NGU Report 2012.043

Helicopter-borne magnetic and radiometric geophysical survey in Kviteseid area, Telemark, Norway

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REPORT

Report no.: 2012.043	ISSN 0800-3416	Grading: Open

Title:
Helicopter-borne magnetic and radiometric geophysical survey in Kviteseid area, Telemark, Norway

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County: Telemark	Commune: Kviteseid, Seljord og Tokke
Map-sheet name (M=1:250.000) Skien	Map-sheet no. and -name (M=1:50.000) 1513 I Bandak, 1514 II Åmotsdal, 1613 IV Seljord, 1614 III Flatdal.
Deposit name and grid-reference: Kviteseid, UTM 32N- 471000, 6585000	Number of pages: 25 Price (NOK): 100,- Map enclosures: 16

Fieldwork carried out: May, 2012	Date of report: September, 2012	Project no.: 327601	Person responsible: Jan S. Rønning

Summary:
In cooperation with the geologist for Buskerud, Telemark and Vestfold, the NGU conducted an airborne geophysical survey in Kviteseid area in May 2012. This report describes and documents the acquisition, processing and visualization of recorded datasets. The geophysical survey results reported herein are 3514 line km.

The 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 130° - 210° and average speed of 98 km/h. A smaller area was also flown at 100 m line spacing 50 m away from larger flight lines so that smaller area could be covered with 50 m line spacing. The average terrain clearance of the helicopter was 65 m.

Collected data were processed in NGU using Geosoft Oasis Montaj software. Raw total magnetic field data were corrected for diurnal variation and also for International Geomagnetic Reference Field (IGRF). Finally, some along-line noises were removed using standard micro-leveling algorithm. Radiometric data were processed using standard procedures recommended by International Atomic Energy Association (IAEA).

Final processed data were gridded with the cell size of 25 m and 12 m for 100 m and 50 m line spacing, respectively. They are presented as a shaded relief maps at the scale of 1:20 000 and 1:10 000, respectively.

Keywords:	Geophysics	Magnetic
Gamma-ray spectrometer	Airborne	Mapping
		Technical report

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1. INTRODUCTION

The objective of the airborne geophysical survey was to obtain a dense high-resolution aero-magnetic 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 geological contacts and structural features of the area. It allows defining the potential of known zones of mineralization, their geological settings, and identifying new areas of interest. In such surveys, it is assumed that footprint of the measurements is an oval of width twice the flying height, and length twice the flying height and the distance travelled during the measurement, i.e. roughly 120 m by 150 m (for a 60 m sensor height with a speed of 100 km/h).

The survey incorporated the use of a high-sensitivity cesium magnetometer, 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 (WGS 84).

2. LOCATION

The survey area is situated west of Kviteseid in Telemark county, Norway (see figure 1). Survey area is marked with two polygons representing larger and smaller survey areas in figure 1. The larger survey area is covered with 100 m line spacing and smaller survey area is covered with 50 m line spacing. The flight lines of the survey and related land are also shown in figure 2.

Figure 1. Location map taken from Google earth of Survey area.

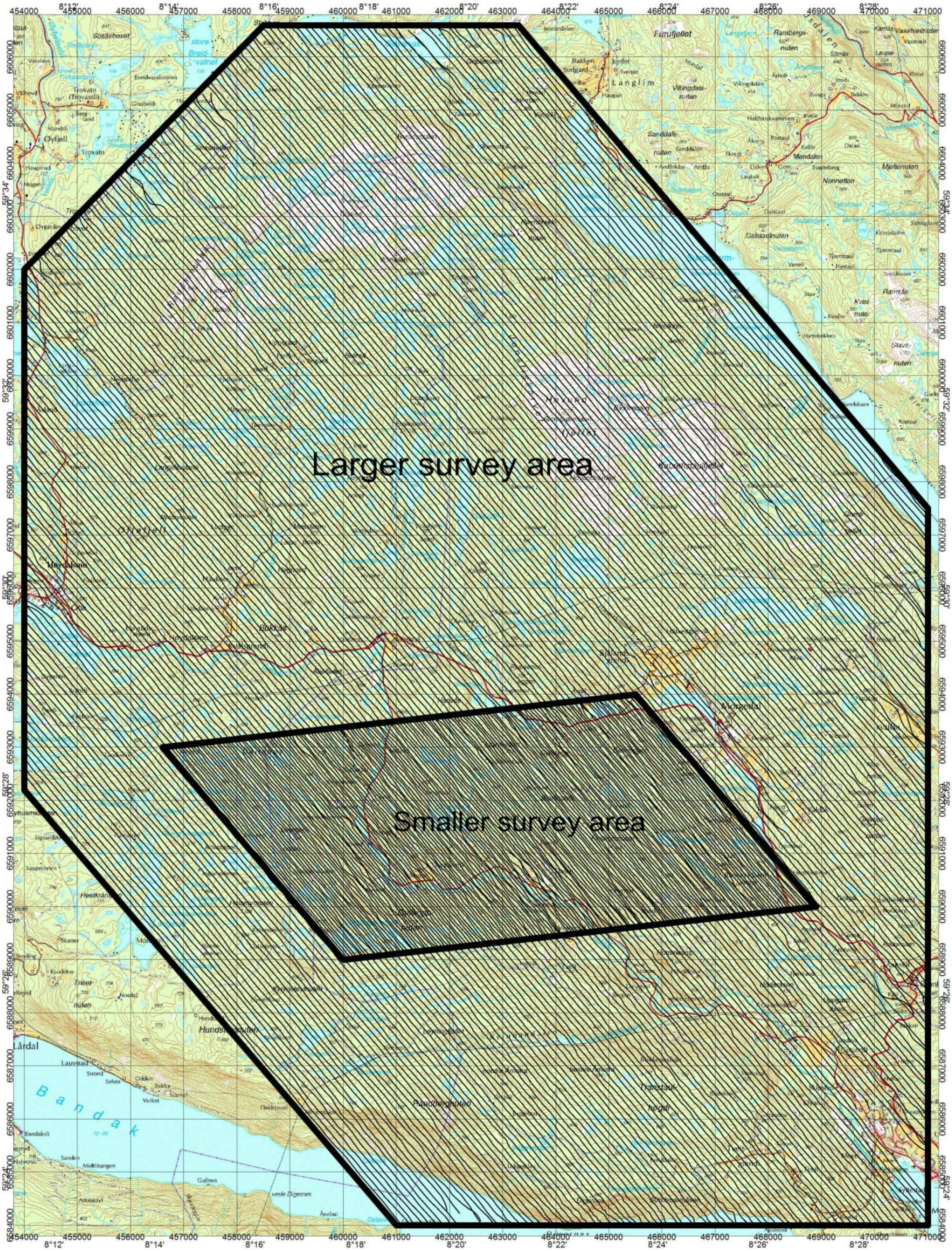

Figure 2. Flight lines with 100 m and 50 m line spacing from larger and smaller regions of Surveyed area, respectively.

3. SURVEY SPECIFICATIONS AND PROCEDURE

Magnetic and gamma-ray spectrometry data were measured in the Kviteseid area. A brief description of these methods is discussed in Appendix A.

3.1 Measuring equipment and data acquisition

NGU used a small magnetic helicopter survey system designed to obtain low level, slow speed, and detailed airborne magnetic and radiometric data. Due to strong topographic relief and safety reasons, it was not possible to fly as low as the specifications for the survey (helicopter 50 meters above the ground). Magnetic bird was towed 15 meters under the helicopter. RSX-5 gamma-spectrometer was attached in a frame underneath the helicopter. The airborne survey began on May 21 and ended on May 31, 2012. A Eurocopter AS350-B2 helicopter from the company Heliscan As, was used to tow the system. The base magnetometer was placed outside of Seljord town (UTM 32N- 478116, 6593273) for first two days of the survey. This location was noisy and some heavy vehicles were passing few times in a day close to the base station. Therefore base station is later moved to further away from the town without any traffic at (UTM 32N- 477043, 6592796). The base station computer clock was synchronized with the data acquisition system (DAS) on a daily basis.

Instrumental problems resulted in noisy magnetic data during the survey. Lines or part of lines with unacceptable noise were re-measured which resulted in acceptable magnetic data quality. Radiometric data was of good quality despite of low concentrations of U, Th and K.

The survey lines were spaced 100 m apart and oriented at a 130° - 210°. A smaller area was covered with 100 m line spacing and 50 m away from larger lines to cover the smaller region with denser 50 m line spacing. The magnetic sensor is housed in a 2 m long bird, which was maintained at an average of 50 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 data at an average height of 65 meters.

The average ground speed of the aircraft was around 65 km/h and it varied depending on topography, wind direction and its magnitude. Magnetic data were recorded at 0.2 second intervals resulting in 3 to 6 m point spacing. Spectrometry data were recorded every 1 second giving an average point spacing of 18 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 petrophysical composition.

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. Instruments used in the survey are listed below for a quick look.

<u>Airborne Magnetometer.</u>

Model:	Scintrex CS-2
Type:	Optically pumped Cesium vapor magnetometer.
Sensitivity:	0.002 nT
Sampling interval:	0.2 sec.
Counter	Kroum KMAG-4

Gamma Spectrometer.

Model:	Radiation Solutions RSX-5
Number of detectors:	4x4 Litre downward, 1x4 Liter upward looking.
Number of channels:	1024
Energy of gamma rays:	0.2 MeV to 3 Mev (channels 1 to 1023), above 3 Mev (cosmic channel at 1024)
Sampling interval:	1 sec.
Stabilisation	Automatic natural peaks

Magnetic Base Station.

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

Radio Altimeter.

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

Barometric Altimeter.

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

Navigation System.

Model:	Topcon GPS receiver
Display:	Remote color screen display for flight path cross-track guidance.
Accuracy:	±5 m
Sampling interval:	1 sec.

Digital Acquisition software.

Manufacturer:	In-house applications for acquisition of navigation and magnetic data.
	Radiation Solution's RadAssist software (RSX-5 spectrometer)
Computer:	Nexcom VTC 6100
Display:	17' LDS 4101D

3.2 Calibrations

The RSX-5 gamma-ray spectrometer was calibrated for K, U and Th sensitivity at NGU in 2011. Stripping ratios and sensitivities for K, U and Th were calculated in Borlange, Sweden over special K, U, Th pads (fixed installation for radiometric calibration purpose) in June 2012 (Grasty 1987, Appendix A). Cosmic coefficients and aircraft background were determined from a special survey as recommended by IAEA (2003) at the same time. Height attenuation coefficients were calculated from a special survey in Kviteseid area following the recommendations of IAEA (2003). Upward detectors were used to correct for atmospheric radon measurements.

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. All three datasets were processed consequently according to processing flow charts shown in Appendix B.

4.1 Total Field Magnetic Data

At the first stage the magnetic data were visually inspected and big spikes were removed manually. There was lot of short length spikes in the data due to a loose connection of wire attached with magnetometer. Therefore these spikes were removed manually with careful investigation and later a three point low-pass filter was applied. Then the data from magbase station were imported in magnetic database using the standard Oasis magbase.gx module. The magbase channel was also inspected for spikes and such spikes were removed manually if necessary. There were some jumps observed in the base magnetic data due to some vehicle passing close to the base magnetometer installation. Later, base was shifted to a better location. Such jumps in base magnetic data in initial days of survey were adjusted inspecting the trend of the base magnetic data and looking over magnetic data measured from helicopter.

The temporal fluctuations referred as diurnal variation in the magnetic field of the earth were removed from the airborne magnetic data set by using base magnetometer data. The average total field value for base magnetometer was 50500 nT. International geomagnetic reference field (IGRF) for 2010 was calculated for each measurement points of the survey area using Geosoft gx 'IGRF' and subtracted from the measured magnetic field to obtain total magnetic field anomaly as shown in eq. 1.

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

where $\mathbf{B}_{Ta}$ is total magnetic field anomaly, $\mathbf{B}_T$ is total magnetic field measured from helicopter, $\mathbf{B}_B$ is base magnetometer reading, $\overline{B}_B$ is average of base magnetometer reading and $\mathbf{B}_{IGRF}$ is IGRF valued for measurement points in survey area.

Lag between logged magnetic data and the corresponding navigational data was 1-2 fids. Translated to a distance it would be no more than 8 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. A flow chart of the magnetic data processing (including the used parameters) is given in Appendix B1. An overview of standard processing for airborne magnetic data is given by e.g. Minty et al. (1997). Flight data were split in flight lines before gridding. For the purposes of data presentation and interpretation, the total field magnetic anomaly data were gridded using minimum curvature method with a cell size of 25 m and 12 m for 100 m and 50 m line spacing, respectively. A micro-leveling technique was applied to the magnetic data to remove small along line leveling errors. A 5x5 convolution filter was passed over the final grid to smooth the grid image in case of magnetic grids.

1st vertical derivative and tilt-derivative of the total magnetic field anomaly was calculated from the resulting total magnetic field anomaly grid using appropriate convolution filters available in Geosoft Oasis Montaj. 1st vertical derivatives show the change of magnetic field anomaly with vertical distance close to surface. Tilt derivative is arctangent of vertical and total horizontal derivatives and it is useful to enhance lineaments/trends. Both 1^{st} vertical derivative and tilt derivative will concentrate magnetic anomaly just above the magnetic body.

4.2 Radiometric data

In processing of the airborne gamma ray spectrometry data, live time corrected Total count (TC), equivalent Uranium (eU), equivalent Thorium (eTh) and Potassium (K) window data were corrected for the aircraft and cosmic background (e.g. Grasty 1987; IAEA 2003). U and Th channels were low- pass filtered with 5 and 3 points for 100 m and 50 m line spacing data, respectively to make the variation smoother. 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, eU and eTh (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 permanent calibration pads at Borlange, Sweden. A list of the parameters used in the processing scheme is given in Appendix B2. For further reading regarding standard processing of airborne radiometric data, we recommend the publication from Minty et al. (1997).

Flight data were split in flight lines before gridding. Final TC, K, eU and eTh data were gridded with a cell size of 25 m and 12 m for 100 m and 50 m line spacing, respectively. A micro-leveling technique was applied to them to remove small along line leveling errors.

5. PRODUCTS

Processed digital data from the survey are presented as:

1. Four Geosoft XYZ files: KviteseidMag_100.xyz, KviteseidMag_50.xyz, KviteseidRad_100.xyz and KviteseidRad_50.xyz are available from NGU on request.
2. Colored maps at the scale 1:20000 for 100 m line spacing and 1:10000 for 50 m line spacing are available from NGU on request.

Table 1 describes various available maps with reference number. Downscaled images of all the maps are shown in figures 3 -19.

Map #	
2012.043-01	Total magnetic field anomaly, 100 m line spacing from Kviteseid
2012.043-02	1st vertical derivative of magnetic anomaly, 100 m line spacing from Kviteseid
2012.043-03	Tilt derivative of magnetic anomaly, 100 m line spacing from Kviteseid
2012.043-04	Uranium ground concentration (ppm), 100 m line spacing from Kviteseid
2012.043-05	Thorium ground concentration (ppm), 100 m line spacing from Kviteseid
2012.043-06	Potassium ground concentration (%),100 m line spacing from Kviteseid
2012.043-07	Total count, 100 m line spacing from Kviteseid
2012.043-08	Ternary map, 100 m line spacing from Kviteseid
2012.043-09	Total magnetic field anomaly, 50 m line spacing Kviteseid
2012.043-10	1st vertical derivative of magnetic anomaly, 50 m line spacing from Kviteseid
2012.043-11	Tilt derivative of magnetic anomaly, 50 m line spacing from Kviteseid
2012.043-12	Uranium ground concentration (ppm), 50 m line spacing from Kviteseid
2012.043-13	Thorium ground concentration (ppm), 50 m line spacing from Kviteseid
2012.043-14	Potassium ground concentration (%), 50 m line spacing from Kviteseid
2012.043-15	Total count, 50 m line spacing from Kviteseid
2012.043-16	Ternary map, 50 m line spacing from Kviteseid

Table 1. Maps in scale 1:20000 (2012-01 to -08) and in scale 1:10000 (2012-09 to -16) for 100 m and 50 m line spacing area respectively available from NGU on request.

6. REFERENCES

1. 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.

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

3. 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.

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

5. Oasis Montaj Geosoft. 2007. Quick start tutorial – Mapping and processing system. (PDF-download of tutorial is available on webpage: http://www.geosoft.com/resources/tutorials/).

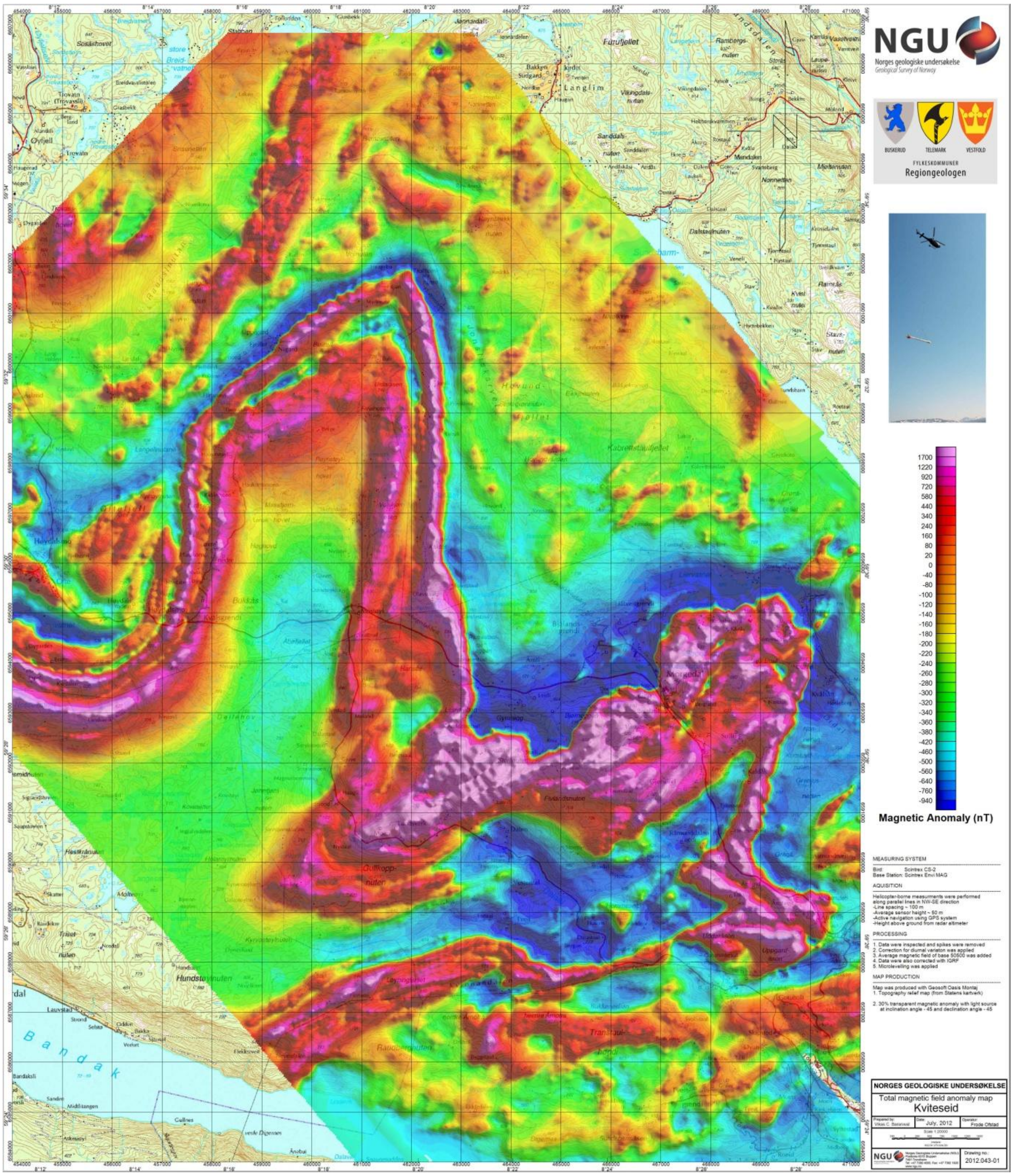

Figure 3. Total magnetic field anomaly map of Kviteseid with 100 m line spacing

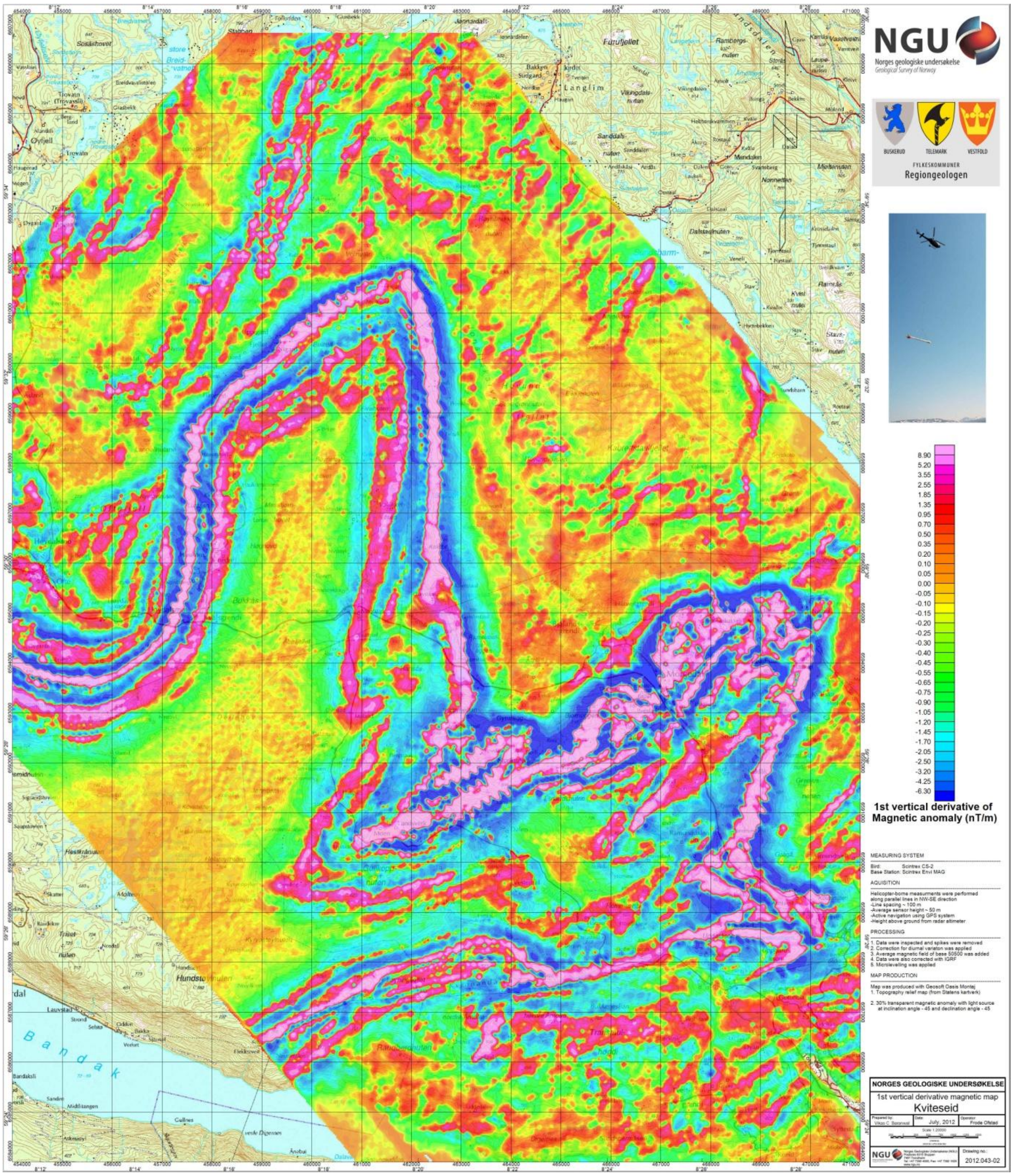

Figure 4. 1st vertical derivative magnetic anomaly of Kviteseid with 100 m line spacing.

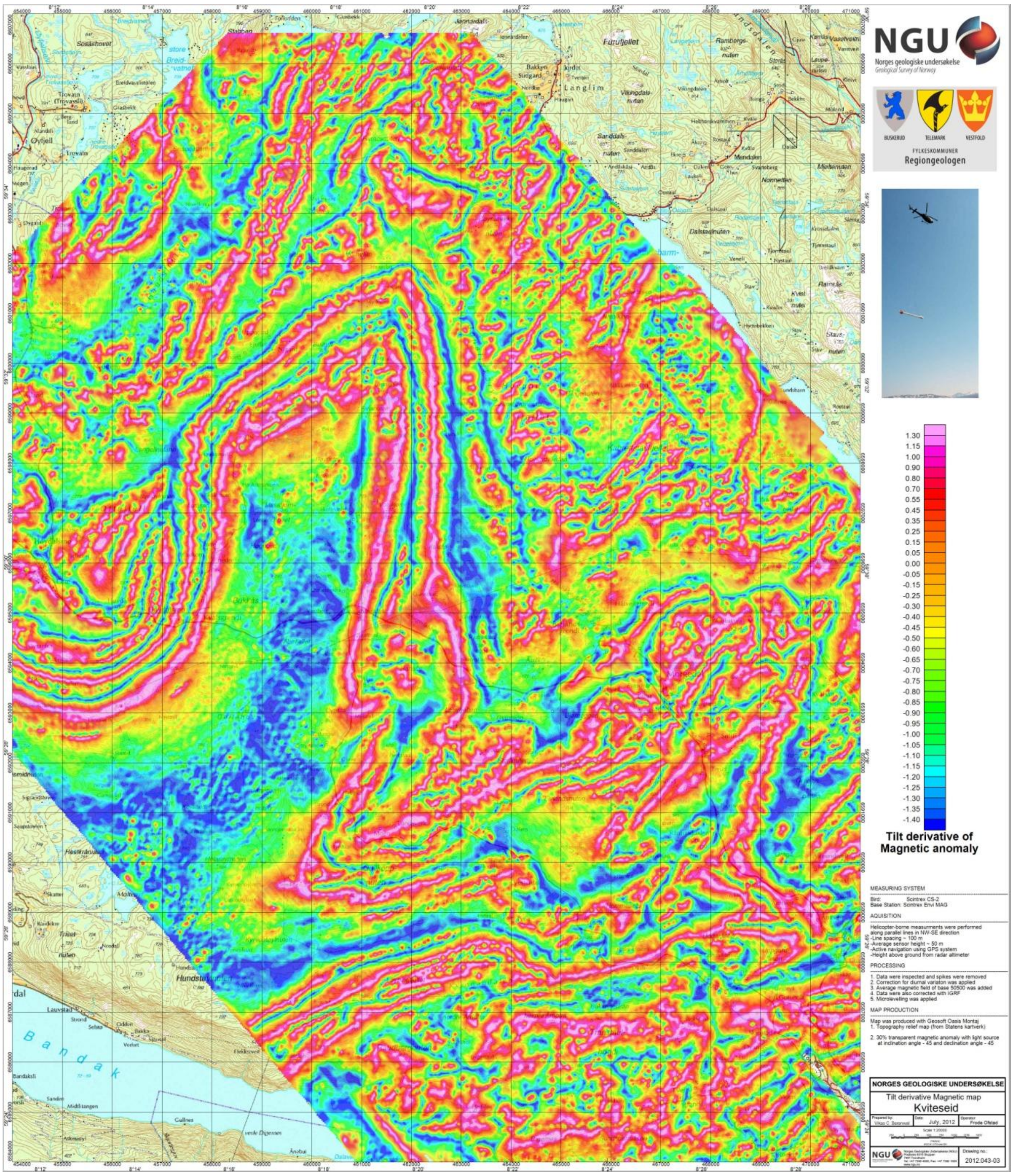

Figure 5. Tilt derivative of magnetic anomaly of Kviteseid with 100 m line spacing

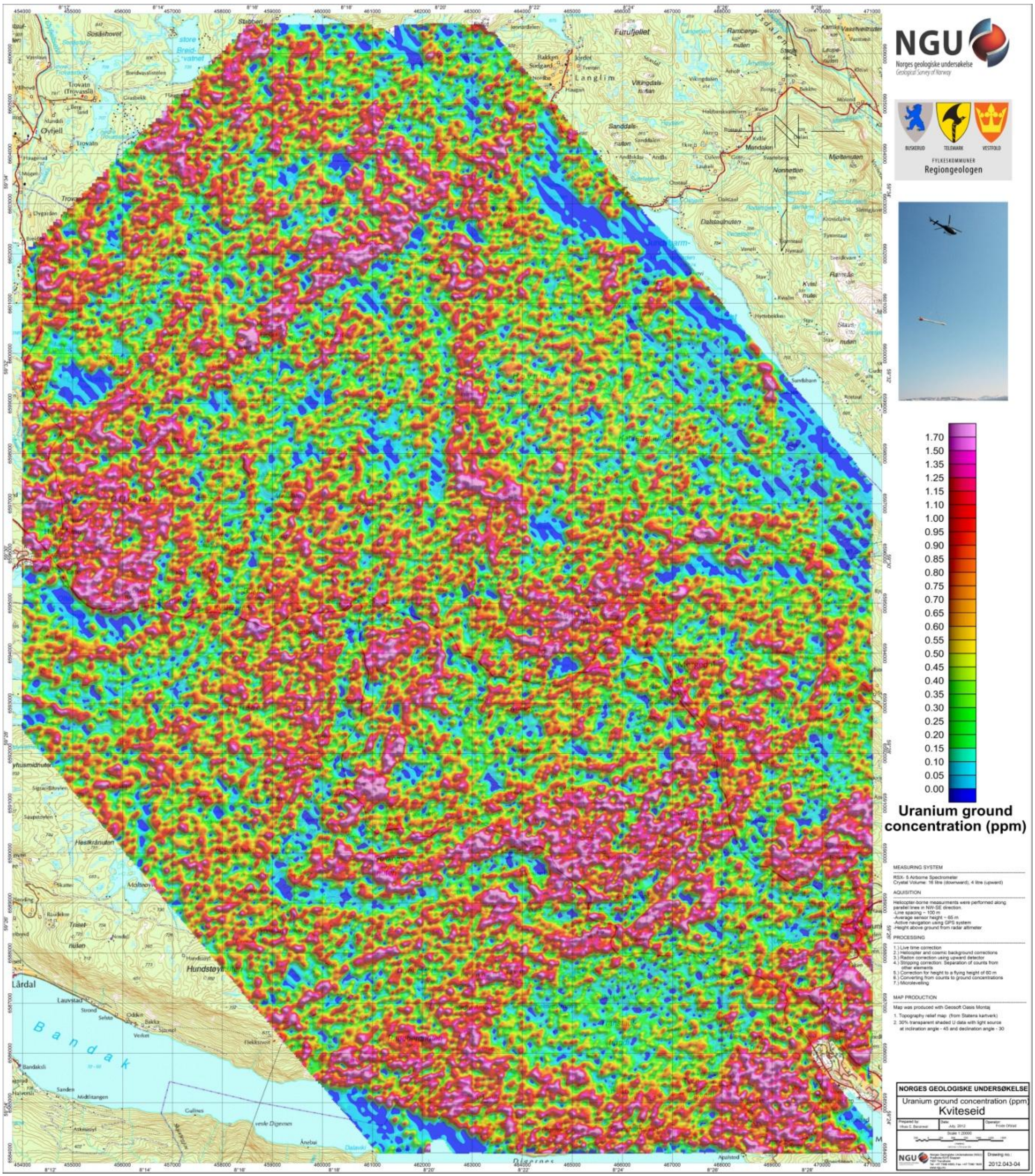

Figure 6. Uranium ground concentration of Kviteseid with 100 m line spacing

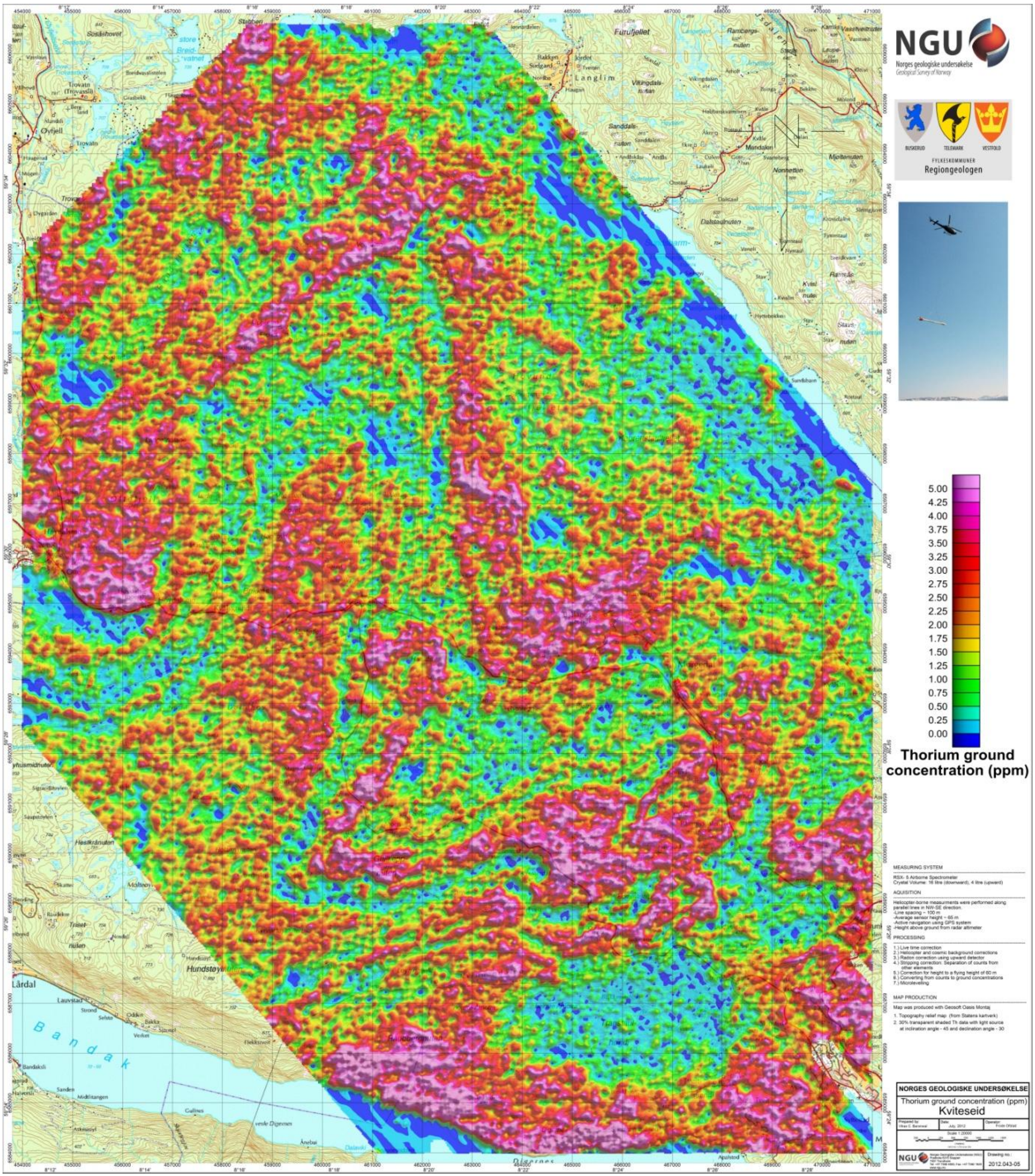

Figure 7. Thorium ground concentration of Kviteseid with 100 m line spacing

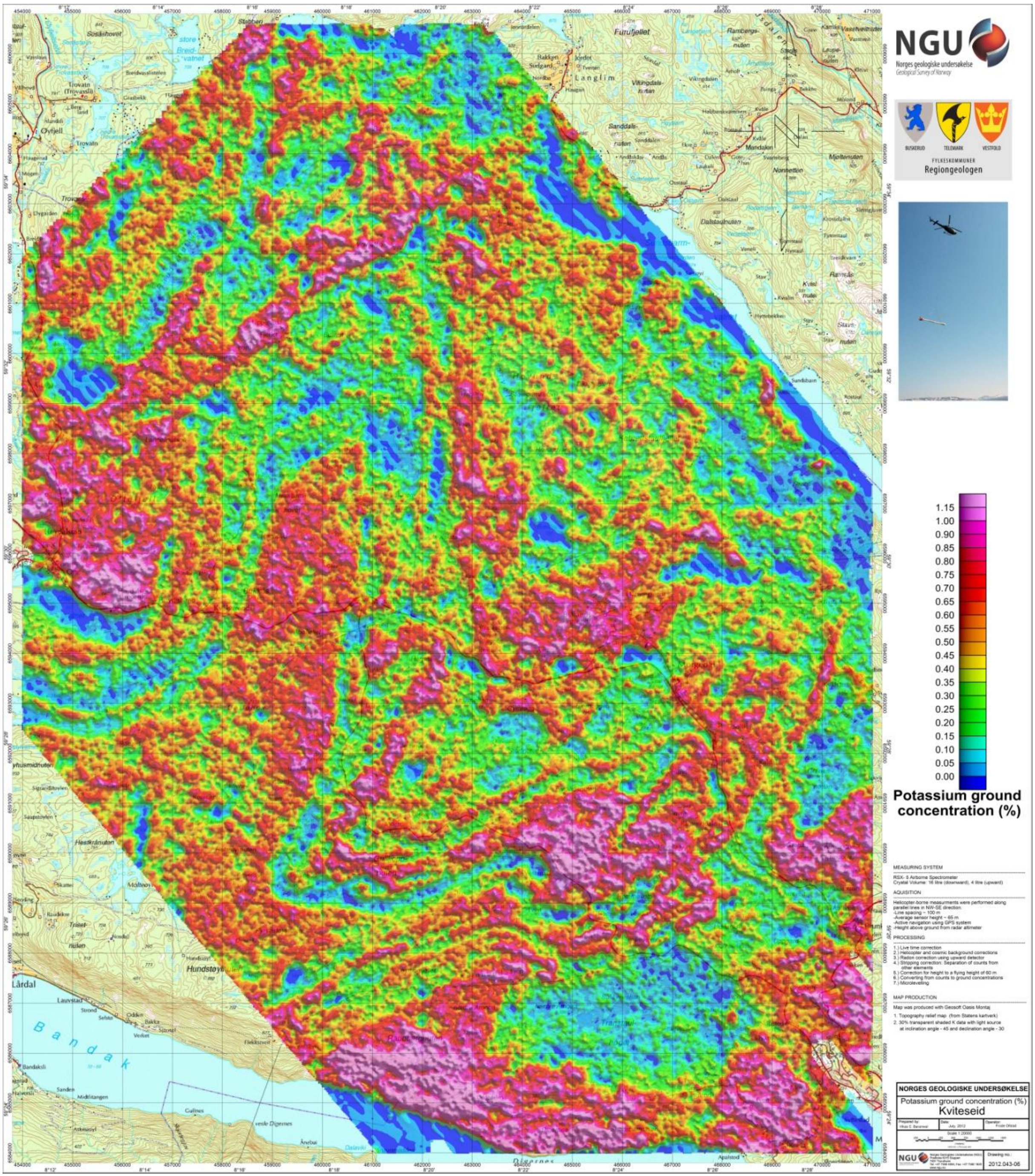

Figure 8. Potassium ground concentration of Kviteseid with 100 m line spacing

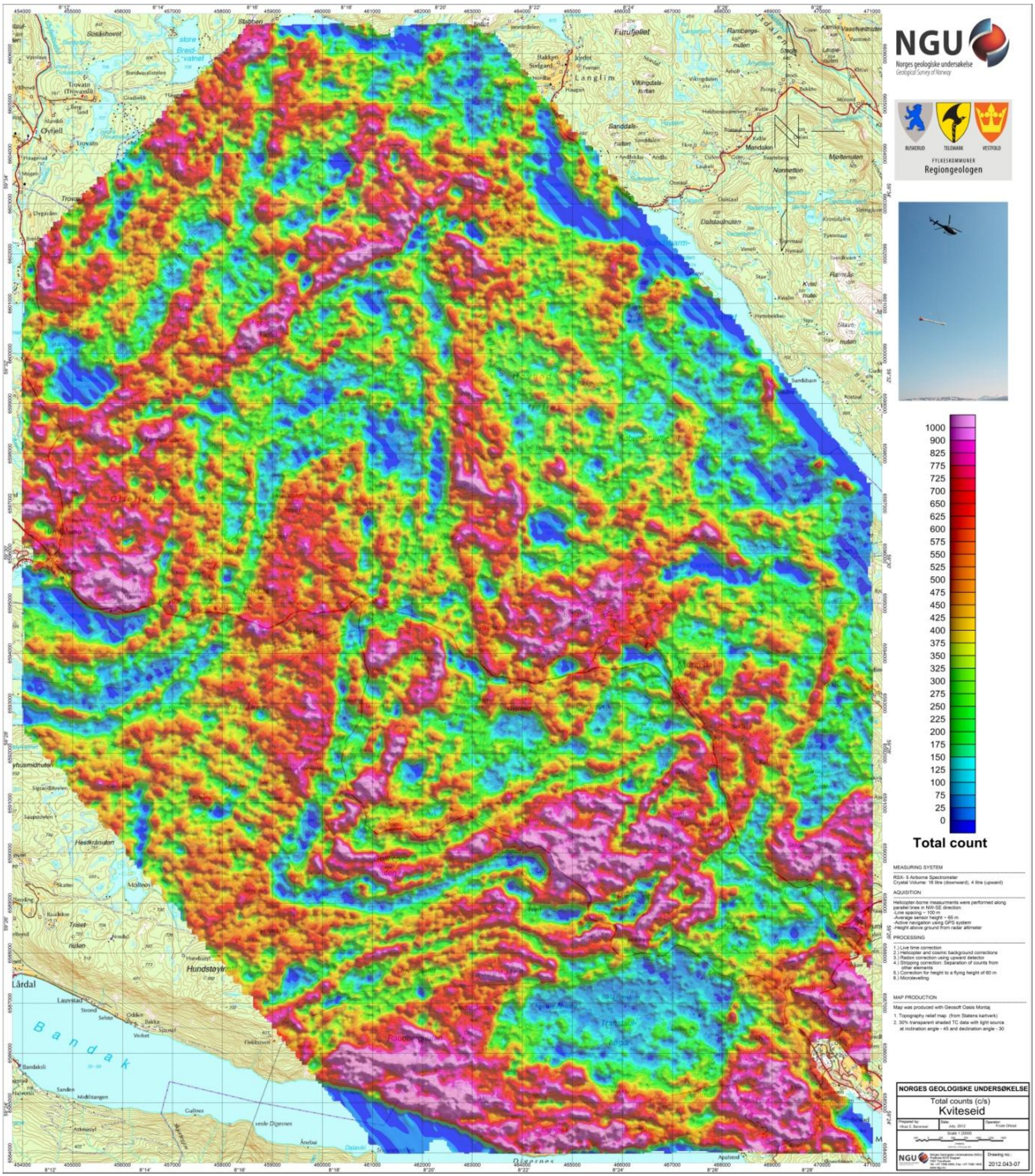

Figure 9. Total Count of Kviteseid with 100 m line spacing

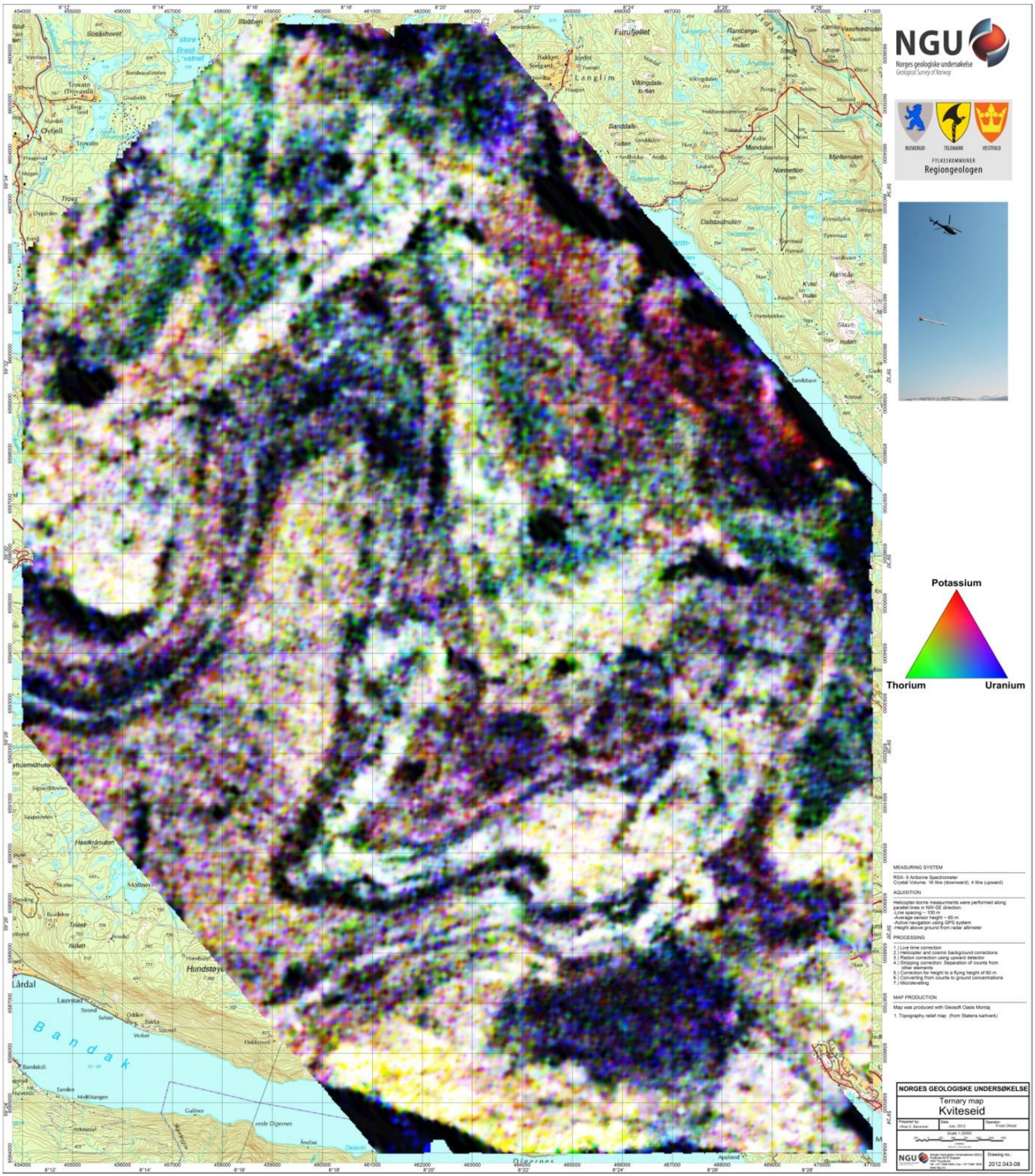

Figure 10. Ternary map of Kviteseid with 100 m line spacing

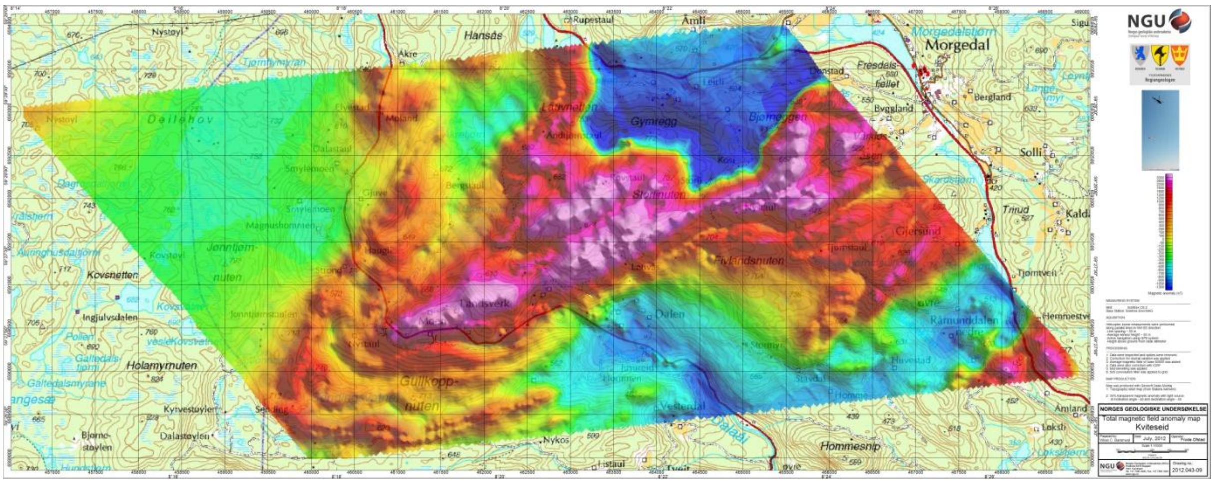

Figure 11. Total magnetic field anomaly map of Kviteseid with 50 m line spacing

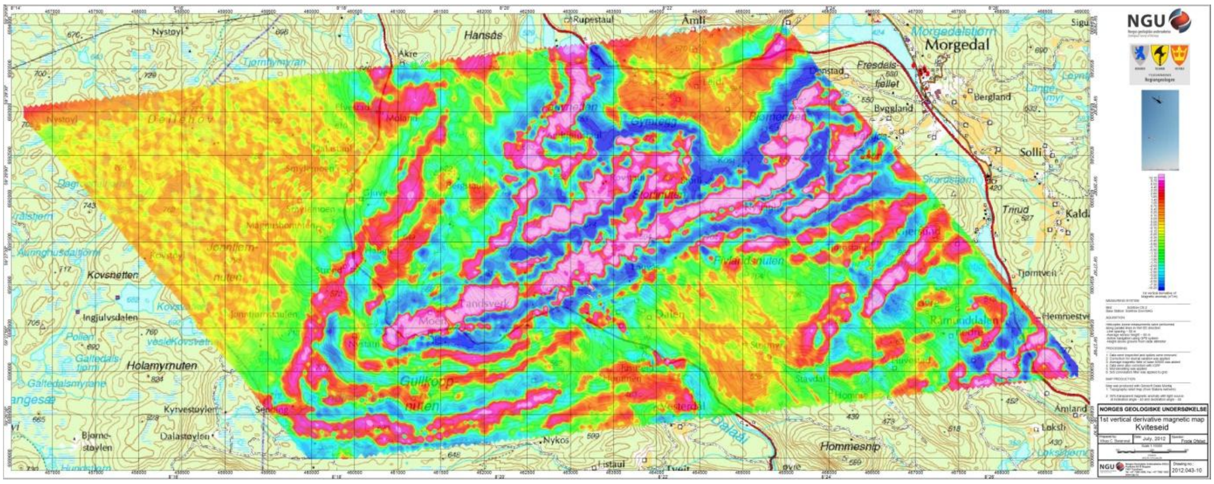

Figure 12. 1st vertical derivative magnetic anomaly of Kviteseid with 50 m line spacing

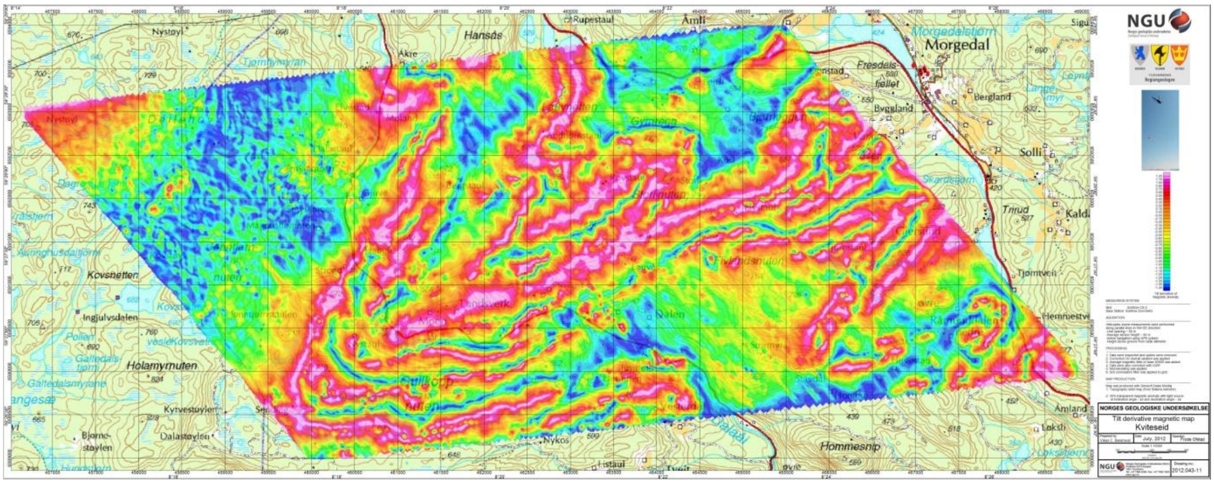

Figure 13. Tilt derivative of magnetic anomaly of Kviteseid with 50 m line spacing

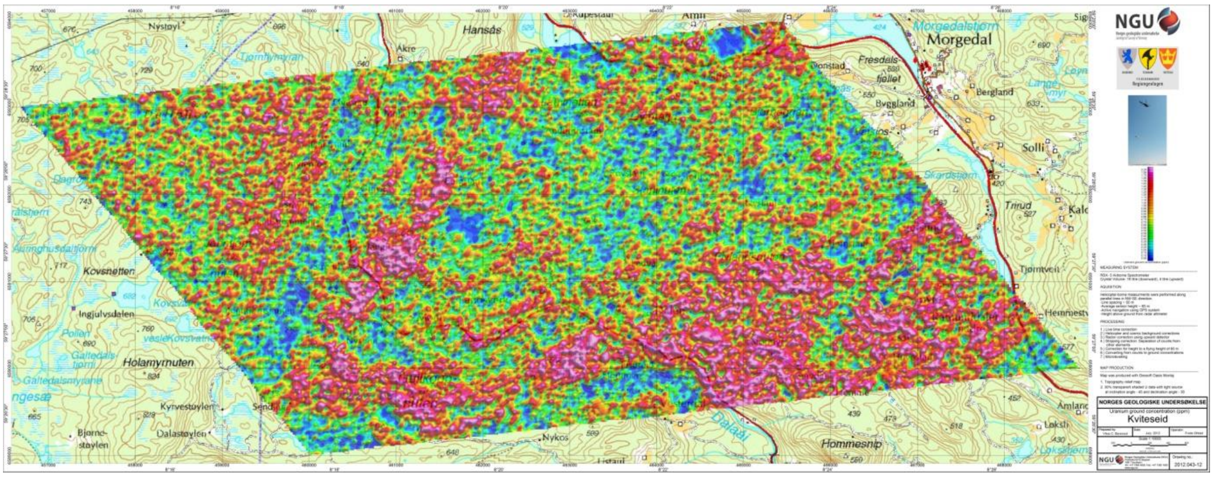

Figure 14. Uranium ground concentration of Kviteseid with 50 m line spacing

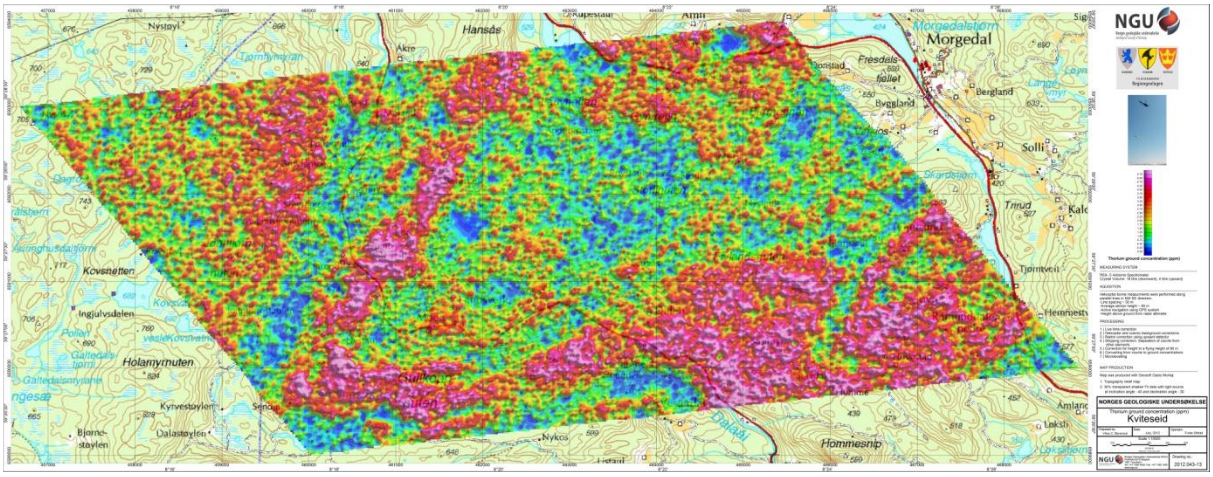

Figure 15. Thorium ground concentration of Kviteseid with 50 m line spacing

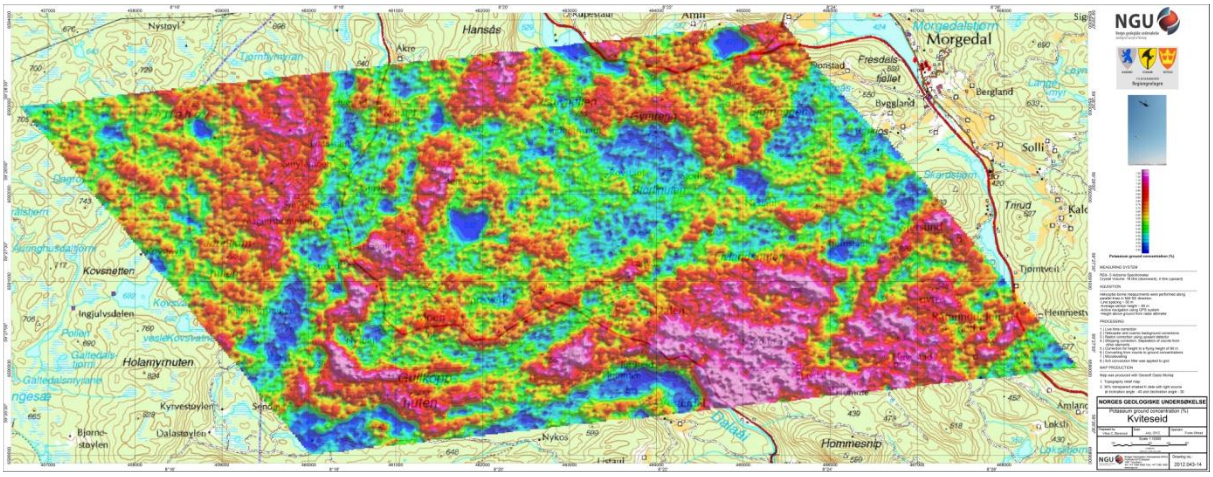

Figure 16. Potassium ground concentration of Kviteseid with 50 m line spacing

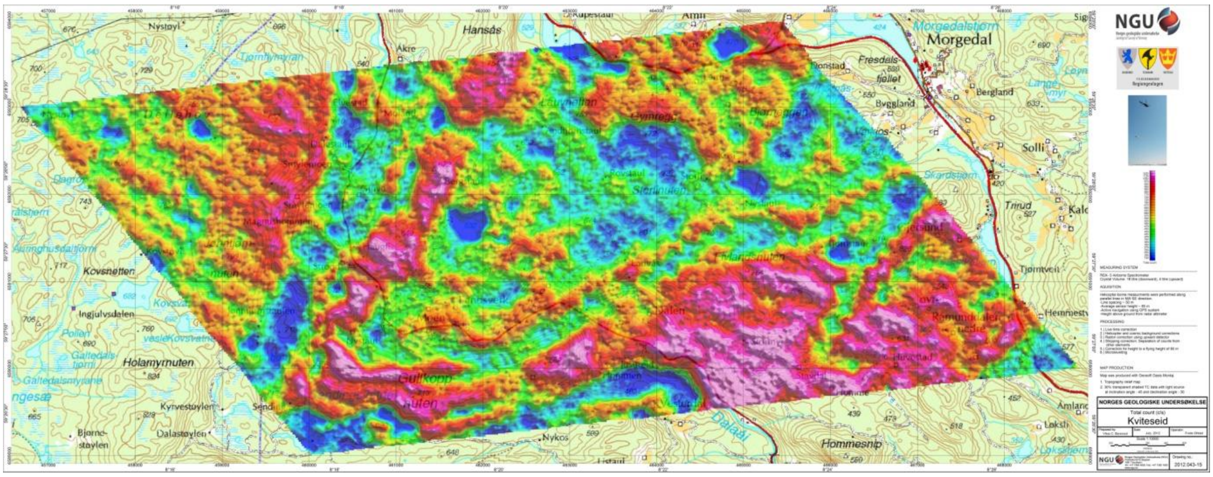

Figure 17. Total Count of Kviteseid with 50 m line spacing

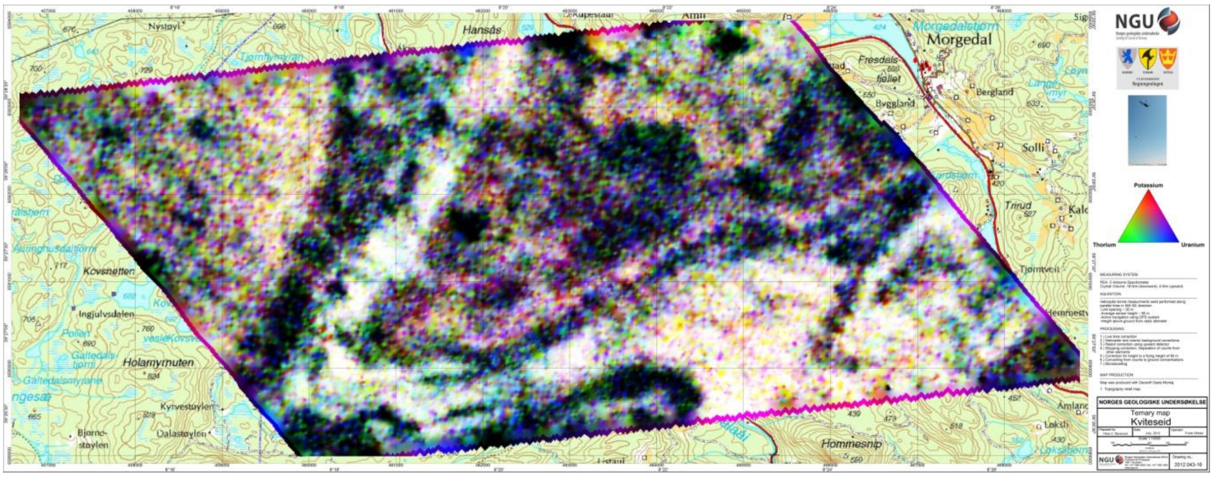

Figure 18. Ternary map of Kviteseid with 50 m line spacing

Appendix A: Short description of magnetic and radiometry methods

Radiometry:

Airborne gamma ray spectrometry (AGRS) is generally used for mapping of the near-surface concentration of the natural isotopes Thorium-232, Uranium-238 and Potassium-40, whose decay series are responsible for mostly all radioactivities from natural sources. ^{40}K has only one daughter product (^{40}Ar), but ^{238}U and ^{232}Th decay in a series of 18 and 11 daughter isotopes until the stable isotopes ^{206}Pb and ^{208}Pb are reached. AGRS can also be used for environmental surveys e.g. to map Cs fallout from the Chernobyl accident. In case of Cs mapping, two isotopes of Cs could be present, ^{134}Cs and ^{137}Cs; however ^{134}Cs has a half-life of only 730 days. All ^{134}Cs from Chernobyl would have effectively disappeared, and so we map only ^{137}Cs which has a longer half-life of 11000 days.

Every product in the decay series has its own specific alpha, beta and/or gamma radiation. During measurements the gamma radiation is recorded by a scintillation detector and arranged into a spectrum of 1024 equally sized energy channels. In the processing, it is possible to separate the contribution of the K, U and Th from the total spectra by using the gamma ray counts in windows around the most significant energy maxima of the decay series. For uranium and thorium series the maxima from the daughter products ^{214}Bi and ^{208}Tl are used. The counts in these windows represent the Uranium and Thorium ground concentrations assuming that the products in the decay series are in equilibrium (it is assumed that no products are depleted or added)[1]. For determining Potassium ground concentrations, counts in a window around the ^{40}K peak are used. Cs concentration is determined from counts in a window around the ^{137}Cs peak.

Any spectrum measured with an airborne system will be a mixture of spectra from various sources including cosmic radiation, aircraft background, atmospheric radon background, naturally occurring ^{40}K, ^{238}U, ^{232}Th from ground, ^{137}Cs from nuclear accidents, and other man-made radioactive nuclides. In natural radioelement surveys, the cosmic, aircraft and atmospheric radon signals are considered as background: for fallout mapping, the gamma rays from natural radioelements in the ground will also be considered as background.

Gamma radiation is strongly attenuated by any type of shielding/covering materials and therefore only the gamma radiation from the upper one meter of the subsurface is recorded by helicopter-borne gamma ray spectrometry. This means that information from gamma ray spectrometry is always limited to the shallow features. Soil and sediments (but also high water concentrations in the shallow ground) can significantly attenuate gamma radiation from underlying rock. However, in region with no or thin overburden, radiometry data can often provide accurate "geological maps", because uranium, thorium and potassium concentrations are closely linked to individual rock types and their origin/development. Because the number of radiation counts from surface material decreases exponentially with the altitude above the ground, data quality of radiometric airborne data is strongly dependent on the flight heights. Weather conditions and air radon concentrations (^{222}Rn) also have a large impact on the data quality and can complicate the data processing. A complete overview (including theory, calibration, acquisition, processing and interpretation) of gamma ray spectrometry methods is given in IAEA (2003).

[1] To emphasize that ^{238}U and ^{232}Th concentrations are not directly measured, finally determined uranium and thorium concentrations are presented in "eU" and "eTh" . The prefix "e" stands for "equivalent" or "effective".

Magnetic:

Airborne magnetic surveying is an efficient method to determine the main geological, near surface structures and lineaments provided that the associated rock types have measurable magnetic properties[2]. Although a magnetic field is a vector field, essentially all modern instruments in common use measure only the total magnetic field. Local magnetic anomalies related to the magnetization of near-surface rock types are superimposed with the much larger main earth fields (in the order of 50000 nT), other regional anomalies and time-varying external fields (usually in the range of ~ 60 nT). The so-called diurnal magnetic field is mainly caused by the interaction of charged particles emitted from the sun with the geomagnetic field. By using a magnetic base station situated close to the surveyed region, the effect of this slowly varying external field can be measured and removed from the magnetic helicopter data. However, in some periods so-called magnetic storms occur that are responsible for strong high-frequency magnetic noise which is difficult to remove using base station corrections. Magnetic surveying should not be carried out during these periods.

[2] The local magnetic field of rocks is typically sensitive to the magnetite content. Therefore classification based on magnetic anomalies varies from other geological classification methods which are often silica based.

Appendix B1: Flow chart of magnetic data processing

Meaning of parameters is described in appendices and referenced literatures.

Processing flow:

- Quality control.
- Visual inspection of airborne data and manual spike removal
- Non-linear filter (Naudy and Dreyer, 1968): 3
- Inspection of base magnetometer data and removal of spikes
- Correction of data for diurnal variation using base magnetometer data
- Adding a constant shift of 50500 nT (mean/median of base magnetic data)
- Calculation of IGRF values and subtraction
- Splitting flights in flight lines
- Gridding using minimum curvature method
- Microleveling using Geosoft menu

  Used parameters for microleveling of survey with 100 m line spacing:

  Naudy (1968) Filter length for 25 m grid: 200 m
  Naudy (1968) Filter length for 12 m grid: 100 m
  Amplitude limit in removing noise : 200 nT
- Smoothing using a 5X5 convolution filter for 25 m grid

  Predefined filter: Least-squares
  No.of passes: 1
- Smoothing using a 3X3 Convolution filter for 12 m grid

  Predefined filter: Hanning
  No.of passes: 1

Appendix B2: Flow chart of gamma-ray spectrometry data processing

Underlined processing stages are not only applied to the K, eU and eTh window, but also to the total. Meaning of parameters is described in appendices and referenced literatures.

Processing flow:

- Quality control
- Airborne and cosmic correction (IAEA, 2003)

  Used parameters: (determined by high altitude calibration flights near Borlange airport 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: 0.18	b_u: 0.65
a_K: 3.44	b_K: 9.28
a_T: 0.53	b_T: 1.42
aTc: 27.39	bTc: 113.6
a_1: 0.031	a_2: 0.026

- Stripping correction (IAEA, 2003)
  Used parameters (determined from measurements on calibrations pads at Borlange in June, 2012):

a	0.0484
alpha	0.2999
beta	0.4755
gamma	0.8313

- <u>Height correction to a height of 60 m</u>
  Used parameters (determined by height calibration flight in Seljord region in May, 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 Borlange calibration pads in June 2012):
  Counts per elements concentrations:

K:	0.00757	%/cps
U:	0.0887834	ppm/cps
Th:	0.154092	ppm/cps

- <u>Microlevelling using Geosoft menu</u>
  Used parameters for microlevelling:

Naudy (1968) Filter length for 25 m grid:	300 m
Naudy (1968) Filter length for 12 m grid:	150 m
Amplitude limit in removing noise :	varied for different elements