SR No. 580-03

MAJOR CRUSTAL FRACTURES IN THE BALTIC SHIELD

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Type II Report for Period July 1972 - April 1973

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15. Abstract

The object of the project is to study the major fracture and fault zones of the Baltic Shield and their relationships to mineral deposits. The first ERTS images were received in late October 1972. Since then B&W enlargements as well as various color composite prints have been produced from the best images. During the reporting period necessary background data have been analysed, a quick evaluation of the ERTS imagery for the survey of Quaternary features and a preliminary analysis of the bedrock features have been carried out, and a thorough analysis of all the data has been started.

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1.0 SUMMARY REPORT

The purpose of this project is to study the major fracture and fault zones of the Baltic Shield and their relationships to the mineral deposits. The test site is situated in northern Finland (Fig. 1) and covers an area of about 180 x 180 km^2.

The objects of the program are approached by analysing ground truth and aerial data of the area by various methods and, on the other hand, analysing ERTS-imagery both visually and with optical filtering, and by densitometric analyses.

During the reporting period a reproduction of the aeromagnetic data has been started as well as an interpretation of the aerial photos (1: 60 000) for a lineament analysis of the test site and its surroundings. At present about a half of this has been carried out.

The first ERTS images (MSS) were received in late October 1972 and since then the preliminary analysis of them has been made and the thorough analysis started by various methods. The images have been reproduced both in B & W and in color on the scales 1: 1 000 000 and 1: 400 000. Some partial enlargements have also been produced.

Technical problems encountered so far have centered largely on the defects in received 70 mm copies, which hampered the processing of new prints. It was found that the quality of 9.5 inch transparencies exceeded that of 70 mm and consequently the first-mentioned has been used in data processing.

Another technical problem has arisen in processing 35 mm input transparencies of ERTS images with suitable contrast for optical filtering and in producing adequate filters.

The quick evaluation of ERTS imagery for the survey of Quaternary features has been carried out although it does not belong to the main objects of this program. The analysis of bedrock features has shown that schist belts, as known from ground surveys, can be discerned from areas occupied by their basement rocks or major plutons. A number of sharp lineaments, apparently faults, are visible. Some major fracture zones that form distinct lineaments in weather satellite pictures and belong to the main objects of this study, are rather indistict in the images but can be traced.

No ground survey of the features discerned has been carried out so far since the test site has been covered with snow and there has been arctic twilight for the most of the time after the imagery was received. Additional coverage of ERTS imagery has also been awaited.

A field survey project for studying the correlations between bedrock, glacial deposits, vegetation and the density variations of ERTS imagery has been planned for the summer 1973. Other short term objectives for the project are:

- To continue the analysis of received ERTS imagery by optical filtering and densitometric analyses using both densitometers and Agfa Contour equidensity material,
- To start systematic directional analysis of the reproduced aeromagnetic data, the lineament maps interpreted from the aerial photos and of the lineament maps compiled on the basis of ERTS imagery.

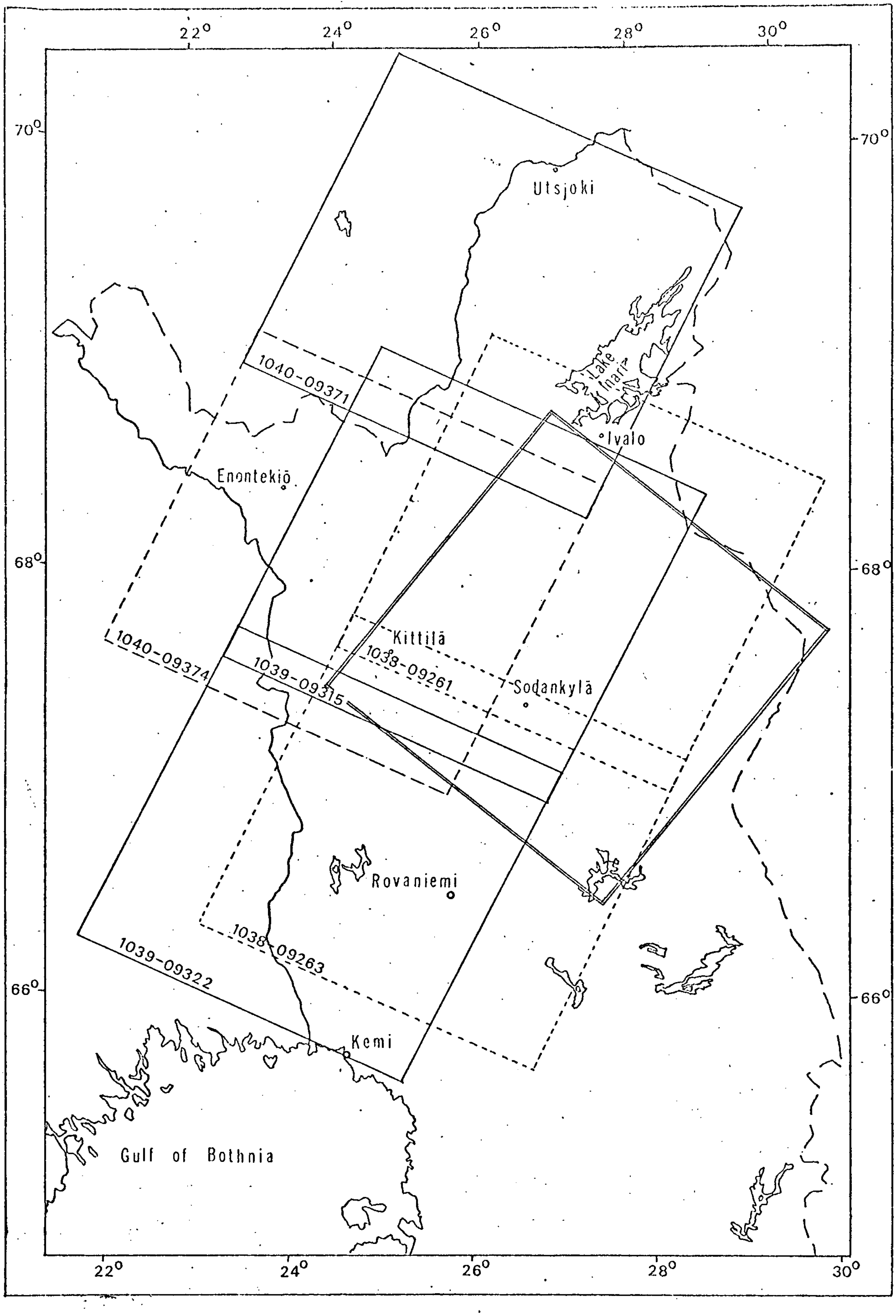

Figure 1. The test site of the program and the coverage of the received ERTS imagery.

	Test site		
———	Cloud cover	< 50%	in the image
— — —	" "	= 50%	" " "
- - - - -	" "	> 50%	" " "

2.0 TECHNICAL REPORT

2.1 Image quality and processing

The first sets of MSS images covering the test site were obtained by ERTS-1 at about the end of August 1972 and received by P.I. in late October 1972 (Table 1). The time between the date of imaging and that of receipt of the product was from 50 to 69 days. There were some defects in the shipment of 70 mm products and a part of the images had too high a cloud cover percentage (as defined by the Forest Research Institute, ERTS-program No SR 580-02) for the purposes of this project (Table 1). It must be noted, however, that the cloud cover percentage (NASA/NDPF User Services 1972) did not exceed the requirements of the standing order of the project.

The best of the images (1039-09315) covers about a half of the test site (Fig. 1). However, since the images 1039-09322, 1039-09315 and 1040-09371 provide a detailed and almost cloud-free picture of a zone extending 500 km north-northeast from the northern coast of the Gulf of Bothnia, they all have been included in the study. The image 1040-09374 would provide a side lap stereo pair with 1039-09315, but unfortunately its eastern half is entirely covered with clouds. Since even in the western parts of the image the clouds and their shadows disturb the picture, it has only been used occasionally so far.

Table 2 summarizes the defects found in the analysed images. The Newton rings in the 70 mm products and the over exposing of the negatives restricted, together with the missing of some 70 mm products, the use of them in the processing of new prints. Moreover, the grain size of the negatives appeared to affect the image quality.

For the visual analysis B & W and various color prints have been processed from the images 1039-09322, 1039-09315 and 1040-09371. Negatives have been contact copied from 9.5 inch transparencies separately for reproduction of B & W and color composite prints. Since the images had rather low contrast, so that the tonal variations were difficult to observe, the reprocessed negatives have been enhanced as shown in figure 2. Tables 3 and 4 summarize the materials used in the process.

The B & W prints have been reproduced using the scale of 1: 400 000 as well as the color composite prints of the spectral band - color combination 4-yellow, 5-red and 7-blue. The image distortions of the B & W enlargements were also roughly corrected. The correction was carried out using an enlarger designed for the correction of bulk aerial photos. A general topographic map (1: 400 000) was used as the basis for the correction. Moreover, several different color composite prints using scale 1: 1000 000 have been produced. In this case the filters for each band were chosen as to follow the "normal" order of the spectrum, that is, the band of the shortest wavelenght appearing as blue and that of the longest as red (Table 4). In order to determine the differences between each combination of the bands, the same filter densities and exposing times have been used in all these combinations.

TABLE 1. RECEIVED ERTS IMAGERY (BULK B & W MSS)

	70 mm negative transparency				70 mm positive transparency				9.5 inch positive transparency				9.5 inch paper print				cloud cover	usefulness of the image for the project
	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7		
1938-09261					x	x	x	x	x	x	x	x	x	x	x	x	90%	not useful
1038-09263					x	x	x	x	x	x	x	x	x	x	x	x	65%	not useful
1039-09315	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	0%	good
1039-09322	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	5%	good
1040-09371	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	20%	good
1040-09374	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	50%	useful

x received

TABLE 2. DEFECTS IN THE IMAGES HAVING CLOUD COVER <50%

	70 negative transparency	70 positive transparency	9.5 inc. positive transparency	9.5 inch paper print	Affect on the investigation
Newton rings	1039-09315-4 1039-09315-5 1039-09322-4 1039-09322-5	1039-09315-4			great
Dark vertical lines (scratches)	1039-09315-4 1039-09322-4	1039-09315-4 1039-09322-4	1039-09315-4 1039-09322-4	1039-09315-4 1039-09322-4	minor
Dust particles	1039-09315-5				none
Horizontal stripes	1039-09315-4 1039-09322-4	1039-09315-4 1039-09322-4	1039-09315-4 1039-09322-4	1039-09315-4 1039-09322-4	some
Nonlinear grey scale	all	all	all	all	minor
Overexposing	all			bands 4 and 5 of all images	great
Banding	bands 4 and 5 of all images	bands 4 and 5 of all images	bands 4 and 5 of all images	bands 4 and 5 of all images	minor
Grain size	all				some

TABLE 3. MATERIALS USED IN THE PROCESSING OF 1: 400 000 B & W PAPER PRINTS (4 x magn. of 9.5 inch transp.)

<u>9.5 inch negative transparencies</u>

Bands 4 and 7:	Film: Agfa Gevaert Gevatone N 33 Developer: Qvalitol, 1:10 dill.
Bands 5 and 6:	Film: Agfa Gevaert Gevatone N 43 Developer: Ph. 2, 1:5 dill.

<u>1:400 000 paper prints (4 x magn.)</u>

Bands 4 and 7:	Paper: Ilford B-3 Ip
Bands 5 and 6:	Paper: Ilford B-3 Ip and Kodak W-Semi M-3

TABLE 4, THE PROCESSING OF COLOR COMPOSITE PAPER PRINTS

9.5. inch negative transparencies

Film: Typon FRN-PE, type A

Developer: Agfa Gevaert G 5 c, dill: 1:7

Developing time: 1,5 min in 20°C

9.5. inch color composite paper prints (scale 1:1 000 000)

Paper and process: see equipment and materials

Filters and exposure coefficients used in the process						
Spectral band combination				processed color	Filter (Kodak Wratten)	Exposure coefficient
5	4	4	4	cyan	red (no. 25)	8.60
6	6	5	5	yellow	blue (no. 47 B)	1.00
7	7	6	7	magenta	green (no. 58)	1.70

9.5. inch positive transparencies

Film: Typon FRN-PE type A

Developer: Agfa Gevaert G 5 c, dill. 1:7

Developing time: 1.5 min. in 20° C

1:400 000 negative transparencies (4 x magn.)

Film: 3 M MC - PE

Developer: Du Pont Kronafin, dill. 1:7

Developing time: 1.5 min. in 20°C

1:400 000 color composite paper prints

Paper and process: see equipment and materials

Filters and exposure coefficients used in the process			
Spectral band	processed color	Filter (Kodak Wratten)	Exposure coefficient
4	yellow	blue (no. 47 B)	1.00
5	magenta	green (no. 58)	1.79
7	cyan	red (no. 25)	6.32

Equipment and materials:	
Enlarger:	Durst G 139 with color head CLS 200
Processor:	Kodak Rapid Color Processor
Paper:	Kodak Ektacolor Professional
Process:	Kodak Process CP 100 (in 114° F)

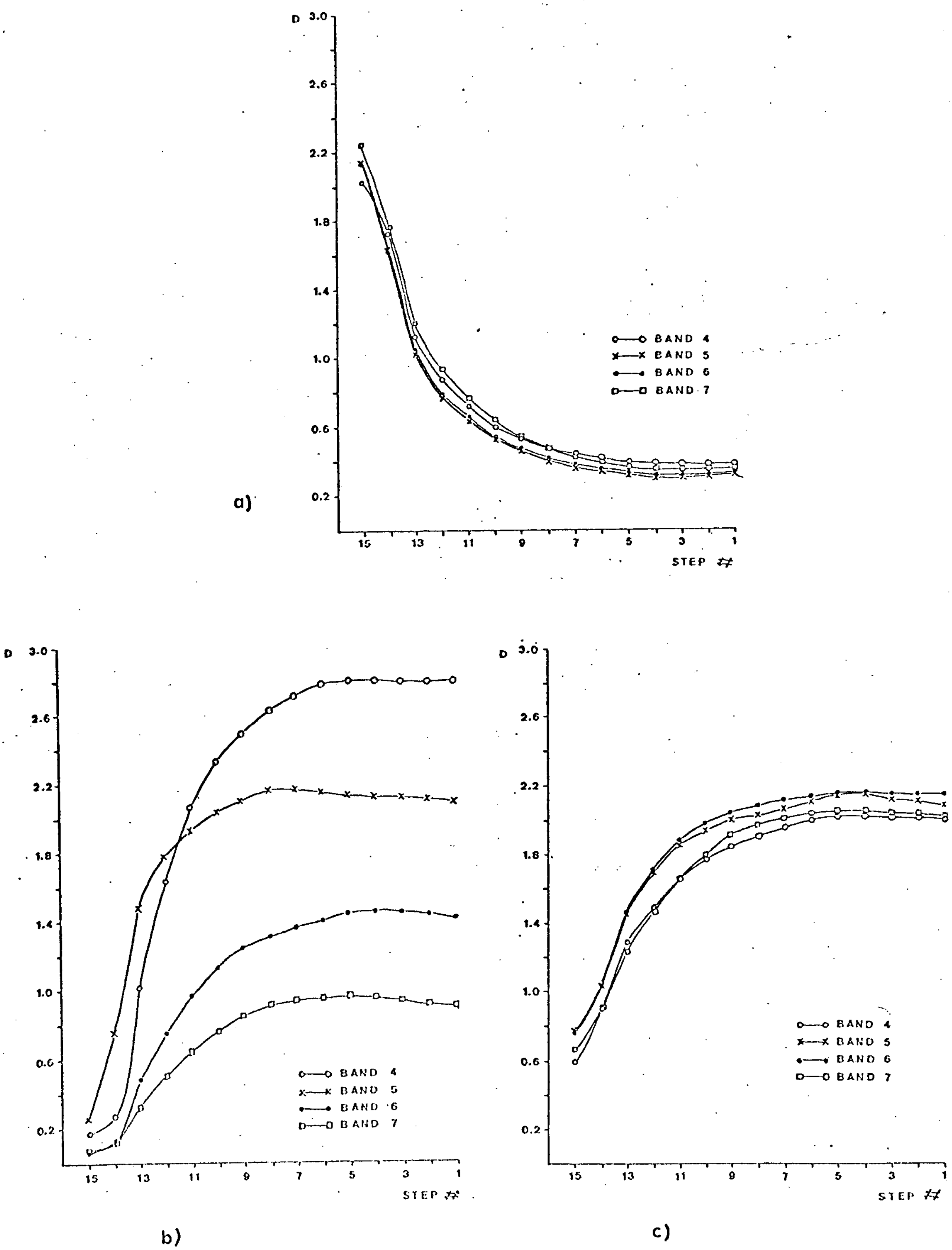

Figure 2. An example of the enhancement of the 9.5 inch negatives: curves of gray scale vs. density for the image 1039-09322.

a) 9.5 inch positives supplied by NASA
b) 9.5 inch negatives reprocessed to enhance land features in B&W 1:400 000 enlargements
c) 9.5 inch negatives for reproduction of color composite prints.

Processing of 35 mm transparencies of ERTS imagery for optical filtering has been tried with the Agfa Gevaert 35 mm materials Copex positive and Copex Pan. The reproduction device was a Leitz Reprovit II a with a Focotar 1:4,5/50 mm objective.
The results have not yet been quite satisfactory. The wedge type optical filters used, as well as most optical filters in general, cause so called edge-effects nearly in the directions of the edges of the filters. These effects are seen in the output as sharp "scanning lines" especially when the input transparency is of variable density type, i.e. an aerial photo or satellite image etc. The effects become disturbingly strong if the input has low contrast, as it has in the case of ERTS imagery.

Efforts will be made to solve these problems by producing variable density filters which do not cause marked edge-effects, or possibly by using density sliced ERTS images as inputs.

Additionally, it has been noted that it would have been desirable to have original copies of the images for each processing method, since the data flow has been somewhat delayed because of having too few 9.5. inch transparencies for the data processing.

2.2 Processing of background data

The following background data are available for the area covered by the images 1039-09322, 1039-09315 and 1040-09371:

- aerial photographs, 1:60 000, alt. 9300 m,
- aeromagnetic maps, profile intervals 400 m, flying alt. 150 m, 1:20 000,
- general geologic maps separately for the basement rocks and quaternary deposits, 1:400 000,
- general gravity maps, 1:400 000.

Moreover there are geologic and geophysical detail maps, drilling data and aerial CIR photos available for various parts of the area.

For the evaluation of the results for a thorough analysis of ERTS imagery it is necessary to compile a small scale aeromagnetic map and a lineament map of the test site and its surroundings. During the reporting period it has been made a routine of the redrawing of the aeromagnetic maps (1:20 000) for processing of the previously mentioned map. The interpretation of aerial photos on the scale 1:60 000 (total about 1000 photos) for the preparation of a photo lineament map of Central Lapland has also been started. The directional analysis of these data will be performed with the optical filter and compared with the results of the optical filtering of ERTS imagery. Figure 3 shows the areas intended to be covered by the afore-mentioned maps and the status of compilation work at the end of the reporting period.

General gravity maps have not been used so far, since new and more accurate maps will be published by the Geodetic Institute of Finland.

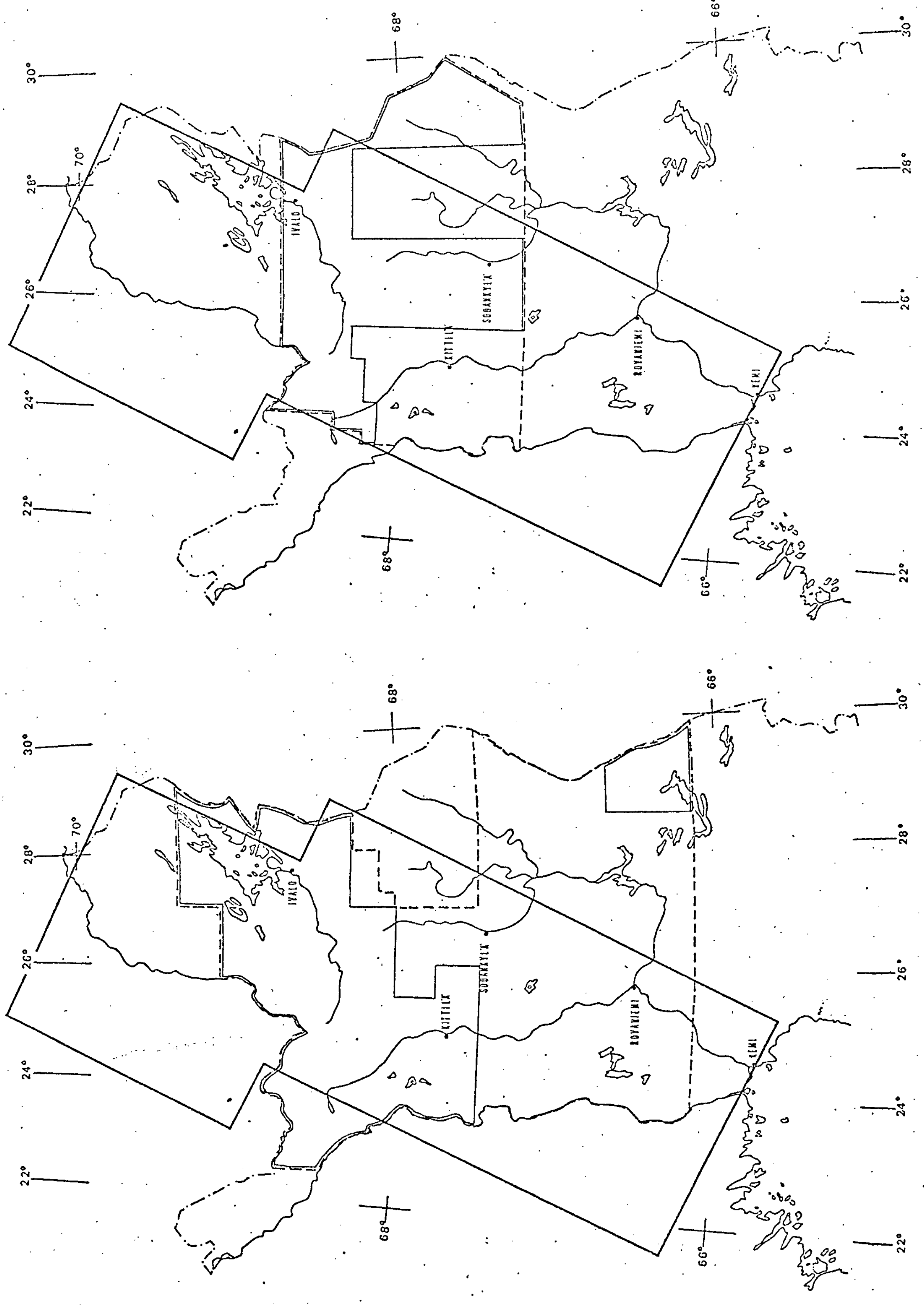

Figure 3. The planned coverages (broken line) of a) reproduced aeromagnetic map, and b) photolineament map. The thin solid line shows the areas compiled during the reporing period. The heavy solid line indicates the areas covered by ERTS images having cloud cover < 50%.

These maps will be used in the final analysis of the results obtained.

The general geologic maps as well as general topographic maps have been used extensively in the preliminary analysis of the imagery and will be used continuously when evaluating the results of the analyses.

2.3. Field surveys

No field survey for studying the features discerned in the different bands of ERTS imagery has so far been done, because the test site has been covered with snow since the time the imagery was received. Moreover, only the first of the three repetitive ERTS-1 coverages planned has been completed.

A field survey of a test plot common with the ERTS-1 project of the Forest Research Institute (ERTS-program No. SR 580-02) has been planned for the summer 1973. The size of the plot is about 96 x 16 km^2 and it covers an area consisting of several different units of metamorphic and plutonic rocks common to Lapland. The intention of the field survey is to study the correlations found between bedrock, glacial deposits, vegetation and the density variations of different spectral bands of ERTS imagery. The results of the study will be used for evaluation of the features discerned elsewhere in the area covered by the images.

2.4. Published articles and papers

No articles or papers have been published during the reporting period.

3.0 SIGNIFICANT RESULTS

3.1. General

B & W paper prints (1:1000 000 and 1:400 000) and B & W positive transparencies (1:1000 000) of the images 1039-09315, 1039-09322 and 1040-09371 with all bands of MSS have been used in the analyses reported here. The color composite prints 1:1000 000 have also been used additionally although not mentioned separately in the following. The quick evaluation of ERTS imagery for the survey of Quaternary deposits was considered necessary although it does not belong to the main objects of this program. The evaluation was mainly carried out using information provided by the field surveys of the Geological Survey of Finland. The discerned bedrock features - especially rock bodies - could be partly correlated with existing general and detailed geologic maps. However, for the indentification of fault structures, in particular, there is little ground data available before the processing of the background data of this program (see page 14) has been completed.

From an initial examination of the MSS images it could be noted that the bands 4 (0.5-0.6 μm) and 5 (0.6-0.7 μm) reveal the major urban areas, agricultural and timbering (especially clear cutting) areas, highways as well as airfields and an open pit mine. Different kinds of forest swamps and bare fell tops were also discerned. Even the border between Norway and Finland was clearly visible, since the grey tones on the Norwegian side were considerably lighter. The reason for this is unknown, but it has been assumed that the reindeer fence at the border and a different quantity of pasturing of reindeers in these areas could be the cause. The lakes, rivers and wet swamps could best be discerned on the IR bands 6 (0.7-0.8 μm) and 7 (0.8-1.1 μm).

3.2. Quaternary features

The most significant Quaternary features visible in the MSS images have been summarized in figure 4.

Charasteristic to the bare fell tops are exposed areas and the block fields formed by frost action (on the image 1040-09371) and periglacial processes (on the image 1039-09315). They appear to have a high reflectance on the shorter wavelenghts and rather weak on the IR part of the spectrum. Thus the blockfields can be distinguished as areas of light grey tones in the B & W images of bands 4 and 5, but cannot be discerned or appear dark in bands 6 and 7.

The ancient shoreline on the image 1039-09322 is seen as a narrow block field especially in bands 4 and 5.

The effects of the Quaternary ice sheet on the morphography can be quite well seen in the images. There are drumlin terrains visible in several places on all the analysed images; they are well revealed in all the bands except 4. This seems to be due to the reflectance difference caused by the vegetation which is different on the drumlins and in the areas in between them, the latter being usually peat bogs. Apparent glacial fluting is also visible on the image 1040-09371 (band 5).

The peat bogs are best discerned in band 5, but can also be traced in bands 6 and 7. The bog areas with sparse pine forest cover and specific flora (sedges and other grass, wild rosemary, dwarf birch etc.) appear light, but with the growing degree of swampiness they turn dark especially on the IR bands. Thus the open wet parts of peat bogs can easily be discerned in bands 6 and 7. Since the peat bogs cover considerable parts of the imaged areas (some 40-50%), only the distinct wet parts (marshes) are marked on Figure 4.

On image 1040-09371 an area was further recognized having an appearance of hummocky moraine terrain. This however, is situated in Norway.

Eskers, glacifluvial deposits and deltas are best distinguishable in bands 5 and 4, but can be traced in places also in the IR bands.

Fluvial deposits are seen in the image 1039-09322 in the valleys of the Tornio and Kemi rivers. They are easily discerned in bands 4 and

5, evidently because of the cultivated fields and pasture lands. In the IR bands they appear to have about the same reflectance as the peat bogs and could not be separated from them.

Bands 4, 5 and 6 of image 1039-09315 reveal parts of eskers and glacifluvial deltas which are affected by eolian activity. Band 6 seems to be especially good for this since the areas affected by the wind seem, on these wavelengths, to have a considerably higher reflectance and thus lighter grey tones than the glacifluvial deposits.

It seems evident that ERTS imagery would be of great help in mapping and evaluating Quaternary features. The size of the area covered by, and the adequately small scale of, ERTS images would provide a total view of features existing in large areas so uncontinously that conventional methods could not reveal the entirety properly. It might further, through careful analysis of suitably enhanced imagery, be possible to extract new information about the movements of the Continental ice sheet. Thus ERTS imagery could likely improve the understanding of the processes involved in the movements of the ice sheet as well as of the history of Quaternary glaciation on the Baltic Shield in general.

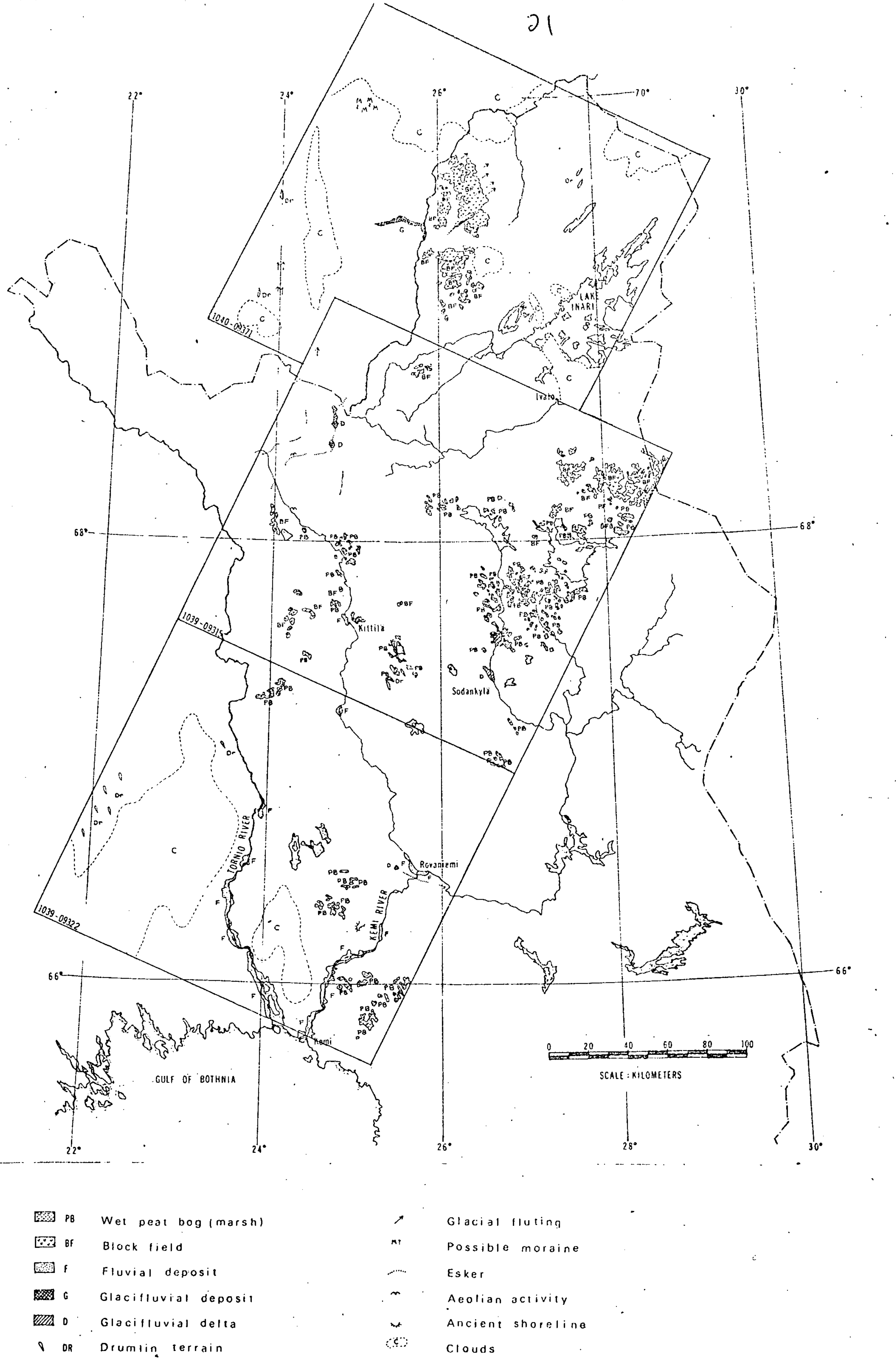

Figure 4. A sketch map of Quaternary features as interpreted in the preliminary analysis of ERTS imagery.

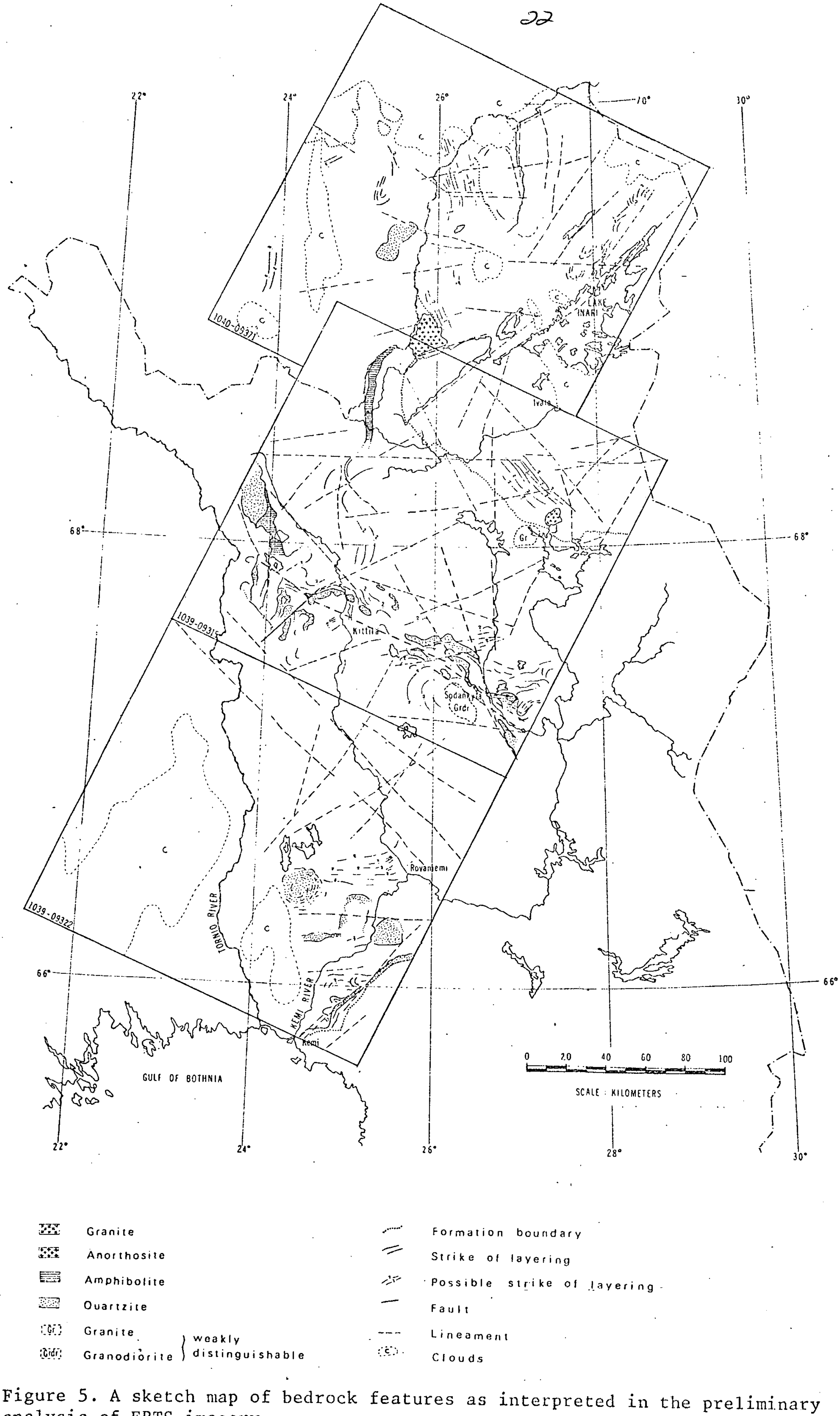

Figure 5. A sketch map of bedrock features as interpreted in the preliminary analysis of ERTS imagery.

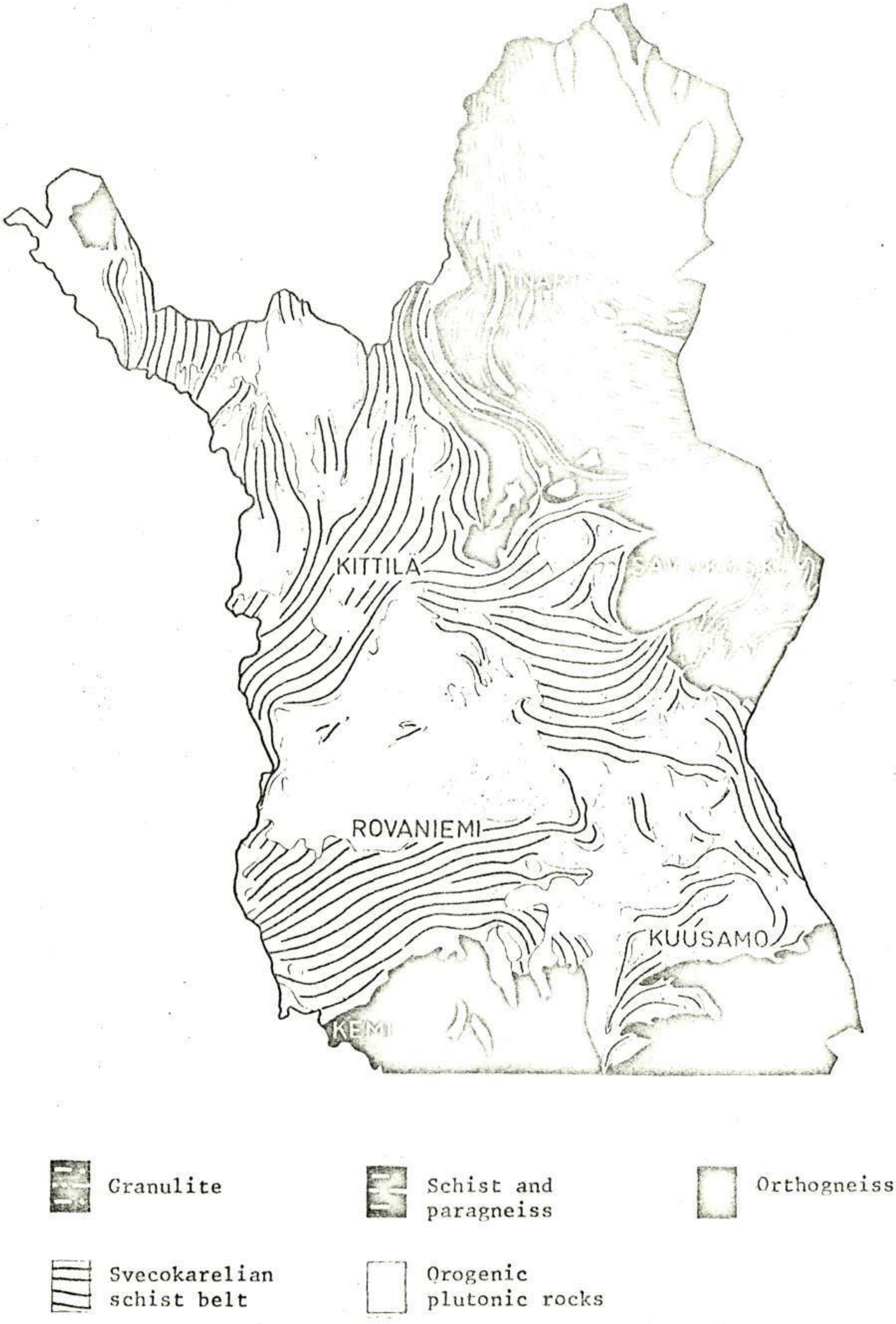

Figure 6. The major basement units of northern Finland (after Simonen 1971).

3.3. Bedrock features

Figure 5 shows the bedrock features studied in the preliminary analysis of the images 1039-09315, 1039-09322 and 1040-09371. The area covered by the images consists of four main basement units existing in Northern Finland, as shown in the figure 6. When studying the images in general, it can be seen that most of these units have a rather specific morphographic appearance ant thus different phototextures and so are easily localized in the images. The granulite complex of Northern Lapland has high relief and is characterized by large exposed areas and block fields. The schist belts of Central Lapland show several different phototextures- from a homogenous small texture of the main greenstone area north of Kittilä to the clearly oriented landforms of quartzites and mica schists to the east of Kittilä. The granitoid area of Central Lapland (between Rovaniemi and Kittilä) has typical drainage patterns which form phototextures different from those of the Kemi-Rovaniemi schist belt to the south of it.

However, the details of the boundaries between different formations are usually hard to detect. The boundary between svecokarelian Kemi-Rovaniemi schist belt and its orthogneiss basement in image 1039-09322 (Fig. 5 and 6) is perhaps the most clear. It is best visible in the IR bands 6 and 7, but is discerned also in bands 5 and 4. Parts of the boundaries of the granulite complex are also readily distinguished in the images 1039-09315 and 1040-09371 (bands 5, 6 and 7), bus mostly they are rather weakly visible.

3.3.1 Rock bodies

Two plutonic rock bodies stand out very clearly in the images (fig. 5) They are a granite massif in 1039-09315 and an anorthosite complex in 1040-09371. Both of them can be discerned best in bands 6 and 7, where they appear darker than their surroundings. Both rock bodies are also distinguished in bands 5 and 4, but far more weakly. In these bands the visibility is mainly caused by a different internal structure in the bodies when compared with that of the surroundings and also by topographic relief specific to the bodies. According to Niini (1964) the granite massif is an uplifted fault block and even on the western boundary of the anorthosite complex he (1967) has suggested faults having vertical components.

In the image 1039-09315 (MSS 6 and 7) there are two other plutons which can also be traced. They do not, however, stand out so clearly.

When studying the schist belts shown in the images it can be noted that the quartizites and amphibolites, having strong weathering resistance, are best visible. They form bedrock ridges which are readily discerned in the red and IR bands (MSS 5, 6 and 7). In this respect band 4 seems to provide least information, although the highest levels of the ridges and occasionally the phototextures of them are visible.

In band 5 of 1039-09315 the amphibolite and quartzite appear in light tones on the tops of the ridges and as rather dark tones on the lower levels. In bands 6 and 7 the grey tones seem to be vice-versa. This is evidently caused by topography and vegetation. The tops of the ridges are bare and on the slopes there are often large bogs with specific flora or dense coniferous forests. In the western half of 1040-09371 a formation can be discerned having the same appearance as the fore-mentioned ridges. The general geologic map of Norway (1:1000 000) confirms this as quartzite. On the basis of the image the quartzite beds could be thought to be rather flat lying, forming a basinlike structure.

Other parts of the schist belts, formed of different mica shists and gneisses are distinguished, especially in bands 6 and 7, showing an oriented phototexture. It is obvious that the general strike of the beds is often visible. In the SW part of image 1039-09315 these rocks stand out rather clearly, forming among other things a distinct folded structure.

3.3.2. Bedrock Structures

As mentioned above, the general strikes of the schist belts can obviously be followed in many places in the images. However, since the infered strikes do not always fit quite clearly with the data provided by general geologic map, they are drawn as possible strikes in various places in Figure 5. The detailed analysis of these features would require more ground truth data and field surveys.

Within the granulite complex a feature not mapped before, is especially clearly seen in bands 6 and 7 of images 1039-09315 and 1040-09371. There are several parallel dark and light stripes of about the same width, which give the impression of alternating beds of different rock types. The stripes have approximately the same strike as mapped for the granulite complex (Meriläinen 1965), and therefore marked with the symbol of a possible strike of layering in fig. 5.

On the boundary between the Kemi-Rovaniemi schist belt and its orthogneiss basement fold structures can be discerned in the beds next to the quartzite ridge (fig. 5 and 6). These folds have been mapped on the ground and appear in a serie of quartzites, volcanics and dolomites (Perttunen 1971). The folds are visible in all the bands, but 4 and 5 seem to be, in this case, somewhat more useful than the IR bands. The explanation of this might be provided by the fact that the folds are revealed entirely by the phototexture caused by vegetational differences; the relief in the area is rather flat. Another clearly visible fold which is also known from the ground surveys (Inkinen 1971), is seen in the SW part of image 1039-09315, as mentioned before. Quartzite ridges in the western parts of the same image show also several folded structures.

Only some of the numerous lineaments transecting the area covered by ERTS images are drawn in Fig. 5. Most of them are new features not mapped or otherwise detected before. In general they obviously represent fracture zones and faults of different sizes. All the bands have been proven useful in detecting them. These structures may be best visible in the IR bands, but even band 4 seems occasionally to provide information not distinguishable or only weakly discerned on other bands. In this respect the information of band 5 is somewhat disturbed by clear cutting areas.

As a good example of a new and obviously marked feature there is a long lineament running in an E-W direction through the upper parts of 1039-09315. It can actually be traced through the entire image, a distance of some 160 kilometers, although in the granulite complex in the eastern parts of the image it becomes more disperse.

A previously known wide zone of approximately NE-SW running lineaments is visible in the areas around Lake Inari in the images 1040-09371 and 1039-09315. These lineaments seem to disappear at the boundary of the granulite complex. However, the zone of Lake Inari is seen in the weather satellite images as one of the major lineaments continuing far into the Swedish side of the shield. Not even the other, more distinct lineaments seen in the weather satellite images, are so easily traced in ERTS images. For the study of structures of this scale it evidently would be better to have pictures of still larger areas, as for instance the photomosaics compiled from the ERTS images.

The lineaments transecting the imaged area divide the bedrock into a mosaic of blocks, some of which have previously been suggested in the literature. For instance, according to Meriläinen (1970) the granulite complex is divided into several major fault blocks, some of which are quite easily distinguished in 1040-09371.

4.0 Conclusions

The results of the preliminary analyses of the ERTS imagery are encouraging when considering their value as a tool in different geologic studies. The multiband approach has proven to be very useful, with each band providing some unique information. On the other hand, the multiband approach requires far more training and experience in remote sensing and image enhancement techniques than conventional photo interpretation. It must be stated that much still has to be learnt in regard to the interpretation of ERTS-1 images.

The resolution of the images is better than was expected and could be considered as approximately adequate for regional geologic mapping. For the studies of large scale structures it might be desirable, however, to widen the image area on the expense of the resolution. This could provide more concentrated pictures of areas large enough for the direct detection of geostructures. This is, of course, possible with ERTS imagery when using photomosaics.

During the time devoted to this study new information on the geology of Lapland has already been obtained and certain earlier suggestions have been verified. It thus seems clear that the use of ERTS data will be of considerable scientific and economical value for geologic surveys and prospecting.

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