Locating and mapping potential environmental hazards in the UK with high resolution airborne geophysics

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Peart, R.J., Cuss, R.J., Beamish, D. and Jines, D.G., 2003. Locating and Mapping Potential Environmental Hazards in the UK with High Resolution Airborne Geophysics. Geoscientist (the Fellowship magazine of the Geological Society of London), **13**, 7, 4-7.

Introduction

During the past fifteen years environmental scientists have applied airborne geophysical techniques increasingly to the mapping and monitoring of potential environmental hazards such as leakages from landfill sites, the spread of polluted groundwaters and the distribution of possibly harmful natural and artificial radionuclides. Explorationists first applied these techniques more than 60 years ago, initially for metallic mineral exploration in Shield areas with subsequent developments in non-geological applications such as the detection of enemy submarines. In later years the techniques have been improved and also applied to hydrocarbon exploration and geological and structural mapping. The rapid emergence of airborne techniques in environmental studies is a response to high profile nuclear accidents, increasingly stringent environmental legislation, the desire of many large corporations for a green image and the numerous benefits delivered by airborne techniques. These latter include relative ease of access to 'difficult' sites, comprehensive data coverage and remote, rapid and non-invasive acquisition of data which in turn informs highly focussed confirmatory ground follow up activities. All of these advantages are especially important in potentially hazardous sites. The success of the airborne techniques results from the use of highly sensitive equipment combined with close flight line spacing, generally low ground clearance and accurate navigation and post survey data location based on differential GPS. In this paper we use data from two recent high resolution airborne geophysical surveys in the UK to show how a broad range of environmental management issues can be addressed. In future volumes further contributions will describe the applications of these airborne data sets to resource exploration and geological and structural mapping.

The airborne surveys

The British Geological Survey has recently acquired two onshore UK high resolution airborne geophysical data sets. The first of these (1998) HiRES-1 (High resolution airborne Resource and Environmental Survey: phase 1) was acquired in collaboration with World Geoscience

Ltd., now part of Fugro Airborne Surveys, and covers 14,000km^2 in central England. Flight line spacing is 400m, closing to 200m over three infill areas of special interest, with ground clearance of 90m rising to 240m over built-up areas. The geophysical data collected are total field magnetics, gamma spectrometry and dual frequency Very Low Frequency electromagnetics (VLF-EM). The HiRES-1 survey was conceived as the first phase of a national strategic airborne geophysical survey and we intend to complete this over the coming decade.

The second data set (1999) comprises a series of site specific trials in the East Midlands over four carefully selected target areas displaying a broad range of potential environmental hazards. These were flown in collaboration with the Geological Survey of Finland (GTK) who for some years have successfully flown a de Havilland Twin Otter with a dual frequency (3.125 and 14.368kHz) wing tip EM system for environmental investigations. These trials were designed to assess how successful this system would be in the generally less favourable UK conditions where, for example, we anticipated lower conductivity contrasts between host geology and conductive targets (leachate plumes etc) and a higher level of electrical noise due to widespread industrial development and infrastructure. A further potential drawback in the UK is that generally the Civil Aviation Authority will not permit survey flying at the low ground clearances (30-40m) routinely achieved in Finland. As far as we are aware our collaborative trial surveys are the first application of airborne EM to environmental investigations in the UK. Other geophysical data collected during the trials were horizontal gradient magnetics (cross track) and gamma spectrometry. Flight line spacing ranged between 50 and 200m with ground clearances in the range 50 to 90m.

Example data applications

Our first examples are of dual-frequency EM data collected over an active colliery and a former, landscaped landfill site, both in north Nottinghamshire. Fig. 1 shows the subsurface conductivity distribution derived from the high frequency data over Thoresby Mine and its environs draped on topography. The mine site (shown on the O.S. map extract) is characterised by high conductivity values, generally greater than about 40mS/m (warm colours), in sharp contrast to the low conductivities (typically less than 15mS/m) displayed by the undisturbed Sherwood Sandstone to the north and west (grey tones). The conductivity distribution in the periphery of the mine site displays numerous sinuous conductive zones (yellow, green and light blue) extending away from the site to the south and east. These are believed to reflect the presence of groundwaters enriched with salts leached from the spoil heaps by percolating rainwater. This is highly significant because part of the UK's second most important aquifer (the Permo-Triassic sandstones) underlies this area at shallow depth. Follow-up fieldwork, using a variety of geophysical methods, has been carried out at a number of the mine sites in the area, all displaying similar behaviour. The ground based observations confirm the airborne results and indicate that enhanced conductivities occur within the aquifer at depths greater than 30m. The chemical nature of these features is to be tested by drilling and sampling of the pore fluids at various depths. The airborne EM data also indicate a subtle change in background conductivities between areas of ancient woodland cover (Sherwood Forest) and neighbouring agricultural land to which fertilisers have been applied, resulting in increased electrical conductivity.

Elsewhere former landfill sites have been detected by airborne EM as relatively conductive features and again have been confirmed by ground measurements. Fig. 2 demonstrates the close correlation in space and amplitude between the airborne and ground measurements over a carefully landscaped former landfill site with no obvious surface expression near Worksop. Several isolated conductive features were detected during the trial airborne surveys for which no apparent source could be identified on maps or flight path video film. Examination in the field, however, revealed many of these conductive features to be former landfill sites that for some reason may not be recorded in modern records. Conductive features in a relatively resistive host (the Permo-Triassic sandstones) represent a comparatively easy target but in southern Nottinghamshire the airborne EM technique was also able to delineate conductive landfills in a highly conductive (greater than 100mS/m) host (Lower Jurassic mudstones and clays). It is reassuring to note that of the landfill anomalies we have examined to date, none appear to indicate lateral leakage of conductive fluids. The airborne data could be used to demonstrate the integrity of such sites over time using repeat surveys. We believe it may also be possible to establish an empirical relationship between the apparent conductivity of landfill sites and the rate of methane generation. This could rapidly inform decisions on where to install venting systems in sealed landfills. Several sewage farms in the trial areas also display airborne conductivity anomalies.

Turning to radiometrics, our HiRES-1 survey mapped relatively high uranium concentrations associated with Carboniferous (Dinantian) Limestones and overlying Namurian Shales in the Peak District. Similarly the Lower Jurassic Marlstone Rock Formation near Melton Mowbray and the Lincolnshire Limestone Formation were both found to yield relatively high thorium counts. Fig. 3 illustrates both the general distribution of relatively high uranium concentrations in the Peak District and also the high uranium count variability within one of the Dinantian horizons, the Bee Low Limestone Formation. The highest uranium concentrations in this unit occur at its western edge and reflect the apron reef limestone facies; elsewhere some of the lowest values indicate where the limestone has been quarried out. The Dinantian limestones of the Peak District, the Lincolnshire Limestone and Marlstone Rock formations are all known to be associated with higher indoor radon levels (>10% of houses above the government's Action Level of 200Bqm–3). Clearly the airborne radiometric technique has the potential to be a very efficient tool for the rapid mapping of variations of radon potential. This would be particularly useful in areas of sparse indoor measurements and for delineating variations within geological units. It would allow better targeting of both indoor radon measurements and protective measures.

Fig. 4 demonstrates the relatively high thorium response of the Marlstone Rock Formation that was formerly extracted as an important iron ore. The cross hatched areas are the old workings and it is interesting to note that these areas display higher thorium values than where the rock was left undisturbed. The reason for this has yet to be established. This unit also displays relatively high uranium values compared to background and so is both thoron and radon prone. Enhanced radioactivity was also observed over both fly ash deposits at coal fired power stations and foundry waste dumps, the latter probably resulting from the presence of zircon rich moulding sands. Fly ash is widely recycled in numerous forms, including building blocks and as a component in concrete, and there may therefore be associated environmental health issues that could be investigated in part using such data.

The HiRES-1 survey also proved anomalous concentrations of certain anthropogenic radionuclides such as 137Cs (resulting from nuclear weapons fallout and the Chernobyl accident) in both the Welsh hills near the Vale of Clwyd and, to a lesser degree, over parts of the Peak District. Similarly the tidal mud flats of the Dee and Mersey Estuaries also display relatively high levels of 137Cs that are believed to result from discharges at Sellafield. Again, the airborne data could form part of a management strategy to address the long term mitigation of this potential hazard.

Aeromagnetic data have potential environmental applications, although these may be less immediately obvious. They include the search for unmapped buried pipelines and the identification of landfill with a high ferrous content that may be worth recycling or the dumping of which is in breach of regulations. One particular numerical transform of the GTK observed cross track magnetic gradient revealed interesting rectilinear patterns in some colliery spoil heaps that may reflect former tramways and related mine-site features.

Conclusions

Our studies show that airborne EM and radiometric data can play a very significant role in locating and mapping the extent of a broad spectrum of both natural and anthropogenic potential environmental hazards, even in a developed, industrialised and hence ‘noisy’ country such as the UK. Airborne geophysical surveys provide a cost effective, quick, safe and non-invasive means of collecting detailed information to depths of several tens of metres. The resulting data can target highly focussed ground follow up activities employing slower and costly surface techniques combined with borehole sampling. The sustainable and safe use of land for industrial, agricultural and resource development, housing and recreation demands a more thorough understanding of surface and shallow subsurface processes. We believe that airborne geophysical data can make a major contribution to such an understanding and we actively seek funding partners to extend the UK’s systematic airborne survey coverage, to undertake research on these methods and implement site-specific applications.

Acknowledgements

We acknowledge the continued cooperation and professionalism displayed by our collaborators, World Geoscience Ltd (now part of Fugro Airborne Surveys) and the Geological Survey of Finland throughout the acquisition and initial processing of the data described here. The trial environmental surveys were co-sponsored by the former Department for the Environment, Transport and the Regions (now the Department for Environment, Food and Rural Affairs) and the Environment Agency. This paper is published with the permission of the Executive Director of the British Geological Survey (NERC).

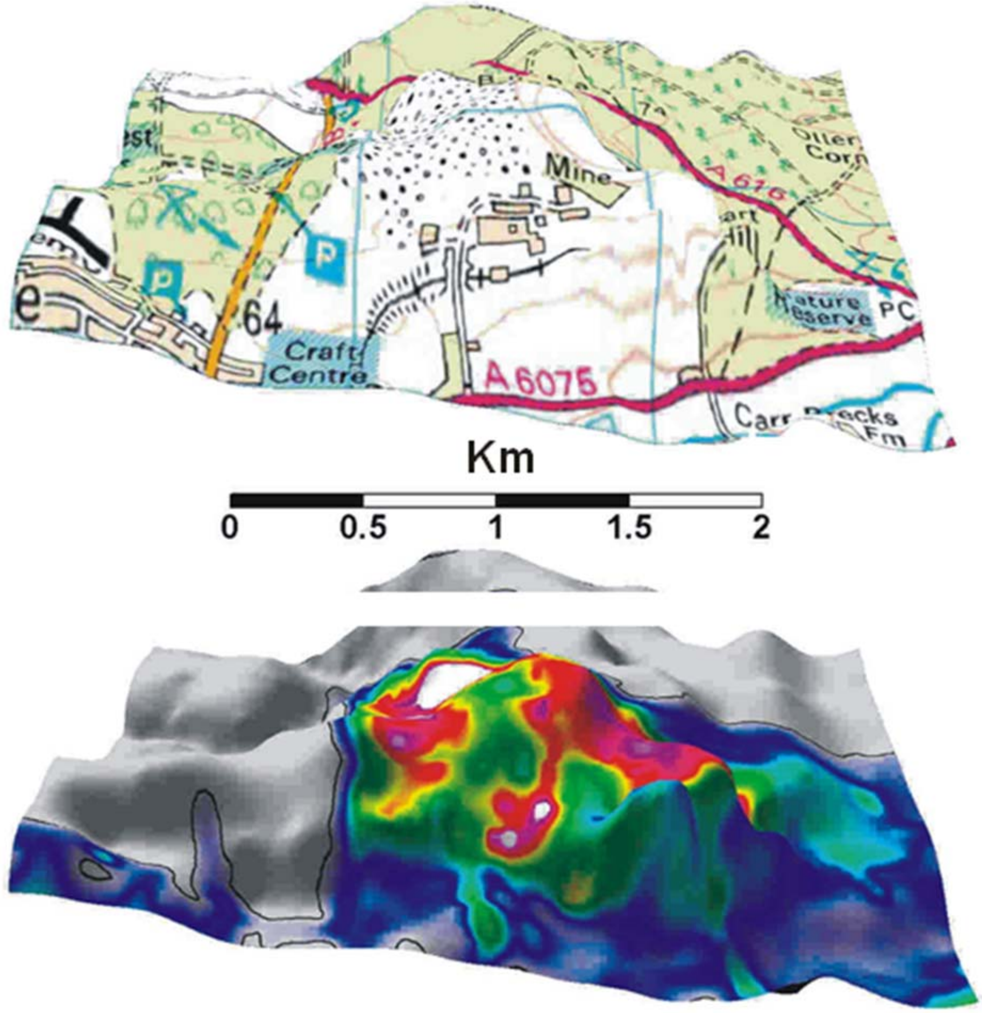

Figure 1

O.S. Map (© Crown copyright. All rights reserved) of the Thoresby Mine site and its environs draped on topography (upper) and the conductivity distribution derived from the airborne EM high frequency measurements also draped on topography (lower). Grey tones represent conductivities less than about 15mS/m and are confined to areas underlain by undisturbed Sherwood Sandstone. The Mine site is characterised by high conductivity values (generally greater than 40mS/m). The sinuous conductive features (yellow, green and light blue) have conductivity values less than 40mS/m.

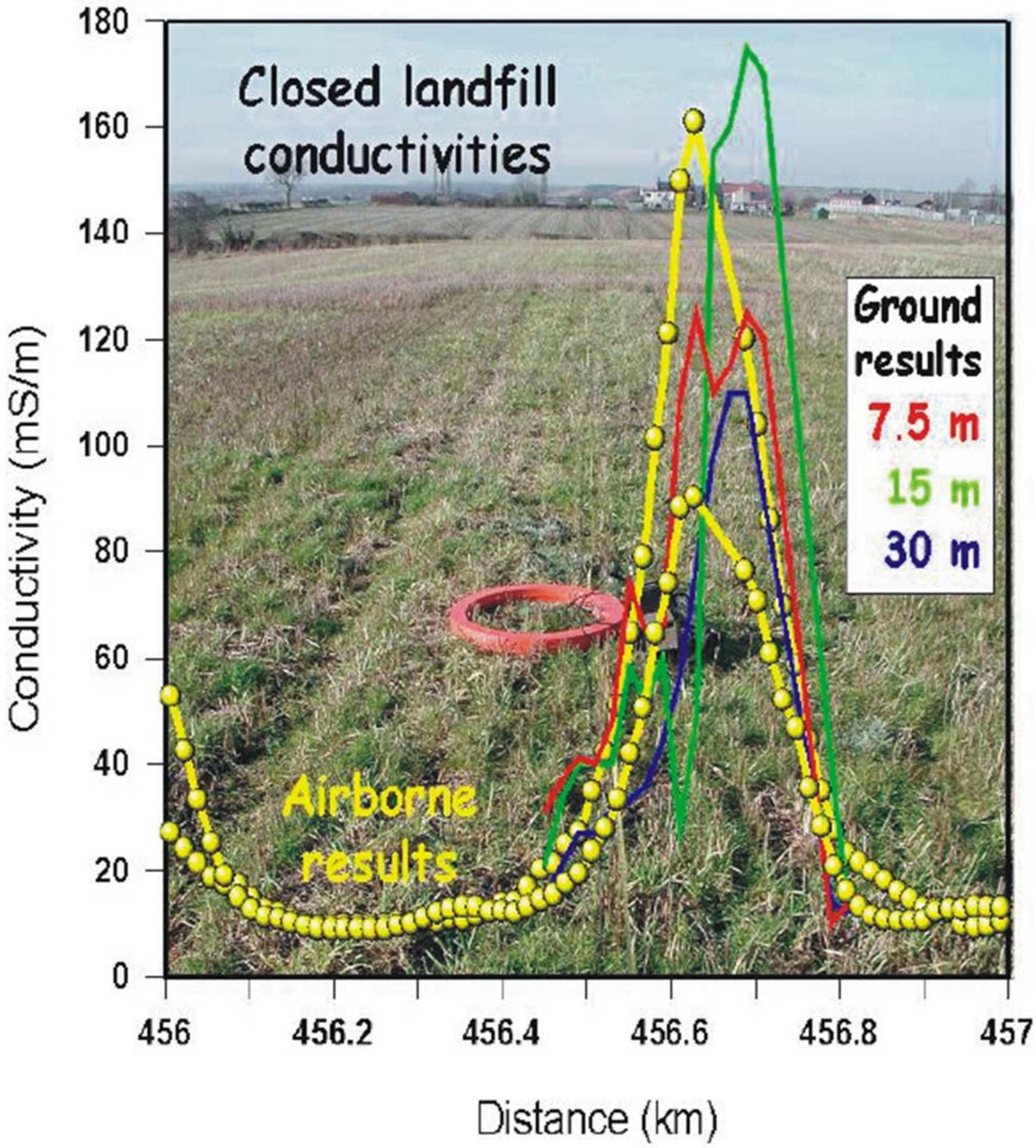

Figure 2

A closed and landscaped landfill site near Worksop in Nottinghamshire is characterised by high electrical conductivities measured at both high and low frequencies with the GTK dual frequency airborne EM system (yellow spheres). Ground-truthing traverses with a conductivity meter show close correspondence in both space and amplitude between airborne and ground data. Variable depths of investigation (red, green and blue profiles) are achieved with the conductivity meter by using different coil separations and orientations.

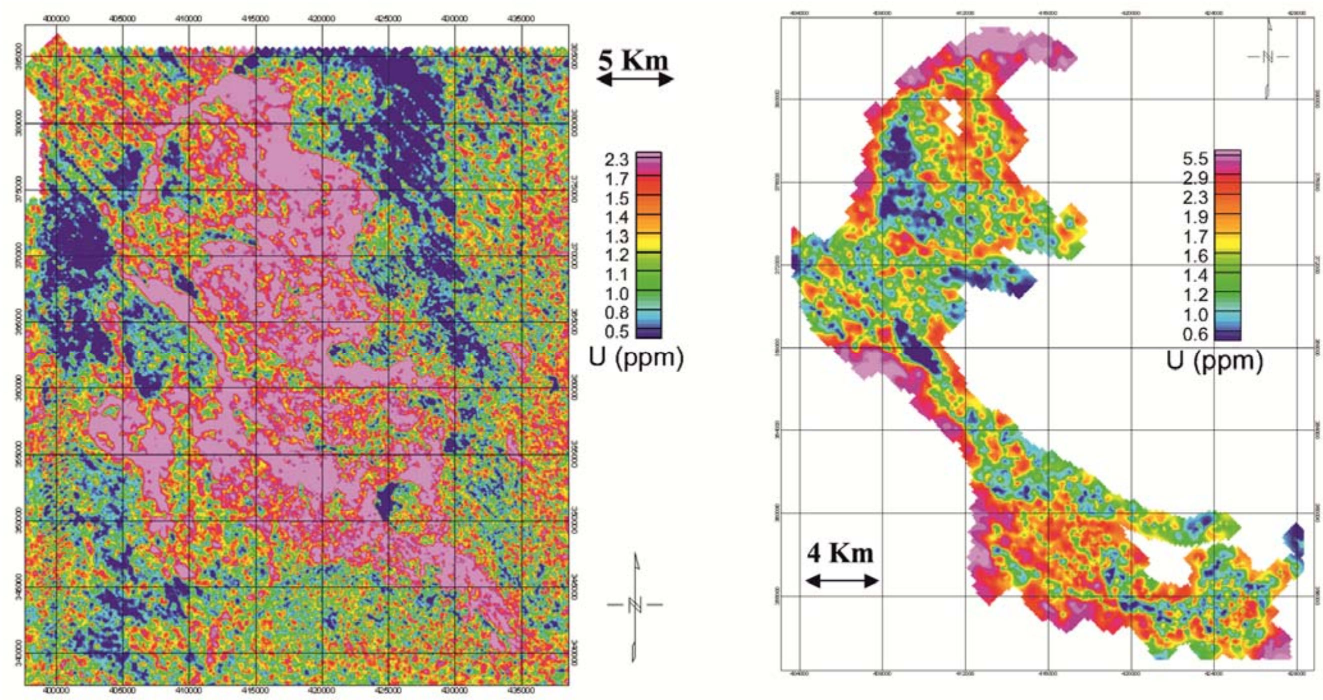

Figure 3

The distribution of relatively high uranium concentrations (pink and red) associated with Dinantian Limestones and overlying Namurian Shales in the Peak District, as measured by the HiRES-1 survey (left). There is high variability in uranium concentration both between and within the various limestone horizons. The image (right) highlights uranium variability within the Bee Low Limestone Formation, with high areas near the western edge representing the apron reef limestones. Lows in some places are large quarries. Variable drift cover will also contribute to the apparent lateral variation in uranium concentration.

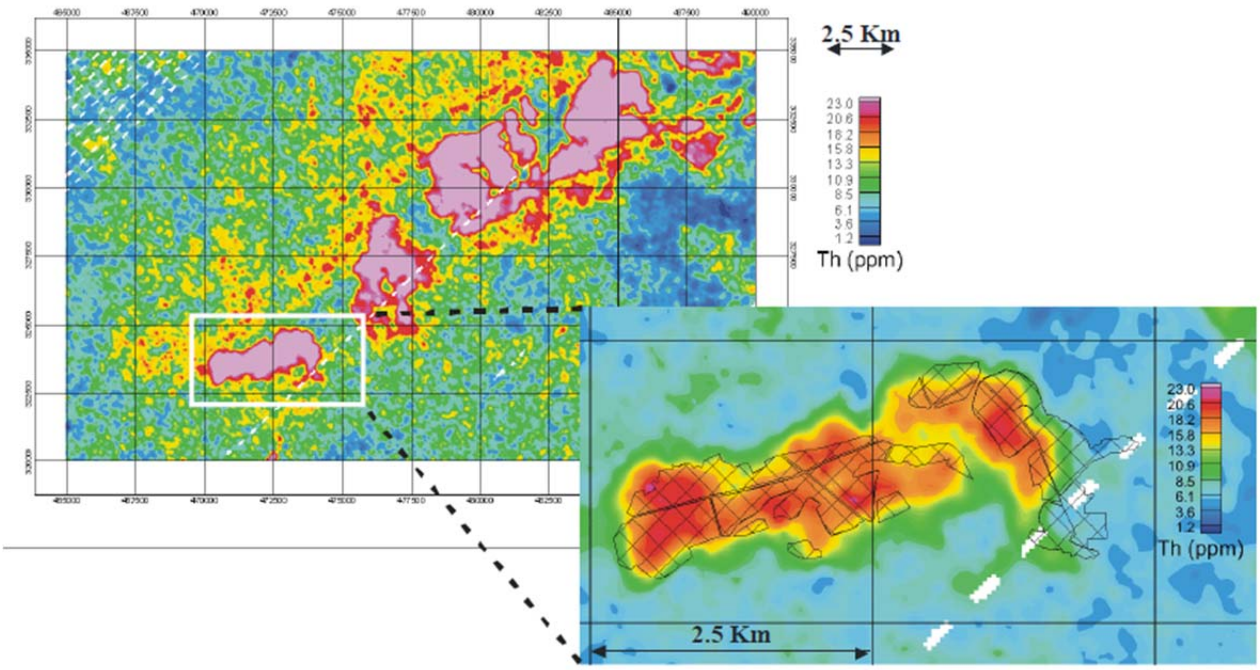

Figure 4

The Lower Jurassic Marlstone Rock Formation is readily characterised in the HiRES-1 data by its relatively high thorium content (left). Again there is variability in thorium content within the Marlstone Rock Formation (right). The hatched pattern shows areas which have been mined and backfilled. For some reason these same areas display higherthorium values than theundisturbed zones.