NGU Report 2014.044

Helicopter-borne magnetic and radiometric geophysical survey at Drangedal, Telemark County.

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REPORT

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Summary:

NGU conducted an airborne magnetic and radiometric survey at Drangedal in Telemark county between May-June 2014 as a part of the MINS project (Mineral resources in South Norway). This report describes and documents the acquisition, processing and visualization of recorded datasets. The geophysical survey results reported herein are approximately 10350 line km, covering an area of approximately 2070 km^2.

A helicopter-borne system designed to obtain detailed airborne magnetic and radiometric data was used in this survey. It had a Scintrex Cs-3 magnetometer in a towed bird and a 1024 channels RSX-5 spectrometer installed under the helicopter belly.

The survey was flown with 200 m line spacing. The flight line direction was 155^o (NW-SE). The average speed for the survey was 67 km/h and was ranged between 40 and 120 km/h depending mainly on the local topography. The average terrain clearance of the bird was about 50 m and about 80m for the spectrometer.

Collected data were processed at NGU using Geosoft Oasis Montaj software. Raw total magnetic field data were corrected for diurnal variations, the IGRF was calculated and subtracted and then the total field anomaly data were levelled using standard micro-levelling algorithm. Radiometric data were processed using standard procedures recommended by International Atomic Energy Association.

Data were gridded with a cell size of 50 x 50 m and presented as shaded relief maps at scale of 1:100.000.

Keywords:	Geophysics	Airborne
Magnetic	Radiometric	Technical report

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TABLES

FIGURES

1. INTRODUCTION

In 2013 the Norwegian government initiated a new program for mapping of mineral resources in Southern Norway (MINS). The goal of this program is to enhance the geological information that is relevant to an assessment of the mineral potential. The airborne geophysical surveys - helicopter borne and fixed wing- are important integral parts of MINS program. The airborne survey results reported herein amount about 10350 line km (2125 km^2) over the surveyed area, as shown in Figure 1.

Table 1. *Flight specifications of the surveyed area*

Name	Surveyed lines (km)	Surveyed area (Km^2)	Flight direction
Drangedal	10350	2070	NW-SE (155°)

Figure 1: Location map. Borders of the surveyed area are shown in red.

The objective of the airborne geophysical survey was to obtain a dense high-resolution aero-magnetic and radiometric data set over the survey area. These data sets are 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 area. It also improves defining the potential of known zones of mineralization, their geological settings, and identifying new areas of interest.

The survey incorporated the use of a high-sensitivity Cesium magnetometer, gamma-ray spectrometer 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).

1. SURVEY SPECIFICATIONS

1.1 Airborne Survey Parameters

A helicopter-borne system designed to obtain detailed airborne magnetic and radiometric data used in this survey. The system uses a Scintrex Cs-3 housed in a 2 m long bird towed 30 meters below the helicopter to record the total magnetic field and a 1024 channel gamma-ray spectrometer installed under the helicopter belly to map ground concentrations of Uranium, Thorium and Potassium.

The airborne survey began on May 19th and ended on June 20th 2014. A Eurocopter AS350-B2 from helicopter company HeliScan AS was employed. The survey lines were spaced 200 m apart throughout the survey, while the fight direction was 155° (NW-SE). Instrument operation was performed by Heliscan AS employees.

Large water bodies, rugged terrain and abrupt changes in topography affected the pilot's ability to 'drape' the terrain; therefore there are positive and negative variations in sensor height with respect to the standard helicopter height, which is defined as 60 m plus a height of obstacles (trees, power lines). The average survey height for the magnetic sensor was about 50m, while for the spectrometer it was about 80m. Due to flight safety rules parts on some profiles were flown at altitudes higher than 150m. Those data were discarded during the radiometric processing.

The ground speed of the helicopter varied from 40–120 km/h depending on topography, wind direction and its magnitude. On average the ground speed during the whole survey was about 67 km/h.

Magnetic data were recorded at 0.2 second intervals resulting in approximately 4 m point spacing. Spectrometry data were recorded every 1 second giving a point spacing of approximately 20 meters.

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 petro-physical composition.

A base magnetometer to monitor diurnal variations in the magnetic field was installed close to the helicopter base during the whole survey period. The topography and the proximity to the areas under investigation impose changes to the helicopter base location, and therefore changes to the base magnetometer locations which are depicted in figure 2. Names and locations of the base magnetometer stations are given in Table 2.

A GEM GSM-19 base station magnetometer (fig. 3) was used to record data every 3 seconds. The CPU clock of the magnetometer was synchronized through the built-in GPS receiver to permit synchronization with the recorded airborne magnetic data and subsequent removal of diurnal drift from them.

Navigation system uses GPS/GLONASS 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.

Table 2. *Magnetic base station locations (UTM zone 32N)*

Basemag	Location	X (m)	Y (m)	Instrument	Sampling interval (sec)
BM1	Skien	528800	6559815	GEM GSM-19	3
BM2	Drangedal	504450	6555250	GEM GSM-19	3

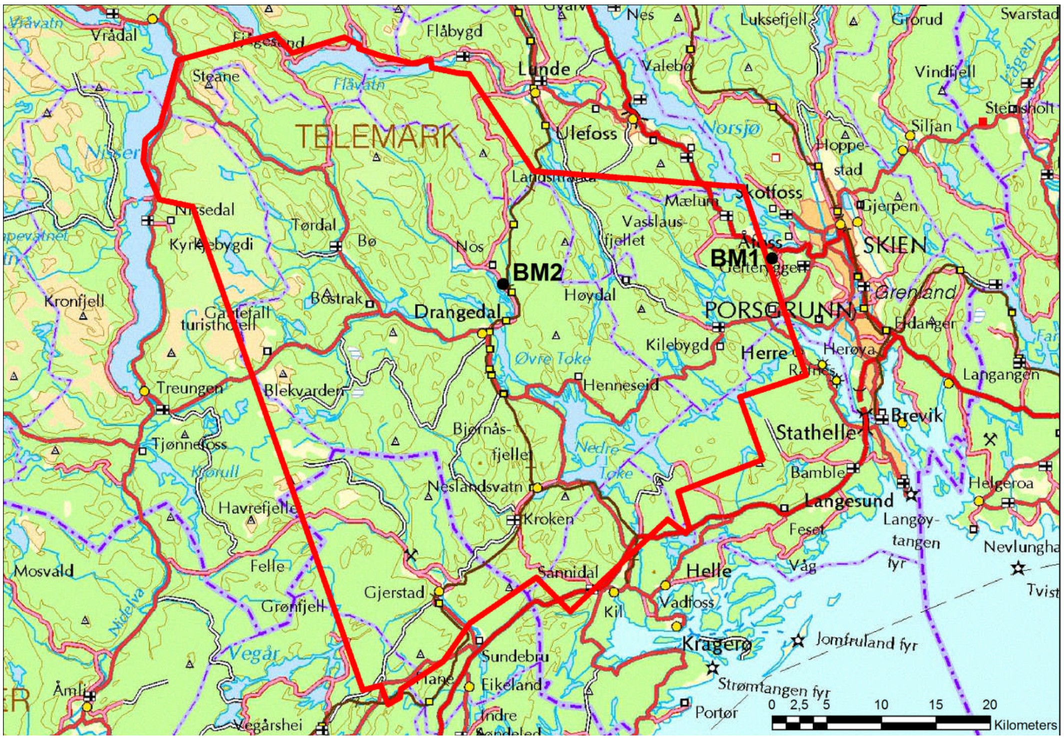

Figure 2: Map showing magnetic base station locations during Drangedal survey.

Figure 3: A GEM GSM-19 magnetic base station.

For quality control, the magnetic, radiometric, altitude and navigation data were monitored on two separate windows in the operator's display during flight while they were recorded in ASCII data streams to the acquisition’s PC hard disk drive.

1.2 Airborne Survey Instrumentation

Instrument specifications are given in table 3.

Table 3. *Instrument Specifications*

Instrument	Producer/Model	Accuracy / Sensitivity	Sampling frequency / interval
Magnetometer	Scintrex Cs-3	<2.5nT throughout range / 0.0006nT √Hz rms	5 Hz
Base magnetometer	GEM GSM-19	0.1 nT	3 s
Gamma spectrometer	Radiation Solutions RSX-5	1024 ch's, 16 liters down, 4 liters up	1 Hz
Radar altimeter	Bendix/King KRA 405B	± 3 % 0 – 500 feet ± 5 % 500 – 2500 feet	1 Hz
Pressure/temperature	Honeywell PPT	± 0.03 % FS	1 Hz
Navigation	Topcon GPS-receiver	± 5 meter	1 Hz
Acquisition system	NGU custom software		

The magnetic and radiometric, altitude and navigation data were monitored on the operator's displays during flight while they were recorded to the PC's 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. The raw data files were backed up onto USB flash drive in the field.

1.3 Airborne Survey Logistics Summary

A summary of the survey specifications is shown in Table 4.

Table 4. *Survey Specifications Summary*

Parameter	Specifications
Traverse (survey) line spacing	200 metres
Traverse line direction	NW-SE (155°)
Nominal aircraft ground speed	40 - 120 km/h
Average aircraft ground speed	67 km/h
Average sensor terrain clearance Mag	50m
Average sensor terrain clearance Rad	80m
Sampling rates:	
Magnetometer	0.2 seconds
Spectrometer, GPS, altimeter	1.0 second

Figure 4: Photo of Heliscan's Eurocopter AS350-B2 (P1). The Mag bird in front of the helicopter and the spectrometer under its belly are also depicted.

2. DATA PROCESSING AND PRESENTATION

All data were processed by Alexandros Stampolidis at NGU. The ASCII data files were loaded into separate Oasis Montaj databases (Geosoft 2010). The datasets were processed consequently according to processing flow charts shown in Appendix A1 and A2.

2.1 Total Field Magnetic Data

At the first stage the raw magnetic data were checked for spikes, using the 4th difference calculation as a flag. Obvious spikes were checked and then manually removed. The data from base stations were also inspected for spikes and spikes were removed manually if necessary. Typically, several corrections have to be applied to magnetic data before gridding – i.e. heading, lag and diurnal correction.

Diurnal Corrections

The temporal fluctuations in the magnetic field of the earth affect the total magnetic field readings during the airborne survey. This is commonly referred to as the magnetic diurnal variation. These fluctuations can be effectively removed from the airborne magnetic dataset by using a stationary reference magnetometer that records the magnetic field of the earth at a given short time interval. Magnetic diurnals that were recorded on the base station magnetometer, were within the standard NGU specifications during the entire survey (Rønning 2013).

Diurnal variations were measured with a GEM GSM-19 base station magnetometer. The base station computer clock was continuously synchronized with GPS clock. The recorded data are merged with the airborne data and the diurnal correction is applied according to equation (1).

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

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

We used two different $\overline{B}_B$ values one for each base station location. The average datum base level ($\overline{B}_B$**)** was set equal to 51022.3 nT for data collected between 19/5 and 27/5, when the base magnetometer was located near Skien (Basemag1 in fig.2), while it was set equal to 50730.5 nT for data collected between 28/5 and 20/6, when the base station was moved close to Drangedal (Basemag2 in fig.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.

Magnetic data processing, gridding and presentation

The total field magnetic anomaly data ($\mathbf{B}_{TA}$) were calculated from the diurnal corrected data ($\mathbf{B}_{Tc}$) after subtracting the IGRF for the surveyed area calculated for the data period (eq.2)

$$\mathbf{B}_{TA} = \mathbf{B}_{Tc} - IGRF \tag{2}$$

IGRF 2010 model was employed in these calculations.

The total field anomaly data were split into lines and then were gridded using a minimum curvature method with a grid cell size of 50 meters. This cell size is equal to one quarter of the 200m average line spacing. In order to remove small line-to-line levelling errors that were detected on the gridded magnetic anomaly data, the Geosoft Micro-levelling technique was applied on the flight line based magnetic database. Then, the micro-levelled channel was gridded using again a minimum curvature method with 50 m grid cell size.

The processing steps of magnetic data presented so far were performed on point basis. The following steps are performed on grid basis. The Horizontal and Vertical Gradient along with the Tilt Derivative of the total magnetic anomaly were calculated from the micro-levelled total magnetic anomaly grid. The magnitude of the horizontal gradient was calculated according to equation (3)

$$HG = \sqrt{\left(\frac{\partial(B_{TA})}{\partial x}\right)^2 + \left(\frac{\partial(B_{TA})}{\partial y}\right)^2} \tag{3}$$

where $\mathbf{B}_{TA}$ is the micro-levelled total field anomaly field. The vertical gradient (VG) was calculated by applying a vertical derivative convolution filter to the micro-levelled $\mathbf{B}_{TA}$ field. The Tilt derivative (TD) was calculated according to the equation (4)

$$\text{TD} = \text{atan}(\text{VG}/\text{HG}) \tag{4}$$

A 5x5 convolution filter was applied to smooth the resulted magnetic grids.

The results are presented in a series of coloured shaded relief maps (1:100.000). The maps are:

A. Total field magnetic anomaly
B. Horizontal gradient of total magnetic anomaly
C. Vertical gradient of total magnetic anomaly
D. Tilt Derivative (or Tilt angle) of the total magnetic anomaly

They are representative of the distribution of magnetization over the surveyed area. A list of the produced maps is shown in Table 6.

2.2 Radiometric data

Airborne gamma-ray spectrometry measures the abundance of Potassium (K), Thorium (eTh), and Uranium (eU) in rocks and weathered materials by detecting gamma-rays emitted due to the natural radioelement decay of these elements. The data analysis method is based on the IAEA recommended method for U, Th and K (International Atomic Energy Agency, 1991; 2003). A short description of the individual processing steps of that methodology as adopted by NGU is given bellow.

Energy windows

The Gamma-ray spectra were initially reduced into standard energy windows corresponding to the individual radio-nuclides K, U and Th. Figure 5 shows an example of a Gamma-ray spectrum and the corresponding energy windows and radioisotopes (with peak energy in MeV) responsible for the radiation.

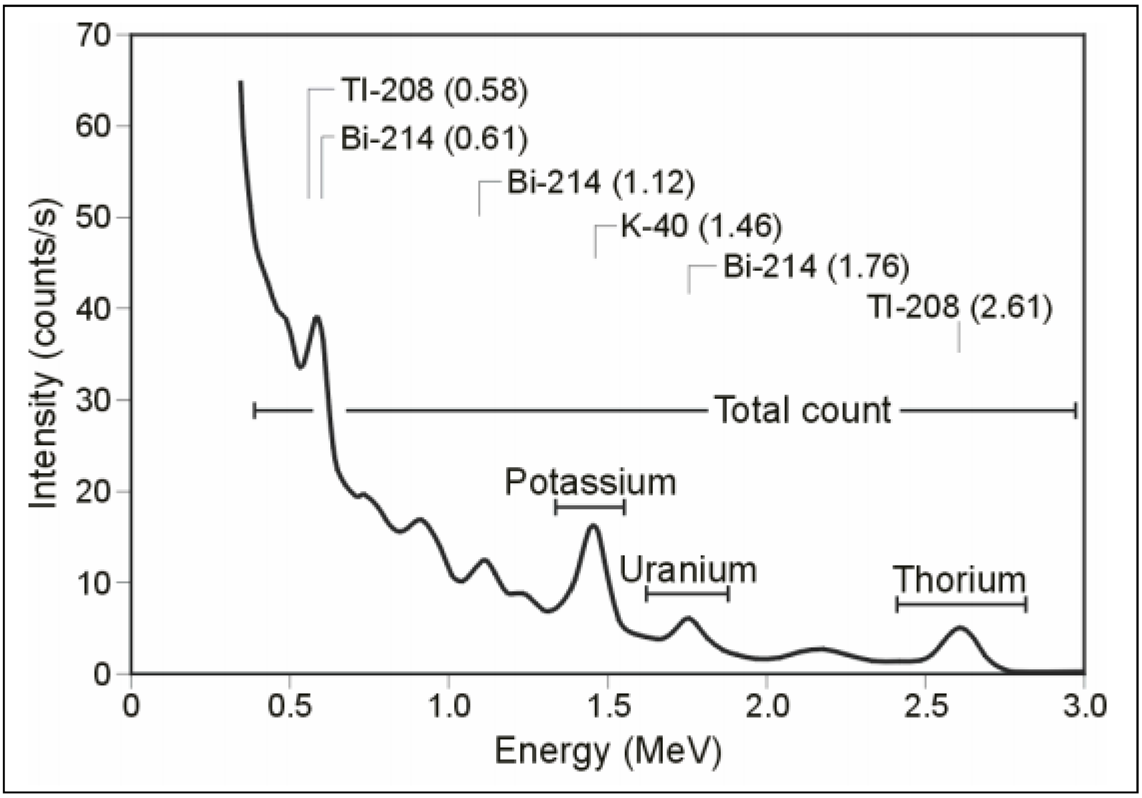

Figure 5: An example of Gamma-ray spectrum showing the position of the K, Th, U and Total count windows.

Table 5. *Specified channel windows for the 1024 RSX-5 systems used in this survey*

Gamma-ray spectrum	Cosmic	Total count	K	U	Th
Down	1022	134-934	454-521	551-617	801-934
Up	1022			551-617	
Energy windows (MeV)	>3.07	0.41-2.81	1.37-1.57	1.66-1.859	2.41-2.81

The RSX-5 is a 1024 channel system with four downward and one upward looking detector, which means that the actual Gamma-ray spectrum is divided into 1024 channels. The first channel is reserved for the “Live Time” and the last for the Cosmic rays. Table 5 shows the channels that were used for the reduction of the spectrum.

Live Time correction

The data were corrected for live time. “Live time” is an expression of the relative period of time the instrument was able to register new pulses per sample interval. On the other hand “dead time” is an expression of the relative period of time the system was unable to register new pulses per sample interval. The relation between “dead” and “live time” is given by the equation (5)

$$\text{“Live time”} = \text{“Real time”} - \text{“Dead time”} \tag{5}$$

where the “real time” or “acquisition time” is the elapsed time over which the spectrum is accumulated (1 second).

The live time correction is applied to the total count, Potassium, Uranium, Thorium, upward Uranium and cosmic channels. The formula used to apply the correction is as follows:

$$C_{LT} = C_{RAW} \cdot \frac{1000000}{Live\ Time} \tag{6}$$

where C_{LT} is the live time corrected channel in counts per second, C_{RAW} is the raw channel data in counts per second and Live Time is in microseconds.

Cosmic and aircraft correction

Background radiation resulting from cosmic rays and aircraft contamination was removed from the total count, Potassium, Uranium, Thorium, upward Uranium channels using the following formula:

$$C_{CA} = C_{LT} - (a_c + b_c \cdot C_{Cos}) \tag{7}$$

where C_{CA} is the cosmic and aircraft corrected channel, C_{LT} is the live time corrected channel a_c is the aircraft background for this channel, b_c is the cosmic stripping coefficient for this channel and C_{Cos} is the low pass filtered cosmic channel.

Radon correction

The upward detector method, as discussed in IAEA (1991), was applied to remove the effects of the atmospheric radon in the air below and around the helicopter. Using spectrometry data over-water, where there is no contribution from the ground sources, enables the calculation of the coefficients (a_C and b_C) for the linear equations that relate the cosmic corrected counts per second of Uranium channel with that of total count, Potassium, Thorium and Uranium upward channels over water. Data over-land was used in conjunction with data over-water to calculate the a_1 and a_2 coefficients used in equation (8) for the determination of the Radon component in the downward uranium window:

$$Radon_U = \frac{Uup_{CA} - a_1 \cdot U_{CA} - a_2 \cdot Th_{CA} + a_2 \cdot b_{Th} - b_U}{a_U - a_1 - a_2 \cdot a_{Th}} \tag{8}$$

where $Radon_u$ is the radon component in the downward Uranium window, Uup_{CA} is the filtered upward uranium, U_{CA} is the filtered Uranium, Th_{CA} is the filtered Thorium, a_1, a_2, a_U and a_{Th} are proportional factors and b_U an b_{Th} are constants determined experimentally.

The effects of Radon in the downward Uranium are removed by simply subtracting $Radon_U$ from U_{CA}. The effects of radon in the other channels are removed using the following formula:

$$C_{RC} = C_{CA} - (a_C \cdot Radon_U + b_C) \tag{9}$$

where C_{RC} is the Radon corrected channel, C_{CA} is the cosmic and aircraft corrected channel, $Radon_U$ is the Radon component in the downward uranium window, a_C is the proportionality factor and b_C is the constant determined experimentally for this channel from over-water data.

Compton Stripping

Potassium, Uranium and Thorium Radon corrected channels, are subjected to spectral overlap correction. Compton scattered gamma rays in the radio-nuclides energy windows were corrected by window stripping using Compton stripping coefficients determined from measurements on calibrations pads (Grasty et al, 1991) at the Geological Survey of Norway in Trondheim (see values in Appendix A2).

The stripping corrections are given by the following formulas:

$$A_1 = 1 - (g \cdot \gamma) - (\mathrm{a} \cdot \alpha) + (\mathrm{a} \cdot g \cdot \beta) - (b \cdot \beta) + (b \cdot \alpha \cdot \gamma) \tag{10}$$

$$U_{ST} = \frac{Th_{RC} \cdot ((g \cdot \beta) - \alpha) + U_{RC} \cdot (1 - b \cdot \beta) + K_{RC} \cdot ((b \cdot \alpha) - g)}{A_1} \tag{11}$$

$$Th_{ST} = \frac{Th_{RC} \cdot (1 - (g \cdot \gamma)) + U_{RC} \cdot (b \cdot \gamma - \mathrm{a}) + K_{RC} \cdot ((\mathrm{a} \cdot g) - b)}{A_1} \tag{12}$$

$$K_{ST} = \frac{Th_{RC} \cdot ((\alpha \cdot \gamma) - \beta) + U_{RC} \cdot ((\mathrm{a} \cdot \beta) - \gamma) + K_{RC} \cdot (1 - (\mathrm{a} \cdot \alpha))}{A_1} \tag{13}$$

where U_{RC}, Th_{RC}, K_{RC} are the radon corrected Uranium, Thorium and Potassium and a, b, g, α, β, γ are Compton stripping coefficients. U_{ST}, Th_{ST} and K_{ST} are stripped values of U, Th and K.

Reduction to Standard Temperature and Pressure

The radar altimeter data were converted to effective height (H_{STP}) using the acquired temperature and pressure data, according to the expression:

$$H_{STP} = H \cdot \frac{273.15}{T + 273.15} \cdot \frac{P}{1013.25} \tag{14}$$

where H is the smoothed observed radar altitude in meters, T is the measured air temperature in degrees Celsius and P is the measured barometric pressure in millibars.

Height correction

Variations caused by changes in the aircraft altitude relative to the ground was corrected to a nominal height of **60 m**. Data recorded at the height above **150 m** were considered as non-reliable and removed from processing. Total count, Uranium, Thorium and Potassium stripped channels were subjected to height correction according to the equation:

$$C_{60m} = C_{ST} \cdot e^{C_{ht} \cdot (60 - H_{STP})} \tag{15}$$

where C_{ST} is the stripped corrected channel, C_{ht} is the height attenuation factor for that channel and H_{STP} is the effective height.

Conversion to ground concentrations

Finally, corrected count rates were converted to effective ground element concentrations using calibration values derived from calibration pads (Grasty et al, 1991) at the Geological Survey of Norway in Trondheim (see values in Appendix A2). The corrected data provide an estimate of the apparent surface concentrations of Potassium, Uranium and Thorium (K, eU and eTh). Potassium concentration is expressed as a percentage, equivalent Uranium and Thorium as parts per million (ppm). Uranium and Thorium are described as “equivalent” since their presence is inferred from gamma-ray radiation from daughter elements (^{214}Bi for Uranium, ^{208}TI for Thorium). The concentration of the elements is calculated according to the following expressions:

$$C_{CONC} = C_{60m} / C_{SENS\_60m} \tag{16}$$

where C_{60m} is the height corrected channel, C_{SENS_60m} is experimentally determined sensitivity reduced to the nominal height (60m).

Spectrometry data gridding and presentation

Gamma-rays from Potassium, Thorium and Uranium emanate from the uppermost 30 to 40 centimetres of soil and rock in the crust (Minty, 1997). Variations in the concentrations of these radioelements largely related to changes in the mineralogy and geochemistry of the Earth’s surface.

The calculated ground concentrations of the three main natural radioelements Potassium, Thorium and Uranium and total gamma-ray flux (total count) were micro-levelled to remove small line-to-line levelling errors, as in the case of the magnetic data, and then gridded using a minimum curvature method with a grid cell size of 50 meters. This cell size is equal to one quarter of the 200m average line spacing. A 3x3 convolution filter was applied to smooth the concentration grids. A list of the produced maps is shown on Table 6.

Quality of the radiometric data was within standard NGU specifications (Rønning 2013).

A list of the parameters used in the processing schemes is given in Appendix A2. For further reading regarding standard processing of airborne radiometric data, we recommend the publication from Minty et al. (1997).

3. PRODUCTS

Processed digital data from the survey are presented as:

1. Geosoft XYZ files:
   Drangedal_Magnetics.XYZ
   Drangedal_Radiometrics.XYZ

2. Georeferenced tiff files (Geo-tiff).

3. Coloured maps (jpg) at the scale 1:100.000 are available from NGU on request (see Table 7.).

Table 6. *Maps available from NGU on request.*

Region	Map #	Scale	Name
Drangedal	2014.044-01	1:100.000	Flight path
	2014.044-02	1:100.000	Total filed magnetic anomaly
	2014.044-03	1:100.000	Magnetic Horizontal Derivative
	2014.044-04	1:100.000	Magnetic Vertical Derivative
	2014.044-05	1:100.000	Magnetic Tilt Derivative
	2014.044-06	1:100.000	Radiometry Total Counts
	2014.044-07	1:100.000	Potassium ground concentration
	2014.044-08	1:100.000	Uranium ground concentration
	2014.044-09	1:100.000	Thorium ground concentration
	2014.044-10	1:100.000	Radiometric Ternary Map

Downscaled images of the maps are shown on figures 6 to 15.

4. REFERENCES

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P1: Photo by Mari Nymoen, Telen Newspaper, Notodden

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
- Inspection of basemag data and removal of spikes
- Import basemag data to Geosoft database
- Correction of data for diurnal variation and IGRF
- Splitting flight data by lines
- Gridding
- Micro-leveling
- 5x5 convolution filter

APPENDIX A2: FLOW CHART OF RADIOMETRY PROCESSING

Underlined processing stages are applied to the K, U, Th and TC windows.
Meaning of parameters is described in the referenced literature.

Processing flow:

- Quality control
- <u>Airborne and cosmic correction (IAEA, 2003)</u>
  Used parameters: determined by high altitude calibration flights (1500 - 9000 ft) near Langøya in 2013

Channel	Background	Cosmic
K	7.3314	0.0617
U	0.8981	0.0454
Th	0.8881	0.0647
Uup	0.3926	0.0423
Total counts	36.291	1.0379

- <u>Radon correction using upward detector method (IAEA, 2003)</u>
  Used parameters (determined from survey data over water and land at Drangedal in May-June 2014):

Coefficient	Value	Coefficient	Value
a_u	0.29006	b_u	0.12497
a_K	0.93652	b_K	2.44555
a_{Th}	0.09081	b_{Th}	0.5195
a_{TC}	17.9128	b_{TC}	15.2241
a_1	0.06675646	a_2	0.0133381

- Stripping correction (IAEA, 2003)
  Used parameters (determined from measurements on calibrations pads at NGU in April 2014):

Coefficient	Value
a	0.0482594
b	0
c	0
α	0.30408
β	0.46654
γ	0.80597

- Height correction to a height of 60 m
  Used parameters (determined by high altitude calibration flights (150 – 600 ft) at Drangedal in May 2014):
  Attenuation factors in 1/m:

Channel	Attenuation factor
K	-0.010532
U	-0.008726
Th	-0.006273
TC	-0.0081

- Converting counts at 60 m heights to element concentration on the ground
  Used parameters (determined from measurements on calibrations pads at NGU in April 2014):
  Sensitivity (elements concentrations per count):

Channel	Sensitivity
K (%/count)	0.007558025
U (ppm/count)	0.087728381
Th (ppm/count)	0.152743376

- Microlevelling using Geosoft menu and smoothening by a convolution filtering

Microlevelling parameters	Value
De-corrugation cutoff wavelength (m)	2000
Cell size for gridding (m)	50
Naudy (1968) Filter length (m)	800

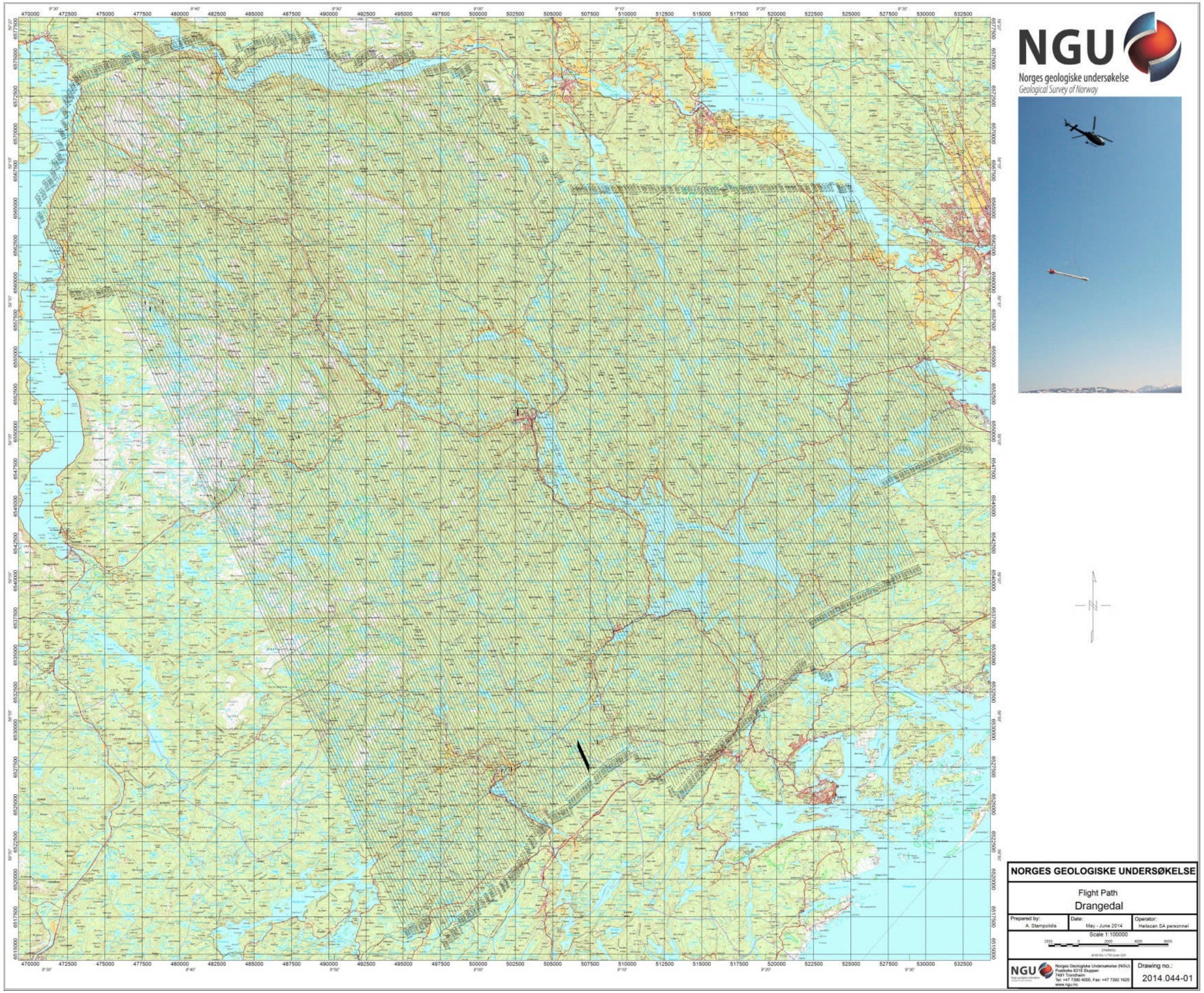
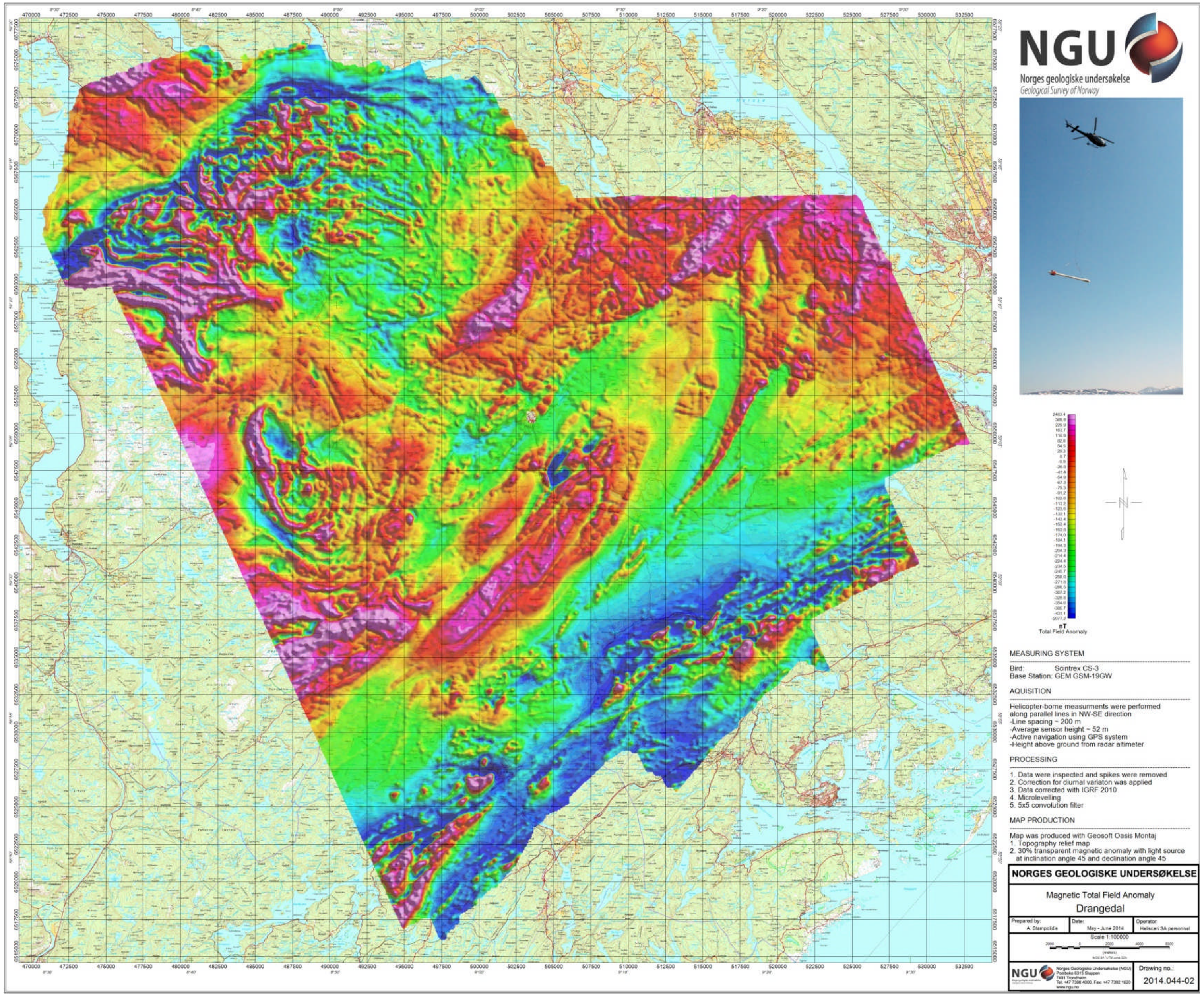


Figure 6: Flight path map



MEASURING SYSTEM

Bird: Scintrex CS-3
Base Station: GEM GSM-19GW

AQUISITION

Helicopter-borne measurments were performed along parallel lines in NW-SE direction
-Line spacing ~ 200 m
-Average sensor height ~ 52 m
-Active navigation using GPS system
-Height above ground from radar altimeter

PROCESSING

1. Data were inspected and spikes were removed
2. Correction for diurnal variaton was applied
3. Data corrected with IGRF 2010
4. Microlevelling
5. 5x5 convolution filter

MAP PRODUCTION

Map was produced with Geosoft Oasis Montaj
1. Topography relief map
2. 30% transparent magnetic anomaly with light source at inclination angle 45 and declination angle 45

NORGES GEOLOGISKE UNDERSØKELSE

Magnetic Total Field Anomaly
Drangedal

Prepared by: A. Stampolidis
Date: May - June 2014
Operator: Heliscan SA personnel

Scale 1:100000

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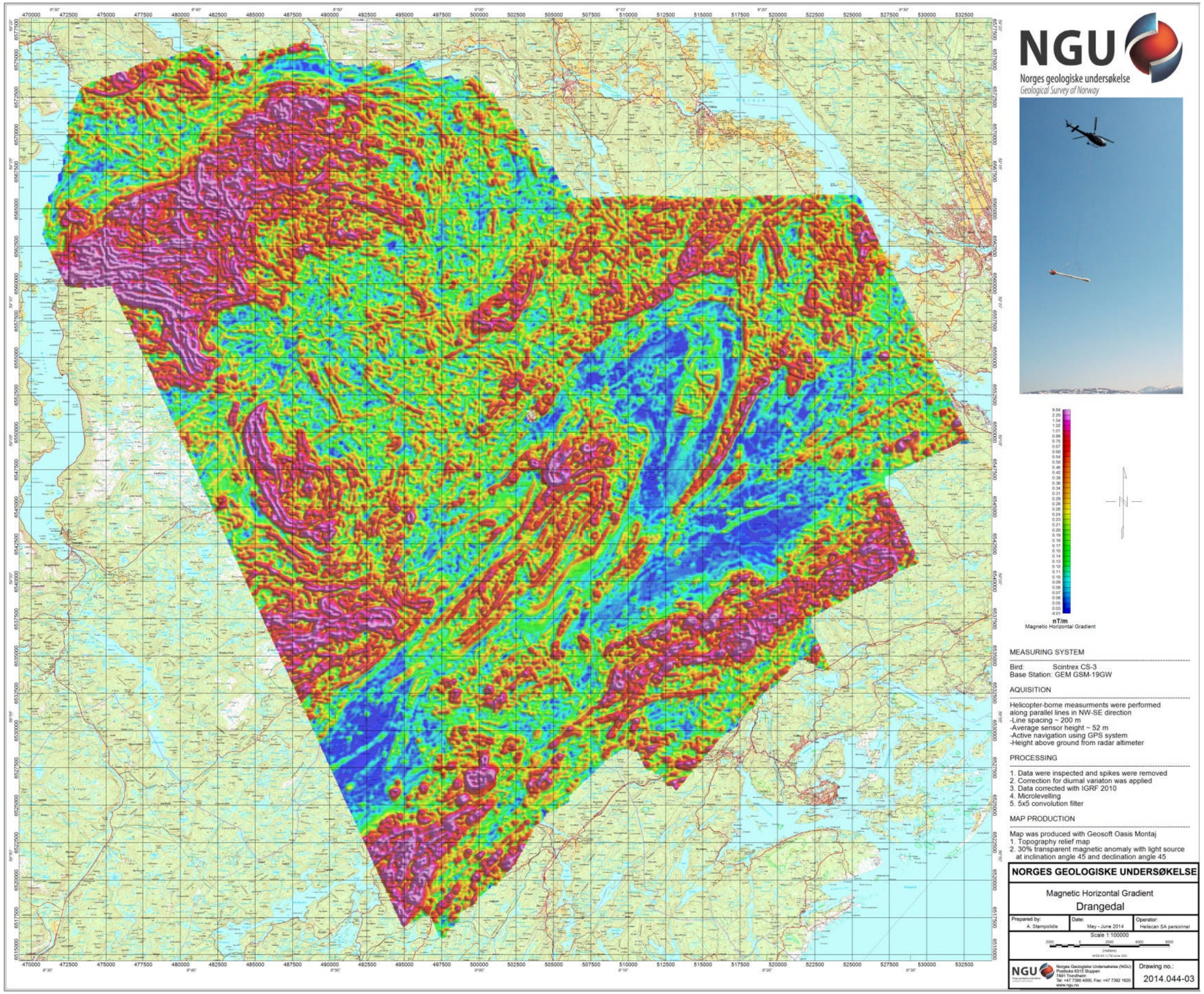
Drawing no.: 2014.044-02

Figure 7: Total Magnetic Field anomaly map



MEASURING SYSTEM

Bird: Scintrex CS-3
Base Station: GEM GSM-19GW

AQUISITION

Helicopter-borne measurments were performed along parallel lines in NW-SE direction
-Line spacing ~ 200 m
-Average sensor height ~ 52 m
-Active navigation using GPS system
-Height above ground from radar altimeter

PROCESSING

1. Data were inspected and spikes were removed
2. Correction for diurnal variaton was applied
3. Data corrected with IGRF 2010
4. Microlevelling
5. 5x5 convolution filter

MAP PRODUCTION

Map was produced with Geosoft Oasis Montaj
1. Topography relief map
2. 30% transparent magnetic anomaly with light source at inclination angle 45 and declination angle 45

NORGES GEOLOGISKE UNDERSØKELSE

Magnetic Horizontal Gradient
Drangedal

Prepared by: A. Stampolidis
Date: May - June 2014
Operator: Heliscan SA personnel
Scale 1:100000

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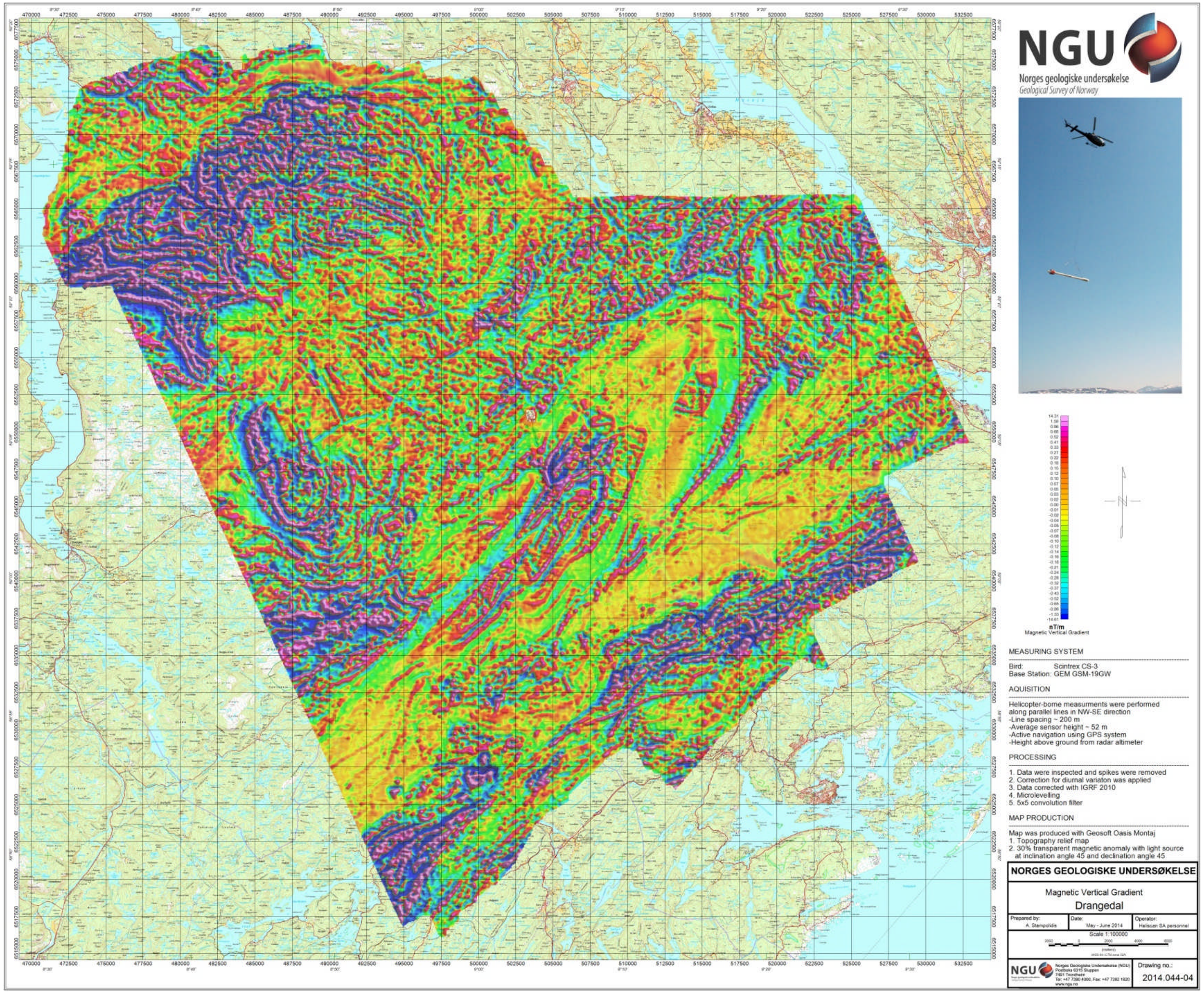
Drawing no.: 2014.044-03

Figure 8: Magnetic Horizontal Gradient map



MEASURING SYSTEM

Bird: Scintrex CS-3
Base Station: GEM GSM-19GW

AQUISITION

Helicopter-borne measurments were performed along parallel lines in NW-SE direction
-Line spacing ~ 200 m
-Average sensor height ~ 52 m
-Active navigation using GPS system
-Height above ground from radar altimeter

PROCESSING

1. Data were inspected and spikes were removed
2. Correction for diurnal variaton was applied
3. Data corrected with IGRF 2010
4. Microlevelling
5. 5x5 convolution filter

MAP PRODUCTION

Map was produced with Geosoft Oasis Montaj
1. Topography relief map
2. 30% transparent magnetic anomaly with light source at inclination angle 45 and declination angle 45

NORGES GEOLOGISKE UNDERSØKELSE

Magnetic Vertical Gradient
Drangedal

Prepared by: A. Stampolidis
Date: May - June 2014
Operator: Heliscan SA personnel
Scale 1:100000

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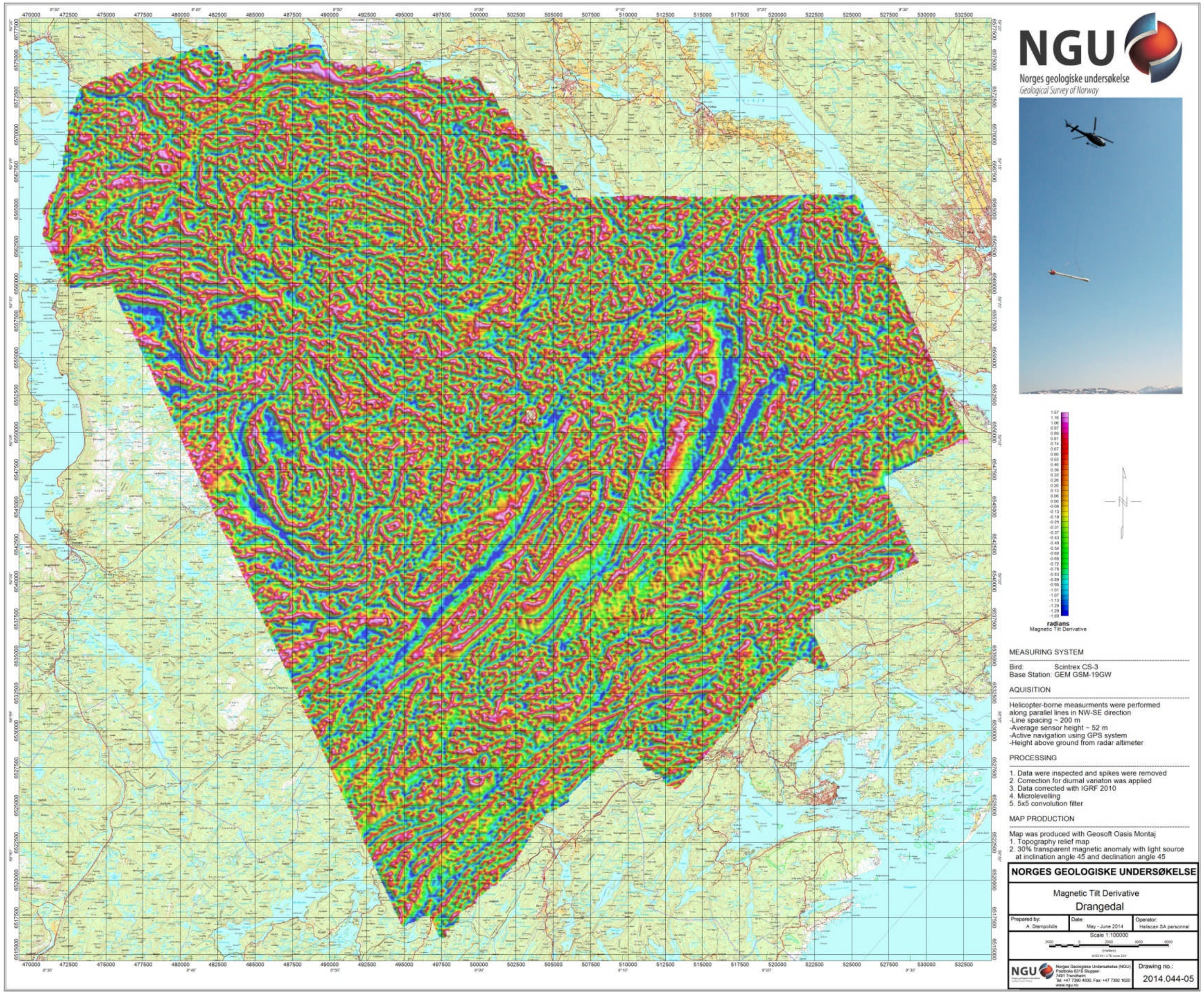
Drawing no.: 2014.044-04

Figure 9: Magnetic Vertical Gradient map



MEASURING SYSTEM

Bird: Scintrex CS-3
Base Station: GEM GSM-19GW

AQUISITION

Helicopter-borne measurments were performed along parallel lines in NW-SE direction
-Line spacing ~ 200 m
-Average sensor height ~ 52 m
-Active navigation using GPS system
-Height above ground from radar altimeter

PROCESSING

1. Data were inspected and spikes were removed
2. Correction for diurnal variaton was applied
3. Data corrected with IGRF 2010
4. Microlevelling
5. 5x5 convolution filter

MAP PRODUCTION

Map was produced with Geosoft Oasis Montaj
1. Topography relief map
2. 30% transparent magnetic anomaly with light source at inclination angle 45 and declination angle 45

NORGES GEOLOGISKE UNDERSØKELSE

Magnetic Tilt Derivative
Drangedal

Prepared by: A. Stampolidis
Date: May - June 2014
Operator: Heliscan SA personnel

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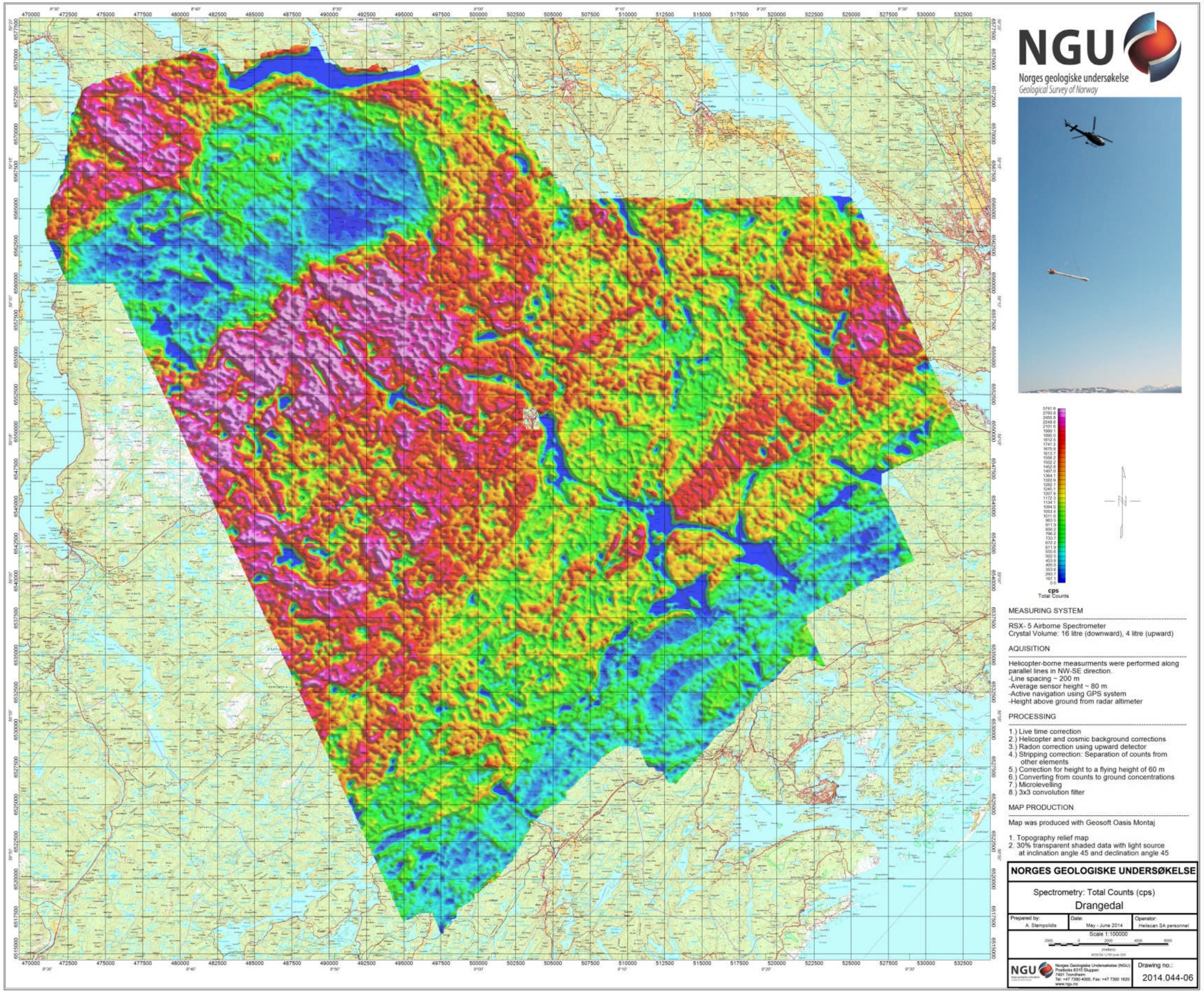
Drawing no.: 2014.044-05

Figure 10: Magnetic Tilt Derivative map



MEASURING SYSTEM

RSX- 5 Airborne Spectrometer
Crystal Volume: 16 litre (downward), 4 litre (upward)

AQUISITION

Helicopter-borne measurments were performed along parallel lines in NW-SE direction.
-Line spacing ~ 200 m
-Average sensor height ~ 80 m
-Active navigation using GPS system
-Height above ground from radar altimeter

PROCESSING

1.) Live time correction
2.) Helicopter and cosmic background corrections
3.) Radon correction using upward detector
4.) Stripping correction: Separation of counts from other elements
5.) Correction for height to a flying height of 60 m
6.) Converting from counts to ground concentrations
7.) Microlevelling
8.) 3x3 convolution filter

MAP PRODUCTION

Map was produced with Geosoft Oasis Montaj

1. Topography relief map
2. 30% transparent shaded data with light source at inclination angle 45 and declination angle 45

NORGES GEOLOGISKE UNDERSØKELSE

Spectrometry: Total Counts (cps)
Drangedal

Prepared by: A. Stampolidis
Date: May - June 2014
Operator: Heliscan SA personnel

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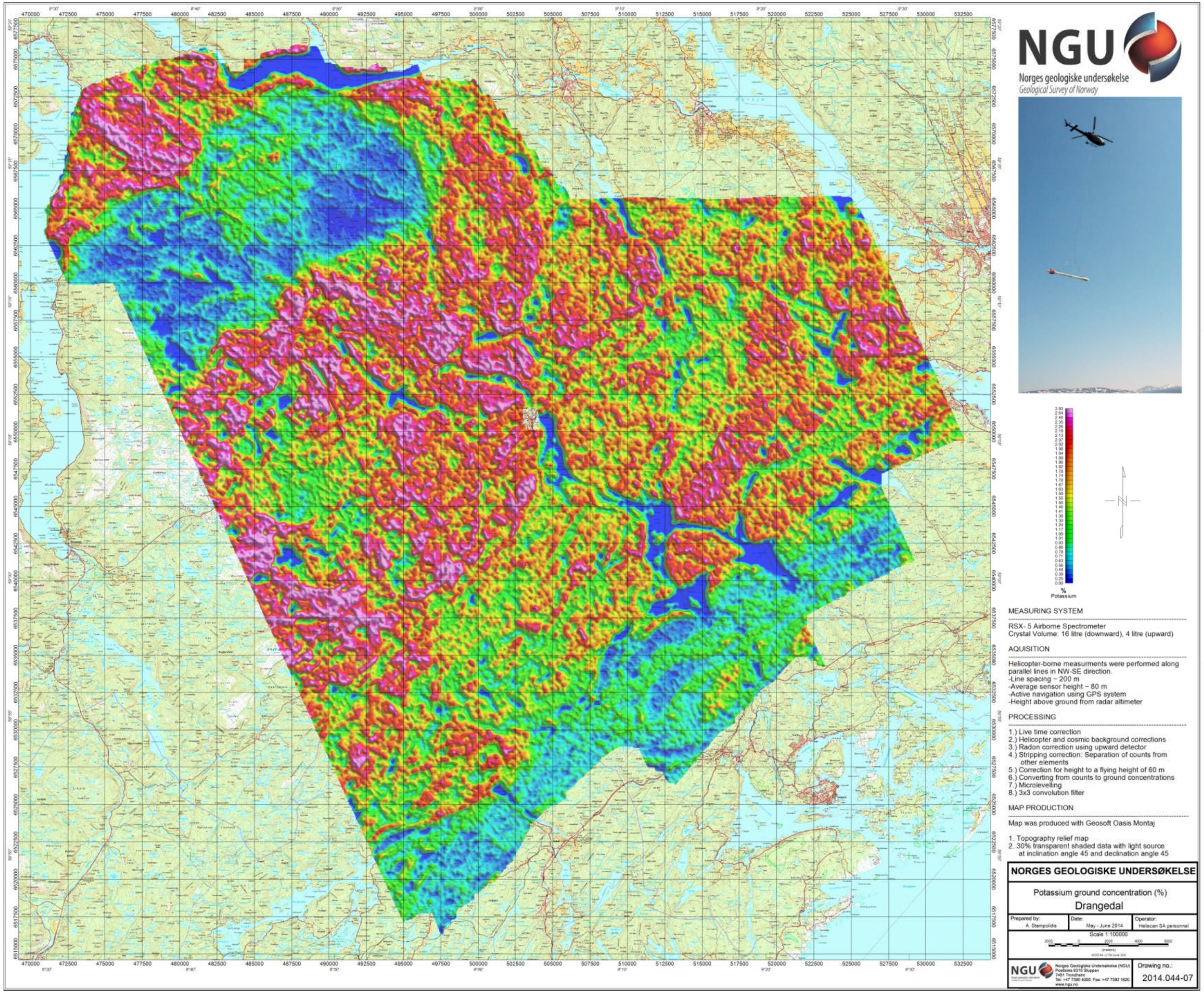
Figure 11: Radiometry: Total Counts map



MEASURING SYSTEM

RSX- 5 Airborne Spectrometer
Crystal Volume: 16 litre (downward), 4 litre (upward)

AQUISITION

Helicopter-borne measurments were performed along parallel lines in NW-SE direction.
-Line spacing ~ 200 m
-Average sensor height ~ 80 m
-Active navigation using GPS system
-Height above ground from radar altimeter

PROCESSING

1.) Live time correction
2.) Helicopter and cosmic background corrections
3.) Radon correction using upward detector
4.) Stripping correction: Separation of counts from other elements
5.) Correction for height to a flying height of 60 m
6.) Converting from counts to ground concentrations
7.) Microlevelling
8.) 3x3 convolution filter

MAP PRODUCTION

Map was produced with Geosoft Oasis Montaj

1. Topography relief map
2. 30% transparent shaded data with light source at inclination angle 45 and declination angle 45

NORGES GEOLOGISKE UNDERSØKELSE

Potassium ground concentration (%)
Drangedal

Prepared by: A. Stampolidis
Date: May - June 2014
Operator: Heliscan SA personnel
Scale 1:100000

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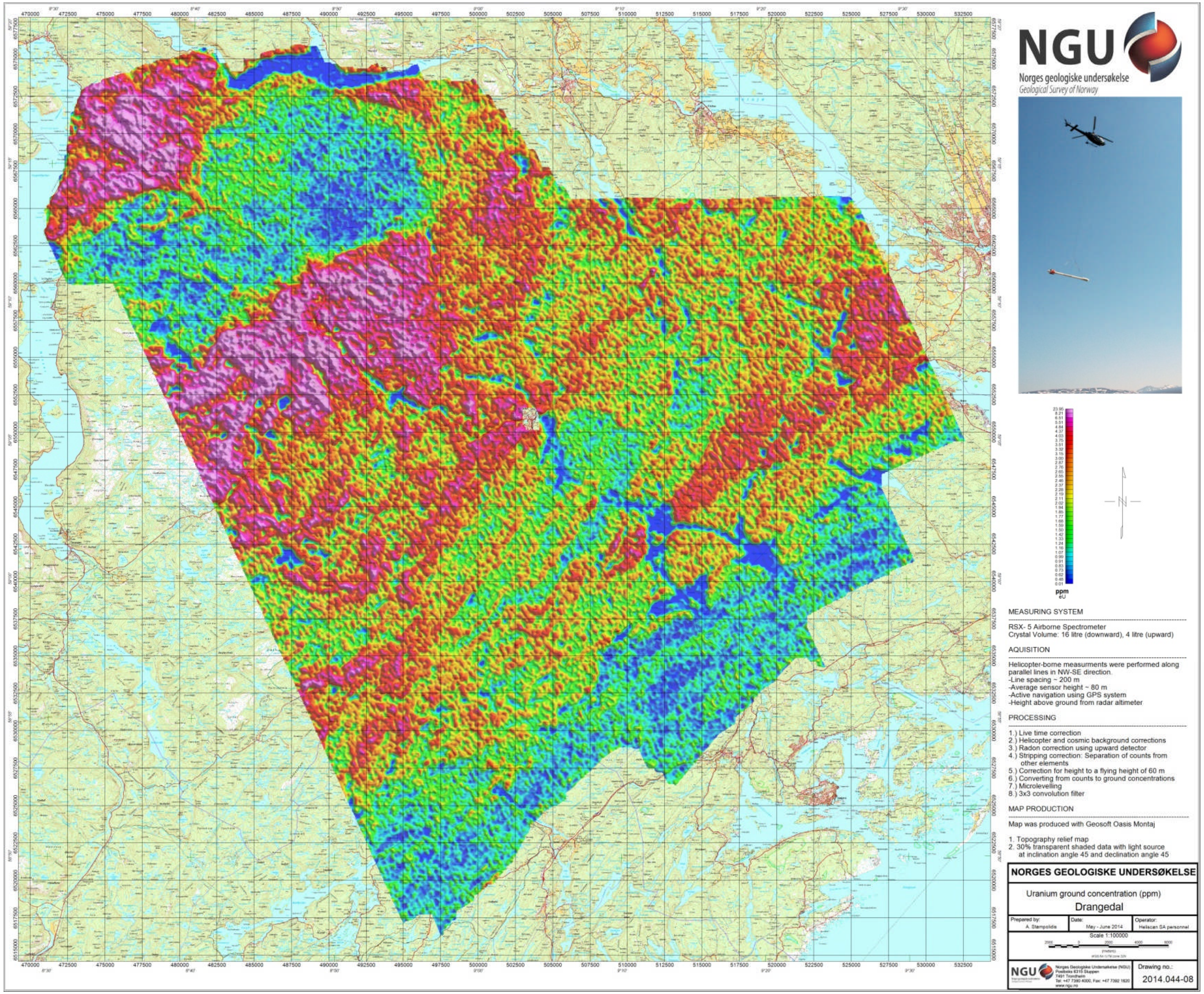
Drawing no.: 2014.044-07

Figure 12: Potassium Ground Concentration map



MEASURING SYSTEM

RSX- 5 Airborne Spectrometer
Crystal Volume: 16 litre (downward), 4 litre (upward)

AQUISITION

Helicopter-borne measurments were performed along parallel lines in NW-SE direction.
-Line spacing ~ 200 m
-Average sensor height ~ 80 m
-Active navigation using GPS system
-Height above ground from radar altimeter

PROCESSING

1.) Live time correction
2.) Helicopter and cosmic background corrections
3.) Radon correction using upward detector
4.) Stripping correction: Separation of counts from other elements
5.) Correction for height to a flying height of 60 m
6.) Converting from counts to ground concentrations
7.) Microlevelling
8.) 3x3 convolution filter

MAP PRODUCTION

Map was produced with Geosoft Oasis Montaj

1. Topography relief map
2. 30% transparent shaded data with light source at inclination angle 45 and declination angle 45

NORGES GEOLOGISKE UNDERSØKELSE

Uranium ground concentration (ppm)
Drangedal

Prepared by: A. Stampolidis
Date: May - June 2014
Operator: Helican SA personnel

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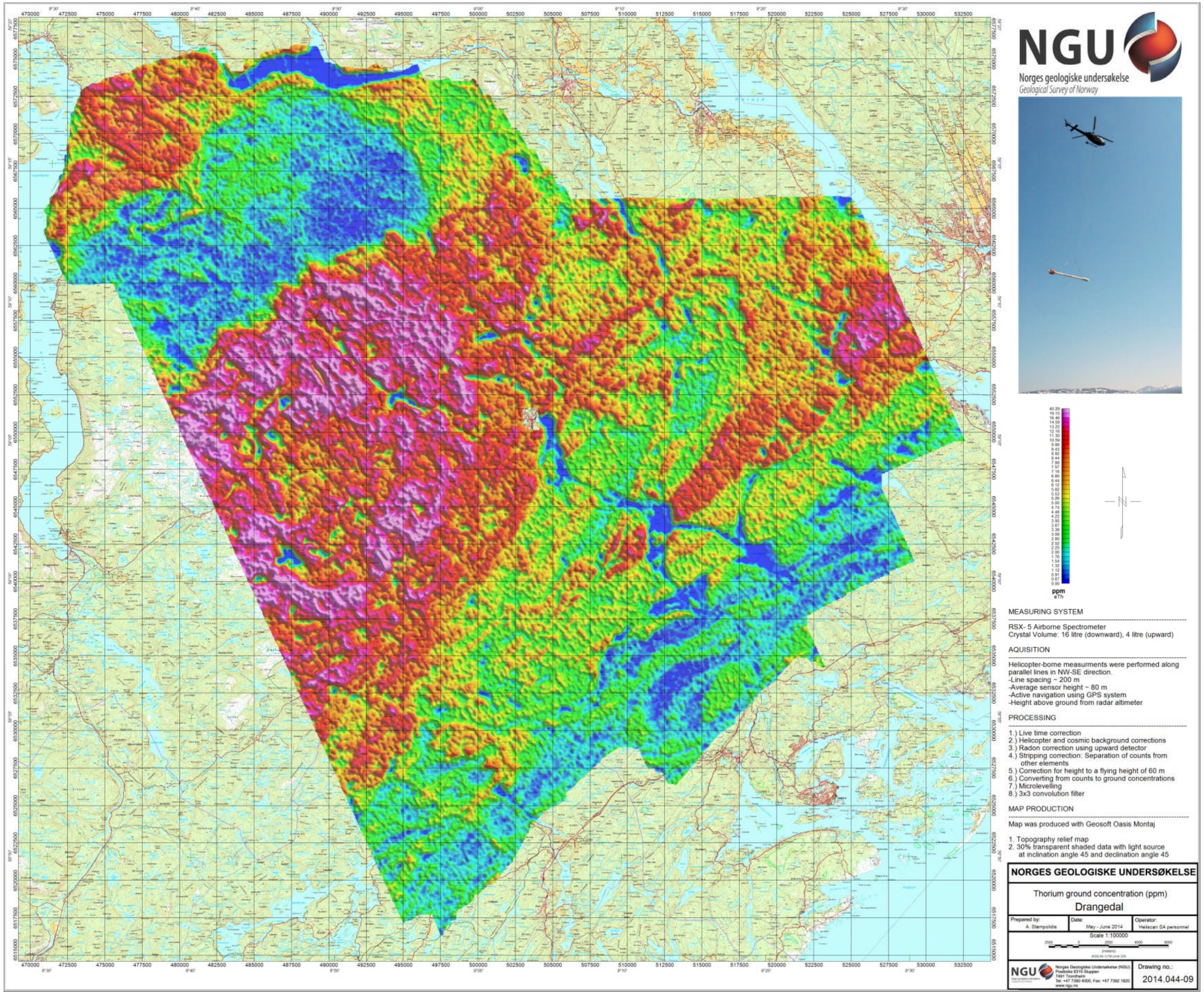
Drawing no.: 2014.044-08

Figure 13: Uranium Ground Concentration map



MEASURING SYSTEM

RSX- 5 Airborne Spectrometer
Crystal Volume: 16 litre (downward), 4 litre (upward)

AQUISITION

Helicopter-borne measurments were performed along parallel lines in NW-SE direction.
-Line spacing ~ 200 m
-Average sensor height ~ 80 m
-Active navigation using GPS system
-Height above ground from radar altimeter

PROCESSING

1.) Live time correction
2.) Helicopter and cosmic background corrections
3.) Radon correction using upward detector
4.) Stripping correction: Separation of counts from other elements
5.) Correction for height to a flying height of 60 m
6.) Converting from counts to ground concentrations
7.) Microlevelling
8.) 3x3 convolution filter

MAP PRODUCTION

Map was produced with Geosoft Oasis Montaj

1. Topography relief map
2. 30% transparent shaded data with light source at inclination angle 45 and declination angle 45

NORGES GEOLOGISKE UNDERSØKELSE

Thorium ground concentration (ppm)
Drangedal

Prepared by:	Date:	Operator:
A. Stampolidis	May - June 2014	Heliscan SA personnel

Scale 1:100000

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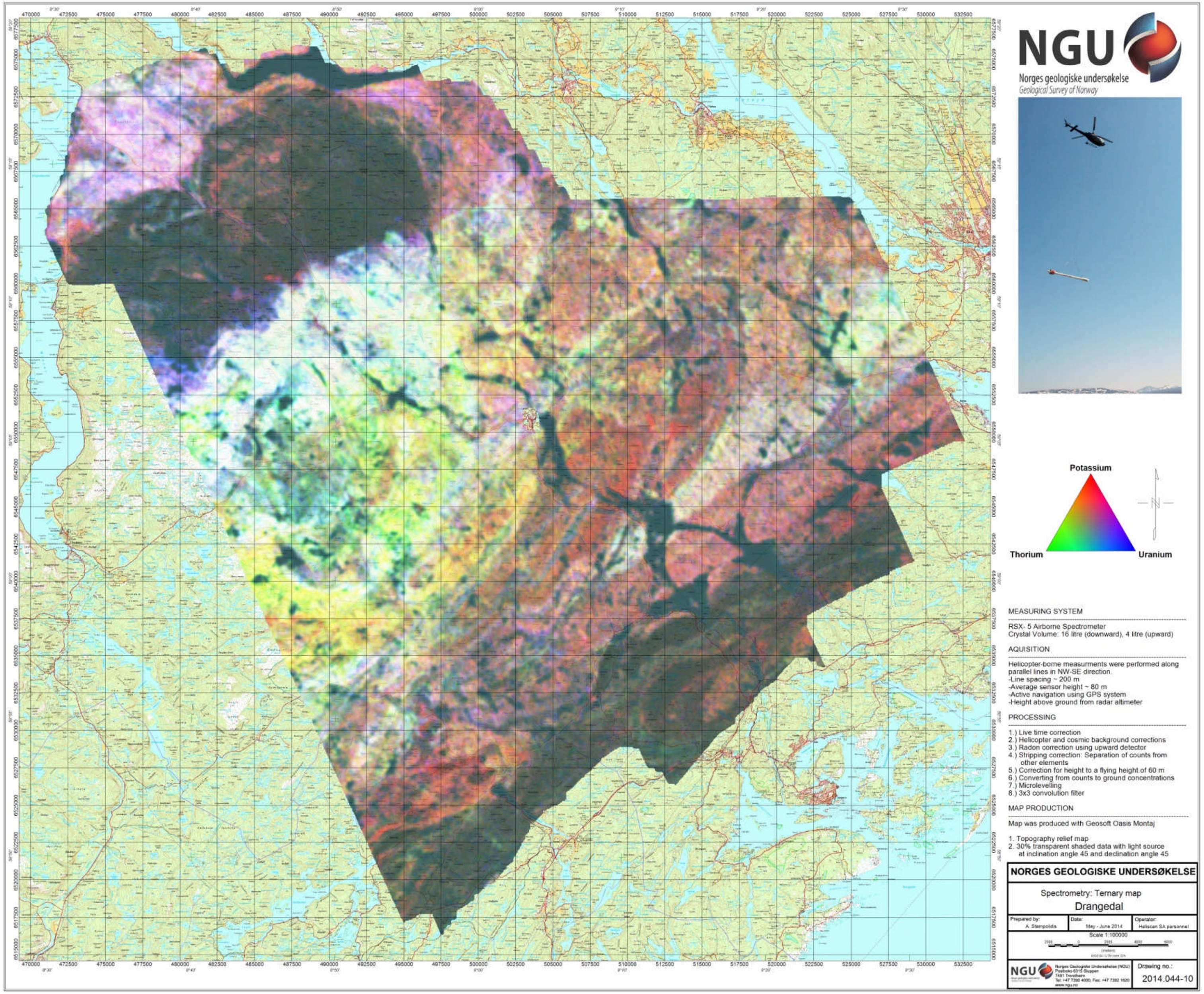
Drawing no.: 2014.044-09

Figure 14: Thorium Ground Concentration map



MEASURING SYSTEM

RSX- 5 Airborne Spectrometer
Crystal Volume: 16 litre (downward), 4 litre (upward)

AQUISITION

Helicopter-borne measurments were performed along parallel lines in NW-SE direction.
-Line spacing ~ 200 m
-Average sensor height ~ 80 m
-Active navigation using GPS system
-Height above ground from radar altimeter

PROCESSING

1.) Live time correction
2.) Helicopter and cosmic background corrections
3.) Radon correction using upward detector
4.) Stripping correction: Separation of counts from other elements
5.) Correction for height to a flying height of 60 m
6.) Converting from counts to ground concentrations
7.) Microlevelling
8.) 3x3 convolution filter

MAP PRODUCTION

Map was produced with Geosoft Oasis Montaj

1. Topography relief map
2. 30% transparent shaded data with light source at inclination angle 45 and declination angle 45

NORGES GEOLOGISKE UNDERSØKELSE

Spectrometry: Ternary map
Drangedal

Prepared by:	Date:	Operator:
A. Stampolidis	May - June 2014	Heliscan SA personnel

Scale 1:100000

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Drawing no.: 2014.044-10

Figure 15: Ternary Image of Radiation Concentration