Airborne Geophysical Surveys in the Weser-Elbe Area, Northern Germany

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SUMMARY

The German Federal Institute for Geosciences and Natural Resources (BGR) carried out six airborne geophysical surveys in Northern Germany close to the estuaries of the Weser and Elbe rivers within the first decade of this century. Two of them were conducted in cooperation with the Leibniz Institute for Applied Geophysics (LIAG). The common aim was the acquisition of a reference data set for monitoring climate or man-made induced changes of the salt-water/fresh-water interface at the German North Sea coast and to build up a data base containing all airborne geophysical data sets. Airborne frequency-domain electromagnetic, magnetic, and radiometric data were collected simultaneously using BGR's helicopter-borne geophysical system. The airborne geophysical results show geological and hydrogeological structures at a wide range of depth levels. The electromagnetic data, converted to resistivity, reveal several hydrogeological important features such as the distribution of sandy or clayey sediments, the extension of salt-water intrusion and buried valleys down to about 100 m depth. The electromagnetic results are supported by magnetic and radiometric data indicating deep basin structures, lateral changes of weakly magnetized shallow sediments and mineral compositions of the top soil. The combination of airborne geophysical data sets provides a data base of a huge area serving as base-line data for a variety of applications and particularly for groundwater modelling and monitoring.

Keywords: Airborne geophysics, electromagnetics, magnetics, radiometrics, Northern Germany

INTRODUCTION

Over the last decade, the German Federal Institute for Geosciences and Natural Resources (BGR) carried out several airborne geophysical surveys in Northern Germany (Siemon et al. 2004; Siemon 2006; Wiederhold et al. 2008). Some of them were conducted in cooperation with the Leibniz Institute for Applied Geophysics (LIAG) in 2008 and 2009 (Wiederhold et al. 2010). The BGR project D-AERO combines the results of all surveys available. Here, the airborne results of six connected survey areas at the estuaries of the Weser and Elbe rivers (Figure 1 and Table 1) are shown.

One aim of the BGR/LIAG project is to create a reference data set as basis for monitoring climate or man-made induced changes of the salt-water/fresh-water interface at the German North Sea coast. Problems arising from groundwater salinization are becoming increasingly important within the context of groundwater extraction and treatment. Thus, a latent risk for the sustainable usage of aquifers exists particularly in coastal areas. Another aim of the project is to build up a geophysics data base (http://www.geophysics-database.de/) which contains all airborne geophysical data sets.

Table 1. BGR airborne surveys of the Weser-Elbe survey area flown at 250 m common line spacing.

<table>
<thead>
<tr>
<th>No.</th>
<th>Survey</th>
<th>Size</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>Cuxhaven</td>
<td>530 km²</td>
<td>2000</td>
</tr>
<tr>
<td>87</td>
<td>Bremerhaven</td>
<td>550 km²</td>
<td>2001</td>
</tr>
<tr>
<td>109</td>
<td>Hadeln</td>
<td>700 km²</td>
<td>2004</td>
</tr>
<tr>
<td>111</td>
<td>Ellerbeker Rinne</td>
<td>280 km²</td>
<td>2005</td>
</tr>
<tr>
<td>132</td>
<td>Glückstadt</td>
<td>1950 km²</td>
<td>2008/09</td>
</tr>
<tr>
<td>138</td>
<td>Nordenham</td>
<td>400 km²</td>
<td>2009/10</td>
</tr>
</tbody>
</table>
Three different helicopter-borne electromagnetic (HEM) systems were used. With an analogue five-frequency system (DIGHEM V-BGR) the areas Cuxhaven (81) and Bremerhaven (87) were surveyed in 2000 and 2001, respectively. Digital RESOLVE systems were used for the other surveys. Hadeln (109) and Ellebeker Rinne (111) were flown in 2004 and 2005 with a five-frequency system whereas Glückstadt (132) and Nordenham (138) were flown in 2008/09 and 2009/10 with a six-frequency system. All transmitter-receiver coil pairs are orientated horizontal- coplanar (HCP). Only the six-frequency system has an additional vertical-coaxial (VCX) coil pair. The four low HCP frequencies of the HEM systems are similar (about 0.4, 2, 8, and 40 kHz) but not identical; the highest frequency of the analogue system (192 kHz) differs from the one of the digital systems (about 130 kHz). The magnetic (Cs magnetometer Geometrics G-822A) and radiometric (gamma-ray spectrometer Exploranium GR-820 with four 4-litre-Nal crystals) systems were the same in all surveys.

The transmitter signals of the HEM system, the primary magnetic fields, induce eddy currents in the subsurface which depend on the electrical conductivity distribution. The relative secondary magnetic fields from these induced currents are measured at the receiver coils in parts per million. The use of different frequencies enables the investigation of different depths as high frequencies resolve the shallower parts of the subsurface and low frequencies the deeper parts. The depth of investigation depends also on the subsurface conductivity distribution as high conductivities constrain the penetration of the electromagnetic fields into the subsurface (Siemon et al. 2009). Typical maximum investigation depths range from about 30 m in salt-water saturated sediments to about 150 m in fresh-water saturated sandy sediments or solid rocks (Siemon et al. 2012). The earth’s magnetic field and the natural gamma radiation of the earth’s surface recorded in addition to the electromagnetic fields are normally used to interpret the structure of the earth’s crust and the mineral composition of the shallowest soil layers, respectively. In addition to information on the North German Basin structure the magnetic data could be used to reveal lateral changes of shallow, weakly magnetized sediments. The joint interpretation of these data sets supports three-dimensional modelling of the subsurface and is also used as a basis for planning and activities in many environmental and economic disciplines, e.g., for regional planning, development of water utilization and water protection concepts.

RESULTS

Electromagnetics

The in-phase and quadrature components of the measured secondary magnetic fields are converted to resistivity (inverse of conductivity) models (Sengpiel and Siemon 2000). Apparent resistivity $\rho_a$ [\(\Omega m\)] and centroid depth $z^* [m]$ values are derived from the data of each single frequency ($f$) based on a homogeneous half-space model (Siemon 2001). Figure 2a shows the apparent resistivity map of the Weser-Elbe area derived from HEM data at about $f = 2$ kHz. Although the different HEM data sets have not been jointly reprocessed (only re-gridded) the apparent resistivites are very consistent. High conductivities and resistivities are coloured red and blue, respectively. It is obvious from Figure 2a and a groundwater salinization map published by Grube et al. (2000) that the HEM results reveal salt-water saturated sediments close to the estuaries of the Weser and Elbe rivers. The slightly elevated moraines, which consist of mainly coarse-grained sediments, appear resistive (typical for fresh-water saturated sands and gravels). Yellow colours indicate resistivities typical for coarse-grained sediments saturated with brackish water or fine-grained sediments such as clay or till saturated with fresh water. The more or less linear structures close to motorway A27 are caused by buried glacial valleys refilled with clayey sediments (Siemon et al. 2004) and the circular structure near Elmshorn correlates with a shallow salt dome. Man-made features often appear highly conductive such as the dumpsite NW of Stade.

Magnetics

The anomalies of the earth’s magnetic field of the Weser-Elbe area only show a regional magnetic low caused by the North German Basin (Gabriel et al. 2012) and, of course, man-made features. After deleting all data affected by undesired, man-made features, high-pass filtering of the data reveals a number of linear structures (Figure 2b). Those structures often correlate with buried valleys, e.g., close to motorway A27, between Oste and Elbe rivers, and between motorways A23 and A7. This typical signature consists of a pair of more or less parallel and elongated magnetic highs and a
magnetic low in-between. The peak-to-peak values are only a few nT.

Radiometrics

The radiometric data show similar results in all standard channels (K, U, and Th). Therefore, it is sufficient to present the potassium concentration. Rather high concentrations (red colours) occur in the marshes which are dominated by clayey soils, whereas the sandy moraines and the wetlands show low (green) or about no (blue) potassium concentrations, respectively. Areas where till exists correlate with slightly higher concentrations (yellow).

CONCLUSION

Airborne geophysical surveys enable huge areas to be surveyed almost completely in a relatively short time at economic cost. The results can generally be used for geological and hydrogeological mapping. Particular the data sets collected by airborne electromagnetic surveys are important for geological or hydrogeological interpretation as the parameter surveyed, the electrical conductivity, depends on both lithology and groundwater status. Thus, the distribution of sandy and clayey sediments as well as salinization zones and fresh-water occurrences down to depths of the upper hundred metres could be revealed from HEM data. These results are supported by airborne magnetic and radiometric data, which are generally simultaneously acquired. The magnetic data reveal both deep sources (several kilometres) caused by the North German Basin and shallow sources (several tens of metres) obviously caused by lateral changes of Quaternary and Tertiary sediments. The radiometric data indicate the various mineral compositions of the soil sediments.

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REFERENCES


Figure 2. Results of six airborne geophysical surveys in Northern Germany: a) Electromagnetics – apparent resistivity at a frequency of about 2 kHz, b) Magnetics – high-pass filtered anomalies of the total magnetic field, c) Radiometrics – Potassium concentration at the surface of the earth.