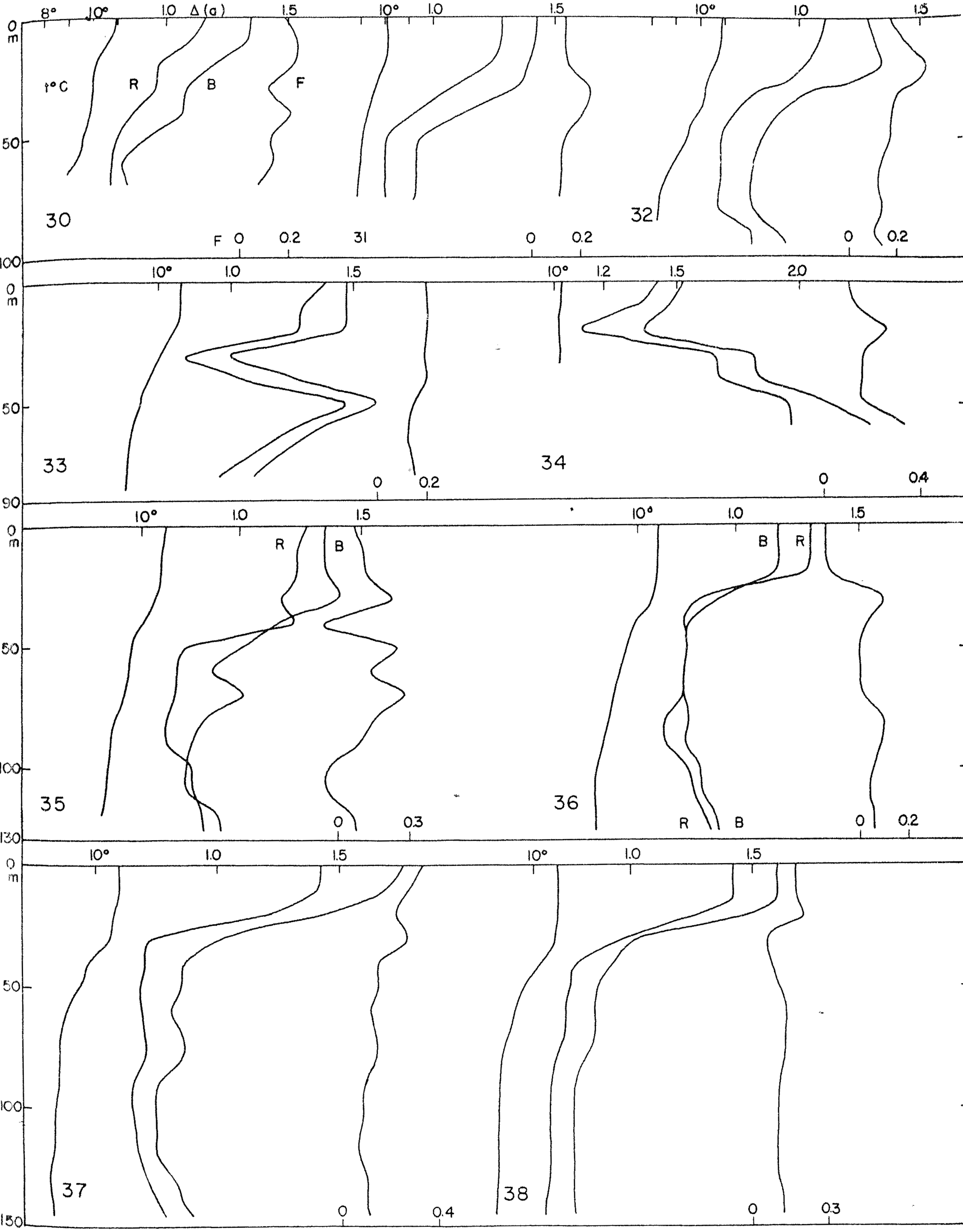


Fig. 2 Vertical distribution of temperature (t° C), attenuation coefficients in the red (Δa (R)) and in the blue (Δa (B)) and their differences (F), the last being a measure of the colour of the sea water, at stations 30-38.

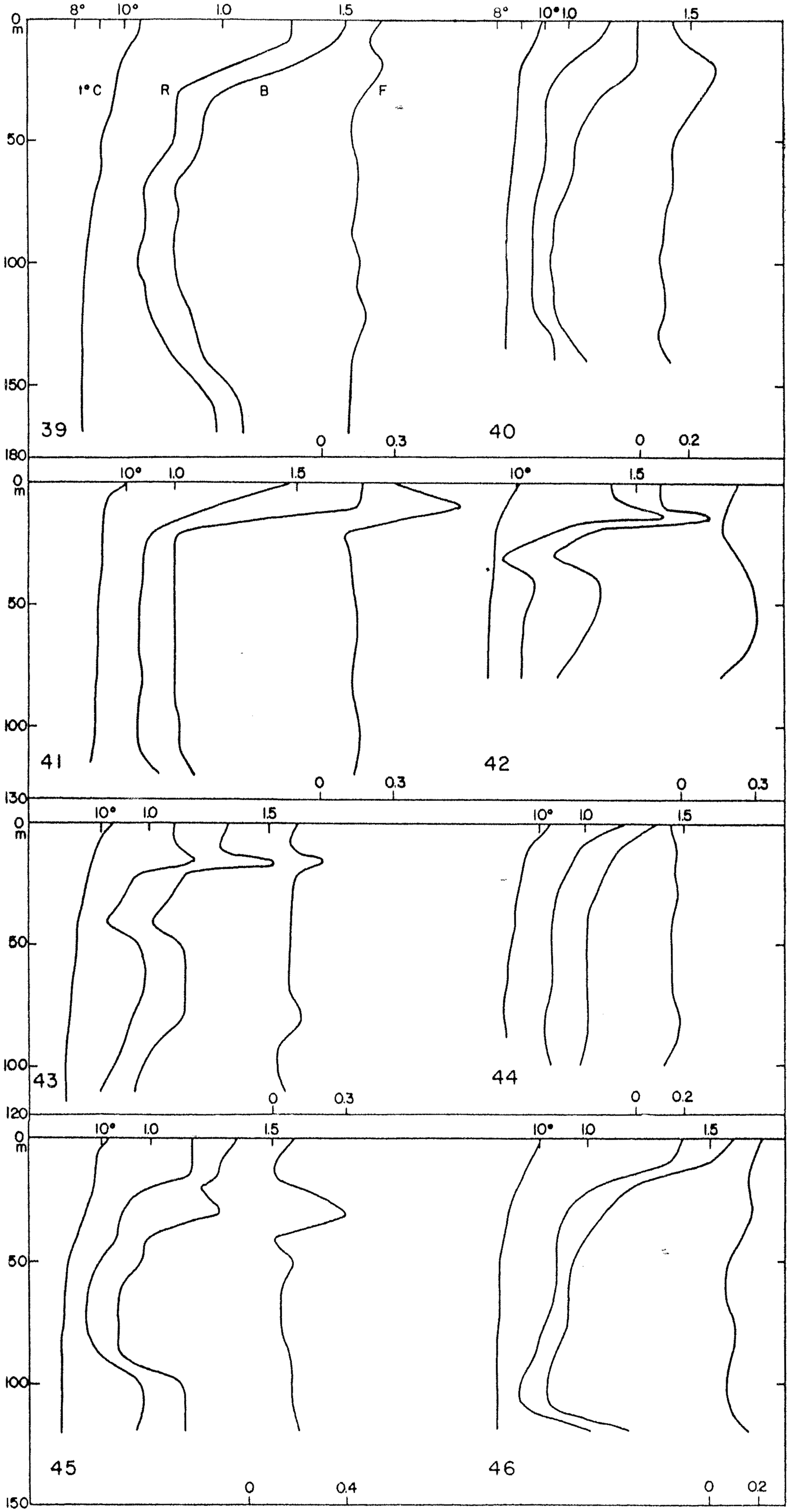


Fig. 3 As Fig. 2 except on stations 39-46.

Fig. 4 Echo soundings carried out from the coast guard vessel "Þór" in the last week of July 1966 N and NE of Surtsey.

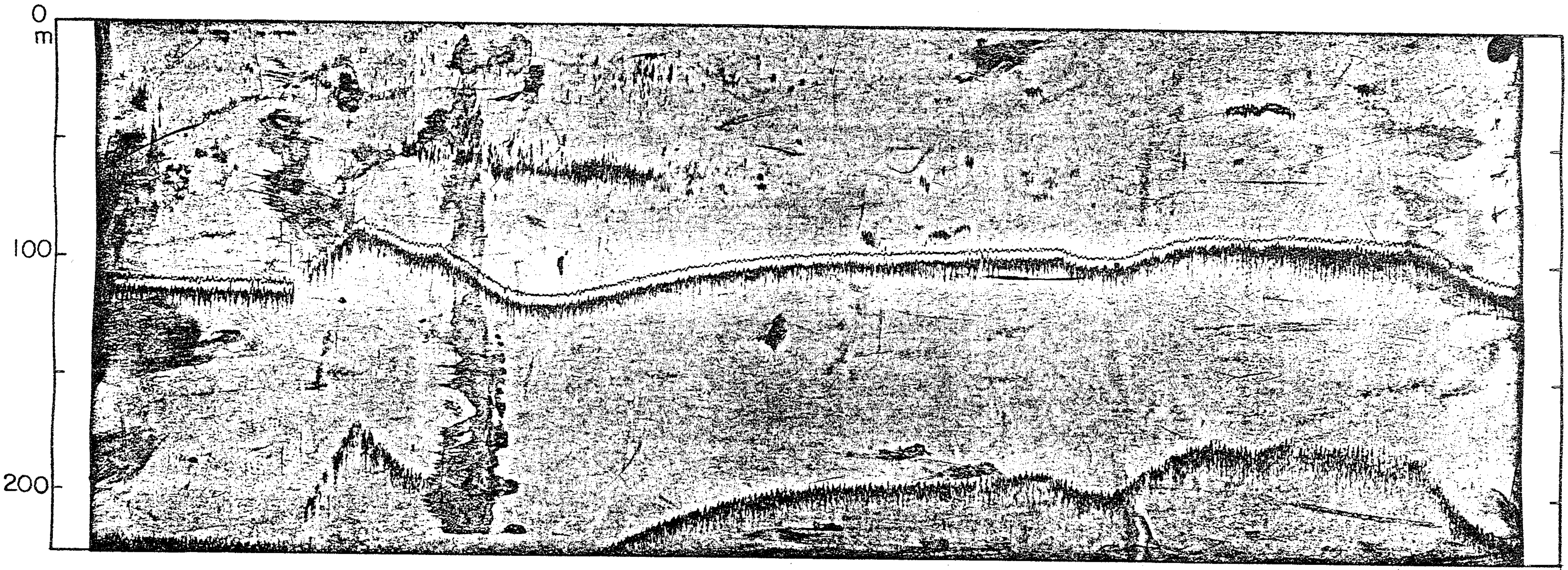


Fig. 5 Echo soundings carried out from the coast guard vessel "Þór" in the last week of July 1966 N and NE of Surtsey.

Fig. 6 Echo soundings carried out from the coast guard vessel "Þór" in the last week of July 1966 N and NE of Surtsey.

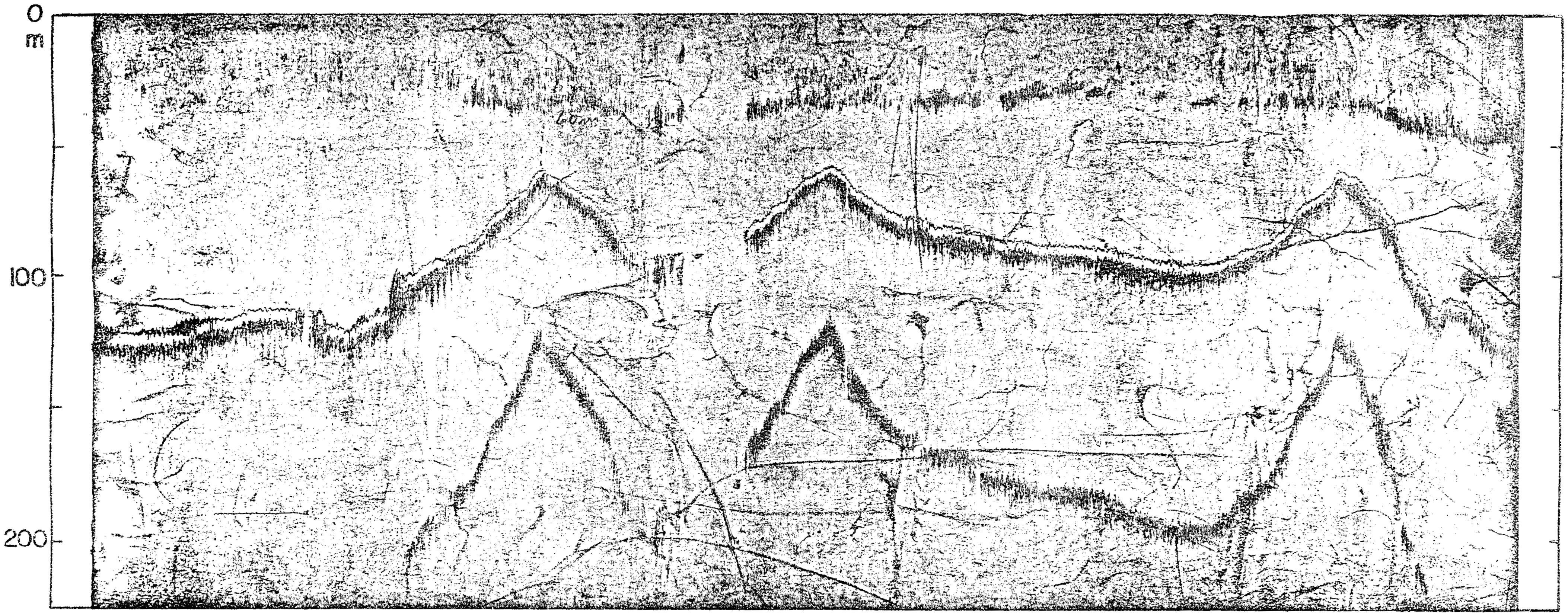


Fig. 7 Echo soundings carried out from the coast guard vessel "Þór" in the last week of July 1966 between Surtsey and Jólnir.

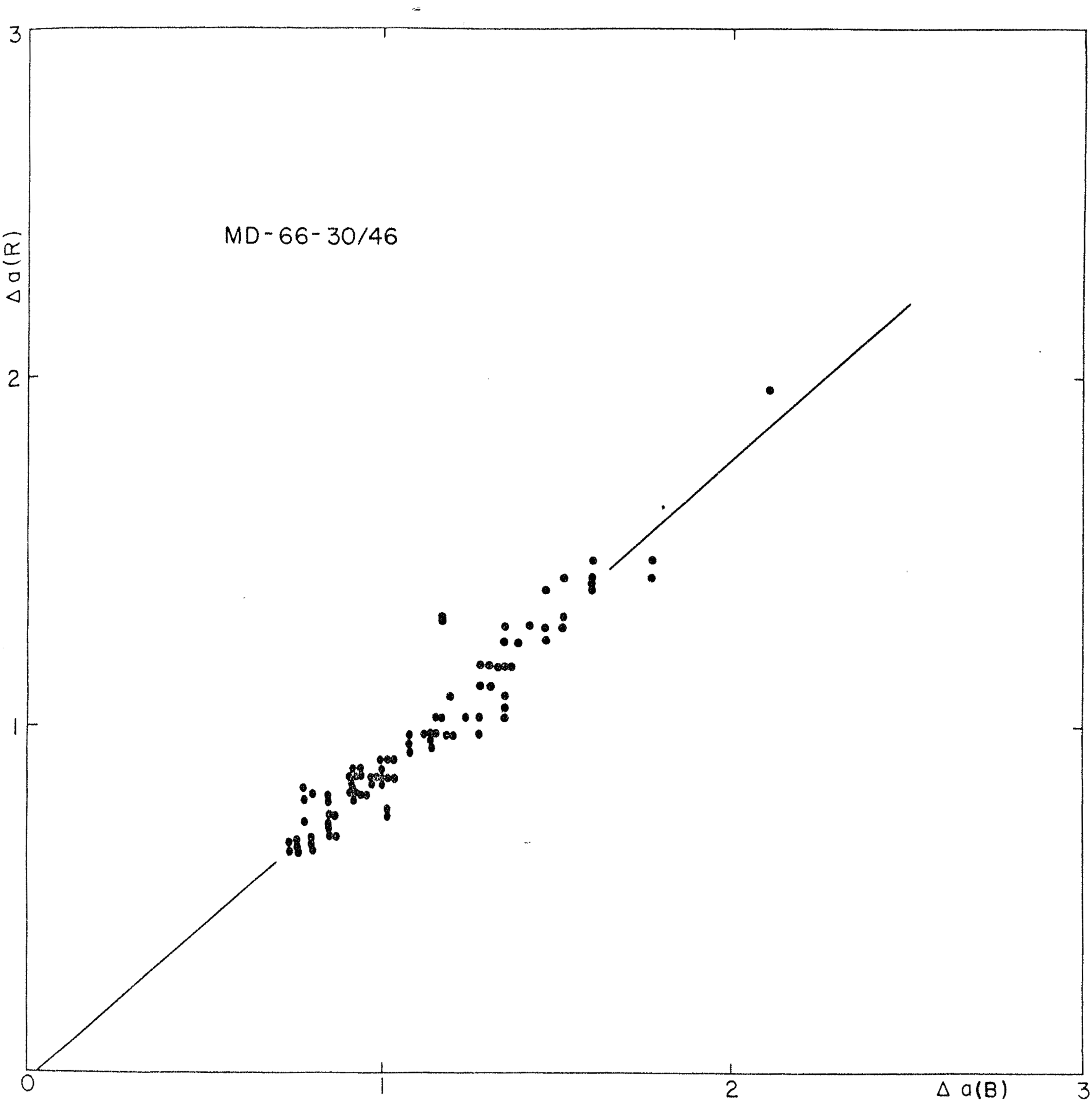


Fig. 8 The relationship between the attenuation coefficients (Δa (R) and Δ a (B)) on all station carried out around Surtsey based on data from 0, 20, 50, 70, 100, 120, 150, and 170 m. depth.

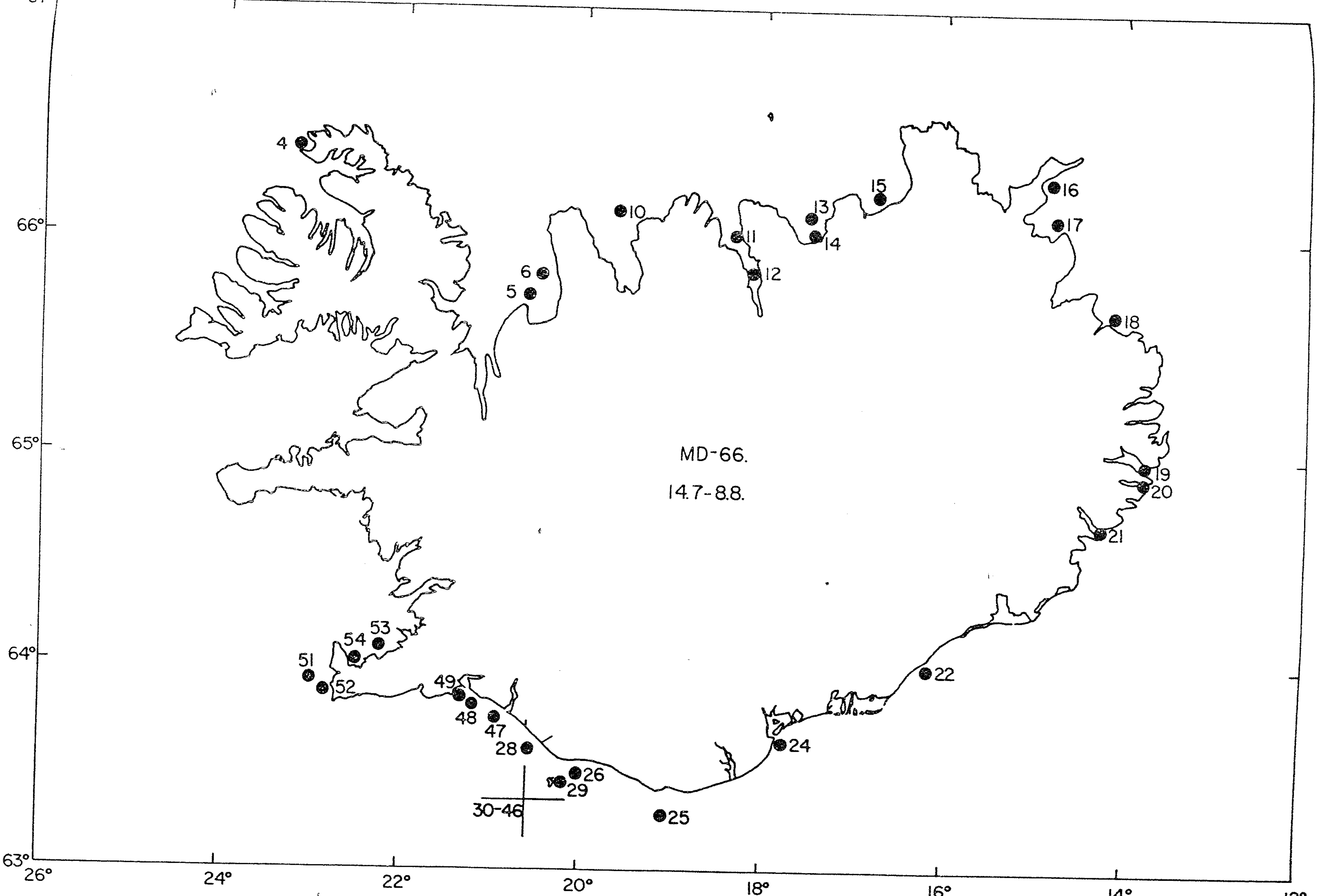


Fig. 9 Location of beam transmittance measurements carried out in the coastal area all around Iceland on July 17-August 8 1966 (Surtsey observation included).

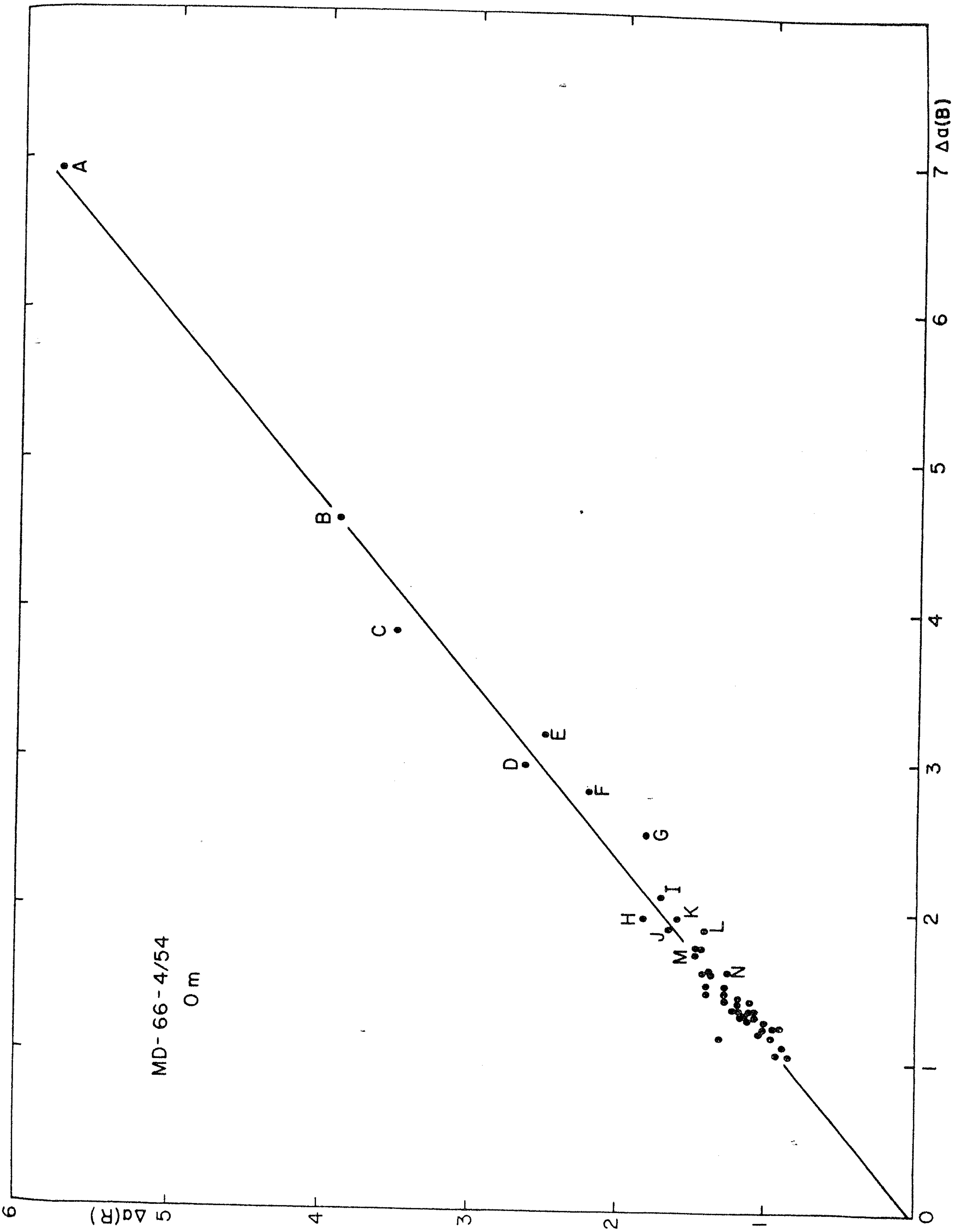


Fig. 10 The relationship between the attenuation coefficients (Δa (R) and Δa (B)) based on sea surface data at the stations shown in Fig. 9.

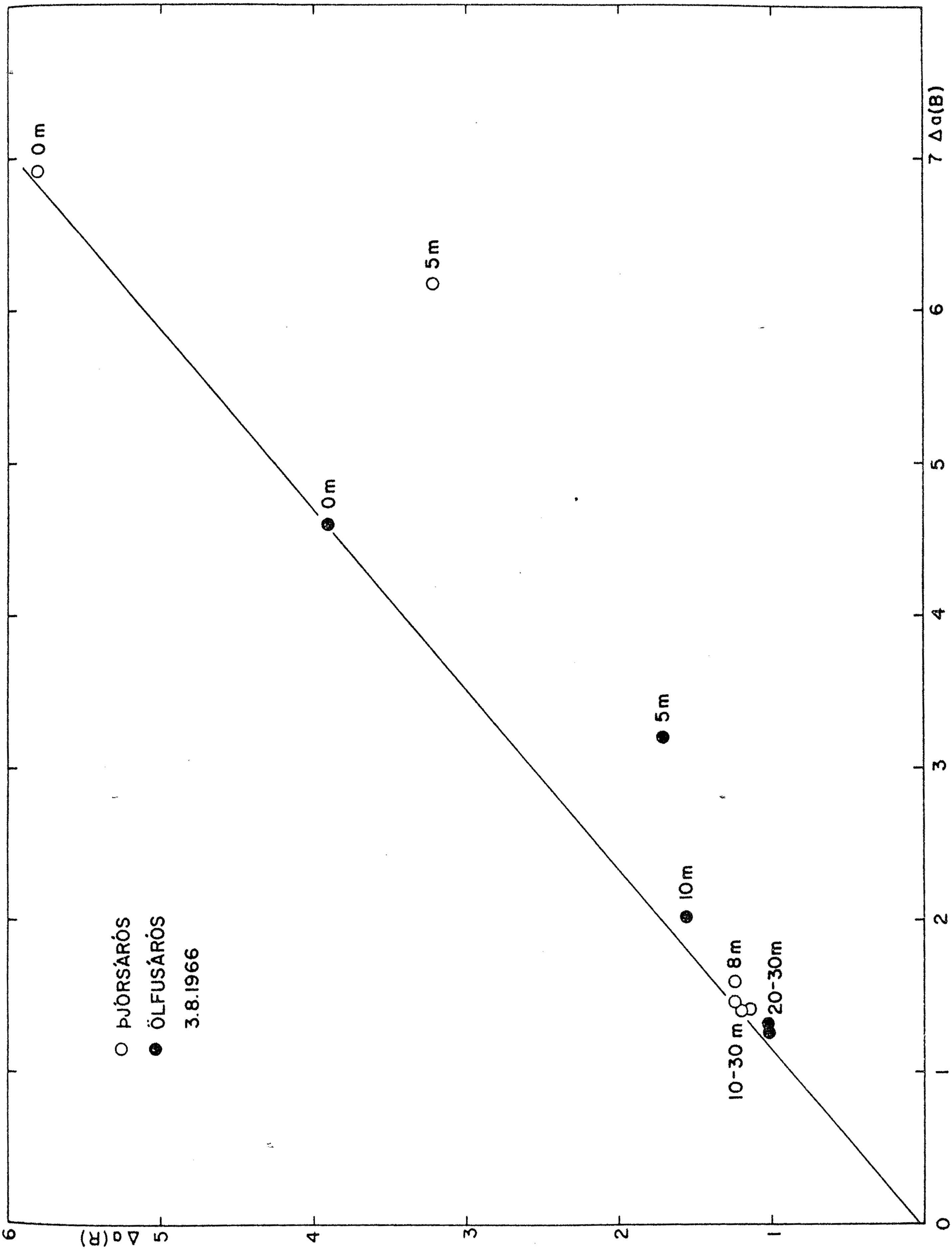


Fig. 11 The relationship between the attenuation coefficients (Δa (R) and Δa (B)) based on data from 0, 5, 10, 20 and 30 m depth at the river outlets of Þjórsá and Ölfusá (Stats. 47 and 49).

LIST OF PUBLICATIONS ON SURTSEY RESEARCH AND RELATED SCIENTIFIC WORK

List of publications on Surtsey research and related scientific work

BIOLOGY

Brock, T.D., 1966: The habitat of Leucothrix Mucor, a widespread marine microorganism. Vol. 11, No. 2, April 1966, pp. 303-307.

Brock, T.D., 1965: Mode of growth of Leucothrix Mucor in pure culture and in nature, as studied by tritiated thymidine autoradiography. Department of Microbiology, Indiana University.

Brock, T.D., 1966: Microbial Life on Surtsey. Surtsey Research Progress Report II, p. 9-13.

Brock, T.D., 1965: Microbial growth in the Marine Environment. Direct analysis by autoradiography.

Brock, T.D. and Brock, M.L. 1966: Temperature optima for algal development in Yellowstone and Iceland hot springs. Nature 209: p. 733-734.

Brock, T.D. and Brock, M.L. 1967: Progress Report on Microbiological studies on Surtsey and the Icelandic mainland. Surtsey Research Progress Report III, p. 6-12.

Cavaliere, A.R. 1968: Marine fungi of Iceland: a preliminary account of Ascomycetes. MYCOLOGIA (In Press).

Einarsson, E. 1965: Report on dispersal of plants to Surtsey Res. Progr. Report I, p. 16-18.

Einarsson, E. 1966: On dispersal of plants to Surtsey. Surtsey Res. Progr. Report II, p. 19-21.

Einarsson, E. 1967: Comparative ecology of colonizing species of vascular plants. Surtsey Res. Progr. Report III, p. 13-16.

Einarsson, E. 1967: The Colonization of Surtsey, The New Volcanic Island by Vascular Plants. Aquilo, Ser. Botanica, Tom. 6, Societas Amicorum Naturae Ouluensis, p. 172-182.

Fridriksson, S., 1965: Fjörukál (Cakile edentula) í Surtsey og fræflutningur á sjó. - Náttúrufræd., 35, p. 97-102.

Fridriksson, S. 1964: The colonization of the dryland biota on the island of Surtsey off the coast of Iceland. Náttúrufræd. 34, p. 83-89.

Fridriksson, S. and Johnsen, B., 1967: The vascular flora of the outer Westman islands. Reprinted from Greinar IV, 3, 1967, Societas Scientiarum Islandica, Reykjavík, Iceland.

Fridriksson, S. 1965: Biological records on Surtsey. Surtsey Res. Progr. Rep. I, p. 19-22.

Fridriksson, S. 1965: The first species of higher plants in Surtsey, the new volcanic island. Náttúrufræd. 35, p. 97 - 102.

Fridriksson, S. 1966: The pioneer species of vascular plants in Surtsey Cakile edentula. Surtsey Res. Progr. Rep. II, p. 63-65.

Fridriksson, S. 1966: The possible oceanic dispersal of seed and other plant parts to Surtsey. Surtsey Res. Progr. Report II, p. 59-62.

Fridriksson, S. 1966: A second species of vascular plants discovered in Surtsey. Surtsey Res. Progr. Rep. III, p. 17-19, and Náttúrufræd. 36, 1966, p. 157-158.

Fridriksson, S. 1968: Life arrives on Surtsey. New Scientist, 28 March 1968, p. 684-687.

Fridriksson, S. 1966: Melgresi í Surtsey. Náttúrufræd. 36, 1966, p. 157-158.

Fridriksson, S.: Um adflutning lífvera til Surtseyjar (The colonization of dry land biota on the island of Surtsey). Náttúrufræd. Vol. 34, No. 2, 1965, p. 83-89.

Fridriksson, S. and Johnsen, B. 1966: Preliminary Report on the vascular flora of the lesser Westman Islands. Surtsey Res. Progr. Rep. II, p. 45-58.

Gudmundsson, F. 1966: Birds observed on Surtsey. Surtsey Res. Progr. Rep. II, p. 23-28.

Gudmundsson, F. 1967: Bird observations on Surtsey in 1966. Surtsey Research Progr. Rep. III, p. 37-41.

Hallsson, S. 1966: Preliminary study of the development of population of marine algae on stones transferred from Surtsey to Heimaey 1965. Surtsey Res. Progr. Rep. II, p. 31-33.

Johnsen, B. and Fridriksson, S. 1967: On the vegetation of the outer Westman Isles 1966. Surtsey Res. Progr. Rep. III, p. 20-36.

Johnson, T.W., Jr. 1966: Rozella marina in Chytridium polysiphoniae from Icelandic waters. MYCOLOGIA, 58: 490-494.

Johnson, T.W., Jr. 1966: Report on research in mycology 30 March - 5 April 1966. Surtsey Res. Progr. Rep. II, p. 29-30.

Johnson, T.W., Jr. 1967: Mycological investigations in Iceland III. Surtsey Res. Progr. Rep. III, p. 42.

Johnson, T.W., Jr. 1968: Aquatic fungi of Iceland: introduction and preliminary account. Jour. Elisha Mitchell Sci. Soc. (In Press).

Jónsson, S. 1966: Initial settlement of marine benthic algae on the rocky shore of Surtsey, the new volcanic island in the North Atlantic. Surtsey Res. Progr. Report II, p. 35-44.

Jónsson, S. 1966: Biologie Marine - Le commencement du peuplement benthique des côtes rocheuses du Surtsey, la nouvelle île volcanique dans l'Atlantique Nord. C.R. Acad. Sci. Fr., 262, 915-918.

Jónsson, S. 1967: Further settlement of marine benthic algae on the rocky shore of Surtsey. Surtsey Res. Progr. Report III, p. 46-56.

Kolbeinsson, A. and Fridriksson, S. 1967: A preliminary report on studies of microorganism on Surtsey. Surtsey Res. Progr. Report II I, p. 57-58.

Lindroth, C.H. 1967: Djurvärlden erövrar en ny ö: Surtsey vid Island, p. 244-252.

Lindroth, C.H., Anderson, H. and Bödvarsson, H. 1966: Report on the Surtsey investigation in 1965, terrestrial invertebrates. Surtsey Res. Progr. Report II, p. 15-17.

Lindroth, C.H., Anderson, H., Bödvarsson, H. and Richter, S. 1967: Report on the Surtsey investigation in 1966. Terrestrial invertebrates. Surtsey Res. Progr. Report II I, p. 59-67.

Nicolaisen, W. 1967: Marine biological studies around Surtsey. Surtsey Res. Progr. Report III, p. 68-69.

Ponnamperuma, C., Young, R.S. and Caren, L.D. 1967: Some chemical and microbiological studies of Surtsey. Surtsey Res. Progr. Report III, p. 70-80.

Sigurdsson, A. 1965: Report on the marine biological survey around and on Surtsey. Surtsey Res. Progr. Report I, p. 23-25.

Skúladóttir, U. 1966: Report on the marine biological survey around and on Surtsey. Surtsey Res. Progr. Report II, p. 67-73.

GEOLOGY

Kjartansson, G., 1966: A contribution to the morphology of Surtsey. Surtsey Res. Progr. Report II.

Kjartansson, G, 1966: Stapakenningin og Surtsey (A comparison of table mountains in Iceland and the volcanic island of Surtsey). Náttúrufræd., Vol. 36, No. 1, p. 1-34.

Rist, Sigurjón, 1967 : Ecographic soundings around Surtsey.
Surtsey Res. Progr. Report III.

Thorarinsson, S., Einarsson, Th., Sigvaldason, G. and Elísson, G., 1964 : The submarine eruption off the Vestmann Islands, 1963-64. Bull. Volcanologique, (Naples), Vol. 27, 1964, p. 435-45.

Thorarinsson, S., 1965 : Surtsey: island born of fire. National Geographic Magazine, Vol. 127, No. 5, 1965, p. 712-26.

Thorarinsson, S., 1965 : Sitt af hverju um Surtseyjargosið (Some facts about the Surtsey eruption). Náttúrufræd., Vol. 35, No. 4, 1965, p. 153-81.

Thorarinsson, S. : Surtsey. The new island in the North Atlantic. Reykjavík Almenna bókafélagid, 1964, and New York, Viking Press, 1967 (Also in German, Danish and Swedish).

Thorarinsson, S., 1964 : Surtsey. The new island in the North Atlantic. Almenna bókafélagid, Reykjavík, 63 pp. and 46 plates.

Thorarinsson, S., 1965 : The Surtsey eruption : course of events and the development of the new island. Surtsey Res. Progr. Report I.

Thorarinsson, S., 1966 : The Surtsey eruption. Course of events and the development of Surtsey and other new islands. Surtsey Res. Progr. Report II.

Thorarinsson, S., 1967 : The Surtsey eruption, course of events during the year 1966. Surtsey Res. Progr. Report III.

Thorarinsson, S., 1967 : The Surtsey eruption and related scientific work. The Polar Record, Vol. 13, No. 86, 1967, p. 571-78.

Einarsson, Th., 1967 : Der Surtsey Ausbruch - Naturwissentschaftliche Rundschau. Band 20, p. 239-247.

GEOPHYSIC

Anderson, R., et.al.: Electricity in volcanic clouds. Science, Vol. 148, No. 3674, 1965, p. 1179-89.

Arnason, B., 1966 : Measurements of the D/H-ratio in hydrogen and water vapour collected on the volcanic island Surtsey during the year 1965 (continued). Surtsey Res. Progr. Report II.

Arnason, B., 1967 : Measurements on the D/H-ratio in hydrogen and water vapour collected at Surtsey (continued III). Surtsey Res. Progr. Report III.

Arnason, B., 1965 : Measurements on the D/H-ratio in H_2-gas and water vapour collected at the volcanic island Surtsey during the year 1964. Surtsey Res. Progr. Report I.

Björnsson, S., 1966 : Radon in magmatic gas at Surtsey and its possible use for determining the content of water in the Magma. Surtsey Res. Progr. Report II.

Björnsson, S., 1965 : Some geophysical observations at Surtsey in 1964 :
(1) atmospheric electric disturbances at the volcanic cloud ;
(2) charge separation at the lavasea contact ;
(3) radon content of magmatic gas.
Surtsey Res. Progr. Report I.

Friedman, D.J., Williams, R.S., Miller, C.D. and Pálmason, G., 1967 : Infrared Surveys in Iceland in 1966. Surtsey Res. Progr. Report III.

Pálmason, G., 1965 : Some geophysical studies in Surtsey 1964 : (1) seismography ; (2) electrical conductivity ; (3) gravity measurements. Surtsey Res. Progr. Report I.

Sigurgeirsson, Th. and Stefánsson, R., 1967 : Seismic measurements in Surtsey. Surtsey Res. Progr. Report III.

Sigurgeirsson, Th., 1967 : Continued geophysical measurements in Surtsey. Surtsey Res. Progr. Report III.

Sigurgeirsson, Th., 1965 : Some geophysical measurements and observations in Surtsey 1963-64 : (1) time-lapse photographs of the cloud; (2) geomagnetic field-measurements ; (3) temperature measurements. Surtsey Res. Progr. Report I.

Sigurgeirsson, Th.: Jardedlisfrædirannsóknir í sambandi vid Surtseyjargosid (Geophysical research in connection with the volcanic eruption in Surtsey). Náttúrufræd., Vol. 35, No. 4, 1965, p. 188-206.

Sigvaldason, G. and Elísson, G., 1966 : Report on collection and analysis of volcanic gases from Surtsey. Surtsey Res. Progr. Report II.

Sigvaldason, G. and Elísson, G., 1967 : Sampling and analysis of volcanic gases in Surtsey in 1966. Surtsey Res. Progr. Report III.

Sigvaldason, G. and Elísson, G., 1965 : Preliminary report on collection and analysis of volcanic gases from Surtsey. Surtsey Res. Progr. Report I.

Thorarinsson, S. and Vonnegut, B., 1964 : Whirlwinds produced by the eruption of Surtsey volcano. Bulletin of the American Meteorological Society, Vol. 45, No. 8, 1964, p. 440-44.

McClaine, L.A., Allen, R.V., McConnell, Jr., and Surprenant, N.F.: Volcanic smoke clouds. Arthur D. Little, Inc. Cambridge, Mass.

GEOCHEMISTRY

Sigurdsson, H., 1966 : Advance report on "acid" Xenoliths from Surtsey. Surtsey Res. Progr. Report II.

Steinthórsson, S., 1965 : Surtsey petrology and chemistry. Surtsey Res. Progr. Report I.

Steinthórsson, S., 1965 : Petrography and chemistry. Surtsey Res. Progr. Report I.

OCEANOGRAPHY

Malmberg, S.A., 1965 : A report on the temperature effect of the Surtsey eruption on the seawater. Surtsey Res. Progr. Report I.

Stefánsson, U., 1965 : Chemical-oceanographic effects of the Surtsey eruption. Surtsey Res. Progr. Report I.

Stefánsson, U.: Influence of the Surtsey eruption on the nutrient content of the surrounding seawater. Sears Foundation : Journal of Marine Research, Vol. 24, No. 2, 1966, p. 141-268.

GENERAL

Einarsson, E.: The eruption in Surtsey in words and pictures. Heimskringla, Reykjavík, 1966. (Also in Icelandic, German and Danish).

Bauer, P., 1965 : Surtsey, Vol. 1, No. 3, February 1965.

Bauer, P., 1965 : Surtsey : First North Atlantic island born in 1100 years. Lodestar, Vol. 17, No. 4, 1965, p. 8-11.

Hermannsson, S., 1968 : Surtsey : Livet landet på en steril ö. Jyllands-Posten, 5.3. 1968, p. 14.

ODDI HF.