NGU Report 98.079

Data Acquisition and Processing—Helicopter Geophysical Survey, Oppkuven and Gran, 1997

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

Geological Survey of Norway
P.O.Box 3006 - Lade
N-7002 Trondheim, Norway
Tel.: 47 73 90 40 11
Telefax 47 73 92 16 20

REPORT

Report no.: 98.079	ISSN 0800-3416	Grading: Open

Title:

Data Acquisition and Processing—Helicopter Geophysical Survey, Oppkuven and Gran, 1997

Authors: Les P. Beard	Client: NGU
County: Akerhus, Buskerud,Oppland, og Oslo	Commune: Bærum, Gran, Hole, Jevnaker, Lunner, Nittedal, og Ringerike
Map-sheet name (M=1:250.000) Oslo	Map-sheet no. and -name (M=1:50.000) 1814 I Asker, 1814 IV Lier, 1815 I Gran, 1815 II Oppkuven, 1815 III Hønefoss
Deposit name and grid-reference:	Number of pages: 20 Price (NOK): 120,- Map enclosures:

Fieldwork carried out:	Date of report:	Project no.:	Person responsible:
June, 1997	29.06.98	2755.01	Jan S. Rønning

Summary:

During June, 1997, a helicopter geophysical survey was carried out over part of Nordmarka, an area immediately northwest from Oslo. The purpose of the survey was to provide geophysical information to improve geological mapping in the area. Approximately 3260 line-kilometers of VLF, radiometric, magnetometric, and electromagnetic data were acquired, covering an area of approximately 650 sq km, mostly over the area covered by NGU's Oppkuven mapsheet. An additional 2020 line-kilometers of radiometric, magnetometric, and VLF data were collected in an adjoining area immediately to the north of the Oppkuven area (Gran mapsheet), covering approximately 400 sq km. In both areas, the average flying height was 80 m above ground level and the nominal line spacing was 200 meters. 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 the Eggemoen airfield. Radiometric data were reduced using procedures recommended by the International Atomic Energy Association. Electromagnetic data, measured as parts per million of the primary field with in-phase and quadrature components, were reduced by subtracting an estimated zero level from the beginning of each flight, then correcting for drift under the assumption of linear drift. It was necessary to apply decorrugation filters to VLF and electromagnetic data sets to remove small line-to-line errors remaining in the processed data. All data were gridded using square cells with 40-m sides. All geophysical maps were produced at a scale of 1:50 000. This report covers aspects of data acquisition and processing.

Keywords: Geofysikk	Radiometri	Magnetometri
Elektromagnetisk måling	Databehandling	Fagrapport

CONTENTS

LIST OF FIGURES

Maps (1:50 000) available for order from NGU:

Oppkuven area:

Map 98.079-01: Total magnetic field
Map 98.079-02: Resistivity—4287 Hz horizontal coplanar coils
Map 98.079-03: Resistivity—32165 Hz horizontal coplanar coils
Map 98.079-04: Resistivity—915 Hz vertical coaxial coils
Map 98.079-05: Resistivity—4551 Hz vertical coaxial coils
Map 98.079-06: Radiometric total counts
Map 98.079-07: Radiometric potassium
Map 98.079-08: Radiometric thorium
Map 98.079-09: Radiometric uranium

Map 98.079-10:	Second vertical derivative of total magnetic field
Map 98.079-11:	VLF-EM, orthogonal + in-line

Gran area:

Map 98.079-12:	Total magnetic field
Map 98.079-13:	Radiometric total counts
Map 98.079-14:	Radiometric potassium
Map 98.079-15:	Radiometric thorium
Map 98.079-16:	Radiometric uranium
Map 98.079-17:	Second vertical derivative of total magnetic field
Map 98.079-18:	VLF-EM, orthogonal + in-line

Additional maps:

Map 98.079-19:	VLF-EM, in-line receiver, Gran
Map 98.079-20:	VLF-EM, orthogonal receiver, Gran
Map 98.079-21:	VLF-EM, in-line receiver, Oppkuven
Map 98.079-22:	VLF-EM, orthogonal receiver, Oppkuven

1 INTRODUCTION

In June, 1997, a helicopter geophysical survey was carried out over part of Nordmarka, an area immediately northwest of Oslo. The survey area lies between longitudes 10°17′ E and 10°44′ E, and latitudes 59°56′ N and 60°30′ N. The survey area was divided into two zones, a southern zone covering approximately the same area as NGU's Oppkuven map sheet, and a northern zone covering a portion of the Gran mapsheet (Fig. 1). In the south, radiometric, electromagnetic, magnetic, and very low frequency electromagnetic (VLF) data were collected. In the north, only magnetic, radiometric, and VLF data were collected. The primary objective of the survey 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 only one flight, but lightning activity from distant thunderstorms caused some noise in the electromagnetic data. Radiometric data can be degraded by airborne radon and by waterlogged soils. Both these factors affected the data collected in the northern (Gran) area. Weather conditions were never caused cancellation of a flight.

Electromagnetic, magnetic, and radiometric data quality was very good on all lines collected. VLF data quality varied considerably 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 average flying height was approximately 80 meters. There were a number of homes in the extreme southeast corner of the survey area, Lommedalen, so for safety reasons this area was flown at a height of about 150 meters. In the Oppkuven area, several power lines caused flight heights to exceed 100 meters. Two of the valleys in the southern and western part of Krokskogen—Djupedalen and Kjaglidalen—were steep walled and forced higher than average flying heights.

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.

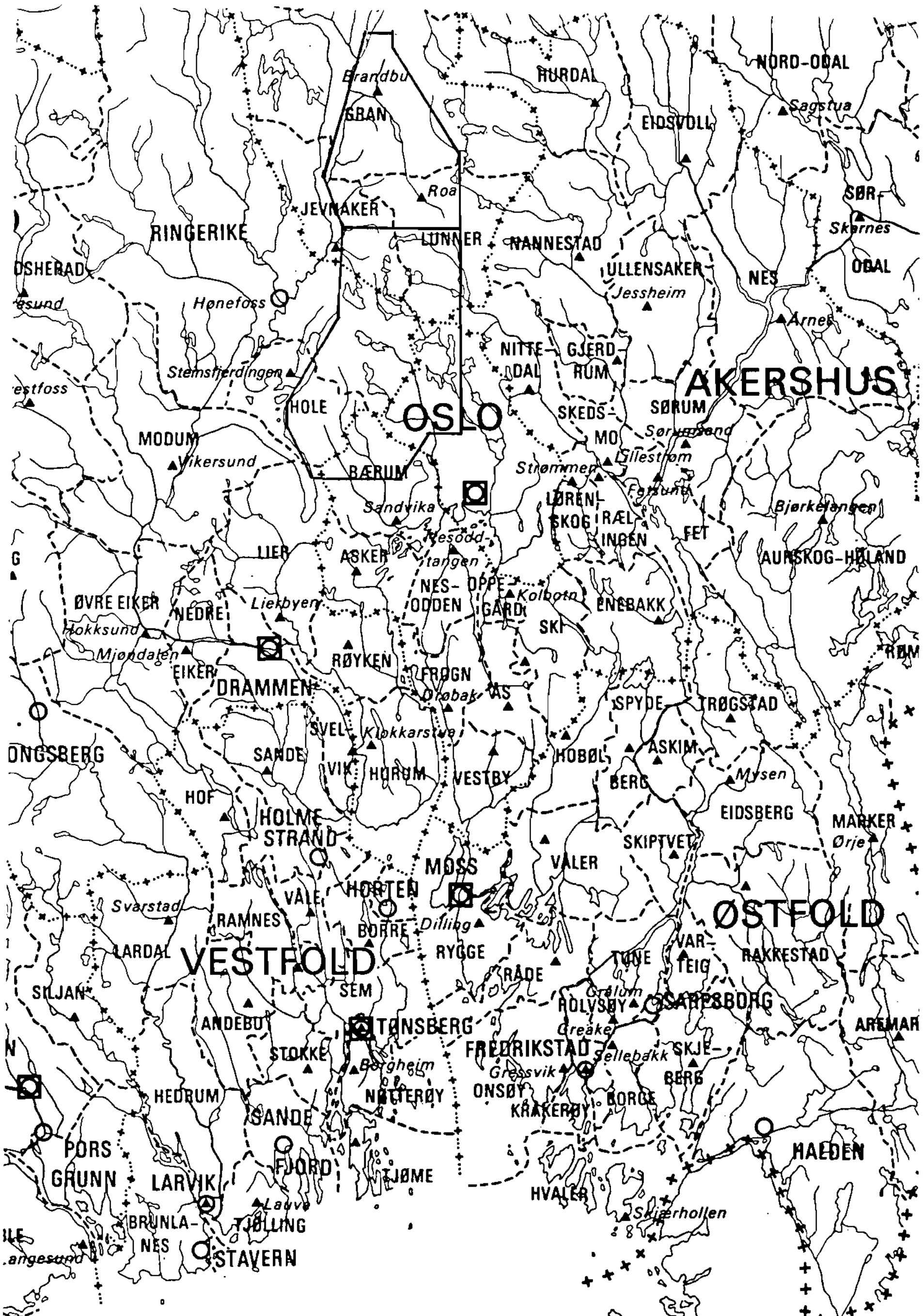


Fig. 1. Location of helicopter surveys. Scale: 1 cm = 10 km.

3 DATA ACQUISITION

The survey aircraft was an Areospatiale Ecureuil B-2. Flying speed was approximately 100 km per hour (28 meters per second). Flight lines over the Oppkuven area were in an east-west direction, whereas those in the Gran area were north-south. The radiometric sensors were mounted beneath the helicopter. Electromagnetic sensors were mounted in a towed bird supported by a 30 m long cable. VLF and magnetic sensors were mounted on the cable.

3.1 Magnetic measurements

A Scintrex cesium vapor magnetometer, the MEP 410, 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 the Eggemoen airfield, north from Hønefoss, 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 15 measurements per minute.

3.2 Electromagnetic measurements

The EMEX-2 electromagnetic system is custom-built by the Aerodat Ltd. of Canada. The system uses two transmitter-receiver coil configurations: horizontal coplanar (HCP) and vertical coaxial (VCA). The HCP configuration operates at two frequencies: 32 kHz and 4.3 kHz. The VCA configuration operates at 4.5 kHz and 0.9 kHz. Transmitter-receiver separation is approximately 6.5 meters for all coil pairs. The sampling rate for all frequencies is 10 measurements per second. The coils are encased in a Kevlar bird suspended 30 meters beneath the helicopter. The system measures the in-phase and quadrature components normalized against the primary inducing field. These values are expressed in parts per million of the primary field.

3.3 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 beneath the helicopter frame.

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.

3.4 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 (ortho), 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), NAA (24 kHz, Cutler, Maine, USA), and JXZ (16 kHz, Helgeland, Norway).

3.5 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.

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 a DAS-8 manufactured by RMS Instruments, 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 on Pentium 200 MHz PCs with GEOSOFT processing software (Geosoft, 1996) designed for Windows-NT operating systems. All maps were gridded using a 40-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 and is necessary in the case of the electromagnetic data and the magnetic data. Before gridding, the flights were split into lines and turns were trimmed away.

Total field magnetic data: A narrow nonlinear filter was applied to the raw magnetic data to remove spikes from spherics or other sources. The data were then inspected flight-by-flight and any spikes which were not completely removed by the filter were 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 60 meters.

In the northern area (Gran), atmospheric radon contaminated the uranium, potassium, and total counts channels. The effects of atmospheric radon were reduced during processing, but the uranium map in particular (Figure 9) still shows some of these effects.

Electromagnetic data: The electromagnetic (EM) data consist of in-phase and quadrature measurements recorded as parts per million (ppm) of the free-space electromagnetic response at the receiver coil produced by the transmitter coil. Processing of the EM data was done using Geosoft software (Geosoft, 1997). Data zero levels were determined, and instrument drift corrected. Spikes were removed using a nonlinear filter and the data were low pass filtered. From the leveled data, nomograms were constructed and half-space resistivities were computed for each frequency and coil configuration. A decorrugation filter was applied to the computed resistivity grids. This filter further reduced any residual leveling errors. It should be noted that drift is generally more severe as frequency increases, so drift in the 32 kHz HCP

EM system is less well compensated than in the lower frequencies. Furthermore, lower frequencies are more susceptible to power line interference than higher frequencies.

VLF-EM data: The raw VLF data channels—orthogonal and in-line receivers—were low pass filtered using a 6.5-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), and JXZ (16 kHz; Helgeland, Norway). GBR was used as the transmitter for in-line receiver in the east-west directed Oppkuven survey, and as the transmitter for the orthogonal receiver in the north-south directed Gran survey. NAA and JXZ were used as the transmitters for the orthogonal receiver in the Oppkuven area, and as the transmitter for the in-line receiver in the Gran area.

5 MAPS PRODUCED

All maps were produced at a scale of 1:50 000. All maps were presented in contoured color with shaded-relief. Shading was from the east (Oppkuven) or south (Gran)—along the flight line direction—and with a sun inclination of 60° above the horizon. The grid cell size for all maps was 40 meters. Flight lines are included on all maps. The following is a list of the maps produced and which can be ordered from NGU:

Oppkuven area:

Map 98.079-01:	Total magnetic field
Map 98.079-02:	Resistivity—4287 Hz horizontal coplanar coils
Map 98.079-03:	Resistivity—32165 Hz horizontal coplanar coils
Map 98.079-04:	Resistivity—915 Hz vertical coaxial coils
Map 98.079-05:	Resistivity—4551 Hz vertical coaxial coils
Map 98.079-06:	Radiometric total counts
Map 98.079-07:	Radiometric potassium
Map 98.079-08:	Radiometric thorium
Map 98.079-09:	Radiometric uranium

Map 98.079-10:	Second vertical derivative of total magnetic field
Map 98.079-11:	VLF-EM

Gran area:

Map 98.079-12:	Total magnetic field
Map 98.079-13:	Radiometric total counts
Map 98.079-14:	Radiometric potassium
Map 98.079-15:	Radiometric thorium
Map 98.079-16:	Radiometric uranium
Map 98.079-17:	Second vertical derivative of total magnetic field
Map 98.079-18:	VLF-EM

Additional maps:

Map 98.079-19:	VLF-EM, in-line receiver, Gran
Map 98.079-20:	VLF-EM, orthogonal receiver, Gran
Map 98.079-21:	VLF-EM, in-line receiver, Oppkuven
Map 98.079-22:	VLF-EM, orthogonal receiver, Oppkuven

In this report, selected samples of these maps are shown in Figures 2 through 10. Contour lines have been left off the figures to enhance clarity. The contours are included on the full-sized maps.

An interpretation of the data contained in these maps, and a geological bedrock map, will be included in an upcoming report to be written in cooperation with geologists from the Bedrock Geology Section of NGU.

9 REFERENCES

Geosoft Inc., 1997: HEM System for Windows 95 and NT, Geosoft Incorporated, Toronto.

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.

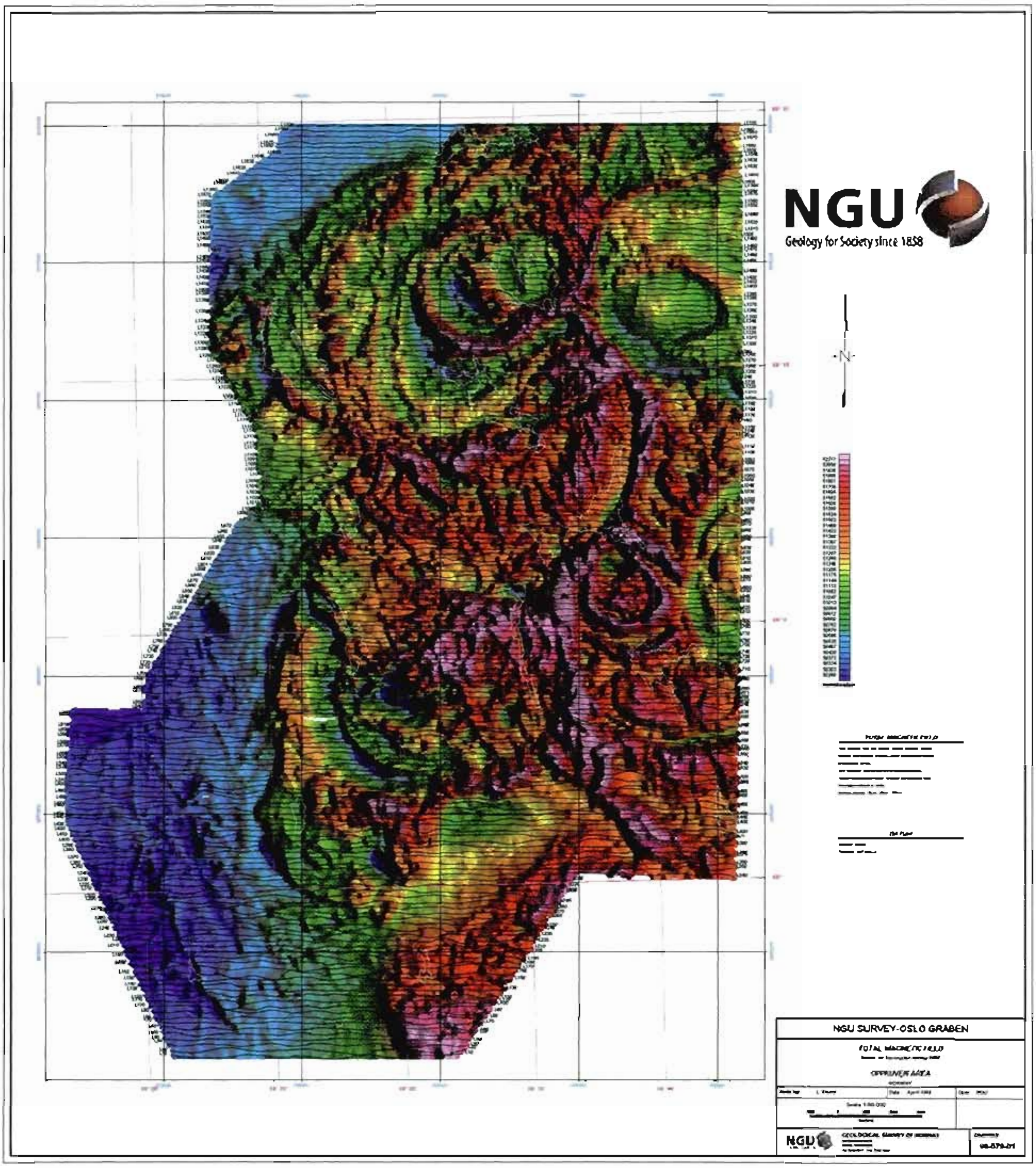


Fig. 2. Total magnetic field, Oppkuven area.

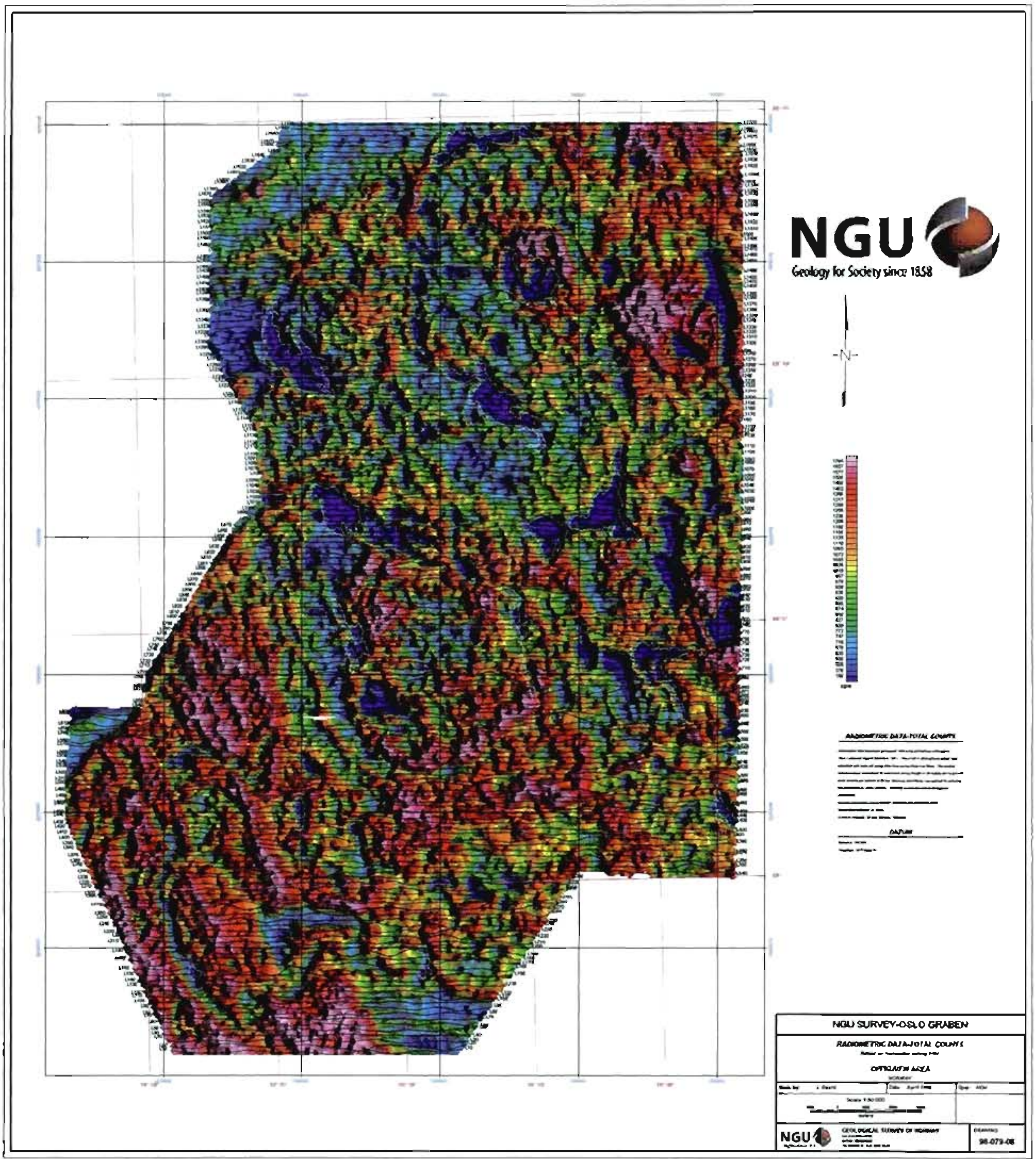


Fig. 3. Resistivity—4551 Hz vertical coaxial coils, Oppkuven area.

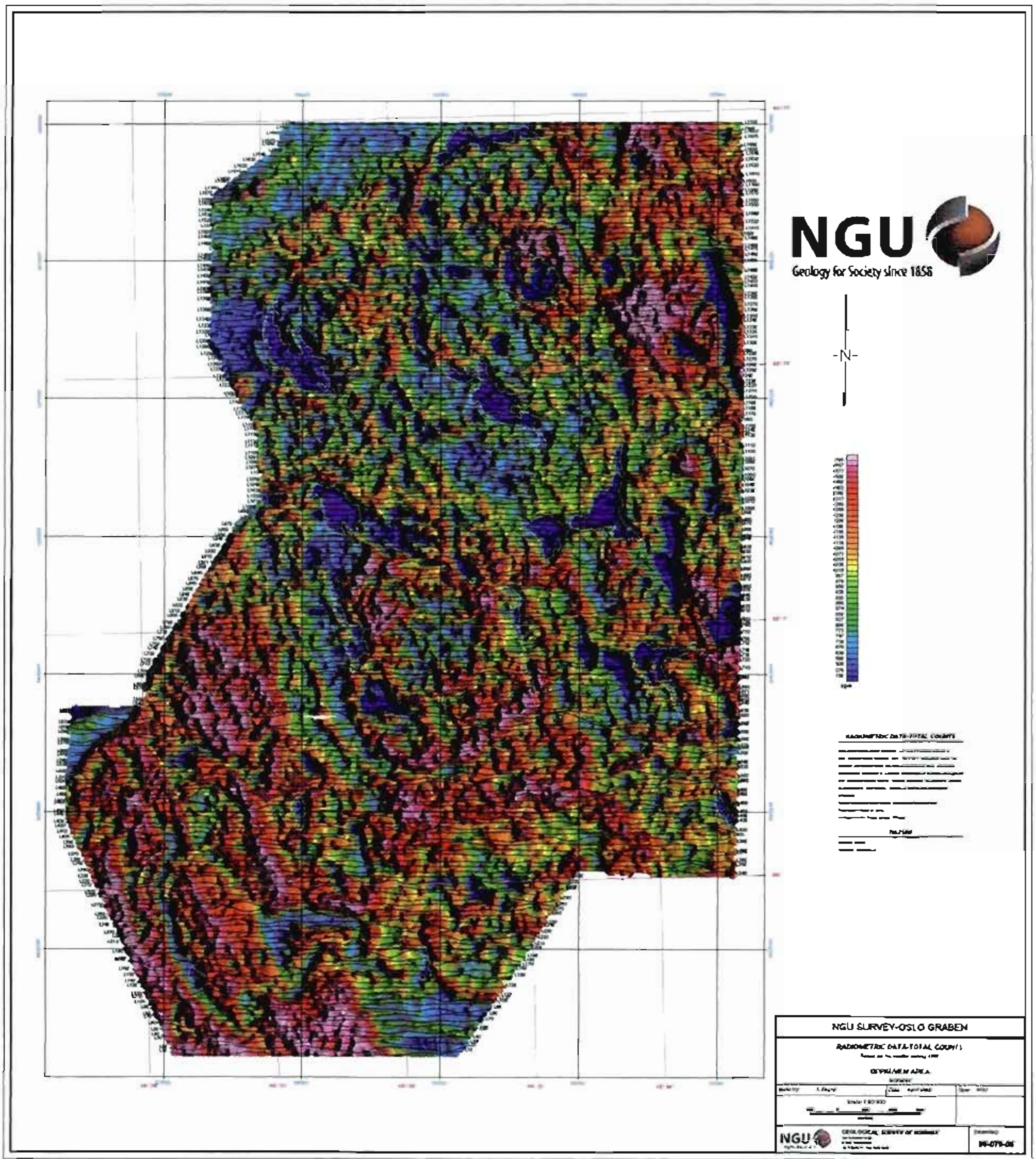


Fig. 4. Radiometric total counts, Oppkuven area.

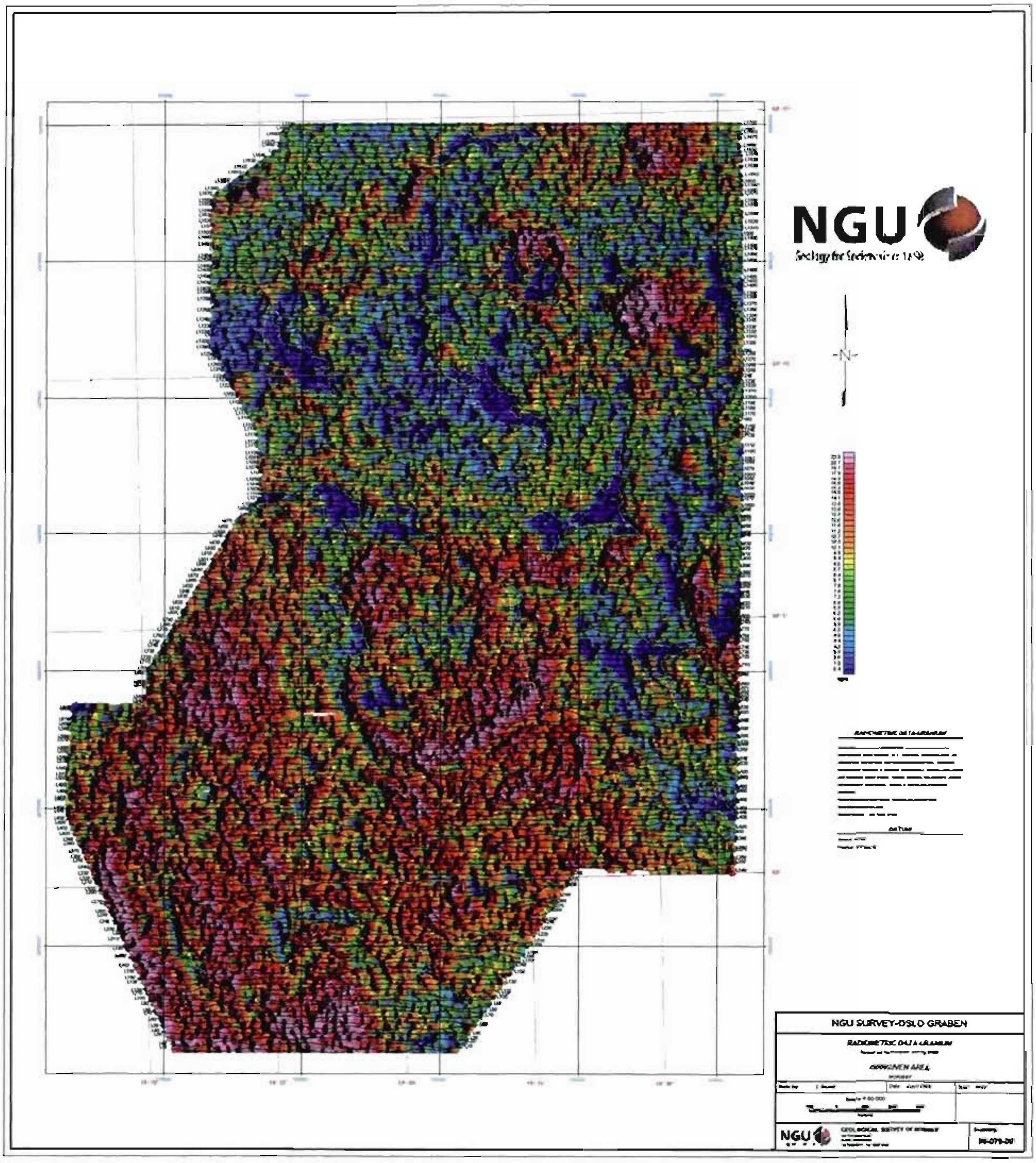


Fig. 5. Radiometric uranium, Oppkuven area.

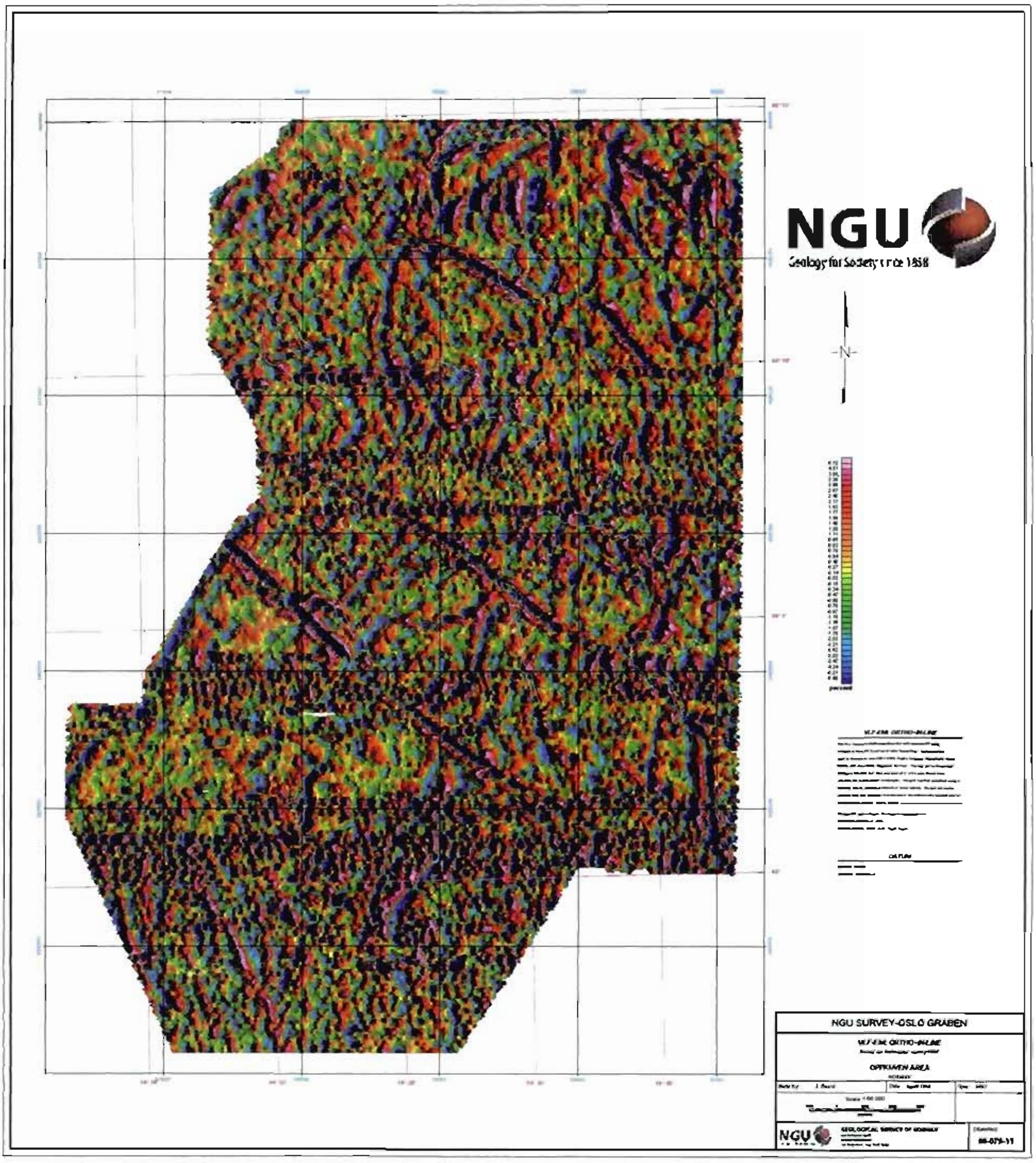


Fig. 6. VLF-EM, summed orthogonal + in-line response, Oppkuven area.

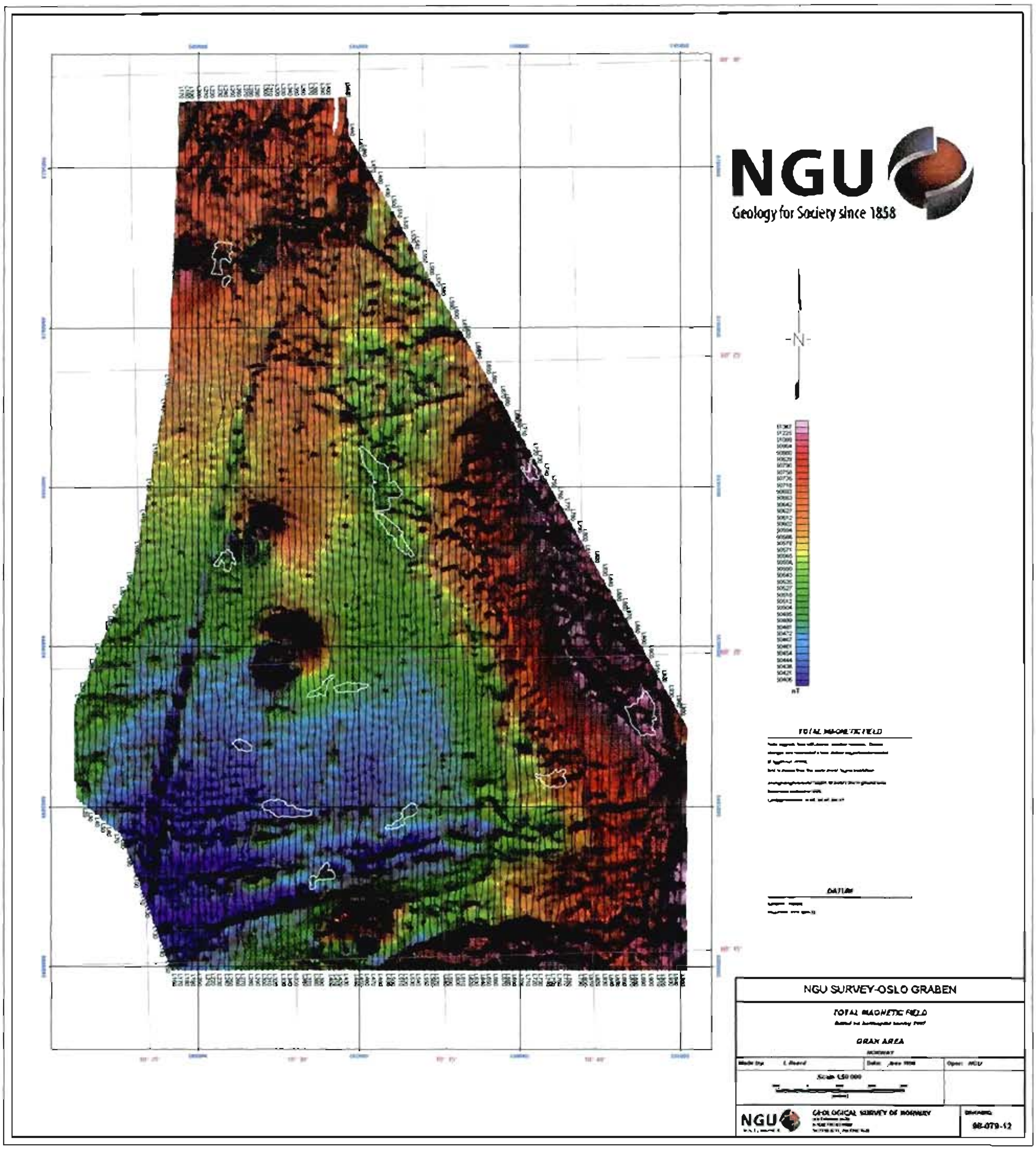


Fig. 7. Total magnetic field, Gran area.

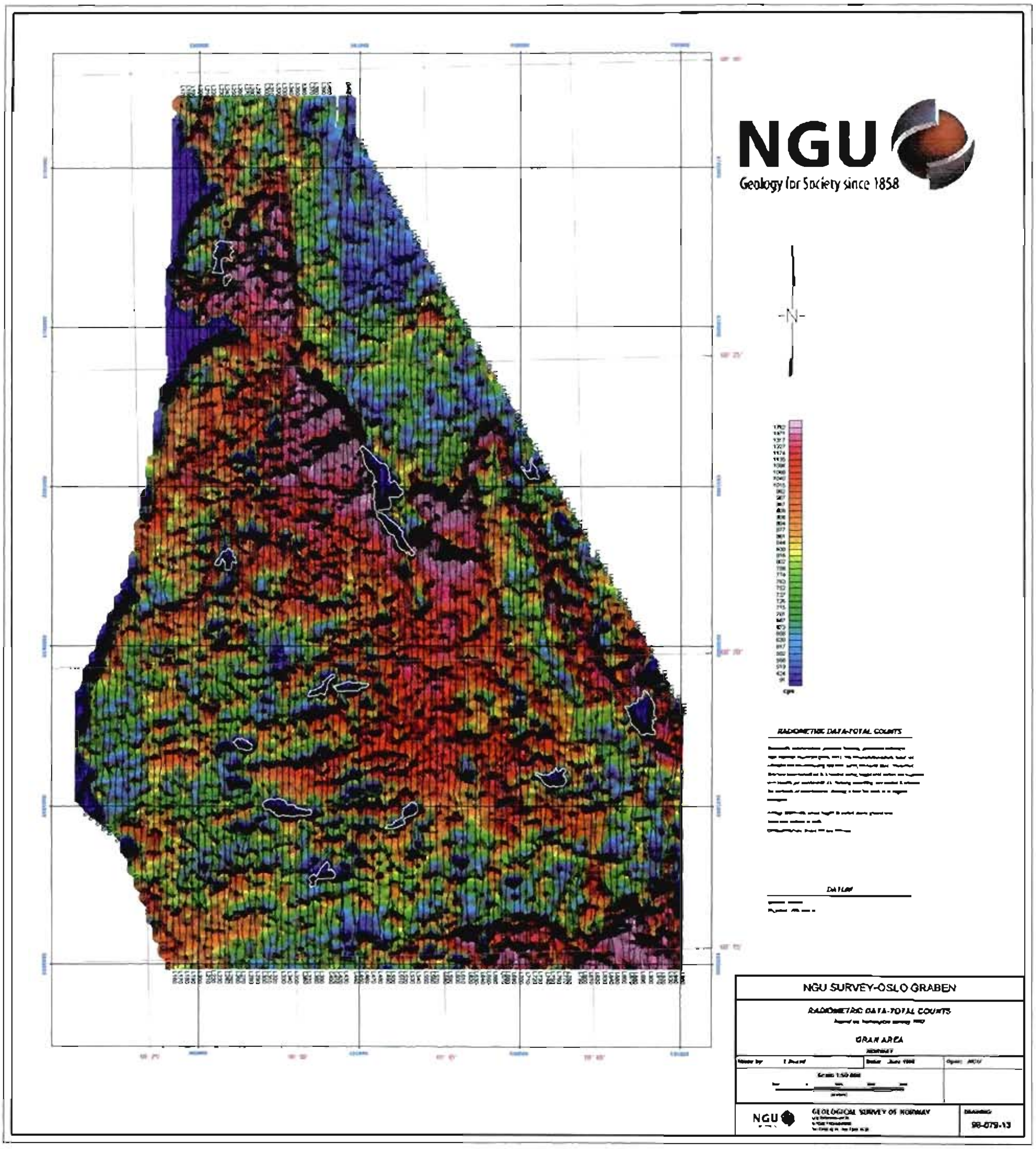


Fig. 8. Radiometric total counts, Gran area.

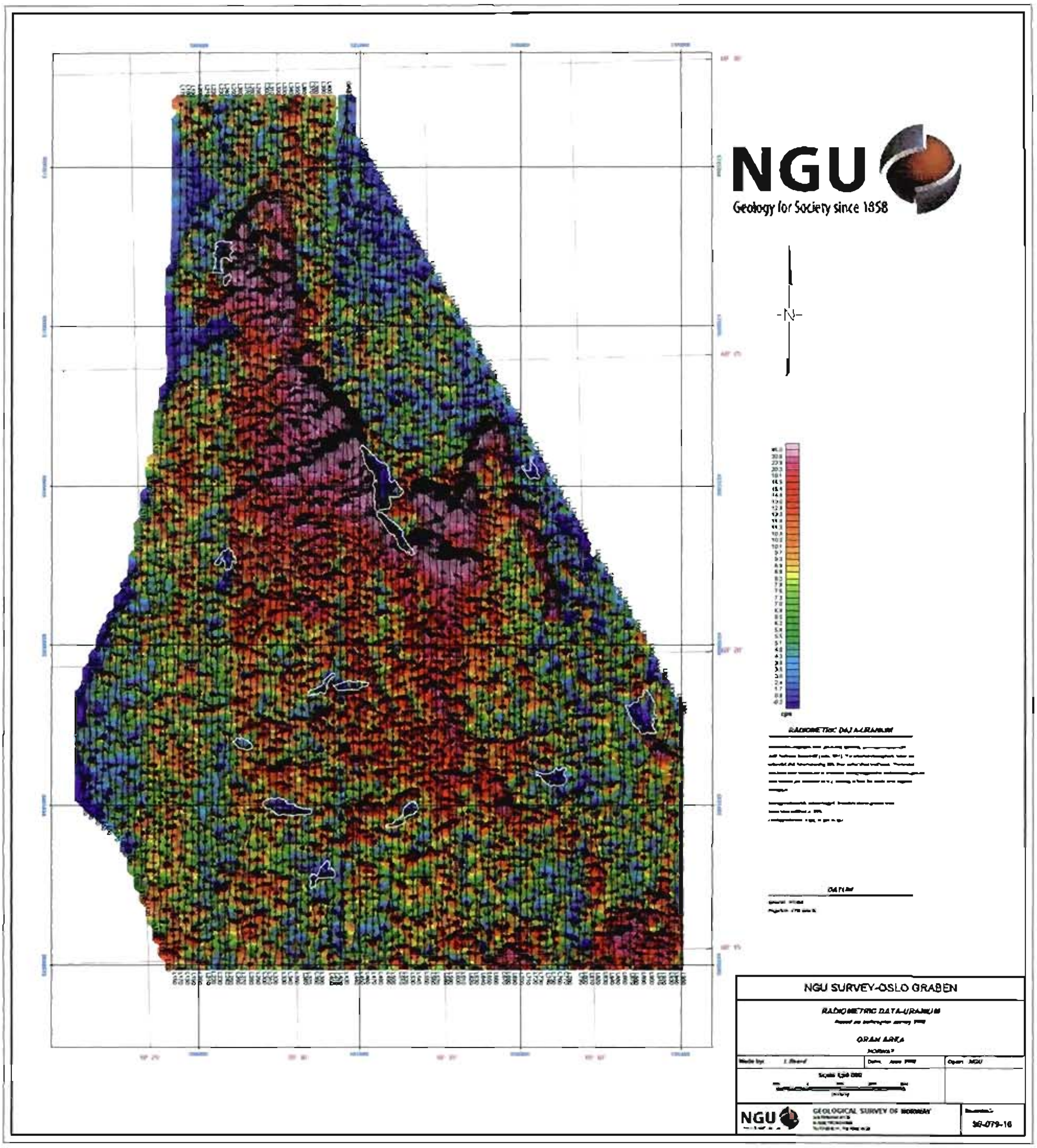


Fig. 9. Radiometric uranium, Gran area.

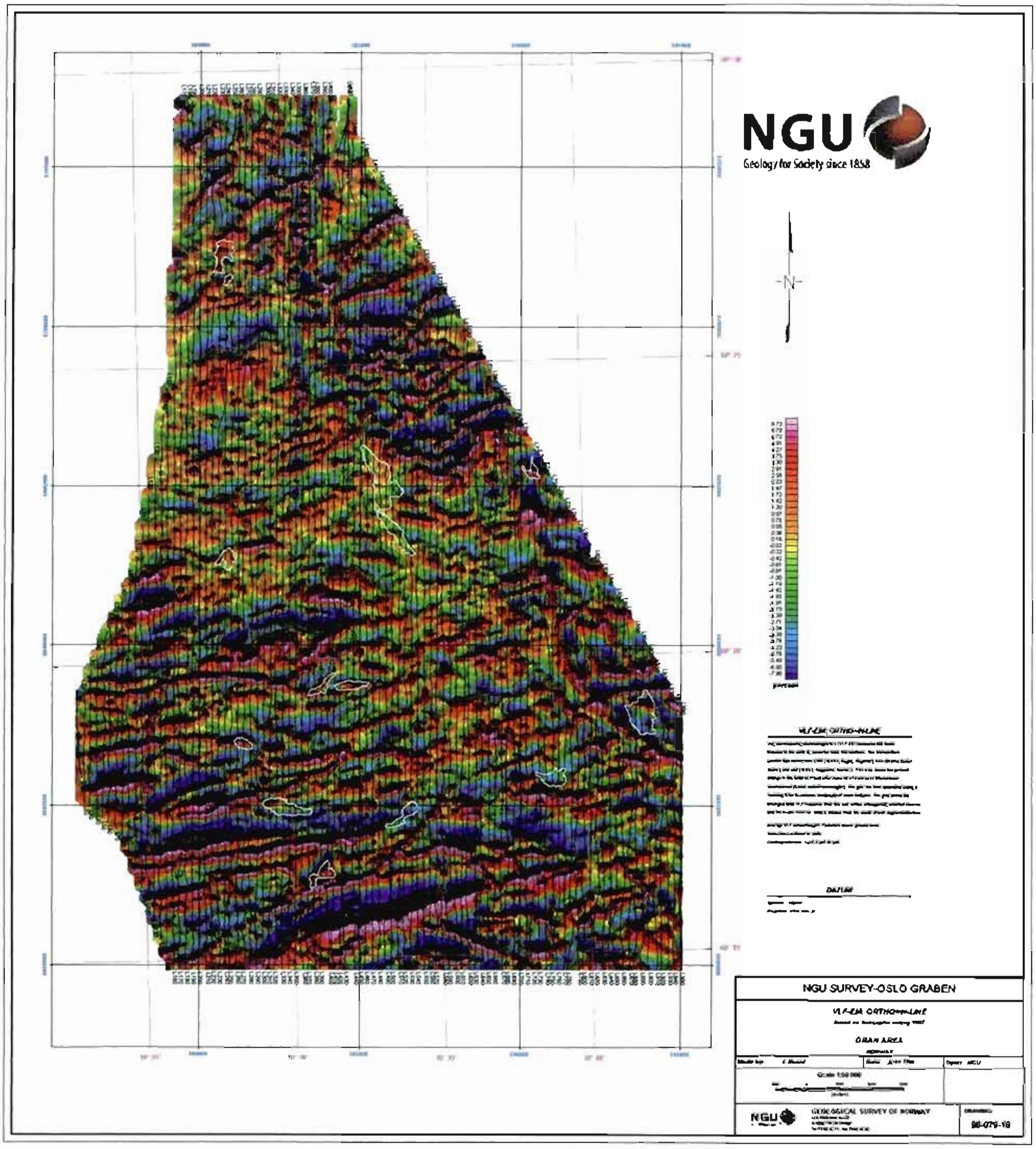
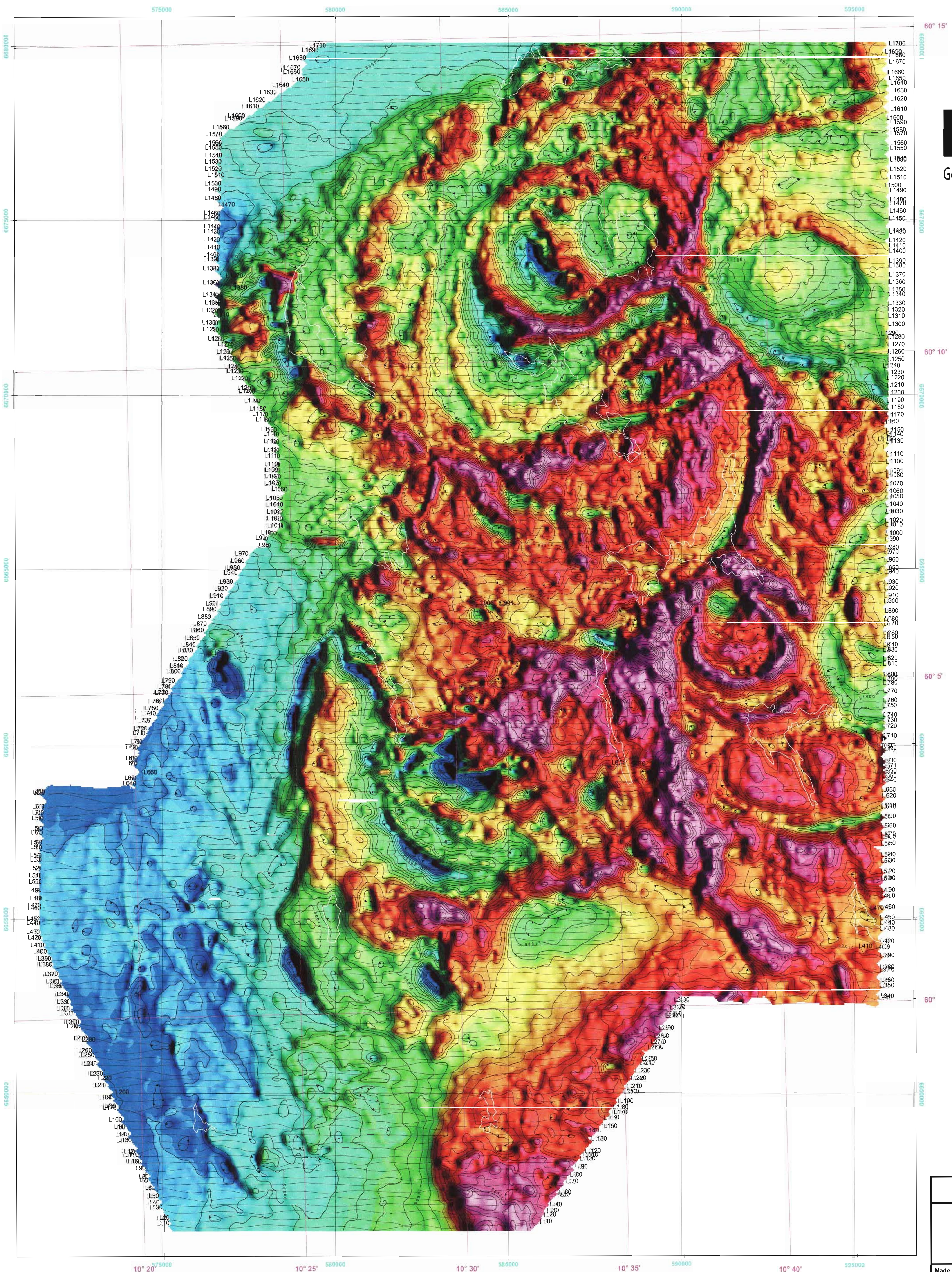
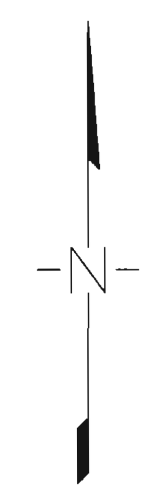
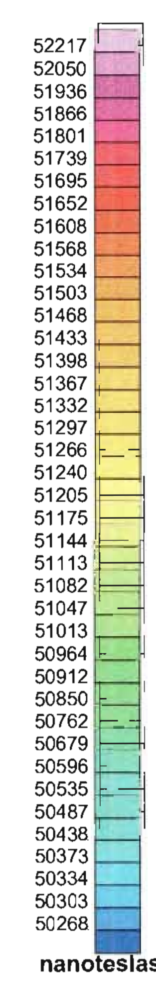


Fig. 10. VLF-EM, summed orthogonal + in-line response, Gran area.







TOTAL MAGNETIC FIELD

Total magnetic field with diurnal variation removed. Diurnal changes were recorded at a base station magnetometer located at Eggemoen airfield.

Grid is shaded from the east at a 60 degree inclination.

Average magnetometer height: 65 meters above ground level.

Some lakes outlined in white.

Contour intervals: 100 nT, 500 nT, 2000 nT.

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

TOTAL MAGNETIC FIELD

Based on helicopter survey 1997

OPPKUVEN AREA

NORWAY

Made by: *L Beard*	Date: *April 1998*	Oper: *NGU*

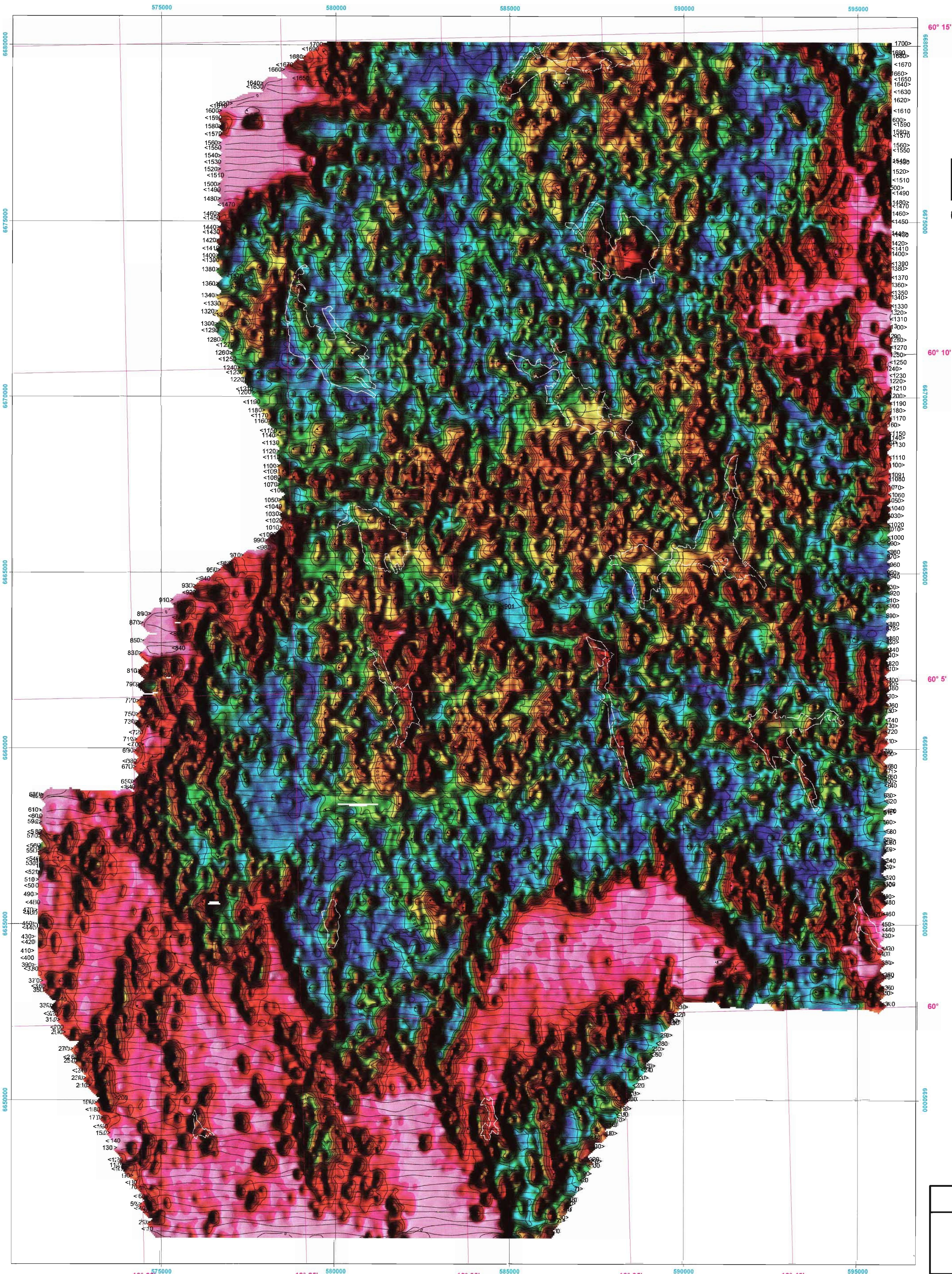
Scale 1:50 000

1000 0 1000 2000 3000

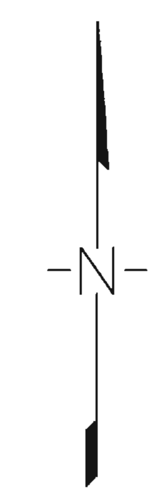
(meters)

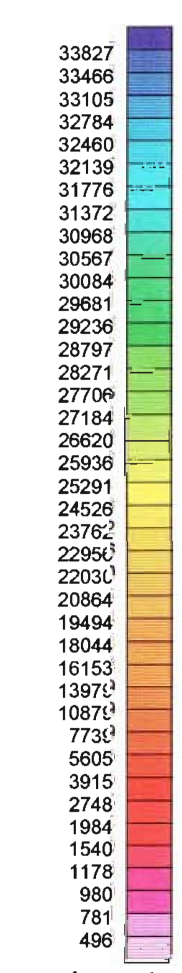
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-01



NGU
Geology for Society since 1858





RESISTIVITY-4287 HZ HCP

Half-space resistivity estimated from 4287 Hz horizontal coplanar coil configuration. Electromagnetic data have been leveled and a decorrugation filter has been applied to the gridded data. The grid has been upward continued 20 meters to enhance continuity of some features.

Average EM sensor height: 50 meters above ground level.

Contour intervals: 2000 ohm-m, 10000 ohm-m.

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RESISTIVITY-4287 HZ HCP

Based on helicopter survey 1997

OPPKUVEN AREA

NORWAY

Made by: *L Beard*	Date: *April 1998*	Oper: *NGU*

Scale 1:50 000

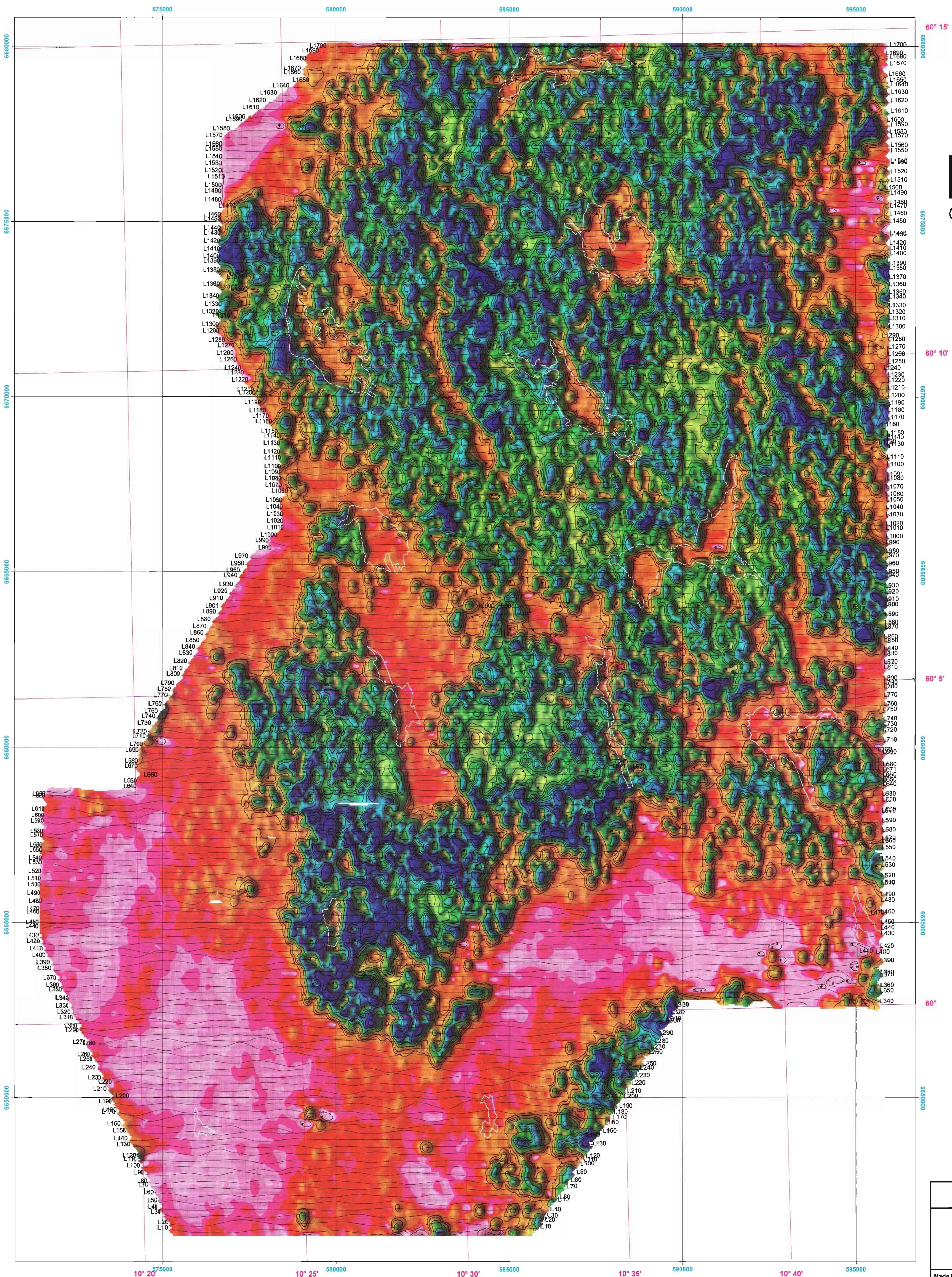
1000 0 1000 2000 3000

(meters)

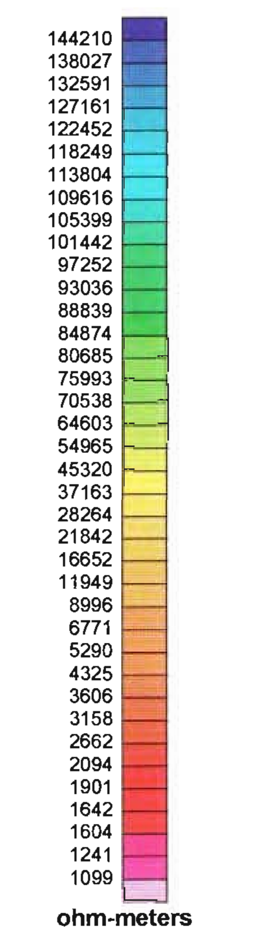
NGU Geology for Society since 1858

GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-02



NGU
Geology for Society since 1858



RESISTIVITY-32165 HZ HCP

Half-space resistivity estimated from 32165 Hz horizontal coplanar coil configuration. Electromagnetic data have been leveled and a decorrugation filter has been applied to the gridded data. The grid has been upward continued 20 meters to enhance continuity of some features. Grid is shaded from the east at a 60 degree inclination.

Average EM sensor height: 50 meters above ground level.

Some lakes outlined in white.

Contour intervals: 10000 ohm-m, 50000 ohm-m.

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RESISTIVITY-32165 HZ HCP

Based on helicopter survey 1997

OPPKUVEN AREA

NORWAY

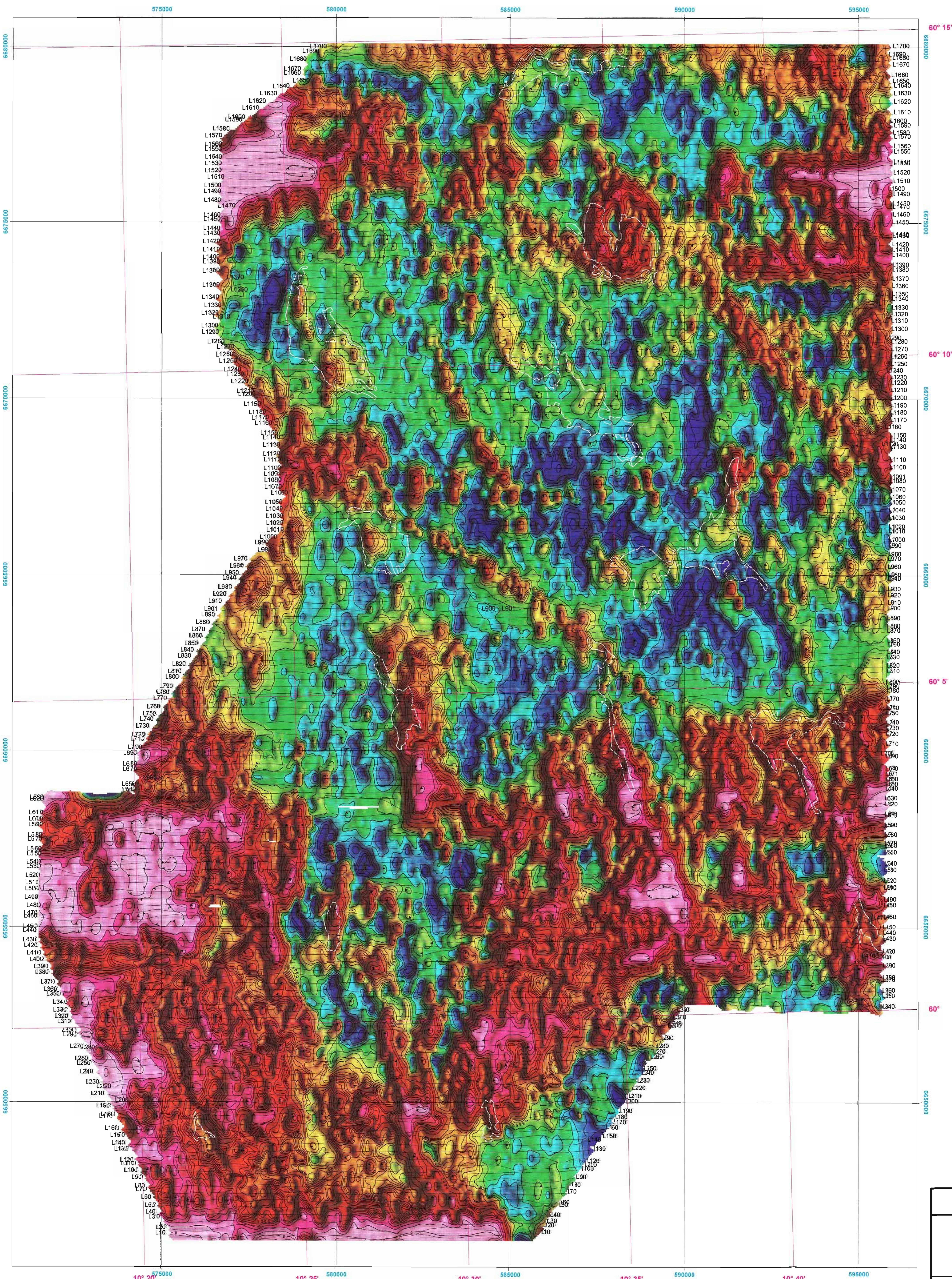
Made by: *L Beard*	Date: *April 1998*	Oper: *NGU*

Scale 1:50 000

1000 0 1000 2000 3000 (meters)

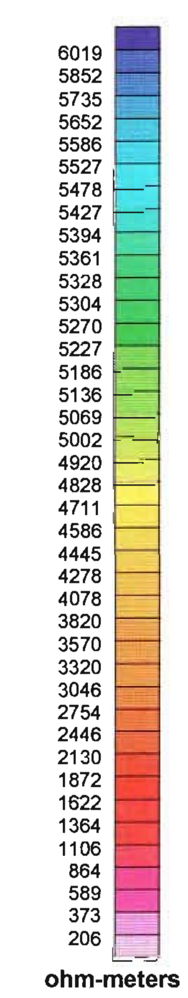
NGU Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-03



NGU

Geology for Society since 1858



RESISTIVITY-915 HZ VCA

Half-space resistivity estimated from 915 Hz vertical coaxial coil configuration.
Electromagnetic data have been leveled and a decorrugation filter has been applied to the gridded data. The grid has been upward continued 40 meters to enhance continuity of some features. Shading is from the east at 60 degrees inclination.
Average EM sensor height: 60 meters above ground level.
Some lakes outlined in white.
Contour intervals: 200 ohm-m, 1000 ohm-m.

DATUM

Spheroid: WGS84
Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RESISTIVITY-915 HZ VCA

Based on helicopter survey 1997

OPPKUVEN AREA

NORWAY

Made by: *L Beard*	Date: *April 1998*	Oper: *NGU*

Scale 1:50 000

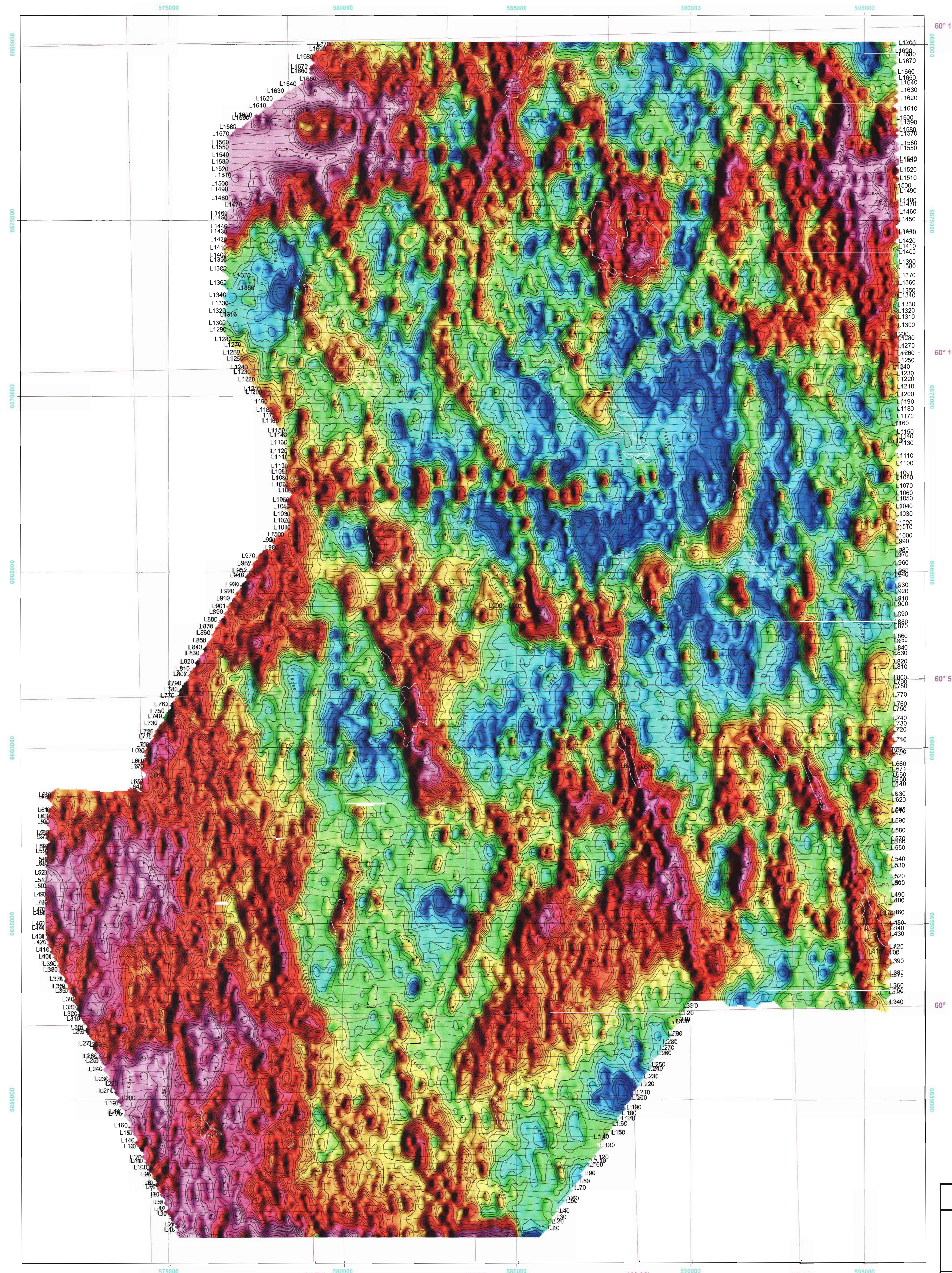
1000 0 1000 2000 3000

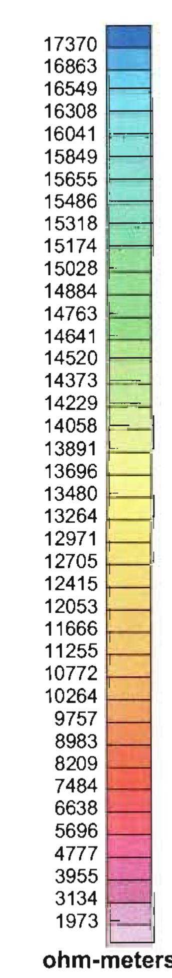
(meters)

NGU Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-04

NGU
Geology for Society since 1858





RESISTIVITY-4551 HZ VCA

Half-space resistivity estimated from 4551 Hz vertical coaxial coil configuration.
Electromagnetic data have been leveled and a decorrugation filter has been applied to the gridded data. The grid has been upward continued 20 meters to enhance continuity of some features. Shading is from the east at 60 degrees inclination.
Average EM sensor height: 50 meters above ground level.
Some lakes outlined in white.
Contour intervals: 500 ohm-m, 2000 ohm-m.

DATUM

Spheroid: WGS84
Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RESISTIVITY-4551 HZ VCA

Based on helicopter survey 1997

OPPKUVEN AREA

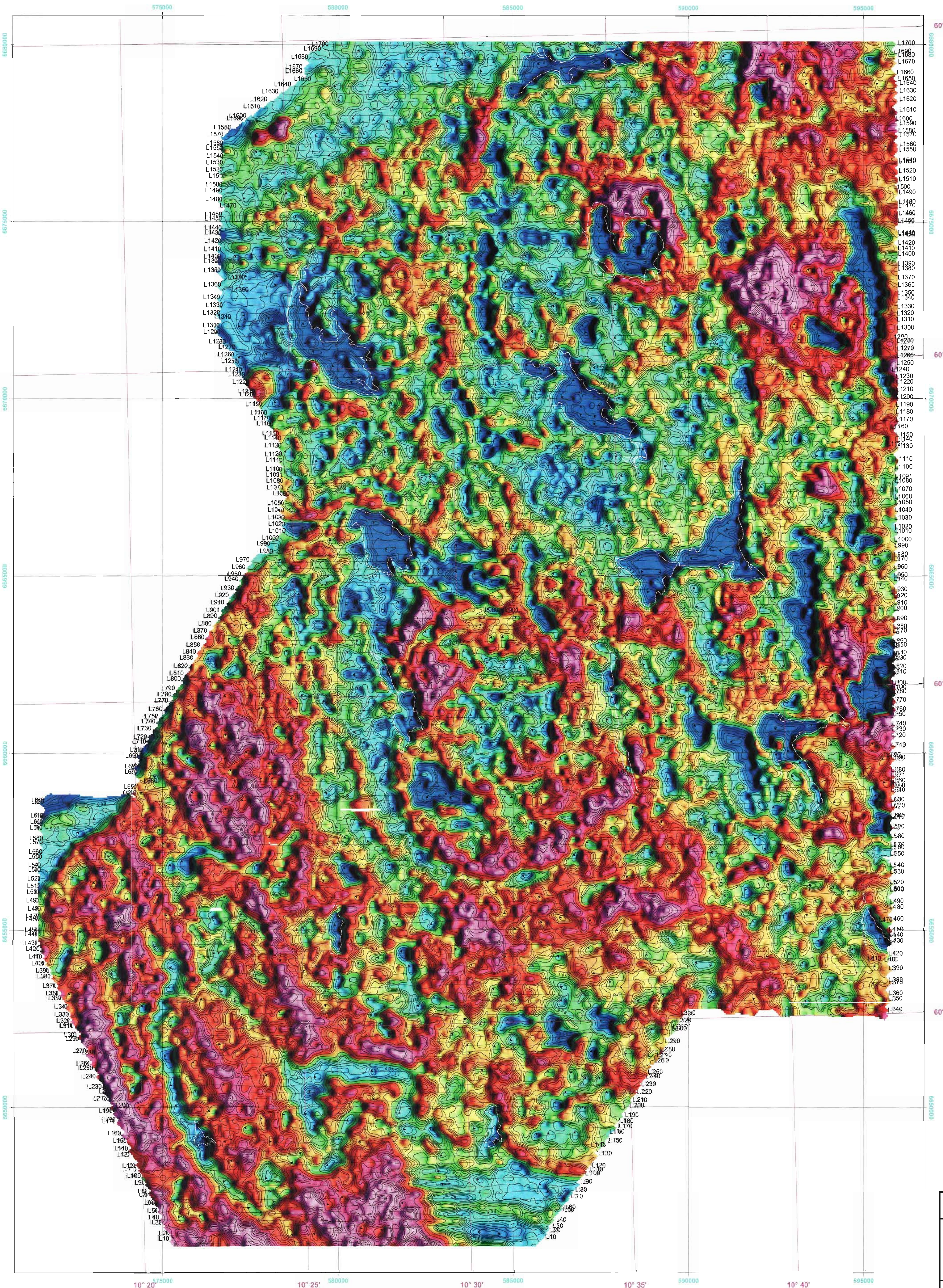
NORWAY

Made by: *L Beard*	Date: *April 1998*	Oper: *NGU*

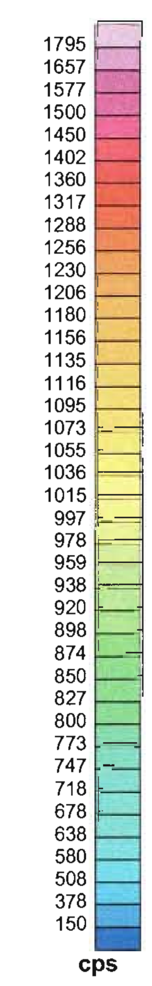
Scale 1:50 000
1000 0 1000 2000 3000
(meters)

NGU Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: **98-079-05**



NGU
Geology for Society since 1858



RADIOMETRIC DATA-TOTAL COUNTS

Radiometric data have been processed following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effect of atmospheric radon was estimated and removed using data from survey lines over lakes. The leveled data have been normalized to a nominal survey height of 80 meters above ground level (counts per second at 80 m). Hanning smoothing was applied to enhance the continuity of some features. Shading is from the east at 60 degrees inclination.

Average radiometric sensor height: 80 meters above ground level.

Some lakes outlined in white.

Contour intervals: 50 cps, 200 cps, 1000 cps.

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RADIOMETRIC DATA-TOTAL COUNTS

Based on helicopter survey 1997

OPPKUVEN AREA

NORWAY

Made by: L Beard	Date: April 1998	Oper: NGU

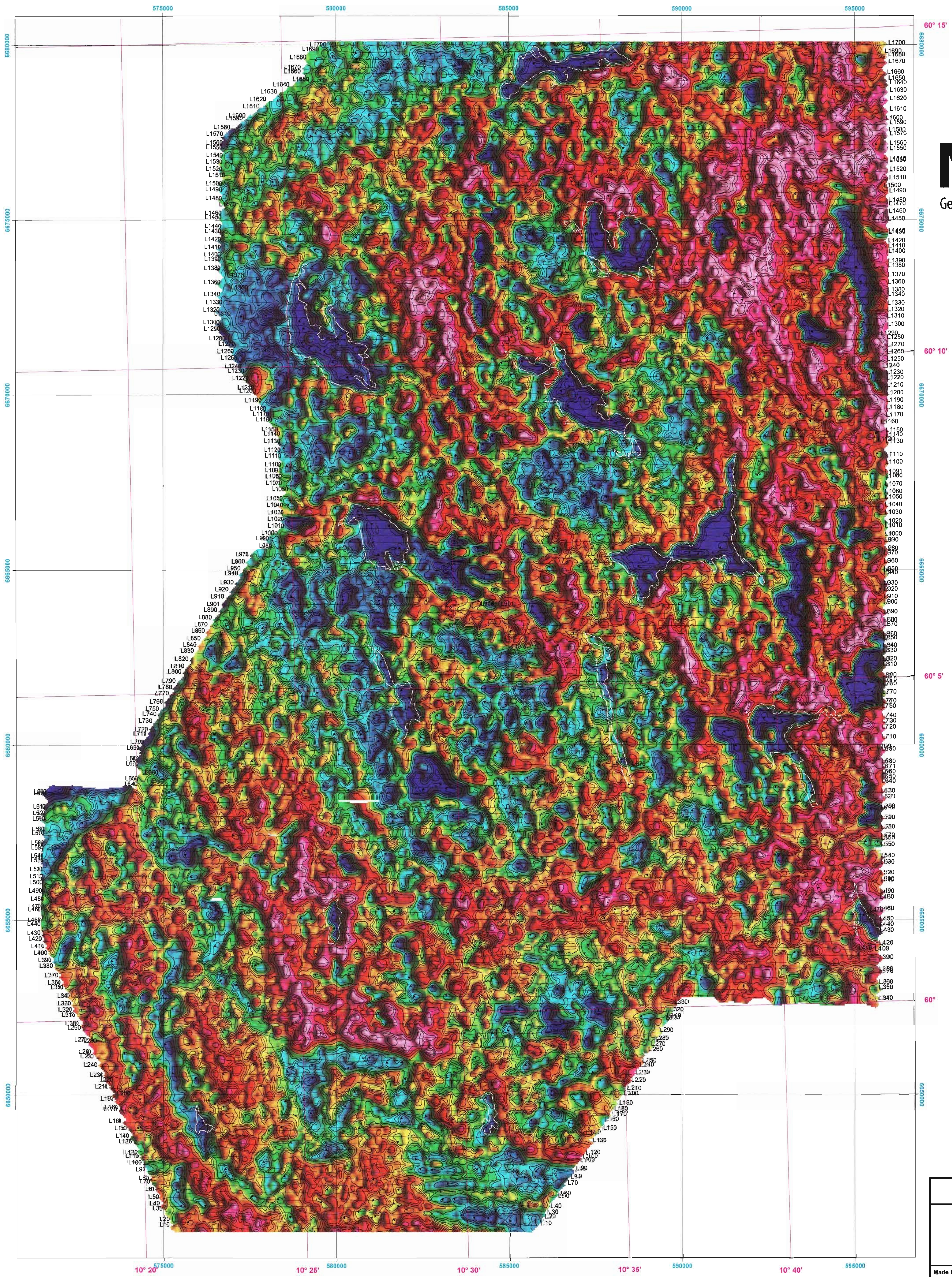
Scale 1:50 000

1000 0 1000 2000 3000

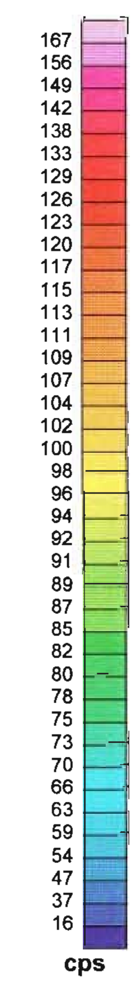
(meters)

NGU
Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11 Fax 73 92 16 20

DRAWING:
98-079-06



Geology for Society since 1858



RADIOMETRIC DATA-POTASSIUM

Radiometric data have been processed following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effect of atmospheric radon was estimated and removed using data from survey lines over lakes. The leveled data have been normalized to a nominal survey height of 80 meters above ground level (counts per second at 80 m). Hanning smoothing was applied to enhance the continuity of some features. Shading is from the east at 60 degrees inclination.

Average radiometric sensor height: 80 meters above ground level.

Some lakes outlined in white.

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

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RADIOMETRIC DATA-POTASSIUM

Based on helicopter survey 1997

OPPKUVEN AREA

NORWAY

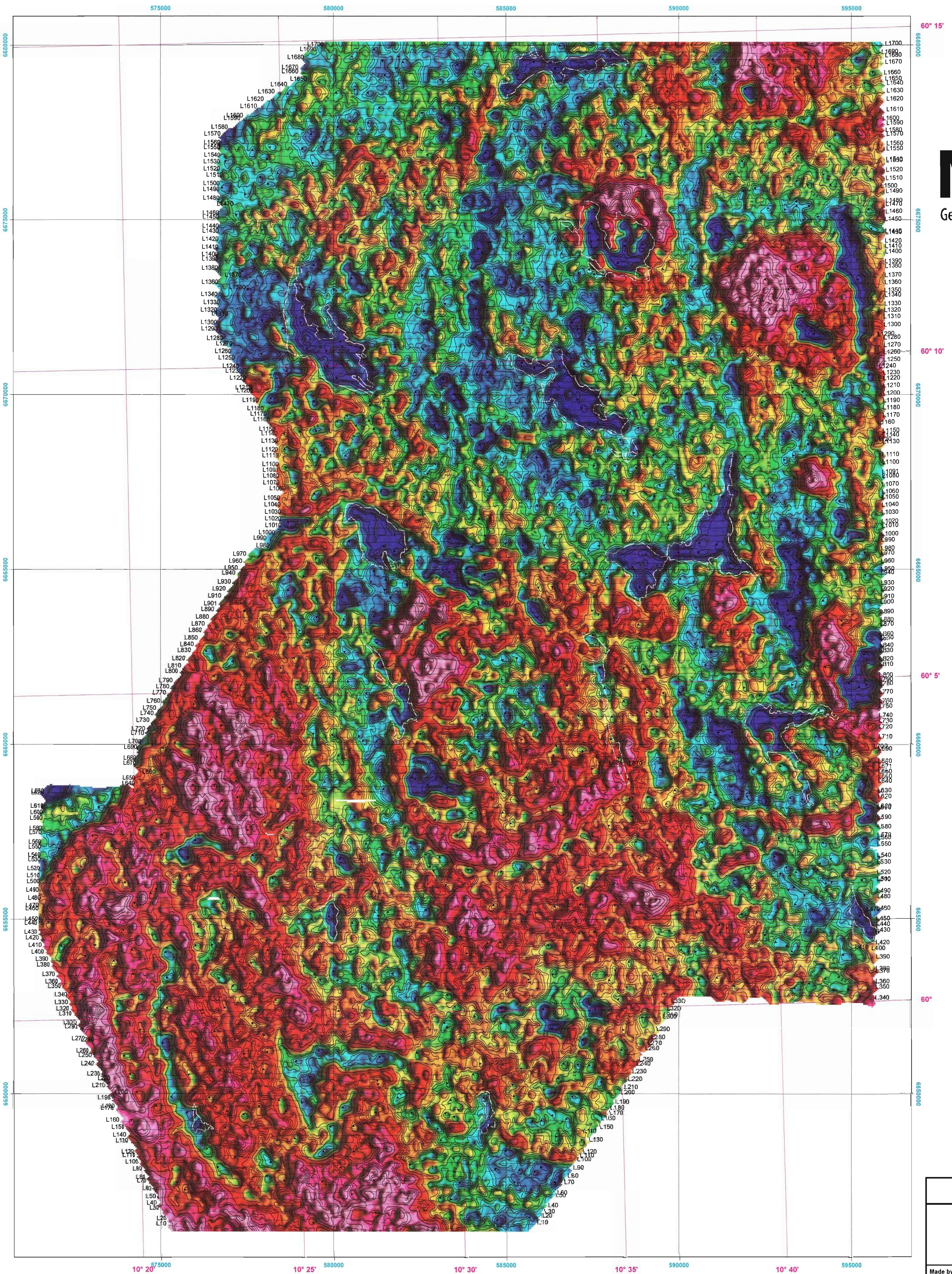
Made by: L Beard	Date: April 1998	Oper: NGU

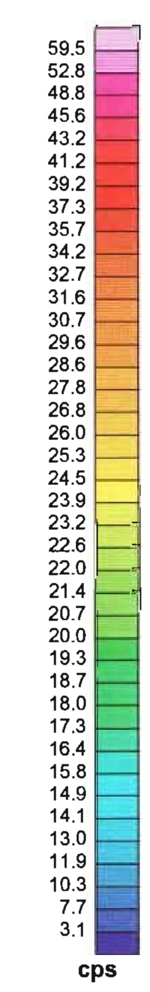
Scale 1:50 000

1000 0 1000 2000 3000 (meters)

GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-07





NGU
Geology for Society since 1858

RADIOMETRIC DATA-THORIUM

Radiometric data have been processed following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effect of atmospheric radon was estimated and removed using data from survey lines over lakes. The leveled data have been normalized to a nominal survey height of 80 meters above ground level (counts per second at 80 m). Hanning smoothing was applied to enhance the continuity of some features. Shading is from the east at 60 degrees inclination.

Average radiometric sensor height: 80 meters above ground level.

Some lakes outlined in white.

Contour intervals: 2 cps, 10 cps, 50 cps.

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RADIOMETRIC DATA-THORIUM

Based on helicopter survey 1997

OPPKUVEN AREA

NORWAY

Made by: L Beard	Date: April 1998	Oper: NGU

Scale 1:50 000

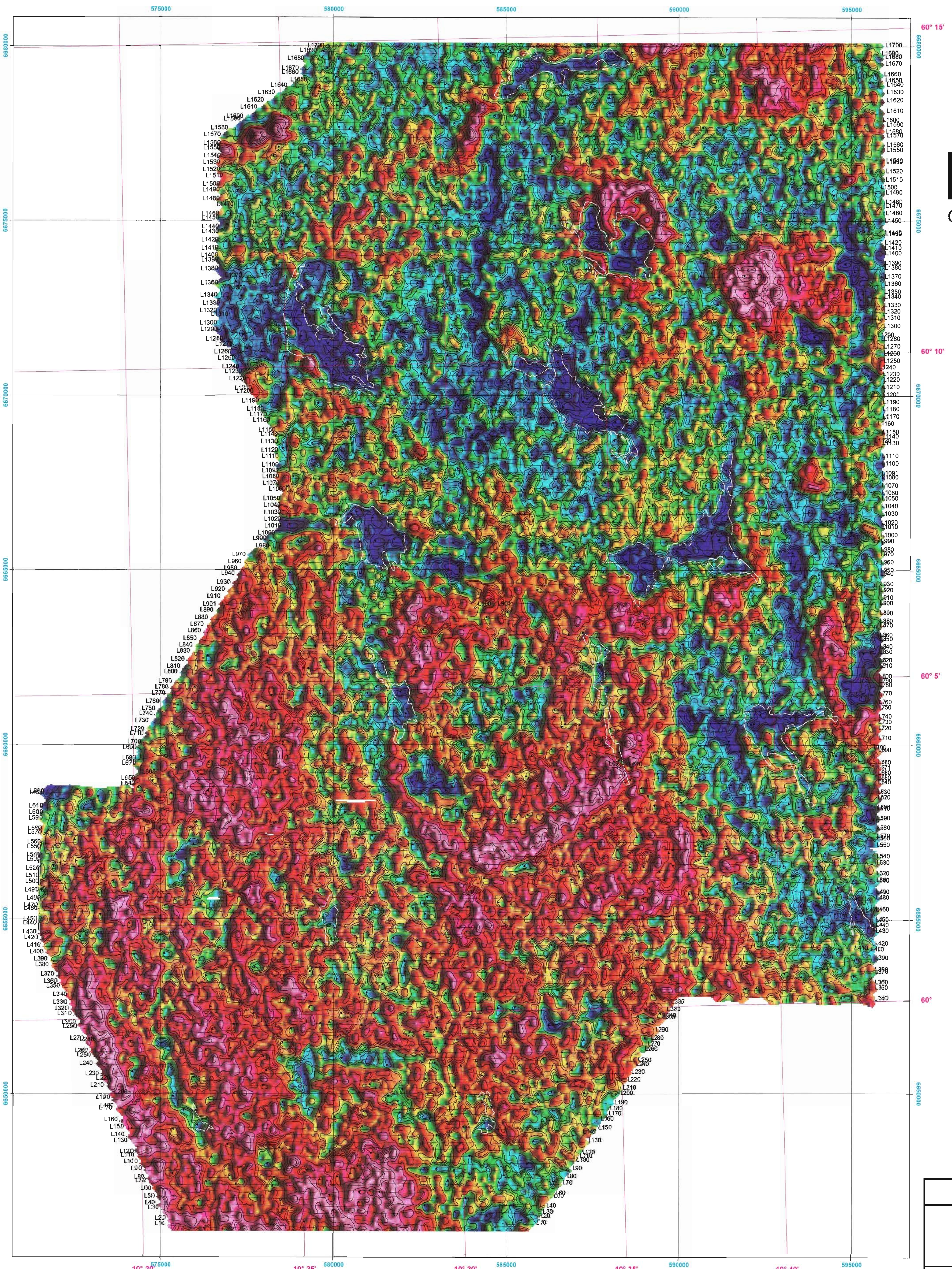
1000 0 1000 2000 3000

(meters)

NGU Geology for Society since 1858

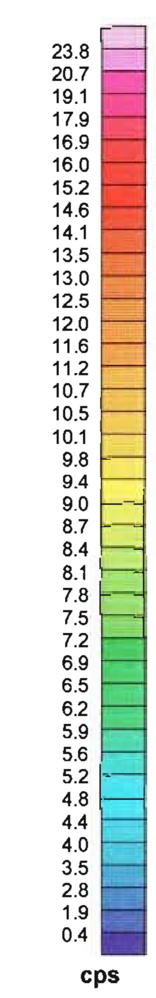
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-08



NGU
Geology for Society since 1858

N



RADIOMETRIC DATA-URANIUM

Radiometric data have been processed following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effect of atmospheric radon was estimated and removed using data from survey lines over lakes. The leveled data have been normalized to a nominal survey height of 80 meters above ground level (counts per second at 80 m). Hanning smoothing was applied to enhance the continuity of some features. Shading is from the east at 60 degrees inclination.

Average radiometric sensor height: 80 meters above ground level.

Some lakes outlined in white.

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

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GABEN

RADIOMETRIC DATA-URANIUM

Based on helicopter survey 1997

OPPKUVEN AREA

NORWAY

Made by: *L Beard*	Date: *April 1998*	Oper: *NGU*

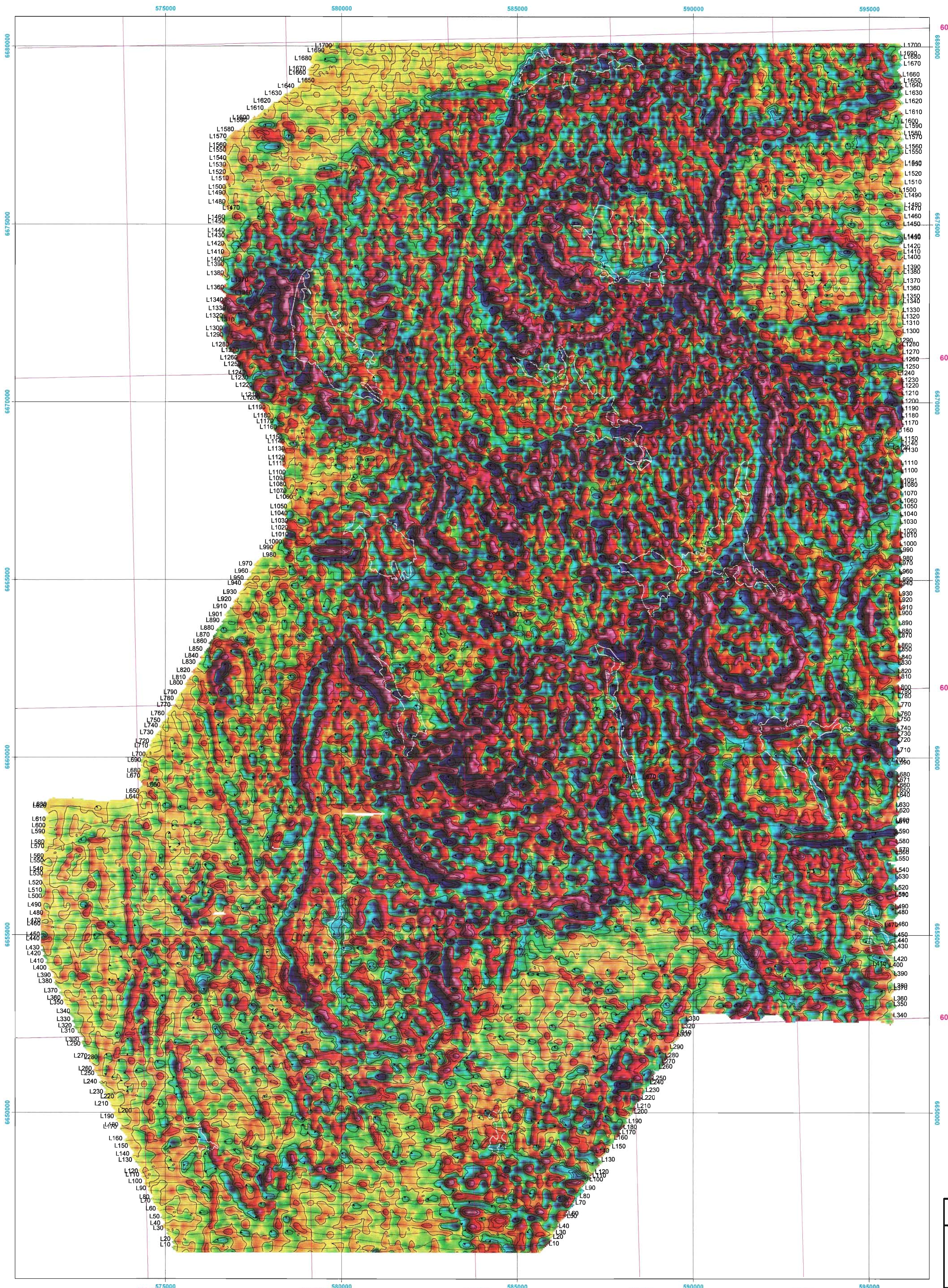
Scale 1:50 000

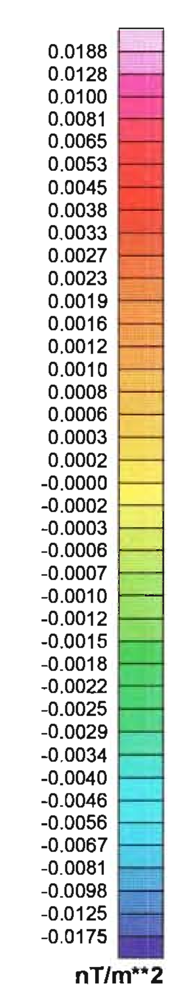
1000 0 1000 2000 3000

(meters)

NGU Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING:
98-079-09





SECOND VERTICAL DERIVATIVE OF TOTAL MAGNETIC FIELD

The second vertical derivative of the total magnetic field with diurnal variation removed. Diurnal changes were recorded at a base station magnetometer located at Eggemoen airfield.
The grid was upward continued through 40 meters to enhance continuity of some features. Grid is shaded from the east at a 60 degree inclination.
Average magnetometer height: 65 meters above ground level.
Some lakes outlined in white.
Contour intervals: 0.002 nT/m**2, 0.01 nT/m**2, 0.05 nT/m**2, 0.25 nT/m**2.

DATUM

Spheroid: WGS84
Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

SECOND VERTICAL DERIVATIVE OF TOTAL MAGNETIC FIELD

Based on helicopter survey 1997

OPPKUVEN AREA

NORWAY

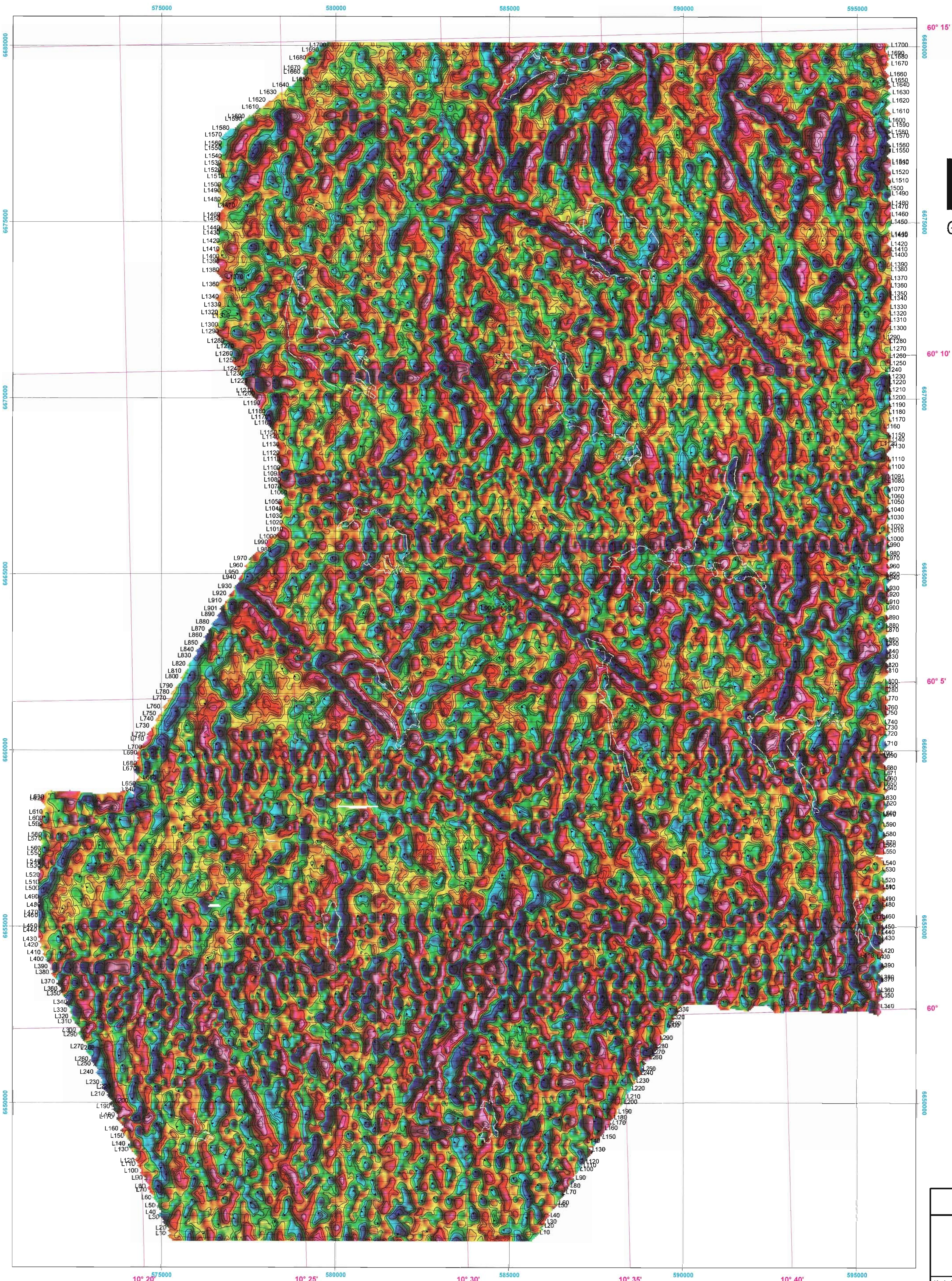
Made by: L Beard	Date: April 1998	Oper: NGU

Scale 1:50 000

1000 0 1000 2000 3000
(meters)

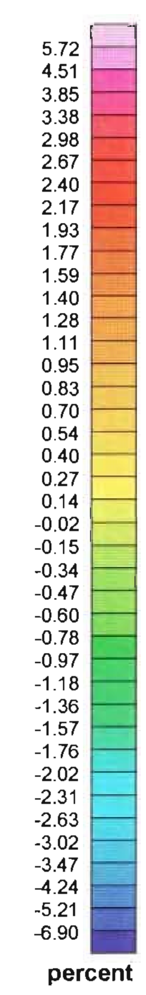
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-10



NGU
Geology for Society since 1858

N



VLF-EM: ORTHO+IN-LINE

Very low frequency electromagnetics (VLF-EM) measures EM fields induced in the earth by powerful radio transmitters. The transmitters used in this survey were GBR (16 kHz, Rugby, England), NAA (24 kHz, Cutler, Maine), and JXZ (16 kHz, Helgeland, Norway). This map shows the percent change in the total VLF field after removal of a low pass filtered base was removed (6.5 km cutoff wavelength). The grid was then smoothed using a Hanning filter to enhance continuity of some features. The grid shows the averaged total VLF response from the sum of the orthogonally oriented receiver and the in-line receiver. Grid is shaded from the south at a 60 degree inclination.

Average VLF sensor height: 73 meters above ground level.
Some lakes outlined in white.
Contour intervals: 0.5pct, 2 pct, 10 pct, 50 pct.

DATUM

Spheroid: WGS84
Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

VLF-EM: ORTHO+IN-LINE

Based on helicopter survey 1997

OPPKUVEN AREA

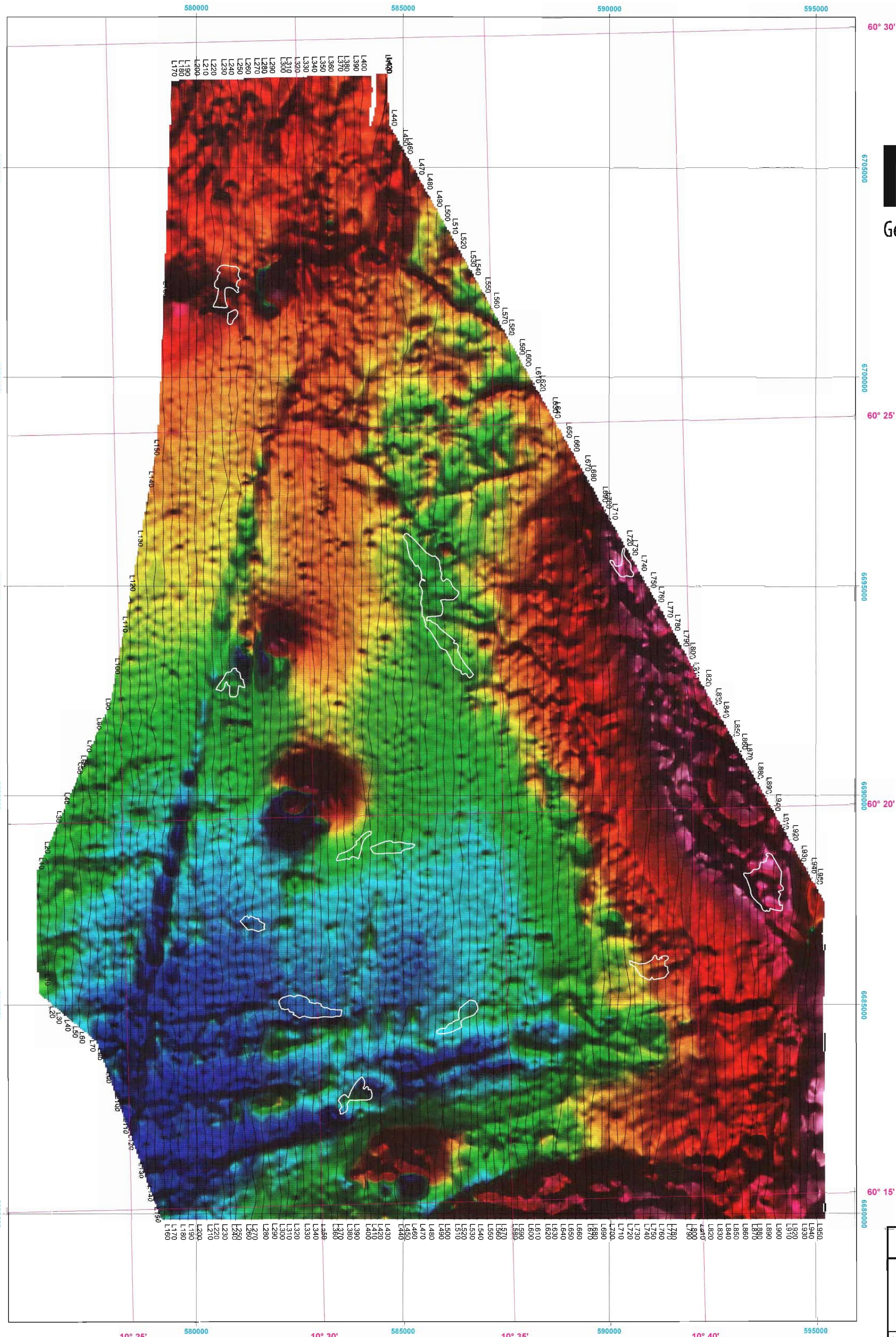
NORWAY

Made by: *L Beard*	Date: *April 1998*	Oper: *NGU*

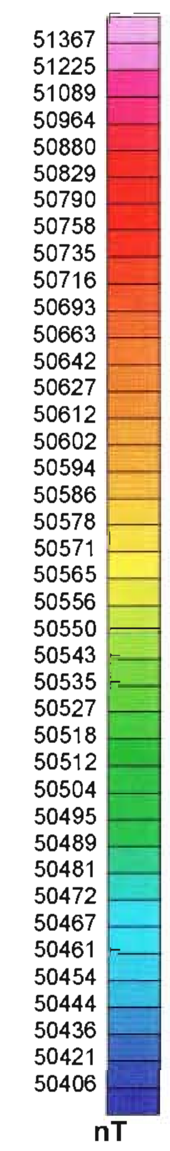
Scale 1:50 000
1000 0 1000 2000 3000
(meters)

NGU
Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-11



NGU
Geology for Society since 1858



TOTAL MAGNETIC FIELD

Total magnetic field with diurnal variation removed. Diurnal changes were recorded at a base station magnetometer located at Eggemoen airfield.

Grid is shaded from the south at a 60 degree inclination.

Average magnetometer height: 65 meters above ground level.

Some lakes outlined in white.

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

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

TOTAL MAGNETIC FIELD

Based on helicopter survey 1997

GRAN AREA

NORWAY

Made by: *L Beard*	Date: *June 1998*	Oper: *NGU*

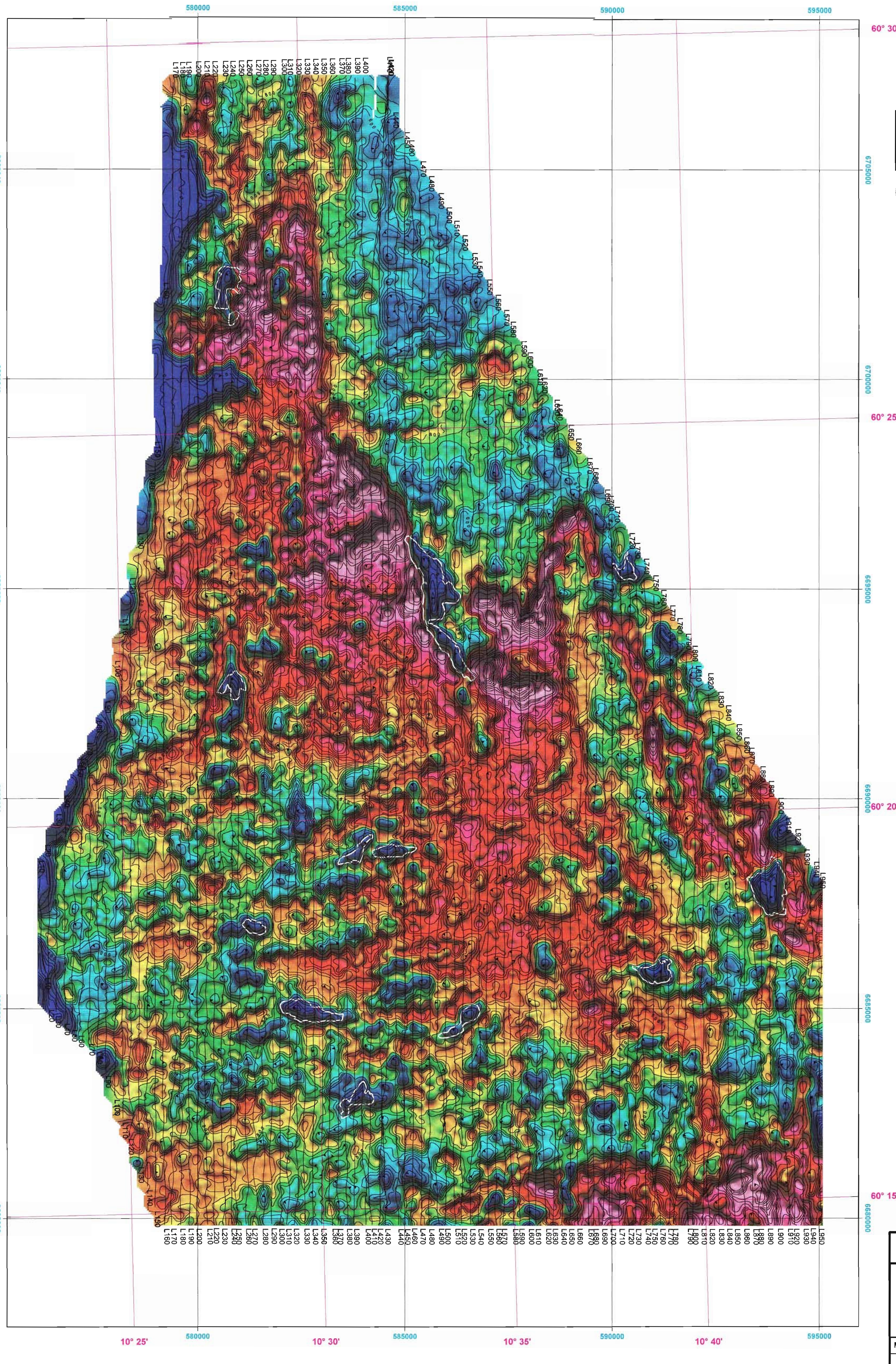
Scale 1:50 000

1000 0 1000 2000 3000

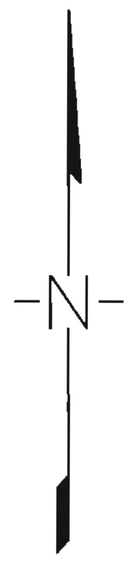
(meters)

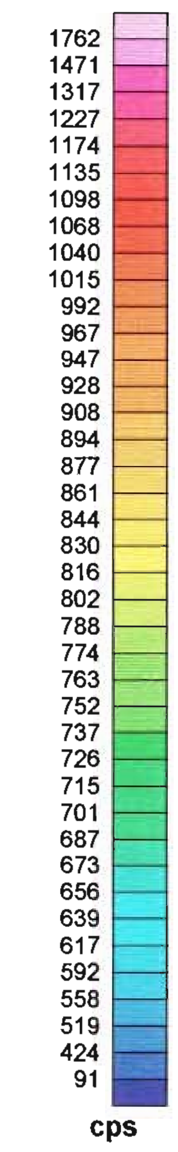
NGU
Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING:
98-079-12



NGU
Geology for Society since 1858





RADIOMETRIC DATA-TOTAL COUNTS

Radiometric data have been processed following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effect of atmospheric radon was estimated and removed using data from survey lines over lakes. The leveled data have been normalized to a nominal survey height of 80 meters above ground level (counts per second at 80 m). Hanning smoothing were applied to enhance the continuity of some features. Shading is from the south at 60 degrees inclination.

Average radiometric sensor height: 80 meters above ground level.
Some lakes outlined in white.
Contour intervals: 50 cps, 200 cps, 1000 cps.

DATUM

Spheroid: WGS84
Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RADIOMETRIC DATA-TOTAL COUNTS

Based on helicopter survey 1997

GRAN AREA

NORWAY

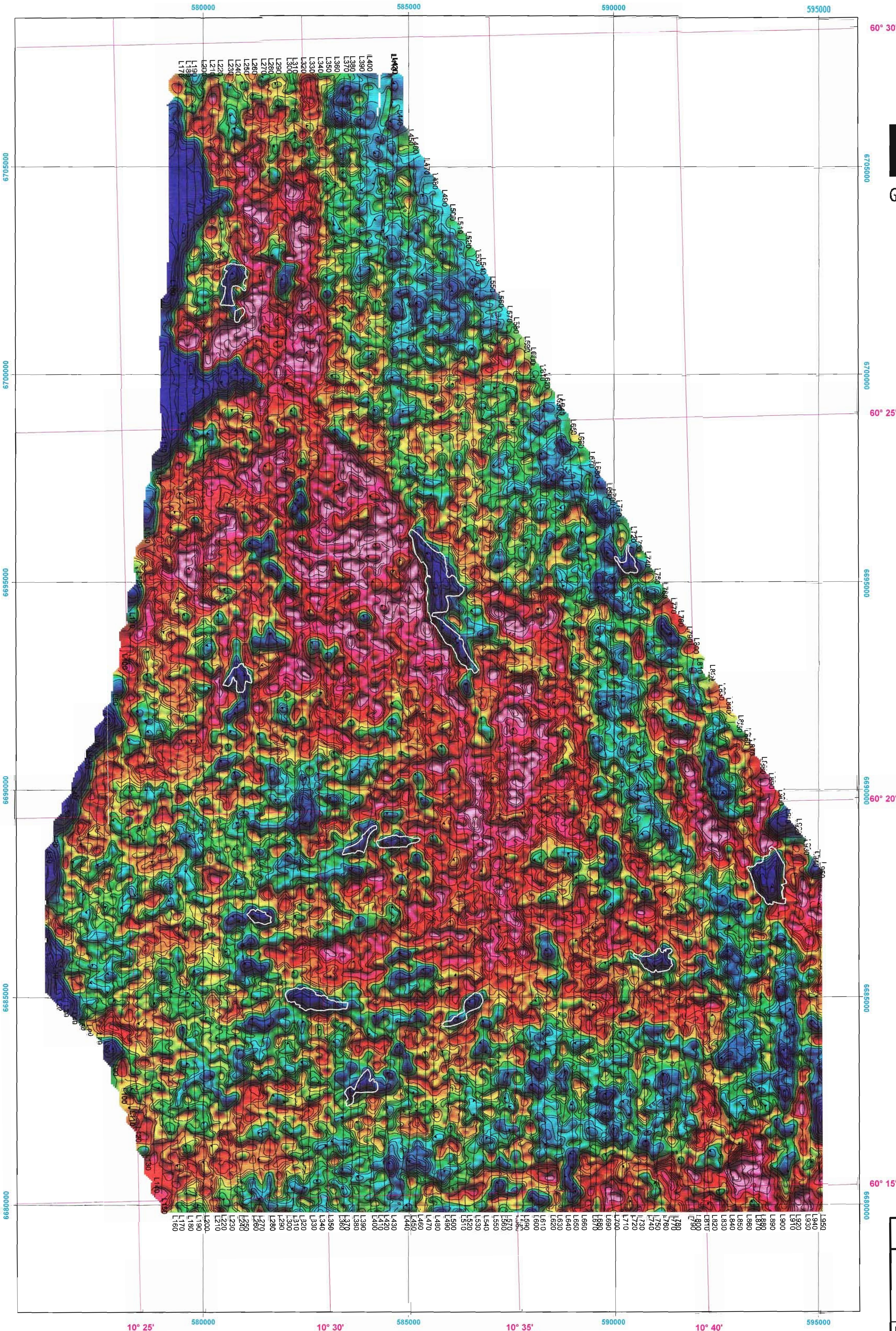
Made by: L Beard	Date: June 1998	Oper: NGU

Scale 1:50 000

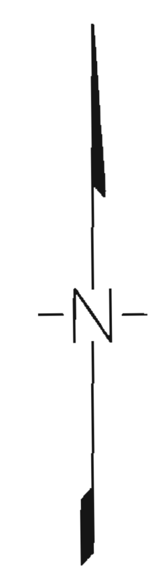
1000 0 1000 2000 3000
(meters)

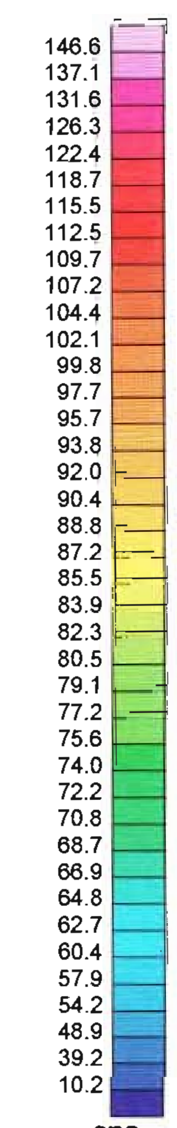
NGU
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING:
98-079-13



Geology for Society since 1858





RADIOMETRIC DATA-POTASSIUM

Radiometric data have been processed following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effect of atmospheric radon was estimated and removed using data from survey lines over lakes. The leveled data have been normalized to a nominal survey height of 80 meters above ground level (counts per second at 80 m). Hanning smoothing was applied to enhance the continuity of some features. Shading is from the south at 60 degrees inclination.

Average radiometric sensor height: 80 meters above ground level.

Some lakes outlined in white.

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

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RADIOMETRIC DATA-POTASSIUM

Based on helicopter survey 1997

GRAN AREA

NORWAY

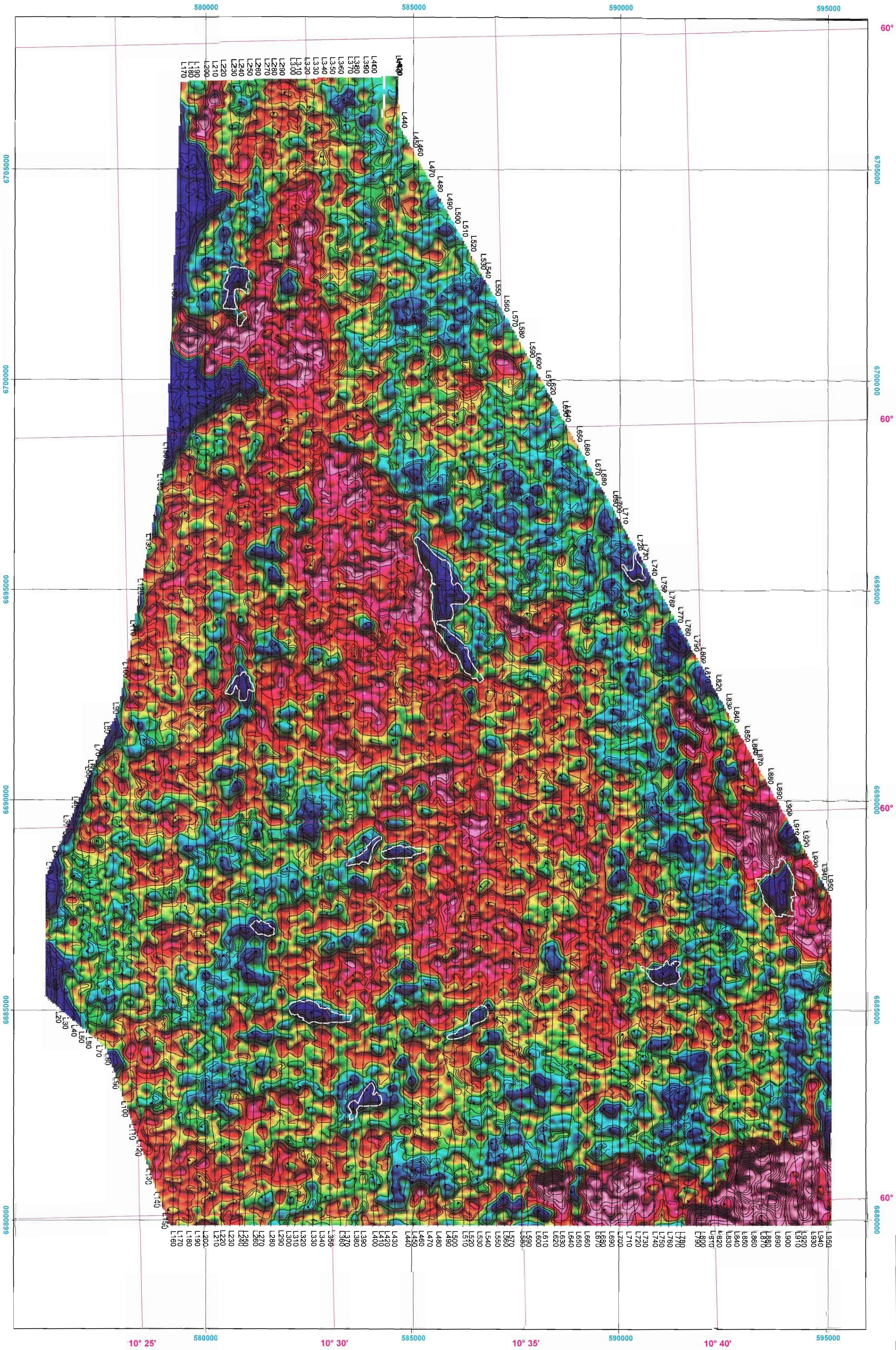
Made by: *L Beard*	Date: *June 1998*	Oper: *NGU*

Scale 1:50 000

1000 0 1000 2000 3000 (meters)

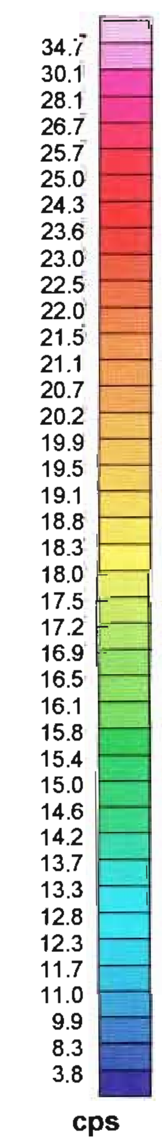
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-14



NGU
Geology for Society since 1858

N



RADIOMETRIC DATA-THORIUM

Radiometric data have been processed following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effect of atmospheric radon was estimated and removed using data from survey lines over lakes. The leveled data have been normalized to a nominal survey height of 80 meters above ground level (counts per second at 80 m). Hanning smoothing was applied to enhance the continuity of some features. Shading is from the south at 60 degrees inclination.

Average radiometric sensor height: 80 meters above ground level.
Some lakes outlined in white.
Contour intervals: 1 cps, 5 cps, 20 cps.

DATUM

Spheroid: WGS84
Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RADIOMETRIC DATA-THORIUM

Based on helicopter survey 1997

GRAN AREA

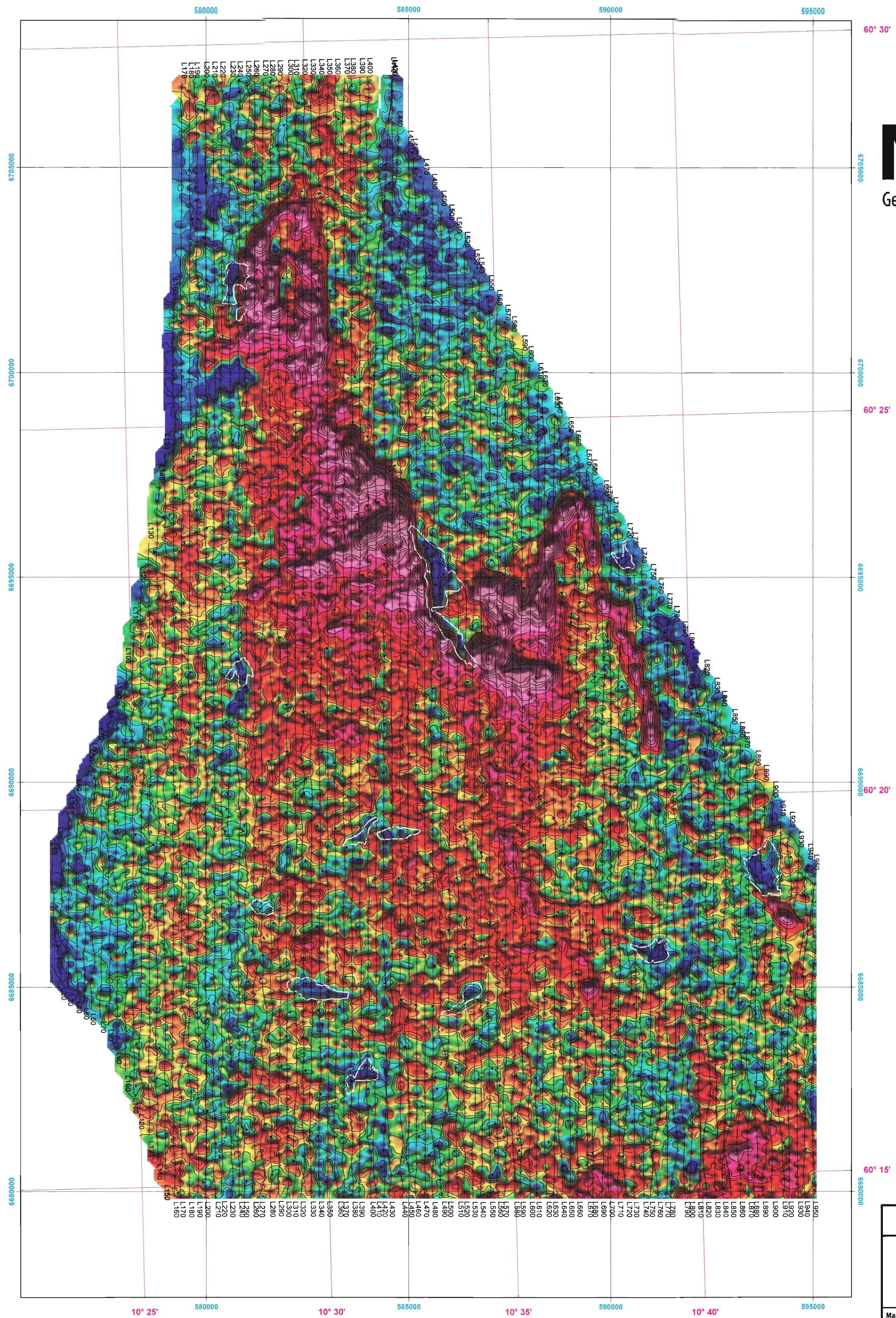
NORWAY

Made by: *L Beard*	**Date:** *June 1998*	**Oper:** *NGU*

Scale 1:50 000
1000 0 1000 2000 3000
(meters)

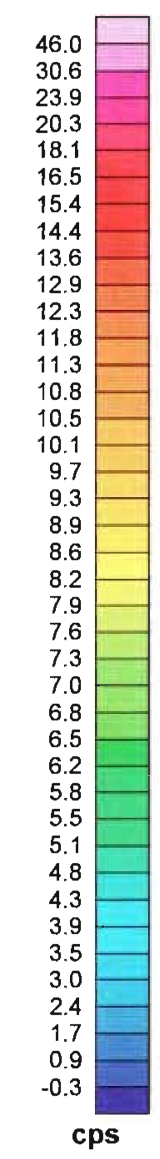
NGU
Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING:
98-079-15



Geology for Society since 1858

N



RADIOMETRIC DATA-URANIUM

Radiometric data have been processed following procedures outlined in IAEA Technical Report 323 (IAEA, 1991). The effect of atmospheric radon was estimated and removed using data from survey lines over lakes. The leveled data have been normalized to a nominal survey height of 80 meters above ground level (counts per second at 80 m). Shading is from the south at 60 degrees inclination.

Average radiometric sensor height: 80 meters above ground level.

Some lakes outlined in white.

Contour intervals: 2 cps, 10 cps, 50 cps.

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

RADIOMETRIC DATA-URANIUM

Based on helicopter survey 1997

GRAN AREA

NORWAY

Made by: *L Beard*	Date: *June 1998*	Oper: *NGU*

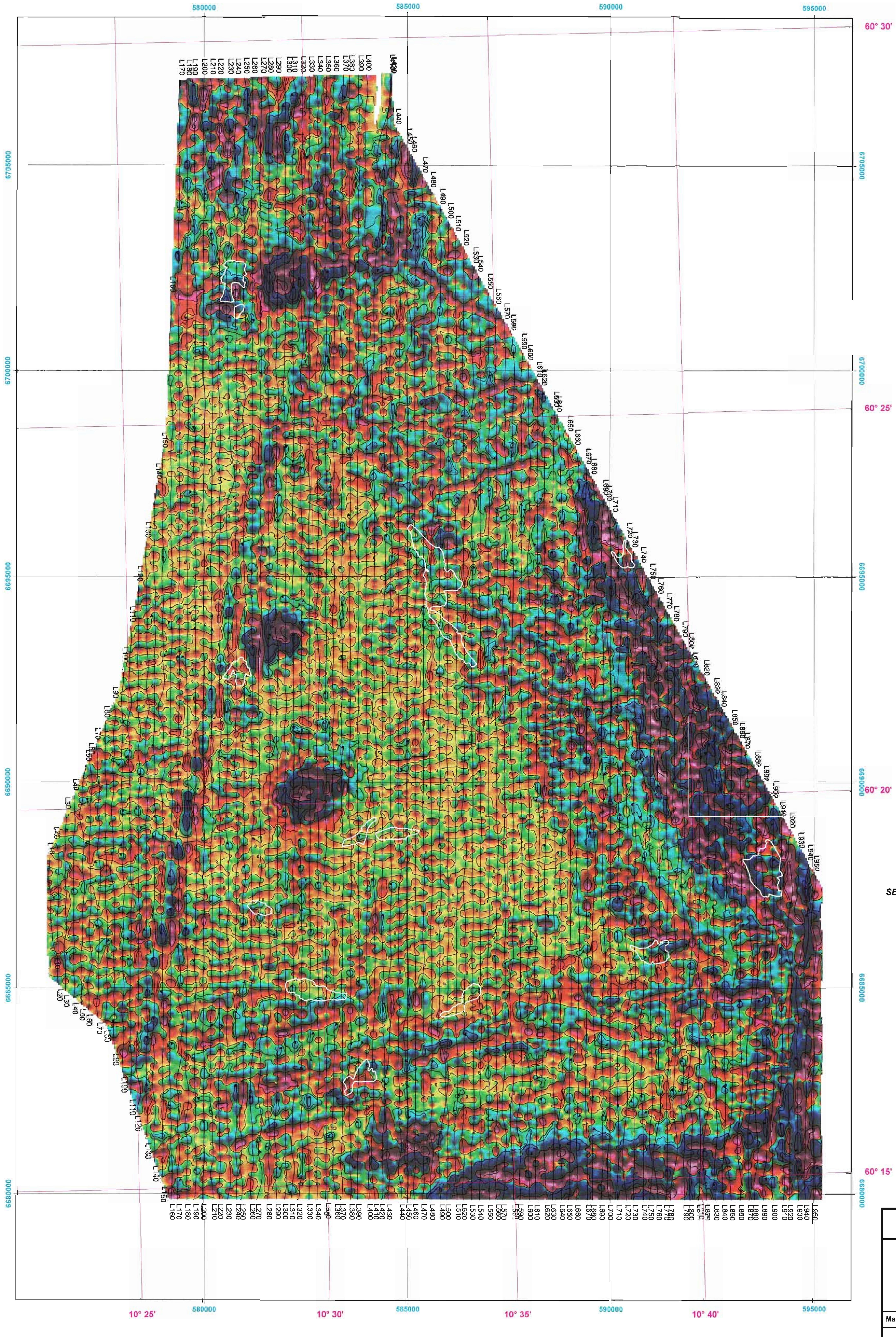
Scale 1:50 000

1000 0 1000 2000 3000

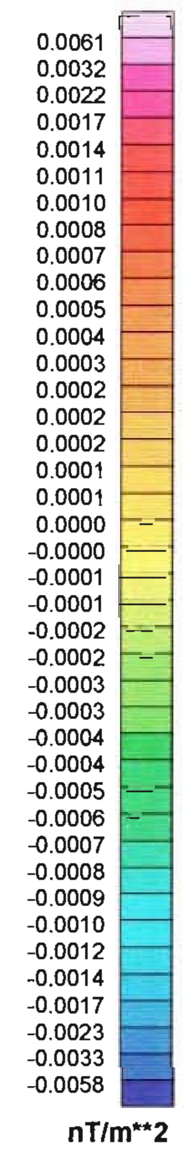
(meters)

GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-16



NGU
Geology for Society since 1858



SECOND VERTICAL DERIVATIVE OF TOTAL MAGNETIC FIELD

The second vertical derivative of the total magnetic field with diurnal variation removed. Diurnal changes were recorded at a base station magnetometer located at Eggemoen airfield. The grid was upward continued through 40 meters to enhance continuity of some features. Grid is shaded from the south at a 60 degree inclination.

Average magnetometer height: 65 meters above ground level.

Some lakes outlined in white.

Contour intervals: 0.0005 nT/m**2, 0.002 nT/m**2, 0.01 nT/m**2, 0.05 nT/m**2.

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

SECOND VERTICAL DERIVATIVE OF TOTAL MAGNETIC FIELD

Based on helicopter survey 1997

GRAN AREA

NORWAY

Made by: *L Beard* **Date:** *June 1998* **Oper:** *NGU*

Scale 1:50 000

1000 0 1000 2000 3000

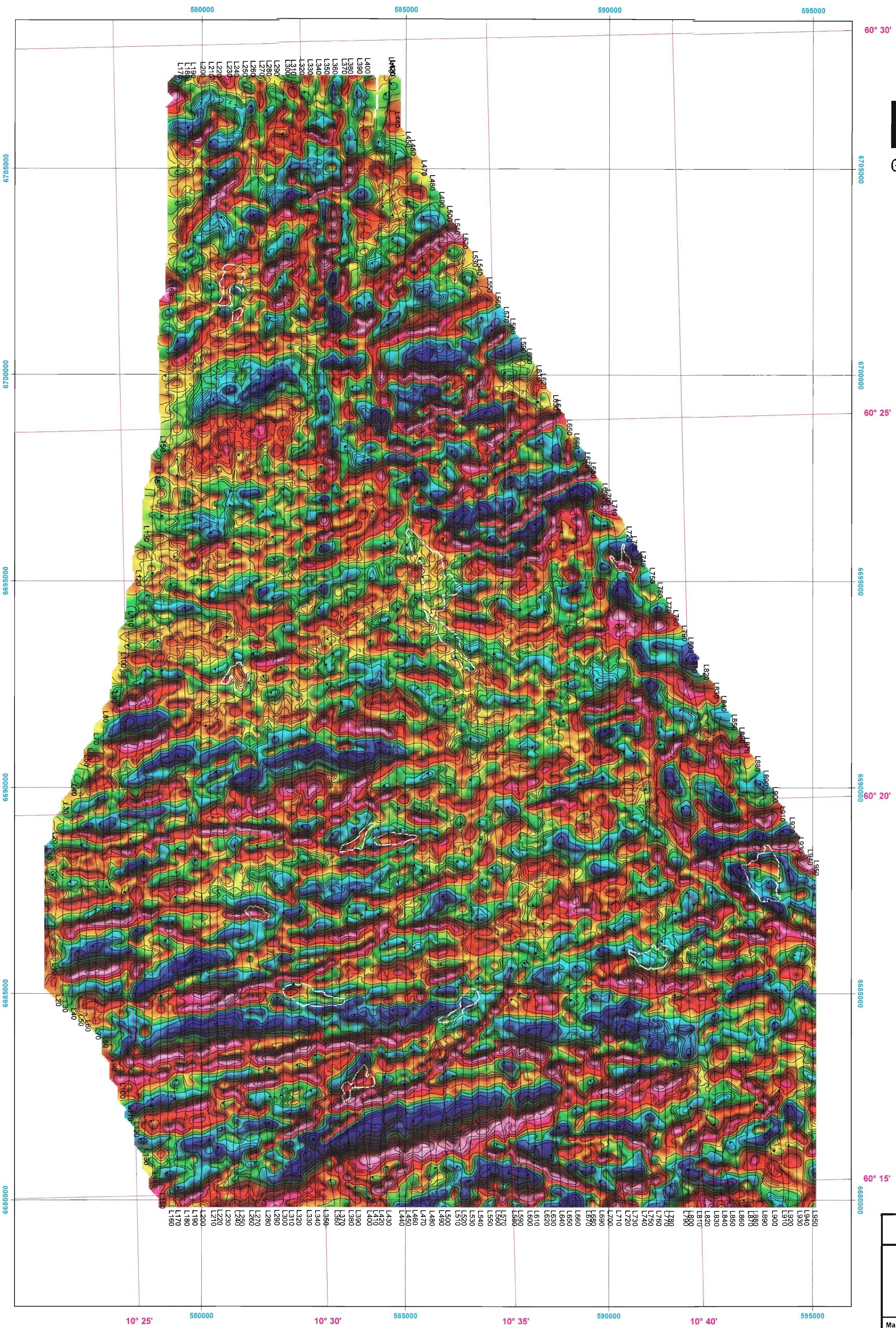
(meters)

NGU
Geology for Society since 1858

GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING:

98-079-17



NGU
Geology for Society since 1858

N

percent
17.46
13.58
11.44
9.83
8.54
7.50
6.60
5.82
5.11
4.46
3.95
3.44
2.85
2.40
1.95
1.49
1.10
0.71
0.33
-0.06
-0.45
-0.84
-1.22
-1.61
-2.00
-2.39
-2.84
-3.29
-3.81
-4.26
-4.78
-5.43
-6.07
-6.79
-7.56
-8.46
-9.56
-10.99
-12.99
-15.97

VLF-EM: ORTHO+IN-LINE

Very low frequency electromagnetics (VLF-EM) measures EM fields induced in the earth by powerful radio transmitters. The transmitters used in this survey were GBR (16 kHz, Rugby, England), NAA (24 kHz, Cutler, Maine), and JXZ (16 kHz, Helgeland, Norway). This map shows the percent change in the total VLF field after removal of a low pass filtered base was removed (6.5 km cutoff wavelength). The grid was then smoothed using a Hanning filter to enhance continuity of some features. The grid shows the measured total VLF response from both the orthogonally oriented receiver and the in-line receiver. Grid is shaded from the south at a 50 degree inclination.

Average VLF sensor height: 73 meters above ground level.
Some lakes outlined in white.
Contour intervals: 1 pct, 5 pct, 20 pct.

DATUM

Spheroid: WGS84
Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

VLF-EM: ORTHO+IN-LINE

Based on helicopter survey 1997

GRAN AREA

NORWAY

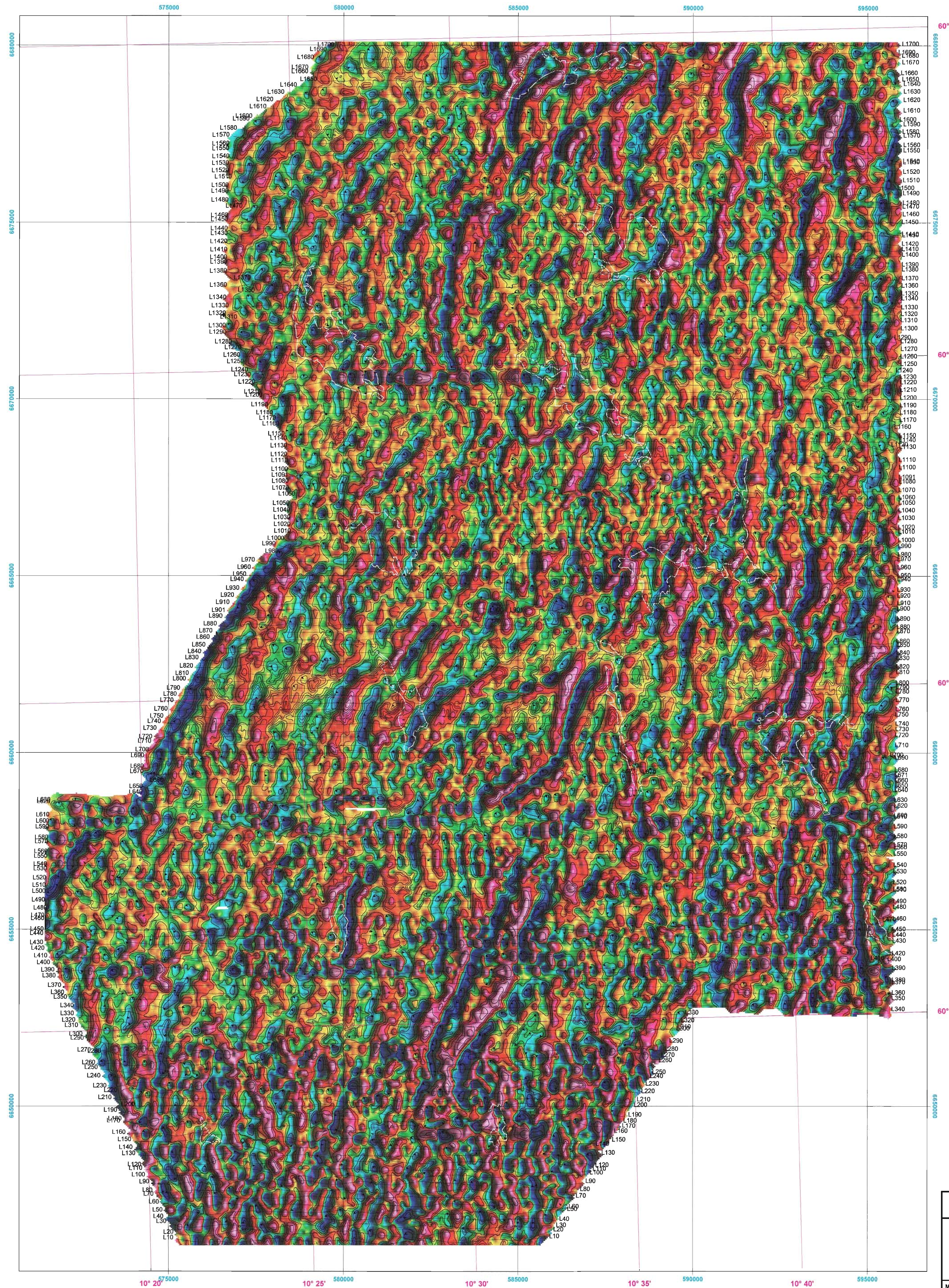
Made by: *L Beard*	Date: *June 1998*	Oper: *NGU*

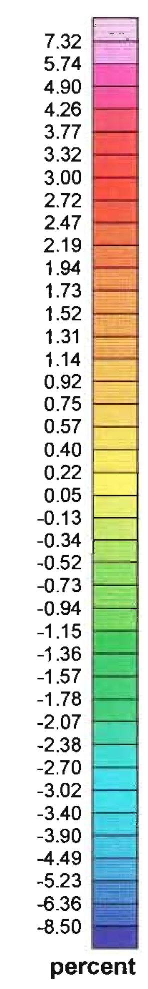
Scale 1:50 000
1000 0 1000 2000 3000
(meters)

NGU
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING:
98-079-18

NGU
Geology for Society since 1858





VLF-EM: IN-LINE

Very low frequency electromagnetics (VLF-EM) measures EM fields induced in the earth by powerful radio transmitters. The transmitters used in this survey were GBR (16 kHz, Rugby, England), NAA (24 kHz, Cutler, Maine), and JXZ (16 kHz, Helgeland, Norway). This map shows the percent change in the total VLF field after removal of a low pass filtered base was removed (6.5 km cutoff wavelength). The grid was then smoothed using a Hanning filter to enhance continuity of some features. The grid shows the measured total VLF response from the in-line oriented receiver. Grid is shaded from the south at a 60 degree inclination.

Average VLF sensor height: 73 meters above ground level.
Some lakes outlined in white.
Contour intervals: 0.5 pct, 2 pct, 10 pct, 50 pct.

DATUM

Spheroid: WGS84
Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

VLF-EM: IN-LINE

Based on helicopter survey 1997

OPPKUVEN AREA

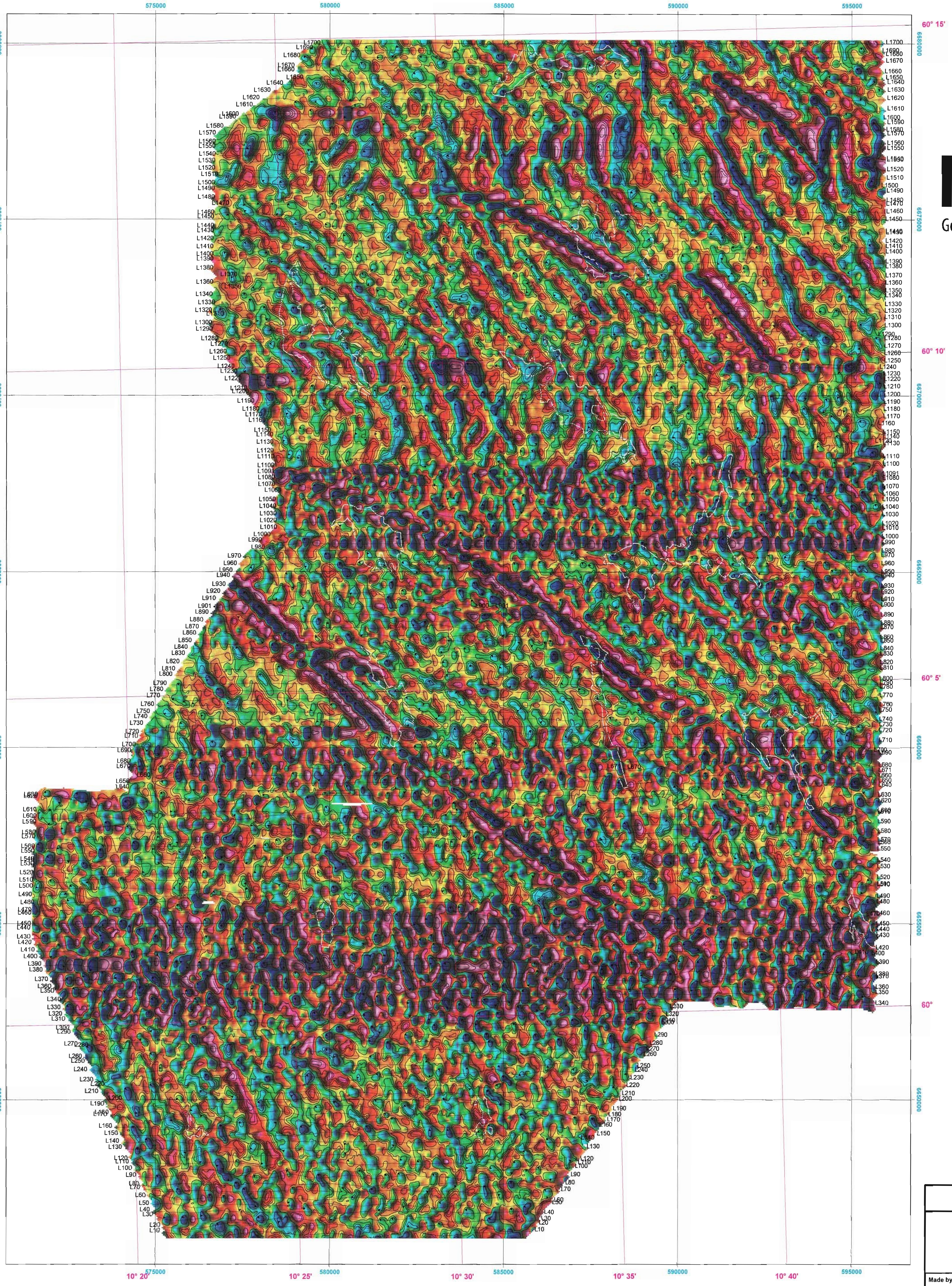
NORWAY

Made by: *L Beard*	Date: *April 1998*	Oper: *NGU*

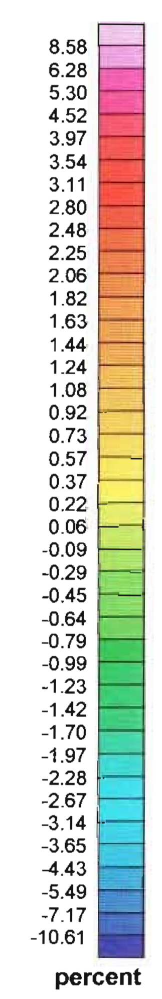
Scale 1:50 000
1000 0 1000 2000 3000
(meters)

NGU
Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: **98-079-19**



NGU
Geology for Society since 1858



VLF-EM: ORTHO

Very low frequency electromagnetics (VLF-EM) measures EM fields induced in the earth by powerful radio transmitters. The transmitters used in this survey were GBR (16 kHz, Rugby, England), NAA (24 kHz, Cutler, Maine), and JXZ (16 kHz, Helgeland, Norway). This map shows the percent change in the total VLF field after removal of a low pass filtered base was removed (6.5 km cutoff wavelength). The grid was then smoothed using a Hanning filter to enhance continuity of some features. The grid shows the measured total VLF response from the orthogonally oriented receiver. Grid is shaded from the south at a 60 degree inclination.

Average VLF sensor height: 73 meters above ground level.
Some lakes outlined in white.
Contour intervals: 1 pct, 5 pct, 20 pct, 100 pct.

DATUM

Spheroid: WGS84
Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

VLF-EM: ORTHO

Based on helicopter survey 1997

OPPKUVEN AREA

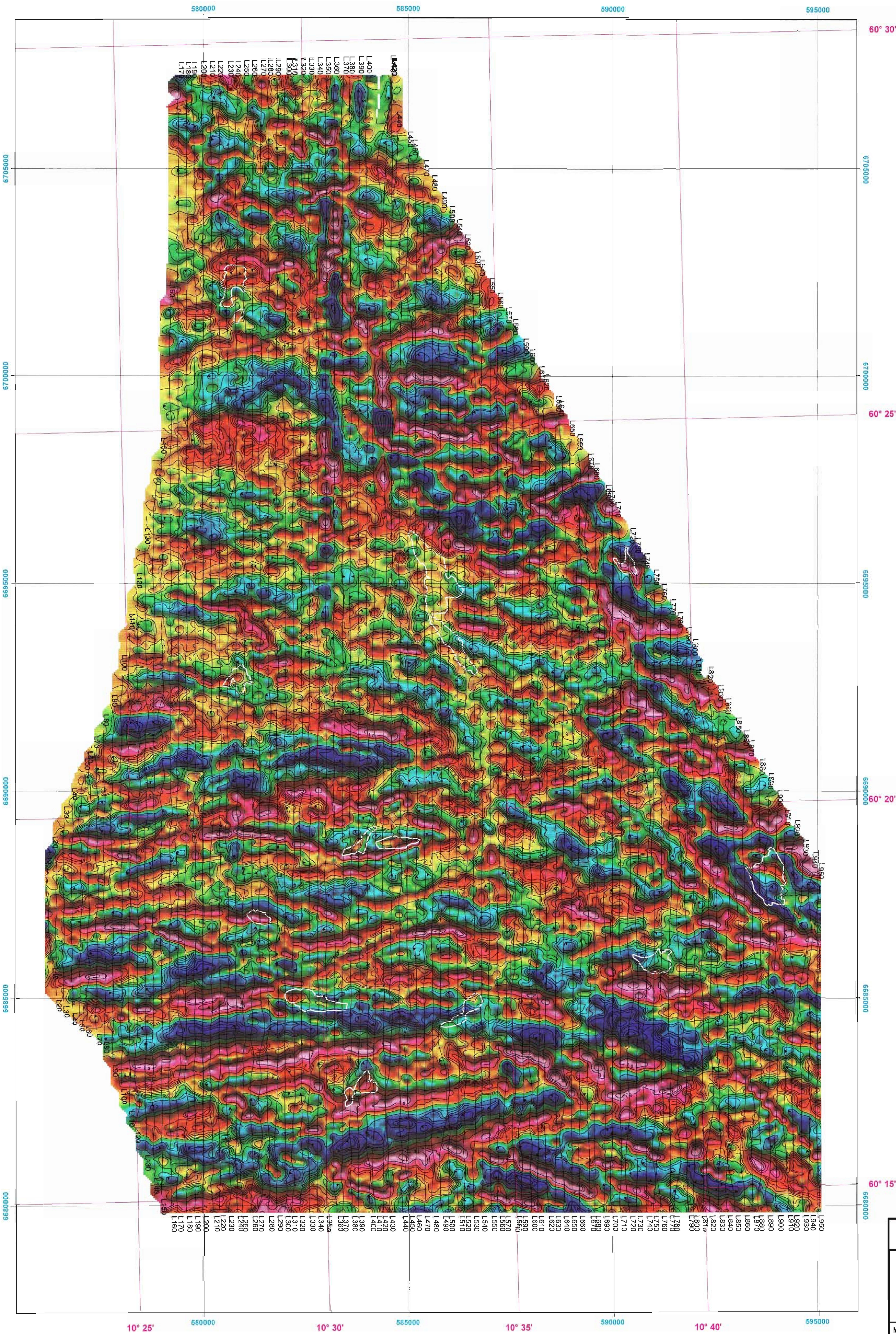
NORWAY

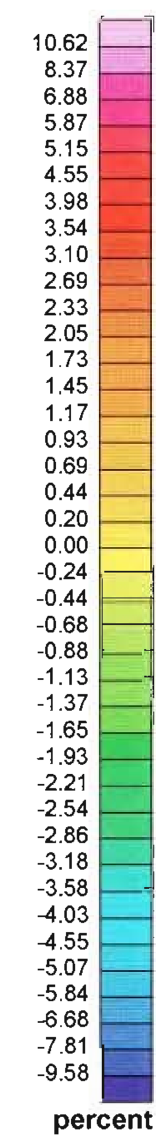
Made by: L Beard	Date: April 1998	Oper: NGU

Scale 1:50 000
1000 0 1000 2000 3000
(meters)

NGU Geology for Society since 1858
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-20





VLF-EM: IN-LINE

Very low frequency electromagnetics (VLF-EM) measures EM fields induced in the earth by powerful radio transmitters. The transmitters used in this survey were GBR (16 kHz, Rugby, England), NAA (24 kHz, Cutler, Maine), and JXZ (16 kHz, Helgeland, Norway). This map shows the percent change in the total VLF field after removal of a low pass filtered base was removed (6.5 km cutoff wavelength). The grid was then smoothed using a Hanning filter to enhance continuity of some features. The grid shows the measured total VLF response from the in-line oriented receiver. Grid is shaded from the south at a 60 degree inclination.

Average VLF sensor height: 73 meters above ground level.

Some lakes outlined in white.

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

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

VLF-EM: IN-LINE

Based on helicopter survey 1997

GRAN AREA

NORWAY

Made by: *L Beard*	Date: *June 1998*	Oper: *NGU*

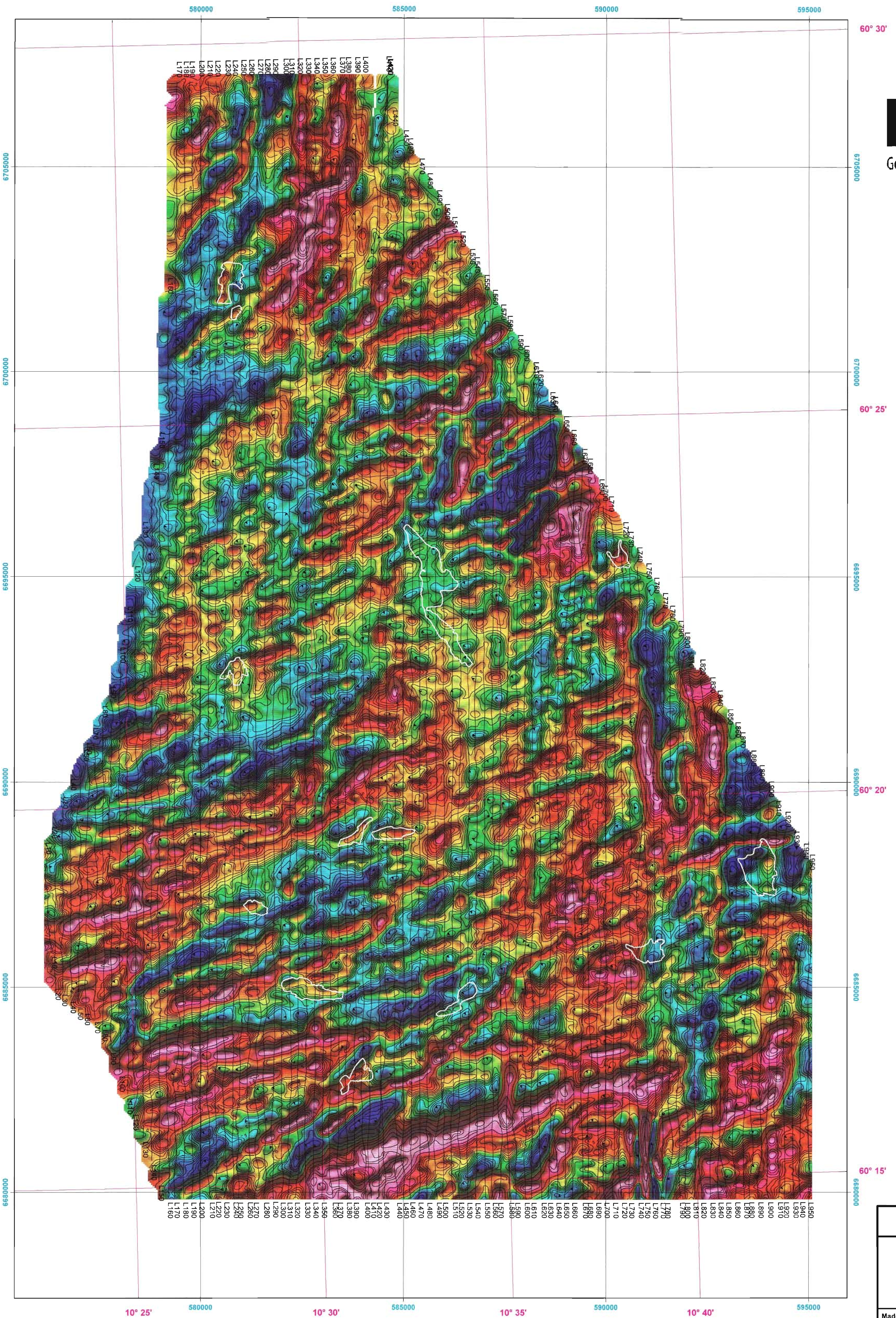
Scale 1:50 000

1000 0 1000 2000 3000

(meters)

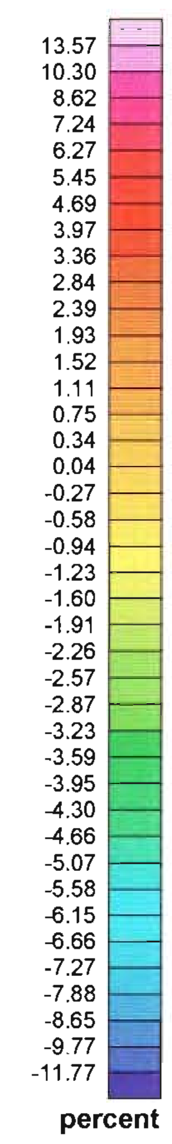
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-21



NGU
Geology for Society since 1858

N



VLF-EM: ORTHO

Very low frequency electromagnetics (VLF-EM) measures EM fields induced in the earth by powerful radio transmitters. The transmitters used in this survey were GBR (16 kHz, Rugby, England), NAA (24 kHz, Cutler, Maine), and JXZ (16 kHz, Helgeland, Norway). This map shows the percent change in the total VLF field after removal of a low pass filtered base was removed (6.5 km cutoff wavelength). The grid was then smoothed using a Hanning filter to enhance continuity of some features. The grid shows the measured total VLF response from the orthogonally oriented receiver. Grid is shaded from the south at a 60 degree inclination.

Average VLF sensor height: 73 meters above ground level.

Some lakes outlined in white.

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

DATUM

Spheroid: WGS84

Projection: UTM zone 32.

NGU SURVEY-OSLO GRABEN

VLF-EM: ORTHO

Based on helicopter survey 1997

GRAN AREA

NORWAY

Made by: *L Beard*	Date: *June 1998*	Oper: *NGU*

Scale 1:50 000

1000 0 1000 2000 3000

(meters)

NGU
GEOLOGICAL SURVEY OF NORWAY
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
Tel 73 90 40 11, Fax 73 92 16 20

DRAWING: 98-079-22