Airborne clay mapping at the East Frisian coast

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ABSTRACT

Airborne geophysical methods enable economic and ecological mapping of subsurface natural resources. Besides groundwater and mineral exploration, the investigation of non-mineral resources is an important task. Electromagnetic methods are able to map lithological units if these are correlated with electrical conductivity. Particularly resistive sands and gravels can be distinguished from conductive clayey materials. Currently most of our recent airborne surveys were flown in the coastal areas of Northern Germany, where saltwater intrusion and clay mapping are the principal topics. The helicopter-borne system operated by BGR was used to survey several areas in Eastern Friesland together with LIAG. The spatial conductivity distribution, which was derived from six-frequency helicopter-borne electro-magnetic (HEM) data, provides information on both lithology and water salinity. Onshore, the HEM results clearly outline a rather complex pattern of higher conductivity which coincides with many boreholes provided by LBEG, in which clayey material was found particularly down to about 20 m depth. This pattern continues offshore and thus obviously outlines areas where fresh groundwater flows into the Wadden Sea. On the islands, the HEM results show some indications for thin clay layers within the freshwater lenses.

INTRODUCTION

The knowledge on saltwater intrusion and distribution of clayey sediments is important for understanding the current status of the dynamic setting in coastal areas, where large storms, rising sea level, and human activity may affect the hydrogeological conditions, and the impact of climate change effects is of particular interest (Hinsby et al. 2011).

Geophysical methods such as electromagnetics (EM) are able to map hydrogeological units if these are correlated with the electrical conductivity (or its inverse, the resistivity). Particularly conductive saltwater can be distinguished from resistive freshwater as well as conductive clayey materials from resistive sands and gravels (Kirsch 2006). Helicopter-borne geophysical methods enable economic and ecological mapping of near-surface natural resources and environmental settings (Siemon et al. 2009). One of the first successful airborne groundwater investigation surveys was conducted on the island of Spiekeroog, Germany, in 1978 (Sengpiel and Meiser 1981) using an early frequency-domain helicopter-borne electromagnetic (HEM) system (DIGHEM II) operated by BGR. Since then, many airborne surveys have demonstrated the applicability of airborne EM in coastal areas, e.g for mapping of saltwater intrusions, freshwater outlets, or freshwater lenses on islands (e.g. Fitterman and Deszcz-Pan 1998; Siemon and Steuer 2011; Siemon et al. 2014).

Two surveys flown in Northern Germany in 2008-2009 cover an area of 20 km by 31 km including the island of Langeoog, the western half of the island of Spiekeroog, the Wadden Sea, and the onshore area to the north of Aurich. The aim of these surveys was the investigation of saltwater intrusion and the distribution of clayey sediments, and on the islands, the freshwater lenses and the lithological structure were studied.

METHODS

The BGR airborne geophysical system enables simultaneous measurements of three geophysical methods: electromagnetics, magnetics, and gamma-ray spectrometry. The electromagnetic sensors are housed in a 10 m long tube, which is towed by a Sikorsky S-76B helicopter on parallel flight lines about 30–40 m above ground level. The processed HEM data are converted to half-space parameters, which are used to define individual multi-layer starting models at each data point for an iterative Marquardt-Levenberg inversion process (Siemon et al. 2009; Steuer et al. 2014). As man-made effects caused by power lines, railway tracks, highways, wind parks or urban areas are able to distort nearby HEM measurements, these data have to be corrected (Siemon et al. 2011).

RESULTS

Assuming that clay/silt is represented by a resistivity ranging from 12 to 35 Ωm, the thicknesses of model layers fulfilling this condition were summed up and displayed on a map (Figure 1). In order to reduce misinterpretation caused by saltwater, only the upper four of six model layers were taken into account as they represent shallow clay/silt layers sufficiently well and the coastal saltwater intrusion mainly affects the lower two model layers. The thicknesses of clayey or silty layers at shallow depths (around 10 m bsl) obtained from the boreholes as well as the location of boreholes without clay and silt layers (LBEG 2014) are also shown on this map. It is obvious that the clay/silt thicknesses estimated from the HEM results are sufficiently correlated with clay/silt thicknesses of most of the boreholes. Some discrepancies occur, for example, at the location boreholes A, B, or C, which are often caused by man-made effects or insufficient borehole descriptions. This finding encourages the use of the airborne results for mapping of shallow clay occurrences.

The freshwater-saltwater interface in this survey is located rather close to the coastline, particularly at shallow depths (Steuer et al. 2014). At greater depth, a straggly distribution of resistive and conductive features crossing the coastline appears (Figure 2). On both sides of the sea dyke, finger-shaped conductivity features appear, which seem to be a continuation of the shallow clay/silt deposits onshore. Therefore, it is likely that the saltwater is linked to clayey sediments and that the fresh groundwater flows out to the Wadden Sea area. This detailed information is necessary for correctly setting-up geological and hydrogeological models (Deus and Elbracht 2014).

On the islands, the HEM results reveal the freshwater lenses (white colours on Figure 2) and show some indications for thin clay layers, which are investigated in detail by ground geophysical methods (Costabel et al. 2014).

DISCUSSION AND CONCLUSIONS

The application of helicopter-borne EM in coastal areas helps to map saltwater intrusion, offshore freshwater outlets and/or clayey sediments. The spatially acquired airborne data are able to close gaps resulting from sparse borehole density and enables improved geological and/or hydrogeological modelling. In this survey area, the knowledge about the distribution of medium to low resistivities was mandatory to successfully map clay/silt occurrences and freshwater-saltwater interfaces as these rather complex patterns were not sufficiently imaged by borehole interpretation alone.

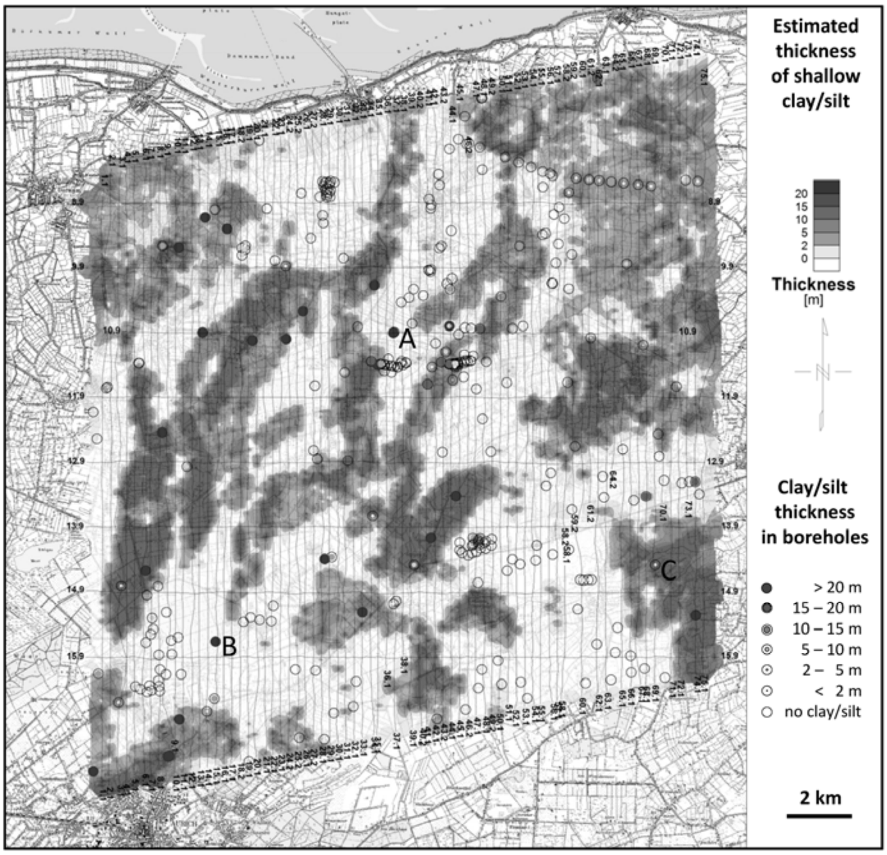

Figure 1. Comparison of clay thicknesses derived from HEM data and found in boreholes at shallow depth plotted on a topographic map (BKG 2008).

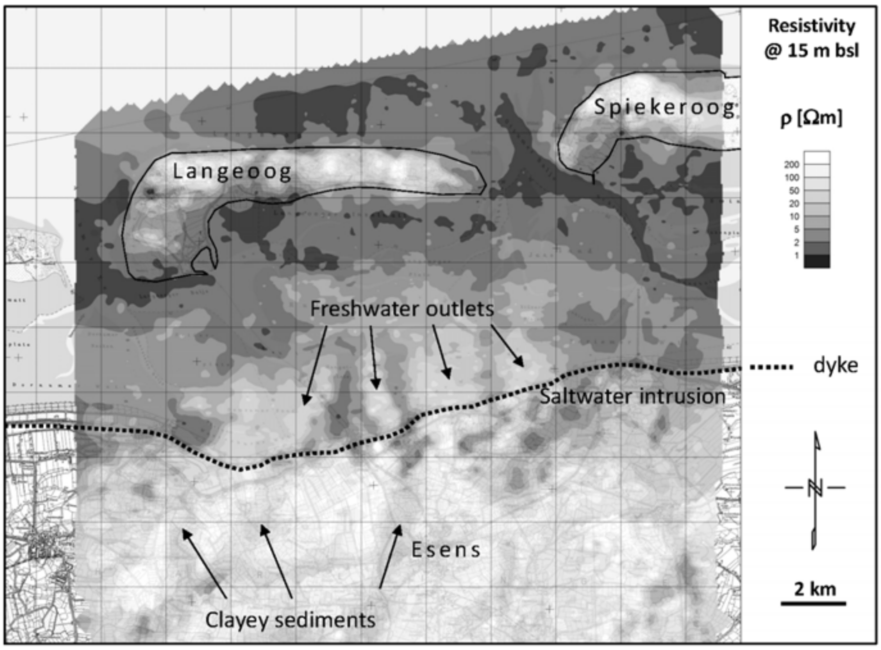

Figure 2. Resistivity at 15 m bsl revealing complex freshwater-saltwater interfaces at the North German coast and on the islands plotted on a topographic map (BKG 2008).

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