COMPARATIVE DIGITAL ANALYSIS

OF SEASAT-SAR AND LANDSAT-TM DATA

OF ICELAND

by

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ABSTRACT

In the past, data available from the microwave range of the spectrum have been recognized as being of high potential for many geoscientific applications.

Within our former investigations, it could be demonstrated, that especially the digital combination of data from different spectral ranges offers extended possibilities for geoscientific application purposes.

For this presentation, we could carry out our investigations on the basis of digitally recorded SEASAT-SAR and LANDSAT-TM data of test areas in Southern Iceland. We want to demonstrate their complementary character and information content as well as the benefits of the digital combination of both data sets.

The results and experiences gathered during the realization of the investigation show, that for a successful application of remote sensing data in complex areas like Iceland, complementary data sets are an indespensable interpretation tool.

This can be justified regarding the supplementary information content of optical and active microwave data:

* object specific reflection and emission also from structural features in the optical domain;
* surface roughness and soil moisture in combination with morphological elements within the radar data.

Throughout the investigation, it became obvious, that in many cases, the understanding of a lonestanding data set can be improved significantly by the availability of additional data from a different part of the spectrum.

However, fundamental requirements for a successful application of both data are:

* the availability of radargrammetric corrected data and
* the application of well suited image processing techniques like the I-H-S- transform for an optimized combination.

1. INTRODUCTION

In the past, data available from the microwave range of the spectrum have been recognized as being of high potential for many geoscientific applications. This mainly is due to the relative independence of weather conditions and the capability to provide additional information on surface characteristics (surface roughness and surface moisture), which can not be collected by other remote sensing systems.

In particular, since the availability of the first spaceborne Radar data of SEASAT in 1978 and Shuttle Imaging Radar SIR-A in 1981, the necessity of this additional information source for geological purposes increased.

Consequently, very much effort has been put into the realization of advanced spaceborne radar systems - a development, which culminates in the European Remote Sensing Satellite ERS-1 in 1990, the SIR-C experiment in connection with the German/Italian X-SAR due to the launch in 1992 and the Canadian RADARSAT in 1994.

Because of the low incidence angle of ERS-1 and RADARSAT, these systems are not optimized for land observation in general. The experiences gained by use of the early SEASAT-SAR data, however, and the unforeseen high interest of geologists in ERS-1 data underline the enormous expectations of the user community.

On the contrary, the quite different and, especially in mountaneous regions very complex geometry of radar data has discouraged many potential users. in this context, it is understandable, that different colleagues have classified radar data as interesting for the elaboration of distinct structural information, but as insufficient for geoscientific mapping purposes.

In the last years, however, the availability of advanced image processing techniques, especially in the field of radargrammetry has improved this situation significantly. In principle, it is now possible to eliminate all the typical radar distortions and to provide the users with data compatible with other standard informations.
Those improvements have been demonstrated by the authors in different presentations (JASKOLLA, et.al., 1985, RAST & JASKOLLA, 1985, JASKOLLA & RAST, 1986, JASKOLLA, 1986) and, presently, by the summary report of the SIR-B experiment in 1984 (FORD, et.al., 1986).

It could be demonstrated, that those improved products of spaceborne radar data enable not only the geometrically correct detection of structural elements, but also an enhanced analysis of the complementary information contained in optical ("spectral component") and radar ("textural component") data. Within our investigations, it could be demonstrated, that the digital combination of both data sources offers very extended possibilities for geoscientific mapping purposes in a meaningful way.

These examples were gained on the basis of SIR-A data requiring that the optically recorded data had to be digitized and consequently, the digital combination with Landsat-MSS data was realized. Thus, the results can only be characterized as general demonstration studies.

For this presentation now, we could carry out our investigations on more sophisticated information, i.e. digital recorded SEASAT-SAR and Landsat-TM data of a test area in Southern Iceland. On the basis of these data and the derived products, we want to demonstrate their different character and information content as well as the improvements of the digital combination of both data sets.

2. BRIEF CHARACTERIZATION OF THE TEST SITE

Iceland is situated on the Mid-Atlantic Ridge, which is a zone of crustal plate separation. The ocean floor north and south-west of the island is spreading at a half-rate of about 1 cm/year with oceanic crust contineously being generated at the ridge`s crest. A zone of recent volcanism and rifting, called the Neovolcanic Zone, crosses Iceland from south-west to north-east and connects with the submerged Mid-Atlantic Ridge north and south-west of the island.

Practically, all rocks exposed in Iceland are of volcanic origin ranging in age from about 16 m.y. up to the recent. 80 - 85 % are basalts, intermediate and acidic rocks constitute about 10 %, while sedimentary rocks, themselves derived from the volcanics, make up less than 10 %.

Icelandic strata conventionally are divided into four groups or series. This division is based on climatic evidence from interlava sediments or volcanic breccias and on paleomagnetic reversal patterns supported by absolute age data. At this place, it is not necessary to discuss the geological construction of Iceland in more details; for a more comprehensive description, the reader is referred to SAEMUNDSSON (1979).

The south and south-western part of Iceland was selected as test site (fig. 1). This region contains all the four stratigraphic series, except the oldest volcanic rocks from the Tertiary. Examples for all interesting geological and geomorphological features found in Iceland are represented in the area:

* the extensively glacially eroded plateau basalts of the Plio-Pleistocene;

* the long parallel palagonite ridges, table mountains and subaerial lava flows of the Upper Pleistocene and Plio-Pleistocene;

* the striking volcanic features of the Neovolcanic Zone, such as crater rows, eruptive fissures, central volcanoes, fissure swarms and faults;

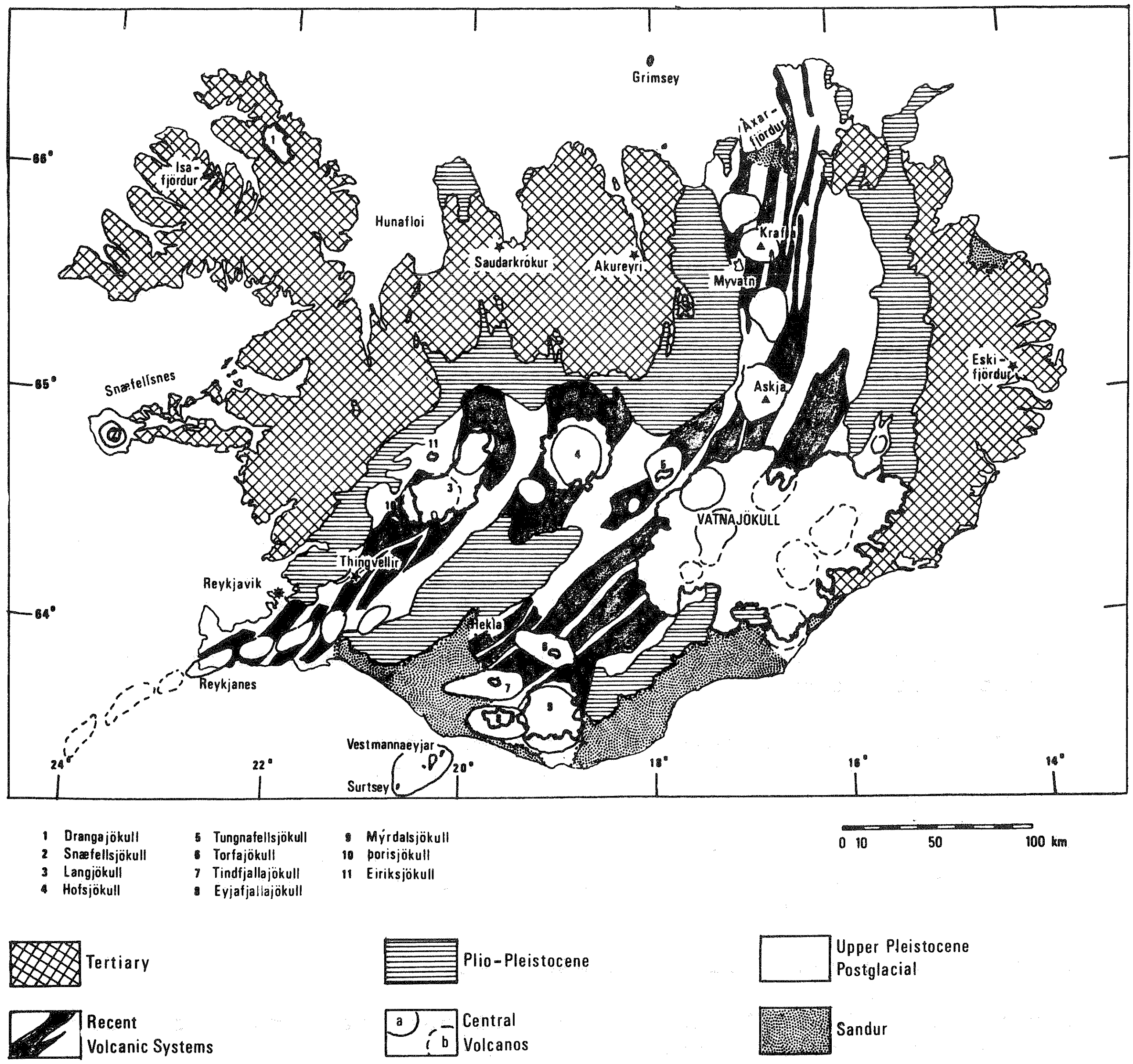
* postglacial lava flows and ash fields;

* extensive fluvioglacial outwash planes (sandurs) and areas of severe wind erosion;

* icecaps with their active outlet glaciers, terminal moraines and glacier margin lakes.

3. DATA AVAILABLE FROM THE TEST AREA

Our investigations were carried out on the basis of the following data:



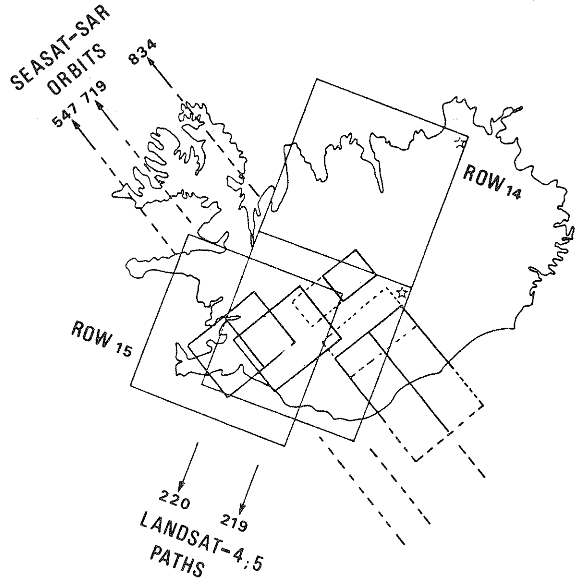


Fig.1 TEST AREA ICELAND
Geological Sketch Map
and Location of Data
Available

* SEASAT-SAR data, which were acquired on August, 21,1978 (Orbit 719/site Thingvallavatn) and August, 24, 1978 (Orbit 834/site Skeidarasandur) and

* Landsat-5 Thematic Mapper, path 220/row 15 from May 22, 1985 and path 219/row 15 from October, 03, 1984 (the Landsat-TM data were provided by ESA-ESRIN in the framework of the "Landsat-TM Pilot Project").

Additionally, we could refer to geological maps from the Geological Survey of Iceland and own results from field checks.

4. RESULTS

Many investigations presented until now have demonstrated the high significance of both SEASAT-SAR and Landsat-MSS and -TM data for geoscientific mapping in Iceland (e.g. MAMULA & VOIGHT, 1982; McDONOUGH & MARTIN-KAYE, 1984).
Therefore, at this place, it is not necessary to repeat all the advantages and disadvantages of both systems in detail, but the complementary information content will be demonstrated.

This shall be realized by an analytic discussion of SEASAT-SAR and Landsat-TM data of selected test sites, which are shown in fig. 1.

The available data have been processed using the hard- and software facilities of the "Arbeitsgruppe Fernerkundung" (AGF); especially the digital combination of the different data required the application of those algorithms of image processing, which guarantee the clear differentiation of relevant surface phenomena; therefore, the I-H-S approach (HAYDN, et.al., 1982; RAST & JASKOLLA, 1985) was best suited to fulfil this requirement.

Here, it shall be pointed out, that the most significant results have been elaborated on color displays of the data available and the derived products.

4.1. Test Site 1 - Thingvallavatn

Parts of the test site in southern Iceland are intensively vegetated. Consequently, the applicability of the Landsat-TM data (fig. 2) for geological mapping is relatively restricted. Disregarding the cloud and snow covered areas, it is obvious, that in relation to the SEASAT-SAR data (fig. 3), neither the different volcanic rocks, nor the volcanic and tectonic elements can be distinguished with the same accuracy. This, impressively, is documented by the interpretation map (fig. 4), which is based on the radar data.

A very interesting phenomenon can be observed on the basis of the thermal band of Landsat-TM (fig. 5).
Most of the bright (=warm) areas are correlated either with non-vegetated areas (e.g. on the coast and within aeolian erosion areas) or morphological features.
On the other hand, north of the lake Thingvallavatn, thermal structures appear, which can not be explained by the effects mentioned above.
The area is relatively homogeneous moss-covered with unusual thin soil cover over postglacial lavas. In general, it can be assumed, that the evapotranspiration of the vegetation diminishes the detectability of thermal anomalies. Additionally, the other remote sensing data available (Landsat-TM and SEASAT-SAR) and derived products (e.g. false color image) point towards a surface anomaly (e.g. variations in vegetation and/or soil moisture).
Therefore, subsurface effects like geothermal fields or other volcanic activities can not explain these thermal phenomena.

According to climatic features during data acquisition (at neighbouring ground stations very low wind velocities have been measured), the morphologic situation in a depression-like structure and slight topographic differences, it is most probable that microclimatic conditions are responsible for these "thermal anomalies" (local heating due to morphology).

By discussing this phenomenon, it should be demonstrated, that radar data have a high potential for geoscientific mapping.
Additionally, this example indicates again the necessity of a multisensor approach for a better understanding of the information content of different remote sensing data.

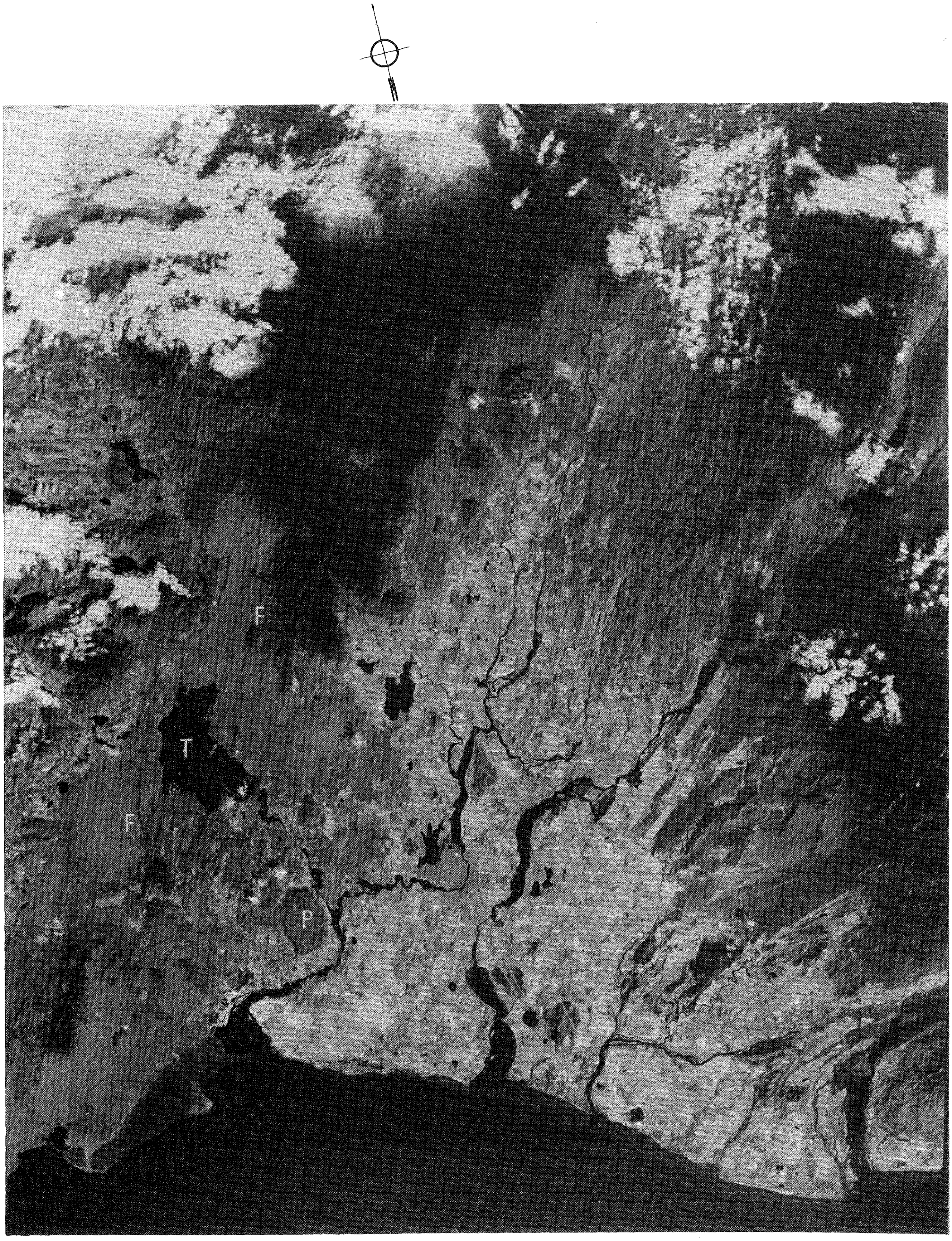


Fig. 2: Landsat-5 TM data - Band 4 - of the Test Site 1 - Thingvallavatn (see also fig. 1); Scale approx. 1 : 600 000
T = Thingvallavatn; F = Fissure Swarms and Normal Faults;
P = Palagonitic Table Mountain

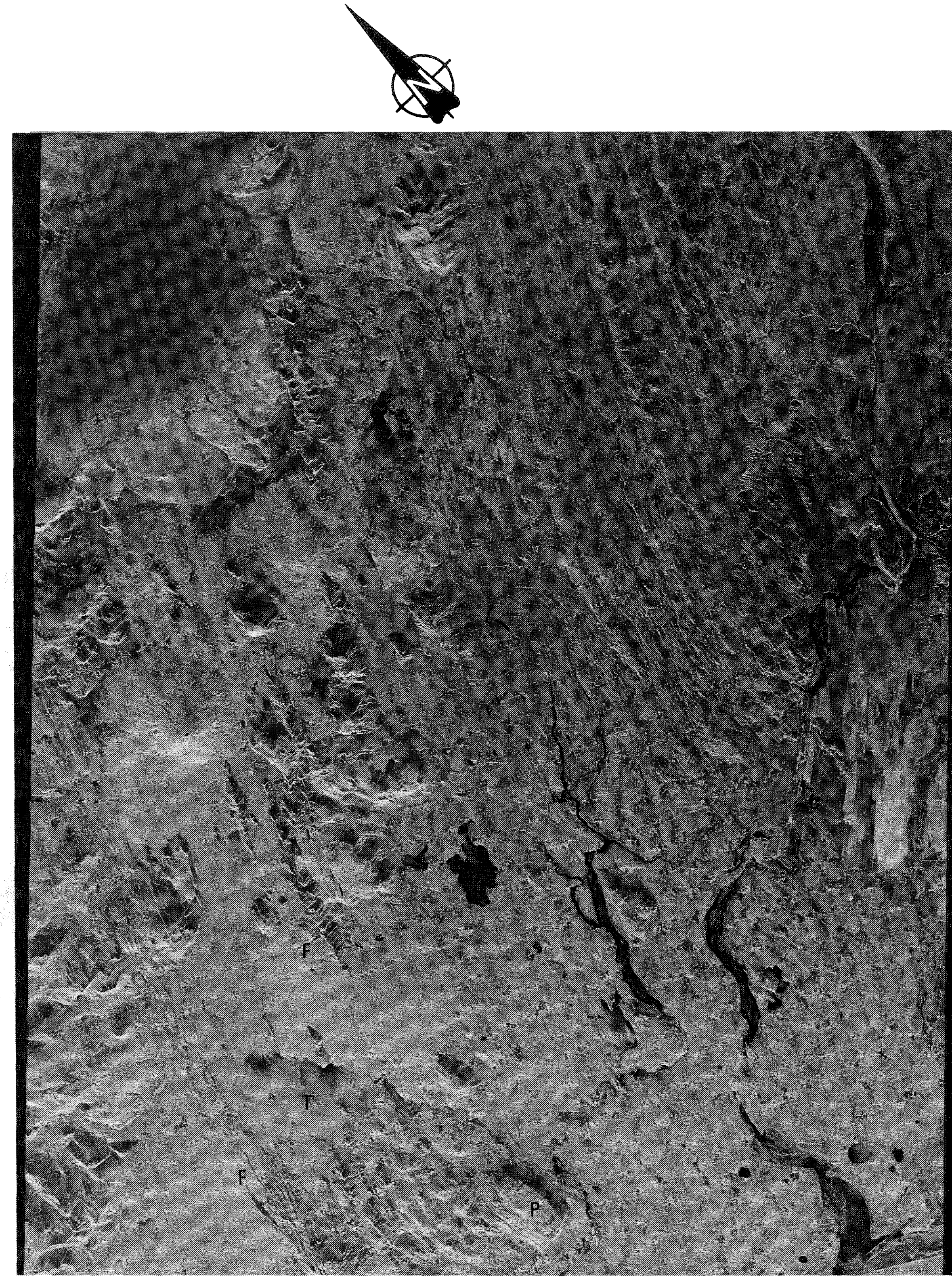


Fig. 3: SEASAT-SAR Data of the Test Site 1 - Thingvallavatn
Orbit 719 from August, 8, 1978, Scale: 1 : 500 000
T = Thingvallavatn, F = Fissure Swarms and Faults;
P = Palagonitic Table Mountain;
A detailed interpretation map, which is also including the information of SEASAT-SAR orbit 547 (capability of stereoscopic interpretation!) is given by fig. 4.

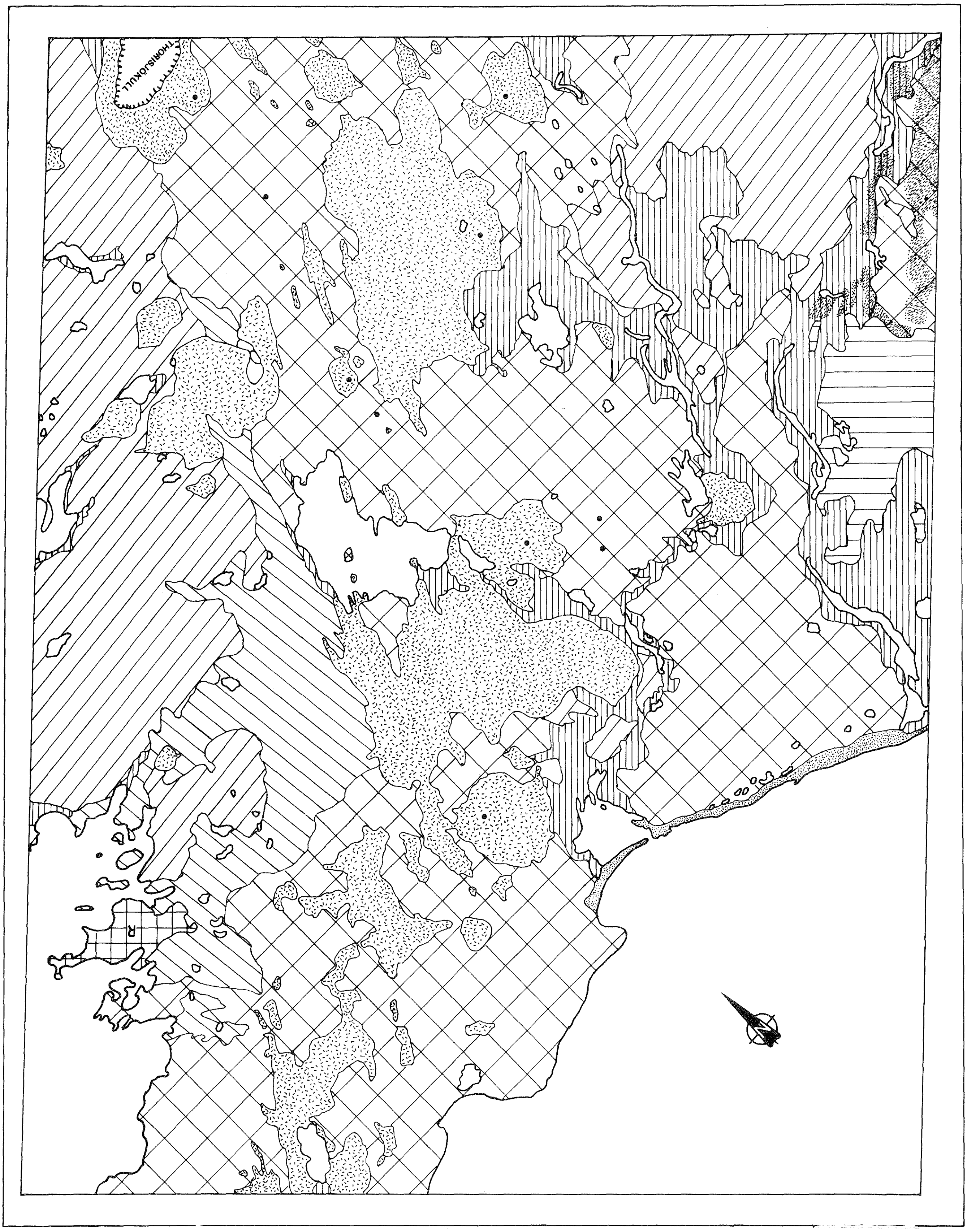


Fig. 4: Interpretation Map of the SEASAT-SAR Data of the Reykjavik-Thingvallavatn Area - Test Site 1
Orbit 0547, scene No SE 223, acquisition date: 04. August 1978 (explanations see next page)

EXPLANATION TO THE INTERPRETATION MAP OF THE SEASAT-SAR DATA OF ICELAND / SCENE REYKJAVIK - ORBIT 0547

Aeolian sediments

Alluvium in general

Basic and intermediate lavas - age: 0.7 m.y. to recent - mainly Postglacial

Basic and intermediate lavas - age: younger 0.7 m.y. - Pleistocene

Basic and intermediate hyaloclastites and tuffaceous sediments ("Palagonite Formation") partly mixed with lavas - age: younger 0.7 m.y. - Pleistocene

Basic and intermediate lavas - age: 3.1 - 0.7 m.y. - Tertiary / Quarternary

Basic and intermediate hyaloclastites and lavas - age: 3.1 - 0.7 m.y. - Tertiary / Quarternary

Craters

Glaciers

Areas with intensive wind erosion

City of Reykjavik

Fig. 5: Landsat-5 TM Data - Band 6 - of the Test Site 1 - Thingvallavatn
see also fig. 1; Scale approx. 1 : 600 000
T = Thingvallavatn; H = High Surface Temperatures of Nonvegetated Areas; R = High Temperatures due to Morphological Features; T = Thermal "Anomalies"

4.2. Test Site 2 - Skeidarasandur

The 2nd test site is situated south of the largest glacier in Iceland, Vatnajökull. It is built up by a wide flooding plain (Skeidarasandur) and basic lavas of postglacial ages.
Again, large parts of the test site are vegetated (natural vegetation dominated by moss) and, thus, the possibilities of Landsat-TM data to distinguish different rock types are reduced; this is demonstrated by fig. 6, where both data sets and an interpretation map of the SEASAT-SAR data are compared.

Due to the surface roughness, which significantly controls the backscattered radar signal and the appearance of selective weathering as a function of the age of the different lavas, the radar data make a clear differentiation of the stratigraphic sequences of the lavas feasible.
In addition, the detection of tectonic structures by use of the radar data is strongly correlated with incidence angle and look direction. It could be demonstrated by former investigations (RAST & JASKOLLA, 1985; JASKOLLA, 1986), that the establishment of the structural inventory of a distinct area is limited due to these parameters, because

* linear structures parallel to the look direction cannot be readily detected in radar imageries,

* the set-up of a rather complete structural inventory by use of radar data is significantly influenced by a suitable incidence angle in dependence on the morphology of the terrain; in general, it could be demonstrated by the evaluation of simulation data and in a comparison of SEASAT-SAR and SIR-A data of a test site in Sardegna, that for flat terrains a low incidence angle offers better possibilities to detect tectonic features; on the contrary, medium incidence angles are required for hilly to mountaneous areas;

* in addition, a falsification of the observed strike direction in relation to the real orientation of the structure vs. the look direction must be considered.

In order to avoid information loss and distortions, both data sets with its typical information content were combined:

* the roughness criterion of the SEASAT-SAT data, which reflects the lithological differences

* a derivate of the more "objective" Landsat-TM data concerning the representation of structural elements.

Fig. 6: Comparison of Landsat-5 TM Data, SEASAT-SAR Data and a Geological Interpretation Map of the Test Site 2 - Skeidarasandur

Fig. 6a: Landsat-5 TM Data - Band 4 and 7; Scale approx. 1 : 600 000 (see also fig. 1)

Fig. 6b: SEASAT-SAR Data - Orbit 834; Scale approx. 1 : 600 000 (see also fig. 1 and fig. 6c)

Fig. 6c: Geological Interpretation Map on the Basis of the SEASAT-SAR Data

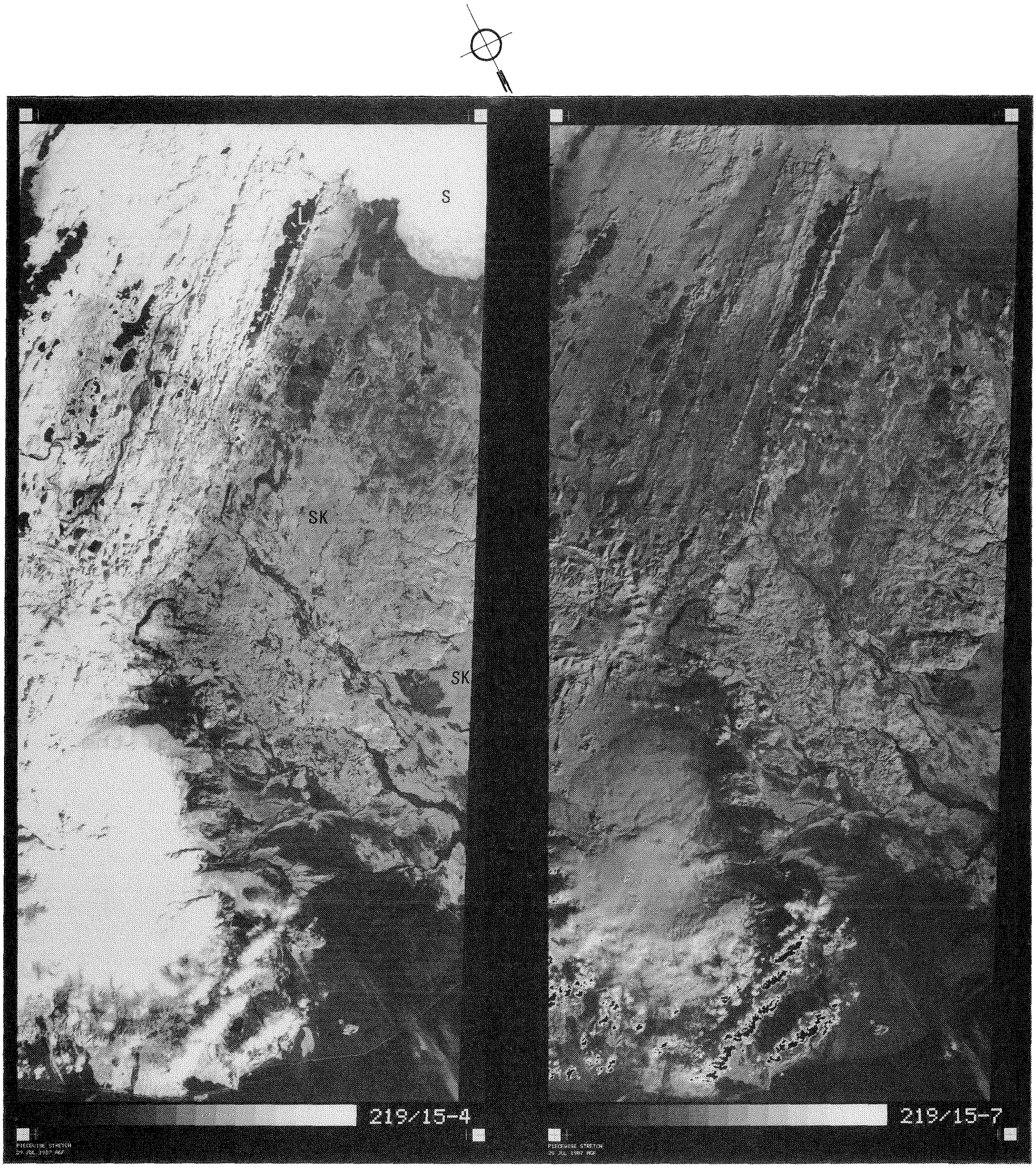


Fig. 6a: Landsat-5 TM Data - Band 4 and 7
S = Sithujökull (= part of the Vatnajokull),
L = Longisjor, SK = Skaftareldahraun

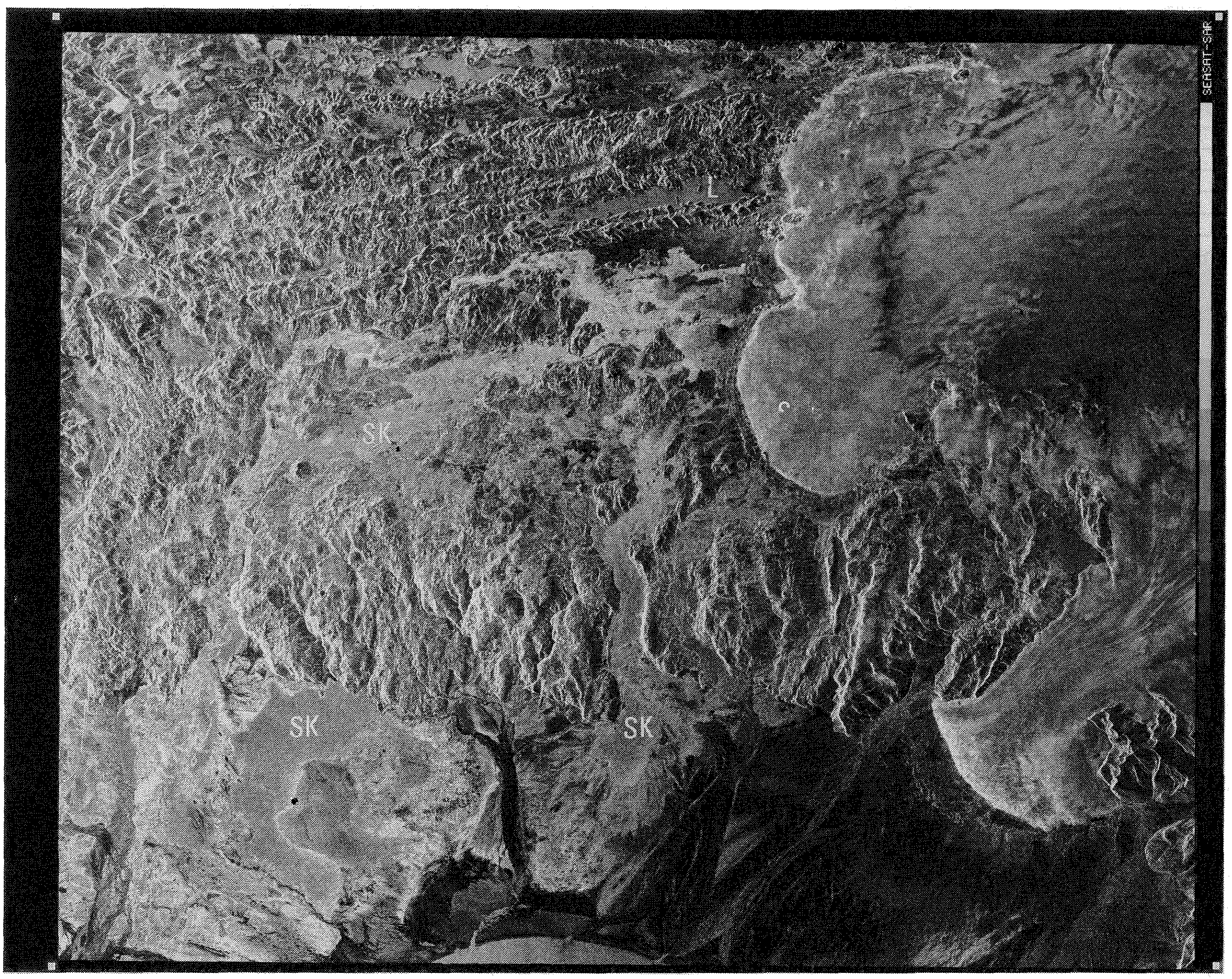


Fig. 6b: SEASAT-SAR Data of the Test Site 2 - Skeidarasandur
Expanation see fig. 6a and 6c

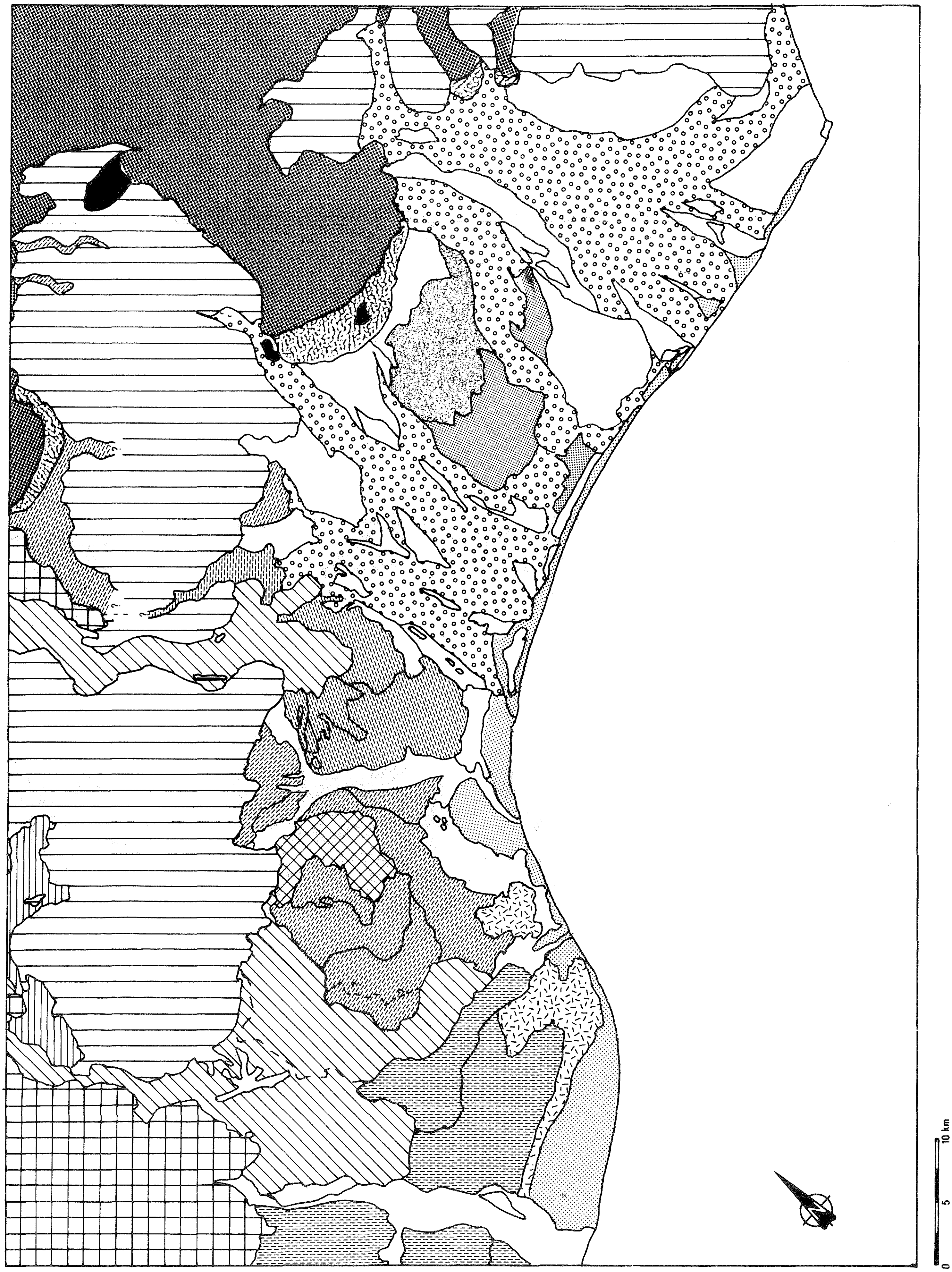


Fig. 6c: Interpretation Map on the Basis of the SEASAT-SAR Data of the Skeidarasandur Area - Test Site 2 (Explanations see next page)

EXPLANATION TO THE GEOLOGICAL INTERPRETATION MAP OF THE SEASAT-SAR DATA OF THE TEST SITE 2 – SKEIDARASANDUR

Glacier lakes

Glacier (Skeidarajökull) with medial moraine

Areas with intensive wind erosion

Aeolian deposits

Potential area of flooding

Active sandur

Vegetated alluvium

Nonvegetated alluvium with striking roughness differentiations

Terminal moraine

Basic and intermediate lavas of the Lakagigar event (1783 / 1784)

Basic and intermediate lavas younger than 4000 B.P. dominated by rootless cones

Basic and intermediate lavas younger than 4000 B.P.

Upper Pleistocene lavas

"Palagonite Formation"

Late Tertiary and lower Pleistocene basic and intermediate rocks

This was realized on the basis of the already mentioned I-H-S approach by the following association:

* I = Landsat-TM band 4 after high-pass filtering the data,

* H = SEASAT-SAR data (original data with an added low-pass filter to suppress linear features and

* S = constant (a constant saturation was selected mainly to avoid a too complex presentation, which can confuse the interpretability of the product).

The result (fig. 7) clearly underlines the significance of the digital combination of the different data sets, because

* an improved and more complete detection of geologically relevant phenomena becomes possible;

* the disadvantages of the different data acquisition systems can be minimized.

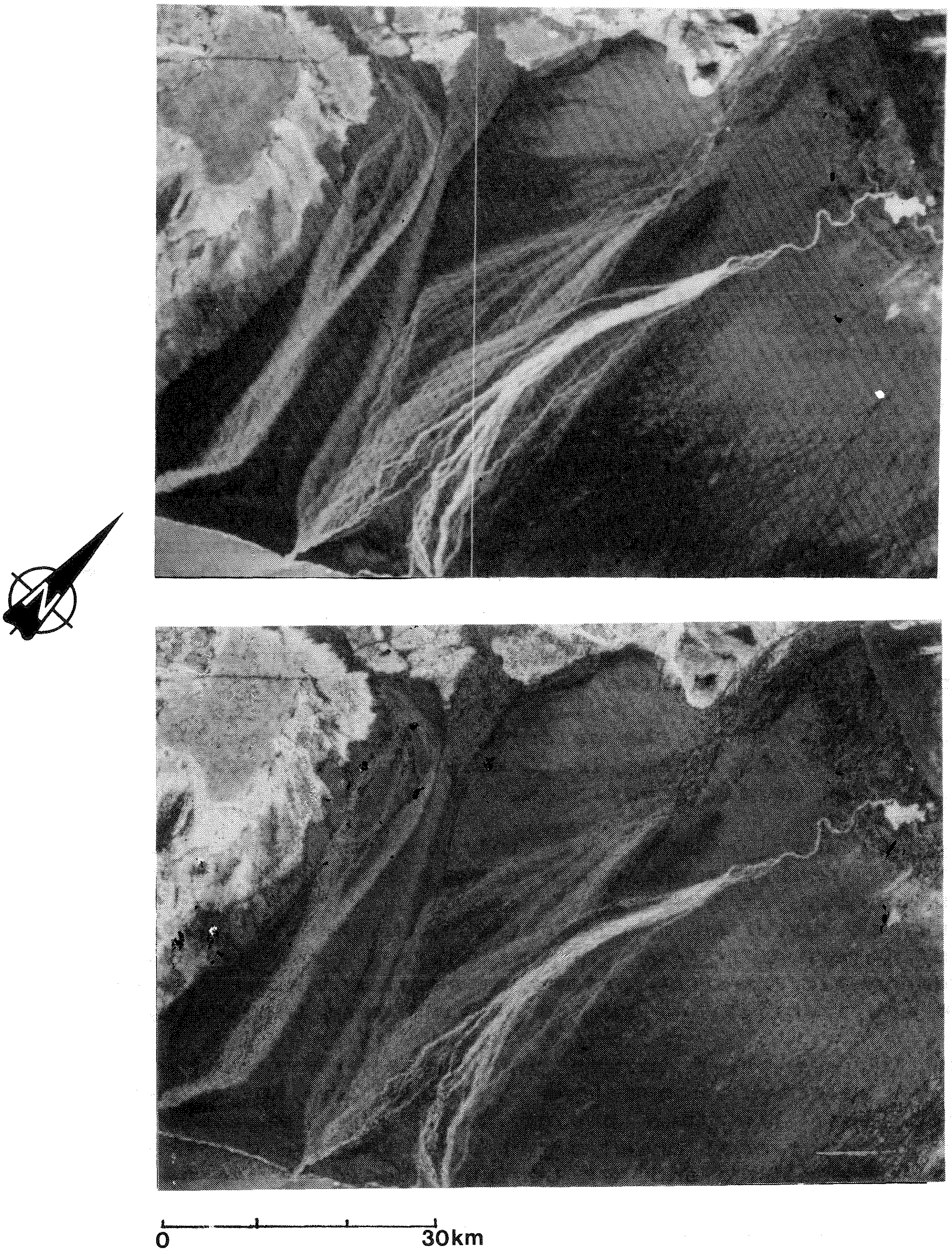
4.3 Test Site 3 - Torfajökull

This 3rd test site was selected, because the geological situation in this area is so complex and interesting, that it seemed to be effective, again, to combine optical and radar data due to the additional information content.

The test site is mainly built up by hyaloclastic and acidic rocks; it is, additionally, characterized by a very large caldera, in which a huge geothermal area has developed.

At this place, it has to be pointed out, that the investigations could not be realized on the basis of Landsat-TM data, because the data made available by ESA/ESRIN in the framework of the "Landsat-TM Pilot Project" showed total snow coverage in this selected test site. Thus, it was necessary to refer to Landsat-MSS data, which have been available at the AGF.

The results, again, underline the statements, which have been made above: in general, it can be summarized that the Landsat-MSS data of this particular test site seem to be more suited to distinguish structural features, while SEASAT-SAR give more information on the lithology.
In consequence, a combination was selected in which it is possible to present both parameters independently.



Landsat-MSS
False Color
Image

Combination of
Landsat-MSS and
SEASAT-SAR Data

Fig. 7: Comparison of a Landsat-MSS false Color Image with the digitally combined MSS/SEASAT-SAR Data (location see fig. 6b). It is obvious, that within the wide non-vegetated sandur area a much more detailed separation of surface units becomes possible by adding the "roughness component" of the SEASAT-SAR data to the spectral information of Landsat-MSS; on the other hand the detectability of the run-off system, which is better in the Landsat-MSS data is preserved in this combination.

In particular the following combination was evaluated of being most effective to solve the task:

* I = structural pattern on the basis of the Landsat-MSS data by applying a high-pass filter

* H = roughness pattern of the SEASAT-SAR data and

* S = constant.

The combination results offer now again the possibility of a better differentiation of the various geological features of the Torfajökull area (fig. 8):

* The acidic extrusive rocks with their typical morphology and low roughness appear in broad variety of colors; in general, however, the brightness is greater than in the surroundings;

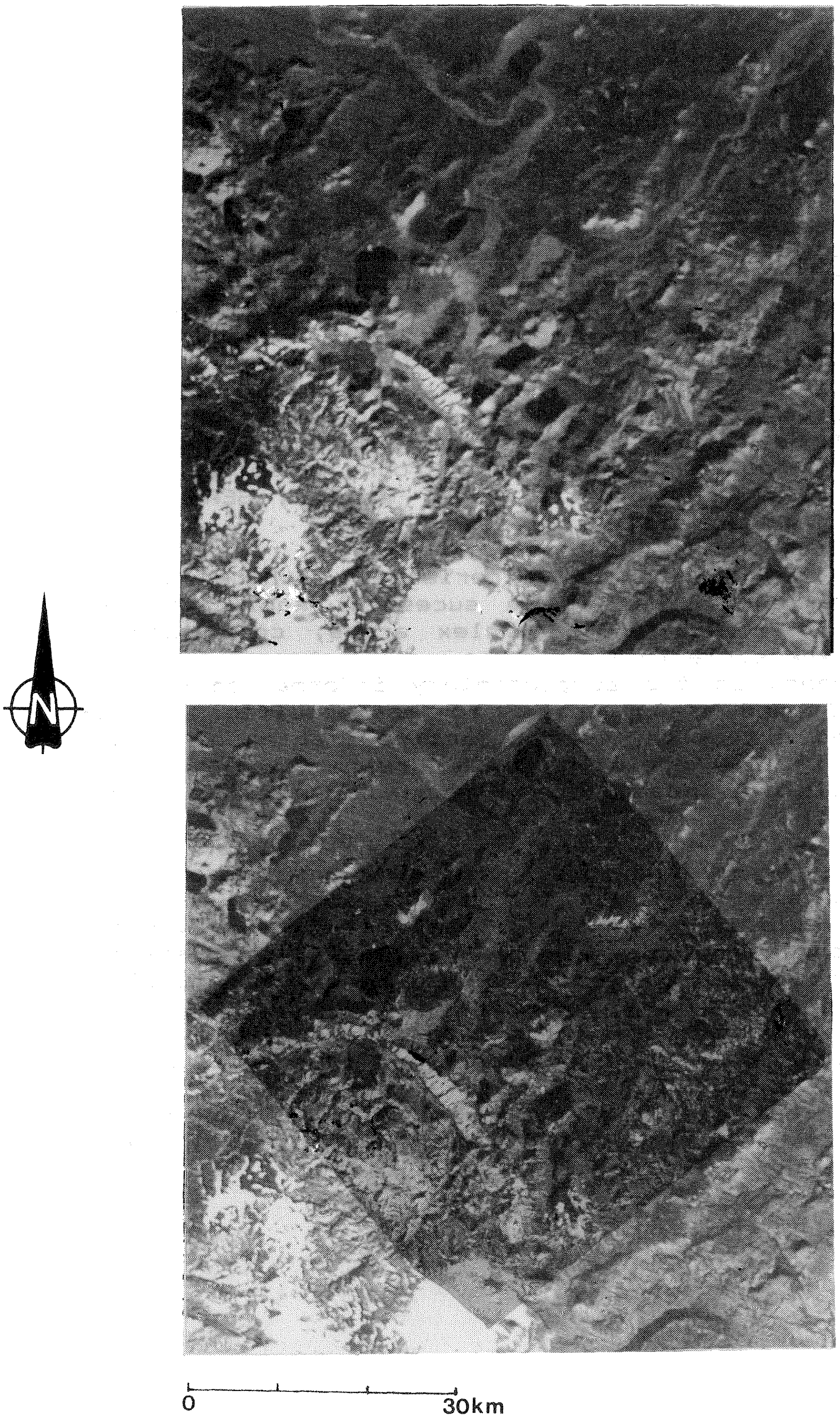
* the relatively rough intermediate to basic hyaloclastic rocks of the surroundings of the caldera are characterized by more greenish and brownish colors; in general, the colors are darker;

* the mostly very fine non consolidated deposits of rivers etc. have very bright blueish and greenish colors;

* additionally, the rim of the caldera, as well as smaller, secondary craters and linear features associated with faults and fissures can be differentiated.

As already outlined within the introduction, the lacking availability of really appropriate data affects the interpretability seriously.
Nevertheless, it could be demonstrated that the combined presentation of information from the optical and radar portion of the electromagnetic spectrum offers an excellent tool for supporting the applicability of remote sensing data in geology.

In addition, it was tried to use the thermal infrared band of Landsat-TM of selected, cloud-free "windows" aiming to detect thermal anomalies; the idea behind being the consideration, that in the snow covered area significant thermal differences between the surroundings and hot springs should become detectable.
However, it was not possible to distinguish any relevant phenomenon unambiguously. This seems to be caused by the insufficient ground resolution of Landsat-TM band 6 as well as the lacking multitemporal data acquisition at suitable hours of the day.



Landsat-TM False Color Image

Combination of the Landsat-TM- and SEASAT-SAR Data

Fig. 8: Comparison of a Landsat-TM False Color Presentation with the Digital Combination with SEASAT-SAR Data of the Torfajokull Area - Test Site 3

5. CONCLUSION

With this presentation, it should be demonstrated, that remote sensing data acquired by optical and radar systems have a very high potential for geoscientific application purposes if the different information content is presented in a logical manner.

The former investigations presented (JASKOLLA, et.al., 1986; RAST & JASKOLLA, 1985; JASKOLLA & RAST, 1986; JASKOLLA, 1986) were realized on the basis of data over arid to semi-arid areas, where, generally, the information content of optical and radar data is significantly more detailed. The realization of similar investigations on the basis of data over Iceland, could prove that also within intensively vegetated areas an improved application of remote sensing data becomes possible - although the data available cannot be designated as optimized for geological purposes (Landsat-TM: ground resolution and time of data acquisition, especially for band 6; SEASAT-SAR: L-band radar with a very steep incidence angle).

In particular, the results and experiences gathered during the investigation show, that for a sucessful application of remote sensing in geologically complex areas, complementary data are an indespensable tool.
This can be founded on the supplementary information content of the optical and radar data (object-specific reflection/emission and extensive, more objective imaging of structural features in the optical domain, respectively surface roughness and moisture in addition with morphological elements in the radar data).

In addition, it became obvious, that in many cases, the understanding of a single data set can be improved significantly by the availability of independent data from different wavelength regions. This actually means, that the implementation of any spaceborne, e.g. radar system requires a parallel data aquisition in the optical region.
Such a data combination gains importance considering e.g. the expected improvements for surface moisture measurements by use of C-band radar data (ERS-1).
It also applies for the use of improved optical and thermal infrared data (possibly HIRIS, HRIS and the Thermal Infrared Multispectral Scanner TIMS) for the same subject.

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7. REFERENCES

FORD, J.P., CIMINO, J.B., HOLT, B. & RUZEK, M.R. 1986: Shuttle Imaging Radar Views the Earth from Challenger: the SIR-B Experiment. - JPL Publication 86-10, Pasadena, California.

HAYDN, R., DALKE, G.W., HENKEL, J. & BARE, J., 1982: Application of the I-H-S Transform to the Processing of Multisensor Data and Image Enhancement. - Int. Symp. Rem. Sens. of Arid and Semi-Arid Lands, Cairo, Egypt.

JASKOLLA, F. & RAST, M., 1986: Requirements of Radar Data for Geological Application - A Case Study by Use of Multistage Data of the Test Site Sardegna/Italy. - ESA/EARSEL Symp. on Europe from Space, Lyngby/Denmark, ESA SP-258.

JASKOLLA, F., 1986: Radaraufnahmen der Erdoberfläche aus dem Weltraum - Anwendungsmöglichkeiten und Grenzen in der Geologie, sowie Anforderungen an zukünftige Systeme. - Habilitationsschrift der Univ. München.

MAMULA, N. & VOIGHT, B., 1982: Structural Analysis of a Divergent Plate Boundary Terrain - a Landsat Perspective.
Proc. Int. Symp. Rem. Sens. Env., 2nd Them. Conf., Rem. Sens. for Mineral Exploration, Fort Worth, Texas.

McDONOUGH, M. & MARTIN-KAYE, P.H.A., 1984: Radargeologic Interpretation of SEASAT imagery of Iceland. - Int. Journ. Rem. Sens., Vol. 5, No. 2.

RAST, M. & JASKOLLA, f., 1985: Digital Combination of SAR and MSS Optical Data for the Identification of Spectral Signatures. - Int. Coll. on Spectral Signatures in Rem. Sens., Les Arcs, France.

SAEMUNDSON, K., 1979: Outline of the Geology of Iceland. - Jökull 29, Reykjavik/Iceland.