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SATELLITE GEOLOGICAL AND GEOPHYSICAL REMOTE SENSING OF ICELAND - PRELIMINARY RESULTS FROM ANALYSIS OF MSS IMAGERY*

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ABSTRACT

A binational, multidisciplinary research effort in Iceland is directed at an analysis of MSS imagery from ERTS-1 to study a variety of geologic, hydrologic, oceanographic, and agricultural phenomena. A preliminary evaluation of available MSS imagery of Iceland has yielded several significant results - some of which may have direct importance to the Icelandic economy. Initial findings can be summarized as follows: (1) recent lava flows can be delineated from older flows at Askja and Hekla; (2) MSS imagery from ERTS-1 and VHRR visible and infrared imagery from NOAA-2 recorded the volcanic eruption on Heimaey, Vestmann Islands; (3) coastline changes, particularly changes in the position of bars and beaches along the south coast (e.g., north and west of Ingólfhöfdi), are mappable; (4) areas covered with

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new and residual snow can be mapped, and the appearance of newly fallen snow on ERTS-1, MSS band 7 appears dark where it is melting; (5) sediment plumes from the discharge of glacial rivers along the south coast can be delineated; (6) the area encompassed by glacial ice (ice caps, valley and outlet glaciers, etc.) can be mapped, including the new position of a surging glacier, Eyjabakkajökull, and such related phenomena as nunataks and moraines; (7) the plotting of changes in position of rivers, changes in size of lakes, and the occurrence of new lakes are feasible; (8) low sun-angle imagery, particularly of snow-covered terrain, markedly enhances the morphologic expression of constructional glacial and volcanic landforms, thus permitting the mapping of previously unrecognized structural features such as central or subglacial volcanoes; (9) the MSS color composites will permit the regional mapping of the gross distribution of vegetation in Iceland; and (10) at least at 1:250,000 map scale and smaller, ERTS-1 imagery provides a means of updating various types of maps of Iceland and will permit the compilation of special maps specifically aimed at those dynamic environmental phenomena which impact on the Icelandic economy.

1. INTRODUCTION

Iceland (Figure 1) is an island republic with a relatively small population of 206,818 (1 Dec. 1971) but with an area of 103,000km^2, resulting in a population density of 2 persons per km^2. Approximately 12,000km^2 of the area is covered by glaciers and 67,000km^2 is lakes, lava, sands, or non-productive land. Only 1,000km^2 is cultivated; the remaining 23,000km^2 is used for grazing, principally by 736,000 sheep, 53,000 cattle, and 33,000 Icelandic ponies. Living as the Icelanders do in the far north, dependent on the surrounding seas for fish and the land for agricultural products, their economic well-being is heavily influenced by the natural environment, and how effectively they use the limited resources available to them. Much of the Icelandic scientific effort is directed at an understanding of their environment because of its importance to the Icelandic economy. The effect of volcanic activity, the impact of frequent changes in climate, the condition of the rangelands (particularly phenological considerations), the hydrology of the country, and distribution and persistence of snow cover, are just some of the dynamic environmental data which

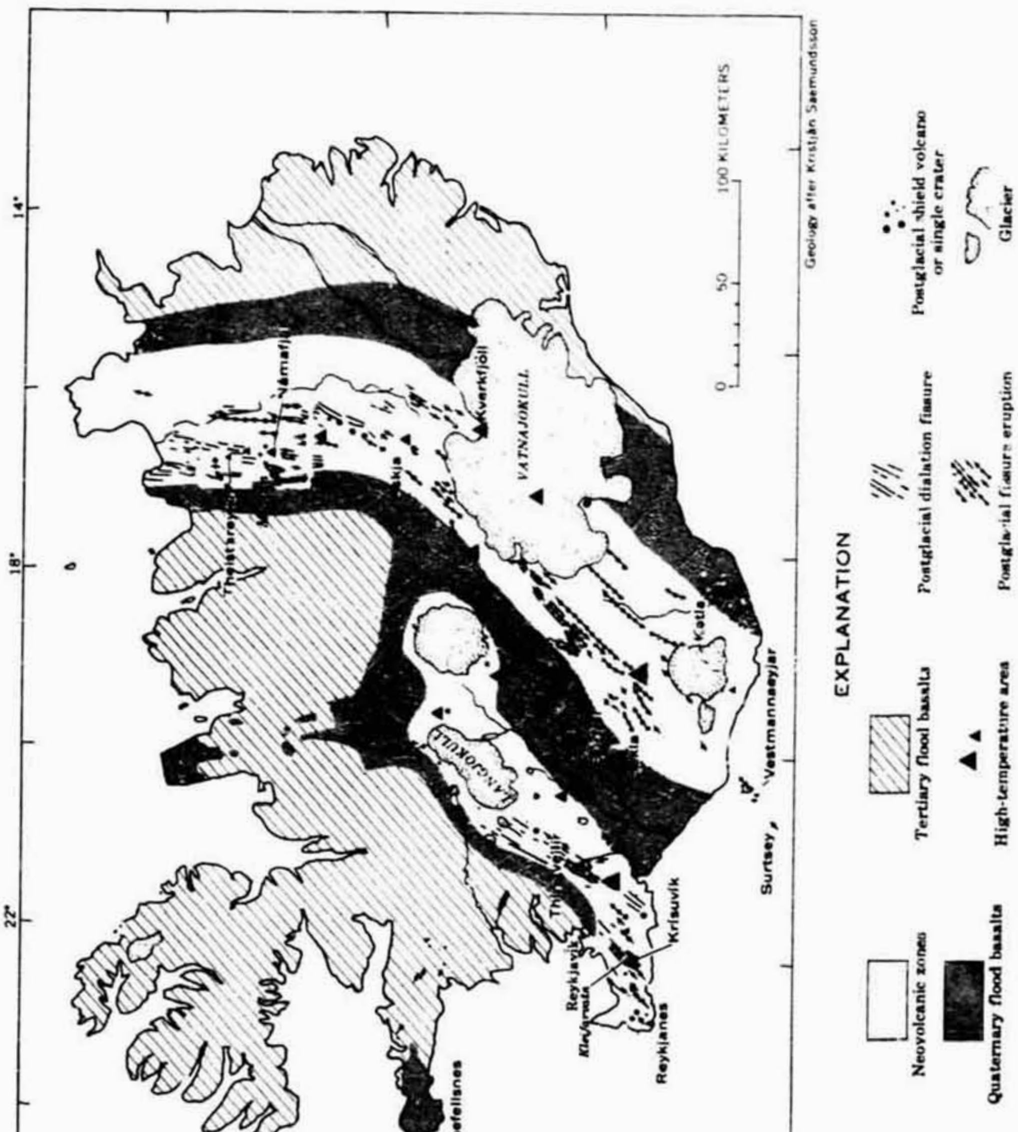

Figure 1. - Index map of Iceland

have a strong economic justification for acquisition. The limited number of scientists, the amount and type of environmental data needed to make effective and accurate decisions on the management of limited resources, and the lack of financial resources limit the acquisition of certain types of environmental data. From the very limited analysis of available ERTS-1, MSS imagery of Iceland, it can be stated that this imagery, when available on a timely basis and in a repetitive manner, can provide, at low cost, the environmental data necessary for resource management decisions. The remainder of the paper will be devoted to a more detailed discussion of the initial results from the series of experiments collectively entitled, Satellite Geological and Geophysical Remote Sensing of Iceland (Williams, 1973).

2. VOLCANIC ERUPTIVE PRODUCTS

Figure 2 shows the Vikrahraun lava flows which flowed out of a fissure in the Askja caldera ($45km^2$) during the period October-December 1961. The lavas encompass an area of $11km^2$ and reach a length of 7.5km. Some of the flows from the 1921-1924 effusive volcanic eruptions appear to be distinguishable southwest and southeast of the lake (Öskjuvatn). There is also the possibility that thermal emission, as recorded on aerial thermographs in 1966 (Friedman, Williams, and Pálmason, 1968) is reflected on the ERTS-1 MSS image as snow-free areas on the eastern shore of Öskjuvatn. Comparison of the ERTS-1 MSS image of the Vikrahraun with the maps published by Thórarinsson and Sigvaldason (1962) and Thórarinsson (1963) and the 1969, 1:100,000 map (Blad 84., Herdubreid) published by the Icelandic Surveying Department shows that the ERTS-1 image provides better detail as to the areal extent of the Vikrahraun than any of the other three maps.

The 1970 lava flows from Hekla (Thórarinsson, 1970) particularly the flows which emanated from Sudurgigar and flowed south and southwest for 5.5km, can be delineated. The Skjólkvíar flows to the north, and the flows to the northwest from an area southwest of Axlargígur are in shadow. It also appears possible that the 1947-48 lava flows on the southeast flank of Hekla can be mapped. The progression of lichen colonization since the cooling of lava flows may be represented in a different spectral reflectance, thus appearing as a different tone on the

Figure 2. - Comparison of ERTS-1, MSS image (14 Oct. 1972, E-1083-12021-5) of a part of northwest Iceland with a 1:500,000 scale map (Geodaetisk Institut, Copenhagen, 1945) of the identical area. Of particular interest are the geologic and hydrologic changes evident and mappable from the ERTS-1 image: (1) Vikrahraun lava flows (1961) 6km northwest of Öskjuvatn, (2) new position of the snouts of Brúarjökull and the surging glacier, Eyjabakkajökull, and (3) appearance, disappearance, and changes of lakes.

ERTS-1 MSS imagery. The position of Toppgígur (Summit Crater) and Axlargígur (Shoulder Crater) can be mapped.

The volcanic eruption on Heimaey, Vestmann Islands, which began on 23 Jan. 1973, was only faintly imaged by ERTS-1 on 3 Feb. 1973. The low sun angle (7°), black lava and tephra, make it very difficult to see all but a faint outline of the island of Heimaey. White steam clouds, where lava flows have reached the sea, apparently can be seen. The main eruption plume can be seen only indistinctly and probably lies off the image to the east. Later imagery (higher sun angle) will be necessary to map the new coastline of the island and the areal distribution of the tephra fall by comparison with previously acquired MSS imagery of the Vestmann Islands volcanic archipelago. (Note: The NOAA-2 satellite made a pass over Heimaey on 25 Jan. 1973 and recorded the eruption plume on both the visible band 0.6-0.7μm) and thermal band (10.5-12.5μm) imagery and thermal emission from the lava flows on the thermal band imagery. Quantitative measurements of radiant emission are being carried out.)

3. MARINE GEOLOGY

Coastline changes are mappable from the ERTS-1 imagery. Changes in the position of bars and beaches along the south coast are evident, particularly along the coast north and west of Ingólfhöfdi. As more imagery becomes available of other coastal areas of Iceland, the imagery will be compared with existing 1:250,000 to 1:1,000,000 maps to show how such maps can be readily updated with ERTS-1 MSS imagery. The image of the Ingólfhöfdi area provides the proof that such coastal changes are mappable. Sediment plumes from the discharge of glacial streams which cross the Skeidarársandur and Medallandssandur can be mapped in the ocean. The size of the plumes over time will be compared with hydrograph records to ascertain if there is any correlation between size of plume and discharge for a particular river.

4. EPHEMERAL SNOW AND ICE

Early fall snowfall and its relationship to elevation can be clearly seen on many of the ERTS-1 images of Iceland. Of particular interest, however, is the appearance of a light (?) snowfall in the Stórisandur area (Figure 3) which appears differently on MSS bands 4 (0.5-0.6μm) and 7 (0.8-1.1μm). On band 4 the snow cover is more extensive than is portrayed on band 7. This is because melting snow appears very dark at infrared wavelengths because of absorption due to free water. Similar dark areas of melted snow can be seen in the highland areas around Eiríksjökull and Okjökull. The mid-winter snow cover and its absence on the low-lying coastal areas (e.g., Skeidarársandur) is mappable. Snow-covered and frozen Lake Graenalón (approx. 3km x 5km) can be delineated.

5. GLACIOLOGICAL FEATURES

Glaciological features are exceptionally well portrayed on the ERTS-1 MSS imagery. Figure 2 shows (black line on 1:500,000 scale map) the current position of part of Brúarjökull and the new position of the snout of the surging glacier, Eyjabakkajökull. It should be noted that MSS band 5 was better than the other 3 bands in plotting the position of the glacier, but that the MSS color composite was mandatory in obtaining the necessary map precision in distinguishing the terminal moraine from the non-glacier covered terrain. The black and white images were difficult to work with because the morainal material of the terminal moraine is composed of the same material as the terrain in front of the glacier, making only a slight reflectance difference between the two. On the 14 Oct. 1972 MSS image the advancing front of Eyjabakkajökull is very steep; a shadow cast by the 15° sun angle enhances the steep front and is clearly delineated from the terrain which it has overridden. The last known surge of Eyjabakkajökull was in 1890 (Thórarinsson, 1964). The current surge of unknown magnitude [0.5 km (?), Thórarinsson, personal communication] still puts the present snout on the MSS image at a recession of 3.5km from the position in 1890.

Comparison of the position of glacial rivers on the MSS imagery with maps at scales as large as 1:250,000 shows many changes. The same is true of ice margin lakes and other lakes in Iceland. ERTS imagery will likely lead to greatly improved maps of such features and provide the capability for periodic revisions.

Early fall MSS imagery of glaciological features of Iceland was best. The best image of Mýrdalsjökull and Eyjafallajökull, with exceptional detail of two of the glaciers of Mýrdalsjökull, Sólheimajökull and Höfdabrekkujökull (Kötlujökull), is from early Sept. 1972. August

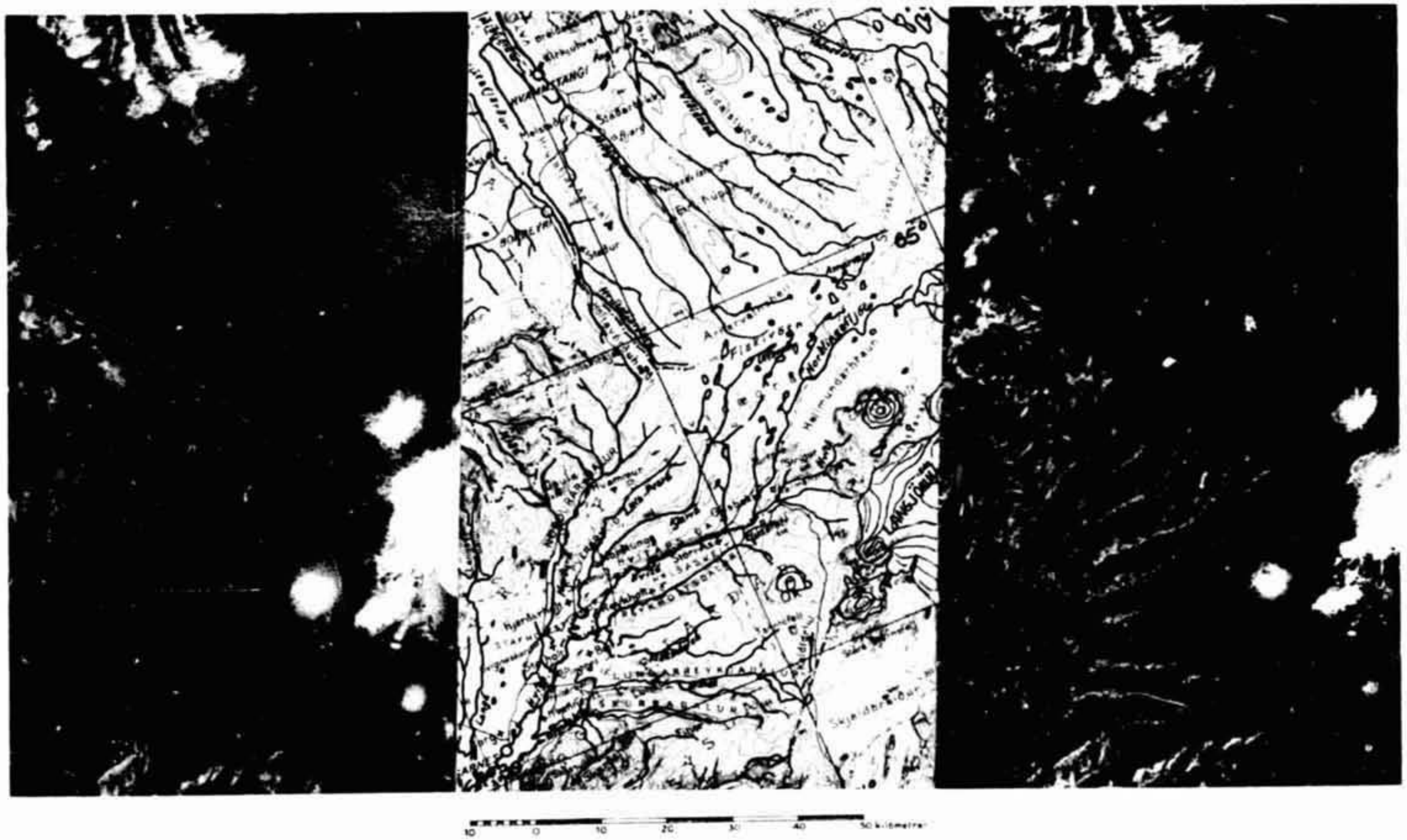

Figure 3. - Comparison of ERTS-1, MSS images (Left: 19 Oct. 1972, E-1088-12305-4; Right: 19 Oct. 1972, E-1088-12305-7) of a part of northeast Iceland with a 1:1,000,000 scale map (Geodaetisk Institut, Copenhagen, 1963) of the identical area. Of particular interest are the geologic and hydrologic phenomena recorded on the ERTS-1 image: (1) changing appearance of light snowfall in the highlands area north of Langjökull (Stórisandur) on band 4 and band 7 and around the ice caps, (2) changes evident in position of ice caps, and (3) circular structural feature at Saudafell which is a central volcano in the Tertiary volcanic rocks.

imagery would be optimum because of time of minimum snow cover, however.

6. STRUCTURAL AND MORPHOLOGIC FEATURES

A mid-winter image of the snow-covered Vatnajökull and the area west and south of this huge icecap in which the sun angle was at 7° shows incredibly fine morphologic and structural details of constructional volcanic and glacial landforms. The crater rows, Laka Gígar in particular, fissures, grabens, etc., are starkly portrayed. Old end moraines around outlet glaciers of Vatnajökull and Hofsjökull are mappable. Considerable detail exists on the snow-covered surface of Vatnajökull some of which definitely reflects the underlying geologic structure. The outline of the Grímsvötn caldera and the summit area of Öraefajökull are striking. Of gr[illegible] interest are at least four other circular features [illegible] the icecap. Two of them in the Kverkfjöll area [illegible]ertainly mark the position of subglacial volcanoes [illegible]arinsson (1950) shows a possible eruption cen[illegible] the upper part of the Dyngjujökull area, but the MS[illegible]age clearly shows that the suspected eruption center is not correctly located. The Hveradalur thermal area (Friedman, Williams, Thórarinsson, and Pálmason, 1972) appears to be structurally related to the second circular feature on the ERTS image. Two other circular or elliptical features on Vatnajökull, one at Bárdarbunga and the other near Hamarinn, may also have a volcanogenetic cause.

In the Torfajökull geothermal area, the largest geothermal area in Iceland ($100 km^2$), the circularity of the structure, recently reported by Saemundsson (1969 and 1972) is portrayed. West of Langjökull, in the Tröllakirkja area, a pronounced circular structure may represent the position of a previously unrecognized central volcano in Tertiary volcanic rocks.

7. GRASSLANDS AND FORESTS

Knowledge of the areal distribution, health, and growth rate of the grasslands of Iceland is vitally important to the economic well-being of the agriculture industry. The vagaries of the climate in Iceland (Eythórsson and Sigtryggsson, 1971), de[illegible]sition of tephra after volcanic eruptions (e.g., after the 1970 Hekla eruption and the 1973 Kirkjufell eruption on Heimaey), and presence and persistence of sea ice off the Icelandic coast all impact on the state of the grasslands. Considerable reclamation work is directed at reseeding of barren areas (Fridriksson and Pálsson, 1970) and reforestation of suitable sites to halt the rate of soil erosion and to provide additional grazing lands for sheep, cattle, and horses. A vegetation mapping program is currently underway to plot the vegetation of Iceland (Thórsteinsson, 1972), but additional, timely data on the health (e.g., lack of winter kill) and growth characteristics of the grasslands is needed for resource management decisions leading to the most effective utilization of the rangelands. A preliminary evaluation of ERTS-1 MSS color composites shows that vegetation distribution can be mapped. Seasonal imagery is needed before changes in the rangelands can be mapped and evaluated. It appears, however, that MSS color composites will provide Iceland with a powerful tool to map the seasonally changing condition of its grasslands, condition of reseeded and reforested areas, and - with an operational satellite - provide the timely data necessary for accurate resource management decisions.

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