Trial airborne EM surveys to assess minewater pollution in the UK

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Extended abstract

Summary

Drainage from mining operations is one of the most significant causes of freshwater pollution in some regions of the UK. Airborne electromagnetic (EM) surveys can map the distribution of subsurface resistivity in a continuous manner and can, under favourable circumstances, track concentrations of anomalous pore fluids. This paper presents trial high resolution EM data collected across the Nottinghamshire coalfield. High conductivities are associated with a sequence of colliery spoil zones and the conductive zones appear to extend both vertically and laterally away from the source material. Near-surface conductivities are enhanced by a factor of >10 above regional values. The airborne information provides spatial continuity which is important when dealing with environmental problems involving flow. The data await additional ground-based information to establish the nature of the links between subsurface geochemisty and the geophysical responses observed.

Introduction

The first high resolution airborne electromagnetic surveys to address specific environmental issues in the UK were carried out jointly by BGS and GTK in 1999. The dual frequency, fixed wing EM system operated by GTK was used in a series of trials to acquire detailed (low elevation, small flight separation) EM data sets in addition to magnetic gradiometer and radiometric information. This paper presents the EM results obtained across one of the larger test areas (13 x 9 km) that encompasses part of the north Nottinghamshire coalfield. The area contains a series of collieries and associated spoil tips that have been in operation for many decades. The area is underlain by the important Sherwood Sandstone aquifer. The environmental issue is one of ‘legacy’ coal-mine drainage in relation to future sustainable land-use and groundwater protection.

The airborne EM survey

The GTK fixed wing airborne EM system used in the surveys is described in detail by Poikonen et al (1998). Jokinen and Lanne (1996) describe environmental applications of the system in Finland. The coils are wing-tip mounted (separation of 21.4 m) and are vertical coplanar. Coupling ratios at two frequencies (3.1 and 14.4 kHz) are recorded simultaneously at 4 Hz. Sampling along the flight direction is typically between 10 and 15 m. The system is calibrated by flying over the sea at different altitudes. For the primary levelling, the zero level was measured before and after each sortie at an altitude of 300 m.

Real and imaginary coupling ratios at each frequency are converted to apparent resistivity and apparent depth using stable procedures. The method is based on the classical concept of the apparent resistivity of a half-space (Fraser, 1978). Four trial areas were flown and a series of altitude ranges (40 to 100 m) and flight spacings (50 to 200 m) were included in the trials to assess technical performance levels. The coalfield test area was flown entirely at low level (40 m) and regional coverage was obtained using 200 m flight lines, together with two infill zones incorporating 50 m flight lines. The latter two areas have provided a wealth of detail on many localised features.

Minewater drainage and leachates

Colliery spoils at the time of extraction are normally neutral or slightly alkaline but as weathering proceeds the spoil may become increasingly acidic. Skarzynska and Michalski (1999) discuss the petrographic and mineralologic compositions of coal mine spoils and the reactions that give rise to potential ennvironmental impacts from coal mine drainage. The leaching of soluble salts such as chlorides and sulphates and some heavy metals (e.g. Mn, Zn and Fe) is particularly important from the environmental perspective. Products of leaching are produced when percolating rainwater and/or groundwater flows through a spoil zone. The effluents are then released into the surface drainage system and, ultimately, into the subsurface groundwater system. Chloride leaching from uncompacted spoils has the capability to increase salinity to values in excess of seawater (Twardowska et al., 1990).

The bulk resistivity of subsurface formations provides a distinct measure of land and water ‘quality’. For porous rocks that are either partially (i.e. above the water table) or wholly saturated (i.e. within an aquifer) the current flow is primarily controlled by ionic conduction. The ions, which conduct the current, result from the dissociation of salts. The conductivity of the in-situ electrolyte depends on both the number of ions present (concentration) and their mobilities. Common ion species with high mobilities include the Na^+, SO_4^-, Cl^-, K^+ and NO_3^- groups. Enhanced concentrations of chlorides and sulphates from minewater drainage are likely to enhance conductivities of pore fluids.

The EM data have the ability to assess subsurface rock/fluid conductivity on a scale of tens of metres. When significant resistivity contrasts exist, the spatial continuity of airborne information should allow the

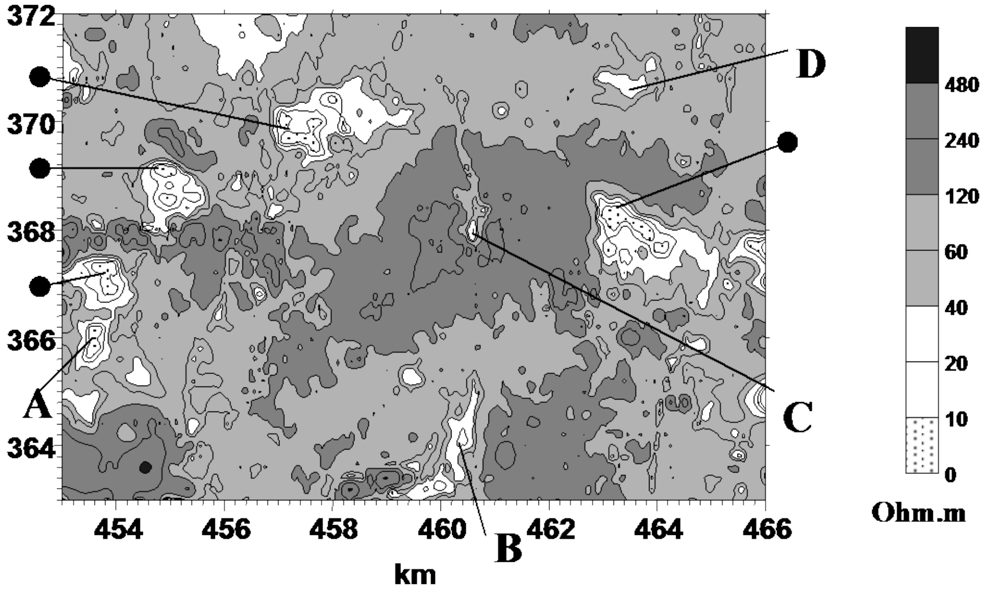

Figure 1. Low frequency (3.1 kHz) apparent resistivity results obtained using 200 m flight lines. Perimeter solid circles denote colliery spoil zones. Other conductive zones are (A) waste ground, (B) railway sidings, (C) water extraction boreholes and (D) Lake/river system

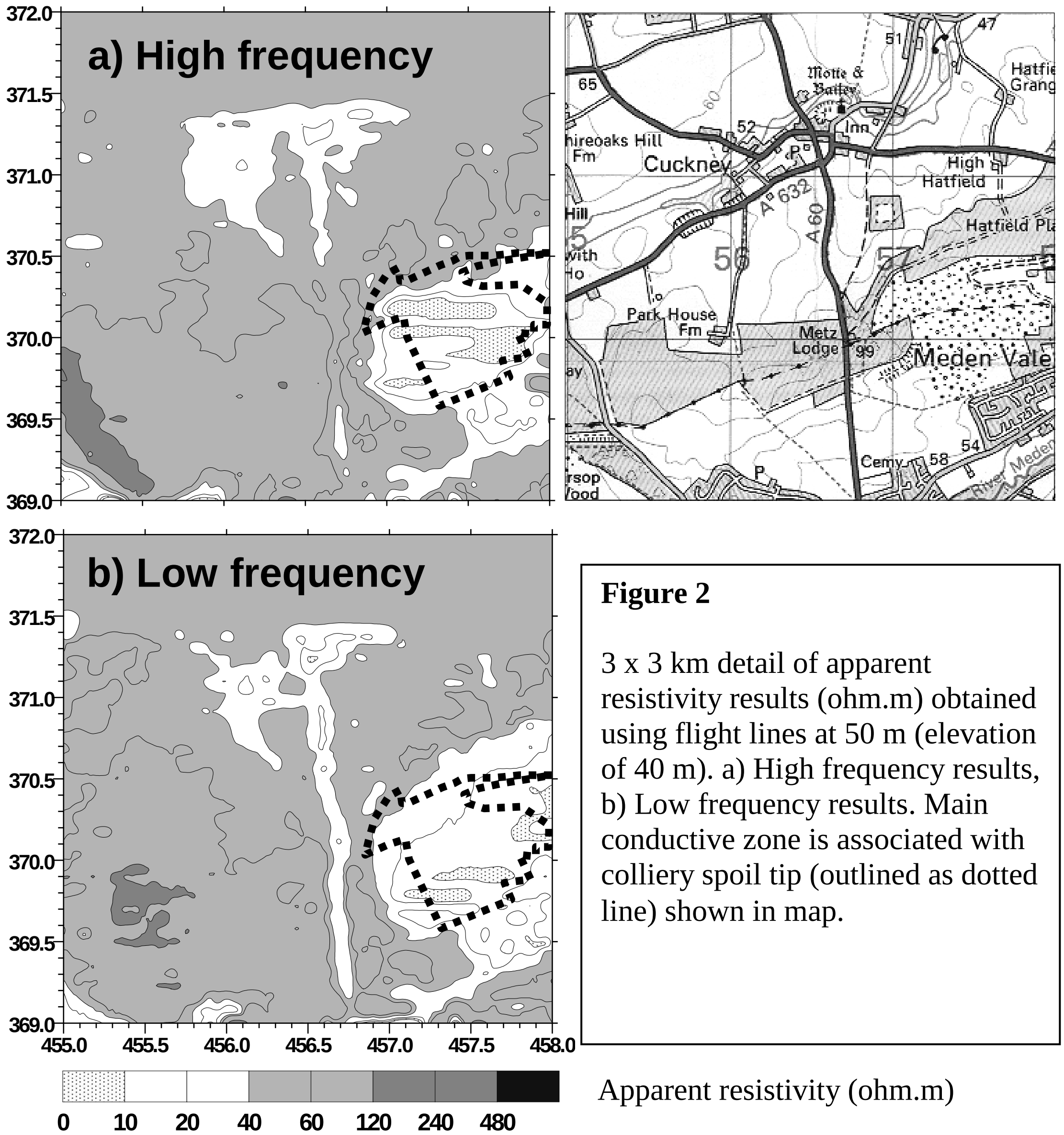

Figure 2

3 x 3 km detail of apparent resistivity results (ohm.m) obtained using flight lines at 50 m (elevation of 40 m). a) High frequency results, b) Low frequency results. Main conductive zone is associated with colliery spoil tip (outlined as dotted line) shown in map.

subsurface zones and, by implication, flowpaths of anomalous pore fluids to be identified.

Results

Targets in the coalfield area (13 x 9 km), to the north of Nottingham, included a series of 4 spoil tips adjacent to two former and two working collieries. Figure 1 shows the processed apparent resistivity data (3.1 kHz) obtained from the 200 m flight line data, which provide regional coverage. White areas denote apparent resistivities < 40 ohm.m. Stippled areas denote highly conductive zones (apparent resistivities < 10 ohm.m). The results indicate that anomalously conductive zones are associated with all four spoil tips. The conductive anomalies extend away from each of the spoil tip zones, in some cases by several kilometres. The four areas are clearly significant in a regional sense when background (normal) resistivities are considered. A fifth related zone is identified as waste ground on the map. Other extensive zones of high conductivity are associated with a variety of other settings as indicated in Figure 1.

An example of the resolution of conductive features obtained with the 50 m flight line data is shown in Figure 2. A 3 x 3 km detail in the vicinity of one of the colliery spoil tip zones is shown. Both high and low frequency apparent resistivities are shown (Figures 2a and 2b, respectively). The perimeter of the spoil tip is shown as a dotted line taken from the inset map of the area. Resistivities within the spoil tip zone are less than 10 ohm.m (stippled) and an extensive zone of < 40 ohm.m is observed. A conductive feature extends to the SW of the colliery spoil zone below a village. The feature then continues westward providing links with the next colliery spoil tip (just visible in the SW corner) some 3 km away. In addition to the colliery/spoil feature, a major N-S linear conductive zone is observed that appears to 'pool' below the village of Cuckney in the next valley to the north. The linear feature shows an obvious correlation with main N-S road through the area, however the source of the anomaly, and why it should pool to the north, is not self-evident. The relationships between many of the at-surface and near-surface installations (e.g. roads and pipelines), typical of populated environments, and the geophysical responses observed remain to be fully investigated.

Conclusions

The first trial airborne EM surveys to address specific environmental issues in the UK have proved successful. When applied to the coalfield area, the data confirm the regional significance of enhanced conductivities arising from the long-term geochemical loading of waste products from coal mining activities. The data reveal a series of subsurface conductive zones. The spatial continuity provided by the airborne data has allowed such zones to be traced from the local to the regional scale. The 50 m flight line data have provided a wealth of data on many other localised features in which enhanced pore fluid conductivities appear to play a part. In order to provide firm diagnostic information the airborne data still require considerable amounts of additional information to establish the links between subsurface geochemistry and the geophysical responses observed.

The dual frequency data obtained are capable of further refinement. Multi-layer inversion to establish quantitative depth estimates together with forward 3D modelling studies are planned.

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