Airborne TDEM geophysics for environmental studies and mine operations

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Summary

There is growing awareness in the international mining community of the need to minimize environmental impacts associated with mine operations. Resource extraction requiring or affecting water is closely scrutinized by the public and regulated by governments. The application of airborne electromagnetic geophysics (AEM) to provide solutions for environmental and geotechnical engineering problems has increased in recent years and the mining community can benefit from these solutions. AEM techniques used by mining companies globally on a routine basis to explore for resources can also provide great value for mapping water and potential hazards in the area of mine operations.

The examples described in this paper focus on data collected by today's advanced helicopter borne time-domain (HTEM) systems. For decades HTEM has been employed to map resources and system development was aimed at mapping increasingly deeper discrete conductors rather than mapping geology (Thompson et al, 2007). Some of today's HTEM systems such as SkyTEM have the capability to resolve subtle resistivity contrasts from the very near surface concurrently with depth of investigation in excess of 500 m. This with the ability to acquire data at speeds up to 150 kph makes HTEM an economic and efficient solution for a wide variety of applications.

This paper also identifies potential career options for earth science professionals who have focused solely on mining and mineral exploration and are now looking for new opportunities.

Introduction

The application of airborne geophysics to environmental and engineering problems has been increasing for the last 20 years. Much of this work was initially carried out with ground geophysical methods and helicopter frequency domain systems (HFDEM) and focused on mapping the very near surface limiting the depth of penetration to approximately 100 m in the case of HFDEM.

Developments in airborne time-domain electromagmetic systems (HTEM) has made it possible to map the near surface and deep geology to depths exceeding 500 m and some systems are able to map both concurrently.

This paper presents examples of HTEM and how it has been recently applied to solve a variety of environmental and engineering problems. The mining industry has traditionally used airborne geophysical methods almost exclusively for mineral exploration and this paper will also give examples of how HTEM can be of benefit to mine operations. All of the examples discussed in this paper have employed SkyTEM TDEM systems. SkyTEM is a truly versatile TDEM technology in that systems can be configured easily to suit various mapping needs, objectives and targets.

SkyTEM technology is constantly evolving and improving. The SkyTEM312*Fast* system described in this paper is one such example with its launch as a commercially available system in 2015. SkyTEM's R&D people work closely with clients, universities and government organizations to access valuable resources and to bring fresh thinking to old problems. This enhances SkyTEM's ability to develop innovative technology appropriate to today's global challenges. It also vastly improves the odds of making useful important scientific advancements through new theoretical insights, new techniques, and new skills.

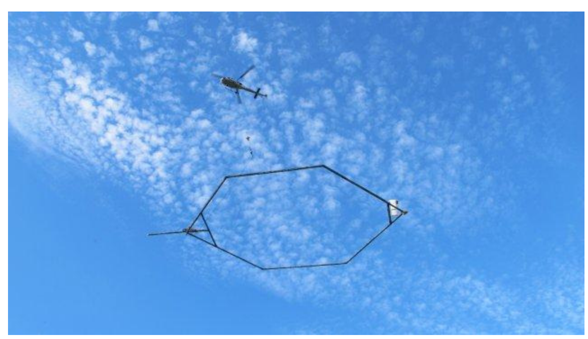

Figure 1 SkyTEM system in flight

The SkyTEM method of TDEM

SkyTEM is a HTEM system designed for hydrogeological, environmental, geotechnical, mineral and oil and gas investigations. The basic concepts of the SkyTEM system are described by Sørensen, K. I. & Auken, E. (2004 and 2012). The system is shown in operation in Figure 1.

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All SkyTEM systems are dual moment and use an extremely rigid airframe. In contrast to other TDEM systems SkyTEM has positioned the receiver coil slightly behind the transmitter wire in a 'null' position where the intensity of the primary field is minimized (Schamper et al. 2013). The SkyTEM system was initially engineered for groundwater mapping and, to reach this goal, employs two transmitter moments each with different currents and different numbers of transmitter wire turns. The low current, or low moment (LM) mode is used to record early-time data that contain near-surface information, while the high current, or high moment (HM) mode improves the signal-to-noise ratio at late-times (Bedrosian et al.2015).

Ancillary data collected includes laser altitude, GPS elevation, transmitter and EM receiver attitude. All sensors are installed on the rigid carrier frame, which is flown as close to the ground as safely possible in order to obtain high data accuracy and highest possible resolution enabling rigorous quantitative interpretation of the EM data and delivery of products within hours of acquisition. The system is light weight, operator-less and easily configured to operate at a range of base frequencies and delay times to optimize for a range of geological mapping objectives. SkyTEM data is clean and robust enough to process soon after the helicopter lands and simple inversions are produced within 24 hours of collecting the data (Brown et al. 2015).

Typical SkyTEM configurations are shown in Table 1 although various configurations as described in the examples presented are also available.

System	Transmitter area m^2	# of loop turns (HM)	NIA
301	314	1	32,000
304	314	4	150,000
312 & 312^{Fast}	314	12	490,000
516	536	16	1,000,000

Table 1: Typical SkyTEM System Configurations

Hydrogeological Mapping in Northeastern British Columbia – SkyTEM312^{Fast}.

In 2015 GeoscienceBC (GBC) launched the Peace Project to collect new information about groundwater within an 8,000 square kilometre area in northeast BC. This region of the province has been a focus of petroleum exploration and development since 1952 and partner companies included the BC Oil and Gas Commission, ConocoPhillips and Progress Energy as well as several Treaty 8 First Nations.

The main priority of the project, comprising of the collection 21,000 line kilometres of TDEM data, was to map aquifers in the area to a depth of at least 300 m. A secondary priority was to complete the airborne data acquisition before hunting and trapping season began requiring all data collection be completed within seven (7) weeks from start up.

SkyTEM312^{FAST} was selected for the data acquistion. This dual moment system has a Low Moment (LM) with a peak of ~ 3,000 NIA at 210 Hz and an early time gate of ~ 5 µs, and a High Moment (HM) with a peak of ~ 490,000 NIA at 30 Hz and a late time gate at 11ms. The system operated at speeds of 120-150 km/h with a transmitter and reciever terrain clearance of 50 metres. All data was acquired in only 43 days.

Figure 2 shows TDEM results (left) and gamma log results (right). The gamma results are shown on a quaternary map with depth to bedrock at each well (numbers near red and yellow dots - yellow dots indicate sand/gravel within the Quaternary section). Note the outline of the paleochannel and how it matches the AEM results. These two data sets were done independently and neither processing group saw the other's results. This paleochannel lies at about 10 metres depth and is about 50 metres deep as mapped by the TDEM.

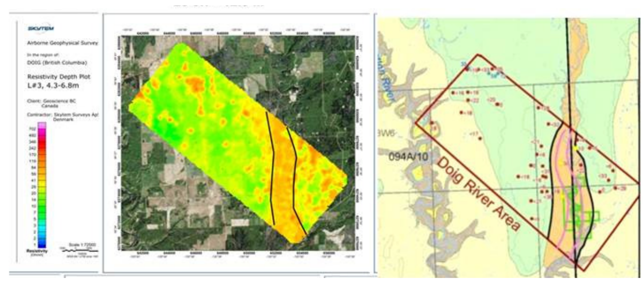

Figure 2 EM (left) and Gamma log (right) results

In the more resistive areas of the survey block the dual moment SkyTEM system also achieved a depth of penetration exceeding 500 m as seen in Figure 3.

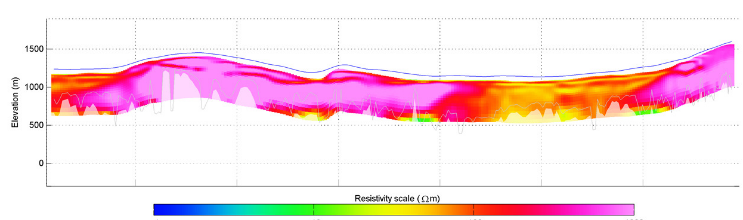

Figure 3 Resolving geological contrasts at 500 m

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Mineral mapping and identification of faults and taliks – SkyTEM516

TMAC Resources conducted a SkyTEM516 TDEM survey in the summer of 2015 over their Hope Bay and Elu gold mining project areas in Nunavut. The survey comprised of the acquisition of 15,000 line kilometres of TDEM data.

SkyTEM516 has a Low Moment with a peak of ~ 5,000 NIA at 210 Hz and an early time gate of ~ 6 µs, and a High Moment with a peak of ~ 1,000,000 NIA at 30 Hz and a late time gate at 10 ms.

With the capability to map the near surface as well as deep targets the data revealed geological features that could have an impact on future mine operations. Figure 4 shows a resistive layer beneath the lake (right) that could cause lake collapse, drainage and debris flow as happened at the Peel Plateau, Northwest Territories in December, 2015 (Kokelj, S.V, 2015). Melting permafrost and melted areas below lakes (taliks) are quite relevant for environmental, groundwater and climatological models as they present longtime risks for developing infrastructure, such as pipelines, roads and runways across Arctic landscapes.

The data also show evidence of a fault (left) characterized by a thin 300 ohm m layer over very resistive rock. This has relevance for geotechnical engineering decisions as the thin layer may present a hazard and not be suitable for constructing mine infrastructure.

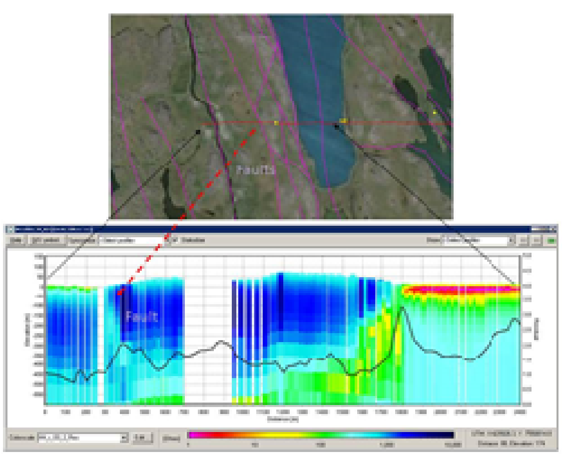

Figure 4 Mapping faults and taliks

Mapping Geo-hazards - SkyTEM304

Approximately 2400 line km of SkyTEM TDEM data were flown over the Horn River basin in April 2011 (Anglin, L., 2012) The SkyTEM304 system was selected for this study because of its global success mapping groundwater

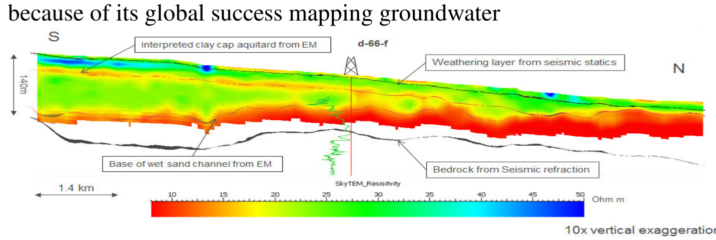

Figure 5 – Mapping faults and taliks

resources as well as for its dual moment and low noise characteristics that make possible the detection of subtle contrasts critical for mapping aquifers (Napier, S.R. 2014).

The survey was flown with the objective of using the TDEM data and models to better understand near surface groundwater resources. The survey successfully accomplished this and the entire data set is available for download at http://www.geosciencebc.com/s/Report2012-04.asp. In addition, and during the course of interpretation, due to the high quality of the data and resulting resistivity models, other important discoveries and applications were developed from airborne dataset.(Napier et al, 2014)

As shown in Figure 5, below the weathering layer the AEM resistivity model shows considerable and significant detail. A thin, continuous conductive layer (red) is imaged throughout the property at a depth ranging from 15-25m. This layer is thought to represent a thin lacustrine clay horizon which has the potential to be an aquitard. Below this clay cap, over most of the property, a relatively resistive and variable thickness layer is imaged below (green). Below this layer the model resistivity drops to relatively low values (< 10 Ωm) before the depth of investigation of the system is reached. The layers below the clay cap are interpreted to represent water charged quaternary paleochannels overlying a basal quaternary clay fill. In this case the paleochannel is filled with water as evidenced by Well d-66-f that has artesian water flow from the quaternary however in adjacent areas clay caps trap significant accumulations of shallow gas and present a potential drilling hazard. It was also found that the highly resistive areas at surface (blue) contained aggregate deposits that could be used for various engineering applications.

Further interpretation of the AEM data can provide a number of verifiable predictions: prediction for the location of ground water resources, prediction for the location of artesian water flow from the quaternary, prediction for the presence (absence) of shallow gas on the property, and a prediction for locations of near surface coarse materials for engineering applications.

Exploiting or avoiding water

In 2013 SkyTEM508 was contracted to collect data over a 99 square mile area of northwestern Nebraska. The area was designated as a Special Management Area by the Natural Resources District (NRD) in response to seasonal water level declines. The data for download and a link to a Google Earth image (shown in Figure 6) can be found at http://www.lpsnrd.org/Programs/gwaem.htm. The State of Nebraska webpage states "…as hoped, the electromagnetic survey provided extensive information about the area's geology, aquifer characteristics and water in storage. The NRD's use of the data is on-going. This summary is intended to help landowners in the project area access data showing the depth to aquifer material, the thickness of the aquifer and other basic information". Figure 6 shows a screen capture from the State NRD's webpage and gives an example of the pop-ups that appear as the mouse moves over the blue areas.

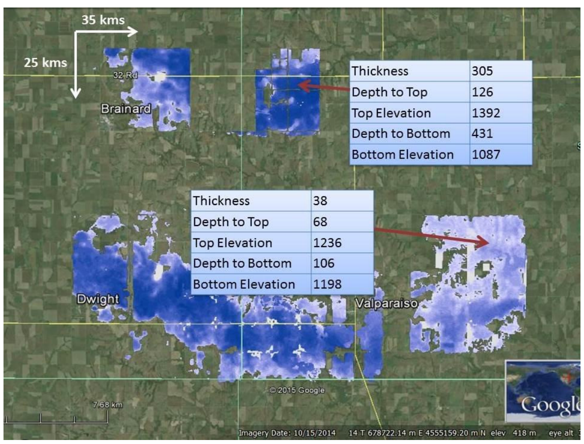

Figure 6 – Screen Capture from State of Nebraska webpage

This is relevant for mine operations as well as mineral exploration programs because the same data set acquired for mineral exploration can be interpreted for determining the presence of water. Once the location of water is know it can be regarded as a potential hazard for underground workings, or, as a less than ideal location for tailings due to the potential for seepage to the water table. It can also be regarded as a resource for mine operations as the volume of available water can be determined from accurate high resolution AEM data.

Conclusion

The application of AEM has greatly improved the ability to represent and interpret geology and can be a solution to a variety of environmental and engineering challenges. AEM data provides a method to characterize large and/or remote areas quicker than traditional methods and when combined with data inversion and statistical analysis can add to confidence in making earth management decisions.

A dual moment AEM system along with a carefully applied EM inversion modelling is capable of providing both near surface resolution (aggregates, engineering materials) as well as the ability to map targets at depth (sand channels, clay caps) and does a good job of discriminating lateral resistivity contrasts and layering.

Subsequent to some of the work shown here SkyTEM has developed more powerful systems that are soon to be launched and capable of achieving greater depths of investigation without comprising the level of detail.

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