SkyTEM helicopter transient electromagnetic surveys of tailings dams

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SUMMARY

The SkyTEM helicopter transient electromagnetic system has been used to map the environs of a number of tailings dams in Australia. Residues from mining and industrial processes typically have high conductivity and can be effectively mapped using airborne electromagnetic methods. Airborne surveys allow complete coverage of tailings sites otherwise inaccessible to surface geophysics.

The SkyTEM system is capable of operating in a dual moment mode, in which measurements with low transmitter current, fast switch off and early-time sampling are interleaved with those performed using a high transmitter moment and measurements to late delay times. This provides high near-surface resolution and the capability to penetrate through thick accumulations of highly-conductive tailings.

Surveys around tailings sites are characterised by significant surface infrastructure, which presents hazards to airborne operations and results in numerous cultural electromagnetic anomalies unrelated to the subsurface. These obstacles can be overcome with appropriate survey planning and careful editing of the airborne data prior to interpretation.

A brief field example from a coal fly-ash dam in Australia illustrates the ability of the SkyTEM system to provide detailed hydrogeophysical information. Useful data were obtained even in close proximity to metallic infrastructure and high-voltage power lines. The SkyTEM survey was able to identify several zones of anomalous conductivity at points downstream of the embankment, which are a priority for future ground follow-up.

Key words: airborne electromagnetics, SkyTEM, tailings, groundwater

INTRODUCTION

Helicopter electromagnetic (HEM) methods are becoming increasingly employed for near-surface investigations around dams used to store electrically conductive residues such as mine tailings or waste materials from coal power generation and metals refining. Examples of such surveys are given by Rutley and Fallon (2000), Morris et al., (2005) and Hammack et al., (2005). The surveys reported by these authors have used frequency-domain HEM systems.

This paper describes the use of the SkyTEM helicopter transient electromagnetic (HTEM) system for tailings dam surveys. A number of SkyTEM surveys have been conducted over tailings dams in Australia since 2009. Residues stored in the dams have typically been highly conductive due to either presence of high acid, base or salt contents of the dam waters.

Typical objectives of such surveys are detection of conductive seepage plumes downstream of dam embankments, mapping of potentially permeable geological structures such as faults or shears, mapping of depth to impermeable bedrock, and assessment of the effectiveness of groundwater interception schemes used to capture waters from known seeps.

HTEM surveys can be a cost-effective adjunct to drilling or small-scale surface surveys, and can be used to more effectively target surface investigations. Continuous coverage can be obtained over areas difficult to access using surface methods, including dams with permanent water cover or those located in rugged terrain. HTEM surveys typically provide data over an area of several square km and anomalies are therefore placed in a semi-regional context.

THE SKYTEM SYSTEM

SkyTEM is a unique HTEM system capable of operating at two transmitter moments, Super Low Moment and High Moment (see Auken et al., 2009 and references therein). The Super Low Moment (SLM) mode uses a low peak current and fast switch-off to obtain TEM data over the time range 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 between times of 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	

Table 1 SkyTEM SLM and HM transmitter parameters.

In most tailings dam 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. The high near-surface resolution information from SLM and deeper information from HM can thus be collected in a single survey pass, a unique capability of the SkyTEM system. This is important for tailings surveys where the main requirement is for shallow information, but it is also desirable to be able to map the conductivity distribution beneath thick accumulations of highly-conductive tailings.

The design of the SkyTEM instrument provides data free of transmitter bias across the range of measurement times. Low pass filters on the receiver coils and receiver electronics are 450 kHz and 300 kHz respectively, providing reliable data at the earliest delay times. The instrument has very low drift 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).

CULTURAL RESPONSES

A common feature of tailings dam AEM surveys is that they are typically conducted in close proximity to operating mines and industrial sites. Above ground infrastructure poses a hazard to airborne operations which can be addressed through careful line planning and close liaison with site staff site. Since 2009, several SkyTEM surveys have been conducted without incident over tailings dams in very close proximity to operating mine and heavy industrial sites.

EM anomalies due to surface and underground infrastructure such as high-voltage power lines, large buildings, metal pipelines, insulated cables, railway lines and fences, are commonly observed in tailings dams surveys. Detailed maps and airphotos showing known infrastructure should be obtained prior to interpretation. Anomalies due to infrastructure are often easily recognisable (Sørensen et al., 2001), but some features (in particular those subparallel to the flight lines) may produce subtle effects. Care should be taken to avoid misinterpreting cultural anomalies (or 2D and 3D artifacts due to such anomalies in layered-earth inversion models) in terms of subsurface geology.

Figures 1 and 2 show examples of SkyTEM responses due to infrastructure. Figure 1 shows low-moment data from a profile crossing a 132 kV high-voltage transmission line (red arrow). The profile crosses from resistive ground at the left hand end to highly conductive ground (mine tailings) at the right hand end, at an angle of about 50 degrees to the trend of the powerline. The increased noise due to the powerline is clearly evident. The zone of disturbed data is asymmetric about the powerline because of the lower signal arising from the resistive ground on the left-hand side of the profile. The zone of disturbance due to the transmission line is some 500 m in width.

Figure 2 shows a high-moment response associated with capacitive coupling to an insulated cable. Capacitive coupling results in decay curves which oscillate between positive and negative responses (Sørensen et al., 2001). In profile, these responses are easy to recognise as anomalies which repeatedly alternate with time between the typical positive ‘M’-shaped z-component anomaly from a thin, elongate conductor, and a negative ‘W’-shaped response. In the example shown, the capacitive coupling has affected data on about 400 m of profile.

FIELD EXAMPLE

Figures 3 and 4 show examples of recent SkyTEM AEM data acquired around a fly ash dam at a coal-firred power station in Eastern Australia. A total of 260 km of SkyTEM SLM and HM data were acquired at a line spacing of 50 m. Line orientation was variable across the site in order to avoid known infrastructure such as the power station buildings and several 132 kV and 256 kV power transmission lines. Part of the survey covered a major fly ash tailings dam. The fly ash residue is electrically conductive due to leaching of salts from the ash, and because the dam is also used to dispose of brines produced as part of the cooling process during power generation (e.g., Lasher et al., 2009).

The geology on the eastern side of the dam comprises generally resistive Devonian sediments, breccias and felsic volcanics. On the western side of the dam, the Devonian units are overlain by Tertiary sediments which contain naturally saline groundwaters.

The SkyTEM data were inverted using the LPC approach (Christensen and Tølbøll, 2009) with a 30-layer model. The thickness of the uppermost layer was 1 m and the depth to the top of the deepest layer was 200 m. Layer thicknesses were held fixed and the data were inverted for the layer resistivities only. Constraints on the vertical variability of model conductivity are imposed through the use of a broadband model covariance matrix (Christensen, 2009), and the final models show a smooth variation of resistivity with depth.

Figure 3a shows a depth slice of average conductivity within the interval 9.7 – 11.5 m below surface, derived from the LPC inversion results. Figure 3b shows the main features of the ash dam, including the embankment, water cover and tailings beach, as well as nearby major infrastructure (major power station buildings and a high-voltage transmission line). A large zone of very high conductivity is located within the tailings dam near the southeasternmost extremity of the embankment, and is associated with saline waters within the tailings. The SkyTEM survey has further identified a number of zones of high conductivity that extend beyond the embankment (A, B and C in Figure 3b), none of which have been adequately tested by existing drillholes. These zones are a high priority for ground follow up in order to determine whether they indicate potential seepage pathways.

Figure 4 shows the near-surface part of the LPC conductivity-depth section for a flight line crossing the tailings dam and embankment (Figure 3b), and illustrates the high near-surface resolution obtained in this conductive environment. The apparent thickness of the tailings within the central part of the line is approximately 10 – 15 m, and low conductivity Devonian bedrock can be seen to underly the tailings between 1500 m and 2000 m along line. The zone of high conductivity which extends from within the dam to the downstream side of the embankment corresponds to feature 'B' shown in Figure 3b.

A shallow borehole on the downstream side of the embankment was logged using an inductive conductivity probe. A low induction number correction was applied to the downhole conductivity data to compensate for underestimation of high conductivities (McNeill, 1986). The borehole conductivity data are plotted on Figure 4 with the same colour bar used to display the SkyTEM inversion results. Despite the very shallow depths, there is good agreement between the borehole and SkyTEM conductivities.

CONCLUSIONS

High-resolution SkyTEM HTEM surveys have been successfully conducted over a number of tailings dams in Australia since 2009. The unique dual-moment transmitter capability of the SkyTEM system offers the ability to provide shallow high-resolution information and deep penetration through conductive tailings in a single survey pass. Useful HTEM data can be acquired even in the presence of significant surface infrastructure and coupling to cultural conductors.

A recent SkyTEM survey over a coal fly ash dam in eastern Australia allowed data to be acquired over rugged and water-covered areas otherwise inaccessible ion the surface. A number of previously unrecognised highly-conductive anomalies downstream of the embankment were identified as priority areas for ground follow-up.

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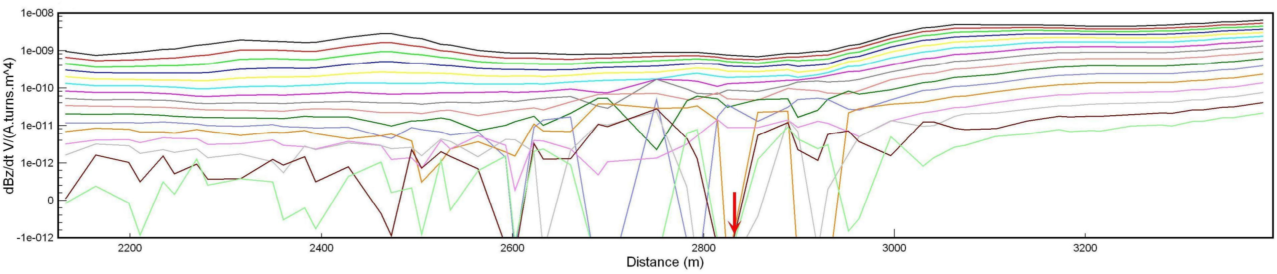

Figure 1 SkyTEM low moment vertical-component data from a profile crossing directly over a 132 kV high voltage transmission line (red arrow). Data are shown from delay times between 28.7 μs and 897 μs.

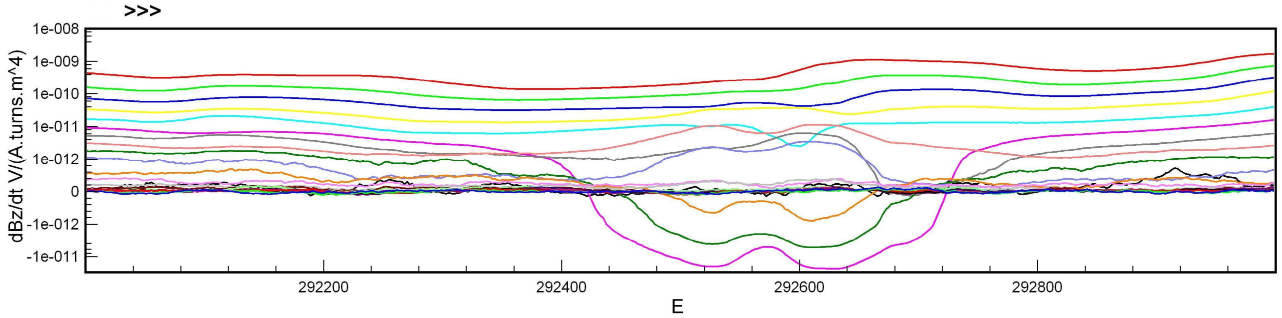

Figure 2 SkyTEM high moment vertical-component profile showing a characteristic anomaly due to capacitive coupling to an insulated cable located at ~292570E. Data are shown from delay times between 47 μs and 8.8 ms.

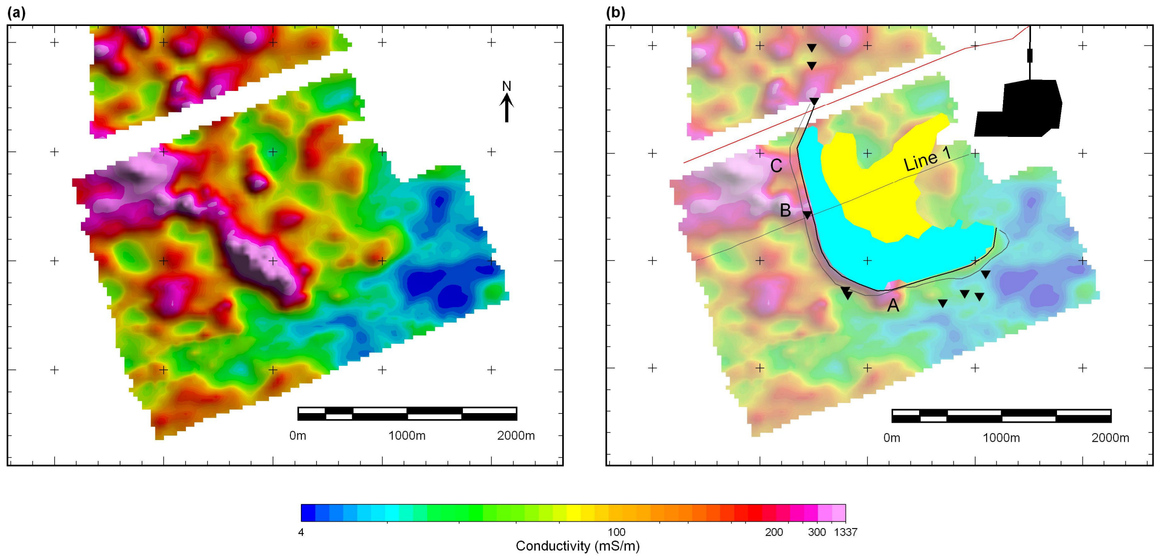

Figure 3 SkyTEM survey results from a coal fly-ash tailings dam. (a) Conductivity depth slice for the interval 9.7 to 11.5 m below ground level. Panel (b) shows the same image as in (a) with the main elements of the dam and nearby major infrastructure superimposed, including the tailings beach (yellow polygon), dam water cover (light blue polygon), major built-up area around the power station (black polygon), high voltage transmission line (red), embankment crest (heavy black line) and toe (grey line), and drillholes (black triangles). Features A, B and C show zones of high conductivity just downstream of the dam embankment.

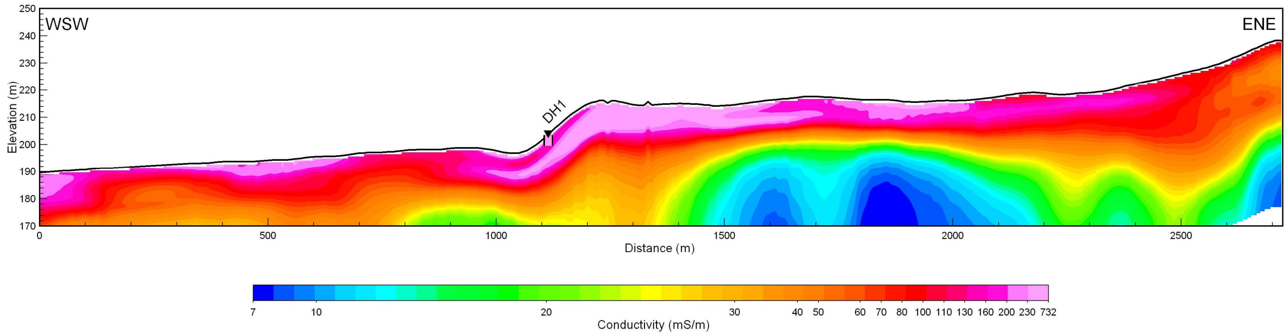

Figure 4 Detail of LPC conductivity-depth cross-section for a flight line crossing the fly ash dam and embankment (Line 1 on Figure 3b). The crest of the embankment is at approximately 1220 m along line, and the fly-ash tailings extend from this point to approximately 2500 m along line. The inductive conductivity log from a shallow borehole on the downstream side of the embankment (DH1) is shown with the same colour bar used to display the HTEM inversion results.