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The Forrestania and Nepean electromagnetic test ranges, Western Australia – a comparison of airborne systems

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SUMMARY

Electromagnetic (EM) systems are often described with varying technical specifications and standards, making it difficult to directly compare and assess their application to practical field examples. Exemplar case studies provided by contractors, whilst highlighting system capabilities, do not necessarily help to refine the suitability of the system across different geological targets and environments. Test ranges provide an opportunity for direct and consistent comparison of multiple systems for objective assessment.

The Forrestania and Nepean EM test ranges in Western Australia consist of readily accessible land, openly available for testing by airborne, ground and downhole EM systems. Multiple conductors at varying depths beneath 10-20 Siemens (S) conductive overburden provide challenging, real-world conductive targets. Surveying using different EM systems allows for a direct comparison of system detection and resolution capabilities in a conductive regolith environment. The conductors have been well defined by drilling and provide a large range of metrics available for measurement, varying from 60-400 m in depth, 5,000-10,000 S in conductance, and with variable lateral profiles and depth extents.

Multiple airborne, ground and downhole EM systems have utilised these test ranges, and several have made their data freely available for review. These include ground methods such as moving loop EM, fixed loop EM, SAMSON, downhole EM, and helicopter systems including HeliSAM FLEM, SkyTEM, VTEM, HELITEM, HeliGEOTEM, XTEM, HoistEM and AeroTEM. The SPECTREM, and Xcite airborne systems plan to fly the test range in the near future. Comparison of the airborne results, show that most of the post-2007 systems have been adequate to good at detecting the shallow IR2 conductor at Forrestania under conductive regolith. Only the hybrid grounded loop HeliSAM system has successfully detected the deep IR4 conductor at Forrestania.

Key words: electromagnetics, Forrestania, Nepean, test range

INTRODUCTION

The electromagnetic (EM) technique is a complex method. Direct comparisons of EM system noise levels, as well as depth of investigation and applicability to exploration settings can often be challenging. This is due to the many, varied system configurations on offer, including airborne vs ground platforms, range of frequencies, and transmitter and receiver specifications. The Forrestania and Nepean EM test ranges represent direct comparison sites. The presence of conductive regolith at the sites is a difficult environment for EM systems, yet a common challenge over much of WA, making these locations good, real world test sites.

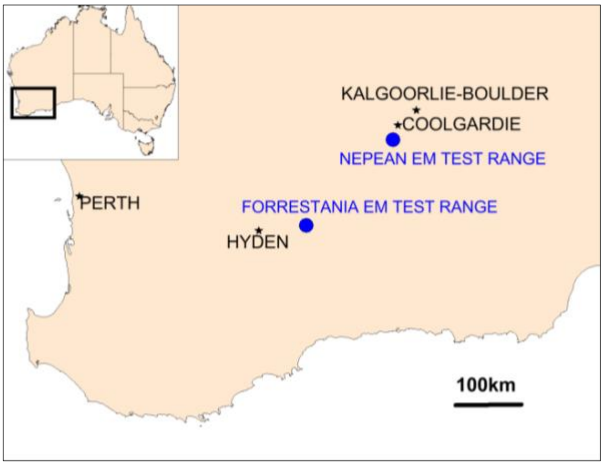

Figure 1. Location of the Forrestania and Nepean EM test ranges, South West of Western Australia.

The Forrestania EM test range is situated approximately 85 km east of Hyden by road and ~350 km east of Perth. Two discrete bedrock conductors were defined during previous geophysical exploration completed on behalf of Image Resources NL. Drilling of both conductors intersected barren, disseminated to semi-massive pyrrhotite and pyrite bodies hosted in granite with associated rafts of banded iron formation (Dance, 2007). The western conductor (IR2) is of limited areal size (<75 x 75 m), shallow depth (<100 m), high conductance (>7000 S) and dips northward at ~30-40 degrees. This conductor is well defined by surface and downhole EM and makes for an interesting airborne EM target. The eastern conductor (IR4) is extensive in strike/plunge extent (>500-600 m) and reasonably well constrained in depth extent (approximately 100-150 m). The conductive source is at considerable depth ~300-325 m (western side) to >400 m (eastern side), is highly conductive ~5,000-10,000 S and dips northward (~30-40 degrees). In the early 2000s, IR4 was considered a more challenging conductive target for surface EM methods given the use of lower powered systems at the time.

The Nepean EM test range is located around the Nepean nickel mine, 24 km by road southwest of Coolgardie and

500 km east of Perth. The Nepean mine produced 34,861 tonnes of nickel at an average recovered grade of 2.99% Ni over a 17 year period to May 1987 (Hill and Gole, 1990). The tenements are held by Focus Minerals Ltd and remain an active exploration area. The site is centred on a series of steeply west-dipping (80 degrees) ultramafic flows. Various amphibolites with intercalated metasedimentary rocks separate the ultramafic units (Sheppy and Rowe, 1975). The entire sequence is intruded by sub-horizontal pegmatite units. The regional country rock comprises granites and metamorphosed felsic and mafic volcanic units. The EM response from the basement units and regolith in the area is variable. It includes responses from moderately conductive regolith (with areas of higher conductivity over ultramafic units) and weakly to highly conductive, confined basement conductors of shales, and massive sulphides (pyrrhotite, pentlandite, pyrite) at varying depths from 60 m below surface.

RESULTS

Nine airborne electromagnetic (AEM) systems are known to have been flown over the test ranges. Survey data and system parameters for seven of these systems are shown in Table 1. All of the systems are helicopter EM systems. The fixed wing SPECTREM^{PLUS} system is planned to fly in the second or third quarter of 2019.

Forrestania EM Test Range

Six heliborne EM systems are known to have flown the Forrestania EM test range. These include SkyTEM, HeliSAM FLEM, HELITEM, VTEM (2007, 2008, 2011), HeliGEOTEM II and Xcite. These systems were all flown between 2007 and 2018, with five surveys flown between 2007 and 2011 and the remaining three surveys flown in 2017 and 2018. Table 1 shows that most of the AEM systems are very similar in terms of general design. All systems acquired data at 25 Hz with the exception of the SkyTEM and HeliSAM FLEM surveys which used lower frequencies of 12.5 Hz and 1.5625 Hz respectively. The HeilSAM FLEM system is the most significantly different to the other systems as it is a hybrid system using a grounded fixed transmitter loop and helicopter-mounted total field EM sensor. These airborne systems can be compared with a variety of ground and downhole EM survey results and modelling.

Southern Geoscience Consultants (SGC) is the custodian of datasets from both EM test ranges and has received survey data from all of the above-mentioned airborne systems except for Xcite, where only a prototype system has been flown to date. Re-surveying using the latest commercially operating Xcite system is expected later in 2019.

The 2008 B-field results from the VTEM Max and HELITEM surveys are compared in Figure 2. This shows that the shallow conductor IR2 has been delineated in close proximity to the location, as modelled from the ground and downhole EM data. The shape and amplitude of the anomaly is very similar in both systems. The VTEM system shows a higher amplitude response but the anomaly is clearly detectable in both systems.

The most recent systems to fly the area are the SkyTEM and HeliSAM FLEM systems. The SkyTEM dB/dt results are shown in Figure 2. The dB/dt coil response shows a clear, strong anomaly to the latest time channels. None of the standard, coincident loop airborne EM systems are able to detect the deeper, large IR4 conductor.

The HeliSAM FLEM hybrid system is the only system that has detected both IR2 and the >300 m deep IR4 conductors, (Figure 4). HeliSAM, in a fixed loop EM mode, is able to significantly increase its dipole moment using a very large loop (1.2 km x 0.8 km). It has also been able to record data at low frequency and directly measure the B-field response which is all important in detecting high conductance targets at depth. However the requirement to lay out grounded loops and the associated issues with coupling mean that this technique is significantly slower and more logistically challenging than standard airborne EM. In this setting, the location of the conductors was well known so it was possible to plan fixed loops to achieve optimal EM coupling.

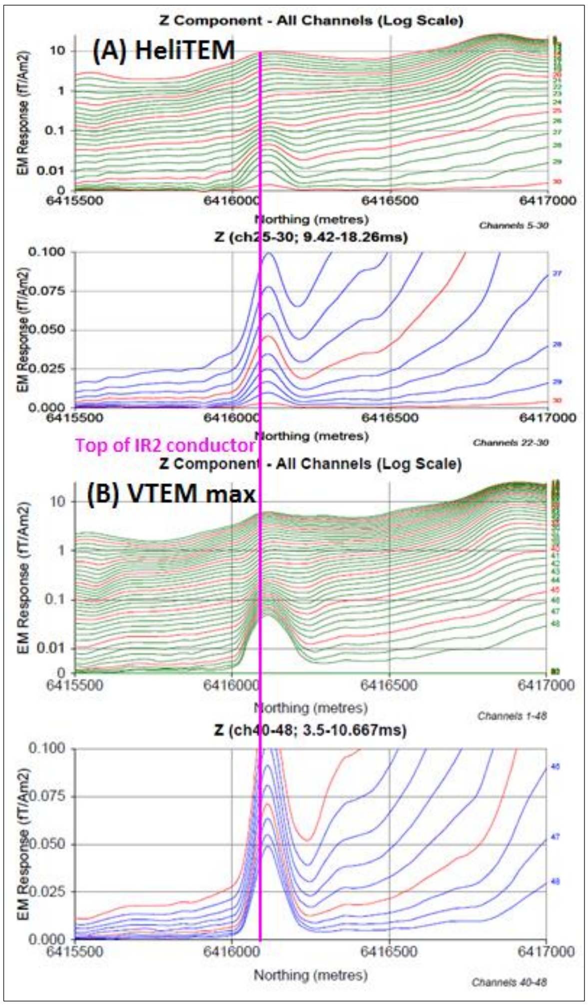

Figure 2. Profile plots of Z component in log (green/red) and linear (blue/red). (A) 2008 HELITEM B-field data compared with (B) 2011 VTEM Max over the shallow IR2 conductor (748150E). Plots are shown with the same dynamic range and normalised to the same. Top of the conductor, as modelled using the ground EM data, shown in pink.

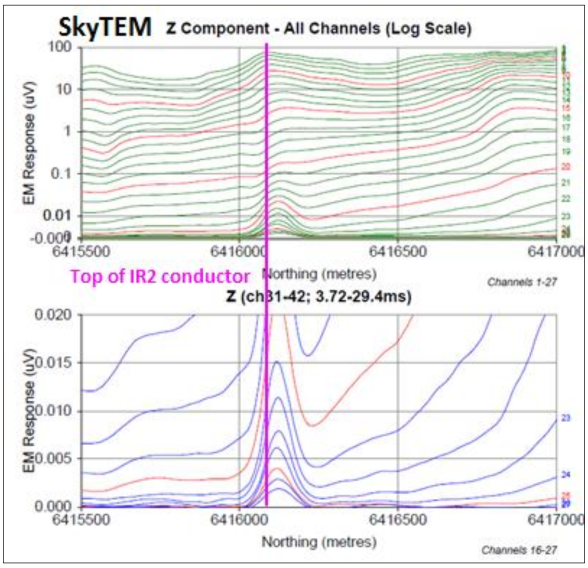

Figure 3. 2018 SkyTEM dB/dt response of the shallow IR2 conductor (748150E). Top of the conductor, as modelled using the ground EM data, shown in pink.

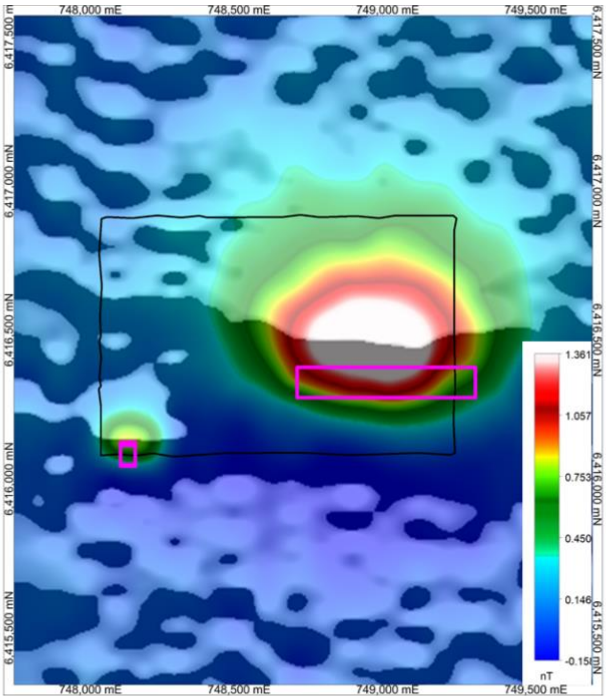

Figure 4. HeliSAM total field EM channel 22 (96.8 ms) fixed ground loop position shown in black and modelled conductor positions shown in magenta (IR4) and red and cyan (IR2).

Nepean Test Range

In 2004, a HoistEM test survey was flown over the Nepean mine at 100 m line spacing (Figure 4). The area was re-flown in 2007 with the VTEM system at 150 m spacing and three of the HoistEM lines were specifically re-flown with VTEM to ensure precise spatial repeatability.

The results of the HoistEM and VTEM comparison are published in Combrinck, et al. (2008). Figure 5 shows the 2007 VTEM survey detected the Nepean bedrock conductors. There is no significant response in the HoistEM data above noise levels after 2.5 ms (Figure 5B). HoistEM appears to have only detected deeper, conductive regolith over weathered ultramafic units and was unable to detect the bedrock conductor.

HeliGEOTEM, HELITEM, AeroTEM, and XTEM systems were flown at Nepean between 2007 and 2011. While all of these systems have reportedly detected the Nepean bedrock conductor in publicity material, the HeliGEOTEM, HELITEM, AeroTEM, data remain confidential and no XTEM data have been provided for independent verification.

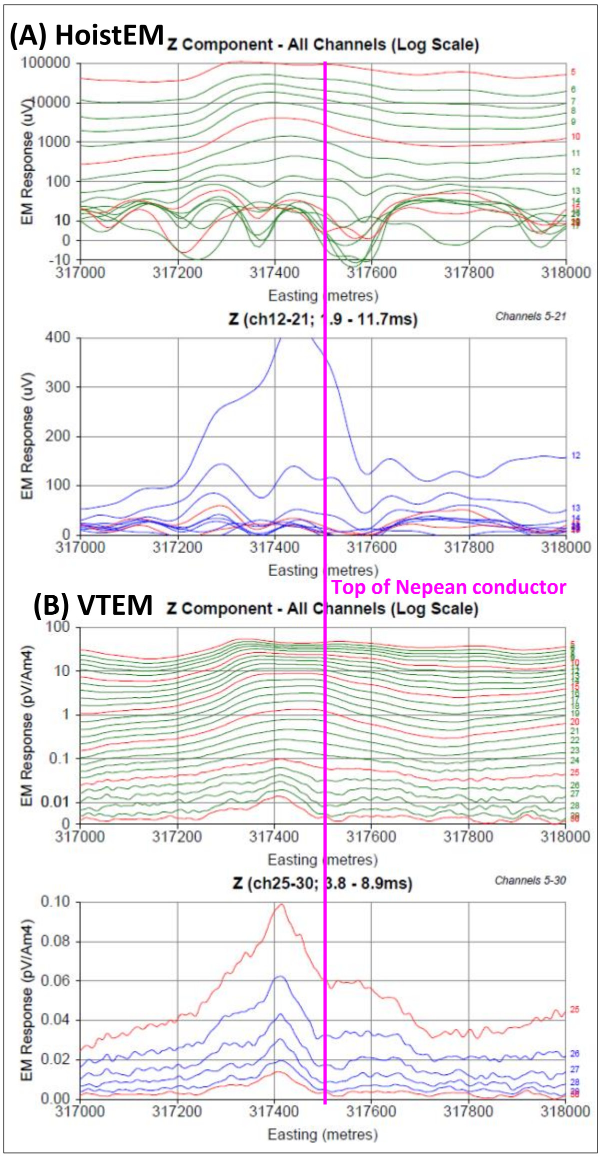

Figure 5. (A) 2004 HoistEM data line 1305 compared with (B) 2007 VTEM line 2040 data over the Nepean conductor, the lines overlap. Top of the conductor, as modelled by the ground EM results, shown in pink.

CONCLUSIONS

The Forrestania and Nepean EM test ranges provide a practical location for testing airborne EM systems. They provide a real world example and system comparison in a conductive environment and provide some challenging conductive targets.

All of the airborne EM systems flown after 2007 have good at detected the shallow IR2 conductor at Forrestania. The Nepean shallow, steeply-dipping target is reported to be detected by all of the systems from after 2007 but not all data has been made available for rigorous, independent assessment. The HeliSAM hybrid system with a large grounded fixed loop is the only airborne system that has been able to detect the deep IR4 conductor at Forrestania. The deep IR4 conductor located under conductive overburden continues to be a challenging target for even modern, high-powered airborne EM systems.

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Table 1. Survey parameters for most of the airborne EM system flown at the Forrestania and Nepean test ranges. Blank fields are unknown, or information has not been supplied.

	HeliSAM FLEM	SkyTEM 312HP	VTEM Max	VTEM	VTEM	HeliGEOTEM	HeliTEM	AeroTEM	HoistEM
Company	Gap Geophysics	SkyTEM Australia	Geotech Ltd	Geotech Ltd	Geotech Ltd	Fugro/CGG	Fugro/CGG	AeroQuest Ltd.	GPX Airborne
Data availability	Public	Public	Public	Public	Public	Confidential	Confidential	Confidential	Public
Date	2017	2018	2011	2007	2008	2008	2011	2009	2004
Base frequency (Hz)	2.083	12.5	25	25	25	25	25	25	25
Waveform / duty cycle	square 50%	trapezoidal 20%	29%	polygonal	polygonal			symmetric bipolar triangular, 14.4%	bipolar-square wave 25%
Current (A)	150	245	232	200	200	1200	1200		320
Peak dipole moment, NIA (Am^2)	144,000,000	~991,000	892,840	625,000	625,000	~700,000	~700,000	350,000	120,000
Tx loop area (m^2)	960,000	337	961	540	540	154	153.94	113	375
Turns	1	12	4	4	4	4	4	5	1
Tx/Rx height (m)	~45	35-45	87	30	30	96 / 59	30	30	30
Rx time gates	22 (0.208-116.8 ms)	27 (0.019-31.9 ms)	35 (0.083-11.458 ms)	30 (0.07-8.9 ms)	30 (0.07-8.9 ms)		30 (0.165-14.26 ms)		21 (0.078-11.72 ms)
Rx sensor	Total B field	dB/dt coil	dB/dt; calculated B field	dB/dt coil	dB/dt; calculated B field			In-loop X and Z	dB/dt coil
Rx area	$1m^2$ B-field	100 m2 (Z), 40.31 m2 (X)	113.1 m^2						
Configuration	Fixed loop	In-loop	In-loop	In-loop	In-loop			Offset loop	In-loop
Tx turn-off time (ms)	2.5	1	2.25	1.1	1.1				0.04
Tx pulse on-time (ms)	120	8	6.25	>7	>7				5