Application of Airborne EM to Bowen Basin Coal Projects

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SUMMARY

In 2011, several Bowen Basin coal exploration projects in central Queensland were surveyed with the SkyTEM airborne electromagnetic system. The aim of these surveys was to trial the effectiveness of the method in for coal applications, with specific focus on mapping the key aspects of the weathering, overburden and hydrology that are most important for effective development of a coal project.

The first survey, which was over an area near Moranbah with 150m of Tertiary overburden with extensive basalt flows, mapped crucial hydrological and geological features important to efficient further development of the project: These included a) a convoluted network of basalt-filled palaeochannels, some of which extend through and into the coal measures b) location, extent and thickness of major saline aquifers, c) depth to base of Tertiary.

Subsequent surveys over different parts of the Bowen basin, showed that SkyTEM was a very effective tool for mapping the thickness of weathering, a parameter very important for drilling out coal resources. The results are surprising in that they not only provide a detailed map of depth of weathering (including volumes of lateritic sediments requiring excavation), but also map more subtle geological features such as synclines (previously only loosely inferred from surface mapping), major faults, previously unknown dykes, dip and strike of the main stratigraphic units, fresh water aquifers and even possibly also various coal seams (generally because they are saline aquifers).

These surveys represent, at least to the authors' knowledge, the first example of modern helicopter-borne transient EM in the Australian coal fields. The results from this project and subsequent projects are surprising in that they have had unexpected applications above and beyond those which were originally forecast. Thus, with informed and thorough use, airborne EM promises to deliver valuable geological and geotechnical information to aid in the further development of Australia's coal resources.

Key words: SkyTEM, coal, dykes, airborne EM, basalt

INTRODUCTION

The Australian coal industry has traditionally had very little use for airborne electromagnetics (EM), as the available technology was not sensitive enough to map the fundamentally subtle conductivity contrasts associated with most geological and hydrological problems. However, the development of the high resolution, helicopter transient EM SkyTEM system for groundwater investigations has quickly uncovered a range of new applications that require the near surface sensitivity for subtle conductivity contrasts as well as good depth of investigation. These include, but are not limited to, tailings dam monitoring, aquifer mapping, pipeline route optimisation, and as this study investigates, coal related geological and geotechnical investigations that have been traditionally limited to ground-based methods and drilling.

The potential for SkYTEM to be used for mapping in coal projects was trialled in central Queensland in 2011. The first survey, a trial over a 5x7km area located ~5km northwest of Moranbah, was in a very challenging environment due to the high overburden conductivities. The geology in this area roughly comprises fresh Permian sandstone-siltstone-coal measures beneath 100-150m of largely unconsolidated Tertiary sediments intercalated with numerous basalt flows and variably saturated with mostly saline groundwater. The boundary between the Permian and Tertiary is a uneven unconformity reflecting the palaeo-drainage pattern. The aim of the SkyTEM survey was to map the Tertiary thickness, hydrogeology, composition, location and thickness of basalt flows, as well as help the geologists better predict where the Tertiary-Permian palaeo-surface had penetrated below the coal measures.

Subsequent surveys showed that in areas with less Tertiary overburden, the SkyTEM results could be used to map the changes in conductivity with depth reflecting the depth of weathering. This information is quite valuable, as it is important for forecasting how deep to put drill casing, as well as predicting areas where weathering may have oxidised the coal sequences. Unfortunately, at the time of writing this paper, these surveys were not able to be published in written form.

THE SKYTEM SYSTEM

SkyTEM is a unique HTEM system capable of operating at two transmitter moments, Super Low Moment and High Moment (e.g., Auken et al., 2009). The Super Low Moment (SLM) mode uses a low peak current and fast switch-off to obtain TEM data between 11.2 μs – 1.4 ms after the start of the current ramp. High Moment (HM) measurements use a high peak current with a longer ramp time to obtain data over the time range 73 µs – 8.8 ms. Essential parameters of the SLM and HM modes are given in Table 1.

Parameter	SLM	HM
Tx moment	3140 Am^2	125,000 Am^2
Peak current	10 A	100 A
No. transmitter turns	1	4
Current ramp	6 µs	45 µs
Base frequency	200 Hz	25 Hz
Duty cycle	32%	50%
Terrain clearance	30 m	
Geometry	In-loop	

Table 1 SkyTEM SLM and HM transmitter parameters.

In most coal surveys, the transmitter is operated in an interleaved mode in which data are acquired sequentially at HM and SLM, with the system continuously alternating between the two modes. This unique dual-moment mode allows concurrent acquisition of shallow and deep information using the interleaved SLM and HM measurements. This is important for coal surveys where there are requirements for both shallow high resolution mapping and the ability to penetrate through thick conductive cover sequences..

The SkyTEM instrument has very low drift and low transmitter bias and no data levelling is required. These characteristics mean that data are suitable for quantitative inversion after only basic data processing in the field. Using the fast, parallelised inversion code iTEM (Christensen, 2002; Christensen and Tølbøll, 2009), preliminary layered-earth inversion results can routinely be delivered within 24 hours of data acquisition. Final inversion is typically performed using an iterative damped least squares approach with lateral parameter constraints (LPC, Christensen and Tølbøll, 2009), or using 1-D laterally constrained inversion as implemented in the Aarhus Workbench software (e.g., Auken et al., 2009).

METHOD AND RESULTS

The SkyTEM survey was flown with 100m line spacing on east west lines with 1000m spaced north-south tie lines for the magnetic levelling. TEM data were acquired in dual mode – SLM and HM. The data were then inverted and using the LPC method described above to produce conductivity sections along the flight lines. These inversions were then gridded as a 3D voxel to enable slicing in arbitrary orientations parallel to seismic lines and/or drill sections. These were then plotted with drill hole lithology logs and downhole petrophysical logs (where available) to help constrain interpretation of the EM conductivity voxel.

Moranbah Trial

The Moranbah trial comprised 350 line km of SkyTEM EM and magnetics data. The EM inversion was plotted with all available drill holes superimposed on the conductivity sections. Using these sections, an interpretation of Tertiary overburden thickness and basalt flows was developed in conjunction with the project geologists, and then extended to project a 3D model of the features of interest. The conductivity sections were also plotted as hard copies with the planned drill hole locations so that the drillers could predict what units they would intersect at what depth, and also at what depth they should intersect the top of the Permian sequences.

Figure 1 shows the SkyTEM flight lines over plan depth slice of the conductivity voxel at ~30 m below surface. Several strong structures are apparent in the data related to the palaeo-drainage pattern of sands and silts. The basalts in the Moranbah area are moderately to highly conductive, thus readily mapped by EM, but the numerous flows are not necessarily particularly magnetic, so magnetic interpretation is less effective than elsewhere. It is worth noting that drilling indicates that the areas of particularly high conductivity are associated with highly porous basalt layers containing saline ground water, and these areas are important to map because they can be problematic during mine development. Similarly, the basalt flows are commonly associated with perched aquifers (as the non-porous basalt layers act as an aquitard), which can also be either hard to excavate or associated with large groundwater flows.

Figure 2 is an example of a simplified interpretation of a section, with drill hole constraints, showing the large, thick developments of basalt and also high conductivity areas associated with saline aquifers in the basalts. Figure 3 is a perspective view of 2D section interpretation results stacked together to show a 3D reconstruction of a basalt-filled palaeochannel network.

DISCUSSION

Airborne EM for coal applications is not trivial, and requires a good understanding of the local geology for each project so that the survey is designed correctly and the results are used appropriately. The aim is not simply to 'map coal' (indeed EM is poorly suited to this application unless the coal is also a saline aquifer), but rather to map the host of other geological and geotechnical factors that ultimately decide the profitability/likelihood of success of any given coal project. Depending on the regional geology, these can include but are not limited to, depth of weathering, thickness of Tertiary overburden, location and extent of magnetic and non-magnetic basalt flows, location of oxidised coal, faults, other structures, groundwater aquifers, dykes and intrusions. When used in this way, the data has potential as a resource of the 'life of mine', both to be used in greenfields exploration as a tool to find where to drill next, as well as in mine design and water storage/influx issues.

Interpretation of the SkyTEM results over each coal project is highly site specific, and ideally should be undertaken with as much geological control as possible. For example, the bulk resistivity of basalt flows is often highly dependent on groundwater chemistry, so what may be conductor in one area will be a resistor in another area. However, when geological control is used conscientiously, the volume and variety of valuable information is outstanding.

The Moranbah SkyTEM results showed the high ground conductivities typical of the Tertiary sediments in this area. This has limited the maximum possible depth of penetration obtainable with a 25Hz 50% duty cycle primary field to around 200m. Greater depth of penetration may be achieved by using a shorter on-time, thus allowing a longer decay measurement period. Nevertheless, the results were very interesting, and showed that numerous features thought to be invisible to EM (such as basalt flows) could actually be very easily detected in the right geological setting.

Airborne EM should not be undertaken without a clear understanding of what needs to be mapped, and whether the conductivity contrasts are sufficient to enable this. The first and best way to assess this is to use the borehole resistivity (or conductivity) logs. Unfortunately, resistivity logs are actually rarely available because they require open boreholes, and in areas with thick unconsolidated overburden sediments, only the bottom of the borehole is uncased. In this case, an inductive conductivity tool through PVC casing is a second option, though most geophysical logging companies engaged by the coal sector do not have this tool available.

One of the key challenges with the EM inversion results is presentation of the high volume of data. The data is best used in a georeferenced, 3D environment, but most common geological modelling programs are unable to handle the data volumes in geophysical results. The best option at present is MapInfo Discover3D, which is particularly well suited to displaying the drilling data in conjunction with the 3D conductivity voxels and/or 2D conductivity sections. This is also a relatively common program so provides a useful environment for the site geologists to directly use the survey results.

CONCLUSIONS

High-resolution SkyTEM HTEM surveys have been successfully conducted over a several coal projects during 2011. The unique dual-moment transmitter capability of the SkyTEM system offers the unique ability to provide shallow high-resolution information and deep penetration in the often quite conductive ground conditions. Applied carefully, conductivity models derived from the EM data can be used for mapping features crucial to coal project development, including but not limited to thickness of Tertiary, depth of weathering, thickness and location of basalt flows, palaeochannels, structural features such as synclines and fault blocks.

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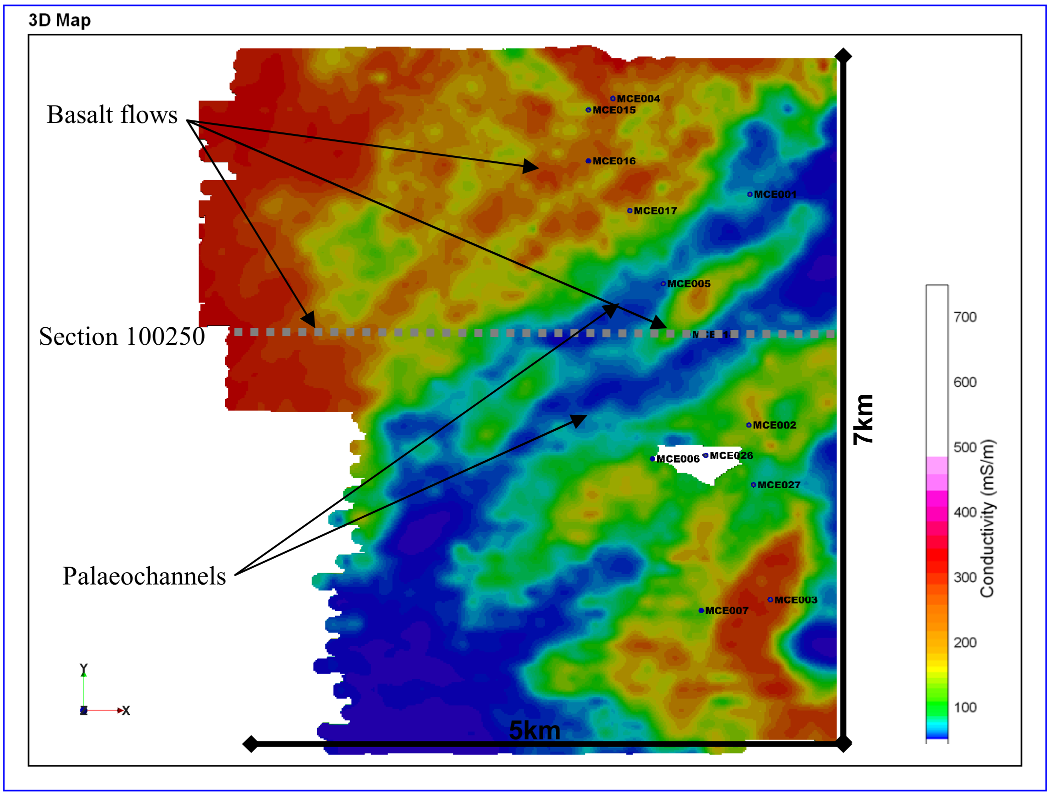

Figure 1. Horizontal slice of the Moranbah SkyTEM conductivity voxel at 221m above sea level (~30m below ground level). Drill hole locations are also labelled. Several palaeo-drainage features are labelled, as are the drill holes. The more conductive zones are generally associated with thicker weathered basalt flows.

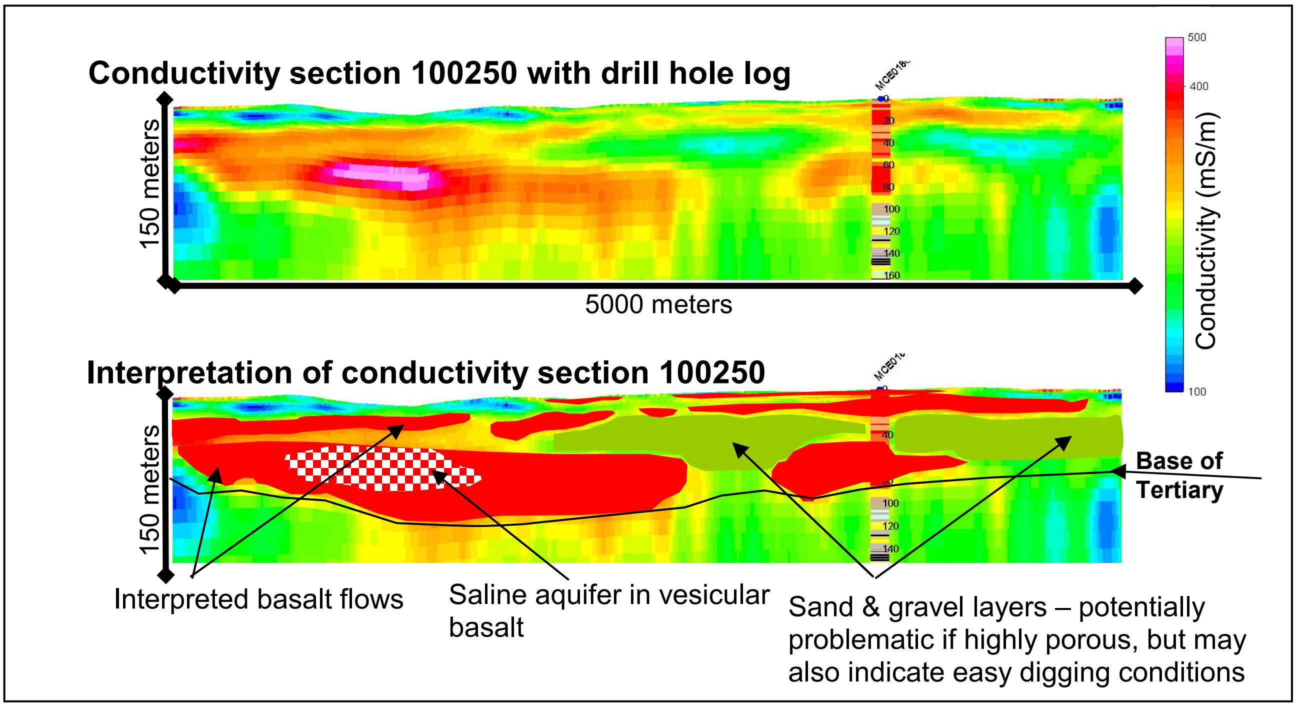

Figure 2. Moranbah iTEM LPC inversion of line 100250 with drill hole results and a simplified interpretation. Tertiary units are shown in reddish colours on the lithology log, with dark red indicating basalt. The underlying Permian sandstones and siltstones are shown in yellow and grey, and coal in black. The line location is shown on Figure 1.

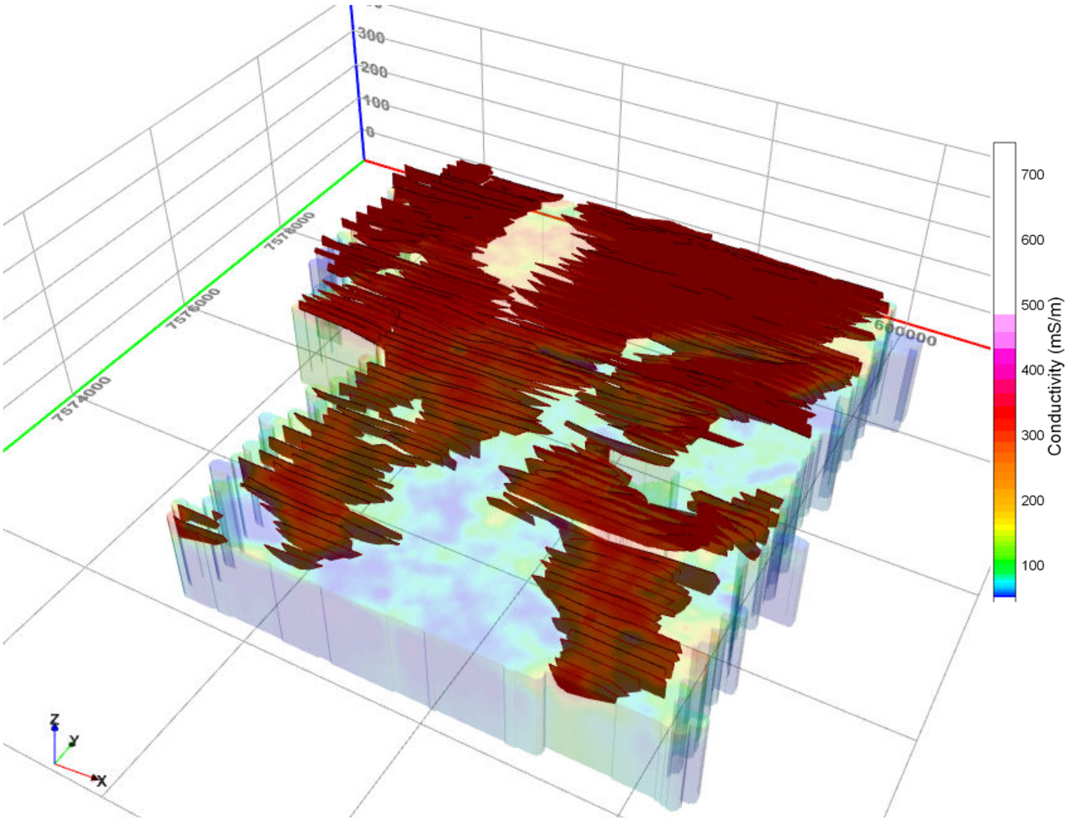

Figure 3. Interpretation of the palaeochannels filled with basalt derived from the SkyTEM sections, stacked and superimposed on a transparency of the 3D conductivity voxel.