P-03-25

Simpevarp site investigation

Helicopter borne geophysics at Simpevarp, Oskarshamn, Sweden

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NGU

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April 2003

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Keywords: Geophysics, helicopter, magnetometry, electromagnetic, radiometric, data processing

Summary

Svensk Kärnbränslehantering AB (SKB) has decided to carry out site investigations in the Simpevarp area after decisions by the Swedish government and the municipality of Oskarshamn and approval from local landowners. As a part of this, geophysical measurements from helicopter were carried out in the area according to general and site-specific program. The Geological Survey of Norway (NGU) was chosen to operate this survey. The NGU used NorCopter and Geophysical Algorithms as subcontractors. The main purpose of the geophysical measurements was to provide information about the bedrock geology in the Simpevarp area.

Measurements were performed along flight lines in north-south direction in an area which is approximately 13x7 km in size. A second smaller area, selected with the purpose to better resolve possible geological structures in a SW-NE direction east of the nuclear power plant, consisted of 36 flight lines perpendicular to the coast immediately northeast of the power plant. The line spacing was 5 metres and nominal flying height 60 metres. Tie-lines were measured for each 500 metres. In the second, smaller area, lines were flown at a 100 metre spacing. Altogether, 2,039 kilometres were measured (1,789 kilometres along lines and 178 kilometres along tie-lines in the large area and 72 kilometres along lines in the small area).

The quality control and first step of processing took place on site, while the final processing was made at Geophysical Algorithms in Canada. Maps in scale 1:20,000 and 1:10,000 were produced at the NGU in Trondheim. This report describes instrument tests, data acquisition, processing of data, map production and data delivery.

Contents

1 Introduction

Svensk Kärnbränslehantering AB (SKB) has decided to carry out site investigations in the Simpevarp area after decisions by the Swedish government and the municipality of Oskarshamn and approval from local landowners. As part of this, geophysical measurements from helicopter were carried out according to general and site-specific programmes /1/, /2/. The Geological Survey of Norway (NGU) was chosen to operate this survey. The NGU used NorCopter and Geophysical Algorithms as subcontractors.

The survey in the Simpevarp area, Figure 1-1, was conducted immediately after a similar survey at Forsmark. Due to this, parts of the calibrations and instrument tests refer to the Forsmark survey.

This report presents the methodology, calibrations and data gained in helicopter borne geophysics at Simpevarp which is one of the activities performed within the site investigation. The work was conducted in accordance with the instructions and guidelines from SKB (activity plan AP PS 400-02-006 and method description MD 211.002, SKB internal controlling documents) under supervision of activity leader Leif Stenberg, SKB and assistant activity leader Hans Lindberg, GeoVista.

Figure 1-1. *Area covered by geophysical measurements from helicopter. Measurement was performed along north-south lines with tie-lines flown east-west.*

2 Objectives and scope

The main purpose of the geophysical measurements was to provide information about the bedrock geology in the Simpevarp area. Knowledge about any bedrock structures that might possibly be water bearing is very important for the safety analysis of a potential repository. The survey also provides information about soil cover. Helicopter surveys are very efficient in acquiring relatively detailed data with good spatial coverage. This will reduce the need for ground based methods and hence reduce the environmental impact of the site investigation.

3 Methodolgy

3.1 Methods

According to method description SKB MD 211.002 (SKB internal controlling document), magnetic, electromagnetic, radiometric and Very Low Frequency ElectroMagnetic (VLF-EM) methods were used.

3.2 Equipment

The equipment used during the survey was as follows:

3.2.1 Magnetic

Mobile magnetometer: Scintrex CS-2 cesium magnetometer, resolution 0.001 nT, 10 samples per second, giving a data spacing of approximately 3 metres. The magnetometer was located in the electromagnetic sonde.

Base magnetometer: Scintrex MP-3 Proton magnetometer, resolution 0.1 nT, one sample every 3 seconds. As a backup, a GSM-19 base magnetometer provided by GeoVista AB was used.

3.2.2 Electromagnetic

Geotech Hummingbird, 5 frequency sonde, resolution 0.1 ppm, 10 samples per second. Coplanar 880, 6,606 and 34,133 Hz, Coaxial 980 and 7,001 Hz. The four lower frequency coils are separated by 6 metres; the 34,133 Hz coils are 4.2 metres apart. The sonde was towed on a cable approximately 30 meters in length.

3.2.3 Radiometric

Exploranium GR 820 with crystal volume 16 litres downward looking and 4 litres upward looking. The spectrometer has 256 channels, covering an energy window from 0.2 MeV to 3.0 MeV. Channel width is 12.5 keV. Channel 255 (cosmic) covers energies above 3 MeV. The crystal pack was thermally stabilized and mounted on a frame located between the skids of the helicopter. The system accumulates radiation in one second before data are stored (one sample each 30 metres).

3.2.4 Very Low Frequency ElectroMagnetic (VLF-EM)

Hertz Totem 2A, total field from two orthogonal stations, IN LINE and ORTHO (orthogonal). The system was sampled 5 times per second which results in approximately 6 metre station distance. Usually the transmitter GBR (16.0 kHz) was used as the INLINE station and NAA (24 kHz) as the ORTHO station. Occasionally NPD was used as ORTHO when NAA was not operating. The sensor antenna was mounted on the tow cable approximately 10 metres below the aircraft.

3.2.5 Navigation

An Ashtech G12 GPS receiver was used for navigation, with an Aztec RXMAR1 RDS receiver for differential corrections from the EPOS system and a Picodas PNAV2000 to provide real time navigation control data to the pilot. The antenna was mounted on the tail of the aircraft. The position is updated once every second. The resulting sampling increment was approximately 30 metres and not 20 metres as described in the method description, SKB MD 211.002 (SKB internal controlling document). Differential GPS gave accuracy better than ±5 m (see appendix B).

3.2.6 Altimeter

Bendix/King KRA 405B, radar altimeter mounted on the helicopter. Accuracy is 5% of measured altitude.

3.2.7 Datalogger

Geotech datalogger, an integrated part of the EM-system.

3.2.8 Helicopter

AS 355 Twin engine, operated by NorCopter AS, Stavanger Norway.

3.3 Performance

The size and location of the survey area can be seen in Figure 1-1. Measurements were performed along north-south lines in an area 13x7 km in size. A second smaller area, selected with the purpose to better resolve possible geological structures in a NE-SW trend, consisted of 36 lines perpendicular to the coast immediately east of the power plant. This area was limited by the following coordinates 1551165E / 6365037N, 1553177E / 6367968N, 1554855E / 6366830N and 1552835E / 6363897N with deviations for the power plant.

The line spacing was 50 metres and nominal flying height 60 metres. Tie-lines were measured for each 500 metres. In the second, smaller area, lines were flown at 100 metre spacing.

Data was collected from September 26th to October 10th. In the period October 5th to October 8th no measurements were made since rain and snow made acquisition impossible. Altogether, 2039 kilometres were surveyed (1,789 kilometres along lines and 178 kilometres along tie-lines in the large area and 72 kilometres along lines in the smaller area).

The survey was performed using the following staff:

Equipment operators:	John Olav Mogaard and Janusz Koziel, NGU
Quality control:	Peter Walker, Geophysical Algorithms, Canada
Pilots:	Frode Belsby and Johan Falkenberg, NorCopter AS

3.4 Base of operation

The base of operations was located at the Oskarshamn airport where flights began and ended and where re-fuelling took place. Fuel was available in permanent fuel tanks on the helicopter landing pad, at a location commonly used for fuelling of helicopters. Location of the helicopter base was: 1541550E / 6358550N (RT90). An on-site processing office was provided by the airport authorities.

A test line was proposed between coordinates 1542160E / 6358800N and 1542160E / 6360300N. The test line was eventually placed between coordinates 1542100E / 6358800N and 1542100E / 6360300N (RT 90) with a length of 1.5 km. The coordinates of a test loop laid across the testline were 1542060–1542140E / 6359720–6359800N.

The base magnetometer was located in a grove of trees to the south of the maintenance hangar at Oskarshamn airport. A second base magnetometer provided by GeoVista AB, was used as a backup. This second magnetometer was located on the edge of a farmer's field several hundred metres east of the airport.

3.5 Activity plan, quality assurance and control

With a few deviations, the measurements at Simpevarp followed the activity plan made specifically for the survey. Quality assurance and control followed the plan prepared for the survey. Deviations were reported according to standard SKB routines (Rutin SD-006, SKB internal controlling document).

4 Tests and calibration

Tests and calibration were performed in three stages: (1) pre mobilization, (2) before, during and after surveying and (3) daily tests.

4.1 Pre mobilization tests

Before the survey started, all instruments were tested and calibrated at the NGU in Trondheim. A pre survey report was delivered to SKB before the survey commenced, and is presented here in Appendix A.

4.2 Tests before, during and after the surveying

According to the activity plan, the following tests and calibrations should be performed before, during (after 10 days of operation) and after the surveying, Table 4-1.

Reports from these tests/calibrations are presented in Appendix B. Due to different events, there are some reported deviations from this plan (see Appendix C and deviation reports).

Table 4-1. Tests before, during and after the surveying.

Method	Test/calibration	Before	During	After
Magnetic	Clover-leaf	X	X	X
	Lag test	X		X
	Base – bird side by side	X		X
ElectroMagnetic	Lag test	X		X
	Phase and calibration	X	X	X
	Temperature drift	X		
Radiometric	Cosmic correction	X		
	Upward-downward relation	X		X
	Altitude attenuation	X		X
GPS navigation	Accuracy test	X		X

4.3 Daily tests

Daily instrument test were mainly performed as described in the activity plan and the NGU quality assurance plan. Deviations are reported directly to SKB according to the standard SKB protocol (Rutin SD-006).

4.4 Quality of data

All magnetic data was collected without any diurnal disturbances giving a very good data quality.

Electromagnetic data had some drift deviations. Profiles with unaccepted drift at the highest frequency (34,133 Hz) were remeasured (line 240 to 350). Minor EM drift deviations at lower frequencies as specified in SKB MD 211.002 were accepted by the SKB representative. In general, EM data can be characterized as good.

Radiometric data was collected within project specifications giving a very good data quality.

Due to safety, there were numerous deviations from flying height specifications (60 ±18 metres), described in the SKB deviation report. Actual flying height can be inspected in data delivery files (RALTM, see Appendix E).

From time to time, strong wind resulted in some deviations from line specifications. In agreement with the SKB representative, no lines were remeasured due to this. Flight paths can be inspected in Map 2002.094-01 (large area) and in Map 2002.094-01–16 (small area).

Minor areas in the northern part of the large area were not measured due to restrictions from landowners.

5 Processing of data

5.1 On-site processing

On-site processing was mainly performed as described in the activity plan. Raw and preliminary processed data was delivered to the SKB representative at the base of operation. Deviations are reported and accepted according to the standard SKB protocol. Processing steps for each method are described in Appendix C.

5.2 Post survey processing

Post survey processing was mainly performed as described in the activity plan. Deviations are reported and accepted in standard SKB manner. Processing steps for each method are described in Appendix C.

6 Results and data delivery

6.1 Digital data

Processed digital data from the survey were delivered on data CD (NGU CD 2002.094-1-3). In agreement with a SKB representative, data is not presented as described in the method description SKB MD 211.002. Data is delivered in seven files; Radiometric data, EM data, NS Magnetic and Magnetic data small area. Production and Test/calibration lines are separated. Data formats (Geosoft XYZ) are described in Appendix D.

The delivered data has been inserted in the database (SICADA) of SKB. The SICADA reference to the present activity is Field note No. 16.

6.2 Geophysical maps

Based on the final processed data (see Appendix C) coloured contour maps were produced using filtering techniques described in Appendix E. The following maps are produced and delivered to SKB, Table 6-1 (digital versions on NGU CD 2002.094-2, see also Appendix E). In Appendix F a pdf. version of the produced and delivered maps is presented.

Table 6-1. Produced and delivered maps to SKB.

Map number	Title	Scale
2002.094-01	Flight Path	1: 20,000
2002.094-02	Magnetic Total Field	1: 20,000
2002.094-03	Magnetic Vertical Derivative	1: 20,000
2002.094-04	EM Resistivity 880 Hz Coplanar	1: 20,000
2002.094-05	EM Stacked Profiles 980 Hz Coaxial	1: 20,000
2002.094-06	EM Resistivity 6606 Hz Coplanar	1: 20,000
2002.094-07	EM Resistivity 7001 Hz Coaxial	1: 20,000
2002.094-08	EM Resistivity 34133 Hz Coplanar	1: 20,000
2002.094-09	Radiometric Total Count	1: 20,000
2002.094-10	Radiometric Potassum	1: 20,000
2002.094-11	Radiometric Uranium	1: 20,000
2002.094-12	Radiometric Thorium	1: 20,000
2002.094-13	Radiometric RGB Composite Map	1: 20,000
2002.094-14	VLF-EM Total In-Line	1: 20,000
2002.094-15	VLF-EM Total Orthogonal	1: 20,000
2002.094-16	Flight Path. Small survey block	1: 10,000
2002.094-17	Magnetic Total Field. Small survey block	1: 10,000
2002.094-18	Magnetic Vertical Derivative. Small survey block	1: 10,000

Due to low signal, no resistivity map for EM 980 Hz Coaxial was produced.

References

/1/ **SKB, 2001.** Platsundersökningar. Undersökningsmetoder och generellt genomförandeprogram. SKB R-01-10, Svensk Kärnbränslehantering AB.

/2/ **SKB, 2001.** Geovetenskapligt program för platsundersökning vid Simpevarp. SKB R-01-44, Svensk Kärnbränslehantering AB.

Appendix A

Pre survey report

Geophysical measurements from helicopter

Forsmark and Simpevarp

Report, pre survey tests

Person responsible:	Jan S. Rønning, NGU
Responsible magnetometers:	Janusz Koziel, NGU
Responsible electromagnetic:	John Olav Mogaard, NGU
Responsible radiometric:	Mark A. Smethurst, NGU
Responsible altimeter:	Norcopter as.

A-1 Introduction

According to activity plans for ”Geophysical measurements from helicopter, Investigations in the Forsmark area” (AP PF 400-02-25), pre survey calibration test of the equipment should be performed and reported. This preliminary report describes tests made at NGU in Trondheim during summer 2002. Calibration of radar altimeter is done by Scandinavian Avionics a/s as per an order from Norcopter. Test and calibration of all instruments were performed according to the manuals.

A-2 Test of Magnetometers

The manuals for the magnetometers describes no test and calibration routines. However, the Scintrex MP-3 proton magnetometers (two of them) have been tested using an external frequency source[1]. Both magntometers responded correctly at the external field.

Scintrex Cs-2 sensor has no test procedure except for running a 4th difference filter. This was done at data from previous surveys, and we found that these data was far out of specifications for the project at Forsmark and Simpevarp. More detailed research documented that the magnetic system does not filter data, and we could document that there is probably an interference between the lowest frequencies at the EM and the magnetometer (see Figure A-1 and Appendix A1). Without disturbances from EM and the magnetic sensor at a fixed location, there is no problem to fulfill the requirement of a 4th difference less than 0.1 nT . To fulfill the requirement in practical work, we need to use a low pass filter before 4th difference is calculated. This low pass filter would simulate the filtered output from other systems.

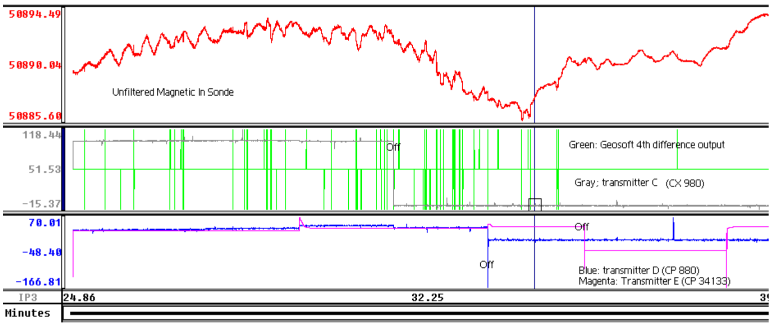


Figure A-1*. Magnetic data recorded at NGU showing that 4th difference less than 0.1 nT is achieved when EM transmitters are turned off.*

[1] Ing. S. Paulsen, Trondheim Norway, Tester for proton magnetometer.

A-3 The Hummingbird HEM system

The Hummingbird HEM system was checked in Bymarka outside of Trondheim by J.O. Mogaard and J. Koziel on August 7, 2002. The checks included phasing and calibration checks in accordance with the manufacturers specifications. The five frequencies were initially phased. Once the phasing checks were done, the amplitudes were then set on each of the in-phase and quadrature channels.

In the phasing and the calibration mode, it is impossible to sample the data, but a printout is possible. Figure A-2 shows how the system is out of phase giving response of the quadrature until the phasing was done. After that time, In phase increases a little bit, while quadrature falls back to zero level. Figure A-3 shows phase test on all frequencies at a time. All In phase components response to the ferrite rod, while all quadratures give no response.

Figure A-4 shows how EM Coplanar 6,606 Hz responds to external and internal Q-coil tests. With external, the response is equal for In phase and quadrature, and the signal showed up to be 65 ppm as expected. (Note that it is impossible to read out the values on the printout, but this seen on the operators screen.) Using the internal Q-coils, the response of In phase and quadrature slightly differs, which is caused by a small irregularity in position of this Q-coil.

The system was then turned on and heated for about one hour and the drift was then monitored for about 4,100 seconds. High frequency noise on all channels was low (within a few ppm, see Figure A-5 a–e), and consistent with the levels one might expect from spheric activity. Drift was good for all channels except on the highest frequency (coplanar 34,133 Hz), where the highest rate was approximately 280 ppm/hour (quadrature). This is attributed to bird warm-up, and the drift rate tends to stabilize on this frequency once thermal equilibrium is reached. The drift on the coplanar 34,133 Hz channels, although high, was linear and therefore would be correctable using normal correction methods. Observed rates of drift after the EM system has been warmed up during a night, tend to be substantially lower, and appear to follow a model that can be described as a thermal relaxation with time constants on the order of 0.02 (inverse) minutes.

A minor step in level at some of the measured parameters between 1,300 seconds and 2,400 seconds are probably caused by a car coming within the influence of the EM system.

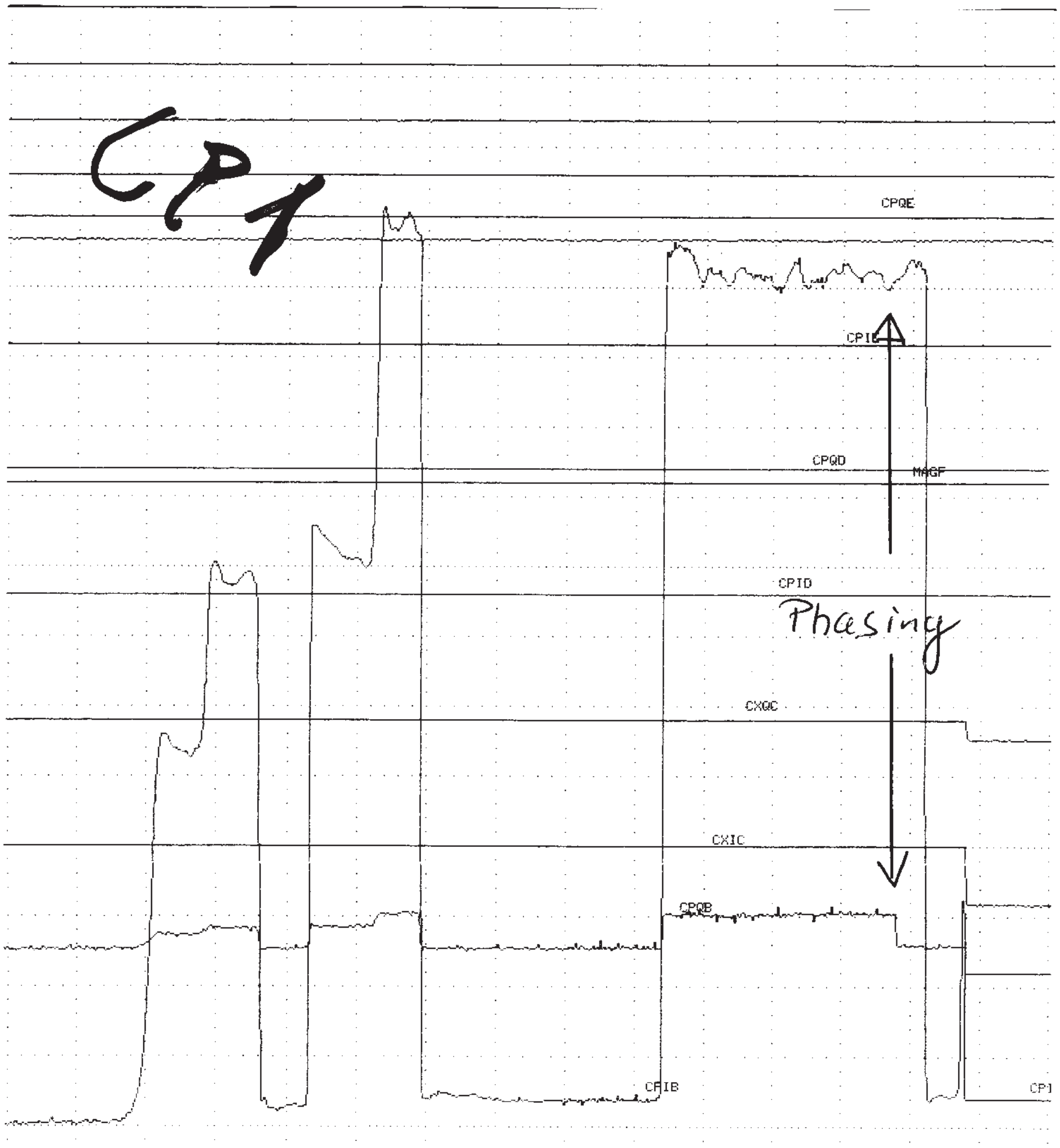


Figure A-2. Example of phase correction on EM Coplanar 6606 Hz.

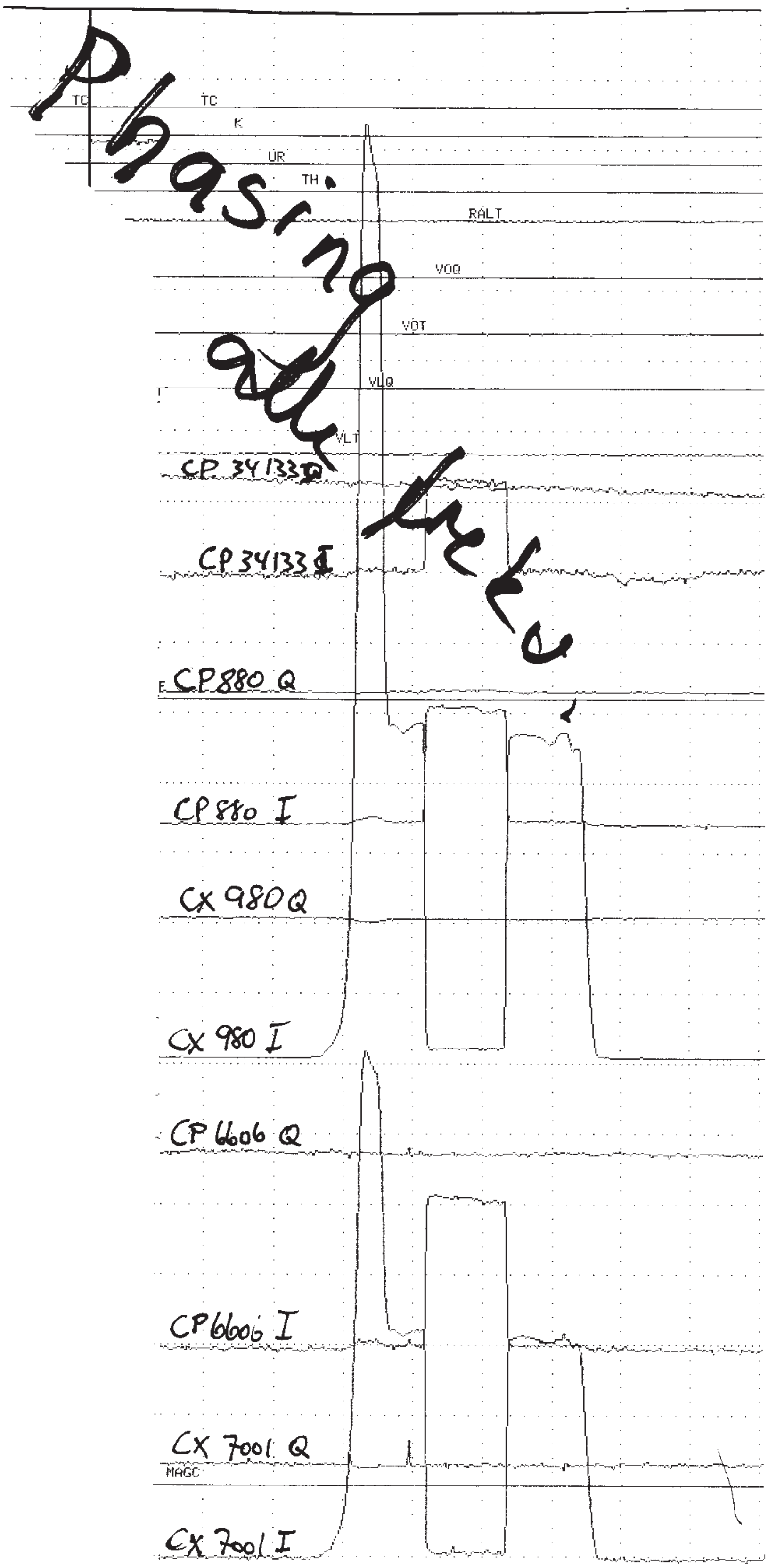


Figure A-3. *Phase test of all frequencies. In phase components give respond to ferrite rod, while all quadratures give no responds.*

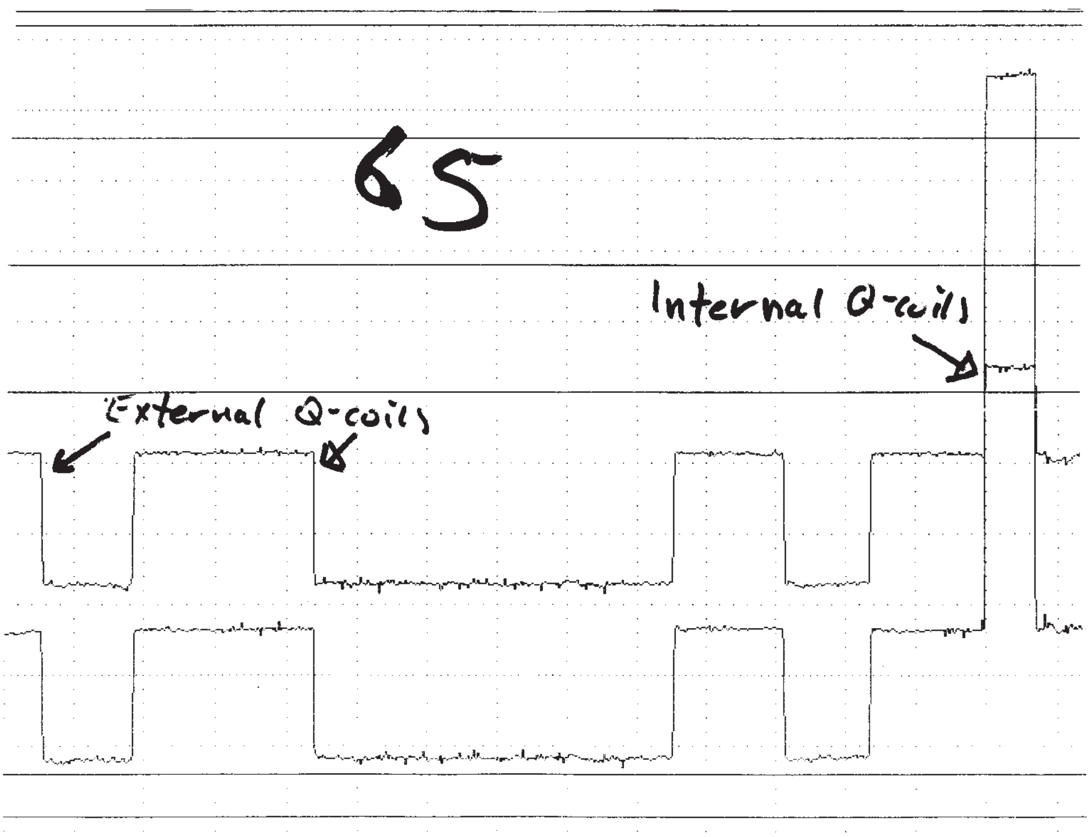
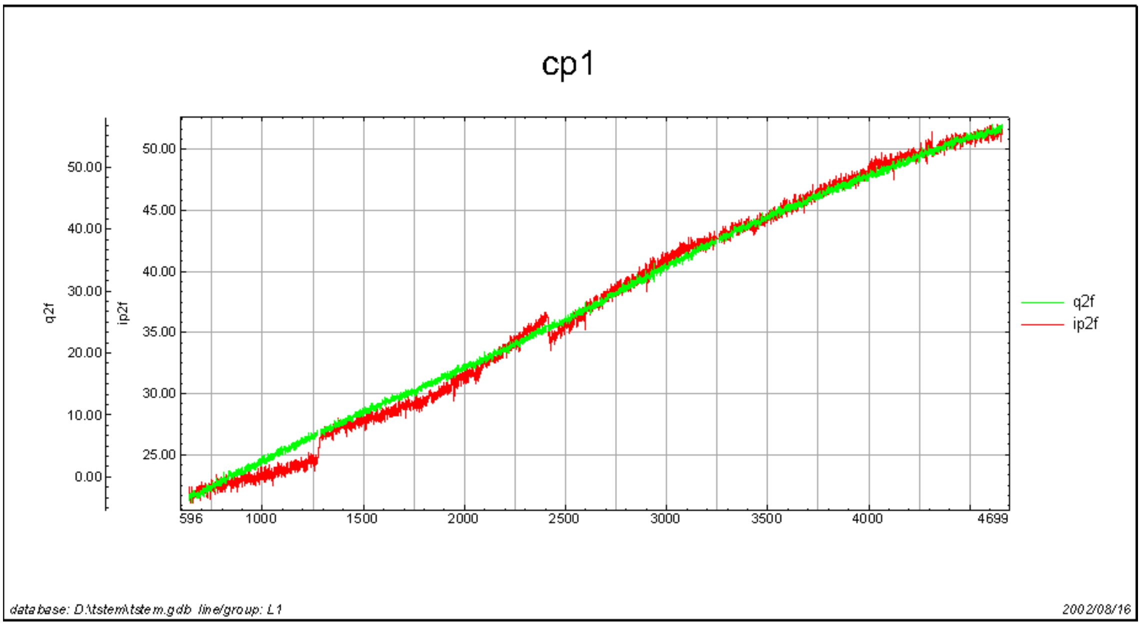


Figure A-4. *External and internal Q-coil test for EM Coplanar 6606 Hz.*



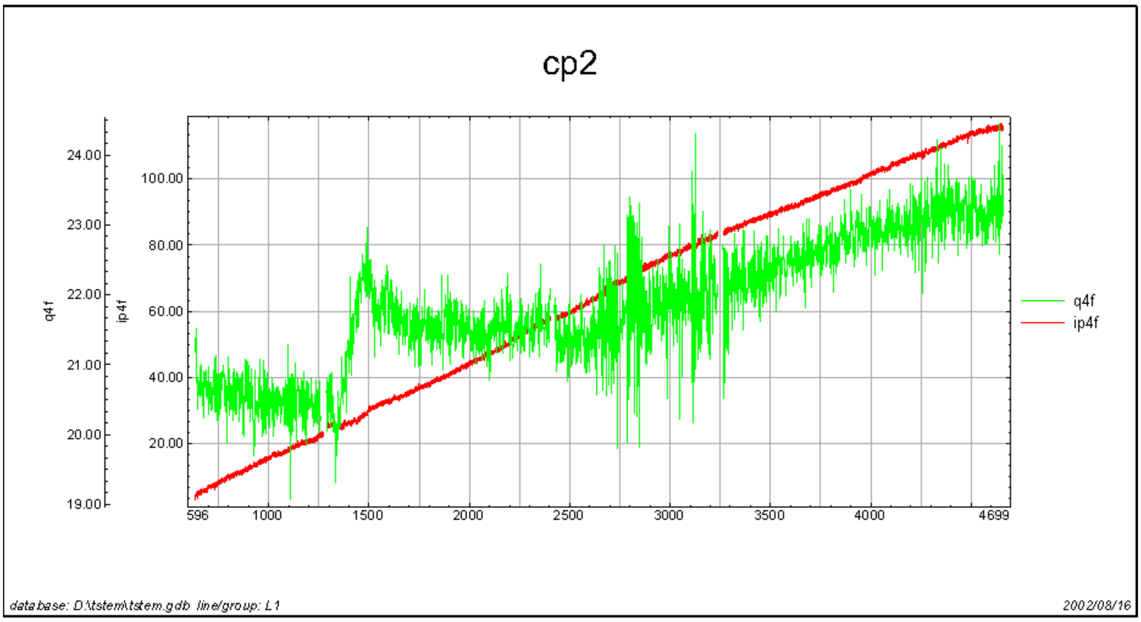
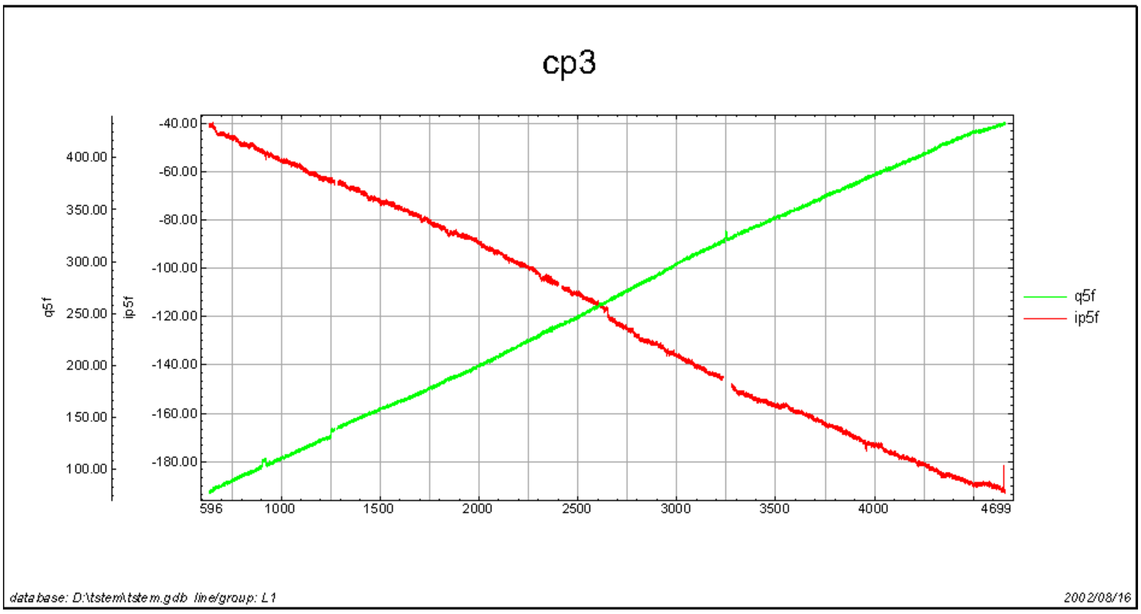


***Figure A-5 a and b**. Drift registration for CP 6606 Hz (CP1) and CP 880 Hz (CP2) (time in seconds).*



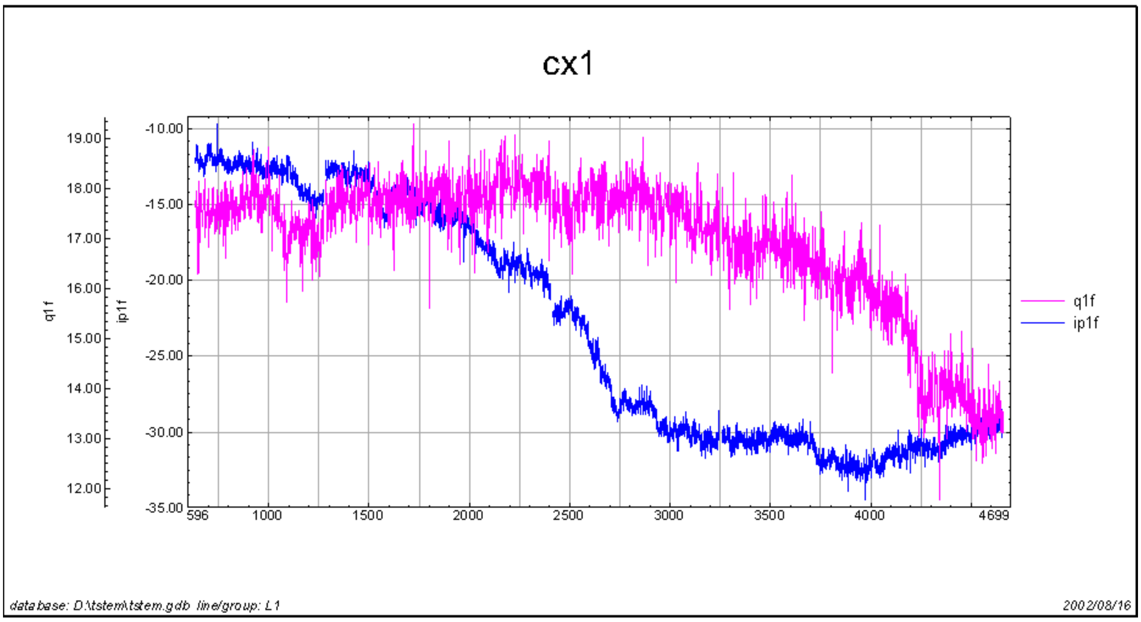


Figure A-5 c and d. *Drift registration for CP 34133 Hz (CP3) and CX 7001 Hz (CX1) (time in seconds).*

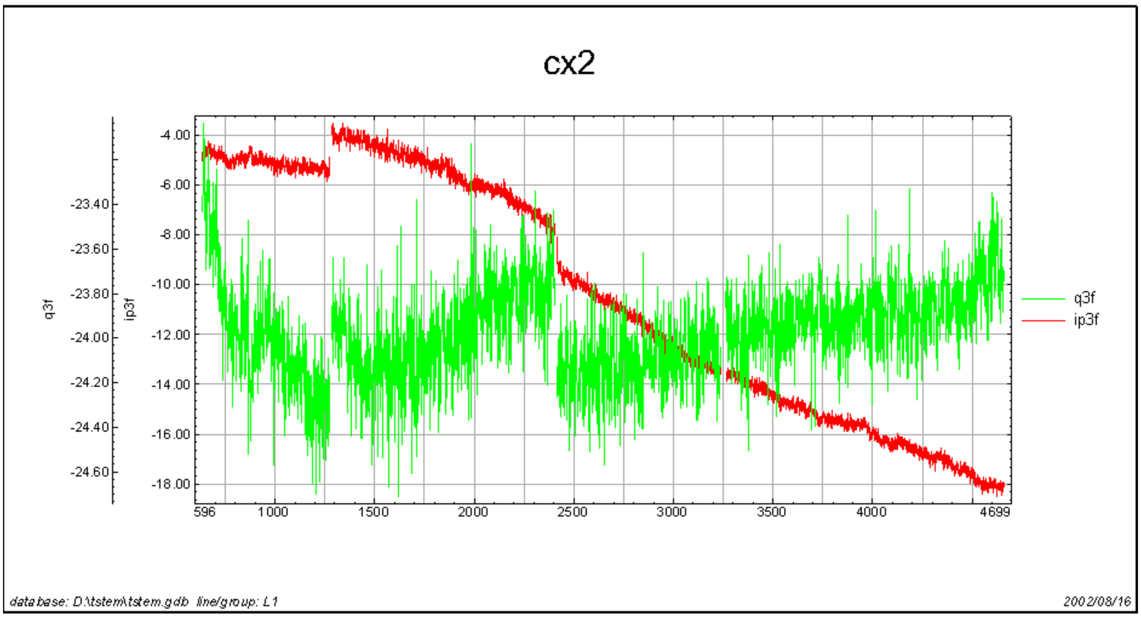


Figure A-5 e. *Drift registration for CX 980 Hz (CX2) (time in seconds).*

A-4 Calibration of the GR820 Gamma Ray Spectrometer (M.A. Smethurst)

Calibration of the gamma ray spectrometer at NGU was done using four portable concrete pads to determine the stripping coefficients and sensitivity conversion from counts to apparent element concentrations. The procedure for determining these coefficients is described below.

A-4-1 Description of calibration pads:

The NGU utilizes four concrete calibration pads measuring 1 m x 1 m x 30 cm each. The pads consist of a background pad, and pads containing known quantities of K-40, U-238 and Th-232. The pads produce approximately 85% of the count rate obtained from infinite sources and geometric corrections can be applied to the measurement data to simulate infinite sources. Detailed descriptions of the pads and their mode of use are offered by the manufacturer W. Grasty in the document "Transportable Calibration Pads for Portable Gamma-ray Spectrometers" (available upon request form the NGU).

Measurements are made on the pads in an area of ground that is flat and relatively homogeneous in its radioactivity. Our current practice is to use one of the parking lots at the NGU, emptied of cars. A mark is made on the ground where measurements are to take place. All pads are placed at least 30 metres away from this mark. First the background pad is placed on the mark and the gamma ray detector placed centrally and orthogonal on it. A measurement of the pad is made over approximately 10 minutes, sometimes more. The background pad is then removed and the K-40 pad placed on the mark. The detector is placed on the K-40 pad and a 10-minute measurement is made. The background pad is then re-introduced and measured, followed by the U-238 pad, the background pad again, and finally the Th-232 pad.

All measurements are stored digitally in full-spectrum and window count rate forms. Window count rates for the K, U and Th pads are background corrected using measurements on the background pad made immediately before. Geometric corrections to simulate infinite sources are then applied and stripping factors determined. Source sensitivities for K, U and Th are calculated given the known concentrations of radioisotopes in the calibration pads. Also FWHM (full width half maximum) values for the K (1.46 MeV), U (Bi-214 1.76 MeV) and Th (Tl-208 2.63 MeV) photo-peaks, are determined from background corrected full spectrum data.

This document summarises the measurement data and derived calibration values for the calibration experiment carried out 07.05.2002 using the NGU's GR820 gamma ray spectrometer and detector with steel mounting for attachment to the underside of a helicopter.

A-4-2 Spectrometer coefficients

Altitude attenuation coefficients for K, U and Th Channels, cosmic stripping and aircraft background coefficients will be computed from measurements made on site following procedures outlined by the IAEA. Airborne radon stripping coefficients a_u, a_k and a_t will be computed from data acquired during the surveys from those line segments over water, as variations in atmospheric radon concentration are necessary to properly derive these data, and such variations can only be expected to occur over a period of several days.

Calibration work carried out:

Date:	07.05.02	
By:	M.A. Smethurst & J.O. Mogaard	
Instrument:	GR820	
Pad placement:	NGU parking lot near delivery bay – pad position marked	
Instrument placement:	Central and orthogonal on top of pad, contacts facing south	
Measurement chronology:	1) Background pad 11:25	1525 seconds
	2) Background pad 11:40	773 seconds
	3) U-238 pad	756 seconds
	4) Background pad 12:20	715 seconds
	5) K-40 pad	743 seconds
	6) Background pad 12:55	527 seconds
	7) Th-232 pad	637 seconds

Properties of the NGU calibration pads.

Pad	Concentration	Unit	Pad density g/cm3	Geometric factor to infinite source
K-40	6.64	%	2.13	1.16
U-238	52.35	ppm	2.2	1.17
Th-232	107.72	ppm	2.3	1.19

Background corrected window values on the pads (counts per second).

Pad	K-40 window	U-238 window	Th-232 window	Cs-137 window
K-40	775.67	0.00	0.00	192.38
U-238	393.66	515.35	36.39	1059.28
Th-232	263.82	156.24	513.57	735.89

Stripping factors.

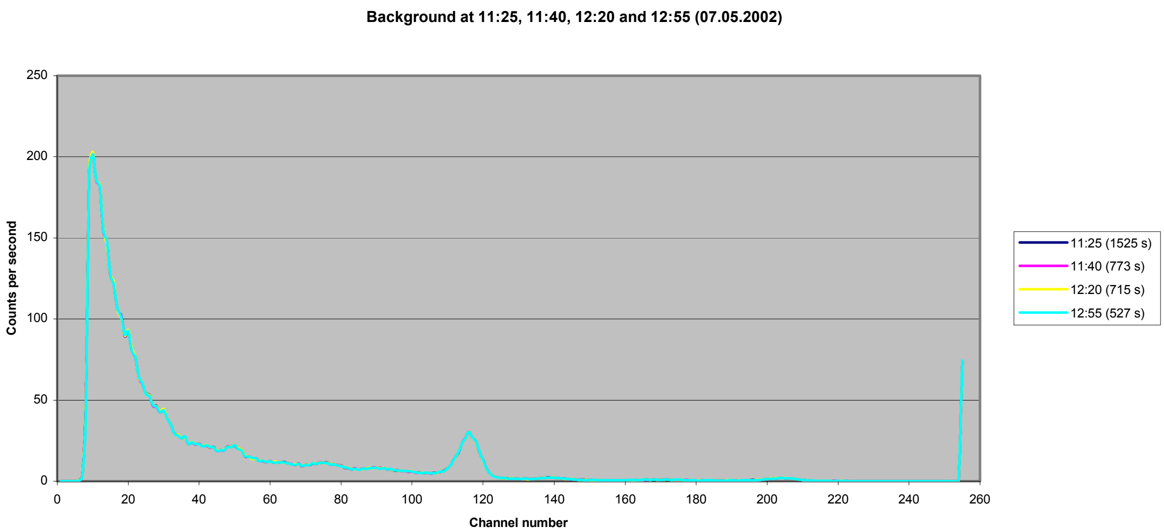
Alpha	0.3042
Beta	0.5137
Gamma	0.7639
a	0.0706
b	0.0000
g	0.0000
K into Cs-137	0.2480
U into Cs-137	2.0555
Th into Cs-137	1.4329

Conversions to concentrations.

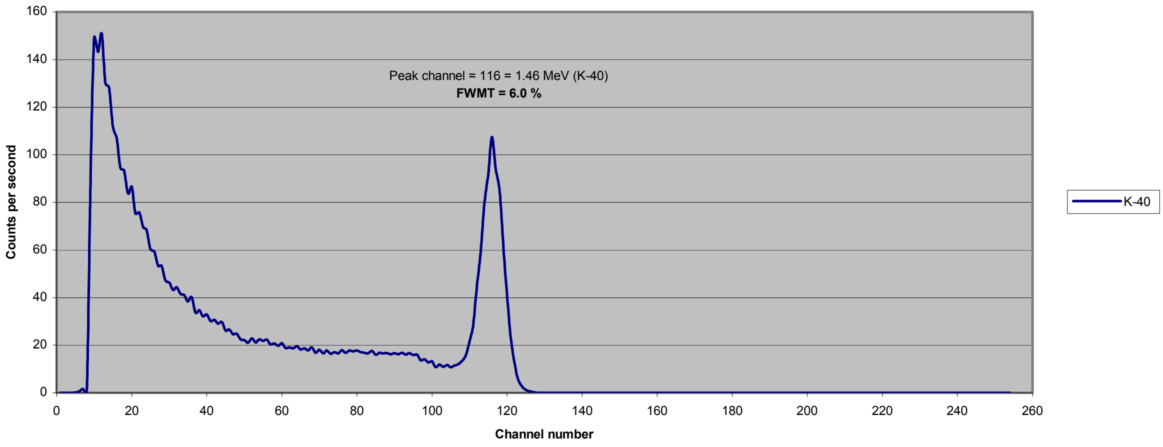
Sensitivities	Factor	Unit
K-40	0.00738	percent/cps
U-238	0.08682	Ppm/cps
Th-232	0.17626	Ppm/cps

FWHM Full width at half maximum (%).

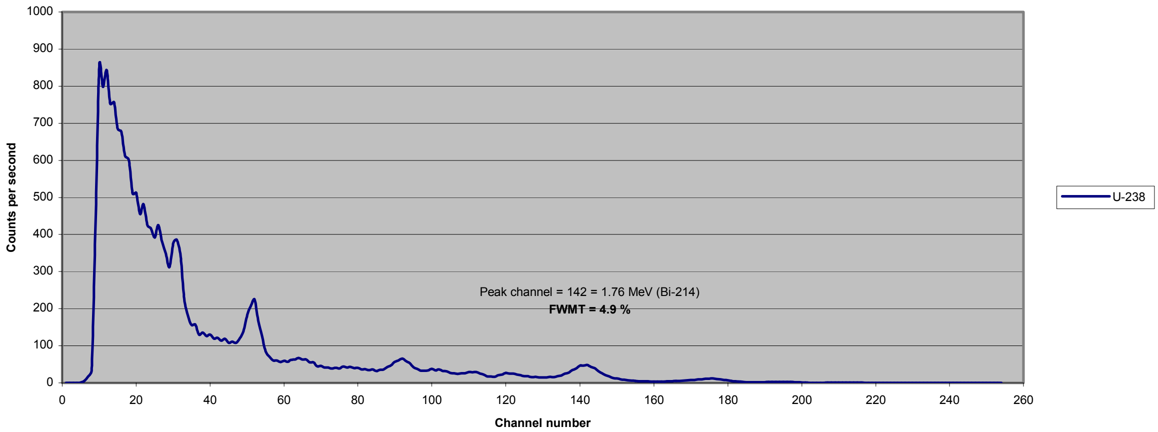
K-40 1.46 MeV	6.0
U-238 1.76 MeV	4.9
Th-232 2.63 MeV	4.6



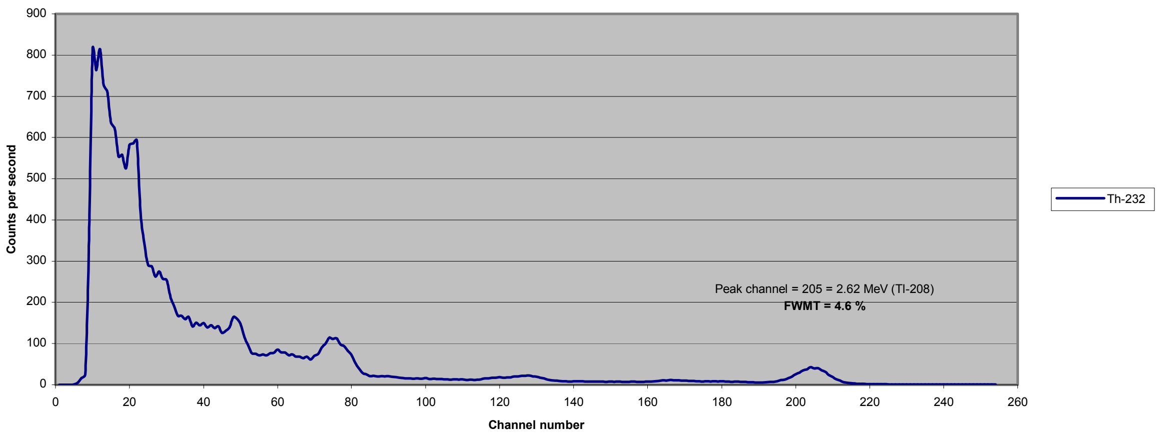
K-40 (743 s) measured after and corrected for background 12:20 (715 s)
07.05.2002



U-238 (756 s) measured after and corrected for background 09:36 (773 s)
07.05.2002



Th-232 (637 s) measured after and corrected for background 12:55 (527 s)
07.05.2002



A-5 Calibration of altimeter, Bendix / King KRA 405B

The altimeter (Bendix / King KRA 405B) was calibrated by Scandinavian Avionics as. Results from tests are shown in Appendix A2. The report confirms that output voltage on AUX_OUT_2 (the output signal which is used by NGUs logging system) is 0.4 V/100 feet as described in manual.

Appendix A1

Mail from Peter Walker (NGU) to Søren Byström (SGU)

Testing of the effect of the EM transmitters on the magnetometer

Dear Søren,

This afternoon we set out the EM sonde at NGU and let the EM system warm up for about an hour. Then we turned off the EM transmitters one by one until no transmitter was on. We then briefly turned on the high frequency EM transmitter.

We recorded the magnetic field from the sensor in the EM sonde and computed the 4th difference. We note a gradual increase in 4th difference noise, followed by a general decrease when the lower frequency EM channel are turned off. The lower frequency transmitters would be expected to have the highest NIA, and there fore cause the largest magnetic field of all the transmitters on board.

The transmitters were turned off at 2 minute intervals.

The manual for the magnetic sensor states that an AC field in the presence of the magnetometer, and orthogonal to the static field, will cause an anomalous reading. I have so far been unable to find a specification for the NIA of the transmitters and so have not been able to calculate the AC field strengths involved.

The data are attached. My number at NGU is 47 73 90 4405.

Please feel free to contact me if you have any comments or suggestions.

Regards,

Peter Walker

Appendix A2

Calibration report for Bendix/King KRA 405 B Radar altimeter

16.AUG.2002 11: 9:14 FAX +45 NORCOPTER AS SCAN-AVIONICS NO.505 P.1/4 001/004

+45 79508099

TELEFAX MESSAGE

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TO:	Norcopter	FROM:	Torben Hyrm
ATTN:	Karl Arvid Andersen/Tor Stenberg	OUR REF:	2012596
YOUR REF:	026	DATE:	2002.08.15
SUBJECT:	Calibration of Radar Altimeter	PAGES:	1 of 4

I hereby send a copy of the calibration report for the Radar Altimeter KRA405B S/N 2285

Torben Hyrm
th@scanav.com

KOPI: JAN S. RØNNING

m VH

G. Stenberg

AlliedSignal
BENDIX/KING COMPONENT MAINTENANCE MANUAL
KRA 405B RADAR ALTIMETER

CALIBRATION REPORT

RADAR ALTIMETER:
P/N: 066-01153-0101
S/N: 2285 WITH INDICATOR S/N 3610
KNI 416.

Altitude (ft)	Altitude_ Test_ Input(v)	Ana_Alt_1/ Aux_Out_1	Aux_Out_2 (-0101)	Aux_Out_2 (-0202)	Pre_Equ_Out
0	0.000	0.400	0.000	0.400	0.000
10	0.100	0.600	-0.040	0.600	-0.100
20	0.200	0.800	-0.080	0.800	-0.200
30	0.300	1.000	-0.120	1.000	-0.300
40	0.400	1.200	-0.160	1.200	-0.400
50	0.500	1.400	-0.200	1.400	-0.500
60	0.600	1.600	-0.240	1.600	-0.600
70	0.700	1.800	-0.280	1.800	-0.700
80	0.800	2.000	-0.320	2.000	-0.800
90	0.900	2.200	-0.360	2.200	-0.900
100	1.000	2.400	-0.400	2.400	-1.000
110	1.100	2.600	-0.440	2.600	-1.100
120	1.200	2.800	-0.480	2.800	-1.200
130	1.300	3.000	-0.520	3.000	-1.300
140	1.400	3.200	-0.560	3.200	-1.400
150	1.500	3.400	-0.600	3.400	-1.500
160	1.600	3.600	-0.640	3.600	-1.600
170	1.700	3.800	-0.680	3.800	-1.700
180	1.800	4.000	-0.720	4.000	-1.800
190	1.900	4.200	-0.760	4.200	-1.900
200	2.000	4.400	-0.800	4.400	-2.000
210	2.100	4.600	-0.840	4.600	-2.100
220	2.200	4.800	-0.880	4.800	-2.200

NOT USED

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BENDIX/KING COMPONENT MAINTENANCE MANUAL
KRA 405B RADAR ALTIMETER

Altitude (ft)	Altitude_ Test_ Input(v)	Ana_Alt_1/ Aux_Out_1	Aux_Out_2 (-0101)	Aux_Out_2 (-0202)	Pre_Equ_Out
240	2.400	5.200	-0.960	5.200	-2.400
250	2.500	5.400	-1.000	5.400	-2.500
260	2.600	5.600	-1.040	5.600	-2.600
270	2.700	5.800	-1.080	5.800	-2.700
280	2.800	6.000	-1.120	6.000	-2.800
290	2.900	6.200	-1.160	6.200	-2.900
300	3.000	6.400	-1.200	6.400	-3.000
310	3.100	6.600	-1.240	6.600	-3.100
320	3.200	6.800	-1.280	6.800	-3.200
330	3.300	7.000	-1.320	7.000	-3.300
340	3.400	7.200	-1.360	7.200	-3.400
350	3.500	7.400	-1.400	7.400	-3.500
360	3.600	7.600	-1.440	7.600	-3.600
370	3.700	7.800	-1.480	7.800	-3.700
380	3.800	8.000	-1.520	8.000	-3.800
390	3.900	8.200	-1.560	8.200	-3.900
400	4.000	8.400	-1.600	8.400	-4.000
410	4.100	8.600	-1.640	8.600	-4.100
420	4.200	8.800	-1.680	8.800	-4.200
430	4.300	9.000	-1.720	9.000	-4.300
440	4.400	9.200	-1.760	9.200	-4.400
450	4.500	9.400	-1.800	9.400	-4.500
460	4.600	9.600	-1.840	9.600	-4.600
470	4.700	9.800	-1.880	9.800	-4.700
480	4.800	10.000	-1.920	10.000	-4.800
490	4.900	10.200	-1.960	10.198	-4.900
500	5.000	10.400	-2.000	10.392	-5.000
600	6.000	10.700	-2.400	12.151	-6.000
700	7.000	11.000	-2.800	13.646	-7.000
800	8.000	11.300	-3.200	14.947	-8.000
900	9.000	11.600	-3.600	16.098	-9.000

NOT USED

AlliedSignal
BENDIX/KING COMPONENT MAINTENANCE MANUAL
KRA 405B RADAR ALTIMETER

Altitude (ft)	Altitude_ Test_ Input(v)	Ana_Alt_1/ Aux_Out_1	Aux_Out_2 (-0101)	Aux_Out_2 (-0202)	Pre_Equ_Out
1000	10.000	11.900	-4.000	17.129	-10.000
1100	11.000	12.200	-4.400	18.065	-11.000
1200	12.000	12.500	-4.800	18.920	-12.000
1300	13.000	12.800	-5.200	19.70[illegible]	-13.000
1400	14.000	13.100	-5.600	20.43[illegible]	-14.000
1500	15.000	13.400	-6.000	21.11[illegible]	-15.000
1600	16.000	13.700	-6.400	21.75[illegible]	-16.000
1700	17.000	14.000	-6.800	22.355	-17.000
1800	18.000	14.300	-7.200	22.92[illegible]	-18.000
1900	19.000	14.600	-7.600	23.45[illegible]	-19.000
2000	20.000	14.900	-8.000	23.962	-20.000
2100	21.000	15.200	-8.400	24.446	-21.000
2200	22.000	15.500	-8.800	24.907	-22.000
2300	23.000	15.800	-9.200	25.347	-23.000
2400	24.000	16.100	-9.600	25.769	-24.000
2500	25.000	16.400	-10.000	26.174	-25.000

Altitude vs. Precision Output Voltages
Table 101, Sheet 3

Appendix B

Simpevarp Quality Control Tests

B-1 Introduction

This document reports the various methodologies used to calibrate and measure the various instrument parameters required to accurately process integrated helicopter survey data.

Results of the various tests at Simpevarp are reported herein, and where necessary, results from the Forsmark tests are quoted.

The quoted Forsmark tests were conducted at Forsmark prior to mobilization to Simpevarp and are equally applicable to the Simpevarp data.

B-2 Magnetometer

B-2-1 Mag Cloverleaf:

The magnetic cloverleaf test is carried out to determine the heading correction that should be applied to the magnetic field data acquired by an aircraft. The procedure is to acquire magnetic data along intersecting, orthogonal profiles, each of which are repeated in opposite directions. Two magnetic cloverleaf tests were done at Simpevarp, both over the magnetic low at 1545000 E and 6367000 N (RT90). This anomaly was chosen because is was large enough to be laterally uniform within the positioning tolerances of the aircraft, thus minimizing the possibility of a heading error being derived as a result of positioning error.

Ideally, magnetic heading errors should be determined over sedimentary basins, where the magnetic gradients are low. Unfortunately, Simpevarp is located in a magnetically active area, and cloverleaf tests are affected by the presence of these gradients.

The first cloverleaf test was done at the beginning of the survey during flight 1 at 2,000 feet altitude. The 2,000-foot altitude was chosen in an attempt to minimize errors in the cloverleaf test due to positioning and altitude variations along the 4 profiles, Table B-1.

Table B-1. Flight 1 Cloverleaf.

Line	Magnetic data (nT)	E RT90	N RT90	Radar altitude (m)
5001 S-N	50481.90	1545016	6366980	380.76 clipped
5002 N-S	50482.54	1545017	6366966	380.94 clipped
5003 W-E	50486.27	1544950	6367004	380.76 clipped
5004 E-W	50478.92	1544900	6367005	380.76 clipped

Unfortunately, these flight 1 results are compromised because of noise on the base magnetometer, subsequently determined to be due to the area lighting at Oskarshamns airport. Additionally, the radar altimeter response was clipped at 5 volts, or 1,250 feet, making it impossible to confirm the altitudes during each of the segments of the cloverleaf was sufficiently precise.

Accordingly, the cloverleaf was reflown at the end of the survey during flight 20 using a 1,200 feet altitude so as to have radar altimeter data available. The results are below (Table B-2), using a filter on the basemag of 18 seconds/unfiltered basemag.

Little difference occurs as a result of filtering the basemag. Results comparing the two cloverleaf test data sets indicate a difference of 100 gammas vertically over 800 feet, or +1/8 gamma per foot or +0.4 gamma /metre. Thus 1.6 gammas should be added to the results for line 5005 in comparison to 5006, and to line 5008 in comparison to line 5007. Accordingly, the data corrected for altitude are as shown in Table B-3.

While there is apparently a 5 gamma heading difference in the magnetic heading from west to east compared with east to west, the heading difference between north to south and south to north is 1.5 gamma. This difference could easily be accounted for by radar altimeter differences, as it amounts to an elevation difference of 3 metres.

Since the lines flown at Simpevarp are north-south, no magnetic heading correction was applied to the data.

Table B-2. Flight 20 Cloverleaf.

Line	Magnetic Data (nT)	E RT90	N RT90	Radar altitude (m)
5005 S-N	50377.35 / 50377.68	1545005	6366953	370.76
5006 N-S	50380.53 / 50380.47	1545000	6366954	374.97
5007 E-W	50381.52 / 50381.89	1544973	6367001	364.94
5008 W-E	50375.08 / 50374.39	1544960	6367006	360.56

Table B-3. Flight 20 Cloverleaf corrected for altitude.

Line	Magnetic Data (nT)	X(E) RT90	Y(N) RT90	Radar altitude (m)
5005 S-N	50379.0	1545005	6366953	370.76 Corrected
5006 N-S	50380.5	1545000	6366954	374.97
5007 E-W	50381.5	1544973	6367001	364.94
5008 W-E	50376.5	1544960	6367006	360.56 Corrected

B-2-2 Magnetic Lag

The magnetic lag test is done to determine the time delay of the magnetic data logged on the data system in comparison to the corresponding navigational data. These differences can be due to the time differences required to acquire the data, or can be caused by the difference in locations of the various sensors. In a helicopter system using the configuration adopted by the NGU, with the GPS sensor on the tail of the helicopter, and the magnetic sensor in the EM sonde, the lag will be a function of flying speed, where higher speeds cause increased lag since air drag causes to sonde to "ride" farther behind the helicopter.

The initial magnetic lag test line was selected from a gridded magnetic data set supplied by the SGU. Magnetic lag was tested over a large magnetic gradient by taking the second derivative (Geosoft 1st derivative is offset, and not useful for lag). Data is found on lines 5100 and 5101. Lag was determined to be 0.2 seconds. However, this lag test was not very satisfactory, as it was difficult to precisely align the anomalies to accurately measure the time difference over the same feature.

One of the difficulties with a lag tests is that a sharp anomaly is required, and gridded data sets are not always suitable of this. It was noted in the course of processing the data that a stone pile (the result of Äspö tunnel excavation) north of Simpevarp nuclear plant provided such an anomaly. The lag was measured on Flight 19 and was determined to be 0.45 seconds. The results are presented below (Figure B-1), and can be viewed in lines 5100 and 5101 in the Flight 19 data.

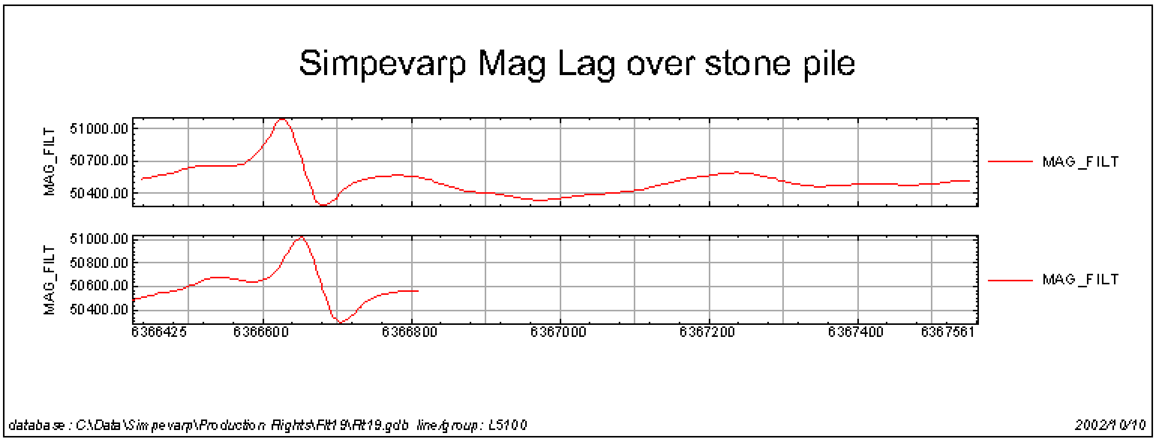


Figure B-1. Control of magnetic lag over a stone pile.

B-2-3 Base station/bird magnetometer comparison:

The base station (proton) and bird magnetometer (cesium) were compared during the spectrometer calibration lines at Forsmark. The base station exhibited some spikes and some excursions of 4–6 seconds in duration. This may be related to the EM noise seen on this flight.

It should be noted that the various proton magnetometers used in the project exhibit similar behaviour. As such, this behaviour is attributed to the electrical environment in which the magnetometers were located.

To make the comparison, the base magnetometer data was loaded into the database and subtracted from the bird magnetometer to yield a MAG_BASE_DIFF channel. The base magnetometer was located some 50 metres from the bird, resulting in a difference of approximately 50 gamma in level. Sections of lines 3000, 3001, 3002 and 3003 were selected and Geosoft statistics computed for them (see Table B-4). The selected areas of the line were without the excursions.

4th Difference after 5-point filtering and spike removal:

Processing using the Geosoft QC software of test flight 3 was shown to Peter Hagthorpe and was deemed to be acceptable at Forsmark.

B-2-4 Base Station High Pass RMS Error:

In accordance with procedure outlined by Peter Hagthorpe, the base magnetometer was high pass filtered with a cutoff of 3 seconds (30 fids) at Forsmark. The results, for sections of the data unaffected by 4–6 second excursions and spikes are summarized below (Table B-5). These deviations were deemed to be acceptable (under 0.3 nT).

Table B-4. Base magnetometer – bird magnetometer comparison (nT).

Line	Min Difference	Max Difference	Av. Difference	Deviation
3001	–53.7	–52.0	–52.6	.30
3001	–53.4	–51.4	–52.5	.53
3000	–55.1	–51.7	–52.7	.54
3000	–53.7	–51.7	–52.6	.44
3003	–53.2	–51.8	–52.6	.35
3002	–53.6	–52.1	–52.7	.35

Table B-5. Base magnetometer high pass filter results (gammas).

Line	Minimum	Maximum	Average	Deviation
3001	–2.2	1.2	0.0	0.24
3001	–.2	.2	0.0	0.06
3000	–.1	.3	0.0	0.07
3000	–.1	.1	0.0	0.04
3003	–.1	.1	0.0	0.03
3002	–.2	.1	0.0	0.04

B-3 EM System

B-3-1 EM Lag:

EM Lag occurs for the same reason the magnetic lag occurs. The EM lag test completed on test line data from Oct 3 Flight 16 lines 4201, 4202, 4203 indicates a lag of 0.5 second. See results presented below (Figure B-2). (Note that lag can change with air speed as the bird follows at different distances behind the helicopter.)

B-3-2 EM Calibration:

EM calibration was checked at the beginning of the survey and was found to be consistent with the Forsmark calibration, Table B-6. EM calibration is really controlled by the manufacturer, and must be set using the on-board software functions supplied with the system.

B-3-3 EM Test line, temperature drift:

The test line, located to the east of Oskarshamns airport, was set out with a loop approximately 80 metres square laid across it. This test line was flown at the beginning of the Simpevarp survey, but results were spoiled by a number of electric fences parallel to and crossing the line. The line was reflown at the end of the survey 5 times with the power to the fences turned off. Results are recorded in Flight 19, lines 119001–119005. Results from four lines are plotted in the figures below of the same name (Figure B-3).

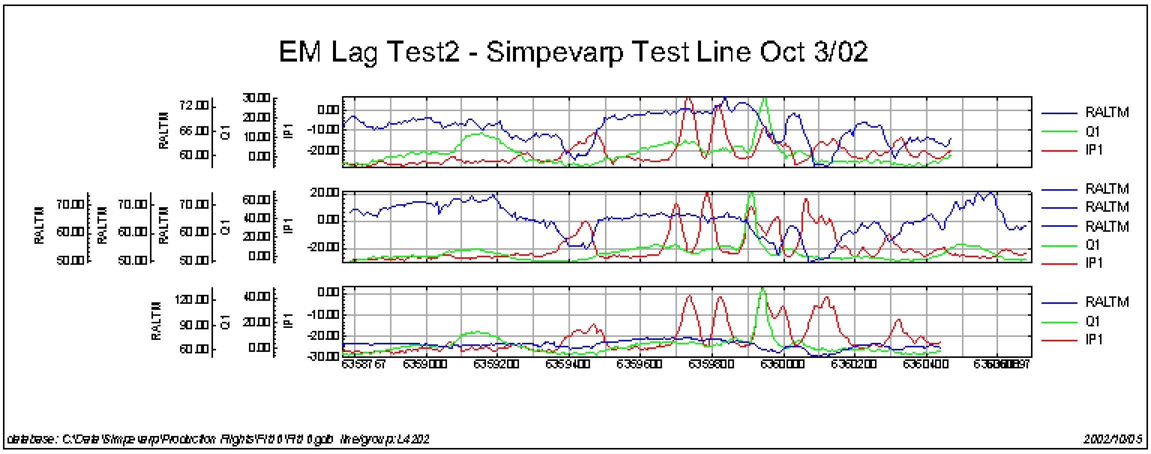


Figure B-2. EM lag test at Simpevarp, 7,001 Hz Coaxial.

Table B-6. Post survey calibration is recorded in flight 18, line 500000. Deflection results in ppm are:

IP1	Qd1	IP2	Qd2	Ip3	Qdd3	Ip4	Qd4	Ip5	Qd5
14.2	134.2	61.4	64.3	117	146	76.7	80	71.7	23.7

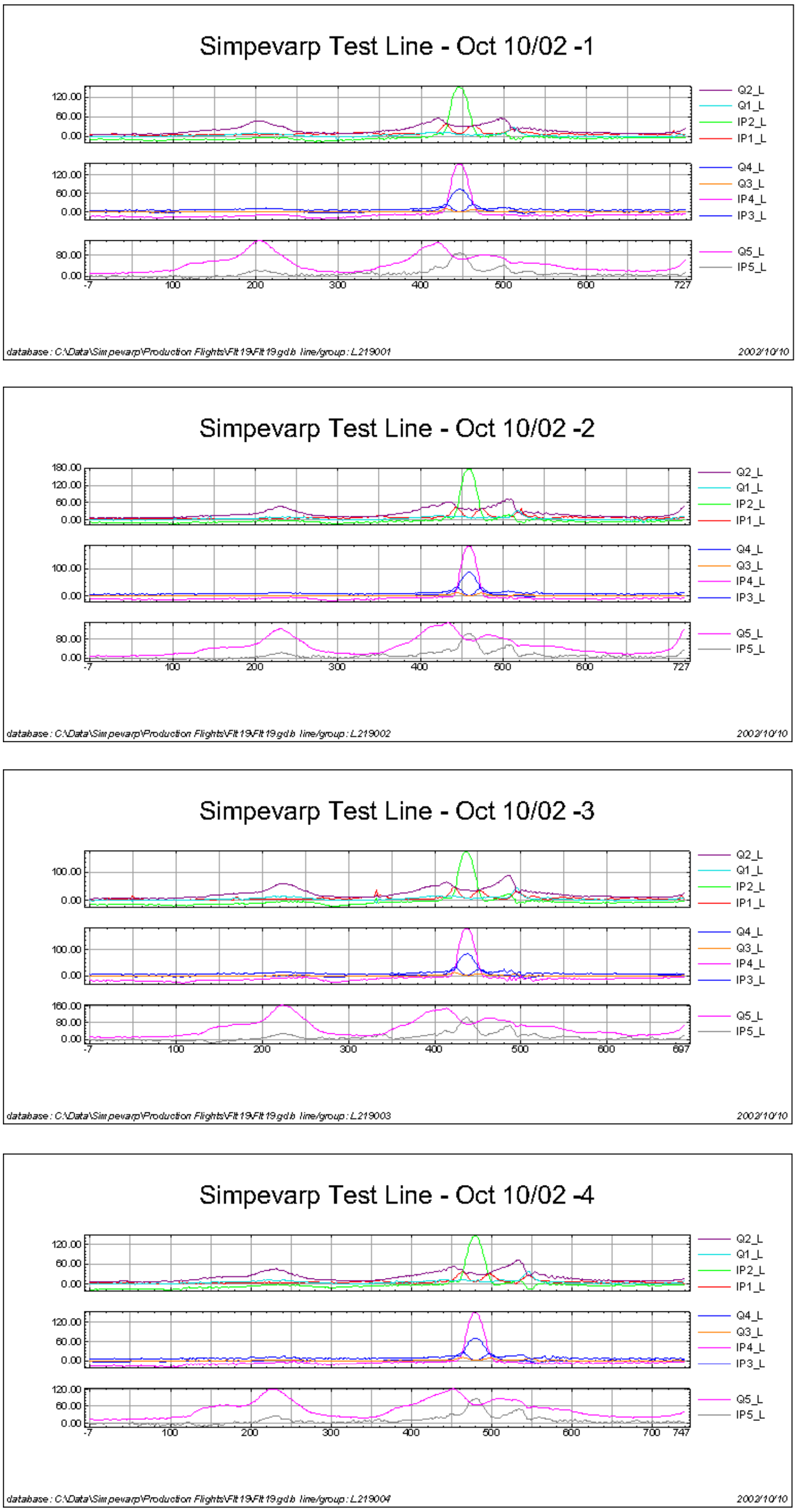


Figure B-3. *Repeated EM measurements at the Simpevarp testline.*

B-4 GPS accuracy test.

A reference GPS location was marked with red paint on the grass. Each Line in Table B-7 represents a sample of approximately 60 seconds taken during spectrometer sample checks prior to flight 1. Confirmation of these data is to be arranged by GeoVista.

Test data from Forsmark is as follows and were approved by Hans Thunehed of GeoVista, Table B-8.

B-5 Radar altimeter

The radar altimeter was calibrated prior to the Forsmark survey by Norcopter, the helicopter service company used in the Simpevarp survey (see Appendix A). The radar was checked using a hover test hovering with the EM tow cable at full length during the Forsmark survey and was found to be consistent with a tow cable length of 30 metres.

B-6 Gamma ray spectrometer tests

The spectrometer was configured to generate the following windowed channels:

U	132–148	1660kev – 1860kev
Th	189–220	2410kev – 2810kev
K	109–125	1370kev – 1570kev
TC	34–220	410kev – 2810kev

Table B-7. Simpevarp GPS Check.

Line	WGS84E/StdDev	WGS84N/StdDev	RT90E/StdDev	RT90N/StdDev
301001	590022.65/.05	6357439.28/.08	1541589.40/.05	6358571.51/.08
301002	590022.85/.05	6357439.69/.03	1541589.61/.05	6358571.91/.03
301003	590022.95/.05	6357439.63/.05	1541589.71/.05	6358571.85/.04
301004	590022.90/.03	6357439.55/.05	1541589.65/.03	6358571.77/.05

Table B-8. Forsmark GPS Check.

Channel	Minimum	Maximum	Mean	Standard Deviation
E_RT90	1634444.9	1634449.3	1634447.8	1.01
N_RT90	6697752.5	6697758.1	6697755.3	1.34

Stripping factors:

The stripping factors were determined by Mark Smethurst and John Mogaard at the NGU and are as follows (see Appendix A):

Alpha	0.3042	(Th–> U)	Beta	0.5137	(Th–> K)
Gamma	0.7639	(U–> K)	a	0.0706	(U–>Th)
b	0.0000	(K–>Th)	g	0.0000	(K–> U)

Sensitivity factors:

The pad sensitivity factors were determined by Mark Smethurst and John Mogaard at the NGU and are as follows (see Appendix A):

K-40	0.00738 %/cps
U-238	0.08682 ppm/cps
Th-232	0.17626 ppm/cps

The pad sensitivity factors must be corrected to the nominal survey altitude of 60 metres.

Full width at half maximum:

The FWHM coefficients were determined by Mark Smethurst and John Mogaard at the NGU and are as follows (see Appendix A):

K-40	6.0%	Accepted value	6%
U-238	4.9%	Accepted value	6%
Th-232	4.6%	Accepted value	6%

The spectral data from line 3004, test flight 2, on Aug 22 were loaded into an Excel spreadsheet (Thorium-line3004- test flight.xls). The counts in the thorium window were summed and the resulting peak at channel 205 had half maximum (determined from inspection) at approximately channels 199.5 and 209.5, a span of 10 channels, or a FWHM of approximately 4.9%. This is close to the 4.6% figure quoted by Smethurst and Mogaard and under the 6% tolerance.

B-6-1 Cosmic correction:

The cosmic stripping coefficients were computed from a cosmic background flight over the Baltic Sea about 3–10 kilometers east of the Forsmark nuclear plant. The cosmic flight data is recorded as Test1 in the flight reports, and consisted of a series of 10 minute lines flown at 4,500, 5,500, 7,000, 8,500, 9,500 and 10,500 feet, Figure B-4. The data at each elevation was corrected for deadtime (except the Uranium window from the upward looking detector) and averaged using Geosoft's averaging software. Results are as follows, with the results in brackets being given as typical by the IAEA, Table B-9.

Table B-9. Aircraft background and cosmic stripping coefficients.

U down	aircraft background	2.9	cosmic stripping coefficient	0.029	(.041)
U up	aircraft background	0.53	cosmic stripping coefficient	0.0077	(.0084)
Th	aircraft background	0.91	cosmic stripping coefficient	0.034	(.055)
K	aircraft background	6.3	cosmic stripping coefficient	0.039	(.050)
TC	aircraft background	62	cosmic stripping coefficient	0.68	(.81)

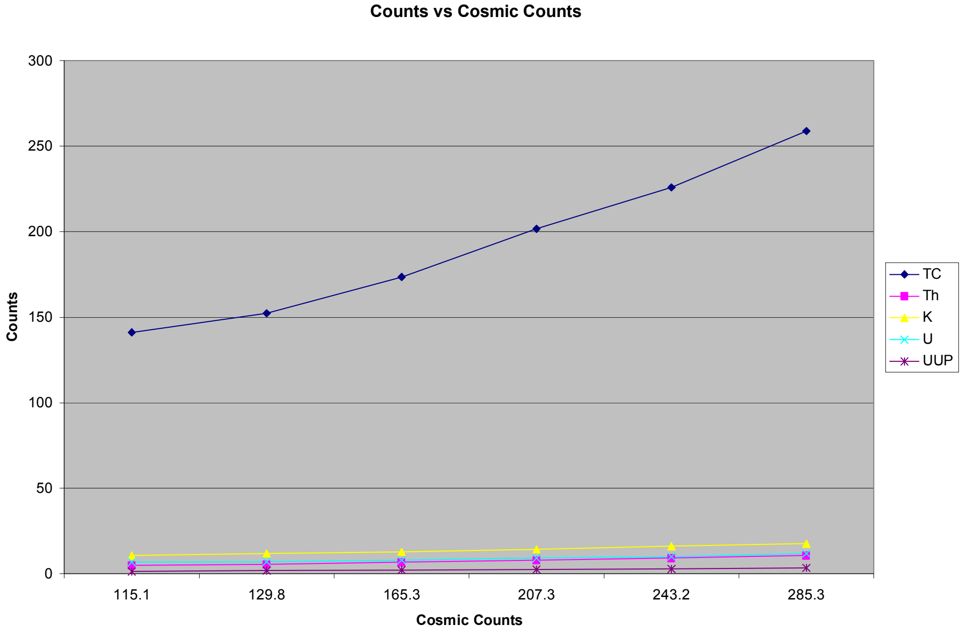
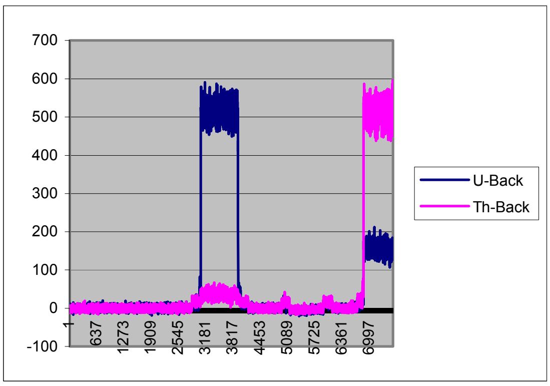


Figure B-4. Total counts vs. cosmic counts at height 4500, 5500, 7000, 8500, 9500 and 10500 feet.

B-6-2 Radiometric Constants A1 and A2:

The radiometric constants A1 and A2 were determined from the NGU pad calibration data (shown left below), and are as follows, together with the standard errors and the R2 coefficient of fit.



	A2	A1
Value	0.00544564	0.04164194
Error	0.00031151	0.00030653
R2	0.99989972	0.14949547

Pads are not optimal for determining A1 and A2 because pad data is subject to localization and do not include atmospheric scattering. (IAEA values are a1= 0.0339 and a2 = 0.0162).

To measure A1 and A2, a number of sites near the Simpevarp reactor were selected to maximize variation of ground uranium and thorium. Each site was selected for adjacency to water, so as to provide background measurement, and for accessibility. Data was acquired at the following points, and are recorded in lines 500000 in flight 19.

The resulting background data is as follows:

Line/Background	Udown	Th	Uup	E (RT90)	N (RT90)
503011/12	53.6	89.7	3.9	1553500	6366647
503013/14	28.4	34.7	2.8	1552867	6368109
503015/16	26.4	28.8	3.6	1552971	6366449
503017/18	27.8	41.3	3.3	1551423	6366519
503019/20	23.8	26.2	2.3	1550249	6365027
503021/22	23.6	25.1	1.4	1551314	6366860
503023/24	29.8	38.1	1.7	1553939	6367850

The results are hypersensitive to the background levels determined for the upward looking uranium crystal, and regression using these data yield a negative coefficient for A2. Accumulating the background into a common ”line” that is used to correct all data results in:

Line	Udown	Th	Uup
503011	53.6	89.7	3.9
503013	28.4	34.7	2.8
503015	26.4	28.8	3.6
503017	27.8	41.3	3.3
503019	23.8	26.2	2.3
503021	23.6	25.1	1.4
503023	29.8	38.1	1.7
Common Background	3.5	0	1.25

Using these data, the following analysis resulted in the skyshine coefficients that were used in the processing, Table B-10:

Table B-10. Coefficients for correction of atmospheric radon content.

Compute a least squares fit using Equations 4.17, 4.18 IAEA manual page 29

Line	A $Ud^2/ ó^2$	b $Th^2/ ó^2$	C $Ud*Th/ ó^2$	d $Uu*Ud/ ó^2$	e $Uu*Th/ó^2$
3011	258.76390	829.49380	463.29590	13.687110	24.505670100
3013	79.48846	154.37050	110.77310	4.948077	6.895512821
3015	51.41275	81.31765	64.65882	5.275980	6.635294118
3017	59.64545	172.29190	101.37270	5.031818	8.552020202
3019	52.16329	86.89114	67.32405	2.698101	3.482278481
3021	50.50125	78.75125	63.06375	0.376875	0.470625000
3023	100.24490	210.37830	145.22170	1.715217	2.484782609
Sum	652.22000	1613.49500	1015.71000	33.733180	53.026183330

determinant =	20686.59	Determinant = ac-bb
a1	0.02751	(ce-bf)/det
a2	0.015547	(af-be)/det

B-6-3 Radiometric upward and downward window relationships

A GX was written (cal_over_water) to select all points with cosmic corrected thorium and total counts as an indicator of the presence of water. Thorium was selected as a water ”detector” channel because it is least affected by the variations in atmospheric radon; high concentrations of atmospheric radon could cause a water auto-detect algorithm based on other channels to indicate land, biasing the results to include only that data sampled during lower radon concentrations.

Data was accumulated from each corrected channel for each line on the survey, with the criteria that thorium counts < 10/sec, total counts < 250/sec, such that at least 10 such occurrences were encountered on a particular line. Processed data included both the overwater background and survey lines, and written to an ascii file whence they were read into Excel and processed to yield the required linear realationships. The best fit was achieved using only the over water lines, indicating that the ”water test” parameters in the ”gx” were not perfect, but could be used to reject suspect points in the over water lines, which in Simpevarp traversed many shallow shoals. These data is presented below.

Data from Simpevarp over-water background lines and resulting regression.

Uup	K	Th	TC	Ud	Uup vs Udown		
1.53	2.96	0.397	43.6	3.07	a_u, b_u	0.291535	0.448503
1.74	3.62	0.381	41.4	3.51	Std.err a,b	0.02982	0.095653
0.813	1.62	−0.121	15.9	1.2	R2,SEY	0.819861	0.299258
1.11	3.76	0.7	42.1	2.32	F,df	95.5769	21
1.37	2.2	0.58	28.3	1.28	SSReg,SSres	8.559426	1.880663
1.5	1.83	0.959	34.3	2.46	K vs Udown		
1.72	6.86	0.742	89.7	5.68	a_k, b_k	0.998442	1.308666
3.17	9.89	2.1	141	8.39	Std.err a,b	0.13552	0.434699
0.819	2.52	0.149	21.9	1.19	R2,SEY	0.721042	1.359985
1.16	4.47	1.34	57.2	2.15	F,df	54.28006	21
0.4	0.298	0.11	0.779	0.11	SSReg,SSres	100.3942	38.84073
0.901	3.17	0.737	28.9	0.87	Th vs Udown		
0.953	2.96	0.501	34.7	1.72	a_t, b_t	0.11563	0.409933
0.941	6.07	0.625	50.9	2.27	Std.err a,b	0.069988	0.224496
0.112	−0.31	0.644	−0.918	−0.803	R2,SEY	0.115028	0.702352
1.05	1.71	0.652	11.9	0.0398	F,df	2.729569	21
0.161	4.92	1.19	37.8	0.926	SSReg,SSres	1.34649	10.35925
2.23	8.84	1.03	96.4	5.79	TC vs Udown		
0.385	1.35	−0.185	17.9	0.943	a_tc, b_tc	14.63316	8.692883
0.993	5.82	2.78	65.8	2.55	Std.err a,b	1.002029	3.214148
0.729	2.57	−0.312	29.9	1.85	R2,SEY	0.910357	10.05568
1.79	4.17	−0.285	72.8	5.12	F,df	213.263	21
1.04	4.63	1.18	55.9	3.28	SSReg,SSres	21564.47	2123.453

Notes:
1. a_x and b_x are the regression of channel x against uranium down: x = a_x u_d + b_x
2. Std Err, a,b are the standard errors in a_x and b_x
3. R2 and SET are the R2 and standard error in Y (channel x) statistic
4. F, df are the F statistic and the degrees of freedom
5. SSReg and SSRes are the regression sum of squares and residual sum of squares

B-6-4 Radiometric altitude attenuation:

Altitude attenuation was measured over a field south east of the intersection with the Sibylla at Fårbo, near Simpavarp. This site was selected because it is near to water for background measurement, relatively flat, clear of trees and compositionally homogenous. Hussein Somali from SGU measured the test area with a calibrated hand spectrometer on October 9th in the afternoon. A test flight was flown on October 10th, Flight 20, lines 34XX. Data is reduced using data averaged at 200, 250, 300 and 400 feet. The computations are illustrated below:

Original data, deadtime corrected, with radar altimeter corrected to STP conditions using temperature 7 °C and pressure 1,025 mb. Samples are averaged over 1 minute:

Line No	Nom.Ht (feet)	TC (cnts)	Th (cnts)	K (cnts)	U (cnts)	Uup	COSMIC	Corr HT to STP(m)
3420	200	1649	35.1	257	29.2	4	69	53.3
3425	250	1467	30.8	214	27.8	4.7	71	68.5
3430	300	1371	28.4	201	24.9	3.6	67	77
3440	400	1114	23.7	151	22.2	3	68	106
420000	200	199	4.6	16	8.4	2.4	64	57

Data with the background removed. This removes radon and cosmic scattering.

Nom.Ht (ft)	TC	Th	K	U	Uup	Corr HT (m)
200	1450	30.5	241	20.8	1.6	53.3
250	1268	26.2	198	19.4	2.3	68.5
300	1172	23.8	185	16.5	1.2	77.0
400	915	19.1	135	13.8	0.6	106.0

Stripped counts with the background removed:

Nom.Ht (ft)	TC	Th	K	U	Corr HT (m)
200	1450	30.77093	223.5074	11.3679400	53.3
250	1268	26.33873	181.2385	11.1914700	68.5
300	1172	24.02067	170.7932	8.8739350	77.0
400	915	19.26413	122.4228	7.4372290	106.0

To compute the attenuation coefficients, fit linear line through the log_e of the count rate as a function of height:

Nom.Ht (ft)	TC	Th	K	U	Corr HT (m)
200	7.279319	3.426571	5.409444	2.430797	53.3
250	7.145196	3.271041	5.199814	2.415152	68.5
300	7.066467	3.178915	5.140453	2.183118	77.0
400	6.818924	2.958245	4.807481	2.006498	106.0

The resulting linear fits produce the decay coefficients below in the second column. Note the discrepancies with the IAEA thorium results which appear to be unreliable compared with the results presented for Forsmark and Simpevarp. The columns to the right illustrate the count rate projected to occur at ground level using the Simpevarp decay coefficients.

	Decay coefficients vs height			Convert to counts at ground level		
	Simpevarp	Forsmark	IAEA p36	IAEA Graph	Ln(Counts)	Counts
U	−0.00864	−0.004707	−0.0084	−0.00828	2.917281	18.49093
Th	−0.0088	−0.00894	−0.0066	−0.00783	3.879237	48.38729
K	−0.01123	−0.01144	−0.0082	0.00945	5.995269	401.5246
TC	−0.00873	−0.00804	−0.0067	−0.00782	7.74288	2305.101

(Note the error in the Forsmark uranium attenuation caused by rain). The Simpevarp attenuation factors generate the following factors used to convert counts from ground level to counts at a nominal survey altitude of 60 metres, Table B-11:

B-6-5 Conversion to a calibrated count rate:

Altitude attenuation was measured over a field south east of the intersection at Fårbo, in the Simpevarp survey, as noted above. This site was independently measured with a calibrated ground spectrometer operated by Hussein Somali on a grid of points over the field where the test was made. Conversion units determined from the SGU data is compared with the pad calibration factors from calibration done at NGU. Results compare well in view of the precision of the data, as measured by the standard deviation of the SGU ground.

Table B-11. Attenuation factors.

U	0.420967
Th	0.441402
K	0.359731
TC	0.445392

Element	Counts at ground level	Error in counts at ground level	Ground spectrom. elemental concent.	Units for ground spectrom data	Units/cps from SGU ground data	Standard deviation: SGU ground spectrom.	Error/cps from SGU ground data	Units/cps from NGU pad calibration
U	18.49093	err ~1.3%	1.1	ppm	0.059489	0.4 ppm	0.021632	0.08682
Th	48.38729	err ~2.5%	9.2	ppm	0.190133	1.3 ppm	0.026867	0.17626
K	401.5246	err~ 2.5%	3.10	%	0.007721	0.2%	0.000498	0.00738

The thorium and potassium attenuation coefficients are almost identical to those computed at Forsmark; results for uranium and total count are different, with the uranium coefficient being more compatible with that expected in comparison, for example, with thorium. This is likely explained by the fact that at Forsmark, the rain, which changed the apparent uranium ground concentrations during the course of measurement, and thus destroyed the uranium attenuation coefficient experiment. Summarizing the sensitivity data, the results are reiterated below, with the NGU pad sensitivity data: any geometric effects due to restricted pad size must be minor indeed!

Accordingly, the following data is used, Table B-12:

Channel	Sensitivity (Simpevarp)	Sensitivity (Forsmark)	Sensitivity (NGU Pads)
Th	5.2 c/ppm	5.6 c/ppm	5.7 c/ppm
U	16.8 c/ppm	14.2 c/ppm	11.5 c/ppm
K	130 c/%	131 c/%	135.5 c/%

Table B-12. Apparent sensitivity used fro converting cps to ground concentration of Th, U and K.

Channel	Pad Sensitivity	Attenuation Coefficient	Factor to convert pad sensitivity to 60 metres	Apparent sensitivity at 60 metres
Th	5.67 c/ppm	–0.00894	1.71	3.32 c/ppm
U	11.5 c/ppm	–0.00864	1.68	6.86 c/ppm
K	135.5 c/%	–0.01144	1.98	68.4c/%
TC		–0.00873		

Appendix C

Helicopter Geophysical Data Processing Methods

Used in the SKB Forsmark and Simpevarp Surveys:

Discussion of the Simpevarp Survey

A report prepared on behalf of the Geological Survey of Norway
for Svensk Kärnbränslehantering AB by

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C-1 Introduction

This document describes the data processing sequence used to reduce helicopter geophysical data on behalf of Svensk Kärnbränslehantering (SKB) in the Forsmark and Simpevarp Surveys that were undertaken in August, September and October, 2002.

The survey apparatus consisted of an integrated data acquisition package consisting of a 5 frequency ”Hummingbird” EM system, a Scintrex cesium vapour magnetometer, a Herz Totem VLF, real time differential GPS, radar altimeter, and a 256 channel spectrometer.

Documentation describing the calibration of this equipment is detailed in a separate report entitled ”Calibration of the Integrated Helicopter Geophysical System Operated by the Geological Survey of Norway – Forsmark and Simpevarp Surveys”.

C-2 Line numbering conventions

Lines represent a time sequence of data used for a particular purpose. The term line originates from the interpretation that this sequence of data represents a usual traverse or survey line. However, as additional calibration checks have been added, lines are used to define sequences of data used to measure various background, verification, and calibration checks.

Line numbering conventions for production lines at Simpevarp are as follows:

Type	Description	Number Range
Traverse	Simpevarp regular survey traverse line	0–3020 by increments of 10
Traverse	Simpevarp repeated line	1–3029 not ending with 0
Traverse	Simpevarp survey line south of reactor	50000–59999
Traverse	Simpevarp survey line north of reactor	60000–69999
Traverse	Simpevarp mag traverse – new area	40000–49999
Tie Line	Simpevarp repeated EW Tie Line	70000–79999
Tie Line	Simpevarp Diagonal Tie Line	80000

Note that some of the test and calibration measurements are common for the Forsmark and the Simpevarp survey. Navigation at test and calibration lines were not always processed, (position does not matter) and hence coordinates are sometimes equal 0.

Line numbering conventions for test and calibration lines are as follows:

Type	Description	Number Range
Rejected	Turns, Aborted Lines, Ferry To Area	9XXX, 99XXX
Bk, Cs,U, Th	Background and Radiometric Samples	3001–3004
Bk, Cs,U, Th	Samples FF = Flight No.	3FFXXX
Hover	Spectrometer Altitude Hover Testing	301X
Altitude	Spectrometer Atteutation Testing	3400–3499
OverWater	Spectrometer Water Line Forsmark	3200–3399
Cosmic	Cosmic Calibration xy = height (ft)/100	34XY
EM	Ground Calibration	4000–4099
Test Line	Forsmark and Simpevarp	4200–4299
EM Lag		41XX
Mag Heading	Cloverleaf check	50XX
Mag Lag		51XX
Radar	Hover at full tow cable extension	6XXX
EM	Background test line	8XXX
EM	Nulling Background FF = Flight no	1FFXXX
Test line	Forsmark and Simpevarp 2FFXXX	
Over Water	Spectrometer OverWater – Simpevarp	4FFXXX

C-3 Loading and initial inspection procedures

Processing the data begins by loading data generated by the Hummingbird Data Acquisition System. This system generates a ".HUM" file for every flight which is converted to a Geosoft compatible ".XYZ" file using the extractor program HUM2XYZ.

When the "*.XYZ" file has been created, it is copied into a *_LINES.XYZ file, which is edited in conjunction with the flight reports to break the continuous stream of data from the flight into separate lines. Once the lines have been defined in the XYZ file, the data is loaded into a Geosoft database for processing and initial inspection.

The procedure is as follows:

Loading Hummingbird Data:

1. Data from Hummingbird is extracted to xyz file using HUM2XYZ
2. *.xyz file is copied to *_lines.xyz.
3. Operators report is used to edit *_lines.xyz to insert line breaks
4. Database is loaded from the *_lines.xyz
5. Lines 9000–9999 and 90000–99999 are deselected in database

Loading Magnetic Base Station Data:

6. Base magnetometer file is copied to flight directory (NGU MP3 base magnetometer, located south of the maintenance hangar at Simpevarp airport)

7. Base magnetometer data is converted to .bas format with a 0 field offset

8. Base magnetometer data is loaded into the mag_heli_base channel using the Geosoft leveling package. To do this the base mag is used to level fid 0 to generate MAG_HELI_BASE. Time reference is UTC from GPS. In the case of the Forsmark survey where the Fiby base station magnetometer was used, the Fiby base station data was loaded into MAG_FIBY, and then MAG_FIBY_300 was generated from MAG_FIBY to bring the Fiby base station magnetic values close the MAG_HELIBASE values.

9. MAG_HELI_BASE is then multiplied by –1 to yield the base mag reading.

10. The channel RAWMAG is filtered with a 5 point lowpass to generate MAG_FILT

11. MAG_HELI_BASE is protected

Preparing Ancillary Data:

12. Radar altimeter RALT (feet) is converted to RALTM metres (= ft x 0.3049)

13. Temperature TEMP (degrees C) channel loaded using data from operators log

14. Barometric pressure BARO channel (mbars) loaded using data from operators log

Preparing GPS Data:

15. X_RT90, Y_RT90 are generated from X,Y (Zone 34N Forsmark, 33N Simpevarp)

16. Run GX to create repositioned RT90 data to correct timing error in GPS. This generates the channels X_RT90Fix, Y_RT90Fix

Initial Delivery:

17. Files in flight directory copied to CD and delivered to SKB

C-4 QC stage

In the QC stage, the quality control checks required by SKB were performed in the field. The QC stages are as follows:

Magnetic Diurnals:

18. High pass filter (cutoff = 30 fids) MAG_HELI_BASE to generate MAG_BASE_HP

19. MAG_HELIBASE is copied into MAG_DIURNAL. MAG_DIURNAL is edited to remove obvious spikes. In the case of Forsmark, where the Fiby magnetic base station was used, MAG_DIURNAL was copied from MAG_FIBY_300.

20. Stat report on MAG_BASE_HP is made to determine base mag noise. Limit is 0.3 nT. MAG_BASE_HP is plotted to determine the base station noise, with the average noise being under 0.3 nT. Spikes in manual MAG_DIURNAL are removed by manual editing.
21. MAG_HELI_BASE is inspected so that the diurnals do not exceed the following:
22. 100 nT; in 60 min or 35 nT in 10 min or 15 nT in 2 min
23. QC (4th difference) is run on MAG_FILT and a map plotted.

Flight Line Parameters:

24. QC is run on altimeter with Geosoft parameters 60, 48, 18 50 and a map plotted. The map was inspected to locate bad sections of data.
25. QC is run on line separation using the Geosoft parameters 50, 100, 75, 500 and a map plotted. The map was inspected to located bad sections of data.

EM:

26. IP*,Q* –> IP_L,Q_L using Geosoft HEM leveling package. Drift inspected for the following limits between background null points:

    A: IP1 < 20 ppm, B: Q1 < 20 ppm, C: IP2 < 20 ppm, D: Q1 < 20 ppm,

    E: IP3 < 10 ppm, F: Q3 < 10 ppm, G: IP4 < 10 ppm, H: Q4 < 10 ppm,

    I: IP5 < 30 ppm, J: Q5 < 30 ppm

    For labeling, see Appendix C7.

27. Because noise was large and unpredictable in both areas, and sporadic and attributed to cultural effects outside the system, high frequency EM system noise was checked by observing the EM profiles over the radon water background lines. Targeted noise values were (99% of samples)

    A: IP1 < 5 ppm; B: Q1 < 5 ppm; C: IP2 < 2 ppm; D: Q2 < 2 ppm;

    E: IP3 < 5 ppm; F: Q3 < 5 ppm; G: IP4 < 2 ppm; H: Q4 < 2 ppm;

    I: IP5 < 5 ppm; J: Q5 < 5 ppm

    For labeling, see Appendix C7.

Spectrometer:

28. 256-channel spectra are copied into EXCEL. FWHM @ 2.62 Mev (Th) < 6% for the Thorium sample (Line 3004)
29. Th Peak at 205 (U at 140, K at 116, Cs at 55)
30. Criterion that no heavy rain had occurred verified.

Data Abundance:

31. A statistical report on the channels was run to verify that the following channels contained the required abundance of data:

    X for more than 95% data, TC for more than 99% of data; RAWMAG for more than 99% of data;

Administration:

32. Lines are accepted for navigation
33. Lines are accepted for mag
34. Lines are accepted for EM
35. Lines are accepted for spectrometer

PreProcessing:

36. Radiometric Data is processed using the Geosoft RPS package with the available coefficients. These coefficients changes as calibration data became available during the surveys.
37. EM Data is leveled using the Geosoft HEM leveling package
38. VLF data is not pre-processed during the QC stage in any manner.
39. Magnetic-VLF, EM and Radiometric data are written out for each flight into separate XYZ data files for each data set and are then imported into a database for each data set. East-West Lines and North-South line data from Forsmark are loaded into separate databases. Simpevarp North-South lines and the special area to the east of Simpevarp Power Plant are loaded into separate databases.
40. Preliminary grids of uranium, thorium, potassium and total count generated from the radiometric database; Preliminary grids of magnetic field are generated from the magnetic database, and first and second derivative grids are generated from the magnetic field grid.

C-5 Post Processing: Differential GPS data.

Positions are defined in RT90 coordinates, and were generated using the Geosoft conversion function from the X, Y coordinate channels logged in WGS84 using UTM zone 33. These data was then relocated to account for a software bug in the Hummingbird data acquisition system using the GX ”xyfix” that was written for the purpose. The data required relocation because the CPU clock in the data system ran slower than the GPS clock by a factor of 17/18, meaning that every 18 seconds (on average), 2 GPS samples were received during a ”1 second” CPU cycle, only one sample of which was logged. This resulted in an apparent jump in position between one-second samples of approximately 56 metres, or equivalently, an apparent doubling of the helicopter speed during this one-second interval. The relocated data has been checked, and when profiles are plotted against the relocated positions, the sampling distance between points is uniform (not so when the apparent speed doubled), indicating the correction made is accurate.

The relocated data was then interpolated to generate the channels RT90_XINT and RT90_YINT that were used for gridding.

C-6 Post Processing: Simpevarp Magnetic Data

This section describes the processing undertaken following Simpevarp survey to generate the final magnetic data sets. The magnetic data processed was loaded into the SimpevarpMagVLF and SimpevarpMag-NewArea databases from the XYZ files generated from each flight.

The original magnetic data, in nanoTesla, is archived in the RAWMAG channel. These data was low pass filtered using a 5-point (1/2 second) filter to generate the MagFixFilt Channel. Base station data is archived in the MAG_HELI_BASE (nanoTesla) channel, and were copied into the MAG_DIURNAL channel where they were inspected for spikes. Spikes were removed manually. The MAG_DIURNAL channel was then linearly interpolated to generate the MAG_DIURNAL_INT channel.

No tie line leveling was performed, since magnetic gradients in the area were large, and would introduce more leveling errors than the tie-line method could resolve. No heading errors were applied, owing to insufficient evidence that a significant heading dependence, in comparison to the gradients present in the survey area, could be measured.

The MAG_CORR channel contains the base station corrected magnetic data, and was generated with MAG_CORR = MagFixFilt – MAG_DIURN_INT + 51000. The MAG_CORR channel was then lagged by 0.4 seconds to generate the MAG_LAG channel. The MAG_LAG channel was then gridded to form a total magnetic field grid.

In the originally defined area covered by the north-south traverse lines, the grid cell size was 15 metres, while in the new area to the east, covered by the northeast-southwest trending lines, the grid cell size was set to 30 metres.

Standard first derivative filters were run over the magnetic data to generate first and second vertical derivative maps.

C-7 Post Processing: Simpevarp EM Data

This section describes the processing undertaken following Simpevarp survey to generate the final EM and resistivity data sets. The EM data processed was loaded into the SimpevarpEM database from the XYZ files generated from each flight. These EM data included both the raw and the leveled data from each flight. The characteristics of the EM system are summarized in the table below.

Label	Frequency Label	Frequency (Hz)	Coil Orientation	Coil Separation (m)
A	F1	7001	Coaxial	6.0
B	F2	6606	H. Coplanar	6.0
C	F3	980	Coaxial	6.0
D	F4	880	H. Coplanar	6.0
E	F5	34133	H. Coplanar	4.2

An initial inspection of the EM data indicated that the in-phase channels for frequencies F1, F2, F3 and F4 were heavily influenced by magnetic susceptibility in the area since much of the area was highly resistive. Accordingly, the apparent resistivity maps were generated using the quadrature and apparent bird height channels to minimize the effect of susceptibility. To test this hypothesis, the effect of the apparent susceptibility on the in-phase response was calculated, and correlated well with the measured magnetic field strength.

The apparent bird height was calculated from the radar altimeter by subtracting 30 metres, the length of the tow cable. The resulting channel exhibited strong variations due, for example, to the effect of tree height, and so was filtered with a 40 point (4 second) non-linear filter to remove spurious variations with data saved in channel BIRD_HT_NLF. It is felt that 4 seconds corresponds to the amount of time the pilot would use to adjust the elevation of the helicopter when approaching a stand of trees.

Electromagnetic measurements are sensitive to the height of the measurement, with signal penetration falling off rapidly as a function of altitude. Accordingly, when the radar altimeter exceeded 80 metres, the calculated resistivity was defaulted out, the result being that large patches, often over powerlines, are defaulted out and are not gridded.

The resistivity data was generated from the initially leveled channels (*_L), which were then filtered to generate (*_LFILT) and subsequently re-leveled data channels (*_LADJ). The filter applied was a 7 point (0.7 second) non-linear filter, which was necessary to remove noise from power lines in the survey area. Re-levelling was required to remove minor level variations that resulted from non-linearity in the drift between background null measurements. Levels were adjusted where striping in the resistivity map was associated with a specific flight line or group of lines subject to common nulling measurements. Level adjustments were made over laterally uniform resistive patches of ground to quadrature channel until this striping was minimized. A certain amount of such striping will always occur in resistivity maps if there is a variation of resistivity with depth and a variation in bird height from line to line. The reason for this is that the average field penetration depth is a function of altitude, so different altitudes will yield different apparent resistivities over vertically inhomogeneous ground. The F3 (980 Hz coaxial) quadrature channel was uniformly close to 0.5 ppm, indicating a slight drift error, but also that the area was sufficiently resistive that the effort to pull resistivity information from F3 would be disproportionate to the effort involved in doing so, particularly given the fact that a resistivity map exists for the F4 880 Hz coplanar channel.

Resistivity channels generated were INV_RES_Q*H, where * represents the frequency number. A lag of 0.25 seconds was applied, and defaults (dummy values) applied where the radar altimeter exceeded 80 meters to generate the resistivity channel RES_Q*H_FINAL.

The processing of the XY channels to generate the positions for the grids is described in the section on magnetic processing.

C-8 Post Processing: Simpevarp Radiometric Data

This section describes the processing undertaken following Simpevarp survey to generate the final radiometric data sets. The EM data processed was loaded into the SimpevarpRadiometric database from the XYZ files generated from each flight. These data included the raw and partially processed data from each flight. The partially processed data was discarded and the radiometric data was processed en masse using the Geosoft RPS software. Extensive documentation has been prepared on the calibration of the radiometric instrumentation in the Simpevarp QC report.

The basic processing steps are as follows. The raw uranium (U), thorium (TH), potassium (K), total count (TC) and upward uranium (UPU) channels (all in counts per second) were deadtime corrected using the instrument livetime channel (LIVETIME, milliseconds). Cosmic corrections were then applied to the deadtime corrected channels using the COSMIC channel (counts per second). No filtering was applied to the data, except for the cosmic channel, which had a 5 second low pass filter applied to improve the counting statistics. Since the survey area was relatively flat, the cosmic count rate should be approximately uniform over it, and filtering should not degrade the resolution of the data. The resulting processed channels are labeled *_FILT.

Background were then removed using the upward looking crystal methods with a 4 second filter. This resulted in a number of RADREF channels being generated. The RADREF channels represent the predicted radon background levels for each radio-element channel. Long filters on the RADREF channel generated unsatisfactory edge effects on the end of the line, while the 4 second filter generated unsatisfactory short period oscillations, unlikely to be representative of the actual radon levels. The RADREF channels were therefore fitted with a 7th order polynomial over each line, with the original RADREF channel being added to the output leveled channels (*_LVL), and the RADREF polynomial fit then subtracted from the leveled data. Inspection of the profiles indicated this processing step was an effective method of representing the effect of the radon clouds in all areas except in the direct vicinity of the Simpevarp reactor. Here, radiometric anomalies had a short spatial wavelength on the order of a few hundred metres, and a 6 second non-linear filter was used. (In the vicinity of the reactor, the raw cosmic count channel exceeds 32,000 counts per second, and the recorded count rate was negative. By subtracting the negative count rates from 32767, this numerical wrapping effect was repaired and recorded in NEWCOSMIC.) The resulting leveled channels are labeled *_LVL and represent the count rate per second due to radiometric sources on the ground.

The leveled data was then stripped and converted to apparent radioelement concentrations on the ground, with the potassium channel KCORR being in %, the THCORR and UCORR channels being in ppm, and the TCCORR being in counts. The channel TCEXP represents the exposure rate in micro-R/hr, and this value was computed using the default value method provided by the Geosoft RPS processing package.

The radar altimeter channel (RALTM) was filtered using a 40 point (4 second) non-linear filter to remove variations, for example, due to reflections from trees and recorded in RALTM_FILT. Grids were prepared by processing the XY navigation data according to the method outlined in the section describing the magnetics processing.

Grids were prepared using a cell size of 15 metres for each of the corrected channels. Herringbone offsets of 56 metres were consistently noticed over the east-west trending shorelines, correlated with the flight path. This distance corresponds to approximately 2 seconds of flight time, and was removed by lagging the radiometric data by 1 second. The resulting data is stored in the *_LAG channels.

C-9 Post Processing: Simpevarp VLF Data

Usually the transmitter GBR (16.0 kHz) was used as the IN LINE station and NAA (24 kHz) as the ORTHO station. Occasionally NPD was used as ORTHO when NAA was not operating.

The only processing of these VLF data was a linear trend removal. Processing was performed at NGU in Trondheim. For map production, se Appendix E.

C-10 Coordinate Transform Methodology in Geosoft

This section documents the transformation used to convert WGS84 XY toWGS84 lat-long and RT90 lat-long.

Define the coordinate system:

XY–>WGS84-LAT-LONG

menu–>COORDINATE–>SET PROJECTION

[PROJECTION][MODIFY]

PROJECTED(X,Y) –>next–> WGS84/ UTMZONE 33 N –> next –> WGS84/ WGS84(WORLD) –> next –> METRE [ok]

Generate WGS84 lat-long:

menu–>COORDINATE–>NEW PROJECTED COORDINATE

x/Y/BLANK/IGNORE –> next –> OK –> LATWGS84/LONGWGS84 –> [MODIFY] (define coordinate) GEOGRAPHIC LAT/LONG –> next

WGS84 –> next –> WGS84 –> OK

Generate RT90 lat-long:

menu–>COORDINATE–>NEW PROJECTED COORDINATE

x/Y/BLANK/IGNORE –> next –> OK –> LATRT90/LONGRT90 –> modify –> GEOGRAPHIC LAT/LONG –> NEXT (datum) RT90

–> (local datum xform) RT90 SWEDEN –> 0K

Generate RT90 XY:

menu–>COORDINATE–>NEW PROJECTED COORDINATE

x/Y/BLANK/IGNORE –> next –> OK –> X_RT90/Y_RT90 –> modify –> Projected(x,y) –> NEXT (datum) RT90 (projection method) Swedish National Projection

–> (local datum xform) RT90 SWEDEN –> 0K

Appendix D

Data delivery formats

Simpevarp Geosoft XYZ file formats, Final Delivery

Data is separated in files for Radiometric data, EM-data and Magnetic/VLF data. ”Production lines” and ”Test and Calibration lines” are also separated and named as indicated underneath **(—Test.xyz** indicating test and calibration data).

Files: Simpevarp Radiometric NS.xyz and Simpevarp Radiometric NS Test.xyz

Flight		Flight number
Date		Date YMMDD; Y = year, MM = month, DD = Day of month
Recnum		Internal record number, ordinal, per flight; incremented at 0.1 per tenth of a second
UTCtime		Universal time
RT90_LAT	deg.min.sec	Latitude,RT90
RT90_LONG	deg.min.sec	Longitude, RT90
RT90_XINT	metres	X, RT90, same as ”X_RT90FIXINT”
RT90_YINT	metres	Y, RT90, same as ”Y_RT90FIXINT”
RALTM	metres	Radar altimeter, unfiltered
TCEXP_LAG	micro/hr	Exposure
TCCORR_LAG 2001/		Apparent total count concentration, /Geosoft,
UCORR_LAG	Ppm	Apparent U concentration
THCORR_LAG	Ppm	Apparent Th concentration
KCORR_LAG	%	Apparent K concentration

Files: Simpevarp EM NS.xyz and Simpevarp EM NS Test.xyz

FLIGHT		Flight number
Date		Date YMMDD; Y = year, MM = month, DD = Day of month
recnum		Internal record number, ordinal, per flight; incremented at 0.1 per tenth of a second
UTCTime		Universal time
X_RT90FIXINT	metres	X, RT90 corrected
Y_RT90FIXINT	metres	Y, RT90 corrected
RT90_LAT	deg.min.sec	Latitude,RT90
RT90_LONG	deg.min.sec	Longitude, RT90
RALTM	metres	Radar altimeter, unfiltered
BIRD_HT_NLF	metres	Computed bird height
IP1_LFILT	Ppm	F1 Inphase
IP2_LFILT	Ppm	F2 Inphase
IP3_LFILT	Ppm	F3 Inphase
IP4_LFILT	Ppm	F4 Inphase
IP5_LFILT	Ppm	F5 Inphase
Q1_LADJ	Ppm	F1 Quadrature
Q2_LADJ	Ppm	F2 Quadrature
Q3_LFILT	Ppm	F3 Quadrature
Q4_LADJ	Ppm	F4 Quadature
Q5_LADJ	Ppm	F5 Quadature
RES_q1h_final	ohm-m	F1 Resistivity
RES_q2h_final	ohm-m	F2 Resistivity
RES_q4h_final	ohm-m	F4 Resistivity
RES_q5h_final	ohm-m	F5 Resistivity

F1 = 7001 Hz Coaxial, F2 = 6606 Hz Coplanar, F3 = 980 Hz Coaxial
F4 = 880 Hz Coplanar, F5 = 34133 Hz Coplanar

Files: Simpevarp Mag NS.xyz, Simpevarp Mag NS Test.xyz and Simpevarp Small Area Mag.xyz

Flight		Flight number
Date		Date YMMDD; Y = year, MM = month, DD = Day of month
recnum		Internal record number, ordinal, per flight; incremented at 0.1 per tenth of a second
UTCTime		Universal time
X_RT90FixInt	Metres	X, RT90, corrected
Y_RT90FixInt	Metres	Y, RT90, corrected
RT90_Lat	deg.min.sec	Latitude,RT90
RT90_Long	deg.min.sec	Longitude, RT90
RALTM	Metres	Radar altimeter, unfiltered
RAWMAG	nT	Raw magnetic total field
MagFixLag	nT	Final magnetic total field
MAG_DIURN_INT	nT	Magnetic diurnals interpolated
VLQ	%	VLF InLine Quadrature
VLT	%	VLF InLine Total
VOQ	%	VLF Orthogonal Quadrature
VOT	%	VLF Orthogonal Total

Reference

Geosoft, 2001. Radiometric Processing System for OASIS Montaj. User guide and tutorial. Manual release 13.08.2001.

Appendix E

Gridding and Map production

Maps produced in scale 1:20,000 (large area) and scale 1:10,000 (small area) were based on the final processed data (see Appendix C). The following data treatment was performed to produce the final maps.

Map number	Title	Scale
2002.094-01	Flight Path. Name - .map and - .tiff: Topo-path Grid name: simpevw.grd No treatment of data Topographic background digitised from "Grøna Kartan"	1:20,000
2002.094-02	Magnetic Total Field. Name - .map and - .tiff: Mag_tot Grid name: Mag_korr_m.grd Grid cell size 15 metres Decorrugation, Differential Median Filters /Mauring and Kihle, 2000/ 1D 500 metres, 2D 1000 metres No other treatment of data	1:20,000
2002.094-03	Magnetic Vertical Derivative. Name - .map and - .tiff: Mag_VD1 Grid name:Mag_VD1.grd Grid cell size 15 metres Calculation first order derivative /Geosoft, 1996/ No other treatment of data	1:20,000
2002.094-04	EM Resistivity 880 Hz Coplanar. Name - .map and - .tiff: EM_Res_880Hz Grid name: Q4H_m.grd Grid cell size 15 metres No other treatment of data	1:20,000
2002.094-05	EM Stacked Profiles 980 Hz Coaxial. Name - .map and - .tiff: EM_980Hz_Coax No treatment of data	1:20,000
2002.094-06	EM Resistivity 6606 Hz Coplanar. Name - .map and - .tiff: EM_Res_6606Hz Grid name: Q2H_resfw_m.grd Grid cell size 15 metres No other treatment of data	1:20,000
2002.094-07	EM Resistivity 7001 Hz Coaxial. Name - .map and - .tiff: EM_Res_7001Hz Grid name: Q1H_m.grd Grid cell size 15 metres No other treatment of data	1:20,000
2002.094-08	EM Resistivity 34133 Hz Coplanar. Name - .map and - .tiff: EM_Res_34133Hz Grid name: Q5H_m.grd Grid cell size 15 metres No other treatment of data	1:20,000
2002.094-09	Radiometric Corrected Total Count. Name - .map and - .tiff: Rad_tot Grid name: TC_ny_fin_m.grd Grid cell size 15 metres No other treatment of data	1:20,000

Map number	Title	Scale
2002.094-10	Radiometric Potassum concentration. Name - .map and - .tiff: Rad_K Grid name: K_fin_m.grd Grid cell size 15 metres No other treatment of data	1:20,000
2002.094-11	Radiometric equivalent Uranium concentration. Name - .map and - .tiff: Rad_U Grid name: U_fin_m.grd Grid cell size 15 metres No other treatment of data	1:20,000
2002.094-12	Radiometric equivalent Thorium concentration. Name - .map and - .tiff: Rad_Th Grid name: Th_fin_m.grd Grid cell size 15 metres No other treatment of data	1:20,000
2002.094-13	Radiometric RGB Composite Map. Name - .map and - .tiff: Rad_comp Grid name: K_fin_m.grd, U_fin_m.grd, Th_fin_m.grd Grid cell size 15 metres RGB composite map produced using Geosoft routine /Geosoft, 1996/ No other treatment of data	1:20,000
2002.094-14	VLF-EM Total In-Line. Name - .map and - .tiff: VLT Grid name: VLT_korr.grd Grid cell size 25 metres Decorrugation, Differential Median Filters /Mauring and Kihle, 2000/ 1D 1000 metres, 2D 1000 metresNo other treatment of data	1:20,000
2002.094-15	VLF-EM Total Orthogonal. Name - .map and - .tiff: VOT Grid name: VOT_korr.grd Grid cell size 25 metres Decorrugation, Differential Median Filters /Mauring and Kihle, 2000/ 1D 1000 metres, 2D 1000 metresNo other treatment of data	1:20,000
2002.094-16	Flight Path. Small survey block. Name - .map and - .tiff: Topo_Path_S Grid name: simpevw.grd No treatment of data Topographic background digitised from "Grøna Kartan"	1:10,000
2002.094-17	Magnetic Total Field. Small survey block. Name - .map and - .tiff: Mag_Tot_S Grid name: Mag_ff_m.grd Grid cell size 30 metres No other treatment of data	1:10,000
2002.094-18	Magnetic Vertical Derivative. Small survey block. Name - .map and - .tiff: Mag_VD1_S Grid name: Mag_ff_VD1_m.grd Grid cell size 30 metresCalculation first order derivative /Geosoft,1996/ No other treatment of data	1:10,000

References

Geosoft, 1996. OASIS Montaj Version 4.0 User Guide, Geosoft Inc. Toronto.

Mauring E, Kihle O, 2000. Micro-levelling of aeromagnetic data using a moving differential median filter. NGU Report 2000.053.

Appendix F

Produced and delivered maps

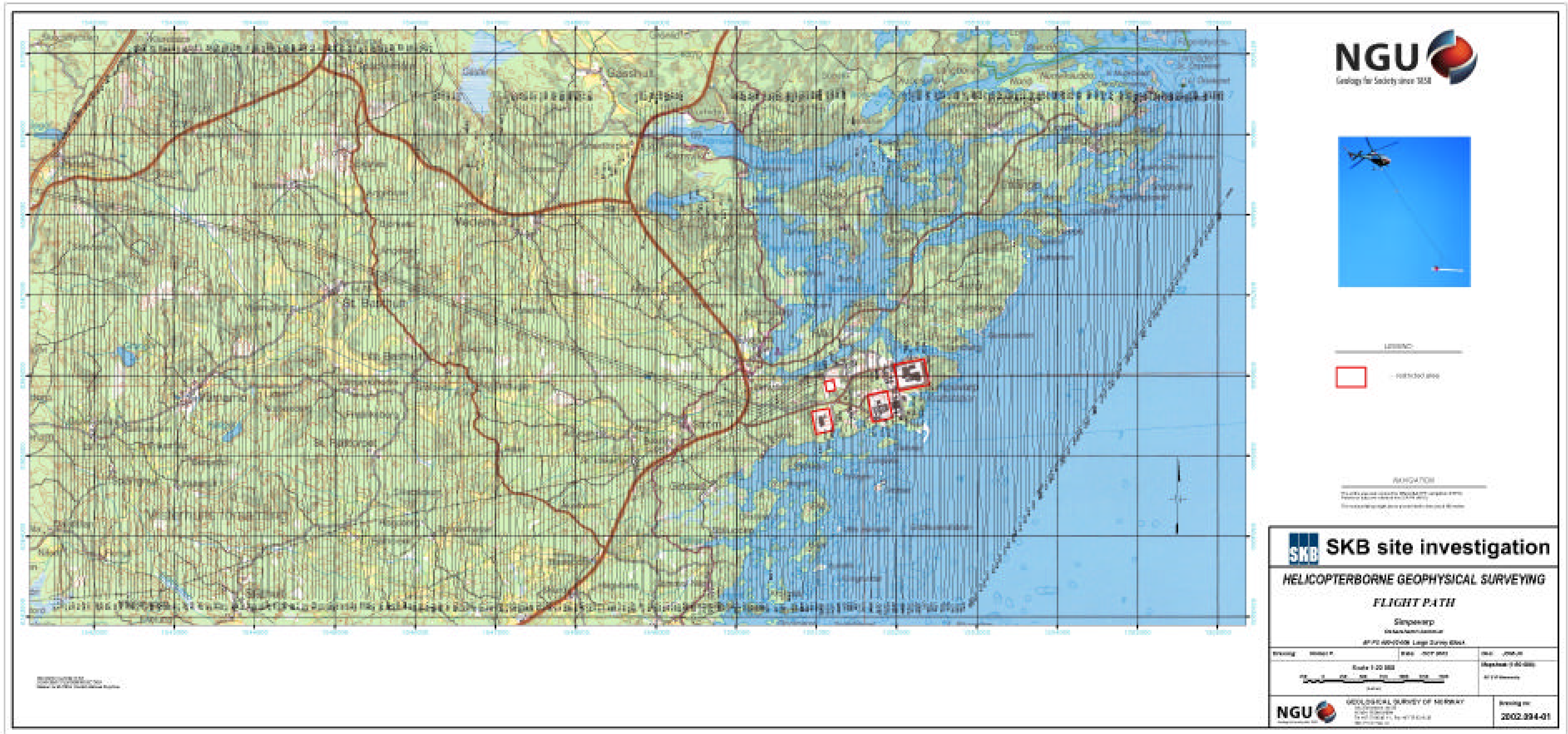

Figure F1. Flight Path. Map number 2002.094-01.

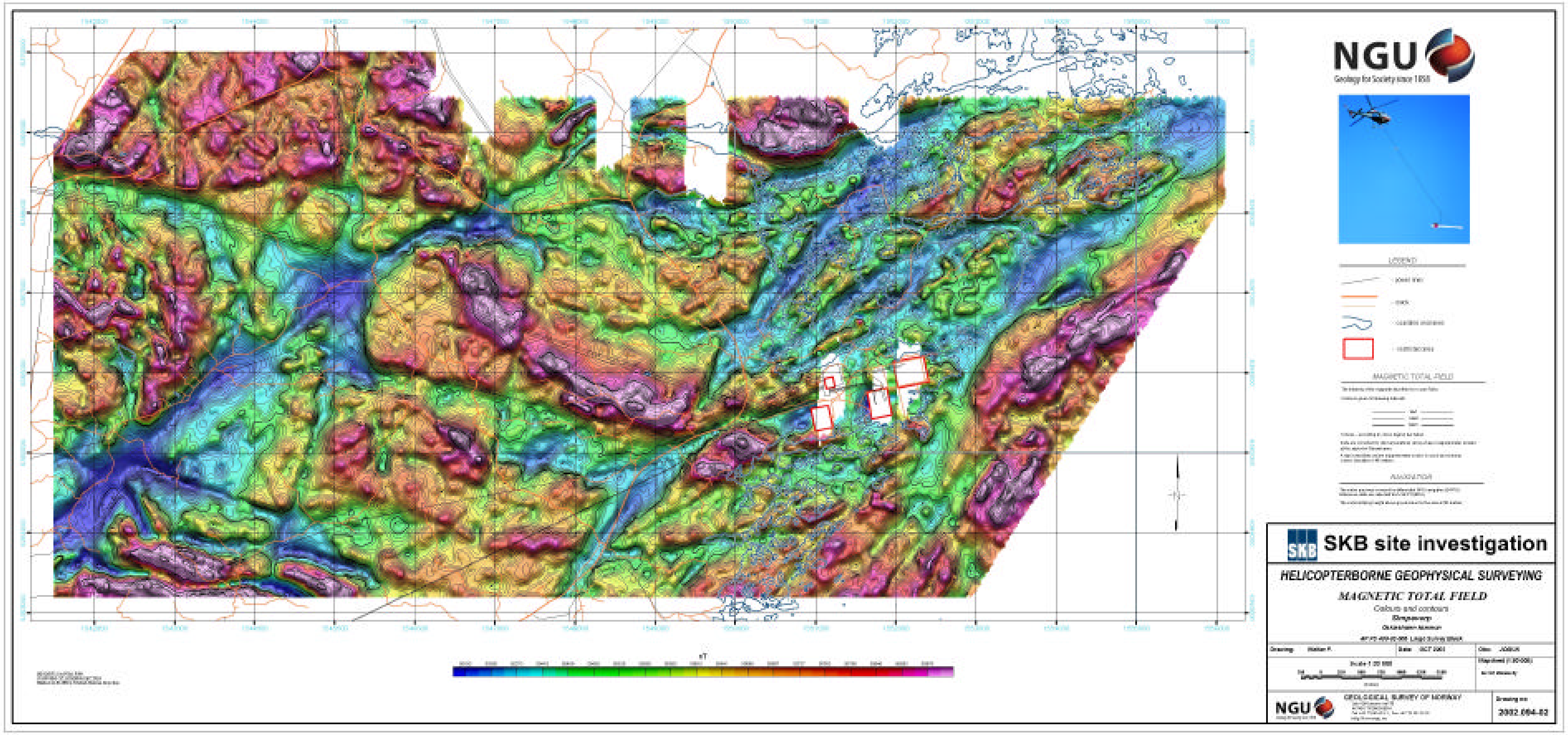

Figure F2. Magnetic Total Field. Map number 2002.094 -02.

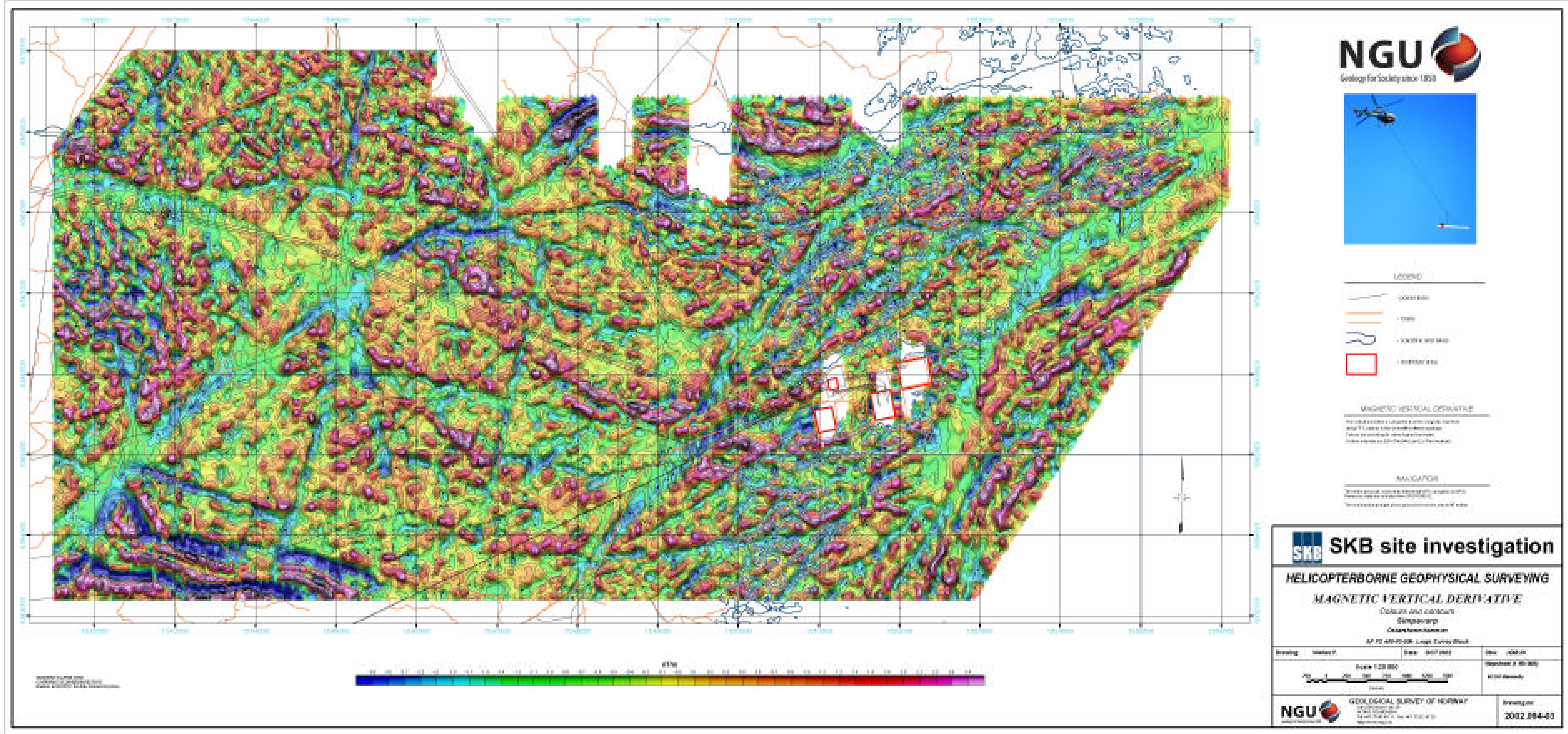

Figure F3. Magnetic Vertical Derivative. Map number 2002.094 -03.

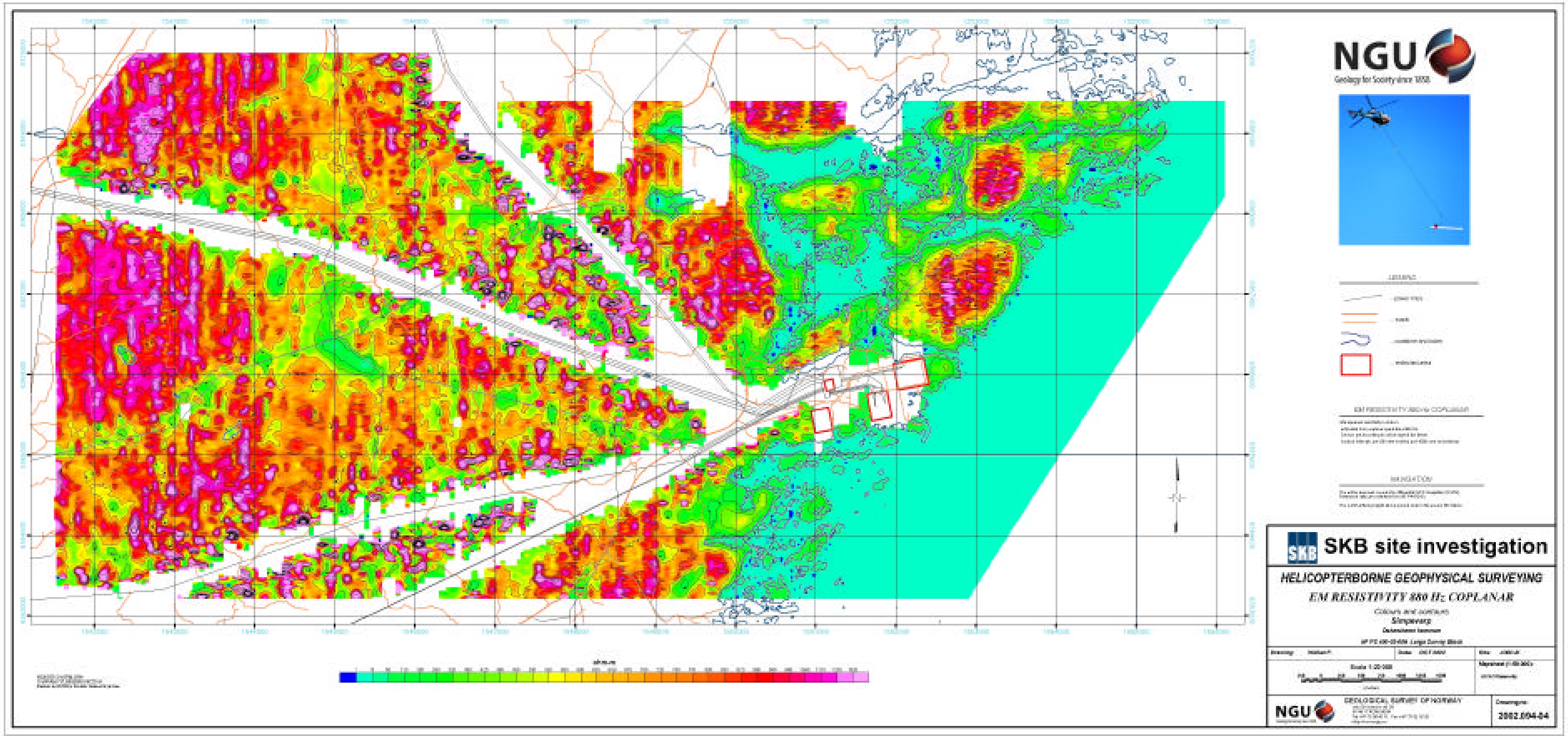

Figure F4. EM Resistivity 880 Hz Coplanar. Map number 2002.094 -04.

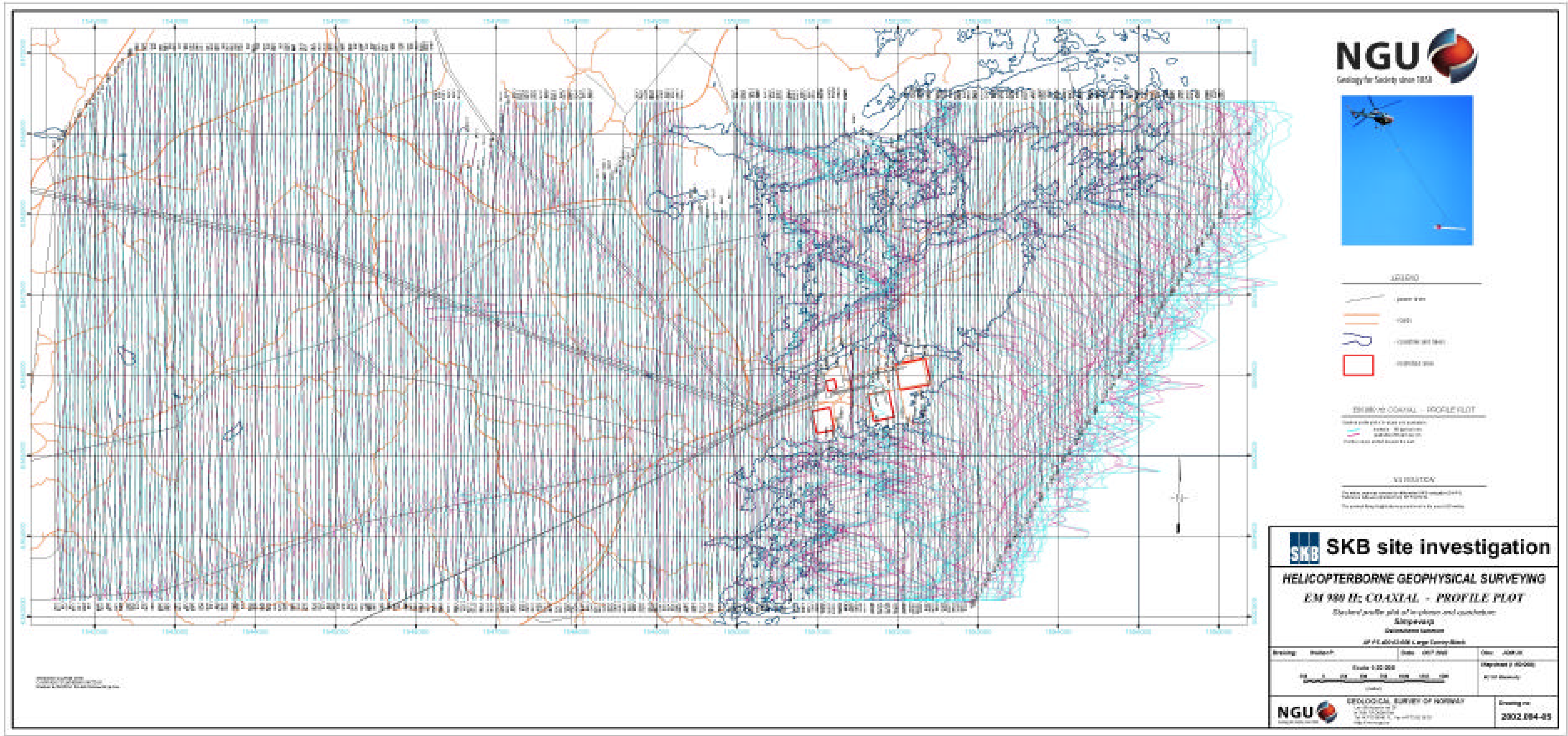

Figure F5. EM Stacked Profiles 980 Hz Coaxial. Map number 2002.094-05.

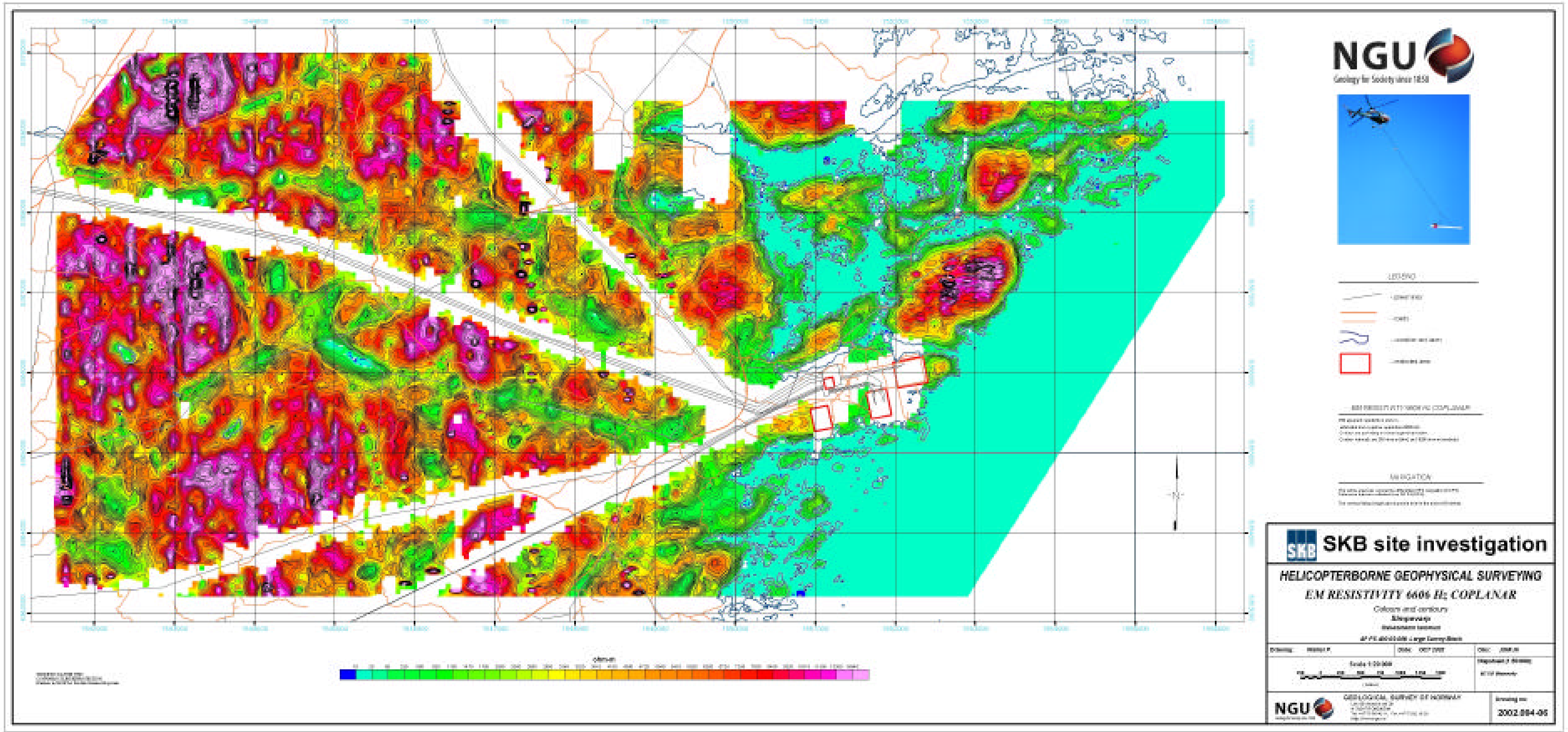

Figure F6. EM Resistivity 6,606 Hz Coplanar. Map number 2002.094-06.

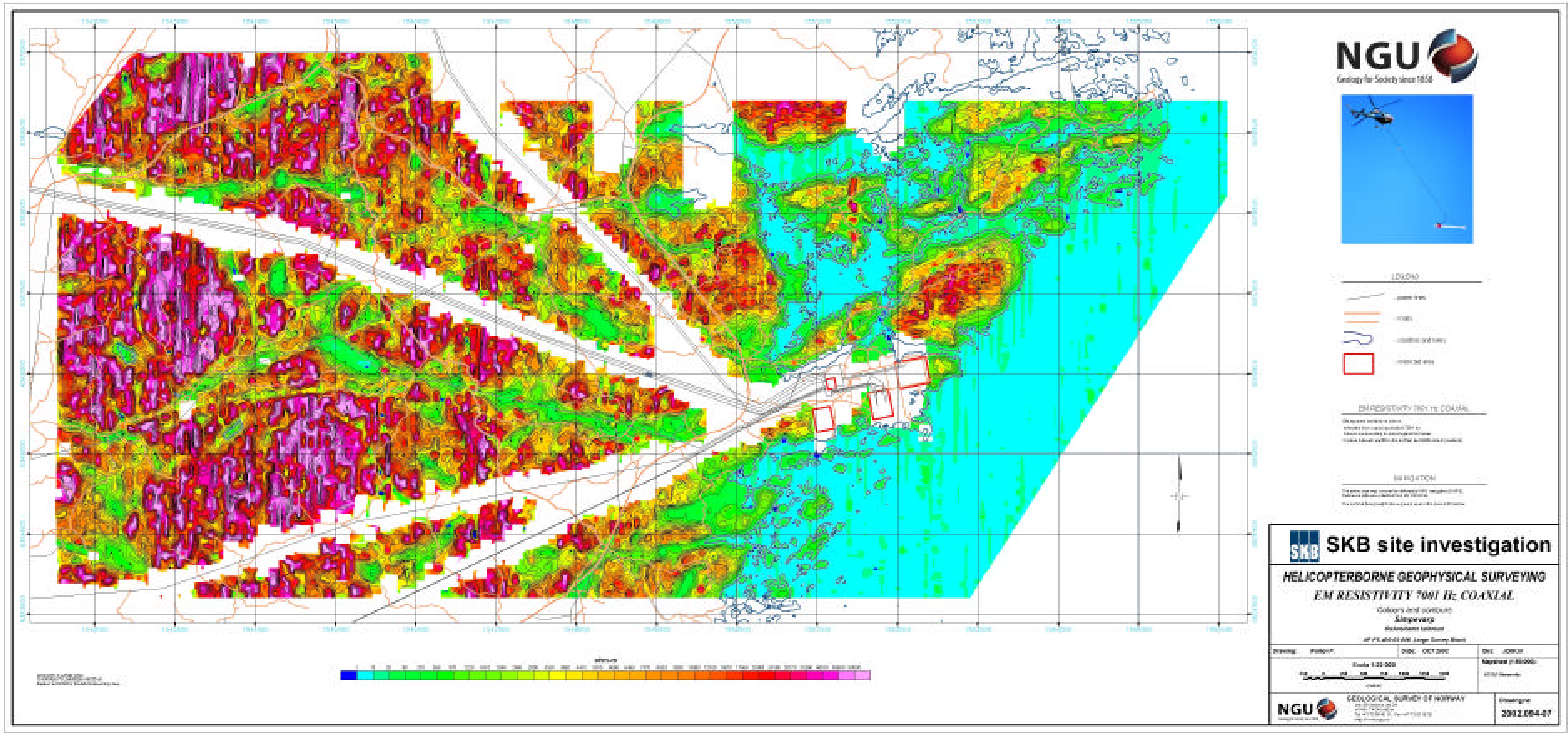

Figure F7. EM Resistivity 7,001 Hz Coaxial. Map number 2002.094-07.

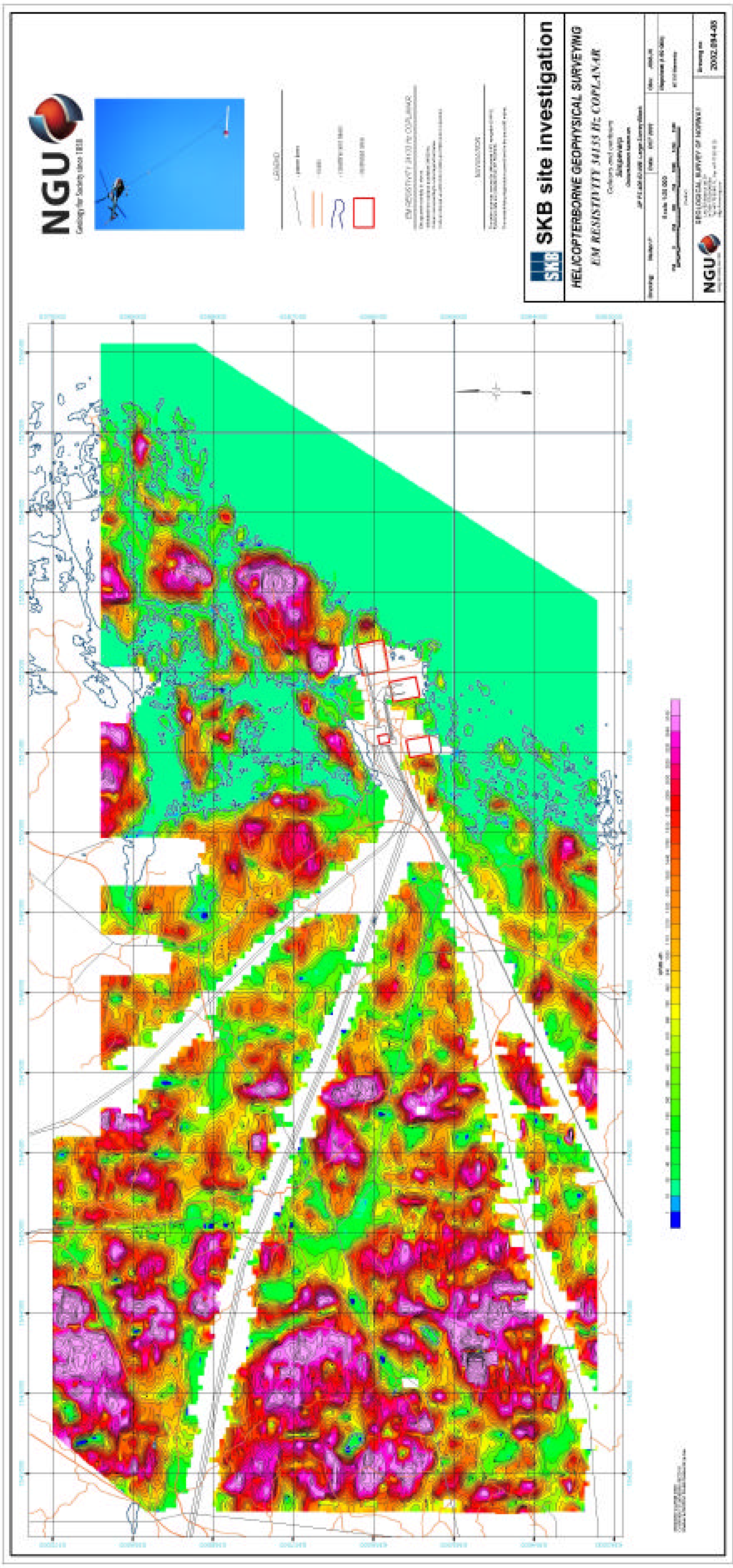

Figure F8. EM Resistivity 34,133 Hz Coplanar. Map number 2002.094-08.

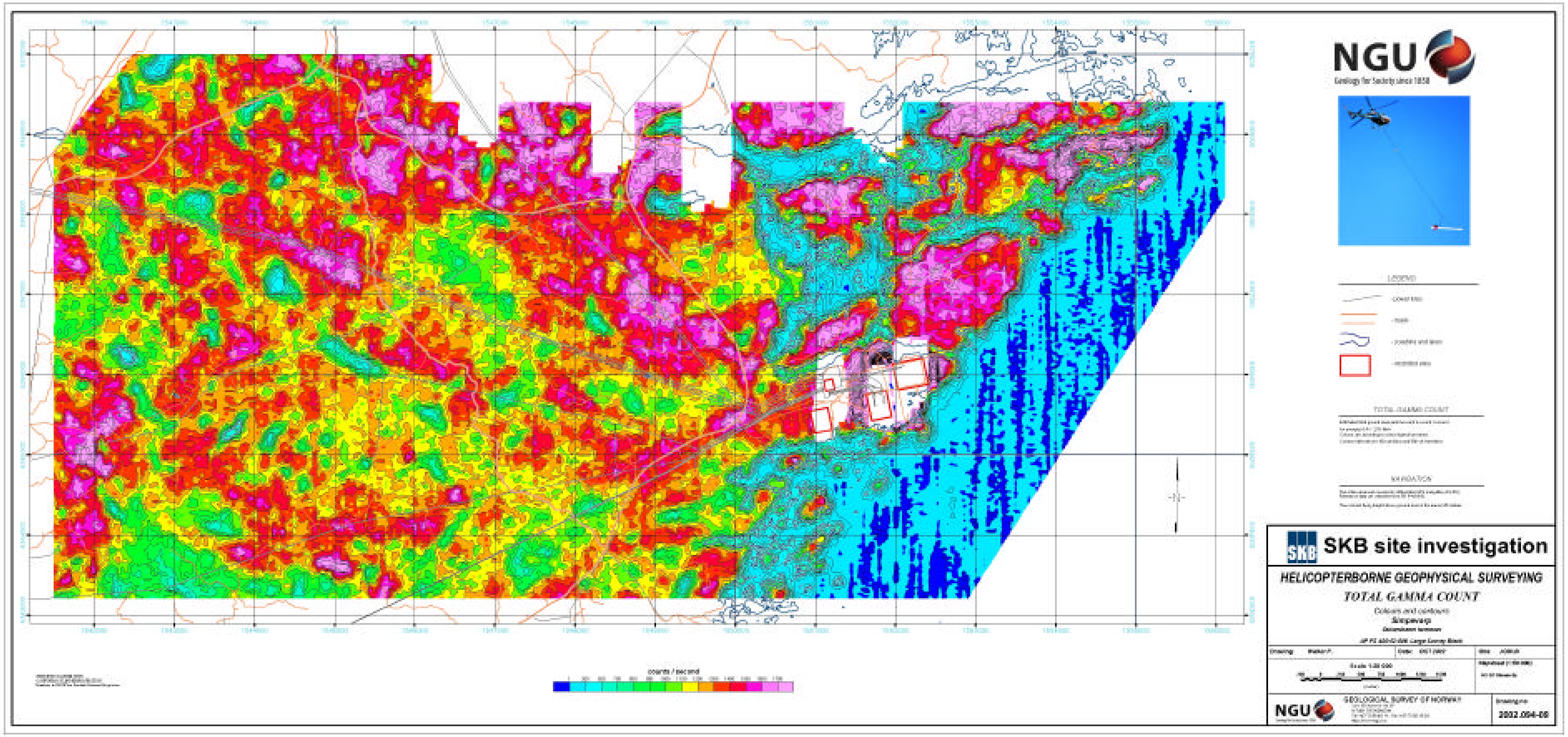

Figure F9. Radiometric Total Count. Map number 2002.094 -09.

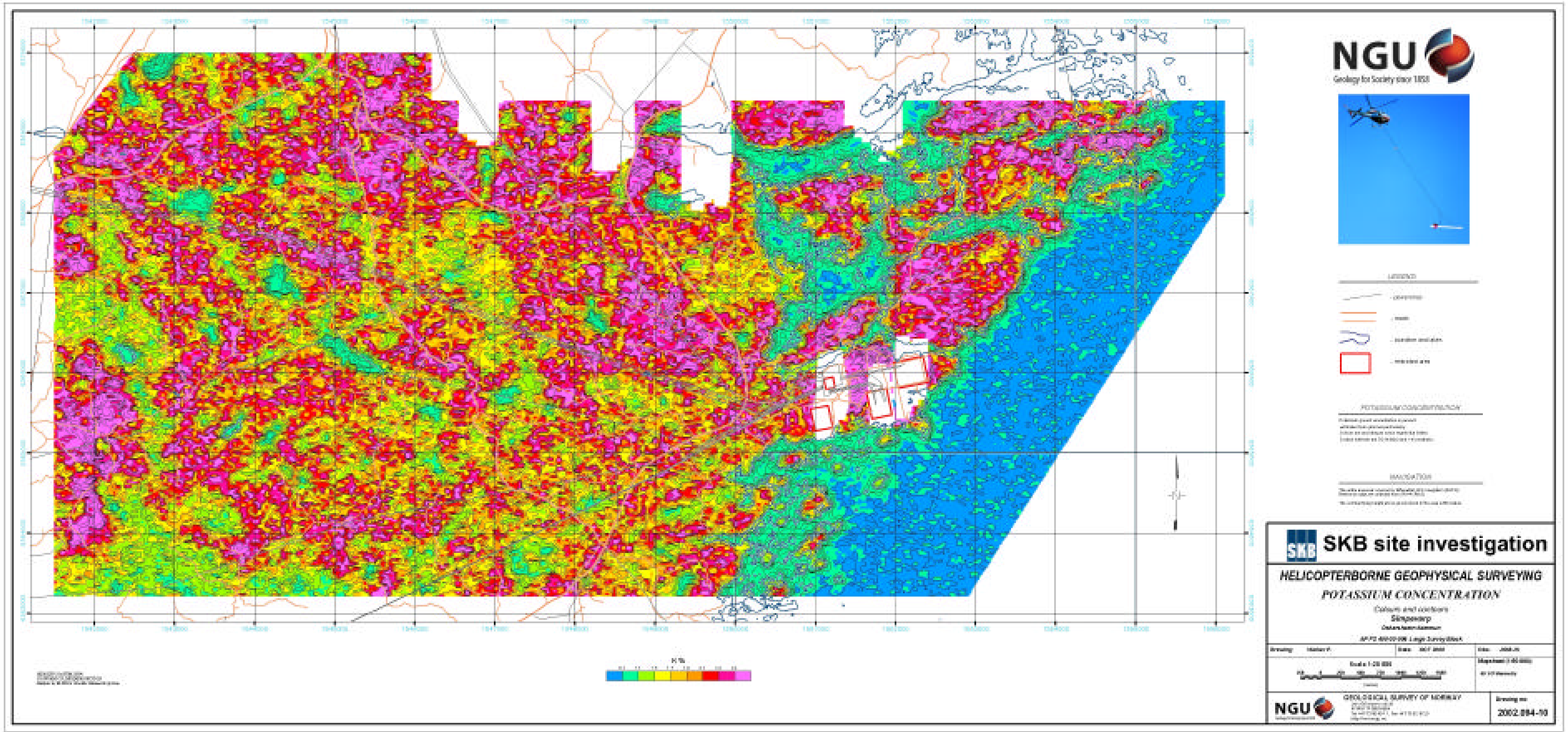

Figure F10. Radiometric Potassium. Map number 2002.094 -10.

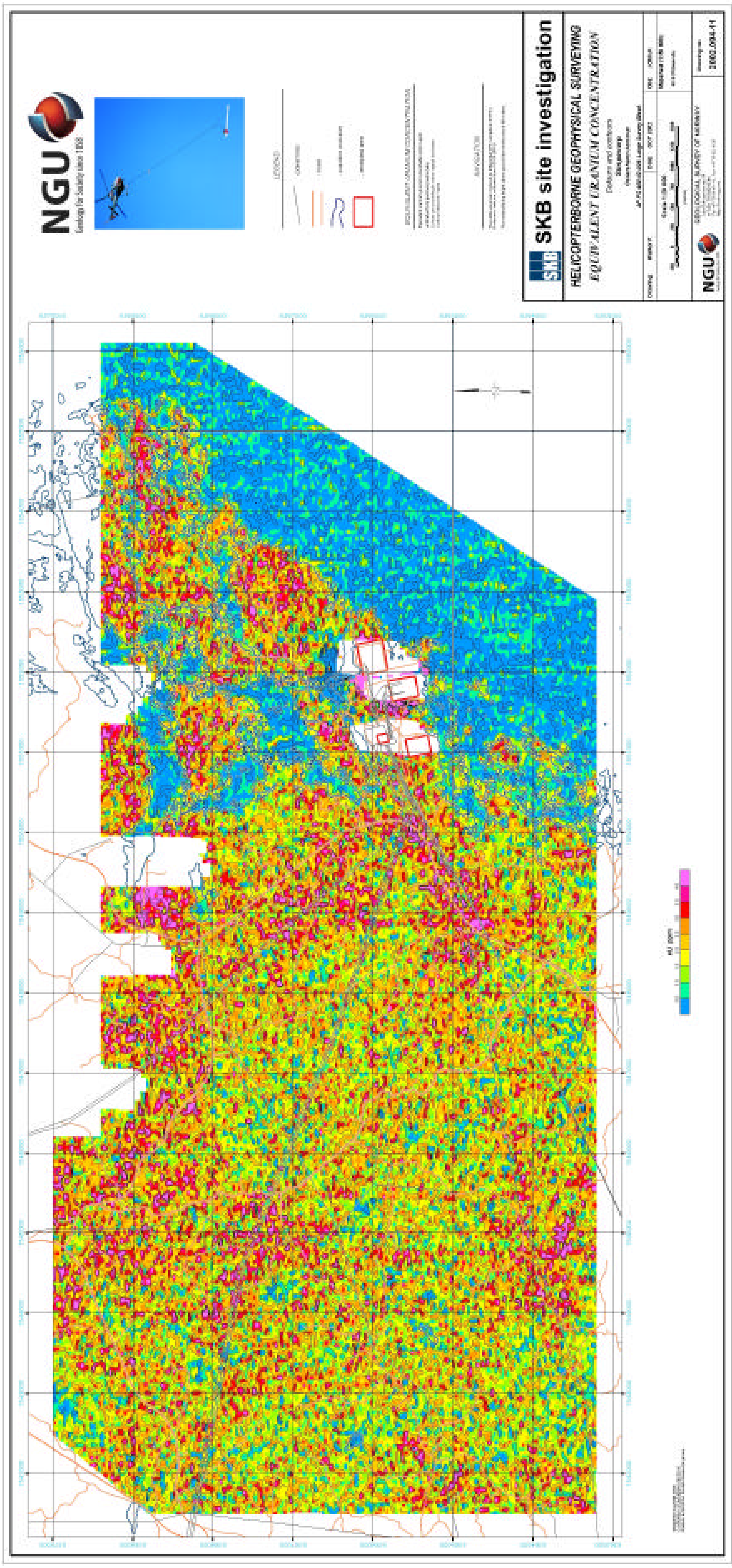

Figure F11. Radiometric Uranium. Map number 2002.094-11.

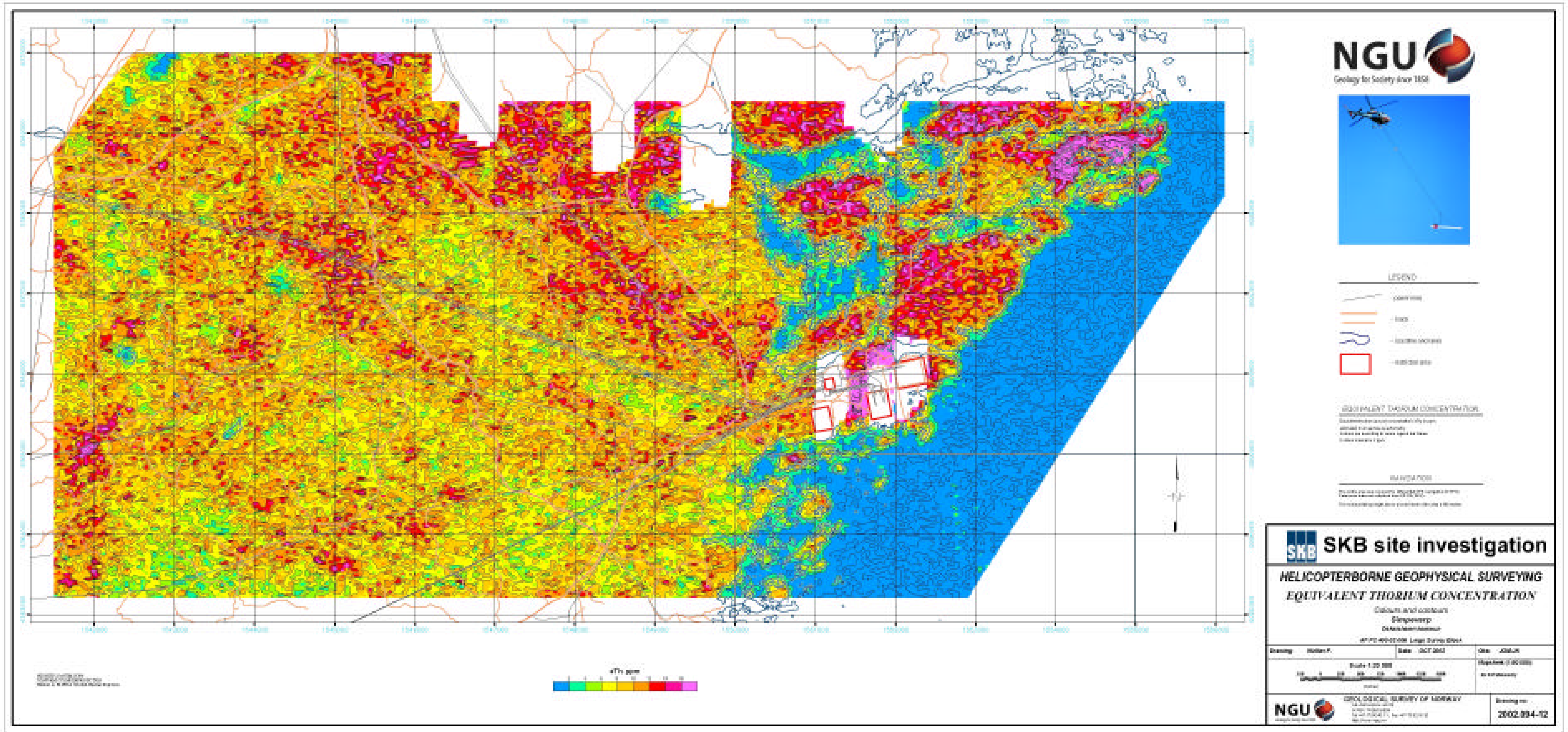

Figure F12. Radiometric Thorium. Map number 2002.094-12.

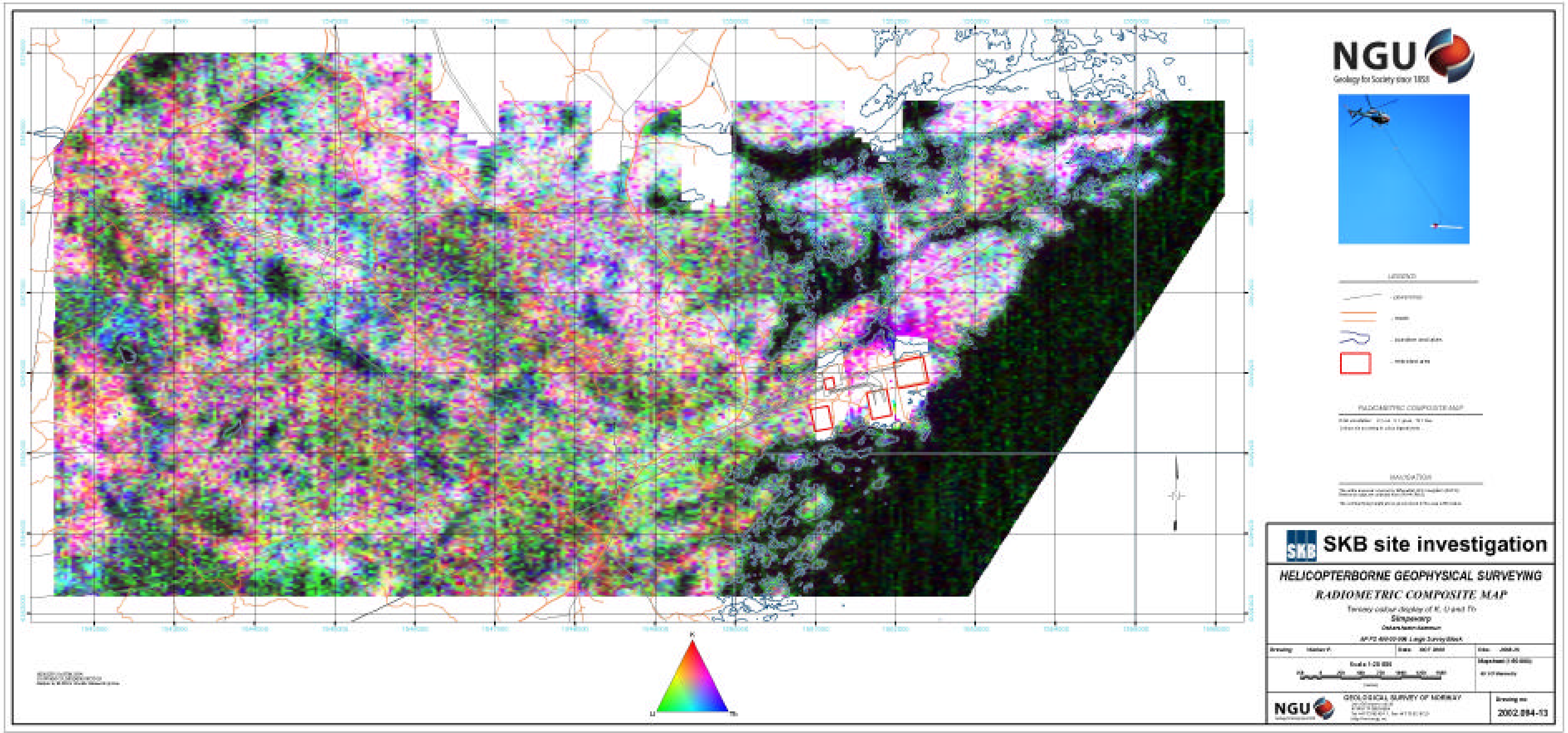

Figure F13. Radiometric RGB Composite Map. Map number 2002.094-13.

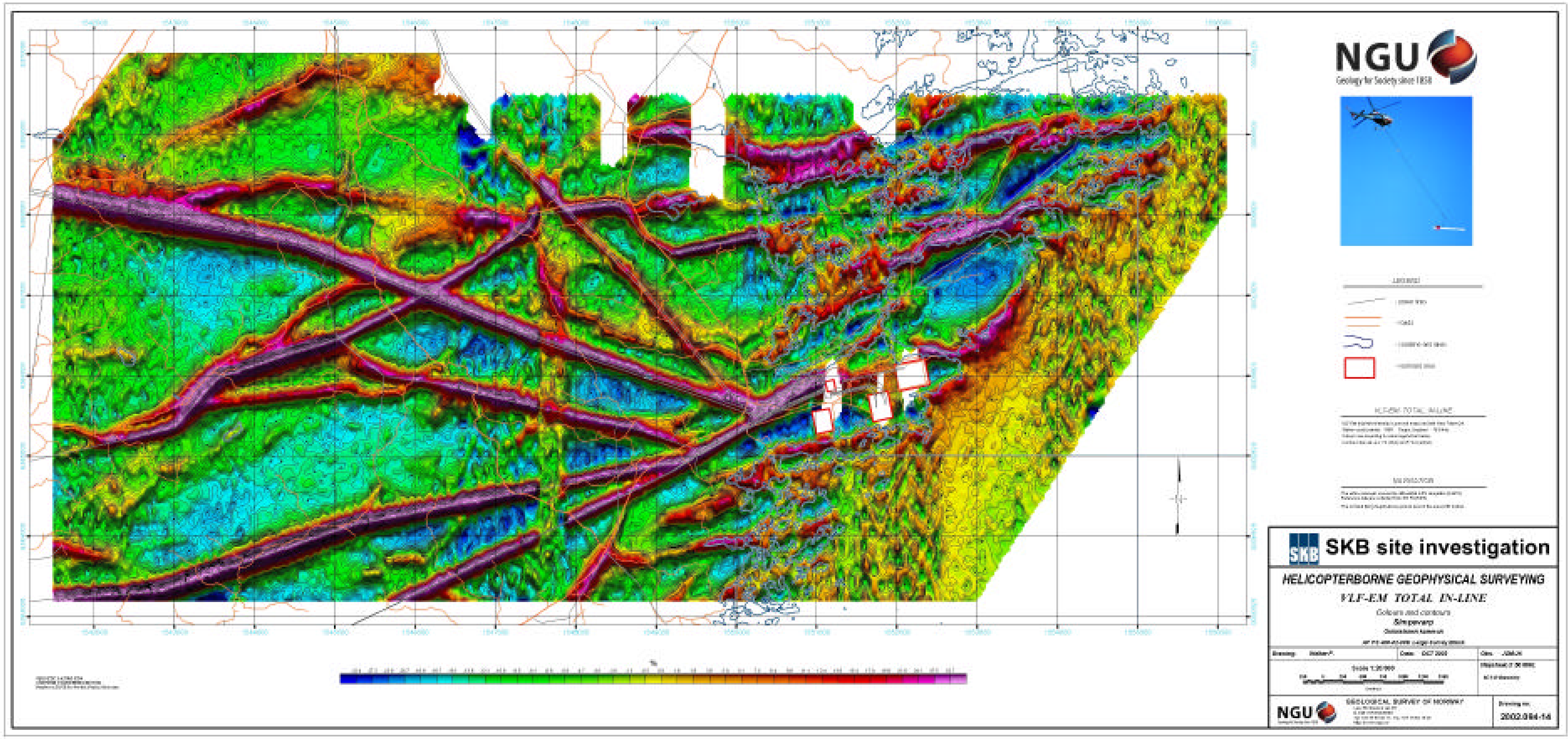

Figure F14. VLF-EM Total In -Line. Map number 2002.094-14.

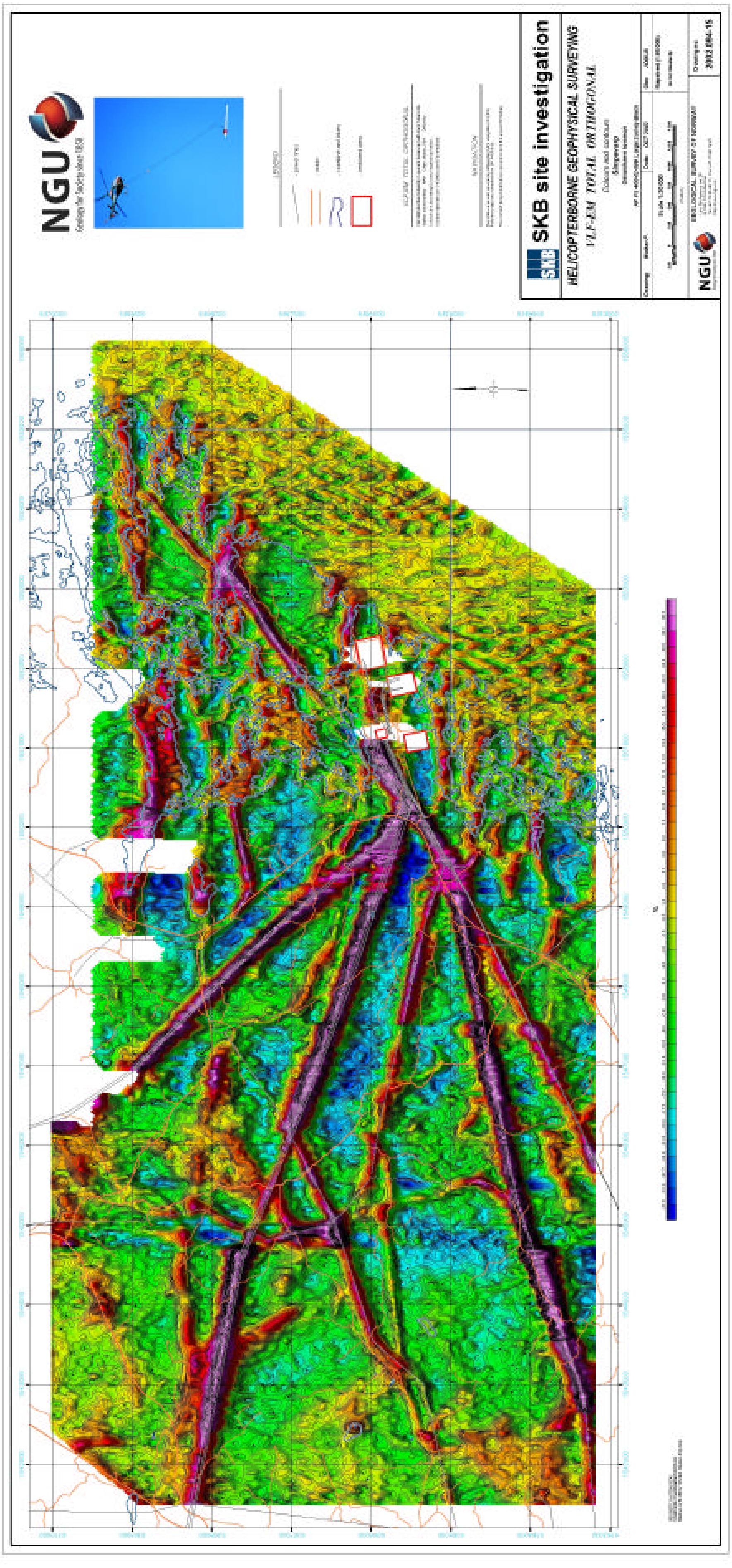

Figure F15. VLF-EM Total Orthogonal. Map number 2002.094-15.

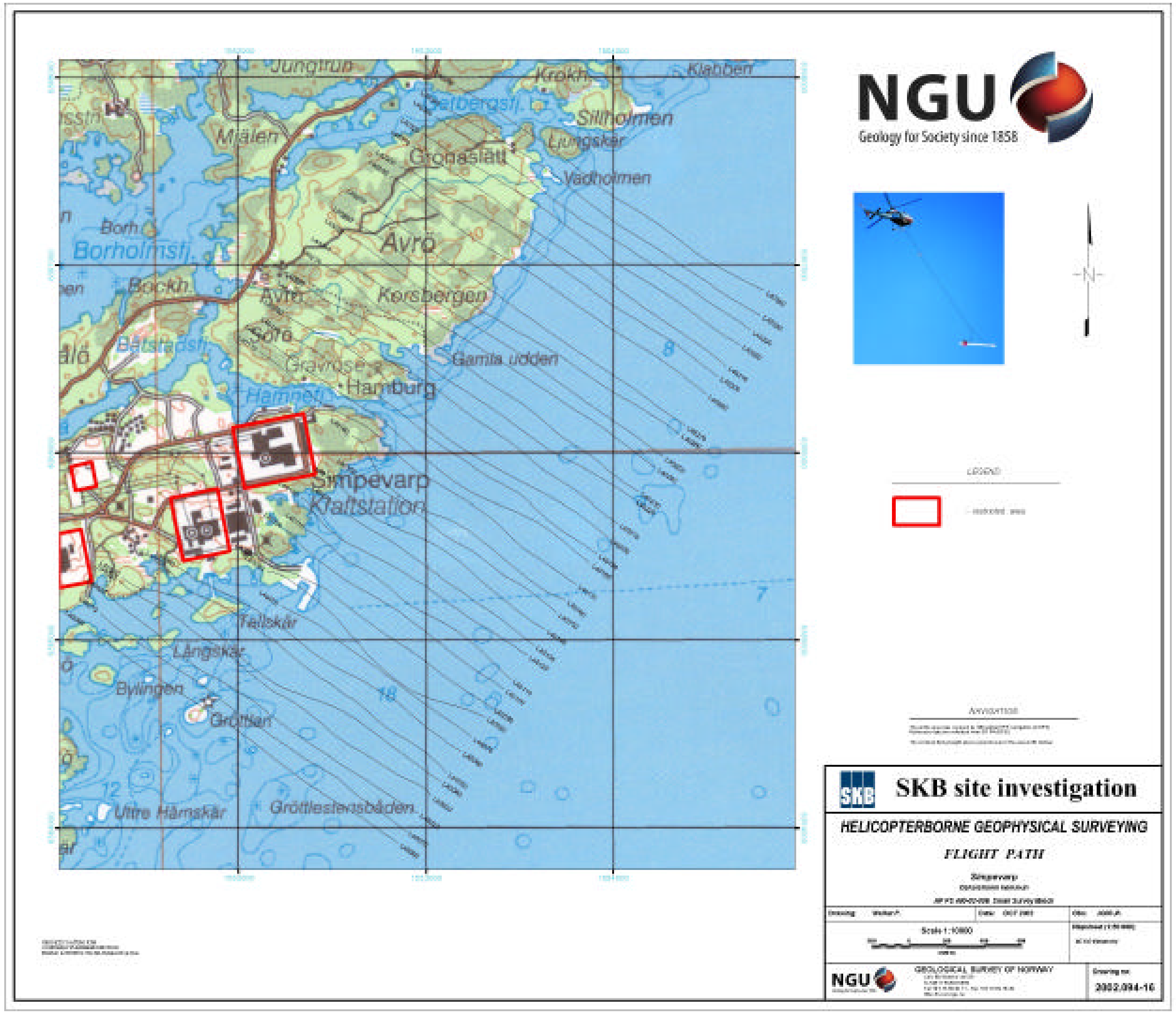

Figure F16. Flight Path. Small survey block. Map number 2002.094-16.

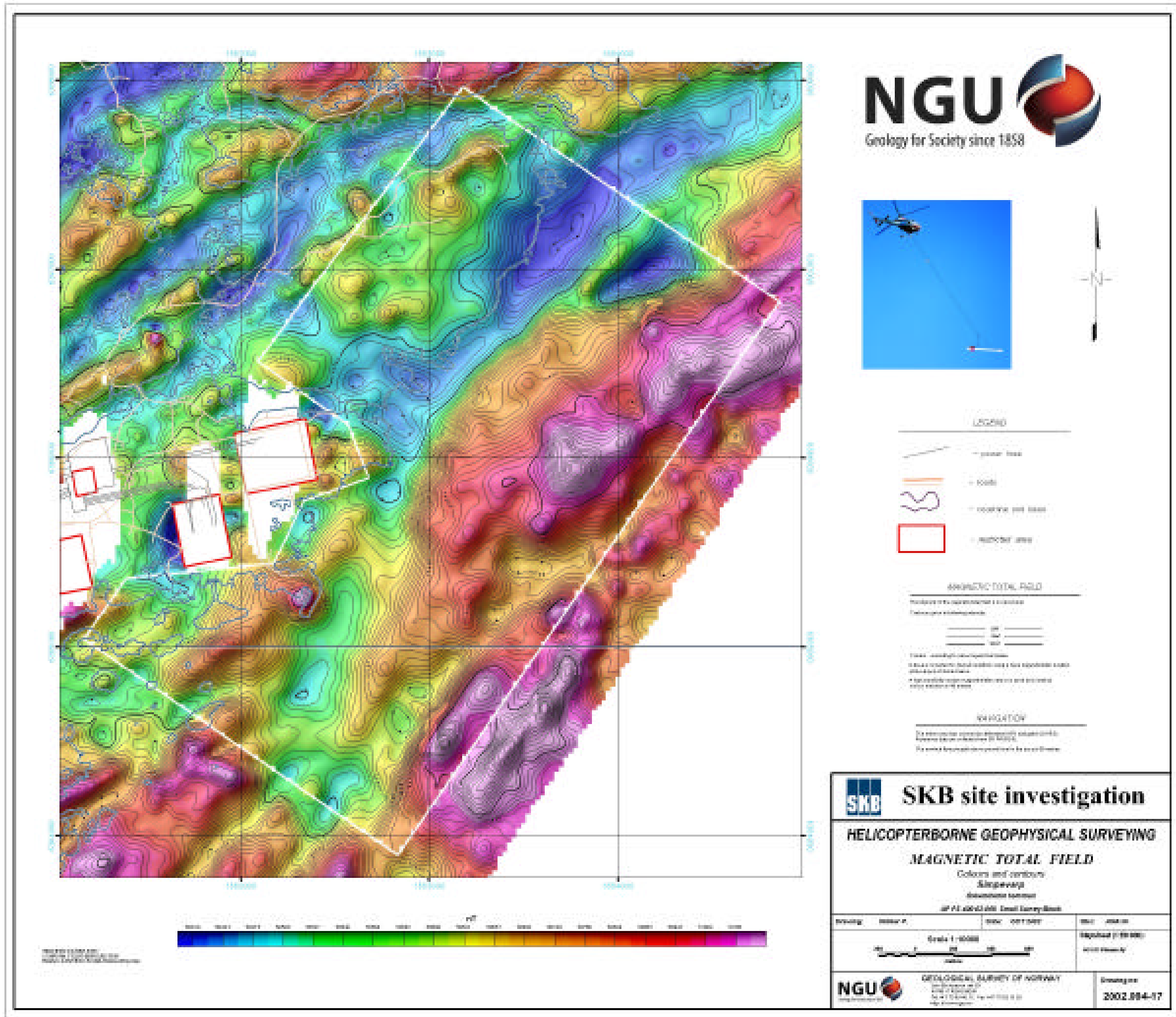

Figure F17. Magnetic Total Field. Small survey block. Map number2002.094-17.

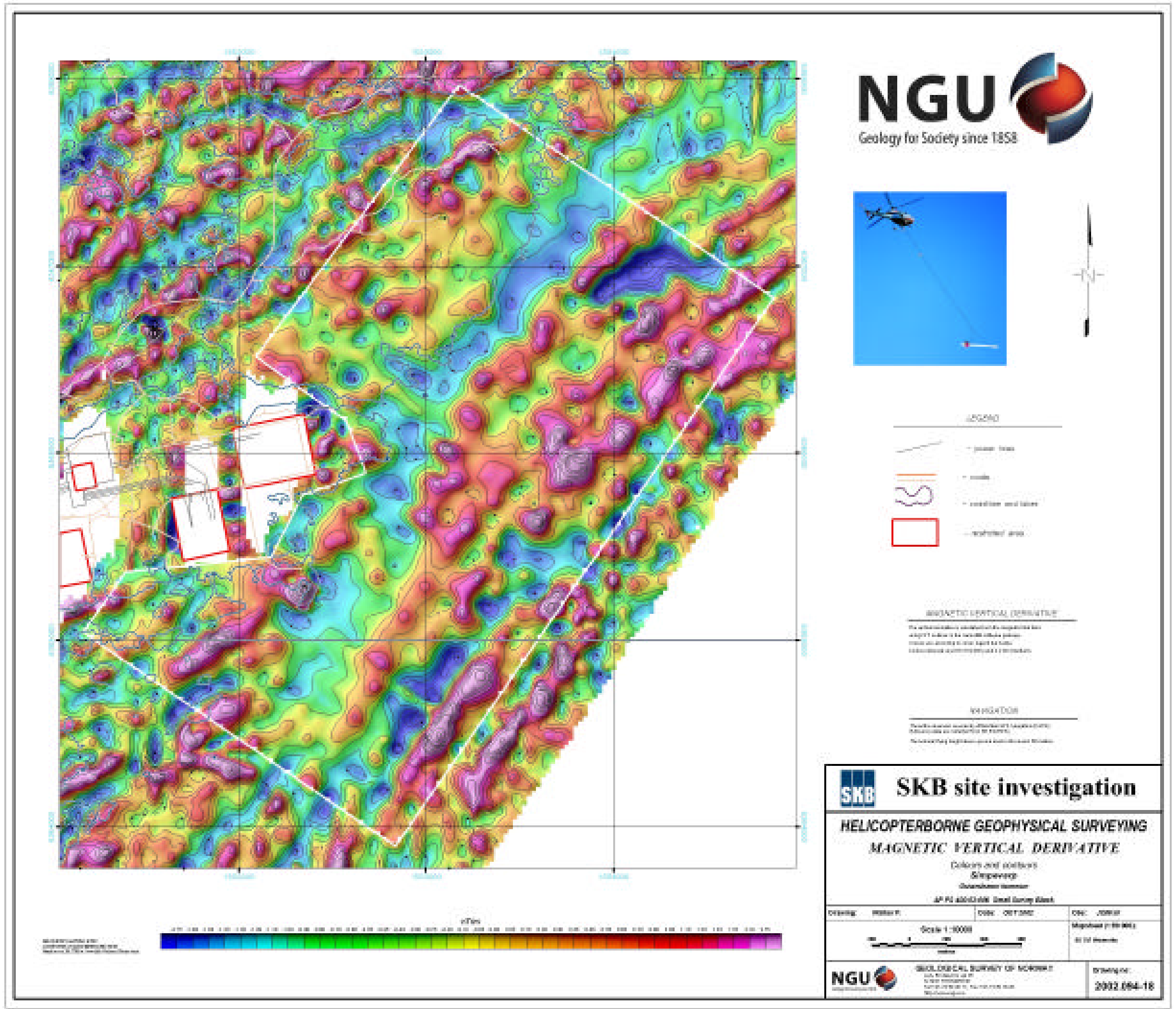

Figure F18. Magnetic Vertical Derivative. Small survey block. Map number2002.094-18.