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# NGU

Norges geologiske undersøkelse  
Geological Survey of Norway



## GEOLOGY FOR SOCIETY



NGU Report 2003.093

Data Acquisition and Processing - Helicopter  
Geophysical Survey, Espedalen,  
Oppland county, Norway



Report no.: 2003.093		ISSN 0800-3416	Grading: Confidential until 15.01.2006
Title: Data Acquisition and Processing - Helicopter Geophysical Survey, Espedalen, Oppland county, Norway			
Authors: John Olav Mogaard & Jan Steinar Rønning		Client: A/S Sulfidmalm	
County: Oppland		Commune: Sør Fron, Gausdal	
Map-sheet name (M=1:250.000) Lillehammer		Map-sheet no. and -name (M=1:50.000) 1717 IV Espedalen, 1717 I Svatsum,	
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Fieldwork carried out: October 2003	Date of report: 19.12.2003	Project no.: 2990.03	Person responsible:
Summary:  <p>In October 2003, a helicopter geophysical survey was carried out over Espedalen, Oppland county. The purpose of the surveys was to provide geophysical information for mineral exploration. The data were collected and processed by Geological Survey of Norway (NGU). A total of about 932 line-km of electromagnetic (EM) and magnetic data were acquired using a nominal 100-m line spacing. The nominal flying height was 60 m above ground level (AGL), and lines were flown in alternating directions at headings of 050 and 230. Noise levels were within survey specifications.</p> <p>All initial processing was carried out on a flight-by-flight basis. Magnetic data, consisting of total field measurements collected by a cesium vapor magnetometer, were corrected by removing diurnal variations as recorded at a magnetic base station at Strand fjellstue, Espedalen. EM data were leveled using data from frequent high altitude excursions 300-m AGL. All final processed data were gridded using 25-m (magnetic) and 50-m square cells (electromagnetic). Geophysical maps were produced at a scale of 1:20 000 and are considered as stand alone products.</p> <p>This report covers aspects of data acquisition and processing.</p>			
Keywords: Geofysikk (Geophysics)		Magnetometri (Magnetometry)	
Elektromagnetisk måling (Electromagnetic measurements)	Databehandling (Data processing)	Fagrapport (Technical report)	



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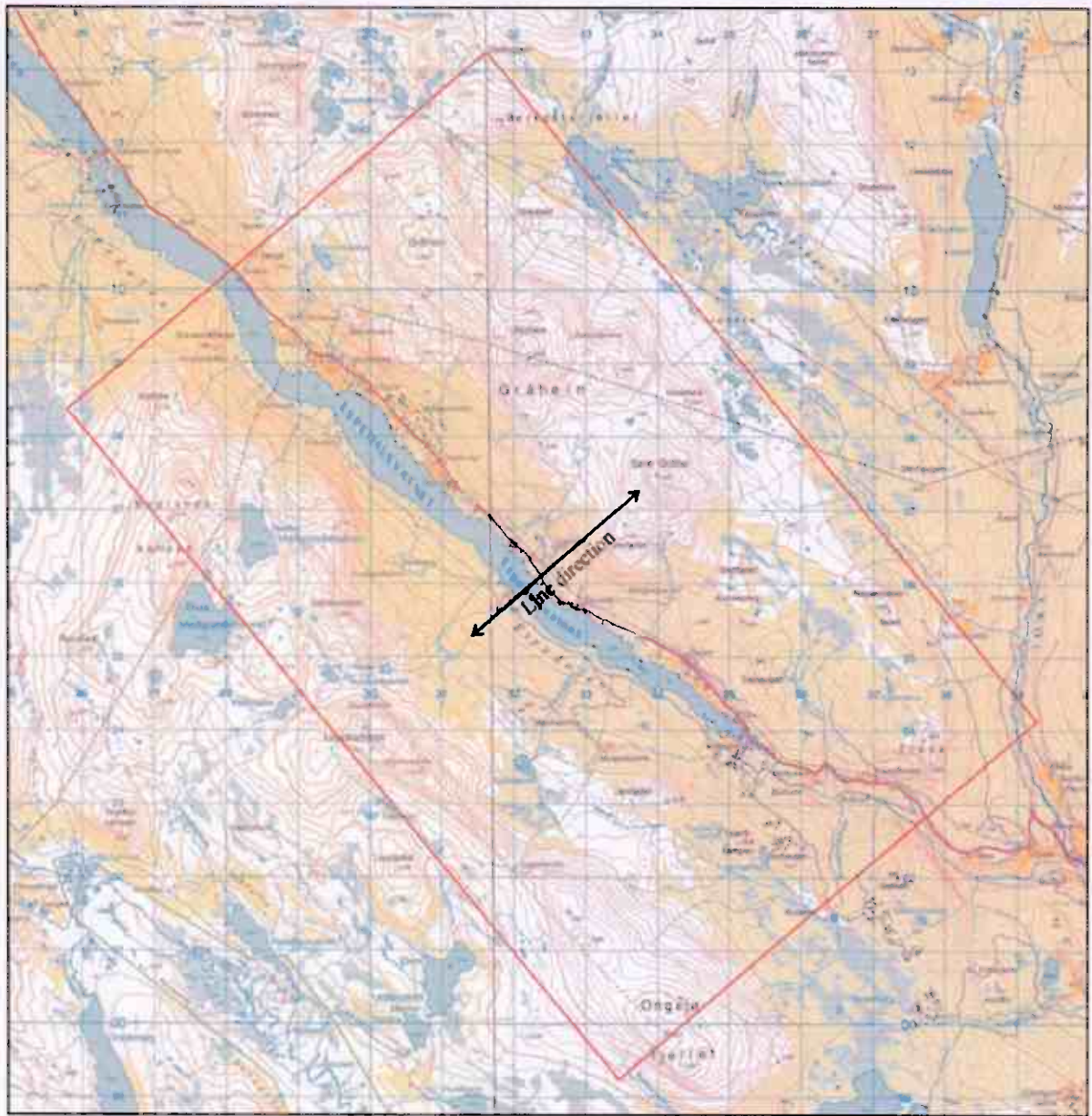
Maps in scale: 1:20 000 produced as stand alone products:

Map 2003.093-01:	Flight path.
Map 2003.093-02:	Total magnetic field.
Map 2003.093-03:	First vertical derivative of magnetic total field.
Map 2003.093-04:	EM stacked profiles 7001 Hz coaxial.
Map 2003.093-05:	EM stacked profiles 6606 Hz coplanar.
Map 2003.093-06:	EM stacked profiles 980 Hz coaxial.
Map 2003.093-07:	EM stacked profiles 880 Hz coplanar.
Map 2003.093-08:	EM stacked profiles 34133 Hz coplanar.
Map 2003.093-09:	EM apparent conductivity 6606 Hz coplanar.
Map 2003.093-10:	EM apparent conductivity 7001 Hz coaxial.



## 1 INTRODUCTION

In October, 2003, a helicopter geophysical survey was carried out over parts of Espedalen, Oppland county. The total area covered is 91 km<sup>2</sup>, and the total distance flown was 932 line-km (see Fig.1). Magnetic and electromagnetic (HEM) data were collected. The primary objective of the survey was to provide geophysical information for mineral prospecting in the area.



*Fig. 1: Outline of the surveyed area (flight direction 050/230°)*



## 2 SURVEY VARIABLES AND CONDITIONS

Several conditions may influence on the quality of the geophysical data.

### 2.1 Weather conditions

Strong wind can increase the noise level of airborne geophysical data. High winds were not frequent during the survey, but were encountered occasionally.

### 2.2 Topographic conditions

The topography in the Espedalen area is of the worst that NGU ever has been surveying. To compensate for this, the NGU used a more powerful helicopter than normal (AS 350 B3 instead of AS 350 B2). NGU had also the pleasure to use the most experienced helicopter pilot in Norway for this kind of operation (Leif Hus). Despite of this, it was impossible to drape the terrain with the bird 30 +/- 10 meters above ground as specified in the contract. The effect of this was alternating flying heights dependent on the directions the profiles were measured.

### 2.3 Magnetic conditions

Diurnal changes in the earth's magnetic field affect magnetic data. The base station magnetic field never indicated strong magnetic storm conditions during the surveys. A few lines on the first flight were reflight due to diurnal changes beyond specifications, which were 10 nT or more from a chord two minutes in length. Magnetic data quality on all lines used for production is very good.

### 2.4 EM data conditions

Strong vertical temperature gradients can affect EM leveling because the temperature at the 300-m nulling altitude is different from the temperature when the EM sensors are only 30 m above ground level. In addition to this, measuring at different altitudes may cause drift effects along profiles. Drift effects between nullings are corrected using standard linear interpolation. EM drift is characterized as low.

The resolution of geophysical sensors decreases exponentially with flying height. To achieve the greatest possible resolution, the aircraft should be flown as low as is safely possible. The target flying height is 60 meters above ground level. Due to the severe terrain, flying height



varied considerably in the present survey. This effected both the magnetic and the electromagnetic datasets.

In general EM signals are low in the area, and this gave severe problems when producing EM conductivity maps, but the quality of the EM data can be characterized as good.

### 3 DATA ACQUISITION

The survey aircraft was an Areospace Ecureuil SA 350 B-3. Flying speed was approximately 100 km per hour (28 meters per second). Flight lines over survey area were in directions 050/230 degrees with a flight line spacing of 100 m. The 5-frequency EM system and the magnetometer were enclosed in a 6-m long 'bird' suspended by cable 30 m beneath the helicopter.

NGU personnel responsible for data acquisition were John Olav Mogaard and Janusz Koziel. Pilot from AIRLIFT was Leif Hus.

#### 3.1 Magnetic measurements

A Scintrex CS-2 cesium vapor magnetometer was used. The magnetometer resolution is 0.01 nT. Sampling rate was 10 measurements per second (approximately 3 meter spacing).

A Scintrex ENVI-mag proton precession magnetometer was located at Strand fjellstue, Espedalen, and was used for base station measurements. Due to some technical problems, this was replaced with a Scintrex MP-3 proton precession magnetometer in parts of the survey. 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 magnetic total field at the base station was digitally recorded during flights every third second.

#### 3.2 Electromagnetic system

The EM system used was the 5-frequency Hummingbird system made in Canada by Geotech, Ltd. The Hummingbird records data at a sampling rate of 10 measurements per second. It has two coil orientations—vertical coaxial (VCA) and horizontal coplanar (HCP). The VCA coils operate at 980 Hz and 7001 Hz. The HCP coils operate at 880 Hz, 6606 Hz, and 34133 Hz. The transmitter-receiver separation is 6 m for lower frequencies and 4.2 m for 34133 Hz. The manufacturer specified noise level for each frequency is 1-2 ppm.



### 3.3 Navigation, altimetry, and data logging

The navigation system used was an Ashtech G12, 12 channel receiver. Position accuracy using this system is better than +/- 5 m.

The navigation console was a PNAV 2001 manufactured by the Picodas Group, Ltd. of Canada. Profile line data are entered into the console and the helicopter pilot can view the traces. The pilot can see his position with respect to these predefined lines and adjust accordingly.

The helicopter is equipped with a King KRA-430 radar altimeter that measured height above ground level. The altimeter was recorded digitally and data were displayed in front of 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 analog.

## 4 PROCESSING

The data were processed at the Geological Survey of Norway in Trondheim using Geosoft processing software (Geosoft 1996, Geosoft 1997) designed for NT operating systems. Obvious inaccuracies in navigation were manually removed from the data. The datum used was WGS84 and the projection was UTM zone 32.

### 4.1 Standard processing

**Total field magnetic data:** The data were 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 station magnetometer at Strand fjellstue. Finally a time lag of 0.5 sec (5 points) were applied to the basemag-corrected (levelled) magnetic data.

**EM data:** EM data were processed on a flight-by-flight basis. Zero levels and drift control for each frequency were obtained by frequent excursions 300m AGL, usually at the end of each flight line. A nonlinear filter was applied to all EM data to remove data spikes resulting from sferics. Before levelling, all data were mildly low passed using a 45 m filter. Noise levels for all frequencies were within an envelope of 2 ppm. Noise levels over 2 ppm occurred near powerlines. Magnetic structures having high susceptibility may produce



negatively oriented in-phase anomalies. A time lag of 0.5 sec (5 points) were applied to all channels before plotting of maps.

## **4.2 Map Production**

Magnetic maps in scale 1: 20 000, Total magnetic field and first vertical derivative, were produced using a grid cell size of 25 x 25 metres. The problems in keeping a correct flying height in parts of the area, created leveling problems. These were significant on a first version of the contour maps, and were corrected for without ruining the information in the data using median micro-leveling procedures created at the NGU (Mauring & Kihle 2000). In order to do this, a resampling of the magnetic data to 5 times a second was necessary. The contoured color maps are produced with a shaded relief of the high frequency content. Shading was from the northeast at 50° sun inclination above the horizon. In agreement with the clients representative, magnetic measurements outside the predefined area was kept in the magnetic maps. Flying height and profile separation may be out of specifications and as a result lower data quality. High quality data (original area) is marked with a frame on the magnetic maps.

As a standard, stacked profiles of all EM frequencies in scale 1: 20 000 were produced following standard procedures. Based on in phase and quadrature data, apparent resistivity was computed for 6606 Hz coplanar and 7001 Hz coaxial using least squares inversion and a homogeneous half space model (Geosoft 1997). In agreement with the company representative, Tony Watts, conductivity maps instead of resistivity maps were produced using 6606 Hz coplanar and 7001 Hz coaxial frequencies. Due to low EM signals (high resistivity), negative EM responses due to high susceptibility and problems to keep a constant flying altitude, it was a very hard job to create conductivity maps with a satisfactory layout. Because of this, first a resistivity grid was created which was micro-leveled using median filtering (Mauring & Kihle 2000) before inverting data to conductivity. Grid cell size was 50 x 50 metres.

## **5 DATA DELIVERIES**

In agreement with the clients representative, the following stand alone maps in scale 1: 20 000 are produced and delivered to the client as printed maps:

- **Map 2003.093-01:** Flight path.
- **Map 2003.093-02:** Total magnetic field.
- **Map 2003.093-03:** First vertical derivative of magnetic total field.
- **Map 2003.093-04:** EM stacked profiles 7001 Hz coaxial.
- **Map 2003.093-05:** EM stacked profiles 6606 Hz coplanar.
- **Map 2003.093-06:** EM stacked profiles 980 Hz coaxial.
- **Map 2003.093-07:** EM stacked profiles 880 Hz coplanar.
- **Map 2003.093-08:** EM stacked profiles 34133 Hz coplanar.



- **Map 2003.093-09:** EM apparent conductivity 6606 Hz coplanar.
- **Map 2003.093-10:** EM apparent conductivity 7001 Hz coaxial.

These maps are also delivered on CD in Geosoft formats.

Digital magnetic and electromagnetic data in Geosoft XYZ file formats and grid files of these data are delivered on CD as described in Appendix A.

## 6 REFERENCES

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

Geosoft Inc.; 1997: HEM System (Windows®95 & NT™) User Guide, *Geosoft Incorporated*

Mauring, E. & Kihle, O. 2000: Micro-levelling of aeromagnetic data using a moving differential median filter. *NGU Report 2000.053*.



## Appendix A: Data delivery formats.

### Espedalen Geosoft XYZ file formats.

#### Final Delivery on CD

#### File: Magnetic\_final.XYZ (including tielines T10 and T20)

<i>x_filt</i>	meters	Final processed x (masked to the extended area polygon)
<i>y_filt</i>	meters	Final processed y (masked to the extended area polygon)
<i>recnum</i>		Internal record number, ordinal, per flight; incremented at 0.1 per tenth of a second
<i>UTCtime</i>		Universal time Hours: Minutes: Seconds. Decimal_seconds
<i>mag_levl_lag</i>	gamma	Levelled and time-lagged magnetic data

#### File: EM\_final.XYZ

<i>x_filt</i>	meters	Final processed x (masked to the area polygon)
<i>y_filt</i>	meters	Final processed y (masked to the area polygon)
<i>recnum</i>		Internal record number, ordinal, per flight, incremented at 0.1 per tenth of a second
<i>UTCtime</i>		Universal time Hours: Minutes: Seconds. Decimal_seconds
<i>bird_height</i>	meters	Processed radar altimeter data minus 30 meter
<i>IP1_f_L_lag</i>	ppm	Filtered, leveled and lagged inphase 7001 Hz Coaxial
<i>Q1_f_L_lag</i>	ppm	quadrature 7001 Hz Coaxial
<i>IP2_f_L_lag</i>	ppm	inphase 6606 Hz Coplanar
<i>Q2_f_L_lag</i>	ppm	quadrature 6606 Hz Coplanar
<i>IP3_f_L_lag</i>	ppm	inphase 980 Hz Coaxial
<i>Q3_f_L_lag</i>	ppm	quadrature 980 Hz Coaxial
<i>IP4_f_L_lag</i>	ppm	inphase 880 Hz Coplanar
<i>Q4_f_L_lag</i>	ppm	quadrature 880 Hz Coplanar
<i>IP5_f_L_lag</i>	ppm	inphase 33133 Hz Coplanar
<i>Q5_f_L_lag</i>	ppm	quadrature 33133 Hz Coplanar
<i>res6606</i>	ohm-m	Apparent resistivity (6606 Hz coplanar)
<i>res7001</i>	ohm-m	Apparent resistivity (7001 Hz coaxial)



The following Geosoft grid files are copied to the CD :

<b><i>mag_levl_lag.grd</i></b>	Grid generated from mag_levl_lag channel (25 m cell size)
<b><i>mag_median_final.grd</i></b>	Micro levelled grid (circular median filter) used in map (25 m cell size)
<b><i>mag_median_final_1D.grd</i></b>	Calculated vertical gradient grid used in map based on the final magnetic grid file .
<b><i>res6606.grd</i></b>	Apparent resistivity grid from res6606 channel (50 m cell size)
<b><i>res7001.grd</i></b>	Apparent resistivity grid from res7001 channel (50 m cell size)
<b><i>cond6606newf.grd</i></b>	Final conductivity grid file used in map after micro levelling 6606 Hz coplanar freq. (50 m cell size)
<b><i>cond7001newf.grd</i></b>	Final conductivity grid file used in map after micro levelling 7001 Hz coaxial freq. (50 m cell size)





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Geological Survey of Norway

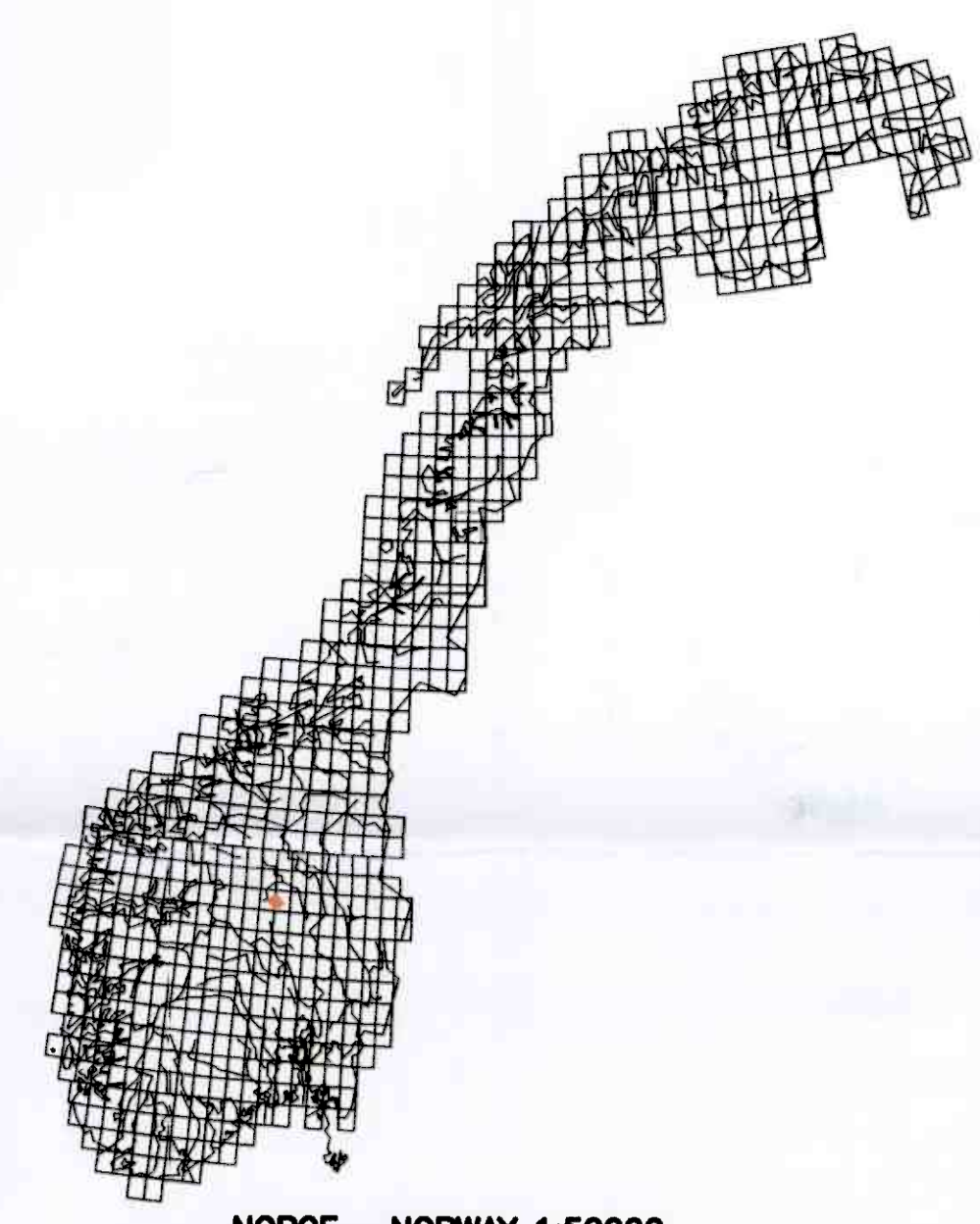
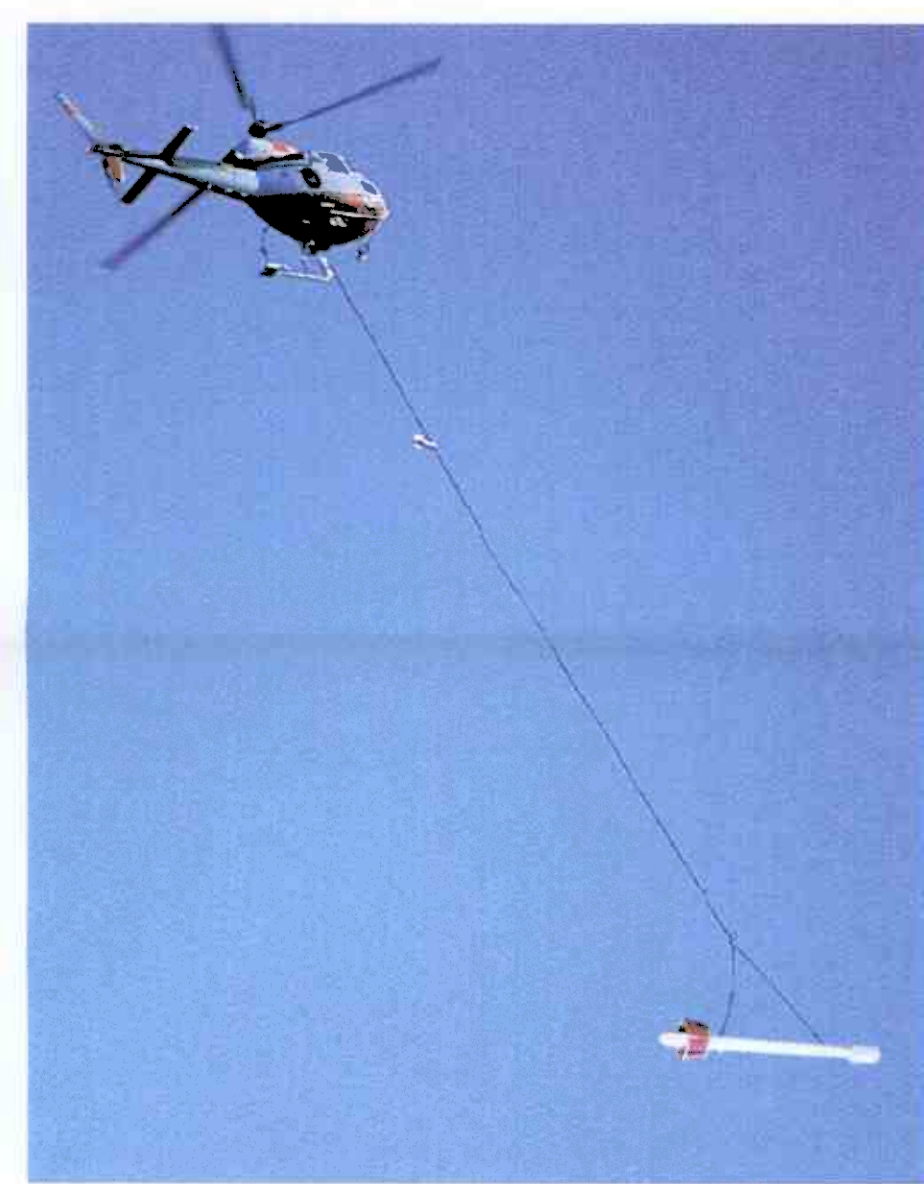
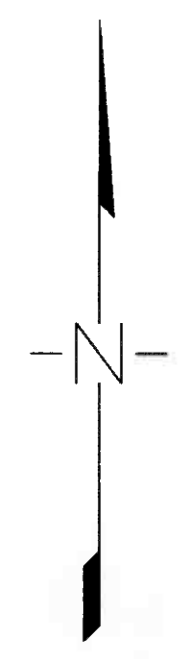
Address for visitors:  
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N-7491 Trondheim, Norway

Phone: +47 73 90 40 00  
Telefax: +47 73 92 16 20

E-mail: [ngu@ngu.no](mailto:ngu@ngu.no)  
<http://www.ngu.no>





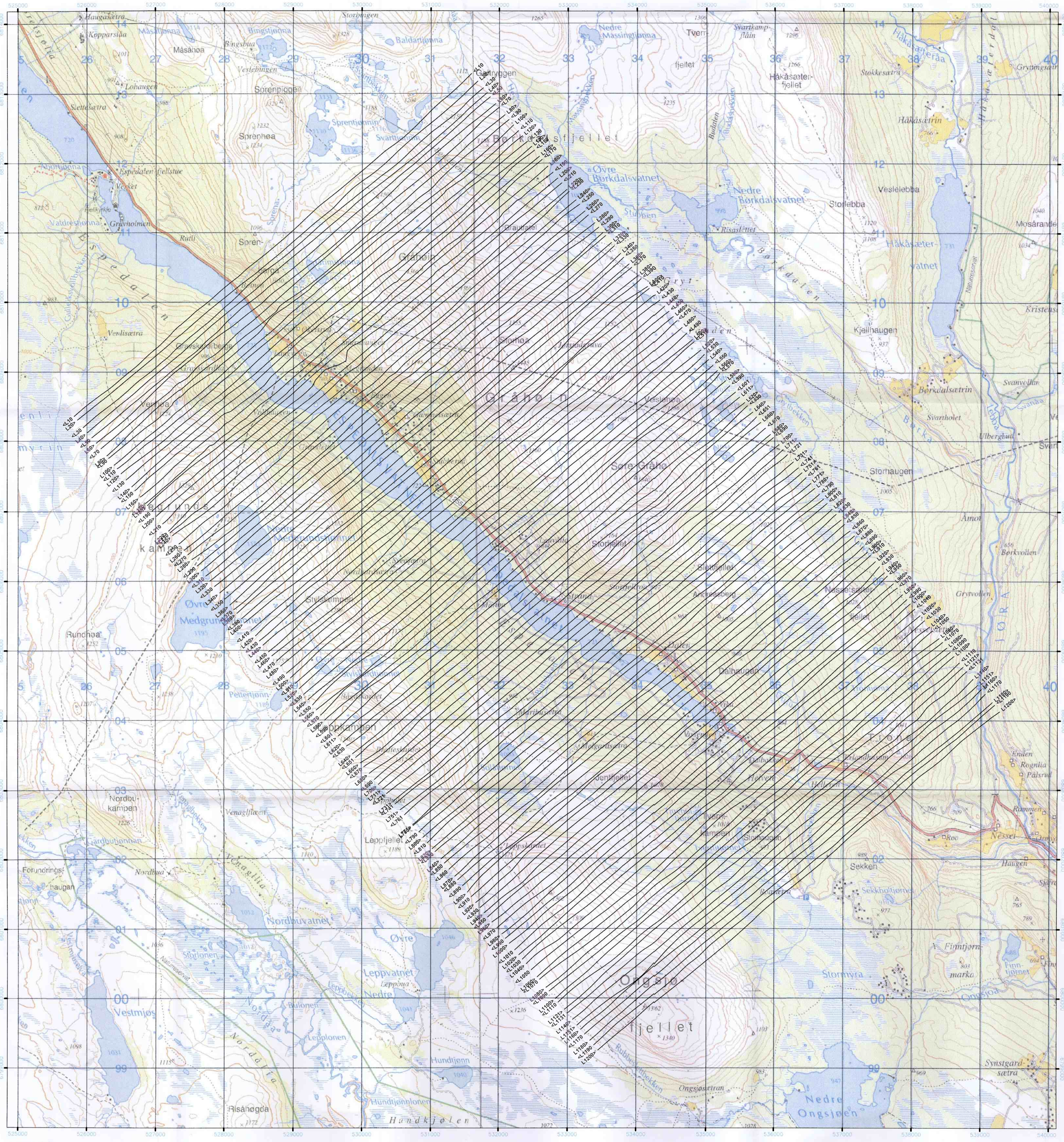
NORGE - NORWAY 1:50000  
**SERIE M711**  
TOPOGRAFISK HOVEDKARTSERIE

**NAVIGATION**  
The entire area was covered by GPS navigation.  
The nominal flying height above ground level in the area is 60 metres.

**A/S SULFIDMALM**  
**FLIGHT PATH**

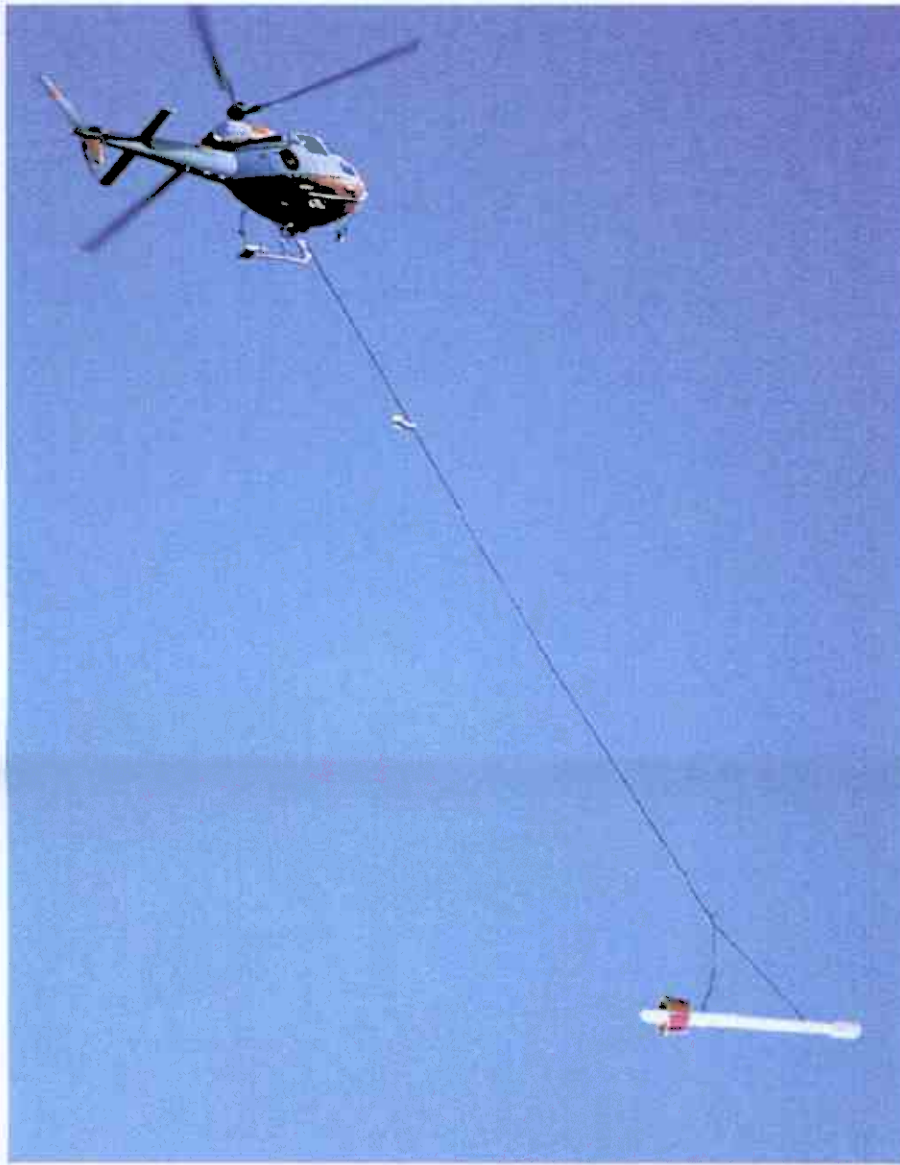
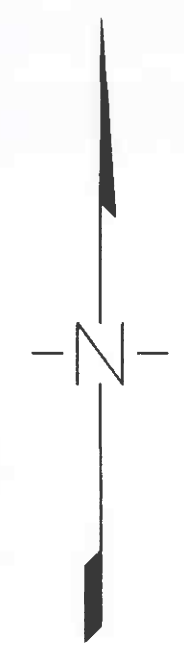
**Espedalen**  
Oppland

Drawing: Mogaard, J.O.	Date: NOV 2003	Obs: JOM/JK
Scale 1:20 000		Mapsheet (1:50 000): 1717 IV Espedalen
250 0 250 500 750 1000 1250 1500 (metres)		1717 I Svatsum



GEODETIC DATUM: WGS84  
CONFORM CYLINDRICAL PROJECTION  
Northing in BLUE in UTM coordinates, zone 32N





**TOTAL MAGNETIC FIELD**

The intensity of the total magnetic field is in nanoTesla.  
Contours given in following intervals:

25nT
50nT
100nT
300nT

Colours - distributed after colourscale.  
Data are corrected for diurnal variations using a base magnetometer located at Strand Fjellnes, Espedalen.  
A high sensitivity custom magnetometer sensor is used and nominal sensor elevation is 30 metres.

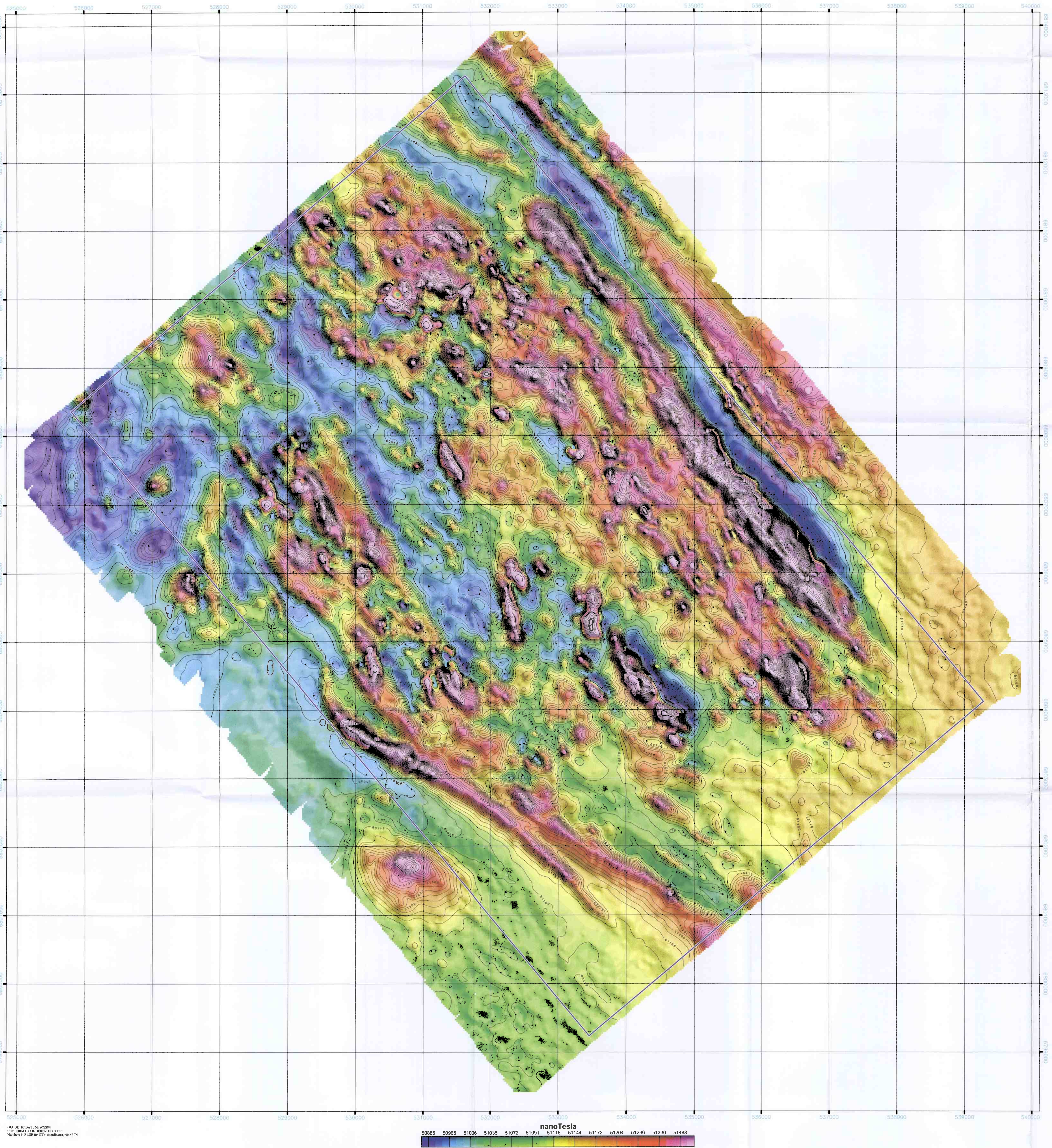
**NAVIGATION**

The entire area was covered by GPS navigation.  
The nominal flying height above ground level in the area is 60 metres.

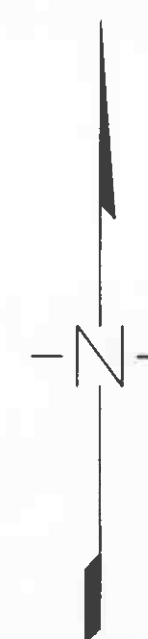
**A/S SULFIDMALM**  
**TOTAL MAGNETIC FIELD**  
Colours and contours

**Espedalen**  
Oppland

Drawing: Mogaard, J.O.	Date: NOV 2003	Obs: JOM/JK
Scale 1:20 000		Mapsheet (1:50 000): 1717 IV Espedalen 1717 I Svartsum
250 0 250 500 750 1000 1250 1500 (metres)		
NGU Geology for Society since 1858		GEOLOGICAL SURVEY OF NORWAY Linn. Hellebrandt 1853 N-7481 TRONDHEIM Tel: +47 73 90 40 90, Fax: +47 73 92 16 20 http://www.ngu.no
		Drawing no: 2003.093-02

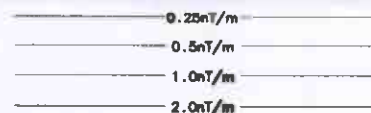






**CALCULATED VERTICAL GRADIENT**

Vertical Magnetic Gradient (in NanoTeslas per meter).  
Calculated from the total field magnetogram and upward continued 25 metres.  
Contours given in following intervals:



Colours - distributed after colourscale.

Cesium high sensitivity magnetometer.  
Sensor elevation - 30 metres.

**NAVIGATION**

The entire area was covered by GPS navigation.  
The nominal flying height above ground level in the area is 60 metres.

**A/S SULFIDMALM**

**CALCULATED VERTICAL MAGNETIC GRADIENT**  
Colours and contours

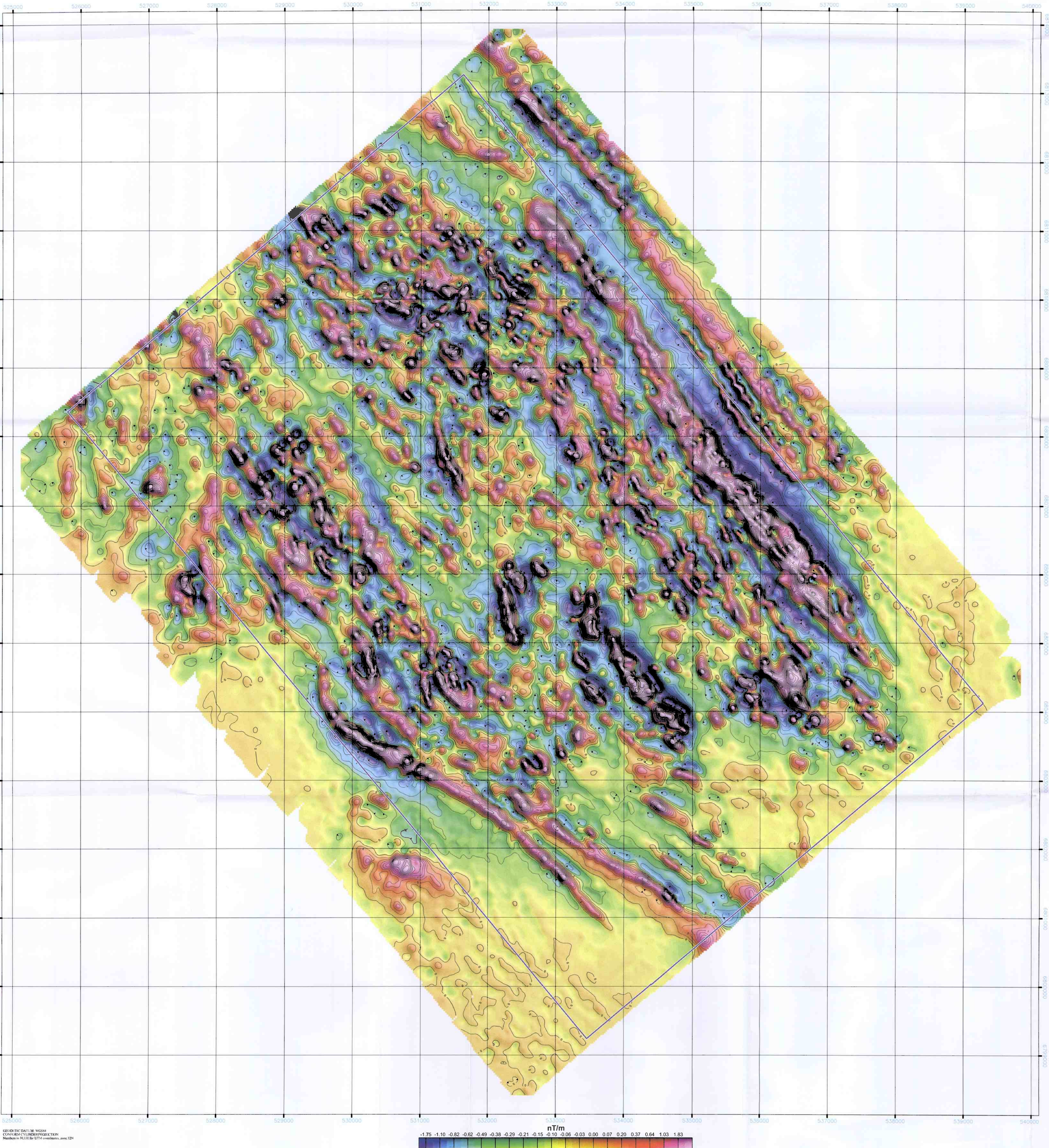
**Espedalen**  
Oppland

Drawing: Mogaard, J.O. Date: NOV 2003 Obs: JOM/JK

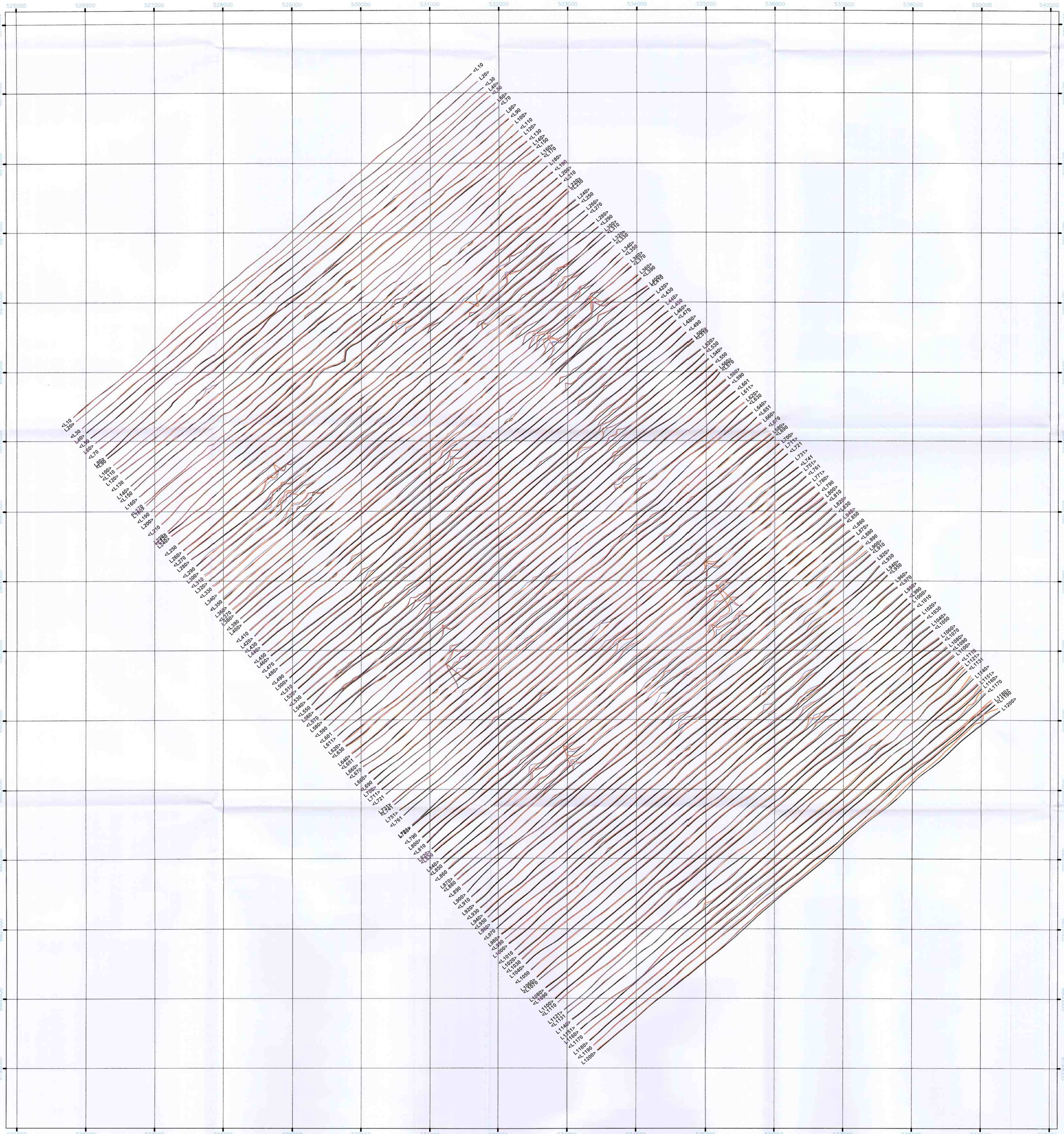
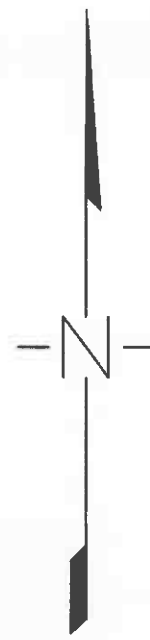
Scale 1:20 000



Mapsheet (1:50 000):  
1717 IV Espedalen  
1717 I Svalbum







HEM 7001 Hz COAXIAL  
Frequency : 7001 Hz (coastal orientation)  
Coil spacing : 6 m  
Inphase : 5 ppm/m  
Quadrature : 5 ppm/m

NAVIGATION  
The entire area was covered by GPS navigation.  
The nominal flying height above ground level in the area is 60 metres.

**A/S SULFIDMALM**  
HEM STACKED PROFILES 7001 Hz COAXIAL

Espedalen  
Oppland

Drawing: Mogaard, J.O.      Date: NOV 2003      Obs: JOM/JK

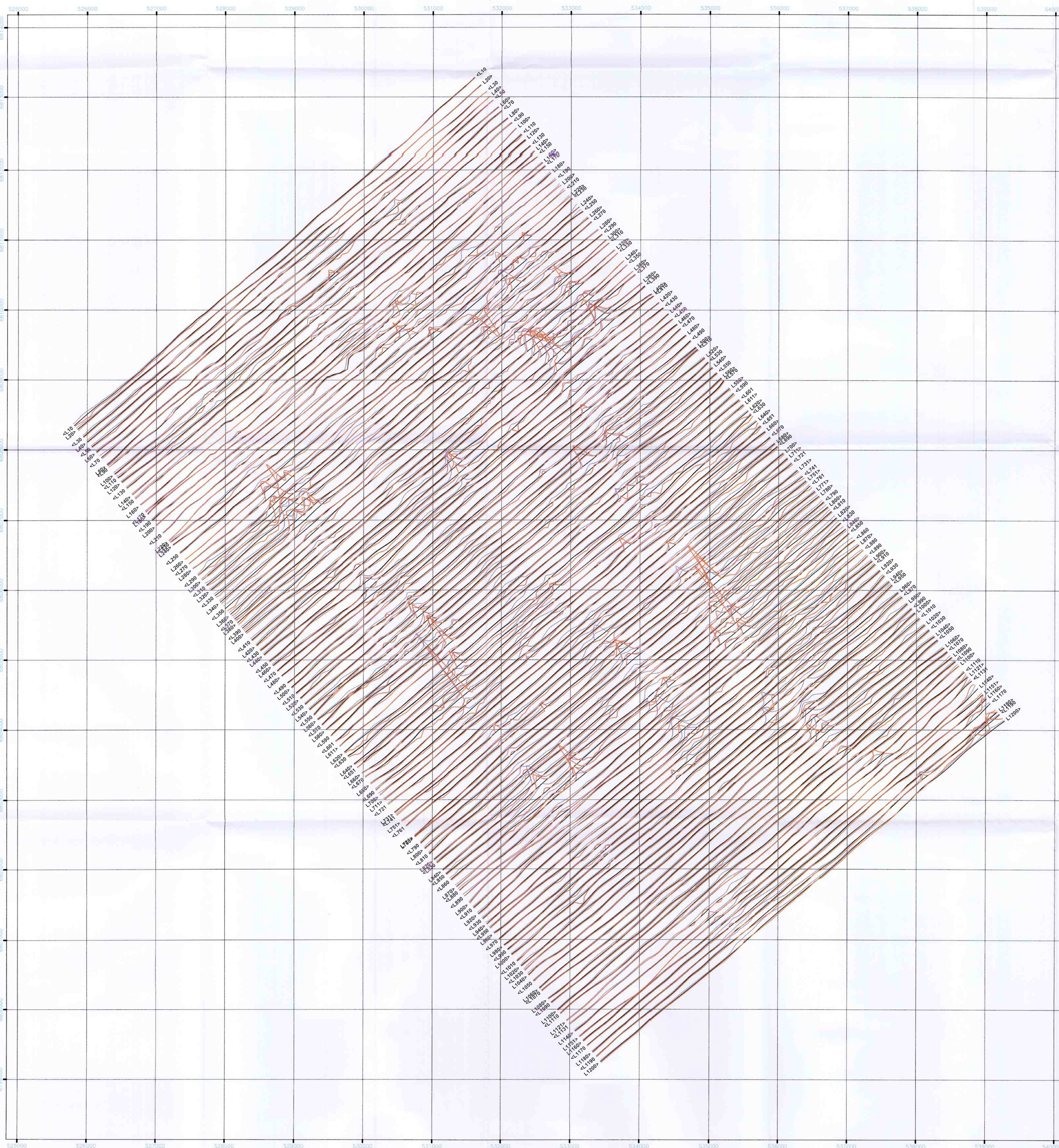
Scale 1:20 000  
250 0 250 500 750 1000 1250 1500  
(metres)

NGU  
Geology for Society since 1858

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http://www.ngu.no

Drawing no:  
2003.093-04





#### HEM 6606 Hz COPLANAR

Frequency : 6606 Hz (horizontal, coplanar orientation)  
Coil spacing : 6 m

Inphase : 10 ppm/mm  
Quadrature : 10 ppm/mm

#### NAVIGATION

The entire area was covered by GPS navigation.  
The nominal flying height above ground level in this area is 60 metres.

### A/S SULFIDMALM

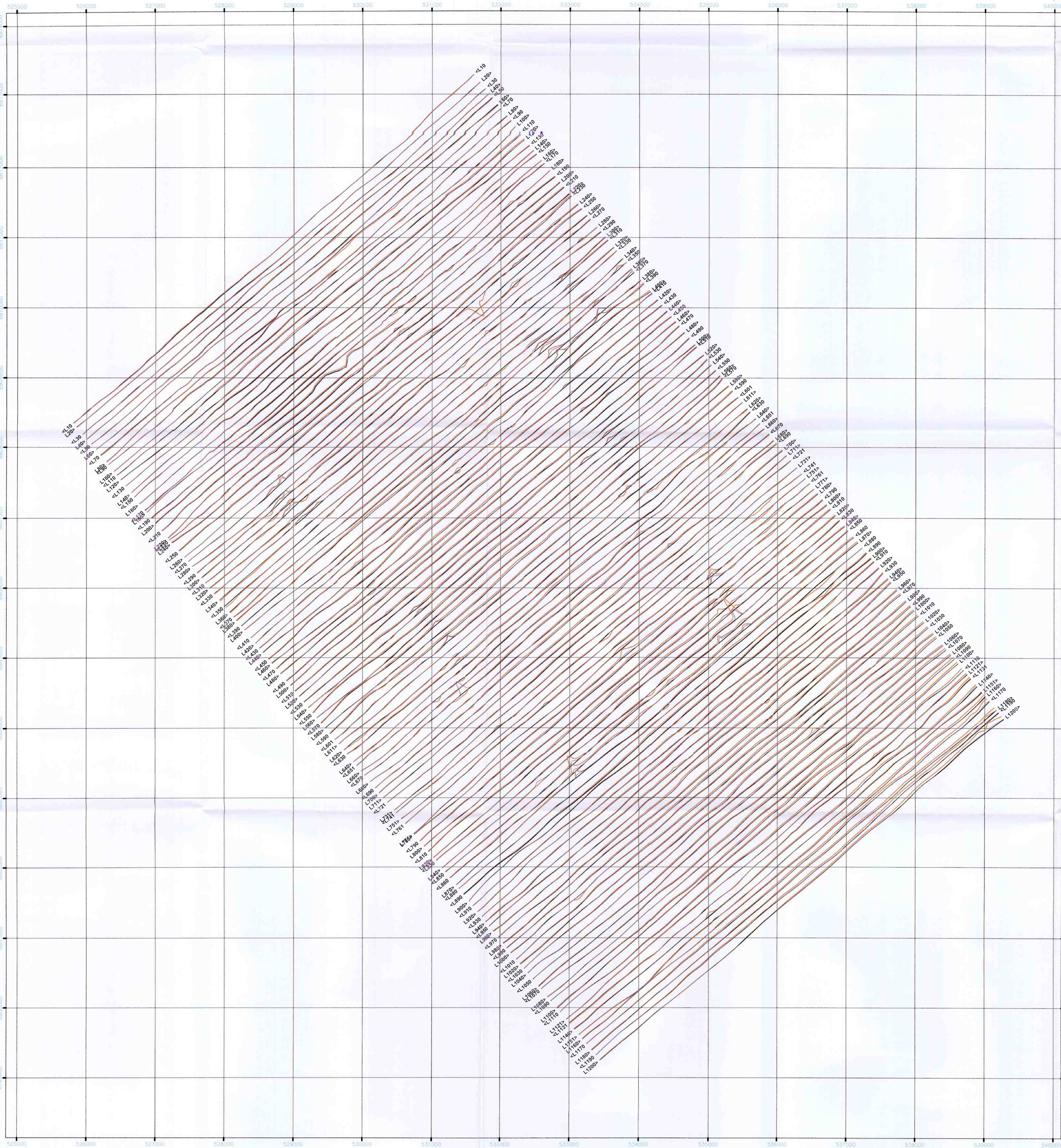
#### HEM STACKED PROFILES 6606 Hz COPLANAR

#### Espedalen

Drawing: Mogaard, J.O. Date: NOV 2003 Obs: JOM/JK

Scale 1:20 000  
250 0 250 500 750 1000 1250 1500  
(metres)





**HEM 980 Hz COAXIAL**

Frequency : 980 Hz (coastal orientation)  
Coil spacing : 6 m

Legend:  
— InPhase  
— Quad

Inphase : 5 ppm/min  
Quadrature : 5 ppm/min

**NAVIGATION**

The entire area was covered by GPS navigation.  
The nominal flying height above ground level in the area is 60 metres.

**A/S SULFIDMALM**

**HEM STACKED PROFILES 980 Hz COAXIAL**

**Espedalen**  
Oppland

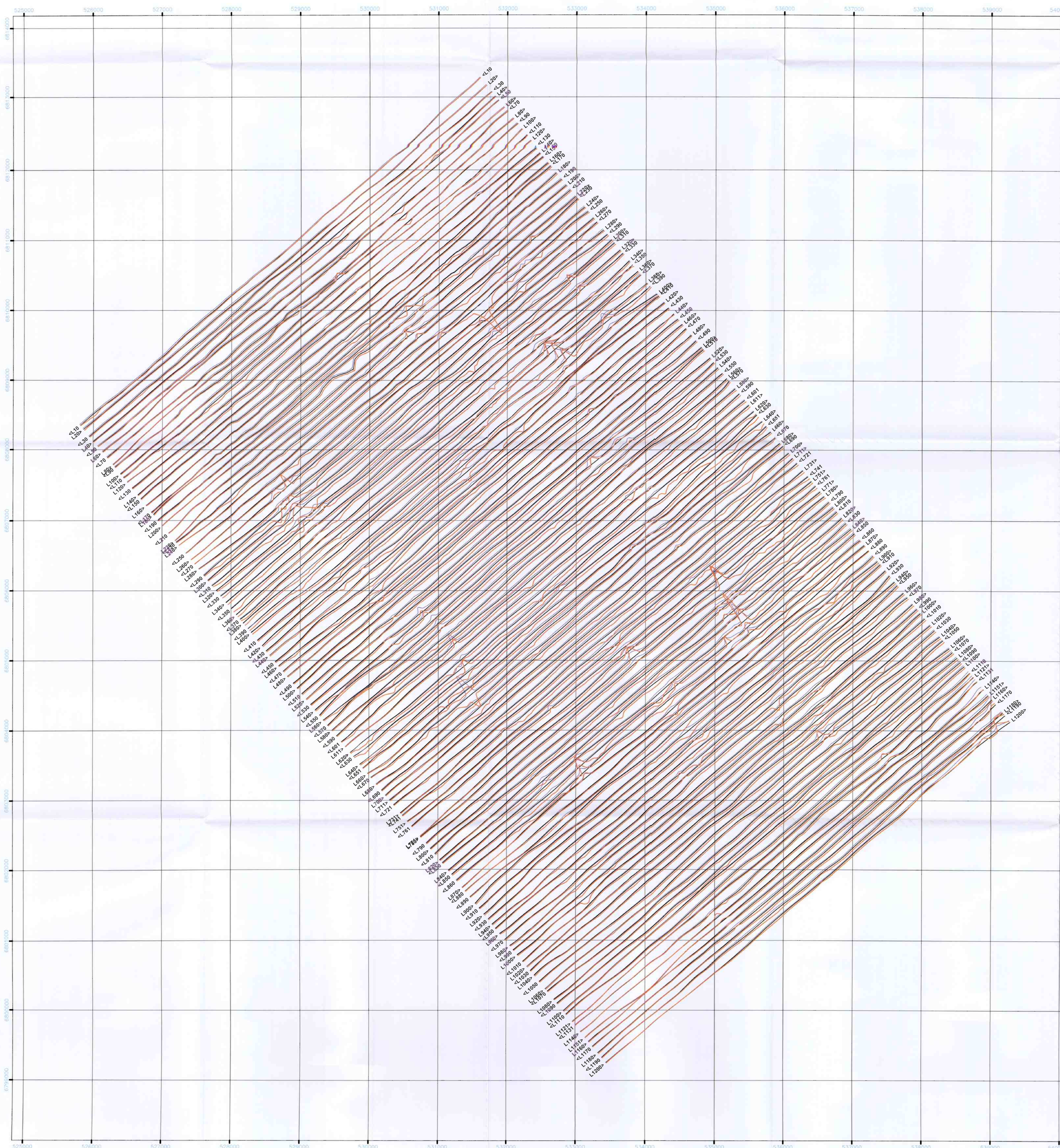
Drawing: Mogaard, J.O. Date: NOV 2003 Obs: JOM/JK

Scale 1:20 000

250 0 250 500 750 1000 1250 1500  
(metres)

Mapsheet (1:50 000):  
1717 IV Espedalen  
1717 I Svastum





Tel +47-73 90 40 00, Fax +47-73 92 16 20  
http://www.ngu.no

The entire area was covered by GPS navigation.

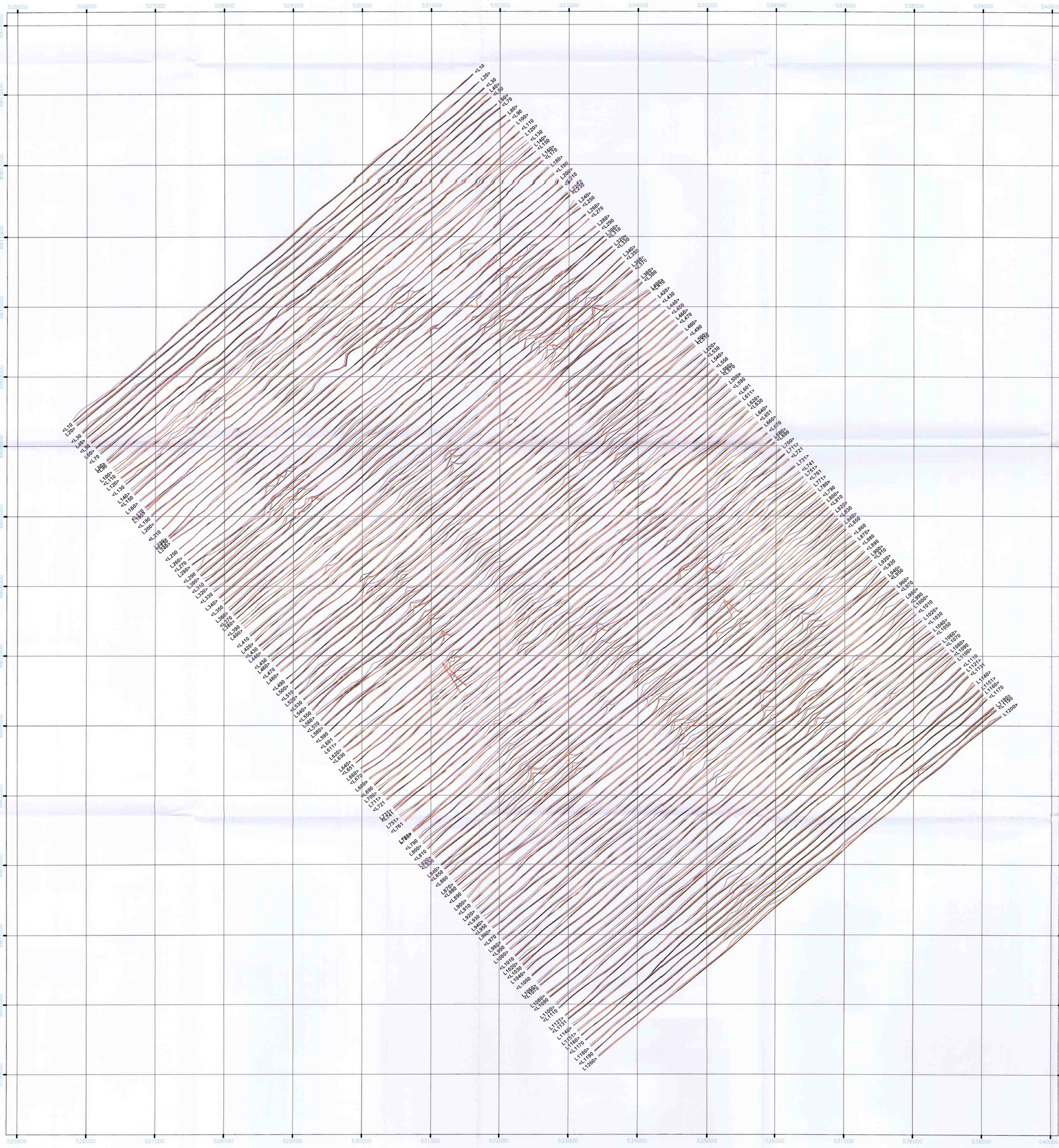
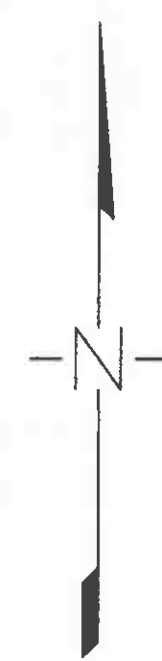
The nominal flying height above ground level in the area is 60 metres.

**NGO**  
(created for societies since 1858)

N-7491 TRONDHEIM  
Tel +47-73 90 40 00, Fax +47-73 92 16 20

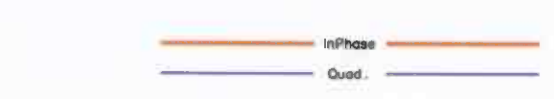
2003.093-0





HEM 34133 Hz COPLANAR

Frequency : 34133 Hz (horizontal, coplanar orientation)  
Coil spacing : 4.2 m



In-phase : 20 ppm/min  
Quadrature : 20 ppm/min

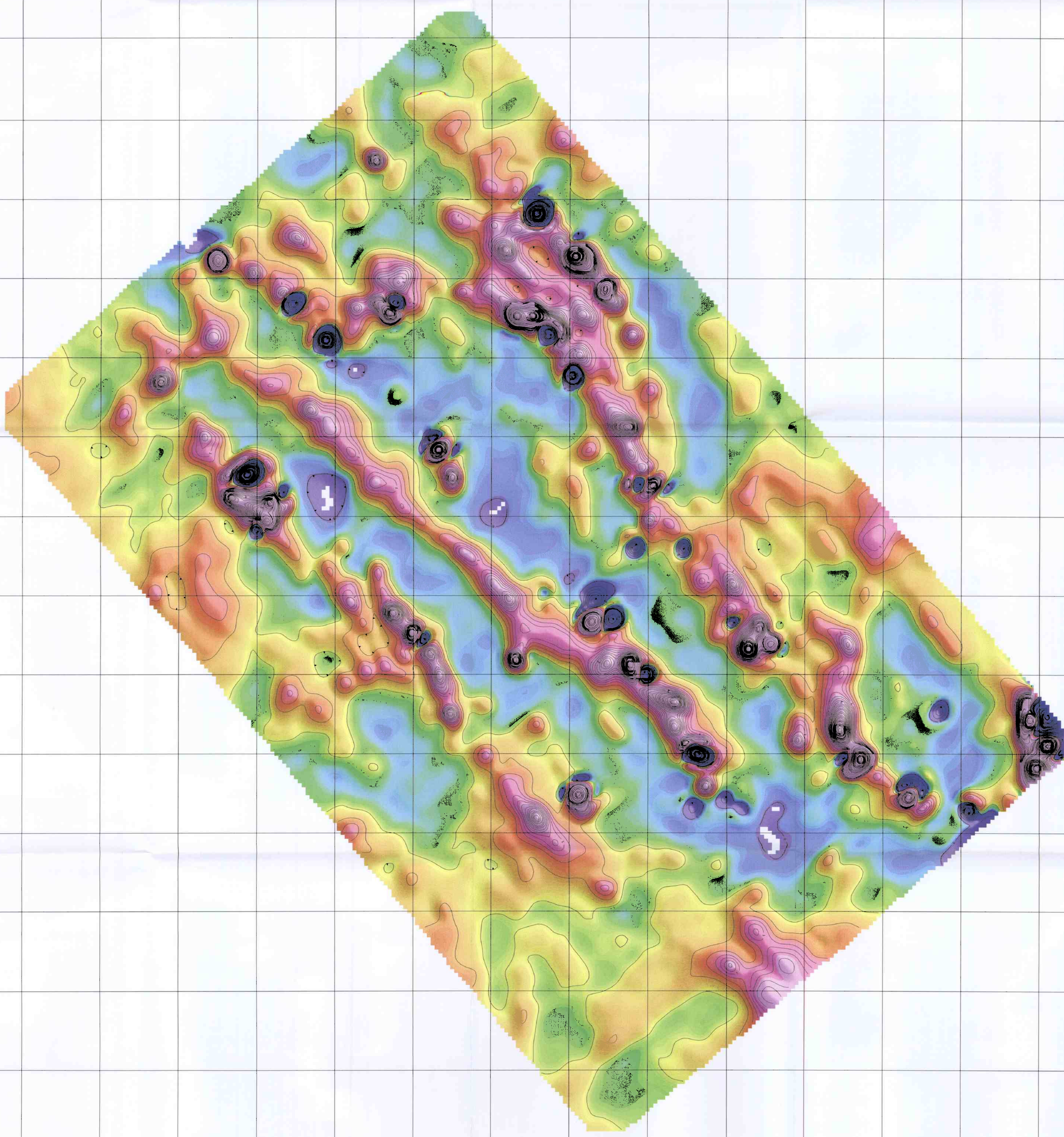
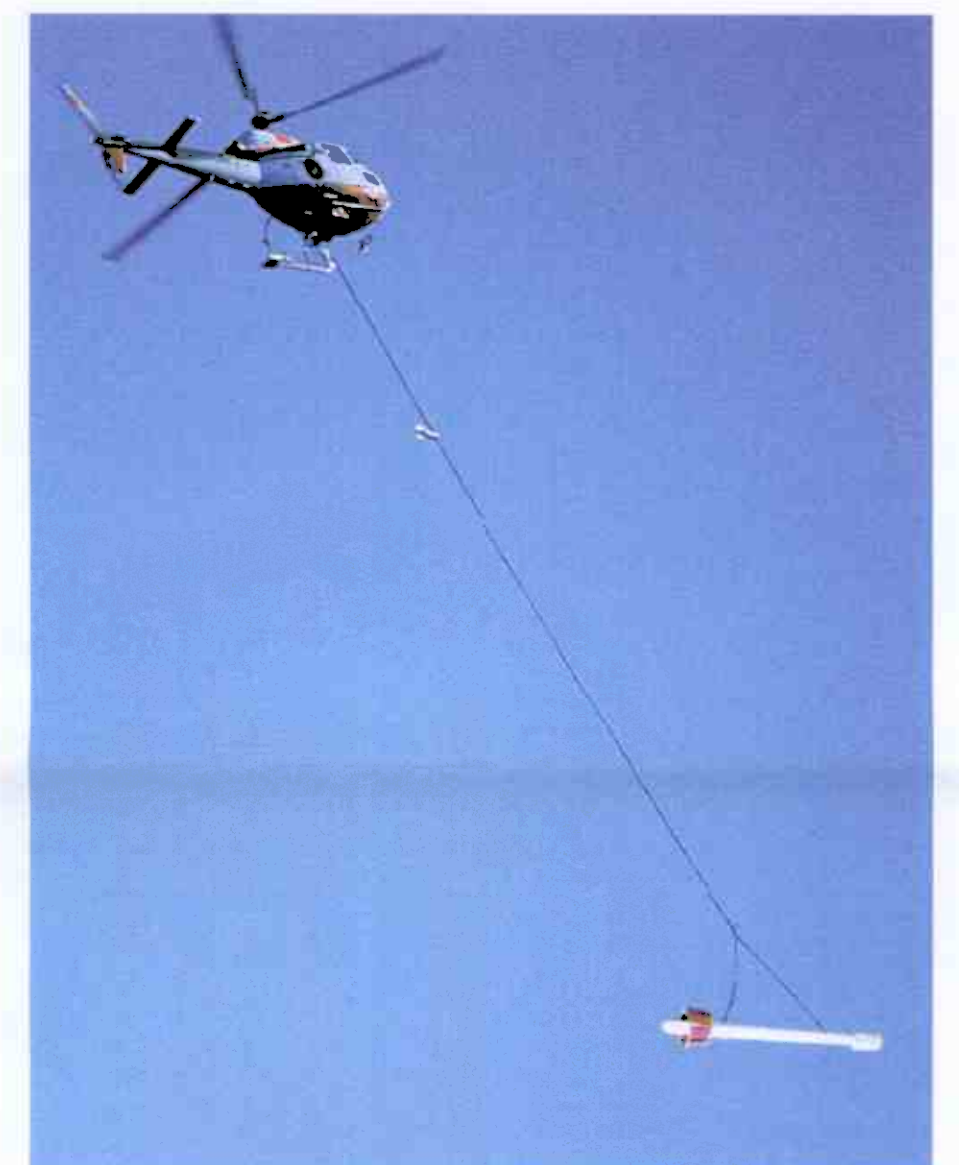
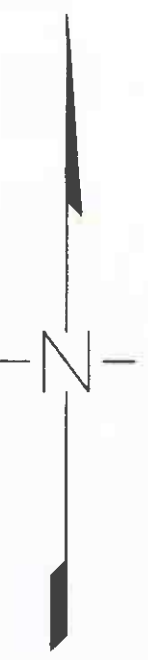
NAVIGATION

The entire area was covered by GPS navigation.  
The nominal flying height above ground level in the area is 60 metres.

A/S SULFIDMALM  
HEM STACKED PROFILES 34133 Hz COPLANAR

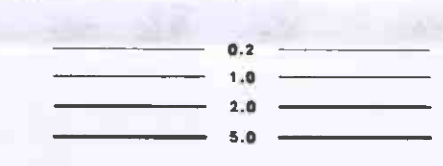
Espedalen Oppland	
Drawing: Mogaard, J.O.	Date: NOV 2003
Obs: JOM/JK	Mapsheet (1:50 000): 1717 IV Espedalen
Scale 1:20 000	
250 0 250 500 1000 1250 1500 (metres)	
1717 I Svatsum	





**APPARENT CONDUCTIVITY**

Calculated from 6606 horizontal coplanar response.  
Contours given in following intervals:



Colours - distributed after colourscale.

Sensor elevation - 30 metres.

**NAVIGATION**

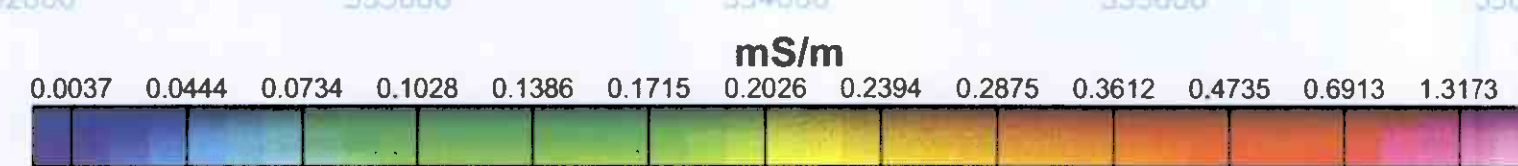
The entire area was covered by GPS navigation.  
The nominal flying height above ground level in the area is 60 metres.

**A/S SULFIDMALM**

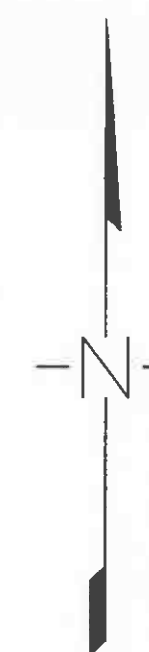
**EM APPARENT CONDUCTIVITY 6606 HZ. H. COPLANAR**  
Colours and contours

**Espedalen**  
Oppland

Drawing: Mogaard, J. O.	Date: NOV 2003	Obs: JOM/JK
Scale 1:20 000		Mapsheet (1:50 000):
250 0 250 500 750 1000 1250 1500		1717 IV Espedalen
		1717 I Svatsum

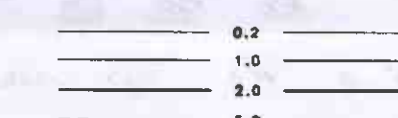






#### APPARENT CONDUCTIVITY

Calculated from 7081 coaxial response.  
Contours given in following intervals.



Colours - distributed after colour scale.

Sensor elevation - 30 meters.

#### NAVIGATION

The entire area was covered by GPS navigation.  
The nominal flying height above ground level in the area is 60 metres.

### A/S SULFIDMALM

EM APPARENT CONDUCTIVITY 7001 HZ. COAXIAL  
Colours and contours

Espedalen

Oppland

Drawing: Mogaard, J.O.

Date: NOV 2003

Obs: JOM/JK

Scale 1:20 000

Mapsheets (1:50 000):  
1717 IV Espedalen  
1717 I Svatsum

