Project to assess the application of Spot and Landsat TM imageries to geological reconnaissance, South-East Greenland

Final report

Tapani Tukiainen, Peter Erfurt
and Leif Thorning

Open File Series 93/8

November 1993

GGU

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Ujarassiortut Kalaallit Nunaanni Misissuisoqarfiat
GEOLOGICAL SURVEY OF GREENLAND

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ABSTRACT

Two sets of orthoscopic satellite image maps have been produced based on the Spot multispectral data: one standard colour composite and the other with extacted geological information. The maps at scale 1:100 000 cover South-East Greenland south of the 62° N latitude. The standard colour composites make a good map base for most of the area they cover. The image maps with extracted geological information based on the spatial enhancement of the IHS-transformed Spot data are not useful for discriminating the lithological features. A more individual and careful spectral and spatial enhancement of the Spot data may in some instances discriminate between major lithological units. The better spectral range of the Landsat TM makes it superior to the Spot system when the enhancement of the lithological features is essential. A processing scheme based on the principal component transformed Landsat TM data turned out to be particularly effective for the enhancement of lithological features.

LIST OF CONTENTS

1. INTRODUCTION

The scope of this report is to give a brief summary of the project and results obtained.

1.1 Project outline, background and targets

The project " Geological Information from Remote Sensing" (GIRS) is a pilot study concerned with the application of satellite based remote sensing in the mineral resource reconnaissance project (SUPRASYD) in South Greenland in 1992 carried out by the Department of Mineral Resources, The Geological Survey of Greenland (GGU).

The projects objectives were:

1. Purchase of orthoscopic 1:100 000 satellite image maps at scale 1:100 000 based on SPOT XS data.

2. Processing of the SPOT XS data to extract information which could facilitate the selection of field targets for mapping and exploration. Production of orthoscopic maps with extracted geological information.

3. Evaluation of the usefulness of the satellite data imagery products during the various stages of the GGU field campaign.

4. Development new tools/products based on the satellite for the geoscience and mineral exploration/mining industry.

5. Training of the department's staff in interpretation and use of satellite imagery

It became clear in the course of the project that the use of Spot Xs (Spot multispectral) imagery alone was insufficient to fullfill the primary objectives of the project. It was, therefore, also decided to acquire a data set based on the Landsat TM.

1.2 Project staff

The Department of Mineral Resources at the Geological Survey of Greenland is responsible for this project.

The project staff consisted of:

Leif Thorning	**statsgeolog, project leader**
Tapani Tukiainen	**senior geologist and computer specialist**
Peter Erfurt	**geologist**

The Swedish Space Corporation (SSC), Kiruna, Sweden was contracted to supply and preprocess the satellite imageries. The SSC arranged a training course in Sweden in February 1992. The project received substantial financial support from the Mineral Resources administration for Greenland.

1.3 Project history

A preliminary survey of the possibilities of using remote sensing data as a tool for the geological reconnaissance in South Greenland by the Department of Mineral Resources was initiated in June 1991. Detailed plans to scope with the various aspects of a remote sensing project were formulated by the end of 1991.

The company Swedish Space Corporation/Satellitbild was contracted on the 22nd of January 1992 for the production of the satellite orthophotos and the image maps with extracted geological information. The SSC arranged a training course/workshop in Kiruna, Sweden on the 24th January - 1st February 1992 where the theoretical and practical aspects of the image processing/interpretation were dealt with. The stay in Kiruna was also used for consultation between GGU geologists and the SSC staff responsible for the map production. The SSC delivered the map products according to the agreed schedule after which the data was available for the SUPRASYD field work July - August 1992.

During the field work it was decided to acquire a Landsat TM scene because it was felt that the Spot data did not fully meet the objectives of the project. The Landsat TM data were received late december 1992. Following the field season selected Spot and Landsat TM data were processed by GGU to find alternative methods for the image processing and the preparation of the final report.

1.4 Project area

The location of the project area and the coverage of the 1:100 000 scale orthoscopic satellite image maps produced during the project are shown in Fig.1.

1.4.1 Physical Outline

Except for some islands at the extreme south, the project area covers the southernmost part of Greenland including the east coast up to latitude 62º N (Fig.1). Most of the area is rugged and mountainous. The area bounded by Tasermiut and Lindenows Fjord may be characterised as alpine in appearance with the highest peaks reaching 2300 m a.s.l.. The terrain along the outer part of the east coast and in western South Greenland is less rugged and more easily accessible. Most of the area is covered by the Inland Ice, and the strip of ice-free land along the east coast is invariably fairly narrow ranging from a few hundred metres up to 20 km. The coastline is dissected by deep fjords often extending far inland with glacier tongues protruding from the Inland Ice. The vegetation is sparse and in large areas virtually absent except for sporadic lichen cover. In contrast the ice-free land areas along the west coast are comparatively larger and extend as much as 50 km inland. Vegetation cover is ubiquitous at lower elevations. In some sheltered valleys the arctic birch may be up to several meters high, which is unusual for Greenland.

1.4.2 Outline of Geology

Most of South Greenland is underlain by the rocks belonging to the early Proterozoic Ketilidian orogenic belt (Fig.1). The southern limit of the Archaean rocks to the north is well established on the west coast (Allaart, 1976). The precise location of the Archaean-Proterozic boundary on the east coast is unknown. Recent field results (Steenfelt et al., 1992) indicate that the boundary most probably lies around 62°N, trending NE-SW. In South Greenland the alkaline intrusive complexes, sandstone and basalt are related to the intense faulting accompanied by the cratogenic depositional and igneous activity of the Gardar period. The Gardar activity has been related to repetitive rifting within the Mid-

Proterozoic supercontinent of North America, Greenland and Europe (Piper, 1982). Rb-Sr isotopic age determinations on the Gardar intrusive centres suggest ages between 1350 and 1150 Ma (Blaxland et al., 1978). The available age determinations indicate that the Ketilidian activity most probably can be bracketed between 1900 to 1600 Ma with the main intrusive activity (granites and related rocks) occurring between 1750 and 1850 Ma ago (Allaart, 1976; Kalsbeek & Taylor, 1985). In summary, the Ketilidian orogenic belt is composed of the following rock types:

1) Granites, mainly occurring in the central and western part of the Ketilides, the main part occurring as a complex of syn- to posttectonic granite, gneissose granite, granodiorite and diorite in a SW-NE trending 80-150 km wide belt (the Granite Zone, Allaart, 1976). Subordinate relics of feldspathic hornblende gneiss and predominantly acid to intermediate volcanics are widespread but only in the Granite Zone.

2) Supracrustal rocks which are predominantly psammitic to semipelitic paragneisses with intercalated amphibolites of volcanic origin and minor horizons of calc-silicate - carbonate rock. This sedimentary-volcanic rock suite chiefly occupies the southern and eastern part of the Ketilides. The rocks are generally metamorphosed in the amphibolite facies, and in places intensely deformed. Migmatization and anatectic granites are a common phenomena. This sedimentary-volcanic sequence is intruded by:

3) Rocks of the rapakivi suite which include true rapakivi-textured granites but are generally ranging in composition from quartz-monzonitic to ultramafic. They occur in the southern part of the Ketilides as a large (several thousand km^2) complex of flat-lying intrusions around which migmatisation of the host paragneisses can be extreme. Smaller rapakivi suite complexes occur in a belt diagonally across the east coast norhtwards to about 61 30'N.

A general geological model for the formation of the Ketilidian orogenic belt have been put forward by Windley (1991), advocating a Himalayan-style continent-continent collision with subduction southwards).

The isotopic work (Kalsbeek & Taylor, 1985) indicates that most of the Ketilidian orogenic belt was formed during a period of major Proterozoic juvenile crustal accretion. Evidence for the involvement of older crust in the formation of Ketilidian granites was only detected in the northern border zone to the Archean rocks on the west coast. Nd-Sm isotopic work by Patchett & Bridgwater (1984) indicates that 5-17 % material of probable Archaean origin was mixed with mantle-derived material to form the Ketilidian crust.

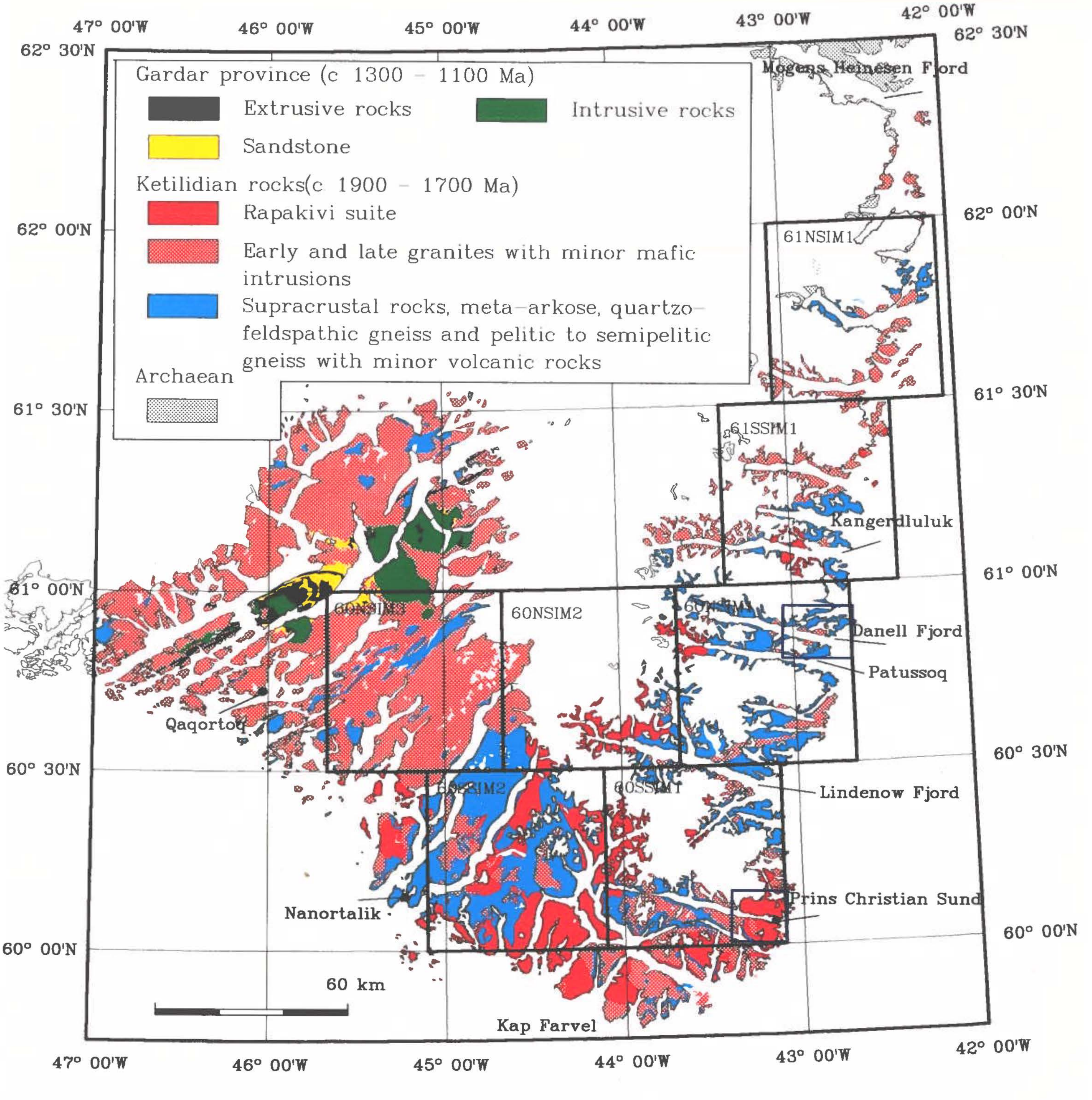

Fig. 1. Simplified geological map of central and east South Greenland. The index of 1:100 000 scale orthoscopic satellite image maps is shown. The location of the areas described in more detail is indicated by rectangles.

2.0 CHOICE OF SATELLITE AND SENSORS

There are three satellite systems which are potential data sources for a study with the current objectives:

MULTISPECTRAL SCANNER	BANDS	SPATIAL RESOLUTION
Landsat MSS (Landsat 1,2,3)	4	79 m
Landsat TM (Landsat 4,5)	7	30 m
Spot	3	20 m (nadir viewing)

The spectral ranges of the systems are summarized in the Fig 2. Landsat MSS scenes are available for most of the project area. Apart from the very southern part of the Kap Farvel - Nanortalik area, the Spot scenes also cover the area of interest. Unfortunately, Landsat TM scenes were not available from the project area because it lies just beyond the direct receiving range of the acquisition station Esrange, Kiruna, Sweden. Acquisition of the Landsat TM scenes for the project area would therefore require a special agreement on programming of the satellite at extra cost with the EOSAT company. Landsat TM passes any one area with an interval of 18 days, so potential recording days with optimal weather/snow conditions are fairly limited in number in South East Greenland. The spectral range clearly advocated the use of Landsat TM, but the fact that the data had to be ready for use in the SUPRASYD field work actually excluded the use of the Landsat TM data in the first instance. Therefore the project was primarily based on the use of the Spot multispectral imagery. The off-nadir viewing facility of the Spot system (e.g. production of stereoscopic pairs, digital elevation models etc.) was not utilized in this project.

Although the spectral limitations of the Spot system practically outruled the detection of various rock alteration pheomena visible as gossans and/or enrichments of iron oxides, hydroxyl-bearing minerals, carbonate etc., it was hoped that the good resolution and stability of the Spot sensors could be expected to detect subtle spectral differences related to the lithological variation between major geological units.

The severe topography with almost vertical mountain walls over considerable distances of the project area implies that the nadir-viewing mode of the imagery is of limited use in many areas. This limitation also applies for the Landsat TM data.

3.0 PROJECT PRODUCTS

In accordance with the contract SSC delivered orthoscopic satellite image maps as seven subsets (Fig.1). The orthoscopic maps are in the UTM projection (zone 23, ellipsoid: NAD 83). For each subset the following material was received:

Item:	media:
1:100 000 'standard' satellite image map as color composite (SIM)	glossy prints
1:100 000 satellite image map 'with extracted geological information' (SIMG)	glossy prints
Masters for SIM and SIMG maps	24x22 cm positive colour film
Digital data	CCT, 6250 bpi, BSQ

Some of these items are available at a price which covers the reproduction and royalties to SSC. The technical details and considerations of the SSC data processing have been included as appendix 1.

In addition to the Spot Xs products, digital data for the Landsat TM scene (path 233/row 017) were purchased by the present project and will be dealt with further on in this report.

4.0 FIELD WORK

The lack of time available before the field season restricted the processing of the received Spot Xs-data by GGU to the export of data from the CCTs into the REMAPP-PC format (Livo et. al 1990). This format facilitated a more flexible extraction of subsets of data from the somewhat bulky datasets on the CCTs. Furthermore, the REMAPP-PC format made the data available for a number of useful image processing routines of the REMAPP-PC system (Remote Sensing Image Processing Software). The system were installed on a Compaq Deskpro 386/33 personal computer which made the basic image processing facilities available in the base camp in Greenland. Numerous versatile routines from this system have also been installed in GGU's VAX 6400. As a part of the export procedure the data was checked for errors. Three CCTs contained corrupted files and/or data was missing. SSC promptly replaced the invalid CCTs with new ones. The field work was thus based on the products from SSC.

4.1 Outline of field work

The field work of this project was considered an integrated part of project SUPRASYD activities. The original intention was first to identify features possibly related to the lithology and/or structure, enhance them and then carry out field checks in selected areas to explain whether the features were related to the underlying lithology or not.

However, apart from outlining areas with vegetation the SSC satellite maps did not reveal features which were sufficiently conspicuous to clearly delineate areas of interest for more detailed field study. The short time between the delivery of the satellite data products and the beginning of the field activities excluded the use of alternative processing techniques to enhance the images. The original working strategy was therefore reversed; it was decided to outline selected representative lithologies first in the field, to examine whether these were discernible on the delivered satellite maps and whether they could t be made visible by alternative processing techniques. As a compromise between satellite map quality and the need for lithological diversity two areas were selected for more detailed study (Fig. 1); the area around Danell Fjord on the east coast and another one around the island of Amitsoq in South Greenland. Approximately one week was used for each locality. The work was done by a two-person field team using a rubber dinghy. Following the field work in Danell Fjord two days were used in a nunataq area west of Danell Fjord. The field work essentially consisted of the comparison of the observed geology and the satellite map. Reference hand specimens from the characteristic lithologies were collected. Graphite and sulphide-bearing supracrustal rocks (pelite and chert) were chip-sampled in three localities.

The field work in the surroundings of Amitsoq did not bring essential new information to the understanding and interpretation of the satellite image maps and the known geology. The description of the field activity here is therefore omited in this report.

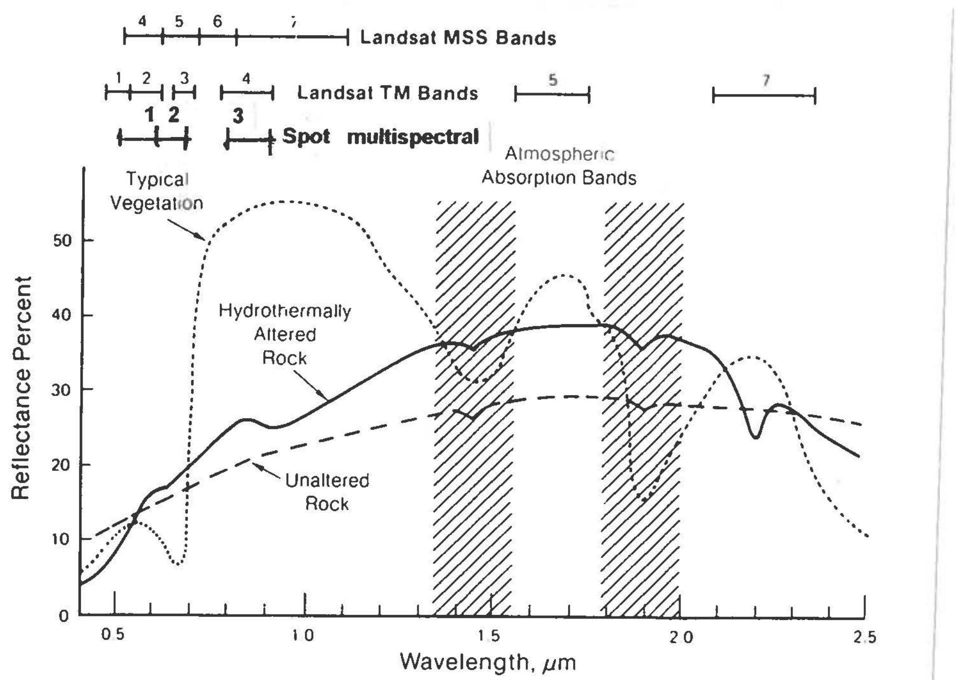

Fig.2. Spectral bands for TM and MSS and SPOT systems. Reflectance curves for vegetation, unaltered rocks, and hydrothermally altered rocks (Sabins, 1983)

4.2 Danell Fjord

The ice conditions restricted the field work to the outer two-thirds of Danell Fjord and the island of Iluileq. The visited area is comprised of an isoclinally folded east - west to north east - southwest trending belt of psammitic to semipelitic gneiss with intercalactions of amphibolite. The field work confirmed the existence of carbonate/calc-silicate rock on the north shore of Danell Fjord. This rock unit comprises a 300 m thick, intensively folded horizon between amphibolite and semipelite. The gneiss is in amphibolite facies and the degree of migmatisation/granitisation is invariably high; over large areas the primary textural and compositional characteristics have been more or less completely obliterated. The mafic/ultramafic rocks occupying the ground around the field camp (Plate 1) postdate the gneiss and are most probably related to the post-orogenic Rapakivi suite. The gneiss and the mafic/ultramafic rocks are cut by east - west striking mafic dykes.

The observed lithological and structural features are schematically shown in Plate 1. The SIM/G-map (Plate 2) was rejected at the very beginning of the field work because it is simply a degradation of the SIM- map (Plate 3). Closer examination of the SIM-map and the digital data drew attention to the following features:

1) dark rocks with more light coloured bands reminiscent of subhorizontal layering in a nunataq approximately 10 km ENE of the bottom of Danell Fjord

2) linear W - E striking features, partly enhanced by the more abundant vegetation

3) scattered darker areas, often with more abundant vegetation (e.g. the surroundings of field camp

The helicopter reconnaissance of the nunataq revealed a spectacular, gently dipping sequence of metavolcanic rocks ranging in composition from mafic to intermediate, overlying the granite. The more felsic varieties of the volcanics are visible as light coloured layers.

The linear W - E trending features turned out to be mafic dykes, the largest of them is almost 300 metres wide.

There are numerous horizons of pelite in the area varying in thickness from some tens of metres up to several hundreds of metres. Seen from a distance the pelite horizons are fairly well discernible as slightly darker units in the field. When sulphide or graphite-bearing the pelite horizons are the most striking rock units in the area. As a rule the SIM -map was not very useful for tracing the observed pelite horizons. In most cases the pelite horizons were first localised in the field and afterwards more or less subjectically 'recognized' on the SIM - map, The sulphide or graphite-bearing pelite horizonts, by virtue of their dark rusty-brown colour, were the easiest recognisable features on the SIM - map. It was, however, very difficult to distinguish the dark pelite horizons from lichen cover and other vegetation. The SIM - map is not able to distinguish between granite/ granitic rocks and psammitic gneiss.

5.0 DATA PROCESSING AFTER THE FIELD SEASON

The REMAPP-PC image processing system made the basic image processing routines accessible during the field work in Greenland. The REMAPP-PC system worked well but suffered from the general limitations of the DOS-based personal computers to handle the voluminous satellite image data. The system was useful for the examination of image details. The Spot data from the selected areas was enhanced both spatially and spectrally in order to extract more information than that seen on the maps prepared by SSC. The image processing was done by using the copyrighted 'KHOROS' public domain system by the University of New Mexico.

5.1 Spot data

The Spot data from the Prins Christian Sund and Iluileq areas were principal component transformed to test if this technique was able to extract more lithological information than the IHS-transformation by SSC.

5.1.1 Prins Christian sund

The satellite image maps by SSC from this area are of particularly poor quality (Platea 4 & 5). This is apparently due to a combination of the less successful contrast stretch and poor signal level in the band Xs1. The colour composite in Plate 6 was made by applying histogram equalisation stretch to the three bands. The image is spatially enhanced by adding the high pass filtered component of the first principal component image on the colour composite. There is a good correlation between the features discernible on the image in Plate 6 and the distribution of the granite lithologies south of Prins Christian Sund as shown by the map of Allaart (1976). The image on Plate 6 indicates that the geological map by Allaart (1976) is over-simplified immediately north of Prins Christian Sund.

5.1.2 Iluileq

It became clear during the field work that the SIM / SIM/G (Plates 2 & 3) map was not able to delineate to any degree of confidence the 'darker coloured' lithologies (pelite, amphibolite) in the areas of more intense mobilisation. Selected subscenes of the Spot data along Danell Fjord were treated with a more careful and vigorous contrast stretch and principal component transformation. The individual contrast stretch of the subscenes did not noticeably improve the spectral differences. The principal component transformation further enhanced the response from vegetation but left the subtle features related to the lithological differences virtually unchanged.

5.1.3 Concluding remarks

The Spot imagery is to a certain extent able to distinguish between 'darker' and 'lighter' lithologies providing these cover large contiguous areas of ground. The relatively sparse vegetation (e.g. lichen cover) is, unfortunately, enough to blurr the spectral response from the 'darker rocks' (pelite, amhibolite etc.), especially when these occur as more irregular minor bodies or thin bands/ layers.

5.2 Landsat TM data

The immediate results of the field work demonstrated that the spectral range of the Spot imagery was insufficient to distinquish between the lithologies observed in the field with any certainity. There were still, however, some possibilities to acquire Landsat TM data covering the project area or at least parts of it.

It was therefore decided while still in Greenland to order programming of the satellite for a 'floating' daytime TM-scene with the scene centre at N60° 47' / W43°57' covering halves of the 'fixed' scenes 233/17 233/18. This would cover the area between Kap Farvel and Kap Herluf Trolle. The orbit parameters of Landsat 4 implied that the potential acquisition dates were Septemper 1st, September 17th, October 3rd and October 19th respectively.

Because of programming errors on the part of EOSAT only scene 233/17 (1st and 17th September) were acquired corresponding to the area between Lindenow Fjord and Mogen Heinesen Fjord. Both acquisitions were hampered by cloud cover which definitively excluded further use of the data acquired on the 17th of September. The acquisitions from October 3rd and 19th were useless because of the cloud and snow cover. The acquisition of the 1st of September, i.e. scene 233/17 was the only potential candidate to supply the project with TM-data over a selected area. The standard classification procedures for TM-data could not be trusted to distinguish between the ice cap and clouds, and the available Xerox copy of the quicklook for the scene was of such a poor quality that its could not be used to distinguish the cloud-free land areas from those covered by snow,ice or clouds. Consequently, a 35 mm colour print of the quicklook for the scene 233/17 was requested from the EOSAT company and received late November 1992.

The colour print showed that the scene had a dense cloud cover in the inner fjord zone between Kangerdluluk and Lindenow Fjord. The other parts of the scene appeared to be of reasonable quality and therefore it was decided to purchase the digital data for this scene. Finally, the digital datwere received late December 1992 leaving very little time for the processing of the image. It is worth noting that 4 months elapsed after the time of programming of the satellite until the data were received at GGU. Such difficulties in obtaining the Landsat TM data within a project of limited time span strongly suggest that the digital data should be made available by the time a project is being planned or initiated.

The data were delivered in EOSAT's standard Fast Format on three CCTs. The export, data check and reformating of the data from the seven bands into the REMAPP format ran without problems. The scene is almost cloud free along the outer coast zone between the fjords Patussoq and Kangerdluluk. The area around Iluileq island provides a good test site for a comparison of Spot and Landsat data because it was covered by the season's field work. A subscene (Fig.1, Plate 7) with 1000 by 1000 pixels was extracted for more detailed study.

5.2.1 Ranking of TM bands

In order to determine the best bands and band combinations for the separation of the different lithologies the ranking method of Crippen (1989) was applied to the correlation matrix of the Iluileq subscene. The ranking index is based on the determinant of the correlation matrix for three bands. This method has been proven to be particularly useful where only a little *a priori* knowledge of an area exists.

Table 1. Correlation matrix for Iluileq subscene

TM1	TM2	TM3	TM4	TM5	TM7
1.00	.934	.937	.932	.477	.453
	1.00	.999	.992	.411	.377
		1.00	.995	.425	.392
			1.00	.500	.465
				1.00	.985
					1.00

Table 2. Ranking of three-band combinations based on the correlation matrix of the Iluileq subscene

Rank	Index	Combination
1	.320	1-4-7
2	.313	1-4-5
3	.151	1-5-7
5	.073	2-4-7
6	.053	3-4-7
7	.015	1-2-3

Index=SQRT($1+2abc-a^2-b^2-c^2$) where a, b and c are pairwise channel correlation coefficients. 1=perfectly three dimensional 0= not three dimensional

Table 3. Correlation matrix for different Landsat TM ratios for Iluileq subscene

1/2	1/3	1/4	1/5	1/7	2/3	2/4	2/5	2/7	3/4	3/5	3/7	4/5	4/7	5/7
1.00	.976	.915	.149	.158	.709	.591	-.167	-.107	.381	-.267	-.193	-.351	-.260	.127
	1.00	.968	.242	.254	.850	.729	-.066	-.004	.492	-.183	-.104	-.279	-.180	.191
		1.00	.420	.423	.889	.868	.130	.181	.697	.010	.081	-.102	-.009	.263
			1.00	.972	.409	.651	.950	.939	.756	.909	.912	.860	.873	.494
				1.00	.424	.645	.920	.964	.732	.876	.935	.828	.902	.683
					1.00	.898	.184	.237	.648	.050	.125	-.051	.045	.301
						1.00	.463	.492	.917	.347	.397	.225	.299	.367
							1.00	.971	.633	.991	.970	.968	.953	.453
								1.00	.635	.954	.993	.927	.978	.653
									1.00	.555	.573	.436	.476	.363
										1.00	.968	.990	.962	.419
											1.00	.953	.993	.632
												1.00	.962	.394
													1.00	.628
														1.00

Table 4. Ranking of TM band ratio combinations based on the correlation matrix

Rank	Index	Combination
1	.870	1/4 - 3/5 - 5/7
2	.862	1/4 - 4/5 - 5/7
3	.851	1/3 - 3/5 - 5/7
4	.850	2/4 - 4/5 - 5/7
5	.829	1/3 - 4/5 - 5/7
6	.821	2/4 - 3/5 - 5/7
7	.701	2/4 - 3/7 - 5/7
8	.634	3/4 - 3/7 - 5/7

The correlation matrices for the Landsat TM bands and band ratios were computed for Iluileq subscene and are given in Tables 1 and 3 respectively.

The ranking of the TM band (Table 2) and band ratio (Table 4) combinations clearly emphasizes the importance of the mid-infrared bands (TM 5 and TM 7) for the discrimination of the lithologies.

5.2.2 Band ratios

The Landsat TM system has been used succesfully worldwide to map iron oxides (hematite and goethite) and phyllosilicate minerals (clays, alunite , pyrophyllite etc.) which are often characteristic byproducts of the ore-forming processes. The TM 3/1 ratio image has customarily been used to detect the areas of the highest iron oxide concentration. The known sulphide and graphite rich localities within the area of Iluileq subscene are too small to be detected by the Landsat TM. The TM 3/1 ratio image (not shown) did not outline other targets with enrichment of Fe oxides.

Whether the present TM data is cabable of detecting various types of alteration (providing they are present in the area) remains to be investigated by further processing and field work.

5.2.3 Principal Component transformation

The six bands of the Iluileq subscene were PC transformed (Table 5). The first three PC images contain 99.71 % of the variance of the original six bands of the subscene. The PC image 1 is dominated by the topographic effects and consequently of minor importance for the enhancement of the lithology. The colour composite of the PC images 2, 3 and 4 (Plate 8) displays many features which are related to observed lithological variations. It is of special interest in this area that the enhancement based on the PC transformation appears to be capable of distinguishing the pelitic units from the semipelitic ones, and that

Table 5 . Percentage of variance represented by the PC images of the Iluileq subscene

PC	Variance	Cum.pct of variance explained
1	75.05	75.05
2	23.10	98.15
3	1.56	99.71
4	0.23	99.94
5	0.005	99.99
6	0.001	100.00

the areas of more intense granitisation and anatectic granite are also clearly delineated.

6.0 DISCUSSION

The present project was primarily based on the Spot multispectral imagery from which two sets of orthoscopic satellite image maps were produced by the contractor. Much effort and a major part of the project funds were used to produce these satellite image maps due to the preliminary intentions of the SUPRA-SYD project to test use the orthoscopic images as an accurate cartographic base for the project activities. For unknown reasons many of the participants in the project preferred to use the old 1: 250 000 topographic maps instead for the new satellite orthophotos.

The set of the SIM maps is a good colour composite for most of the area they cover. There are, however, many localities along the east coast where it is almost impossible to distinguish between land and sea both appearing very dark. To overcome this it would have been necessary to perform a more careful and individual contrast stretching in selected areas.

The processing behind the SIM/G maps is essentially a spatial enhancement of the SW-NE trending structures which were applied to the intensity component of the IHS-transformed data. The method as such is unlikely to enhance the lithological differences to any significant extent. In fact the structural enhancement has degraded the overall readibility of the images to such an extent that they are of very limited use, and cannot be recommended for other purposes.

The lack of more sophisticated spectral enhancement implies that the amount of lithological information extractable from the Spot satellite image maps is comparable to what can be seen on ordinary black and white aerial photographs. Because of the spectral limitations of the spot data, the features related to the various lithologies appears to be too subtle to be detected by standard processing of a multiscene mosaic. As shown by the example from the Prins

Christian Sund area a fairly simple spectral enhancement of the Spot images may locally yield much more lithological information than can be seen on the SIM and SIM/G maps made by SSC. During the training course at SSC, Kiruna, the decorrelation stretch was applied to selected examples of the PC-transformed Spot data. A more careful decorrelation stretch based on the local characteristics of Spot data set used in this study would certainly have genererated a more useful product. The fact that the PC-loadings are scene-dependent implies that the systematic enhancement of the whole Spot data would have been fairly time consuming and laborious and probably impossible to do within the time available before field work.

The ranking of the Landsat TM band and band-ratio combinations illustrate the importance of the mid-infrared wavelength region (TM bands 5 and 7) for displaying the lithological differences. The fact that the Landsat TM bands 1, 2, 3 and 4 essentially contain the whole spectral width of the present Spot system illustrates Spot's limitations in the practical applications where the spectral capabilities are essential. The superiority of information which is extractable from the PC-transformed Landsat TM data as compared to that of the Spot system is well illustrated in the Iluileq area.

The Landsat TM system is to a considerable extent spectrally tailored to respond to the geological phenomena and is therefore superior to Spot regarding the discrimination of lithologies and certain types of rock alteration. The better spatial resolution of the Spot (20 x 20 m and 28 x 28 m for Spot Xs and Landsat TM respectively) is therefore hardly a decisive factor for campaings of reconnaissance character. The spectral range along with the lower cost and better availability makes the Landsat TM data a more versatile basis for the geological remote sensing studies. The Spot system has two advantages over Landsat: higher resolution and stereo imaging capabilities. The first makes the Spot imagery a more detailed basis for the structural analysis than Landsat TM, and secondly, reliable - although fairly expensive, digital terrain models can be generated for a wide range of cartographic/topographic, and structural applications. Unfortunately, this was outside the scope of the present project.

7.0 CONCLUSIONS

1. Spot produced good base maps (SIM) with some problems in certain areas to distinguish between land and water. They may be the most accurate maps for this part of Greenland because they were rectified with the most up-to-date ground control points supplied by the Kort og Matrikelstyrelsen. These maps can be used for general purposes and for structural analysis.

2. The extraction of geological information performed by SCC (SIM/G-maps) cannot be said to be very useful. Certain structural trends have been enhanced at the cost of degradation of other map information. These maps cannot be recommended for further use.

3. A careful spectral enhancement of the PC-transformed Spot data may extract lithological information in some instances.

4. Due to the data acquisition problems the Landsat TM data were received at termination of the present project. The limited processing of the Landsat TM data has, however, demonstrated that the data are superior for geological purposes also in arctic mountainous regions and the slightly reduced spatial resolution do not seem to give serious problems in relation to the reconnaissance type of the work.

5. A processing scheme based on the principal component transformation has been shown to be capable of discriminating between the major rock types to such a degree of confidence that the method is useful tool for rationalising the geological field campaigns.

6. The special conditions created by high relief, snow and ice, lichen cover etc. demand special care in processing. It is not uncommon that the initial evaluation of both Spot and Landsat TM images by EOSAT and others has been incorrect because of the unusually large areas covered by snow or ice has been

erroneously classified as cloud. It is probably necessary to use the digital data or, as a minimum a colour photo, for the correct scene evaluation.

7. Because of climatic conditions and programming requirements for the satellites, there are complications in obtaining new data from areas of interest within a project life span as short as that of the present project. In order to be useful for field work, the digital data should be available 6 months before the start of the field season so that there is time for careful processing and evaluation before going to the field area.

8. The use of satellite imagery as a tool for geological reconnaissance work of the type carried out in the SUPRASYD project is useful provided that the reservations in 7 have been taken into consideration. The Landsat TM data are the best to use, Spot (panchromatic mode; 10 x 10 m resolution) should be used in studies where the cartographic aspect (digital elevation model, contoured maps) and/or structural interpretations are essential.

9. The availability of the image processing facility in Greenland in connection with field work is essential for the dynamic use of remote sensing in the various aspect of the field work. The system which was used during the SUPRASYD was definitely useful but the system's image processing speed and repertoire is clearly insufficient. There are numerous commercial, low-cost image processing systems available for various portable computer platforms.

8.0 RECOMMENDATIONS

1. Satellite data, preferably Landsat TM or similar, but also SPOT in some cases, should be used for spectral and spatial enhancement to facilitate the interpretation of lithological and structural features prior to the field work. The processing and interpretation should be commenced at least half a year before the

start of the field season. Experience from the present project suggests a processing scheme based on the principal component transformation of the Landsat TM data.

2. Successful interpretation of satellite data is a dynamic process which requires immediate availability of the image processing hardware and software and expertise as well as geological expertise.

3. A library of good quality Landsat TM or similar data is a necessary base for using remote sensing in geological tasks in Greenland. Careful checking and selection of existing data is required. It is obvious that programming of satellites must be ordered for data acquisition in some parts of Greenland where the existing Landsat TM data is of poor quality or altogether missing. As a minimum new scenes should be acquired covering the parts of South Greenland where no Landsat TM data exist at present.

9.0 REFERENCES

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10.0 PLATES

Plate 1. Observed geology of the Danell Fjord area. Map base is the 1:250 000 topographic map by Kort og Matrikkelstyrelsen. The areas of the Iluileq subscenes (Plates 2,3 and 7,8 respectively) are shown.

Plate 2. Satellite image map with extracted geological information (SIM/G) by **SSC**, Danell Fjord area.

Plate 3. Satellite image map (SIM) by **SSC**, Danell Fjord area area.

Plate 4. Satellite image map with extracted geological information (SIM/G) by **SSC**, Prins Christian Sund area.

Plate 5. Satellite image map (SIM) by **SSC**, Prins Christian Sund area area.

Plate 6. Colour composite of the SPOT Xs1 (red), Xs2 (green) and Xs3 (blue). The histogram equalisation stretch is applied to the three bands. The high pass filtered component of the first principal component image is added on the composite. A section of the geologiacl map by Allaart (1976) is included.

Plate 7. Color composite of the Landsat TM bands 4 (red), 3 (green) and 2 (blue), Iluileq area. The high pass filtered component of the first principal component image is added on the composite.

Plate 8. Colour composite of the histogramme stretched 2nd (red), 3rd (green) and 4th (blue) principal component image of the **Landsat TM** bands 1,2,3,4,5 and 7. The pixels with ice/snow, vegetation and sea/lake water are masked.

11.0 DANSK SAMMENDRAG

Projekt 'GIRS' (Geological Information From Remote Sensing) er pilotprojekt til undersøgelse af Remote Sensing data anvendt i rekognoseringsfasen af en geologisk undersøgelse med henblik på at vurdere områdets potentiale for mineralske råstoffer. Som testområde valgtes en del af Syd Grønland, som også var genstand for undersøgelser i projekt 'SUPRASYD' gennemført af Afdeling for mineralske råstoffer i 1992. GIRS-projektet løb fra Januar 1992 til Januar 1993. Det indebar indkøb af Spot scener, på grundlag af hvilke SSC (Swedish Space Corporation, Kiruna, Sverige) fremstillede syv kortsæt hver i målestok 1:100 000 bestående af to typer kort: standard ortokort (SIM) og kort, hvor geologisk information er søgt uddraget (SIM/G). Kortsættene blev leveret til GGU umiddelbart før feltsæsonen 1992, og i samarbejde med projekt SUPRASYD blev kortene anvendt i feltarbejdet, især blev deres værdi som hjælpemiddel i en typisk GGU feltkampagne vurderet. Allerede under feltarbejdet kunne det konstateres, at Spot data kun havde en begrænset anvendelse i det pågældende feltområde. Efterfølgende processering af data, gennemført af GGU, bekræftede dette indtryk. Det blev derfor besluttet at bestille også Landsat TM data, som spektralt dækker et bredere område. Dette indebar, at satelliten skulle specielt programmeres, til at optage området i Syd Grønland, fordi området ikke kan nås ved direkte nedtagning af billeder. Det lykkedes først at få disse data leveret til GGU December 1992. I løbet af efteråret 1992 gennemførtes en processering af Spot data, for at prøve alternative metoder til at fremdrage geologisk information. I løbet af Januar - Februar 1992 gennemførtes en lignende processering af Landsat TM data.

På grundlag af GIRS projektets arbejde kan et antal konklusioner fremlægges:

1. Standardkort produceret fra Spot data ('SIM') er generelt af god kvalitet, når undtages visse områder hvor adskillelsen mellem vand og land ikke er tilfredsstillende. Disse kort kan være de mest nøjagtige fra området fordi de nyeste oplysninger fra Kort og matrikkelstyrelsen er anvendt. Kortene vil være velegnede til generelle formål og strukturelle undersøgelser.

2. Den processering som SSC har anvendt for at frembringe SIM/G - kort kan ikke anbefales. Visse strukturelle trends er fremhævet, men på bekostning af en degradering af anden information i kortet.

3. GGU:s undersøgelser viser dog, at en omhyggelig spektral behandling af PC (= principal component) -transformerede Spot data i visse tilfælde kan fremdrage litologisk information.

4. Selvom der indenfor projektet kun har været tid til en meget begrænset processering af Landsat TM data står det dog klart, at disse data er klart overlegne når det gælder geologiske fænomener også i arktiske bjergrige områder. Den noget reducerede spatielle opløsning af Landsat - data, sammenlignet med Spot data synes ikke give nogen problemer.

5. Det er påvist, at processering af Landsat TM data baseret på PC-transformation kan diskriminere mellem hovedbjergartstyper med en sådan grad af sikkerhed at det må betegnes som et brugbart værktøj med henblik på at rationalisere geologisk feltarbejde.

6. De specielle forhold skabt af ujævnt terræn, sne og is, lavbevoksninger o.l. gør, at der skal tages specielle hensyn i processeringen. Det er ikke ualmindeligt at der allerede i den indledende evaluering af både Spot og Landsat TM data, som EOSAT gennemfører, sker fejl, fordi de usædvanligt store områder dækket af sne og is bliver klassificeret som skyer.

7. På grund af klimatiske betingelser og nødvendigheden for programmering af satellitterne kan det være kompliceret at få fat på nye data fra områder af interesse indenfor et projekt med en varighed så kort som GIRS. Hvis satellitdata skal være nyttige med henblik på feltarbejde, er det nødvendigt, at de skal være til rådighed mindst seks måneder før feltsæsonens start, så der er tid til at gennemføre en omhyggelig processering/interpretation inden man går i felten.

8. Under forudsætning heraf kan processering/fortolkning af satellitdata med fordel anvendes som et værktøj ved geologisk rekognoseringsarbejde af den type, som nu gennemføres i projekt SUPRASYD. Det er i næsten alle tilfælde bedst at anvende Landsat TM data, mens Spot data kan anvendes i studier hvor, kartografiske og strukturelle aspekter er essentielle.

9. Udover en forudgående behandling af satellitdata er det også væsentligt, at råde over en billedbehandlingsfacilitet i Grønland under feltarbejdet, således at de observationer, der gøres i felten, dynamisk kan udnyttes til en forbedring af tolkningen

På grundlag af de erfaringer som er indvundet under projekt GIRS anbefales det derfor:

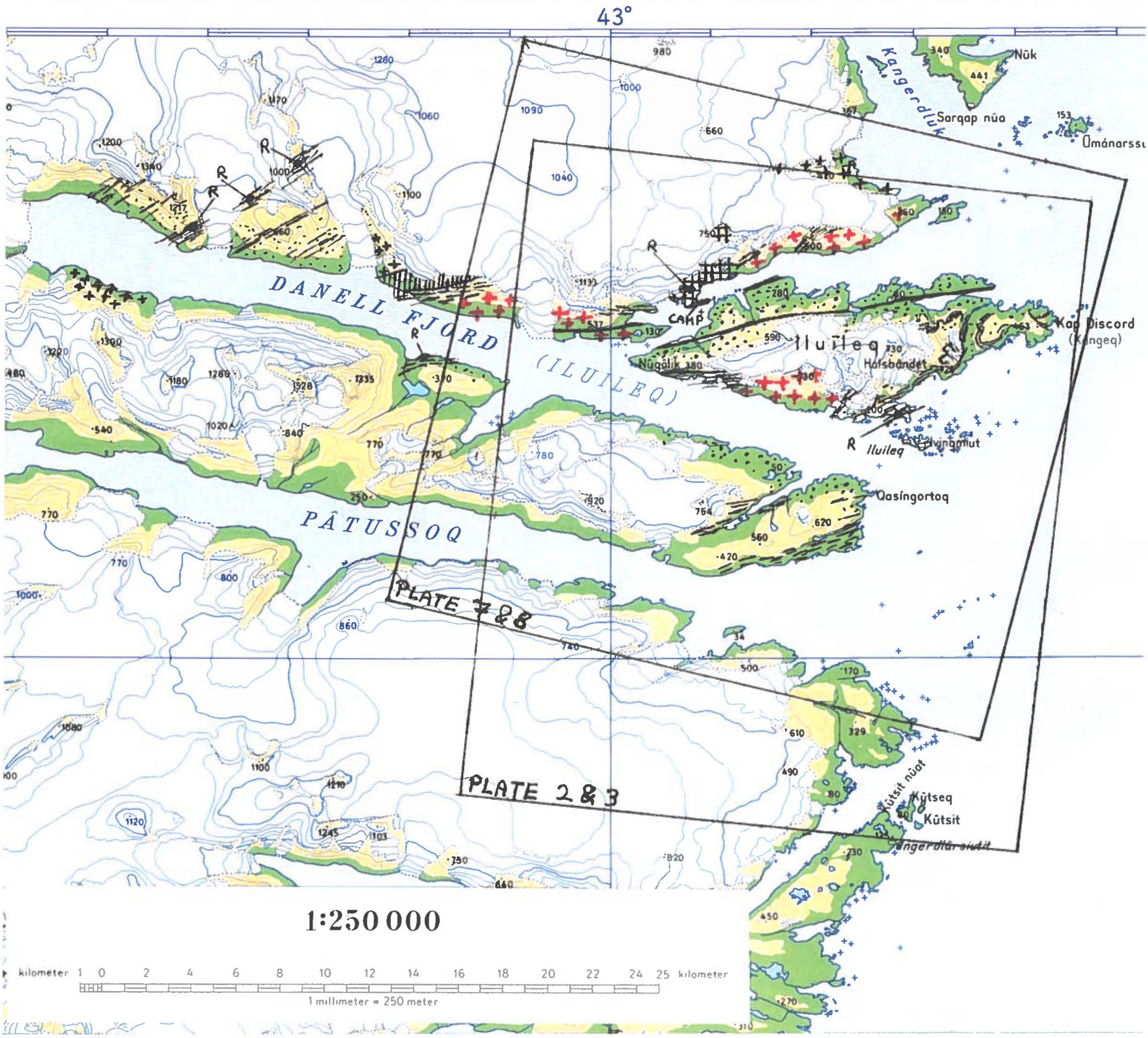
1. Satellitdata, helst Landsat TM eller lignende skal bruges til både spektral og spatiel enhancement til at fremme fortolkningen af litologiske og strukturelle elementer før feltarbejdet påbegyndes. Processeringen bør påbegyndes mindst 6 måneder før feltarbejdets start. En processeringsmetode baseret på PC-transformation vil i mange tilfælde være velegnet.
2. En vellykket fortolkning af satellitdata er en dynamisk process, der forudsætter umiddelbar adgang til såvel hardware/software som geologisk viden.
3. Et bibliotetk med f.eks. Landsat TM data af god kvalitet er en forudsætning for succesfuld anvendelse af satellitdata i forbindelse med geologisk arbejde i Grønland. For at opnå det, kræves en omhyggelig gennemgang og udvælgelse af eksisterende data samt programmering af satellitter med henblik på optageklse af nye data fra områder, der ikke er dækket. Som et minimum bør der anskaffes data dækkende resten af Syd Grønland med henblik på feltarbejdet i 1994.

12.0 APPENDIX 1

Processing report by the Swedish Space Corporation (in swedish):

Satellitkartor till GGU
Processrapport
Torbjörn Westin & Per Zeidlitz
15 juli 1992

The copies of the referred reports and publications are not included.



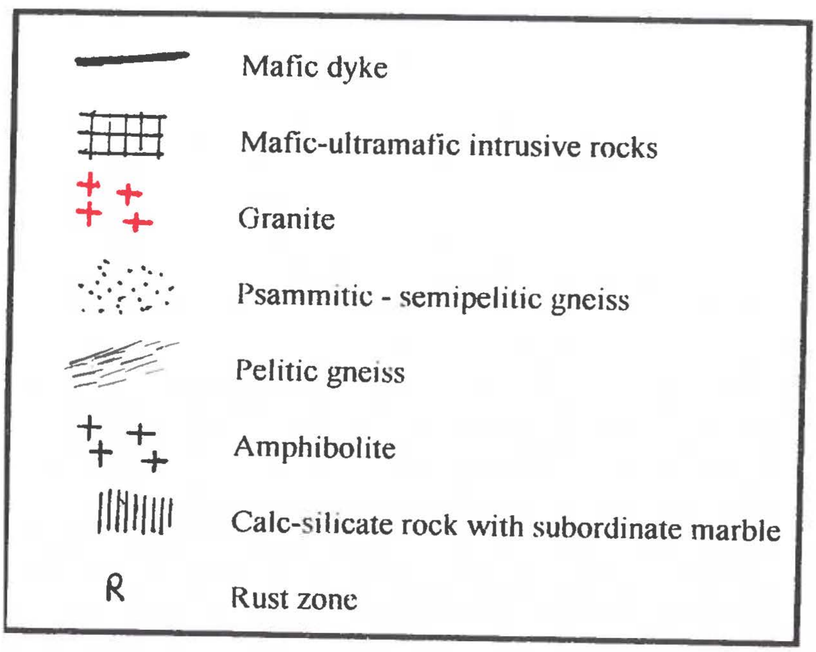


Plate 1. Observed geology of the Danell Fjord area. The map base is the 1:250 000 topographic map by Kort og Matrikkelstyrelsen. The areas of the SPOT and LANDSAT TM subscenes are shown.

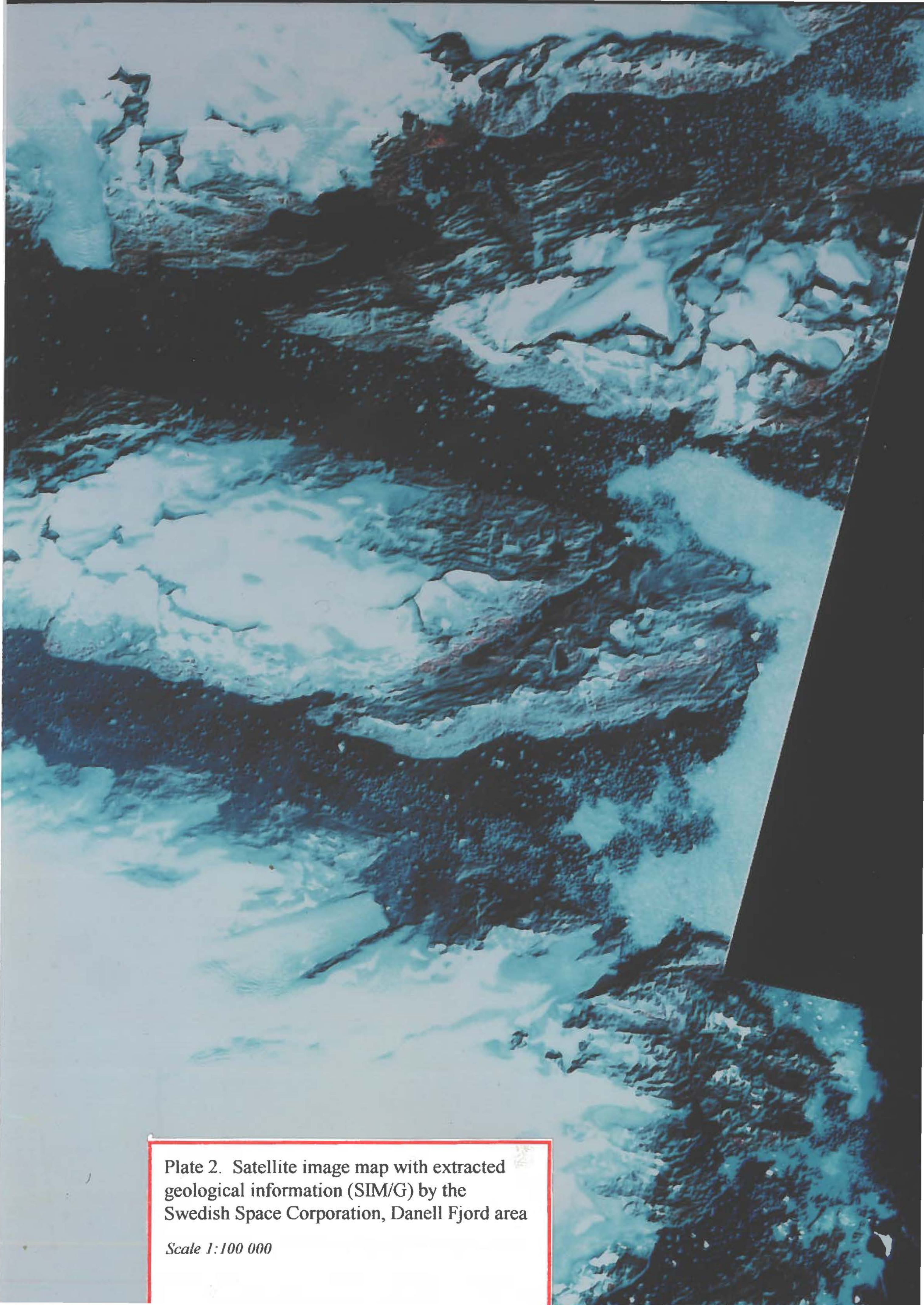


Plate 2. Satellite image map with extracted geological information (SIM/G) by the Swedish Space Corporation, Danell Fjord area

Scale 1:100 000

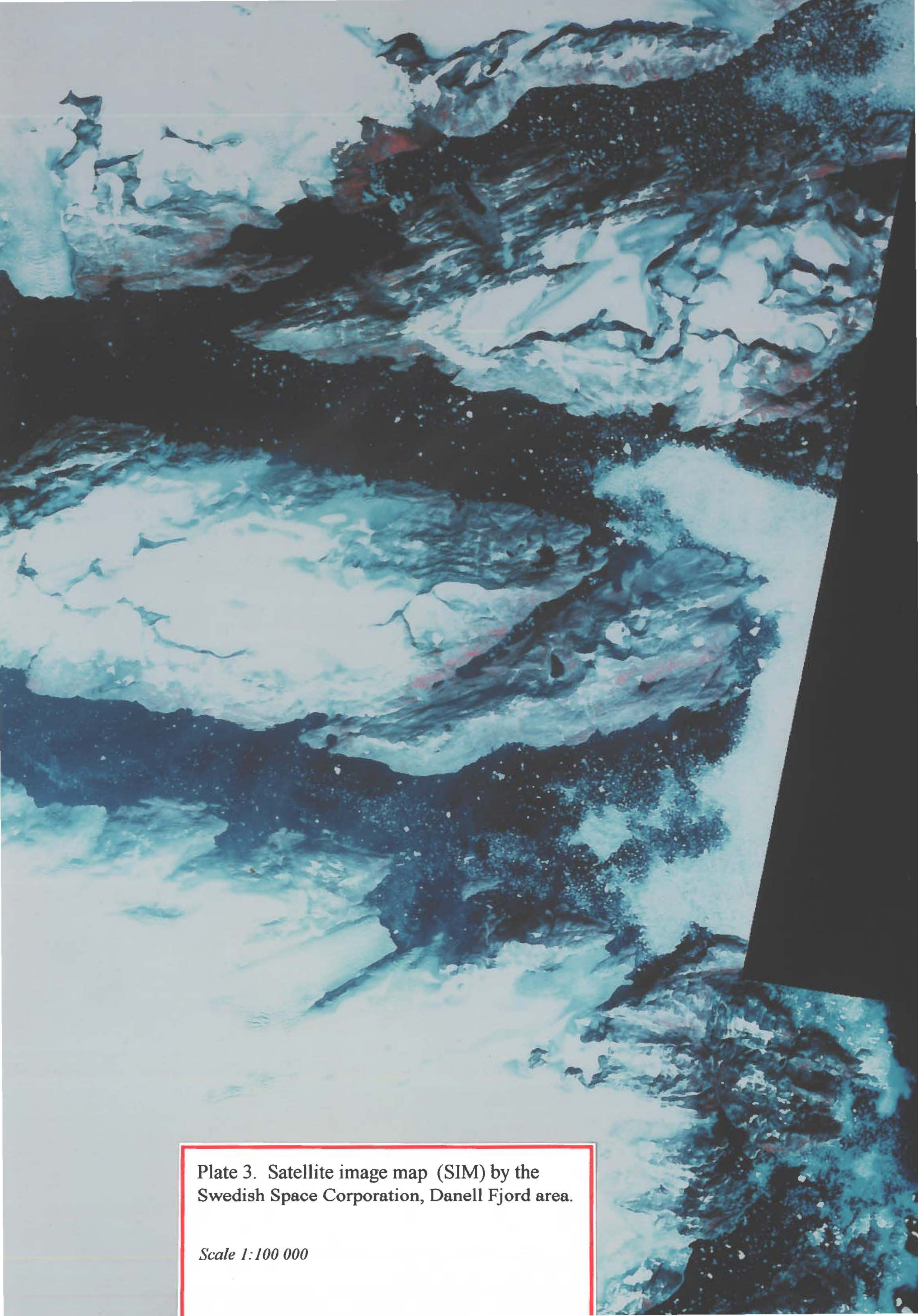


Plate 3. Satellite image map (SIM) by the Swedish Space Corporation, Danell Fjord area.

Scale 1:100 000

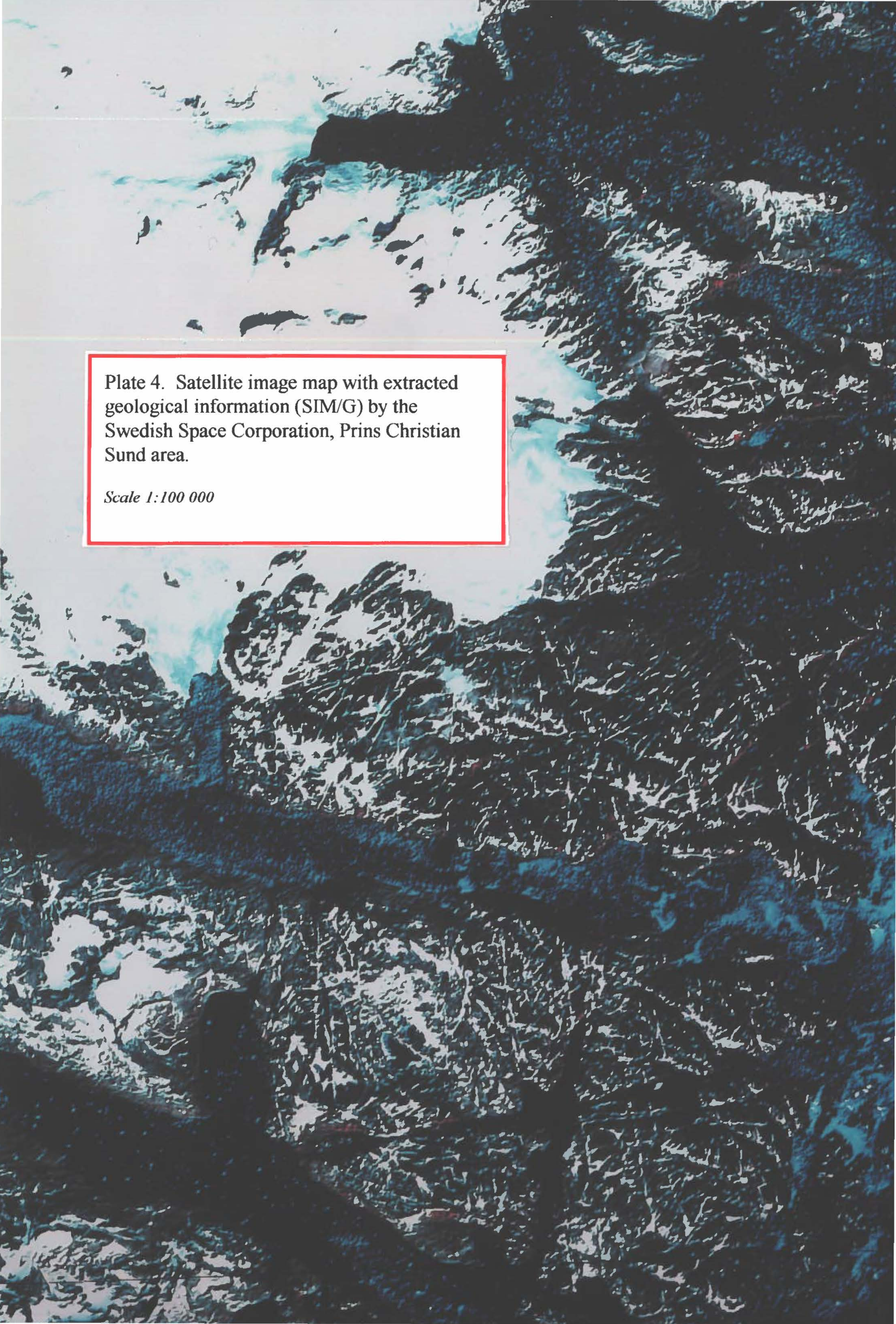


Plate 4. Satellite image map with extracted geological information (SIM/G) by the Swedish Space Corporation, Prins Christian Sund area.

Scale 1:100 000

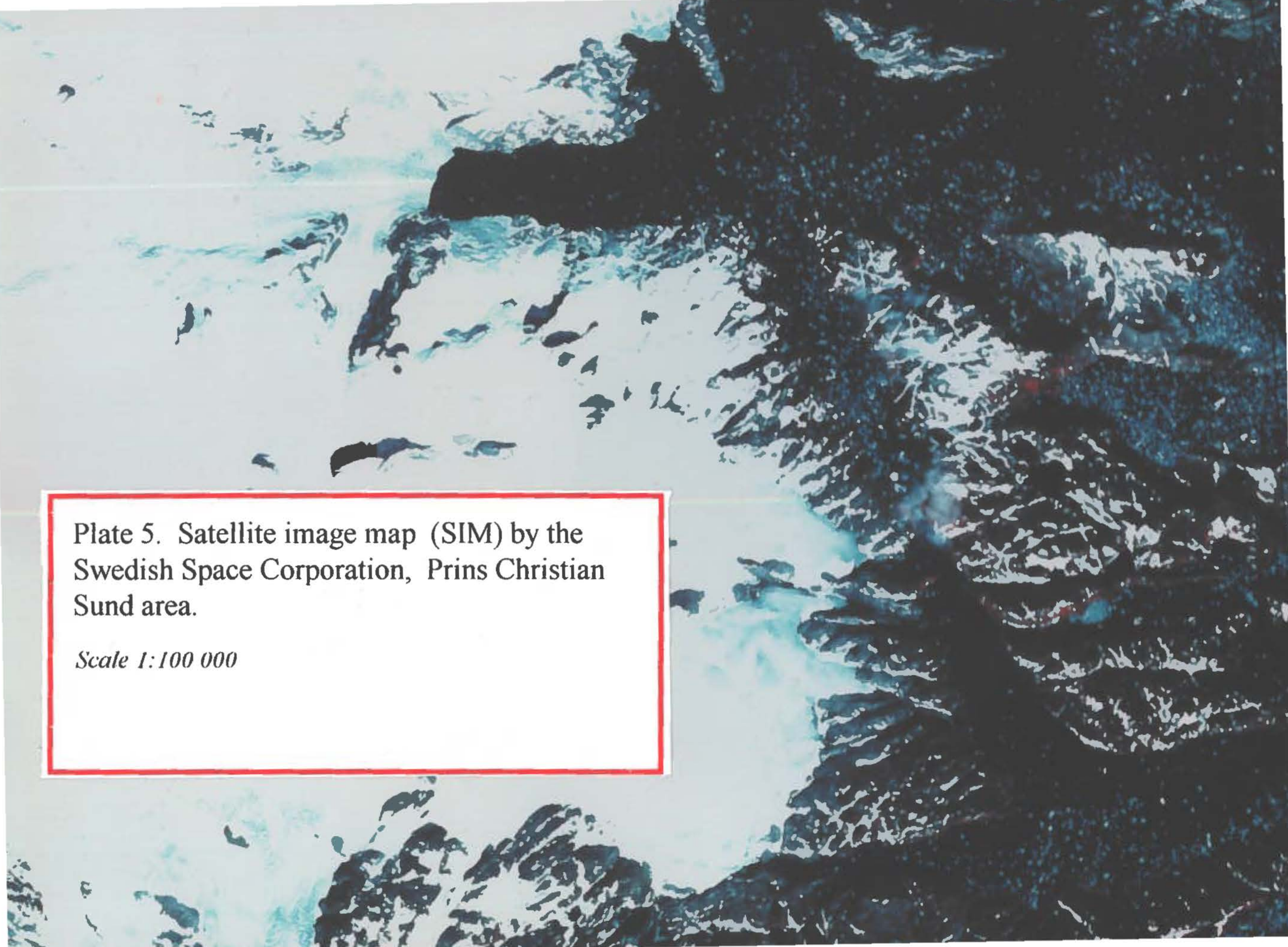


Plate 5. Satellite image map (SIM) by the Swedish Space Corporation, Prins Christian Sund area.

Scale 1:100 000

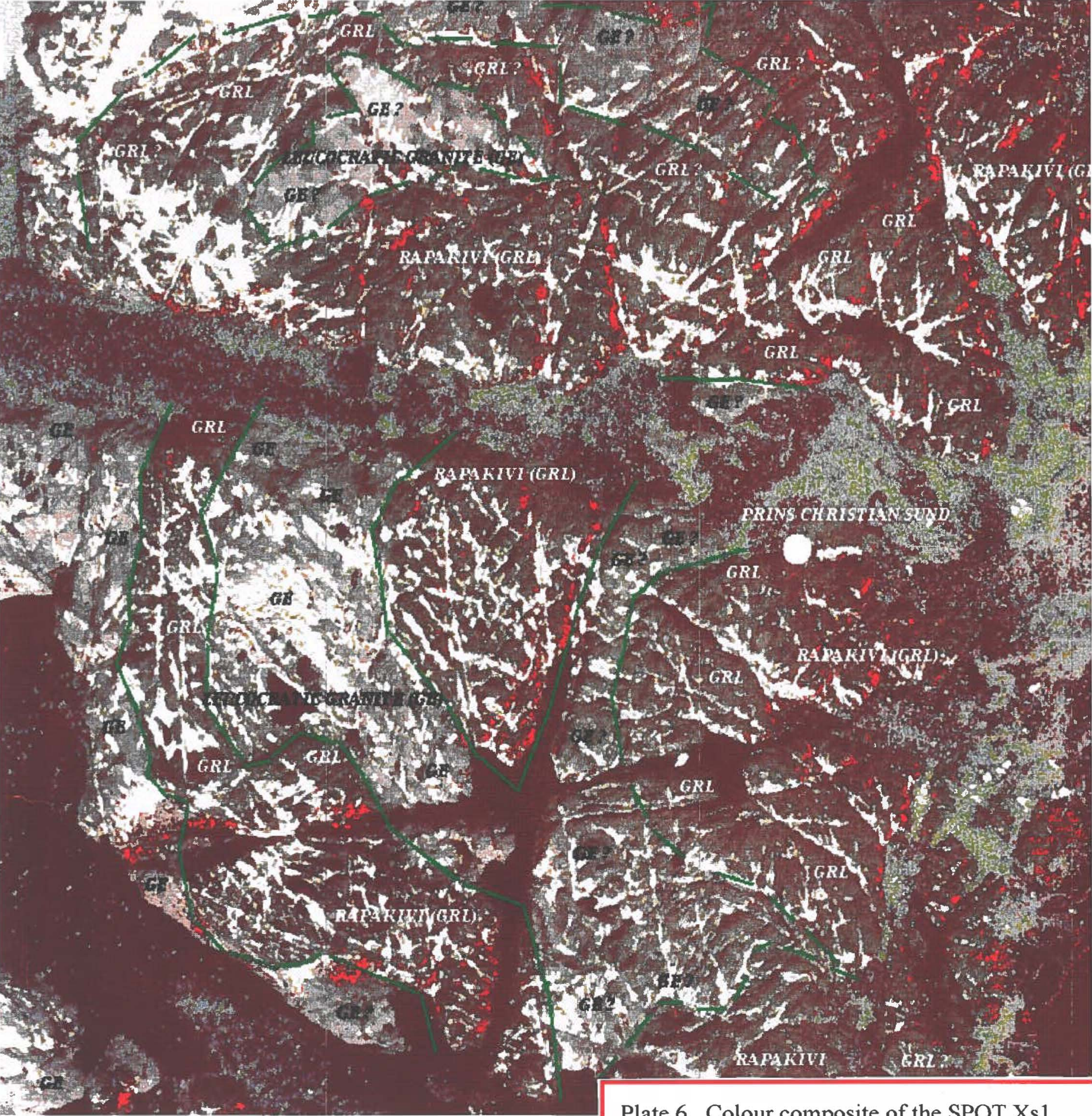
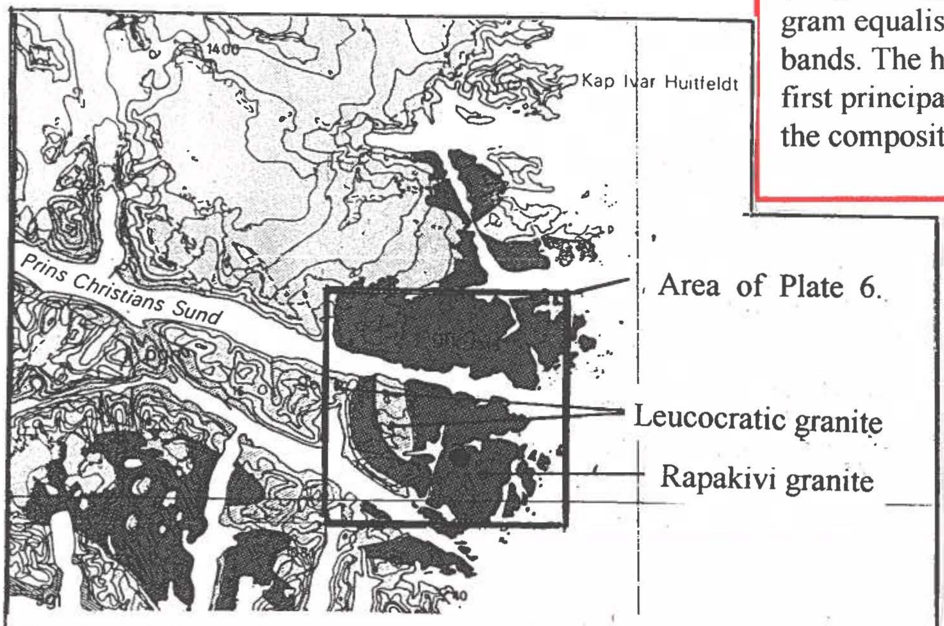


Plate 6. Colour composite of the SPOT Xs1 (red), Xs2 (green) and Xs3 (blue). The histogram equalisation strech is applied to the three bands. The high pass filtered component of the first principal component image is added on the composite.



Section of the geological map by Allaart (1976) *Scale 1:500 0000*

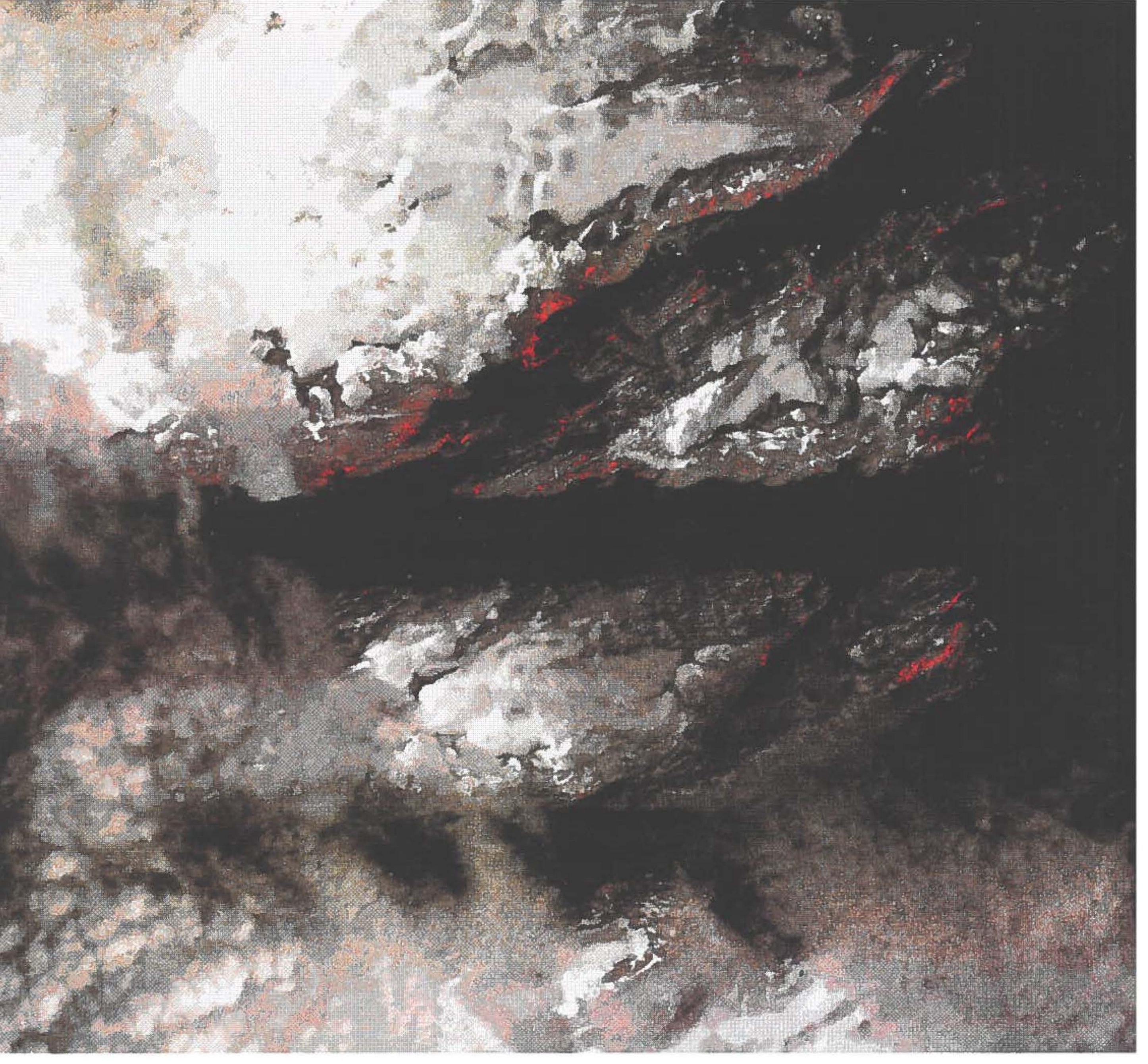
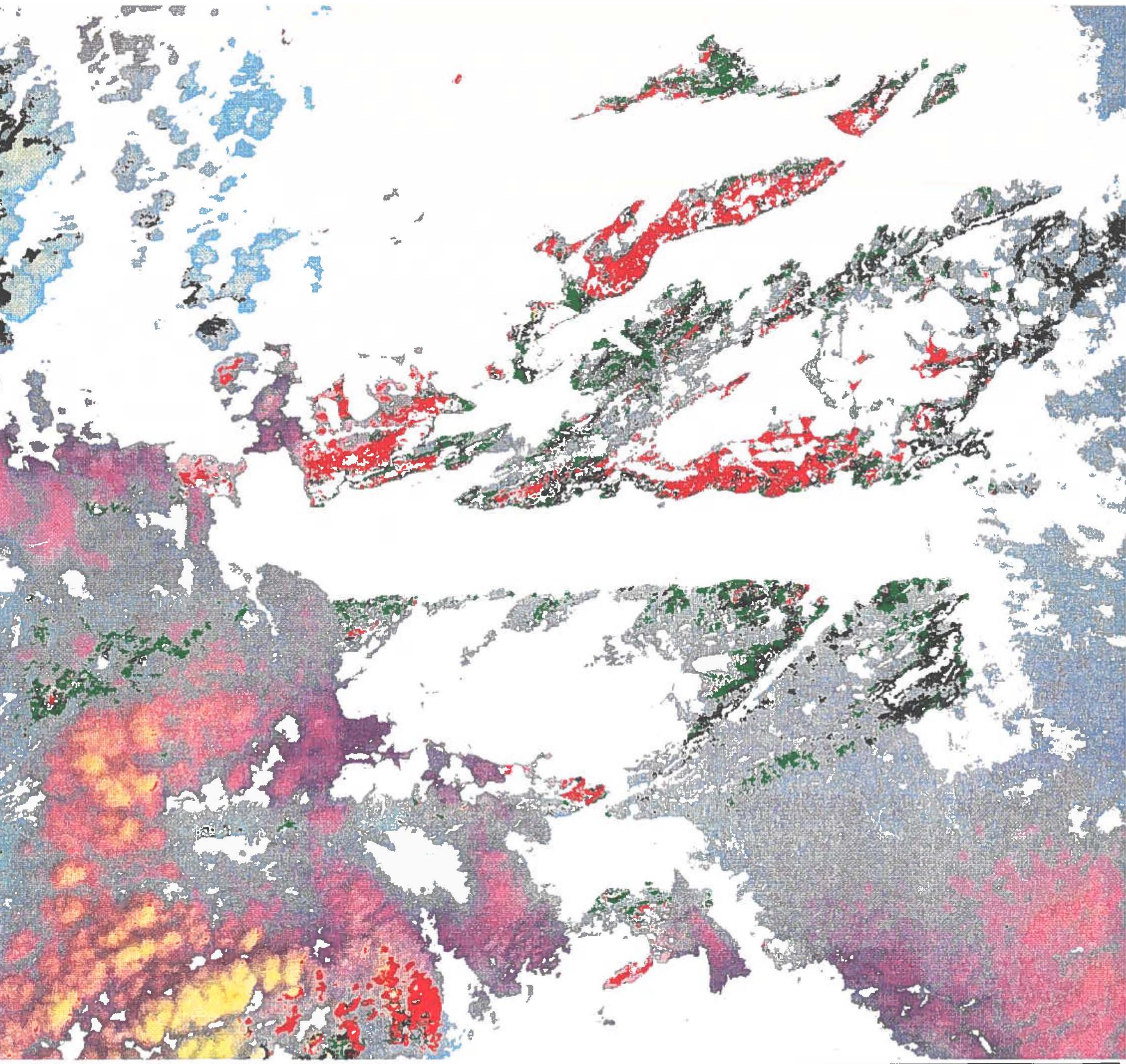


Plate 7. Colour composite of the Landsat TM bands 1 (red), 4 (green) and (blue), Iluileq area. The high pass filtered component of the first principal component image is added on the composite.



Interpretation:

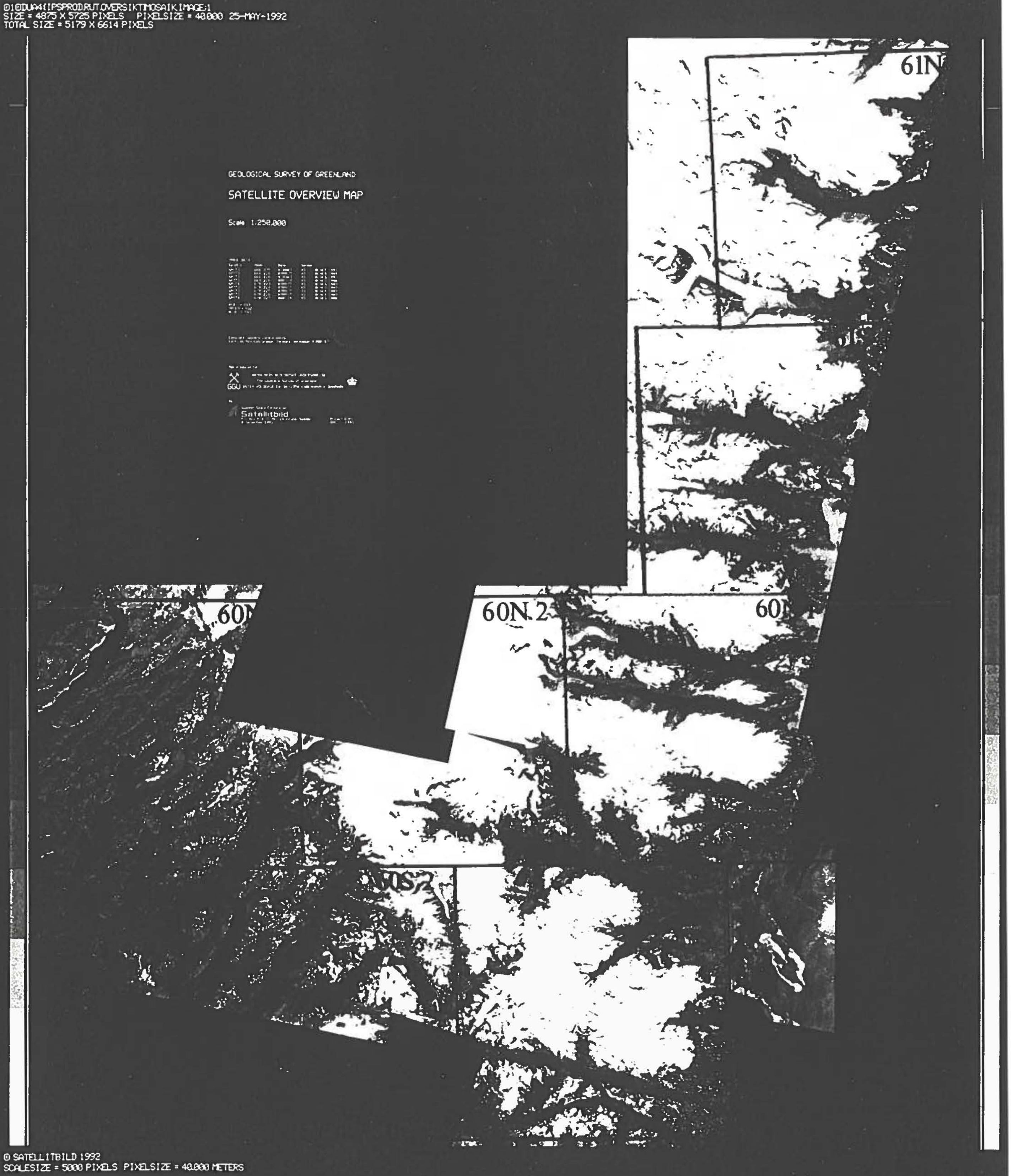
Red pixels = Granite

Black pixels = Pelite

Green pixels= Semipelite and mafic rocks

Grey pixels = Psammite

Plate 8. Colour composite of the histogramme stretched 2nd (red), 3rd (green) and 4th (blue) principal component image of the Landsat TM bands 1, 2, 3, 4, 5 and 7. The pixels with ice/ snow, vegetation and sea/lake water are masked.



Torbjörn Westin
Per Zeidlitz

15 juli 1992

Satellitbildskartor till GGU

FÖRORD

Föreliggande rapport utgör en beskrivning på produktion utförd av SSC Satellitbild till Grønlands Geologiske undersøgelse (GGU) inom projekt GIRS - Sydgrønland.

Vi vill främst tacka Peter Erfurt, Troels Nielsen, Leif Thorning (projektledare) och Tapani Tukiainen på GGU. Vilka vi haft direkt och god kontakt med och utan vars initiativ, fält och ämneskännedom produktionen stått sig slätt.

Vi vill även speciellt tacka Christer Andersson och Mats Öberg på SSC Rymdbolaget för kompetent handledning vid kurs.

INNEHÅLL

Satellitbildskartor till GGU
Processrapport

1. INLEDNING

På uppdrag av GGU (Grønlands Geologiske Undersøgelse) har SSC Satellitbild över ett undersökningsområde på södra Grönland producerat 7 st 1:100 000 Satellitbildskartor av ortofotokvalitet och 7 st 1:100 000 Satellitbildskartor med speciellt framhävd geologisk information.

Produktionen har utförts inom projekt GIRS - Sydgrønland (Geological Information from Remote Sensing) , se Thorning (1992).

Programmering för nya satellitregistreringar pågår. Satellitdataproduktionen inom GIRS förväntas vara komplett efter sommaren 1992 på södra Grönland och de områden där data idag saknas (se cover) därmed registrerats.

I denna processrapport anges närmast nyttjat utgångsdata, därefter beskrives produktionsfasen. Fördjupad information enligt bilagda referenser.

2. UTGÅNGSDATA

2.1 Av GGU tillhandahållet material

A. Geologisk kort over Grønland. Sydgrønland. 1:500 000. GGU 1975.

- nyttjad vid val av begränsningar för och indelning av undersökningsområde kontra satellitdata.

B. - Kort over Grønland. 60 V.2 Nanortalik. 1:250 000. G.I 1979.

- Kort over Grønland. 60 Ø.1 Prins Christians sund. 1:250 000. G.I 1966.

- Kort over Grønland. 61 Ø.1 Kap Tordenskjold. 1:250 000. G.I 1979.

- nyttjade som topografiska kartor vid upprättandet av satellitortofoton. Digital höjdmodell skapad, se 3.2 F.

C. Geodetiska stödpunkter. KMS permission A200/87.

- nyttjade som markstödpunkter vid upprättandet av satellitortofoton, se 3.2 C och D.

D. Geologisk kort. 60 V.1 syd Nanortalik. 1:100 000. GGU 1973.

- nyttjad som referens vid val av metod för att framhäva den geologiska informationen på satellitbildskartorna, se 3.5.

2.2 Satellitdata

A. SPOT XS scener. Satellitbild 1992.

- nedan är node (K-J) och registreringsdatum för nyttjade SPOT XS scener angivna. Dessutom anges de producerade kartblad respektive scen nyttjats för.

K-J	datum	kartblad
666-225	910803	60N 3 Lichtenau fjord.
666-226	910803	60N 3 Lichtenau fjord, 60N 2 Lindenow fjord.
666-226	890825	60N 3 Lichtenau fjord, 60S 2 Tasermiut.
669-226	880719	60S 2 Tasermiut, 60N 2 Lindenow fjord, 60S 1 Prins Christian sund.
670-223	890825	61N 1 Kap Cort Adelaer.
670-224	890825	61S 1 Kap Herluf Trolle, 61N 1 Kap Cort Adelaer.
670-225	890825	60N 2 Lindenow fjord, 60N 1 Danell fjord, 61S 1 Kap Herluf Trolle.
670-226	890815	60S 1 Prins Christian sund, 60N 1 Danell fjord.
670-227	880719	60S 1 Prins Christian sund.

3. PRODUKTIONSFASEN

3.1 Radiometrisk korrektion

A. Detektornormalisering med kalibrerade gain och bias för varje individuell detektor i CCD-arrayerna. Dessa värden kalibreras med ca 2 månaders intervall av CNES och appliceras standardmässigt av alla mottagningsstationer för SPOT. Resultatet blir en radiometriskt homogen bild eftersom randighet beroende på detektorernas olika känslighet elimineras. En viss resteffekt kan dock förekomma på grund av små variationer som har perioder mindre än kalibreringsintervallet. Dessa är dock vanligtvis mindre än en digitalnivå i storlek, och kan endast observeras i homogena mörka områden, som vattenytor.

B. Reduktion av koherent brus genom filtrering. Alla SPOT-scener påverkas till en liten grad av ett brus som yttrar sig i att varannan kolumn och varannan linje är ljusare och mörkare. Vid SSC Satellitbild har utvecklats ett speciellt filter som reducerar detta brus. Filtret appliceras standardmässigt av SSC Satellitbild på alla precisionskorrigerade produkter från SPOT. För detaljer om filtret, se Westin (1990a).

3.2 Geometrisk korrektion

A. Geometrisk modell. En rigorös satellitmodell används för den geometriska korrektionen. Parametrar i modellen är satellitbanans parametrar samt attitydvinklar. Den rigorösa modellen gör lösningen väldigt stabil och behovet av stödpunkter lågt. Detaljer om satellitmodellen och dess estimering finns i Westin (1990b).

B. Stråktriangulering. För att ytterligare stabilisera geometrin utnyttjades på Grönland att flera scener var registrerade i sekvenser i stråk. Geometrin för ett helt stråk löses då i en simultan utjämning. Därigenom minskas ytterligare behovet av stödpunkter, alternativt fler punkter bidrar till överbestämning och bättre geometri. Detaljer om stråkutjämning finns i Westin (1991a,1991b).

C. Stödpunkter. KMS kontrollpunkter redovisade på flygbilder och tillhandahållna av GGU har använts. På grund av skalskillnaden mellan flygbild och satellitbild var de flesta KMS punkter omöjliga att identifiera i satellitbilderna, men i genomsnitt 5 punkter per scen kunde markeras med acceptabel precision.

D. Resultat av utjämningen. Rms i restfelen i kontrollpunkterna blev:

$$RMS_X = 32m$$
$$RMS_Y = 29m$$

Restfelen visar primärt hur noggrant det gick att identifiera kontrollpunkterna i bilderna. Den slutliga modellen kan antas ha en högre noggrannhet genom dess stabilitet och överbestämningar från kontrollpunkter.

E. Resampling. Den uppdaterade satellitmodellen används nu för att interpolera den råa satellitbildens pixlar till det grönlänska koordinatsystemet UTM zon 23. För interpolationen används kubisk faltning baserad på SINC-funktionen (SinX/X) begränsad till en 4x4 pixlars omgivning.

F. Eliminering av terrängförskjutningsfel. På grund av att flera av SPOT scenerna var registrerade med sned spegelvinkel, tillsammans med den höga terrängreliefen på Grönland, bedömdes det nödvändigt att utföra en speciell korrektion av höjdparallaxer. En digital höjdmodell skapades först genom digitalisering av höjdkurvor på Grönlänska 1:250,000 kartor över kartläggningsområdet. Höjdmodellen användes sedan under resamplingen för att korrigera positionen på varje pixel så att resultatet blir en ortobild.

3.3 Digital mosaik

A. Relativ kontrastsättning. Före sammanfogning av två scener måste deras relativa färgbalans stämma. Detta bestäms genom visuell kontraststräckning av två delbilder inom överlappzonen mellan de två scenerna.

B. Utläggning av scenskarv. Den linje utefter vilken de två scenerna ska skarvas, läggs ut interaktivt så att man undviker så mycket som möjligt av eventuellt dåliga områden (moln etc.) i vardera scenen.

C. Sammanfogning. Den slutliga sammanfogningen sker inte genom en skarp gräns, utan genom en gradvis övergång inom ett ca 20 pixlar brett område på vardera sidan om begränsningslinjen.

3.6 Färdigställande av produkter för leverans

Satellitbildskartorna har levererats digitalt och analogt till GGU från Satellitbilds avdelningar dataproduktion respektive fotolaboratorium.

A. Digitala produkter. Levererade på CCT, 6250 bpi, BSQ.

B. Analoga produkter. Diaoriginal har levererats som Fire 24x22 cm på Kodak positive colour film. Fotoförstoringar har levererats på Ilford Cibachrome glossy.

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