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SATELLITE GEOLOGICAL AND GEOPHYSICAL REMOTE SENSING OF ICELAND

Richard S. Williams, Jr.
U.S. Geological Survey
Reston, Virginia 22090

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ICELAND: PRELIMINARY RESULTS OF GEOLOGIC, HYDROLOGIC, OCEANOGRAPHIC, AND AGRICULTURAL STUDIES WITH ERTS-1 IMAGERY

Richard S. Williams, Jr., U. S. Geological Survey, EROS Program Office, Reston, Virginia 22092;
Ágúst Böðvarsson, Icelandic Surveying Department;
Sturla Friðriksson, Agricultural Research Institute;
Guðmundur Pálmason, National Energy Authority;
Sigurjón Rist, National Energy Authority;
Hlynur Sigtryggsson, Icelandic Meteorological Service;
Kristján Sæmundsson, National Energy Authority;
Sigurður Thorarinsson, University of Iceland;
Ingvi Thorsteinsson, Agricultural Research Institute;
Reykjavík, Iceland

BIOGRAPHICAL SKETCH

Richard S. Williams, Jr., is a geologist with the EROS Program Office of the U. S. Geological Survey, where he is responsible for the technical coordination of all Department of Interior ERTS-1, Skylab, ERTS-B, and other satellite experiments. For the past decade he has specialized in geological remote sensing, primarily in thermographic and photogeologic studies with aircraft and satellite sensors of the thermal regime of active volcanic and geothermal areas, with particular reference to Iceland. Williams received his B.S. and M.S. from the University of Michigan and his Ph.D. from the Pennsylvania State University. His publications total 37. Williams is currently the principal investigator of one of the 327 ERTS-1 experiments, "Satellite Geological and Geophysical Remote Sensing of Iceland," a binational, multidisciplinary research effort in Iceland.

ABSTRACT

The wide variety of geological and geophysical phenomena which can be observed in Iceland, and particularly their very direct relation to the management of the country's natural resources, has provided great impetus to the use of ERTS-1 imagery to measure and map the dynamic natural phenomena in Iceland. Under a binational, multidisciplinary research program, MSS imagery is being used to study a large variety of geological and geophysical (geothermal, volcanic eruptive products, geologic structure, volcanic geomorphology, and marine geology), hydrologic (ephemeral snow and ice, glaciological features, and river flooding), oceanographic (sea ice), and agricultural (rangelands and forests) phenomena of Iceland. Some of the preliminary results from this research project are: (1) a large number of geological and volcanic features can be studied from ERTS imagery, particularly imagery acquired at low sun angle, which had not previously been recognized; (2) under optimum conditions the ERTS satellite can discern geothermal areas by their snowmelt pattern or warm spring discharge into frozen lakes; (3) various maps at scales of 1:1,000,000 and 1:500,000 can be updated (changes in coastline, glaciers, lakes, etc.) and made more accurate with ERTS imagery; (4) the correlation of water reserves with snowcover can improve the basis for

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planning electrical production in the management of water resources; snowcover mapping, particularly the persistence of snow in the highland areas during the summer months, has important ramifications to rangeland management; and (5) false-color composites (MSS) permitted the mapping of four types of vegetation: forested, grasslands, reclaimed, and cultivated areas, and the seasonal change of the vegetation, all of high value to rangeland management when complete and repetitive coverage of Iceland is achieved with an operational satellite.

INTRODUCTION

The launch of the first earth resources technology satellite (ERTS-1) last year (23 July 1972) provided environmental scientists with the first feasible means of measuring and mapping certain categories of dynamic environmental phenomena over much of the earth's surface. Of even greater importance, however, was the fact that the ERTS-1 system provided a completely new source of information on environmental phenomena which was heretofore unavailable (except of limited areas and at high cost) to resource managers. Although ERTS-1 is but the vanguard of more and better earth resources technology satellites to be orbited in the future by national and perhaps even supra-national organizations, ERTS-1 could not have become a quasi-operational system at a more opportune time from an ecological viewpoint, because it gives environmental scientists, for the first time, not only a global view of the dynamic environment of our planet but of mankind's impact on the surface.

Although the full ramifications of free access to such satellite data by scientists and resource managers will take years, if not decades, to be fully established. Some organizations and countries have already recognized the significance of such data to their own problems and are moving rapidly to exploit this new source of environmental information. One of these countries is Iceland, an island republic with a relatively small, but growing, population of 206,818 (1 Dec 1971) in an area of 103,000km^2 (about 2 persons per km^2). Iceland, because of its cool climate, low population density, and lack of natural resources, quickly recognized the potential value of ERTS-1 imagery to provide, cheaply and quickly, certain types of environmental data. Because the Icelanders depend on the surrounding seas for fish and the limited area of arable land for agricultural products, their economic health is strongly dictated by the natural environment. Understanding and recognizing changes in, and redirecting human and capital resources in response to, the often vagarious nature of the natural environment of Iceland has decidedly important economic and social implications.

From a list of ten separate experiments originally proposed in the multidisciplinary ERTS-1 experiment in Iceland, several of the experiments were expected to provide the type of environmental data necessary for resource management decisions. There turned out to be at least four principal areas where Iceland could benefit from such a satellite system, if available on a timely basis (within 30 days) and in a repetitive manner (every orbit over Iceland). The four principal areas (Five if a thermal sensor were included, because then the precise mapping of ocean currents around Iceland would be possible, of high value to the fishing industry) are: (1) improvement in the mapping of certain features (e.g., glaciers, coastline, etc.) to maps of scales of 1:250,000 or smaller; (2) preparation of thematic maps showing the distribution of snow over time and particularly the persistence of snow into the summer months (of value to rangeland management and prediction of runoff for present or planned hydroelectric power generation); (3) mapping of the distribution, concentration, and movement of sea ice (important to coastal shipping and fisheries operations and its climatic effects on the rangelands); and (4) monitoring of the seasonal changes in grasslands. The latter capability holds great promise in the optimum management of Iceland's rangelands.

This report, then, is a preliminary report on the early results of the analysis of ERTS-1 imagery of Iceland for each of the 10 experiments, with particular reference to the initial results from those experiments of greatest value to Iceland: improved mapping, mapping of the seasonal distribution of snowcover, mapping of sea ice, and mapping of seasonal variations in and extent of rangelands and forests. Important findings from an earlier paper (Williams, and others, 1973) will be briefly summarized where they are of special interest to the objectives of this Symposium on the Management and Utilization of Remote Sensing Data.

GEOTHERMAL

One of the objectives of the ERTS-1 experiment in Iceland is to determine the minimum size (and heat flow) of a geothermal area which can be delineated from analysis of MSS imagery of the 13 high-temperature geothermal areas in Iceland (Williams, 1972). It was anticipated that if delineation of several Icelandic geothermal areas by the snow-melt pattern method could be achieved, a more accurate estimate of heat flow from poorly known geothermal areas (within Iceland and for other areas in the world) could be made by comparison with snow-melt patterns of well-known geothermal areas.

On 9 March 1973 the first snow-covered, nearly cloud-free ERTS-1, MSS image of Iceland was acquired (1229-12142) in which this hypothesis could be tested. The image of north-central Iceland included 5 of the 20 so-called high-temperature geothermal areas: Þeistareykir, Krafla, Námafjall, Askja, and Kverkfjöll (Figure 1). Except for Askja all of these areas were cloud free; however, part of the Þeistareykir, Askja, and Kverkfjöll geothermal areas were in shadow. The Krafla geothermal area, which lies north of the Námafjall geothermal area, was too small to be discerned (0.5km^2). Only the Námafjall area was cloud free and not obscured by shadow. Table 1 gives the area and heat flow of these geothermal areas:

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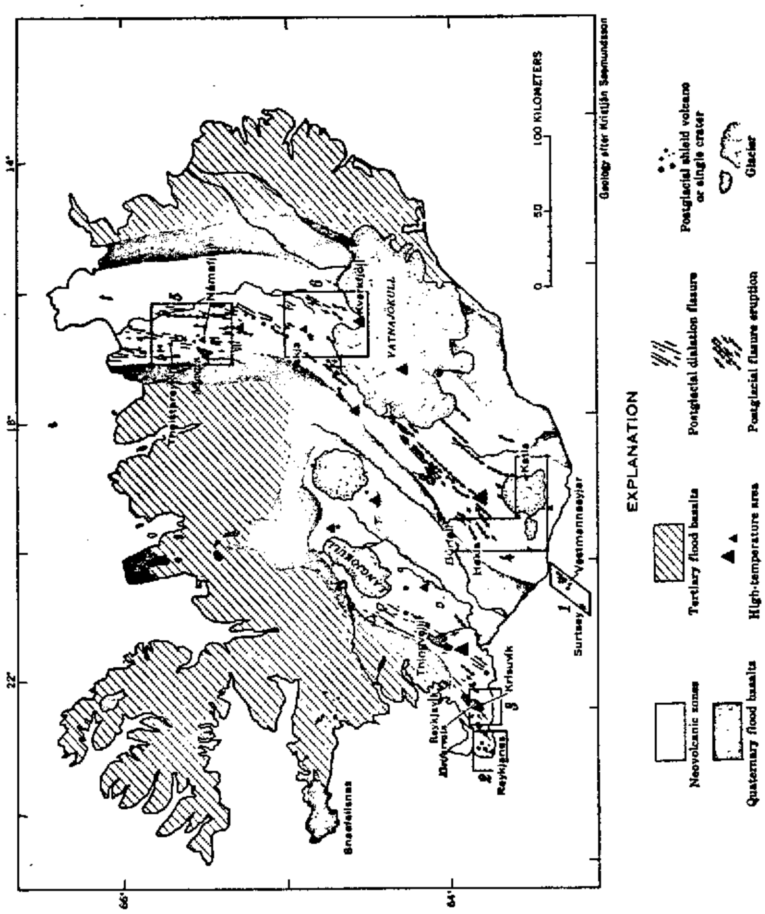

Figure 1. - Index map of Iceland. The numbered test sites show selected areas of priority coverage available from aerial thermographic and photographic surveys by Air Force Cambridge Research Laboratories in 1966 and 1968 and by the National Aeronautics and Space Administration in 1968 and 1973 (ERTS-1) as part of the long-term geological and geophysical remote sensing project in Iceland. The size of the triangles in the geothermal areas is proportional to heat flow. (From figure 4 in Friedman, and others, 1969, p. 91).

Table 1. - Size and Heat Flow of Selected Icelandic Geothermal Areas (From Table 4 in Böðvarsson, 1960, p. 49)

NAME OF GEOTHERMAL AREA	AREA (KM^2)	
Þeistareykir	2.5	$5-25x10^6$ cal/sec
Krafla	0.5	$5-25x10^6$ cal/sec
Námafjall	2.5	$25-125x10^6$ cal/sec
Askja	?	$5-25x10^6$ cal/sec
Kverkfjöll	10	$25-125x10^6$ cal/sec

The Námafjall geothermal area appears as a light grey (or black, depending on MSS band), linear, "ragged" area surrounded by bright white snow. Therefore, under optimum conditions the ground resolution capability of the ERTS-1, MSS sensor can distinguish a small geothermal area ($2.5km^2$) with a heat output of $25-125x10^6$ cal/sec by its snow-melt pattern.

Part of the Þeistarekyrir geothermal area can possibly be seen but is mostly in shadow. Krafla apparently cannot be discerned, probably because it is too small (both size and heat output). The geothermal areas at Askja (in SE and E part of caldera) are in shadow, but a possible snow-melt pattern or lack of ice on the shore of the lake may be present. Most of the Kverkfjöll geothermal area is in shadow but two features: a partially frozen lake (thermal springs discharging into it) and a (ice) cauldron subsidence feature in the ice cap, the result of subglacial geothermal activity, can be clearly seen.

A most interesting aspect of this ERTS-1 image is the open water on the eastern shore of lake Mývatn which is due to thermal spring activity near Vogar (Rist, 1959, p. 121-127; Barth, 1950, p. 18). The other open water areas are due to the high volume of spring discharge (near Kálfaströnd) or at the main river outlet of the lake (Álabrot). A complex pattern of open water occurs at lake Grænavatn, just to the south of Mývatn. In the search for geothermal areas, and when one considers that the surface expression of such areas is rather small from a satellite's viewpoint, it should not be overlooked that the "size" of a thermally active area can be markedly increased if the discharge of hot groundwater enters a lake. This is especially important when searching for geothermal areas on satellite thermography or when studying satellite imagery of snow-covered terrain or frozen lakes such as the ERTS-1 image of Mývatn. Even though the Námafjall geothermal area can be discerned on the ERTS-1 image, the open water areas on a "frozen" lake stand out very sharply.

VOLCANIC ERUPTIVE PRODUCTS

There have been four volcanic eruptions in Iceland during the past 15 years: Askja, 1961; Surtsey, 1963-1967; Hekla, 1970; and during the period of the ERTS-1 experiment, Heimæy, January 23 to July 3, 1973. Lava flows from the eruptions at Askja (Thorarinsson, 1963) and Hekla (Thorarinsson, 1970) can be easily delineated on the ERTS-1 imagery. The outline of, and the two primary craters on, the volcanic island of Surtsey can also be clearly seen. The use of ERTS imagery to study and monitor the volcanic eruption on Heimæy, an inhabited island in the same archipelago (Vestmannæyjar) as Surtsey, was pretty much stymied by poor weather. Of the 14 possible images acquired by NASA, only 3 are usable for study (21 November 1972, 1121-12143; 3 February 1973, 1195-12260; and 9 March 1973, 1229-12151), and one of these images (21 November 1972) is a pre-eruptive view of the island. Clouds obscured the island on the other 11 images. Figure 2 is a comparison of the pre-eruptive and eruptive views of Heimæy. Additional imagery of Iceland during the summer of 1973 may provide a post-eruptive view of the island, of great scientific interest because of the increase in area ($2.5 km^2$) of Heimæy (Johnsen, 1973) and major changes in coastline configuration on the southeastern edge of the harbor and along the eastern side of the island. Although there has been reseeding of tephra (airborne eruptive products) covered areas, it is expected that there will be a marked reflectance decrease in such areas on MSS bands 6 and 7 of post-eruption imagery.

It is interesting to note that the more frequent coverage afforded by the NOAA-2 satellite albeit at an 8-fold reduction in "resolution," increased the chance of imaging the island during brief periods of fair weather. On January 25, 1973, both the visible (.6-.7μm) and infrared (10.5-12.5μm) sensors on the NOAA-2 satellite recorded the effusive volcanic eruption approximately 33 hours after it began.

GEOLOGIC STRUCTURE

Iceland, because of its high-latitude location, has a variable solar elevation angle during the time of satellite passage throughout the year: from about 2° to about 53°. Low sun angle imagery, particularly when combined with a snow cover, markedly enhances the geologic structure and terrain morphology of Iceland. MSS imagery of Iceland, with solar elevations as low as 7°, have revealed fine structural and morphologic detail, particularly in the area around and within the large icecap, Vatnajökull, and in other areas as well. New structural alignments and lineations, some of which extend for 10's of kilometers, are evident on several of the ERTS-1 images of Iceland, and new subglacial structural features have also been recognized (Thorarinsson, Sæmundsson, and Williams, in press). The recognition of large structural features in Iceland has important implications to an understanding of the tectonic fabric of the island. Iceland's position on the Mid-Atlantic Ridge, and the fact that it is the largest supramarine area along the Ridge has made Iceland a prime testing ground for examining the concepts of sea-floor spreading and plate tectonics.

The circularity and size of Tertiary and Quaternary central volcano complexes in Iceland make them prominent features on the ERTS-1 imagery of Iceland. Several new or suspected

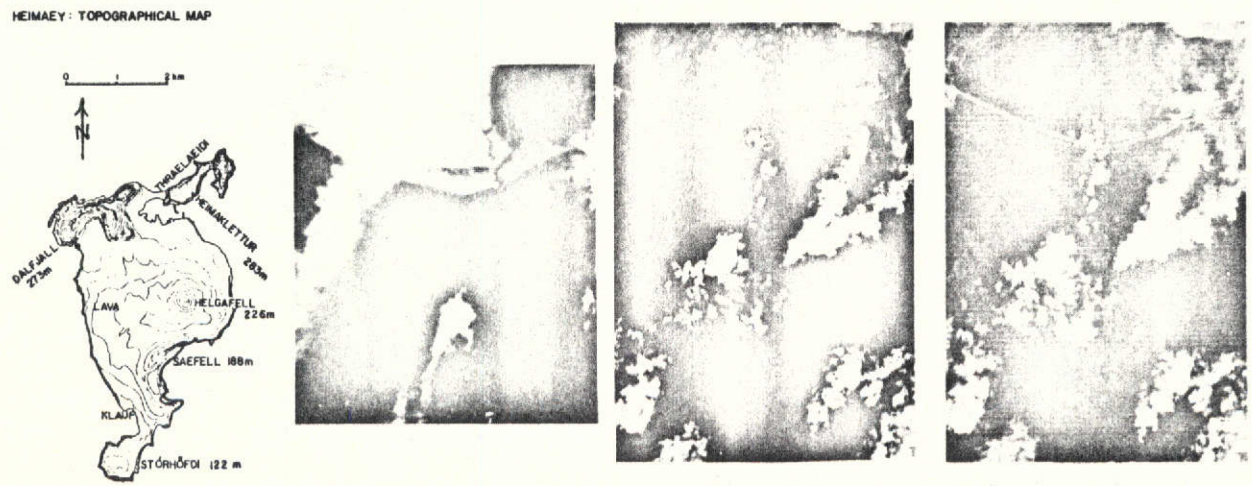

Figure 2. - Topographic map of Heimæy, Vestmann Islands, Iceland, showing the configuration of the island prior to the new volcanic activity which began on 23 January 1973. (Map is from figure in Friðriksson, and others, 1972, p. 53). The ERTS-1 image on the left was acquired on 21 November 1972 (1121-12143, band 7) and also shows the island prior to the eruption. The western shoreline is partially obscured by a long, linear cloud. The middle ERTS-1 image and the one to the right, bands 5 and 7, respectively, were acquired on 9 March 1973 (1229-12151), during an active phase of the eruption. Although partially obscured by clouds, the outline of the island can be seen, with the eruption plume ascending to the east from the east side of the island. The volcanic eruption apparently terminated on 3 July 1973 (Th. Sigurgeirsson, personal communication); thus, post-eruptive ERTS-1 imagery, if acquired, will show the areal increase of the island caused by lava flows to the east and northeast. The eruption plume on the 9 March 1973 image obscures nearly all of the new land. The approximate map scale for the 3 ERTS-1 images is 1:500,000.

central volcanoes have been identified, but extensive field work will be necessary to provide absolute confirmation.

VOLCANIC GEOMORPHOLOGY

The study of the volcanic landforms of Iceland on ERTS imagery has barely begun. There is no question, however, that the regional portrayal of the extraordinary volcanic morphology of Iceland's neovolcanic zone provides quite a different view of such features when compared with previous aerial photography, observations in the field, or topographic maps. The extreme linearity of fissures, crater rows, and grabens, particularly in the area between the icecaps, Mýrdalsjökull and Vatnajökull, and in other areas, is very evident on the ERTS-1 imagery.

The difference between volcanic landforms which have formed under subaerial conditions as compared to those which were formed wholly or partly in a subglacial environment is marked, particularly the numerous shield volcanoes and their subglacial counterparts, the so-called móberg- or table-mountains. The study of Iceland's complex assemblages of volcanic landforms on such small-scale imagery provides for a unique vantage point of such phenomena, which we have previously only had of our moon and the planet Mars. Studies of Icelandic volcanic landforms and volcanic landforms in other regions of the earth on ERTS-1 imagery may very well assist astrogeologists to a better understanding of lunar and martian terrain analogues.

MARINE GEOLOGY

Although the marine geology studies were directed at mapping of coastline changes, shoals, and areas of kelp, only the first objective has been reached with available imagery. Particularly on Iceland's south coast, comparison of ERTS-1 imagery with existing 1:1,000,000, 1:500,000, and 1:250,000 maps shows many discrepancies. This coast is subject to almost daily changes because of the effect of coastal storms and discharge of sediment-laden rivers from ablating glaciers. As was noted in my recent paper on evaluation of ERTS-1 imagery of Cape Cod (Williams, 1973), improvement in accuracy of mapped shorelines at 1:1,000,000- and 1:500,000-scale maps can be achieved by avoiding the subjective differences in cartographic representation by the same cartographer on one map or between different cartographers on adjoining maps which are caused by generalization of features. When ERTS imagery is used as a basis for map data, no generalization is needed. The cartographer can draft the map directly. Discrepancies on Icelandic maps at the aforementioned scales are caused by the combination of cartographic generalization and by dynamic changes in the position of the coastline and estuaries.

Part of the new coastline of Heimæy can be discerned on the ERTS-1 imagery, although the eruption plume obscures most of the new land (Figure 2). Changes in the outline of Surtsey can be clearly seen, particularly the growth of the prominent ness on the northern part of the island. A study of ERTS-1 imagery of Surtsey as compared with previously acquired aerial photography and aerial photography taken in 1973, has been initiated.

Sediment plumes from glacial rivers, in particular, are very marked on ERTS-1 imagery, especially so on MSS band 4. Not only is it possible to measure changes in size of plumes on a seasonal basis, dispersion of sediment-laden freshwater plumes in a marine environment could have an influence on optimum locations for fishing. Such a correlation will be examined. In addition, the size of the plume from a particular river is probably related to river discharge. A study of such a correlation will also be pursued.

EPHEMERAL SNOW AND ICE

Snow cover mapping in Iceland has important economic ramifications, because persistence of snow into the growing season (in grasslands of highland areas) can limit the growing season and reduce the yield of grass for sheep. ERTS-1 imagery of Iceland provides the capability to map snow cover over time and has been so demonstrated. Late spring and early summer imagery is not available for Iceland (tape recorder problem), which is unfortunate, but mid-summer (1973) imagery does record snowcover in many highland areas, the result of heavy snows during the winter of 1972-1973. With the increased frequency of imagery acquisition of Iceland by an operational satellite, the mapping of snow cover, particularly changes in snow cover with time, could be carried out as a joint function of the Icelandic Meteorological Service and the Agricultural Research Institute.

ERTS-1 imagery of Iceland has also recorded the change in and breakup of ice cover on several lakes. It is expected that the mapping of ice freeze-ups and thaws of lakes, particularly in remote areas, will assist in the assessment of local climate, because Iceland's sparse population and relatively uninhabited interior areas limit the acquisition of climatic data in much of Iceland's interior. This is particularly true during the extended winter, because storms and deep snow render large areas of the interior inaccessible for weeks, if not months, at a time. The use of unattended meteorological and hydrological data collection platforms (DCP's) could also revolutionize the acquisition of weather data in Iceland's interior. When combined with ERTS imagery, such a hybrid system would be of very great value to Iceland.

GLACIOLOGICAL FEATURES

Glaciological features in Iceland are very prominent phenomena on the ERTS-1 imagery of Iceland. The many icecaps contrast sharply with the generally dark basaltic bedrock or erosional byproducts of much of the country (Figure 3). Moraine-mantled snouts of glaciers are sometimes difficult to distinguish from non-icecovered terrain in front of the glaciers, particularly on MSS band 7, but MSS band 5 or color composites permit differentiation to be made. One outlet glacier, Eyjabakkajökull, from the northeast part of the largest ice cap in Iceland, Vatnajökull, was actually surging forward at the time of imaging in October 1972. The ERTS imagery is being used to map its new position. It is interesting to note that comparison of the snout of Eyjabakkajökull on ERTS imagery with existing maps cannot be made, because of the frequency at which maps are revised in Iceland is far longer than fluctuations of its icecaps and outlet glaciers. The frequency (or potential frequency) of ERTS coverage, however, is sufficient to record such changes if they are of sufficient magnitude to be "resolved" by ERTS (probably ±100m).

During the course of the project the four largest icecaps, that is those with areas in excess of 500km^2, will receive special attention. Available imagery should permit the compilation of orthoimage maps or orthoimage mosaic maps of Vatnajökull (8400km^2), Langjökull (1020km^2), and Mýrdalsjökull (700km^2) (Figure 3). Part of Hofsjökull (996km^2) will also be studied, but cloudiness over its southwestern one-third has prevented imaging of the entire icecap. Lack of late July and August imagery of the ice caps (minimum snow cover in the highlands) makes the study of the smaller icecaps somewhat difficult, except in special cases. (It is difficult to tell where a small icecap ends and its surrounding snow cover begins on ERTS imagery, other than on late summer imagery.).

Of particular interest has been the finding of considerably more morphologic detail within the margins of the Vatnajökull than was previously known or even suspected. ERTS-1 imagery of Vatnajökull shows, among other features, a number of depressions, both circular and linear. Several of these depressions can be related to the occurrence of jökulhlaups ("glacier bursts"), large glacial floods, which can be the results of subglacial geothermal or volcanic activity or rapid draining of glacial lakes. It is evident that frequent ERTS imagery of Vatnajökull can monitor such changes in surface morphology.

Besides the volcanically or geothermally induced jökulhlaups there are the equally common, if not more common, limnological jökulhlaups, large glacial floods resulting from the rapid draining of glacier margin, supraglacial, or subglacial lakes. Intensive study of one glacier margin lake, Grænalón, which is an ice-dammed lake on the southwestern margin of Vatnajökull, is underway. The two-dimensional outline and area of the lake can be easily mapped from ERTS imagery. Field work is planned to measure the slope of the terrain on one end of the lake basin as well as the level of the lake. As the lake rises the extension of the lake into the area of known slope can provide information on the depth of the lake, thus offering a means of remotely measuring the changing depth of the lake. Previous research has shown that when the lake reaches a certain depth it will lift the ice dam, resulting in a rapid draining of the lake and a catastrophic flood across the sandur plains of southern Iceland. After the lake has drained the cycle begins anew.

It should also be noted that under conditions of low solar illumination (<10°), recessional moraines and some types of

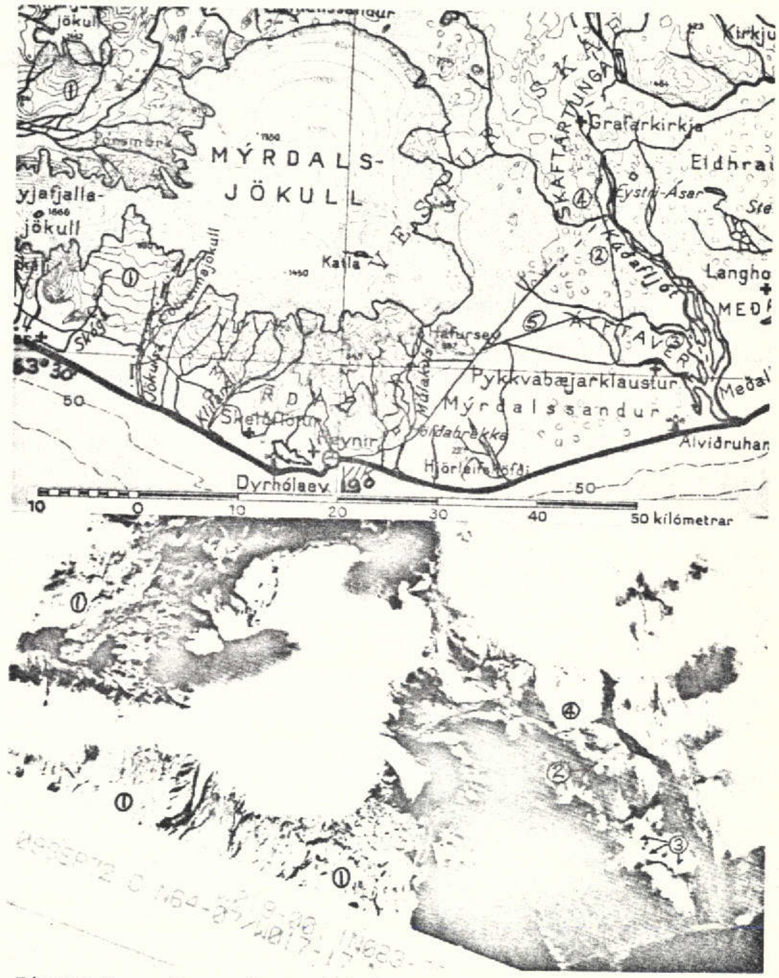

Figure 3. - Comparison of 1:500,000-scale map of Iceland (Ísland, Geodætisk Institut, Copenhagen, 1945) with ERTS-1 image (band 7) of the same area which was acquired on 9 September 1972 (1048-12080). Note different outline of Mýrdalsjökull and some of its outlet glaciers. Four different vegetation classes (plus barren lands - 5) can be mapped on the false-color composite image of this scene: natural grassland, 1; reclaimed land, 2; cultivated land, 3; and forests, 4; by their different color tones.

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medial moraines stand out very sharply. Mapping of such relatively low-relief features in remote areas (e.g., northern Canada, Greenland, etc.) under such illumination conditions, appears quite feasible.

RIVER FLOODING

Most aspects of the river flooding experiment have not been able to be carried out because of lack of suitable ERTS imagery, particularly during the spring and early summer months. This was primarily caused by the tape recorder malfunction during the optimum period for the acquisition of pertinent imagery.

Enough imagery does exist of at least part of the sandur outwash plains of south-central Iceland to show the expected seasonal variation in water flow across this area because of changes in rate of ablation of the outlet glaciers from Vatnajökull. Additional study of the imagery of this area is planned.

SEA ICE

As with the river flooding experiment, the sea ice experiment could not be carried out because of the lack of ERTS imagery of sea ice in the waters north of Iceland. This was primarily due to five factors: (1) the size of study area was too small; (2) the winter of 1972-1973 was not followed by significant amounts of sea ice close to Iceland; (3) cloudiness prevented periodic assessment of sea ice conditions; (4) very few satellite orbits over Iceland covered the western part of the island, and no imagery was received of the extreme northwestern part of Iceland, the usual point of closest approach of sea ice; and (5) problems with the tape recorder precluded the acquisition of imagery during the late spring and early summer. Of each of these factors the inclination of the satellite orbit (parallel to the usual front of the sea ice boundary), and the lack of orbital passes over western Iceland were the most important.

Only one ERTS image of Iceland (in May 1973) recorded any sea ice at all. This image will be compared with Icelandic sea ice maps and with available imagery from other satellites. Additional imagery of the area northwest of Iceland, which lies outside the original study area, will also be examined for distribution of sea ice.

Another problem with sea ice mapping with ERTS imagery north of Iceland is low solar illumination during nearly one-third of the year, that is the months of December and January and much of November and February. It is evident that a thermal channel on future MSS systems on ERTS-type satellites will be needed to overcome this deficiency. Supplemental coverage by other satellites (e.g., NOAA-2, DAPP) with poorer resolution but greater frequency of coverage is mandatory in sea ice studies at such latitudes. A valuable spinoff of having a thermal sensor to map sea ice, at least as far as Iceland is concerned, is that satellite thermography could provide much needed data on the variation in marine currents around

Iceland, of great value to the fishing industry. A preliminary evaluation of NOAA-2 thermography, in conjunction with the ERTS-1 imagery, has established the promise such satellite thermography holds for mapping of marine currents off the coast of Iceland.

GRASSLANDS AND FORESTS

The agricultural industry of Iceland is heavily dependent on the areal amount, health, and growth rate of the grasslands. The grasslands are usually divided into lowlands and highlands, the latter being used for grazing by sheep during the summer months, and the former by cattle and Icelandic ponies during the late spring, summer, and early fall. The highland grasslands are used in their natural state, while some of the lowland grasslands have been subjected to extensive ditching to lower the water table, thus improving the soil properties and increasing the grass yield. On the homefields (Icelandic tún), the application of fertilizer, ditching, and seeding have markedly increased the yield of such areas. The harvesting of hay from the homefields provides the feed for the animals kept through the winter months.

There is considerable effort being expended to reclaim the overgrazed lands through reseeding and fertilizing of barren areas (Friðriksson and Pálsson, 1970). Many areas are also being reforested to reverse the post-settlement trend of soil erosion. The reclamation program is directed at an increase in the area of grazing lands to meet the future resource needs of a rapidly growing Icelandic population.

Although an excellent vegetation mapping program has been underway for several years (Thorsteinsson, 1972), it will be many more years before the mapping will be completed. Field observations are being plotted on aerial photographs acquired in ca. 1960 and later transferred to base maps. When completed, the vegetation mapping project will provide an inventory of Iceland's vegetation as mapped over a fifteen year period. For resource management decisions, however, additional, timely data on the state of the grasslands is required in order that the rangelands can be most effectively utilized. Seasonal imagery is needed so that gross changes in the rangelands can be mapped and evaluated. Not only is an operational ERTS satellite needed to provide such data, but a means of making newly acquired imagery (MSS false-color composites) available to Icelandic agricultural experts within 10 days to 2 weeks after acquisition is also required. Information on dynamic phenomena, such as health and growth characteristics of rangelands, is "perishable" in resource management decisions, if not used promptly.

A preliminary study of MSS, false-color composites of various parts of Iceland has shown that at least four vegetation types can be mapped on ERTS imagery (Figure 3). These are: (1) bushes, dwarf trees, and shrubs; (2) natural grasslands; (3) reclaimed land; and (4) cultivated homefields. Although much of the ERTS imagery of Iceland has been unsuitable for vegetation mapping, because much of the imagery was acquired outside the normal growing season, intensive study of one image (early September 1972) permitted five-fold (including barren lands) classification to be accomplished. Additional imagery from the summer of 1973 may result in additional classification groups.

One interesting finding from a study of MSS false-color composites is that the grasslands apparently must reach a certain density and/or size before they can be imaged even as a light pink. In other words, no pink or reddish color exists in the barren lands until an unknown areal distribution and/or density of grass is present. What this threshold value is will require careful field observations or correlation with preexisting vegetation maps.

The variations in the climate of Iceland (Eythorsson and Sigtryggsson, 1971), falls of volcanic ash, and presence, persistence, or absence of sea ice off the coast of Iceland all can have their effect on the state of the grasslands. Imagery from ERTS-type satellites offers, over a long period of time, the means of monitoring the effect of such phenomena on the grasslands and forests. Aside from the importance of an operational satellite to resource management decisions relative to the Icelandic grasslands, such long-term studies can have equal value in a better knowledge of the response of the grasslands to long-term climatic variation.

CARTOGRAPHY

Although not a separate experiment in the original proposal the cartographic applications of ERTS-1 imagery of Iceland have grown to the point where a separate study has become both necessary and desirable. Several applications of ERTS imagery to improvement of existing small-scale Icelandic maps appears quite feasible and are being pursued.

Mapping of the changing coastline and estuarine areas of Iceland can be accomplished on at least 1:500,000-scale maps, perhaps even to 1:250,000-scale maps. An experiment has been undertaken to try to determine whether stereopairs of adjacent (sidewise overlap) ERTS-1 images of high relief areas of Iceland can give meaningful relative elevation differences. Some success has been achieved in a preliminary study, using photogrammetric instrumentation (Kern PG-2), of measuring relative elevation of mountains where considerable overlap exists in successive orbits. A ground feature is imaged on 3 successive orbits at the latitude of Iceland (65° N. latitude) with about a 130km baseline separation between the "first" and "third" orbits. Sufficient parallax separation existed on a table mountain with 1,000 m of local relief to warrant additional research on the use of ERTS-1 imagery to measure local relief differences of such magnitude. The stereoplotter operator stated that he thought he could draft 10 contour lines within the 1,000 m elevation difference, giving a 100 m relative height measurement capability from ERTS. It should be noted that the stereomodel from MSS imagery is badly distorted over the full area of the image because of the 14 or so computer corrections impressed on the original videotape data in the creation of the ERTS image.

RBV imagery would, therefore, be far more suitable for such photogrammetric measurement. It should be stressed that the reliability of elevation measurements from MSS imagery, therefore, is very suspect.

The repetitive ERTS-1 imagery (MSS) acquisition over Iceland has caused a very large cataloging problem. For that reason a geographic matrix for Iceland has been created to place each image in its proper geographic area. Table 2 shows how each image (and repetitive images of the same area) has been arbitrarily given a specific geographic name. [Computers handle numbers rather well; most humans conceptually prefer an areal connotation to a particular image.] Each matrix square (image) contains one or more images of pretty much the same area. Successive images differ only in their date (season) and the amount of cloud cover (obscuration). The handling of ERTS-1 imagery then becomes quite similar to map or aerial photo handling. (Maps are generally on a quadrangle basis keyed to geographic coordinates, an index map of a state, county, etc.; aerial photos are generally keyed to a mosaic which is in turn based on geographic coordinates or to a country, state, etc.)

In a true sense, then, the arbitrary geographic matrix for ERTS-1 imagery of Iceland becomes a series of "quadrangle maps," easy to fit into existing map and aerial photographic coverage. NASA should consider holding the orbit quite closely over time (more frequent correction) and holding the "framing" to the same area. In this way successive ERTS-1 (for a specific satellite) images would become "maps" of specific areas. Study of dynamic phenomena ("change detection") could be more easily carried out, particularly computer-assisted "change-detection mapping."

Several experimental special maps will be compiled from available ERTS imagery of Iceland. A 1:1,000,000-scale uncontrolled, orthoimage mosaic (MSS band 7) has been completed. Orthoimage mosaics at the same scale will be compiled for MSS bands 4 and 5. At least one uncontrolled, orthoimage mosaic of Iceland will be compiled at a 1:500,000-scale. Special experimental maps will also be compiled at 1:500,000- and perhaps even 1:250,000-scales of at least 3 of the large icecaps: Vatnajökull, Mýrdalsjökull, and Langjökull. Initially these maps will be in the form of orthoimage mosaics. Consideration is being given to overprinting with topographic contours and geographic place names.

One finding of particular interest to interpretation of ERTS-1 imagery and in the compilation of special maps is that the 1:500,000-scale image is the "best". Tonal quality, "resolution," and size of area presented all seem optimum at the 1:500,000-scale. Larger scale enlargements of the image cause a degradation in apparent tonal quality, "resolution," and visual "grasp" of the area. Images which are smaller in scale than 1:500,000 have excellent tonal quality and "resolution," but the size of the features imaged become too "small" for ease of visual "grasp". My subjective assessment of the most useful scale of the image

NDPF Computer Abscissa

NDPF Computer Ordinate		133	119	105	91	77	63	49	35	21	7	Iceland Project Ordinate
13		A1	A2	A3 KOLBEINSEY	A4	A5 SLÉTTU-GRUNN	A6	A7	A8	A9	A10	A
14		B1	B2	B3 SKAGI	B4 EYJAFJÖRDUR	B5 TJÖRNES	B6 AXAR-FJÖRDUR	B7 MELRAKKAS-LÉTTA	B8 LANGANES	B9 LANGANES-GRUNN	B10	B
15		C1	C2	C3 HVAMMS-FJÖRDUR	C4 LANGJÖKULL	C5 AKUREYRI	C6 MÝVATN	C7 ÓDÁDAHRAUN	C8 LAGARFLJÓT	C9 SEYDIS-FJÖRDUR	C10 GLETTINGA-NES	C
16		D1 JÖKULDJÚP	D2	D3 REYKJAVÍK	D4 THING-VALLAVATN	D5 HEKLA	D6 ÞÓRISVATN	D7 VATNA-JÖKULL	D8 INGÓLFS-HÖFDI	D9 HOFN	D10	D
17		E1 ELDEYJAR-GRUNN	E2	E3 SKERJADJÚP	E4 GRINDA-VÍKURDJÚP	E5 SURTSEY	E6 VEST-MANNÆYJAR	E7 VÍK	E8 KÚDAFLJÓT	E9	E10	E
18		F1 ATLANTS-HAF(SV)	F2	F3	F4	F5	F6	F7	F8 SKAFTÁR-DJÚP	F9	F10	F
		1	2	3	4	5	6	7	8	9	10	

Iceland Project Abscissa

Iceland ERTS-1 Data Acquisition Matrix

TABLE 2. - GEOGRAPHIC NAMES FOR ERTS-1 IMAGERY OF ICELAND

is that the 1:500,000-scale image or derivatives are optimum with the ERTS-1 system.

Although mentioned previously, I would like to reemphasize the importance of low solar angle imagery in structural geology, geomorphic, and related studies and also in cartographic representation of phenomena. Low sun angle imagery is of particular importance in polar areas where the often snowcovered terrain can mask terrain, glacial or sea ice features at high solar angles. Not so at low sun angle of illumination, where extremely subtle surface irregularities can be discerned and mapped.

The high surface albedo (reflectivity) of snow permits imagery to be acquired under low intensity of solar illumination, that is at low solar angles. Consideration should be given to extending the programmed coverage of polar areas with the ERTS satellite to solar elevation angles as low as 5°, perhaps even lower. In addition, consideration should also be given to the acquisition of ERTS imagery during the polar summer when the midnight sun should offer sufficient illumination.

CONCLUSIONS

ERTS-1 imagery of Iceland provides the basis for the study of several different geological and geophysical phenomena which relate in an important way to the natural resources of Iceland. Preliminary analyses of available ERTS-1 imagery of Iceland clearly shows that techniques (operational earth resources technology satellite) are within reach. These can enable Icelandic research institutes and governmental agencies to measure and map important environmental features which have great economic implications in Iceland.

False-color imagery (MSS color composites) from ERTS is of particular importance to Iceland because such imagery, when used to map the distribution of and changes in the rangelands, could very well have vast ramifications for rangeland management in Iceland. The present status of and historical use of the rangelands are presently under serious review by agricultural research organizations and other authorities, because of their strong relationship to soil conservation problems in Iceland. At least four vegetation types can be directly mapped from color composites.

The hydrological conditions in Iceland can be studied in considerable detail by satellite observations, and already the analysis of ERTS imagery has demonstrated its usefulness in observing the movement of glaciers, mapping the current extent of glacier margins, and noting surficial changes associated with jökulhlaups (glacial floods). The correlation of water reserves with snow cover appears entirely feasible. This could greatly improve the basis for planning electrical production in the management of water resources. Accurate snow cover mapping possible with ERTS imagery also has important ramifications to rangeland management, because of the effect that persistence of snow cover into the summer months has on yield of highland rangelands.

ERTS-1 imagery of Iceland can be used to update maps at 1:1,000,000- and 1:500,000-scales by depicting the current shoreline and estuarine configuration, position of glacier margins, and changes in glacier margin lakes and other lakes.

Finally, a large number of geological and volcanic features can be studied from the ERTS imagery which hitherto have not been recognized. Thus, the satellite imagery of large geographical areas at certain times of the year, when the solar elevation angle is low (late fall, mid-winter, or during the midnight sun), can give entirely new information about the geology and geomorphology of Iceland. Also of particular value to geothermal studies in other areas is the fact that, under special conditions, geothermal areas can be imaged by the ERTS-1 satellite by snowmelt patterns or discharge of hot springs into "frozen" lakes. A small Icelandic geothermal area ($2.5 km^2$), with a heat output of $25\text{-}125 \times 10^6$ cal/sec could be identified by its snowmelt pattern.

Because of the wide variety of geological and geophysical phenomena which can be observed in Iceland, and because of the very clear and direct relation to the management of the country's natural resources, Iceland is particularly well suited for experimental studies to establish operational feasibility of the use of operational earth resources technology satellite sensors and other systems to meet resource inventory and management needs on a timely and cost-effective basis. Success with such an operational system in Iceland will point the way to the use by other countries of the techniques and concepts proven in Iceland. Iceland shares with the United States and with most other countries of the world a need for accurate and timely information on the status of its natural resources, in order to make wise decisions concerning the optimum utilization of such resources. The ERTS-1 satellite, the progenitor of a line of earth resources technology satellites, provides a "first-time" capability for the acquisition of environmental information, particularly for data on dynamic environmental phenomena.

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