Introduction

High resolution airborne electromagnetic (EM) data have been proven in Finland and Ireland to be an effective mapping tool. As well, the data can be used for many environmental and geotechnical applications, including aquifer mapping, identifying liquid transport pathways, delineation of salt water incursion into aquifers, aggregate prospecting, and plume monitoring. The combinations of EM, magnetic, gamma-ray spectrometry and possibly gravity data are powerful tools for geological mapping and characterization of a wide range of geology and targets.

The SGFEM System

The SGFEM system is a unique frequency-domain EM system on a Twin Otter airplane. SGFEM has four transmitters (912, 3,005, 11,962, and 24,510 Hz) mounted in a wingtip pod and four corresponding receivers on the opposite wing. The coil pairs are mounted in a vertical-coplanar orientation with the coil axes horizontal in the flight direction (CpX, often called VCP) which reduces motion noise. Additional sensors can include a gravimeter, magnetometer, gamma-ray spectrometer, methane sensor and scanning LIDAR.

***Figure 1**: SGFEM frequency-domain EM system.*

Models

Yin and Hodges (2007) showed that the horizontal axis orientation concentrates the induced currents into a path underneath the transmitter, perpendicular to the flight path, as shown in **Figure 2**. This current density pattern enhances the sensitivity for linear, current-channelling conductors like shear zones, conductive paleochannels, and man-made linear conductors. This high resolution in the forward (X) direction also provides for high spatial resolution on crossed geological contacts.

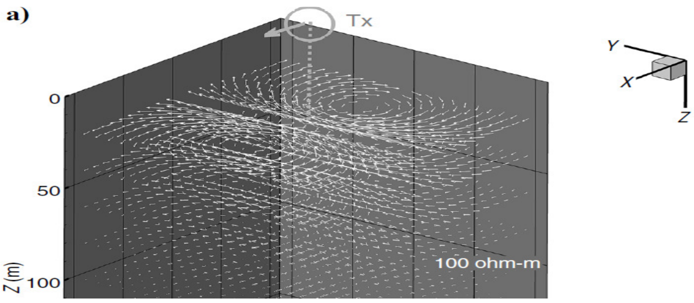

***Figure 2**: Current vectors for X (horizontal axis) transmitter over a homogeneous earth (from Yin and Hodges 2007)*

It is important to recognize that for engineering surveys, lateral resolution is as important as vertical resolution – it is the lateral changes in the ground that are of most interest, and most expensive to detect with drilling. The model of a linear channel perpendicular to the flight path applies equally to any linear target, including steeply dipping plate-like conductors (where the top edge appears as a linear target) and many anthropogenic targets, like pipelines.

The current density distribution of a horizontal-X transmitter also improves the resolution of discrete conductors. Figure 3 shows a multi-frequency model for a shallow, 10 ohm-m conductive channel, 20m wide, 10m thick, and 400m long, perpendicular to the survey path, hosted in 1000 ohm-m geology. The modeling program was the AMIRA program MarcoAir. The upper models are “normal” coplanar (CpZ or HCP) helicopter EM coil pairs with short separation at 30m altitude. The lower graph shows the response of a SGFEM CpX coil pair flown at 60m over the same target. The helicopter CpZ system anomaly is a double-bump with a half-width of about 140m. The “depth” of the low between the two peaks will be limited or even disappear in conductive host geology. The SGFEM anomaly halfwidth is about 60m - considerably narrower. The lost resolution due to high altitude is more than compensated by the improvement in resolution due to the coil orientation.

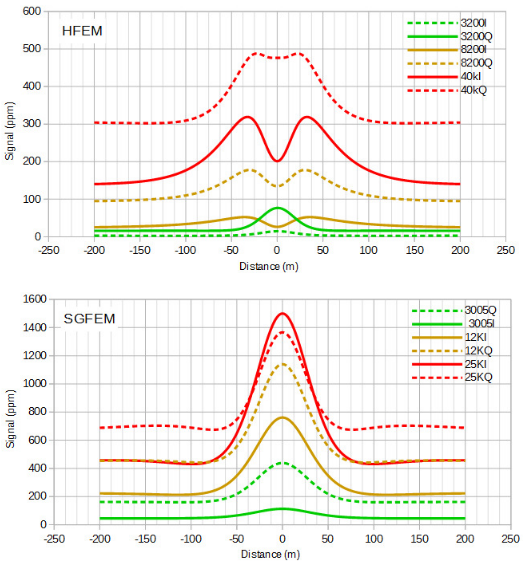

Figure 3*: HFEM and SGFEM Models for a conductive channel, showing resolution of the SGFEM compared to standard HFEM*

A towed-receiver, fixed-wing EM system (not shown) typically has a lateral transmitter-receiver offset of 100m or more, and with an aircraft flying height of 100m would give an anomaly halfwidth of 240m, due to the long transmitter-receiver offset.

Also, as the graphs in **Figure 3** show, the ratio of target anomaly to host (layered earth response) is about 3:1 for SGFEM compared to about 2:1 for CpZ HEM at comparable frequency.

Mapping Applications

Electromagnetic conductivity mapping has been used as an exploration tool for decades, and magnetic data even longer. The Geological Survey of Finland (GTK) had one of the first, and most ambitious EM mapping programs. Peltoniemi (2005) states “On account of the mutual correlation of survey data and the costs involved, aeromagnetic, airborne electromagnetic, and airborne gamma-ray surveys have traditionally been, and are currently undertaken simultaneously with a systematic countrywide coverage as an ultimate goal.” Peltoniemi goes on to describe a series of EM systems that were developed for this project, evolving over time into the modern SGFEM system.

More recently, a program of multi-method airborne geophysics mapping was instituted in Northern Ireland by the British Geological Survey and GTK, Beamish and Young (2009) described the surveys over Northern Ireland in 2005 and 2009. **Figure 4** shows the EM conductivity and a simplified geology map from Young, 2007. There is enough correlation between the conductivity and geology to give confidence that the method is mapping geology, and enough new geology apparent in the conductivity map to show the value of the EM data.

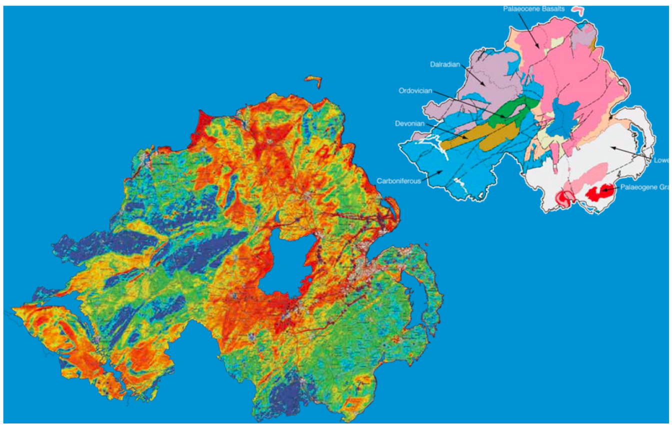

Figure 4*: EM Conductivity and low-res geology of northern Ireland. The correlations and new features show that the EM is useful for mapping. From Young, 2007*

In 2011-2012, and again in 2015, Sander Geophysics flew a large frequency-domain EM, aeromagnetic, and gamma-ray survey for the Geological Survey of Ireland (GSI) and the Geological Survey of Northern Ireland (GSNI). This survey is part of the multi-year Tellus project in Northern Ireland and Ireland. For this phase, called

Tellus Border, 57,682 line kilometres were flown at 200 m line spacing at 60 m altitude (to maximize resolution). Although the wide line spacing common for regional mapping applications is not ideal for environmental and engineering surveys, the Tellus Border data have been used for various environmental and geotechnical purposes.

A new concept in complementary processing of multi-method, 3D aerogeophysical mapping was described by Tschirhart et al (2013). They used frequency-domain EM-derived magnetic susceptibility to constrain the near-surface susceptibility when conducting regional-residual separation.

The addition of the AIRGrav airborne gravity sensor to the instrument array on the Twin Otter adds a hitherto-unavailable method to the mapping system, and a new rock property to the interpretation.

Environmental Applications

Lahti et al (2005) describe a number of surveys that had successful environmental application, showing data flown by the Geological Survey of Finland using forerunners of the SGFEM system that had fewer EM frequencies. (Airborne EM has the advantage over ground EM of not exposing field crew to any hazards associated with contaminated sites.) **Figure 5** shows an example of AEM conductivity collected over the Rovaniemi landfill, showing the conductivity of the landfill, and a contaminant plume. A layer model interpretation of the plume indicates conductivity thickness of 0.1S (Jokinen and Lanne, 1996).

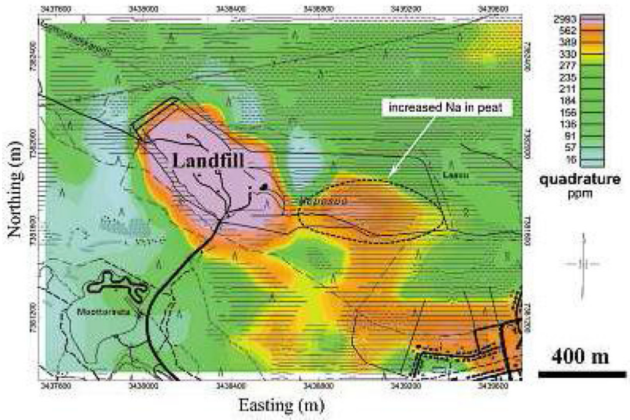

***Figure 5**: AEM quadrature map from the Rovaniemi landfill, northern Finland, showing leakage from the site (from Lahti et al, 2005)*

O'Connell and Daly (2013) used the SGFEM data to map groundwater pathways, and their structural controls, and the freshwater-seawater interface along the coast. **Figure 6** shows a map of the 25kHz apparent conductivity along a stretch of coast between Dromiskin and Cocklehill, County Louth, Ireland. The heavy black dot-dash line shows the coast, and the dotted line the extent of saline influence into the Dromiskin groundwater bodies – as much as 500m inland. As well, there is a conductive linear feature, marked (x), extending about 2km inland. The feature is progressively weaker on lower frequencies, indicating a near-surface source. Line 1 of ground ERT (shown on the map) was recorded over this feature from north-to-south, and shows the extent and edge of the conductive zone. The 2D inversion results of the ground data are shown in **Figure 7**.

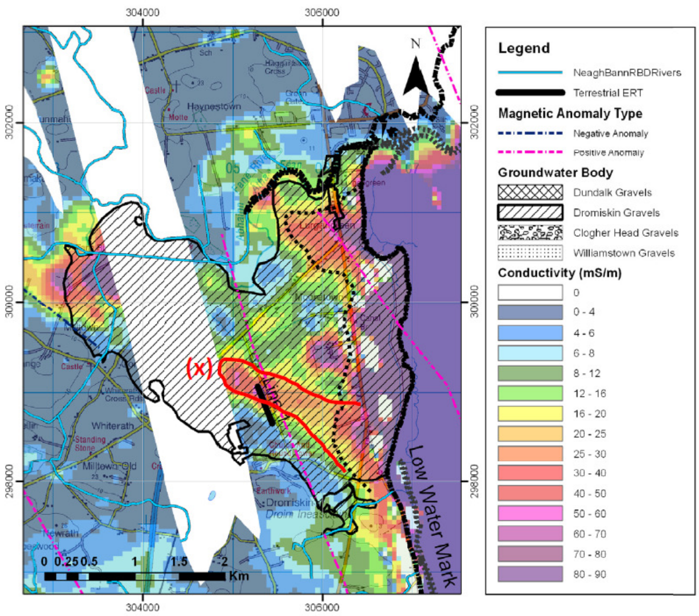

***Figure 6**: 25kHz Apparent Conductivity showing saline influence along the coast and inland. (from O'Connell and Daly, 2013)*

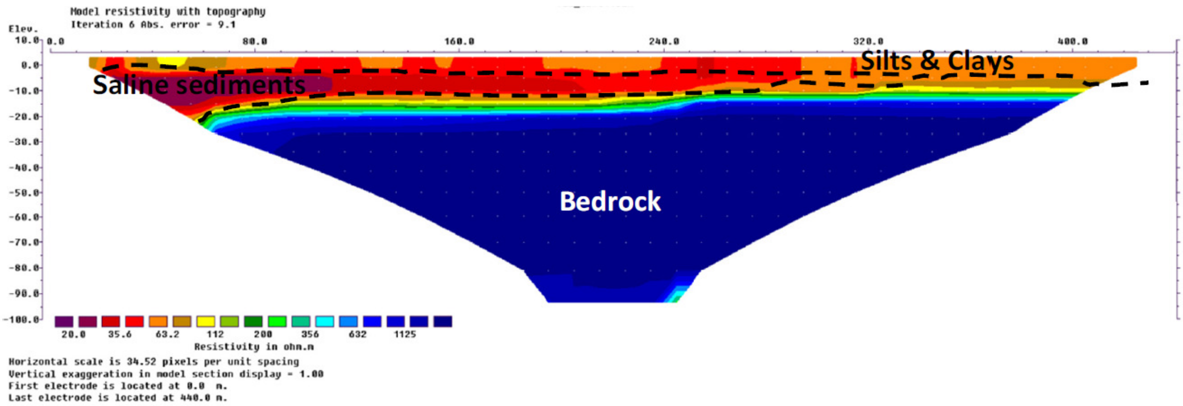

***Figure 7**: Ground ERT section Line 1 across feature (x) in Figure 6 showing saline soils to the north. (from O'Connell and Daly, 2013)*

Conclusions

The SGFEM fixed-wing, wingtip FDEM system has been developed over many years to be highly effective for mapping geology, especially when combined with magnetic and radiometric sensors. The addition of gravity is a new possibility to enhance the range of geology detectable. The horizontal-axis coil orientation gives high resolution results from 60m altitude for environmental and engineering applications, including groundwater, salinity, and contaminant surveys.

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