A brief discussion of helicopter time-domain EM systems

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SUMMARY

A number of helicopter time-domain systems have been introduced to the exploration industry over the last decade. This paper discusses some of these new AEM systems, including AeroTEM, ExplorHEM, HoisTEM, THEM and VTEM. These systems differ in their geometries, data bandwidths and dipole moments. Field data acquired across mineralisations including the Shabogamo prospect, Labrador, the Uitkomst complex, South Africa, the Gogama massive sulfide, Ontario, a channel iron deposit in the Pilbara, W.A. and the Caber deposit, Quebec were modelled with Occam inversions and EMFlow, which in all cases outline the locations of these mineralisations.

Key words: airborne electromagnetics, EM data modelling, layered-earth inversions, transient EM.

INTRODUCTION

The past decade has seen the development of a number of helicopter-borne time-domain EM systems. These systems are generally more expensive to operate than fixed-wing EM systems such as GEOTEM and TEMPEST, but offer better spatial resolution and can be flown at higher altitude. Compared to helicopter frequency-domain systems such as DIGHEM and HUMMINGBIRD, helicopter time-domain systems offer better depth penetration. This paper discusses the specifications of a number of systems including AeroTEM, ExplorHEM, HoisTEM, THEM and VTEM. Other helicopter transient EM systems not discussed here include NEWTEM (Eaton et al., 2004), HeliGEOTEM (Fountain et al., 2005), SkyTEM (Sorenson et al. 2004) and ORAGS-TEM (Beard et al., 2004). All of these systems are flown for mineral exploration at survey heights above 25 m, except ORAGS-TEM, which is flown for the detection of unexploded ordnances 2-3 m above ground.

In the following each system is briefly introduced with data examples given. Conductivity-depth sections were derived using EMFlow (Macnae et al., 1998) and an Occam layered-earth inversion (Constable et al., 1987). The technical specifications of all helicopter time-domain systems known to the author are summarised in Table 1.

AEROTEM

The AeroTEM system is operated by Aeroquest, which has recently launched the AeroTEM IV system, which has a bigger transmitter moment (NIA=395,000 Am2) than its predecessors Aerotem II and III (NIA=40,000 Am2 and 250,000 Am2, respectively). AeroTEM data discussed in the literature include surveys for the exploration of nickel deposits (Balch, 2004a, 2004b) and kimberlites (Jansen and Witherly, 2004). The AeroTEM II and III systems record x- and z-component data at the centre of the transmitter loop. For the AeroTEM IV (see Figure 1) a split-coil design is used for the z-component coil, which is positioned near the edge of the transmitter loop.

Figure 1. The AeroTEM IV system.

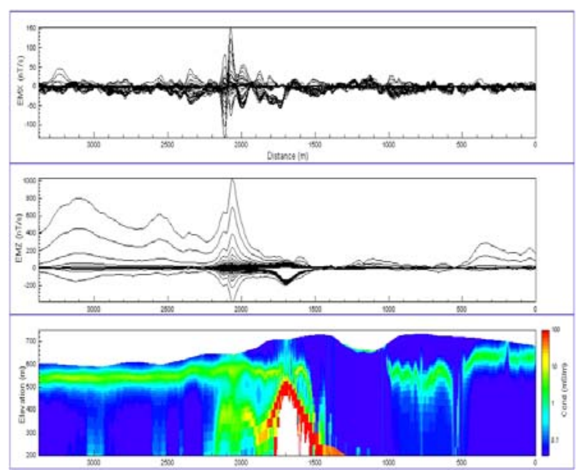

Figure 2. AeroTEM II data across Ni-Cu mineralization at Shabogamo prospect, Labrador, Canada. Shown are the x- and z-component data (top and centre) and the z-component Occam inversion result (bottom). The z-component shows a strong non-decaying on-time response (negative polarity) above the highly conductive mineralisation.

The AeroTEM system measures during the transmitter on- and offtime. The use of a triangular rather than a square waveform energizes lower decay time-constants in the subsurface, which makes high-conductance bodies easier to detect. The high primary field at the receiver location is removed with a bucking coil. This requires a high rigidity and weight of the system, which places a limitation on the transmitter loop size and dipole moment. The AeroTEM II has a diameter of 5m (350 kg), which for the AeroTEM III and IV have been increased to 9m (520 kg) and 12m (630 kg), respectively.

Figure 2 shows Aerotem II data with the derived conductivity-depth section across a mineralization at the Ni-Cu Shabogamo prospect in Labrador, Canada. The data were acquired in 2004 using a basefrequency of 150 Hz. The high conductance of the main conductor is indicated by the absence of an off-time response across it, clearly demonstrating the benefit of on-time measurements. Drill holes intersected disseminated to semi-massive sulphides between 70-90 m below surface.

EXPLORHEM

The geometry of the ExplorHEM system, operated by SpectremAir, is shown in Figure 3. The system represents a helicopter version of the fixed-wing SPECTREM system (Leggatt et al., 2000). The B-field processing of the recorded x, y and z-component data allows for the application of a survey-height correction (Green, 1998). In order to record broad-bandwidth EM data, a 100% duty-cycle square-wave with a RMS dipole moment of 25,600 Am2 is transmitted at a basefrequency of 75 Hz. The broad bandwidth of the data is advantageous for near-surface exploration, such as for kimberlites.

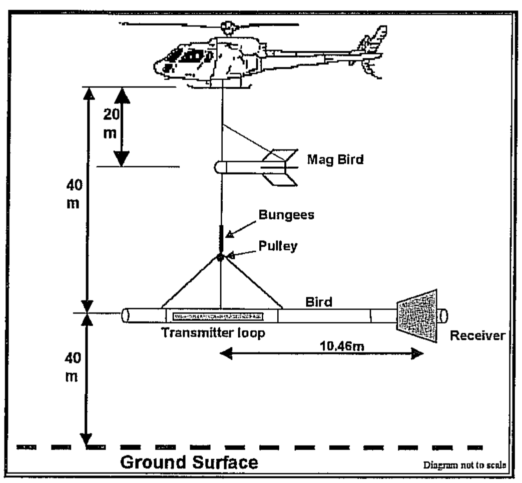

Figure 3. Geometry of the ExplorHEM system.

ExplorHEM data acquired in 2000 across the Uitkomst ultramafic complex, Mpumalanga, South Africa are shown in Figure 4. The line was flown across the Bushveld satellite body, which has been drilled to be located at shallow depth (17-36 m below surface) dipping 10-15 degrees west and is weathered down to 50 m depth. The two anomalies near the centre of the flight line are related to two small, steeply dipping, massive sulfides at about 40 m depth with no base metal credit (Polome, 2006, pers. communication).

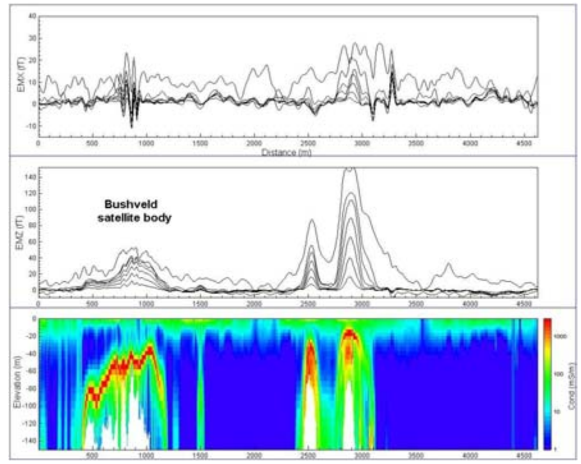

Figure 4. ExplorHEM data across the Uitkomst complex, South Africa. Shown are the x- and z-component data (top and centre) and the z-component Occam inversion result (bottom).

HOISTEM

The HoistEM system is jointly operated by GPX and Geosolutions and is described by Boyd (2004).

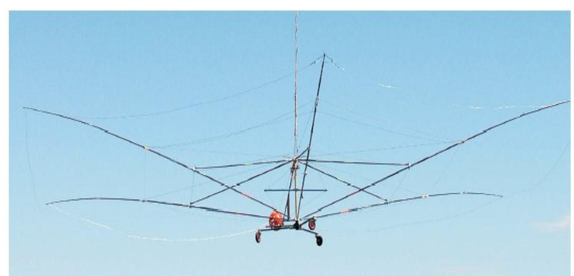

Figure 5. The HoistEM system.

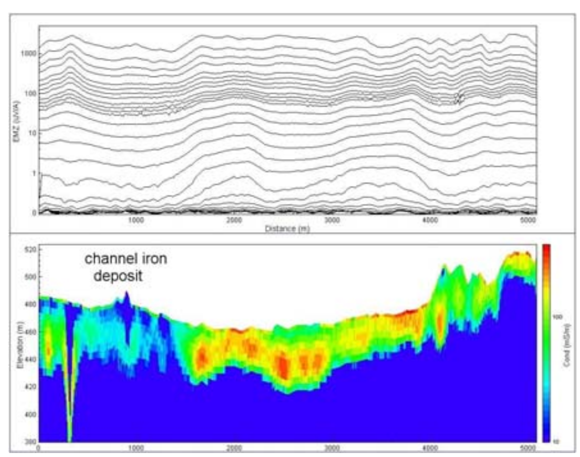

Figure 6. HoistEM data and EMFlow conductivity-depth section acquired across a channel iron deposit in the Pilbara, W.A.

HoistEM surveys are discussed by Hashemi and Meyers (2004), Hashemi et al. (2005), Stolz (2005) and Vrbancich and Fullagar (2004). The system, which measures the z-component response at the centre of the transmitter loop is shown in Figure 5. A 5 ms square-pulse with a peak dipole moment of 120,000 Am2 is transmitted at a basefrequency of 25 Hz. Due to the large primary field during the on-time, which would saturate the receiver electronics, the EM response is recorded during the off-time only.

HoistEM data acquired across a channel iron deposit in the Pilbara, W.A.,.in 2002 are shown in Figure 6. The lack of clay development over this deposit makes it stand out as a resistive unit, surrounded by conductive saprolite.

THEM

The THEM system is operated as a joint venture between McPhar Geosurveys and T.H.E.M. Geophysics. The current survey geometry is displayed in Figure 7. The receiver is located about 24 m above and 12.5 m ahead of the transmitter centre. The system transmits a half-sine pulse with a peak moment of 124,000 Am2 at a basefrequency of 30 Hz and the receiver measures x, y and z-component data during the transmitter on- and offtime. Figure 8 shows a line of THEM data across a massive sulfide acquired near Gogama, Ontario, Canada. The mineralization is clearly indicated by the EM profile and is modelled at 150 m depth.

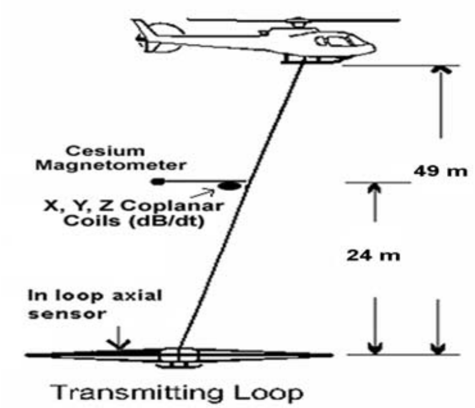

Figure 7. Geometry of the THEM system.

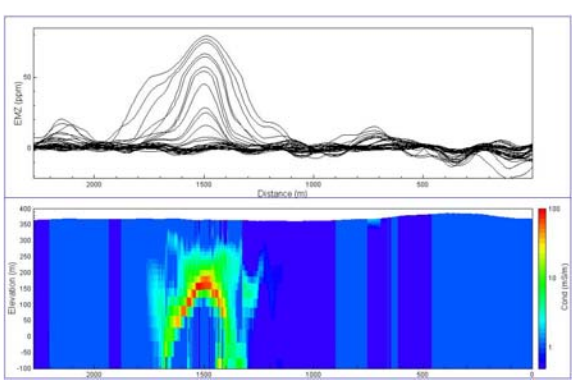

Figure 8. THEM z-component data and derived Occam inversion result across a massive sulfide near Gogama, Ontario, Canada.

VTEM

The VTEM system is operated by Geotech and has been described by Witherly et al. (2004a). The receiver is located at the centre of the transmitter loop (see Figure 9) and measures z-component data during the transmitter off-time. The system transmits a trapezoidal pulse, 4.5 ms wide, at a basefrequency of 30 Hz. With a transmitter loop diameter of 26 m, a peak moment of 600,000 Am2 is achieved, which is the highest currently available moment for helicopter systems. VTEM survey results are discussed by Hammack et al. (2004) and Witherly et al. (2004a, 2004b).

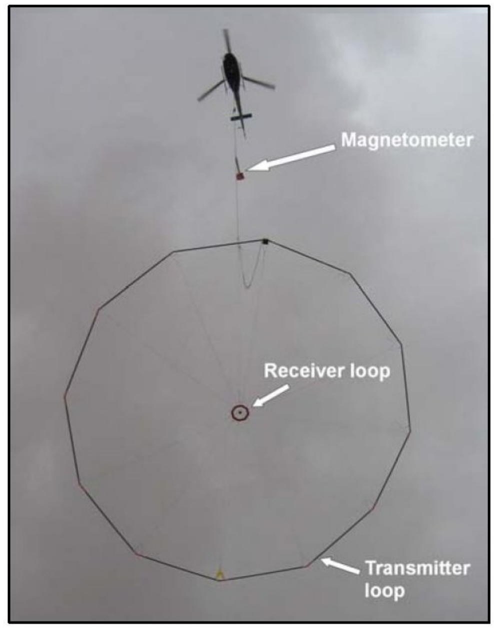

Figure 9. The VTEM system.

VTEM data flown across the Caber volcanic massive sulphide deposit are shown in Figure 10. The Zn-Cu mineralisation ranges from 150-500 m below surface (Allard, pers. communication) and is strongly indicated by the EM profile and Occam inversion.

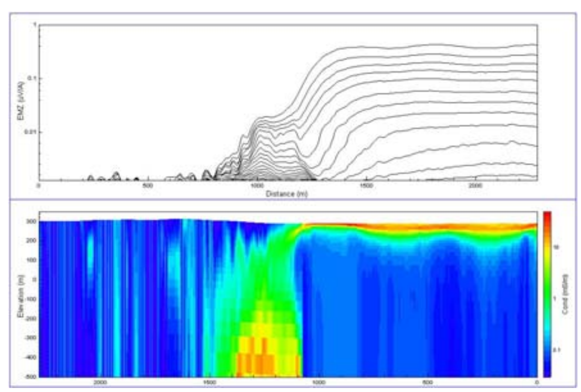

Figure 10. VTEM data with modeled conductivity-depth section across the Caber deposit, Quebec, Canada.

DISCUSSION

All of the helicopter EM systems use a vertical transmitter and measure the z-component response. The current HoisTEM and VTEM systems measure z-component data only. AeroTEM also measures the x-component, whereas ExplorHEM and THEM also measure the x- and y-component responses. Recording components other than the z-component helps substantially to resolve the geometry of subsurface conductors.

Recording the full waveform of the EM response during the transmitter on- and offtime, as done by AeroTEM, ExplorHEM and THEM has a number of advantages: (1) the full data bandwidth is recovered, with the high-frequency information recorded during the turn-on and turn-off ramps improving the resolution of near-surface structure; (2) the data can be converted to B-field responses, which makes profiles easier to interpret and high-conductance bodies easier to detect (Smith and Annan, 1998; Wolfgram and Thomson, 1998); (3) the detection of "perfect" conductors, which have no offtime response, becomes possible.

Perfect conductor detection also requires the exact removal of the primary field, since the EM response of a perfect conductor is a pure inphase response. The primary field can be eliminated with a bucking coil at the acquisition stage or computed and removed during data processing. For the former, a very rigid and heavy system structure is needed. For the latter, a highly accurate knowledge of the transmitted current and system geometry is required for every measurement, which is difficult to achieve. AeroTEM uses a bucking coil which removes 99.98% of the primary field (Balch, 2004a). The data shown in Figure 2 suggest that enough primary-field is removed this way to detect perfect conductors.

The sensitivity of helicopter frequency-domain data to magnetic permeability anomalies is well documented (Fraser, 1981; Huang and Fraser, 2000). Helicopter time-domain data are also affected, especially during the transmitter ontime, but the effects on the data are less obvious. Hence, the modelling and interpretation of helicopter time-domain EM data acquired in magnetically polarisable areas should take into account the effect of magnetic permeability.

CONCLUSIONS

The data profiles and derived conductivity-depth sections indicate that AeroTEM on-time data allow for the detection of highly conductive bodies undetectable with off-time data. The square waveform and step-response processing of the ExplorHEM system give it a wide bandwidth resulting in excellent near-surface resolution and relatively good depth penetration for a low-moment system. Modelling results of the shown HoisTEM data successfully outline the location of a channel iron deposit. AEM data acquired with the lightweight THEM system indicate a massive sulfide at 150 m below surface. The high-power VTEM system indicates the Caber mineralisation at a depth below 150 m.

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REFERENCES

Balch, S., 2004a, The emerging role of helicopter time-domain EM systems: 17th Geophys. Conference and Exhibition, Austr. Soc. Expl. Geophys., Extended Abstracts.

Balch, S.J., 2004b, Conductor thickness and its effect on EM interpretation: 74th Ann. Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, MIN P1.7.

Beard, L.P., Doll, W.E., Holladay, J.S., Gamey, T.J., Lee, J.L.C, and Bell, D.T., 2004, Field tests of an experimental helicopter time-domain EM system for unexploded ordnance detection: Geophysics 69, 664-673.

Boyd, G.W., 2004, HoisTEM – a new airborne electromagnetic system: PACRIM Proceedings, Adelaide.

Constable, S.C., Parker, R.L, and Constable, C.G., 1987, Occam's inversion: a practical algorithm for generating smooth models from electromagnetic sounding data: Geophysics 52, 289-300.

Eaton, P., Anderson, B., and Lubbe, B., 2004, NEWTEM adventures in thin air: 74th Ann. Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, MIN 3.4.

Fountain, D., Smith, R., Payne, T., and Lemieux, J., 2005, A helicopter time-domain EM system applied to mineral exploration: system and data: First Break 23, 73-78.

Fraser, D.C., 1981, Magnetite mapping with a multicoil airborne electromagnetic system: Geophysics 46, 1579-1593.

Green, A., 1998, Altitude correction of time domain AEM data for image display and geological mapping using the Apparent Dipole Depth (ADD) method: Exploration Geophysics 29, 87-91.

Hammack, R.W., Witherly, K., Zellman, M.S., Lipinski, B.A., and Harbert, B., 2004, Using helicopter TDEM surveys to identify flooded workings in underground mines; the first attempt: SAGEEP, 128-139.

Hashemi, A., and Meyers, J., 2004, HoisTEM data processing for discovery of high-grade manganese ore under regolith cover: Exploration Geophysics 35, 272-276.

Hashemi, A., Meyers, J., and Rothery, E., 2005, SAM surveying for shallow occurrences of conductive manganese ore, Woodie-Woodie area, W.A.: Exploration Geophysics 36, 170-175.

Huang, H. and Fraser, D.C., 2000, Airborne resistivity and susceptibility mapping in magnetically polarizable areas: Geophysics 65, 502-511.

Jansen J., and Witherly, K., 2004, The Tli Kwi Cho Kimberlite complex, NWT, Canada: a geophysical case study: 74th Ann. Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, MIN 1.3.

Leggatt, P.B., Klinkert, P.S., and Hage, T.B., 2000, The Spectrem AEM system - further developments: Geophysics 65, 1976-1982.

Macnae, J., King, A., Stolz, N., Osmakoff, A., Blaha, A., 1998, Fast AEM processing and inversion: Exploration Geophysics 29, 163-169.

Smith, R., and Annan, P., 1998, The use of B-field measurements in an airborne time-domain system: Part I.

Benefits of B-field vs dB/dt data: Exploration Geophysics 29, 24-29.

Sorenson, K.I., and Auken, E., 2004, SkyTEM - a new high-resolution helicopter TEM system: Exploration Geophysics 35, 194-202.

Stolz, E.M.G., 2005, Regolith mapping in hypersaline environments: a comparison of SAM with helicopter TEM: Exploration Geophysics 36, 157-162.

Vrbancich, J., and Fullagar, P., 2004, Towards seawater depth determination using the helicopter HoistEM system: Exploration Geophysics 35, 292-296.

Witherly, K., Irvine, R., and Morrison, E.B., 2004a, The Geotech VTEM time-domain helicopter EM system: 74th Ann. Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, MIN 3.5.

Witherly, K., Irvine, R., and Godbout, M., 2004b, Reid Mahaffy test site, Ontario, Canada: an example of benchmarking in airborne geophysics, 74th Ann. Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, MIN 3.1.

Wolfgram, P., and Thomson, S., 1998, The use of B-field measurements in an airborne time-domain system – part II: examples in conductive regimes: Exploration Geophysics 29, 225-229

	AeroTEM IV (II)	ExplorHEM	HoisTEM II	THEM	VTEM	HeliGEOTEM 30 Hz (90 Hz)	NewTEM	ORAGS-TEM	SkyTEM
Tx area (m^2)	113 (20)	16	375	44.2	531	95	300	36	283
Tx turns	7 (8)	8	1	2	4	2	1	4	4
peak dipole moment (Am^2)	395,000 (39,200)	25,600 RMS	120,000	123,700	630,000	230,000 (212,800)	80,000	4,320	94,000
Tx current (A)	500 (250)	200 RMS	320	1400	300	1210 (1120)	265	30	83
Basefrequency (Hz)	30/90 (90/150)	75	25	30	25/30	30 (90)	25/30	90 (270)	25
Rx position (m) wrt Tx (dx/dy/dz)	6/0/0 (0/0/0)	10.46/0/0	0/0/-3	12.5/0/24	0/0/0	21/0/35	14/0/26	0/4/0	-12/0/-1.9
Tx orientation	z	z	z	z	z	z	z	z	z
Rx components	x, z	x, y, z	z	x, y, z	z	x, y, z	x, y, z	z & vertical gradient	x, z
full waveform recording	yes	yes	no	yes	planned	yes	no	no	no
B-field processing	-	yes	no	no	planned	yes		no	no
Rx bandwidth	30/90-23,040 (90/150-19,200)	75-19,200	25-19,722	30-30,720	25/30-25,000	30-11,520 (90-92160)	25/30-100,000	90/270-5,400	
Tx waveform	triangular	square 100% duty cycle	square 25% duty cycle	half-sine	trapezoidal	half-sine	square	square 50% duty cycle	trapezoidal with long turn-on ramp
Tx pulse width (ms)	1.86	3.33	5	4	4.5	4 (2)		2.8 (0.9)	10
Digitisation rate (Hz)	46,080 (38,400)	38,400	8,873/ 39,444	61,440	50,000	23,040 (184,320)	200,000	10,800	

Table 1. Current technical specifications of helicopter time-domain systems. Most systems can be operated at a range of basefrequencies.