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Digital Landsat TM-data used in the mapping of large scale geological structures on the coast of central Norway

Norges geologiske undersøkelse

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Tittel:

Digital Landsat TM-data used in the mapping of large scale geological structures on the coast of central Norway.

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Sammendrag:

Landsat-5 Thematic Mapper (TM) data has been used to map linear structures of three areas of Trøndelag, central Norway, where offshore activities demand more information about onshore geological structures.

The aim of the project was to utilise digital TM-data through an image processing system to enhance detection and analysis of large-scale planar structural features in the bedrock of these areas. Different types of image enhancements were tested before a simple procedure of linear stretching of the TM-channels and generation of colour composites was developed.

Interpretation of large-scale linear features was done from the colour composites. Bedrock foliation, joints and related linear features representing fault zones, fracture zones etc. were plotted on base maps and then digitized to produce rosediagrams and sector maps.

Emneord	EDB	~~Strukturgeologi~~
Fjernanalyse	Rapport	

1. INTRODUCTION

Satellite remote sensing is a widely used and a potentially powerful tool in the mapping of large-scale geological structures. The Multispectral Scanner (MSS) onboard Landsat satellites series is familiar to many geologists ,but, unfortunately, the poor resolution of the scanner has minimized its use. Beginning with the Landsat 4, however, the Thematic Mapper (TM) instrument delivered data with improved resolution, thus allowing for better identification of large- and small-scale structural features not previously detectable.

The Tromsø Telemetrystation (TT) is the National Point of Contact (NPOC) between the European Space Agency (ESA) and Norwegian users of satellite remote sensing. In early 1985, ESA, through their NPOC's, offered the digital TM-data at distribution cost only to remote sensing institutes. This was done to initiate pilot projects which could introduce TM's capability to the remote sensing community. In this connection the Geological Survey of Norway (NGU), decided to try the system as they had been looking for an opportunity to use TM-data in the interpretation of geological structures.

Research funds from the Technical Research Council of Norway (NTNF) made it possible for our group to use the image processing system of the Tromsø Telemetrystation freely for one week. The work was organized as a cooperative venture between the NGU and the Research Council of the Tromsø University (FORUT); the image processing was done on the IIS-system at the TT, and the geological evaluation of the enhanced images at the NGU in Trondheim.

NGU provided people with geologic, remote sensing and image processing expertice, while FORUT kept the expertice of the specific image processing system at Tromsø Telemetrystation.

The aim of the project was to evaluate the benefit of digital Landsat TM-data used in the mapping of geological structures. Of special interest was it to compare TM-data with older Landsat MSS-data from the same area, and to compare the results of a digital approach with an interpretation based on standard B/W photoproducts.

Three test areas were chosen for trying out the TM sensor's suitability for structural mapping with special emphasis on fracture related lineaments but also its suitability for distinguishing bedrock foliation from other lineaments. Two of the test areas, Roan and Vikna, are located on the coast of Trøndelag, central Norway, an area of poorly known geology covered only by reconnaisance mapping in connection with the compilation of the 1:1.000.000 bedrock map of Norway (Sigmond et al.1984). The third area, Verdal, situated inland in Trøndelag, is geologically better known and was chosen as a reference area (see Fig. 1).

2. LANDSAT THEMATIC MAPPER

TM is a second generation sensor system for surveillance of the earth's surface and is one of the electro-magnetic spectrum sensing instruments onboard the American earth resource satellites of the Landsat series. The first TM-sensor was onboard the Landsat-4, but failed in 1983 after less than one year of operation, having recorded only a few hundred scenes.

Landsat-5 was launched in March 1984 and is still operative, recording almost 150 scenes every day. The orbit of Landsat 5 is near polar at an altitude of 705 km and is completed in 16 days.

The amount of data has increased considerably from MSS to TM, because of an increase in the number of spectral bands (4 -> 7 channels), in radiometric resolution (64 -> 256 digital levels) and in geometric resolution (80 -> 30 meter). As compared to a MSS-scene that contains ca. 180 Megabits of information, a TM-scene contains ca. 2000 Megabits.

Compared with the MSS-instrument,TM has two additional channels in the reflected infrared area and one channel in the termal infrared area (see figure 2). The thermal channel has a resolution of 120x120 m2. The geometric resolution or pixel size of TM is 30x30 m2 compared to MSS's 56x79 m2. The TM-sensor has a swath width of 185 km which gives scenes of 185x185 km2. The principal use of TM is in the mapping of vegatation, soil, bedrock and water quality.

The TM-sensor got a competitor in February 1986 when the French satellite SPOT was put into orbit. SPOT is together with TM also called the second generation earth resource satellites. The SPOT-sensor has less spectral bands than TM, but a geometric resolution of 20 meters in multispectral mode and 10 meters in panchromatic mode.

3. DIGITAL IMAGE PROCESSING

Data from one TM-scene is stored on seven 2400 foot magnetic tapes and the administration of these data is quite time consuming, especially the reading of data from tape to disc. This is the major drawback when dealing with digital image processing of TM-data.

The digital image processing system of the Tromsø Telemetrystation includes an International Imaging System (IIS) Model-70 and Model-75 image processor, system 500 and system 575 software installed on a VAX-11/730 computer, an Optronix C-4300 film-printer and a Honeywell Matrix-3000 videoprinter for 35 mm or polaroid film.

The investigated TM-scene has reference number 50204-10063 and is recorded 21. sept. 1984. It has a low radiometric quality because of the low sun angle (24 degrees). This is clear for the thermal channel (channel 6), and this channel is not used. Best radiometric quality was found on channels 4 and 5 followed by channels 1 and 7, whereas channel 2 and 3 had the lowest radiometric quality. For geological applications, channel 4 was found most suitable, but the channels 3, 5 and 7 were also useful. The right-half side of the TM-scene is generally cloud-covered, but the other half of the scene is of excellent quality.

As TM has got quadric pixels, there was no need for any geometric rectification of the data prior to the geologic evaluation of the data.

During the digital image processing several techniques for image enhancement were used. Most of the techniques were performed on an image of 512 x 512 pixels, which, for TM-data covers an area of ca. 15 x 15 km2 on earth. Skipping every second pixel meant that an area of 30 x 30 km2 could be displayed without loosing much information of the structural features in the image area. This was checked by analyzing a few parallel full-resolution images, but these images did not yield much more structural information than the half-resolution images. In fact, we found that by using only every third or fourth pixel, we could get a synoptic view of very large areas which favoured the recognition of large geological structures.

Colour composites based on three TM-channels were found to give valuable information without involving timeconsuming calculations. Various combinations of channels 1, 2, 3, 4, 5 and 7 were used, but the most useful combinations all contained channel 4. The only needed treatment prior to colour composite generation was linear stretching of each of the three input channels; this helped to improve the contrast of the image.

A colour composite based on ratios between 4 input channels contained much information on thematic variations, but were less useful for detecting linear fetures. This is caused by the fact that ratios remove topographic features, which is the footprint of linear structures. If the input-channels were 2, 3, 4 and 7, the colour composite would be: R=2/3, G=3/4; B=4/7.

Changing between various pseudocolours was useful for detecting certain features in the image. Interpretation of the images was carried out by visual inspection of the colour monitor and plotting of the linear features on a base map, usually a black-and-white print of the TM-scene at 1:250,000 scale. The colour composites with the most information were then reproduced on positive colour film by using the Matrix-3000 video-tube.

A synoptic view of big areas is the major advantage of using satellite remote-sensing techniques. A Landsat TM-scene gives the same view as a Landsat MSS-scene, but TM's improved geometric resolution makes it possible to detect objects about one fifth the size of what MSS can. As most image processing systems can display

512x512 pixels on a colour monitor, this means that with MSS-data one can display an area on 40x40 km2 compared to TM's 15x15 km2. The conclusion of this is that an image processing system suitable for TM-data should at least be able to display 1024x1024 pixels on a colour monitor. As mentioned earlier, our project used a procedure of skipping every second pixel to be able to have the same synoptic view of large areas as with Landsat MSS.

4. STRUCTURAL GEOLOGY

A lineament can be defined as a linear feature seen on a satellite image. The lineaments may be surface expressions of geological structures like faults, bedrock boundaries, bedrock foliation, crushing zones, etc. and these are of great importance for the geologist. The mapped lineaments from the three test areas were digitized and analysed on a Hewlett Packard 3000 computer at the Geological Survey of Norway (NGU). The software system for handling the lineaments is developed at NGU (Rindstad, 1982) and can produce a variety of discrimination diagrams including histograms, rose diagrams, sector maps and gridded maps.

4.1 Introduction.

The Trøndelag area has received attention in a number of regional Landsat MSS lineament studies some of which have also attempted to integrate their interpretation with published geophysical, magnetic and gravity data.

Among the principal contributors are Ramberg et al.(1977), Ramberg & Gabrielsen(1978), Gabrielsen & Ramberg(1979), Gabrielsen et al.(1981), Aanstad et al.(1981) and Offield et al.(1982). Most of these studies have shown that many MSS lineaments can be correlated with tectonic-fracture zones, but that some lineaments are related to bedrock foliation and have undoubtedly been included with fracture-zone lineaments. Many fracture-zone lineaments have been shown to be the site of renewed fracturing of importance in the Mesozoic, to a large extent controlling and influencing the faulting and fracturing of sedimentary rocks in the shelf areas.

On the basis of MSS imagery and ground-based geological studies, Norway has been divided into five major tectonic intensity zones some of which are still seismically active. The Verdal area is within the socalled Møre-Trøndelag fault zone, one of the most active earthquake-zones in the country. In addition to establishing the fracture-pattern of the region our Landsat imagery analysis detected a province of major basement domes in central and north Nord-Trøndelag.

The bedrock of this region of central Norway can be broadly subdivided into cover rocks consisting of stratified metasedimentary and metavolcanic rocks belonging to nappes overthrust during the Caledonian Orogeny, ca 4-500 My ago, and rocks belonging to the former Baltoscandian shield, which served as the basement to the overthrust Caledonian nappes.

The basement rocks consist of strongly- to weakly-deformed granitic to tonalitic gneisses (Sigmond et al.1984).

The southwestern part of this basement-dome province is characterized by a uniform NE-SW linear strike direction, parallel or subparallel to the strike of the Møre-Trøndelag fault zone. The northeastern part of this province is characterized by more tonalitic to gabbroic gneisses as well as high-grade supracrustal cover rocks deeply infolded between basement gneiss domes. The basement rocks in these two areas also have a different aeromagnetic anomaly pattern(Boyd, 1985).

4.2 The Vikna Archipelago.

The Vikna archipelago is located in the northern part of coastal Nord-Trøndelag. The bedrock on main islands of Indre, Mellom and Ytre Vikna consists mainly of Precambrian granodiorite gneisses and migmatites that vary in their degree of deformation. The westernmost island, Kalvøya, is mainly relatively highly metamorphosed sediments.

A major tectonic zone, the Måholmsråsa fracture-zone, separates the Vikna islands from young granitic plutons (Raudøya, Kvaløya) and a supposedly younger and low-grade sequence of metasedimentary rocks to the north. The Måholmsråsa tectonic zone can be seen to trend E-W on the TM colour composite (Fig. 6a). Another important tectonic zone, the Nærøysundet fault-zone, can be seen running SW-NE in the eastern part of this subarea.

The bedrock in this area is deformed by tight to isoclinal upright folds with axial planes generally striking NE-SW and dipping steeply NW or SE. The strike of a major set of fracture planes in this area is parallel or subparallel to this direction, and which is also the main direction of nearby fjords and sounds. Another major set of fracture planes trends NNE (Fig. 4a) which is the strike of the Rana Fault Complex in this region (Gabrielsen et al.,1984), and also the trend of a lesser number of fjords. The Rana Fault Complex is located just west of the Vikna islands, and separates the Mesozoic and Cenozoic strata in the shelf areas from the Precambrian and Lower Palaeozoic crystalline rocks that crop out on the seabottom to the east.

A lineament interpretation based on colour aerial photographs (1:40000) gives the same major lineament directions as the TM interpretation considering lineaments with a length of 1 km or more (Bering et al.,1986).

Folding is best seen in the metasedimentary rocks on the Kalvøya and in the gneisses SW of the island. Major folds in the gneisses and metasediments on Mellom-and Indre Vikna are also evident on the TM colour composite. The major strike direction of the gneisses stands out clearly (Fig. 3a and 6a), but it is not possible to discern foliation pattern from fracture pattern.

Spectral information on the colour composite (Fig. 6a) was used to map the amount and types of vegetation in the area. This information can be a subtle indicator of rock-type. The heavily vegetated low-land areas, for example, stand out in blue because of the response in the reflective IR channel(4). Similarly granodiorite gneisses are yellow on exposed rock surfaces and light green on scarsely vegetated areas of moss and heather whereas metasedimentary rocks on Kalvøya and Lysøya, Mellom Vikna, and amphibolite gneisses on the Vikna islands are more heavily vegetated and appear dark green (Fig. 6a).

The granitic rocks in the pluton on Kvaløya, north of Måholmsråsa, show a response close to the granodiorite gneiss areas, but the low Raudøya is heavily vegetated and give a high response in the reflective IR channel.

4.3 The Roan Area.

This area is situated on the coast of Sør-Trøndelag about 100km NNW of Trondheim. The area contains both basement gneisses and infolded metasedimentary rocks. The basement gneisses are a heterogeneous suite of diorite, granodiorite and granite gneisses and migmatites. The metasedimentary rocks are mainly biotite gneisses and schists including minor marble and amphibolite gneisses.

The basement can be subdivided into two units; a western area, including the Roan peninsula, characterised by a very pronounced magnetic and gravimetric anomaly. This anomaly generally follows the coastal areas but here and in the Lofoten-Vesterålen islands it is found onshore. The Roan peninsula consists partly of granulite-facies rocks rocks which are generally but not always retrograded to amphibolite facies (Møller, pers.comm.1985).

The eastern basement area is characterised by granodiorite and migmatite gneisses with deeply infolded metasedimentary rocks, deformed into a uniform (NE-SW) strike direction. The trace of one such spectacular synform trends NE-SW, diagonally across the image (Fig. 6b and 3b). The SW part of this synform is transected by a curved lineament which can be traced south to the Verran fault(Oftedahl 1972, 1975). The TM image clearly shows that bedrock structures are not continuous across this lineament, and because the structures have no obvious lateral displacement, most probably represents a normal or reverse fault. The rose diagram of lineaments in the area illustrates the prominent NW lineament-direction in the area Ørland-Namdalseid; a direction which is also the most important magnetic dislocation set in this area(Bering et al.1986). This NW lineament direction is not prominent on the Roan peninsula.

The lineament trending NE-SW between Skjøraf jorden and Brandsfjorden is a possible thrust zone. Magnetic susceptibility measurements indicate low magnetic rocks in this lineament and in the lineament east of Harbaken indicating alteration of magnetic minerals(Olesen pers.comm.,1985).

Comparing the lineament interpretation of MSS channel 5 (Fig. 5) with that of TM (Fig. 3b), TM gives substantially more information on lineaments shorter than ca. 5 km and the ability to discern foliation-related lineaments from tectonic lineaments is greatly improved. The steeply dipping foliation facilitates this ability.

The colour composite (Fig. 6b) is excellent for distinguishing different types of vegetation, and exposed rocks from vegetation. There is, however, not much lithological information to be gained, owing to the fact that much of the upland areas in this region are covered by bogs regardless of rock type.

4.4 The Verdal Region.

This Verdal region is located approximately 80km NE of Trondheim, in the inner part of Trondheimsfjorden. It is nearly completely covered by vegetation. Agriculture is restricted to the valleys below the marine limit, with dense spruce forest above. The cover in the areas below the marine limit is mostly clay.

The bedrock consists of metamorphosed supracrustal nappe units, emplaced during the Caledonian orogeny. Within the area covered by the colour composite (Fig. 6c) there are rock-units from the Middle and Upper Allochthon, including the Leksdal Nappe, the Skjøtingen Nappe, the Levanger Nappe and the Støren Nappe (Wolff,1984). The rock-types include metasandstone, amphibolite and greenstones.

The bedrock in this region is penetrated by hydrothermal alteration zones that contain thorium minerals and fluorite. These alteration-zones represent a late stage in the formation of the Trondheimsfjord penetrating the intrusive rocks of the area. The hydrothermal zones are to narrow to be shown directly on the TM image, but several NE-trending lineaments and curvilineaments probably correspond to such zones (Fig. 3c).

Pronounced lineament directions within the image window are NNE and ENE; curvilineaments trend generally NE (Fig. 3c and 6c). The shape of inner Trondheimsfjord, as well as Børgin and Leksdalsvatnet, has been influenced by these directions. The TM image does not reveal as much about the bedrock structures here as it did in the Vikna and Roan area, but the TM image does show the presence of flat lying rocks in the northern part of the Verdal area, and the SW-NE strike direction of bedrock units at Ytterøy and SE of Levanger.

As shown in the Roan area, TM gives substantially more information on lineaments shorter than ca. 5 km. Because of the extensive marine clay cover and gently dipping bedrock, foliation structures are not as evident as in the Vikna and Roan area.

The rock fracture pattern gives more information on lithologies than vegetation does, the Inderøy metasandstones having a very pronounced fracture pattern.

The colour composite (Fig. 6c) distinguishes grainfields, meadows and forest well, but in this area it is not possible to define lithologies on the basis of this classification.

4.5 TM versus MSS.

The superiority of TM-analysis over conventional MSS-analysis is evident when applied to large-scale geologic examples. TM-analysis is especially helpful in discerning foliation lineaments from tectonic lineaments. Fig. 5 shows a one channel MSS-based lineament interpretation. Comparison with the TM image (e.g.Roan area, Fig. 3b) shows the superiority of TM in foliation mapping. The MSS image resolution is so low that it is impossible, in many cases, to distinguish between valleys eroded along foliation zones and valleys developed along fractures or faults.

Steeply dipping foliation are more readily discernible than flat-lying foliation which needs some topographic expression to be visible. The combination of steeply dipping foliation, good rock exposure and indented topographic relief is excellent for the interpretation of the Roan area (Fig. 3b). The Verdal area has flat-lying foliation partly marine clay cover and gentle relief resulting in less difference between the MSS interpretation (Fig. 5) and the TM interpretation (Fig. 3c).

The fact that TM has more spectral bands than MSS means that certain structural features can be more easily detected than by conventional MSS-analysis. Other multi-spectral information (e.g. channel 7), can be useful in the mapping of large-scale hydrothermal zones or of large regions of hydrothermally altered rocks; such uses, however, are likely to be of limited value in Norway. Porphyry-type ore-deposits which have been prime targets for remote sensing exploration will not be as easy to target in glaciated and vegetated areas such as Norway. Use of spectral information for detection of stressed vegetation-areas poisoned by heavy metal toxins does, however, hold some promise for the future.

5. CONCLUSION

Data from the TM-instrument onboard the Landsat-5 satellite has proven very useful for detailed interpretation of geological structures. For structures with a length of 1 km or more, TM gives as much information as high altitude aerial photographs.

Compared with MSS-data, the TM-data gives more information about structures of length less than 5 km. This means that TM can give information about foliation, which MSS cannot.

Digital image processing of TM-data gives more information than the use of standard black-and-white photographs, especially in areas with extensive soil cover. Image processing consists of linear stretching of individual TM-channels and a generation of colour composites. Four combinations of TM-channels were found to be useful, each of them contain channel 4. These combinations are: 2/3/4, 1/4/7, 3/4/7 and 4/5/7.

The spectral quality of the TM-scene is not always impressive, in part because of the low sun angle of only 24 degrees. The low sun angle is, however, an advantage in lineament mapping, because the shadows enhance subtle linear features.

For the thermal infrared channel 6, the pixel values lies within 8 digital levels, making most data almost useless. Channel 6 can have great geologic importance in application, however, and should be used when interpreting TM-data from the months of June, July or August.

When interpreting large geologic structures from TM-data, using every second or third pixel is an advantage when using image processing systems with colour monitors limited to 512x512 pixels. This gives a synoptic view of larger areas which is the major advantage of using satellite remote sensing techniques.

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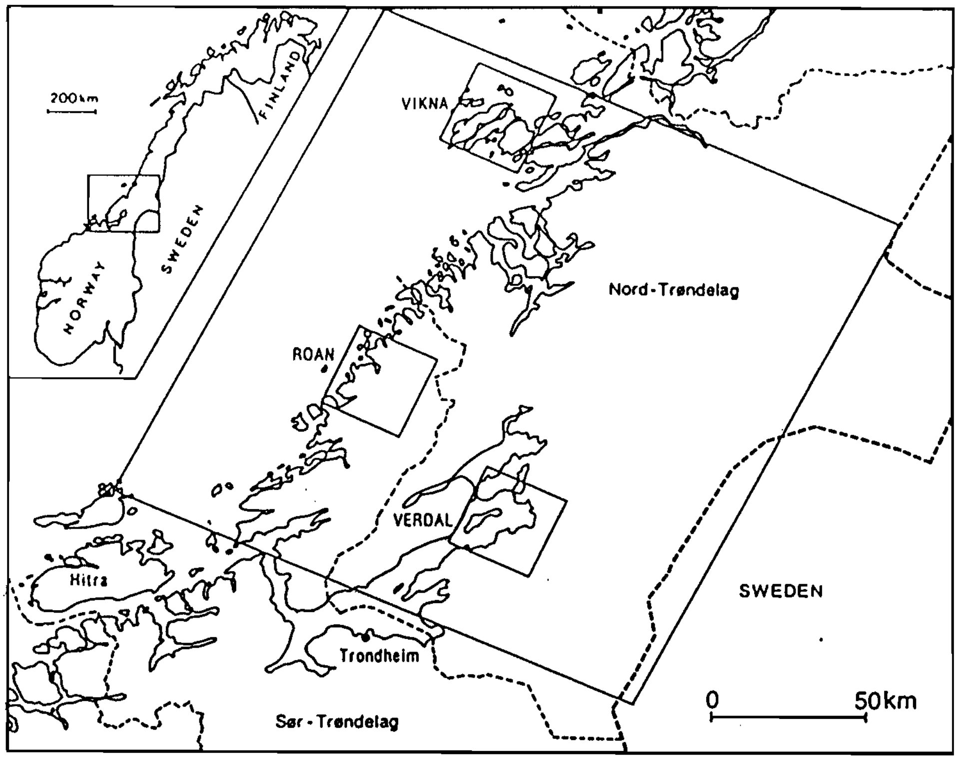
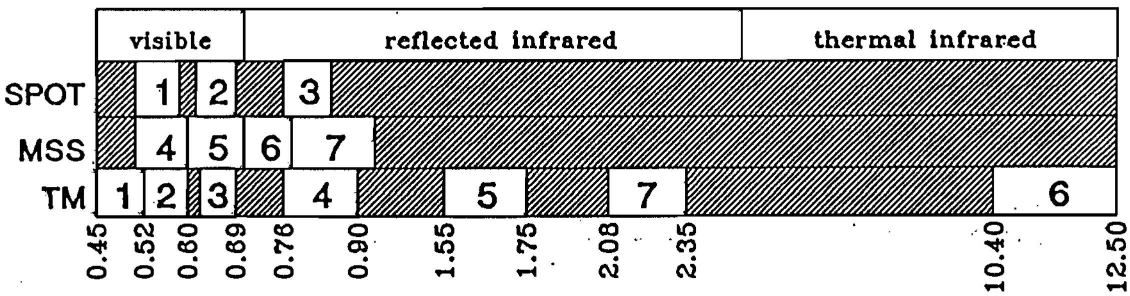


Fig.1 Location map of subareas Vikna, Roan and Verdal.
Each subarea is 30kmx30km.
Landsat TM-scene 50204-10063, taken 21.Sept.1984.



THE SPECTRAL BANDS OF SPOT AND LANDSAT TM AND MSS
(wavelength in micrometers)

Figure 2.

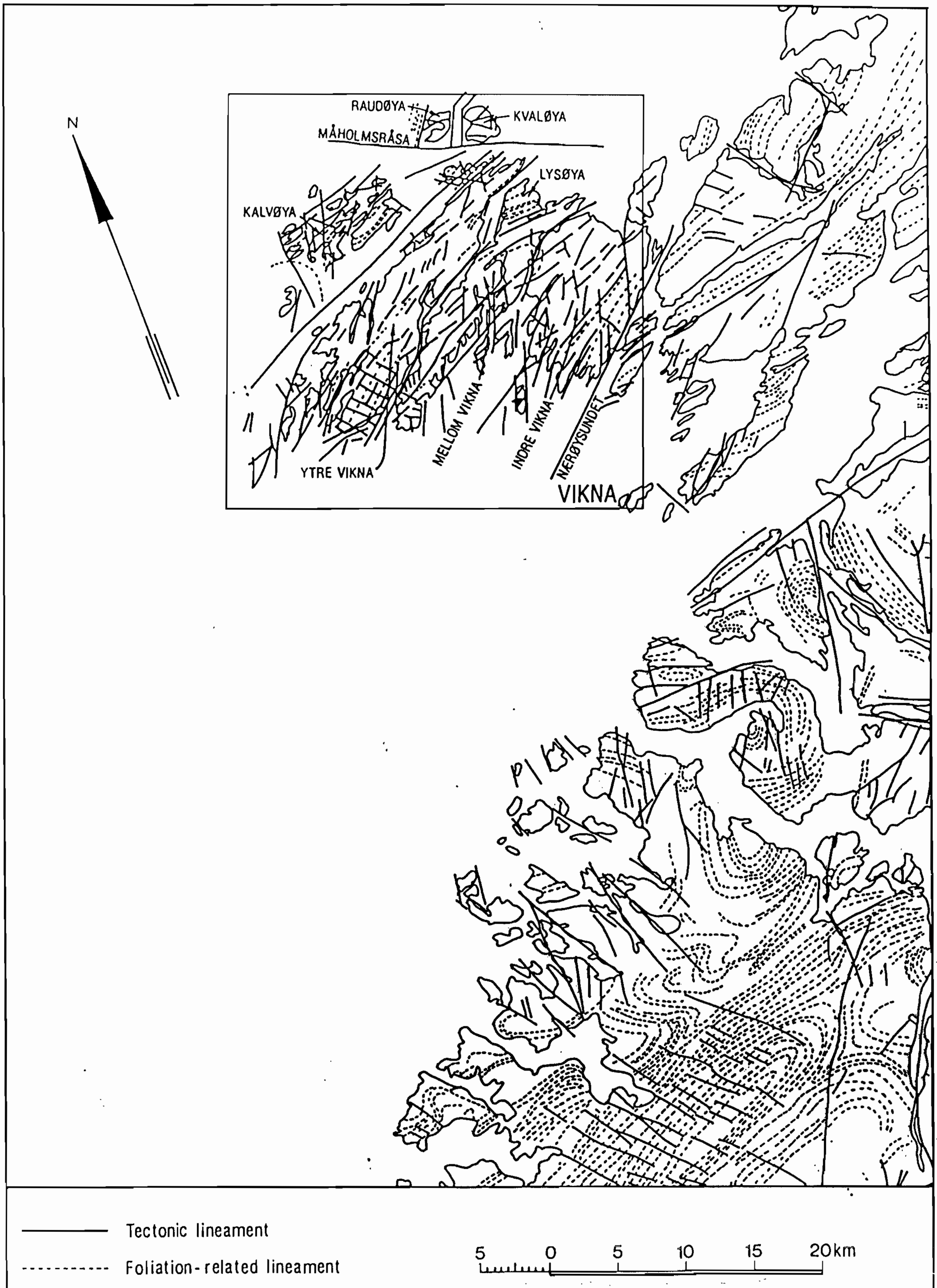


Fig.3a Interpreted tectonic and foliation-related lineaments, from Landsat TM-scene, in the Vikna subarea. Subarea is approximately 30km x 30km (1024 x 1024 pixels).

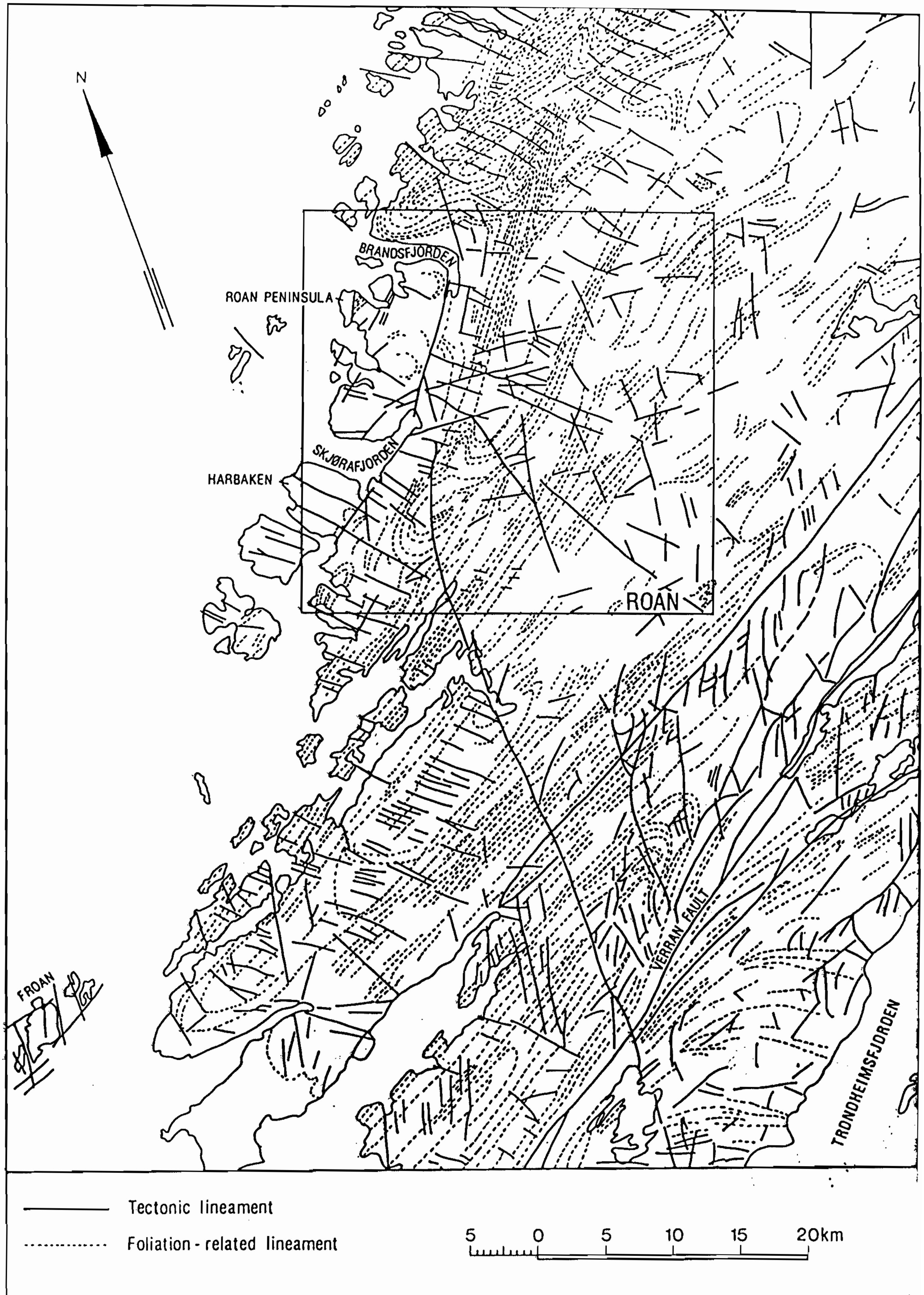
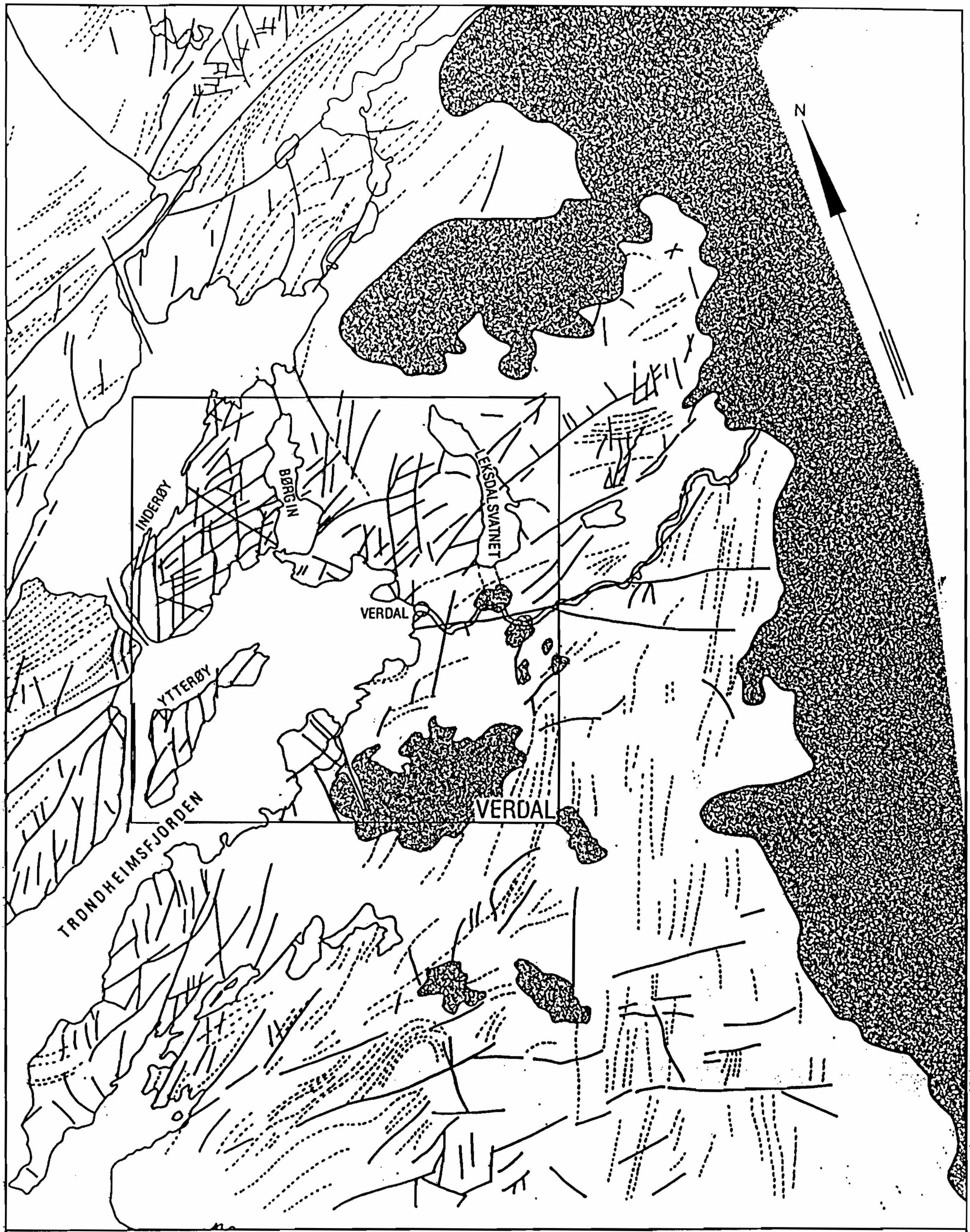


Fig.3b Interpreted tectonic and foliation-related lineaments, from Landsat TM-scene, in the Roan subarea. Subarea is approximately 30km x 30km (1024 x 1024 pixels).



Tectonic lineament

Foliation-related lineament

Cloud cover

5 0 5 10 15 20km

Fig.3c Interpreted tectonic and foliation-related lineaments, from Landsat TM-scene, in the Verdal subarea. Subarea is approximately 30km x 30km (1024 x 1024 pixels).

Fig.4a

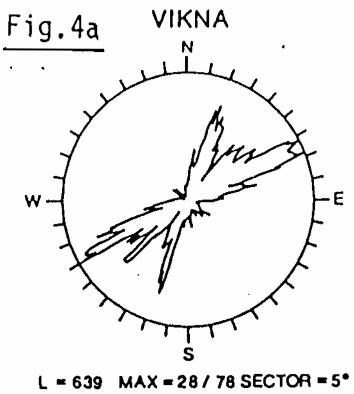


Fig.4b

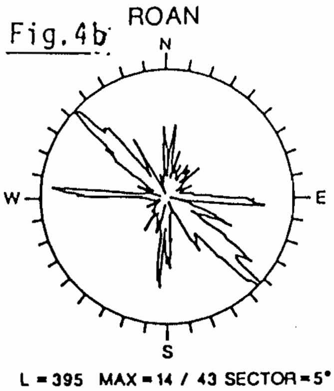


Fig.4c

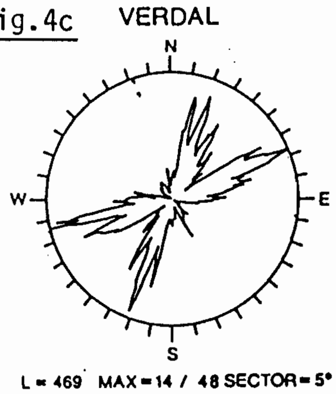


Fig.4 a b c Lineament frequency/length diagrams for tectonic lineaments of the Vikna, Roan and Verdal subareas. Left-half signifies frequency, right-half signifies length.

N= number of lineaments

L= length of lineaments in km

MAX= radius in km

SECTOR= filter size

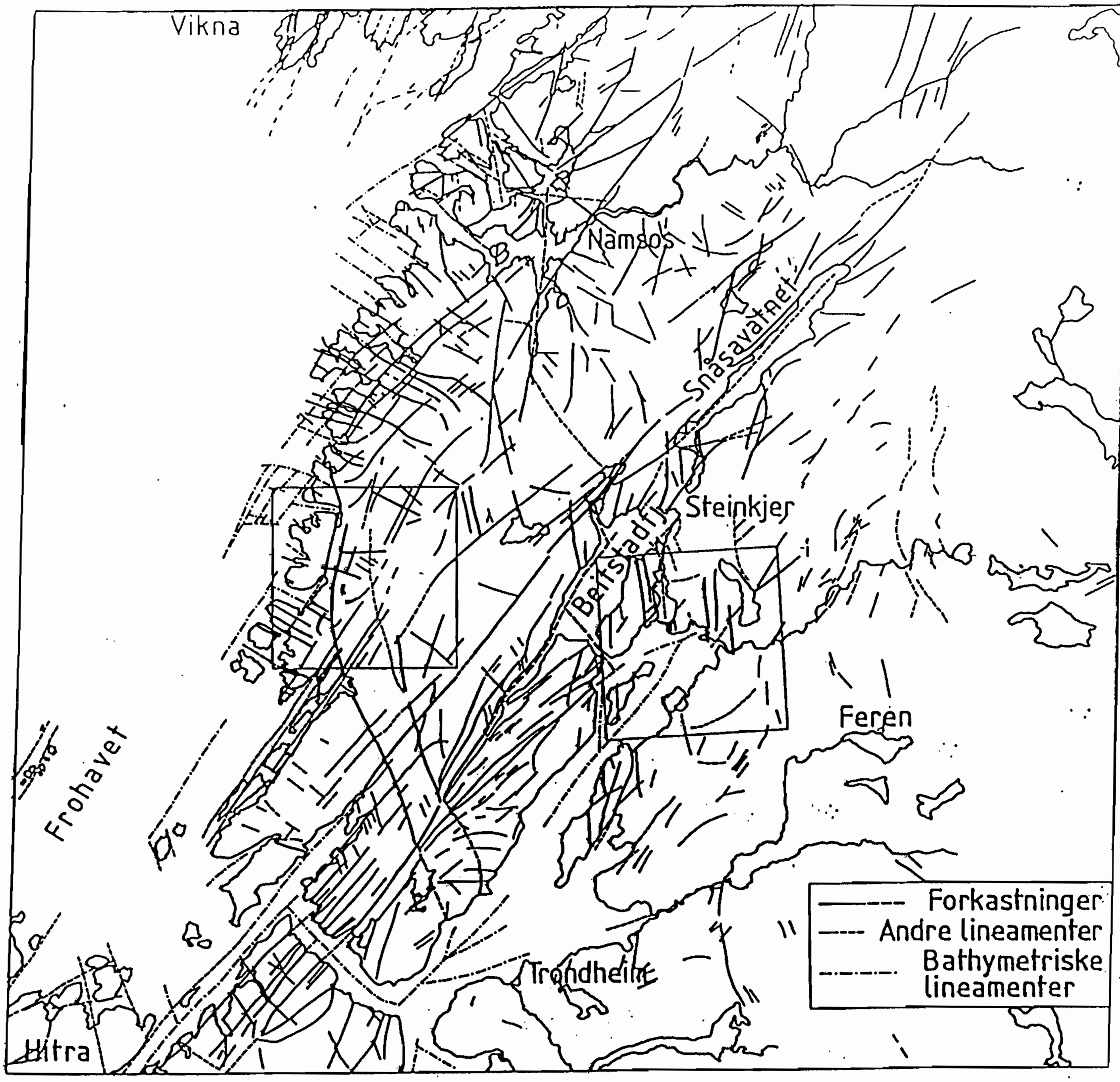


Fig.5 Lineament interpretation map of coastal Trøndelag based on Landsat MSS-data (channel 5 B/W photographic image).
Western square is the Roan subarea; eastern square is the Verdal subarea. Both subareas are approximately 30km x 30km.

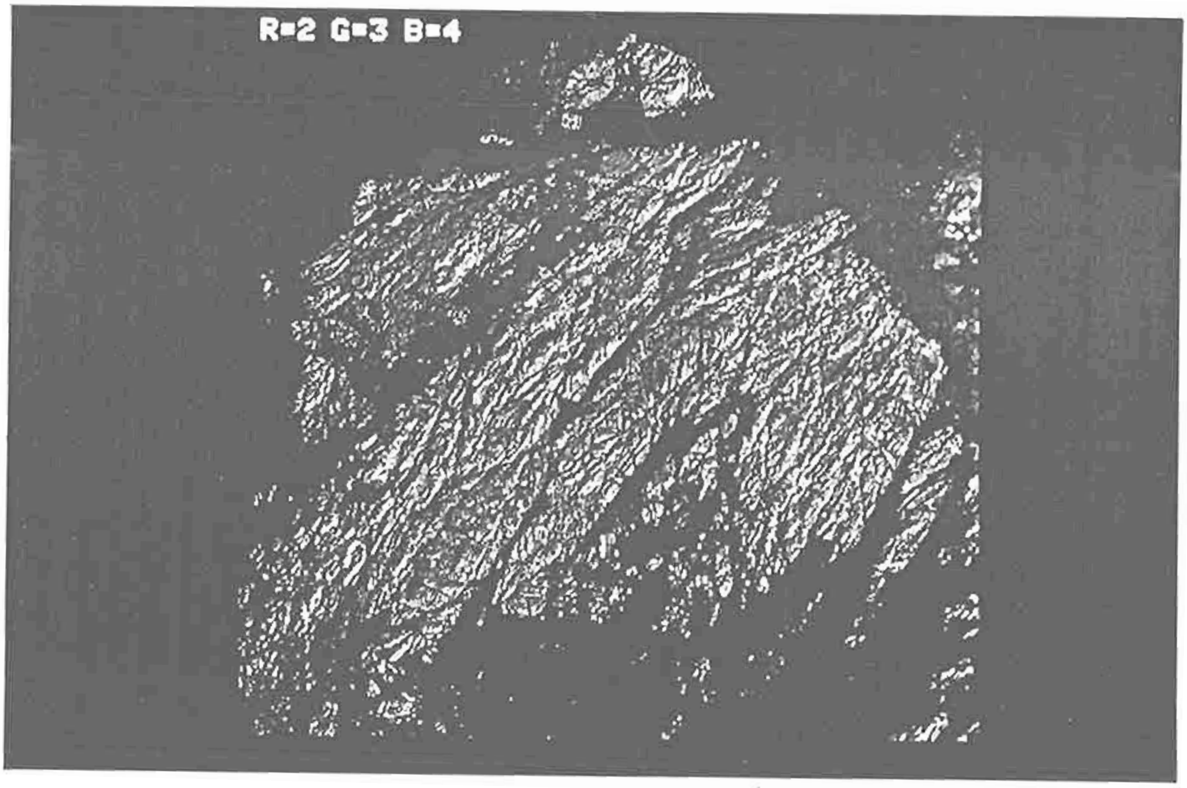


Fig.6a Vikna subarea. Colour composite photograph based on a combination of TM channels 2/3/4 displayed as red, green and blue, respectively. Area is 30km x 30km (1024 x 1024 pixels).

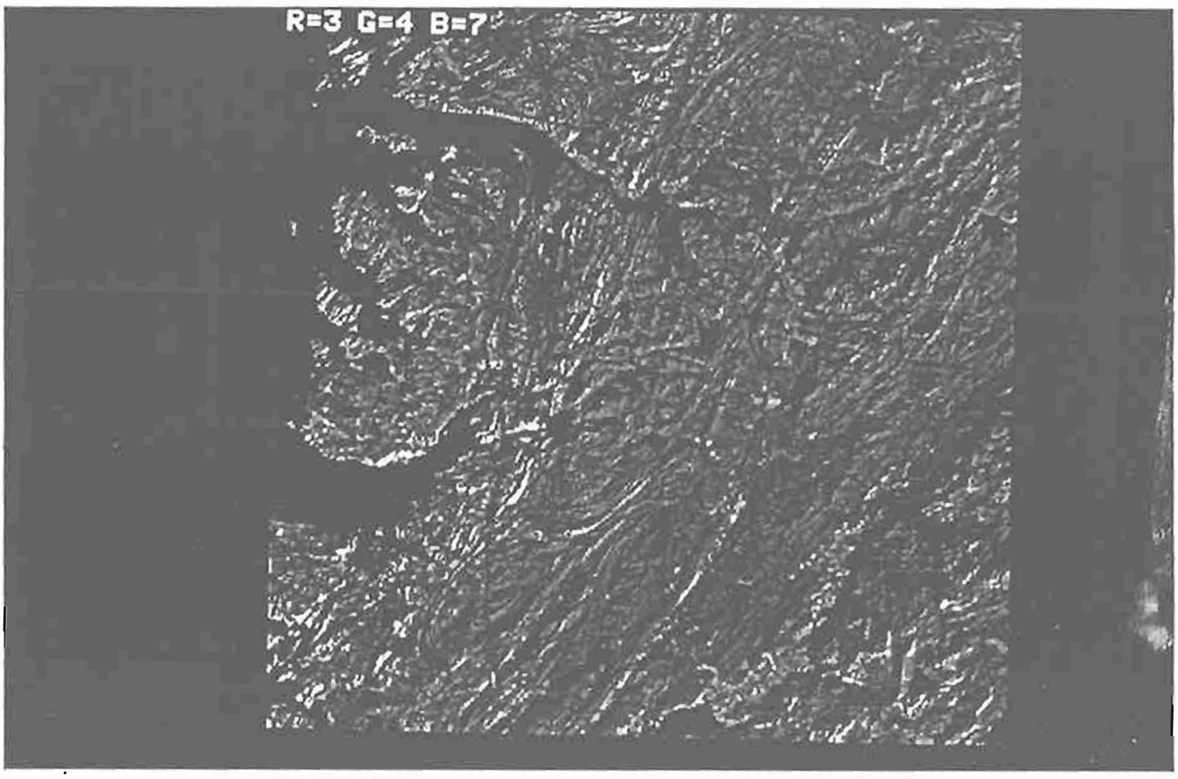


Fig.6b Roan subarea. Colour composite photograph based on a combination of TM channels 3/4/7 displayed as red, green and blue, respectively. Area is 30km x 30km (1024 x 1024 pixels).

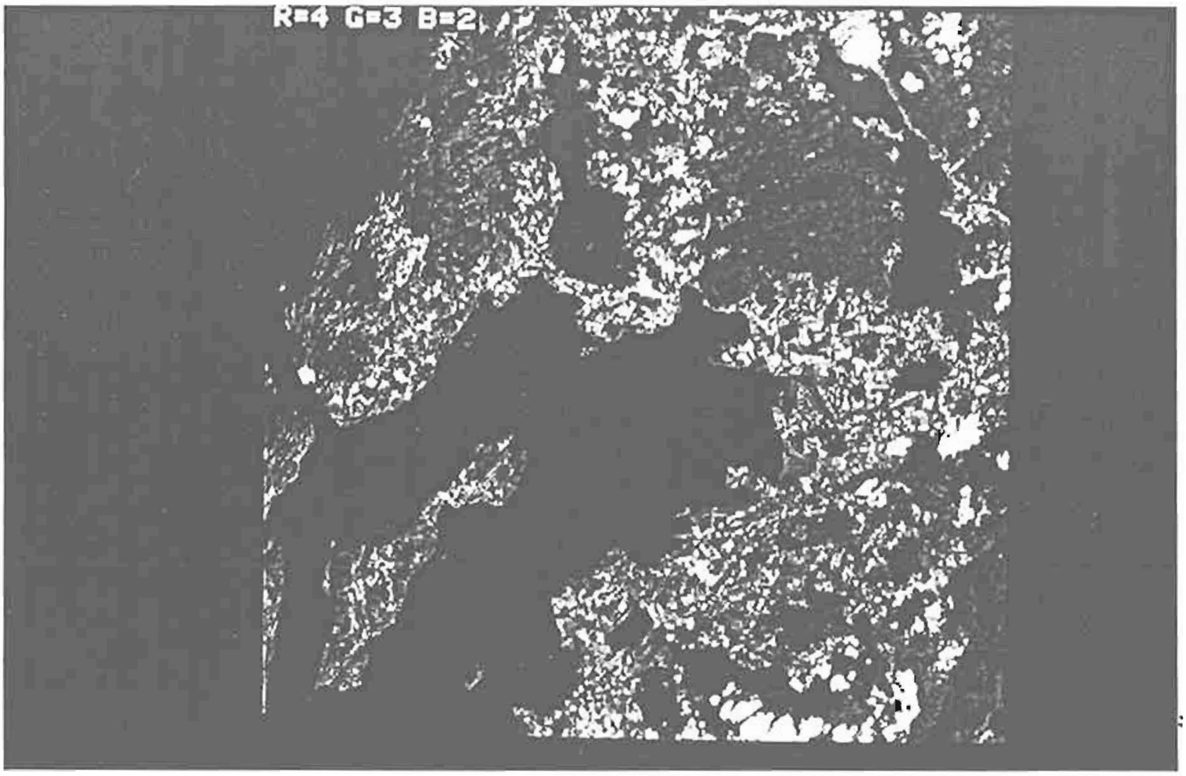


Fig.6c Verdal subarea. Colour composite photograph based on a combination of TM channels 4/3/2 displayed as red, green and blue, respectively. Area is 30km x 30km (1024 x 1024 pixels).