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Helicopter-borne magnetic, electromagnetic
and radiometric geophysical survey in the
Alta - Kvænangen area, Troms and Finnmark.

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REPORT

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Title:
Helicopter-borne magnetic, electromagnetic and radiometric geophysical survey in the Alta - Kvænangen area, Troms and Finnmark.

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Summary:

NGU conducted an airborne geophysical survey in Kvænangen area in September - October 2012. This report describes and documents the acquisition, processing and visualization of recorded datasets. The geophysical survey results reported herein are 5526 line km.

The Geotech Ltd. Hummingbird frequency domain system supplemented by optically pumped ceasium magnetometer and 1024 channels RSX-5 spectrometer was used for data acquisition. The survey was flown with 200 m line spacing, line direction 90° W-E in the western part of the area and 125° in the eastern part with the average speed 93 km/h. The average terrain clearance of the EM bird was 58 m.

Collected data were processed at NGU using Geosoft Oasis Montaj software. Raw total magnetic field data were corrected for diurnal variation and levelled using standard micro levelling algorithm. EM data were filtered and levelled using both automated and manual levelling procedure. Apparent resistivity was calculated from in-phase and quadrature data for each of the five frequencies separately using a homogeneous half space model. Apparent resistivity dataset was levelled and filtered. Radiometric data were processed using standard procedures recommended by International Atomic Energy Association.

All data were gridded with the cell size of 50 m and presented as a maps at the scale of 1:50 000.

Keywords: Geophysics	Airborne	Magnetic
Electromagnetic	Gamma spectrometry	Radiometric
		Technical report

Table of Contents

FIGURES

TABLES

1. INTRODUCTION

Recognising the impact that investment in mineral exploration and mining can have on the socio-economic situation of a region, the government of Norway recently initiated MINN programme (Mineral resources in North Norway). The goal of this program is to enhance the geological information that is relevant to an assessment of the mineral potential of the three northernmost counties. Airborne geophysical surveys - helicopter borne and fixed wing- are important integral part of MINN program. The airborne survey results reported herein amount to 5526 line-km flown over the Alta - Kvænangen survey area.

The objective of the airborne geophysical survey was to obtain a dense high-resolution aero-magnetic, electromagnetic and radiometric data over the survey area. This data is required for the enhancement of a general understanding of the regional geology of the area. In this regard, the data can also be used to map contacts and structural features within the property. It also allow to better define the potential of known zones of mineralization, their geological settings and identify new areas of interest.

The survey incorporated the use of a Hummingbird™ five-frequency electromagnetic system supplemented by a high-sensitivity Ceasium magnetometer, gamma-ray spectrometer, barometric altimeter, and radar altimeter. A GPS navigation computer system with flight path indicators ensured accurate positioning of the geophysical data with respect to the World Geodetic System 1984 geodetic datum (WGS-84).

2. SURVEY SPECIFICATIONS

Location of the surveyed area, Alta – Kvænangen, is shown in figure 1.

2.1 Airborne Survey Parameters

NGU used a Hummingbird™ electromagnetic and magnetic helicopter survey system designed to obtain low level, slow speed, detailed high resolution airborne magnetic and electromagnetic data (Geotech 1997). In addition, a 1024 channel gamma-ray spectrometer was used (Radiation Solutions 2008).

The airborne survey began on September 23 and ended on October 29 2012. A Eurocopter AS350-B2 helicopter was used to tow the bird. The survey lines were spaced 200 m apart. Lines were oriented at 90° W-E in the western part of the area, and 125° in the eastern area. The magnetic and electromagnetic sensors are housed in a single 7.5 m long bird, which was maintained at an average of 56 m above the topographic surface. Gamma spectrometer, pressure and temperature transducers were installed under the belly of the helicopter registered natural gamma ray radiation simultaneously with the acquisition of magnetic/EM data. Average sensor height was 95 m.

Rugged terrain and abrupt changes in topography affect the aircraft pilot’s ability to ‘drape’; therefore there are positive and negative variations in sensor height with respect to the estimated range, which is higher than the standard height of 30 m.

The ground speed of the aircraft varied from 30 – 120 km/h depending on topography, wind direction and its magnitude. In average, the ground speed is estimated to be 93 km/h. Electromagnetic were recorded at 0.1 second intervals resulting in 3 to 4 m observation points spacing. The magnetometer was sampled 5 times a second and point spacing became 6 – 8 m. Spectrometry data were recorded every 1 second giving an average point spacing of ca 25 m. The above parameters were designed to allow for sufficient detail in the data to detect subtle anomalies that may represent mineralization and/or rocks of different lithological and petrophysical composition.

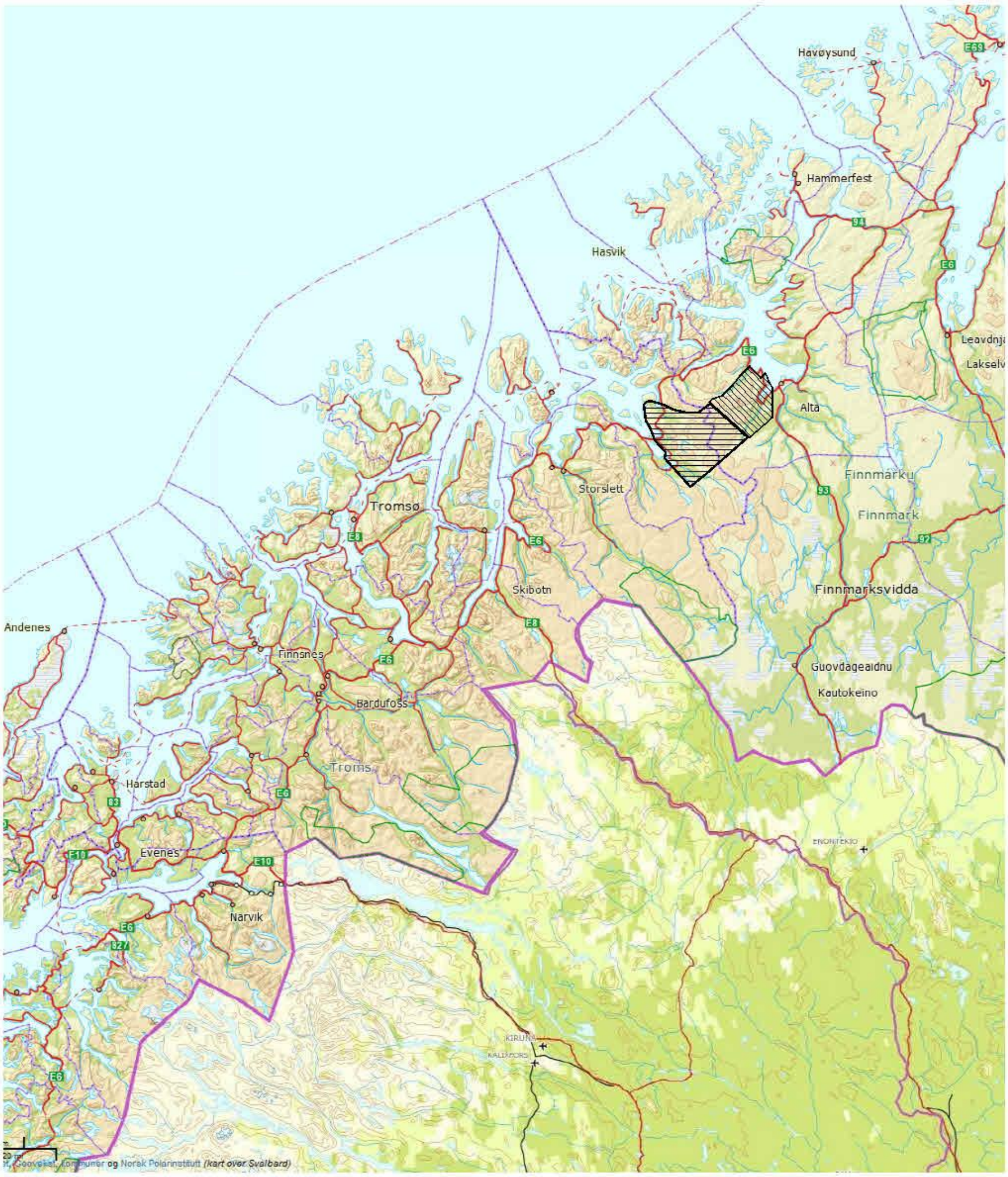

Figure 1: Alta - Kvænangen survey. Location map.

Navigation system uses GPS satellite tracking systems to provide real-time WGS-84 coordinate locations for every second. The accuracy achieved with no differential corrections is reported to be ± 5 m in the horizontal directions. The GPS receiver antenna was mounted externally to the tail tip of the helicopter.

2.2 Airborne Survey Instrumentation

Instrument specification is given in table 1. Frequencies and coil configuration for the Hummingbird EM system is given in table 2.

Table 1: Instrument specifications.

Instrument	**Producer/Model**	**Accuracy**	**Sampling frequency**
Magnetometer	Scintrex Cs-2	0,002 nT	5 Hz
Base magnetometer	Scintrex EnviMag	0,1 nT	3,3 Hz
Electromagnetic	Geotech Hummingbird	1 – 2 ppm	10 Hz
Gammaspectrometer	Radiation Solutions RSX-5	1024 kanaler, 16 liter ned, 4 l opp	1 Hz
Radar altimeter	Bendix/King KRA 405B	± 3 % 0 – 500 fot ± 5 % 500 – 2500 fot	1 Hz
Pressure/temperature	Honeywell PPT	± 0,03 % FS	1 Hz
Navigation	Topcon GPS-receiver	± 5 meter	1 Hz
Acquisition system	Geotech Ltd		

Table 2: Hummingbird electromagnetic system, frequency and coil configurations.

Coils:	**Frequency**	**Orientation**	**Separation**
A	7700 Hz	Coaxial	6.20 m
B	6600 Hz	Coplanar	6.20 m
C	980 Hz	Coaxial	6.025 m
D	880 Hz	Coplanar	6.025 m
E	34000 Hz	Coplanar	4.87 m

The electromagnetic, magnetic and radiometric, altitude and navigation data were monitored on the operator's displays during flight while they were recorded to the DAS hard disk drive. Spectrometry data were also recorded to internal hard drive of spectrometer. The data files were transferred to the field workstation via USB flash drive. Base station magnetometer data were recorded once every 3 second. The magbase data were transferred to the field workstation through com port. The CPU clock of the base magnetometer computer was synchronized to the CPU clock of the DAS on a daily basis. The raw data files were backed up onto USB flash drive in the field.

3. DATA PROCESSING AND PRESENTATION

The acquired data were uploaded to NGU FTP server on daily basis. The data were processed by AR Geoconsulting in Calgary. The ASCII and binary data were downloaded from FTP server, converted and imported to Oasis Montaj databases daily. All datasets were processed according to processing flow charts shown in Appendix A.

3.1 Total Field Magnetic Data

At the first stage the magnetic data were visually inspected and large spikes were removed manually. Then the data from magbase station were imported in magnetic database using the standard Oasis magbase.gx module. Diurnal variation channel was also inspected for spikes and spikes were removed manually if necessary. Since the airborne data were smooth and contained no significant cultural noise, filtering of the raw data was not necessary. Magbase data were slightly filtered with 6 sec low pass filter.

Typically, several corrections have to be applied to magnetic data before gridding - heading correction, lag correction and diurnal correction.

Diurnal Corrections.
The temporal fluctuations in the magnetic field of the earth affect the total magnetic field readings recorded during the airborne survey. This is commonly referred to as the magnetic diurnal variation. These fluctuations can be effectively removed from the airborne magnetic data set by using a stationary reference magnetometer that records the magnetic field of the earth simultaneously with the airborne sensor.

The base magnetometer was located at the Alta airport, a few km north-east of the measured area. The average total field value for this point was 53103 nT. The base station computer clock was synchronized with the DAS clock on a daily basis. The recorded data are merged with the airborne data and the diurnal correction is applied according to equation (1).

$$\mathbf{B}_{Tc} = \mathbf{B}_T + \left(\overline{B}_B - \mathbf{B}_B\right), \qquad (1)$$

Where:

$\mathbf{B}_{Tc}$ = Corrected airborne total field readings

$\mathbf{B}_T$ = Airborne total field readings

$\overline{B}_B$ = Average datum base level

$\mathbf{B}_B$ = Base station readings

Corrections for Lag and heading.
Neither a lag nor cloverleaf tests were performed before the survey. Herringbone pattern of gridded data suggested that the lag was 5 fids, so observed total magnetic field data were lag corrected to compensate the difference in position of sensors and GPS antenna.

Magnetic data gridding and presentation.
Before gridding, flight data were split by lines. The International Geomagnetic Reference Field (IGRF) was calculated for the survey area and removed from the diurnally corrected and lagged magnetic data. A micro levelling technique was applied to the magnetic data to remove small line-to-line levelling errors. For the purposes of data presentation and interpretation the

total field magnetic data are gridded with a cell size of 50 m. The resulting grid was used for calculation of vertical gradient of total magnetic field and tilt derivative.

3D inversion of magnetic data in the western part of the survey area was performed using Mag3D version3 UBC inversion software (UBC 2005). One of the magnetic susceptibility cross-section derived from the inversion is presented in this report as an example of the advanced processing of magnetic datasets. (**Feil! Fant ikke referansekilden.**). Complete results of the 3D inversion are available on a request.

3.2 Electromagnetic Data

The DAS computer records both an in-phase and a quadrature value for each of the five coil sets of the electromagnetic system. Instrumental noise and drift should be removed before computation of an apparent resistivity.

3.2.1 Instrumental noise.

In-phase and quadrature data were filtered with 3 fiducial non-linear filter to eliminate spheric spikes which were represented as irregular spikes of large amplitude in the records. Simultaneously, a 30 fiducial low-pass filter was also applied to suppress high frequency components of instrumental and cultural noise. The cultural noise in the survey area was low, but instrumental noise was variable and affected the quality of the data in several flights. Instrumental noise could not be completely supressed by filtering and remains visible on records.

3.2.2 Instrument Drift

In order to remove the effects of instrument drift caused by gradual temperature variations in the transmitting and receiving circuits, background responses are recorded during each flight. To obtain a background level the bird is raised to an altitude of approximately 1000 ft above the topographic surface so that no electromagnetic responses from the ground are present in the recorded data. The EM traces observed at this altitude correspond to a background (zero) level of the system. If these background levels are recorded at 20-30 minute intervals, then the drift of the system (assumed to be linear) can be removed from the data by resetting these points to the initial zero level of the system. The drift must be removed on a flight-by-flight basis, one frequency at a time, before any further processing is carried out. Geosoft HEM module was used for applying drift correction. Residual instrumental drift, often non-linear, was manually removed on line-to-line basis.

*Note: Nonlinearity of the drift of 34 kHz channels was so high during several flights that it was not possible to level these channels with reasonable precision. Also, due to instability in the system, the phasing of 34 kHz was wrong at several flights. As a result, the quality of data for 34 kHz was found to be not acceptable and these data have not been processed and presented.

3.2.3 Apparent resistivity calculation and presentation

When levelling of the EM data was complete, apparent resistivity was calculated from in-phase and quadrature EM components using a half space homogeneous model of the Earth (Geosoft HEM module) for 4 frequencies only. Threshold of 2 ppm was set for inversion for 6.6 kHz data and 1 ppm for 880 Hz, 7 kHz and 980 Hz.

Secondary electromagnetic field decays rapidly with the distance (height of the sensors) – as z^{-2} – z^{-5} depending on the shape of the conductors and, at certain height, signals from the ground sources become comparable with an instrumental noise. Levelling errors or precision of levelling can sometimes lead to appearance of artificial resistivity anomalies when data are collected at high instrumental altitude. Application of threshold allows excluding such data from an apparent resistivity calculation, though not completely. It's particularly noticeable in low frequency datasets. Resistivity data were visually inspected; artificial anomalies associated with high altitude measurements were manually removed and then levelled. Revised resistivity data were gridded with a cell size 50 m and convolution filter was applied to smooth the grids.

Inversion for multi-layered model of the Earth was performed for the line 1940 using EM1DFM UBC inversion package (UBC 2000). Resistivity cross-section is shown on Figure **3**.

3.3 Radiometric data

In processing of the airborne gamma ray spectrometry data, live time corrected U, Th and K were corrected for the aircraft and cosmic background (e.g. Grasty 1987; IAEA 2003). The upward detector method, as discussed in IAEA (2003), was applied to remove the effects of radon in the air below and around the helicopter. Window stripping was used to isolate count rates from the individual radio-nuclides K, U and Th (IAEA, 2003). For several reasons, the sensor was not always at a constant altitude. Stripped window counts were therefore corrected for variations in flying height to a constant height of 60 m. Finally, count rates were converted to effective ground element concentrations using calibration values derived from calibration pads at the Geological Survey of Norway in Trondheim. A list of the parameters used in the processing scheme is given in Appendix B1. For further reading regarding standard processing of airborne radiometric data, we recommend the publication from Minty et al. (1997).

*Note: A correlation between upward looking detector data and radon concentration varied significantly from day to day, probably due to weather. Most notably, it was observed during flights 13, 14, 15 and 16. Flights 29, 30, 31 were flown when snow already covered the ground. In these circumstances, radon calculation and removal was applied on flight by flight basis. Tie-line corrections were used to level the effect of attenuation of radiation from snow cover.

4. PRODUCTS

Processed digital data from the survey are presented as:

1. Three Geosoft XYZ files: Kvænangen_Mag.xyz, Kvænangen_EM.xyz, Kvænangen_Rad.xyz, available from NGU on request.
2. Coloured maps at the scale 1:50000 available from NGU on request.

Table 3: Maps in scale 1:50000 available from NGU on request.

Map #	Name
2012.065-01	Total magnetic field
2012.065-02	Total magnetic field. Vertical gradient
2012.065-03	Total magnetic field. Tilt derivative
2012.065-04	Apparent resistivity, Frequency 6600 Hz, coplanar coils
2012.065-05	Apparent resistivity, Frequency 880 Hz, coplanar coils
2012.065-06	Apparent resistivity, Frequency 7000 Hz, coaxial coils
2012.065-07	Apparent resistivity, Frequency 980 Hz, coaxial coils
2012.065-08	Uranium ground concentration
2012.065-09	Thorium ground concentration
2012.065-10	Potassium ground concentration
2012.065-11	Radiometric Ternary map
2012.065-12	Radiometric Total count

Downscaled images of the maps are shown on figures 5 - 16

5. REFERENCES

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Grasty, R.L. 1987: The design, construction and application of airborne gamma-ray spectrometer calibration pads – Thailand. Geological Survey of Canada. Paper 87-10. 34 pp.

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Minty, B.R.S., Luyendyk, A.P.J. and Brodie, R.C. 1997: Calibration and data processing for gamma-ray spectrometry. AGSO – Journal of Australian Geology & Geophysics. 17(2). 51-62.

Naudy, H. and Dreyer, H. 1968: Non-linear filtering applied to aeromagnetic profiles. Geophysical Prospecting. 16(2). 171-178.

Radiation Solutions 2008: Instruction manual, RSX-5 gamma-ray spectrometer.

UBC 2000: Manual for running the program "EM1DFM". UBC - Geophysical Inversion Facility, Department of Earth & Ocean Sciences, University of British Columbia, Vancouver, CANADA. July, 2000.

UBC 2005: MAG3D. A Program Library for Forward Modelling and Inversion of Magnetic Data over 3D Structures. UBC - Geophysical Inversion Facility, Department of Earth & Ocean Sciences, University of British Columbia, Vancouver, CANADA. May, 2005.

6. Appendix A1: Flow chart of magnetic processing

Meaning of parameters is described in the referenced literature.

Processing flow:

- Quality control.
- Visual inspection of airborne data and manual spike removal
- Conversion of ASCII data file from magbase station to Geosoft *.bas files
- Import magbase data to Geosoft database
- Inspection of magbase data and removal of spikes
- Correction of data for diurnal variation
- Conversion of WGS-84 geographic coordinates to UTM 33N coordinates
- Splitting flight data by lines
- IGRF calculation and subtraction of IGRF from observed total field.
- Gridding
- Microlevelling

7. Appendix A2: Flow chart of EM processing

Meaning of parameters is described in the referenced literature.

Processing flow:

- Filtering of in-phase and quadrature channels with non-linear and low pass filters
- Automated leveling
- Quality control
- Visual inspection of data.
- Conversion of WGS-84 geographic coordinates to UTM 33N coordinates
- Splitting flight data by lines
- Manual removal of remaining part of instrumental drift
- Calculation of an apparent resistivity for each frequency
- Manual removal of artificial resistivity anomalies
- Microlevelling of apparent resistivity.
- Gridding
- Convolution filter.

8. Appendix A3: Flow chart of radiometry processing

Underlined processing stages are not only applied to the K, U and Th window, but also to the total count.
Meaning of parameters is described in the referenced literature.

Processing flow:

- Quality control
- Conversion of WGS-84 geographic coordinates to UTM 33N coordinates
- Splitting flight data to lines
- Calculation U,Th,K,TC windows
- Livetime correction
- Airborne and cosmic correction (IAEA, 2003)
  Used parameters: (determined by high altitude calibration flights near Seljord in June 2012)

  Aircraft background counts:

K window	7
U window	2
Th window	0
Uup window	0
Total counts	44

Cosmic background counts (normalized to unit counts in the cosmic window):

K window	0.0701
U window	0.0463
Uup window	0.0505
Th window	0.0664
Total counts	1.1228

- Radon correction using upward detector method (IAEA, 2003)
  Used parameters (determined from survey data over water and land):
  Parameters were calculated individually for sertain flights or group of flights.

- Stripping correction (IAEA, 2003)
  Used parameters (determined from measurements on calibrations pads at the NGU and Borlänge airport):
  a 0.04840;
  b -0.00121;
  g -0.00074;
  alpha 0.2999
  beta 0.4755
  gamma 0.8314

- <u>Height correction to a height of 60 m</u>
  Used parameters (determined by height calibration flight at near Seljord in June 2012):
  Attenuation factors in 1/m:
  K: -0.0072
  U: -0.0058
  Th: -0.0058
  Total counts: -0.0056

- Converting counts at 60 m heights to element concentration on the ground
  Used parameters (determined from measurements on calibrations pads at the NGU and Borlänge airport):
  Counts per elements concentrations:
  K: 0.00757 %/counts
  U: 0.087834 ppm/counts
  Th: 0.154092 ppm/counts

- <u>Microlevelling using Geosoft menu</u>
  Used parameters for microlevelling:
  De-corrugation cutoff wavelength: 800 m
  Cell size for gridding: 50 m
  Naudy (1968) Filter length: 800 m

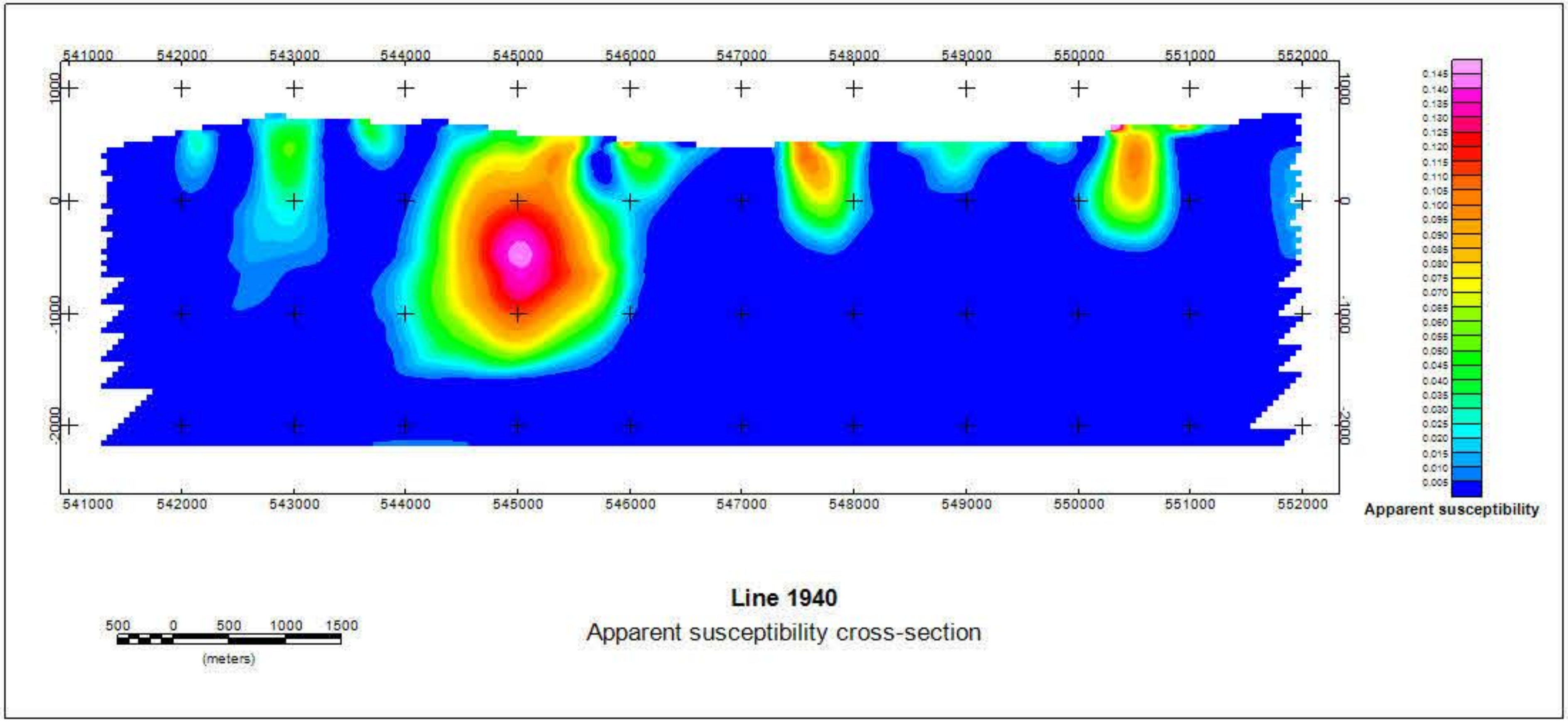

Figure 2: Apparent susceptibility cross-section, line 1940 (see Figure 4).

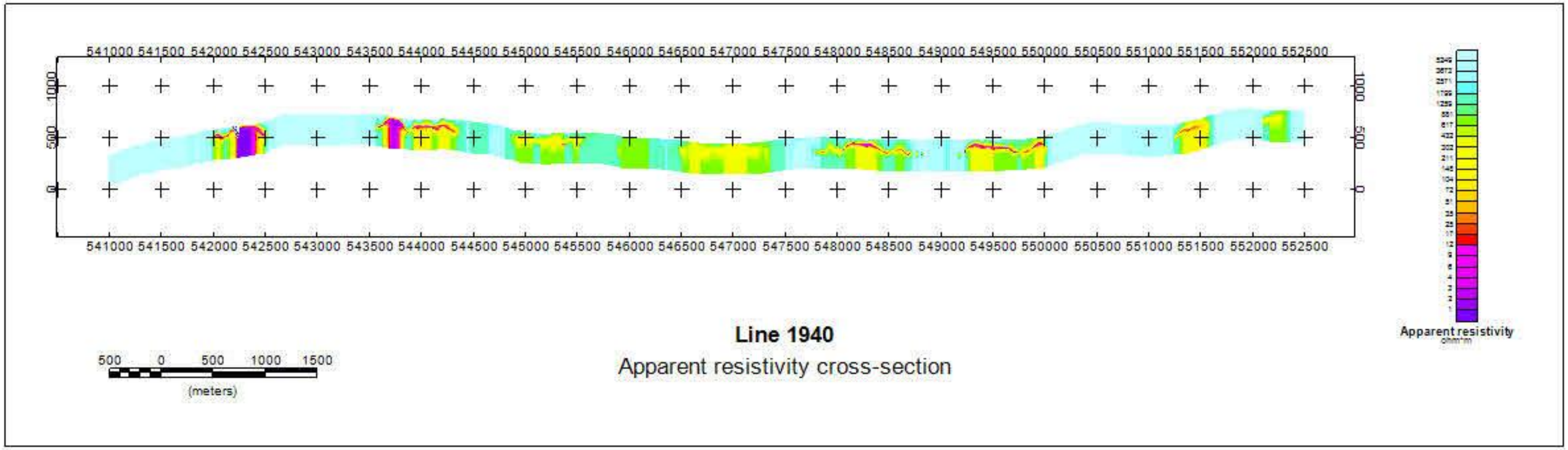

Figure 3: Apparent resistivity cross-section, line 1940 (see figure 4).

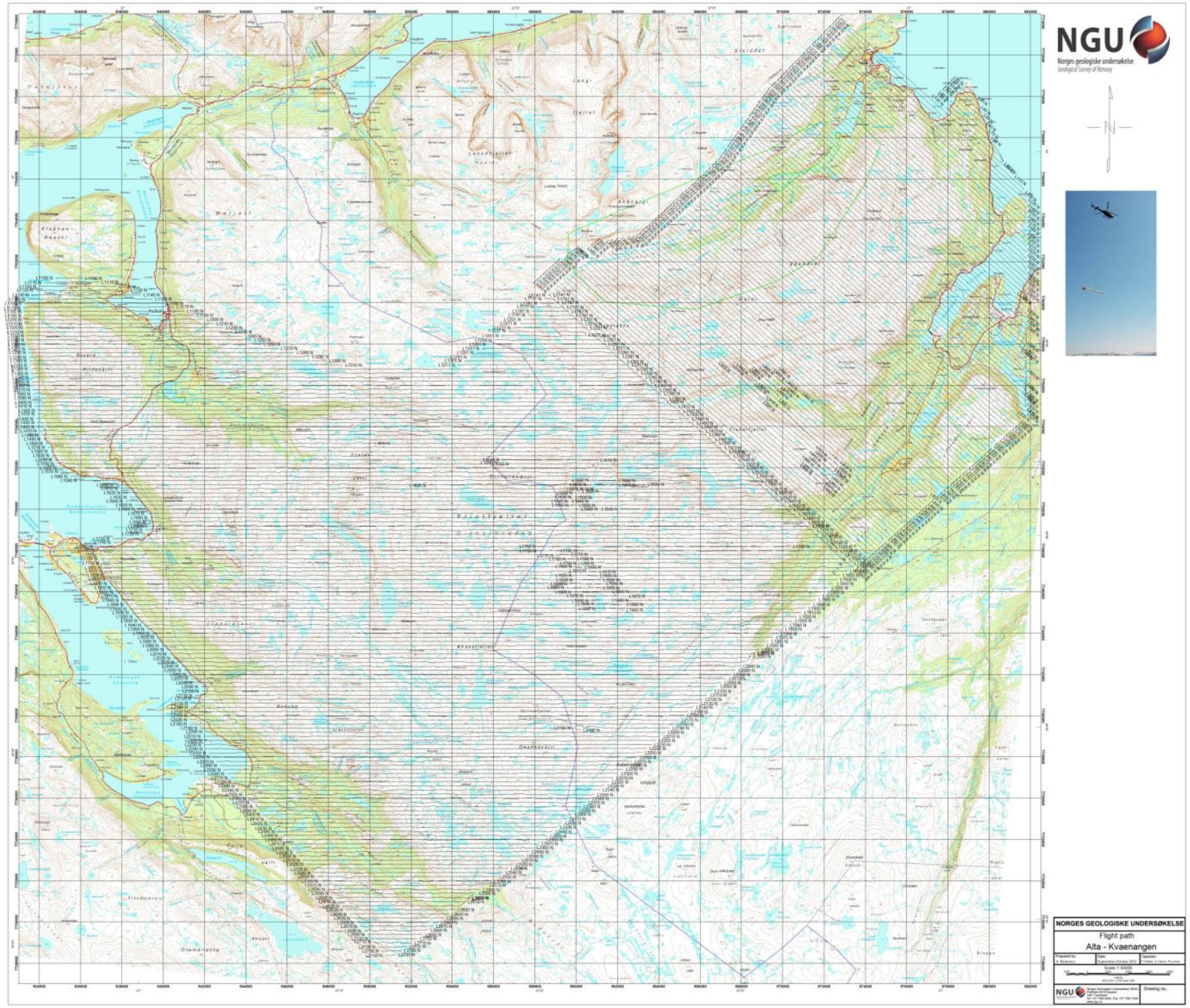

Figure 4: Kvænangen survey. Flight path.

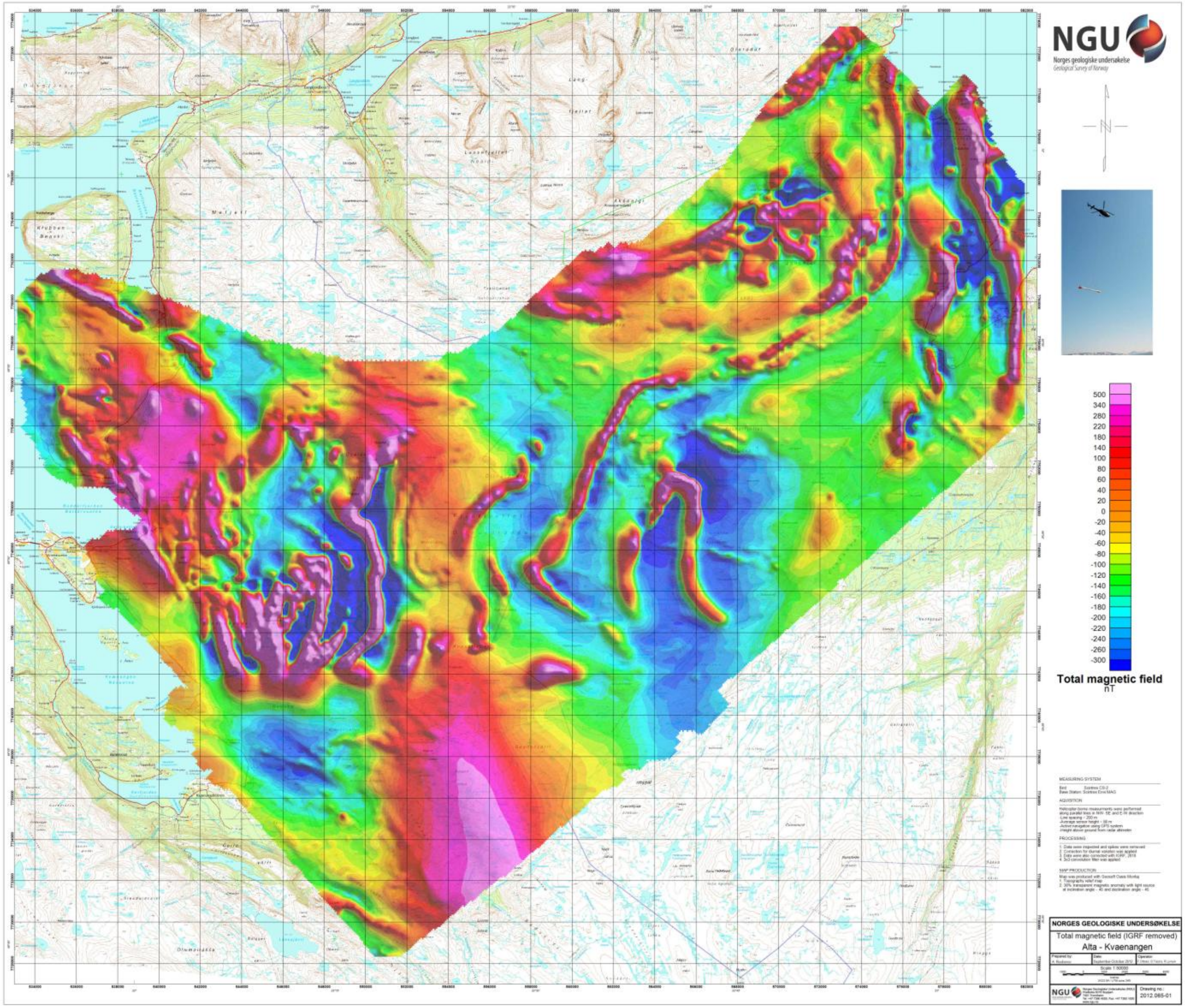

Figure 5: Total magnetic field

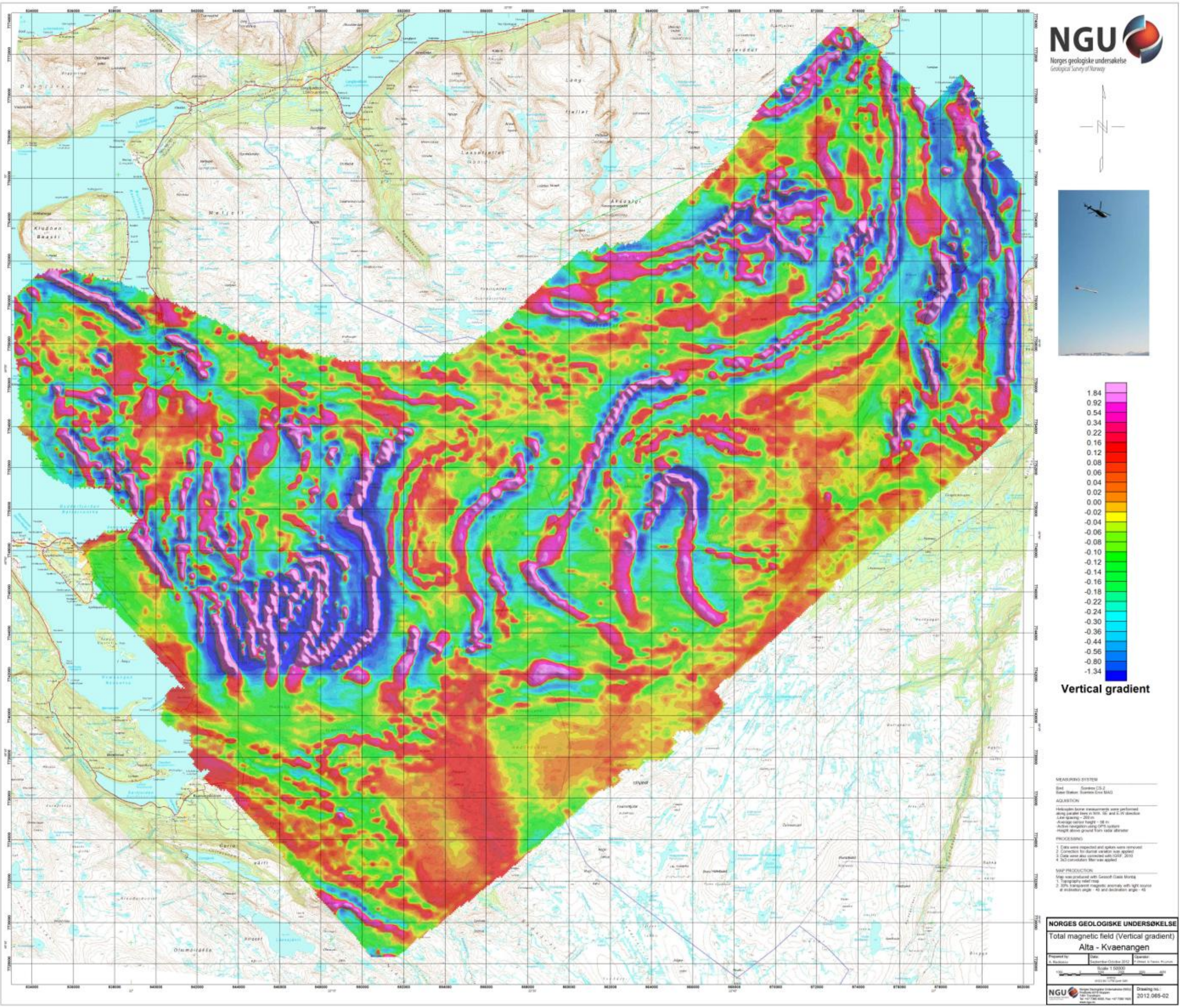

Figure 6: Total magnetic field. Vertical gradient.

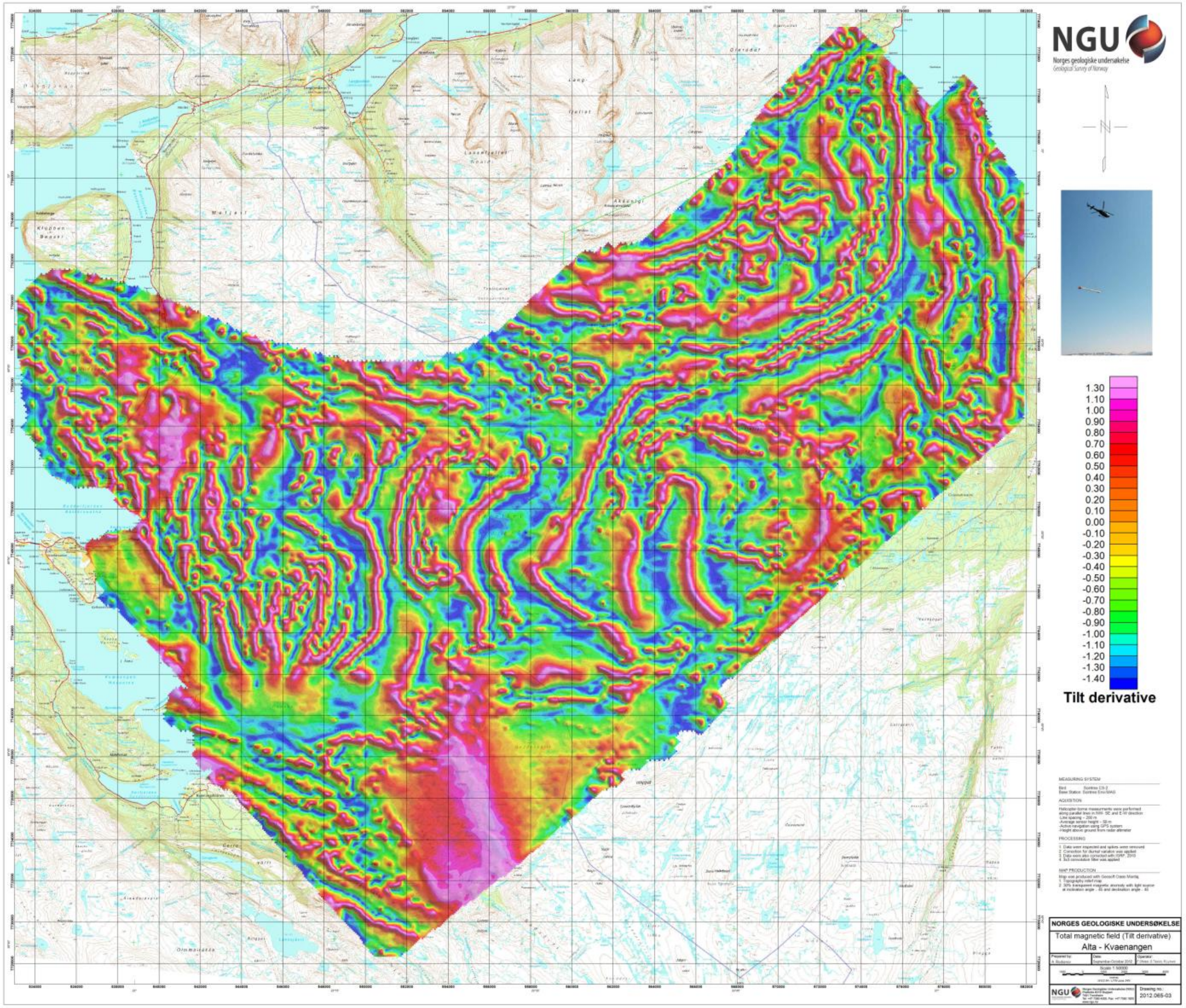

Figure 7: Total magnetic field. Tilt derivative.

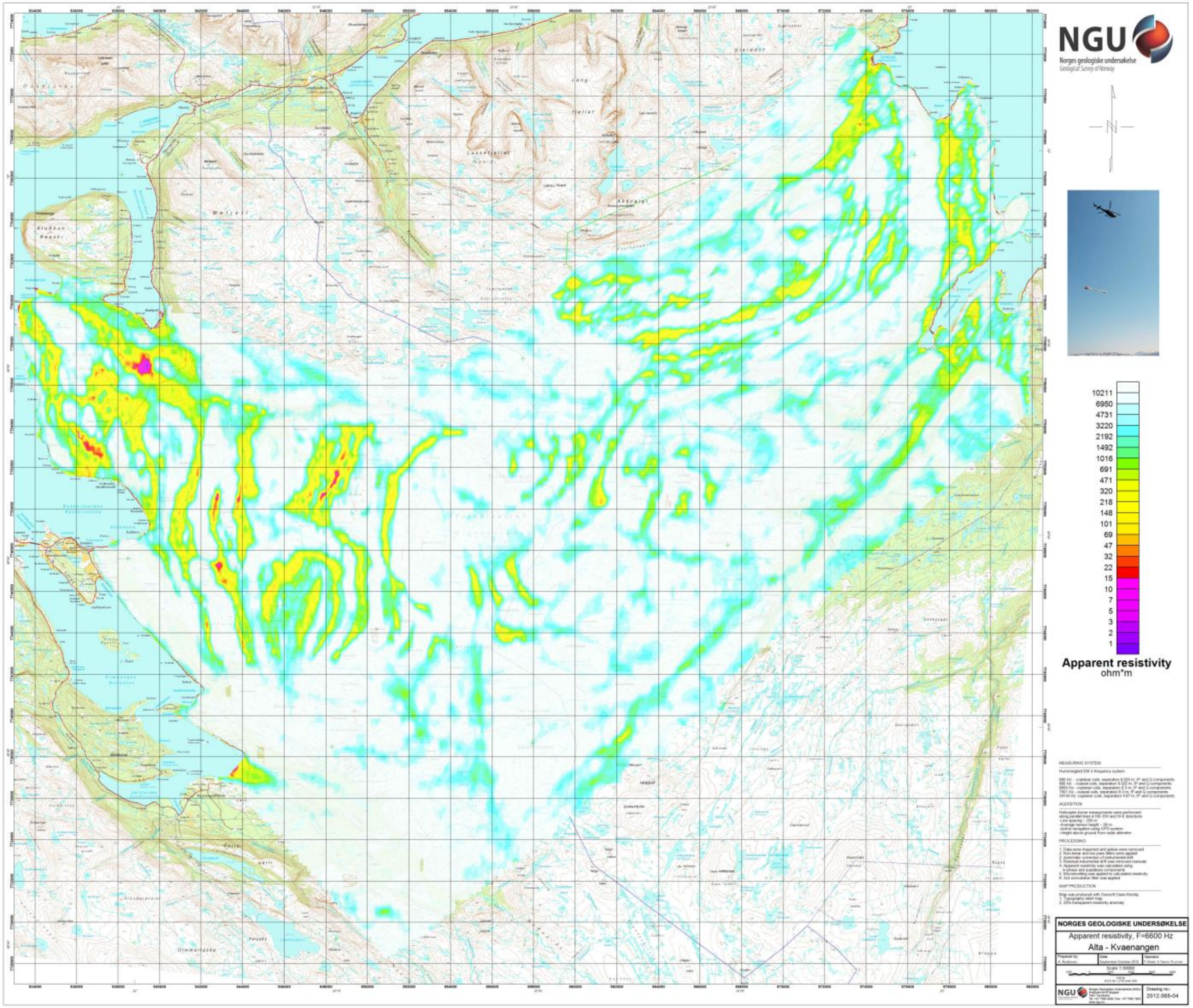

Figure 8: Apparent resistivity. Frequency 6600 Hz, Coplanar coils

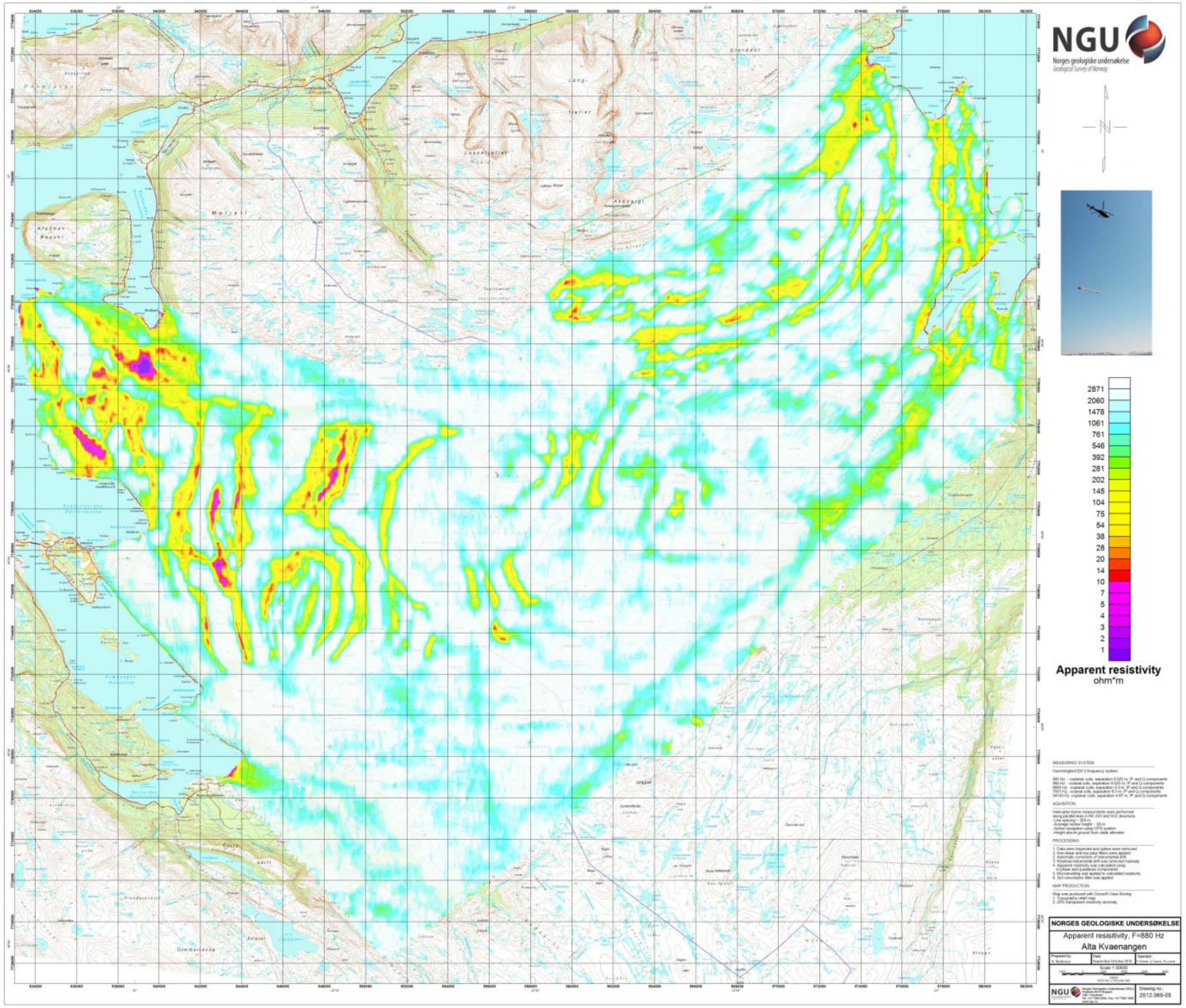

Figure 9: Apparent resistivity. Frequency 880 Hz, Coplanar coils

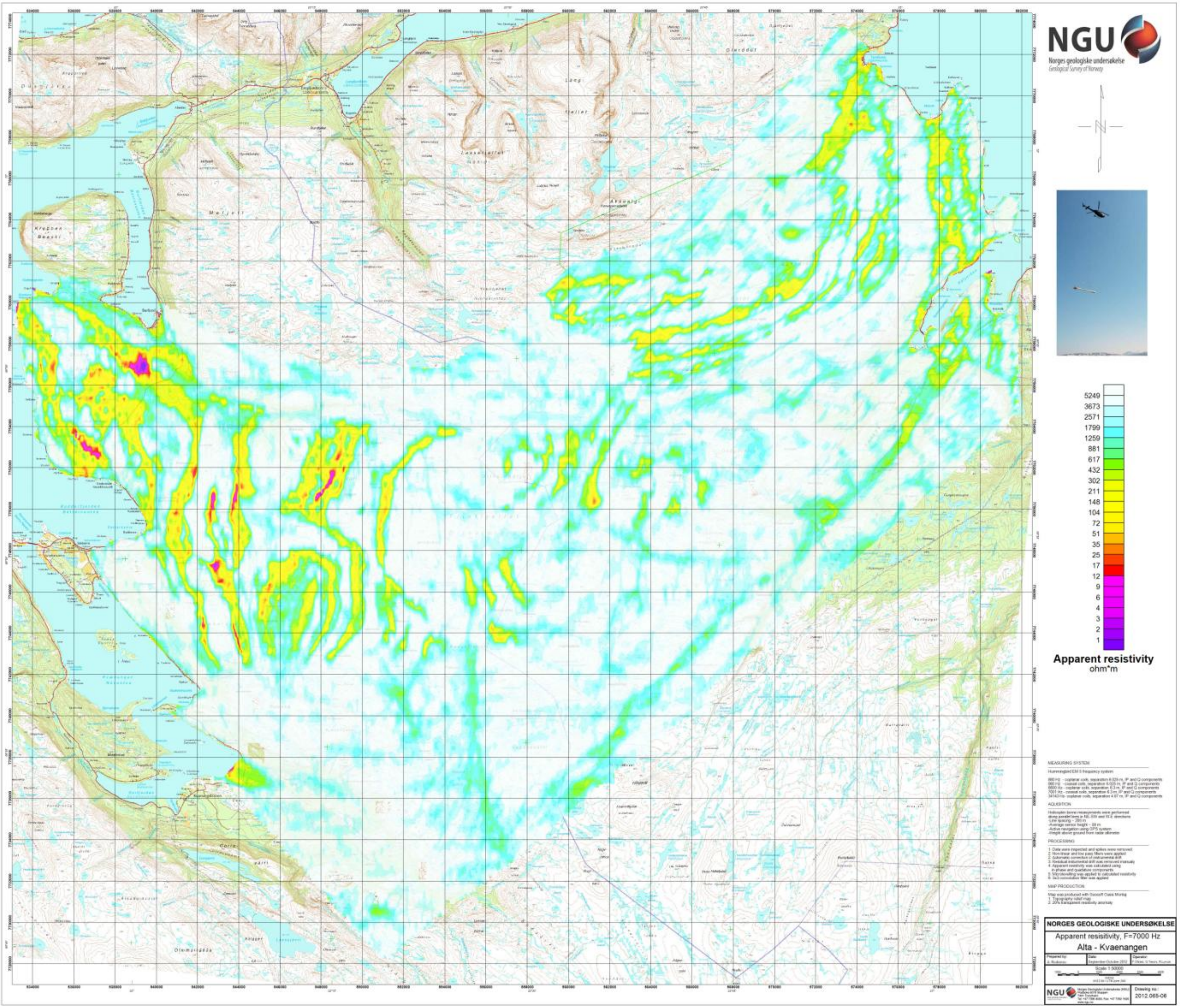

Figure 10: Apparent resistivity. Frequency 7000 Hz, Coaxial coils

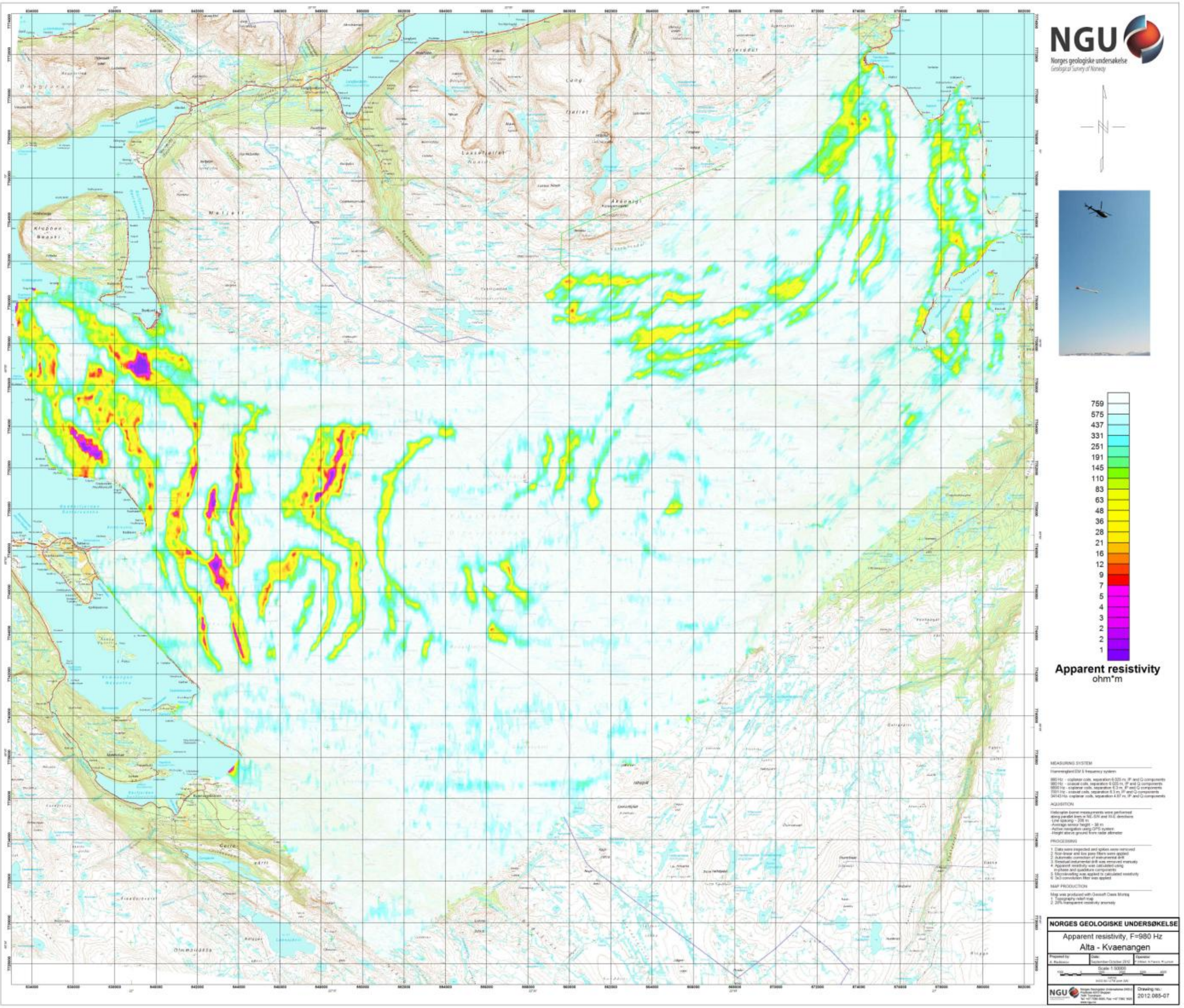

Figure 11: Apparent resistivity. Frequency 980 Hz, Coaxial coils

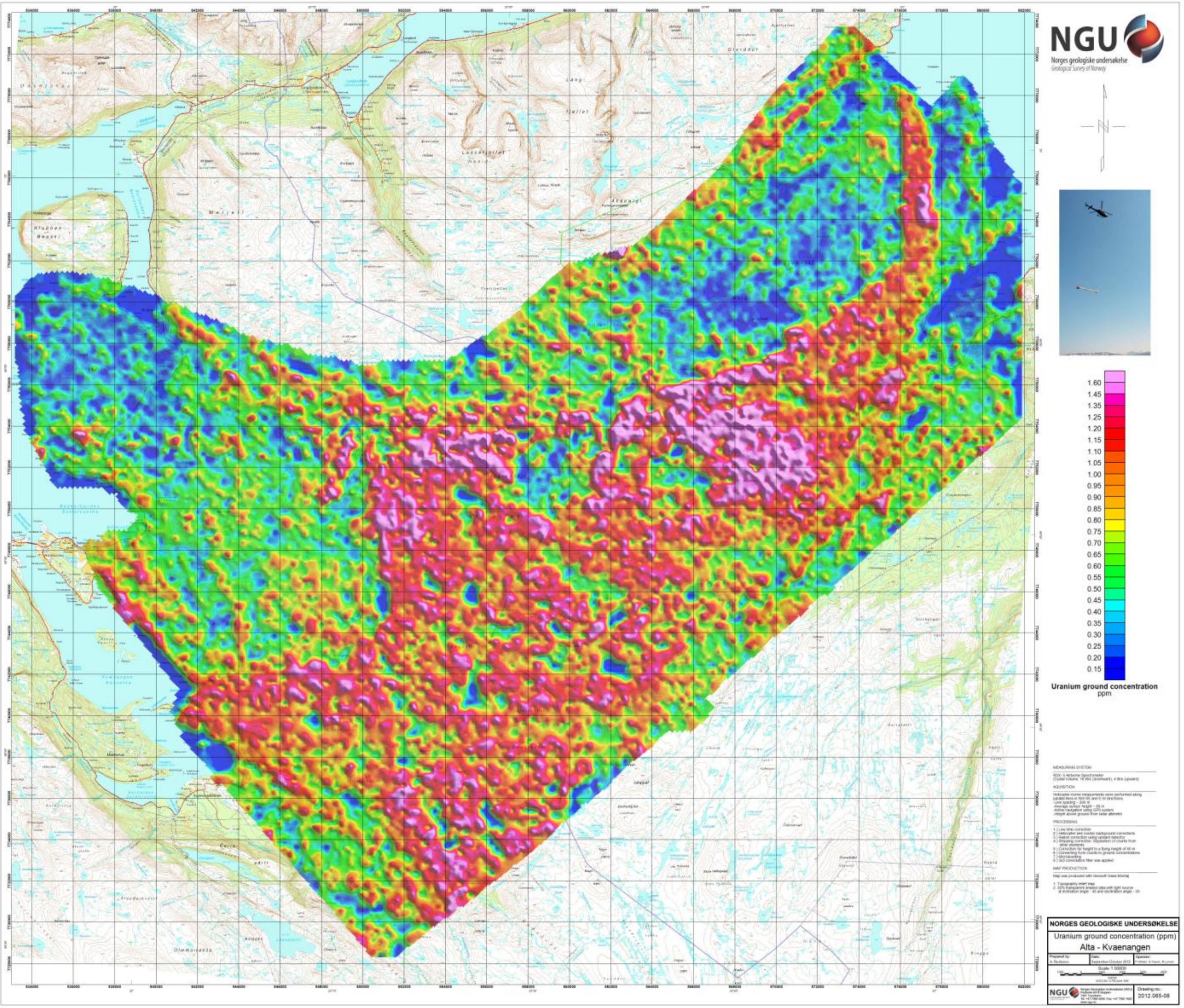

Figure 12: Uranium ground concentration

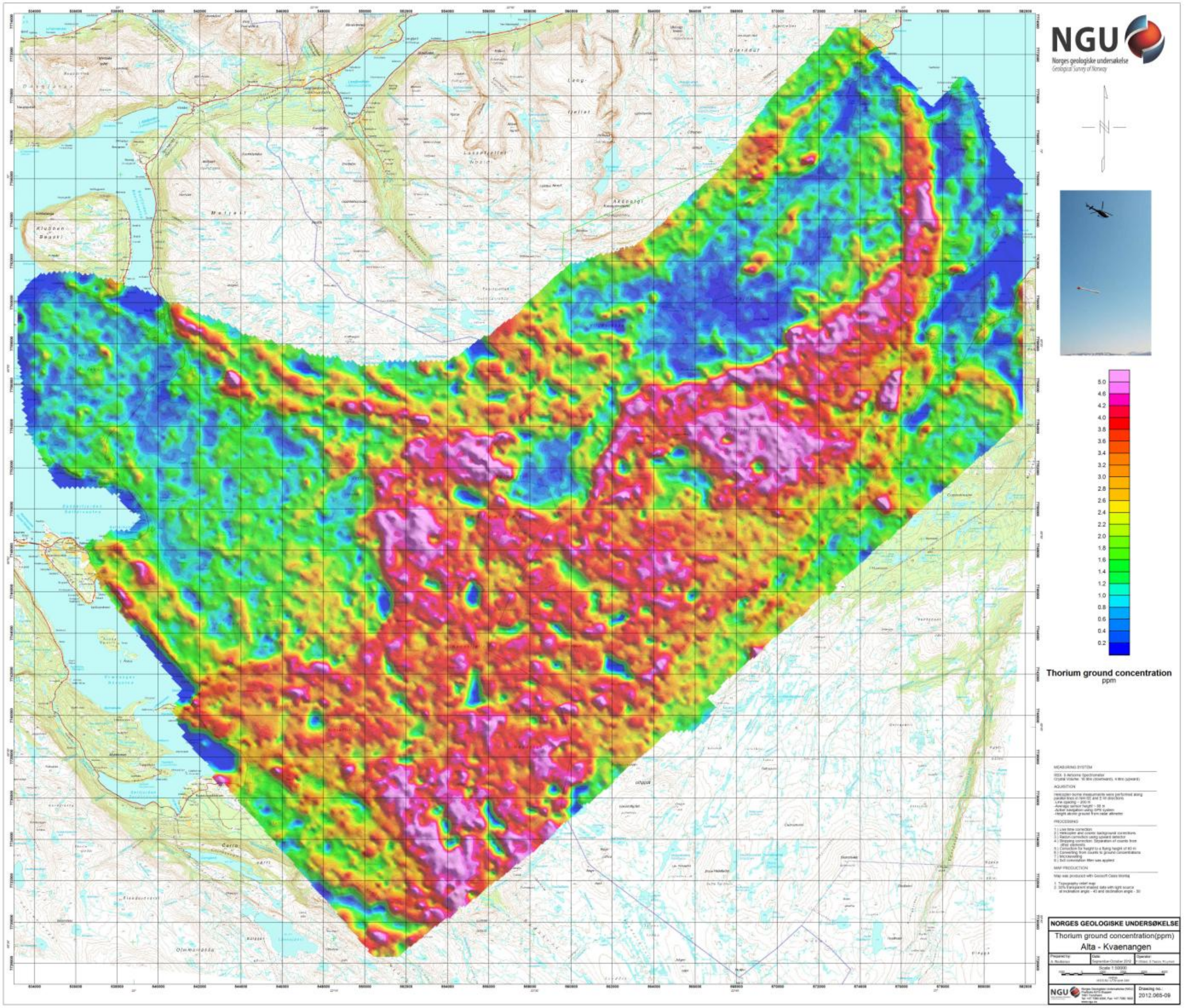

Figure 13: Thorium ground concentration

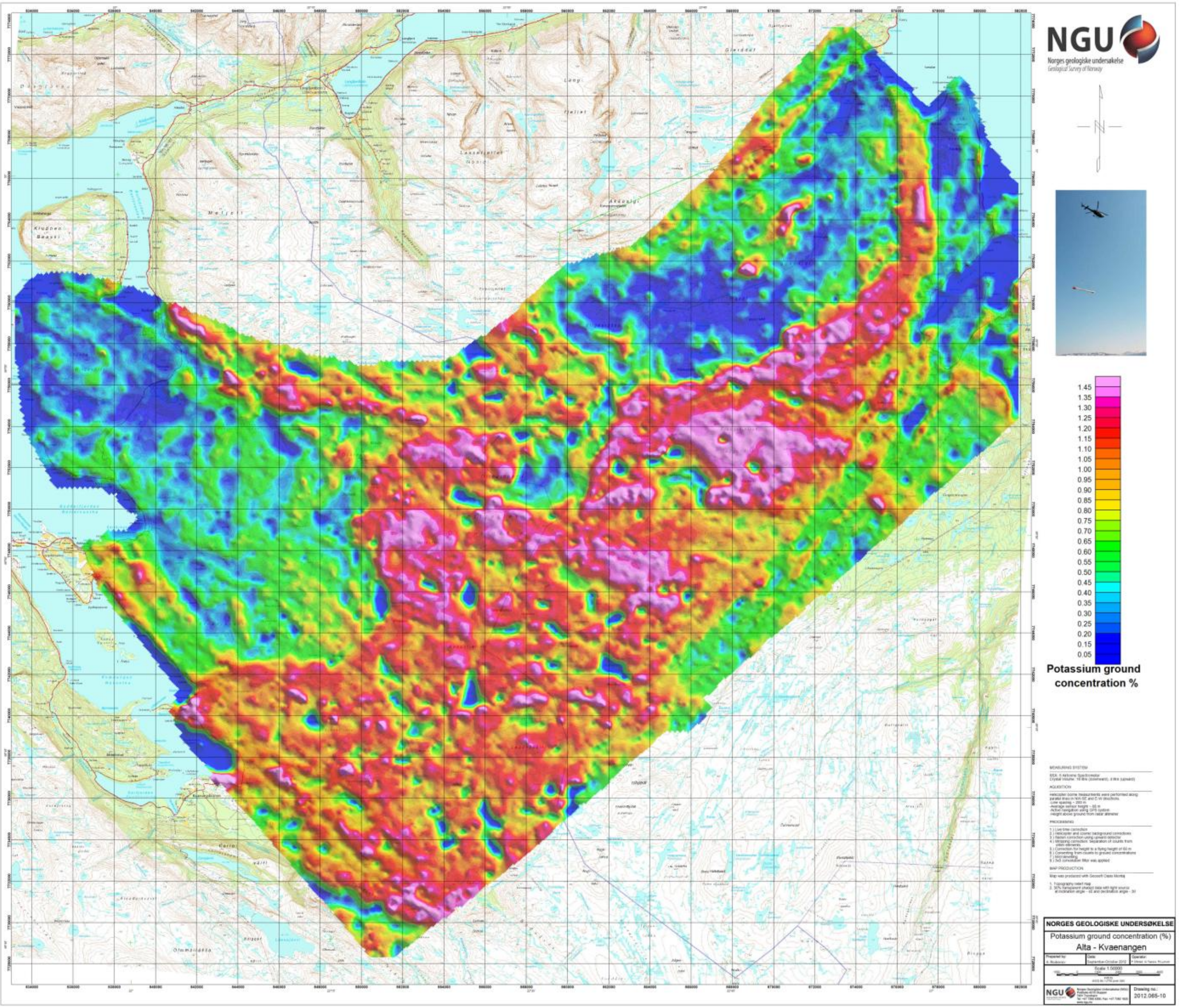

Figure 14: Potassium ground concentration

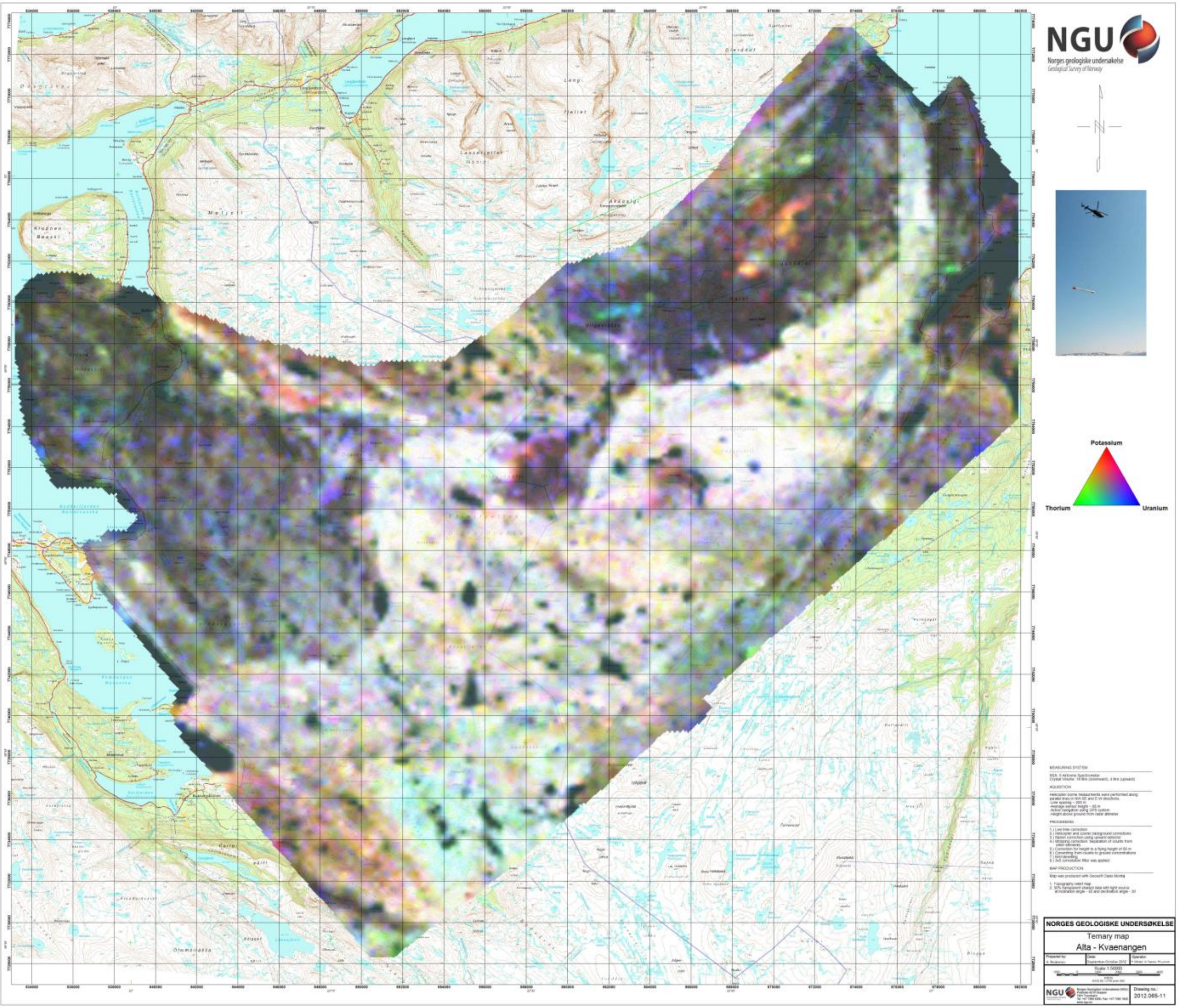

Figure 15: Radiometric ternary map

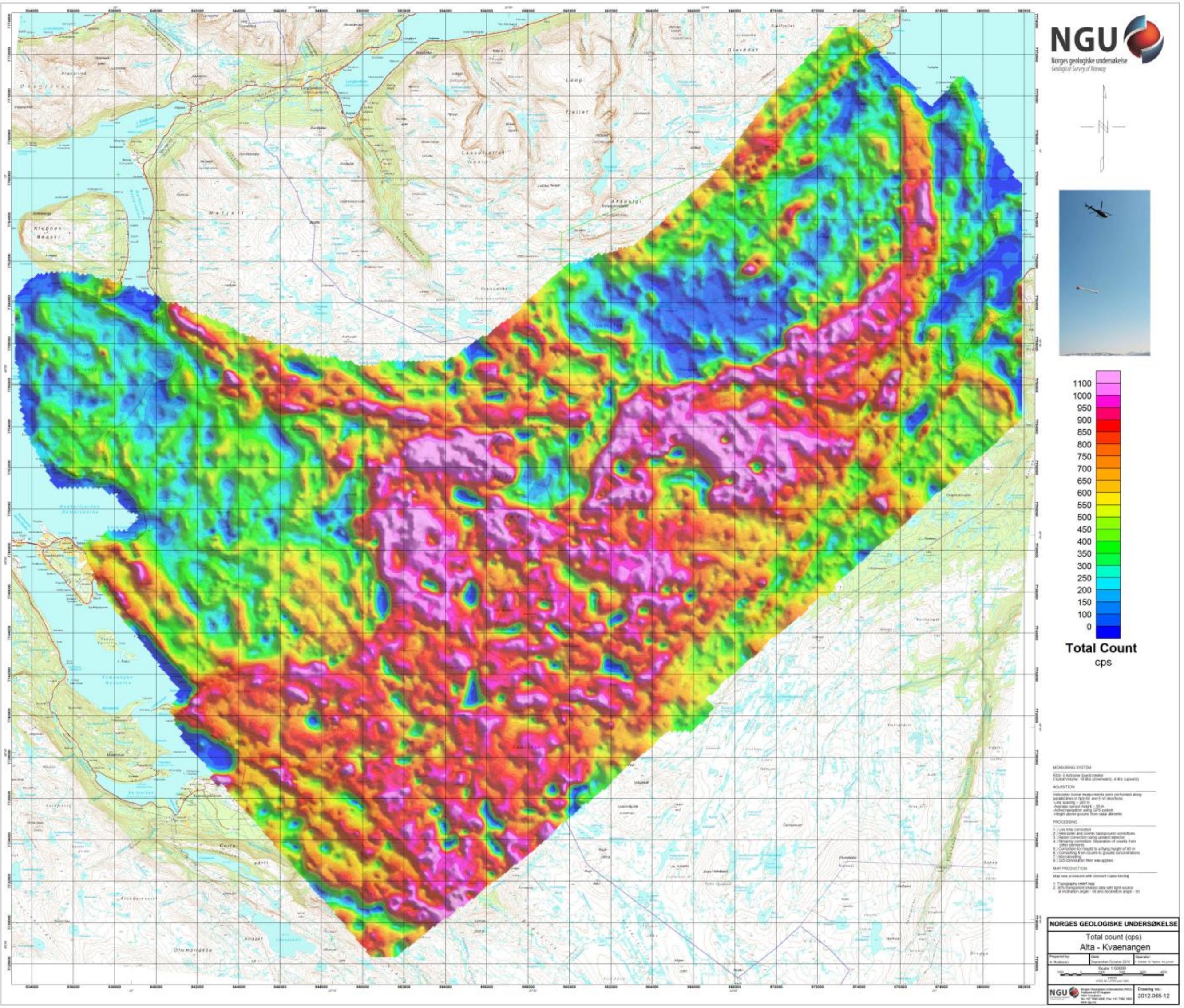

Figure 16: Radiometric total count.