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NGU Report 2012.021

Helicopter-borne magnetic, electromagnetic and radiometric geophysical survey of Vanna, Karlsøy, Troms

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REPORT

Report no.: 2012.021	ISSN 0800-3416	Grading: Open

Title: Helicopter-borne magnetic,electromagnetic and radiometric geophysical survey at Vanna, Karlsøy, Troms	
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County: Troms	Commune: Karlsøy
Map-sheet name (M=1:250.000) Tromsø	Map-sheet no. and -name (M=1:50.000) 1535 I, 1535 II, 1635 III
Deposit name and grid-reference:	Number of pages: 23 Price (NOK): 120,- Map enclosures:

Fieldwork carried out: June 2011	Date of report: March 2012	Project no.: 342900	Person responsible: Jan S. Rønning

Summary:

NGU conducted an airborne geophysical survey in Vanna area in June 2011 as a part of MINN project. This report describes and documents the acquisition, processing and visualization of recorded datasets. The geophysical survey results reported herein are 1336 line km.

The modified 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 200 m line spacing, line direction of 27° NW and average speed 106 km/h. The average terrain clearance of the bird was 59 m.

Collected data were processed in 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 four frequencies separately using a homogeneous half space model. Apparent resistivity dataset was filtered and levelled. 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 shaded relief maps at the scale of 1:50 000.

Keywords: Geophysics	Airborne	Magnetic
Electromagnetic	Gamma spectrometry	Radiometric
		Technical report

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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 initiated MINN programme (Mineral resources in North Norway) in 2010. 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 results reported herein amount to 1336 line-km flown over the Vanna 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 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, and radar altimeter. A combined GPS/GLONASS 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

Vanna island is situated in the Karlsøy municipality, Troms county (Figure 1) and centred at approximately 70° 09' N; 19° 47' E.

Figure 1. Vanna survey. Location map

The area is located about 60 km northeast of the city of of Tromsø. Access to the area is possible by ferry from Hansnes or by helicopter.

The flight path of the survey and related land can be seen in Figure 2

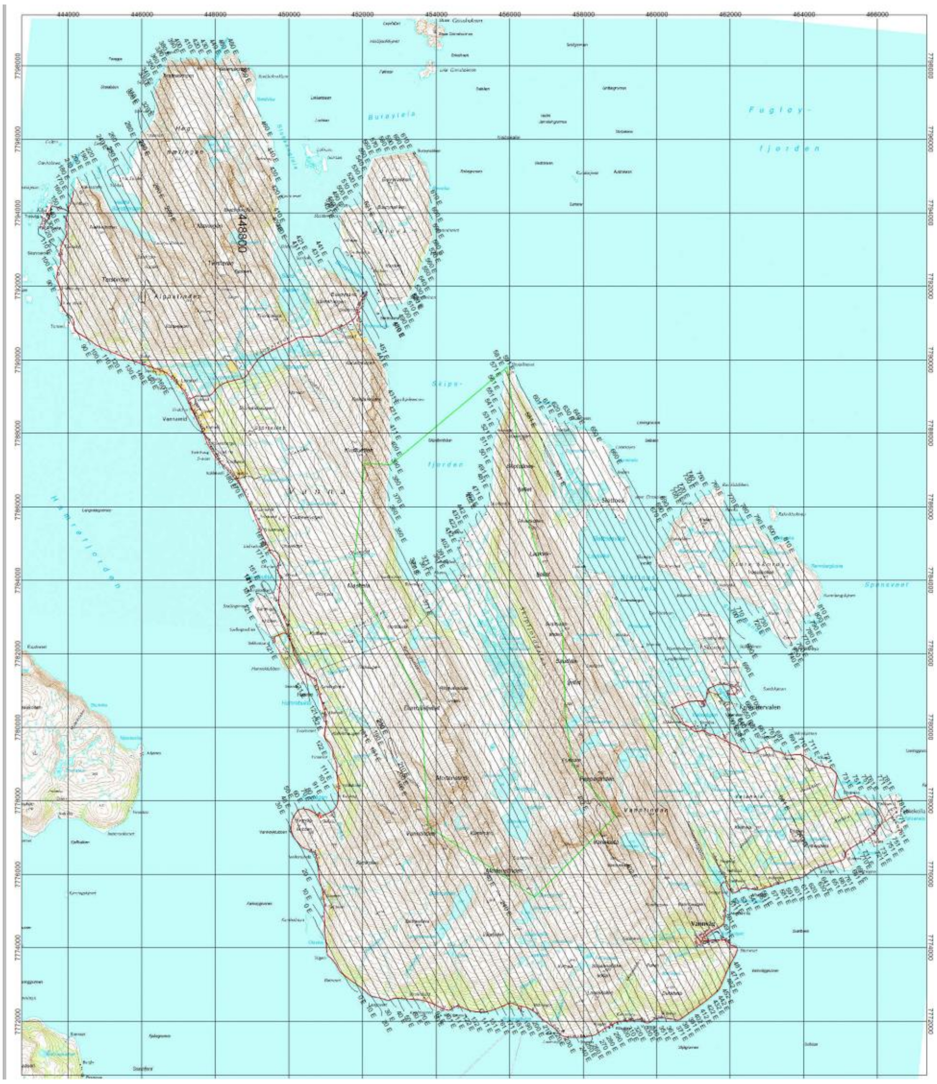

Figure 2. Vanna survey. Line Path

3. SURVEY SPECIFICATIONS

3.1 Airborne Survey Parameters

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

The airborne survey began on June 25 and ended on June 28, 2011. A Eurocopter AS350B helicopter was used to tow the bird. The survey lines were spaced 200 m apart and oriented at a 327° to NW – 147° SE (see figure 2). The magnetic and electromagnetic sensors are housed in a single 7.5 m long bird, towed 33 m below the helicopter at average 59 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. In average, the helicopter height above ground was 92 m.

The ground speed of the aircraft varied from 30 – 110 km/h depending on topography, wind direction and its magnitude. On average the ground speed is estimated to be 106 km/h. Magnetic data were recorded at 0.2 second intervals resulting in 6 to 8 m point spacing. EM data were recorded at 0.1 second intervals resulting in data with a sample increment of 3 to 4 m along the ground. Spectrometry data were recorded every 1 second. 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.

Navigation system uses both GPS and GLONASS satellite tracking systems to provide real-time WGS-84 coordinate locations for every tenth datum (each second). The accuracy achieved by using both GPS and GLONASS satellites with no differential corrections is reported to be ± 5 m in the horizontal directions.

3.2 Airborne Survey Instrumentation

3.2.1 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 1).
Sample Rate: 10 samples per second (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

3.2.2 Airborne Magnetometer

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

3.2.3 Gamma Spectrometer

Model: Radiation Solutions RSX-5
Number of detectors: 4x4L downward, 1x4L upward.
Number of channels: 1024
Sampling interval: 1 sec
Stabilisation Automatic multi-peak

3.2.4 Magnetic Base Station

Model:	Scintrex EnviMAG
Type:	Proton magnetometer.
Sensitivity:	0.1 nT
Sampling Interval:	Variable, 1 sec for this survey.
Counter	Kroum KMAG-4

3.2.5 Radio Altimeter

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

3.2.6 Barometric Altimeter

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

3.2.7 Navigation System

Model:	Topcon receiver
Display:	Remote colour screen display for flight path cross-track guidance.
Accuracy:	±10 m
Sampling interval:	1 second

3.2.8 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)
Computer:	Nexcom VTC 6100
Display:	17' LDS 4101D
Interface Cards:	USB Flash drives

3.3 Airborne Survey Instrumentation Summary

The aircraft used for the survey was a Eurocopter AS350B. The rack mounted digital data acquisition system (DAS), spectrometer console, navigation computer and barometric altimeter was 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/GLONASS receiver antenna was mounted externally to the tail of the helicopter.

The electromagnetic, magnetic, radiometric, altitude and navigation data were monitored on four separate windows in the operator's display during flight while they were recorded in three data ASCII streams to the DAS hard disk drive. Spectrometry data were also recorded to internal hard drive of spectrometer. The ASCII data files were transferred to the field workstation via USB flash drive. Base station magnetometer data were recorded once every second to a laptop computer HDD as an ASCII file. The data were transferred to the field workstation. 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:	200 metres
Traverse line direction:	327° NW – 147° SE
Nominal aircraft ground speed:	30 - 110 km/h
Average sensor terrain clearance:	59 metres
Sampling rates:	0.2 seconds - magnetometer
	0.1 seconds - electromagnetics
	1.0 second - spectrometer, GPS, altimeter

4. DATA PROCESSING AND PRESENTATION

The data were processed at the Geological Survey of Norway office in Trondheim. The ASCII data files were loaded into three separate Oasis Montaj databases. UTC time channel was used as a reference. All three datasets were processed consequently according to processing flow charts shown in Appendix A.

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 and if necessary, they were removed manually. Since the data from both - airborne and magbase magnetometers- were smooth and contained no significant cultural noise filtering of the raw data was not necessary. Typically, several corrections have to be applied to magnetic data before gridding - heading correction, lag correction, diurnal correction.

4.1.1 Diurnal Corrections

The temporal fluctuations in the earth magnetic field 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 field camp at Sletmo (UTM 450750 – 7771500) inside the measured area. The average total field value for this point was 51491 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. According to previous reports the lag between logged magnetic data and the corresponding navigational data was 1-2 fids. Translated to a distance it would be no more than 10 m - the value comparable with the precision of GPS. A heading error for a towed system is usually either very small or non-existent. So no lag and heading corrections were applied.

4.1.3 Magnetic data gridding and presentation

Before gridding, flight data were split by lines. For the purposes of data presentation and interpretation the total field magnetic data are gridded with a cell size of 50 m, which represents one quarter of the 200 m average line spacing. A micro levelling technique was applied to the magnetic data to remove small line-to-line levelling errors and a 5 x 5 convolution filter was passed over the final grid to smooth the grid image.

The analytic signal of the total magnetic field was calculated from the resulting total magnetic field map. The analytical signal transforms the shape of the magnetic anomaly from any magnetic inclination to positive body-centred anomaly and it's widely utilized for mapping of structures**.**

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.

4.2.1 Instrumental noise

In-phase and quadrature data were filtered with 3 fiducial non-linear filter to eliminate spheric responses and instrumental noise. Simultaneously, a 20 fids low-pass filter was also applied to suppress high frequency components of instrumental noise and cultural noise.

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 both in-phase and quadrature EM components using a half space homogeneous model of the Earth (Geosoft HEM module) for each frequency separately. Resistivity data were visually inspected and then levelled. Revised resistivity data were gridded with a cell size 50 m and convolution filter was applied to smooth the grids.

4.3 Radiometric data

In processing of the airborne gamma ray spectrometry, live time corrected U, TH, K data 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 B1. 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 presented as:

1. Three Geosoft XYZ files: VannaMag.xyz, VannaEM.xyz, VannaRadiometrics.xyz
2. Coloured maps at the scale 1:50000 (Table 2 . **Maps**

Map #	Name
2012.010-01	Total magnetic field, Vanna
2012.010-02	Analytic signal, Vanna
2012.010-03	Apparent resistivity, Frequency 34000 Hz, coplanar coils
2012.010-04	Apparent resistivity, Frequency 6600 Hz, coplanar coils
2012.010-05	Apparent resistivity, Frequency 880 Hz, coplanar coils
2012.010-06	Apparent resistivity, Frequency 7000 Hz, coaxial coils

2012.010-07	Uranium ground concentration
2012.010-08	Thorium ground concentration
2012.010-09	Potassium ground concentration

Table 2 . Maps in scale 1: 50.000 available from NGU on request

Downscaled images of maps are shown on figures 5 -13.

6. REFERENCES

Geotech 1997: Hummingbird Electromagnetic System. Users manual. Geotech Ltd. October 1997.

UBC 2005: 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.

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.

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.

IAEA. 2003: Guidelines for radioelement mapping using gamma ray spectrometry data. *IAEA-TECDOC-1363*, Vienna, Austria. 173 pp.

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.

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
- Splitting flight data by lines
- Gridding
- Microlevelling

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
- Visual inspection of data.
- Splitting flight data by lines
- Manual removal of remaining part of instrumental drift
- Calculation of an apparent resistivity for each frequency using both - in-phase and quadrature channels
- Gridding
- Micro evelling of apparent resistivity channels.
- Convolution filter.

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.
Meaning of parameters is described in the referenced literature.

Processing flow:

- Quality control
- Airborne and cosmic correction (IAEA, 2003)
  Used parameters: (determined by high altitude calibration flights near Narvik airport in August, 2011)

  Aircraft background counts:

K window	9
U window	3
Th window	0
Uup window	0
Total counts	150

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

K window	0.0610
U window	0.0454
Uup window	0.0237
Th window	0.0626
Total counts	1.0536

- Radon correction using upward detector method (IAEA, 2003)
  Used parameters (determined from survey data over water and land):

a_u: 0.03	b_u: 1.30
a_K: 0.70	b_K: 8.40
a_T: 0.46	b_T: 1.57
a_I: 40.0	b_I: 61.0
a_1: 0.171	a_2: -0.106

- Stripping correction (IAEA, 2003)
  Used parameters (determined from measurements on calibrations pads at the NGU):

a	0.0482
alpha	0.3087
beta	0.4807
gamma	0.7953

- <u>Height correction to a height of 60 m</u>
  Used parameters (determined by height calibration flight at near Narvik airport in August, 2011):
  Attenuation factors in 1/m:

K:	0.0107
U:	0.0067
Th:	0.0062
Total counts:	0.0076

- Converting counts at 60 m heights to element concentration on the ground
  Used parameters (determined from NGU calibration pads):
  Counts per elements concentrations:

K:	69.1 counts/%
U:	7.71 counts/ppm
Th:	4.38 counts/ppm

- <u>Microlevelling using Geosoft menu and smoothening by a convolutuion flitering</u>
  Used parameters for microlevelling:

De-corrugation cutoff wavelength:	800 m
Cell size for gridding:	200 m
Naudy (1968)Filter length:	800 m

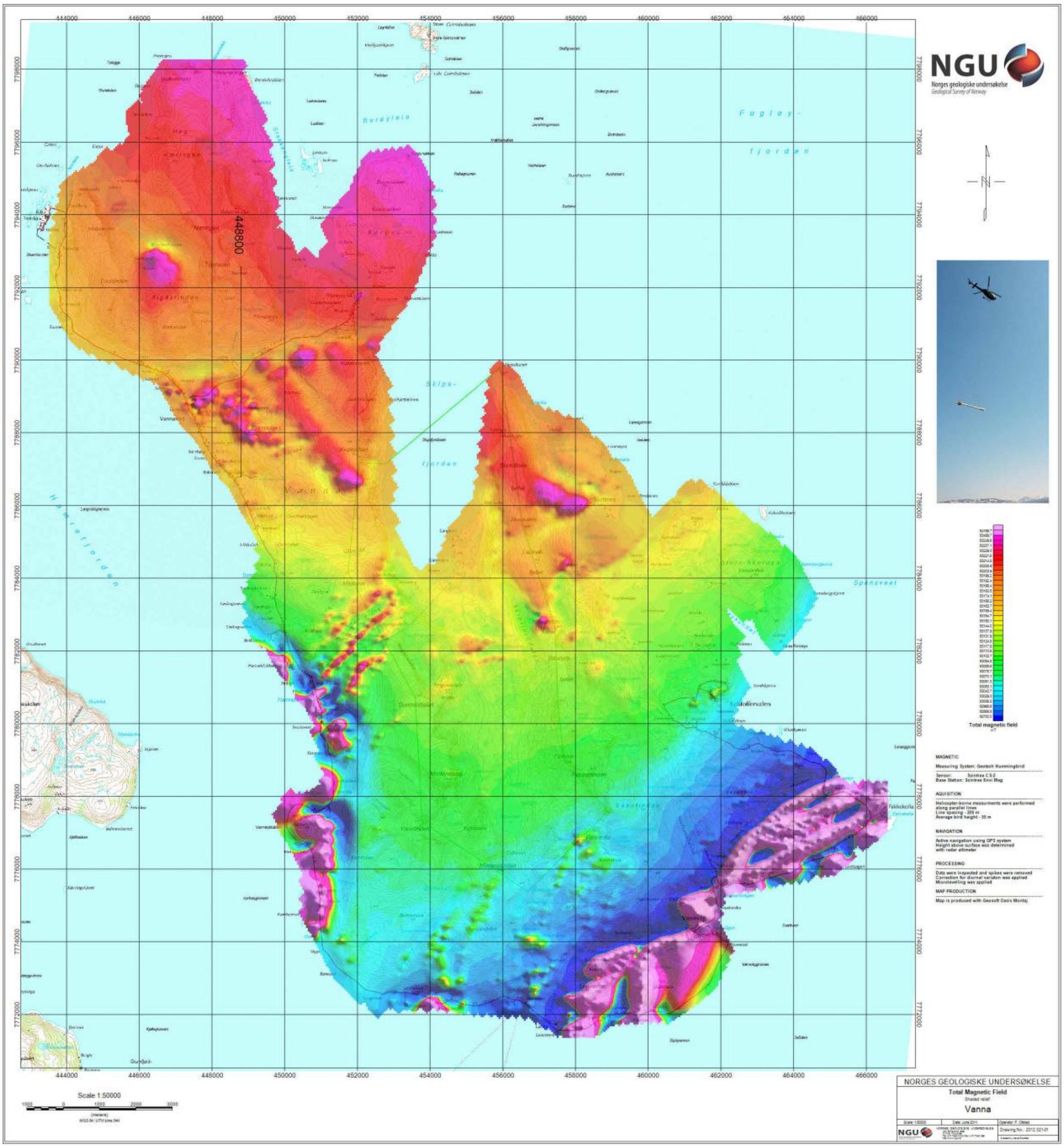

Figure 3. Total magnetic field

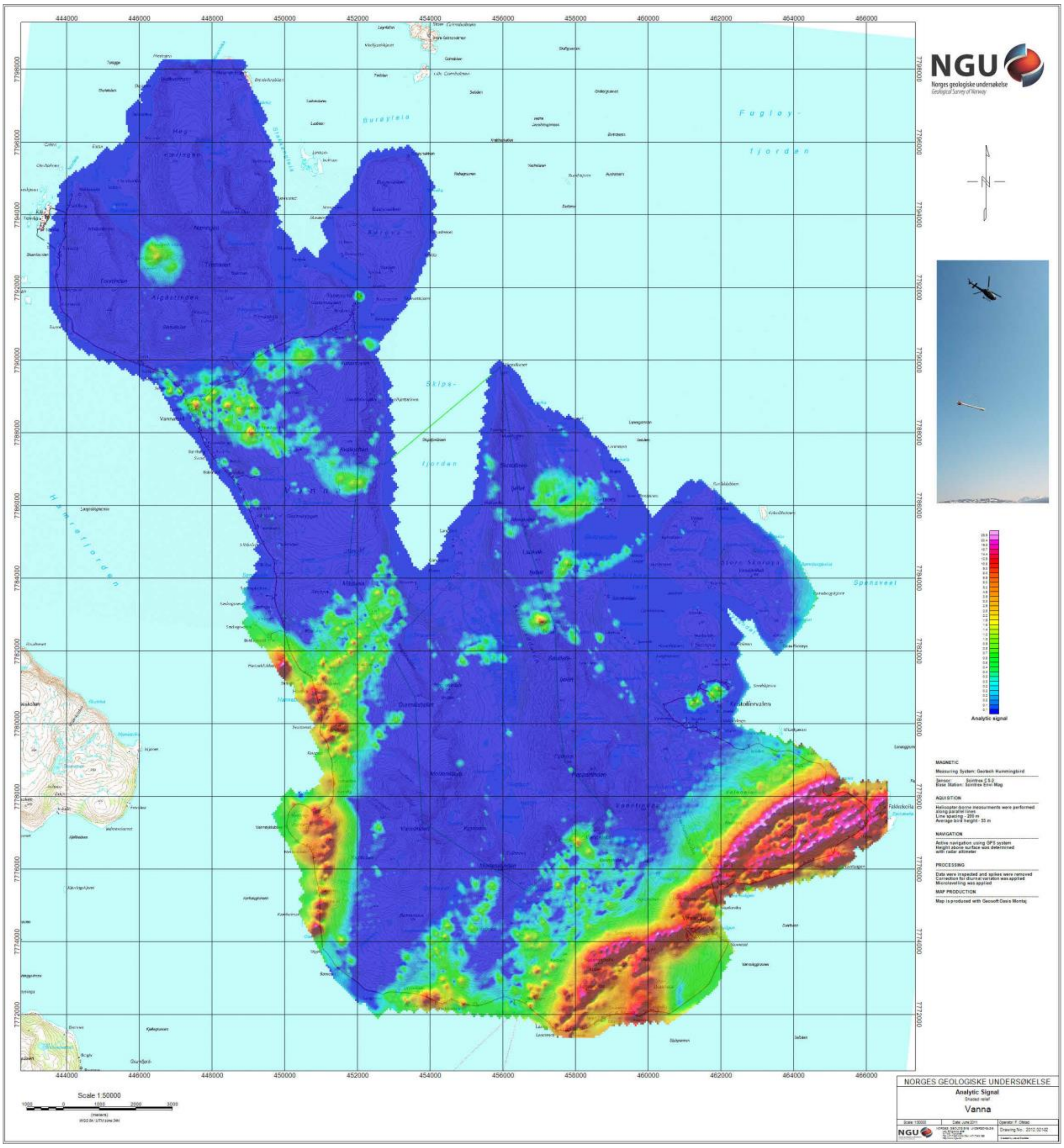

Figure 4. Magnetic Analytic Signal

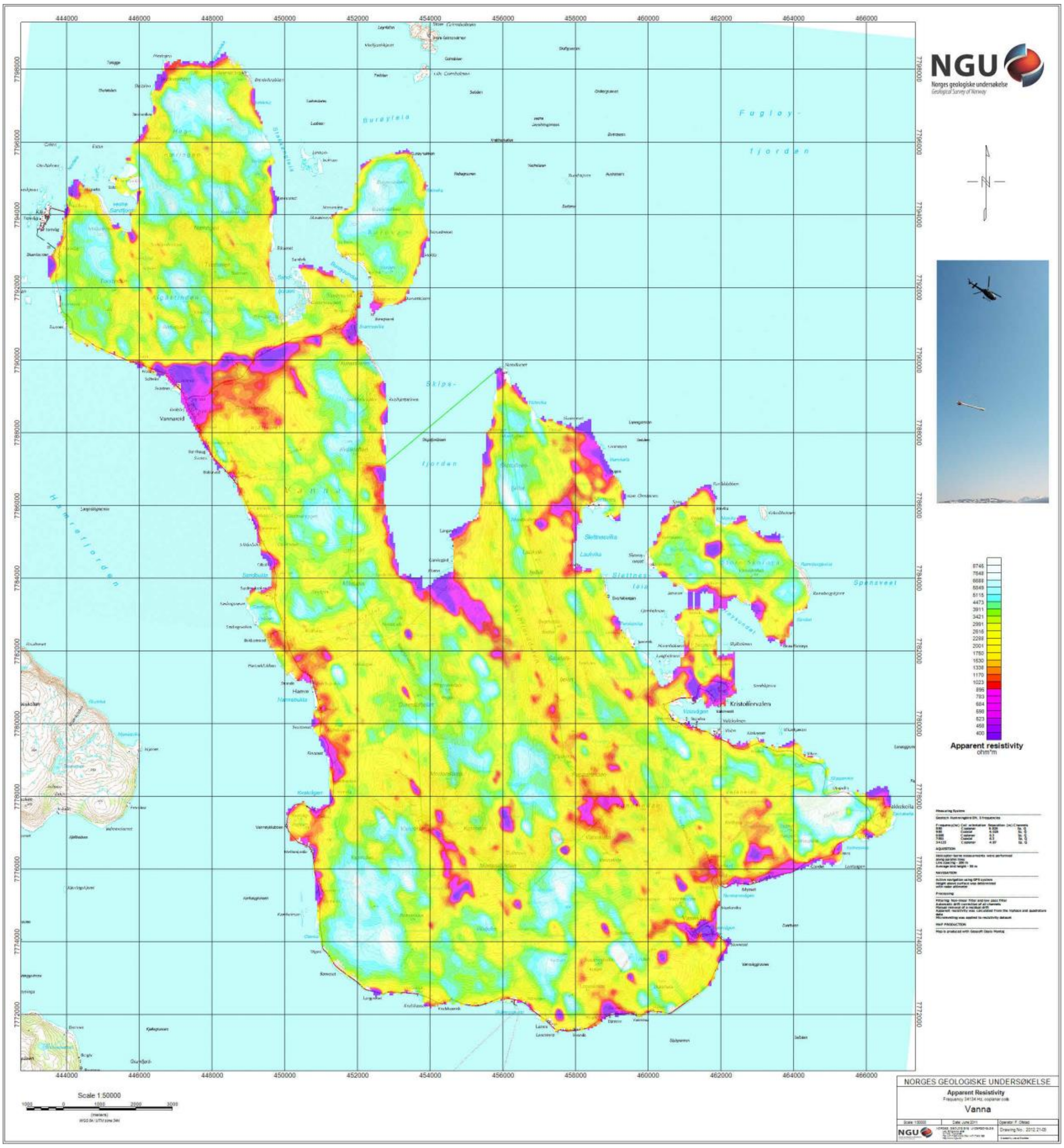

Figure 5. Apparent resistivity. Frequency 34000 Hz, Coplanar coils

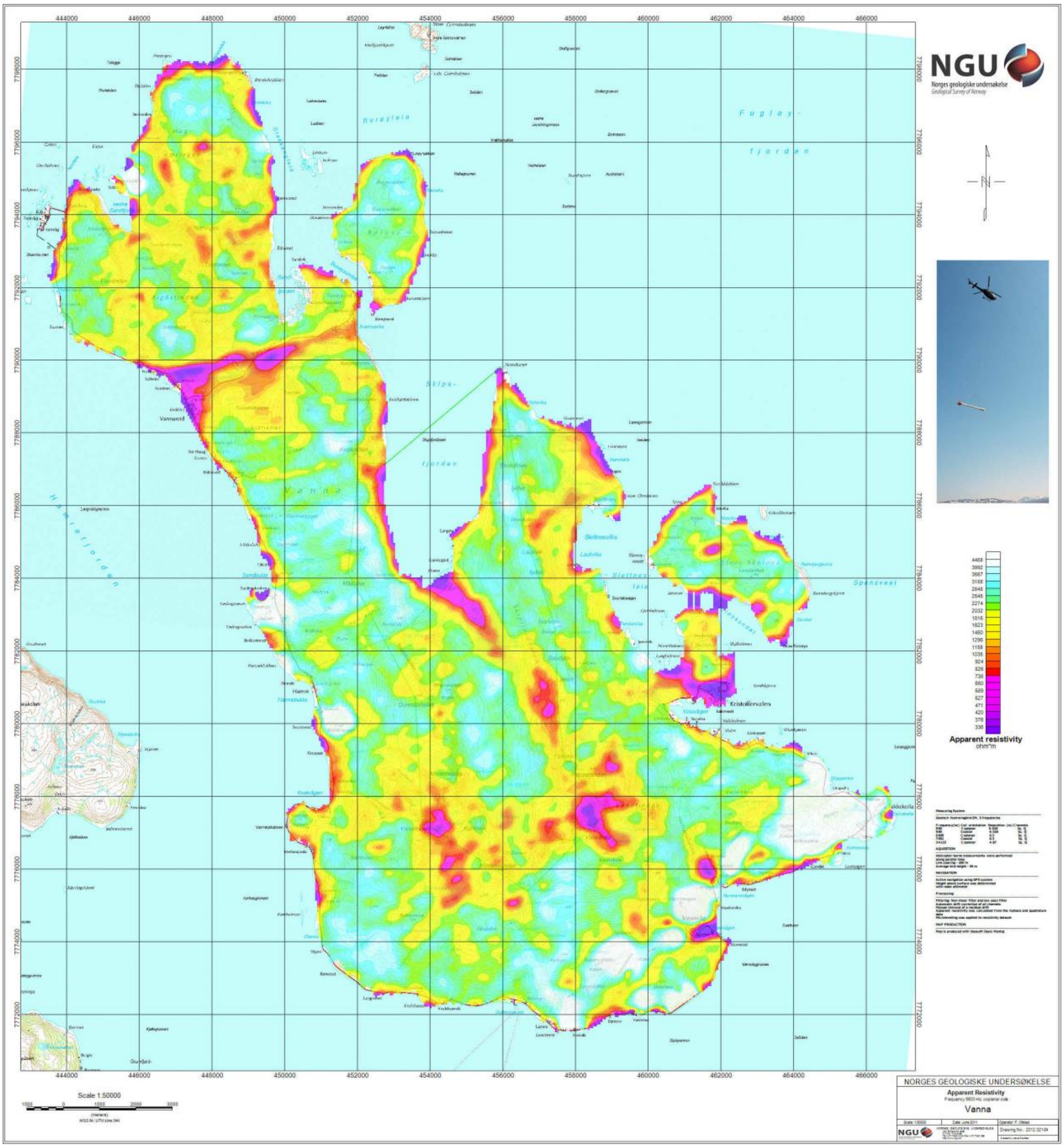

Figure 6. Apparent resistivity. Frequency 6600 Hz, Coplanar coils

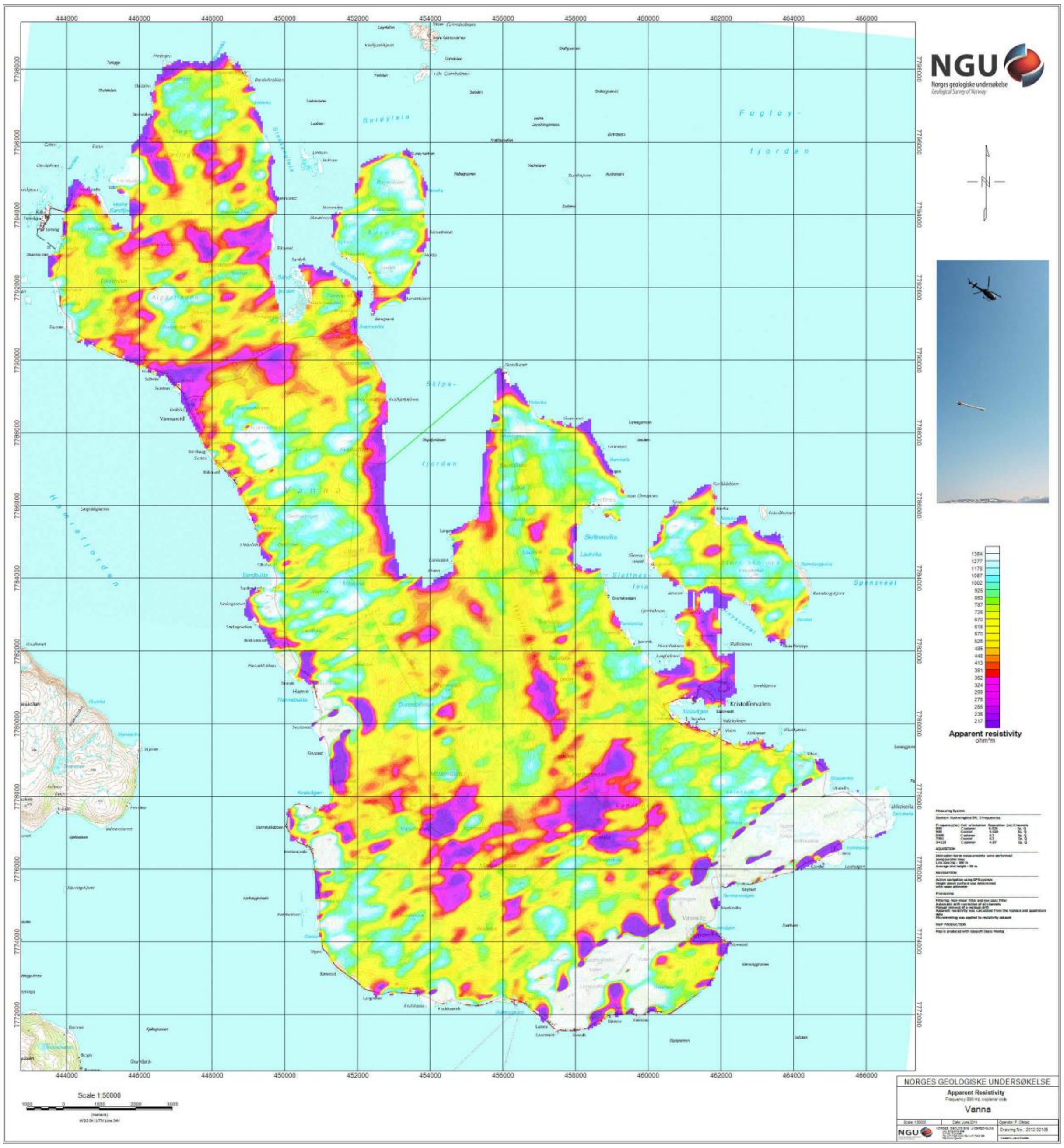

Figure 7. Apparent resistivity. Frequency 880 Hz, Coplanar coils

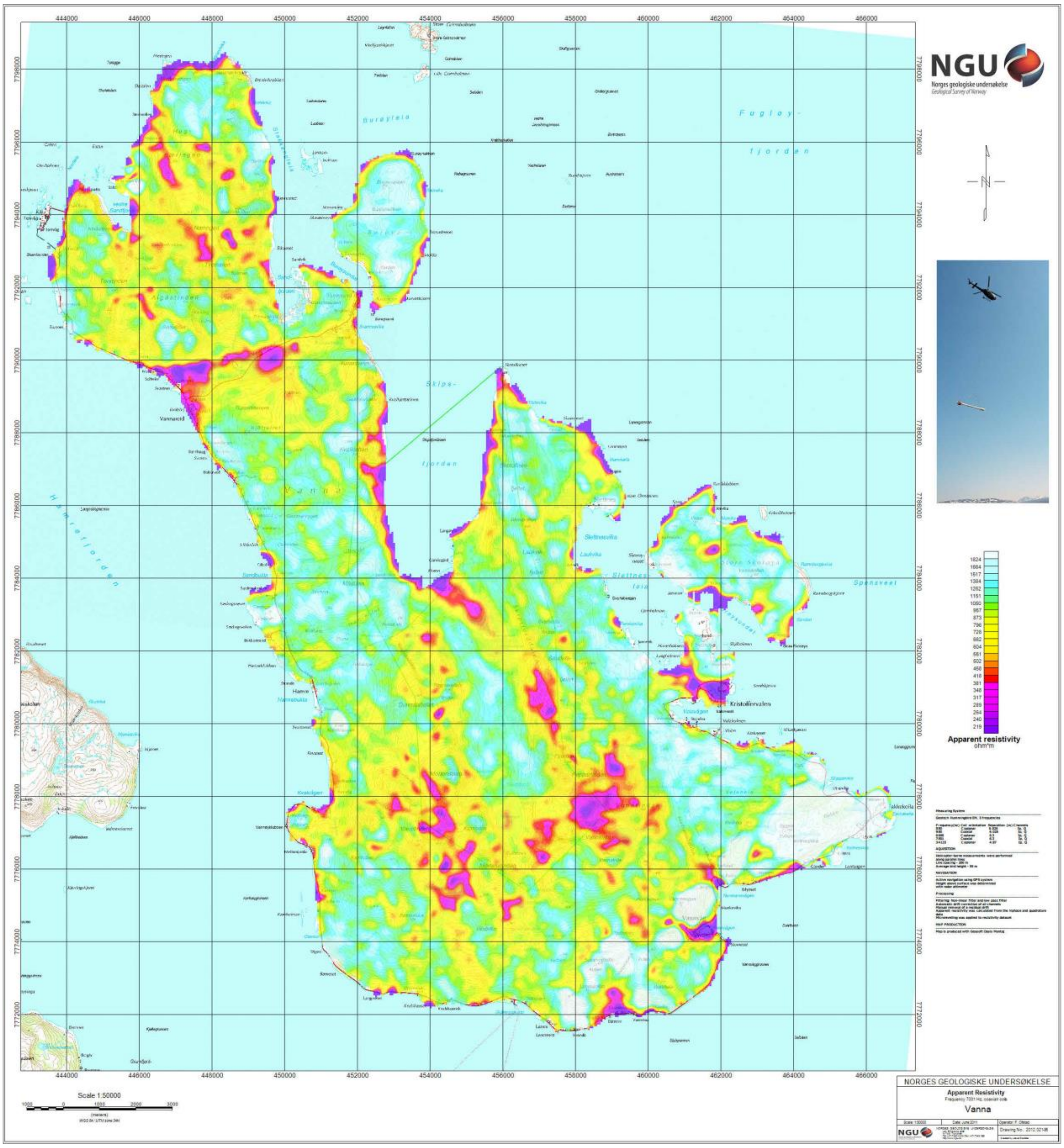

Figure 8. Apparent resistivity. Frequency 7000 Hz, Coaxial coils

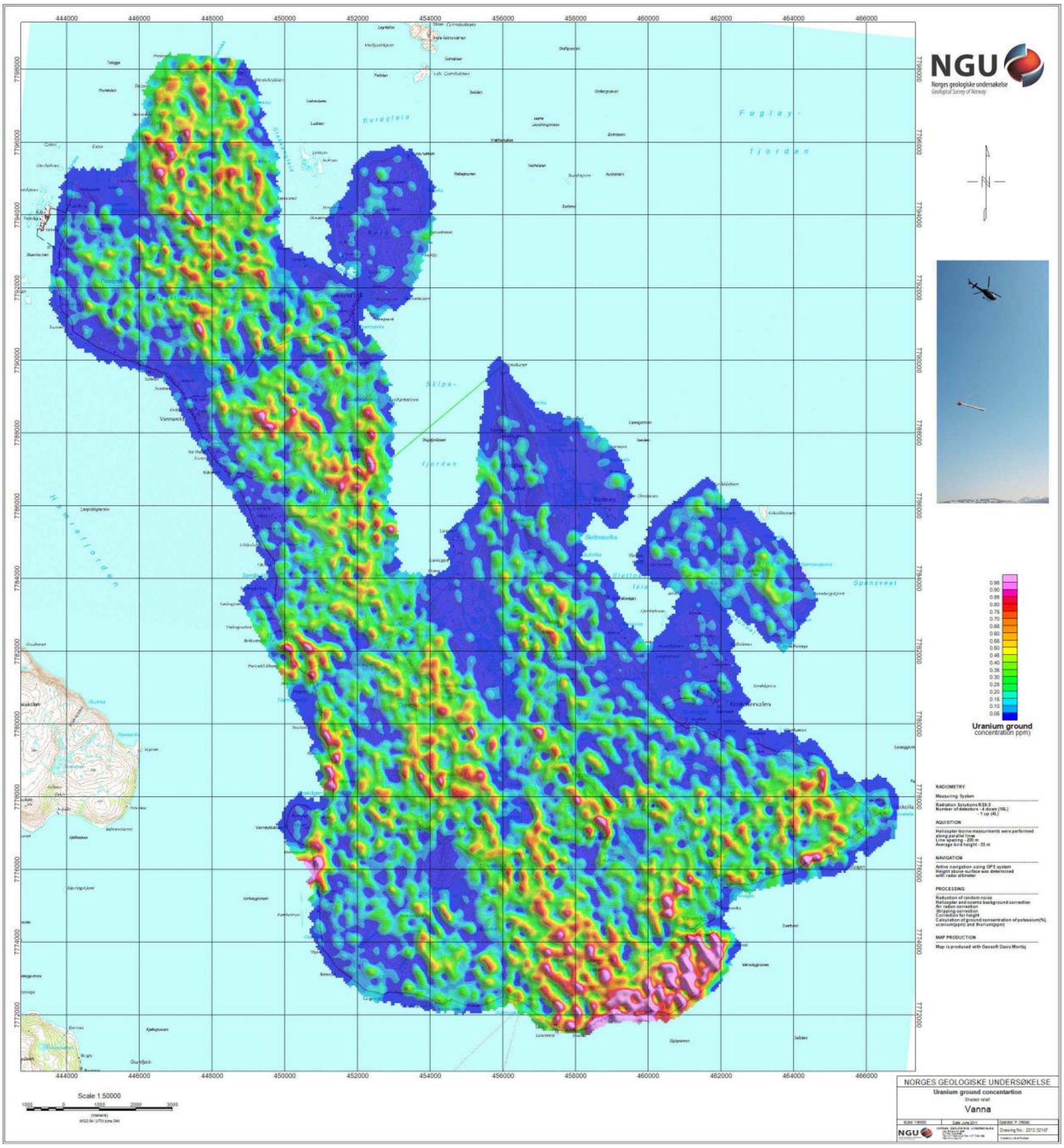

Figure 9. Uranium ground concentration

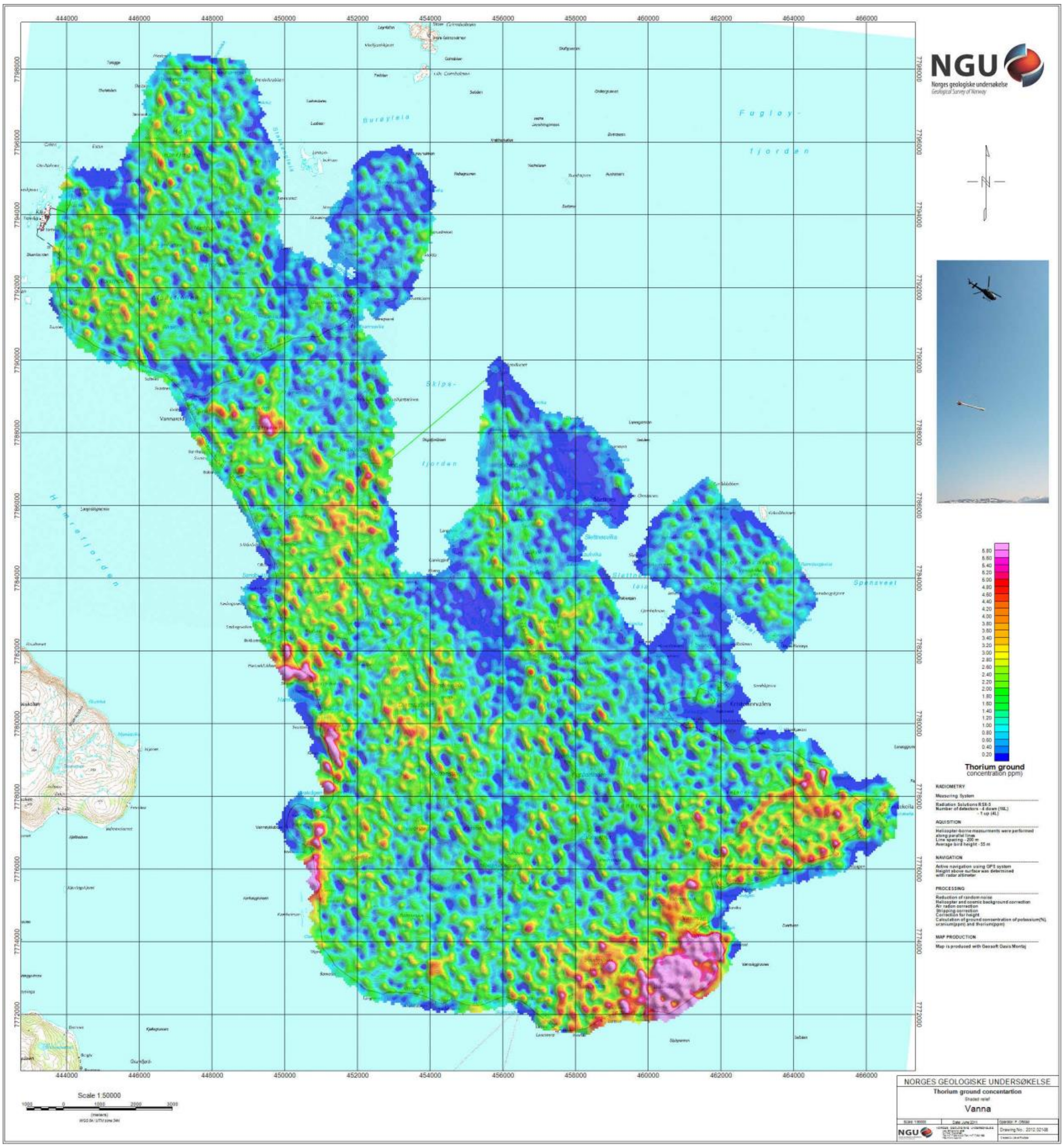

Figure 10. Thorium ground concentration

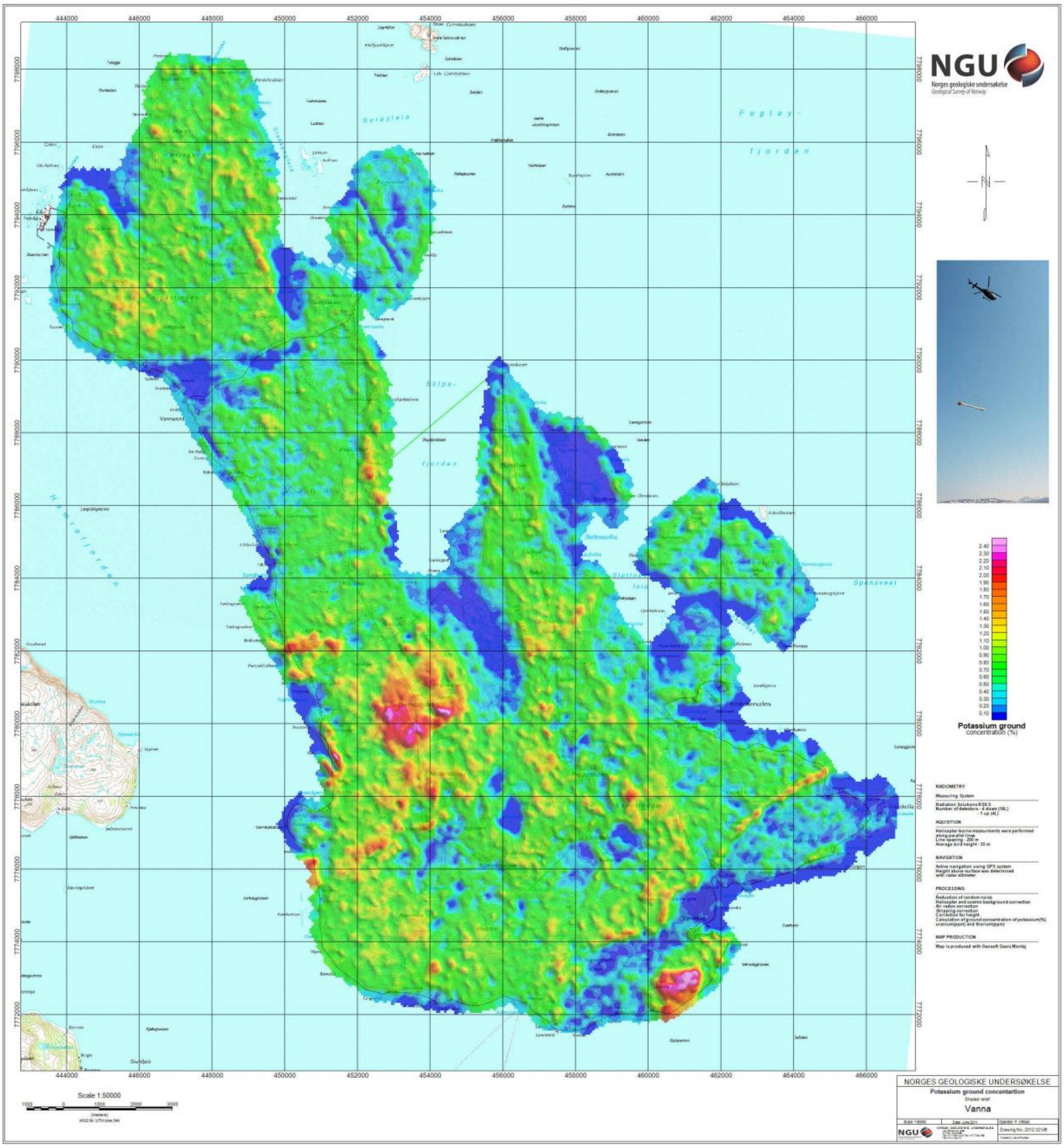

Figure 11. Potassium ground concentration