B. Siemon, D. Eberle, H.-J. Rehli, W. Voß, J. Pielawa

Airborne Geophysical Investigation of Buried Valleys

Survey Area
Ellerbeker Rinne, Germany
2005/2006

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Survey Area: Ellerbeker Rinne, Germany
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Technical Report on the Interreg IIIB Project

Ancient Groundwater Reservoirs in Buried Valleys – Sustainable Water Resources for the Future (BurVal)

In Cooperation with

LANU
Landesamt für Natur und Umwelt Schleswig-Holstein, Flintbek, Germany

BSU
Behörde für Stadtentwicklung und Umwelt, Hamburg, Germany

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Table of contents

List of figures ................................................................................................................ ....... III
List of tables ................................................................................................................. ........ IV
List of maps ................................................................................................................... ........V
List of vertical resistivity sections .........................................................................................VII
Abbreviations .................................................................................................................. ...VIII

1. Summary ........................................................................................................................ 1

2. Introduction ................................................................................................................... 3

3. Airborne Survey ............................................................................................................. 5

  3.1. Ellerbeker Rinne Survey Area ......................................................................................... 5

  3.2. The BGR Airborne Geophysical System ......................................................................... 7

     3.2.1. The Helicopter........................................................................................................................... 7

     3.2.2. The Geophysical Survey Systems............................................................................................. 8

  3.3. Tasks and Function of the Airborne Geophysical System..............................................13

     3.3.1. Electromagnetics ...................................................................................................................... 16

     3.3.2. Magnetics ................................................................................................................................ 16

     3.3.3. Gamma-Ray Spectrometry ....................................................................................................... 17

     3.3.4. Navigation and Positioning....................................................................................................... 18

     3.3.5. Data Recording ........................................................................................................................ 18

     3.3.6. Video System ............................................................................................................................ 19

     3.3.7. Base Station ............................................................................................................................. 19

4. Processing and Presentation of the Survey Data............................................................. 20

  4.1. Processing Steps ........................................................................................................... 20

  4.2. Field Data Processing .................................................................................................... 20

     4.2.1. Data Handling ......................................................................................................................... 20

     4.2.2. Tree-Canopy Effect .................................................................................................................. 22

  4.3. Processing of the Electromagnetic Data ........................................................................23

     4.3.1. Calibration of the HEM System ............................................................................................... 23

     4.3.2. Zero-Level Determination ....................................................................................................... 24

     4.3.3. Data Correction ......................................................................................................................... 24

     4.3.4. Transformation of the Secondary Field Values into Half-Space Parameters ...................... 25

     4.3.5. 1-D Inversion of the HEM Data .............................................................................................. 26

     4.3.6. Effect of Anthropogenic Influences on the HEM Data ......................................................... 27

     4.3.7. Statistical Levelling ................................................................................................................ 27
4.3.8. Presentation of the Results ................................................................. 28
4.4. Processing of the Magnetic Data .......................................................... 28
4.4.1. Magnetic Total Field ........................................................................... 28
4.4.2. IGRF Calculations ............................................................................... 29
4.4.3. Diurnal Variations ............................................................................... 29
4.4.4. Statistical Levelling ............................................................................ 29
4.4.5. Presentation of the Results ................................................................. 30
4.5. Processing of the Gamma-Ray Spectrometry Data ................................. 30
4.5.1. Removing Cosmic and Aircraft Background ................................. 30
4.5.2. Correcting Instrument Dead-Time/Live-Time Effects ....................... 31
4.5.3. Adjustment of Radar Altimeter Data to Standard Temperature and Pressure .................................................. 32
4.5.4. Evaluation of Stripping Ratios on Calibration Pads and Stripping Correction ................................................................. 32
4.5.5. Compton Correction ........................................................................... 33
4.5.6. Height-Attenuation Reduction ............................................................ 33
4.5.7. Calculation of Radio-Element Concentrations and Exposure Rate ................................................................. 34
4.5.8. Statistical Levelling ........................................................................... 35
4.5.9. Presentation of the Results ................................................................. 35
4.6. Map Production with GEOSOFT Software ........................................... 36
5. Cartographic Work .................................................................................. 37
5.1. Topographic Maps ................................................................................. 37
5.2. Flight-Line Maps ................................................................................... 37
5.3. Thematic Maps ...................................................................................... 37
5.4. Digital Elevation Models ...................................................................... 38
6. Archiving .................................................................................................. 38
7. Personnel .................................................................................................. 40
8. References .................................................................................................. 41
Signatures ....................................................................................................... 42
Appendix I: Ellerbeker Rinne Survey ............................................................... 43
Appendix II: Final Data Format Description .................................................. 47
Appendix III: CD-ROM .................................................................................. 55
Appendix IV: Maps ....................................................................................... 56
Appendix V: Vertical Resistivity Sections ....................................................... 97
List of figures:

1. Regions funded by the Interreg IIIB North Sea Programme
2. Ellerbeker Rinne survey area and boundary of the 1:50,000 topographic map
3. BGR Sikorsky S-76B helicopter and bird on ground
4. The airborne geophysical system
5. Block diagram of the airborne geophysical system
6. Block diagram of the data processing steps
7. HEM inversion based on a homogeneous half-space or a layered half-space
8. Calculation of the starting model from apparent resistivity, centroid depth, and apparent depth of a five-frequency HEM data set
List of tables:

1. Survey parameters for the Ellerbeker Rinne survey area
2. Specifications of the BGR helicopter D–HBGR
3. The geophysical survey systems
4. Navigation and positioning systems
5. Altimeters
6. Data acquisition and recording systems
7. Additional equipment
8. Base stations
9. Radiation sources and corresponding spectrometer parameters
10. Calibration factors of the HEM systems
11. Filters used for the removal of the tree-canopy effect
12. IGRF values for the Ellerbeker Rinne survey area
13. Aircraft background and cosmic stripping factor
14. Stripping ratios
15. Height Attenuation Coefficient
16. Element concentrations at Allensteig/Austria
17. Sensitivities at Allensteig/Austria
18. Grid parameters
19. Coordinates of the corners of the 1:50,000 Ellerbeker Rinne topographic map sheet
20. Contents of the CD-ROM
List of maps:

1. Flight lines,
2. Digital elevation model,
3. Apparent resistivity at 133,200 Hz (rhoa5),
4. Apparent resistivity at 41,550 Hz (rhoa4),
5. Apparent resistivity at 8225 Hz (rhoa3),
6. Apparent resistivity at 1820 Hz (rhoa2),
7. Apparent resistivity at 387.2 Hz (rhoa1),
8. Centroid depth at 133,200 Hz (zst5),
9. Centroid depth at 41,550 Hz (zst4),
10. Centroid depth at 8225 Hz (zst3),
11. Centroid depth at 1820 Hz (zst2),
12. Centroid depth at 387.2 Hz (zst1),
13. Resistivity of the second layer (rho2),
14. Resistivity of the third layer (rho3),
15. Resistivity of the fourth layer (rho4),
16. Resistivity of the fifth layer (rho5),
17. Depth of the upper boundary of the second model layer in m b.g.l. (z2),
18. Depth of the upper boundary of the third model layer in m b.g.l. (z3),
19. Depth of the upper boundary of the fourth model layer in m b.g.l. (z4),
20. Depth of the upper boundary of the fifth model layer in m b.g.l. (z5),
21. Resistivity at 00m b.s.l.,
22. Resistivity at 05m b.s.l.,
23. Resistivity at 10m b.s.l.,
24. Resistivity at 15m b.s.l.,
25. Resistivity at 20 m b.s.l.,
26. Resistivity at 25m b.s.l.,
27. Resistivity at 30 m b.s.l.,
28. Resistivity at 35m b.s.l.,
29. Resistivity at 40m b.s.l.,
30. Resistivity at 45m b.s.l.,
31. Resistivity at 50 m b.s.l.,
32. Resistivity at 55m b.s.l.,
33. Resistivity at 60m b.s.l.,
34. Resistivity at 65 m b.s.l.,
35. Resistivity at 70 m b.s.l.
36. Anomalies of the total magnetic field (ΔT),
37. Concentration of Potassium (K),
38. Concentration of Thorium (Th),
39. Concentration of Uranium (U),
40. Stripped total count rate (TC),
41. Ground level exposure rate in μR/h.
List of vertical resistivity sections:

### Survey 2005:

<table>
<thead>
<tr>
<th>Tie lines</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. VRS 1.9</td>
<td>11. VRS 70.1,</td>
</tr>
<tr>
<td>2. VRS 1.8</td>
<td>12. VRS 73.1,</td>
</tr>
<tr>
<td>3. VRS 2.9</td>
<td>13. VRS 76.1,</td>
</tr>
<tr>
<td>4. VRS 2.8</td>
<td>14. VRS 79.1,</td>
</tr>
<tr>
<td>5. VRS 3.9</td>
<td>15. VRS 82.1,</td>
</tr>
<tr>
<td>6. VRS 3.8</td>
<td>16. VRS 85.1,</td>
</tr>
<tr>
<td>7. VRS 4.9</td>
<td>17. VRS 88.1,</td>
</tr>
<tr>
<td>8. VRS 4.8</td>
<td>18. VRS 91.1,</td>
</tr>
<tr>
<td>9. VRS 5.9</td>
<td>19. VRS94.1,</td>
</tr>
<tr>
<td>10. VRS 6.9</td>
<td>20. VRS 97.1,</td>
</tr>
<tr>
<td></td>
<td>21. VRS 97.2,</td>
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<td></td>
<td>114. VRS 270.1,</td>
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<tr>
<td></td>
<td>115. VRS 271.1,</td>
</tr>
<tr>
<td></td>
<td>116. VRS 272.1</td>
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</table>
Abbreviations

°       degree
'       minute
%       per cent
1-D     one-dimensional
α,β,γ,a,b,g stripping ratios
a       aircraft background
Ah      ampere hour
a.m.s.l. above mean sea level
b       cosmic stripping factor
Bi      bismut
b.g.l.  below ground level
BGR     Bundesanstalt für Geowissenschaften und Rohstoffe
BSU     Behörde für Stadtentwicklung und Umwelt, Geologisches Landesamt Hamburg
BurVal  buried valleys
°C      degrees Celsius
C       concentration
C       cosmic channel count
cm      centimetre
cps     counts per second
Cs      cesium
©       copy right
δ       residual
Δ       difference
d a     apparent depth
D a     apparent distance
DEM     digital elevation model
DC      direct current
DGPS    Differential Global Positioning System
DGPS-Z  vertical DGPS component
E       east
E       ground level exposure rate
ED      European Datum
EM      electromagnetic(s)
e       base of the natural logarithm (1/e ≈ 0.37)
ERDF    European Regional Development Fund
F       normal magnetic field
f       frequency
ft      feet
GBA     Geologische Bundesanstalt

GPS  Global Positioning System
h  bird altitude
h_e  effective height
HEM  helicopter electromagnetic(s)
Hz  hertz
i  counter
IAEA  International Atomic Energy Association
IAGA  International Association of Geomagnetism and Aeronomy
IGRF  International Geomagnetic Reference Field
K  potassium
kg  kilogram
kHz  kilohertz
km  kilometre
km²  square kilometre
km/h  kilometres per hour
LANU  Landesamt für Natur und Umwelt Schleswig-Holstein
L  litre
L/h  litres per hour
log  logarithm
lt  life time
m  metre
MAG  magnetics
mbar  millibar
MeV  mega electronic volts
mm  millimetre
m.s.l.  mean sea level
mV  millivolt
µ  adsorption value / attenuation coefficient
µR/h  microroentgens per hour
n  number of frequencies
N  north
N  background radiation
n, N  raw, corrected count rate
NaI  sodium iodid
nT  nanotesla
Ωm  ohm metre (Ohm*m)
P  barometric pressure
PC  personal computer
ppm  parts per million
Q  quadrature or out-of-phase component of the HEM data
R  inphase component of the HEM data
r  distance parameter
ρ  resistivity
ρ a  apparent resistivity
S  south
S  sensitivity
s, sec  second
SCI  radiometrics (scintillometry)
STP  standard pressure and temperature
t  thickness (of a model layer)
t  time variable
t  corrected count rate
T  temperature
T, TMI  total magnetic field
ΔT  anomalies of the total magnetic field
Th  thorium
Tl  thallium
U  uranium
UTC  Coordinated Universal Time
UTM  Universal Transverse Mercator Projection
TC  total count
VRS  vertical resistivity section
V  volt
Vm  mean of diurnal variation
ΔV  diurnal (magnetic) variations
W  west
WGS  World Geodetic System
x, y, z  cartesian coordinates, z depth axis
z*  centroid depth
ζ, λ  geographical coordinates (ζ = latitude, λ = longitude)
1. Summary

Buried valleys or sub-glacial melt-water drainage channels are subject of the project “Ancient groundwater reservoirs in buried valleys (BurVal) – sustainable water resources for the future” which has been jointly launched by several European partners in Germany, Denmark and The Netherlands in 2004. The project focuses mainly on groundwater reservoirs found in the shallow strata deposited during Quaternary Late Middle and Upper Pleistocene times, which include three major Ice Ages, the Elsterian, Saalian and Weichselian glacial periods. The Quaternary morphology of this area is dominated by several buried channels. Their origin is attributed to sub-glacial melt-water transport incising the underlying sedimentary strata during periods of glacial coverage. Such channels were commonly developed in the melting zones of the glaciers. After the retreat of the glaciers, the ground floor topography was filled by marine and glacio-marine sediments, often in form of fine grain sediments like clays and silts.

The aims of the BurVal project can be summarized to deliver knowledge and understanding of the structural and hydrological properties of deeper groundwater resources found in buried valleys, to focus on the vulnerability of surface contamination or other human impacts, and to investigate interactions with other water reservoirs and saltwater intrusions. This should lead to the development of spatial planning strategies that take these ancient groundwater reservoirs into account. The project is part-financed by the European Union (Interreg IIIb North Sea Programme of the European Regional Development Fund - ERDF) and focuses on six special project areas in Germany, Denmark and The Netherlands. Details can be found on the web site of the project (http://www.burval.org).

In charge of the German Landesamt für Natur und Umwelt des Landes Schleswig-Holstein (LANU) and Behörde für Stadtentwicklung und Umwelt, Geologisches Landesamt Hamburg (BSU), one of the six pilot projects is carried out in the Ellerbeker Rinne area, Germany, where a buried valley stretches from the small town Barmstedt in southern Schleswig-Holstein in southeast direction at a length of about 25 km to the downtown area of the Free and Hanseatic City of Hamburg. A helicopter-borne survey, split in two parts, was conducted by the airborne group of the German Federal Institute for Geosciences and Natural Resources (BGR) in April 2005 and in May 2006. The airborne survey comprises a 8-12 km by 28 km wide area from about 9°40’E to 9°59’E and 53°38’N to 53°55’N. With 7 flights 99 ENE–WSW profile lines and 6 NNW–SSE tie-lines were flown, totalling about 893 line-km. The nominal flight-line spacing was 400/600 m for the profile lines and 2000 m for the tie-lines.

The BGR helicopter-borne geophysical system includes five-frequency electromagnetics (HEM), magnetics (MAG) and gamma-ray spectrometry (SCI). The electromagnetic system provides information about the distribution of electrical conductivity in the earth down to a maximum depth of 150 m. The intensity of the earth’s total magnetic field is measured with a magnetometer. Magnetic anomalies may have deep sources as well as shallow ones. The intensity of the gamma radiation is registered by a gamma-ray spectrometer. The radiation measured is mainly emitted from the elements thorium, uranium, and potassium. The origin of this radiation is normally close to the earth’s surface.
The helicopter-borne system consists of the BGR-helicopter, the geophysical equipment and electronic equipment for navigation. The HEM and MAG sensors, the GPS antenna and a laser altimeter are installed inside a towed tube, called the bird. The navigation instruments and the gamma-ray spectrometer are mounted in the helicopter. A ground base station records the time-variant data required to correct the airborne data.

The survey altitudes of the sensors are normally 30–40 m for electromagnetics and magnetics and 70–80 m for gamma-ray spectrometry. HEM and MAG data are recorded 10 times per second during a survey flight and SCI data is recorded once per second. At an aircraft speed of about 140–150 km/h, this leads to mean sampling intervals of about 4 m and 40 m, respectively.

The collected geophysical data and the corresponding positioning data are stored on a ZIP disk during the flight. The digital data is checked immediately after the flight. Further processing of all survey data, including the data of the simultaneously operating base station which records the variations of the total magnetic intensity and the variations of the atmospheric pressure, take place in the field and finally at BGR in Hannover.

This “Technical Report” describes the survey operations and the survey equipment used, as well as the data processing and the presentation of the results as vertical resistivity sections and thematic maps. The processed data, the thematic maps and the vertical sections are stored on CD-ROMs, accompanying this report.
2. Introduction

Buried valleys or sub-glacial melt-water drainage channels are subject of the project “Ancient groundwater reservoirs in buried valleys (BurVal) – sustainable water resources for the future”. The project focuses mainly on groundwater reservoirs found in the shallowest strata deposited during Quaternary Late Middle and Upper Pleistocene times, which include three major Ice Ages, the Elsterian, Saalian and Weichselian glacial periods. The Quaternary morphology of this area is dominated by several buried channels. Their origin is attributed to sub-glacial melt-water transport incising the underlying sedimentary strata during periods of glacial coverage (Huuse & Lykke-Andersen, 2000; Huuse et al. 2003). Such channels were commonly developed in the melting zones of the glaciers (Boulton et al., 1995; Boulton & Caban, 1995). After the retreat of the glaciers, the ground floor topography was filled by marine and glacio-marine sediments, often in form of fine grain sediments like clays and silts (Gausland, 1998; Huuse & Lykke-Andersen, 2000).

Today, these ancient valleys are buried by Quaternary sediments. Buried valleys are often important groundwater reservoirs. Valleys located close to the coast are threatened by saltwater intrusions while valleys beneath farming land might be contaminated by deep penetrating nitrate. As it is important to investigate buried valleys, the project BurVal has been jointly launched by several European partners in Germany, Denmark and The Netherlands in 2004.

The aims of BurVal are to deliver knowledge and understanding of the structural and hydrological properties of deeper groundwater resources found in buried valleys, to focus on the vulnerability of surface contamination or other human impacts, and to investigate interactions with other water reservoirs and saltwater intrusions. This should lead to the development of spatial planning strategies that take these ancient groundwater reservoirs into account. The project is part-financed by the European Union (Interreg IIIB North Sea Programme of the European Regional Development Fund (ERDF) and project areas: A: Groningen Valley, Germany, B: Cuxhaven Valley, Germany, C: Ellerbek Valley, Germany, D: Rødekro Valley, Denmark, E: Tysring Valley, Denmark, and F: Bording Valley, Denmark.)
The Regional Development Fund – ERDF and focuses on six special project areas in Germany, Denmark and The Netherlands. Details can be found on the web site of the project (http://www.burval.org).

One of the six pilot projects is carried out in the Ellerbeker Rinne area, Germany, where a buried valley stretches from the small town Barmstedt in southern Schleswig-Holstein in south-east direction at a length of about 25 km to the downtown area of the Free and Hanseatic City of Hamburg (C in Fig. 1). The water reservoir of this valley is used by the Hamburger Wasserwerke and the Pinneberger Wasserwerke. Drillings reveal that the composition of the aquifer in the valley shows distinct lateral variations from medium to coarse sands in the southern part to fine sand to silt in the northern part. That means that the yield of the aquifer is high in the south and low in the north. The aquifer is covered with mica clay (Lauenburger Ton). In the area of Tangstedt (about 5 km NE of Pinneberg) the Ellerbeker Rinne is crossed by another, probably younger, valley. In this area the covering mica clay is replaced by boulder till.

A helicopter-borne survey, split in two parts, was conducted by the airborne group of the German Federal Institute for Geosciences and Natural Resources (BGR) in April 2005 and in Mai 2006. As the valley crosses the boundary between two German federal states, both the Landesamt für Natur und Umwelt des Landes Schleswig-Holstein (LANU) and Behörde für Stadtentwicklung und Umwelt, Geologisches Landesamt Hamburg (BSU) are responsible for the coordination of the measurements and the interpretation of the diverse data sets.

This “Technical Report” describes the survey operations and the survey equipment in use, as well as the data processing and the presentation of the results as vertical resistivity sections and thematic maps. The processed data, the thematic maps and the vertical sections are stored in a CD-ROM accompanying this report.
3. **Airborne Survey**

3.1. **Ellerbeker Rinne Survey Area**

Four of the six pilot areas have been surveyed by BGR using its helicopter-borne survey system. The Ellerbeker Rinne survey area is situated to the north-east of the Free and Hanseatic City of Hamburg, Germany. It comprises a 8-12 km by 28 km wide area from about 9°40’E to 9°59’E and 53°38’N to 53°55’N. A map of the survey area (red dots) is shown in **Fig. 2**, which also shows the boundary (dashed black line) of the 1: 50,000 topographic map used to present the geophysical results.

![Fig. 2: Ellerbeker Rinne survey area (red dots) and boundary of the 1:50,000 topographic map (dashed black line)]
An area of approximately 280 km² was surveyed with 7 flights on April 19–20, 2005 and May 16–19, 2006. There were 99 ENE–WSW profile lines and 6 NNW–SSE tie–lines flown, totaling about 893 line-km. The nominal flight-line spacing was 600 m in 2005 and 400 m in 2006 for the profile lines and 2000 m for the tie-lines. As a new HEM system has to be used for the survey in 2006, it covers the entire survey area but without tie-lines. The survey flights commenced from Hartenholm airport (32 m a.m.s.l.). The survey parameters are given in Table 1.

Table 1: Survey parameters for the Ellerbeker Rinne survey area

<table>
<thead>
<tr>
<th>BGR area no.</th>
<th>111</th>
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</table>
| Field period | April 19–20, 2005  
May 16–19, 2006 |
| Size of survey area | 280 km² |
| Total length of survey lines | 893 km |
| Number of survey flights | 7 |
| Flight numbers | 11100–11107 |
| Mean flight altitude of the EM sensor above ground | 50 m |
| Speed during survey flight | 100–170 km/h |
| Number of profile-line flights | 6 |
| Number of profile lines | 99 (106) |
| Profile-line lengths | 9-12 km |
| Profile-line directions (angle to N) | ENE–WSW (28° / 208°) |
| Profile-line spacing | 400/600 m |
| Number of tie-line flights | 1 |
| Number of tie-lines | 6 (10) |
| Tie-line lengths | 7–11 km |
| Tie-line directions (angle to N) | NNW–SSE (118° / 298°) |
| Tie-line spacing | 2000 m |

The survey had to be split into two parts due to technical problems with the helicopter in April 2005. As the helicopter had been shipped to Banda Aceh, Indonesia, in spring 2005 for several months, the completion of the survey could not commence until spring 2006. The lines flown primarily northwards or eastwards are normally given an even profile number, while the ones flown in the opposite directions are odd numbered. The profile lines have the extension “.1” (after the profile number) or “.2” for split lines, and the tie-lines have the extension “.9” or “.8” for split lines. Details of the survey flights are given in Appendix I.

The average altitude of the helicopter was 90 m above ground level within the survey area. During a survey flight, particularly before the first and after the last profile, the altitude was increased to >350 m to check the calibration of the HEM system far from any disturbing influences.
3.2. **The BGR Airborne Geophysical System**

BGR’s airborne geophysical system simultaneously records the electromagnetic, magnetic, and gamma-ray spectrometry data. The geophysical instrumentation, the navigation and positioning systems, the analogue and digital recording units, as well as other equipment needed for the survey flights are integrated in one measuring system carried by a Sikorsky S–76B helicopter (Fig. 3). The HEM and MAG sensors, the GPS antenna and a laser altimeter are installed inside a towed tube, called the bird. The navigation instruments and the gamma-ray spectrometer are mounted in the helicopter. A ground base station records the time-variant data required to correct the airborne data.

![BGR Sikorsky S-76B helicopter and bird on ground](image)

**Fig. 3:** BGR Sikorsky S-76B helicopter and bird on ground

3.2.1. **The Helicopter**

The helicopter, a Sikorsky S-76B (see Table 2), was purchased in 1986 by the Federal Ministry for Economic Cooperation and Development and assigned to BGR, mainly for technical cooperation projects.

**Table 2:** Specifications of the BGR helicopter D–HBGR

<table>
<thead>
<tr>
<th>Type</th>
<th>Sikorsky S-76B (Manufacturer: Sikorsky, USA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of manufacture</td>
<td>1986</td>
</tr>
<tr>
<td>Engines</td>
<td>2 turbines Pratt &amp; Whitney PT6B-36A with 1033 SHP (shaft horse power) for each</td>
</tr>
<tr>
<td>Maximum gross weight</td>
<td>11,700 pounds (5363 kg)</td>
</tr>
<tr>
<td>Maximum payload</td>
<td>3300 pounds (1500 kg)</td>
</tr>
<tr>
<td>Maximum flight duration</td>
<td>2¾ hours</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>350–400 L/h</td>
</tr>
</tbody>
</table>
3.2.2. **The Geophysical Survey Systems**

The units of the airborne geophysical systems are summarized in Tables 3–8.

**Table 3:** The geophysical survey systems

<table>
<thead>
<tr>
<th>The Geophysical Survey Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Five-Frequency Electromagnetic System (HEM)</strong></td>
</tr>
<tr>
<td><strong>Function</strong></td>
</tr>
<tr>
<td><strong>System description</strong></td>
</tr>
<tr>
<td><strong>Frequencies</strong></td>
</tr>
<tr>
<td><strong>T-R coil separation</strong></td>
</tr>
<tr>
<td><strong>Coil orientation</strong></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
</tr>
<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td><strong>Bird</strong></td>
</tr>
<tr>
<td><strong>II. Magnetometer</strong></td>
</tr>
<tr>
<td><strong>Function</strong></td>
</tr>
<tr>
<td><strong>System description</strong></td>
</tr>
<tr>
<td><strong>Location of sensor</strong></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
</tr>
<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td><strong>Helicopter</strong></td>
</tr>
<tr>
<td><strong>III. Gamma-Ray Spectrometer</strong></td>
</tr>
<tr>
<td><strong>Function</strong></td>
</tr>
<tr>
<td><strong>System description</strong></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
</tr>
<tr>
<td><strong>Type</strong></td>
</tr>
</tbody>
</table>
During the second part of the survey in 2006 a digital five-frequency HEM system was used which frequencies and coil separations slightly differ from those of digital five-frequency HEM system used in 2005.

**Table 4: Navigation and positioning systems**

| Helicopter | Function | On-line determination and display of the GPS navigational information required by the pilot: position of helicopter, deviation from the planned flight path, and distance to next way point. With the coordinates of the area corners, the profile direction [in degrees] and the spacing of the flight lines as input, the navigation computer calculates the coordinates of the starting and end points for all survey profiles. The planned profiles, the actual flight line, and the position of the helicopter are shown on a display. A separate display gives the pilot in graphical and digital form all the information used to fly a profile with the highest possible precision.  
| Manufacturer | Navigation computer and display: AgNav, Canada  
DGPS receiver: CSI Wireless, Canada |  
| Type | Navigation computer: PNAV 2100  
DGPS receiver: DGPS MAX |

| Bird | Function | Determination and recording of the geographic position and altitude of the HEM bird above mean sea level  
| Manufacturer | CSI Wireless, Canada |  
| Type | DGPS MAX |
### Table 5: Altimeters

<table>
<thead>
<tr>
<th>Altimeters</th>
<th>Function</th>
<th>System description</th>
<th>Manufacturer</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radar Altimeter</strong></td>
<td>Recording of the altitude of the helicopter above ground level or above obstacles, such as forests and buildings</td>
<td>Radar impulses are transmitted from an antenna mounted at the bottom of the helicopter. The altitude of the helicopter is determined by evaluating the travel time of the impulses to the ground and back to the antenna. The radar altimeter responds to the very first reflections arriving from below, which means, for example, when the helicopter is over a forest the distance between the antenna and the treetops will be obtained instead of the distance to the ground. The radar altitude is recorded 10 times per second.</td>
<td>Sperry, USA</td>
<td>AA-200</td>
</tr>
<tr>
<td><strong>Barometric Altimeter</strong></td>
<td>Recording of the altitude of the helicopter above mean sea level</td>
<td>The air pressure is recorded and transformed into altitude values (in units of feet) and recorded 10 times per second</td>
<td>Rosemount, USA</td>
<td>1241A5B</td>
</tr>
<tr>
<td><strong>Laser Altimeter</strong></td>
<td>Recording of the altitude of the HEM bird above ground with high precision</td>
<td>The laser altimeter hosted by the HEM bird emits impulses down to the ground. Evaluation of the travel time of impulses reflected at the ground surface provides the distance between the bird and the ground surface. Since the laser beam is extremely narrow it often penetrates the vegetation at the ground surface thus delivering the height of the HEM bird above ground surface. The laser altitude is recorded 10 times per second.</td>
<td>Riegl, Austria</td>
<td>LD90-31K</td>
</tr>
</tbody>
</table>
### Table 6: Data acquisition and recording systems

<table>
<thead>
<tr>
<th>Data Acquisition System</th>
<th>Function</th>
<th>System description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Digitizing the analogue signals, recording of the digital signals, organizing the selected data into data blocks, and transferring data blocks to digital and analogue data recorders</td>
<td>All signals to be recorded are managed by the data acquisition system. Sequence and intervals of data acquisition from the various sensors are adapted to the needs of data properties. Individual data are compressed into data blocks. Data blocks are then sent to digital (ZIP drive) and analogue data recorders during well defined time intervals. A digital display supports supervision of correct data transfer.</td>
</tr>
</tbody>
</table>

| Manufacturer | RMS, Canada |
| Type         | DAS 8       |

<table>
<thead>
<tr>
<th>Digital Data Recorder</th>
<th>Function</th>
<th>System description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recording of the data using a digital device</td>
<td>Data blocks containing ASCII and binary formatted data are recorded on a ZIP disk once a second.</td>
</tr>
</tbody>
</table>

| Manufacturer | RMS, modified by BGR |
| Type         | n/a                  |

<table>
<thead>
<tr>
<th>Analogue Recorder</th>
<th>Function</th>
<th>System description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Producing analogue records of all essential data during survey flight</td>
<td>Signals from up to 32 analogue and digital data channels are plotted by a high-resolution thermal printer onto 321 mm wide endless paper.</td>
</tr>
</tbody>
</table>

| Manufacturer | RMS, Canada |
| Type         | GR33A       |
### Table 7: Additional equipment

<table>
<thead>
<tr>
<th>Helicopter</th>
<th>Additional Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video System</td>
<td>Recording of the flight track and monitoring of the movements of the HEM bird during take-off, landing and flight</td>
</tr>
<tr>
<td>Function</td>
<td>The flight track is continuously filmed and taped using a video camera mounted on the floor of the helicopter. The pilot and the operator monitor the movements of the HEM bird via two screens placed in the cockpit and the instrument rack.</td>
</tr>
<tr>
<td>System description</td>
<td></td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Camera: Pulnix, USA Video recorder: Toshiba, Japan</td>
</tr>
<tr>
<td>Type</td>
<td>Camera: TMC-63M; Video recorder: V701 TO</td>
</tr>
<tr>
<td>Central Power Unit</td>
<td>28 V DC on-board voltage of the helicopter filtered by a 24 Ah buffer battery is connected to a central power unit. From there it is distributed to the individual components of the system with fuses built-in to protect devices from overvoltage.</td>
</tr>
<tr>
<td>Basic principle</td>
<td></td>
</tr>
<tr>
<td>Central Signal Distribution</td>
<td>Distributing the analogue signals onto the digital recorder, visualizing the most important analogue and digital survey data.</td>
</tr>
<tr>
<td>System description</td>
<td></td>
</tr>
<tr>
<td>Instrument Rack</td>
<td>19” rack to mount all components of the airborne geophysical system. Shock absorbers between the base of the rack and a wood board which is firmly screwed to the floor of the helicopter minimize the transfer of vibrations originating from the rotor.</td>
</tr>
<tr>
<td>Characteristics</td>
<td></td>
</tr>
</tbody>
</table>
Table 8:  Base stations

<table>
<thead>
<tr>
<th>Base Station</th>
<th>Magnetic and Barometric Base Station</th>
<th>Function</th>
<th>Recording of the variations of the total magnetic intensity (TMI) and of the atmospheric pressure for corrections to be applied on some of the collected survey data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base station</td>
<td></td>
<td>System description</td>
<td>The base station is portable, weather-proof and equipped with own power supply. It serves to automatically record the variations of the TMI and atmospheric pressure. Routinely, one reading is taken per second. Since these readings have to be synchronized with the airborne survey data, the GPS time of each reading is also recorded.</td>
</tr>
<tr>
<td>Manufacturer</td>
<td></td>
<td></td>
<td>Base station: FAS, Canada</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Barometer: MPXS4115A, Motorola, USA</td>
</tr>
<tr>
<td>Type</td>
<td></td>
<td></td>
<td>CF1 Data Logger</td>
</tr>
</tbody>
</table>

3.3. Tasks and Function of the Airborne Geophysical System

A sketch of the BGR airborne geophysical system is shown in Fig. 4; a simplified block diagram of the survey system is shown in Fig. 5. The bird is connected to the helicopter by a cable of approximately 45 m length. Depending on the flight speed, the bird is towed about 41 m beneath the helicopter. This length of cable was chosen to avoid the influence of the helicopter on the highly sensitive magnetic and electromagnetic sensors.

The shell of the approximately 10-m-long cigar-shaped “bird” with a diameter of 0.5 m is made of Kevlar to obtain high flexural strength. This material has an extremely high mechanical stability and poor electric conductivity.
Fig. 4: The airborne geophysical system
Fig. 5: Block diagram of the airborne geophysical system
3.3.1. Electromagnetics

The transmitter coils of the HEM system create sinusoidal magnetic fields at discrete frequencies. These primary fields induce eddy currents in electrically conducting earth. In turn, these currents generate magnetic fields, the secondary fields, which are detected by the receiver coils (Fig. 4). The strength and the phase shift of these very weak secondary fields depend on the electric conductivity in the subsurface, the frequency used, and the altitude of the system above ground level.

The HEM system uses separate coil systems (transmitter, receiver, bucking, and calibration coils installed horizontally and coplanar) for each of the five frequencies between 375/387.2 Hz and 128.5/133.2 kHz (Table 3). As the secondary fields are related to the primary fields at the receivers, which are compensated using bucking coils with exactly known specifications, relative units are useful. The unit ppm (parts per million) is used because the strength of the secondary field is much smaller than the strength of the primary field at the receiver coils. Internal calibration coils generate calibration signals in the receivers. These signals which ppm values are provided by the manufacturer are used to determine the conversion factors for the measured secondary field voltages.

The electrical conductivity (or its reciprocal: resistivity) can be calculated from amplitude and phase shift or from in-phase and out-of-phase components of the secondary field. Due to the electromagnetic skin effect, the electromagnetic fields are associated with different penetration depths for each of the frequencies used: The lower the frequency and the higher the resistivity, the greater the penetration depth. With the lowest frequency of 375 Hz currently used, investigation depths up to 150 m are obtainable under ideal conditions.

The HEM system is not only sensitive to the electrically conductive subsurface but also to anthropogenic objects like, e.g., buildings, metallic bodies, and electrical installations, which have influence on the data measured, particularly at lower frequencies. As the helicopter itself is such an object, the HEM system is installed in a rigid tube, called “bird” (Table 3), which is towed at a sufficiently large distance (about 40 m) underneath the helicopter.

3.3.2. Magnetics

The total intensity $T$ of the earth’s magnetic field is measured with a highly sensitive cesium magnetometer. This magnetic field is composed of three parts: The total magnetic intensity field of the earth – with its minimum at the equator and its maximum at the poles – is overlain by anomalous magnetic fields from geogenic sources (e.g., magnetite-containing minerals and mineral deposits) as well as from fields of anthropogenic nature (buildings, industrial plants, waste deposits and others). The more general geogenic anomalies cover a larger area than anomalies resulting from anthropogenic sources, which are mostly of local nature.

The cesium sensor provides a signal with a frequency called the Larmor frequency, which is directly proportional to the total field intensity. The proportionality constant is 3.4986 Hz per nT. The operating range of the instrument is 20,000–100,000 nT.
Owing to the sensitivity of the cesium sensor, which determines the total magnetic field with a resolution of 0.01 nT, the sensor is installed in the middle of the bird, preferably far from the helicopter. The sensor is mounted so that it can be adjusted with respect to the flight line direction to get the maximum signal strength.

### 3.3.3. Gamma-Ray Spectrometry

BGR uses a standard spectrometer system consisting of four sodium iodide (NaI) crystals to detect the ground gamma radiation and one upward looking crystal to detect the radon radiation in the air. For geophysical investigations the count rates of the common terrestrial radioactive elements (or their isotopes and daughter products) Tl-208 (thorium series), Bi-214 (uranium series), K-40 (potassium) are of interest. The different distributions of these three elements in the ground are useful for geological mapping.

The spectrometer crystals are placed together in an aluminium box. Each crystal has a volume of approximately 4 L (10×10×40 cm). Incident gamma radiation is absorbed by the crystals and transformed into light impulses. These impulses are converted into electric impulses by a photomultiplier; the amplitudes of the electrical impulses are directly proportional to the energy of incident gamma radiation. Depending on their energy, the pulses are sorted into one of the 255 energy channels covering the entire energy spectrum from 0 to 3 MeV; channel 256 is provided for cosmic radiation between 3 and 6 MeV. Integrated over one second, gamma radiation in the energy windows for the total radiation, for potassium, uranium and thorium, as well as for each channel of the spectrum, is recorded. Energies and channels for the different radiation sources are shown in Table 9. The spectrometer is calibrated and stabilised against an internal standard. This is done for each of the four downward-looking crystals using the thorium peak. Shifts of the thorium peak (2.62 MeV) relative to the nominal value are identified and the gain of the photomultiplier of the respective crystal corrected automatically. A cesium probe is used to stabilize the gain of the upward looking crystal.

**Table 9: Radiation sources and corresponding spectrometer parameters**

<table>
<thead>
<tr>
<th>Radiation Source</th>
<th>Energy Window in MeV</th>
<th>Peak Energy in MeV</th>
<th>Channel Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total count</td>
<td>0.41–2.81</td>
<td>—</td>
<td>34–233</td>
</tr>
<tr>
<td>Potassium (K-40)</td>
<td>1.37–1.57</td>
<td>1.46</td>
<td>115–131</td>
</tr>
<tr>
<td>Uranium (Bi-214)</td>
<td>1.66–1.86</td>
<td>1.76</td>
<td>139–155</td>
</tr>
<tr>
<td>Thorium (Tl-208)</td>
<td>2.41–2.81</td>
<td>2.62</td>
<td>202–233</td>
</tr>
<tr>
<td>Cosmic radiation</td>
<td>3.0–6.0</td>
<td>—</td>
<td>255</td>
</tr>
</tbody>
</table>
3.3.4. Navigation and Positioning

The navigation system (Table 4) provides the pilot with all the information necessary to carry out a survey flight. The navigation computer calculates the coordinates of the starting and the end points of all survey profiles from the coordinates of the corners of the survey area, the profile direction and the spacing of the flight lines. These profiles are shown on a display and the line being flown is highlighted.

The pilot obtains all the information required to fly this profile as accurately as possible from a second display. The most important information is the lateral deviation from this line. The deviation appears digitally in metres, as well as on a bar diagram. The navigation computer receives information about the position of the helicopter from a DGPS navigation receiver whose antenna is fixed outside on the helicopter. The error in the navigation data is less than 1–2 m.

The positioning system (Table 4) provides the coordinates of each and every geophysical measurement. A second DGPS navigation receiver is used for this purpose, whose antenna is fixed outside at the bird. The spatial positions of the sensors are determined from this positioning data. The error of the coordinates is also in the order of 1–2 m.

A radar altimeter attached to the bottom of the helicopter determines its altitude above the ground or above obstacles (e.g., large stands of trees and buildings) with a precision of ±3 m. The altitude is needed to process the radiometric data. A barometric altimeter is used to determine the altitude of the helicopter above mean sea level, but is employed only as a backup for the DGPS receivers. The altitude of the bird above the ground must be accurately known for the processing of the electromagnetic data and to generate a digital terrain model. A laser altimeter inside the bird provides this altitude with a precision of ±0.2 m. A further advantage of the laser altimeter, in addition to its precision, is the focused laser beam, which when above a forest often allows the distance to the surface to be determined and not only to the treetops, as is the case with the radar altimeter. The digital elevation model is derived from the elevation of the HEM bird in m a.m.s.l. minus the laser altitude. The altimeters are described in Table 5.

3.3.5. Data Recording

All the data are stored digitally on an IOMEGA ZIP disk during a survey flight (Table 6). The most important data channels are plotted on chart paper to enable continual checking of the data during the flight. Immediately after a flight, the analogue plots are checked more accurately in order to obtain an impression of the geophysical results, but also to detect any problems with the survey system. The digital data are transferred to a PC, checked and prepared for further processing.
3.3.6. Video System

A video camera is mounted in the bottom of the helicopter. Two monitors, one in the cockpit and one in the operator’s rack, allow monitoring of the bird at take-off and landing and during the flight.

The video recording of the flight path is used to locate sources of anomalous or disturbed data on the ground. By including the GPS time and a record counter on the video record, the flight path can be correlated directly with the analogue and digital data.

3.3.7. Base Station

The total magnetic field of the earth is not constant and the temporal variations can range from milliseconds to many hours. The normal magnetic daily variations recorded during the surveys show peak-to-peak values from 20 nT to 100 nT. The atmospheric pressure also shows temporal variations.

The total magnetic field and the atmospheric pressure is recorded at a base station (Table 7) equipped with a magnetometer and a barometer. During a survey it is placed at a location with low magnetic disturbances. The daily variations are determined from the values collected for both parameters. They are used to correct the total magnetic field and barometric altitude measured during the flight. The airborne and base station data are correlated using the GPS time recorded by both devices.
4. **Processing and Presentation of the Survey Data**

The general objectives of the data processing may be summarized as follows:

- removal of noise and bias in the data;
- conversion of the data into physical parameters;
- presentation of the results as maps and vertical sections.

4.1. **Processing Steps**

The airborne geophysical data were verified in the field for plausibility and for correctness to determine whether a flight needed to be repeated. If the data is accepted, the subsequent processing include the following steps (see Fig. 6):

- coordinate transformation;
- removal of the tree-canopy effect;
- fixing of the ends of the profiles;
- removal of spiky data;
- reduction of high-frequency noise by digital filtering;
- conversion of the data to the desired geophysical parameters;
- levelling of the data;
- storage of survey data and geophysical parameters for each of the profiles;
- production of maps and vertical sections (only HEM).

The filed data processing and the calculation of the physical parameters for each method are described in more detail in the following chapters.

4.2. **Field Data Processing**

4.2.1. **Data Handling**

The main tasks of the field data processing are:

- check and correction (if necessary) of the binary flight data;
- splitting of the binary flight data file into ASCII parameter files;
- transformation of the GPS coordinates to local coordinates used for map production;
- combination of parameters necessary for the geophysical methods;
- storage of ASCII flight data files for three geophysical methods.
Original flight data disks

Field Data Processing
- Error analysis of geophysical data
- Correction of coordinates
- Plot of flight lines

Electromagnetics
- "Spike" elimination
- Digital filtering
- Zero-level adjustment and calibration
- Calculation of half-space parameters
- Profile plots
- Levelling of survey data
- 1-D Inversion

Magnetics
- "Spike" elimination
- Digital filtering
- Reduction of diurnal variations
- Reduction of IGRF
- Profile plots
- Correction of "heading errors"
- Levelling of survey data

Radiometrics
- Digital filtering
- Reduction of background
- Reduction of Compton effects
- Altitude correction
- Profile plots
- Conversion of cps in equivalent concentrations
- Levelling of survey data

Vertical Sections
- multi-layer resistivity sections (VRS) along flight lines, including topography and original data

Graphic Program Modules
- Programs (GEOSOFT OASIS montaj, AVS/UNIRAS etc.) for preparation of colour maps and output on screen and plotter
- Creation of data grids

Final Thematic Maps
- Apparent resistivity maps
- Layer resistivity and boundary maps
- $\Delta T$ magnetic field maps
- $\Delta T$ derivative maps (hill-shading)
- K, U, Th concentration maps
- Flight-line and height-contour maps

Fig. 6: Block diagram of the data processing steps
4.2.2. Tree-Canopy Effect

As the measurements of the radar altimeter (helicopter) and laser altimeter (bird) may be affected by the tree canopy or other reflectors, the distance between the helicopter containing the radiometric system or the bird containing the electromagnetic and magnetic systems and the ground is often not correctly measured resulting in radar and laser altitudes which are too low and topographic elevations which are too high (Fig. 7).

As the accuracy of the measurements of the laser altimeter is higher than those of the radar altimeter, first the radar altitude values are adjusted to the laser altitude values:

\[ h_{\text{radar}} \text{[m]} = h_{\text{radar [mV]}} \cdot a + b \]

where

- \( h_{\text{radar [m]}} \) = adjusted radar altitude (unit: m),
- \( h_{\text{radar [V]}} \) = radar altitude (unit: V) measured by the altimeter,
- \( a \) = conversion factor (unit: m/V) containing the unit conversion (4 mV/ft, 1 ft = 0.3048 m) and the laser altitude based correction factor (1.04),
- \( b \) = averaged distance (unit: m) between the helicopter and the bird (including an offset in the radar altitude measurements), 2005: 47 m; 2006: 44 m.

Extreme laser altitudes are then replaced by adjusted radar altitudes. The topographic relief derived by the difference of GPS based bird elevation and laser altitude is used to correct the laser altitude using a combination of several checks and filter techniques (Table 10). First a noise filter is used to determine the areas where trees or other obstacles exist (high noise level, threshold: 0.3 m) or not (low noise level). Then a minimum filter is applied to the high-noise elevation data followed by a low pass filter eliminating all effects caused by single or small groups of trees. The effect of broad, dense forests, however, is not always removed sufficiently and has to be corrected manually. Afterwards, the laser altitude values are recalculated from the corrected topographic elevation values.

Table 10: Filters used for the removal of the tree-canopy effect

<table>
<thead>
<tr>
<th>Type of filter</th>
<th>Filter parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise (normal distribution)</td>
<td>Window length: 5 points (about 20 m)</td>
</tr>
<tr>
<td>Minimum</td>
<td>Window length: 51 points (about 200 m)</td>
</tr>
<tr>
<td>Low pass</td>
<td>Window and cut-off wave length: 101 points (about 400 m)</td>
</tr>
</tbody>
</table>
4.3. Processing of the Electromagnetic Data

The conversion of the measured R and Q values (in mV), i.e., the real part (in-phase or 0°-phase) and the imaginary part (out-of-phase or 90°-phase), to secondary field values (in ppm) is done in four steps:

- verification of phase and gain, and correction if necessary;
- zero level determination and correction if necessary;
- conversion of the data using calibration factors;
- correction of erroneous data.

The apparent resistivities and the centroid depths are then derived from the values of the secondary fields for each individual frequency and 1-D inversion models are calculated for each survey point using the data of all (or selected) frequencies.

4.3.1. Calibration of the HEM System

The HEM system was calibrated on highly resistive ground by the manufacturer in Mountsberg Conservation Area, Canada, using well-defined external calibration coils. On the basis of these known values, the signals caused by internal calibration coils are determined in ppm.

At the beginning of each survey flight and at high flight altitude, phase and gain of the EM system are adjusted automatically for each frequency using internal calibration coils. Due to instrumental drift, the calibration has to be checked several times during the flight. The calibration signals (in V) caused by internal calibration coils are compared with known calibration signals in ppm (provided by the manufacturer), and phase shifts and gain correction factors are calculated (Table 11). Using these values and after zero levelling (see Section 4.3.2) the raw data (in V) is phase shifted, if necessary, and then converted into ppm values.

Table 11: Calibration factors of the HEM systems

<table>
<thead>
<tr>
<th>System</th>
<th>Frequency</th>
<th>External R, Q [ppm]</th>
<th>Correction factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gain [%], phase [°]</td>
</tr>
<tr>
<td>2005</td>
<td>375</td>
<td>210, 205</td>
<td>2, 0.0</td>
</tr>
<tr>
<td></td>
<td>1778</td>
<td>220, 225</td>
<td>-5, 0.0</td>
</tr>
<tr>
<td></td>
<td>8510</td>
<td>220, 210</td>
<td>27, 0.0</td>
</tr>
<tr>
<td></td>
<td>37,830</td>
<td>660, 660</td>
<td>0, 0.0</td>
</tr>
<tr>
<td></td>
<td>128,500</td>
<td>560, 560</td>
<td>20, -50; -10, 18; -15, -5.5</td>
</tr>
<tr>
<td>2006</td>
<td>387.2</td>
<td>208, 208</td>
<td>-5, -1.5</td>
</tr>
<tr>
<td></td>
<td>1820</td>
<td>170, 173</td>
<td>0, -0.7</td>
</tr>
<tr>
<td></td>
<td>8225</td>
<td>141, 141</td>
<td>27, 0.0</td>
</tr>
<tr>
<td></td>
<td>41,550</td>
<td>636, 638</td>
<td>0, 0.4</td>
</tr>
<tr>
<td></td>
<td>133,200</td>
<td>977, 993</td>
<td>0, 2.0</td>
</tr>
</tbody>
</table>
As the highest-frequency data of the original 139.6 kHz frequency of the HEM system used until 2005 was very noisy due to interferences with the third frequency (8510 Hz), the highest system frequency has to be changed to 128.5 kHz. Unfortunately, this frequency change demands a recalibration of the system, which could not be carried out up to now due to missing own calibration facilities. To overcome this problem, a flight over highly conductive North Sea water during the Brædstrup survey in Denmark has been used to check the calibration values. The evaluation of this data set yielded a set of phase and gain corrections used for the processing of the Ellerbeker Rinne HEM data collected in 2005. Enormous phase shifts occurred in the highest-frequency data for the first part of the survey, which were corrected by a trial and error procedure. Therefore, it is still uncertain if the system used until 2005 has been calibrated accurately enough. The second part of the survey was flown with a new system that was carefully adjusted on the basis of several flights over sea water of the Andaman Sea.

4.3.2. Zero-Level Determination

The zero levels of the HEM data are generally determined at flight altitudes >350 m several times during a survey flight because the ground response is negligible at this altitude, i.e., the secondary field should be close to zero. Zero-level reference points are set at such high-altitude profile segments, preferably where the signal is not noisy. Signals measured at these high altitudes may still contain some non-compensated parts of the primary fields generated by the HEM system. The zero level is obtained by linear interpolation of the picked values at adjacent zero level reference points. The zero-level picking has to be repeated because the zero level may drift caused by temperature changes.

This procedure enables to remove the long-term, quasi-linear drift. Short-term variations caused by temperature changes due to altitude variations, however, which occur particularly in the highest-frequency data, cannot be corrected successfully by this procedure. Therefore, additional reference points – also along the profiles at normal survey flight altitude – have to be determined where the secondary fields are small but not negligible. At these locations, the estimated half-space parameters are used to calculate the expected secondary field values, which then serve as local reference levels.

4.3.3. Data Correction

Noise from external sources (e.g., from radio transmitters, power lines) are eliminated from the HEM data by appropriate filtering or interpolation. Induction effects from buildings and other electrical installations (see Section 4.3.6) or effects from strongly magnetized underground sources are normally not erased from the data.
4.3.4. Transformation of the Secondary Field Values into Half-Space Parameters

The calibrated values of the secondary field R and Q (in ppm) for all frequencies are converted (Siemon, 2001) to the parameters of a homogeneous half-space (Fig. 7),

- apparent resistivity \( \rho_a \) (\( \Omega \text{m} \)) and
- apparent distance \( D_a \) (m) from the sensor to the top of the conducting half-space.

The calculated distance \( D_a \) may differ from the observed HEM sensor altitude (in m above ground), i.e., the top of the conducting half-space model need not coincide with the surface of the earth as determined by the altimeters. The difference between the two is defined as the apparent depth \( d_a = D_a - h \). If \( d_a \) is positive, a resistive cover is assumed above the half-space. If \( d_a \) is negative, a conductive cover is assumed.

In addition to the apparent resistivity \( \rho_a \) and apparent distance \( D_a \), the centroid depth \( z^* \) can be determined. The centroid depth is a measure of the mean penetration of the induced underground currents. The resulting sounding curves, \( \rho_a(z^*) \), provide the initial approximation of the vertical resistivity distribution.

Fig. 7: HEM inversion based on a homogeneous half-space or a layered half-space
4.3.5. 1-D Inversion of the HEM Data

The model parameters of the 1-D inversion are the resistivities $\rho$ and thicknesses $t$ of a layered half-space (Fig. 8), where the thickness of the underlying half-space is assumed to be infinite. Marquardt’s inversion procedure is used (Sengpiel and Siemon, 2000), which requires a starting model. This starting model is derived from the apparent resistivity vs. centroid depth values $(\rho^a, z^*)$, $i=1,\ldots,n$. The standard model contains as many layers as frequencies used ($n$) plus a highly resistive cover layer. The layer resistivities are set equal to the apparent resistivities, the layer boundaries are chosen as the logarithmic mean of each two neighbouring centroid depth values. The thickness of the cover layer is derived from the apparent depth $d_a$ of the highest frequency used for the inversion. If this apparent depth value is less than a given minimum depth value, the minimum depth value (e.g. 0.5 m) is used.

As the highest-frequency data may not be accurately calibrated (see Section 4.3.1), the starting model used for the inversion was derived by combining the second layer and third layer, which were rather thin, i.e., a five-layer model was calculated (Fig. 9).

The inversion procedure is stopped when a given threshold is reached. This threshold is defined as the differential fit of the modelled data to the measured HEM data. We normally use a 10% threshold; i.e., the inversion stops when the enhancement of the fit is less than 10%.

Fig. 8: HEM inversion based on a homogeneous half-space or a layered half-space
4.3.6. **Effect of Anthropogenic Influences on the HEM Data**

In addition to the geogenic contribution to the secondary fields measured over densely populated areas, there is often an anthropogenic contribution from buildings and electrical installations etc. Generally, these have little influence on the HEM data and the data can be corrected using the standard data processing tools. In some cases, e.g., large buildings with a high metal content, the anthropogenic components in the HEM data are no longer negligible. This can be seen particularly in the lower frequency data because the geogenic contribution to the secondary fields is comparatively smaller than at higher frequencies.

The anthropogenic influence lowers the calculated resistivity and associated depth. Low resistivities and low depths often correlate with villages or streets, particularly for the lower frequencies. When the 1-D resistivity models are placed side by side to construct a vertical resistivity section, the conducting layers appear to descend on either side of the anthropogenic source. Thus such three-dimensional effects cannot be interpreted adequately by the layered half-space model.

Anthropogenic influences can be detected in HEM data due to their typical form or by correlation with magnetic data. A topographic map of the survey area, an analysis of the video film or an on-site inspection can help identify such influences.

4.3.7. **Statistical Levelling**

In order to identify and to correct zero-level errors in the HEM data a grid based micro-levelling using GEOSOFT’s OASIS-montaj software is applied to half-space parameters ($\log \rho_a$ and $d_a$).

First the half-space parameters of the 2006 survey were levelled which then served as a basis for the 2005 survey data. This procedure was chosen for two reasons: 1) The calibration of the HEM system used in 2005 was not as accurate as the calibration of the system used in 2006. 2) The system frequencies changed slightly and those of the new system were selected as reference.
Strong HEM anomalies are smoothed by two-dimensional lateral filtering of the micro-levelling procedure. Therefore, after micro-levelling, the half-space parameter values are converted to secondary field values which are compared with the corresponding unlevelled values. The strongly smoothed differences of the levelled and unlevelled values are assumed to characterize the zero-level errors and they are used to correct the HEM data without losing details. The levelling is done prior to the 1-D inversion of the HEM data.

4.3.8. Presentation of the Results

The HEM results are presented on maps and vertical resistivity sections (VRS). The maps are produced (see Section 4.5) for the half-space parameters, apparent resistivity and centroid depth. In addition, maps of the resistivity and depth (upper boundary) of the model layers 2-5 are derived from the 1-D inversion results after a weak levelling of the layer parameters. The latter are used to produce smooth 1-D inversion models from which the resistivity at certain depth levels (0-70 m b.s.l. at 5 m intervals) are picked and mapped. All the maps prepared from the results of this survey are listed in Chapter 6.

The VRS, also based on the 1-D inversion results, are produced for each of the survey lines. These vertical sections are constructed by placing the resistivity models for each sounding point along a survey profile next to each other using the topographic relief as base line (in m a.m.s.l.). The topographic elevation is derived from the EM system minus the laser altitudes. The altitude of the EM system with respect to m.s.l. is derived directly from the DGPS (DGPS-Z) readings or – if the GPS-Z data is not available – from the barometric altitude of the helicopter minus the mean effective cable length. The altitude of the EM sensor, information about the data processing, the fitting error of the inversion, and the HEM data, which are described in a legend, are plotted above the resistivity models.

4.4. Processing of the Magnetic Data

4.4.1. Magnetic Total Field

The earth’s total magnetic field \( T \) at a point \( r \) and at a time \( t \), e.g., measured with an airborne system, is the sum of the following parameters:

\[
T(r,t) = F(r) + \Delta V(t) + \Delta T_e(r) + \delta(r,t)
\]

where

- \( F(r) \) = geomagnetic main field (IGRF = International Geomagnetic Reference Field),
- \( \Delta V(t) \) = diurnal variations of the earth’s magnetic field,
- \( \Delta T_e(r) \) = the anomalous field in the survey area,
- \( \delta(r,t) \) = small residual errors.
The anomalies of the total magnetic field $\Delta T_e(r)$ are of interest. While the IGRF $F(r)$, which can be calculated from table values, and the diurnal variations $\Delta V(t)$, which are recorded at a local base station, can be subtracted from the measured total field, the residual errors $\delta(r,t)$ cannot be quantified independently. They are superposed on the anomalies $\Delta T_e(r)$, i.e., the derived $\Delta T$ values contain both the geogenic part and the disturbing anthropogenic part, whose sources (e.g., buildings) are mostly at the earth’s surface or are caused by the helicopter itself.

### 4.4.2. IGRF Calculations

The IGRF (International Geomagnetic Reference Field) can be calculated for any point on and above the earth’s surface at a specific time on the basis of spherical harmonic coefficients, which are updated every five years by the International Association of Geomagnetism and Aeronomy (IAGA, 1992). The IGRF 2005 of the particular epoch was calculated for the desired date at every point of the survey area (Table 12) using the geographical coordinates $\zeta$ and $\lambda$, ($\zeta$ = latitude, $\lambda$ = longitude).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGRF Epoch</td>
<td>2005</td>
</tr>
<tr>
<td>Mean inclination / declination</td>
<td>+68.6° / +1.0°</td>
</tr>
<tr>
<td>Mean IGRF</td>
<td>49,417.0 nT</td>
</tr>
<tr>
<td>Mean value $V_m$ / at base station</td>
<td>49,500.0 nT</td>
</tr>
</tbody>
</table>

### 4.4.3. Diurnal Variations

The base station for recording the time variant parts of the total magnetic field, the diurnal variations $\Delta V(t)$, was placed close to the airport. As usual, the mean value at the base station $V_m$, which is the mean value of the magnetic diurnal variations recorded during the survey, is used as the base for the local magnetic field and not the IGRF value at the site of the base station. This has the advantage that local anomalies can also be taken into consideration. The $\Delta V$ values, reduced by $V_m$, are subtracted from the recorded values during a survey flight. The recorded GPS times in the helicopter are synchronized with those recorded by the base station.

As no base-station data was available for the 2005 survey, only the magnetic data of the 2006 survey has been processed.

### 4.4.4. Statistical Levelling

In order to identify level errors in the data of the survey flights, the differences at the intersections of the flight lines with the tie-lines are determined and averaged. Afterwards, the correction values
are applied to the data. The correction values can be calculated for each profile line or for all of the profiles of a survey flight. The levelling also includes the elimination of so-called heading errors that occur as a result of the differing flight directions. If necessary, the line levelling is followed by a micro-levelling using GEOSOFT’s OASIS-montaj software.

Due to the missing of the tie-lines for the 2006 survey, a statistical levelling of the flight lines was not possible. The correction of the heading error was carried out by determination of the mean value for $\Delta T$ of all flight lines flown in the same direction. The difference of both values was added to each $\Delta T$ value of every flight line. At least, the data of the total field was micro-levelled using GEOSOFT’s OASIS-montaj software.

4.4.5. Presentation of the Results

The maps produced to display the magnetic anomaly data are listed in Chapter 6.

4.5. Processing of the Gamma-Ray Spectrometry Data

Corresponding to the recommendations of the IAEA (1979), the count rates of the radio elements potassium (K), uranium (U) and thorium (Th) recorded in the helicopter have to be converted into equivalent concentrations on the surface of the earth. The natural gamma radiation of the rocks and the soil is based mainly on these three sources. Moreover, the raw count rates include non-geogenic components, e.g., cosmic radiation and radiation from the helicopter itself. Radon, which varies considerably and can affect the interpretation because its radiation is detected by the uranium channel, is measured by the upward looking crystal and then corrected. As far as possible, these disturbing influences should be eliminated.

The following preparatory work and corrections are necessary:

- determination of cosmic and aircraft background count rates by flights over extensive bodies of water;
- evaluation of the absorption constants under survey conditions (atmospheric pressure and temperature) by means of ascending flights over land;
- reduction of the Compton effect, which occurs when the radiation penetrates the soil, the air and the sensor;
- correction of count rates recorded at different flight altitudes with respect to a standard flight altitude of 75 m in this case;
- conversion of the count rates from the standard flight altitude of 75 m to count rates on the ground;
- calculation of equivalent concentrations from the count rates on the ground.

4.5.1. Removing Cosmic and Aircraft Background

Cosmic radiation background is caused by high-energy cosmic ray particle interaction with the atmosphere. There is also background radiation from the immanent natural radioactivity of the
helicopter and its equipment. The background values for the gamma radiation had been derived once with the aid of a special flight about 50 km off-shore of Swakopmund, Namibia, by measurements over the Atlantic Ocean, where geogenic parts are negligible and “radon-free” conditions can be assumed. The measurements were taken at 1000, 3000, 5000, 6900, 7900, 8900, 9800, and 11500 ft a.m.s.l.. The measuring time at each altitude level was 10 minutes. The count rates were live time corrected according to the next chapter.

The cosmic and aircraft background correction will be done due to the following formula:

\[ N = a + b \cdot C \]

\( N \) = combined cosmic and aircraft background for each channel
\( a \) = aircraft background for each channel
\( b \) = cosmic stripping factor for each channel
\( C \) = filtered (low-pass) cosmic channel count

The values \( a \) and \( b \) are received for each channel K, U, Th, TC (total count) by linear regression of the filtered count rates in each spectral window of each altitude interval against the filtered cosmic channel count rates of each interval. The background values for the aircraft and the cosmic stripping factors are listed in Table 13.

Table 13: Aircraft background \( a \) and cosmic stripping factor \( b \)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Aircraft background ( a ) [counts per second]</th>
<th>Cosmic Stripping Factor ( b ) [counts per cosmic count]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>68.77</td>
<td>0.7771</td>
</tr>
<tr>
<td>K</td>
<td>8.32</td>
<td>0.0417</td>
</tr>
<tr>
<td>U</td>
<td>2.16</td>
<td>0.0363</td>
</tr>
<tr>
<td>Th</td>
<td>1.59</td>
<td>0.0338</td>
</tr>
</tbody>
</table>

4.5.2. Correcting Instrument Dead-Time/Live-Time Effects

The BGR spectrometer records a live time channel, so a live time correction can be easily performed due to:

\[ N = n \cdot 10^3 / lt \]

with

\( N \) = corrected count rate
\( n \) = raw recorded count rate
\( lt \) = recorded equipment live time in milliseconds
4.5.3. Adjustment of Radar Altimeter Data to Standard Temperature and Pressure

In order to apply the radiometric analysis techniques, it is necessary to convert actual conditions of the survey to “standard” conditions. This includes the adjustment of the measured ground clearance to standard temperature and pressure (STP-conditions). The corrected ground clearance value called “effective height” has the same mass of STP air between the ground and the helicopter as the actual one during data acquisition. Our program applies the correction as follows:

\[
he = \frac{h \cdot P \cdot 273}{1013 \cdot (T + 273)}
\]

- \(he\) = effective height above ground level at STP (metres)
- \(h\) = lightly filtered (despiked) radar altitude (metres) to remove the effect of sudden jumps
- \(T\) = measured air temperature in °C (25°C assumed)
- \(P\) = barometric pressure in mbar. \(P\) is derived from measured barometric altimeter data from the equation:

\[
P = 1013.32 \cdot e^{-h/8581}
\]

where \(h\) is the filtered barometric altitude in metres.

4.5.4. Evaluation of Stripping Ratios on Calibration Pads and Stripping Correction

The stripping ratios had previously been recorded over calibration pads of the Geologische Bundesanstalt (GBA) in Vienna, Austria in 2003. The values are listed in Table 14.

**Table 14: Stripping ratios**

<table>
<thead>
<tr>
<th>Stripping Ratio</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>U/Th (\alpha)</td>
<td>0.3044</td>
</tr>
<tr>
<td>K/Th (\beta)</td>
<td>0.5128</td>
</tr>
<tr>
<td>K/U (\gamma)</td>
<td>0.7361</td>
</tr>
<tr>
<td>Th/U (a)</td>
<td>0.0767</td>
</tr>
<tr>
<td>Th/K (b)</td>
<td>0.0043</td>
</tr>
<tr>
<td>U/K (g)</td>
<td>0.0066</td>
</tr>
</tbody>
</table>

These ratios were computed using the PADWIN software.

The values of \(\alpha, \beta, \gamma\) increase with altitude of the helicopter above ground level and have to be corrected on the base of STP equivalent altitude according to the following factors (see IAEA, 1991):
\[ \alpha_e = \alpha + 0.00049 \cdot h_e \]
\[ \beta_e = \beta + 0.00065 \cdot h_e \]
\[ \gamma_e = \gamma + 0.00069 \cdot h_e \]

\( h_e \) = equivalent height above ground level at STP in metres.

The stripping corrections are then applied to pre-processed and background-removed data as described in the next chapter.

### 4.5.5. Compton Correction

The dispersion of gamma rays by matter is called the Compton effect. This has the effect that part of the thorium radiation disperses into the energy ranges of the uranium and potassium windows. In similar manner uranium radiation disperses into the potassium channel. To obtain the net count rates of the particular channels, the stripping ratios have to be applied to the recorded and pre-processed data:

\[
N_{K,K} = \frac{[N_{Th}(\alpha \gamma - \beta) + N_u(a \beta - \gamma) + N_k(1 - a \alpha)]}{A}
\]
\[
N_{U,U} = \frac{[N_{Th}(g \beta - a \alpha) + N_u(1 - b \beta) + N_k(b \alpha - g)]}{A}
\]
\[
N_{Th,Th} = \frac{[N_{Th}(1 - g \gamma) + N_u(b \gamma - a) + N_k(a \gamma - b)]}{A}
\]

with

\[ A = 1 - g \gamma - a (\alpha - g \beta) - b (\beta - \alpha \gamma) \]

where \( N_{Th}, N_k, N_u \) represent the background and STP corrected count rates, \( N_{Th,Th}, N_{U,U}, N_{K,K} \) are the stripping corrected count rates, and \( \alpha, \beta, \gamma, a, b, g \) the STP corrected stripping ratios. No Compton correction is applied to the total radiation values (see IAEA, 1991).

### 4.5.6. Height-Attenuation Reduction

The intensity of the gamma radiation from the surface of the earth decreases with increasing height of the sensor above ground because of absorption in the air. The energy-dependent absorption constant \( \mu \) of the air is determined according to the procedure described in IAEA (1991). The absorption depends mainly on the density and humidity of the air. The value of \( \mu \) is also influenced in the uranium channel by the fluctuating radon concentration in the air. Using these absorption values \( \mu \), the count rates \( N_m \) measured (background corrected and stripped) at the flight altitude \( h \) can be converted to the radiation intensities at a nominal survey altitude \( h_0 = 75 \) m.

\[ N_i = N_m \cdot e^{-[\mu \cdot (h_0 - h)]} \]

\( N_i \) = the count rate normalized to the nominal survey altitude \( h_0 \)

\( N_m \) = the background corrected, stripped count rate at STP effective height \( h_e \)

\( \mu \) = the attenuation coefficient for the spectral window
The values $\mu_{\text{TC}}, \mu_{\text{K}}, \mu_{\text{Th}}, \mu_{\text{U}}$ had been evaluated over the Allensteig test range in Austria in 2003. BGR conducted a calibration flight at different heights over the calibration range. The values are tabulated in Table 15.

**Table 15: Height Attenuation Coefficient $\mu$**

<table>
<thead>
<tr>
<th>Window</th>
<th>Height Attenuation Coefficient $\mu$ (per metre at STP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>-0.007438</td>
</tr>
<tr>
<td>K</td>
<td>-0.00875</td>
</tr>
<tr>
<td>U</td>
<td>-0.008868</td>
</tr>
<tr>
<td>Th</td>
<td>-0.006780</td>
</tr>
</tbody>
</table>

### 4.5.7. Calculation of Radio-Element Concentrations and Exposure Rate

The IAEA recommends converting the count rates for the three gamma radio elements into surface concentrations. The advantage of this is that the results of the measurements with different instruments (e.g., with different crystal volumes) can be compared with each other. The calculated count rates at ground level are converted into apparent concentrations of the three radio elements K (in %), U and Th (both in ppm) at ground surface using calibration factors. These factors were determined on the calibration range Allensteig in Austria. Following the IAEA recommendations, the total radiation is referenced by the ground level exposure rate. The equivalent concentrations refer to an infinitely extended and permanently radiating plane. They may differ from the actual concentrations of the elements ground surface, especially if the areas of radiation are distributed irregularly. Over dense and extensive forests the count rates are generally too small because of absorption by biomass and underestimation of the radar altitude, which reflects the distance from the helicopter to the tree canopy instead of the distance to the ground level.

At the Alleinsteig test range the concentrations of K, Th and U are known. They are listed at Table 16.

**Table 16: Element concentrations at Allensteig/Austria**

<table>
<thead>
<tr>
<th>Channel</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>3.64 ± 0.47 %</td>
</tr>
<tr>
<td>U</td>
<td>4.55 ± 1.03 ppm</td>
</tr>
<tr>
<td>Th</td>
<td>29.00 ± 5.47 ppm</td>
</tr>
</tbody>
</table>
The conversion of count rates to apparent radio-element concentration follows the relation:

\[ C = \frac{N_s}{S} \]

Here:
- \( C \) = apparent concentration of the element (K in %, U in ppm, Th in ppm)
- \( N_s \) = the count rate for each window (after height attenuation and stripping)
- \( S \) = the broad source sensitivity for the spectral window (see Table 9)

The broad source sensitivities \( S \) are given in Table 17 for the Allensteig area. The term apparent concentration refers to the concentration in the ground of the elements potassium (K), uranium (U) and thorium (Th).

**Table 17: Sensitivities at Allensteig/Austria**

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 % K</td>
<td>32.45 cps</td>
</tr>
<tr>
<td>1 ppm Th</td>
<td>2.31 cps</td>
</tr>
<tr>
<td>1 ppm U</td>
<td>3.58 cps</td>
</tr>
</tbody>
</table>

Finally, the ground level exposure rate is calculated as a function of the K, U, and Th concentrations:

\[ E = 1.505 \cdot K + 0.653 \cdot U + 0.287 \cdot Th \]

\( E \) = ground level exposure rate [\( \mu \text{R/h} \)]

using the following conversions (IAEA, 1991, p. 52):
- 1 % K = 1.505 \( \mu \text{R/h} \),
- 1 ppm U = 0.653 \( \mu \text{R/h} \),
- 1 ppm Th = 0.287 \( \mu \text{R/h} \).

**4.5.8. Statistical Levelling**

In order to correct levelling errors in the data from different survey lines, the equivalent concentrations are micro-levelled using GEOSOFT’s OASIS-montaj software.

**4.5.9. Presentation of the Results**

The results of the gamma-ray survey are presented as maps of the equivalent concentrations of the radio elements potassium, uranium, and thorium and the ground level exposure rate. The maps produced to display the radiometric data are listed in Chapter 6.
4.6. Map Production with GEOSOFT Software

Coloured contour maps were produced for each parameter of interest. The topographic map described in Chapter 5 was used as map base. The surveyed flight lines are plotted where the map scale is large enough to distinguish between them.

The grids for the geophysical thematic maps are produced using the software package GEOSOFT’s OASIS-montaj. Table 18 shows the grid parameters used for the Ellerbeker Rinne survey. The final maps including geophysical, topographical and legend information are prepared using the program CorelDRAW 12. Adobe Acrobat is used for preparing the PDF documents.

Table 18: Grid parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gridding method</td>
<td>Minimum curvature</td>
</tr>
<tr>
<td>Grid size [m]</td>
<td>50</td>
</tr>
<tr>
<td>Search radius [m]</td>
<td>400</td>
</tr>
<tr>
<td>Cell extend beyond data</td>
<td>10</td>
</tr>
<tr>
<td>Log option</td>
<td>log $\rho$ (else linear)</td>
</tr>
</tbody>
</table>
5. Cartographic Work

5.1. Topographic Maps

A topographic map was produced as the base map for all thematic maps displaying the airborne geophysical results. A scale of 1:50,000 was chosen for the survey area. A Gauss-Krüger coordinate grid, based on the Bessel ellipsoid, is included on the topographic maps. Table 19 contains the corner coordinates of the map sheet.

**Table 19: Coordinates of the corners of the 1:50,000 Ellerbeker Rinne topographic map sheet**

<table>
<thead>
<tr>
<th>Map corners</th>
<th>Geographic coordinates (Bessel ellipsoid)</th>
<th>Gauss-Krüger coordinates (Bessel ellipsoid)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Easting</td>
<td>Northing</td>
</tr>
<tr>
<td>SW</td>
<td>9°40’</td>
<td>53°38’</td>
</tr>
<tr>
<td>NW</td>
<td>9°40’</td>
<td>53°55’</td>
</tr>
<tr>
<td>NE</td>
<td>9°59’</td>
<td>53°55’</td>
</tr>
<tr>
<td>SE</td>
<td>9°59’</td>
<td>53°38’</td>
</tr>
</tbody>
</table>

The map is based on the raster data of the »Topographische Karte 1:50,000«, © Landesvermessungsamt Schleswig-Holstein. The following map sheets were used:


The map has a digitally constructed border and tick marks indicating coordinates in the Gauss-Krüger coordinate system. The grey-shading of the topography of the thematic map has a screen density of 50% of the original digital topographic map.

5.2. Flight-Line Maps

The flight-line maps show the position of the surveyed profiles on the topographic maps. The corresponding line number is shown at the end of a profile at which the flight for that profile commenced. Positions of selected time marks (records), e.g., every 100th, are marked with an “x”. Every tenth plotted time mark is labelled with its number. The flight-line maps permit fast and easy correlation of data from profiles and vertical sections and their position in the survey area.

5.3. Thematic Maps

Geophysical thematic maps (Table 20) were produced for all survey areas, together with the topography. Each of the maps has a detailed legend which contains information about the survey area, the base maps, the scale, the plotted geophysical parameter(s), and the people participating and institutions.
5.4. **Digital Elevation Models**

Digital elevation models (DEM) can be derived from the altitude of the HEM bird minus the laser altitude of the bird. The bird altitude is obtained directly from the DGPS-Z readings or – if the DGPS-Z data is not available – from the barometric altitude of the helicopter minus the effective cable length, i.e., the distance of the HEM bird from the helicopter.

6. **Archiving**

All data sets and plots are stored on CD-ROMs and archived at BGR section B 3.13 – Applied Airborne and Ground Geophysics. The data formats of processed data are described in Appendix II. A technical report, the vertical sections, and the thematic maps (as PDF files) are stored together with the final data (ASCII-coded in GEOSOFT-XYZ format) on CD-ROM Table 20. This report encloses a copy of the CD-ROM listed in Appendix III. Appendix IV and Appendix V contain copies of all maps and vertical resistivity sections, respectively, reduced to smaller scales fitting the A4 format of this report.
Table 20: Contents of the CD-ROM

<table>
<thead>
<tr>
<th>Directory</th>
<th>Description of contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>\Adobe Acrobat</td>
<td>Adobe® Acrobat Reader in diverse versions for popular system software</td>
</tr>
<tr>
<td>\Report</td>
<td>Technical report of the project in PDF format</td>
</tr>
<tr>
<td>\HEM</td>
<td>ASCII file with processed data (<em>.dat) ASCII file with derived parameters (</em>.app) ASCII file with starting models for the 1-D inversion (<em>.sta) ASCII file with results of the 1-D inversion (</em>.inv) ASCII file with synthetic data derived from the 1-D inversions (*.syn)</td>
</tr>
<tr>
<td>\MAG</td>
<td>ASCII file with data of the total magnetic field, IGRF, base station data, diurnal variations etc.</td>
</tr>
<tr>
<td>\SCI</td>
<td>ASCII file with data of the equivalent concentrations of potassium, uranium and thorium and the total radiation</td>
</tr>
<tr>
<td>\HEM</td>
<td>Half-space resistivity maps and centroid depth maps at a scale of 1:50,000 for the frequencies 387.2 Hz, 1820 Hz, 8225 Hz, 41,550 Hz, 133,200 Hz in PDF format Resistivity maps and depth maps at a scale of 1:50,000 for layers 2–5 based on five-layer inversion results in PDF format Resistivity maps at a scale of 1:50,000 at 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, and 70 m below mean sea level based on five-layer inversion results in PDF format</td>
</tr>
<tr>
<td>\MAG</td>
<td>Magnetic anomalies map at a scale of 1:50,000 in PDF format</td>
</tr>
<tr>
<td>\SCI</td>
<td>Maps of the equivalent concentrations of the radio elements potassium, uranium, and thorium, the total radiation and the ground level exposure rate at a scale of 1:50,000 in PDF format</td>
</tr>
<tr>
<td>\Flight lines</td>
<td>Flight line map with topography at a scale of 1:50,000 in PDF format</td>
</tr>
<tr>
<td>\DEM</td>
<td>Digital elevation model at a scale of 1:50,000 in PDF format</td>
</tr>
<tr>
<td>\Vertical sections</td>
<td>Vertical resistivity section based on five-layer inversion results for each profile of the survey area at a horizontal scale of 1:50,000 and at a vertical scale of 1:5000 in PDF format</td>
</tr>
</tbody>
</table>
7. Personnel

**Field Crew**
Hans-Joachim Rehli, management and system engineering, B3.13, BGR
Karl-Heinz Meinhardt, system operation and engineering, B3.13, BGR
Josef Scheiwein, helicopter engineering, B3.13, BGR
Michael Schütt, pilot, Wiking Helikopter Service GmbH
Hanno Schmidt, navigation and field data processing, B3.13, BGR
Wolfgang Voß, navigation and field data processing, B3.13, BGR

**Office Crew**
Dr. Uwe Meyer, head of section B3.13, BGR
Dr. Bernhard Siemon, HEM data evaluation, B3.13, BGR
Dr. Detlef Eberle, radiometric data evaluation, B3.13, BGR
Wolfgang Voß, magnetic data evaluation, B3.13, BGR
Jens Pielawa, cartographic work, B3.13, BGR

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Germany
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3238 (Rehli)
3488 (Siemon)
Fax: +49 511 643 3663
Email: heli@bgr.de, u.meyer@bgr.de, b.siemon@bgr.de, h-j.rehli@bgr.de
8. **References**


BUNDESANSTALT FÜR GEOWISSENSCHAFTEN UND ROHSTOFFE
BGR, HANNOVER

(Dr. H.-R. Kudraß)
Director and Professor
Division
"Geophysics,
Marine and Polar Research"

(Dr. B. Siemon)
Section
"Applied Airborne and
Ground Geophysics"
### Appendix I

**Ellerbeker Rinne – Survey 2005**

<table>
<thead>
<tr>
<th>Flight</th>
<th>Date</th>
<th>Time (UTC)</th>
<th>Lines</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| 11100  | 19.04.05| 09:08 – 11:16  | 115.1 W, 118.1 E, 121.1 W, 124.1 E, 127.1 W, 130.1 E, 133.1 W, 136.1 E, 139.1 W, 142.1 E, 143.1 W, 144.1 E, 112.1 W, 109.1 E | Basis: Airport Hartenholm  
Airport elevation: 32 m  
EM: Bird BKS 60  
EM: noise in the highest frequency (128.5 kHz) during the whole flight  
Line 112.1, Fid 672 - 680: strong noise in EM and Mag due to a radio transmitter  
Weather: clouded, rain, 5° C, wind from 70° with 10 to 16 knots  
Profile kilometres: 80 |
| 11101  | 19.04.05| 15:11 – 17:07  | 1.9 S, 2.9 N, 3.9 S, 4.9 N, 5.9 S, 6.9 N | Basis: Airport Hartenholm  
**Cross Profiles**  
EM: noise in the highest frequency (128.5 kHz) during the whole flight  
Weather: sunny, 12° C  
Profile kilometres: 136 |
| 11102  | 20.04.05| 07:41 – 09:46  | 106.1 E, 103.1 W, 100.1 E, 97.1 W, 94.1 E, 91.1 W, 88.1 E, 85.1 W, 82.1 E, 79.1 W, 76.1 E, 73.1 W, 70.1 E | Basis: Airport Hartenholm  
EM: noise in the highest frequency (128.5 kHz) during the whole flight  
Line 70.1: oscillation of the 4th frequency right from the beginning of the line  
Weather: sunny, wind from 10° with 20 knots, 12° C  
Profile kilometres: 84 |
<table>
<thead>
<tr>
<th>Flight</th>
<th>Date</th>
<th>Time (UTC)</th>
<th>Lines</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>11103</td>
<td>16.05.06</td>
<td>13:43 – 15:51</td>
<td>201.1 W &lt;br&gt; 202.1 E &lt;br&gt; 203.1 W &lt;br&gt; 204.1 E &lt;br&gt; 205.1 W &lt;br&gt; 206.1 E &lt;br&gt; 207.1 W &lt;br&gt; 208.1 E &lt;br&gt; 209.1 W &lt;br&gt; 210.1 E &lt;br&gt; 211.1 W &lt;br&gt; 212.1 E &lt;br&gt; 213.1 W &lt;br&gt; 214.1 E</td>
<td>Basis: Airport Hartenholm &lt;br&gt; Airport elevation: 32 m &lt;br&gt; Coordinates of the magnetic base station: 53.9164810° N; 10.0352259° E &lt;br&gt; EM: Bird BKS 36a &lt;br&gt; Weather: clouded, occasionally rain, 12° C, strong wind with 20 to 25 knots &lt;br&gt; Profile kilometres: 168</td>
</tr>
<tr>
<td>11104</td>
<td>17.05.06</td>
<td>07:39 – 10:08</td>
<td>215.1 W &lt;br&gt; 216.1 E &lt;br&gt; 217.1 W &lt;br&gt; 218.1 E &lt;br&gt; 219.1 W &lt;br&gt; 220.1 E &lt;br&gt; 221.1 W &lt;br&gt; 222.1 E &lt;br&gt; 223.1 W &lt;br&gt; 224.1 E &lt;br&gt; 225.1 W &lt;br&gt; 226.1 E &lt;br&gt; 227.1 W &lt;br&gt; 228.1 E &lt;br&gt; 229.1 W &lt;br&gt; 230.1 E &lt;br&gt; 231.1 W &lt;br&gt; 232.1 E</td>
<td>Basis: Airport Hartenholm &lt;br&gt; Weather: clouded, 10° C, wind with 5 knots from 300° &lt;br&gt; Profile kilometres: 211</td>
</tr>
<tr>
<td>Flight</td>
<td>Date</td>
<td>Time (UTC)</td>
<td>Lines</td>
<td>Remarks</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td>------------------</td>
<td>------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| 11105  | 17.05.06   | 11:42 – 13:59    | 272.1 E 271.1 W 270.1 E 269.1 W 268.1 E 267.1 W 266.1 E 265.1 W 264.1 E 263.1 W 262.1 E 261.1 W 260.1 E 259.1 W 258.1 E 257.1 W 256.1 E 255.1 W 254.1 E 253.1 W 252.1 E 251.1 W 250.1 E | Basis: Airport Hartenholm  
Weather: clouded, 16° C, moderate wind  
Profile kilometres: 129 |
| 11106  | 18.05.06   | 11:46 – 12:48    | 249.1 W 248.1 E 247.1 W 246.1 E 245.1 W 244.1 E 243.1 W 242.1 E | Weather: clouded, 13° C, strong wind with 15 to 28 knots  
Stop of the survey flight after line 242.1; Q-coil anomalies can’t be switched on.  
Profile kilometres: 56 |
<table>
<thead>
<tr>
<th>Flight</th>
<th>Date</th>
<th>Time (UTC)</th>
<th>Lines</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>11107</td>
<td>18.06.05</td>
<td>13:36 – 14:45</td>
<td>241.1 W 240.1 E 239.1 W 238.1 E 239.1 W 238.1 E 237.1 W 236.1 E 235.1 W 234.1 E 233.1W 232.2 E</td>
<td>Weather: sunny, 21° C, strong wind with 20 knots  Profile kilometres: 77</td>
</tr>
</tbody>
</table>
Appendix II

Final Data Format Description

Electromagnetics

Description of the five ASCII-coded data files containing the final (leveled) data of a helicopter-borne electromagnetic (HEM) survey

General HEADER:
/BGR HEADER (SHORT VERSION):
/ /AREANAME /Ellerbek /AREACODE /111 /C_MERIDIAN, ZONE AND GEOID /9 3 BESSEL /BIRD /61 /NUMFREQ /5 /FREQUENCY /375.00 1778.00 8510.00 37830.00 128500.00 (system parameters of the 2005 survey) /387.20 1820.00 8210.00 41550.00 133200.00 (system parameters of the 2006 survey) /COILSEPARATION /7.92 7.91 7.96 8.03 7.92 (system parameters of the 2006 survey) /7.94 7.93 7.93 7.91 7.92 (system parameters of the 2006 survey) /COILGEOMETRY (1 = hor. copl.) /1.00 1.00 1.00 1.00 1.00 /TOWCABLE /37.00 /DUMMY /9999.990 /DECIMATIONVALUE /1 /PRIVTEXT /programm: hem05 /BERECHNETE HALBRAUMPARAMETER /PROGRAMM: HEM_KOR05 /KORRIGIERTE DATEN VON E:\SIEMONB\GEBIETE\111_ELLERBEKER-RINNE\KOR\HEM1110019DAT.XYZ /UEBERTRAGEN AM 19-JUN-06 17:39:34
DATA:

'xxx' internal area number: 112 for Ellerbeker Rinne

1) HEM‘xxx’_dat.xyz :

Example:

```
/ X   Y   RECORD  TOPO  H_RADAR  H_LASER  BIRD_NN  H_BARO  REAL_1  QUAD_1  REAL_2  QUAD_2  REAL_3  QUAD_3  REAL_4  QUAD_4  REAL_5  QUAD_5
TIE  1.9
545408 5968554 14950  8.02  59.12  59.81  58.99  73.94  29.07  59.81  36.05  69.49  78.34  177.52  140.83  323.98  129.62  429.56  86.06
545410 5968551 14951  8.00  59.61  59.79  58.92  73.84  29.10  36.10  69.71  78.00  177.69  141.32  324.94  130.77  431.60  87.39
545412 5968548 14952  7.97  58.88  59.67  58.86  73.75  29.11  36.14  69.79  77.66  177.83  141.75  325.83  131.86  433.49  88.69
```

lines beginning with '/' are comment lines
lines beginning with 'LINE' mark the beginning of a new profile line
lines beginning with 'TIE' mark the beginning of a new tie line (cross-flown)

In this data file all measured parameters are stored in the order of the following description:

- **X** = Gauß-Krüger easting in m (Zone 3), these coordinates have a false easting of 3000000 metres.
- **Y** = Gauß-Krüger northing in m (Zone 3), these coordinates have no false northing.
- **RECORD** = time mark increasing by 1 every 0.1 seconds.
- **TOPO** = topographic elevation (in metre above sea level).
- **H_RADAR** = smoothed value of the radar altitude (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude in metre above ground level.
- **H_LASER** = smoothed value of the laser altimeter (in metre); corresponds to the bird altitude in metre above ground level.
- **BIRD_NN** = smoothed bird altitude (in m a.m.s.l. = metre above mean sea level).
- **H_BARO** = filtered value of the barometric sensor (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude in metre above mean sea level.
- **REAL_1** = filtered value (in ppm) of the inphase component at the frequency $f = 387.2$ (375) Hz.
- **QUAD_1** = filtered value (in ppm) of the out-of-phase component at the frequency $f = 387.2$ (375) Hz.
- **REAL_2** = filtered value (in ppm) of the inphase component at the frequency $f = 1820$ (1778) Hz.
- **QUAD_2** = filtered value (in ppm) of the out-of-phase component at the frequency $f = 1820$ (1778) Hz.
- **REAL_3** = filtered value (in ppm) of the inphase component at the frequency $f = 8225$ (8510) Hz.
- **QUAD_3** = filtered value (in ppm) of the out-of-phase component at the frequency $f = 8225$ (8510) Hz.
- **REAL_4** = filtered value (in ppm) of the inphase component at the frequency $f = 41550$ (37830) Hz.
- **QUAD_4** = filtered value (in ppm) of the out-of-phase component at the frequency $f = 41550$ (37830) Hz.
- **REAL_5** = filtered value (in ppm) of the inphase component at the frequency $f = 133200$ (128500) Hz.
- **QUAD_5** = filtered value (in ppm) of the out-of-phase component at the frequency $f = 133200$ (128500) Hz.
2) HEM'xxx'_app.xyz :

Example:

```
TIE     1.9
545408   5968554  14950      8.02     59.12     59.81     58.99     73.94    15.83   21.74    73.44    37.17    5.19   41.5 8     57.77   -1.71   19.02     52.63   -0.03     9.36     39.78    0.32    4.75
545410   5968551  14951      8.00     59.61     59.79     58.92     73.84    15.83   21.71    73.42    36.74    5.46   41.6 4     57.95   -1.78   18.98     53.10   -0.14     9.28     40.47    0.19    4.66
545412   5968548  14952      7.97     58.88     59.67     58.86     73.75    15.84   21.79    73.50    36.44    5.80   41.8 2     58.13   -1.74   19.06     53.56   -0.15     9.32     41.18    0.17    4.67
```

lines beginning with '/' are comment lines
lines beginning with 'LINE' mark the beginning of a new profile line
lines beginning with 'TIE' mark the beginning of a new tie line (cross-flown)

In this data file all necessary measured parameters as well as the calculated parameters rhoa, da and zstern are stored in the order of the following description:

- X = Gauß-Krüger easting in m (Zone 3), DHDN system (Bessel-Ellipsoid); these coordinates have a false easting of 3000000 metres.
- Y = Gauß-Krüger northing in m (Zone 3), DHDN system (Bessel-Ellipsoid); these coordinates have no false northing.
- RECORD = time mark increasing by 1 every 0.1 seconds.
- TOPO = topographic elevation (in metre above sea level).
- H_RADAR = smoothed value of the radar altitude (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude in metre above ground level.
- H_LASER = smoothed value of the laser altimeter (in metre); corresponds to the bird altitude in metre above ground level.
- BIRD_NN = smoothed bird altitude (in m a.m.s.l. = metre above mean sea level).
- H_BARO = filtered value of the barometric sensor (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude in metre above mean sea level.
- RHOA_1 = apparent resistivity (in Ohm*m) at the frequency f = 387.2 (375) Hz
- KDA_1 = apparent depth (in metre) of the ground level to the top of the conductive half-space at the frequency f = 387.2 (375) Hz
- ZST_1 = centroid depth (in metre) at the frequency f = 387.2 (375) Hz
- RHOA_2 = apparent resistivity (in Ohm*m) at the frequency f = 1820 (1778) Hz
- KDA_2 = apparent depth (in metre) of the ground level to the top of the conductive half-space at the frequency f = 1820 (1778) Hz
- ZST_2 = centroid depth (in metre) at the frequency f = 1820 (1778) Hz
- RHOA_3 = apparent resistivity (in Ohm*m) at the frequency f = 8225 (8510) Hz
- KDA_3 = apparent depth (in metre) of the ground level to the top of the conductive half-space at the frequency f = 8225 (8510) Hz
- ZST_3 = centroid depth (in metre) at the frequency f = 8225 (8510) Hz
- RHOA_4 = apparent resistivity (in Ohm*m) at the frequency f = 41550 (37830) Hz
- KDA_4 = apparent depth (in metre) of the ground level to the top of the conductive half-space at the frequency f = 41550 (37830) Hz
- ZST_4 = centroid depth (in metre) at the frequency f = 41550 (37830) Hz
- RHOA_5 = apparent resistivity (in Ohm*m) at the frequency f = 133200 (128500) Hz
- KDA_5 = apparent depth (in metre) of the ground level to the top of the conductive half-space at the frequency f = 133200 (128500) Hz
- ZST_5 = centroid depth (in metre) at the frequency f = 133200 (128500) Hz
3) HEM'xxx'_sta.xyz :

Example:

/tie X Y RECORD TOPO  H_RADAR  H_LASER  BIRD_NN  H_BARO   RHO_S_1  D_S_1   RHO_S_2  D_S_2   RHO_S_3  D_S_3   RHO_S_4  D_S_4   RHO_S_5
TIE 1.9
545408 5968554 14950 8.02 59.12 59.81 58.99 73.94 5000.00 0.82 45.75 12.52 57.7 7 14.78 37.17 27.14 15.83
545410 5968551 14951 8.00 59.61 59.79 58.92 73.84 5000.00 0.69 46.36 12.58 57.9 6 14.84 36.74 27.17 15.83
545412 5968548 14952 7.97 58.88 59.67 58.86 73.75 5000.00 0.67 46.96 12.65 58.1 3 14.91 36.45 27.21 15.84

lines beginning with '/' are comment lines
lines beginning with 'LINE' mark the beginning of a new profile line
lines beginning with 'TIE' mark the beginning of a new tie line (cross-flown)

In this data file all necessary measured parameters as well as the starting model parameters for the 1D-inversion rho and d are stored in the order of the following description:

X = Gauß-Krüger easting in m (Zone 3), DHDN system(Bessel-Ellipsoid), these coordinates have a false easting of 3000000 metres.
Y = Gauß-Krüger northing in m (Zone 3), DHDN system(Bessel-Ellipsoid), these coordinates have no false northing.
RECORD = time mark increasing by 1 every 0.1 seconds.
TOPO = topographic elevation (in metre above sea level).
H_RADAR = smoothed value of the radar altitude (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude in metre above ground level.
H_LASER = smoothed value of the laser altimeter (in metre); corresponds to the bird altitude in metre above ground level.
BIRD_NN = smoothed bird altitude (in m a.m.s.l. = metre above mean sea level).
H_BARO = filtered value of the barometric sensor (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude (in metre above mean sea level).
RHO_S_1 = resistivity (in Ohm*m) of the first (top) layer of a five-layer starting model
D_S_1 = thickness (in metre) of the first (top) layer of a five-layer starting model
RHO_S_2 = resistivity (in Ohm*m) of the second layer of a five-layer starting model
D_S_2 = thickness (in metre) of the second layer of a five-layer starting model
RHO_S_3 = resistivity (in Ohm*m) of the third layer of a five-layer starting model
D_S_3 = thickness (in metre) of the third layer of a five-layer starting model
RHO_S_4 = resistivity (in Ohm*m) of the fourth layer of a five-layer starting model
D_S_4 = thickness (in metre) of the fourth layer of a five-layer starting model
RHO_S_5 = resistivity (in Ohm*m) of the fifth layer of a five-layer inversion model
4) HEM'xxx'_inv.xyz :

Example:

/         X                 Y        RECORD  TOPO  H_RADAR H_LASER H_BIRD_NN H_BARO  H_RHO_I_1   D_I_1   H_RHO_I_2   D_I_2   H_RHO_I_3   D_I_3  H_RHO_I_4   D_I_4   H_RHO_I_5  QALL
TIE     1.9
545408   5968554   14950      8.02     59.12     59.81     58.99     73.94   5033.38   1.26      41.47     7.69    59.04   1 3.21     45.80   43.32    10.81    3.98
545410   5968551   14951      8.00     59.61     59.79     58.92     73.84   5033.77   1.11      42.25     7.69    59.10   1 3.11     45.45   44.34    10.39    3.92
545412   5968548   14952      7.97     58.88     59.67     58.86     73.75   5032.17   1.05      43.17     8.00    59.30   1 3.26     45.32   43.89    10.26    3.79

lines beginning with '/' are comment lines
lines beginning with 'LINE' mark the beginning of a new profile line
lines beginning with 'TIE' mark the beginning of a new tie line (cross-flown)

In this data file all necessary measured parameters as well as the results of a 1D-Inversion rho, d and qall are stored in the order of the following description:
X = Gauss-Krüger easting in m (Zone 3), DHDN system (Bessel-Ellipsoid), these coordinates have a false easting of 3000000 metres.
Y = Gauss-Krüger northing in m (Zone 3), DHDN system (Bessel-Ellipsoid), these coordinates have no false northing.
RECORD = time mark increasing by 1 every 0.1 seconds.
TOPO = topographic elevation (in metre above sea level).
H_RADAR = smoothed value of the radar altitude (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude in metre above ground level.
H_LASER = smoothed value of the laser altimeter (in metre); corresponds to the bird altitude in metre above ground level.
BIRD_NN = smoothed bird altitude (in m a.m.s.l. = metre above mean sea level).
H_BARO = filtered value of the barometric sensor (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude (in metre above mean sea level).
H_RHO_I_1 = resistivity (in Ohm*m) of the first (top) layer of a five-layer inversion model
D_I_1 = thickness (in metre) of the first (top) layer of a five-layer inversion model
H_RHO_I_2 = resistivity (in Ohm*m) of the second layer of a five-layer inversion model
D_I_2 = thickness (in metre) of the second layer of a five-layer inversion model
H_RHO_I_3 = resistivity (in Ohm*m) of the third layer of a five-layer inversion model
D_I_3 = thickness (in metre) of the third layer of a five-layer inversion model
H_RHO_I_4 = resistivity (in Ohm*m) of the fourth layer of a five-layer inversion model
D_I_4 = thickness (in metre) of the fourth layer of a five-layer inversion model
H_RHO_I_5 = resistivity (in Ohm*m) of the fifth layer of a five-layer inversion model
QALL = misfit of the inversion (in percent)
5) **HEM**'xxx'\_syn.\text{xyz} :

Example:

```
/         X                Y         RECORD    TOPO H_RADAR H_LASER BIRD_NN H_BARO   REAL_1  QUAD_1   REAL_2  QUAD_2   REAL_3  QUAD_3   REAL_4   QUAD_4   REAL_5   QUAD_5
TIE     1.9    545408   5968554    14950      8.02    59.12     59.81     58.99     73.94     25.70    34.15     67.75    73.77    178.96   133.44    330.42   130.28    425.12     90.33
      545410   5968551    14951      8.00    59.61     59.79     58.92     73.84     25.93    34.09     67.75    73.83    179.30   133.78    331.07   131.35    427.17     91.76
      545412   5968548    14952      7.97    58.88     59.67     58.86     73.75     26.11    34.14     67.88    73.85    179.44   134.29    332.16   132.50    429.34     93.00
```

lines beginning with '/' are comment lines
lines beginning with 'LINE' mark the beginning of a new profile line
lines beginning with 'TIE' mark the beginning of a new tie line (cross-flown)

In this data file all synthetic data derived from 1-D inversion models are stored in the order of the following description:

- **X** = Gauß-Krüger easting in m (Zone 3), DHDN system (Bessel-Ellipsoid), these coordinates have a false easting of 3000000 metres.
- **Y** = Gauß-Krüger northing in m (Zone 3), DHDN system (Bessel-Ellipsoid), these coordinates have no false northing.
- **RECORD** = time mark increasing by 1 every 0.1 seconds.
- **TOPO** = topographic elevation (in metre above sea level).
- **H_RADAR** = smoothed value of the radar altitude (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude in metre above ground level.
- **H_LASER** = smoothed value of the laser altimeter (in metre); corresponds to the bird altitude in metre above ground level.
- **BIRD_NN** = smoothed bird altitude (in m a.m.s.l. = metre above mean sea level).
- **H_BARO** = filtered value of the barometric sensor (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude (in metre above mean sea level).
- **REAL_1** = inphase component of the model data (in ppm) at the frequency $f = 387.2 \text{ (375) Hz}$
- **QUAD_1** = out-of-phase component of the model data (in ppm) at the frequency $f = 387.2 \text{ (375) Hz}$
- **REAL_2** = inphase component of the model data (in ppm) at the frequency $f = 1820 \text{ (1778) Hz}$
- **QUAD_2** = out-of-phase component of the model data (in ppm) at the frequency $f = 1820 \text{ (1778) Hz}$
- **REAL_3** = inphase component of the model data (in ppm) at the frequency $f = 8225 \text{ (8510) Hz}$
- **QUAD_3** = out-of-phase component of the model data (in ppm) at the frequency $f = 8225 \text{ (8510) Hz}$
- **REAL_4** = inphase component of the model data (in ppm) at the frequency $f = 41550 \text{ (37830) Hz}$
- **QUAD_4** = out-of-phase component of the model data (in ppm) at the frequency $f = 41550 \text{ (37830) Hz}$
- **REAL_5** = inphase component of the model data (in ppm) at the frequency $f = 133200 \text{ (128500) Hz}$
- **QUAD_5** = out-of-phase component of the model data (in ppm) at the frequency $f = 133200 \text{ (128500) Hz}$

Dummy value 9999.99
### Magnetics

Description of the ASCII-coded data file containing the final (leveled) data of a helicopter-borne magnetic survey

MAG'xxx'.xyz

'xxx' internal area number: 111 for Ellerbeker Rinne

"/" are comment lines

"*" are dummy values

Line 201.1 is the line header for line number 201.1

/ XYZ EXPORT [07/13/2006]
/ DATABASE [.MAG.gdb]
/
/ X   Y   Lat_WGS_84   Lon_WGS_84   RECORD   Radar   Laser   Bird_NN   Topo   mag_base   Igrf   incli   decli   diurnal   f_mag   delta_T_Korr   delta_T_lev
/ Line 201.1
554405 5974590 53.8993565 9.8266068 6197 55.43 56.26 68.50 17.41 49507.00 49447.26 68.67 1.04 7.00 49536.18 80.66 84.956
554402 5974589 53.8993443 9.8265607 6198 54.88 56.09 68.30 17.40 49507.00 49447.26 68.67 1.04 7.00 49536.04 80.56 84.902
554399 5974588 53.8993322 9.8265145 6199 54.36 55.81 68.00 17.40 49507.00 49447.25 68.67 1.04 7.00 49535.95 80.50 84.859

Channel description:

- **X**  Gauß-Krüger easting in m (Zone 3), DHDN system (Bessel-Ellipsoid), these coordinates have a false easting of 3000000 metres
- **Y**  Gauß-Krüger northing in m (Zone 3), DHDN system (Bessel-Ellipsoid)
- **Lat_WGS_84**  Latitude Value (degrees) WGS84 system
- **Lon_WGS_84**  Longitude value (degrees) WGS84 system
- **RECORD**  time mark increasing by 1 every 0.1 seconds
- **Radar**  smoothed value of the radar altitude (in metre) minus the effective cable length (37 metre) from the helicopter to the bird; corresponds to the bird altitude in metre above ground level
- **LASER**  smoothed value of the laser altimeter (in metre); corresponds to the bird altitude in metre above ground level.
- **BIRD_NN**  smoothed bird altitude (in m a.m.s.l. = metre above mean sea level).
- **TOPO**  topographic elevation (in metre above sea level).
- **mag_base**  total field value at mag base station at ground [nT]
- **lgrf**  IGRF value at lat/long value for the altitude of the Bird (bird_NN), Epoch 2006.4 [nT]
- **incli**  inclination of main magnetic field at lat/long value in Degrees
- **decli**  declination of main magnetic field at lat/long value in Degrees
- **diurnal**  diurnal variation at mag base station subtracting mean value [nT]
- **f_mag**  despiked and filtered value of the total magnetic field [nT]
- **delta_T_korr**  heading error corrected value of the total magnetic field and subtraction of lgrf and diurnal variations [nT]
- **delta_T_lev**  leveled value of the anomalous magnetic field [nT]
Radiometrics

Description of the ASCII-coded data file containing the final (leveled) data of a helicopter-borne radiometric survey

SCI'xxx'.xyz

'xxx' internal area number: 111 for Ellerbeker Rinne

lines with "/" are comment lines
line 70.1 line number
tie 1.9 tie line number

/ ------------------------------------------
/ XYZ EXPORT [09/14/2006]
/ DATABASE [\sci111.gdb]
/ ------------------------------------------
/ X                Y        Lat_WGS_84   on_WGS_84 Record   Radar   Baro  s_tot    c_pot   c_tho   c_ura   tc_expo
/=================================================================ereço ===========================================
/ Line  70.1
550506 5957223 53.7437063         9.7644468       6285      99.35     101.37     232.69       0.82       2.21       0.52         2.21
550533 5957240 53.7438600         9.7648518       6286      97.20       99.32     229.71       0.79       2.25       0.53         2.19
550559 5957258 53.7440158         9.7652542       6287      96.21       97.25     228.27       0.77       2.29       0.53         2.17

Channel description:

X Gauß-Krüger easting in m (Zone 3), DHDN system(Bessel-Ellipsoid), these coordinates have a false easting of 3000000 metres
Y Gauß-Krüger northing in m (Zone 3), DHDN system(Bessel-Ellipsoid)
Lat_WGS_84 Latitude Value (degrees) WGS84 system
Lon_WGS_84 Longitude value (degrees) WGS84 system
Record time mark increasing by 1 every second
Radar smoothed value of the radar altitude (in metre); corresponds to the helicopter altitude in metre above ground level
Baro filtered value of the barometric sensor (in metre); corresponds to the bird altitude (in metre above mean sea level).
s_tot stripped total count rate in counts per second [cps]
c_pot concentration of K40 [%]
c_tho concentration of Thorium Th [ppm]
c_ura concentration of Uranium U [ppm]
TC_expo Total count exposure rate TC_expo [micro Roentgens/h]
Appendix III

CD-ROM

Acrobat Reader
    lie smich.txt
Acrobat Reader/Linux
    AdobeReader_deu-7.0.5-1.i386.tar.gz
Acrobat Reader/Mac
    AdbeRdr708_de_DE.dmg
Acrobat Reader/Win 3.1
    rs16d301.exe
Acrobat Reader/Win 95
    rp505deu.exe
Acrobat Reader/Win NT
    AdbeRdr708_DLM_de_DE.exe
Acrobat Reader/Win XP
    AdbeRdr708_DLM_de_DE.exe

Data

Data/HEM
    HEM111_APP.xyz
    HEM111_DAT.xyz
    HEM111_INV.xyz
    HEM111_STA.xyz
    HEM111_SYN.xyz
    readme_hem.txt

Data/MAG
    MAG111.xyz
    readme_mag.txt

Data/SCI
    readme_sci.txt

Maps

Maps/DEM
    TK50 Ellerbeker Rinne DEM.pdf
    TK50 Ellerbeker Rinne Flight lines.pdf

Maps/HEM
    TK50 Ellerbeker Rinne resistivity -00m.pdf
    TK50 Ellerbeker Rinne resistivity -05m.pdf
    TK50 Ellerbeker Rinne resistivity -10m.pdf
    TK50 Ellerbeker Rinne resistivity -15m.pdf
    TK50 Ellerbeker Rinne resistivity -20m.pdf
    TK50 Ellerbeker Rinne resistivity -25m.pdf
    TK50 Ellerbeker Rinne resistivity -30m.pdf
    TK50 Ellerbeker Rinne resistivity -35m.pdf
    TK50 Ellerbeker Rinne resistivity -40m.pdf
    TK50 Ellerbeker Rinne resistivity -45m.pdf
    TK50 Ellerbeker Rinne resistivity -50m.pdf
    TK50 Ellerbeker Rinne resistivity -55m.pdf
    TK50 Ellerbeker Rinne resistivity -60m.pdf
    TK50 Ellerbeker Rinne resistivity -65m.pdf
    TK50 Ellerbeker Rinne resistivity -70m.pdf
    TK50 Ellerbeker Rinne resistivity rho2.pdf
    TK50 Ellerbeker Rinne resistivity rho3.pdf
    TK50 Ellerbeker Rinne resistivity rho4.pdf
    TK50 Ellerbeker Rinne resistivity rho5.pdf
    TK50 Ellerbeker Rinne rhoa1.pdf
    TK50 Ellerbeker Rinne rhoa2.pdf
    TK50 Ellerbeker Rinne rhoa3.pdf
    TK50 Ellerbeker Rinne rhoa4.pdf
    TK50 Ellerbeker Rinne rhoa5.pdf
    TK50 Ellerbeker Rinne upper boundary z2.pdf
    TK50 Ellerbeker Rinne upper boundary z3.pdf
    TK50 Ellerbeker Rinne upper boundary z4.pdf
    TK50 Ellerbeker Rinne upper boundary z5.pdf
    TK50 Ellerbeker Rinne zst1.pdf
    TK50 Ellerbeker Rinne zst2.pdf
    TK50 Ellerbeker Rinne zst3.pdf
    TK50 Ellerbeker Rinne zst4.pdf
    TK50 Ellerbeker Rinne zst5.pdf

Maps/MAG
    TK50 Ellerbeker Rinne Anomalies of the magnetic field.pdf

Maps/SCI
    TK50 Ellerbeker Rinne Exposure rate.pdf
    TK50 Ellerbeker Rinne Potassium.pdf
    TK50 Ellerbeker Rinne Thorium.pdf
    TK50 Ellerbeker Rinne Total count.pdf
    TK50 Ellerbeker Rinne Uranium.pdf

Report

Vertical sections
    VRS 1110018.pdf
    VRS 1110019.pdf
    VRS 1110028.pdf
    VRS 1110029.pdf
    VRS 1110038.pdf
    VRS 1110039.pdf
    VRS 1110048.pdf
    VRS 1110049.pdf
    VRS 1110059.pdf
    VRS 1110069.pdf
    VRS 1110701.pdf
Appendix IV
Maps
ANCIENT GROUNDWATER RESERVOIRS IN BURIED VALLEYS (BURVAL) – SUSTAINABLE WATER RESOURCES FOR THE FUTURE

The project is co-financed by the European Union

Barmstedt

Scale 1:50 000

( cm 1 km) =

Topography and flight lines

AIRBORNE GEOPHYSICAL SURVEY ELLERBEKER RINNE / GERMANY

Tick marks indicated in the margin show...
The topography was assembled by the following

Gauß-Krüger-coordinates, Bessel Ellipsoid base maps 1:50,000:
L 2124 Bad Bramstedt
L 2324 Pinneberg

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Ellerbeker Rinne Area:

Parameter:

April 2005 and May 2006;

Hans-Joachim Rehli, Josef Scheiwein, Hanno Schmidt, Bernhard Siemon, Wolfgang Voß, Michael Schütte (Wiking Helikopter Service GmbH)

Karl-Heinz Meinhardt, Uwe Meyer, Jens Pielawa,

B 3.13 · Applied Airborne and Ground Geophysics
Hannover 2006 · www.burval.org · heli@bgr.de

Field operation and processing:

Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) Hannover, Federal Republic of Germany

Landesamt für Natur und Umwelt Schleswig-Holstein (LANU) Flintbek, Federal Republic of Germany

Behörde für Stadtentwicklung und Umwelt (BSU) Hamburg, Federal Republic of Germany

Record number Profile-line number Tie-line number Nominal distances between flight lines400 m 2000 m 85000
Alle anderen Karten und Vertikalsektionen sind in dieser Web-Fassung des Berichtes nicht enthalten.

All other maps and vertical resistivity sections are not included in this web edition of the report.