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Helicopter-borne magnetic, electromagnetic and radiometric geophysical survey in the Storforshei area, Rana, Nordland

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REPORT

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Title:
Helicopter-borne magnetic, electromagnetic and radiometric geophysical survey in the Storforshei area, Rana, Nordland

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Summary:

NGU conducted an airborne geophysical survey in Mo I Rana area in July 2012. This report describes and documents the acquisition, processing and visualization of recorded datasets. The geophysical survey results reported herein are 1414 line km.

The Geotech Ltd. Hummingbird frequency domain system supplemented by optically pumped cesium magnetometer and 1024 channels RSX-5 spectrometer was used for data acquisition. The survey was flown with 100 m line spacing, line direction of 180° North-South (in the west) and 150° NorthWest-SouthEast (in the east) with the average speed 96 km/h. The average terrain clearance of the bird was 55 m.

Collected data were processed in by AR GeoConsulting 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 25 m and presented as a shaded relief maps at the scale of 1:25 000.

Keywords: Geophysics	Airborne	Magnetic
Electromagnetic	Gamma spectrometry	Radiometric
		Technical report

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1. INTRODUCTION

A helicopter borne geophysical survey was performed in the neighbourhood of Storforshei in Rana during June- July 2012. The survey was a part of the MINN project (Mineral resources in North Norway) with financial support from Rana Gruber AS . 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 program. 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. The airborne geophysical surveys - helicopter borne and fixed wing- are important integral part of MINN program. The airborne survey reported herein amounts to 1414 line-km flown over the Rana survey area.

The objective of the airborne geophysical survey was to obtain 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 allows 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 cesium 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. LOCATION AND ACCESS

Rana Gruber survey area is situated in the Rana commune, Nordland and centred at approximately UTM 33 W 479000 - 7365000. The area is located in close proximity to the village of Storforshei, 25 km NE of Mo i Rana (**Figure 1**). Access to the area is possible by plane to Røssvollen airport, by car from E6 highway or by railway. The flight path of the survey and adjacent areas can be seen in **Figure 4**.

3. SURVEY SPECIFICATIONS

3.1 Airborne Survey Parameters

NGU used a Hummingbird™ electromagnetic and magnetic helicopter survey system designed to obtain low level, slow speed, detailed airborne magnetic and electromagnetic data (Geotech 1997).

A Eurocopter AS350-B2 helicopter was used to tow the bird. The survey lines were spaced 100 m apart. Lines were oriented 180° at the western part of the survey area and 150° at the eastern part. The magnetic and electromagnetic sensors are housed in a single 7.5 m long bird, which was maintained at an average of 55 m above the topographic surface. Gamma spectrometer installed under the belly of the helicopter registered natural gamma ray radiation simultaneously with the acquisition of magnetic/EM data.

Extremely 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 – 110 km/h depending on topography, wind direction and its intensity. The average ground speed is estimated to be 96 km/h. Magnetic data were recorded at 0.2 second intervals resulting in 3 to 8 m point spacing. EM data were recorded at 0.1-0.2 second intervals resulting in data with a sample increment of 3 to 8 m along the lines. Spectrometry data were recorded every 1 second. The above parameters were designed to allow sufficient detail in the data in order to detect subtle anomalies that may represent mineralization and/or rocks of different lithological and petrophysical composition.

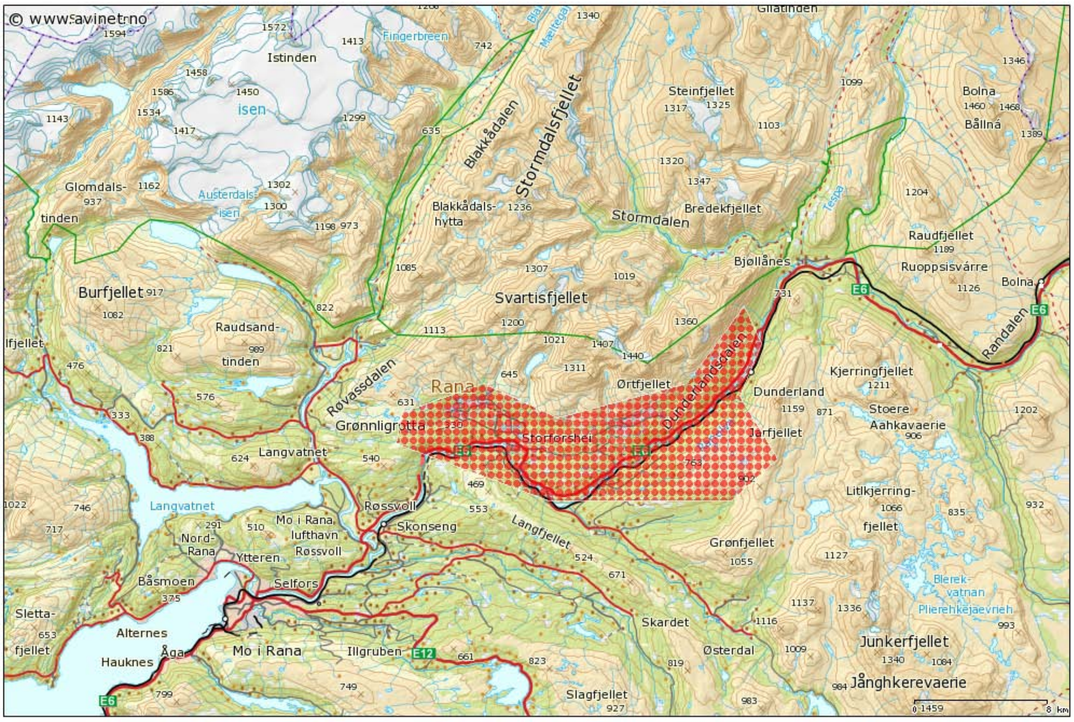

Figure 1: Rana Gruber survey. Location map.

Navigation system uses GPS satellite tracking systems to provide real-time WGS-84 coordinate locations every second. The accuracy achieved with no differential corrections is reported to be ± 5 m in the horizontal directions.

The airborne survey began on June 27. Survey crew encountered multiple problems with the geophysical equipment from the start of the survey. Numerous spikes and gaps in recording of magnetic, electromagnetic channels and GPS were observed at flights 2 – 13. Instrumental drift of 34 kHz and 880 Hz of EM channels did not comply with Hummingbird specification and was mostly non-linear. As a result of equipment malfunction, some data could not pass quality control and 34 lines were partially or completely re-flown. All attempts to find and fix equipment problem in the field were unsuccessful and, on July 4, decision was made to suspend survey and return Hummingbird system to Trondheim. Hummingbird system was repaired at NGU office. Some electronic components of digital acquisition system and acquisition software were replaced. Electromagnetic subsystem was fully recalibrated and after test flights the survey continued on July 18 and ended on July 19, 2012.

3.2 Airborne Survey Instrumentation

Electromagnetic System

Model: Hummingbird™ manufactured by Geotech Ltd.
Type: Towed bird with 2 maximally coupled coil configurations for 5 distinct frequencies: 2 vertical coaxial and 3 horizontal coplanar (**Table 2**).
Sample Rate: *10* samples per second (5-10 Hz)
Noise level: 1 – 2 ppm

Table 1. Hummingbird electromagnetic 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

Airborne Magnetometer

Model: Scintrex CS-2
Type: Optically pumped Cesium vapour magnetometer.
Sensitivity: 0.002 nT
Sampling Rate: 5 Hz
Counter Kroum KMAG-4

Gamma Spectrometer

Model: Radiation Solutions RSX-5
Number of detectors 4x4 Litre downward, 1x4 Litre upward.
Channels: 1024
Sampling Rate: 1 sec
Stabilisation Automatic multi-peak

Magnetic Base Station

Model: Scintrex EnviMAG
Type: Proton magnetometer.
Sensitivity: 0.1 nT
Sampling Rate: 3 sec.

Radio Altimeter

Model: Bendix/King KRA 405B
Type: Radar altimeter
Accuracy: ±3% at 0-500ft and 5% at 500-2500ft
Sampling Rate: 1 Hz

Barometric Altimeter

Model:	Honeywell Inc. PPT
Type:	Digital Pressure Transducer
Accuracy:	±0.03% FS
Sampling Rate:	1 Hz

Navigation System

Model:	Topcon receiver
Display:	Remote color screen display for flight path cross-track guidance.
Accuracy:	±5 m
Sampling Rate:	Recording at 1 Hz

Digital Acquisition software

Manufacturer:	2 separate "In-house" build applications for acquisition of 1) navigation/magnetic, 2) EM data. Radiation Solutions RadAssist software (RSX-5 spectrometer) Geotech (navigation, magnetic, EM and spectrometry data were recorded in single file starting from flight 18)
Computer:	Nexcom VTC 6100/ Hummingbird DAS
Display:	17' LDS 4101D
Interface Cards:	USB Flash drives

3.3 Airborne Survey Instrumentation Summary

The aircraft used for the survey was a Eurocopter AS350-B2. The rack mounted digital data acquisition system (DAS), spectrometer console, navigation computer and barometric altimeter were installed onto the floor in the rear passenger compartment of the aircraft. A skin cable, passed through the belly of the aircraft, connected the DAS to the tow cable. The DAS computer screen was mounted on the rack to the left side of the operator's seat. The navigation screen displaying navigation information and an altitude of the helicopter was installed on the instrument panel on the pilot side of the cockpit. The GPS receiver antenna was mounted externally to the tail tip of the helicopter.

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 the 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.

3.4 Airborne Survey Logistics Summary

Traverse (survey) line spacing:	100 metres
Traverse line direction:	150° SE – NW in the eastern part 180° S-N in the western part
Nominal aircraft ground speed:	30 - 110 km/h
Average sensor terrain clearance:	55 metres
Sampling intervals:	0.2 second - magnetometer 0.1 second - electromagnetics 1.0 second - spectrometer, GPS, altimeter

4. 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 consequently according to processing flow charts shown in Appendix A1.

4.1 Total Field Magnetic Data

At the first stage the magnetic data were visually inspected and 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 if present, they 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 4 sec low pass filter. All data were collected within standard diurnal specifications (Rønning 2012).

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

4.1.1 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 Røssvoll Airport, approximately 10 km sout-west of the surveyed area. The average total field value for this point was 52587 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

4.1.2 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 variable and changed from -5 to +7 fids. Thereby, lag correction was applied on line by line basis and even so, some herringbone offsets still can be noted, especially in the western part of the survey area.

4.1.3 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 25 m, which represents one quarter of the 100 m average line spacing. Resulting grid was used for calculation of vertical gradient of total magnetic field and tilt derivative.

3D inversion of magnetic data in the central part of the survey area was performed using Mag3Dv3 UBC inversion software (UBC 2005). One of the magnetic susceptibility cross-section derived from the inversion is presented on maps as an example of the advanced processing of magnetic datasets.

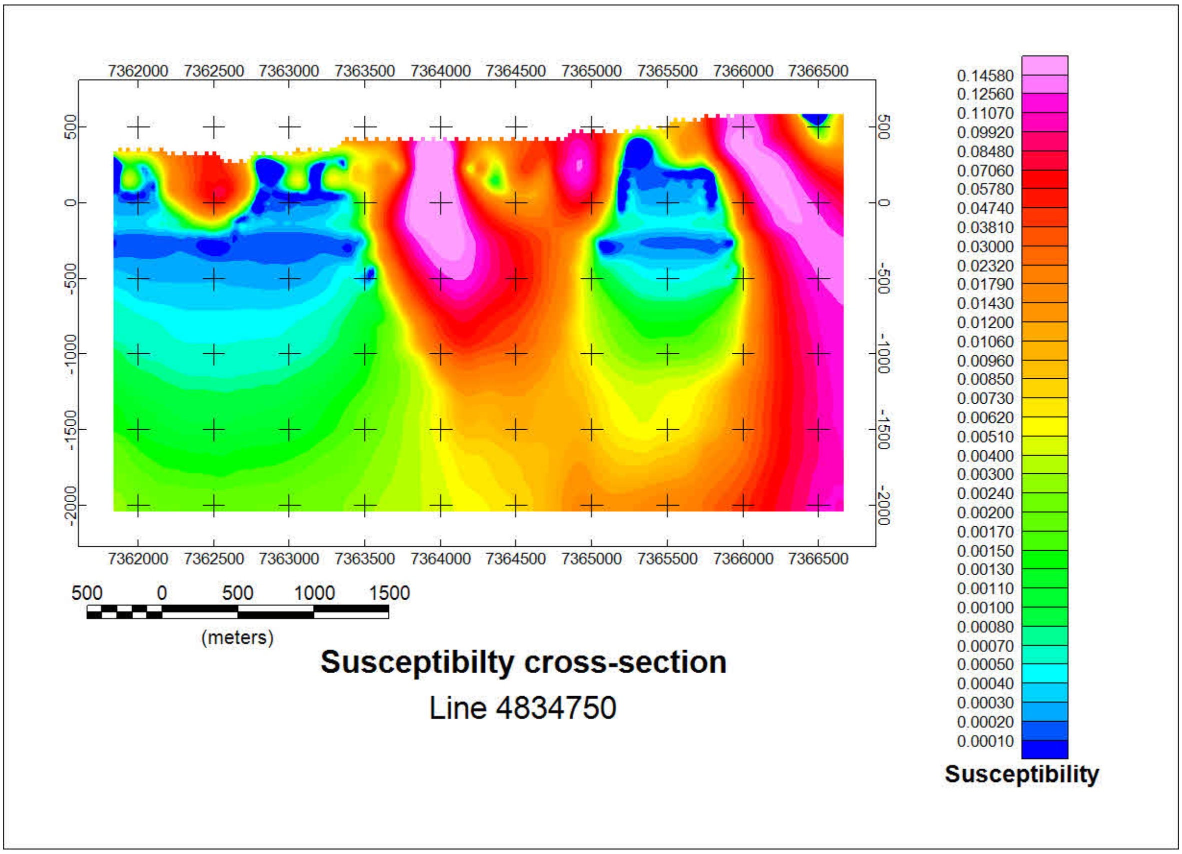

Figure 2: Magnetic susceptibility cross-section (SI unit, for location: see figure 5).

4.2 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. A flowchart of the EM data processing is given in Appendix A2.

4.2.1 Instrumental noise

In-phase and quadrature data were filtered with 3 fids non-linear filter to eliminate spheric responses and instrumental noise which was represented as irregular spikes of large amplitude in records. Simultaneously, the 30 fids low-pass filter was also applied to suppress high frequency components of instrumental and cultural noise. It's necessary to note that cultural noise level was very high in some parts of the survey area and could not be removed by filtering. Industrial noise affected mostly high frequencies quadrature components and resulted in bad quality of data of 34 kHz.

4.2.2 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 traces. 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.

4.2.3 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 all five frequencies separately. Threshold of 2 ppm was set for inversion 34 kHz and 6.6 kHz data and 1 ppm for all other frequencies. Due to bad quality of 34 kHz quadrature component, resistivity for this frequency was calculated from in-phase component only. Resistivity data were visually inspected and then levelled. Revised resistivity data were gridded with a cell size 25 m and convolution filter was applied to smooth the grids.

Multi-layered inversion of all resistivity data along line 1600 was performed using EM1DFM UBC inversion package (UBC 2000). Resistivity cross-section is shown on **Figure 3** and on the resistivity maps.

4.3 Radiometric data

In processing of the airborne gamma ray spectrometry data, live time 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). The topography in the region was rough, and 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 A3. For further reading regarding standard processing of airborne radiometric data, we recommend the publication from Minty et al. (1997).

5. PRODUCTS

Processed digital data from the survey are presented as:

1. Three Geosoft XYZ files: Rana_Mag.xyz, Rana_EM.xyz, Rana_Rad.xyz, available from NGU on request.
2. Coloured maps at the scale 1:25000 available from NGU on request.

Table 2. Maps in scale 1:25000 available from NGU on request.

Map #	Name
2012.044-01	Total magnetic field
2012.044-02	Total magnetic field. Vertical gradient
2012.044-02	Total magnetic field. Tilt derivative
2012.044-04	Apparent resistivity, Frequency 34000 Hz, coplanar coils
2012.044-05	Apparent resistivity, Frequency 6600 Hz, coplanar coils
2012.044-06	Apparent resistivity, Frequency 880 Hz, coplanar coils
2012.044-07	Apparent resistivity, Frequency 7000 Hz, coaxial coils
2012.044-08	Apparent resistivity, Frequency 980 Hz, coaxial coils
2012.044-09	Uranium ground concentration
2012.044-10	Thorium ground concentration
2012.044-11	Potassium ground concentration
2012.044-12	Ternary map
2012.044-13	Total count

Downscaled images of the maps are shown on figures 5 - 17

6. REFERENCES

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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

7. 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
- Gridding
- Microlevelling

8. 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
- Microlevelling of apparent resistivity.
- Gridding
- Convolution filter.

9. 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 in Telemark 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):
  a_u: 0.1866 b_u: 0.6265
  a_K: 1.488 b_K: 3.2984
  a_T: 0.3009 b_T: 1.0807
  a_{Tc}: 25.52 b_{Tc}: 20.2
  a_1: 0.1060 a_2: 0.0083

- Stripping correction (IAEA, 2003)
  Used parameters (determined from measurements on calibrations pads at the NGU and Borlänge airport):
  a 0.0484
  alpha 0.2999
  beta 0.4755
  gamma 0.8314

- Height correction to a height of 60 m
  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

- Microlevelling using Geosoft menu and smoothening by a convolution filtering
  Used parameters for microlevelling:
  De-corrugation cutoff wavelength: 400 m
  Cell size for gridding: 25 m
  Naudy (1968) Filter length: 400 m

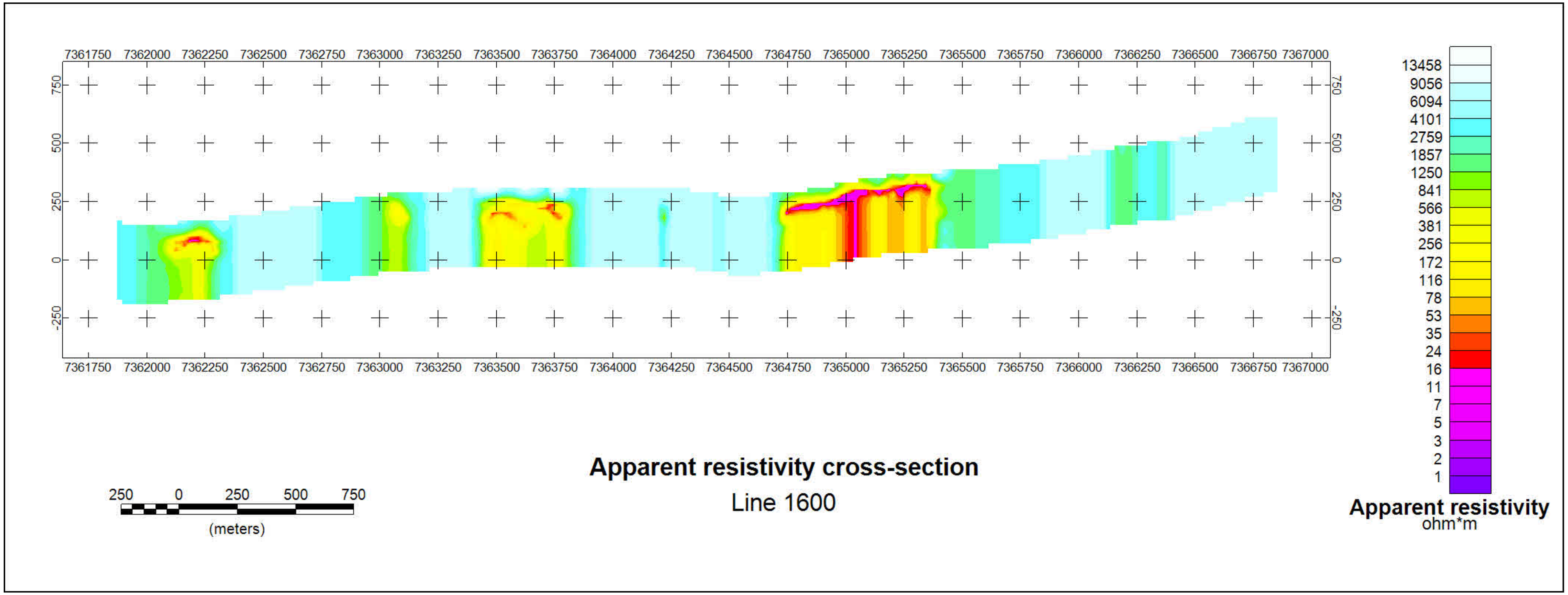

Figure 3: Apparent resistivity cross-section line 1600 (for location: see figure 4).

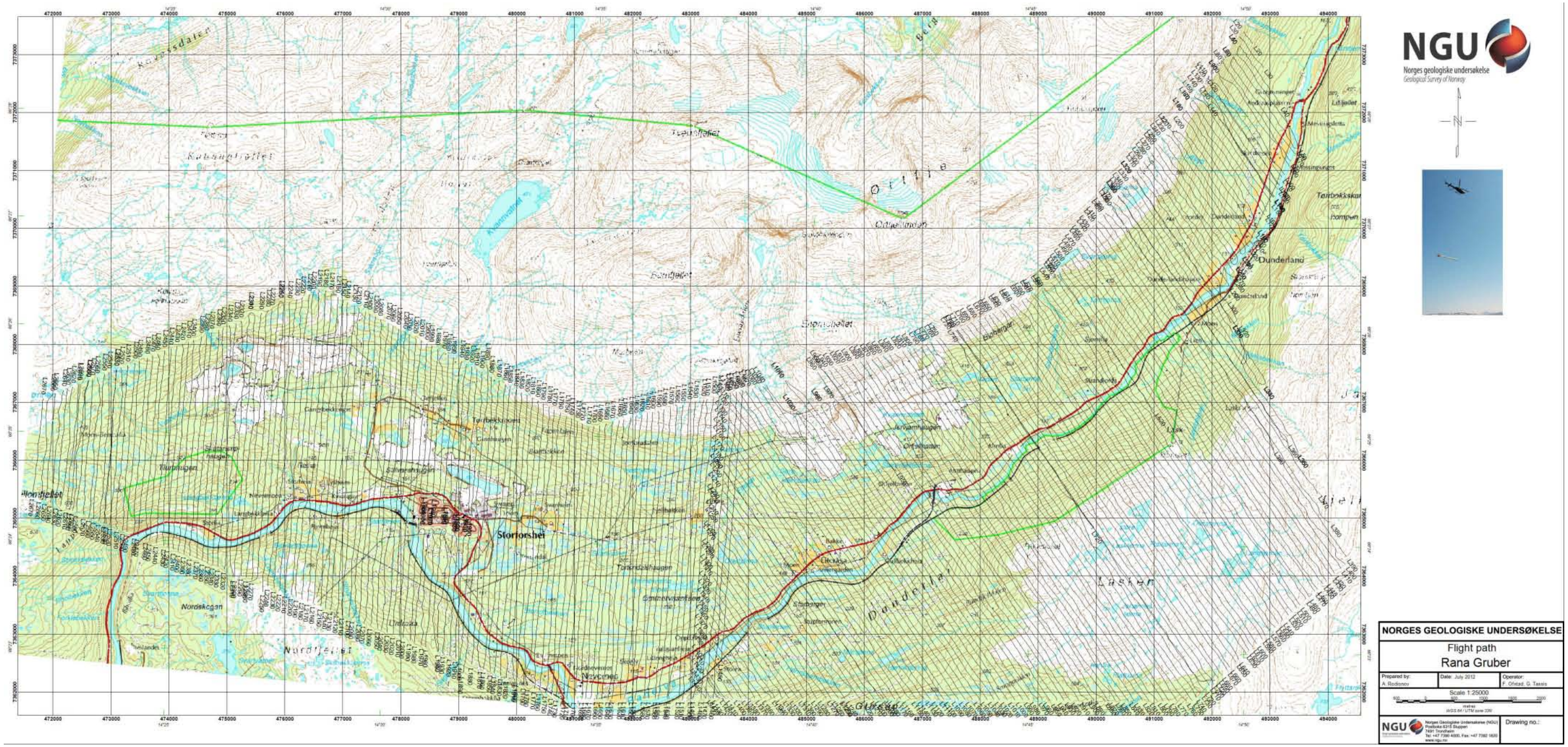

Figure 4: Rana survey. Flight path.

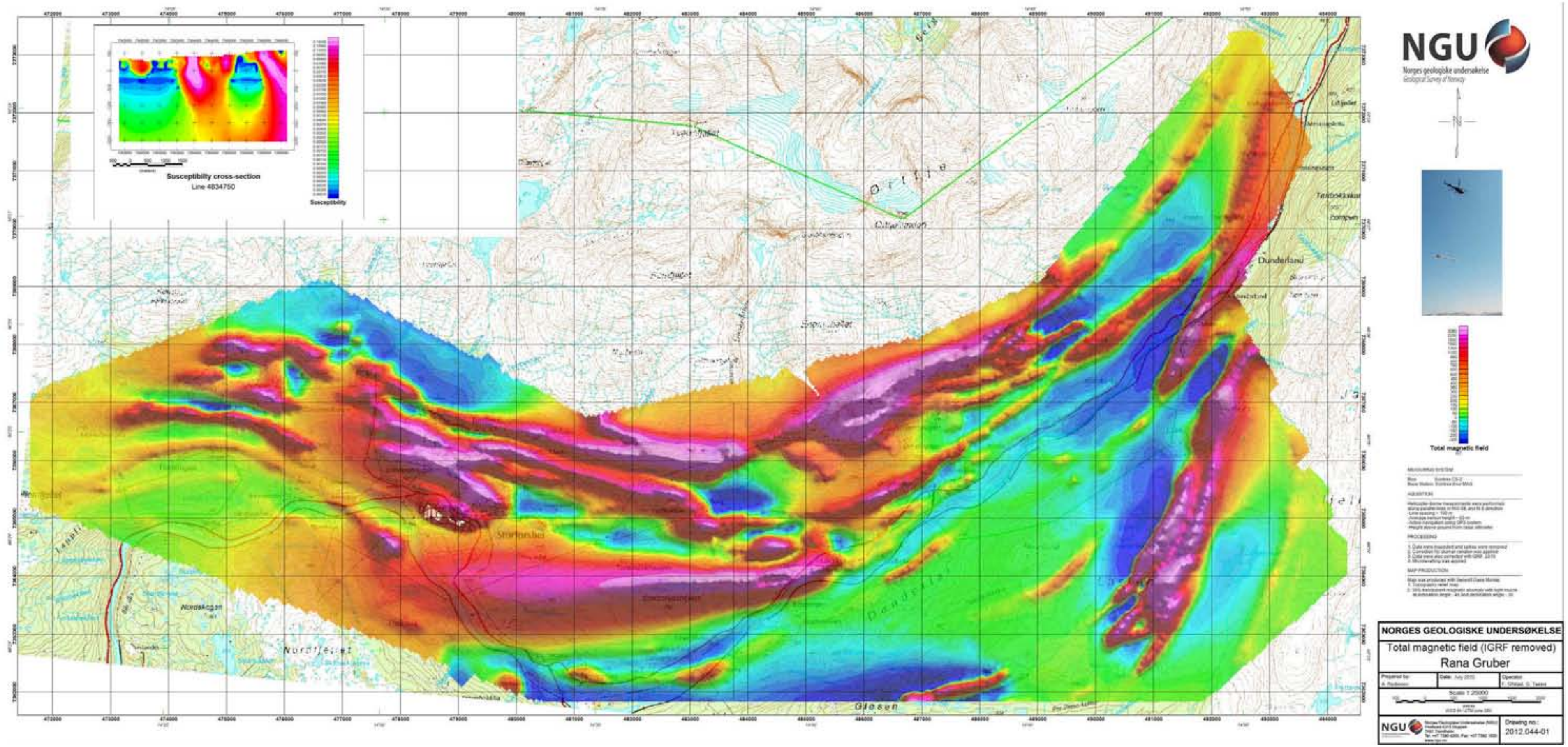

Figure 5: Total magnetic field

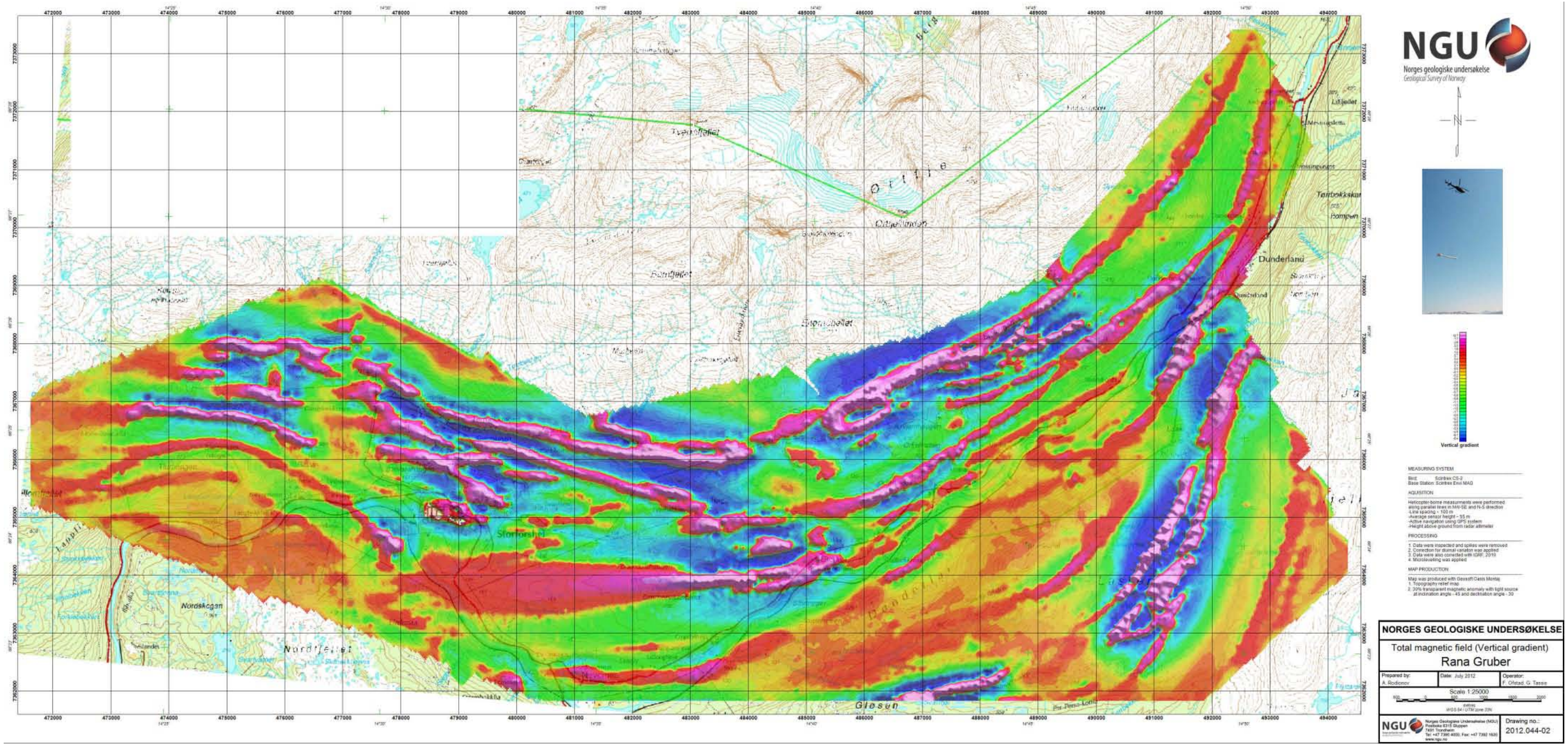

Figure 6: Total magnetic field. Vertical gradient

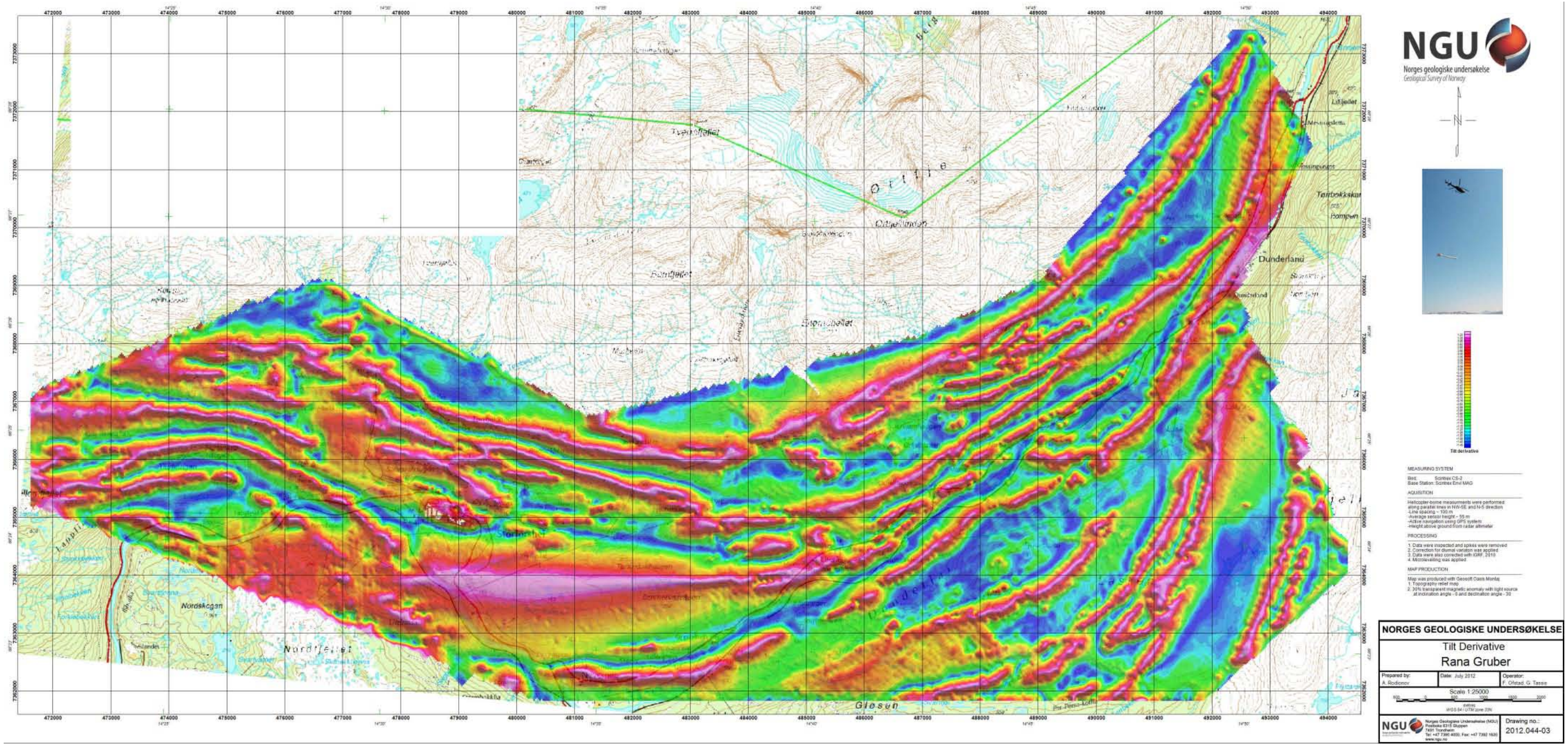

Figure 7: Total magnetic field. Tilt derivative

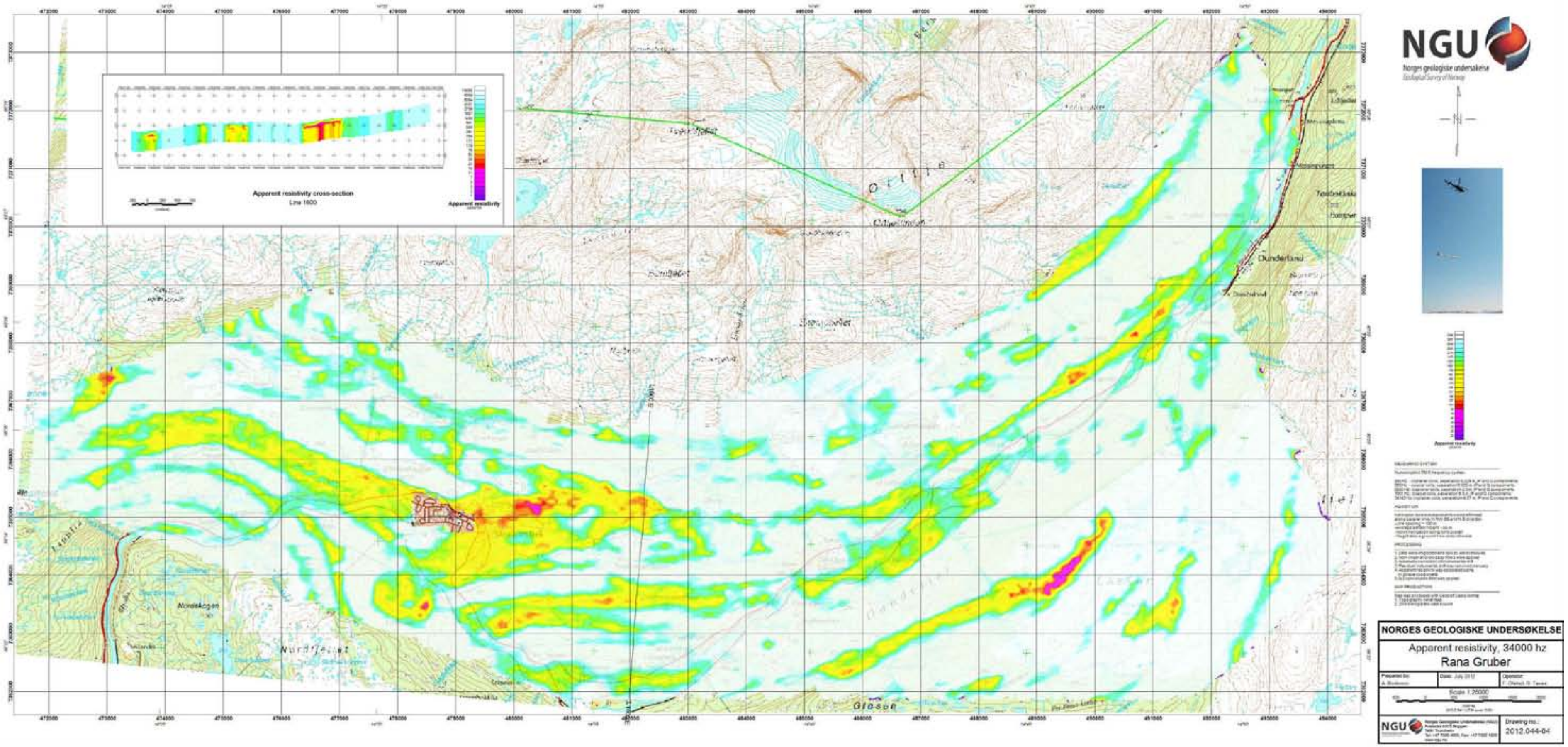

Figure 8: Apparent resistivity. Frequency 34000 Hz, Coplanar coils

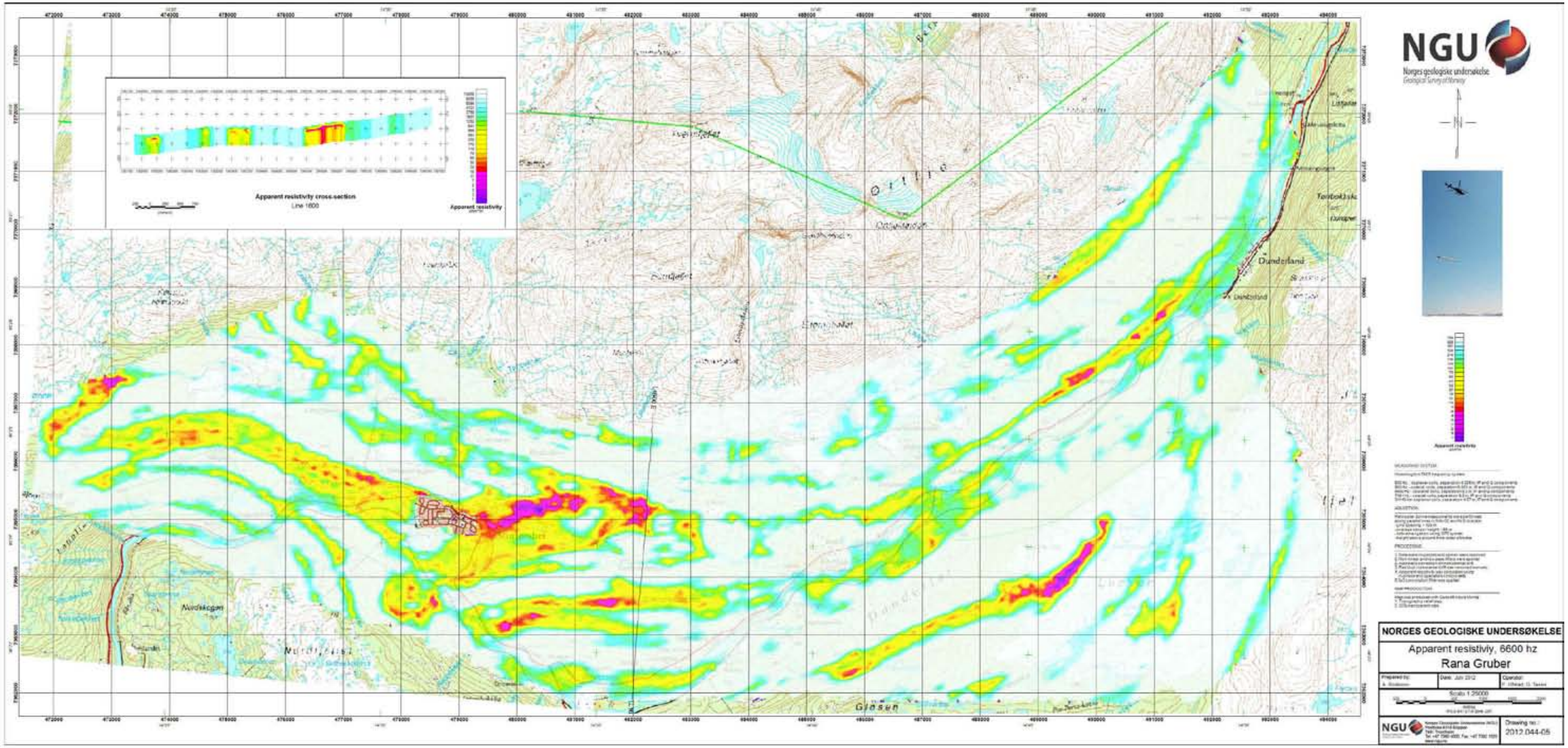

Figure 9: Apparent resistivity. Frequency 6600 Hz, Coplanar coils

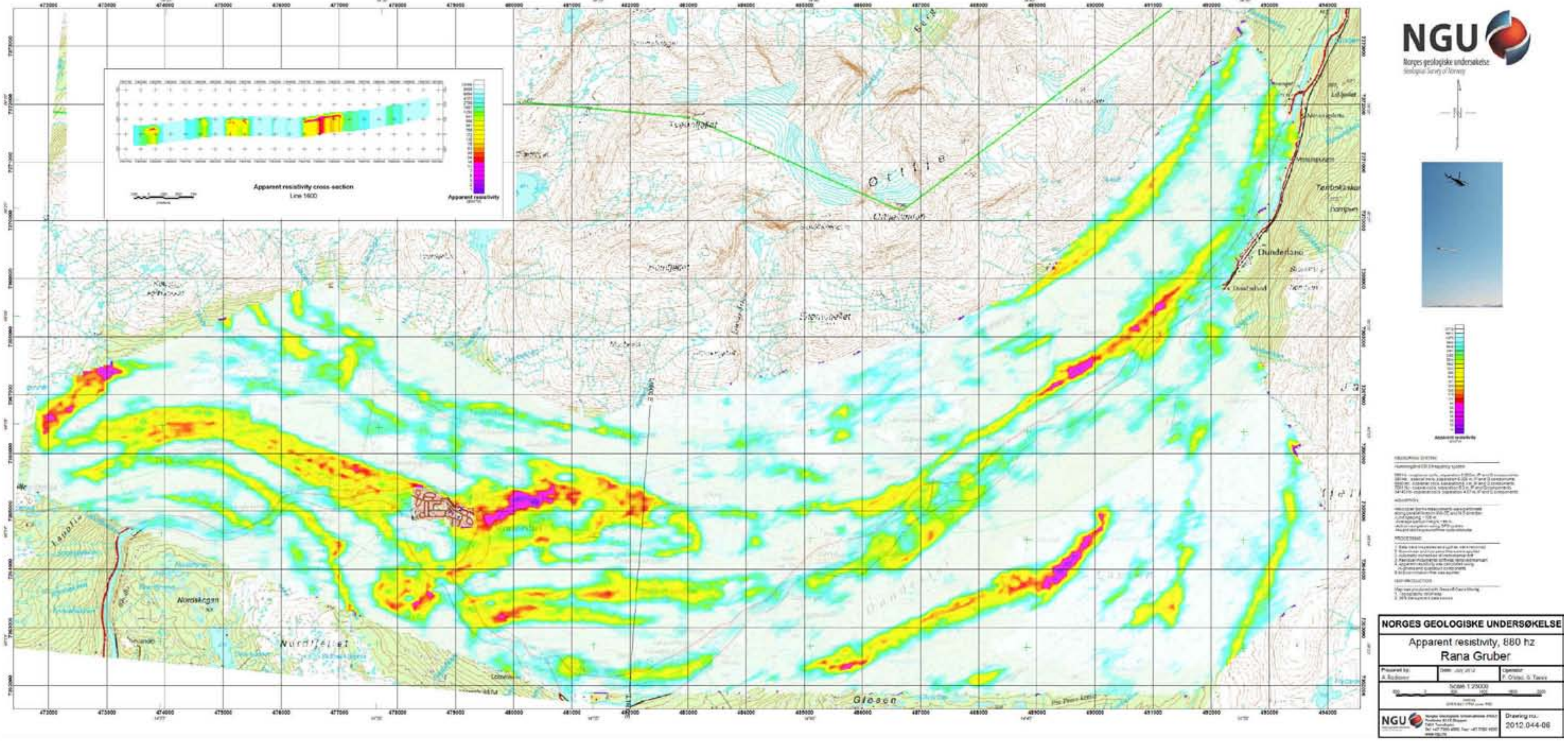

Figure 10: Apparent resistivity. Frequency 880 Hz, Coplanar coils

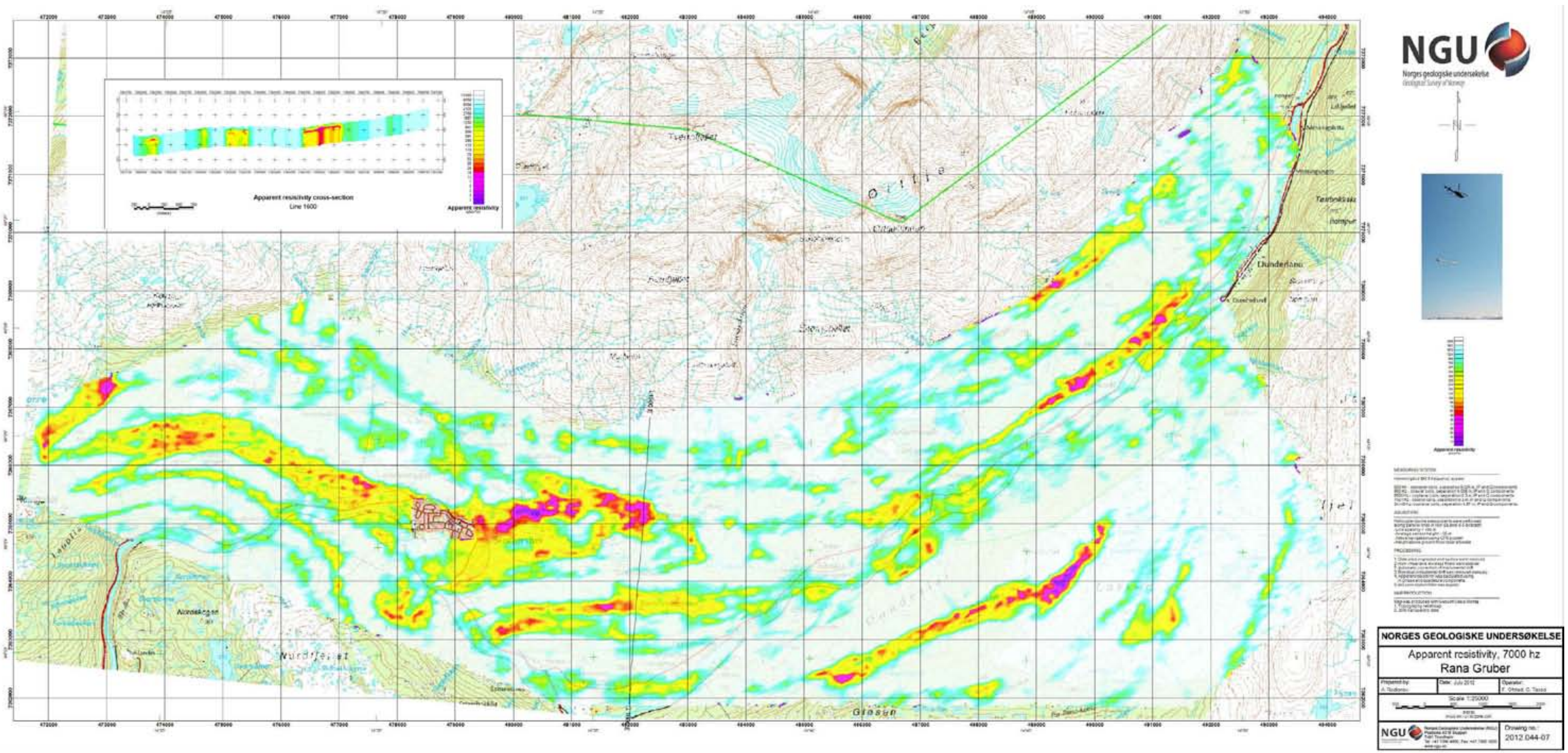

Figure 11: Apparent resistivity. Frequency 7000 Hz, Coaxial coils

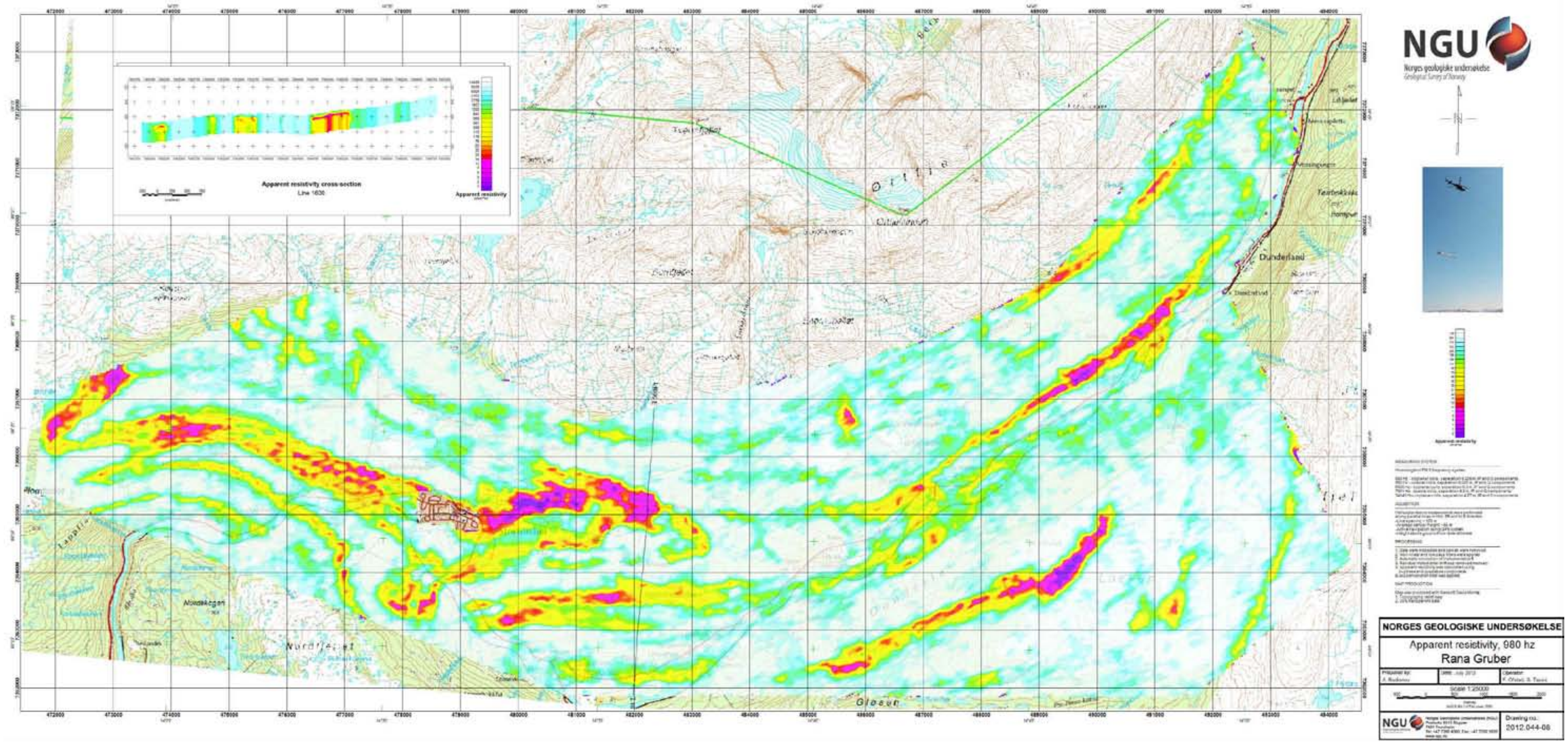

Figure 12: Apparent resistivity. Frequency 980 Hz, Coaxial coils

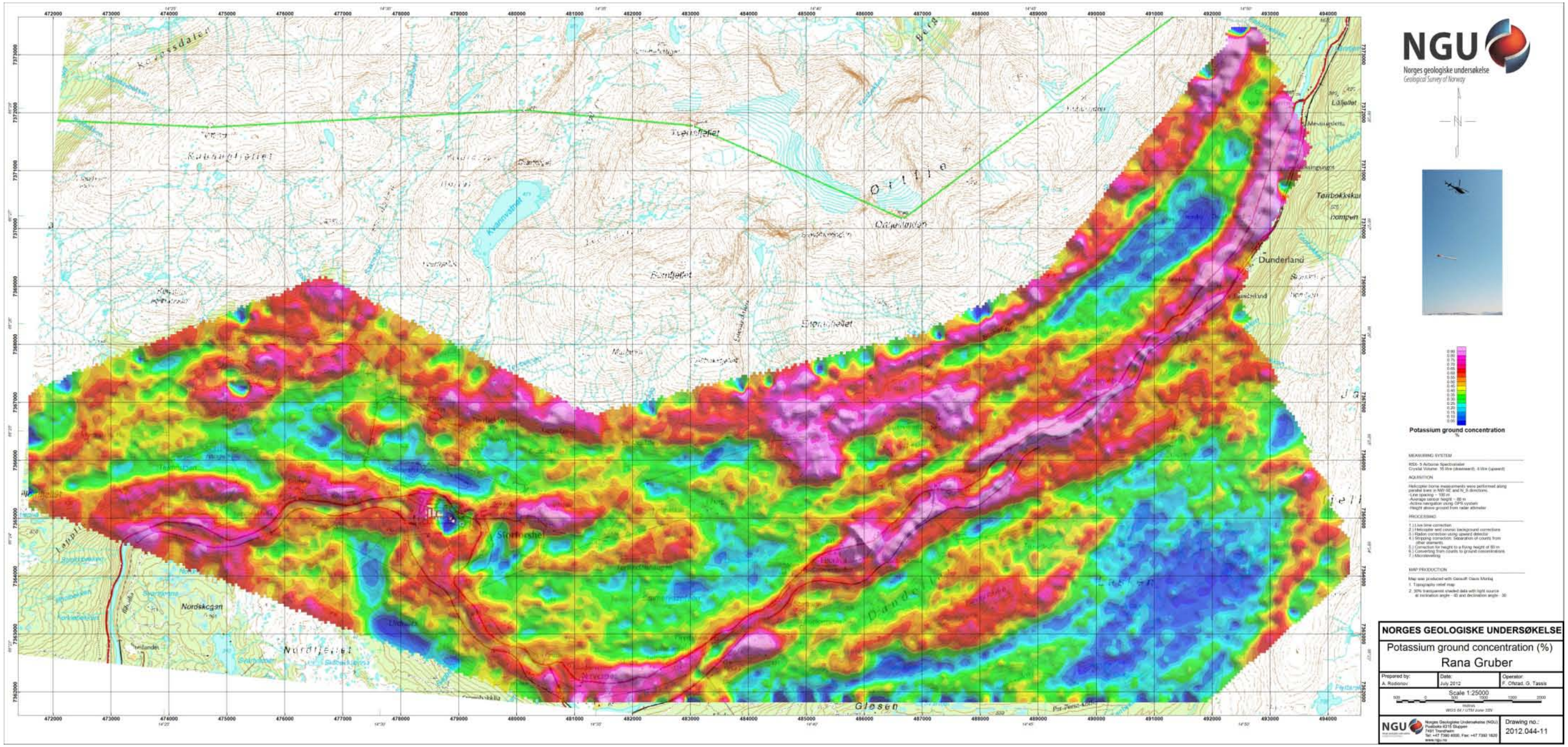

Figure 13: Potassium ground concentration

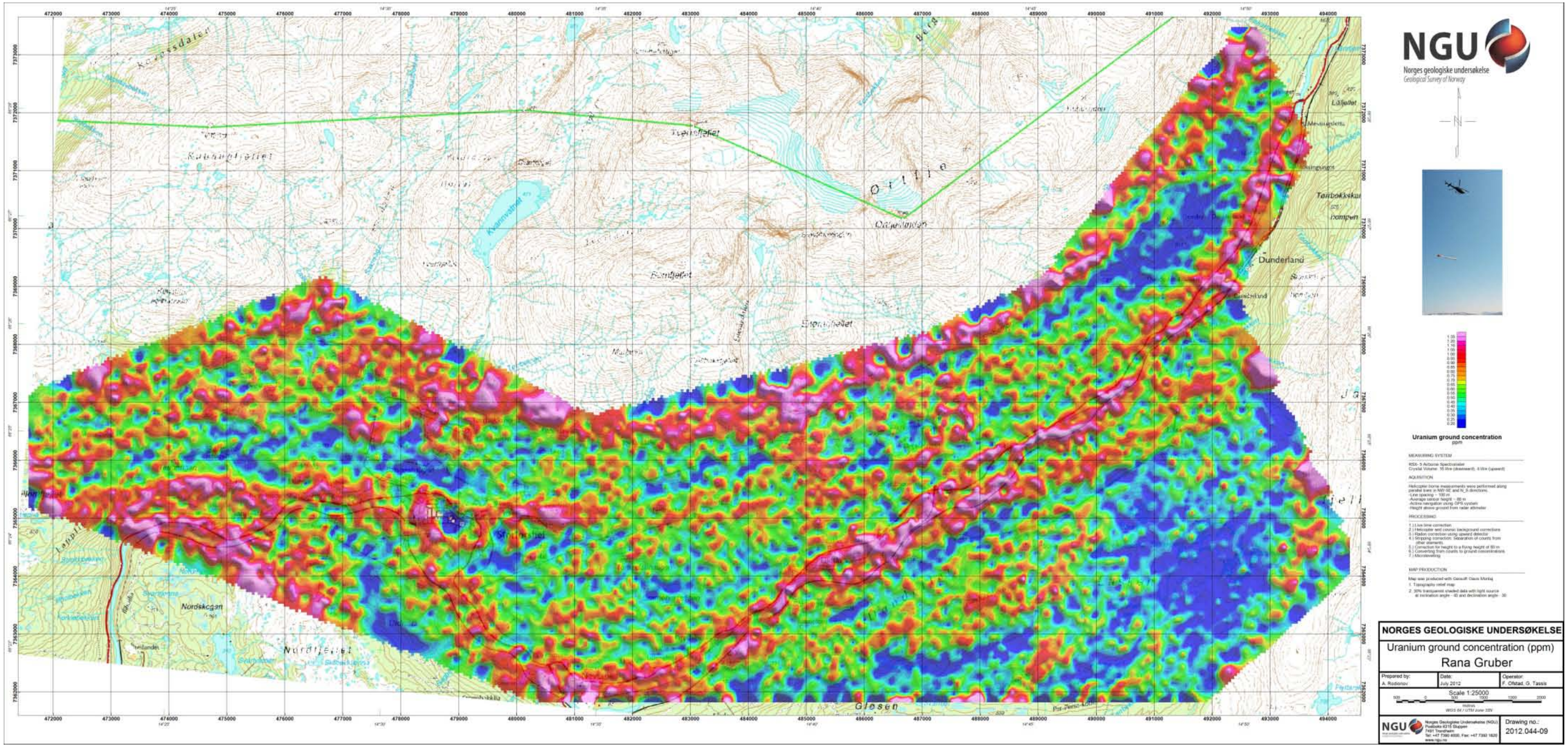

Figure 14: Uranium ground concentration

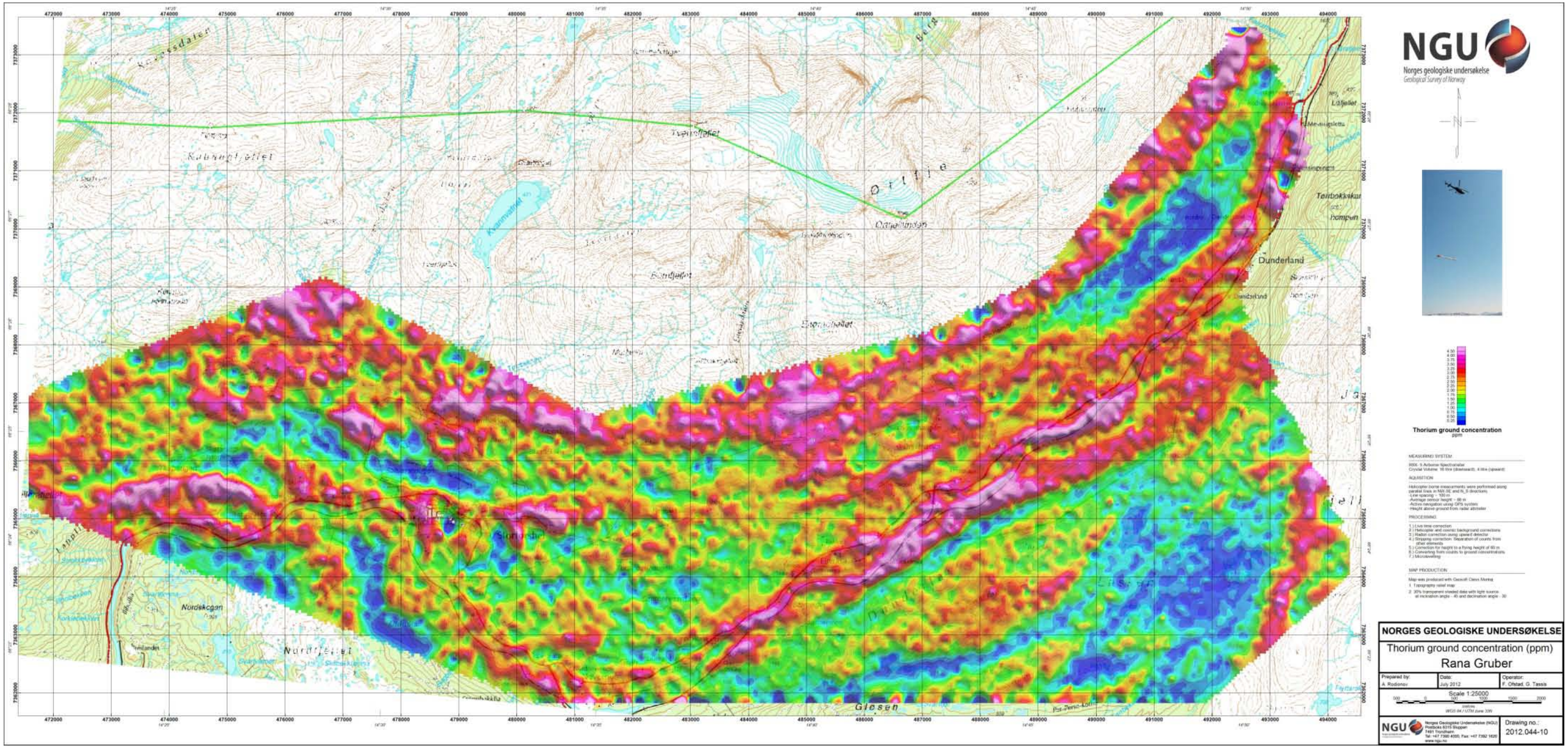

Figure 15: Thorium ground concentration

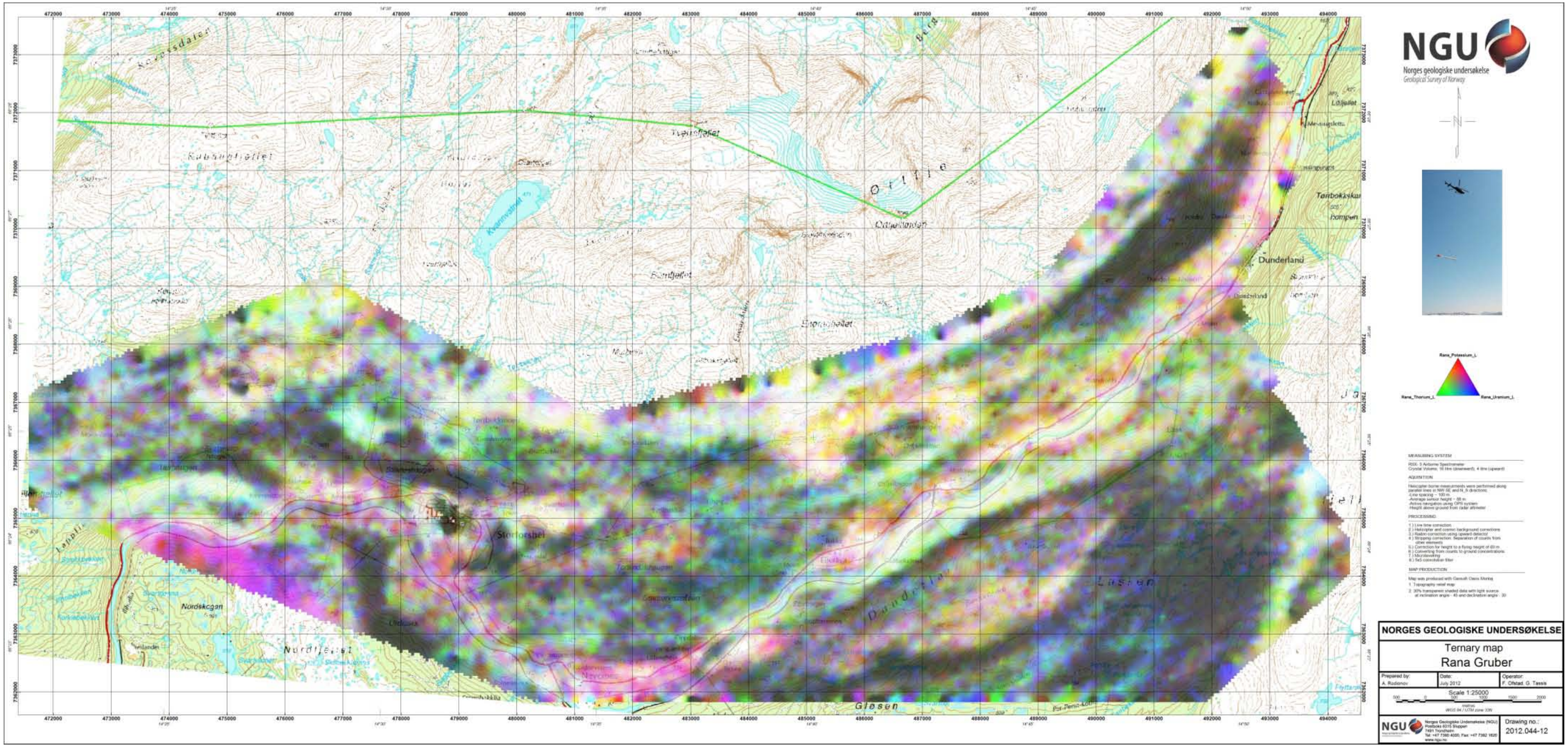

Figure 16: Radiometric ternary map

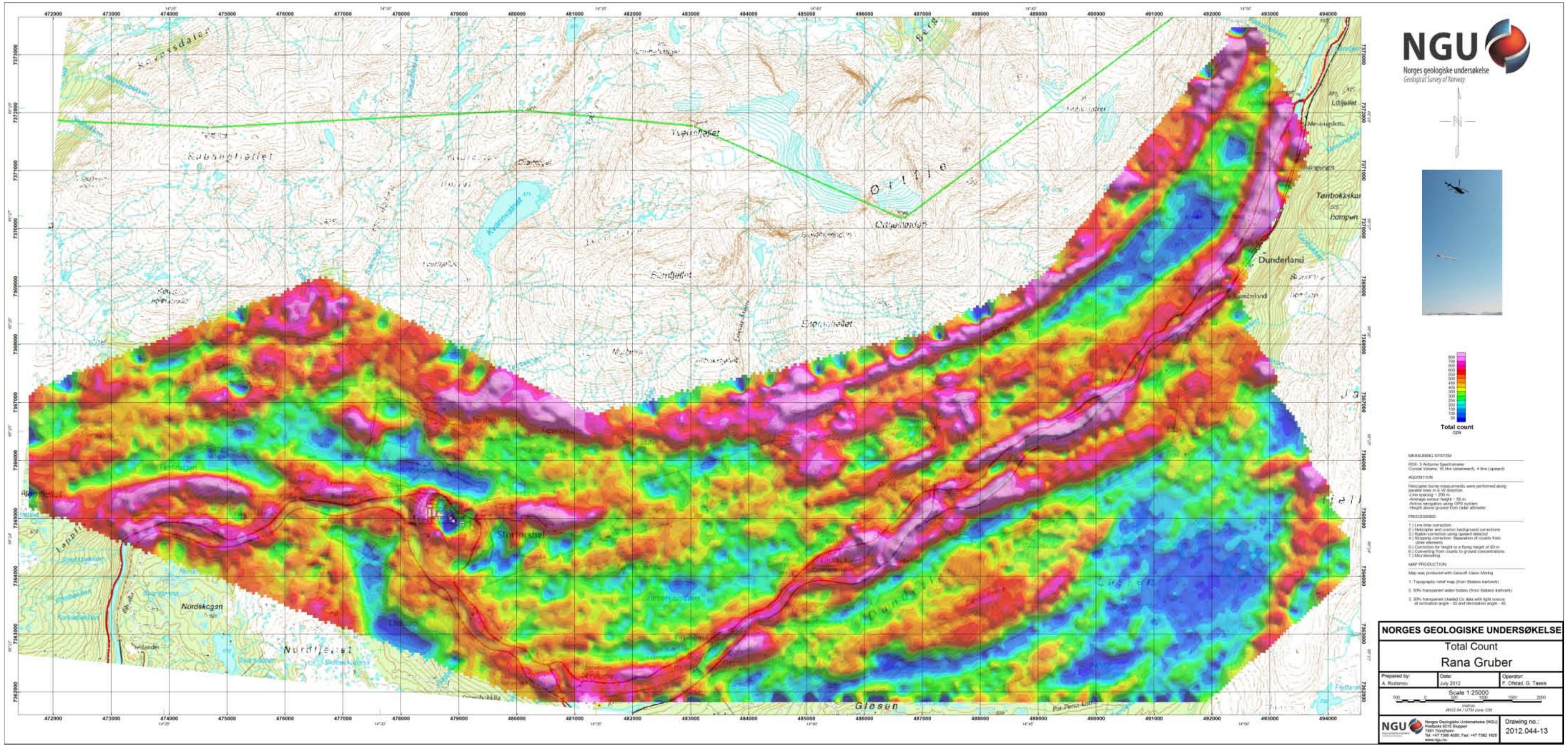

Figure 17: Radiometric total count