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Compilation of magnetic and radiometric data measured from helicopter in the Troms - Northern Nordland area

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Compilation of magnetic and radiometric data measured from helicopter in the Troms – Northern Nordland area.

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Summary:
NGU conducted airborne magnetic and radiometric surveys at the area of Troms and Northern Nordland between June 2011 and October 2014 as a part of the MINN project (Mineral resources in North Norway). The data from those surveys were processed by NGU and presented as 13 separate open reports. Furthermore, processed flight data and high resolution maps from each survey are made available to the public. This report describes and documents the processing and visualization of the compilation of available magnetic and radiometric helicopter-borne data in the region. The compilation is covering an area of approximately 126.300 km^2.

Two helicopter-borne systems designed to obtain detailed airborne magnetic and radiometric data used for data acquisition. The first system was able to collect EM, magnetic and spectrometry data, while the second was designed to collect only magnetic and spectrometry data.

Available data were processed at NGU using Geosoft Oasis Montaj software. Magnetic and spectrometry data were reprocessed to produce homogenised datasets for compilation. In 9 out of 13 surveys EM data were also available, but not included in this report.

Data were gridded with a cell size of 50 x 50 m and presented as shaded relief.

Keywords: Geophysics	Airborne	Magnetic
	Gamma spectrometry	Radiometric
	Compilation	Technical report

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1. INTRODUCTION

In 2011 the Norwegian government initiated a new program for mapping of mineral resources in Northern Norway (MINN). 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 parts of MINN program. Between 2011 and 2014 NGU contacted surveys at 13 regions in the Troms and northern Nordland area (Table 1 and Figure 1) covering about 126.300 km^2. A compilation of magnetic and radiometric data from those surveys is documented and presented herein. EM data collected in 9 out 13 regions are not dealt with in this report.

The compilation includes data from 13 sub-regions, collected during a four year acquisition period. The hatched filling in the sub-regions on the location map of Figure 1 is similar to the actual flight direction of the region and its colour is indicative of the acquisition time. Table 1 describes the names of the areas, acquisition time, documentation report and equipment used for the different geophysical methods.
Mauken (A in Fig.1) and Rombaken (B in Fig.1) were measured in 2011. They are shown in dark green hatches in NE-SW and E-W direction.

Finnsnes (C in Fig.1), Kvæfjord (D in Fig.1) and Andøya (E in Fig.1) were measured in 2012. They are shown in dark blue hatches having different directions. The northern part of Sørreisa and a great part of Senja which were also measured in 2012 in a NW-SE a NE-SW direction, respectively, are also shown in dark blue hatches.

Langøya (F in Fig.1), Austvågøya (G in Fig.1) and Evenes (H in Fig.1) were measured in 2013. They are shown with pink hatches. Langøya was measured in two stages having different flight directions, the eastern part in a E-S direction and the western part in a NW-SE direction, overlapping each other at the central part of the island where geological formations exhibit also a NW-SE direction. Available older helicopter-borne magnetic data from 1987 (shown with light green colour in Fig.1) were used to fill gaps over water covered areas of Langøya.

Western part of Austvågøya, Hinnøya, Tjeldøya and Hadseløya (I in Fig.1) and Altevann (J in Fig.1) were also measured in 2013. Those areas are shown in red hatches to distinguish them from other areas measured in 2013 shown in pink, because they were measured with a system that only had magnetometer and spectrometer installed. The small area west of Hinnøya shown in pink hatches is Nipa.

Senja (K in Fig.1) was measured in three consequent years (2012-2014). The main part was surveyed in 2012 in a NE-SW direction and therefore is shown in dark blue hatches.

Dividalen (L in Fig.1) and Gratangen and Sørreisa (M in Fig.1) were measured in 2014. They are shown in brown hatches. The system used on those surveys collected only magnetic and spectrometry data.

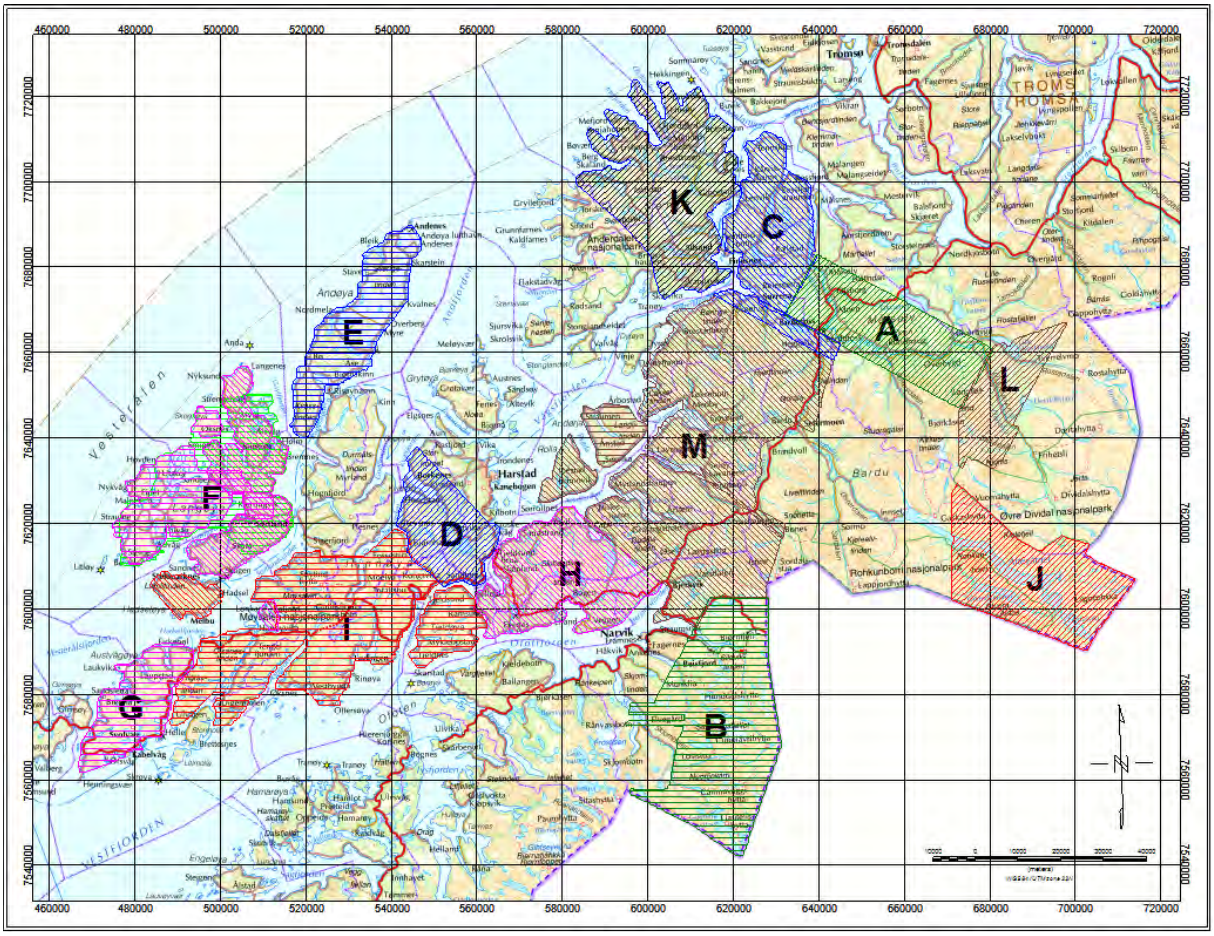

Figure 1: Surveyed areas. Codes are shown in Table 1.

Table 1. *Areas surveyed by NGU in the Troms and northern Nordland area.*

	County	Area	Data aquisition year	NGU report	Instrumentation used
A	Troms	Mauken	2011	2012.010	CS-2, RSX-5, EM
B	Nordland	Rombaken	2011	2012.022	CS-2, RSX-5, EM
C	Troms	Finnsnes	2012	2012.047	CS-2, RSX-5, EM
D	Troms	Kvæfjord	2012	2012.055	CS-2, RSX-5, EM
E	Nordland	Andøya	2012	2012.056	CS-2, RSX-5, EM
F	Nordland	Langøya	2013	2013.044	CS-2, RSX-5, EM
G	Nordland	Austvågøya	2013	2013.045	CS-2, RSX-5, EM
H	Nordland and Troms	Evenes	2013	2013.046	CS-2, RSX-5, EM
I	Nordland and Troms	Austvågøya, Hinnøya, Tjeldøya and Hadseløya	2013	2014.007	CS-3, RSX-5
J	Troms	Altevann	2013	2014.009	CS-3, RSX-5
K	Troms	Senja	2012-2014	2014.039	CS-2, RSX-5, EM
L	Troms	Dividalen	2014	2015.003	CS-3, RSX-5
M	Troms	Gratangen and Sørreisa	2012 and 2014	2015.011	CS-3, RSX-5

The objective of each airborne geophysical survey in Table 1 was to obtain dense high-resolution aero-magnetic, radiometric and electromagnetic data sets over each surveyed area. These data sets are required for the enhancement of a general understanding of the regional geology. 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.

2. SURVEY SPECIFICATIONS

Two helicopter-borne systems designed to obtain detailed airborne magnetic and radiometric data used for data acquisition within the framework of MINN project, between 2011 and 2014.

The first system was a Hummingbird™ electromagnetic and magnetic (Scintrex Cs-2 magnetic sensor) helicopter survey system designed to obtain low level, slow speed, detailed airborne magnetic and electromagnetic data (Geotech 1997). The system was supplemented by 1024 channel RSX-5 gamma-ray spectrometer which was used to map ground concentrations of U, Th and K. This system is operating since the beginning of the MINN project.

The second system uses a Scintrex Cs-3 magnetic sensor housed in a 2m long bird towed 30 m below the helicopter to record the total magnetic field and a 1024 channel RSX-5 gamma-ray spectrometer installed under the helicopter belly to map ground concentrations of U, T and K. This system was introduced in 2013.

A Eurocopter AS350-B2 from helicopter company HeliScan AS was employed in 2011 and 2012 surveys to tow the Hummingbird™ system. A second helicopter a Eurocopter AS350-B3 replaced the AS350-B2 in 2013. Since then the AS350-B2 is towing the second system.

The survey lines were spaced 200 m apart almost throughout of the surveyed areas. A small part of Senja (graphite area at Skaland and Trælen) was measured with 100 m line spacing (see NGU report 2014.039).

Instrument operation for the first system was performed by NGU's employees, while for the second system 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 50 m, while for the spectrometer it was about 80m. Due to flight safety rules parts of 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 40–140 km/h depending on topography, wind direction and its magnitude. On average the ground speed was about 70 km/h.

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

The above parameters were designed to allow for sufficient details 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 every 3 seconds in the magnetic field, was installed close to the helicopter base during the data acquisition period. 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. In case of failure of the base magnetometer the continuous recordings every 10 seconds from the Magnetic Observatories of Tromsø or Andenes were used instead. These observatories are relative close to the surveyed areas.

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 less than ± 5 m in the horizontal directions. The GPS receiver antenna was mounted externally to the tail tip of the helicopter.

Instrument specifications are given in table 2.

Table 2. *Instrument Specifications for Magnetic and Radiometric surveys*

Instrument	Producer/Model	Accuracy / Sensitivity	Sampling frequency / interval
Magnetometer	Scintrex Cs-2 (2011-2014)	0.002nT	5 Hz
	Scintrex Cs-3 (2013-2014)	<2.5nT throughout range / 0.0006nT √Hz rms	5 Hz
Base magnetometer	Scintrex Envi-Mag (2011-2013)	0.1 nT	3 s
	GEM GSM-19 (2013-2014)	0.1 nT	3 s
Gamma spectrometer	**NGU's** Radiation Solutions RSX-5 (2011-2014)	1024 ch's, 16 liters down, 4 liters up	1 Hz
	NRPA's Radiation Solutions RSX-5 (2013-2014)	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		

3. DATA PROCESSING AND PRESENTATION

Databases from each of the 13 surveyed areas copied from the NGU dataserver were reprocessed by Alexandros Stampolidis at NGU. Magnetic and radiometric flight line based databases include channels with information from all the processing steps described in the related reports. These databases were arranged in two groups one for the magnetic and one for the spectrometry compilation.

3.1 Magnetic compilation

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.1)

$$\mathbf{B}_{TA} = \mathbf{B}_{Tc} - IGRF \qquad (1)$$

We decided to use the total field magnetic anomaly data ($\mathbf{B}_{TA}$) from Gratangen and Sørreisa (NGU report 2015.011) as a core of our compilation and to bring all other datasets to their level.

Magnetic databases used in the compilation of the magnetic data are shown in Table 3.

Table 3. *Magnetic databases*

	NGU report	Database name	Reprocessing
A	2012.010	Mauken_Mag_2015_proc.gdb	Microlevelling
B	2012.022	Rombaken_Mag_2015_proc.gdb	IGRF, Microlevelling
C	2012.047	Finnsnes_Mag_2015_proc.gdb	Remove lag, Microlevelling
D	2012.055	Kvaefjord_Mag_2015_proc.gdb	Remove lag, Microlevelling
E	2012.056	Andøya_Mag_2015_proc.gbd	Remove lag, Microlevelling
F	2013.044	Langøya1_Mag_2015_proc.gdb Langøya2_Mag_2015_proc.gdb 1987_Helicopter_data.gdb	Microlevelling Microlevelling IGRF, Microlevelling
G	2013.045	Austvagoya_Mag_2015_proc.gdb	Microlevelling
H	2013.046	Evenes_Mag_2015_proc.gdb	Microlevelling
I	2014.007	Hadseloya_Mag_2015_proc.gdb Hinn_Aust_Tjeld_Mag_2015_proc.gdb Nipa_magnetics_2015_proc.gdb	Microlevelling Microlevelling Microlevelling
J	2014.009	Altevann_Mag_2013_Drape1.gdb	Microlevelling
K	2014.039	Senja_Mag_2015_proc.gdb	no
L	2015.003	DiviNord_Mag_2015_lines.gdb	Microlevelling
M	2015.011	Sørreisa_Mag_2014_lines_v1.gdb Sørreisa_Mag_2012_lines.gdb Gratangen_Mag_2014_lines.gdb	no no no

Total filed magnetic anomaly re-calculations

Magnetic data in two databases (i.e. Rombaken and Langøya 1987) were presented in the form of diurnal corrected data ($\mathbf{B}_{Tc}$). The IGRF channel was calculated and the total field anomaly ($\mathbf{B}_{TA}$) was estimated using equation (1).

Lag correction was applied on magnetic data measured in 2012 (i.e. Andøya, Kvæfjord, Finnsnes). Because neither a lag nor cloverleaf tests were performed before any survey this correction was rather unjustified and was removed. 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. This step improves the homogeneity of the data.

In a few databases (i.e. Mauken, Andøya, Kvæfjord, Finnsnes, Evenes, Langøya, Austvågøya) microlevelling was applied on the diurnal corrected data ($\mathbf{B}_{Tc}$). The resulted total field anomaly calculated from equation (1) exhibits higher frequency content than in case we applied the microlevelling as a last processing step and not an intermediate. We recalculated the total field anomaly for those databases excluding the intermediate microlevelling step.

Microlevelling was reapplied on almost every database using the same parameters used in the Gratangen and Sørreisa (NGU report 2015.011 p.19). Again, this step improves the homogeneity of the data.

The microlevelled channel was gridded using a minimum curvature method with 50 m grid cell size. The parameters used in the gridding are presented in the Appendix.

Bringing magnetic data to the same level

Areas that were measured about the same period they often share the same base magnetometer. In case that their diurnal fields measured by two different base magnetometers their form was similar. We used this property to estimate the relative shift that we have to apply on them to bring them to the same level.

Data collected in 2011 (i.e. Rombaken and Mauken) are overlapping with later datasets, so no shift had to be estimated manually, since stitching subroutine (Geosoft 2013) takes care of it.

Surveys conducted on islands in 2012 (i.e. Andøya and Senja) did not overlap with any other surveys. Fortunately, they were measured about the same period with other inland surveys (i.e Finnsnes, Sørreisa, Kvæfjord) and therefore it was possible to find flights on common dates in two surveys and since they share the same base magnetometer to estimate the relative shift on their level. Table 4 shows the estimated level differences that have to be applied on the grids in order to bring them to the same level with Senja. Andøya base magnetometer was installed close to the Andenes Observatory (about 3 km), so they had similar diurnal field. We used this property to estimate the relative level shift between Andøya and Kvæfjord, and between Andøya and Senja.

Sørreisa 2012 and Sørreisa 2014 have the same level because their base magnetometer was leveled to Tromsø Observatory, in fact for Sørreisa 2014 we used the actual Tromsø Observatory data to correct for diurnal.

Table 4. *Level changes applied on 2012 grids*

	Area	Data aquisition year	NGU report	Common date	Level shift (nT)
C	Finnsnes	2012	2012.047	13.8.2012	+11
D	Kvæfjord	2012	2012.055	28.8.2012	-43.5
E	Andøya	2012	2012.056	12.9.2012	-3
K	Senja	2012-2014	2014.039		0
M	Sørreisa	2012	2015.011	31.7.2012	20

Langøya1 and Langøya2 shared the same base magnetometer on 26.07.2013, making possible to estimate their level difference. Hadseløya also shared the same base magnetometer with Langøya1. First we brought Langøya1, Langøya2 and Hadseløya to the same level by adding 12 nT to Langøya2 and then we tried to link them to Hinnøya survey. This proved to be possible since on 25.07.2013 they shared the same base magnetometer (Table 5).

Altevann was measured at the same period as Evenes in 2013, so we were able to estimate their level difference (Table 5). Altevann had to be leveled by 17.6 nT.

Table 5. *Level changes applied on 2013 grids*

	Area	Data aquisition year	NGU report	Common date	Level shift (nT)
F	Langøya1 Langøya2	2013	2013.044	26.7.2013 26.7.2013	0 +12
I	Hadseløya	2013	2014.007	16.7.2013	0
I	Hinnøya	2013	2014.007	25.7.2013	-5.7
H	Evenes	2013	2013.046	01.9.2013	0
J	Altevann	2013	2014.009	01.9.2013	17.6

Magnetic compilation outline

We used Oasis Montaj stitching subroutine (Grid Knitting, Geosoft 2013) to join grids that overlap, while we used mosaic subroutine to join grids without overlap. The suture method was selected for the grid stitching. We choose to make Sørreisa 2014 a core to our compilation and we tried to bring all data into its level. Therefore, during the stitching process we let the subroutine to estimate the appropriate static shift and apply it to the stitched grid. Level on mosaic grids was applied manually. The processing flow used in the magnetic compilation was divided into two parts, North and South part.

North part

Step 1.: Grid stitching Sørreisa 2012 + Sørreisa 2014 →(no level shift)
Step 2.: Grid stitching (Step 1) + Gratangen →(static shift on Gratangen)
Step 3.: Level shift Andøya (-3)
Step 4.: Level shift Finnsnes (+11)
Step 5.: Level shift Kvæfjord (-43.5)
Step 6.: Mosaic Andøya + Kvæfjord + Finnsnes + Senja
Step 7.: Level shift (Step 6) (-20)
Step 8.: Grid stitching (Step 2) + (Step 7) →(static shift on Step 7)
Step 9.: Grid stitching (Step 8) + Mauken →(static shift on Mauken)
Step 10.: Grid stitching (Step 9) + Dividalen →(static shift on Dividalen)
Step 11.: Level shift Altevann (+17.6)
Step 12.: Mosaic (Step 11) + Evenes
Step 13.: Grid stitching (Step 10) + (Step 12) →(static shift on Step 12)
Step 14.: Grid stitching (Step 13) + Rombaken →(static shift on Rombaken)

The outcome of Step 14 is the North part compilation grid.

South part

Step 1.: Level shift Langøya2 (+12)
Step 2.: Grid stitching Langøya1 + (Step 1) →(no level shift)
Step 3.: Grid stitching (Step 2) + Langøya1987 →(static shift on Langøya1987)
Step 4.: Mosaic (Step 3) + Hadseløya
Step 5.: Level shift (Step 4) (+5.7)
Step 6.: Grid stitching (Hinnøya-Austvågøya-Tjeldøya) + Nipa →(no level shift)
Step 7.: Grid stitching (Step 6) + Austvågøya →(static shift on Austvågøya)
Step 8.: Mosaic (Step 4) + (Step 7)

The outcome of Step 8 is the South part compilation grid.

Final step:

Grid stitching North part + South part → (static shift on South part)

The file “**Stitch_Final_Mag_miclev.grd**” is the compiled micro-levelled total magnetic anomaly grid of Troms and Northern Nordland.

The Horizontal and Vertical Gradient along with the Tilt Derivative of the total magnetic anomaly were calculated from the compiled micro-levelled total magnetic anomaly grid. The magnitude of the horizontal gradient was calculated according to equation (2)

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

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 (3)

$$TD = \mathrm{atan}(VG/HG) \tag{3}$$

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

The results are presented in a series of colored shaded relief maps (1:700.000). 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 Troms and Northern Nordland area. A list of the produced maps is shown in Table 8.

3.2 Radiometric data compilation

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.

Radiometric databases used in the compilation of the spectrometry data are shown in Table 6.

Table 6. *Radiometric databases*

	NGU report	Database name	Reprocessing
A	2012.010	Mauken_Rad_2015_SpectrFinal.gdb	S, H, C, M
B	2012.022	Rombaken_Rad_2015_reproc.gdb	S, H, C, M
C	2012.047	Finssness_Rad.gdb	S, H, C, M
D	2012.055	Kvaefjord_Rad.gdb	S, H, C, M
E	2012.056	Andoya_Rad_final.gdb	S, H, C, M
F	2013.044	Langoya1_Rad.gdb Langoya2_Rad.gdb	S, H, C, M S, H, C, M
G	2013.045	Austvagoya_Rad.gdb	S, H, C, M
H	2013.046	Evenes_Rad_Reproc.gdb	S, H, C, M
I	2014.007	Hadseløya_Rad_2013_Final.gdb Hinn_Aust_Tjeld_RAD_2013_lines.gdb Nipa_Rad_2013_Final.gdb	S, H, C, M S, H, C, M S, H, C, M
J	2014.009	Altevann_Rad_2013_Final_Mask.gdb	S, H, C, M
K	2014.039	Senja_Rad_2014_Final.gdb	no
L	2015.003	Dividalen Nord_RAD_2014_lines.gdb	S, H, C, M
M	2015.011	Sørreisa_Rad_2012_Final_Mask.gdb Sørreisa_All_Rad_sorted.gdb Merged_Gratangen_Rad_2014_lines_sorted.gdb	S, H, C, M no no

S=Stripping, H=Height attenuation, C=Concentration, M=Microlevelling

In order to homogenize the data sets we reprocessed the radiometric databases. We re-estimated the Compton stripping correction, the height correction and conversion to ground concentration (see Table 6).

Microlevelling was reapplied on almost every database using the same parameters used in the Gratangen and Sørreisa (NGU report 2015.011 p.19). This step inproves the homogeneity of the data (see Table 6).

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).

The stripping corrections are given by the following formulas:

$$A_1 = 1 - (g \cdot \gamma) - (a \cdot \alpha) + (a \cdot g \cdot \beta) - (b \cdot \beta) + (b \cdot \alpha \cdot \gamma) \quad (4)$$

$$U_{ST} = \frac{Th_{RC} \cdot ((g \cdot \beta) - \alpha) + U_{RC} \cdot (1 - b \cdot \beta) + K_{RC} \cdot ((b \cdot \alpha) - g)}{A_1} \quad (5)$$

$$Th_{ST} = \frac{Th_{RC} \cdot (1 - (g \cdot \gamma)) + U_{RC} \cdot (b \cdot \gamma - a) + K_{RC} \cdot ((a \cdot g) - b)}{A_1} \quad (6)$$

$$K_{ST} = \frac{Th_{RC} \cdot ((\alpha \cdot \gamma) - \beta) + U_{RC} \cdot ((a \cdot \beta) - \gamma) + K_{RC} \cdot (1 - (a \cdot \alpha))}{A_1} \quad (7)$$

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.

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:

$$C_{60m} = C_{ST} \cdot e^{C_{ht} \cdot (60 - H_{STP})} \quad (8)$$

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

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}Tl for Thorium). The concentration of the elements is calculated according to the following expressions:

$$C_{CONC} = C_{60m} / C_{SENS\_60m} \quad (9)$$

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

Table 7 has information about the source of the coefficients used in the re-processing (see Appendix for details). Senja was not re-processed as shown in Table 6. Details about the coefficients used for Senja could be found in NGU report 2014.039.

Table 7. *Location and date of tests contacted for the estimation of coefficients used in the re-processing. Stripping/Sensitivity tests were performed at NGU, while the instrument involved is shown in parenthesis.*

	Database name	Height attenuation	Stripping/ Sensitivity calibration
A	Mauken_Rad_2015_SpectrFinal.gdb	Rombaken 2011	05.08.2010 (NGU)
B	Rombaken_Rad_2015_reproc.gdb	Rombaken 2011	05.08.2010 (NGU)
C	Finssness_Rad.gdb	Rombaken 2011	28.03.2012 (NGU)
D	Kvaefjord_Rad.gdb	Rombaken 2011	28.03.2012 (NGU)
E	Andoya_Rad_final.gdb	Rombaken 2011	28.03.2012 (NGU)
F	Langoya1_Rad.gdb Langoya2_Rad.gdb	Frosta 2014 Frosta 2014	06.05.2013 (NGU) 06.05.2013 (NGU)
G	Austvagoya_Rad.gdb	Frosta 2014	06.05.2013 (NGU)
H	Evenes_Rad_Reproc.gdb	Frosta 2014	06.05.2013 (NGU)
I	Hadseløya_Rad_2013_Final.gdb Hinn_Aust_Tjeld_RAD_2013_lines.gdb Nipa_Rad_2013_Final.gdb	Frosta 2014 Frosta 2014 Frosta 2014	06.05.2013 (NRPA) 06.05.2013 (NRPA) 06.05.2013 (NRPA)
J	Altevann_Rad_2013_Final_Mask.gdb	Frosta 2014	06.05.2013 (NRPA)
K	Senja_Rad_2014_Final.gdb	Report 2014.039	Report 2014.039
L	Dividalen Nord_RAD_2014_lines.gdb	Frosta 2014	08.04.2014 (NGU)
M	Sørreisa_Rad_2012_Final_Mask.gdb Sørreisa_All_Rad_sorted.gdb Merged_Gratangen_Rad_2014_lines_sorted.gdb	Rombaken 2011 Frosta 2014 Frosta 2014	28.03.2012 (NGU) 08.04.2014 (NGU) 08.04.2014 (NGU)

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, using the same parameters used in the Gratangen and Sørreisa (NGU report 2015.011 p.19). The microlevelled channel was gridded using a minimum curvature method with 50 m grid cell size. This cell size is equal to one quarter of the 200m average line spacing. The parameters used in the gridding are presented in the Appendix.

Radiometric compilation outline

We used Oasis Montaj stitching subroutine (Grid Knitting, Geosoft 2013) to join grids that overlap, while we used mosaic subroutine to join grids without overlap. The suture method was selected for the grid stitching.

Radiometric data, if processed ideally, shows no level changes when joined. This means that all parameters involved in their processing have to be as close to their real values as possible, which is not always the case. We used two RSX-5 spectrometers that have the same crystal's volume and similar characteristics. Calibration tests performed at NGU (i.e. Stripping and Sensitivity) proved to be robust since they show a small envelope of deviations of calculated coefficients through time, but height attenuation, cosmic and background tests, if not performed by the book, could introduce errors in the calculated coefficients. Furthermore, the choice of inappropriate water and land bodies for the Radon correction could introduce unwanted signal to the calculations and distort the estimated statistics.

The suture method was adopted during the stitching process. We forbid any level changes to be applied by the stitching algorithm. Instead we estimated the level differences between adjacent grids and applied it manually, preserving at the same time values close to zero, which characterizing water bodies.

The processing flow used in the radiometric compilation was divided into two parts.

North part

Step 1.: Grid stitching Sørreisa 2014 + Gratangen
Step 2.: Grid stitching (Step 1) + Evenes
Step 3.: Grid stitching Finnsnes + Mauken
Step 4.: Grid stitching (Step 3) + Sørreisa 2012
Step 5.: Mosaic Andøya + Kvæfjord + (Step 4)
Step 6.: Mosaic Altevann + Dividalen
Step 7.: Mosaic (Step 2) + (Step 6)
Step 8.: Level shift (Step 5) →[U=0.2], [Th=0.1], [K=0], [TC=50]
Step 9.: Grid stitching (Step 7) + (Step 8)
Step 10.: Level shift Senja →[U=0.3], [Th=0.1], [K=0], [TC=50]
Step 11.: Mosaic (Step 9) + (Step 10)
Step 12.: Level shift Rombaken →[U=0.5], [Th=0.6], [K=0], [TC=150]
Step 13.: Mosaic (Step 11) + (Step 12)

The outcome of Step 13 is the North part compilation grid.

South part

Step 1.: Grid stitching (Hinnøya-Austvågøya-Tjeldøya) + Nipa
Step 2.: Grid stitching Langøya1 + Langøya2
Step 3.: Mosaic (Step 1) + Hadseløya
Step 4.: Level shift (Step 2) →[U=0.1], [Th=0.2], [K=0], [TC=150]
Step 5.: Level shift Austvågøya →[U=0.15], [Th=0.25], [K=0], [TC=200]
Step 6. Mosaic (Step 4) + (Step 5)
Step 7. Grid stitching (Step 6) + (Step 3)

The outcome of Step 7 is the South part compilation grid.

Final step:

Grid stitching North part + South part

The file "**Stitch_Final_South_X_miclev.grd**" is the compiled micro-levelled radiometric grid of Troms and Northern Nordland, where X is U, Th, K or TC.

A 3x3 convolution filter was applied to smooth the concentration grids. A list of the produced maps is shown on Table 8.

4. PRODUCTS

Processed digital data from the survey are presented as:

1. Georeferenced tiff files (Geo-tiff).

2. Coloured maps (jpg) at the scale 1:700.000 are available from NGU on request (see Table 8.).

3. Reprocessed magnetic and radiometric databases (Geosoft XYZ-files)

Table 8. *Maps available from NGU on request.*

Region	Map #	Scale	Name
	2015.022-01	1:100.000	Total field magnetic anomaly
	2015.022-02	1:100.000	Magnetic Horizontal Derivative
	2015.022-03	1:100.000	Magnetic Vertical Derivative
	2015.022-04	1:100.000	Magnetic Tilt Derivative
	2015.022-05	1:100.000	Radiometry Total Counts
	2015.022-06	1:100.000	Potassium ground concentration
	2015.022-07	1:100.000	Uranium ground concentration
	2015.022-08	1:100.000	Thorium ground concentration
	2015.022-09	1:100.000	Radiometric Ternary Map

Downscaled images of the maps are shown on figures 2 to 10.

5. REFERENCES

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6. APPENDIX

Stripping correction

Parameters determined from measurements on calibrations pads at NGU:

2011 survey data (NGU): Calibration on 5th of August 2010

Coefficient	Value
a	0.04824
b	0
c	0
α	0.30867
β	0.48072
γ	0.79531

2012 survey data (NGU): Calibration on 28th of March 2012

Coefficient	Value
a	0.048403
b	0
c	0
α	0.299933
β	0.475485
γ	0.831354

2013 survey data (NGU): Calibration on 6th of May 2013

Coefficient	Value
a	0.049524
b	0
c	0
α	0.296983
β	0.471384
γ	0.829054

2013 survey data (NRPA): Calibration on 6th of May 2013

Coefficient	Value
a	0.046856
b	0
c	0
α	0.303459
β	0.479926
γ	0.823157

2014 survey data (NGU): Calibration on 8th of 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

Parameters determined by high altitude calibration flights (150 – 600 ft). Attenuation factors in 1/m:

2011-2012 survey data (NGU): Rombaken 2011

Channel	Attenuation factor
K	-0.0107
U	-0.00676
Th	-0.0062
TC	-0.0076

2013-2014 survey data (NGU): Frosta in 2014

Channel	Attenuation factor
K	-0.00888
U	-0.00653
Th	-0.00662
TC	-0.00733

2013-2014 survey data (NRPA): Frosta in 2014

Channel	Attenuation factor
K	-0.009523
U	-0.006687
Th	-0.007394
TC	-0.00773

Converting counts at 60 m to element concentration on the ground

Parameters determined from measurements on calibrations pads at NGU:

2011 survey data (NGU): Calibration on 5th of August 2010

Channel	Sensitivity
K (%/count)	0.007615734
U (ppm/count)	0.086685504
Th (ppm/count)	0.15723096

2012 survey data (NGU): Calibration on 28th of March 2012

Channel	Sensitivity
K (%/count)	0.00757
U (ppm/count)	0.087834
Th (ppm/count)	0.154092

2013 survey data (NGU): Calibration on 6th of May 2013

Channel	Sensitivity
K (%/count)	0.007544793
U (ppm/count)	0.088909372
Th (ppm/count)	0.151433049

2013 survey data (NRPA): Calibration on 6th of May 2013

Channel	Sensitivity
K (%/count)	0.007457884
U (ppm/count)	0.087729968
Th (ppm/count)	0.156658412

2014 survey data (NGU): Calibration on 8th of April 2014

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

Gridding and Microlevelling parameters

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Microlevelling parameters	Value
De-corrugation cutoff wavelength (m)	1000
Cell size for gridding (m)	50
Naudy Filter length (m)	600

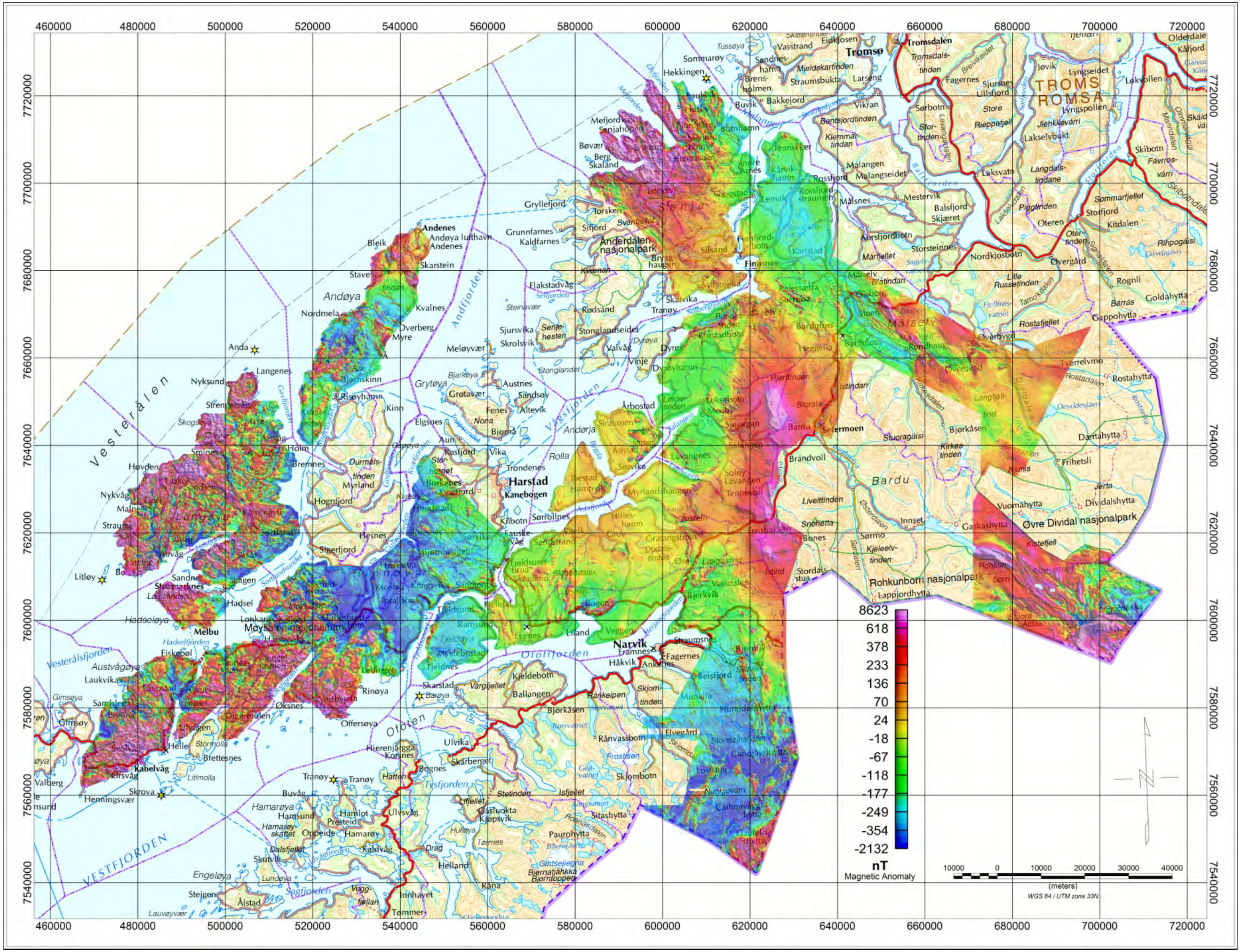

Figure 2: Total Magnetic Field anomaly map

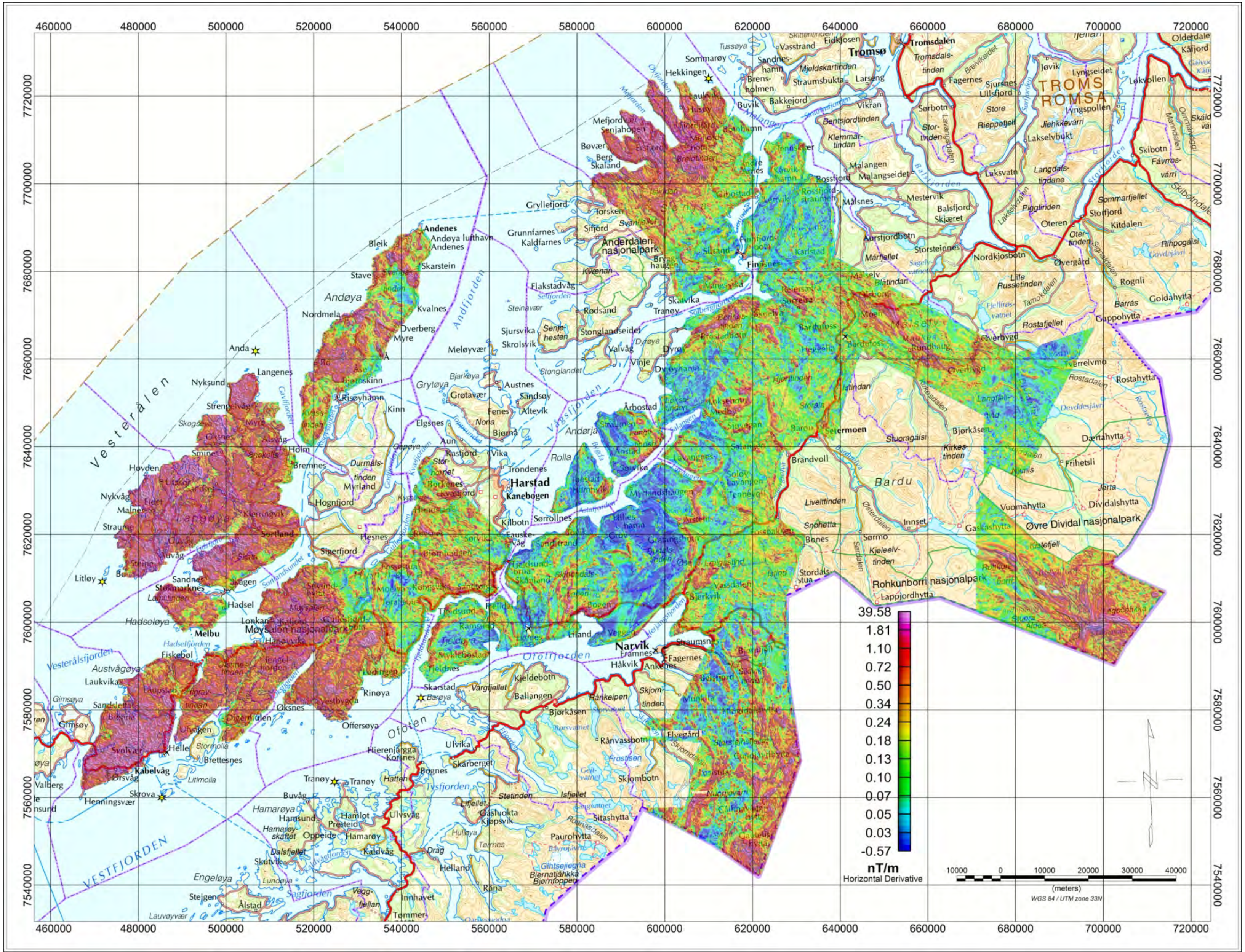

Figure 3: Magnetic Horizontal Gradient map

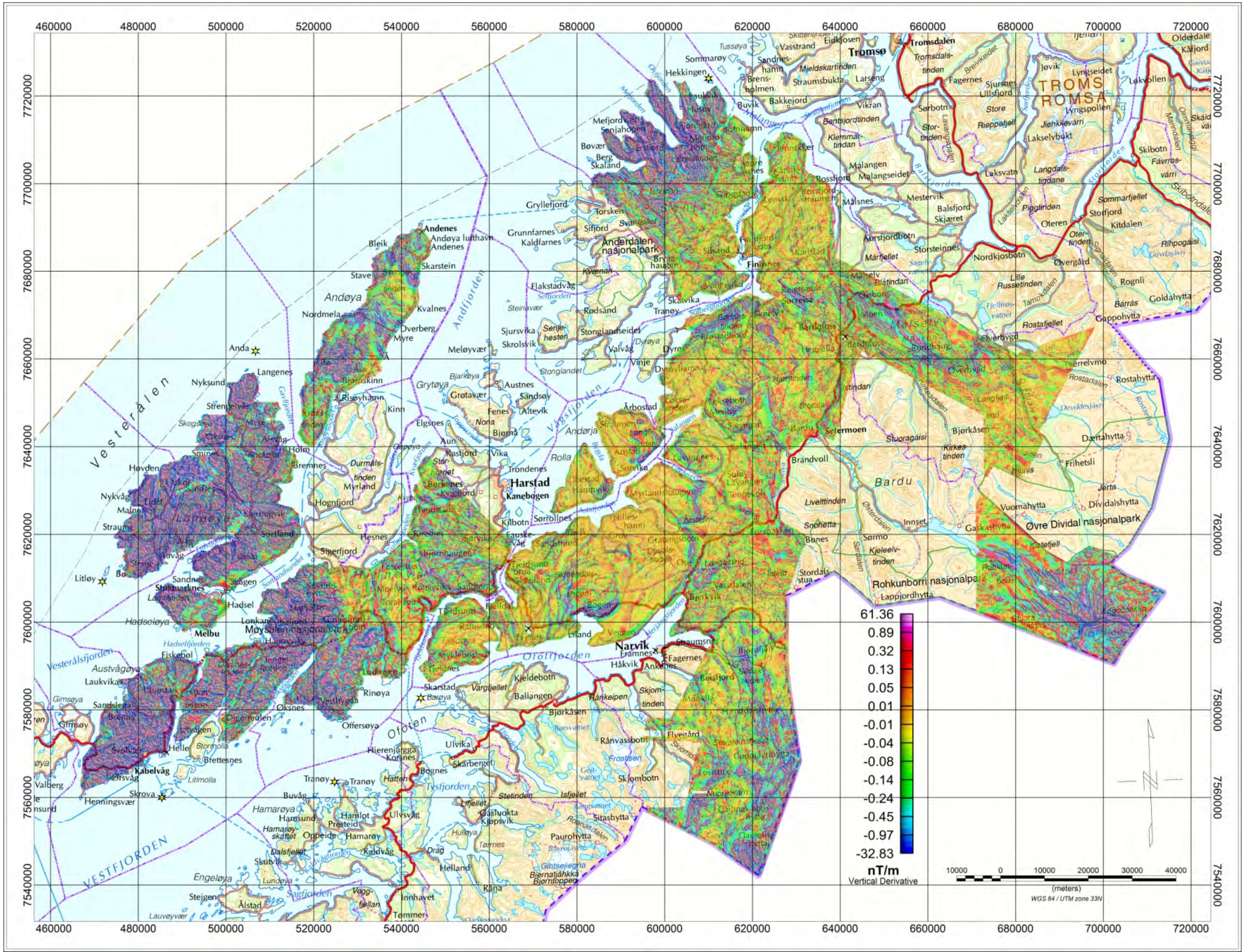

Figure 4: Magnetic Vertical Gradient map

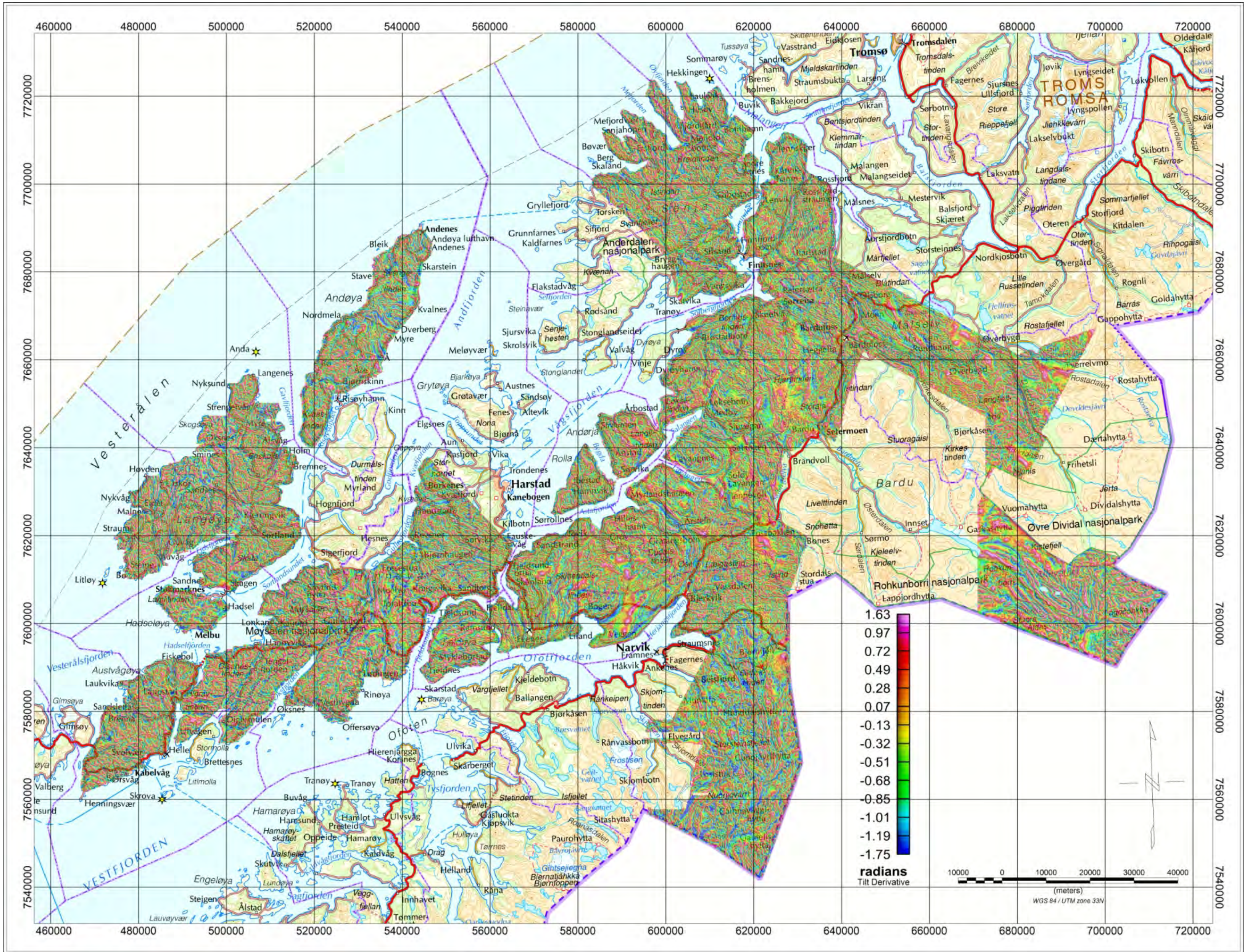

Figure 5: Magnetic Tilt Derivative map

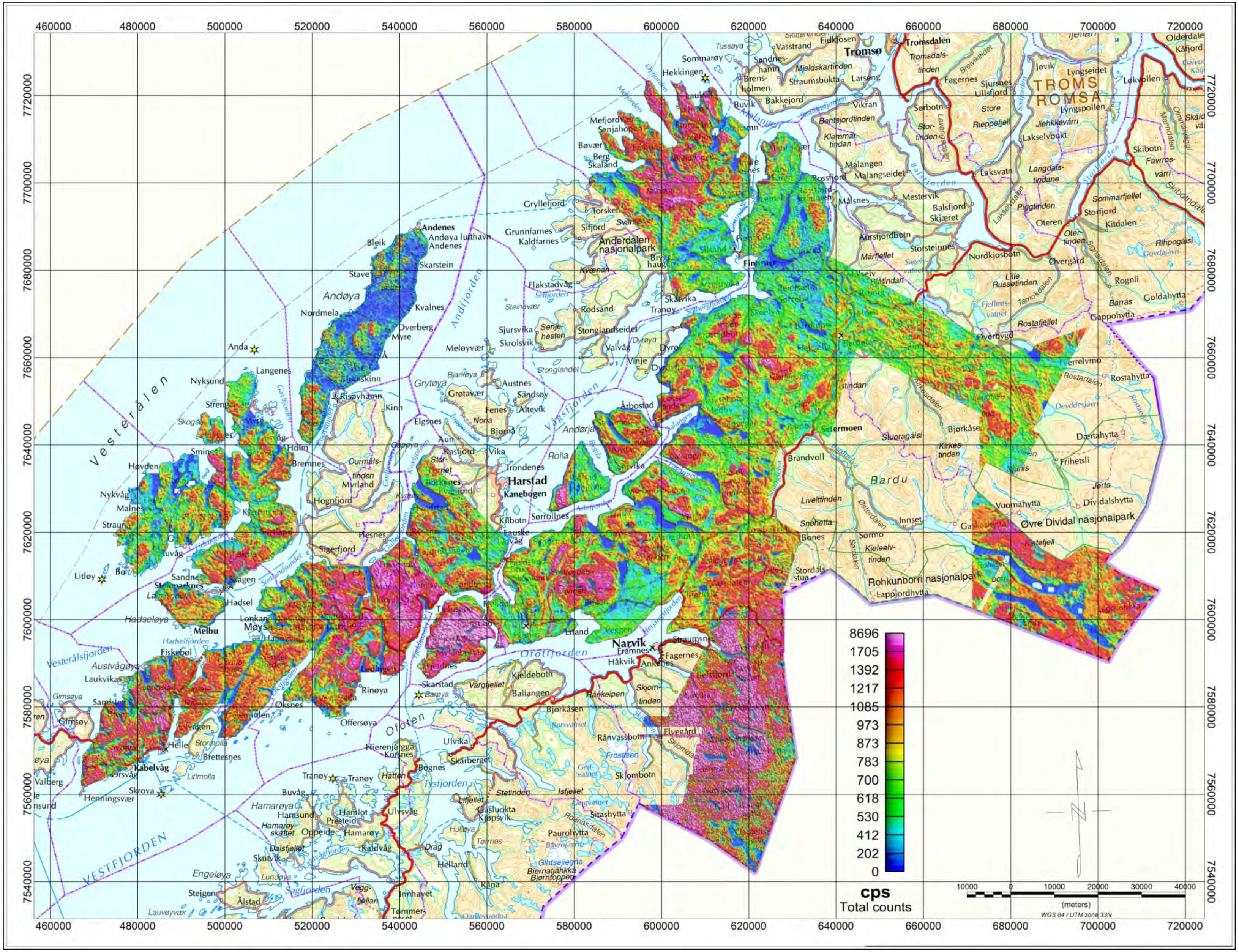

Figure 6: Radiometry: Total Counts map

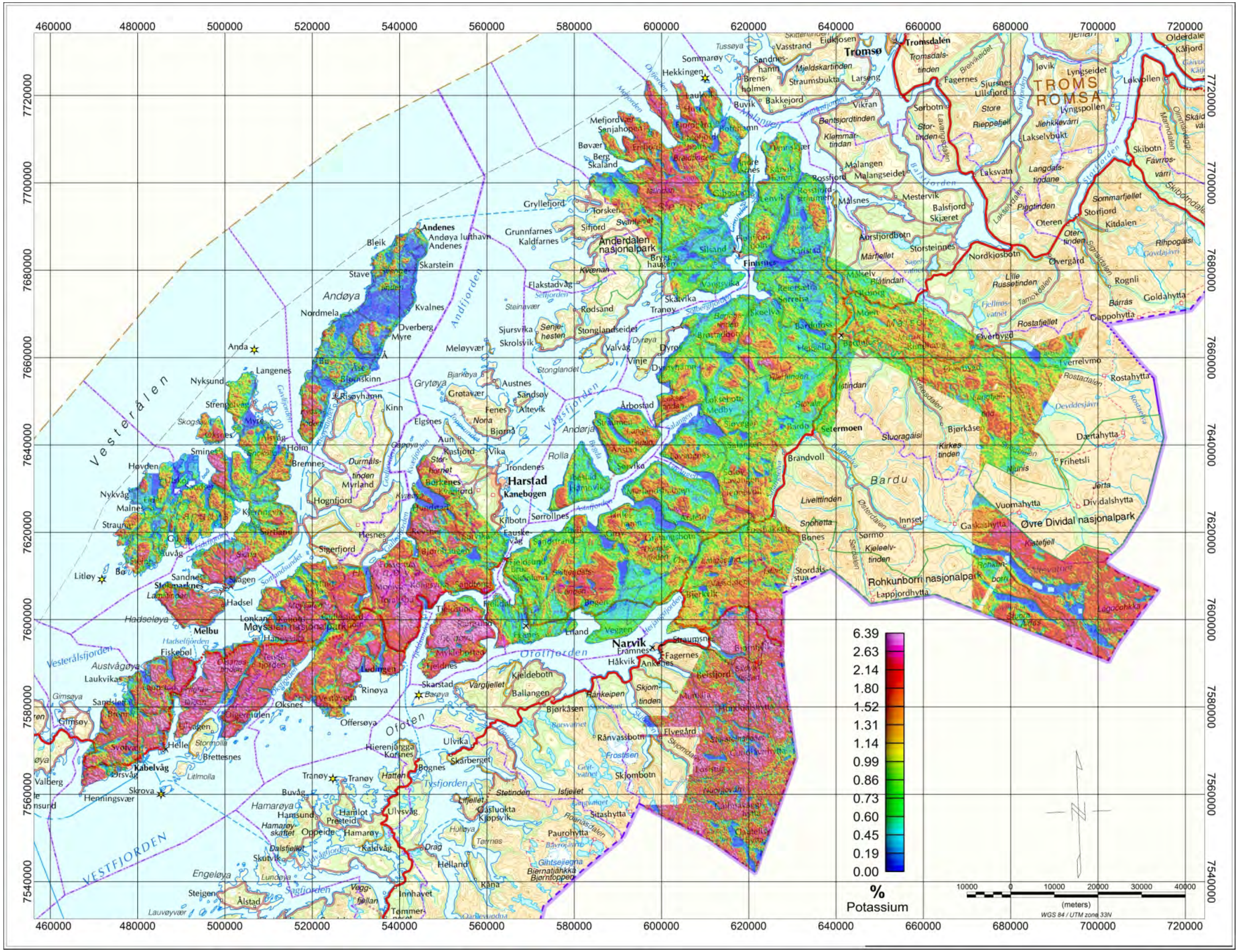

Figure 7: Potassium Ground Concentration map

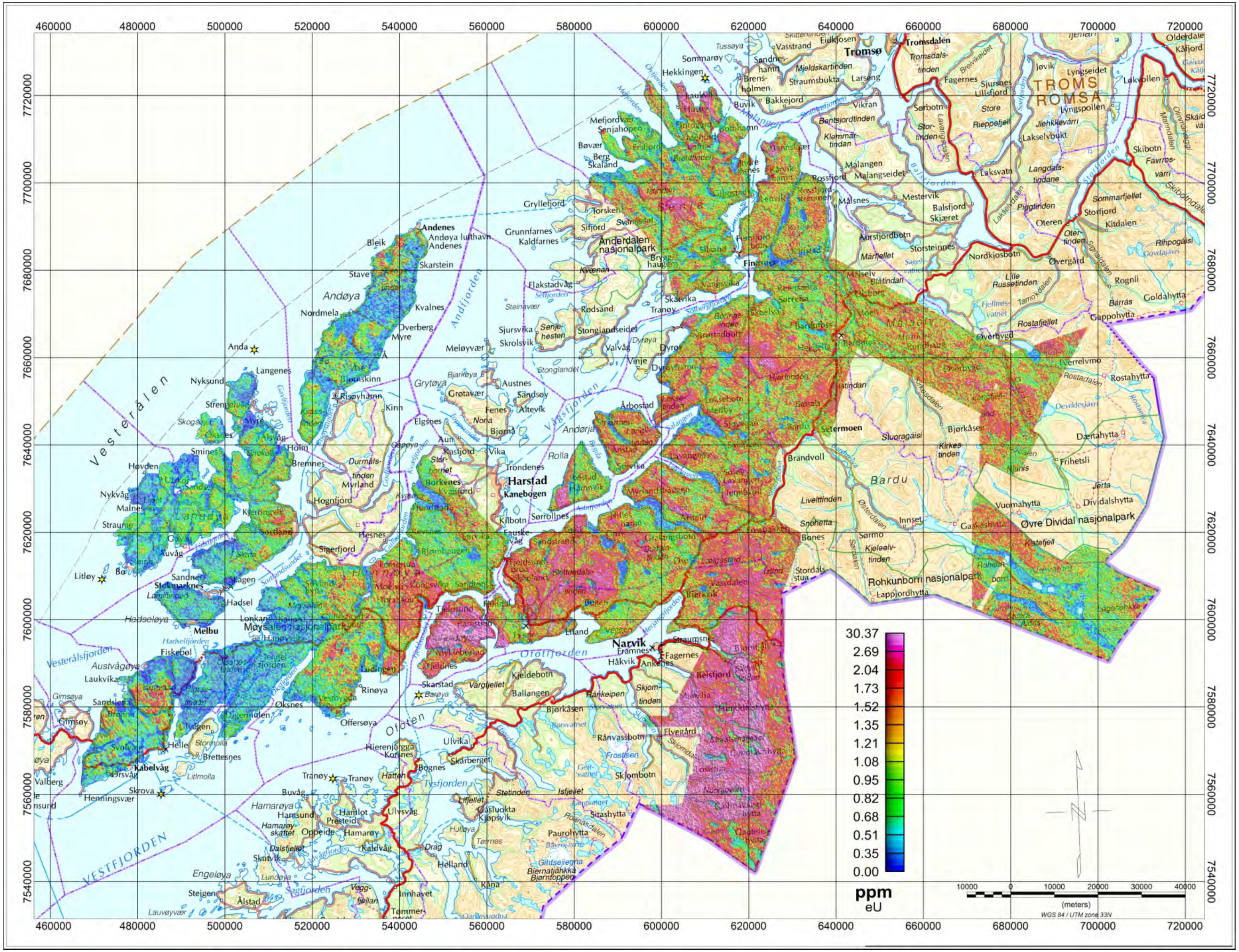

Figure 8: Uranium Ground Concentration map

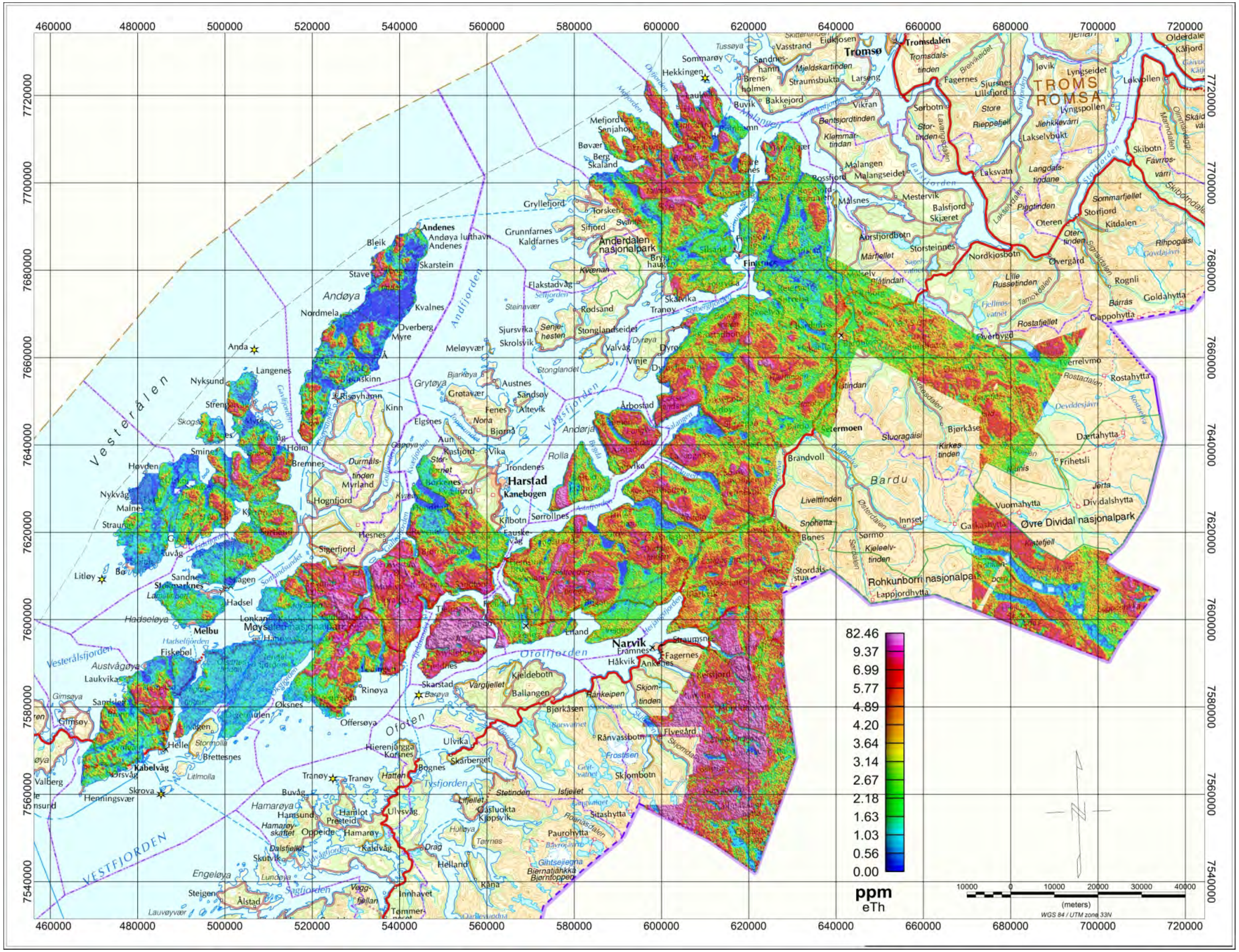

Figure 9: Thorium Ground Concentration map

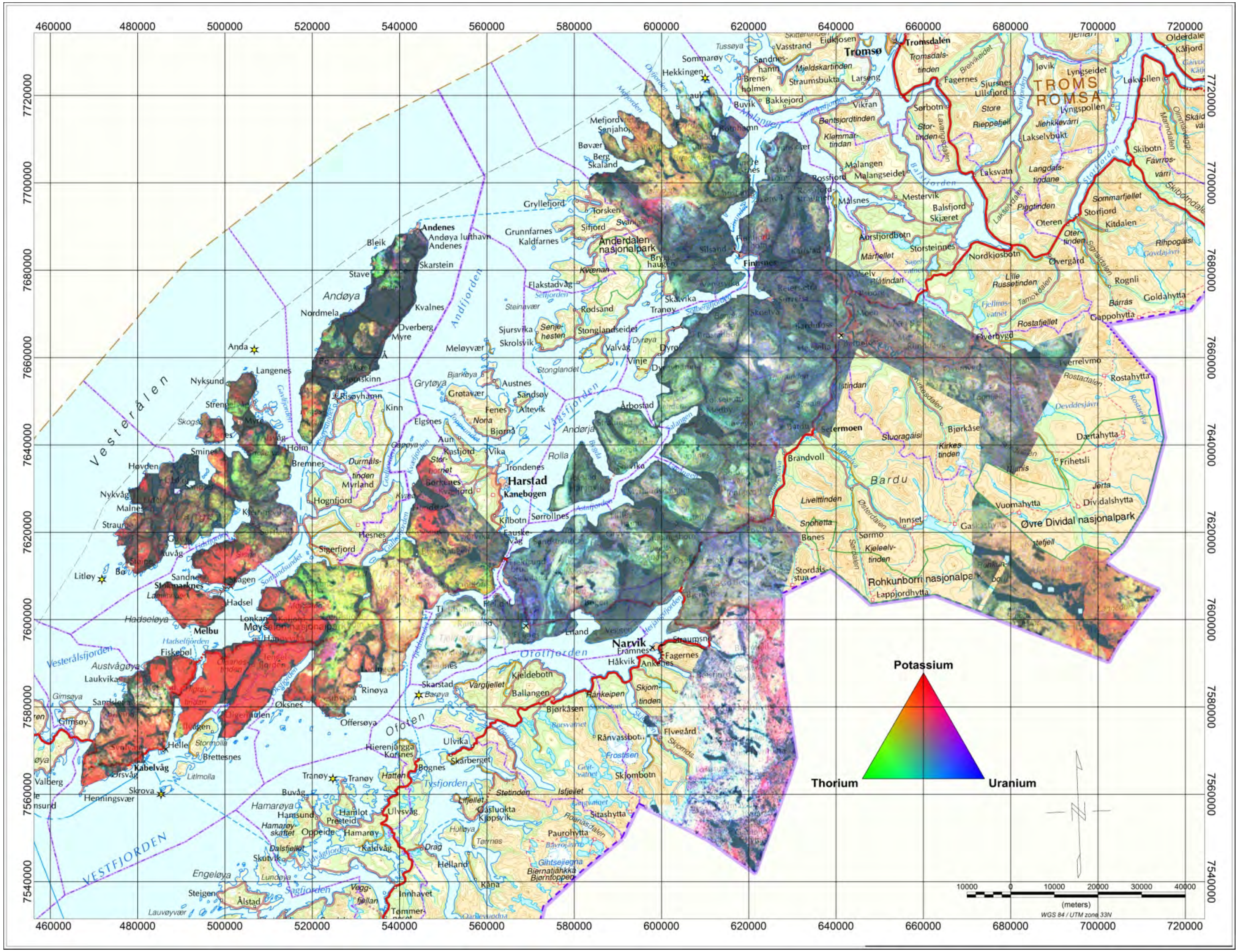

Figure 10: Ternary Image of Radiation Concentration

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