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BOSTON COLLEGE ENVIRONMENTAL CENTER SUMMER INSTITUTE ON SURTSEY AND ICELAND

by Cyril Ponnamperuma and James W. Skehan

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BOSTON COLLEGE ENVIRONMENTAL CENTER

SUMMER INSTITUTE ON SURTSEY AND ICELAND

Edited by

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1. INTRODUCTION

by Cyril Ponnamperuma

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The island Surtsey was born on November 14, 1963, when an eruption occurred beneath the ocean about 20 miles south of Iceland (ref. 1). The island became permanent when the explosive eruption changed in nature to a lava eruption (April 4, 1964); scientists world-wide became interested in this rare opportunity to examine geology as an active and developmental process (ref. 2). When eruptions on and near Surtsey ceased in July 1967, the scientific emphasis shifted from volcanology to biology as scientists documented the gradual invasion of life onto this initially relatively sterile island (ref. 1).

To coordinate the work of so many scientists, many from abroad, the Surtsey Research Society was formed with both national and international support (refs. 1, 2). This Society has periodically held conferences and published outlines of proposed research projects and the results of those completed. Many studies are still in progress as they involve the examination of developmental processes which may continue for several years before an equilibrium is reached. Results of studies on Surtsey have also appeared in other journals; the selected bibliography on Surtsey which is a part of this report indicates what a fertile field for study Surtsey has proved to be.

The purpose of the present report is to describe the interdisciplinary Boston College Environmental Center Summer Institute on Surtsey and Iceland which took place June 15-July 1, 1970. The program was jointly sponsored by the National Aeronautics and Space Administration, the National Science Foundation, the Surtsey Research Society, and the Boston College Environmental Center. Using a combined lecture-field program, the geology, geochemistry, and biology of these areas were studied as remarkable examples of new and extreme environments.

The senior faculty was composed of scientists from universities and federal agencies in the United States of America, as well as Icelandic scientists from the Surtsey Research Society, the Museum of Natural History, the Industrial and Development Institute, and the Agricultural Research Institute. Fifteen college and university teachers, research faculty members, and advanced graduate students enrolled in this program as trainees; one assistant from the Surtsey Research Society participated as a field guide.

The scope of the program ranged from background material on relevant aspects of Iceland (its geography, geochemistry, and biology - both past and present) to lectures concerning exobiology and the origin of life, and how studies of Surtsey can contribute to these areas of endeavor. In the field, geologic studies included the examination of various forms of volcanism, glaciation, thermal sites, nunatak formation, and palagonite fields. Biologic field studies emphasized the primary and secondary colonization of newly formed land, comparative ecology, and the study of extreme environments. The hot springs and glaciers provided an excellent chance to determine how life has adapted to harsh conditions, some of which are similar to those which may be encountered in our search for extraterrestrial life, especially on Mars.

The geology of Surtsey, Iceland, and the Westman Islands is also useful for testing the tools of exobiology. "New" areas of land previously covered by ice are denuded periodically by melting glaciers. It was originally planned to use the life-detection devices designed for planetary exploration to study the early stages in the biological succession of organisms onto this initially relatively sterile piece of land. Although the equipment was not completed in time to be tested during this Summer Institute, it will hopefully be used in subsequent studies on Surtsey.

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3. LOGISTICS AND ADMINISTRATION OF THE BOSTON COLLEGE ENVIRONMENTAL CENTER SUMMER INSTITUTE ON SURTSEY AND ICELAND

by Samuel Aronoff

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It will be apparent to all that the substance of much of the following is the result of inexperience coupled with the uniqueness of indigenous problems, but it is precisely these which make a discussion of the logistics of value. An old hand will find little or nothing novel.

Preplanning

The initial planning of the proposal contained at least two major items of gross concern. One related to the philosophy of the program: the extent of group interaction *vis-à-vis* individual contributions; the other was that of the budget. The first aspect was embedded in the objectives of the program and how they were to be obtained. The second major item was that of the budget. A *tight* budget - one that is highly detailed and closely approximated - is a very confining device. It is virtually impossible to cope with any of a number of problems if the budget is tight. For example, we were faced on arrival with the economical and logistical complexities of a general strike. There was absolutely no premonition of this during the course of preparation of the proposal and no foreseeable way to counterbalance the extra expenses forced by rearrangement of the itinerary. In a similar vein, the vagaries of the weather contributed to the necessity for the flexibility of decisions.

In planning future institutes, it would be highly desirable for some notion of internal expenses to be ascertained in advance. In our case, we had been advised by the travel agency supervising our operation that the internal cost (in Iceland) per individual would be $386 for board and room plus $50-$100 for internal travel.

Experience demonstrated that our logistic, as well as scholastic, success was due in very large measure to the generous efforts made by our Icelandic hosts. Without their assistance, the entire period could have been well-nigh catastrophic. As a corollary, the planning of the logistics by a local travel agency was not enough. Once away from the home base (of the travel agency), numerous problems developed, completely unforeseen, which required on-the-spot solutions. Most of these were extremely difficult for us as foreigners, and were fortunately resolved by our accompanying indigenous scientists. Thus the entire program - philosophy, logistics, and budget - should be planned with the intimate cooperation of the indigenous scholastic group.

Our experience has suggested that such groups should include both a Scientific Director and an Administrative Director. The latter will then have two major responsibilities: logistics and finances.

A third factor is that of allowing adequate time. It is not probable that the program will develop completely as planned regardless of the length of time - some unexpected elements will always go awry - but it is highly desirable to have at least six months from complete assurance of the budget by the funding agency to initiation of the program. The following elements should be developed as early as possible:

(a) The planning of the itinerary. (This will determine primarily the initial and concluding dates.)

(b) The reservation of major travel accommodations (flights and initial and final hotel sites). The intermediate sites should also be done, of course, but they may require "adjustment" as the result of unforeseen circumstances.

(c) The extent or need of specialized equipment. Ours turned out to be minimal, thanks to the kindness of the local scientists.

A successful device for establishing and maintaining contact with the participants, prior to travel, was to issue memoranda from a single coordinator, presumably the Administrative Director. In our case, we alerted participants to the status of the program, changes of plans, and the unique aspects of the itinerary (passport and health requirements, custom requirements [e.g., soil and biologic entrance permits], power characteristics [voltage and frequency], and weather conditions, etc.).

On-Line Aspects

The diversity of geographic origin of the participants presented a unique problem. Alternative modes of ticketing were: (a) to provide through tickets to all in advance (i.e., meeting on the plane) or (b) to provide overseas tickets at the departure site, allowing personal schedules to that site. The latter procedure was used successfully, providing the bonus of meeting individuals and associating names and faces in advance of overseas travel. An omission in this program was the relative lack of intercommunication regarding the interests and professional responsibilities of each participant. To save time in future institutes, photographs would be highly desirable to enable participants to couple names with faces more easily.

Care must be exercised at the transfer point to ensure transfer of baggage to the proper destination. A frequent error in our case was the sending of baggage to Luxembourg instead of Reykjavik, as the former was only a stop en route to a final destination.

A pre-arranged contact man at the foreign debarkation site should be established in advance. In our case, it was a young scientist from The Surtsey Research Society, with whom we were cooperating.

A minor but annoying problem occurring at each point was the confusion attendant on room assignments: i.e., who had singles, who had doubles, and with whom. To the extent that these can be arranged in advance, they would ease the temper of the group and facilitate logistics.

At each stop the head waiter (or equivalent) should be contacted to arrange *group meals*. Individual use of menus is both chaotic and expensive. Mere courtesy should include time arrangements for meals, and be known both to the hotels and participants. There was never any problem in arranging box lunches for field trips at any point of the itinerary and required no earlier request than the preceding evening. In most cases, the contents of the lunch could be left to the discretion of the hotel.

Whenever possible, the detailed program, including times, should be made available to participants in printed form (mimeo, Xerox, etc.). As a minimum, announcement of the subsequent day's program should be made at the previous dinner.

Travel between sites is done readily by bus and between major towns by plane. It should be realized that, except for the Keflavik-Reykjavik stretch, the roads in Iceland are gravel, with varying quality. While buses are capable of going almost anywhere, small groups are advised to rent four-wheel drive cars (Jeeps or Land Rovers).

Comments on Specific Sites

Reykjavik.- Overseas transports land at Keflavik. Passengers are bussed (30 miles) to Reykjavik. Customs at Keflavik is short and perfunctory. (No items were restricted - money, cigarettes, film, etc.). There are two major hotels, the Loftleider and the Saga. A third is planned for occupancy about a year from now. Both are modern and approximately equally expensive. Approximate costs for group meals are: breakfast, Kr. 200 ($1 = Kr. 88); lunch, Kr. 250; and dinner, Kr. 400. The Loftleider has a small, rather warm pool and sauna; the Saga has only the latter, plus an exercise room. The Saga is within walking distance of downtown; the Loftleider is somewhat farther away, but taxis are abundant and reasonable (ca. Kr. 80 to town) and the Loftleider is a bus-line terminus (Kr. 10 to town). The Saga has meeting rooms; the Loftleider does not. The cuisine at the two are comparable; the Loftleider has an excellent smorgasbord in addition to *á la carte*; the Saga essentially only the latter.

Laugaskoli.- Laugaskoli sits on the slope of a broad, grassy valley, palming a vigorous river. The dormitory is rather new, normally being used as an all-grade boarding school. We reached it by bus, following an air flight to Akureyri. Accommodations are somewhat spartan, single or double, and contain a wash bowl. Shower facilities and bathrooms are on each of the two floors. An excellent meeting room containing a blackboard is available. Breakfast was adequate (no juice); the box lunch was substantial.

Myvatn.- This well-known resort area has one main hotel and one smaller hotel, the latter being more like a lodging house. The main hotel is near-modern; the food is adequate but not outstanding. A small co-op grocery and variety store exists. Nearby is a diatomaceous earth plant, based on diatomite in the lake basin and the availability of heat from numerous fumaroles. There is a well-known pair of caves containing a hot running spring (40°C) for bathing. Midges can be a very real deterrent to enjoyment of the lake and nearby streams, especially if fishing is contemplated; therefore, bring face nets or buy them locally. The midges, which do not themselves feed or bite, are accompanied by a smaller fraction of flying insects (mosquitoes?) which do - severely. Fishing for trout in the rivers can be excellent. A typical license fee is Kr. 150 for 12 hours.

Hallormsstadur.- This children's school is quite new and was graciously opened for our convenience a few days in advance of schedule. The decor is excellent and the service is good. The institution is in a wooded area adjacent to a lake. (The waters are said to be sufficiently muddy to affect the taste of the fish.) A State Forestry Station is nearby and the Director kindly showed us the more than 200 varieties of foreign trees being tested for suitability in Iceland. Trees are also grown for sale to the public at very nominal prices.

Höfn.- This is a modern hotel near a rather well-stocked general co-op store in a small (population, 5000) relatively prosperous town. Although no rooms are available in the hotel for meeting (the dining room which would be ample for 200 is not available), there is a town meeting hall (alternating as a cinema) which can be used for lectures, discussions, etc., as the townsfolk are very cooperative. Direct air flights to Reykjavik are available, but the size of our group (30, the maximum capacity of the plane) required a special flight directly to the Westman Islands, usually reached only from Reykjavik. Food at the hotel is good.

Hotel "H.B." (Vestmannaeyar).- This is a rather old hotel, badly in need of additional plumbing and with unusually small and sparsely furnished rooms. There is only a single shower (no tubs) for the entire hotel, whose rooms occupy the third and fourth floors of the four-floor structure. The shower drain is not adequately vented so that fourth floor drainage occasionally - and unexpectedly - comes up through the drain of the third floor shower. The food, however, was among the best in the entire trip, and the owners were very accommodating.

Passage to Surtsey was arranged from here by one of our Icelandic colleagues. A tug was rented which was able to proceed to about 100 meters from shore. A rubber raft with rope tied fore and aft was lowered, the fore rope swum to shore, and the raft then permitted ferrying of individuals to and from the island by pulling alternately on the fore and aft ropes. The water can be quite choppy, and seasickness is common. As use of the raft is not feasible in rough water, planning for this trip is highly subject to weather; the calmest breeze is that from the south. A well-built hut with sleeping bunks for six or seven, a stove, and a chemical privy is available on the island by cooperation with the Surtsey Research Society.

Financing

A financing procedure which worked rather well was to transfer funds to a Reykjavik bank by cable. On reaching Reykjavik, the individual handling the finances can transform these funds into a bank account and issue checks as necessary. Our travel agency in Iceland assumed responsibility for collecting all hotel bills, bussing, etc. We followed the procedure of issuing checks only for emergencies and for paying a large fraction of the gross costs to the travel agency. The latter, however, assumed responsibility for most local costs and forwarded them to the administrator after his return to the States.

4. ROADLOG AND MAP OF THE BOSTON COLLEGE ENVIRONMENTAL CENTER SUMMER INSTITUTE ON SURTSEY AND ICELAND

by Gudmunder Sigvaldason

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June 15, 1970:

Members of the Summer Institute arrived in Reykjavik.

June 16, 1970:

Hekla.- The eruption of Hekla was studied from the volcanic region nearby. This was followed by a 2-1/2-hour drive through the hot springs area of Hveragerdi. Formations of pillar lava were observed near Hellisheidi. The lava from the May 5, 1970, eruption of Hekla was still pushing its way forward. Samples of fresh ash were collected for laboratory analysis.

June 17, 1970:

Krisuvik.- During the visit to the Krisuvik area, photosynthetic organisms were found in the hot springs; the temperatures of these hot springs ranged from 40° to 96°C, and the pH from 2 to 8.

June 18, 1970:

Reykjavik-Akureyri-Laugar.- The group traveled by airplane from Reykjavik to Akureyri. The road from Akureyri to Laugar swings around the southern end of Eyjafjördur and across Vaðlaheidi (Tertiary plateau basalts) to Fnjóskadalur. In Fnjóskadalur are remnants of the original birch forest which covered Iceland when it was initially settled by man. On the sides of the valley are shorelines indicating different water levels of an ice-dammed lake which occupied the valley at the end of the last ice age. In going through Ljósavatnsskard to Godafoss, a waterfall was seen in Skjálfandafljót. The river flows over a lava stream emanating from Trölladyngja, Iceland's largest shield volcano. The group was quartered for the night at Laugar, a school center which is heated by natural hot water.

June 19, 1970:

Laugar-Mývatn.- Námaskard is one of Iceland's most active thermal areas. Extensive drilling has provided steam for a diatomite plant and an electrical power station. Maximal downhole temperatures have been measured at 280°C. Surface manifestations of thermal activity include a fumarolic field with many acid mud pots and boiling ponds, as well as the encrustation of elementary sulphur and various sulphates. Shallow ground water is heated by escaping steam from a deep reservoir. In places the ground water, as found in lava fissures, reaches a comfortable bathing temperature of 40°C.

June 20, 1970:

Mývatn.- The Lúdent and Hverfjall craters represent two episodes of explosive volcanic activity in the Mývatn area. Effusive volcanic activity is demonstrated by the rows of craters on the Lúdentsborgir and Threngslaborgir fissures. Silicic lava on Lúdent shows the flow structures characteristic of viscous lavas.

June 21, 1970:

Mývatn-Hallormsstadur.- Dimmuborgir is an area containing peculiar lava pillar structures; they are believed to have been formed as a result of the damming of a lava lake that solidified, but was subsequently drained, thereby leaving individual solidified pillars standing in a more or less isolated fashion.

Nýjahraun.- Nýjahraun contains a lava flow of 1875 from the fissure Sveinagjá.

Mödrudalur.- The last stop in the Neovolcanic zone on the way east was at a farmstead which is situated 450 m above sea level; as such, it is the most highly elevated farmstead in Iceland.

Hallormsstadur.- The group was quartered overnight in an elementary school which is used as a hotel in the summer. Hallormsstadur is an especially well-located forestry station.

June 22, 1970:

Hallormsstadur-Höfn í Hornafirdi.- The excursion was joined by Dr. Sturla Fridriksson and visited the nursery station in Hallormsstadur.

Thingmúli central volcano.- A stop was made close to the eroded core of the volcano, which is one of many central volcanoes in the Tertiary formation of Eastern Iceland.

Breiddalur.- Tertiary basalts were seen which dip under the central part of the Breiddalur central volcano. Amygdale fillings abound. (A stop was made in order to purchase minerals.)

Berufjördur.- The road crossed successive layers of the main basalt types in eastern Iceland: porphyritic series, olivine basalts, tholeiitic basalts. Intercalated between the basalts were layers of silicic ash, some with ignimbritic textures (Skessutuff).

June 23, 1970:

Höfn í Hornafirdi.- Moraines of the retreating glacier Fláajökull were inspected. At the glacier tongue Hoffellsjökull, a gabbroic intrusion was visited. Noteworthy are pyroxene pegmatites and small aplitic dikes.

June 24, 1970:

Höfn-Skaftafell-Höfn.- At the National Park Skaftafell, members of the Summer Institute had a good view of Iceland's highest mountain, Öraefajökull, which is a Quaternary volcano and was active in historic times (1362, 1727). An impressive layer of columnar basalt was seen at Skaftafell.

June 25, 1970:

Höfn-Vestmannaeyjar.- The Vestmannaeyjar are a group of islands formed by submarine eruptions. On the main island is one of Iceland's largest fishing stations.

June 26, 1970:

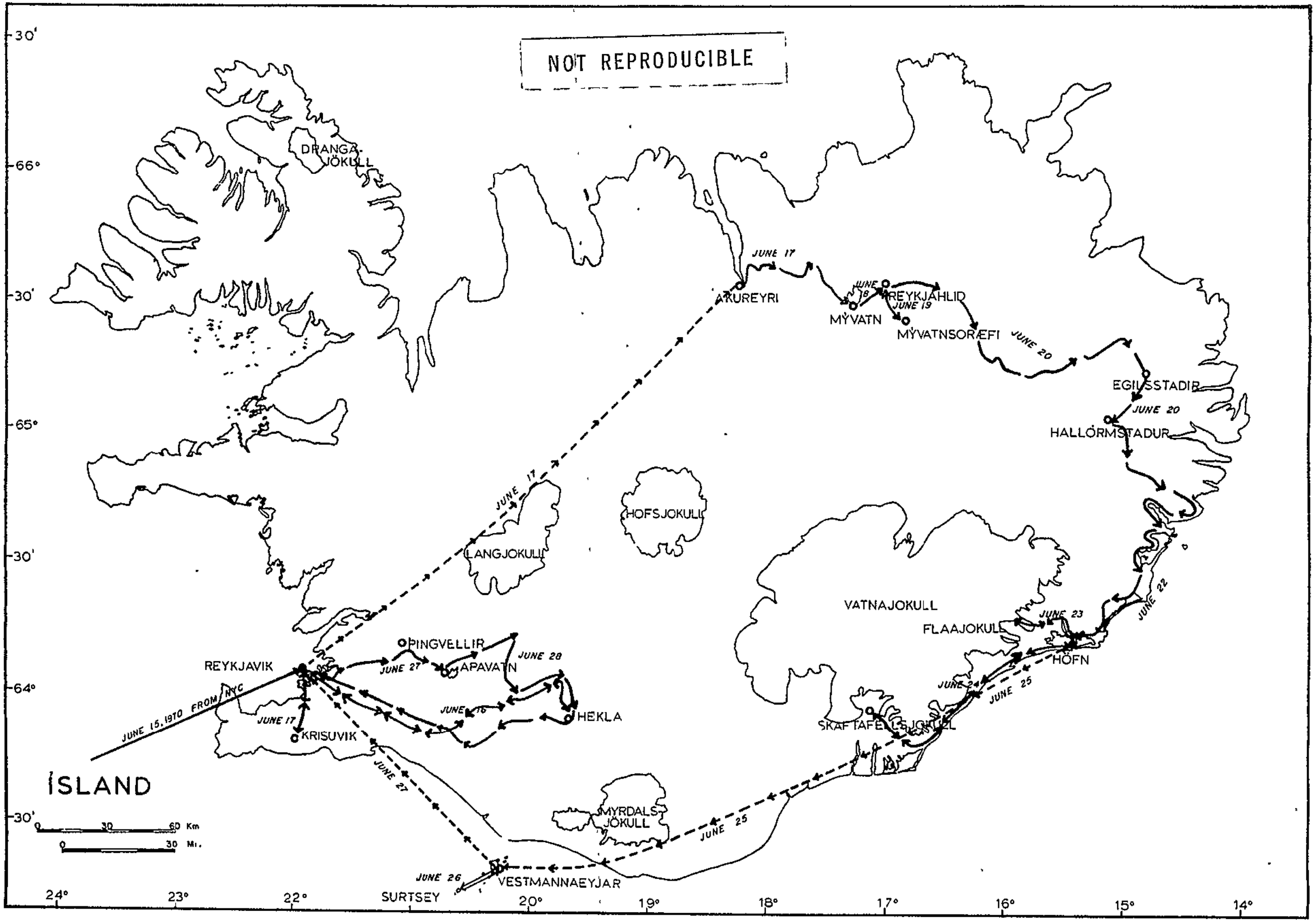
Vestmannaeyjar-Surtsey-Vestmannaeyjar.- See Section 5.5, Highlights of the Surtsey Eruption: 1963-1967.

June 27, 1970:

Vestmannaeyjar-Reykjavík-Laugarvatn.- The excursion stopped at Thingvellir, the old assembly place of the Icelandic Althing, which was established in 930 A.D. At Laugarvatn, a school center located in a natural hot spring area, the group spent the night.

June 28, 1970:

Laugarvatn-Hekla-Reykjavík.- At the Haukadalur hot spring area, the Great Geysir and an alkaline hot spring area with extensive silica sinter deposits were studied. The Great Geysir does not erupt anymore because the underground water channels have narrowed due to the precipitation of silica. The geysir Strokkur is, however, active at short intervals. The Hekla volcano started an eruption on May 5, 1970. Craters both on the southeastern end of the volcano and northwest of the volcano proper were quite active during the first few days. When the northwest craters were visited, some activity was still observed - intermittent explosions, a little ash fall over the crater, and flowing lava. The excursion returned to Reykjavík in the evening.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5.1. ICELAND: A PECULIAR ENVIRONMENT OF MAN

by Sigurdur Thorarinsson

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Far out in the northernmost Atlantic, touching the Arctic Circle, is Europe's second largest island, with an area of 103,000 km^2 and a population of 200,000. This island was discovered by Irish hermits in the 8th century and rediscovered by Scandinavian vikings about 870 A.D. It is a country of contrasts, a land of fire, but bearing not quite undeservedly a colder name than any other country.

Geologically, three facts are important: (1) it is situated on the Mid-Atlantic Ridge rift zone, (2) it is also situated on the ridge that runs across the Atlantic between Greenland and Great Britain, and (3) it has a central position within the Brito-Arctic plateau basalt area. Plateau basalts of Miocene-Pliocene age build up the eastern and western parts of the country; these sections are separated by a median zone built up, to a great extent subglacially, by the Pleistocene Móberg Formation, which covers about half the country. The postglacially and historically active volcanic areas - mainly confined to a median belt that divides in two in South Iceland - covers about one-third of the country. This belt is characterized by a nearly anachronistic mass production of basalts from fissures and shield volcanoes and by a great variety of volcanic phenomena; nearly all existing types of volcanoes are represented there. About thirty volcanoes have been active since the colonization; eruptions occur on the average every fifth year. Some eruptions, such as the Hekla eruption of 1104, the Öroetajökull eruption of 1362, and the Lakagígar eruption of 1783, have made havoc with their surroundings. As a direct and indirect result of the Lakagígar eruption, about 10,000 people (20% of the entire population) died from starvation, fluorine poisoning, and other diseases. Tephrochronological studies have proved very helpful in supplementing the knowledge about the activity of the volcanoes preserved in written sources.

Climatically, Iceland is situated in the boundary zone, the polar front between air masses of "polar" and "tropical" origin. Iceland has a cold-tempered oceanic climate; it is strongly influenced by the North Atlantic Drift (a continuation of the Gulf Stream) which washes its south and west coasts, keeping the harbors open the year round, and by the East Greenland Current which flows clockwise along the north and east coasts. The climate is also greatly affected by the movement of the Arctic drift ice border; its approach means a reduction both in temperature and precipitation, thus changing the climate to a more continental, Arctic type. The average July temperature in Iceland is about 11°C; the average January temperature in coastal areas is near the freezing point.

The consequences of the climate more than anything else made Iceland as an environment of man different from the countries from which the immigrants came. One consequence is that grain-growing could never become an occupation of importance for Icelandic farmers; from the beginning, they have depended on the raising of sheep, cattle, and horses as well as on fresh- and saltwater fishing. The second important consequence of the climate and the isolation of Iceland is that since the Ice Age there have been no woods in Iceland except birchwoods. When settlement began, these birchwoods covered about 20% of the country, or about 20,000 km^2.

There has always been a shortage of building materials in Iceland; for this reason one sees no impressive historical ruins. The most common rocks in Iceland do not lend themselves well to cutting, ornamental carving, or building purposes and the Icelandic birchwoods could not be used in buildings of any size. Driftwood made up for this shortage to some extent. The change in design of Icelandic farmhouses from spacious longhouses during the first centuries to the small passagehouses of later centuries, built mostly of turf and stone, was at least partly caused by the increasing shortage of timber. The consequent inability of the people to renew their ships and so ensure transportation to Iceland proved fatal to its independence; this was one of the reasons Iceland lost its independence in 1262.

Iceland is unique in being the only large inhabitable area on earth where no primitive tribes ever lived. Before the settlement there were no grazing mammals in the country; the arrival of man with his grazing livestock upset the unstable balance between soil-building and soil-eroding processes, thereby causing soil destruction on a catastrophic scale which is still going on. Nearly half the area covered by loessial soil at the time of settlement is now bare of soil and more than three-fourths of the country is now without vegetation cover. As regards vegetation, Iceland was obviously a better country during the first centuries of settlement than now. Climatically, these centuries were also favored , but toward the beginning of the 12th century the climate began to deteriorate, reaching a low during the period ca. 1550-ca. 1850. During the period 1920-1965 it was again comparable with that of the first centuries of settlement. Thus Iceland's two periods of independence, 870-1262 and since 1918, have both been climatologically favored.

The Icelanders have never been engaged in war with other nations, but they have fought a hard fight against the elements - ice, fire, and inclement weather.

About 1100 the population in Iceland numbered about 80,000, about one-third the population of Norway at that time. In 1800 it had dropped down to 47,000. Since 1800 it has grown steadily.

Modern Iceland is no longer a country depending mainly on primitive farming. Fishing is the main export industry, accounting for 90% of the export, and about 2% of the world's total catch of fish; even so, the number of professional fishermen is only about 6,000. More than 80% of the population now live in towns and villages, as opposed to 20% in the year 1900.

The main natural resources of the country are hydropower and geothermal energy, and the utilization of these resources has now started on a considerable scale. There was a time when the subterranean fire of Iceland gave rise to the belief that Hell was situated there. Today the same fire helps more than most other things to make life agreeable in this northern land.

But although the Icelanders are nowadays less dependent on their geographical and geological environment than they were before, yet I think this small nation will even in the future have stamped on it marks of this peculiar environment, which is different from those in which most other nations have their being.

5.2. THE "HEKLA FIRES": A PRELIMINARY REPORT OF THE 1970 MT. HEKLA VOLCANIC ERUPTION. A REPORT FROM THE SMITHSONIAN INSTITUTION CENTER FOR SHORT-LIVED PHENOMENA, 15 JUNE 1970

N71-17968

by Sigurdur Thorarinsson

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After an unusually short repose of 22 years, an eruption broke out in Hekla and its immediate vicinity on May 5, 1970. The seismographs in Reykjavík registered earthquake shocks which began at 2058 and culminated at about 2200, maximum magnitude about 4 Richter. The eruption started visibly about 21h 30m when fissures opened up nearly simultaneously on the southwest and south flanks of the Hekla ridge (Hekla proper). The fissure on the south flank was about 0.5 km long, the fissure on the southwest flank about 300 m (rough estimates), and a single small vent opened up just beneath the lava crater of 1947/48. The 5-km-long fissure, which during major Hekla eruptions splits the Hekla ridge lengthwise and did so in 1947, did not open up this time. About 10h 30m, a fissure, some few hundred meters long, opened up in Skjólkvíar, a short distance northeast of Hekla.

The initial phase of the eruption lasted 2 to 3 hours and was characterized by a very vigorous fountain activity, especially in the craters on the south flank where the fountains reached at least 750 m in height. In Skjólkvíar they reached about 500 m in height. The vapor column above Hekla reached 15,000 m in height.

The tephra production was considerable, totaling approximately 30 million m^3. It was carried toward the NNW and reached the north coast, 180 km distant from Hekla, at midnight. The area on land receiving more than 100 tons/km^2 was about 9,500 km^2, or nearly one-tenth of the country. Along the axis of maximal thickness, the tephra layer was 7 cm thick at a distance of 15 km from the volcano. At a distance of 180 km, the maximum thickness was 0.4 mm.

The tephra proved unusually rich in fluorine (up to at least 1500 ppm) and caused lethal fluorine poisoning in the grazing livestock, especially sheep. The situation is really very serious, especially in some districts on the north coast where the tephra is very fine grained and washes out more slowly than expected. The new grass growing through this ash is also poisonous.

On May 20, outpouring of lava had ceased in all the fissures that opened up on May 5th. The new lava then covered nearly 19 km^2, whereof nearly 9 km^2 had flowed from the craters on the south flank and 7 km^2 from the craters in Skjólkvíar (Hlídargígar).

On the evening of May 20, a new fissure nearly 1 km in length opened up about 1 km north of the new craters in Skjólkvíar. This fissure split a whaleback-shaped Móberg ridge and fountains were seen playing on the entire fissure. Production of tephra was negligible, but the lava production considerable. From May 20 until the middle of June, various numbers of craters (Öldugígar) were active on the new fissure, building up spatter cones and producing lava which is partly superimposed on the Hlídargígar lava, but also has added some square kilometers to its area. The total amount of lava produced during the "Hekla Fires" is probably nearing 200 million m^3. All the lava produced during the eruption is a typical apalhraun (a-a) lava.

During the initial phase on May 5, a great amount of xenoliths were thrown up, especially from the craters in Skjólkvíar. A lot of these are acid, and among them are typical ignimbrites that may throw some new light on the early history of the Hekla volcano.

5.3. COLONIZATION OF LIFE ON REMOTE ISLANDS

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N71-17969

The biota of various islands differ widely in origin, richness, and composition. Islands that have undergone recent nudation or have recently emerged from under the ice or out of the sea are ecologically poorly advanced. Biologically, such islands are interesting subjects and, due to their simplicity in species, are well suited for basic ecological investigation. This report briefly describes a few ecological aspects of Iceland, the Westman Islands, and the newborn volcanic island of Surtsey. There one may compare the conditions of smaller islands with those of the larger ones, and primitive communities with those which are more complex and more advanced in succession.

Iceland is a volcanic island in the North Atlantic Ocean. It has been suggested that the island was completely covered with ice during the last glaciation and that all species in the present flora and fauna must have been dispersed postglacially over the ocean.

When man settled in Iceland 1100 years ago, the only mammal found was the arctic fox. There were no herbivorous mammals in Iceland prior to that settlement, and the vegetation may be considered to have been in perfect balance with other natural forces. However, with the introduction of domestic animals, there was a drastic change in the biotic harmony and an upset of the equilibrium which the vegetation had reached with the environment. The vulnerable borderlines of the vegetation were soon injured by the influence of this biotic introduction, man and his animals. The total vegetation cover decreased and the forest retreated before the advancing grassland. Culture plants and weeds were introduced, some of which spread rapidly and invaded the native communities.

Since that time there has been a sporadic introduction of different species by various gardeners, the Agricultural Research Institute, and the Forestry Department. Many of the introduced varieties have become well established and may be considered permanent members of the present flora, whereas others are dependent on rather artificial man-made habitats and are only temporary immigrants. It is obvious that a greater number of species than those that were present in the original native flora are able to survive in Iceland.

The poverty of species found in Iceland can be traced to its recent geological origin (i.e., its recent emersion from the glacial dome) and its edaphic and climatic conditions, the latter being rather selective due to the subarctic location of the country. But the oceanic barrier and the distance from the source of available species must also have affected greatly the quantity of species in the native flora. There are, for example, no plants with burrs or bristles which were dispersed with mammals.

The general effect of the oceanic barrier can to some extent be studied on islands which have previously been devoid of life; an example is the volcanic island, Surtsey, off the coast of Iceland.

Surtsey is a new member of a group of islands named Vestmannaeyjar (Westman Islands) off the southern coast of Iceland. All the islands are of volcanic origin with palagonite tuff or basaltic lava. Their soil is loessy, often rich in organic matter due to extensive bird droppings. In comparison with the mainland, their climate is relatively warm and moist. The precipitation is the seventh highest and the mean temperature the third highest in Iceland. The vegetation is correspondingly more European than Arctic in nature, ranging from a few species of vascular plants on the smaller skerries to 30 species on the larger islands, and to 150 species on Heimaey, the largest member. On these islands the environment is quite selective; topographic conditions are limited in variability and are comparatively stable. Their vegetation has also become stabilized in four major types of climax communities in their respective habitats.

Surtsey is the southernmost and the most recent member of these islands. The eruption that gradually built up the island started on November 14, 1963. In the spring of 1964, the first biological observations were made and detailed studies have continued ever since at fairly regular intervals. The dispersal of living beings is constantly being studied as is the colonization of plants and animals. The factors to be studied include: (1) the location of the territory, (2) the source of available species, (3) the means of dispersal, and (4) living conditions on the island. Since Surtsey is an island in the North Atlantic Ocean, it primarily limits a great number of possible colonizers of the island to arctic and subarctic forms. Further, all the invading biota must be transported over an ocean barrier, which again obviously excludes a vast number of species that might otherwise have a chance to colonize the island. The colonization of Surtsey is in that respect not comparable to isolated areas on land or areas with similar substrata on the mainland, such as new lava flows or barren sand stretches.

Present records indicate that some 18 species of birds have been seen on the island. Some 64 species of insects and 71 species of terrestrial arthropods have been collected. Over 100 species of lower plants and 5 species of vascular plants have been found.

The amount of plant material dispersing to Surtsey is found to be roughly inversely proportional to the distances of the sources of available plants. This generalization is, however, biased by some special and local conditions, such as strong air and ocean currents and the selective long-distance dispersal by migratory birds. Surtsey is one of a group of islands; the nearest is the skerry of Geirfuglasker, 5.5 km away. It is reasonable to consider this island and the other outer islands to be the most likely habitats from which plants could colonize Surtsey. In our study we have thus conducted a thorough examination of the vegetation of these individual islands. Since we have found their vegetation to vary in the number of species, this survey enables us to determine the minimal distance a species has to be transported in order to reach Surtsey. Thus the spreading potentiality of various species is reflected again. A dispersal from the mainland of Iceland is also extremely probable; the vegetation of the southern part has an obvious advantage over the more arctic element of the interior and the northern districts. Finally, there is the possibility of a long-distance dispersal. This would most likely be from other European countries, although America and other sources should not be excluded.

Although the study of the colonization of Surtsey is of great interest *per se*, it also furnishes information on the long-distance dispersal of plants in the North Atlantic basin. In addition, it may provide valuable insights into the argument between those who believe that all life was completely eradicated in Iceland during the last glaciation (i.e., the *tabula rasa* theory) and those who oppose this theory and believe that life in Scandinavia and Iceland survived the last glaciation on ice-free centres or nunataks.

So far, the species of vascular plants that have colonized Surtsey have all been coastal plants which have been dispersed by ocean as drifting seeds. These species are *Cakile edentula, Hockenya peploides, Elymus arenarius*, and *Mertensia maritima*.

The second phase of this problem is the growth condition on an island for the newly arrived plant part, i.e., the limitation extended by the edaphic and climatic factors. These factors are being thoroughly studied on Surtsey and compared with conditions on other islands in the Westman Island group, as well as with selected areas on the mainland of Iceland. The necessary prerequisite for an effective colonization by primary plant invaders of a nude area is the presence of favorable substrata. The substrata of Surtsey is characteristically of volcanic origin and of low water retention capacity. The substrata is mainly composed of three types of material - lava, tephra, and secondary beach substrata.

It will take a long time for these different habitats to be completely colonized, but it is an intriguing task for ecologists to follow these events and to compare them with the climax communities of the older Westman Islands and the communities of various successional orders on the mainland of Iceland.

5.4. A FEW NOTES ON THE GEOLOGY OF ICELAND

by Gudmunder Sigvaldason

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For over a century Iceland has been a target for geological excursions including students of geology from both sides of the Atlantic Ocean. The interest in Icelandic geology arises from the fact that few places on the surface of the earth have such a display of endogenic and exogenic forces within a relatively easily accessible area. Practically all known examples of volcanic crater forms, lava types, and tephras can be demonstrated in Iceland. Permanent icecaps and glacier tongues with associated fluvioglacial and moraine deposits are in abundance. Examples of erosion by rivers, glaciers, wind, and ocean are better demonstrated on a short bus ride than on many pages in an elementary textbook. Tectonic features, especially in the central rift zone, are prominent factors in the topography and can easily be recognized even by the most inexperienced observer.

For students who have passed the most elementary stages of geological study, Iceland has even more to offer. Situated on the Mid-Atlantic Ridge, Iceland occupies a unique position in the controversial problem of mid-ocean ridges and ocean-floor spreading. It has frequently been pointed out that Iceland provides a unique opportunity for data collection on ocean-ridge problems. First of all, the structure of major volcanic features of Iceland can be directly paralleled with submarine volcanoes, as volcanic activity during the Pleistocene ice ages in Iceland occurred essentially in a subaquatic environment. Secondly, it is possible to study the petrography of volcanic rocks in the Icelandic Rift Zone, using geological parameters, which cannot possibly be applied to dredge samples from the submerged parts of the Mid-Atlantic Ridge.

The geological history of Iceland covers a timespan of only 20 million years. The oldest rocks are exposed in the coastal areas in the east, north, and west. This Late Tertiary formation is made up principally of plateau basalts, but approximately one-tenth of the rock pile is intermediate or silicic in character. Three main types of volcanic activity have contributed to the formation of these rocks. Fissure eruptions and shield volcanoes have produced the main bulk of the basaltic rocks, but so-called "central volcanoes" have produced basaltic, intermediate, and silicic rock types. Intense glacial and river erosion has dissected these volcanic structures down to the very core, and beautiful exposures of their internal structure can be observed in the coastal valleys and fiords.

Volcanic activity continued through the Tertiary period and the Pleistocene epoch in Iceland, probably at a rate similar to present-day activity. In early Pleistocene times, the volcanic activity shifted from the plateau basalt areas in the east and west and was from then on confined to a rift zone extending across the country from southwest to northeast. This rift zone is an extension of the Mid-Atlantic Ridge.

At the beginning of the Pleistocene epoch, drastic climatic deterioration resulted in a more or less complete ice cover in Iceland and the ice thickness reached at least 1000 m in the central part of the country. The rate of volcanic activity continued, however, on the same scale as before, but due to the ice cover the eruptions now occurred in a subaquatic environment.

As an eruption starts below a glacier, the volcanic heat melts the ice above the vent and a melt water lake is formed within the glacier. The eruption products are mainly pillow lavas and glassy tuffs which pile up within the glacier lake. Eventually, the eruption products fill the lake and the uprushing lava is removed out of contact with water, resulting in regular lava flows that form a solid cover on the loose pillows and tuffaceous material below. An eruption under subaerial conditions would have formed a shield volcano, but eruptions under ice result in high "table mountains." Fissure eruptions under ice give rise to elongated ridges. The subglacial volcanic forms are extremely prominent topographic features along the Icelandic Rift Zone, and one is tempted to compare these directly to the submarine topography along the ocean ridges.

In postglacial times, which in Iceland is considered to span the last 11,000 years, volcanic activity continued producing vast lava plains and a multitude of volcanic crater forms. During the last 1000 years, or since the country was settled by man, eruptions have occurred every fifth year on the average. Some of these eruptions have been on an enormous scale; the fissure eruption of Laki in 1783 produced 12.3 km^3 of basaltic lava in less than one year, a volume larger than that produced by any other single eruption in the recorded history of the earth.

During the last decade three eruptions have occurred; one of these produced a new oceanic island, Surtsey, some distance off the Icelandic south coast. The last eruption started in the volcano Hekla on May 5, 1970, and its last phase could be observed by members of this Summer Institute. This eruption was relatively small, as measured in the amount of produced lava. The total lava production was on the order of 0.2 km^3 or about one-fifth the material produced by Surtsey. A unique and rather unexpected feature of this eruption was the serious effect it had on agriculture in the areas where some of the ash fell, because of the high amount of fluorine contained on the surface of the ash particles. Later studies of sublimates from volatile matter deposited around steam vents in the new lavas and craters have shown high amounts of ammonia, fluorine, bromine, thallium, lead, zinc, cadmium, and other elements besides sulphur and chlorine. Studies of volcanic gases collected during the Surtsey eruption have provided information that can possibly be used to estimate the amount of individual elements in the magma.

The volcanic activity in Iceland is accompanied by a high regional geothermal gradient. Values for the geothermal gradient outside the volcanic zone in Iceland range from 32° to well above 100°C/km. Within the volcanic zone, and especially in the thermal areas, the gradient occasionally approaches 300°C/km. Meteoric water circulating to depths within these areas of high thermal gradient is eventually discharged to the surface as thermal water within a more or less well-defined thermal area. A distinction is made between these areas and low-temperature thermal areas which occur outside the neovolcanic zone. The maximum temperature measured in drill holes in this type of thermal areas is 150°C. High-temperature areas occur within the neovolcanic zone and the highest temperature measured in areas of this type is 280°C. The high-temperature areas are mostly characterized by strong fumarolic activity. The fumaroles, or steam vents, result from steam escaping from a boiling ground water table at some depth below the surface. Along with the steam, other volatiles such as hydrogen, carbon dioxide, and hydrogen sulfide escape to the surface. The hydrogen sulfide is oxidized to sulphuric acid at the surface, resulting in a very low pH of the condensed water forming in the steam vent. The acid solutions attack the surrounding rock and alter it into soft clay. The steam vents are thus not directly connected with the thermal water reservoir, and do not show but a limited part of the chemical system involved. This is better demonstrated where the geology and topography of a high-temperature area permits the thermal water to reach the surface and flow out as hot springs. It can then be shown that the thermal water is always alkaline in character and very high in silica.

These few and very brief notes on some of the main features of Icelandic geology show how important the volcanoes and volcanic features are in the past and present geological history of the country. Students of volcanology will find a trip through Iceland an inspiring experience. Those who have not been exposed to the earth sciences before cannot help realizing that inorganic nature can be very much alive.

5.5. HIGHLIGHTS OF THE SURTSEY ERUPTION: 1963-1967

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The volcanic eruption of Surtsey was first witnessed at 07h 15m in the morning of November 14, 1963. It is not known how long the eruption may have been going on underwater before visible explosions broke through the ocean surface. The ocean depth at the site of the eruption was approximately 125 m before the eruption started and it may have taken some time to build up a subaquatic volcanic cone before the explosions became visible on the surface. Five days after the visible explosions started, an island had been formed, 60 m high and 600 m long; by the end of December 1963, the dimensions of the island had increased to a height of 145 m and a maximum length of 1100 m. The activity in this crater continued until the end of January 1964. On February 2, 1964, the activity shifted to a new crater NW of Surtur I. The new crater, Surtur II, eventually barred itself from the sea and on April 4, 1964, the explosive activity changed to effusive activity, producing thin-flowing lava. At this point, the island had reached its maximum height above sea level, 174 m, and its area measured 1.05 km^2.

The lava flow from Surtur II continued until the middle of May 1965. The total area of the lava flow above sea level was by then 1.53 km^2 and the area of the island, 2.45 km^2. As soon as the lava eruption stopped on Surtsey, a new submarine eruption started 600 m to the ENE of the island. This eruption continued until October 17, 1965. As a result of this eruption, an island was formed, which occasionally grew to considerable dimensions, but was repeatedly broken down again by marine erosion. The maximum height of this island above sea level was 67 m, and its maximum diameter 650 m. A week after the eruption stopped, this island, which had been named Syrtlingur, was washed away.

From October 17 until December 26, 1965, no activity was observed on or around Surtsey. On December 26, activity started again about 900 m SW of Surtsey. This new eruption lasted until August 10, 1966. The island that eventually formed was called Jólnir, or Christmas Island. This island reached a height of 70 m above sea level and its maximum area was 28 hectares (70 acres). A month later this island had been eroded away by the ocean waves.

Nine days after the activity came to an end in Jólnir, a new eruption started in the Surtur I crater on Surtsey, producing lava from a fissure 220 m long. This lava eruption continued throughout the year 1966 and until the volcanic activity came to an end on June 5, 1967. In January 1967, new fissures opened, producing lava flows on the northern side of the island and threatening the hut that had been built on Surtsey by the Surtsey Research Society. This activity soon came to an end. The lava from the 1966/1967 eruption covered about 250 acres, and the area of Surtsey at the end of the eruption was 2.8 km^2. The Surtsey eruption as a whole lasted 3 years and 7 months and is the second longest eruption in historic times in Iceland; only the Mývatn Fires of 1725-1729 lasted a few months longer.

A short and dry chronicle accounting events during the Surtsey eruptions does little justice to the multitude of impressions and new information gathered during the eruption. For further information, the reader is referred to the Surtsey Research Progress Reports, which are available from the Surtsey Society, Reykjavik.

5.6. CHEMICAL EVOLUTION: ITS RELEVANCE TO SURTSEY

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INTRODUCTION

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Chemical evolution is the study of the processes which culminated in the formation of life. Its working hypothesis is that of Oparin and Haldane, who independently postulated the formation of a primordial soup composed of abiogenically synthesized compounds as a necessary prerequisite for the emergence of life. Once life began, the principles of biological evolution took over to guide life to the stages in which we see it today.

Although the theory of chemical evolution has been supported by extensive investigations in the laboratory, Surtsey has provided a unique opportunity for earth-based "field studies," so to speak. The volcanic formation of Surtsey off the coast of Iceland in 1963 simulated some of the conditions probably found on the primitive earth; it was therefore possible that organic molecules had been formed and could be detected in the gases flowing out of the volcano or in freshly fallen lava ash. One such study has been done (ref. 1). Further, since Surtsey was a relatively sterile piece of land at birth, it is still biologically impoverished enough to serve as an excellent testing ground for the life-detection techniques designed for planetary exploration. The sensitivity of such equipment to minute quantities of microorganisms could profitably be tested by measuring the initially small numbers of microbes one would expect to be among the first colonizers. Although this equipment was not built in time to be used during this Summer Institute, it is hoped it will be tested at Surtsey when completed.

HISTORICAL CONSIDERATIONS

When did life begin? The oldest evidence of life has been dated at about 3.4 billion years. If the earth is approximately 4.5 billion years old, then life presumably began sometime between these two dates. Going backward, the age of the solar system is about 5 billion years, and that of the universe is perhaps between 10 and 20 billion years (ref. 2).

A cosmic process of evolution can be envisioned which spans the genesis of the universe to the time intelligence evolved. In the initial inorganic stage, small molecules could have been formed, such as the elements H, C, N, O, and P; in the subsequent organic stage, molecules like amino acids, purines, and pyrimidines could have been synthesized and then polymerized. The aggregation of these macromolecules into precellular "eobionts" could have culminated in the emergence of life - and with it, biological evolution. All that went before biological evolution could be considered chemical evolution. The continuity inherent in the hypothesis of evolution implies a stage in which it would be very difficult to distinguish the living from the nonliving; one such example is a virus particle.

EXPERIMENTAL BASIS OF CHEMICAL EVOLUTION

Early Considerations

The theory of spontaneous generation as expounded by Aristotle was disproved (on the microbial level) by a series of brilliant experiments by Pasteur in the mid-1800's. On the molecular level, however, this theory reappeared, and with a new interpretation: the gradual synthesis of organic compounds from which replicating systems could eventually emerge. In a letter to a friend, Charles Darwin stated in a nutshell the whole concept of chemical evolution by visualizing ". . . some warm little pond, with all sorts of ammonia and phosphoric salts - light, heat, electricity, etc., present that a proteine compound was chemically formed ready to undergo still more complex changes . . ." (ref. 3). When one considers that the entire variety of life we see today is based on just a handful of chemicals, the conclusion is inescapable: all life on earth must have had a common chemical origin.

Physical Parameters

Primitive atmospheres.- In order to design valid experiments on the origin of life, an understanding of conditions on the primitive earth is essential. The primitive atmosphere must have been particularly important since it provided the raw material. Because our atmosphere contains only small amounts of the noble gases relative to their cosmic distribution, it has been concluded the original atmosphere was almost completely lost and replaced by a secondary atmosphere during the formation of the earth. Although initially similar in chemical composition to its predecessor, the secondary atmosphere probably lost most of its free hydrogen due to its high rate of escape; the remaining principal components of this primitive terrestrial atmosphere must have been water vapor, methane, ammonia, and small amounts of hydrogen.

Most evidence indicates that the early atmosphere was probably reducing in nature. Free hydrogen accounts for 90% of the known universe. In the presence of such an excess of hydrogen, the equilibrium constants of carbon, nitrogen, and oxygen reveal that these elements would have been present in their reduced form. Indeed, meteorites as old as the earth contain metals in the reduced form. The primitive atmospheres retained by the planets Jupiter and Saturn abound in methane, ammonia, hydrogen, and water.

The conversion of this atmosphere from reducing to oxidizing was probably due to two factors, the photodissociation of water in the upper atmosphere by short wavelength ultraviolet light and by plant photosynthesis. The latter process probably evolved when the supply of abiogenically synthesized organic compounds was depleted by heterotrophs; autotrophs which had incorporated molecules such as porphyrins were able to utilize the longer wavelengths of light for photosynthesis and thus enjoyed a selective advantage.

Energies.- The sources of energy available for prebiotic syntheses of organic compounds, in the order of their importance, were solar ultraviolet light, electric discharges (such as lightning and corona discharges from pointed objects), ionizing radiation, and heat. Some energy was also available from radioactive decay.

Experiments

On the hypothesis that molecules which are important now were important when life emerged, some of the biologically important significant micromolecules have been synthesized; under the same conditions, some of these molecules have been condensed, or polymerized, to give rise to macromolecules (ref. 4).

Monomers.- Miller and Urey performed the classical electric discharge experiment in 1953 (ref. 5). From a mixture of methane, ammonia, water, and hydrogen, many organic compounds were obtained, including five amino acids. Other amino acids, fatty acids, purines, and porphyrins have since been synthesized under possible prebiotic conditions. Although no monosaccharides or polysaccharides have yet been detected, a precursor of these compounds, formaldehyde, has been formed. Hydrogen cyanide is apparently a key intermediate in many of these prebiotic syntheses.

Vulcanism and possible residual heat in the earth's crust may have accounted for the prebiological synthesis of many amino acids. In one such simulation experiment, a mixture of methane, ammonia, and water was passed over quartz sand or alumina at a temperature of approximately 900°-1000°C; it has been claimed that 14 amino acids were found.

Hydrothermal springs are another geological niche found in Iceland which have been simulated in experiments in chemical evolution. When aqueous solutions of formaldehyde were refluxed with suspended kaolinite, various sugars - trioses, tetroses, pentoses, and hexoses - were formed.

Polymers.- Dehydration-condensation reactions are generally involved in the formation of more complex molecules. Condensation reactions occurring under possible prebiological conditions have been demonstrated both in the presence of water (to simulate the primordial ocean) and under hypohydrous conditions (to simulate the shore of the ocean or the dried-up bed of a lagoon).

Under aqueous conditions, dipeptides and tripeptides have been synthesized photochemically. Polymerized amino acids were also formed during an electric discharge through methane, ammonia, and water.

Vulcanism has been promulgated as a means by which amino acids could have been polymerized in the absence of water. Experimentally employed temperatures range from 180°-200°C; the polymerized amino acid product is called "proteinoid" and is being extensively studied.

Some oligonucleotides have been formed during the thermal phosphorylation of nucleosides by inorganic phosphate salts. The temperature required for this reaction (about 150°C) is consistent with a volcanic action site.

CONCLUSION

In laboratory experiments simulating conditions on the primitive earth, organic compounds of biologic significance have been synthesized; these results lend support to the hypothesis of chemical evolution and the possible existence of extraterrestrial life. Certain areas of Surtsey and Iceland are relevant in that they resemble, in some respects, conditions found on the primordial earth and those which may be encountered in the search for life on other planets.

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5.7. THE PLANETS AND LIFE

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Exobiology is a research program, the basic objective of which is to cast light on the question of the origin and early evolution of life (refs. 1 and 2). There are many avenues of approach to such research. One approach is through chemical evolution: the sequence of events presumed to have taken place on the primitive Earth or on some other primitive planet in which macromolecules were synthesized nonbiologically and which led to the origin of life. Organic geochemistry - the study of the ancient chemical and biological fossil record of a planet - can be included under chemical evolution. A second area is the study of the environmental extremes in which terrestrial forms of life are capable of surviving and growing. A third part of exobiological research is the development of life detection and organic analytical techniques for use in terrestrial and extraterrestrial environments.

Surtsey and Iceland are geologically and biologically ideal for studies in these latter two areas of exobiology. They contain a wide range of harsh environments (e.g., glaciers and geysers) which may resemble conditions that could be encountered in our search for extraterrestrial life. Moreover, Surtsey and areas of Iceland recently exposed by melting glaciers (nunataks) are only sparsely populated with various forms of life; they are therefore ideally suited for testing highly sensitive life-detection devices. This equipment was not built in time to be used during this Summer Institute, but it is anticipated it will be used in Surtsey and Iceland when completed.

A very important component of exobiological research is relating the results of such research to contemporary terrestrial problems. We must look at the origin and early evolution of life as being inseparably interwoven with the origin and evolution of the planet. The cause and effect relationship between a biota and its parent planet is one of the major problems of the contemporary Earth and one to which research encompassed by exobiology can contribute a great deal of basic as well as practical information.

Since the planet Earth is overwhelmed by its biota, it is almost impossible to look back into the history of Earth and determine the succession of events that preceded life. It may be that only by going to another planet with a history similar to that of Earth will we be able to get at this early record of prebiological evolution in a natural environment.

Of the nine planets in our solar system, Mercury and Venus have such high surface temperatures as to virtually preclude the presence of water and organic molecules on the surface of these planets. It has been speculated that the upper atmosphere of Venus (which is composed of large quantities of carbon dioxide, small amounts of water, carbon monoxide, and oxygen, as well as traces of hydrofluoric and hydrochloric acids) may contain a bio-zone where the temperatures are in the 60°-90°F range. Such a speculation would require a completely airborne ecology.

The atmosphere of Jupiter contains methane, ammonia, water, and hydrogen. It thus partially resembles the atmosphere of a primitive planet, and it is possible organic molecules are being synthesized there today.

Little is known about the outer planets Saturn, Uranus, Neptune, and Pluto. To characterize these planets, a "Grand Tour" is planned in which a single spacecraft will be launched on a trajectory which utilizes the gravitational field of the large planets as an acceleration-assisting mechanism, so that all of the planets can be flown by in a single spacecraft. This trip requires an alignment of the planets which occurs only once in over 100 years.

Although the chemical composition of the asteroids and comets in our solar system is also potentially relevant to exobiology, it is certain to be some time before these bodies are studied in enough detail to assess accurately their role in the production of planetary organic matter.

The most interesting planet in the solar system from the point of view of exobiology is Mars. Its day-night cycle is comparable to that on Earth, almost 24 hours, but its seasons are almost twice as long as on Earth. Although most of Mars is heavily cratered, some regions inexplicably have no craters at all. The Martian surface is further distinguished by its reddish-orange color, light and dark areas, and polar caps which wax and wane with the seasons. As the polar cap in the southern hemisphere disappears during the summer months, the dark areas grow progressively darker; this "wave of darkening" had been interpreted as the response of Martian vegetation to the availability of water from the polar cap. However, the 1969 Mariner flybys confirmed ground-based observations that the polar caps are composed primarily of carbon dioxide and only a trace of water.

Mars does have a tenuous atmosphere composed primarily of carbon dioxide. The only other molecules that have been detected are water and carbon monoxide. Water appears to be present in amounts varying from 0 to about 50 microns of precipitable water, which is about 1/1000th that in the Earth's atmosphere. The amount of water in the atmosphere of Mars appears to vary with the season. Nitrogen was not detected in the Martian atmosphere by the Mariner spacecraft; however, atmospheric nitrogen is not a requirement for biological activity. Nitrogen may well be present in the surface material in the form of nitrate or ammonia salts. In addition, the sensitivity of the ultraviolet photometer in Mariners 6 and 7 was such that there could still be as much as 1% nitrogen in the Martian atmosphere and not be detected.

There appears to be little or no magnetic field, so that the ultraviolet flux at the Martian surface is quite high. This presents a problem for biological activity, but since ultraviolet light is relatively easy to shield, it is not considered to preclude biological activity.

The temperature at the surface of the planet ranges from as high as 70°F at the equator during the day to about -100°F at night, so that there is a tremendous diurnal freeze-thaw cycle, even at the equator. The mean temperature is probably about 40° below that of the Earth; however, this does not preclude the possibility of biological activity.

In 1975, the Viking mission will be launched, in which a spacecraft will be soft-landed on the surface of Mars. This will be an orbiter-lander combination, the orbiter serving as the relay station for lander data, plus performing visual and spectrophotometric experiments in conjunction with the lander. The lander has exobiological objectives as primary to the mission. These include the direct search for biological activity, organic soil analysis, the search for water, meteorological measurements, and atmospheric measurements, both on the surface and during entry. All the measurements are generally aimed at the question of life, detecting the presence of organic molecules, and measuring those environmental parameters that are most directly relevant to the life question.

It is hoped that these preliminary experiments will produce sufficient data to provide us with basic information about the presence of organic matter and the presence or absence of life, so that more sophisticated and detailed experiments can be designed for subsequent missions, perhaps including the eventual exploration of Mars by manned expeditions.

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6.1. INTRODUCTION TO GEOLOGICAL STUDIES

N71-17974

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Surtsey volcano in particular, and Iceland as a whole, have many varied significant characteristics for improving our understanding of certain fundamental principles or problems of geology, both as an independent science and as these relate to problems involving other sciences, especially those common to new and extreme environments. The recognition that Iceland is a subaerial continuation of the Mid-Atlantic Ridge and that the central Quaternary Neovolcanic Zone of Iceland is a probable continuation of the Median Rift Zone (Fig. 1, Boettcher) has made the area of present study one of great importance in research bearing on an understanding of related important scientific problems. Since the recognition of the existence of a world-girdling ridge system by Columbia University scientists less than 20 years ago, the mechanism of formation of the ridges and of the coastal rift valley of the Mid-Atlantic Ridge has received a good deal of study. In recent years, renewed interest in continental drift as a theory and in mechanisms of drift has resulted in considerable research on ridge systems of the world, especially submerged portions.

Iceland was chosen as the site of the 1970 Summer Institute because it abounds in significant disciplinary and interdisciplinary problems. Iceland has been built up by vulcanism during the past 20 million years and is of exceptional interest as an extreme and relatively new environment; active volcanoes cover about one-third of the country, eruptions in one of them occurring about every 5 or 6 years. It is estimated that about one-third of the extrusion of lava at the earth's surface in the past 500 years has taken place in Iceland. Such outpourings usually take place from crater rows along fissures or from shield-shaped volcanoes. As part of this persistent vulcanism, several volcanic centers on Hekla began eruptive activity in May 1970; one crater was active in the latter half of June, when it was visited by the Institute group on two occasions.

A most fruitful subject of common interest to geologists, chemists, and biologists alike is the fumaroles and hot springs in which Iceland abounds. Thermal sources were studied by the group in several parts of the country including Surtsey.

The following papers are by no means written as a compendium attempting to summarize existing geological knowledge of Surtsey and mainland of Iceland. These contributions have developed as a result of the interdisciplinary interchange that took place in the field, in lectures, and in discussions; certain important scientific discoveries of the past are highlighted and areas of research in Icelandic geology and interdisciplinary science that give promise of fruitful results are sketched. In some cases, individual participants have been able to initiate original research projects of limited scope whose preliminary results are incorporated in this volume.

6.2. SEA-FLOOR SPREADING AND THE COMPOSITION OF ICELANDIC LAVAS

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> *Stands Scotland where it did?*
>
> Shakespeare, Macbeth, Act IV, Sc. 3

Topographically, Iceland is an aerial exposure of the Mid-Atlantic Ridge, and many aspects of this concept have been considered in a recent symposium (ref. 1). Structurally, tectonically, and petrologically, the Quaternary Neovolcanic Zone (fig. 1) is generally accepted as an integral part of this Ridge, but the overall relationship of the Tertiary rocks and their spatial and temporal role in the evolution of Iceland and the Ridge are less certain (ref. 2).

Beginning with Thoroddsen (ref. 3), many students of this problem have considered the Tertiary lavas as the result of volcanic activity along a ridge system extending from Scotland to Greenland, the so-called Wyville-Thompson Ridge. According to this view, volcanic and tectonic activity then ceased during a hiatus approximately at the beginning of the Quaternary Period, followed by renewed activity along the Mid-Atlantic Ridge.

An opposing view is that volcanic activity along the Mid-Atlantic Ridge has operated more or less continuously from the Tertiary to the present time, and that the distribution of rocks on Iceland (fig. 1) reflects spreading from the geographically central Neovolcanic zone, resulting in older (Tertiary) rocks farthest from this zone.

If Iceland is to be viewed as a natural laboratory where the processes associated with sea-floor spreading and ridge tectonics can be studied, the profound significance of an understanding of the relationships between the Tertiary and Quaternary rocks of Iceland is apparent. Equally patent is the necessity of an interdisciplinary approach to the question; the solution lies within the purviews of geology, geophysics, and geochemistry.

Seismic refraction studies have been underway in Iceland since about 1959, and most of the data have been presented and interpreted by Pálmason (ref. 4). His results reveal nearly horizontal layering that he prefers to interpret as the extension of the Tertiary flood basalts under nearly all of Iceland. This interpretation would be difficult to reconcile with any mechanism of the spreading of lavas away from a single, central ridge source, nor is it consonant with the concept of dike emplacement (ref. 5), as shown schematically in figure 2(A), unless the magma sources have migrated toward the center with time as shown in figure 2(B). This picture is consistent with the geological evidence of Walker (ref. 6) and Th. Einarsson (ref. 7). However, the layering revealed by the refraction studies can also be interpreted as horizons along which metamorphic phase changes occur (ref. 4, p. 75), e.g., as in the formation of amphibolite at depth.

Geomagnetic surveys on Iceland and the Reykjanes Ridge reveal arrays of linear magnetic anomalies, but several interpretations of these configurations have been suggested (refs. 8-10). Presently, these data are insufficient to reveal the relationship between the Tertiary and Quaternary rocks.

Potentially, one of the most direct and informative approaches to an understanding of this relationship lies in a systematic and comprehensive investigation of the composition and ages of the Icelandic lavas. Sigvaldason (ref. 11) has made a significant contribution in his review of the chemistry of Quaternary rocks from the Neovolcanic zone. Although only 34 chemical analyses were available, some indications were revealed. Firstly, and perhaps most importantly, a plot of these analyses on an iron-enrichment diagram, ($FeO + Fe_2O_3/FeO + Fe_2O_3 + MgO$) vs. SiO_2, showed that the youngest (historic) lavas possessed the highest $FeO + Fe_2O_3$ and SiO_2 contents, suggesting advanced differentiation. The prehistoric Quaternary rocks have more primitive compositions on this diagram, and some of them have low K_2O contents (0.02, 0.14, and 0.16 weight percent for three samples), which is similar to primitive basalts dredged elsewhere from the Mid-Atlantic Ridge (ref. 12). Of course, processes of magmatic differentiation have operated at many of the individual sites of Quaternary volcanism (e.g., at Hekla, ref. 13), but the overall chemistry of the analyzed rocks, ranging from primitive to advanced, suggested to Sigvaldason (ref. 11) that these rocks represent a long-term evolutionary cycle, probably complete and independent of the Tertiary volcanic events.

Obviously, it would be most desirable to expand this chemical study of Quaternary lavas and to perform a similar investigation of the Tertiary rocks. To date, only very few detailed chemical-petrological studies of Tertiary volcanic centers have been completed (e.g., refs. 14 and 15). A large number of analyses from carefully selected rocks would reveal whether the Tertiary and Quaternary rocks evolved from common lines of descent. This study would also disclose any regional zoning in the chemistry of Icelandic rocks. Sigvaldason (ref. 11) noted a chemical grouping of various basalts on Iceland as well as on various areas of the Mid-Atlantic Ridge.

To aid in the interpretation of any parameter of petrochemistry, petrographic studies, augmented by microprobe analyses of selected minerals, should be used to detect any secondary alteration of the rocks. Furthermore, it would be particularly advantageous to obtain radiogenic age determination from as many samples of unknown age as possible to determine if a hiatus does exist between Tertiary and younger rocks.

Moorbath *et al.* (ref. 16) determined K-Ar ages for some Icelandic lavas, and the oldest age recorded was no more than 20 million years for the exposed Tertiary rocks.

These approaches would require a cooperative effort. Samples must be selected with the assistance of those thoroughly familiar with the geology of Iceland. On the other hand, chemical analyses and age determinations must be accomplished by those equipped and trained for the purpose. New methods of instrumental analysis on selected elements in rocks and minerals would significantly reduce the cost of this research. Consequently, many more analyses and more meaningful results would be realizable.

Another significant aspect of this research is that the analyzed samples of unaltered rock provide valuable materials for use in high-pressure, high-temperature laboratory studies relating to the genesis of basaltic magmas and their derivatives (e.g., ref. 17).

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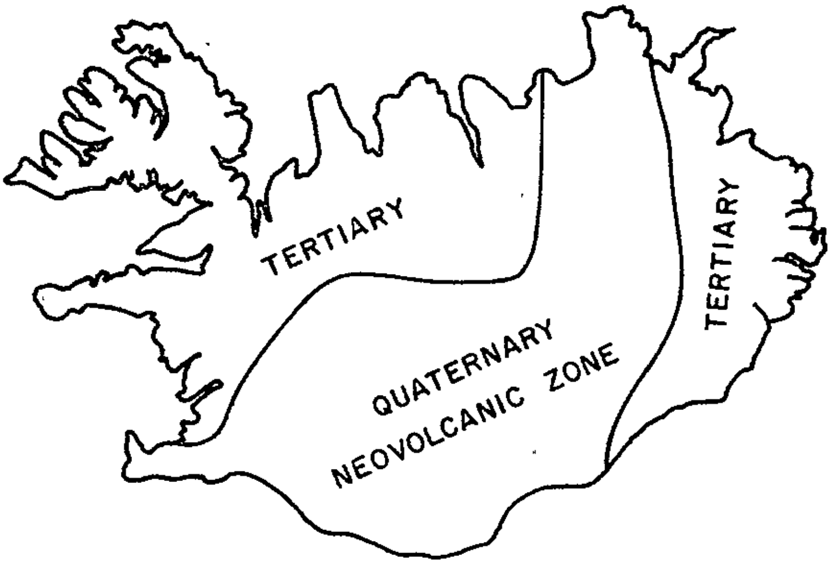

Figure 1. Map of Iceland showing distribution of Tertiary and Quaternary rocks.

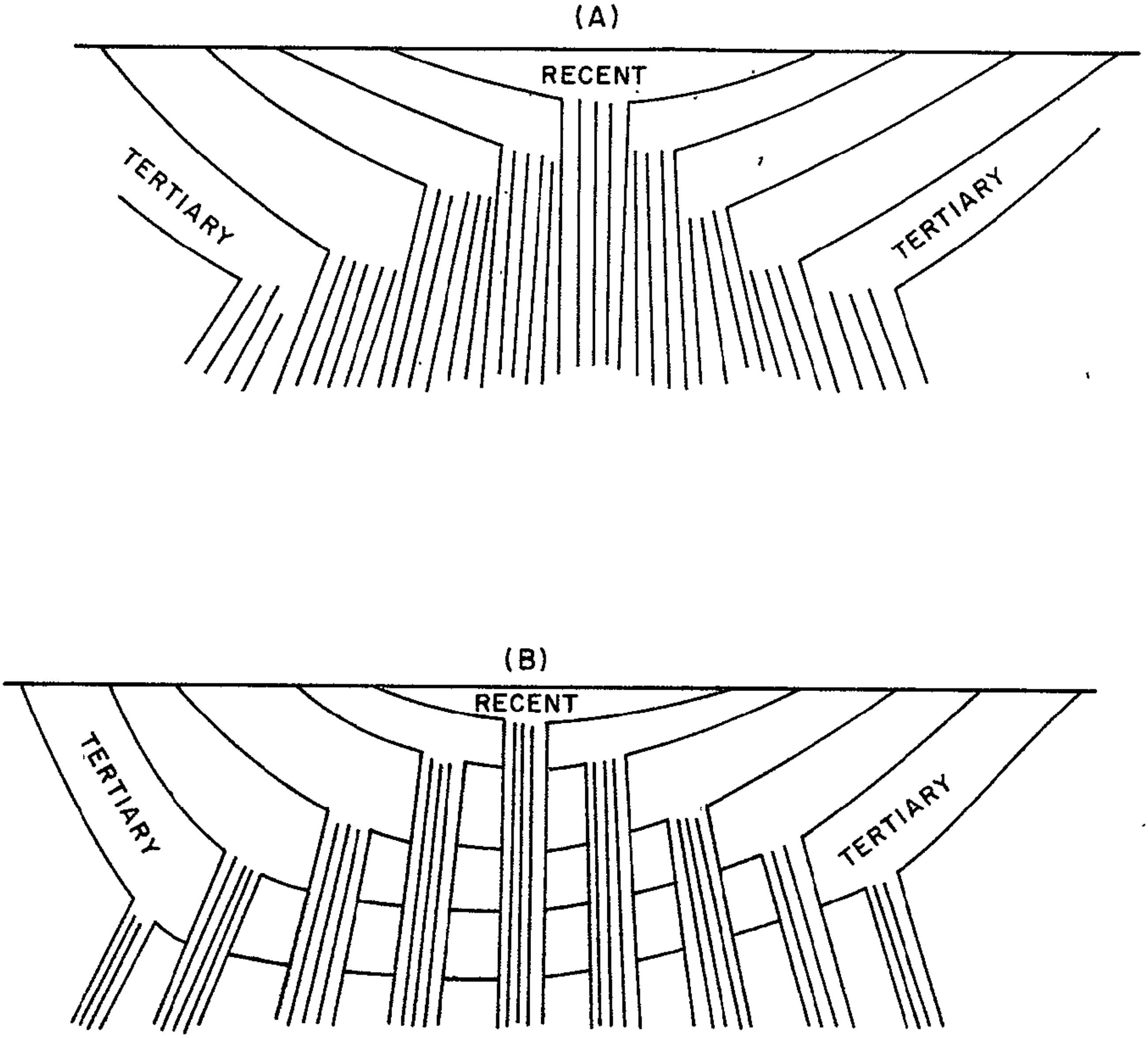

Figure 2. Schematic diagrams illustrating the concept of spreading or drift resulting from emplacement of dikes (A) from a central source and (B) from sources that migrate toward the center.

6.3. HEKLA AND THE 1970 ERUPTION

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INTRODUCTION

Hekla, Iceland's most famous volcano, is located approximately 100 km east of Reykjavik in southwestern Iceland. It is part of a belt of active volcanoes trending NE-SW along the northwest border of the eastern branch of the neovolcanic zone. The volcano represents a ridge, trending N60°E-S60°W, built up of repeated eruptions of acid, intermediate, and basic lavas and tephra (ref. 1).

Morphologically, Hekla is in an intermediate stage between a fissure volcano and a stratovolcano (ref. 2). Typically, Icelandic fissure or linear volcanoes show only a single, non-tephra eruption from a single fissure. In contrast, the stratovolcanoes have had many eruptions of both tephra and lava of different composition from the same vent. Therefore, Hekla is classified as a tephra-producing linear volcano of the central volcano type producing highly differentiated eruption products.

ERUPTIONS IN HISTORIC TIMES

From 1104 to 1948, Hekla has produced 14 major eruptions with the current 1970 eruption representing number 15. The average length of time between successive eruptions is approximately 58 years. The 1970 eruption represents a period of repose of only 22 years, in contrast to the 1947-48 eruption which culminated a span of 102 years since the previous activity.

According to Thorarinsson (ref. 3), Hekla has had five postglacial cycles. Each cycle starts with a mixed, rather basic eruption and ends after an interval of quiescence lasting several centuries with highly explosive rhyolitic eruptions. Single eruptions show two phases - one more acidic and the other rather basic in composition. However, both phases terminate with approximately the same composition of 55% silica.

Each eruption starts with an explosive phase producing both lava and tephra; 80 to 90% of the tephra is produced during the first day or even the first few hours (ref. 2). During historic times Hekla produced approximately 1 km^3 of tephra and 8 km^3 of lava; the predominant composition of these materials is acid to intermediate.

Compositionally, Hekla shows a differentiation series from alkaline-olivine basalt, extruded from associated fissures, to andesites and dacites to rhyolites (ref. 2). The SiO_2 content of the initial eruptive products is a nearly linear function of the length of the preceding repose of the volcano - the longer the interval of time between eruptions, the higher the SiO_2 content of the initial material.

The range of variation in the composition of the eruptive products is considerable, ranging from 73.7% SiO_2 (xenolith) to 45.5% SiO_2 as shown during the 1947-48 eruption (ref. 4). Of the approximately 9 km^3 of material erupted from Hekla during historic times, Thorarinsson (ref. 2) estimates that over 80% is acidic to intermediate in composition.

Theories suggested to explain the high percent of acid and intermediate rocks produced by Hekla include: (1) differentiation of a primary basaltic magma by crystal fractionation and (2) assimilation or mixing of a sialic substratum by a basaltic magma. Thorarinsson (ref. 2) states that because of the high percentage of acid to intermediate rocks and the presence of acid xenoliths from Hekla, it is difficult to explain the products of Hekla by simple gravitational crystal fractionation. The presence of an acid substratum below the basaltic cover in the neovolcanic zone, while not definitely established by seismic studies, is not excluded (ref. 4). Tomasson (ref. 5) has suggested, based on a study of the mineralogy and petrography of Hekla lavas, that two magma chambers exist under Hekla. One chamber of basic magma is located at a depth of 40-60 km and a shallower source of acid magma at a depth of only a few kilometers. Mixing of the deeper-seated magma with the more acid magma during eruption is thus suggested to explain the evolution of Hekla products.

1970 ERUPTION

The most recent Hekla eruption started on May 5, 1970. The initial phase consisted of an explosive tephra discharge from a series of fissures on the southwest and south flanks of the Hekla ridge (Thorarinsson, personal communication, July 1970). This explosive phase produced about 30 million tons of tephra within the first two hours of activity covering approximately one-tenth the area of the country (Thorarinsson, personal communication, July 1970).

On May 20th, activity ceased at the initial fissures and a new lateral vent opened northeast of the Hekla ridge. The new fissure is nearly 1 km long and several craters formed, expelling both tephra and lava.

On June 16th and 28th, this author visited Hekla to observe the eruptive activity. On June 16th, tephra production was at a minimum, consisting mainly of bombs and lapilli ejection from the one active crater. Most of this material fell back into the vent or on the flanks of the cinder core. The finer ash materials were still accumulating at distances of several kilometers from the vent.

An Aa lava flow of intermediate composition was flowing from the northern edge of the crater and had covered an area of more than 20 km^2. The front of the Aa flow, located 2 to 3 km from the vent, was moving at a rate of only a few inches per minute. Megascopically, the lava is hypocrystalline and porphyritic. Less than 5% of the rock is composed of subhedral, glassy, phenocrysts of plagioclase feldspar and minor olivine (?). The phenocrysts average about 1 mm, but crystals occur up to 5 mm. These are set in a fine-grained to glassy ground mass. Lava near the top of the flow is highly vesicular with over 50% of the rock made up of elongate vesicles. On the other hand, lava blocks near the base of the flow contain less than 10% vesicles.

Observations on June 28th showed a slight decline in tephra production. However, bomb and lapilli ejection near the vent were still quite active. A large breached zone at the northern end of the crater provided access for the emergence of an Aa flow. Within the vent, an almost continuous eruption of lava fountains hurled lava fragments several hundred feet in the air. Lava ejected from the vent by this fountaining activity, plus material bubbling over the rim of the vent, provided the source for the Aa stream which flowed south through the breached zone in the crater. At a distance of approximately 1 km from the vent, the Aa flow was traveling at a velocity of approximately 1 m/sec.

The SiO_2 content of the initial Hekla tephra products is approximately 55% (Sigvaldason, personal communication, July 1970). This compares with an initial SiO_2 content from the 1947-48 eruption of approximately 62% (ref. 4). However, as noted earlier, the high correlation between the length of the preceding interval of Hekla repose and the SiO_2 content of the initial products would predict this low SiO_2 content because of the short repose interval of only 22 years.

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6.4. ICELAND AS AN ATYPICAL EXAMPLE OF THE PETROLOGY OF THE MID-ATLANTIC RIDGE

N71-17977

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Like other marine geologists, the petrologists working on the Mid-Oceanic Ridges (MAR) collect their material by dredging hard rocks, by coring sediments, and by recording topographical and geophysical profiles. All these operations are blind, that is, the scientists cannot look at the outcrops of rocks that they are sampling. Since it lies on the MAR, Iceland presents a fine opportunity for a petrologist to observe directly the geological relationships between various rock suites of one portion of the Mid-Atlantic Ridge. But we must be careful when we compare the geology of the MAR in Iceland with that of the submerged part of the ridge. There are fundamental discrepancies with regard to some aspects of the petrology and tectonics of the MAR as compared to Iceland. As an example, table 1 compares the rock types seen in Iceland with those which have been dredged from the Equatorial Mid-Atlantic Ridge (ref. 1).

The only major similarity between these two regions is the abundance of basalts accompanied by some gabbros; nevertheless, the latter are much rarer in Iceland.

On the other hand, there are three striking discrepancies:

1. Peridotites are extensively dredged along both the slopes of transform faults or the bottom of rift valleys on the Equatorial MAR; such rocks have never been found in Iceland.
2. Metamorphism has been much weaker in Iceland where no rocks belonging to the amphibolite facies have been found and where the greenschist facies is uncommon. Moreover, many propyllitized rocks from Iceland could be classified as "greenstone," but they are local accidents due to hydrothermal activity through intrusions; it does not mean that propyllitization does not occur in the MAR rocks, but it seems to be much less common.
3. Acidic and intermediary volcanic and subvolcanic rocks (hypabyssal or near surface) are frequently associated with basalts in Iceland; they have never been dredged from the submerged MAR.

The first two discrepancies arise from the same cause, that is, the radically different tectonic styles which dissect at the present time the basalt pile in these two regions of the MAR.

In addition to its central rift valley, the immersed MAR is often interrupted and displaced by transform faults as shown by the two maps of the Atlantic Ocean floor (refs. 2 and 3). The best known, the Romanche trench, Vema fracture, St. Peter and Paul fracture, etc., lie between 11.5°N and 2°S. They are 3 to 4 km deep, 600 km long, and up to 40 km wide and have been surveyed in detail. Basalts and gabbros, metamorphosed basalts and gabbros, and peridotites have been commonly dredged along the slopes of transform faults around the Equator, and also at 10°N, 22°N, 28°N, 31°N, etc. Some equatorial trench walls seem to be mainly peridotite plugs up to 2 to 3 km high (ref. 4).

There is nothing visible in Iceland which could be compared with the slopes of the equatorial deep trenches from which we have commonly dredged so many plutonics and metamorphic rocks. In Iceland, the 1.5- to 4-km-thick basalt pile above the sea floor (ref. 5) has been affected in an early time by flexures and individual blocks have been tilted variously (ref. 6). Later, Iceland was faulted and finally the whole country was uplifted (±500 m) as an isostatic response to erosional and glacial unloading; these faults have a major SW-NE direction in southern Iceland and a N-S direction in the northern country. They give Iceland its present tectonic pattern: longitudinal fissure systems parallel to a central active Rift. What a petrologist can observe and sample in Iceland is the upper part of a very thick basalt pile: a 3- to 4-km-thick upper basalt layer resting on a 10- to 20-km-thick "blister" formed by basaltic flows intruded by many dykes (ref. 7). Consequently, one dredges just basalts on the immersed part of the Reykjanes Ridge and only a few gabbros and no peridotites have been found in all Iceland. For the same reason the metabasalts of Iceland do not reach such a high metamorphic facies as in the rest of the MAR.

If transform faults exist in Iceland, they must be buried under younger volcanites, between Snaefellsnes and Askja where the SW-NE tectonic direction of the southern country changes to the N-S direction of the northern country. Geophysical methods could probably answer this question. Another place to check for probable transform faults would be the steep slope off the SE shore of Iceland where depths of more than 2000 m are reached.

The tectonic pattern does not explain the presence in Iceland of acidic and intermediary rocks. The apparent absence of those acidic or intermediary rocks in the submerged MAR could be ascribed to their scarcity and their uneven distribution; there is a maximum of 10-12% of these rocks in the Tertiary basalt plateau of Eastern Iceland (ref. 8) and large fractions of the country are very poor in acidic rocks. What is the chance of dredge hauls bringing back rocks which form 10% of the sea floor? Sufficient dredgings have been made up to the present time on the MAR that the probability of finding rocks ten times less frequent than the common basalts is now high; in the Romanche trench we have found a nepheline gabbro which was less than 1% of the total dredge haul (ref. 9). The alkali basalts from the immersed MAR (refs. 10 and 11) represent much less than 10% of the dredge hauls in which they have been found.

On the other hand, the Icelandic acidic and intermediary rocks are mostly related to central volcanoes which have never been mentioned in the submerged MAR and we can be sure that our geophysical and topographical recordings are sensitive enough to detect a submarine central volcano of 10 to 20 km diameter; many smaller seamounts have been found by the same methods.

At this point, one can assume that a sialic crust exists under Iceland which does not exist under the immersed MAR. On the one hand, the Icelandic acidic and intermediary rocks seem to result from the differentiation of basaltic magma as indicated by the S^{87}/S^{86} and K/Rb ratios (refs. 12-16) and not from melting or assimilation of a sialic crust. On the other hand, seismic refraction studies (ref. 17) point out a layer with seismic velocities close to that of a granite, but this layer is not as continuous as a sial is expected to be and, moreover, it cannot be regionally related to the central volcanoes which produced the acidic rocks.

The only logical explanation which would explain the discrepancy between the Icelandic and immersed MAR relative to the acidic rocks would be the various thicknesses of basaltic (and gabbroic) layer in these two areas: a maximum of 2 to 3 km of basalts and metabasalts for the crest of the submerged MAR and a 4-km crust resting on a "blister" of 10 to 20 km in Iceland.

The basaltic magmas of Iceland have more opportunity to differentiate during their ascent because they have to cross a much thicker crust formed of older basalt. Because of their higher viscosity and explosivity compared with the deep submarine* basaltic products, the acidic lavas help to build the central volcanoes of Iceland; the location of these volcanoes is also due to the different tectonic style of this country.

CONCLUSIONS

Due to the above-mentioned petrological and tectonic reasons, major discrepancies between Iceland and the immersed MAR must be taken into account when geologists compare these two regions.

The Tertiary basalt plateau of Eastern Iceland is similar to an oversimplified model of the MAR if the observer keeps in mind that no counterparts of the Icelandic central volcanoes (partly composed of acidic rocks) have been found on the Atlantic floor.

As a whole, Iceland is more similar to the active ridges of the Pacific Ocean, which are smoother than the Atlantic one, and where acidic rocks (ref. 18), but not peridotites, have been found.

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*Due to the different hydrostatic pressures exerted by overlying water layers of different depths, the deep-seated submarine volcanoes of the MAR have little to do with the so-called submarine activity observed during the Surtsey (1963-1967) or Capelinhos eruptions (1957-1958), which were both shallow-water (less than 200 m) volcanoes.

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Table.1

			Mid-Atlantic Ridge	
			In Iceland	On the equator (from 11.5°N to 2°S)
Igneous Rocks	Volcanites	Basic volcanites	Basalts Mainly tholeiitic B. with few alkali B.	Basalts Mainly tholeiitic B. with few alkali B.
		Acidic & intermediate volcanites	Frequent rhyolites, dacites, andesites	None
		Acidic subvolcanites	Few "granophyres"*	None
	Plutonites	Basic plutonites	Few gabbros	Frequent gabbros, olivine G., qz. G., nepheline G., norites, etc.
		Acidic plutonites	"Granites"*	Rare quartz diorite
		Ultramafites	None	Various peridotites & serpentinites
Metamorphic Rocks		Metabasalts	Frequently zeolitized basalts & some rocks in zeolitic facies	Rarely in zeolitic facies
			Rarely in greenschist facies	Frequently in greenschist facies
			No amplibolite facies	Few in amphibolite facies
		Metagabbro	None	Few in greenschist facies & in amphibolite facies

*Except for the xenoliths from Surtsey (ref. 19), the rocks called "granophyres" and "granites" in the geological maps of Iceland are actually quartz-bearing subvolcanic rocks.

6.5. THE MID-ATLANTIC RIDGE IN ICELAND

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INTRODUCTION

Iceland is located at the junction of the Mid-Atlantic Ridge with the not very well-defined Wyville-Thompson Ridge. It is the largest land mass on the worldwide oceanic ridge system and provides a unique opportunity to study the rifting and volcanism of oceanic ridge systems on dry land. According to the concepts of sea-floor spreading, new oceanic crust is generated at the ridge crests. Oceanic crust is, in turn, destroyed at the location of deep sea trenches. Iceland is located at lithospheric plate boundaries. The study of these boundaries in Iceland by geological and geophysical means can provide important information to test the validity of the hypothesis of sea-floor spreading and continental drift.

South of Iceland, sea-floor spreading has been shown to be symmetric about the Reykjanes Ridge (ref. 1), where the magnetic lineations are clearly defined for hundreds of kilometers on either side of the ridge crest. North of Iceland, magnetic lineation patterns, symmetric about the Iceland-Jan Mayen Ridge, have been described by Vogt *et al.* (ref. 2). However, in Iceland itself, the Mid-Atlantic Ridge crest is not very clearly defined. The neovolcanic rift zones are arranged in a complicated geometric pattern which cannot be easily understood in terms of a simple extension of the Mid-Atlantic Ridge through Iceland.

The central magnetic anomaly of the Reykjanes Ridge has been traced to the eastern end of the Reykjanes Peninsula in southwestern Iceland (refs. 3 and 4). It is not possible, however, from aeromagnetic data alone, to trace these characteristic anomalies over central and northern Iceland (ref. 5) and therefore the ridge crest cannot be defined magnetically. Ward *et al.* (ref. 6) defined the Mid-Atlantic Ridge crest through Iceland as presently active microearthquake zones. Characteristic of his proposed ridge configuration is a major transform offset of the Reykjanes Ridge crest about 200 km to the east in southern Iceland, a change in trend of the offset ridge to a more northerly direction in the vicinity of Askja volcano, and another transform offset of the ridge crest by about 100 km to the west in northern Iceland to the Iceland-Jan Mayen Ridge. This transform fault zone, the Tjórnes fracture zone, was first proposed by Sykes (ref. 7).

The problem of locating the Mid-Atlantic Ridge crest in Iceland and the geotectonic relationships of the various rift zones to each other is far from solved. Detailed geophysical surveys may help to better understand the geotectonic relationships in Iceland and an effort should be made to map out various geophysical parameters in great detail, particularly the gravity and magnetic fields of Iceland. Continued microearthquake studies may prove very useful to delineate the Mid-Atlantic Ridge crest through Iceland (ref. 6), and fault plane solutions are needed to study the nature of the ridge offsets in southern and northern Iceland.

GRAVITY

A Bouguer gravity map of Iceland has been published by Einarsson (ref. 8). The gravity field is characterized by a regional, bowl-shaped, 30 to 40 milligal gravity low, centered over Iceland, indicating a regional isostatic compensation of the topography, probably at the crust-mantle interface. The contour lines follow the Icelandic coastline in surprising detail, which is interpreted by Einarsson (ref. 4) as evidence that isostatic balance was achieved by downfaulting of the Icelandic crustal block. The most surprising feature of the gravity field is the complete absence of any gravimetric expression of the neovolcanic rift zones. The gravity station locations are not given on Einarsson's map, except for the northwestern part of Iceland, and it seems possible that the station density may not have been great enough to detect anomalies that could be associated with the rift zones. A more detailed gravity survey of Iceland may well result in the discovery of gravimetric trends associated with the rifting processes. The detailed gravity data, if combined with already available seismic refraction data (ref. 9), could then be interpreted in terms of crustal structures of the various geological provinces of Iceland.

MAGNETICS

Detailed ground and aeromagnetic surveys, at close profile spacings, should prove to be very useful in tracing the characteristic anomalies of the Reykjanes Ridge across Iceland and in defining more exactly the locations at which these anomalies are obscured by complicated tectonic relationships in central and northern Iceland.

The two ridge offsets (fracture zones?) in southern and northern Iceland are of particular importance for future detailed geophysical, geological, and petrological research. If sea-floor spreading is presently taking place in Iceland, the nature of the faulting in these fracture zones is expected to be transform.

SOUTHERN "FRACTURE ZONE"

Three major active zones of rifting and historic volcanism are found in southern Iceland: the Snaefellsnes Rift Zone, the Reykjanes Rift Zone, and the East Iceland Rift Zone. The three zones are separated by northeasterly trending early Quaternary flood basalts, the "Old Grey Basalts." Volcanic fissures, dikes, and other linear tectonic elements in these rift zones *predominantly* strike northeast, except in the Snaefellsnes Rift Zone, where most linear elements strike in a west-northwesterly direction, more or less parallel to the postulated trend of the south Iceland fracture zone as defined by microearthquake locations (ref. 6). In the other two rifts, easterly trends are only relatively well developed on the Reykjanes Peninsula, where numerous easterly, "en echelon" offsets of volcanic fissures and lines of volcanoes can be observed.

The tectonic relationships of the three southern rift zones to each other and to the postulated fracture zone of southern Iceland (ref. 6) is very difficult to understand, due to the almost complete absence of transverse tectonic elements in the eastern rift and in the blocks separating the three rifts. A thorough geological and geophysical study of this particular region is therefore very desirable. The Tjórnes Fracture Zone just north of Iceland, again only defined by a zone of earthquake epicenters, is, in its major portion, only accessible to marine geophysical investigations. A detailed mapping of the bathymetry and the magnetic and gravity field could provide valuable information to locate this postulated fracture zone by other than seismic means. Seismic profiling could be used to detect possible deformation of the sedimentary strata in the fracture zone. No bathymetric evidence for the presence of such a zone has yet been found.

The research potential of Iceland is enormous. If the hypothesis of sea-floor spreading is correct, worldwide processes at lithospheric plate boundaries in the form of ridge crests, as well as fracture zones, are readily accessible for study in Iceland. The products of at least three distinct spreading periods are exposed in Iceland: the Tertiary Plateau Basalt, the early Quaternary "Old Grey Basalts," and the neovolcanics. From a geomorphological point of view, the similarity of subglacially erupted, elongated, serrated ridges and of table-mounts of the Pleistocene Móberg Formation to subaquatically erupted volcanic features, such as elongated ridges paralleling the Mid-Atlantic Ridge crest and flat-topped table-mounts observed to be rising from the sea floor, is striking. New and extreme environments are continuously created in Iceland by two major agents, volcanism and glacial action. New volcanic cones, lava flows, ash falls, hot springs, as well as retreating glaciers, provide new grounds for settlement by the biota. The extremeness of the environment is further stressed by the high latitude of Iceland. Thus Iceland is particularly well suited for studies of an interdisciplinary nature, involving, for example, biology, geochemistry, petrology, geology, geomorphology, volcanology, and geophysics.

This 1970 Summer Institute on Surtsey and Iceland has been an important step forward in bringing scientists of these various fields together and in making each other aware of the individual problems to be solved in these fields.

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6.6. PHYSICAL FEATURES OF ICELANDIC LAVA FLOWS

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INTRODUCTION

Lava flows that range widely in age, composition, and physical characteristics were observed during this Institute. The physical characteristics are the most obvious features of these flows and will be discussed and later used to compare the Icelandic basalts with the Columbia River flood basalt province in the northwestern United States. Only the subaerial flows of the Tertiary in eastern Iceland and the Recent and Pleistocene flows in the neovolcanic zone of central Iceland are included in this discussion; cones will not be covered.

Discussion of the physical features of lava flows may appear at first glance to be a futile exercise in descriptive classification. However, I believe it has been demonstrated that a better understanding of these features aids the field investigator in correlating and in interpreting the mode of formation of lava flows (e.g., see refs. 1 and 2).

GROSS FEATURES - SIZE AND SHAPE

A lava flow is a tabular body of fine- to medium-grained igneous rock that was extruded onto the earth's surface before complete solidification. The greatest lava eruption on earth in historic times occurred in Iceland at Lakagigar in 1783 with an estimated 12.3 km^3 of lava (ref. 3). The volumes of the older Quaternary and Tertiary flows are unknown because of a lack of stratigraphic control. The apparent discontinuity of many of the older flows in the fiord walls of eastern Iceland may mean that flows with volumes greater than the 1783 Laki flow are rare, but only more field investigation can validate this prediction. There are no known flows in Iceland which can compare with the conservative estimates of many hundreds and perhaps thousands of cubic kilometers given for the Roza flow(s) in Washington and Oregon (refs. 4 and 5).

The paths of the younger Quaternary flows in Iceland seem to be confined to river valleys. Widespread flooding of several tens of thousands of square kilometers such as that which occurred in the Columbia River Plateau is not evident in Iceland but may be recognized when more stratigraphic detail is known.

MAJOR LAVA FLOW TYPES

Aa and Block Lava

Lava flows have been subdivided into three categories on the basis of the manner of flowage and the resultant physical appearance of the end product (ref. 5).

Block lava and aa (Apalhraun in Icelandic) are terms which refer to lava flows with a fragmental surface. Block lava is considered by Finch (ref. 6) as having greater regularity of the surface of its blocky fragments. The new Hekla flow of 1970 is considered by Thorarinsson (personal communication) to be an aa flow while the flow near Luðent Crater is block lava. The distinction is often difficult to make since the two types are transitional.

Pahoehoe Flows

Pahoehoe (Helluhraun) flows, typical of basaltic extrusions, seem to outnumber the aa and block lavas in Iceland. The following discussion is concerned with the physical features of these flows and their bearing on a comparison between Iceland and the northwestern United States.

Upper Portion of Pahoehoe Flows

The tops of pahoehoe lava flows exhibit several features which aid both in distinguishing flow contacts and in understanding the cooling history of the flow. Gas bubbles rising to the surface of a pahoehoe flow form a zone of vesicles that may make up as much as one-third of the flow's total thickness. These vesicles are usually spheroidal in shape and if filled with minerals after burial, are called amygdules. Vesicular tops were seen in many of the flows. The best amygdaloidal top was seen at Teigarhorn where the dominant filling was by minerals of the zeolite group. Chalcedony is another common amygdule mineral in Iceland, but most of the chalcedony found was in float blocks in the glacial and fluvial deposits.

Columnar jointing is often developed in the tops of pahoehoe flows although it is usually less well-developed than in the lower portion. Many examples were seen in which the columns extended a meter or two down into the flow from its upper surface.

Even though they have very low viscosity, pahoehoe flows may break up when there is stress on the already solidified crust. This process causes some striking morphological features on the surface of the flow, namely, pressure ridges and domes. These were common features of the landscape in our travels across Iceland wherever the road crossed over a pahoehoe lava flow. One pressure ridge in particular was a source of relief to our visiting group because beneath it is a pool of crystal clear hot (44°C) water for bathing. This pressure ridge and others in the same area east of Myvatn were unusual, however, since they were exceptionally long and paralleled the tectonic lineaments in the area.

Another distinctive feature of pahoehoe flows is their ropy surfaces. Thingvellir offered some of the best examples of this characteristic but it was also seen on the tops of many of the other flows, including the flows on Surtsey. The group had an opportunity to see these being formed in the films on Surtsey and Askja.

Internal Part of Pahoehoe Flows

Fewer exposures of the internal parts of flows were seen because dissection is necessary. Typically, pahoehoe flows are more dense in the interior than in the top or at the base. Columnar jointing may be absent and a fluidal subhorizontal structure is noticeable, especially if the flow solidified while it was mobile. This fluidal structure is often seen in thin section by the alignment of plagioclase microlites and phenocrysts. Many of the interiors of flows showed fluidal structures internally, particularly the older 1964-65 flow on Surtsey.

Lower Portion of Pahoehoe Lava Flows

Some of the most interesting and useful features of pahoehoe flows occur in their lower portions. Vesicles are common in the lower parts although they seldom approach the quantity found in the upper parts. Distinctive elongated pipe vesicles may extend from the lower contact several centimeters up into the flow. These record the direction of flow if the upper part of the pipe vesicle is bent or inclined in some particular direction. Measurement of a great number of these is necessary for validity. The best pipe vesicles were seen at Teigarhorn,where they were filled with zeolites,and at Thingvellir, where the few observed seemed to indicate movement toward the southeast. This corresponds to the known movement of northwest to southeast for the flows at Thingvellir. Pillows may develop in the base of flows that enter a body of water but none of these were seen on this trip. The extensive pillows observed were in the table mountains and were due to subglacial extrusions. Lava tubes also occur in the base of a pahoehoe flow and may extend well up into the flow. These are tunnels in which rivers of lava continue to flow beneath the solidified crust. An excellent example of this was seen east of Myvatn where a lava lake was drained after its dam was destroyed. The walls and ceiling of the tunnel are well exposed and covered with small stalactite-like droplets of lava.

Columnar jointing did not seem to be well developed in the lower parts of the flows seen on this trip in comparison to the flows of the Columbia River Plateau. At the falls at Skaftafell, however, they were exceptionally well developed in what was probably a ponded flow. At this locality, the columns had horizontal "chisel marks" of unknown origin on the joint faces. An interesting note regarding columnar jointing is the use of columns for headstones in many of the cemeteries in Iceland.

COMPARISON OF ICELAND WITH THE COLUMBIA RIVER PLATEAU

Our rather rapid reconnaisance of Iceland allows for some speculation as to the origin of this volcanic pile and how it compares with the Columbia River Plateau. Gibson (ref. 7) has recently compared these two areas. Several contrasts stand out: Iceland is located on a mid-oceanic ridge while the Columbia River Plateau is not; Iceland has salic central volcanic complexes intermixed with the basalts while these are absent from the basalts of the Columbia River Plateau. Both areas have rocks of variable composition, but the salic central volcano complexes give Iceland a much greater range of rock type. With regard to the physical features discussed in this paper, it appeared as if the Icelandic basalt flows lack many of the features which are so common in the Columbia River basalt flows. The Icelandic flows seem to be much less regular and extensive. Well-formed columnar jointing does not appear to be as ubiquitous as it is in the flows of the Columbia River area. Much more work needs to be done to substantiate these generalizations, but if they hold true, it then appears that these two flood basalt provinces had quite different histories. The Icelandic volcanic pile may well have been formed by the processes going on today in the neovolcanic zone of central Iceland. This would be much different from the process of basin-filling by ponded lakes of lava that occurred in Washington.

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6.7. PLUTONIC ROCKS OF ICELAND

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OCCURRENCE

Although the bulk of the Tertiary to Holocene igneous rocks of Iceland are basaltic volcanics, coarse-grained plutonic rocks which range in composition from gabbro to granite are also exposed locally. Three types of occurrence have been recognized:

(1) Inclusions, ranging in composition from gabbro to granite, have been found in flow basalts at such widely scattered localities as Hekla, Surtsey, and Myvatn. Inclusions are also present in basaltic vent ejecta in the maars of the Krysuvik district. Most of the inclusions probably represent crystal cumulates formed in fractionating magma chambers in the crust or uppermost mantle. To date, inclusions which might represent pristine mantle samples carried upward by basalt magmas have not been recognized.

(2) Coarse-grained igneous rocks are most common in the eroded cores of central volcanoes where they may form sizable plutons. Most of these plutonic complexes are gabbroic, but rocks ranging in composition to granite and syenite are also present. The gabbro complex at Hoffell is probably a typical example of a magma chamber which crystallized beneath a central volcano.

(3) Granitic rocks occur as dikes and veins cutting fine-grained basaltic volcanics (?) in the "mixed lavas" of the Lon district. The genesis of these silicic dikes is uncertain.

RESEARCH POTENTIAL

Further studies of the coarse-grained igneous rocks of Iceland may contribute to basic and applied research in the earth and biological sciences. A few such research topics are listed below:

(1) Petrologic research: Chemical and petrographic studies of plutonic rocks will be useful in evaluating mechanisms of magmatic differentiation such as crystal settling, liquid immiscibility, and filter pressing. Attempts to compute the initial composition of mantle melts beneath Iceland will require knowledge of the chemical composition and mineral phases of both extrusive and intrusive igneous rocks. A study of the relationship of alkalic igneous rocks to tectonic features and physical characteristics of the mantle in Iceland may provide clues to the genesis of alkalic rocks and the mechanics of sea-floor spreading.

Knowledge of the plutonic rocks of Iceland and their genesis may aid in understanding the processes involved in the formation of the coarse-grained igneous rocks which are being recovered in increasing numbers by dredging on, and adjacent to, the Mid-Atlantic Ridge.

(2) Geologic research related to the biological sciences: An evaluation of the roles played by physical, chemical, and biological weathering in soil development on both fine- and coarse-grained igneous rocks will be useful for the biologist studying the development and succession of organisms in the extreme environments of Iceland. Similar studies will be of interest to arctic and alpine geomorphologists.

(3) Economic geology research: Iceland's economy suffers from a lack of metallic mineral resources. The plutonic igneous rocks associated with central volcanoes locally exhibit disseminated sulfide mineralization and are often surrounded by hydrothermal alteration halos. Deposits of copper, iron, titanium, molybdenum, precious metals, and rare-earth elements may be present in association with mafic to alkalic plutons in this central volcano setting. Prospecting for such deposits will be difficult because post-ore cover of younger volcanics and glacial ice probably conceals many plutonic complexes. Extensive regional and local geophysical, geochemical, and geologic surveys will be required to assess fully the distribution and economic potential of the plutonic rocks of Iceland.

6.8. TEXTURAL ANALYSIS OF SURTSEY TEPHRA:

A PRELIMINARY REPORT

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INTRODUCTION

Textural analysis of modern pyroclastic and hydroclastic deposits provides a means of characterizing ancient tephra units. The grain-size distribution is also useful for interpretation of transportation and deposition mechanisms related to the various modes of eruption and emplacement. Iceland has several historic volcanic centers that are well suited for textural analysis of tephra. Surtsey is one of the best of these centers because of the well-documented eruption, good exposures, unique environment, and wealth of interdisciplinary studies (ref. 1). The information herein reported is a result of the Summer Institute on Surtsey and Iceland during June 1970.

SAMPLES

Tephra samples were collected from nine widely separated points on both Surtur I and Surtur II (fig. 1). Samples were taken from a single bed (5 to 10 cm thick) at each location. An attempt was made to represent a variety of stratigraphic levels and textures. Because of the reconnaissance nature of the expedition and the relatively few samples, it should be assumed that some textural varieties exist that fall outside the range of those sampled. Two samples of beach sands (7 and 8 of fig. 1) were collected from the berm 5 m above the high-tide line for comparison with the tephra.

RESULTS

Standard mechanical size analyses were made using 10-inch screens with a 1-phi interval for the tephra and 3-inch screens with a 0.5-phi interval for the beach sand. Results of the size analyses are presented in figures 2 and 3. The data are plotted with cumulative weight percent on a log-probability scale so that the statistical parameters can be readily evaluated (refs. 2 and 3).

Certain characteristics of the particle-size distribution are evident. The tephra curves are all of the same general form. Rather than a log-normal distribution that would be a straight line on probability paper (ref. 4), the curves are convex upward representing the fine-skewed nature of the distribution. This general form is characteristic of Rosin's law distribution that results from mechanical crushing (ref. 5) rather than a dispersal in a fluid medium such as ash flow or a water-worked ash. The degree of fit to Rosin's law is now being tested by linear regression analysis because this characteristic can be used to distinguish shallow marine tephra explosions from other types of tephra with similar sorting parameters. The median size (-1.05 to 1.65 phi) and very poor sorting (2.6 to 3.4) are also useful in characterizing this tephra and distinguishing it from subaerial or water-worked volcanic particles.

To illustrate the unique sorting character of this tephra, two samples of beach sand were analyzed. These sands are composed of the same materials as the tephra, but they have been reworked and sorted by wave action. This difference is seen graphically in figure 3 as well as by the sorting parameters of the beach sand: median size (0.09 phi) and very good sorting (0.5).

CONCLUSION

The Surtsey tephra represent a unique environment that can be adequately characterized by grain-size parameters. The samples are poorly sorted and fine skewed. The distribution more closely approximates a Rosin's distribution than a log-normal distribution. Profitable study in the future would involve detailed sampling to test for the range in grain size and to relate changes in mean size and sorting to stratigraphic level. It would also be meaningful to compare other submarine tephra cones with those found on Surtsey.

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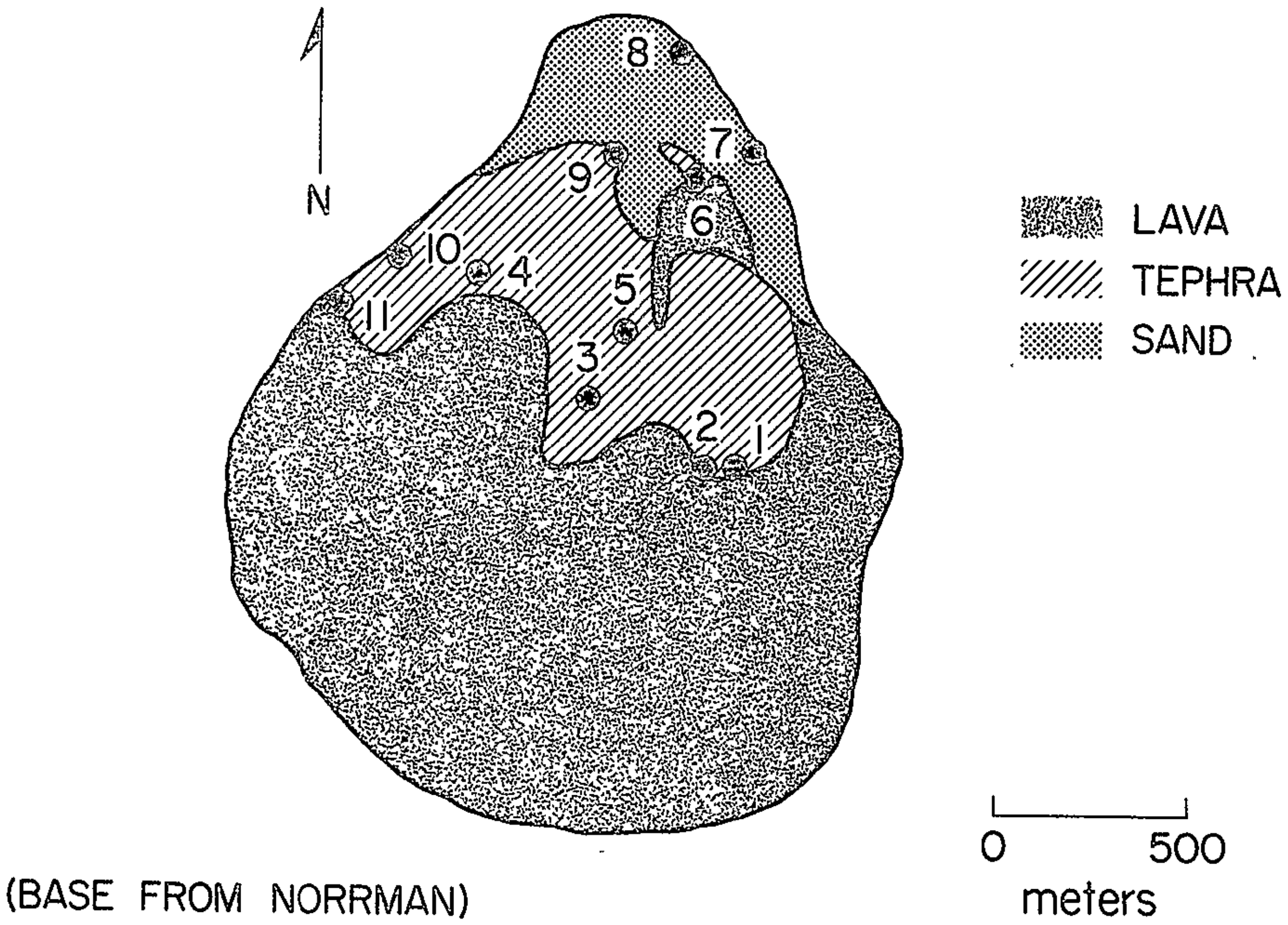

Figure 1. Location of samples. Base from Norrman, 1970.

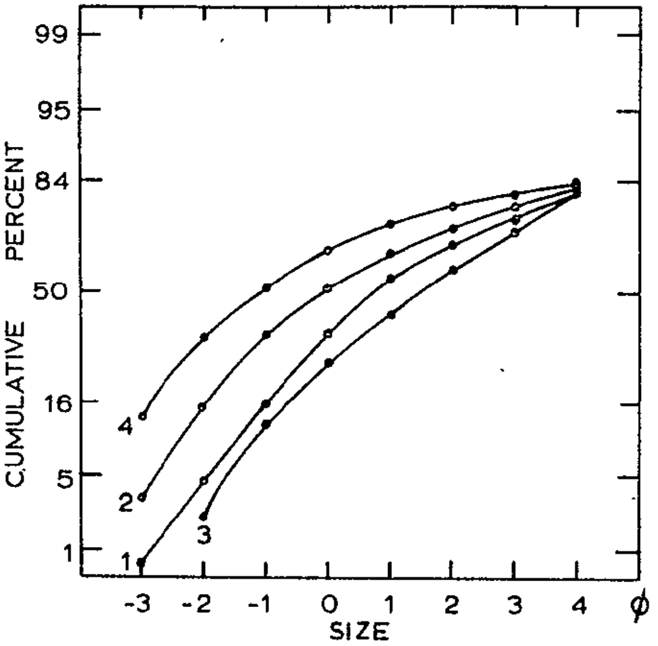

Figure 2. Size data of tephra samples 1 through 4. Similarity of size distribution is obvious.

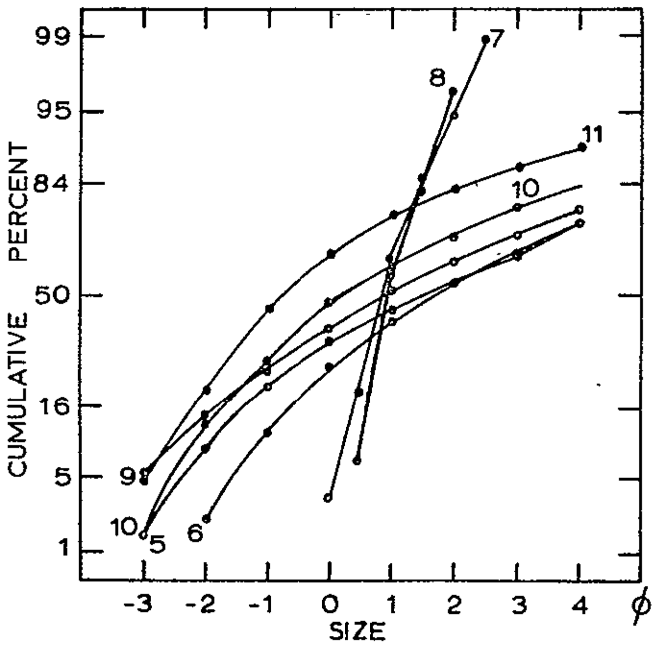

Figure 3. Size data of tephra samples 5 and 6 and 9 through 11. Note the different plots for beach sand samples 7 and 8.

6.9. FLUORINE-BEARING ASH FROM THE HEKLA ERUPTION, 1970: DISTRIBUTION, EFFECT ON ENVIRONMENT, AND IMPLICATIONS FOR MEDITERRANEAN ARCHEOLOGY AND GEOMYTHOLOGY

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By reason of its location with respect to inhabited districts and the frequency of its eruptions, Hekla poses more of a threat to the economy of Iceland than any of the other volcanoes of that country. The eruption which began about 11:30 p.m. on May 5, 1970, has been no exception. In the first two hours of activity, ash was showered on an area of some 20,000 km^2, roughly one-fifth of Iceland. Figure 1 shows the approximate distribution of that ash. In terms of thickness the amount of ash was not serious; even near the volcano we noted that the grass was growing up through the tephra cover. What caused serious damage was the fluorine adsorbed on the ash particles. The coarser ash that fell near Hekla contained 100 ppm of leachable fluorine; the finer particles that spread over important grazing areas as much as 200 km or more to the north and northwest contained 2,000 ppm. It is estimated that about 100,000 head of sheep and an unspecified number of cows were poisoned.

Although locally the concentration was heavy enough to kill the grass, the fluorine generally did not affect the vegetation itself. The livestock were poisoned as a result of eating grass on which the ash particles had settled - for unfortunately many farmers did not heed official warnings to keep their animals indoors until rains could wash away the contaminated ash. The effects on the animals are of two kinds - acute and chronic. In sheep which ingest 500-1000 ppm F (per dry grass) the acute symptoms are loss of appetite, a drop in the Ca content of the blood, inflammation of the mucous membranes of throat and lungs, loss of lambs by ewes, and death within a few days. Those which ingest 50 ppm F develop fluorosis, which produces swellings, growths, and soft spots in the bones, particularly in the forelegs; this causes the animals to fall to their knees. Furthermore, and particularly in young animals, the teeth grow abnormally outward, deforming the mouth. In either case, the chronically affected animals cannot graze, and starve to death. Similar effects occur in cows.

In addition to its effect on the environment in Iceland, this occurrence of fluorine-bearing ash in the 1970 eruption of Hekla, as in the 1947 eruption of that volcano, has interesting implications in connection with Mediterranean archeology and geomythology. In about 1450 BC, the volcano Santorin (Thera) in the Aegean Sea erupted violently and covered

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*Publication authorized by the Director, U. S. Geological Survey.

most of Crete (100 km away at the nearest point) with a blanket of ash tentatively estimated to have been of the order of 10 cm thick. This, together with the tsunami which almost certainly resulted from the caldera collapse of Santorin, plus possible earthquakes, have been credited with causing the abrupt downfall of Minoan civilization (refs. 1-3). Moreover, that eruption - which undoubtedly was the most violent catastrophe ever to have affected the Mediterranean world - has been credited with engendering the myths of Atlantis and Deukalion's deluge, the plagues of Egypt, and many other myths and traditions too numerous to list here.

In several published works (refs. 1, 3) and in discussions at the International Scientific Congress on the Volcano of Thera held in Greece in 1969, reference has been made to the Bluish Haze accompanying the Lakagigar eruption of 1783 and the resulting Haze Famine in Iceland, not only in connection with the possible effects of the Santorin eruption on Crete, but also with the "murrain of beasts" which was the fifth plague visited on the Egyptians. This analogy to the Lakagigar eruption does not seem to me to be very valid. The Bluish Haze (containing SO_2) accompanied a continuous outpouring of lava that lasted for some eight months; it was continuously produced and was not dispersed by the wind, but hung over Iceland all summer; as a result the grass crop was stunted and about three-fourths of the livestock and one-fifth of the people starved to death.

The Minoan eruption of Santorin was a pumice eruption, occurring in several very violent outbursts of unknown but relatively brief duration. Any noxious gases emitted should have been dissipated by the wind by the time they traveled great distances from the source. A far more plausible Icelandic analogy is Hekla's fluorine-bearing ash. On semi-arid Crete, the 10-cm ash blanket would have been sufficient to render the land infertile for many years, with or without fluorine. But Egypt, being 500 km away and in a downwind direction, would have received too little ash in terms of thickness to cause any adverse effects, unless it carried adsorbed fluorine or some other toxic substance, concentrated most highly in the finest (and therefore farthest borne) particles, as in the case of Hekla. [The information on the Hekla ash of 1970 contained in this report was obtained from Drs. Gudmundur Sigvaldason, Sturla Fridriksson, and Sigurdur Thorarinsson (oral communications).]

When indulging in speculations involving several unprovable assumptions, it is highly desirable to base one's inferences on cases that are truly comparable. Thus it seems more likely that the 1970 eruption of Hekla, far more than the Laki flows of 1783, may furnish a clue as to how the Santorin eruption of 1450 BC could have been responsible for the "very grievous murrain" visited upon the cattle, horses, asses, camels, oxen, and sheep of the Egyptians (Exodus 9:3-7) - provided it should turn out that ca. 1450 BC is the correct date for the Exodus, as some biblical scholars maintain but others dispute.

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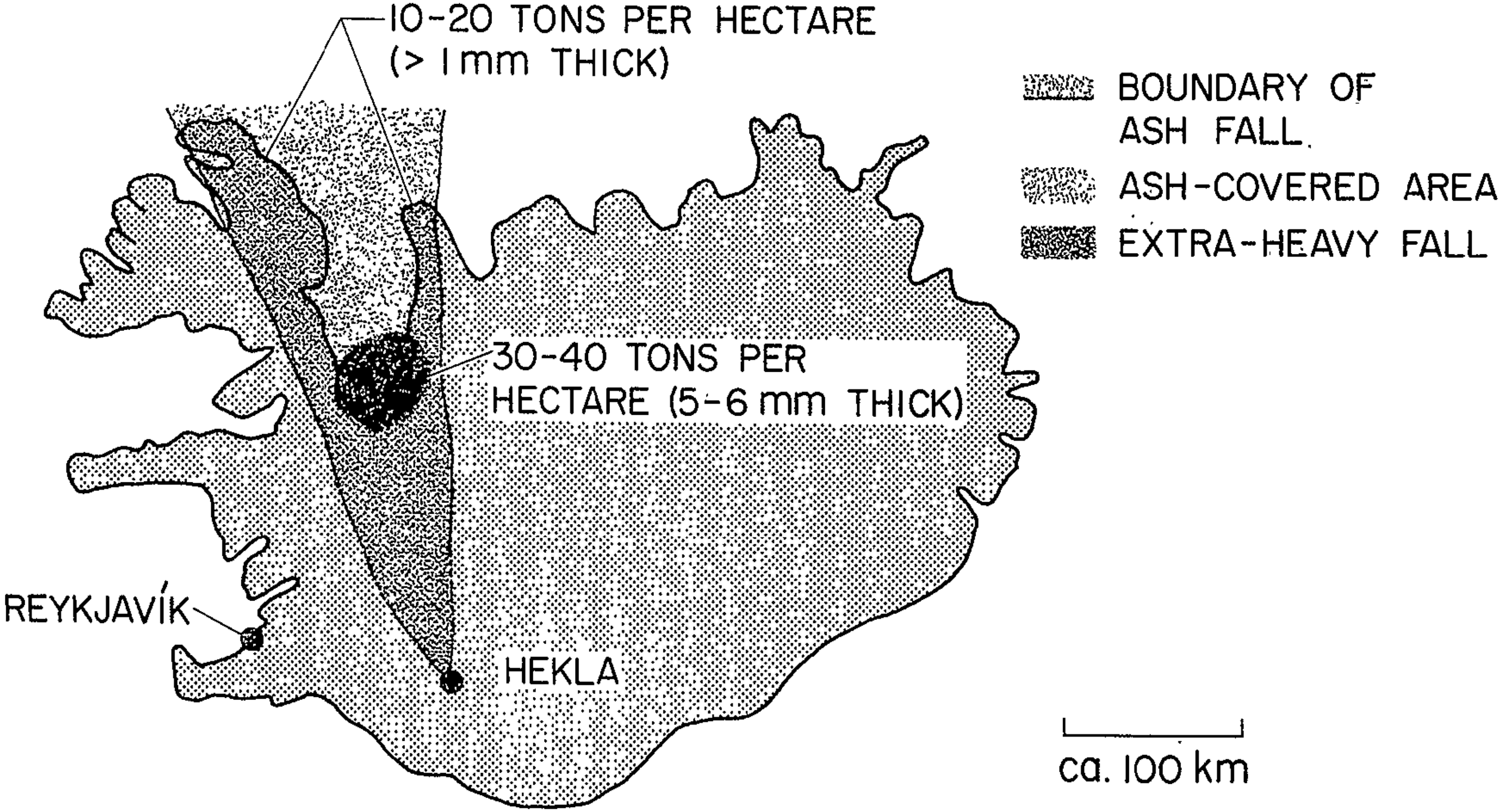

Figure 1. Distribution of ash; 1970 eruption of Hekla.

6.10. CONCLUSION OF GEOLOGICAL STUDI

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From the preceding papers on certain restricted aspects of geology and related interdisciplinary topics, it is clear that important contributions to the understanding of fundamental scientific problems will be forthcoming from research in Iceland. Pioneering and significant disciplinary research in Iceland has been done by many geologists over the years and must be taken into account as foundation studies upon which to build interdisciplinary research. Some of the areas of research which give promise of early answers to important scientific principles are related to geophysical and tectonic studies.

Airborne magnetic research over Iceland as compared with results from marine studies over the Ridge are of very great importance in our attempts to evaluate the importance or even the validity of theories linking magnetic reversals, as described by patterns of symmetrical magnetic stripes on either flank of the Mid-Atlantic Ridge, to sea-floor spreading.

The measure of the degree of success of this Institute must be the cross-fertilization of ideas and future collaboration on projects of mutual interest between scientists of different disciplines. It is clear to me that there was much fruitful interchange of ideas of this type in the course of the program. Perhaps one of the greatest benefits consisted in a better understanding of what kinds of observations constitute significant research in other disciplines, particularly biology in the natural environment. This was particularly rewarding as regards insights gained as various kinds of data were collected in the course of biological and related chemical studies in hot springs, fumarole, and geyser environments. Similar studies of the terrain vacated by melting glaciers in recent years, of the 6-1/2-year-old volcanic island, Surtsey, and of the varied volcanic terrains of Iceland were also useful. In the course of this study expedition, it became clear that many geologists have much to gain and to contribute by collaborative efforts and exchange of ideas with biologists and organic geochemists working on common research. Commonly, for instance, otherwise unexplained mineralization processes may be attributed either in part or in whole by the geologist to the action of bacteria. A better defined idea of the limitations of organic, geochemical, and biological processes has resulted from discussions with scientists of these other disciplines.

From the papers in this volume, it is clear that a wealth of important research remains to be done in Iceland, including that of a truly interdisciplinary nature. Part of the objective of these papers is to sketch the nature and directions that such research should take.

7.1. ORGANIC GEOCHEMISTRY OF ICELAND'S EXTREME ENVIRONMENTS

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The academic question of how life originated as well as the practical question of how to detect life, past or present, in future exobiological studies, such as the exploration of Mars or Venus (where life forms may differ considerably from those on Earth), require a detailed knowledge of the organic compounds formed under specific abiogenic conditions and those produced by biological systems in extreme environments. Unfortunately, large quantities of the organic matter in living organisms are in the form of polymers, and most of the organic matter in coals and shales is compacted in the form of kerogen, which is extremely difficult to analyze.

It is, therefore, much more convenient to look for "biological markers" that depend for their formation on complex biosynthetic pathways. Gas chromatography, often in conjunction with mass spectrometry, is an invaluable tool for the separation, isolation, and characterization of these low-molecular-weight compounds. One of the most frequently analyzed compound series has been the hydrocarbons, which represent the end product of diagenesis. Compounds such as pristane and phytane are easily identified and display a recognizable structure specificity indicative of known biological precursors such as chlorophyll, squalene, and other compounds built from isoprene subunits. Other isoprenoids frequently found in sediments, such as C_{15}, C_{16}, C_{18}, and C_{21}, are thought to arise either by microbial degradation or abiotic cracking. Fatty acids have been isolated from shales in small quantities. It is assumed that they represent material closer to the original organic matter found in biosystems, although there is some evidence that they may be formed from existing hydrocarbons.

GLACIERS

If a core could be drilled through an uncontaminated portion of a glacier and the sections dated and the organic matter present analyzed, information regarding the evolution of organic matter in the atmosphere might be ascertained. In this case, the ice at Flaajokull had a considerable amount of finely ground particles suspended in it, making the value of such determinations questionable.

HOT SPRINGS

The extremity of conditions we encountered in Icelandic hot springs ranged from a pH of 0.5 to 10 and included temperatures approaching 100°C. In one sample taken from a hot spring of pH 2 and temperature of 97°C at Myvatn (Namaskard), no bacteria were detected. A determination of the hydrocarbons and acids, if they exist in this spring, may reflect components from thermal recycling of organic matter or indicate organic matter contributed to the spring from the surrounding surface and from the atmosphere, since it would be difficult to postulate any biological *in situ* origin for such material.

The ambiguity that still surrounds thio-bacteria which are postulated to be responsible for the conversion of H_2S to H_2SO_4 at elevated temperatures might be clarified by an extensive core to establish their presence. The organic material isolated from segments of the core might yield information about the mechanism of reduction of sulfur-containing organic material, a comparatively unexplored area of organic geochemistry.

HEKLA VOLCANIC ASH

Two previous studies on the gases from an erupting volcano have been done (refs. 1 and 2). Sigvaldason and Elisson (ref. 1) detected CO_2 and CO, with a later evolution of H_2S, in the gases evolving from Surtsey. Heald *et al.* (ref. 2) detected CO, CO_2, and CH_4 in the gases given up by lava from the Hawaiian volcano Kilauea. In a similar vein, Ponnamperuma *et al.* (ref. 3) detected small amounts of glycine, serine, alanine, and aspartic acid in freshly fallen volcanic ash collected at Surtsey in 1966; hydrocarbons were not detected.

In this study, large pieces of hot volcanic ash were collected from the erupting volcano Hekla in sterile Mason jars on June 16. On June 28, ash was collected on aluminum foil, wrapped in the foil, and sealed in a polyethylene bag. These ash samples have been washed in 4:1 benzene/methanol and pulverized. They will be extracted with the same solvent and any hydrocarbon or acid constituents analyzed.

An attempt has been made to observe the gases trapped in volcanic ash with a specially constructed stainless steel, theoretically vacuum-tight, screw-type crusher that opens into the inlet system of a CEC 21-110B mass spectrometer. In one scan, intense ions at m/e 18, 43, and 58 could be distinguished from the background. The relative intensity of the isotope peak at m/e 59, as well as the fragment at m/e 43, was suggestive of butane, although high-resolution studies are necessary to be certain. The peak at m/e 18 may represent water. In a scan of the second sample, a rather intense m/e 16 was observed which might indicate methane. Interestingly enough, m/e 58 (attributed to CH_4N_3-C_3H_6O) and methane were also observed in the lunar sample by Burlingame *et al.* (ref. 4). Ponnamperuma *et al.* (ref. 5) has also reported C_1-C_4 hydrocarbons in the lunar sample and in the Canyon Diablo meteorite. Friedman *et al.* (ref. 6) has reported water in a lunar analysis. Further work is needed in the present study to cut down the background, establish correlations between ion intensities and partial pressures, and confirm these preliminary results.

Because bacterial contaminants of the volcanic ash could theoretically multiply in the transparent Mason jars used to transport the ash samples, airtight metal containers are suggested for future studies. Immediate immersion in a solvent such as carbon tetrachloride would further reduce any harmful biological activity. Ideally, components of interest could be extracted before being transported for final analysis.

SURTSEY VOLCANIC ASH

Surtsey provides a unique opportunity to determine the influx of organic matter from the air and from the ocean. To my knowledge there is no tabulation of which of these processes is more efficient, although it is generally assumed by both biologists and geologists that the ocean provides the greatest supply of organic matter. It would be of value to determine how incoming organic matter, by each of these modes, becomes attached to the surface of the ash. The concentration of the organic matter as a function of the rare-earth elements has long been known, although the mechanism is not completely understood. Such a study would correlate well with the algal and bacterial studies of Schwabe (ref. 7).

The finding of plants and mosses on Surtsey presents another unique area of research. By periodic sampling of the "soil" in the vicinity of these plants, one would have an unusual chance to observe the concentration of organic matter from its associated microorganisms as well as the organic matter excreted by the plant. Over a period of a few years, one could observe the concentration of organic matter in a sediment whose detailed composition and history were known.

A sample was selected from the area where a green algal growth had taken place in a lagoon type of environment. This was marine in origin and was the direct result of water washing in from the ocean. The algae found in this area have been very well defined in the Surtsey Research Progress Reports, volumes 2-4. Hydrocarbons and acids from this environment again represent those of a very well-defined, recent marine sediment.

The most valuable aspect of this Summer Institute, however, was its educational function. The consequences of this opportunity may be very subtle and deep-rooted but such an experience is essential for full insight into geochemical problems. Just as the volcanic island of Surtsey functions as a sponge soaking up the organic components from its surroundings, so the organic geochemist in such a situation may absorb vitally relevant information from both geologists and biologists. The opportunity to spend a few weeks seeing Iceland has given each of us an understanding of their geological environment with its 24-hour-day summers, its isolated ecological development dictating the diet of fish and lamb, and the unique expression of beauty found in Icelandic poetry, music, sculpture, and concepts.

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7.2. BIOGEOCHEMISTRY OF PHOSPHORUS: ITS ROLE IN ECOSYSTEM DEVELOPMENT. A PRELIMINARY STATEMENT ON SOME POSSIBLE RESEARCH TOPICS RELEVANT TO SURTSEY AND ICELAND

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The recent formation of Surtsey Island provides an unusual opportunity to conduct certain short-term and long-range studies of importance to ecosystem development. The primary interest in ecological development of an insular environment is of two parts: chemical and biological. Although the two parts are intrinsically related, the primary emphasis here is on those geochemical aspects of interest. For the geochemist, Surtsey offers the rare opportunity to observe and measure the processes of chemical and biochemical weathering of primary volcanic rock, the subsequent soil formation, and the role that both of these processes play in the transport and accumulation of nutrients in the system as a whole.

Because phosphorus is a constituent of nucleic acids, phospholipids, and numerous phosphorylated compounds, phosphorus is one of the nutrients of major importance to the development and maintenance of biological systems. Furthermore, because the ratio of phosphorus to other elements in organisms tends to be considerably greater than the ratio of phosphorus to other elements in the available primary sources, phosphorus quickly becomes ecologically significant as the most likely limiting or regulating element in primary productivity.

ECOSYSTEM DEVELOPMENT: BIOENERGETICS

Normally in the early stages of ecological succession, the rate of primary production or total photosynthesis (P) exceeds the rate of community respiration (R) (fig. 1). However, in a case such as Surtsey, where the available nutrients and other chemical and physical[†] factors were not initially conducive to the establishment of higher order plants, the initial colonization appears to have been predominantly by heterotrophic microorganisms utilizing organic matter from external sources. A question of some interest here is: What conditions are required for significant colonization by higher vascular plants (e.g., extent of soil formation, etc.)? When the P/R ratio becomes greater than 1, organic matter and biomass will accumulate in the system and hence begin to contribute more significantly to biochemical weathering and soil formation.

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[†] For instance, lack of sufficient water or continual shifting of ash layers and possibly the continued out-gassing from the volcanic rock, to name just a few.

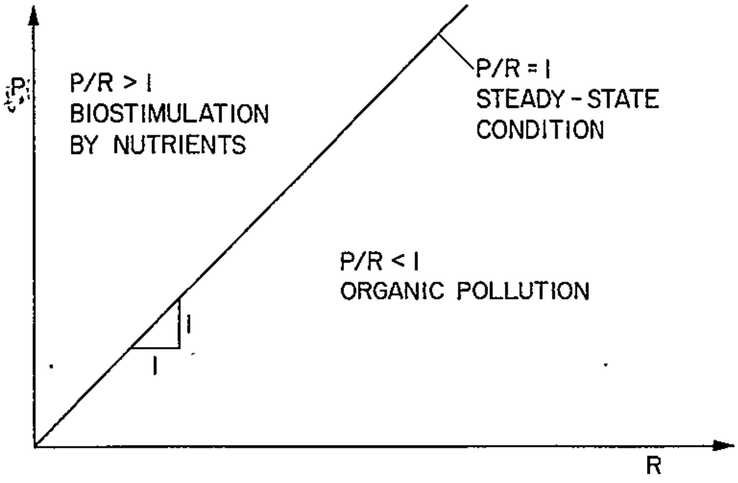

Figure 1. Primary productivity vs. respiration for an ecosystem.

Of major interest in a young ecosystem is information on the increase in quantity and diversity of organic compounds, those within the biomass as well as those secreted and excreted into the general environment as by-products of the community metabolism. Biochemical diversity within whole systems has been studied very little. What forms of organic-P are most stable in sediments and soils, and what stabilizes them? This particular point is of interest to investigators looking into the problem of chemical evolution. They are interested in the possible stabilizing effects of adsorption on clays and metallic hydrous oxides of such molecules as DNA or RNA, sugar phosphates, and nucleotides. In this respect, the investigation of soils and recent sediments might give added insight into chemical evolution while providing basic information about the organic-P constituents in modern sediments.

The cause and effect relationship between diversity and stability on molecular, cellular, population, and community levels is not clear and should be studied from several points of view. Surtsey is an ideal model for such a study.

NUTRIENT CYCLING IN ECOSYSTEMS

Biogeochemical cycles can be divided into two categories: the sedimentary type such as the phosphorus and sulfur cycles, and the gaseous type such as the nitrogen, oxygen, and carbon cycles. One of the significant processes in developing ecosystems is the closing of the biogeochemical cycling of major nutrients such as N and P. The main sources of P are the weathering of rocks, volcanic gases, airborne particulate matter, and detrital organic material.

For their nutrition, plants generally require inorganic phosphate, typically as orthophosphate ions. In passing through the various trophic levels, the phosphorus is transferred as organic phosphate and is subsequently broken down to the inorganic form again.

High rates of productivity in young terrestrial ecosystems cannot be maintained without compensating inputs of new nutrients because of the loss of nutrients through leaching of soluble organic or inorganic species. Classical textbook theory states that in moving toward the equator, a larger percentage of the available nutrient reservoir is held in the biomass with a corresponding reduction in the percent held by the soil or sediment. With sufficient field data it would be possible to test this hypothesis.

Weathering of primary rock will be one of the major contributions to the phosphorus reservoir of the ecosystem on Surtsey. The geochemical analyses of Surtsey lava and ash show typical percentages of phosphorus, in the range of 0.2-0.3% as P_2O_5. Another source of possible quantitative importance in the early stages of development might be the P_2O_5 outgassing and subsequent condensation. Unfortunately, no data are yet available on the quantity of gaseous phosphorus from the volcanic material.

The relative roles of chemical and biochemical weathering in the overall weathering process is poorly understood. The importance of chelation by organic molecules as a weathering and transport mechanism should be studied both in the laboratory and in the field. A second related problem of importance is the kinetics of weathering as a function of particle size (i.e., surface area). For very small particles, the reactions may be quite different due to the accumulation of weathering products in pore spaces. Parenthetically, where reactions occur on solid surfaces, caution should be exercised in the use of such terms as concentration, diffusion, and pH; care must be taken that conceptually clear notions amenable to mathematical treatment are used if there is to be any hope of dealing quantitatively with the microheterogeneity of the system.

METAL-ION BUFFERING IN MICROENVIRONMENTS

Orthophosphate forms typically very insoluble solid phases and soluble complexes with such metal ions as Ce^{+3}, Co^{+2}, Ni^{+2}, Cu^{+2}, Ag^{+}, Zn^{+2}, Cd^{+2}, Bi^{+3}, Pb^{+2}, Ca^{+2}, Fe^{+3}, and Al^{+3}. Does orthophosphate play any significant role in buffering heavy metal ions in microenvironments? Studying this question should prove both interesting and useful.

SUMMARY

The increasing problem of pollution of our aquatic environment has brought special focus on the europhication of lakes and water impoundments throughout the world. The role of phosphate as a possible limiting algal nutrient has intensified interest in the limnological and geochemical role of phosphate in natural waters. In soil and surface waters, organisms and their abiotic environment are interrelated and interact with each other; the perpetual sequence of nutrient assimilation and the decomposition of organic matter accompanied by the physical pulses of circulation and stagnation leads to a progressive retention of the fertilizing constituents. Such enrichment in nutrients, principally N and P, in a body of water may lead to a disturbance of the balance between photosynthetic activity and respiratory activity. To gain insight into the regulatory role of sediments and soils in the limnological transformation of phosphorus, it is necessary to consider many factors that are relevant to an understanding of the enrichment process and of primary productivity in natural systems. The new environment on Surtsey presents an ideal opportunity to observe and investigate the development of an ecosystem and possibly better understand the role of nutrients in that developmental process. New insights into the knowledge of ecosystem development in aquatic and terrestrial environments cannot help but aid in understanding possible changes or shifts in the ecological make-up of a natural system due to present or future pollution.

Information on the phosphate chemistry of sedimentary interstitial water and of the sediment-water interface and present knowledge of the biogeochemical cycle of phosphate and P-compounds in soil and surface waters is inadequate and at best only qualitative. The physical-chemical state and complex formation of phosphate in soil and surface waters, the chemical composition of aquatic microorganisms, the mechanisms of biological uptake of phosphorus from the environment, chemical changes brought about by the biota, interbiological interactions, and post-depositional changes in the sediments are but some of the areas in which research efforts and quantitative information are needed to understand better the problems of the biogeochemistry of phosphorus and its relation to primary productivity in natural systems.

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7.3. ENVIRONMENTAL RELATIONSHIPS TO THE CHEMISTRY OF THERMAL WATERS

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The distribution of anions in natural waters and particularly thermal springs is critical in determining their chemical characteristics. The chemical characteristics of these natural waters in many respects determines whether they are suitable environments for organic growth..

The geochemistry of natural waters has been discussed by many authors, including reviews in the new serial edition of the *Data of Geochemistry*. Chapter F on the "Chemical Composition of Subsurface Waters" by White *et al.* (ref. 1) and Chapter K on "Volcanic Emanations" by White and Waring (ref. 2) have both been published. In these publications it is readily noted that on the earth's surface large differences in chemical composition can be found in thermal waters from superficially similar active areas. Of particular interest is a review article by White (ref. 3) on "Thermal Waters of Volcanic Origin." Although he does not include specific data from Icelandic thermal waters, White presents many generalizations of importance in considering Icelandic hot springs. He indicates that most thermal waters he considered appear to be primarily of meteoric origin and at most contain only a very small amount of water from a magmatic source. Hence the type of magma and stage of crystallization in a volcanic area probably makes only a minor contribution to the water chemistry. The temperature and pressure of the systems, chemical composition, depth of penetration, and mixing of meteoric water, and reactions with wall rocks appear to play a greater role in determining the water chemistry. It is of interest to note that while White (ref. 3) states that one of the most common types of thermal water is that characterized by a dominance of sodium chloride, it is not common in Iceland.

The chemistry of thermal waters and gases in Iceland has been extensively studied by Sigvaldason (ref. 4). He discusses the thermal activity from both low-temperature (less than 150°C) and high-temperature areas. The analyses of waters from both types of areas show some similarities, particularly when the higher solubility of silica at high temperatures is taken into account.

On the basis of the chemistry of the Icelandic waters, Sigvaldason (ref. 4) concluded that:

> . . . the chemical components of thermal water in Iceland could be adequately accounted for on the basis of wallrock

leaching, and that the generally accepted view of magmatic origin would need some revision. In their paper on experimental interaction between hot water and rocks ELLIS and MAHON (1964) concluded, that the dissolved components in thermal fluids could in most cases be explained on the basis of wallrock leaching. The components could be divided into two groups. Those which are governed by solution equilibria with minerals in the wallrock, and those which cannot be accommodated in the structure of secondary minerals and become concentrated in the water phase. As would be expected one finds similar amounts of components of the first group in waters from thermal fields with similar base temperatures. Chemical components on the other hand, which are not governed by solution equilibria are in such low concentrations in the Icelandic waters compared to thermal waters from other parts of the world, that this calls for a separate explanation. The components in question are among others chloride, bromide, boron and arsenide. In the Icelandic waters the amount of these elements is a whole order of magnitude less than in thermal waters from New Zealand, Japan or the U.S.A. The highest concentration of chloride in high temperature thermal water from Iceland is 600 ppm, but 100-200 ppm is a more common figure. In New Zealand and the U.S.A. the thermal water contains 1000-2000 ppm Cl and 4000 ppm Cl has been reported from Japan (WHITE, HEM and WARING, 1963).

If we accept wallrock leaching as a primary mechanism in determining the chemical composition of thermal waters, two possible explanations of these differences might be suggested. The first concerns the availability of the elements in the rocks. There are some indications suggesting a very low boron content in Icelandic rocks as compared to volcanic rocks of strictly continental origin. The available data are, however, too few in order to give any conclusive evidence. The second and favoured explanation is a low rock/water ratio in the Icelandic thermal systems. This would indicate either a very small contact area between water and rock or a high rate of flow through permeable layers.

In a young volcanic structure like Iceland, with recent fault systems, one would expect high permeability. In this case, and in order to maintain a high rock/water ratio, the rate of flow through the thermal system has to be considerable in order to explain the dilute character of the water. The age of the thermal area will also be a significant factor since the readily soluble elements would be removed from the rock/water contact area in the early stages of the life of the system.

Sigvaldason (ref. 5) in his investigation of the geochemical and hydrothermal aspects of the 1961 Askja eruption has also noted that moderate variations of water chemistry may take place with time. These changes were noted over a six-day interval during a period of high activity and probably are due for the most part to changes in reservoir and circulation of the ground water. Should similar changes take place over a longer time range they might impose severe constraints on the organisms that could adapt to these thermal spring environments.

Although much careful work has been done on the analyses of thermal waters, it seems apparent that if the chemistry of specific areas is to be understood the chemistry of the local rocks, including those at depth, must be studied in additional detail. It is this rock chemistry that would determine the distribution of nutrient, inhibitor, or even toxic trace elements in thermal waters. Waters in environments like Iceland which are primarily basaltic in nature differ from those such as California which have great thicknesses of geosynclinal sediments. Dissolved elements common to sedimentary areas such as combined nitrogen may just be part of a long-term cycle. The high ammonia content of the waters from Sulfur Bank, Lake County, California, may be derived from decomposing organic matter in deep-seated sedimentary graywackes. Likewise, recent organic matter accumulating in a hot spring area could contribute ammoniacal nitrogen in a shorter cycle.

With the above ideas in mind, samples were collected during the Boston College Environmental Center Summer Institute on Surtsey and Iceland trip so that selected trace elements could be determined in rocks from various volcanic and hot spring areas. Of particular interest are the elements sulfur, carbon, nitrogen, and boron. Sulfur seems to have the best chance of not being a cyclic element in hot springs. It often is emanated as H_2S and subsequently oxidized and trapped as insoluble sulfates. Nitrogen (ammoniacal) has not been investigated in detail in Iceland or many other volcanic areas but has been shown to be present in relatively high abundance in a few localities such as Sulfur Bank and Mt. Vesuvius.

Preliminary analyses for carbon and nitrogen performed on the 1970 samples are given in table 1. The carbon and nitrogen contents of the few rocks studied are similar to other basalts. It is of interest to note that the sample of altered basalt taken from the rim of a thermal spring at Krisuvik has significantly higher nitrogen and carbon contents. Several samples were collected from this area and will be studied in further detail. The method of analysis has been described by Gibson and Moore (ref. 6) and Moore and Lewis (ref. 7).

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Table 1.- Nitrogen and Carbon Contents of Icelandic Rocks*

Sample	N (ppm)	C (ppm)
Altered Krisuvik basalt (1)	72	---
Altered Krisuvik basalt (2)	500	1200
Altered Surtur 2 vent basalt	59	170
Hekla fine tephra (1970 eruption)	39	144
Hekla bomb interior (1970 eruption)	34	72

*Chemical analyses performed by Ronald Gooley and Frederick Delles.

7.4. A PRELIMINARY REPORT ON SOME MINERALOGICAL ASPECTS OF ICELAND AND SURTSEY

by Sheldon Sommer

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My participation in the Summer Institute introduced me to numerous problems of which I would not normally be aware. The broad and very well-planned introduction to the Iceland and Surtsey environment provided samples and information for two specific problems and initiated thinking concerning a host of interdisciplinary studies. The collaboration on this trip of biologists, geologists, geochemists, etc., suggests joint efforts to study such problems as the possible physical (grain size, porosity, etc.) and chemical variation between newly located plant sites and barren sites on Surtsey, the location and mineralogical association of organic constituents, and silica deposition by or on hot spring algae and bacteria.

My present research efforts associated with the Summer Institute are directed toward delineating the environment of zeolite formation in the Tertiary basalts of southeastern Iceland and the stability of recently formed minerals in the beach sands of Surtsey.

The zeolite minerals of the Berufjordur area constitute a mineral assemblage within different zones of the lava flows. The different zones reflect the changing temperatures at which the various zeolite minerals formed. I will analyze the minerals by electron microprobe, x-ray milliprobe, and luminescence spectroscopy to determine the population of impurity (i.e., trace elements) ions acting as activators on individual cation sites. The site population is indicative of temperature of formation or subsequent reheating.

The minerals comprising the Surtsey beach sands were deposited during several eruptive events and should indicate a wide range of structural stability/instability. The exposure of this material, which ranges from shocked or poorly crystalline to well-crystallized minerals, to a beach environment suggests an ideal situation for the study of early signs of physical and chemical alteration. Samples of beach sands were taken from the surf zone through the berm. Analysis will be by x-ray diffraction, microprobe, and luminescence spectroscopy. Changes in composition and phase will be studied as well as the more subtle effects of bond distance, ordering, and perhaps, site population. This is a preliminary attempt, and if successful, will require future trips to these and similar environments.

If one can measure the success of this venture by the degree of interest generated, amount of new research areas developed, awareness of the necessity of interdisciplinary cooperation, and the degree of friendships, then the Summer Institute was an overwhelming success.

8.1. INTRODUCTION TO BIOLOGICAL STUDIES

by Thomas D. Brock

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My activities on this trip can be divided into three sections: (1) advice and liaison with the biological participants, (2) lectures and discussions to the whole group, and (3) research on the microbiology of extreme environments.

PARTICIPANTS

The participants in the program from biology were selected because of their interest in the biology of extreme environments and in evolutionary processes. Individuals representing the subdisciplines of ecology, physiology, molecular biology, entomology, geomicrobiology, microbial ecology, and phycology participated. Some had had fairly extensive field work whereas others had done little field work but had considerable laboratory experience. Apparently, all participants benefited from the trip, both in terms of furthering their research interests and in gaining new insights. Many stated that the opportunity to interact with geologists and geochemists was especially valuable.

LECTURES AND DISCUSSIONS

I gave four formal lectures and led one discussion. Lectures were: (a) the biology of thermal and acid environments, (b) the role of microorganisms in geological processes and in the evolution of microorganisms, (c) the colonization of new land surfaces, and (d) the biology of Surtsey. I led a panel discussion on the biology of extreme environments with the following participants: R. Young, S. Siegel, and R. W. Castenholz.

RESEARCH

As part of a continuing study of the biology of extreme environments, I made a number of observations on the presence of bacteria in Icelandic hot springs of different temperature and pH values. Earlier studies in thermal areas of Yellowstone Park, western United States, New Zealand, and Japan had shown that at neutral and alkaline pH values, bacteria live in springs even at the boiling point. However, in springs of progressively greater acidity, the upper temperature at which bacteria are found decreases, suggesting that acidity imposes an additional stress which makes impossible the function of life processes at the highest temperatures. For instance, at pH 3 the upper temperature limit is about 80°-85°C.

It was of interest to examine Icelandic hot springs to see if the same picture would be found here as elsewhere. To this end, 40 hot springs were sampled, mainly in the Myvatn and Geysir areas. Temperature was measured with a Yellow Springs Instrument Company thermistor probe at the precise site of sampling. Water was taken at each site and the pH measured a few hours later when the water had cooled, using an Orion pH meter and combination glass electrode. Care was taken to be sure that gases were retained during cooling of the water, so it is safe to conclude that the pH values represent those of the springs. Samples of mud or rock submersed in the springs were removed for bacterial examination. Sediment or rock scrapings were examined with a Carl Zeiss phase microscope, usually at 400×. In most cases, the presence or absence of bacteria could be easily determined, although in a few cases bacterial numbers were low and it was hard to decide if the few bacteria seen were autochthonous. The data obtained are being incorporated into a paper currently in press in Science.

An interesting sidelight to this study concerns the pH values of Icelandic springs. As can be seen in table 2, the pH values of the springs have a bimodal distribution, with many acid and alkaline springs and few or none at pH values of 5-8. A similar bimodal distribution curve has been found in Yellowstone and New Zealand. One difference in the Icelandic distribution is that the alkaline springs tend to have higher pH values than those in the other two habitats. Thus springs with pH values over 9 are common in Iceland and rare in Yellowstone and New Zealand. A geochemical explanation for this phenomenon is needed.

STUDIES ON SURTSEY

My previous two visits to Surtsey coincided with the Syrtlingur and Jodlar eruptions and most of the potential sites for biological development were being covered with fine ash. It was thus gratifying to see that now that Surtsey has ceased erupting, life is moving in quickly. Bacteria, algae, protozoa, mosses, and vascular plants were found. The distribution of life seems closely associated with the availability of moisture, either as steam condensation from fumaroles or in lava crevices near the sea, where higher humidities would be expected. The main thrust of my studies on Surtsey concerned the relative importance of the blue-green algae and higher plants (mosses and vascular plants) as primary colonizers. I took a number of samples of plant stands for quantitative study, but even the qualitative observations made so far seem clear cut; blue-green algae are *not* the primary colonizers of Surtsey, except in thermal areas where higher plants cannot grow. This observation is at variance with previous notions of plant succession on new volcanic substrates, and hence deserves further confirmation, especially through quantitative studies.

FUTURE WORK IN ICELAND

A much more detailed survey of Icelandic thermal areas is needed. Most of the work which has been done, either by myself or others, has been in the Reykjavik-Hveragerdi-Geysir area or in the Myvatn area. Most of the extensive thermal areas in the center of Iceland have not been visited at all, although they are relatively accessible in summer by Land Rover. I suggest that studies on these thermal areas would be desirable to confirm other studies. In addition, since these thermal areas are away from populated areas they are less disturbed and hence should be available in an unchanged state for long-term studies.

Continuing study of the colonization of Surtsey is, of course, essential. It is encouraging that Surtsey has been set aside as a research area and the Icelanders are to be complimented for the extensive support they are giving to research on Surtsey. As life develops further on Surtsey, ecological studies of a more quantitative nature will become possible and should be done.

Table 1.- Bacteria in Icelandic Hot Springs of Various Temperatures and pH Values

Sample number	Temperature, °C	pH	Bacteria
32-1	91.5	5.6	---
32-2	89	1.4	---
32-4	95.5	5.55	---
32-5	96.5	5.7	---
32-6	95.5	3.15	---
32-7	85	4.6	---
32-8	97	5.4	---
32-9	97	2.85	---
V949	94.5	4.25	---
V947	81.5-84	3.4	---
V883	85	3.65	---
18-3	97.5	9.35	+
18-5	95-97	9.45	+
19-2	88	4.25	±
30-2	98	9.7	+
34-1	83	9.95	+
34-2	88.5	9.82	+
34-3	92	9.75	+
35-1	93.5	10.1	+
35-2	84	3.6	---
35-3	92.5	3.1	?
V937	86	3.95	---
36-2	75	9.45	+
36-3	97-98	9.55	+
36-4	92	9.55	?
37-1	99	8.7	±
37-2	80	8.1	+
37-3	93	9.9	+
38-1	74-75	5.8	+
38-2	84-85	6.15	+
38-3	84.5-86	3.05	?
38-5	93	4.1	---
39-3	99.2-99.9	10.0	---
40-1	96	4.8	+
40-2	94	9.35	+
40-4	99-100	5.95	?
41-1	83	8.7	?
41-2	97-98	5.15	±
V905	83	4.85	---
V855	97	9.1	±

+Many bacteria present, ±some bacteria present, ---no bacteria present, ?questionable

Table 2.- Frequency of Hot Springs of Various pH Values in Iceland

pH range	Number of springs
1-1.5	1
1.55-2.0	0
2.05-2.5	0
2.55-3.0	1
3.05-3.5	4
3.55-4.0	3
4.05-4.5	3
4.55-5.0	3
5.05-5.5	2
5.55-6.0	5
6.05-6.5	1
6.55-7.0	0
7.05-7.5	0
7.55-8.0	0
8.05-8.5	1
8.55-9.0	2
9.05-9.5	4
9.55-10.0	8
10.05-10.5	2

Observations of springs in the Myvatn and Geysir areas.

8.2. PRELIMINARY REPORT ON THERMOPHILIC BLUE-GREEN ALGAE AND MICROORGANISMS IN ICELAND AND SURTSEY

by Richard W. Castenholz

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The following studies were initiated or continued:

Impoverished Number of Thermophilic Blue-Green Algae in Icelandic Hot Springs

An earlier study (ref. 1) indicated the low number of thermophilic algal species in Iceland's hot springs compared to the hot springs in North America and Europe. Dispersal problems were suggested as the main causes of this situation. Samples were again collected in 1970 from several of the same hot springs. Collections were also made in five additional hot spring areas in northern and southwestern Iceland. All samples have been examined in a cursory manner. At this point, there are no indications of additional species not previously found in Iceland. The samples containing blue-green algae have also been inoculated in appropriate culture media and incubated under conditions that would normally enrich for species common to other hot spring areas, as a further check for new species. Any additions or revisions of the thermophilic blue-green algal picture in Iceland should be detected shortly.

INTRODUCTION OF THERMOPHILIC BLUE-GREEN ALGAE TO SURTSEY

Although there are no thermal springs on Surtsey, steam vents are common in the vicinities of both the main craters, particularly Surtur II. The condensing steam provides moist warm areas around these orifices which should be able to support normal thermophilic types if they are transported there. The pH of several of these areas was above 7. Schwabe listed eight species of blue-green algae around the steam vents of Surtsey in 1968 (ref. 2) and almost double that number in 1969 (personal communication), but these appear to be merely mesophilic species that may grow at temperatures only as high as 40°-45°C and be tolerant of temperatures only a little higher.

On June 26, 1970, samples of moist ash and thin algal mat were collected around approximately ten steam vents in the region of Surtur II. The microscopic examination of these samples indicated that *Mastigocladus laminosus* may be present in at least three collections from ash in which the temperature rose to about 60°C. Portions of all the collections have been inoculated in liquid and in solidified "*Mastigocladus*"-type medium and incubated at 60°, 45°, and 30°C; insufficient time has presently elapsed to evaluate these cultures. *Mastigocladus laminosus* is a cosmopolitan thermophile which will grow at temperatures as high as 63°C, and is common in Icelandic hot springs (ref. 1). The probable new introduction of this truly thermophilic blue-green alga to Surtsey raises the question of the method of transport from a mainland hot spring to a few steam vents on the slopes of Surtsey. There are no thermal waters on the Westman Islands or nearby on the mainland of Iceland.

THERMOPHILIC FLEXIBACTERIA IN ICELANDIC HOT SPRINGS

Collections of carotenoid-containing flexibacteria were made from several Icelandic hot springs. Some of the springs were unusual in that these filamentous organisms appeared to dominate the substrate almost to the exclusion of blue-green algae. Recent investigations of hot spring flexibacteria have demonstrated the presence of one or more types of bacteriochlorophyll pigments, hitherto unknown in gliding filamentous organisms (Pierson and Castenholz, submitted for publication). The purpose of the Icelandic collections was to verify the ubiquity of these organisms in hot springs (in Iceland as well as North America) by spectrophotometric pigment analyses of live and preserved samples and by the isolation of pure cultures from these various sources.

THERMOPHILIC HALOPHYTES

The unique saline hot springs at Reykjanes (ca. 52,000 μmhos conductivity; pH 5.5) were sampled on June 30 to provide inoculum for enrichment cultures for photosynthetic microorganisms that have adapted both to high temperature and high salinity. Although there are indications that such organisms are not present in these springs in Iceland, definitive culture results are not known as this report goes to press.

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8.3. BIOLOGICAL ASPECTS OF ACID THERMAL WATERS IN ICELAND

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The thermal springs, fumaroles, and soils in Iceland and throughout the world can be divided into two general classes which are distinguished by their characteristic flora and are defined by the pH of their environment - thermal areas with a pH greater than 5.0 and thermal areas with a pH less than 5.0. In this discussion I will refer to the former as alkaline areas and the latter as acid areas, with the full realization that this contradicts the chemical definition of alkalinity and acidity. In the alkaline thermal areas of Iceland, the predominant organisms are the blue-green algae and various species of bacteria. In the acid areas, however, the blue-green algae are absent and the predominant organisms are various species of eucaryotic algae. Bacteria as well as fungi may also be present but represent only a small percentage of the total biomass.

In a typical acid thermal gradient with a source temperature of 98°C and a pH of 2.0, at temperatures greater than 55°-57°C but less than 70°-80°C, the predominant organisms are bacteria with algae being completely absent. At temperatures between 35°-40°C and 55°-57°C, the predominant organism is the phycocyanin-containing, eucaryotic alga, *Cyanidium caldarium*. At temperatures below 35°-40°C, various species of diatoms, *Chlamydomonas* species (*Chlamydomonas acidophila*), *Euglena mutabilis*, and *Zygogonium* species may be present. In Iceland, however, the acid streams are uncommon and, indeed, only one small partial thermal gradient was observed at Namascard. In that gradient *Cyanidium caldarium*, *Chlamydomonas* species, and *Euglena mutabilis* were present. In the acid areas visited at Krisuvik, Namascard, and Geysir, mats of *Zygogonium* were not observed.

The predominant habitat for *Cyanidium caldarium* in Iceland is not in thermal streams but rather in the acid soils which border mud pots, pools, and fumaroles. Here the acid probably arises by the oxidation of H_2S to sulfur and then to sulfate. In Iceland, the pH of most of these areas was greater than 2.0.

Previous studies by T. D. Brock and myself in acid thermal areas of Yellowstone National Park, California and Nevada, and studies by T. D. and M. Louise Brock of acid thermal areas in Italy, New Zealand, and Japan have established that *Cyanidium caldarium* is present in all these areas, that the upper temperature limit is 55°-57°C, and that *Cyanidium caldarium* is restricted to habitats with pH less than 5.0. These field observations have been substantiated by field studies on natural populations and by studies of axenic cultures of the organism. Its presence in Iceland then is not unusual, although it was reported only recently by Castenholz.

Most earlier studies, however, concentrated solely on the organisms in the alkaline thermal springs. The presence of *Cyanidium caldarium* in all the acid areas visited would suggest that it is not a recent invasion.

The restriction of *Cyanidium caldarium* to thermal areas with a pH of less than 5.0 is of biogeographic interest since each acid area represents an island that is separated from other areas by relatively short distances, as from Krisuvik to Geysir, or by extremely long distances, as from Iceland to Italy. Such organisms, in order to have arrived at these areas, must have had some means of dispersal. Also, once established, these organisms may become genetically distinct. The means of dispersal of *Cyanidium caldarium* and the degree to which various disjunct or island populations are related is currently being investigated.

Although this report has emphasized the biological aspects of acid thermal waters, it should be noted that these organisms are affected by the chemical and physical properties of their environment. It is therefore important for the biologist to have an understanding of the geology and the chemistry of the environment. In turn, organisms also affect the physical and chemical factors, so it is equally important that the geologist have an understanding of the biology. For this reason, field trips such as this are important, for they provide the opportunity for scientists of diverse fields of interest to exchange ideas.

8.4. SOME PRELIMINARY OBSERVATIONS ON THE INSECTS OF ICELAND AND SURTSEY

by Dorothy Feir

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Iceland presents an excellent opportunity to study a number of unusual environments within a relatively small area. Within two weeks we were able to survey hot springs, glaciers and glacier moraines, fresh water and marine environments, large areas of bare rock or with very little vegetation, and some areas covered with vegetation. Although there was not time in any one area to do any real research, there was time to observe the type of geology and something about the associated biota. The emphasis of the trip was predominantly on the land forms, their formation, and their composition. There were numerous discussions on the evolution of the land forms and the possible relationships to the evolution of life. These were very worthwhile discussions and opened new paths for my own thoughts on evolution.

As an insect physiologist, I was struck by the paucity of insects in all areas except Lake Myvatn, where *Chironomidae* (lake midges) were present in tremendous numbers. Lake midges frequently occur in large numbers, for example, Lake Oshkosh, Wisconsin, and are a nuisance to people in the area. However, they do not bite and the larvae are important sources of food for fish. For these reasons chemical control of these insects is seldom attempted. *Chironomidae* were observed in almost every place we stopped although there were no other large populations seen. The insects of Iceland have been catalogued by Carl Lindroth. I only saw a small portion of the insects listed there, but this is not surprising considering that it takes many hours to collect any but the most common insects in an area and we did not spend much time in areas with much vegetation. The following insects were collected in the field: five species of *Diptera*, two immature and one adult *Lepidoptera* species, and two species of *Coleoptera*. As would be expected in cold climates, there are relatively few species and relatively large numbers of the species present; this is in contrast to the tropics in which there are a large number of species but relatively few of each species. In the least favorable environments, that is, mostly rock, sand, and little vegetation, spiders were more conspicuous than insects; at least six species of spiders were observed.

Two of the procedures that I intended to do involved the collection of blood from living insects. Collection of blood necessitates the sacrifice of small insects; I therefore only tried to collect blood from insects which I had collected in the largest numbers and these were all various species of flies. Unfortunately, I was not able to obtain enough blood for my procedures which included total blood-cell counts, differential blood-cell counts, and collecting a small amount of blood on sterile filter paper for electrophoresis. Scientifically, it is undesirable to pool blood samples from insects from different localities, so I was limited in the numbers of insects available for these procedures. The only insects present in large numbers were the midges at Lake Myvatn and I could not obtain any blood from them. I am not certain of the reasons for their lack of bleeding.

After a few collecting stops, I could see that I could not obtain enough insects from any one site to do cold-hardiness measurements. There simply was not enough time. In addition, there was no place I could obtain dry ice which was necessary for the equipment I brought to use in measuring cold hardiness. However, since this was primarily a learning institute and not a research expedition, I feel that these unsuccessful procedures were minor compared to the insights I obtained concerning particularly the relationships between the fields of geochemistry and biology. Before this trip I was vaguely aware of the importance of minerals in the soil for plant growth and subsequent insect growth; however, this trip and the association with geologists and geochemists emphasized the importance of this relationship and the need for studies on the interactions between the rocks, soil, and plant and animal life in areas that have been recently formed (e.g., by volcanic action) or have been relatively untouched by man such as are found in Iceland. There are many areas in the United States that are somewhat similar to areas in Iceland (glaciers, hot springs, bare rock, etc.) and these would be excellent areas for studies on the minimum needs of plants and insects, on the broad boundaries of capabilities of adaptation of organisms, and to some extent on the evolution of species.

The most striking environmental factor in Iceland, however, was the continuous light and I think that the effects of this on plants and animals deserves further attention. I do not think the light conditions in Iceland in the summer can be adequately duplicated in the laboratory without tremendous expense; this is therefore a case where *in situ* studies are necessary. A number of insects in the United States depend on a minimum period of darkness to enter diapause and, evidently, to become cold hardy in order to survive the winter. How are Icelandic insects signalled to prepare for winter? When and how do Icelandic insects become cold hardy?

The visit to Surtsey was an exciting and scientifically stimulating experience. To see a really new land fills the mind and imagination with questions on the origin of life, the colonization of land with plants and animals, and the subsequent speciation of these organisms. Surtsey presents an unequalled opportunity to study these questions. Long-term studies are required to derive the most information on the appearance and disappearance of various plants and animals, the simple accidental presence of animals, the ability of animals to go through their life cycles under the conditions on Surtsey, and the related recordings of temperature, wind, and precipitation. Constant surveillance of the beach areas seems important for the appearance of dead animals and parasites. The most fundamental types of relationships between soil development and associated biota could be studied in this situation.

The lasting impressions from this institute will be included in my expanding interest in the stresses the environment places on living organisms and the mechanisms by which organisms meet these stresses. I was particularly impressed by the work of the geochemists and the importance and relationship of this work to many aspects of biology. This was an aspect of interdisciplinary studies which was quite new to me.

8.5. MICROBIOLOGICAL STUDIES OF SURTSEY - 1970

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Ash samples were collected from various locations on Surtsey and processed by conventional bacteriological techniques. These determinations were made to screen the samples for subsequent detailed analysis by photomicrography using colored infrared film, and to estimate the changes in the microbial population since Merek and Young's investigation in 1967 (ref. 1).

MATERIALS AND METHODS

The bacteriological media used in the present study consisted of ZoBell's 2216 agar for marine organisms (ZoBell, 1941) and a non-marine medium containing Bacto Peptone (0.2%), Bacto Yeast Extract (0.1%), glucose (0.1%), and Bacto Agar (1.5%) dissolved in tenfold diluted sea water to provide the necessary salts.

Ash and moraine samples were prepared by aseptically weighing approximately 0.3 gram of material into screw-cap tubes containing 5 ml of sterile tenfold diluted sea water and vigorously shaking the mixture to disperse the bacteria. The suspension was settled for 2 minutes after which duplicate plates of each medium were inoculated with 0.1 ml of the suspended material. All petri dishes were incubated at 30°C for 48 hours and then counted for bacterial outgrowth.

RESULTS AND DISCUSSION

The results of this study are presented in table 1; the accompanying map of Surtsey indicates the locations where some of the samples were collected.

Disregarding those samples collected in 1967 which had temperatures over 100°C (samples 1, 2, and 3) and the freshly fallen ash from Syrtlingur (sample 6a and 6b), Merek and Young estimated the microflora to vary between 300 and 1500 counts/gm of ash for surface samples collected at the lagoon and on a slope on the northeast side of the island (ref. 1). Since samples were not collected at any depth, no direct comparison can be made to the findings presented here other than that the microflora several inches below the surface in 1970 is several orders of magnitude greater than it was in selected surface samples in 1967 (ref. 1). The 1967 data revealed the presence of a large number of fungi in contrast to current findings of a total of 20 fungi for all samples tested (ref. 1).

The recent survey indicated the dry surface ash samples tended to be devoid of microorganisms (samples 49, 56, and 62) since a total of only one bacterial colony developed on the four plates made of each sample.

Wet or moist surface samples around fumaroles, at the base of lava fragments, near the ocean, or near plants (samples 45, 46, 48, 55, and 65) had high bacterial contents with the non-marine medium generally supporting greater numbers of microorganisms than the 2216 marine agar (samples 48 and 55).

Samples collected at greater depths in the tephra (between 1 and 6 inches) showed increased bacterial numbers relative to the corresponding surface counts (samples 50, 57, 58, 63, and 64); this is probably a result of increased moisture content at these depths. Again, the non-marine agar supported greater bacterial outgrowth than the 2216 medium on those samples collected away from the ocean (samples 57 and 58). Samples collected near the ocean contained a high bacterial population when plated on either of the two media employed (samples 63, 64, and 65).

Several actinomycetes were detected in one of the samples (sample 46).

The two media used in this study differed principally in their salt content, with one medium being optimal for marine bacteria (ZoBell's 2216) and the other intended for non-marine or terrestrial forms. The division of bacteria into marine or non-marine groups on the basis of salinity has been the subject of considerable discussion. Bacteria have considerable variability in their salt tolerance with even true halophiles yielding cultures that grow at low salt concentrations (ref. 2). ZoBell (refs. 3 and 4) and Liston (ref. 5), however, found that sea-water media gave higher bacterial counts than fresh-water media, and on the basis of this, ZoBell maintained that there existed a truly distinct marine microflora. Although many marine bacteria perform functions similar to terrestrial microbes, such as sulfate reduction, the characteristic that clearly distinguishes the marine organism is its ability to survive and grow in sea water (ref. 6).

If one accepts as a definition that marine microbes are sea-water-requiring, then the use of the differential plating technique employed should enable one to speculate on the possible origin of segments of the microflora on Surtsey.

If a sample contained predominantly marine bacteria, then the count on ZoBell's marine agar should be equal to or greater than the count on the non-marine medium, allowing for some variation in salt tolerance. Terrestrial or airborne forms should yield greater counts on the non-marine medium.

The data for samples collected at the shoreline of the island (samples 63, 64, and 65) and from the vicinity of the plastic tub filled with algae suggest the microflora in these locations is of marine origin as one might expect. The shore samples were flooded with sea water, and the plastic tub apparently serves as a nesting area for sea birds. The freshly exposed glacial moraine (sample 39), however, yielded bacterial counts that differ by more than an order of magnitude, suggesting the microflora to be of a non-marine origin.

Based on their differential growth on the two test media, samples obtained at higher elevations or greater distances from the ocean (samples 50, 55, 57, and 58) contain a microflora that appears to be non-marine. These data suggest that terrestrial organisms may be carried to Surtsey by winds and colonize the island at higher elevations, while the ocean may be the principal source of organisms and nutrients at lower elevations and near the shore.

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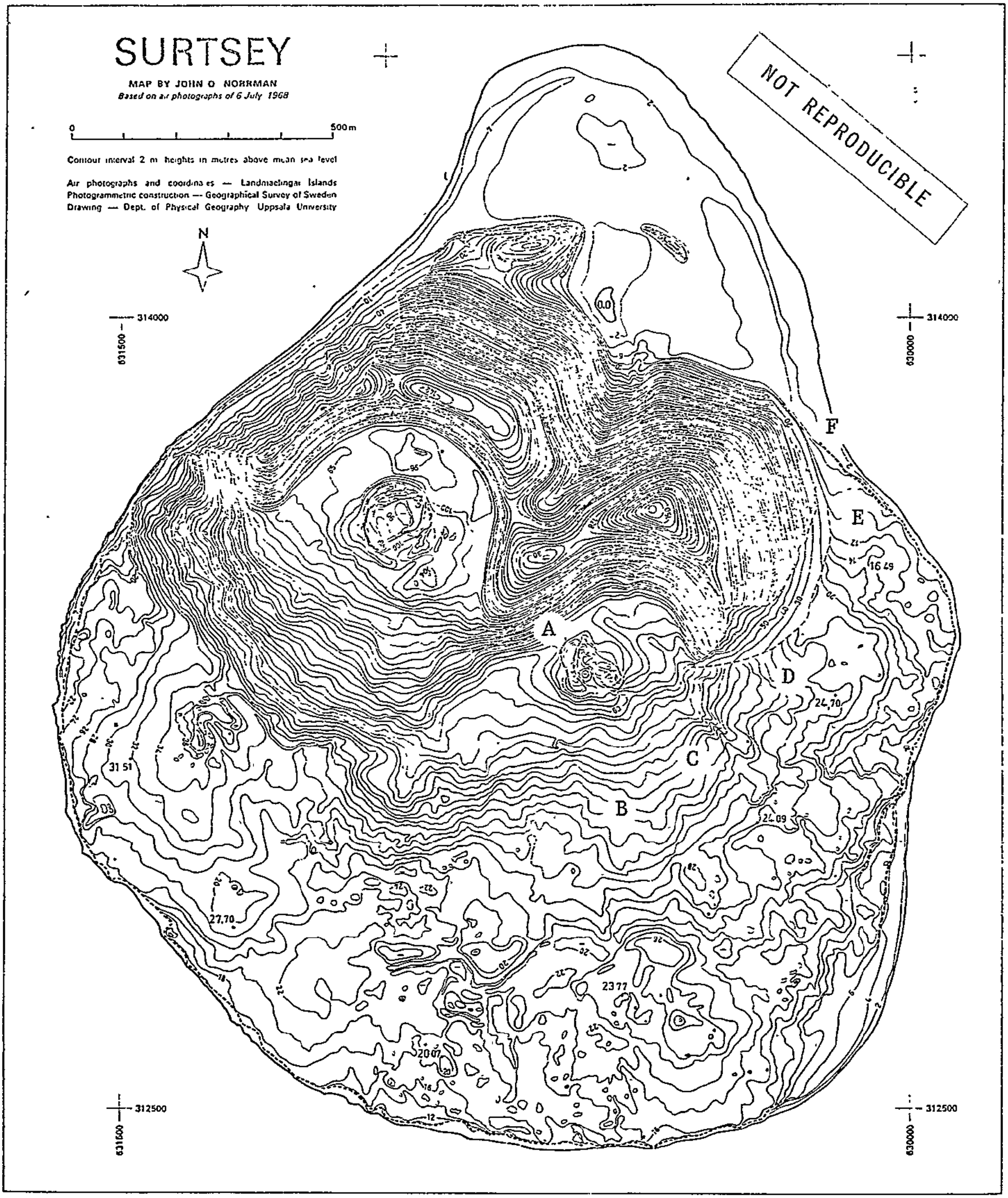
Table 1.- Results of Preliminary Screening of Surtsey Samples

	Bacterial count, number of organisms per gram of ash		
Sample No.	PYG agar	ZoBell's 2216 agar	Sample location and description
39	1.1×10^4	7×10^2	Fresh samples of glacial moraine from 1970 glacial retreat of Flaajokull
45	1.1×10^5	1.9×10^5	Damp ash in lava flow area ~8 feet from algal tub
46	$>2.5 \times 10^5$	$>2.5 \times 10^5$Δ	Wet ash from mouth of fumarole where algae were observed
48	$>1.5 \times 10^5$	4.9×10^4	Ash near moss bed on southeast side of island
49	$<1.5 \times 10^2$	$<1.5 \times 10^2$δ	Dry ash on south side ~200 feet from moss bed; surface sample
50	3.1×10^4	1.9×10^2*	Sample from same area as sample 49, but 5 inches below surface
55	$>3.3 \times 10^5$	1.3×10^4	Wet ash under rock on top of Surtur II
56	$<2.5 \times 10^2$*	$<2.5 \times 10^2$δ	Samples collected at base of Surtur II; surface sample
57	3.4×10^3	3.4×10^2	Collected from same area as sample 56, 1 inch below surface
58	3.7×10^4	$<1.2 \times 10^2$δ	Collected from same area as sample 56, 4 inches below surface
59	$>1.6 \times 10^5$	$>1.6 \times 10^5$	Ash from inside mouth of small fumarole
62	$<2.5 \times 10^2$	$<2.5 \times 10^2$δ	Ash near ocean (about 60 feet away from surf); surface sample
63	$>1.0 \times 10^5$	$>1.0 \times 10^5$	Collected from same area, 1-1/2 inches below surface
64	$>1.2 \times 10^5$	$>1.2 \times 10^5$	Collected from same area, 6 inches below surface
65	$>1.6 \times 10^5$	$>1.6 \times 10^5$*	From beach ash collected at shoreline (on beach ~1/2 mile from hut)

*Fungi present.
ΔActinomycetes present.
δNo organisms detected.



Station	Sample Number
A	55
B	56, 57, and 58
C	49 and 50
D	59
E	62, 63 and 64
F	65

8.6. INFLUENCE OF DEGASSING FROM LAVA ON THE PRIMARY COLONIZATION BY ORGANISMS: A HYPOTHESIS

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The factors influencing the initial settlement of terrestrial and marine organisms on newly formed volcanic surfaces are still in discussion. According to Jonsson (ref. 1), the first benthic colonizers are diatoms and filamentous green algae. Following Fridriksson (ref. 2) and our own observations, terrestrial lava is primarily colonized by mosses and a very few phanerogamic plants. Considering that the primary attachment of diaspores is influenced by physical and chemical factors as well (refs. 3 and 4), it should be taken into consideration that the outgassing of fresh lava could be responsible for the long-term lack of inhabitants and the following specific sequence of colonization.

During this summer's expedition, rock samples of various ages were collected and the starting phases of various organisms were studied in the laboratory immediately after returning from Iceland.

The material was collected in plastic bags and fresh unspoiled surfaces were tested in two different ways:

(1) By bringing the substrate in direct contact with the rock surface and then adding various types of plant diaspores, and

(2) By introducing pieces of lava of various ages into a closed system of covered petri dishes. The substrate with the diaspores was thus exposed to the exhalation of the rocks for a certain period of time.

The results of the first type of experiments which demonstrated the degassing influence as well as the leaching out from the lava specimen into the germination substrate are given in table 1.

The results of the experiments which are restricted to the influence of the outgassing of lava on the organisms are given in table 2.

These very preliminary experiments suggest an influence of the degassing processes from lava on the primary settlement of organisms and various aspects can be discussed.

First of all, the age of lava seems to be decisive in determining the possibility of settlement. As shown by geochemistry, the process of intensive degassing is restricted to a relatively short time after the lava appears on the surface and cools down; about 80-90% of its volatile constituents are liberated (refs. 5-7). Degassing of the remaining 10-20% goes very slowly, for months or maybe years (refs. 8 and 9). During the

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latter period, changes in the gaseous composition during the cooling and solidification of the lava are remarkable (refs. 10-12).

Both these features of the degassing process (changing in concentration and in chemical composition with time) can influence not only the degree and the rate of colonization, but may also be responsible for the specific sequence of various organisms in the colonization process (succession); thus organisms less sensitive to the actual chemical compounds with a distinct concentration will be the pioneers. The least resistant ones will follow at a later stage. So, the initially surprising fact that lichens are not yet found on the Surtsey lavas may be explained by the well-known high sensitivity of lichens to air pollution (ref. 13), a fact which has made these organisms a pollution indicator in urban areas.

The influence of degassing on the sensitive starting phase of organismic life may also be important for further exobiological approaches; apparently, the microenvironment of the lava substrate has very special properties that should be taken into consideration for various steps in prebiological evolution.

The surface of young lava seems to be unsuitable for attachment and colonization because it is "anti-biotic" in a certain sense, on account of the outgassing process. The aquatic environment hence intensifies the leaching-out processes and so enables earlier settlement; this too was observed at Surtsey.

These experiments show once more that the term "extreme environment" should be used in a more critical way. Extreme environmental conditions for organisms, in general, do not exist, but only for each distinct species, or even better, for each ecotype. Each of them has its own specific cardinal points of growth, mostly interconnected in the form of an optimum curve, which starts and ends with minimum and maximum extreme conditions, respectively. Furthermore, one should distinguish between the processes which are exposed to the various environmental factors. Most physiological and biochemical processes, like germination, attachment, reproduction, enzyme activities, etc., have their very specific limits with regard to the external conditions. Additionally, extreme environment acts differently on active life processes and on resting stages with their kryptobiotic activities. The latter is much less sensitive than the former to extreme factors. Decisive for both is the microenvironment, as demonstrated by the above-mentioned preliminary experiments on the interaction between degassing lava samples and germinating organisms.

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Table 1.- Direct Contact Between Organisms and Lava Surface

Sample: type of lava	Age, days	Seed[a] germination, %	Pollen[b] germination, %	Fungal spore[c] germination, %		Moss[d] spore germination, %	Algal[e] attachment, O.D. 430 nm
				Botrytis	*Sclerotinia*		
Young hot lava from Hekla, collected 6.18.70	1	41	30	7	93[+]	36	0.459
Porous lava from 6.16.70 Hekla eruption	14	66	42	76[++]	96	45	.534
Solid lava from May 1970 eruption of Hekla	60	58	65	72	99	55	.400
Surtur II eruption, 1968, from Surtsey	±2 yrs	92	20[+]	54[++]	95	61	.333
Control	-	99	85	94	96	60	.518

[+] Long germination tubes.

[++] Variation between the individual tests about 20%.

[a] Germination test with seeds from *Lepidium sativum;* 100 seeds each, on moist filter paper, 20°C.

[b] Germination test with fresh pollen from *Petunia hybrida,* clonal material, after 6 hours in 10% sucrose and 0.01% boric acid, 22°C. All tests carried out twice.

[c] Germination test with suspensions of fungal spores of *Botrytis cinera* and *Sclerotinia fruticola,* after 95 hours, room temperature; all tests carried out five times by Dr. van den Ende (Nijmegen).

[d] Germination of *Marchantia polymorpha* (livermoss) spores in distilled water after 96 hours, 23°-24°C, in light; carried out by Dr. van den Ende.

[e] Attachment test with *Chlorococcus* species zoospores; samples were placed in cell suspension for 96 hours, extracted with 1 N methanolic KOH; O.D. of the chlorophyll extract was determined colorimetrically at 430 nm. Control glass slides. Carried out by Drs.H. Kroes.

Table 2.– Gas Phase Exhalation

Lava: origin of sample	Age, days	Seed[a] germination, %	Pollen[b] germination, %	Fungal spore[c] germination, %		Moss spore[d] germination, %
				Botrytis	*Sclerotinia*	
Young hot lava from Hekla, collected 6.18.70	1	59	21	51	98	26
Porous lava from 6.16.70 Hekla eruption	14	68	15	76	96	33
Solid lava from May 1970 eruption of Hekla	60	76	20	87	98	35
Surtur II eruption, 1968, from Surtsey	±2 yrs	57	27	91	96	58
Control	–	100	78	95	99	60

[a-d] See explanation in table 1.

8.7. PLANT SUCCESSION AT SKAFTAFELLSJÖKULL

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On the southern coast of Iceland, an ideal situation was found to study the development of an ecosystem from an originally unvegetated glacial ice front to a well-developed birch community. This report results from a brief inspection of the outwash plain of Skaftafellsjökull and is intended to be only an outline of future problems for study.

STUDY AREA

Skaftafellsjökull is an outlet glacier originating from Vatnjökull. Both Skaftafellsjökull and Svinafellsjökull have tended to show negative water budgets in the last several decades. The rate of retreat for Skaftafellsjökull has been recorded, but these data were not available at the time this report was submitted. Melt water originating from Skaftafellsjökull flows as a braided glacial stream southward across Skeidarsandur to the Atlantic. The area studied extends from the ice front of Skaftafellsjökull southwest 500 m. This transect was divided into five stations at 0, 20, 120, 250, and 500 m.

PHYSIOGRAPHY

The ice front was characterized by unsorted, highly mobile till. This till became pitted in the area included between 20 to 250 m southwest from the ice front. These pits averaged about 3-4 m in depth. The older alluvium beyond 250 m became progressively less pitted and was elevated 3 to 4 m above the ice-front till.

MICROCLIMATE

Air temperature changed with increasing distance from the ice front. At 0 m the air temperature was 12°C and at 500 m it was 24°C.

TERRESTRIAL FLORA

Succession on the alluvium may be divided into roughly three stages: pioneer, meadow, and early shrub.

Pioneer Stage

0 m:

The ice front was characterized by the absence of vegetation. The wet, highly mobile till provided a poor substrate for colonization. Approximately 20 m from the ice front, pioneer species were observed, although their occurrence was sparse. *Arenaria* species, *Cerastium alpinum*, and *Racomitrium* species were the pioneer plants colonizing bare gravel. Vegetational cover was erratic and amounted to less than 1% of the area.

120 m:

Vegetation covered approximately 5-10% of the area. Most of the plants were concentrated on the sides of the pits in the glacial alluvium. These pits provided a microenvironment that favored colonization. The pioneer species *Arenaria* species, *C. Alpinum*, and *Recomitrium* species were more numerous. *Sedum acre* and *Poa glauca* also occurred in this pitted area.

Meadow Stage

250 m:

The average cover-abundance value rose to approximately 75% at this station. The alluvium was level and the air temperature 19°C. Extensive mats of the *Racomitrium* species intermixed with colonies of the fruticose lichen *Stereocaulon* species covered the fine gravel. *P. glauca* and *Alchemilla alpina* occurred in these mats. Crustose lichens colonized larger rocks.

Early Shrub Stage

500 m:

A mature community composed of *Betula* and *Empetrum nigrum* growing in dense mats of *Racomitrium* species covered 75-100% of the gravel. *A. alpina* and *P. glauca* occurred more frequently than at 250 m. *Betula* and *E. nigrum* appeared to have invaded the glacial outwash from established stands to the west.

Soil samples were collected at each station to determine the occurrence of soil algae. These samples are presently being cultured.

AQUATIC FLORA

Melt water from Skaftafellsjökull was highly turbid with the photic zone limited to only a few millimeters in flowing water. The carrying capacity of the melt water decreased in side pools allowing sufficient light penetration for photosynthesis. The green alga *Zygnema* species developed extensively in these clear pools, growing at a temperature of 5°-10°C and a pH of approximately 5-6. The paucity of areas with sufficient light for photosynthesis seemed to be the most important factor limiting the development of an aquatic flora.

8.8. BIOCHEMICAL DIFFERENTIATION OF *EQUISETUM* SPECIES FROM ICELANDIC AND NORTH AMERICAN LOCATIONS

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About 3.5 billion years ago, life arose - once or, at most, a few times. That all life forms had a common origin is implicit in the observations that all life as we know it possesses (1) a complex lipo-protein bimolecular leaflet-micellar, osmotically sensitive, selective membrane separating the outside from the inside of the cell; (2) an information storing system composed of nucleic acids and read as a "triplet code"; (3) efficient methods of catalysis carried out by large protein molecules, such as catalase, with a turnover of approximately 5×10^6 substrate molecules per second; and (4) self-reproducing mechanisms in which replication rather than duplication is the copying mode.

During this period, about 1.5 million species of organisms have arisen by what the neo-Darwinians describe as "mutation and natural selection." All mutations that occur and give rise to new, relatively stable populations occur at the molecular level, and all changes in the environment which act as selective pressures must *per se* be perceived by molecules within the cell. Hence, any change in the organism or species must first be reflected by changes occurring at the subcellular level. Enzymes, although secondary gene products (messenger RNA being considered a primary gene product), have distinct advantages for scientific study over the primary ones: (1) they are highly specific in their reactions; (2) because of their catalytic activity they can easily be detected in extremely low concentrations, about 10^{-11} M; and (3) are indicative of evolutionary, developmental, and environmental parameters of the organism.

Scientists have attributed the distribution of some species to continental land-mass movements and the disappearance of land bridges; those species which are ubiquitous in the northern hemisphere of North America, Asia, and Europe evolved relatively early in evolutionary history, whereas those that are unique to one continent appear to be late branches from the evolutionary tree. For example, grasses are found throughout the world, but corn, which is one species in the grass family, evolved "late" and was originally known only in North America. Primates are found on all continents, but the monkeys fall into two distinct classes - the Old World group found in Asia, Europe, and Africa, with a short, essentially nonfunctional tail (like man), and the New World monkeys with their long prehensile tails. Australia separated (or was separated) from the land mass of Asia before the placental mammals became established; hence there virtually every environmental niche is filled with marsupials, whereas elsewhere they have virtually ceased to exist.

Table 1.- Peroxidase and Catalase Distribution in *Equisetum* Species

Sample	Plant height, cm	Growth habit*	Peroxidase		Catalase
			Soluble	Insoluble	
Hofn-roadway	20	E	-	+(node)	±
Hofn-hot springs area	5	R	-	±(node)	+2
Myvatn-lake shore	5	E	?	±(node)	+1
Myvatn-alpine meadow	6	E	+1	+3	+3
Laugarvatn	12-15	R	-	+3(leaves & nodes)	+1
Valhöl	12-15	B	-	±	+2
Westman Islands-Heimsey	12-15	R	+3	+5	+3
Geysir, near run-off water	7-8	E	-	+(nodes)	+2
Hekla, ash area	5	E	-	+2 (everything)	+2
British Columbia, near Vancouver	20	E	-	-	±
Alberta, Moraine Lake	1-2	E	-	±	+2
Alberta, Banff	12-15	E	-	+(diffuse)	+

*E = erect, R = reclining, B = branched with erect and reclining portions.

By comparing the number of mutations in a given protein in several species, it is possible to establish the time when evolutionary divergence must have occurred; these data can be further substantiated from the fossil record. However, all these studies make one assumption which has never been verified; namely, that the rate of mutation is the same for all organisms, under almost all environmental conditions, and that it has remained constant throughout biological history.

Changes in the genetic constitution of a population as compared to the genetics of an organism may also occur when selective factors such as edaphic features and the presence or absence of other organisms are altered. Furthermore, adaptations to an insular environment, such as Iceland and Hawaii, present significantly altered patterns when compared to large land masses. Using the Hardy-Weinberg equation for gene frequencies in a population, let us assume only one gene with two alleles (i.e., altered forms of one gene such as blue eyes vs. brown, or lobed ears vs. unlobed) with a continental frequency of $\text{Gene}_A = 0.9$ and $\text{Gene}_a = 0.1$. This frequency will remain constant as long as no adaptively superior organism evolves and the population remains large and randomly interbreeding. However, if two members of this population were to establish themselves on an island, the probability that both alleles or gene forms would be retained is less than 35%, and the probability that the same gene frequencies would exist on the island is less than 3%. Hence, island populations, regardless of the time of their establishment, are generally distinct from the population that spawned them. Given time, a unique evolutionary pathway can develop, such as in the Hawaiian Islands, where each valley has a separate and distinct species of snail which has evolved in the last 20-25 million years. Iceland, conversely, has developed relatively few endemic species in about the same period of time. Possible reasons are: (1) the mutation rate in the subarctic is slower than in the subtropics; (2) new organisms have arisen but because of a relatively harsher environment have not found the niches in which to survive; (3) that extensive changes have occurred at the subcellular level affecting rates of catalysis, biosynthetic pathways, etc., but may not be reflected at the gross morphological level; and (4) that Iceland is so continually and heavily contaminated by "continental" organisms that endemics have failed to evolve.

By studying the heme enzymes, especially the isozymic variants revealed by electrophoretic techniques, it might be possible to detect intra-Icelandic variations and to compare these to similar or identical species found elsewhere. Initially, we have looked at the isoperoxidases and catalases in *Equisetum* species (horsetails). Preliminary results are given in table 1, and appear to indicate that although the heme enzymes are morphologically relatively similar, the variation in their amount and location is significant.

8.9. A ROLE FOR LICHENS AS ANTAGONISTS TOWARD SEED PLANTS

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Traditionally, lichens are cast in the role of hardy pioneers, invading bare rock or other new or clean surfaces and preparing the way for ferns and seed plants. The lichens break down rock surfaces to which they are intimately appressed by combined mechanical and chemical processes, and upon dying, contribute their own substance to the humic pool.

The validity of this role for lichens is incontestable, but its universality is open to doubt. Experiments of past years have shown that some geographic races of lichens, *Cladonia cristatella*, for example, have powerful inhibitors of seed germination, whereas others of the same species have none. This observation also applies to the *Umbilicaria* resident on Mount Washington, New Hampshire, U.S.A. The same or a similar form collected in the lava lake area near Myvatn, Iceland, has also shown growth inhibitor activity in preliminary experiments using barley seeds. These results are shown in the following data:

Incubation time, hr	Index	Control	+290 mg Lichen
15	Percent germination	80	28
20	Percent germination	100	60
28	Root elongation (mm/hr)	.66	.58
	Root numbers/seedling	3.9	3.2
40	Root elongation (mm/hr)	.86	.63
	Number of roots/seedling	5.3	4.2
40	Percent of green shoots	72	64

The regional and world importance of this antibiological feature of some lichens remains to be established by further combined field and laboratory studies.

8.10. DWARFING, LIGNIFICATION, AND LAND PLANT EVOLUTION

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Both the availability of molecular oxygen and the stress of gravity have been hypothesized as factors governing ascent of the massive, upright land plant. The biological medium of the plant-environment interaction is the formation of a group of compounds, the lignins, and their deposition in the loose, highly compressible cellulosic form of the young cell wall. This modification changes the bulk modulus of the wall, rendering it crush-resistant. Laboratory culture under modified centrifugal regimes has supported the gravitomechanical hypothesis, but equally, it is of importance to note whether or not plant-size varieties in a natural population are reflective of varied quantities of lignin. Analysis of dwarf and giant variants of familiar alpine plants found in rigorous environments has shown that lignin content is, in fact, closely correlated with height.

When normal-, under-, and oversized specimens of mosses, horsetails, and herbaceous to semiwoody flowering plants are compared with respect to the relationship between lignin content and plant height, the following approximation results:

$$y = ke^{x^2}, \quad \text{where } y = \text{lignin content and } x = \text{stem height}$$

Iceland, with its abundance of alpine and subarctic environments, offers a rich supply of dwarf forms of familiar regular-sized plants. Returned specimens, including members of the *Cruciferae* (mustards), *Ericaceae* (blueberry), *Ranunculaceae* (buttercups), and *Caryophyllaceae* (pinks), are being analyzed for size and lignin content, together with their closest relatives of larger size.

8.11. SEARCH FOR A PRE-CAMBRIAN RELICT MICROORGANISM, *KAKABEKIA BARGHOORNIANA*

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Kakabekia barghoorniana is a living microorganism, morphologically almost identical with a form first described as a fossil from the Gunflint chert of S. Ontario and dated at ca. 2×10^9 years. Both forms are umbrella-like, average 10-20 micra in diameter, and are as yet unidentified with any other group, living or fossil (fig. 1). The living species was found in W. Wales in topsoil, was cultured in saturated ammonia-water with nutrients (glucose), and does not require oxygen.

Barghoorn and Tyler described the environment where the fossil was found as "restricted and selected," that is, severe. This description fits the living form in culture well.

Recent finds of living *Kakabekia* on the flanks of the Mendenhall glacier and elsewhere in Alaska lead to the suggested localization at or above the 50th parallel (fig. 2). Iceland is one of the places suited to the projected biogeography, whatever the localizing factor may be. We have sampled varied locations - glacial, thermal, and others - in our search for this relict form; it is now clearly demonstrated to be present in Iceland (fig. 3). Even our as yet superficial study shows one abundant source on the moss- and turf-covered talus slope below the palagonite-covered sea-floor outcrops, first visited near Reykjavik, northwest of Blafjöll; a secondary source is near Lake Myvatn.

Other samples yet to be examined include Myvatn moraine, Flaajökull Glacier, and Westman Island soils. Surtsey, as well as the ash and lava fields around Hekla, will also be further studied, but as negative controls.

Iceland thus fills a major gap at northern latitudes, giving *Kakabekia* a longitudinal range of about 150° and a latitudinal range of about 18°.

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Table 1.- Preliminary Sample Data for *Kakabekia* in Iceland.

Sample: Date and location	Presence of *Kakabekia*		
	Evidence before culture	In ammonia culture	
		20 hrs.	72 hrs.
6-16 (1/3)* near Bláfjöll to Burfells Station	+	+	+
6-17 (1/3)* Krýsuvik	-	-	-
6-18 Loftleider Hotel Excavation	-	-	-
6-19 (1/3)* Mývatn - thermal area	-	-	-
6-19 (4/7)* Mývatn (Reykjahlid)	+	+	+
6-20 (1/4)* Mývatn (Reykjahlid) Icefield on terminal moraine	+	-	X
6-21 (1/4)* Lava lake area	-	+	X
6-23 (1/3)* Edge of Fláajökull glacier, NW of Hofn	-	+	X
6-23 (4)* Glacier lakeshore, Fláajökull	-	-	-
6-26 (1)* Moss turf near steam vent, Surtsey	-	-	-
6-30 (1)* Geysir, runoff (30°C)	-	-	-

*Field-notebook code referring to specific nature of sample and number of samples taken at or near specified site.

[X] Samples have not yet been investigated.

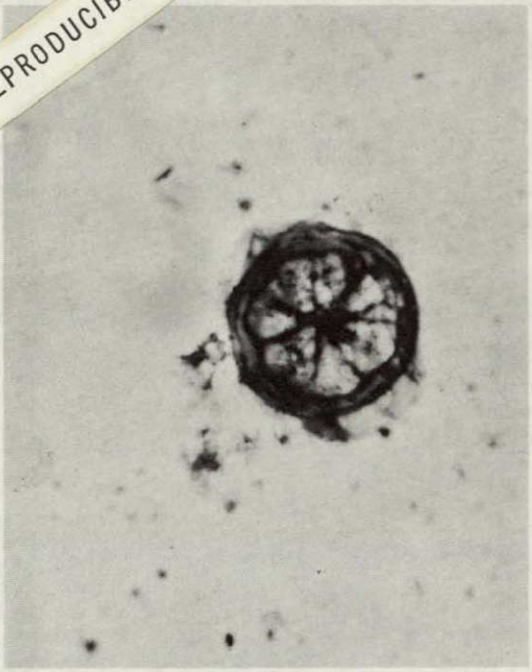

Figure 1. Stained specimen of *K. barghoorniana* cultured from Welsh soil in 1964. 950× magnification.

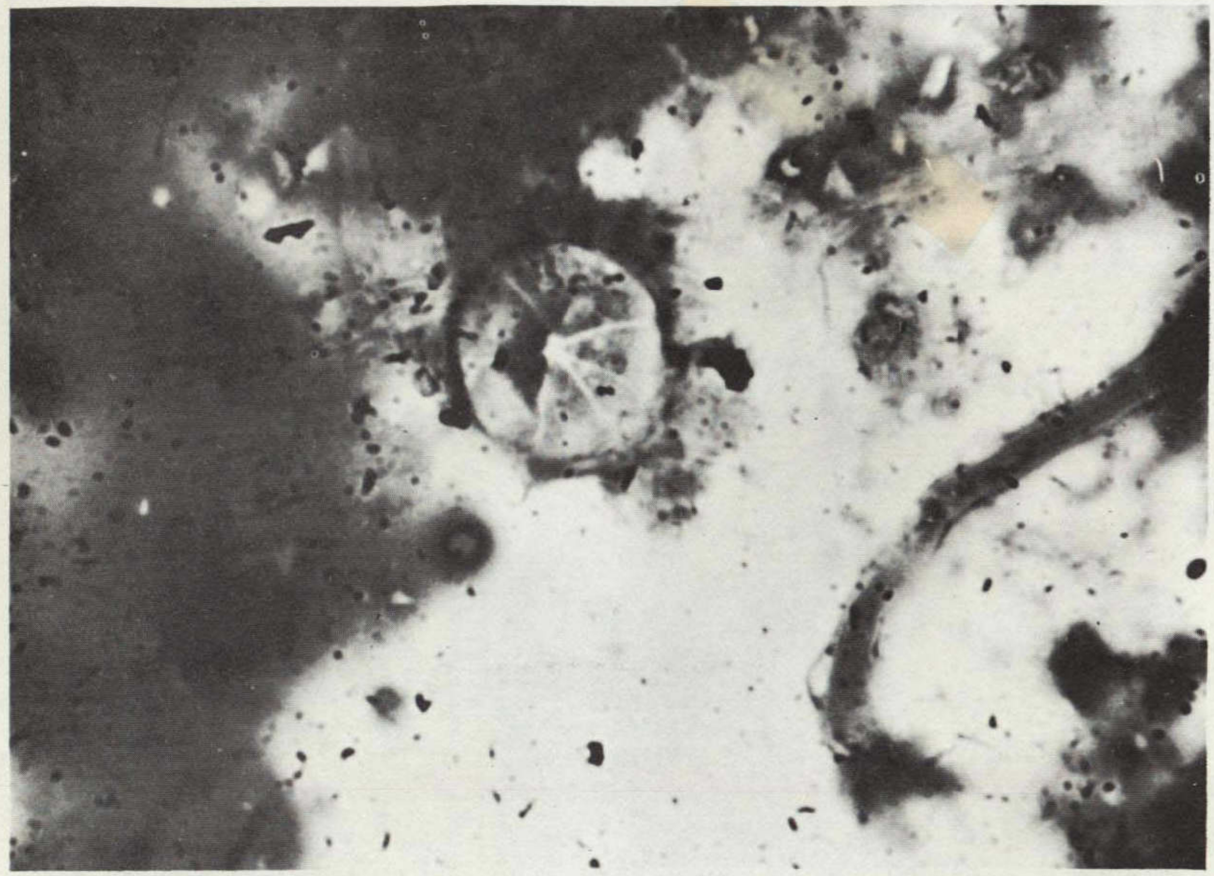

Figure 2. Stained specimen of *K. barghoorniana* cultured from Alaskan soil (lateral moraine, Mendenhall Glacier) in 1969. Photographed at about 1250× magnification.

NOT REPRODUCIBLE

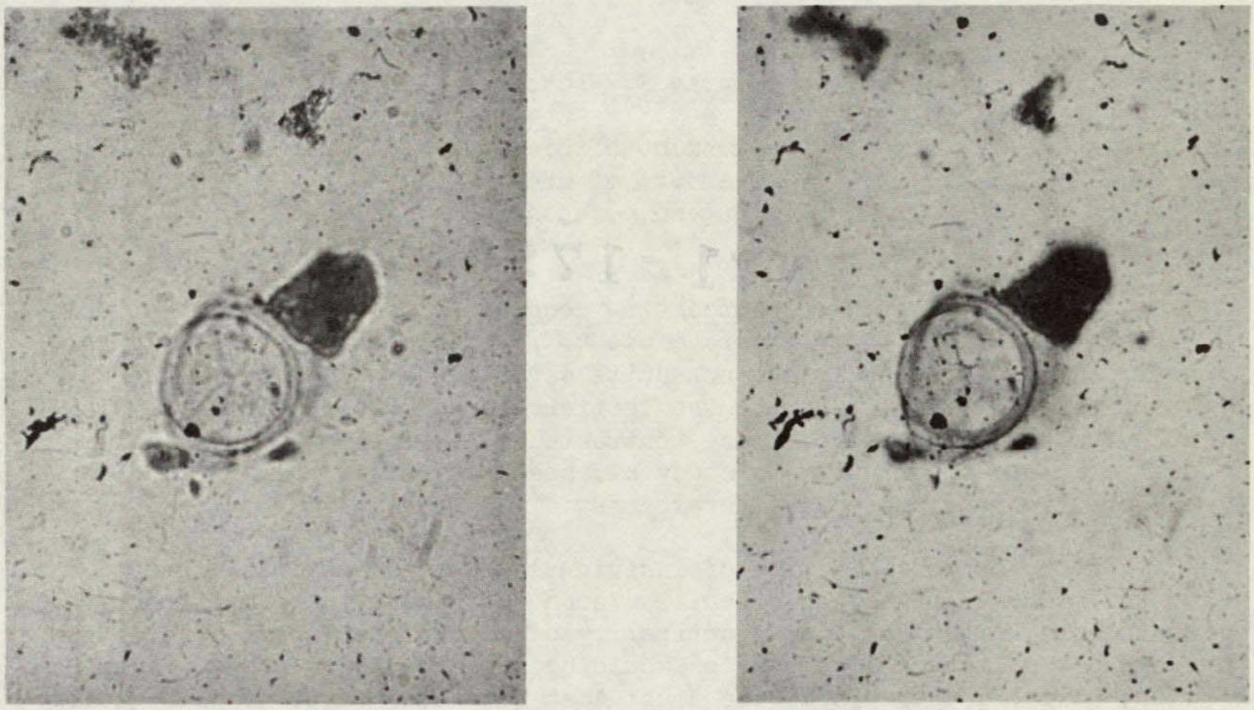

Figure 3. Specimen of *K. barghoorniana* from Blafjöll area of Iceland, from a 72-hour ammonia culture. 1250× magnification.

8.12. PRELIMINARY REPORT ON THE DISPERSAL OF THERMOPHILIC ALGAE TO SURTSEY

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Iceland is a land of contrasting conditions - from very recent volcanism to glaciers, from waters close to freezing temperatures to waters near boiling, from an island not quite seven years old to an island at least partially formed during the Tertiary; one could continue the list much further. Because of these contrasts, Iceland offers to the scientist a unique opportunity to study his specialty under various conditions of formation and subsequent development.

While the possibilities of individual study are obviously great, one of the major values of an expedition such as this is in pointing out the usefulness, potential, and practicality of interdisciplinary studies in Iceland. A list of such studies would be much too long to begin enumeration; however, there is little doubt that questions basic to both geology and biology could be answered and new ones attacked by these studies.

The work discussed below is of basic interest to microbial ecologists, yet the studies described are of greater value with the realization that the newly exposed potential habitats of Surtsey are indeed present.

The geographical distribution of an organism reflects its dispersal. However, dispersal outward from a source population is not sufficient by itself to explain a distribution pattern. The organism must also reach an environment in which it can become established. The more generalized the environmental requirements of an organism, the more difficult it becomes to gather information about its dispersal from a source area. For example, of the 15 vascular plant species represented in the debris washed up on the shores of Surtsey during the summer of 1968, only 3 can be traced to mainland Iceland since the remaining 12 also occur on the other islands of the Westman group (ref. 1). The presence of thermophilic algae on Surtsey would indicate probable dispersal from the mainland since there are no natural thermal habitats on any of the Westman group. Thus, thermophilic blue-green algae and bacteria can provide information concerning microbial dispersal from one area to another in general and more specifically from mainland Iceland to Surtsey.

Although many microorganisms are motile, this does not seem a reasonable means of large-scale dispersal. Rather, some form of passive transport seems likely. Various microorganisms have been isolated from atmospheric collections and were shown to be viable (e.g., ref. 2). Similarly, attachment to and transport on other organisms has been shown to be a potential mode of dispersal (e.g., ref. 3).

Both of these dispersal schemes require that the organism being transported be tolerant to some degree of drying and perhaps other environmental stresses. In addition, with regard to microorganisms of rather limited growth requirements, such as thermophiles, there is the problem of the probabilities of dispersal to a suitable habitat. For example, the probability of some bird picking up a microorganism from one thermal area, flying a considerable distance, and then alighting in another thermal area of appropriate temperature and water chemistry before permanent damage is done to the microorganism must be extremely small. Whether the probabilities are so small as to be nonexistent is not known; therefore, the mechanism remains a possibility.

A third passive mechanism that would appear to decrease the problems discussed above, but is usually overlooked, particularly with respect to thermophilic organisms, is that of water transport. Export of biological material from a thermal stream is known (ref. 4), but the fate of this material has never been studied. In the case of dispersal to Surtsey from the mainland by this mechanism, it is reasonable to envision exported material from a hot spring entering a connected fresh-water system, being transported to the coast, and then being carried to the new island under the power of wind-guided surface waters or marine currents. The inoculum could then be deposited at a thermal area by some means such as spray, which apparently reaches most points on the island (ref. 5). All steps of this mechanism would have been occurring continuously since the establishment of populations in thermal streams on Iceland, yet could not be expressed until the appearance of Surtsey.

The basic assumptions of this mechanism are that thermal organisms are present in a fresh-water system(s) which enters the Atlantic; marine currents do exist which could carry this material from the mainland in the north to Surtsey; and that the organisms can remain viable after exposure to the temperatures and salinities encountered during transport. The first of these assumptions could be tested by release of some artificially marked materials into appropriate thermal streams; however, prediction of success would be quite small as it would probably not be reasonable to release within several orders of magnitude the number of disseminules released each day into fresh-water systems by the hot springs on Iceland. Indirect evidence for the second assumption has already been presented and discussed by Fridriksson (refs. 1 and 6) and Jónsson (ref. 7).

The potentialities of the thermal organisms under consideration to withstand the unusual environmental conditions inherent to this proposal have not been examined. At present this writer is preparing to test a series of thermal algae, both present on and absent from Surtsey, under conditions likely to be encountered during transport by water. In addition, their capacity to withstand desiccation will be examined. Culture isolations from Surtsey and the mainland are now being made.

The actual mechanism bringing thermal microorganisms to Surtsey is quite obviously a matter for conjecture at the present time; however, it is interesting to note that Maguire (ref. 8) found extremely few organisms in rain and air samples compared to areas influenced by marine splash and spray.

In summary, the water-transport scheme for dispersal of thermophilic microorganisms to Surtsey from the mainland has three primary advantages over the others: (1) it provides a constant inoculum, (2) it is a more direct route for the inoculum with fewer chance events, and (3) the environmental conditions during water transport may be much less severe than during air transport.

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