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Data Acquisition and Processing - Helicopter
Geophysical Surveys, Larvik, 1998

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<p>Summary:</p> <p>In September, 1998, two helicopter geophysical survey were carried out over parts of Larvik and Porsgrunn municipalities. The purpose of the survey was to provide geophysical information to improve geological mapping in the area. A combined total of 3684 line-kilometers of VLF, radiometric, and magnetometric data were acquired in the two surveys, covering an area of approximately 553 square km with a 150-m line spacing. Additionally, 640 line-kilometers of radiometric, magnetometric, and VLF data were collected in June, 1997 in a test area east from Larvik. The 1997 survey covered covering approximately 64 square km with a 100-m line spacing. In both areas, the average flying height was 80 m above ground level. The data were collected by Geological Survey of Norway (NGU) personnel and processed at NGU using software developed by Geosoft, Inc. Magnetic data, consisting of total field measurements collected by a cesium vapor magnetometer, were leveled by removing diurnal variations as recorded at a magnetic base station at an airfield near Larvik. Radiometric data were reduced using standard procedures recommended by the International Atomic Energy Association. All data were gridded using square cells with 30-m sides. The grids produced by the three surveys were stitched together, and geophysical maps were produced at a scale of 1:50 000. This report covers aspects of data acquisition and processing.</p> <p>In order to examine structures in Eidangerfjord, the magnetic data from this area has been gridded separately and maps were produced at scales of 1:25 000 and 1: 10 000.</p>			
Keywords: Geofysikk	Radiometri	Magnetometri	
Elektromagnetisk måling	Databehandling	Fagrapport	

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1:50 000

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1 INTRODUCTION

In June, 1997 and September, 1998, three helicopter geophysical surveys were carried out in the vicinity of Larvik, Vestfold. The surveyed area lies between longitudes 9°40' E and 10°15' E, and latitudes 58°57' N and 59°11' N (Fig. 1). The total area covered in the three surveys is approximately 617 km². Radiometric, magnetic, and very low frequency electromagnetic (VLF) data were collected. The primary objective of the surveys was to provide geophysical information in order to enhance geological mapping in the area.

2 SURVEY VARIABLES AND CONDITIONS

Heavy rain and strong wind can increase the noise level of airborne geophysical data. High winds were frequent during the survey, but were not strong enough to cause a flight to be aborted. Rain was encountered on at least two flights, strong winds on three. Radiometric data can be degraded by airborne radon and by waterlogged soils. Weather conditions never caused cancellation of a flight.

Magnetic and radiometric data quality was good on all lines collected. VLF data quality varied because VLF transmitters changed their power or switched off completely at times during the survey. These transmitters are controlled by naval defense authorities for submarine communication, and their power output cannot be predicted or controlled during a survey.

The resolution of geophysical sensors decrease exponentially with flying height. To achieve the greatest possible resolution, the aircraft should be flown as low as is safely possible. The target height was 60 meters above ground level, and this height was achieved over level terrain. However, because of the extreme topography around Larvik the average flying height was approximately 80 meters. Flying heights were higher over power lines and near the city of Larvik.

Diurnal changes in the earth's magnetic field affect magnetic data. The base station magnetic field never indicated a magnetic storm severe enough to degrade the aerial magnetic data.

3 DATA ACQUISITION

The survey aircraft was an Areospace Ecureuil B-2. Flying speed was approximately 100 km per hour (28 meters per second). Flight lines over the western half of the survey area were in an northeast-southwest direction, whereas those in the eastern area were on a heading of 285° (15° north of west). The radiometric sensors were mounted immediately beneath the

helicopter. VLF and magnetic sensors were mounted on a cable 10m and 15m, respectively, beneath the helicopter.

NGU personnel responsible for data acquisition were John Mogaard and Oddvar Blokkum.

3.1 Magnetic measurements

A Scintrex CS-2 cesium vapor magnetometer was used. The magnetometer resolution is 0.01 nT. Sampling rate was 5 measurements per second. The magnetometer is suspended 15 meters beneath the helicopter.

A Scintrex MP-3 proton precession magnetometer was located at an airfield near Larvik, and was used for base station measurements. The base station magnetometer was synchronized with the helicopter-borne magnetometer to ensure proper removal of diurnal magnetic changes from the helicopter magnetic measurements. The total magnetic field was digitally recorded during flights at a rate of 4 measurements per second.

3.2 Radiometric measurements

The radiometric system, purchased from Exploranium, Ltd. Of Canada, consists of four sodium iodide (NaI) crystals having a total volume of 1024 cubic inches (16.78 liter). The NaI crystals are coupled to an Exploranium GR820 gamma ray spectrometer. Registration rate is one per second. No upward looking crystal was used in this survey. The crystal package is mounted in a frame underneath the helicopter.

The spectrometer is an energy pulse height analyzer which sorts data into 256 channels according to energy magnitude. Every channel is 0.012 MeV wide. Windows constructed from selected groups of channels record the contributions of Potassium-40, Bismuth-214 (the daughter product of Uranium-238), and Thallium-208 (the daughter product of Thorium-232). These windows are labeled potassium, uranium, and thorium respectively. A fourth window, called the total count window, measures gamma ray energy between 0.4 MeV and 3 MeV.

3.3 VLF-EM system

The VLF measurements were made with Totem-2A VLF receivers purchased from Hertz Industries, Ltd. of Canada. The three receivers are mounted orthogonally and measure fields in the direction of the flight line (in-line), normal to the flight direction (orthogonal), and vertical fields. The energy sources for VLF signals are powerful transmitters used by various military establishments for communication with submarines. Their frequencies are in the range 15-30 kHz, depending on the individual transmitter. The VLF receivers are suspended 10 meters beneath the helicopter. Registration rate is five per second.

Good VLF targets are shallow (a few 10s of meters), linear conductors which are on a line with one of the monitored VLF transmitters. For this survey, the VLF stations monitored were GBR (16 kHz, Rugby, England), used for in-line receiver measurements, and NAA (24 kHz, Cutler, Maine, USA), used for orthogonal receiver measurements.

3.4 Navigation, altimetry, and data logging

The navigation system consists of a Trimble SVeeSix 6 channel GPS receiver and a Seatex DFM-200 RDS reference receiver connected to a laptop computer. GPS signals are corrected in real time using a correction signal in RDS format from NRKs P2 transmitter. Differential GPS is calculated using software from Seatex, and the data is transferred to the navigation console and data logger. Position accuracy using this system is better than 10m.

The navigation console is a PNAV 2001 manufactured by the Picodas Group, Ltd. of Canada. Profile line data are entered into the console and the traces can be viewed by the helicopter pilot. The pilot can see his position with respect to these predefined lines and adjust accordingly. Visual navigation can also be used if necessary.

A King KRA-10A radar altimeter measures height above ground level, and is recorded digitally and displayed before the pilot. The altimeter is accurate to 5 percent of the true flying height.

The data logging system is an integral part of the Hummingbird electromagnetic system, manufactured by Geotech, Ltd. of Canada. Data is recorded both digitally and on a scroll.

4 PROCESSING

The data were processed at the Geological Survey of Norway in Trondheim using Geosoft processing software (Geosoft, 1996) designed for Windows-NT operating systems. All maps were gridded using a 30-m grid cell size. Obvious inaccuracies in navigation were manually removed from the data. The datum used was WGS-84 in UTM Zone 32. All leveling procedures were conducted flight-by-flight rather than a line-by-line, as this is the most efficient approach. Before gridding, the flights were split into lines and turns were trimmed away.

The 1997 data had been processed by John Mogaard (Mogaard, 1998). For each of the three surveys, a grid was produced for each data channel. These grids were then stitched together using Geosoft's GridKnit software package.

Total field magnetic data: The data were then inspected flight-by-flight and any cultural anomalies were identified and manually removed. A base station correction was applied to each flight using corrections based on the diurnal measurements from the base magnetometer

at the airport. A lag correction was also applied. The lines were gridded without decorrugation or further smoothing.

Radiometric data: The Geosoft radiometric processing package (Geosoft, 1995) follows the procedures outlined in International Atomic Energy Agency Technical Report No. 323 (IAEA, 1991). A narrow nonlinear filter was applied to the radiometric data to remove spikes and a low pass filter was applied to smooth the data slightly prior to further processing. Background radiation levels were estimated by flying background calibration lines over water, usually two or three per flight, with one at the beginning and another at the end of the flight. After background reduction, the data were corrected for spectral overlap using experimentally determined stripping ratios. The processed data are presented as counts per second of the uranium, potassium, and thorium channels normalized to a height of 80 meters.

Atmospheric radon did not appear to have been a major source of data contamination in any of the surveys.

VLF-EM data: The raw VLF data channels - orthogonal and in-line receivers - were low pass filtered using a 20-km cutoff wavelength. The low passed channels were subtracted from the original data, leaving residual VLF anomalies. The removal of the low pass filtered channels from the original data caused little distortion in the VLF anomalies because the low pass cutoff wavelength was large with respect to the width of the VLF anomalies, typically a few hundred meters wide. A single pass of a Hanning filter was applied to slightly smooth the residual grids. The maps from the gridded data show VLF anomalies from a receiver orthogonal to the flight direction, one in-line with the flight direction, and an averaged sum of the two maps - (orthogonal + in-line)/2.

VLF stations monitored during the survey were GBR (16 kHz; Rugby, England), NAA (24 kHz; Cutler, Maine, USA). GBR was used as the transmitter for in-line receiver. NAA was used as the transmitters for the orthogonal receiver.

5 MAPS PRODUCED

All Larvik maps were produced at a scale of 1:50 000, and were presented in contoured color with shaded-relief. Shading was from the east at 60° sun inclination above the horizon. The grid cell size for all maps was 30 meters. Flight lines are included on all maps. Four additional maps were produced which highlight magnetic anomalies in Eidangerfjord, on the extreme west end of the survey area. These maps are at scales 1:25 000 and 1:10 000. Shading for the Eidangerfjord maps was from the east at 45° sun inclination above the horizon.

In this report, selected samples of the 1:50 000 Larvik area maps are shown in Figures 2 through 4 (total magnetic field, total radiometric counts, and VLF, respectively). Figure 5 shows a 1:10 000 sample of magnetic data from Eidangerfjord.

A list of the 13 maps available for order from NGU is shown on page 3 of this report.

6 REFERENCES

Geosoft Inc., 1996: OASIS montaj Version 4.0 User Guide, *Geosoft Incorporated, Toronto.*

Geosoft Inc., 1995: OASIS Airborne Radiometric Processing System Version 1.0 User's Guide, *Geosoft Incorporated, Toronto.*

IAEA, 1991: Airborne Gamma Ray Spectrometer Surveying, Technical Report 323, *International Atomic Energy Agency, Vienna.*

Mogaard, John O., 1998: Geofysiske målinger fra helikopter ved Larvik, Vestfold 1997, teknisk rapport: *NGU Rapport 98.021.*

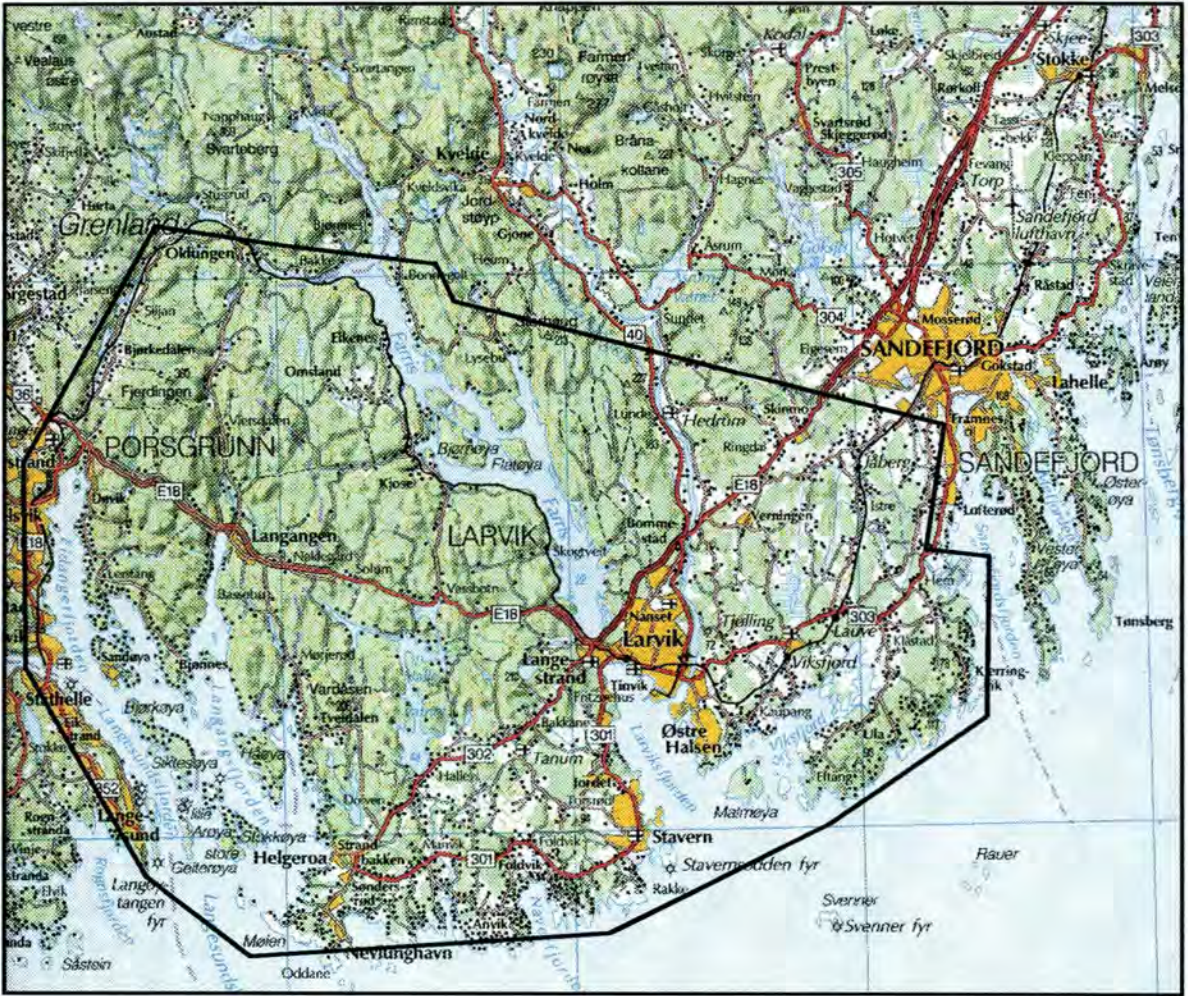


Figure 1. Outlined area shows extent of three helicopter surveys, including 1997 survey. Scale 1cm = 2.5 km.

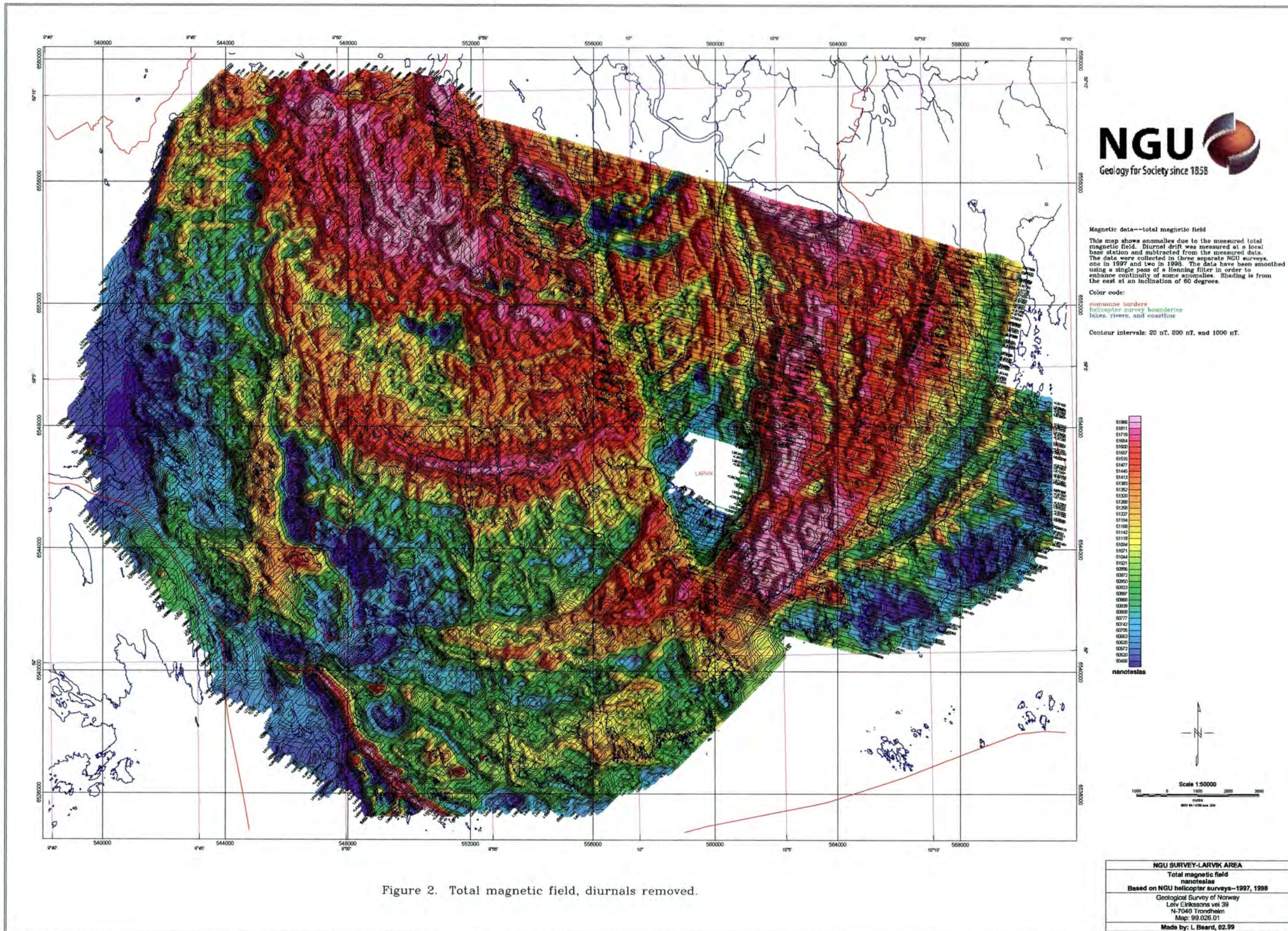


Figure 2. Total magnetic field, diurnals removed.

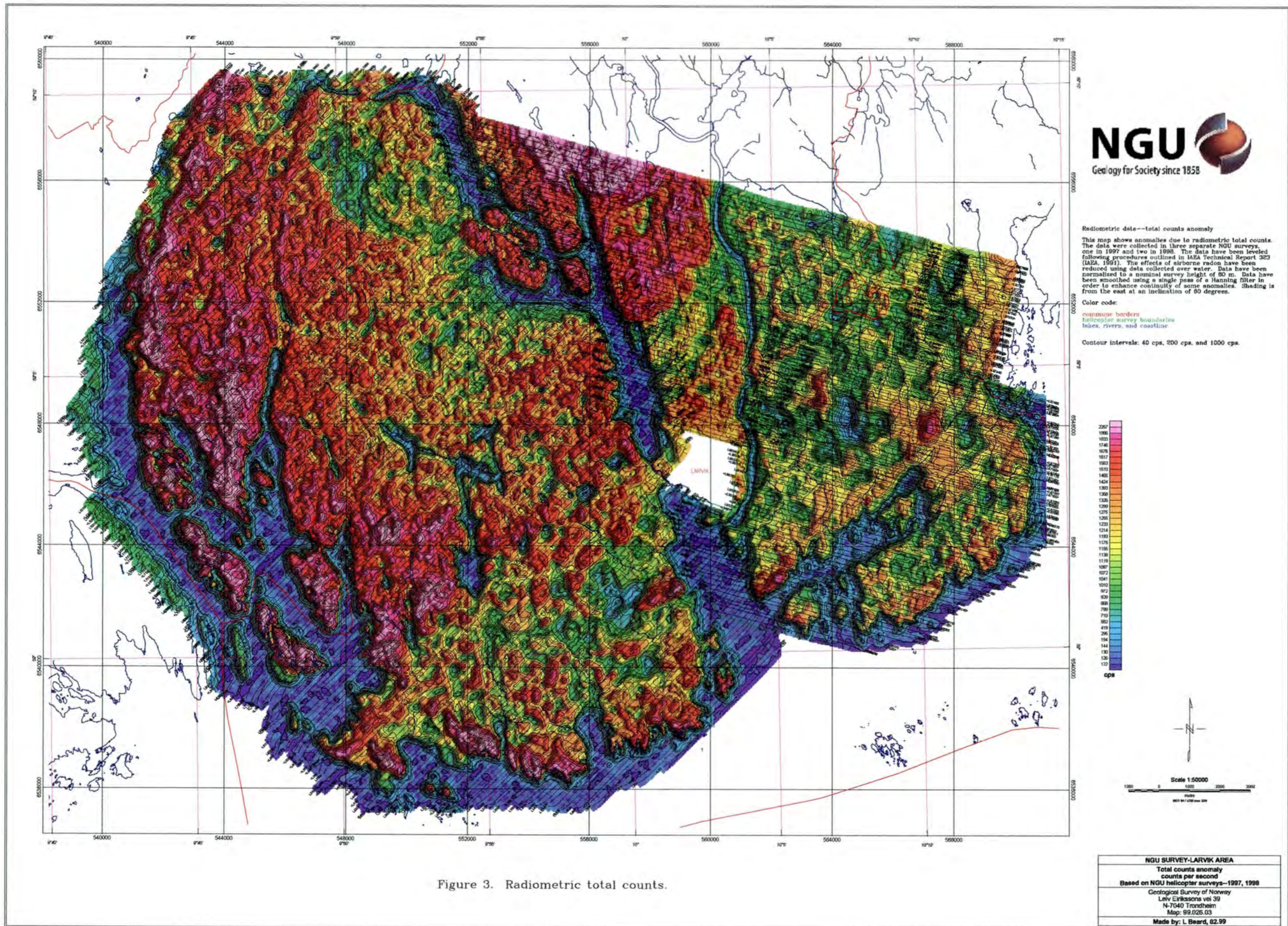
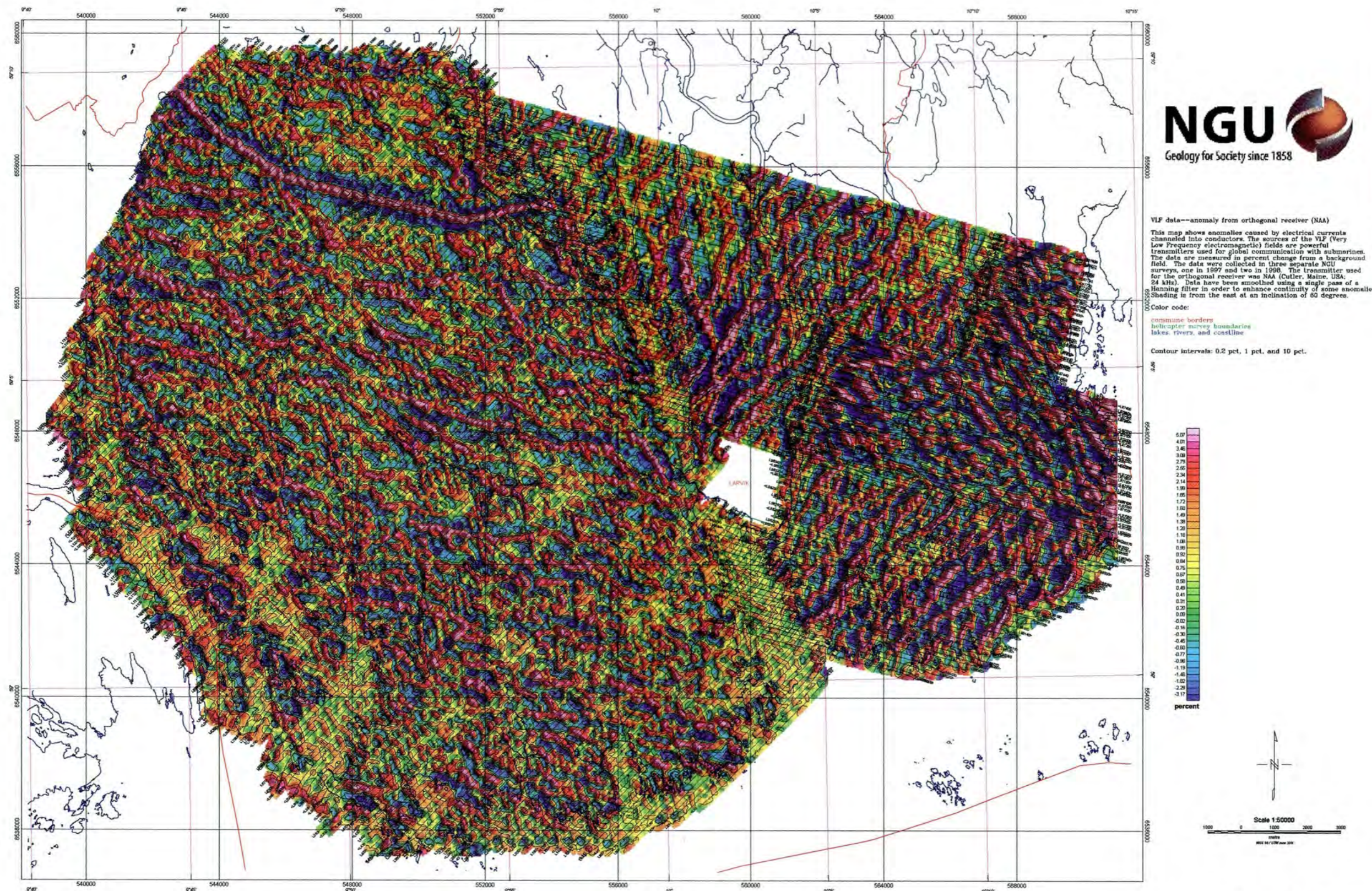


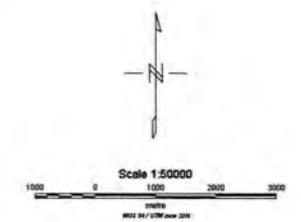
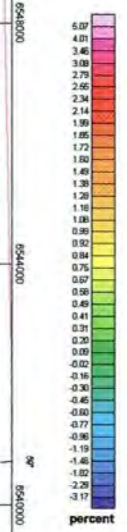
Figure 3. Radiometric total counts.



VLF data--anomaly from orthogonal receiver (NAA)
 This map shows anomalies caused by electrical currents channeled into conductors. The sources of the VLF (Very Low Frequency electromagnetic) fields are powerful transmitters used for global communication with submarines. The data are measured in percent change from a background field. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. The transmitter used for the orthogonal receiver was NAA (Cutler, Maine, USA; 24 kHz). Data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 60 degrees.

Color code:
 commune borders
 helicopter survey boundaries
 lakes, rivers, and coastline

Contour intervals: 0.2 pct, 1 pct, and 10 pct.



NGU SURVEY-LARVIK AREA
 VLF anomaly--orthogonal receiver (NAA)
 percent change over background
 Based on NGU helicopter surveys--1997, 1998
 Geological Survey of Norway
 Leiv Eirikssons vei 39
 N-7040 Trondheim
 Map: 99.026.09
 Made by: L Beard, 02.99

Figure 4. VLF--orthogonal receiver.

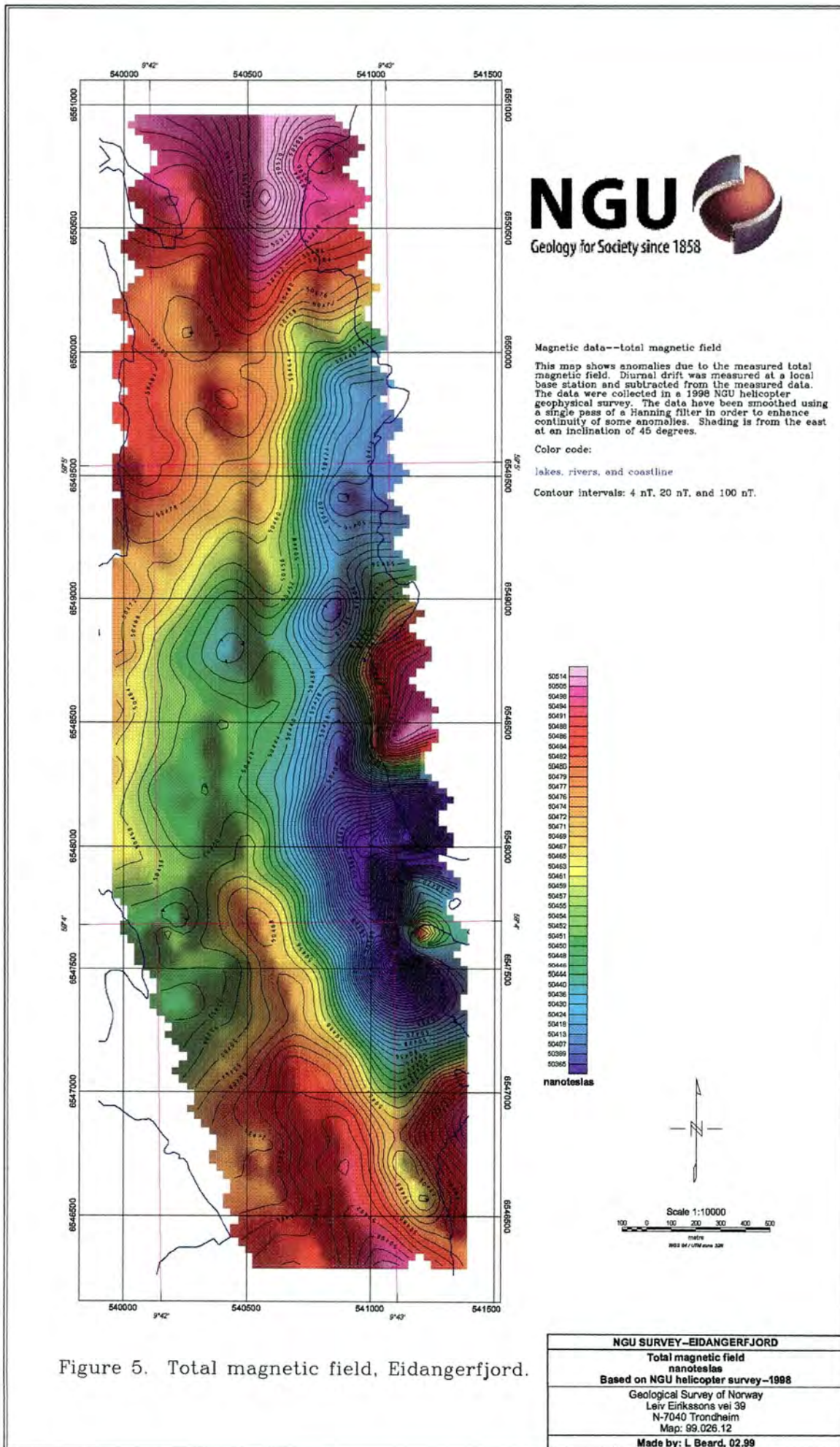
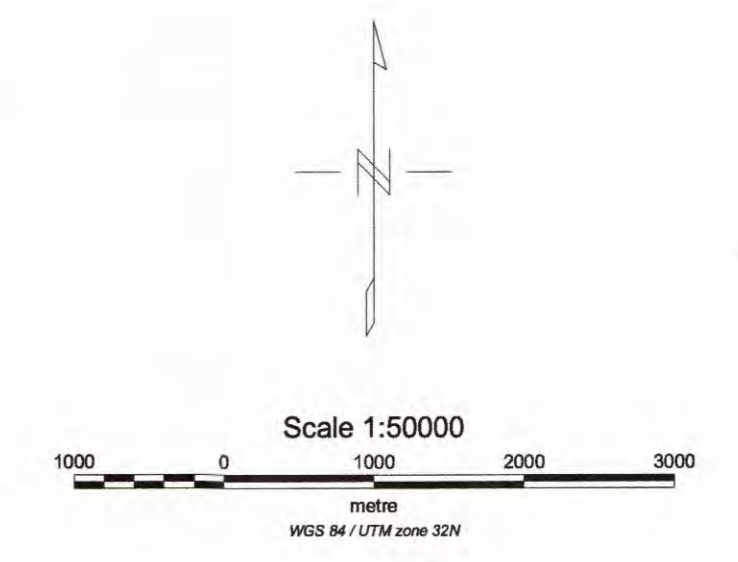
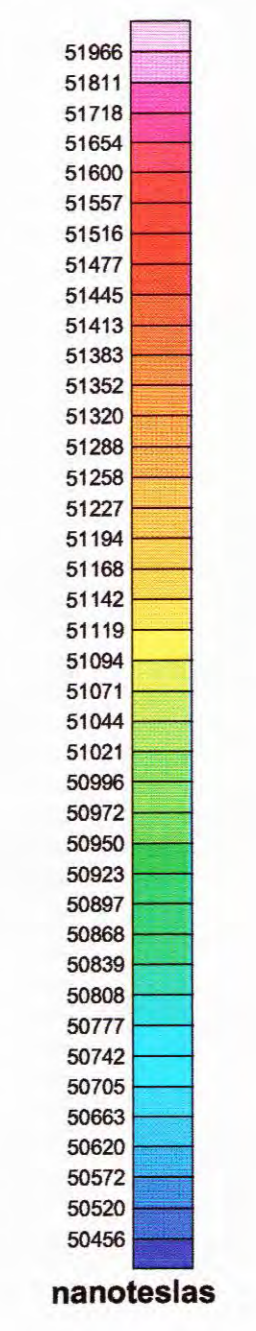


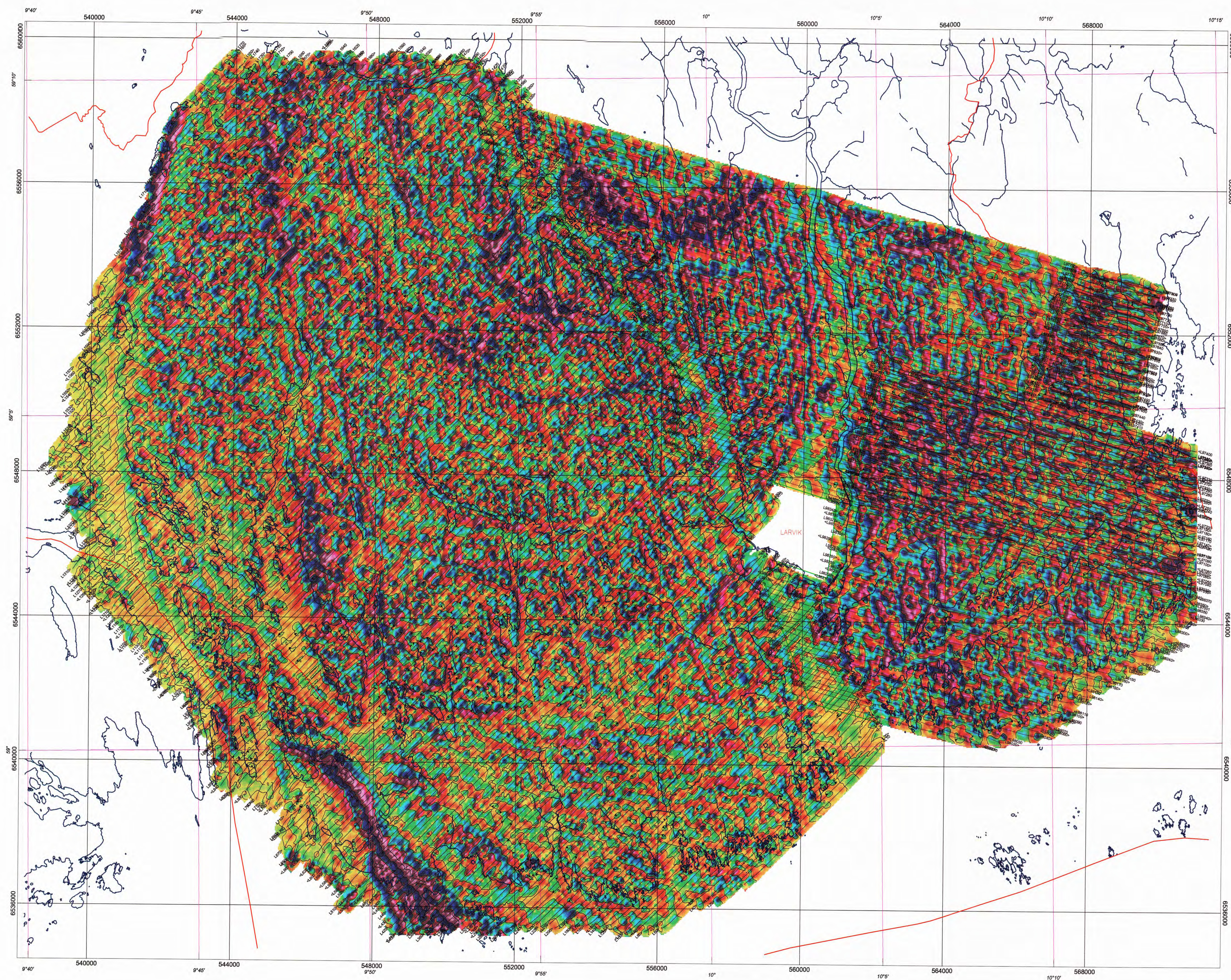
Figure 5. Total magnetic field, Eidangerfjord.

Magnetic data--total magnetic field
This map shows anomalies due to the measured total magnetic field. Diurnal drift was measured at a local base station and subtracted from the measured data. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. The data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 60 degrees.

Color code:
— commune borders
— helicopter survey boundaries
— lakes, rivers, and coastline

Contour intervals: 20 nT, 200 nT, and 1000 nT.



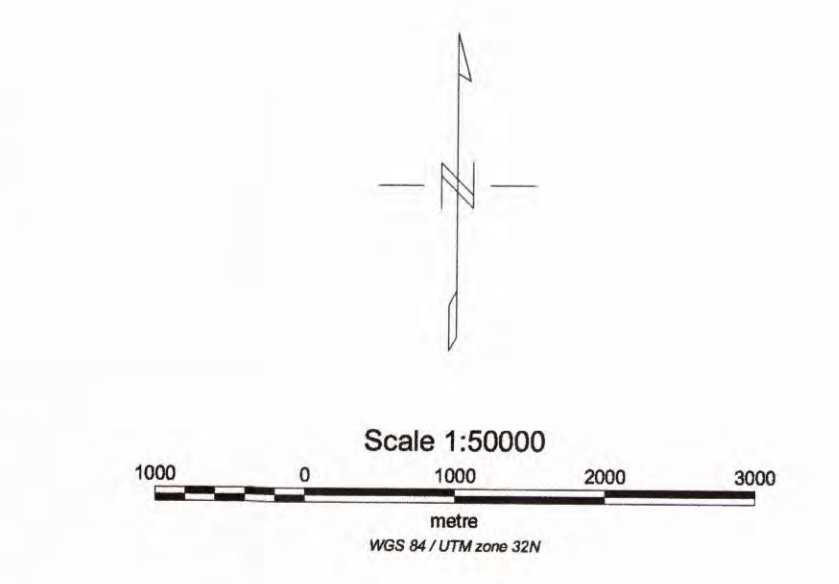
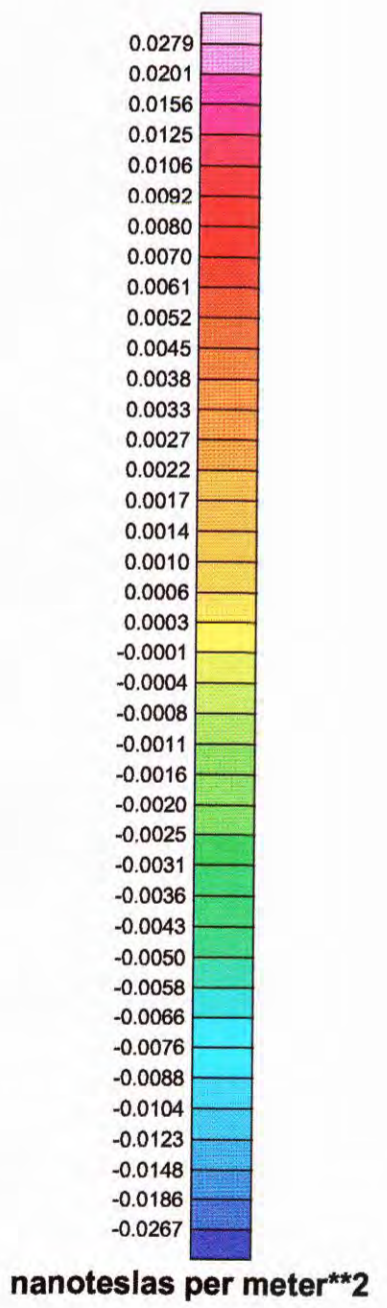


Magnetic data--second vertical derivative

This map shows anomalies due to the computed second vertical derivative of the measured total magnetic field. The data have been upward continued 20 m in order to enhance continuity of some features. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. Shading is from the east at an inclination of 60 degrees.

Color code:
 commune borders
 helicopter survey boundaries
 lakes, rivers, and coastline

Contour intervals: 0.05 nT per m**2, 0.2 nT per m**2, and 1 nT per m**2.



NGU SURVEY-LARVIK AREA
 Second vertical derivative of total magnetic field
 nanoteslas per m**2
 Based on NGU helicopter surveys--1997, 1998
 Geological Survey of Norway
 Leiv Eirikssons vei 39
 N-7040 Trondheim
 Map: 99.026.02
 Made by: I. Beard, 02.99

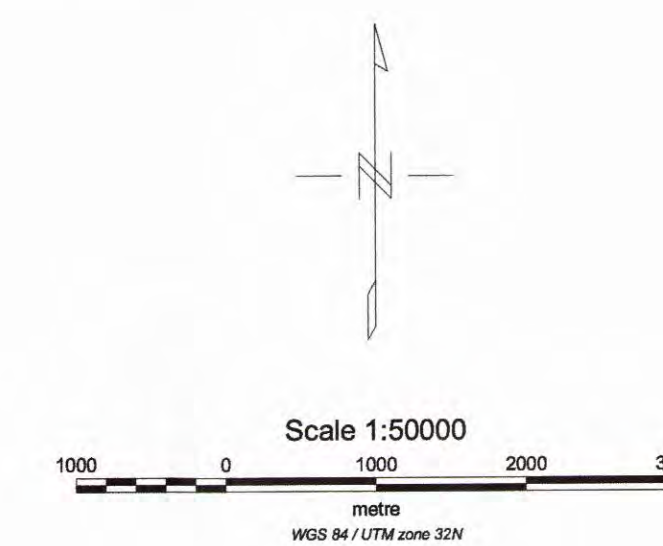
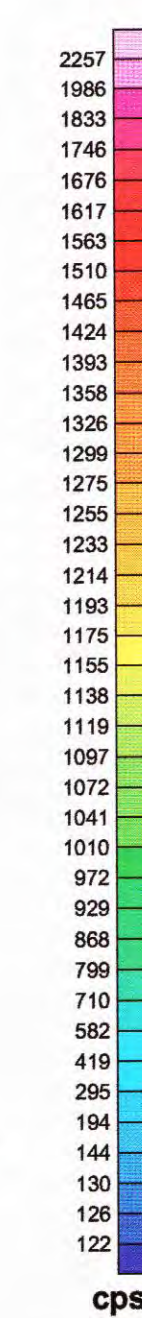
Radiometric data--total counts anomaly

This map shows anomalies due to radiometric total counts. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. The data have been leveled following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effects of airborne radon have been reduced using data collected over water. Data have been normalized to a nominal survey height of 80 m. Data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 60 degrees.

Color code:

- commune borders
- helicopter survey boundaries
- lakes, rivers, and coastline

Contour intervals: 40 cps, 200 cps, and 1000 cps.



NGU SURVEY-LARVIK AREA
Total counts anomaly
counts per second
Based on NGU helicopter surveys--1997, 1998
Geological Survey of Norway
Leiv Eirikssons vei 39
N-7040 Trondheim
Map: 99.026.03
Made by: L Beard, 02.99

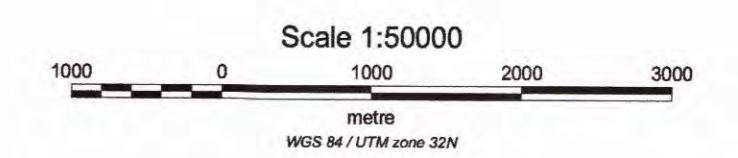
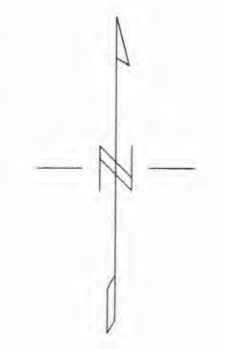
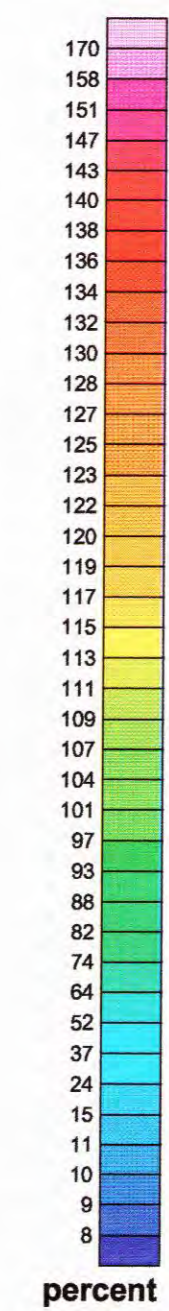
Radiometric data--potassium anomaly

This map shows anomalies due to radiometric potassium. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. The data have been leveled following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effects of airborne radon have been reduced using data collected over water. Data have been normalized to a nominal survey height of 80 m. Data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 60 degrees.

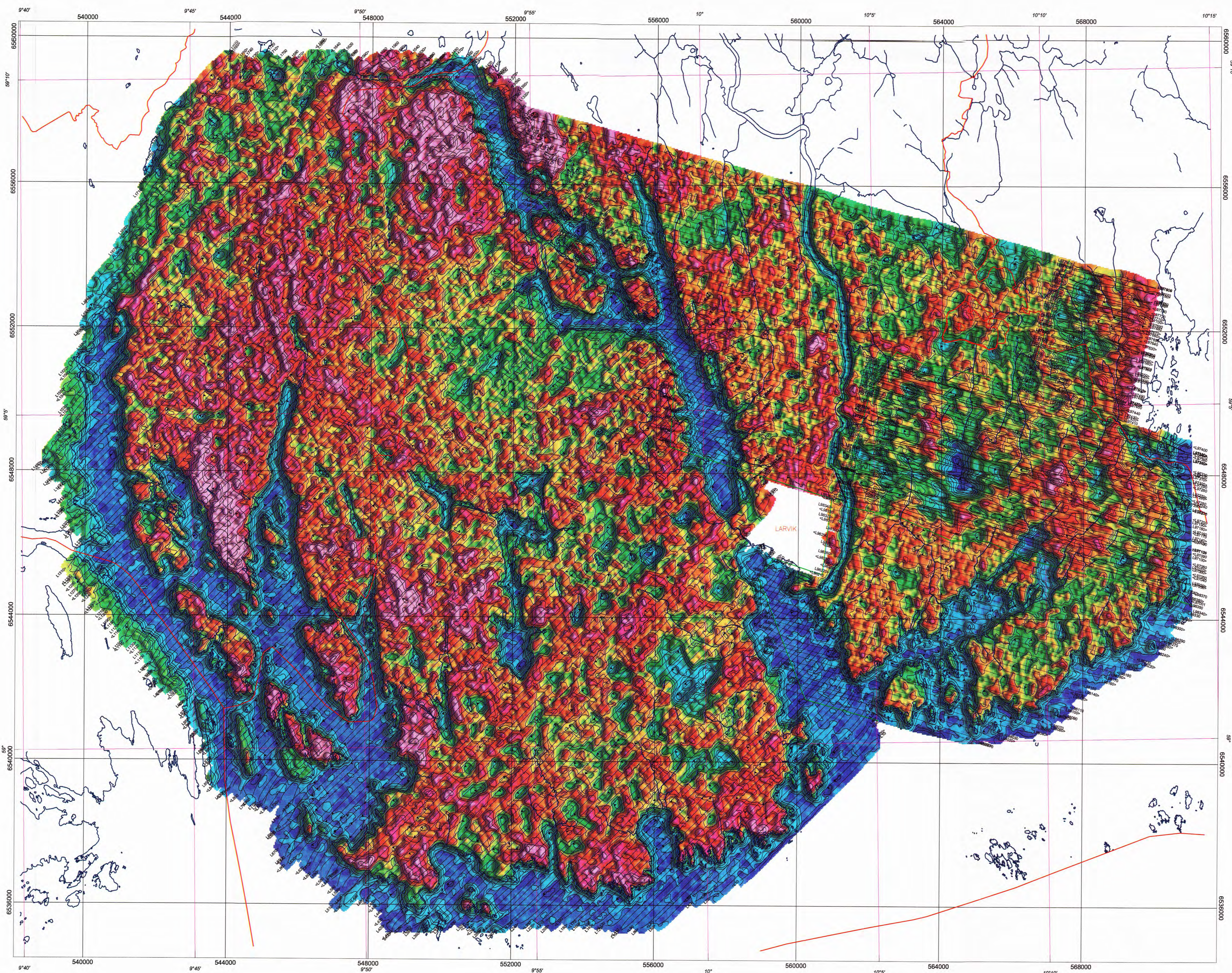
Color code:

- commune borders
- helicopter survey boundaries
- lakes, rivers, and coastline

Contour intervals: 5 cps, 20 cps, and 100 cps.



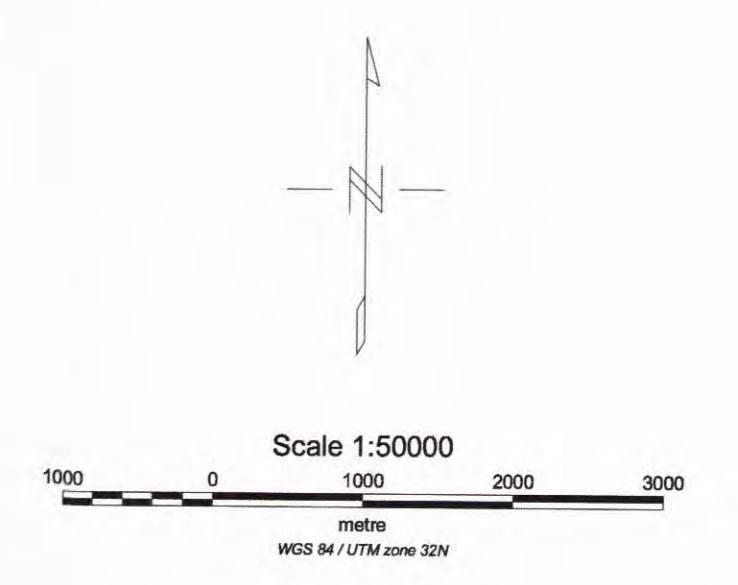
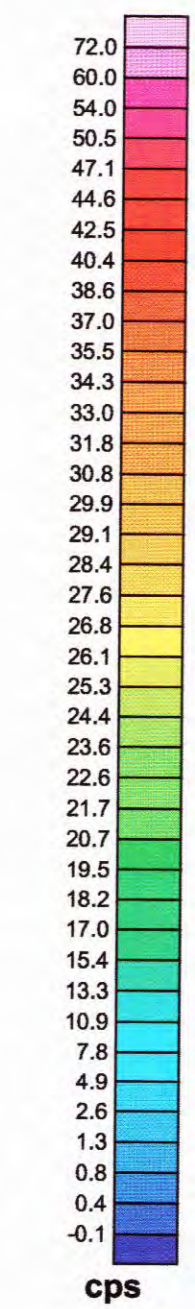
NGU SURVEY-LARVIK AREA
Potassium anomaly
counts per second
Based on NGU helicopter surveys--1997, 1998
Geological Survey of Norway
Leiv Eirikssons vei 39
N-7040 Trondheim
Map: 99.026.04
Made by: L. Beard, 02.99



Radiometric data--thorium anomaly
This map shows anomalies due to radiometric thorium. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. The data have been leveled following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effects of airborne radon have been reduced using data collected over water. Data have been normalized to a nominal survey height of 80 m. Data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 60 degrees.

Color code:
— commune borders
— helicopter survey boundaries
— lakes, rivers, and coastline

Contour intervals: 1 cps, 5 cps, and 20 cps.



NGU SURVEY-LARVIK AREA
Thorium anomaly
counts per second
Based on NGU helicopter surveys--1997, 1998
 Geological Survey of Norway
 Leiv Eirikssons vei 39
 N-7040 Trondheim
 Map: 99.026.05
 Made by: L Beard, 02.99

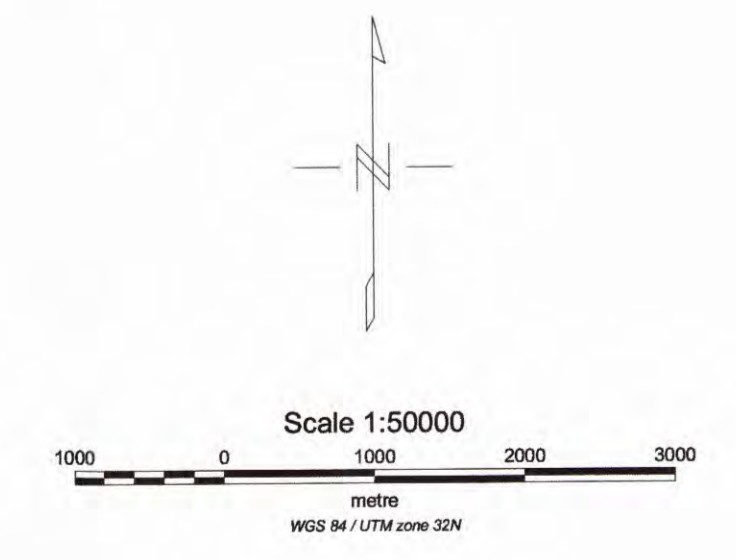
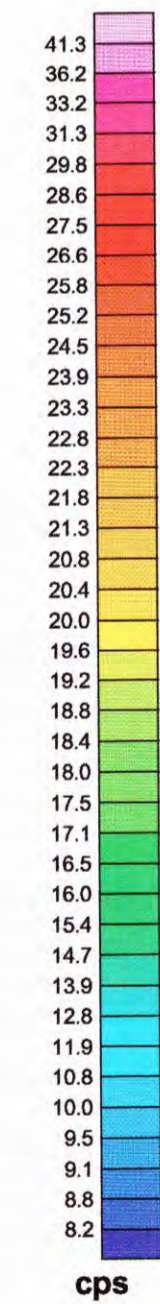
Radiometric data--uranium anomaly

This map shows anomalies due to radiometric uranium. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. The data have been leveled following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effects of airborne radon have been reduced using data collected over water. Data have been normalized to a nominal survey height of 80 m. Data from each of the 3 grids have been decorrelated to remove line errors and have been smoothed using two passes of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 60 degrees.

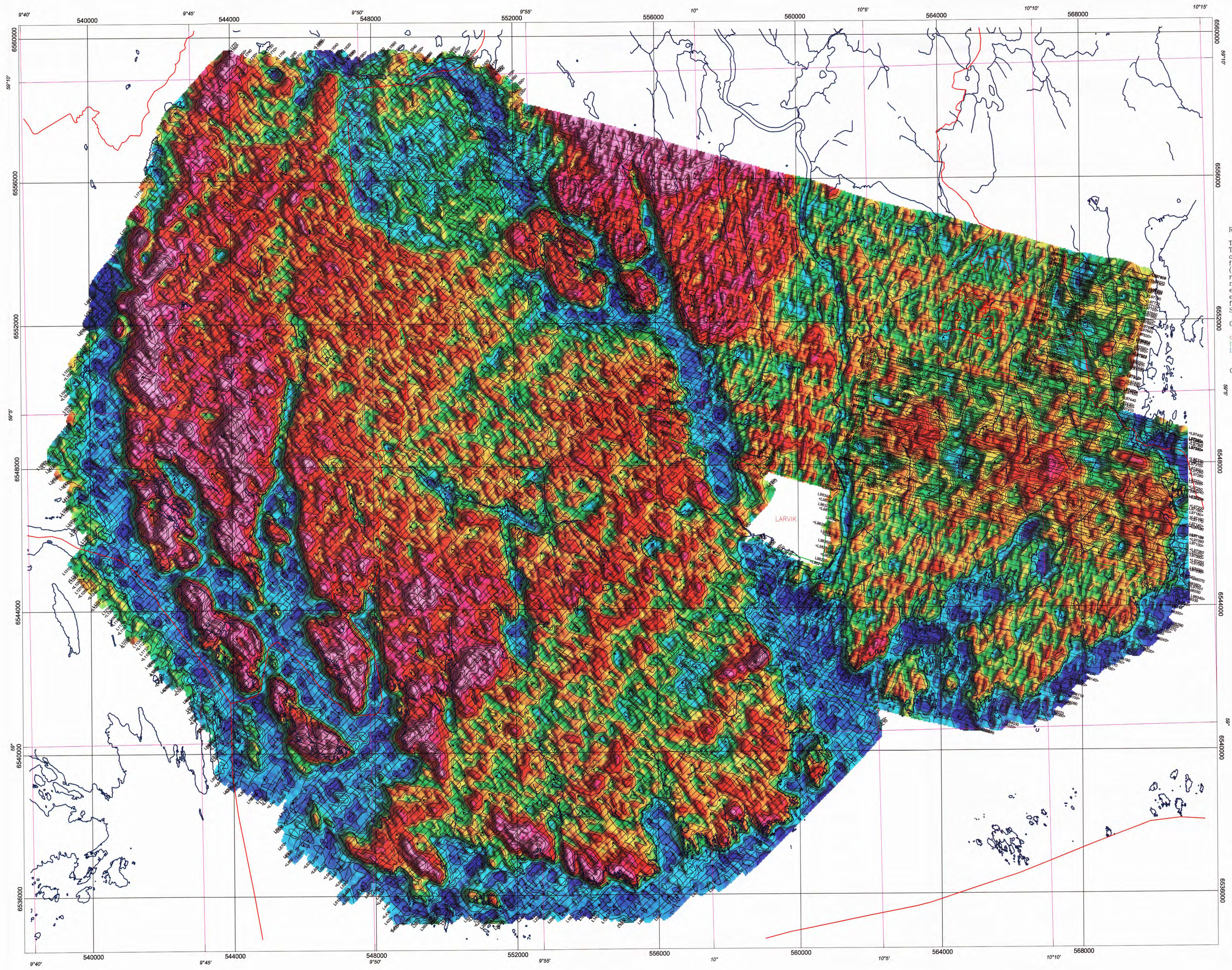
Color code:

- commune borders
- helicopter survey boundaries
- lakes, rivers, and coastline

Contour intervals: 1 cps, 5 cps, and 20 cps.



NGU SURVEY-LARVIK AREA
Uranium anomaly
counts per second
Based on NGU helicopter surveys--1997, 1998
Geological Survey of Norway
Leiv Eirikssons vei 39
N-7040 Trondheim
Map: 99_026.06
Made by: L Beard, 02.99

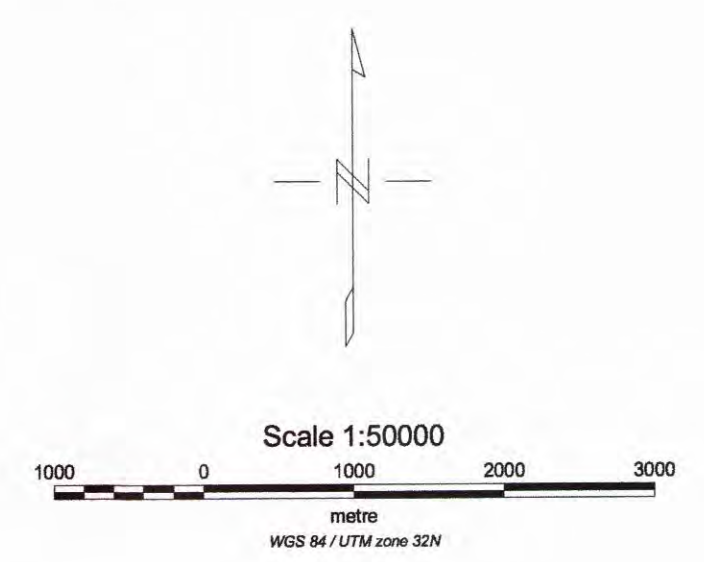
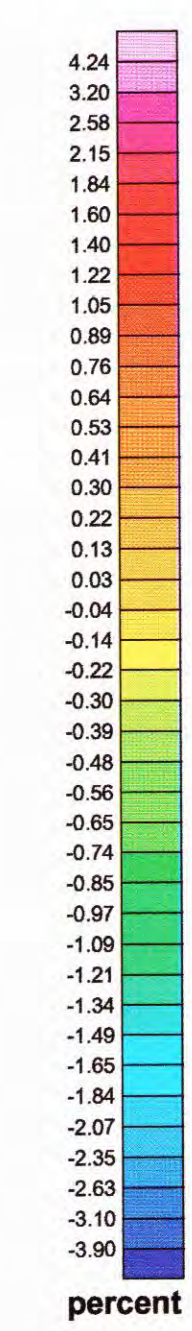


VLF data--anomaly from orthogonal+in-line receivers

This map shows anomalies caused by electrical currents channeled into conductors. The sources of the VLF (Very Low Frequency electromagnetic) fields are powerful transmitters used for global communication with submarines. The data are measured in percent change from a background field. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. The transmitter used for the orthogonal receiver was NAA (Cutler, Maine, USA; 24 kHz), and the in-line receiver was GBR (Rugby, England; 16 kHz). The anomalies of the two receivers were directly summed and averaged. Data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 60 degrees.

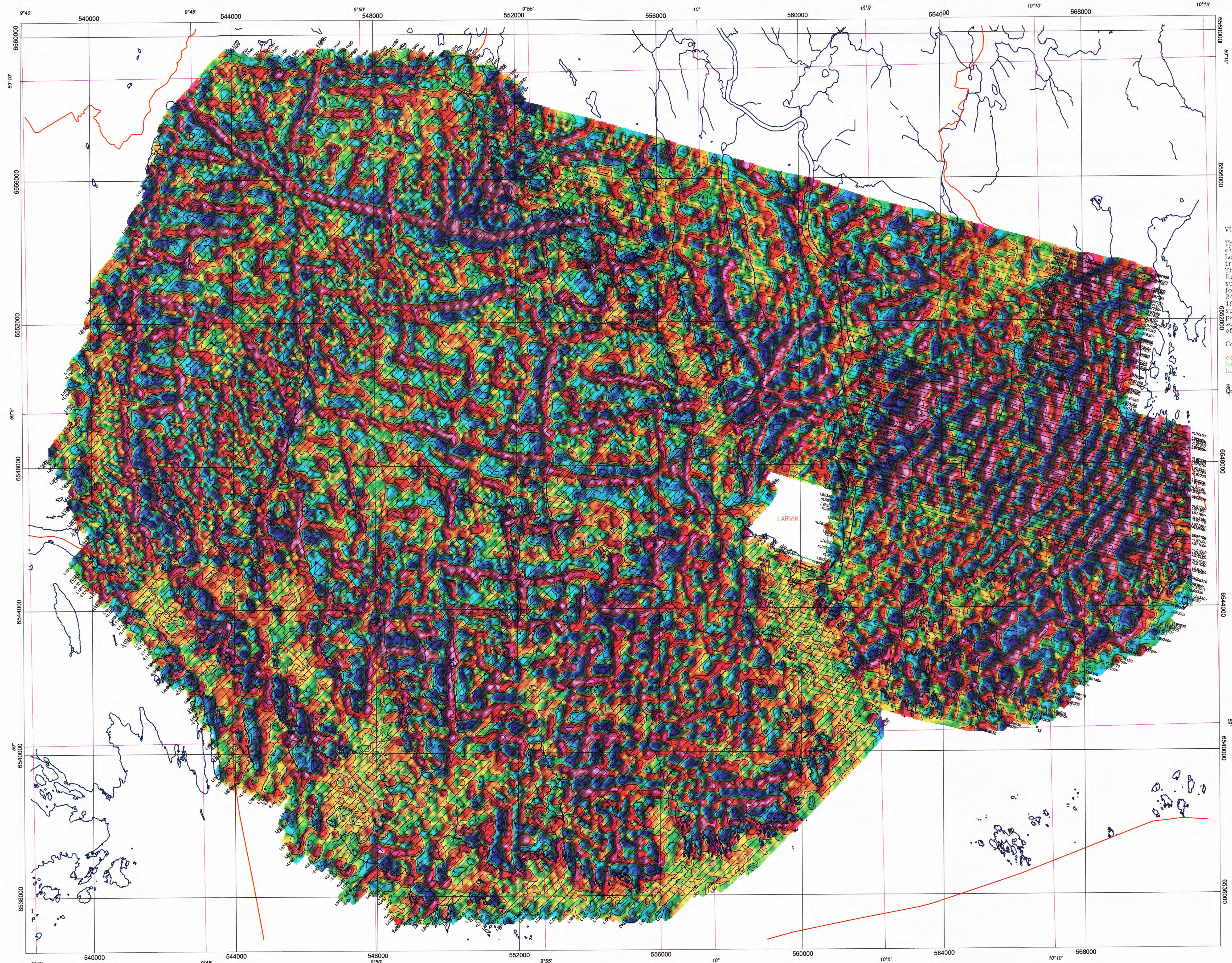
Color code:
 commune borders
 helicopter survey boundaries
 lakes, rivers, and coastline

Contour intervals: 0.2 pct, 1 pct, and 10 pct.



NGU SURVEY-LARVIK AREA
 VLF anomaly--in-line+ortho receivers
 percent change over background
 Based on NGU helicopter surveys--1997, 1998

Geological Survey of Norway
 Leiv Eirikssons vei 39
 N-7040 Trondheim
 Map: 99.026.07
 Made by: L. Beard, 02.99



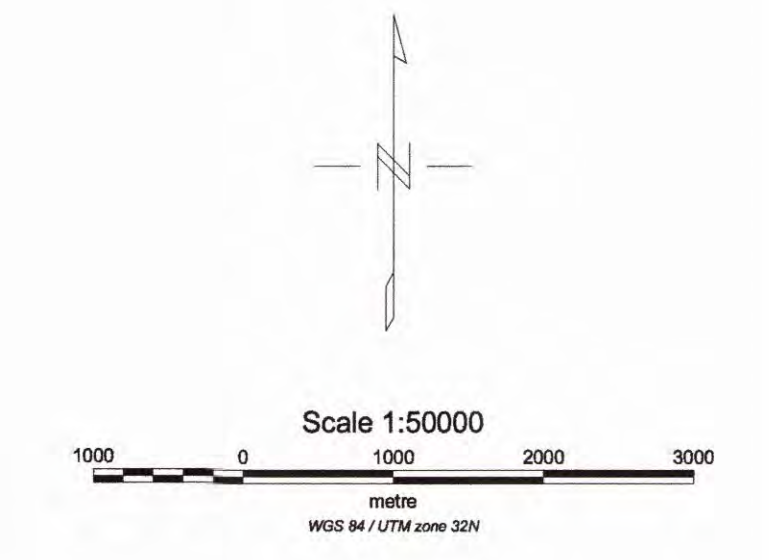
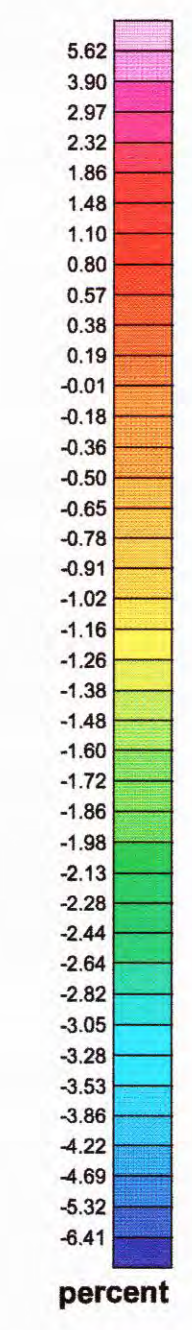
VLF data--anomaly from in-line receiver (GBR)

This map shows anomalies caused by electrical currents channeled into conductors. The sources of the VLF (Very Low Frequency electromagnetic) fields are powerful transmitters used for global communication with submarines. The data are measured in percent change from a background field. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. The transmitter used for the in-line receiver was GBR (Rugby, England; 16kHz). Data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 60 degrees.

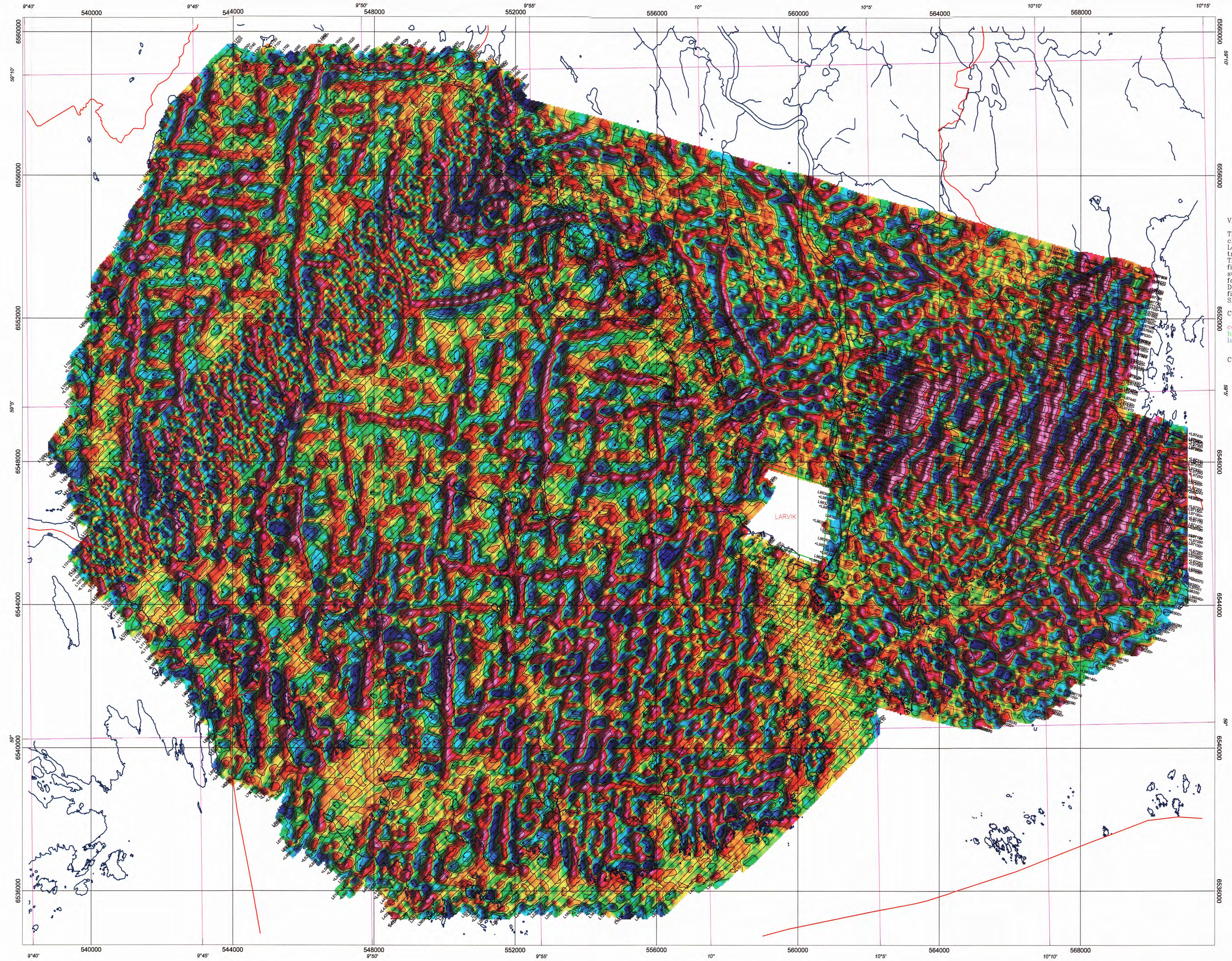
Color code:

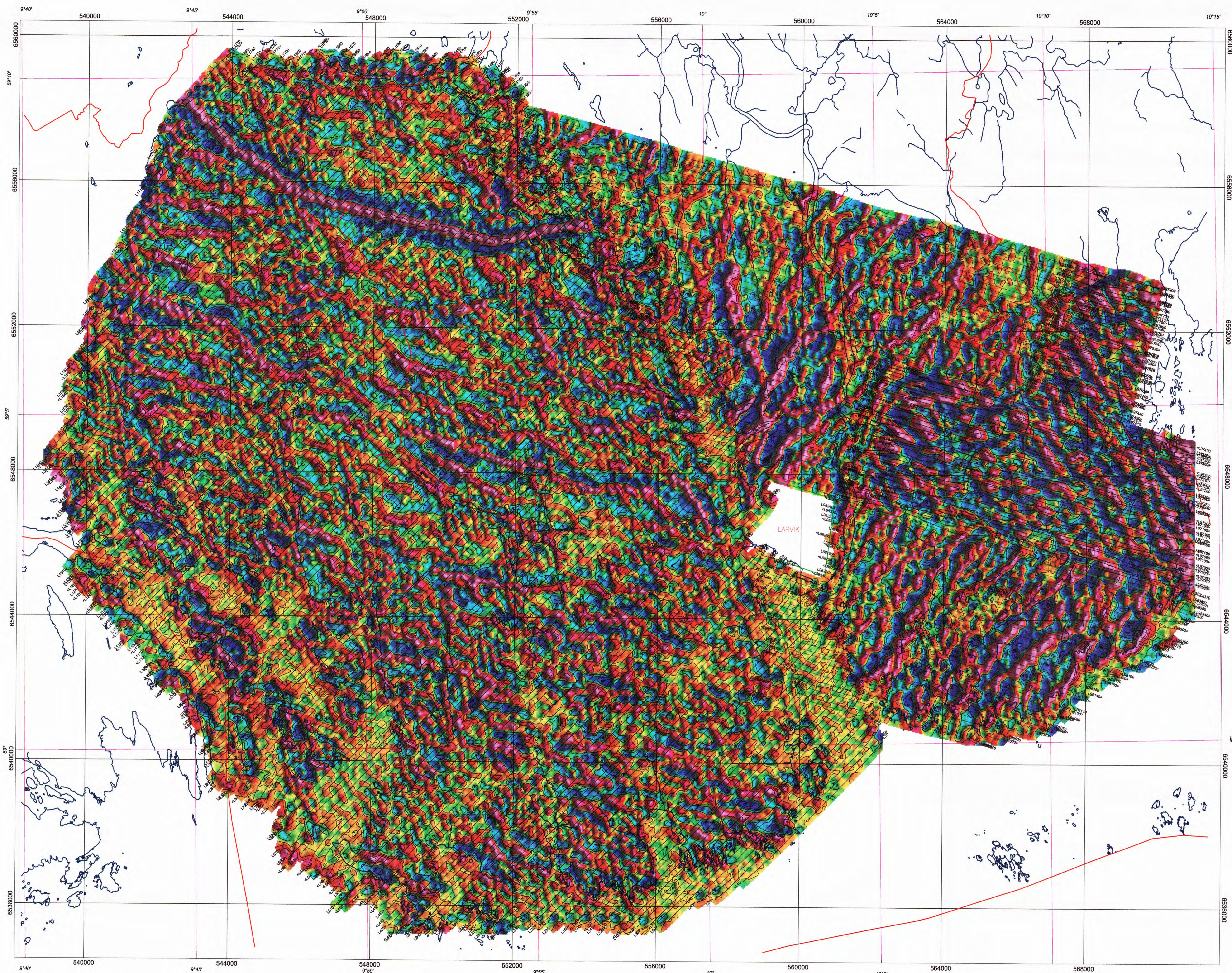
- commune borders
- helicopter survey boundaries
- lakes, rivers, and coastline

Contour intervals: 1 pct, 5 pct, and 20 pct.



NGU SURVEY-LARVIK AREA
 VLF anomaly--in-line receiver
 percent change over background
 Based on NGU helicopter surveys--1997, 1998
 Geological Survey of Norway
 Leiv Eirikssons vei 39
 N-7040 Trondheim
 Map: 99.026.08
 Made by: L. Beard, 02.99



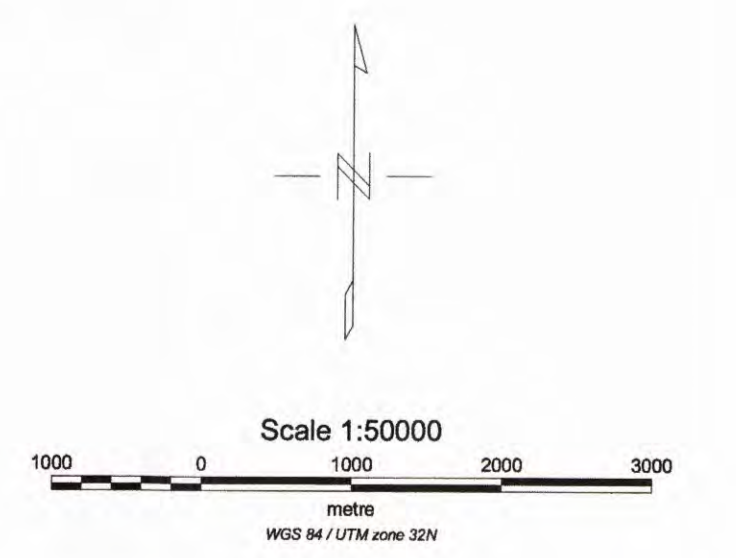
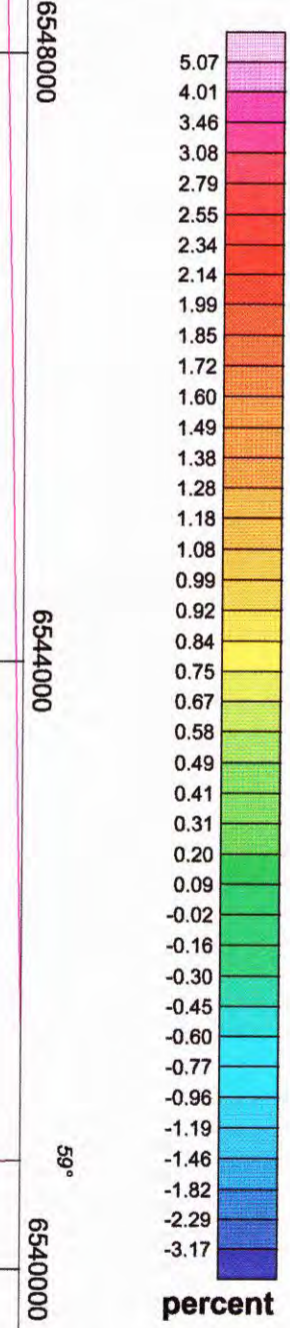


VLF data--anomaly from orthogonal receiver (NAA)

This map shows anomalies caused by electrical currents channeled into conductors. The sources of the VLF (Very Low Frequency electromagnetic) fields are powerful transmitters used for global communication with submarines. The data are measured in percent change from a background field. The data were collected in three separate NGU surveys, one in 1997 and two in 1998. The transmitter used for the orthogonal receiver was NAA (Cutler, Maine, USA; 24 kHz). Data have been smoothed using a single pass of a flanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 60 degrees.

Color code:
 commune borders
 helicopter survey boundaries
 lakes, rivers, and coastline

Contour intervals: 0.2 pct, 1 pct, and 10 pct.



NGU SURVEY-LARVIK AREA
 VLF anomaly--orthogonal receiver (NAA)
 percent change over background
 Based on NGU helicopter surveys--1997, 1998

Geological Survey of Norway
 Leiv Eirikssons vei 39
 N-7040 Trondheim
 Map: 99.026.09

Made by: I. Beard, 02.99

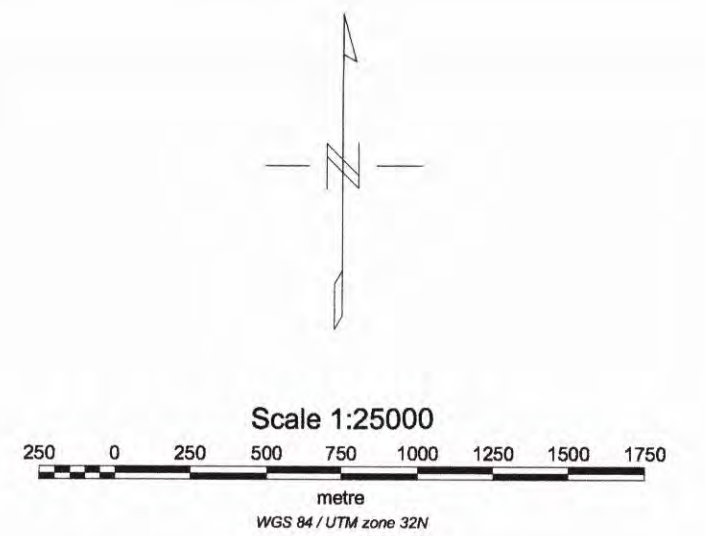
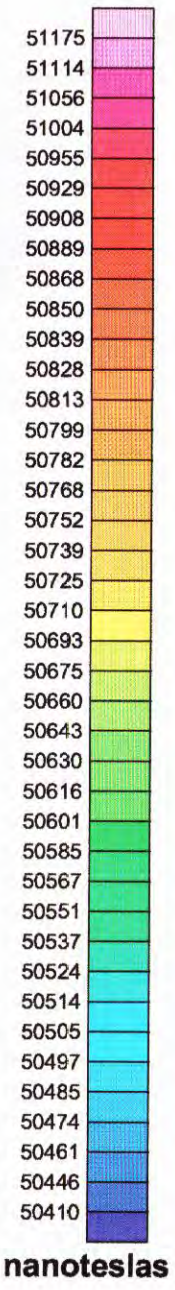
Magnetic data--total magnetic field

This map shows anomalies due to the measured total magnetic field. Diurnal drift was measured at a local base station and subtracted from the measured data. The data were collected in a 1998 NGU helicopter geophysical survey. The data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 45 degrees.

Color code:

commune borders
lakes, rivers, and coastline

Contour intervals: 20 nT, 100 nT, and 500 nT.



NGU SURVEY--EIDANGERFJORD
Total magnetic field nanoteslas
Based on NGU helicopter survey--1998
Geological Survey of Norway Leiv Eirikssons vei 39 N-7040 Trondheim Map: 99.026.10
Made by: L. Beard, 02.99

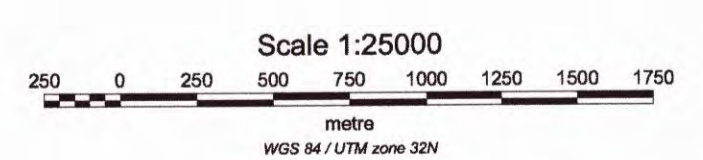
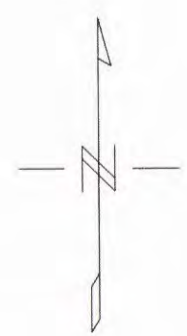
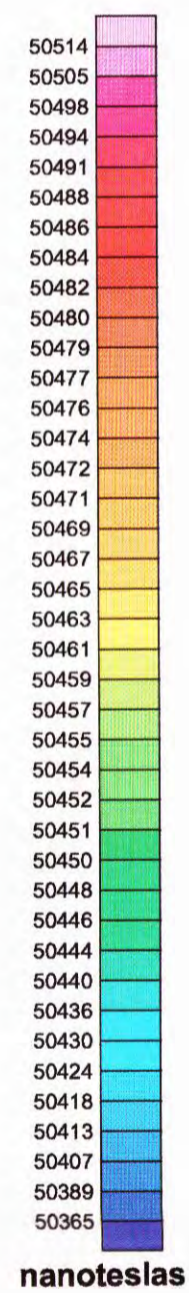
Magnetic data--total magnetic field

This map shows anomalies due to the measured total magnetic field. Diurnal drift was measured at a local base station and subtracted from the measured data. The data were collected in a 1998 NGU helicopter geophysical survey. The data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 45 degrees.

Color code:

- commune borders
- lakes, rivers, and coastline

Contour intervals: 4 nT, 20 nT, and 100 nT.



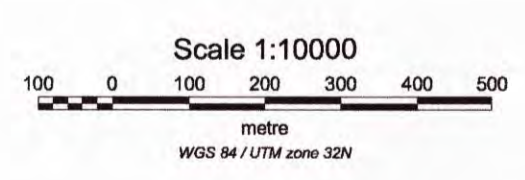
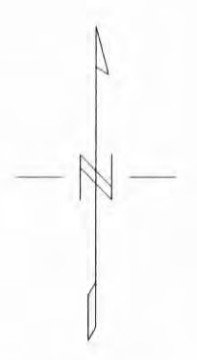
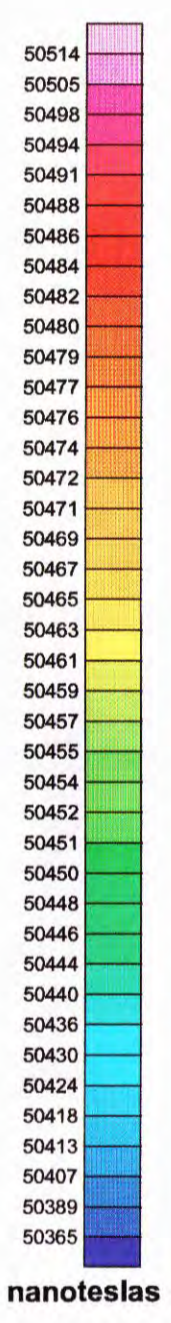
Magnetic data--total magnetic field

This map shows anomalies due to the measured total magnetic field. Diurnal drift was measured at a local base station and subtracted from the measured data. The data were collected in a 1998 NGU helicopter geophysical survey. The data have been smoothed using a single pass of a Hanning filter in order to enhance continuity of some anomalies. Shading is from the east at an inclination of 45 degrees.

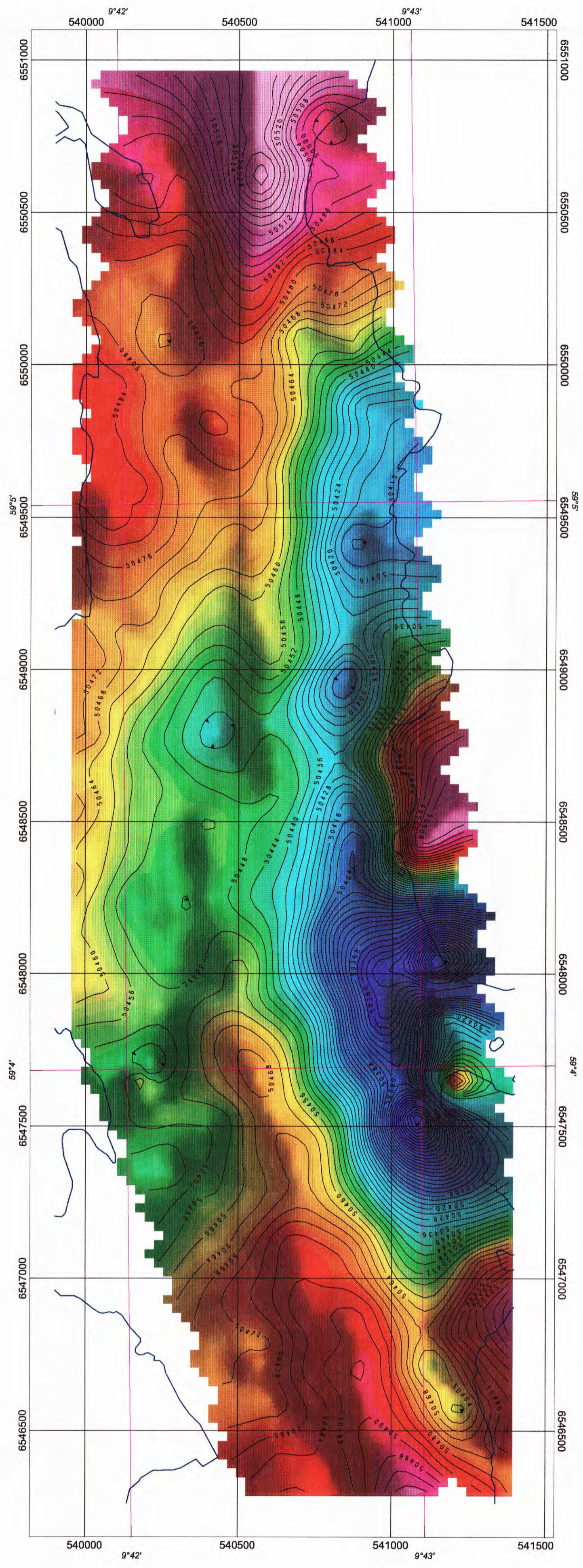
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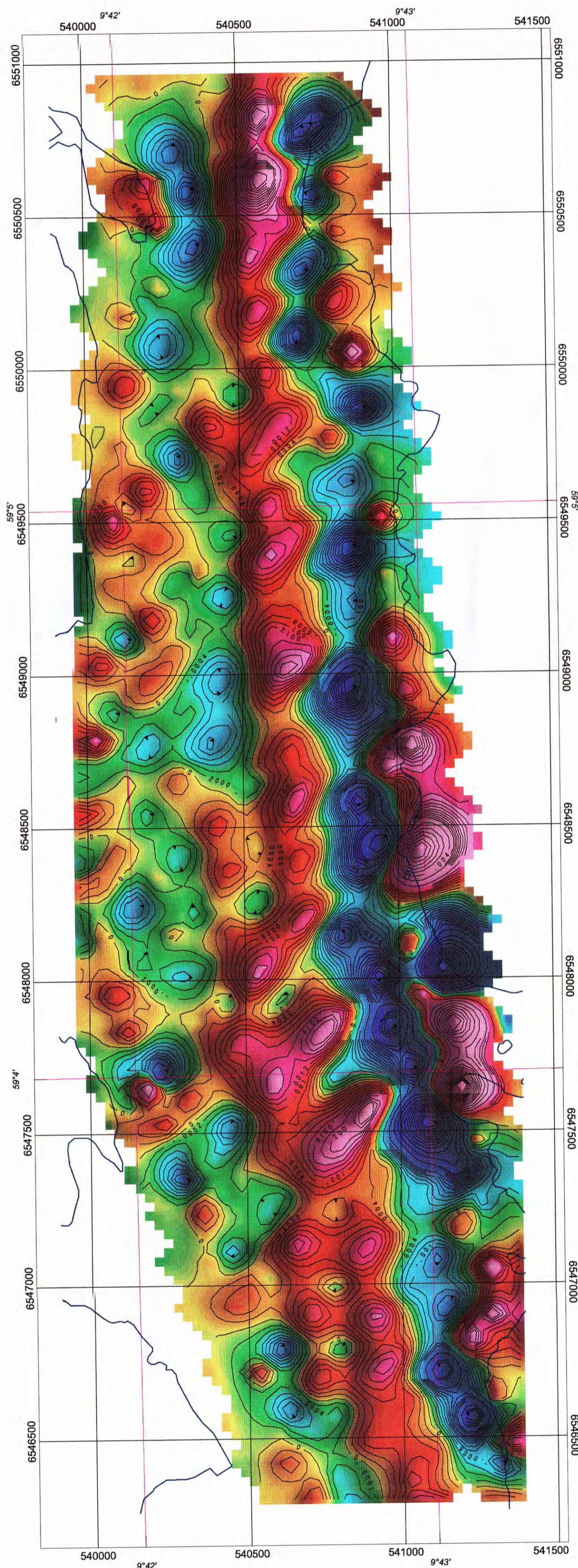
lakes, rivers, and coastline

Contour intervals: 4 nT, 20 nT, and 100 nT.



NGU SURVEY--EIDANGERFJORD
Total magnetic field nanoteslas
Based on NGU helicopter survey--1998
Geological Survey of Norway Leiv Eirikssons vei 39 N-7040 Trondheim Map: 99.026.12
Made by: L Beard, 02.99





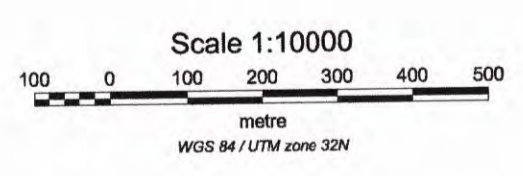
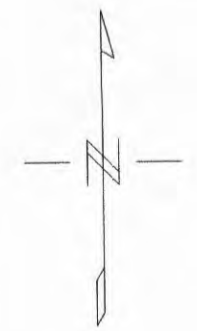
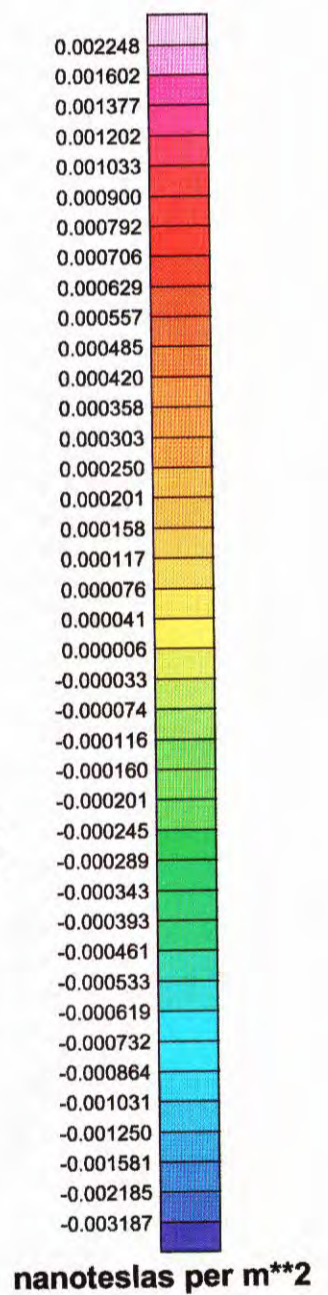
Magnetic data--second vertical derivative

This map shows anomalies due to the computed second vertical derivative of the measured total magnetic field. The data have been upward continued 30 m in order to enhance continuity of some features. The data were collected in a 1998 NGU helicopter geophysical survey. Shading is from the east at an inclination of 60 degrees.

Color code:

lakes, rivers, and coastline

Contour intervals: 0.0002 nT per m**2 and 0.001 nT per m**2.



NGU SURVEY--EIDANGERFJORD
Second vertical derivative of the total magnetic field
nanoteslas per meter2**
Based on NGU helicopter survey--1998

Geological Survey of Norway
 Leiv Eirikssons vei 39
 N-7040 Trondheim
 Map: 99.026.13

Made by: L Beard, 02.99