SkyTEM Final Report for Western Desert Resources at Spring Hill, NT

Geoforce Job Number: SK850WD

Authors: Grant Couston, Tristan Kemp, Russell Eade

Reviewed by: James Reid

Table of Contents

1 Summary

Geoforce Job Number	SK850WD
Survey Company	Geoforce Pty Ltd
Dates Flown	11th September 2008 – 12th September 2008
Client	Western Desert Resources Ltd
Terrain Clearance	30 m (nominal)
Total Line km	283 kms
Datasets acquired:	Time-domain EM
	Digital Terrain Model
EM System	SkyTEM High Moment
Helicopter company	HeliWest
Helicopter type	AS350 Super D2
Helicopter registration	VH-NRW
Traverse Line Spacing	150 m
Traverse Line Direction	090 – 270
Navigation	DGPS
Coordinate System	MGA52 / GDA94

2 Personnel

The following personnel were employed for this project:

2.1 Field Operations

Crew Chief	Kate Godber
Technical Assistants	Chris Ward-Allen, David Duxbury
Pilot	Ian Pullan

2.2 Base Operations

Project Manager	James Reid
Data Processing	Russell Eade, Tristan Kemp.

3 Flight plan

The flight plan and line numbers are shown in Figure 1.

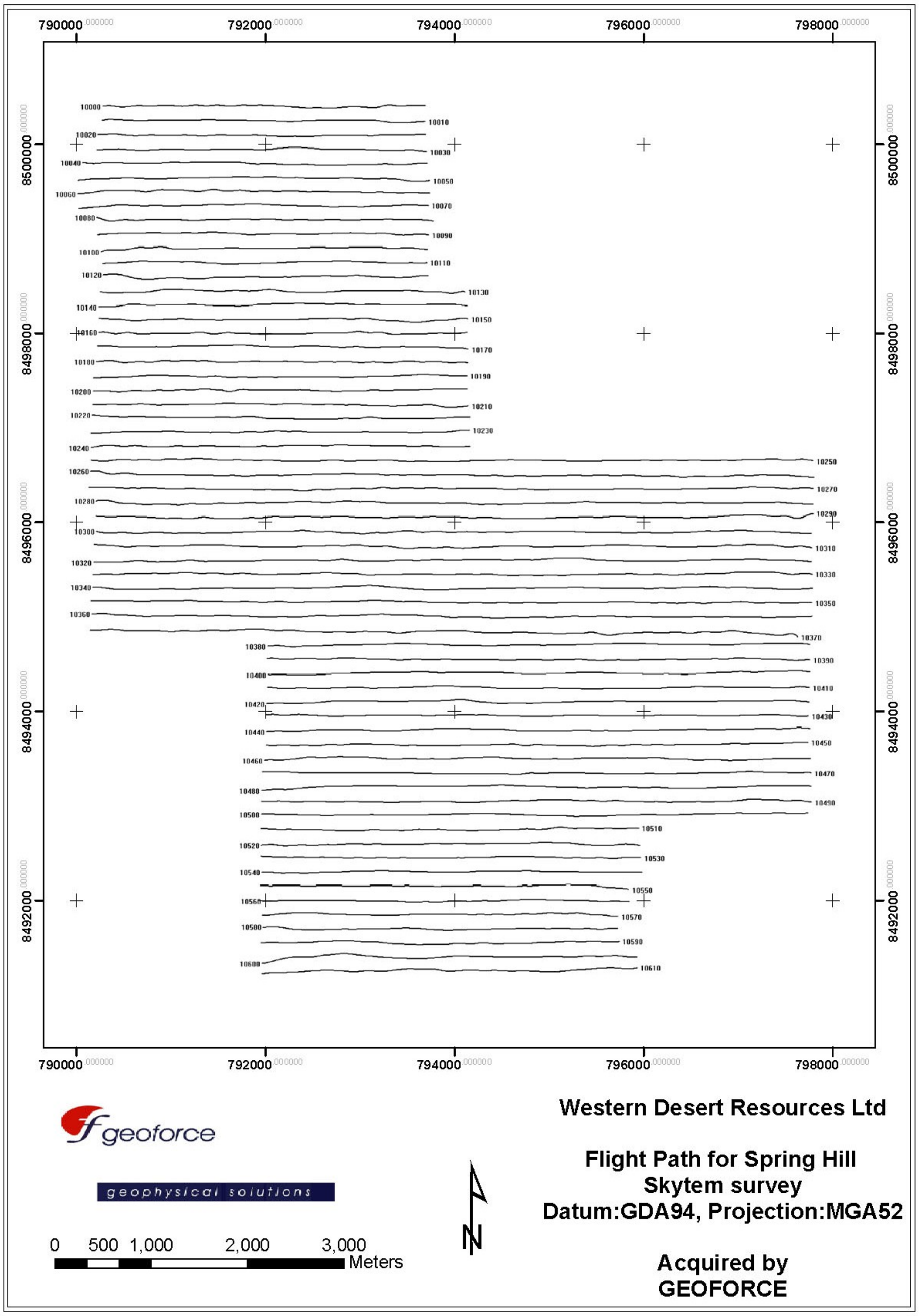

Figure 1: Flight path map for Spring Hill SkyTEM Survey (MGA52/GDA94 coordinates).

4 Logistics

The survey was flown between 11th September 2008 to 12th September 2008.

A logistics summary report is attached (SK850WD-logistics summary.pdf).

Known Technical Issue
A cable running to the x coil came unattached due to human error, resulting in no x measurements for the flight on 11th September. Lines flown during this flight were subsequently repeated.

5 Geometry

Geometry of the system is illustrated below. X, Y and Z coordinates of each sensor are given with respect to the centre of the Tx loop. The Z-coordinate is positive above the Tx loop wire. Positive X and Y-axes are in the flight direction and to the starboard side respectively.

Sensors are as follows:

Z-coil:	EM Z-axis sensor (Sign convention for EM data +ve up)
X-coil:	EM X-axis sensor (Sign convention for EM data +ve in the flight direction)
Tilt1:	Tiltmeter set 1 (measures tilts from horizontal with respect to both X and Y axes)
Tilt2:	Tiltmeter set 2 (measures tilts from horizontal with respect to both X and Y axes)
Alt1:	Laser Altimeter 1
Alt 2:	Laser Altimeter 2
GP1:	GPS 1 Antenna
GP2:	GPS 2 Antenna (RTK DGPS via Fugro Omnistar HP Service)

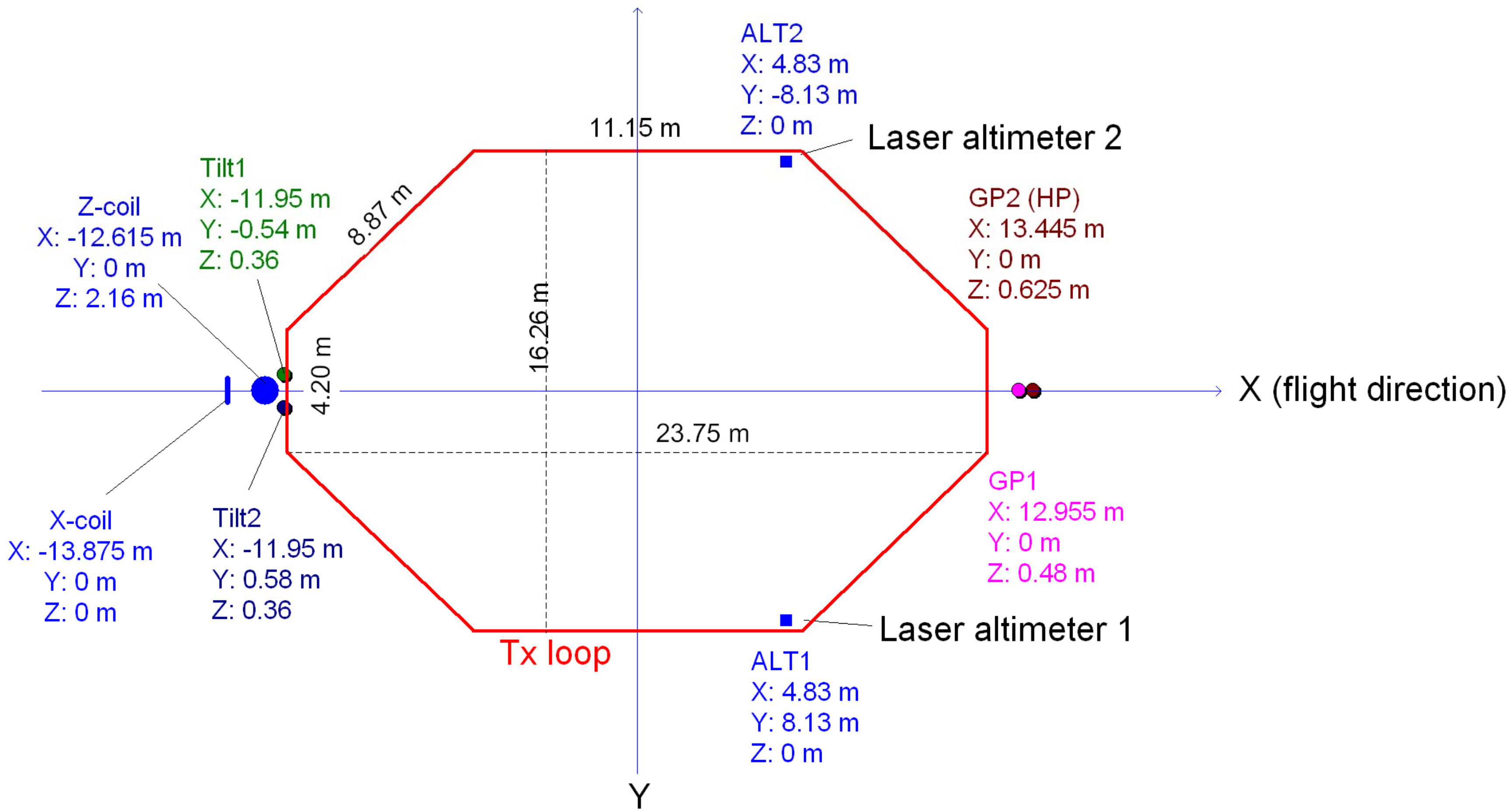

Figure 2: Sensor geometry for Spring Hill SkyTEM survey. See main text for explanatory notes.

6 SkyTEM System specifications

EM Transmitter – High Moment	
Transmitter loop area	311 m^2
Number of transmitter loop turns	4
Average peak current	92.9 A
Peak moment	115,568 A.turn.m^2
Tx loop height (nominal)	30 m
Tx Waveform – High Moment	
Base frequency	25 Hz
Tx duty cycle	50%
Tx waveform	Bipolar
Tx on-time	10 ms
Tx off time	10 ms
Tx ramp time	40 μs

Table 1: Skytem TX specifications.

EM Receiver	
EM Sensors	dB/dt coils
Rx coil effective area (Z and X)	31.4 m^2
Low pass cut-off frequency for Rx coils	450 kHz
Low pass cut-off frequency for Rx electronics	300 kHz
Z-component Rx coil position	
Behind Tx loop centre	12.62 m
Above plane of Tx loop	2.16 m
X-component Rx coil position	
Behind Tx loop centre	13.88 m
Above plane of Tx loop	0 m

Table 2: Skytem RX specifications.

7 SkyTEM data processing

Raw (binary) SkyTEM data have been processed using the proprietary software package SkyPro (Build 43) to generate ASCII data files. All positions, altitudes etc in processed data are relative to the centre of the transmitter loop. Altitudes have been corrected for Tx loop attitude, and are averages of data from both altimeters following application of a local maximum filter. Electromagnetic data have been stacked using a moving average filter of width 2 seconds, representing a stack of ~100 transients for high moment data.

Stacked data have been output every 0.25 seconds (~6 m on the ground at 80km/h groundspeed).

EMaxAir processing

Z-component XYZ data have been converted to apparent conductivity vs depth using EMax_air v2.24a (Fullagar and Reid, 2001). The apparent conductivity data have been 'sharpened' in order to yield improved depth resolution of conductive layers. The sharpening process treats the apparent conductivity (σ_a) generated by the initial transformation as a depth average, ie

$$\sigma_a(z) = \frac{1}{z - z_0} \int_{z_0}^{z} \sigma(u) du$$

The above equation can be inverted for the 'sharpened' conductivity, which provides improved depth resolution of conductive layers.

$$\sigma(z) = \sigma_a(z) + (z - z_0) \frac{d\sigma_a}{dz}(z)$$

Figure 3 compares original and sharpened apparent conductivity curves for a synthetic three-layered model.

Conductivity-depth data files have extension *.CDI. A complete description of the CDI file format can be found in Appendix E.

Images of CDI sections for each flight line are also provided on CD.

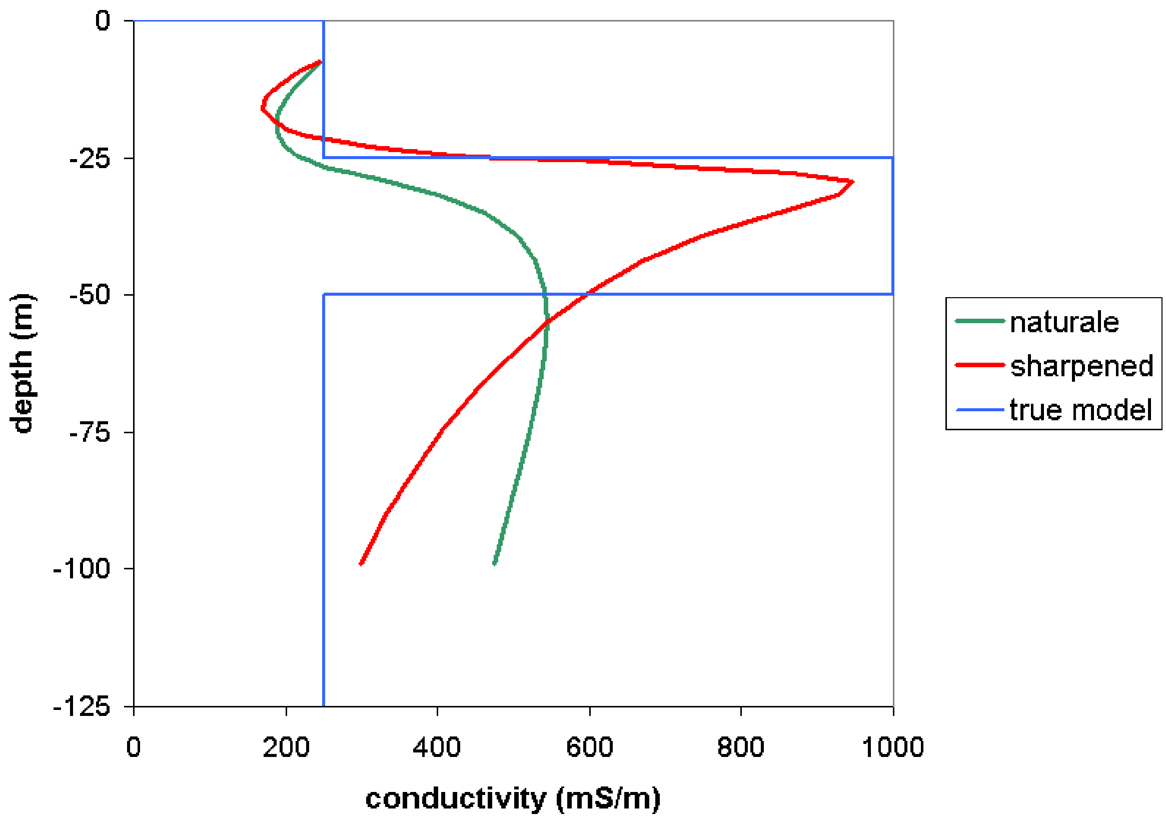

Figure 3 Comparison of original (green) and sharpened (red) conductivity-depth curves for a synthetic three-layer model (blue) (Fullagar et al., 2008)

8 GPS Positioning

Two GPS receivers were employed for the Spring Hill survey (see Section 5 above). GP1 is a standard GPS unit used as a backup receiver which could be post-processed with a base GPS unit if needed. GP2 is a real-time kinematic (RTK) unit for which differential corrections are received in real time from the Fugro Omnistar HP service.

All processed data delivered with this report uses elevations and positions from GP2. Elevation data are relative to the GRS80 ellipsoid.

9 Navigation

Navigation was done through the proprietary software SkyMap version 16 using flight lines provided to Geoforce by Western Desert Resources. Accurate frame location was obtained from the RTK Omnistar HP GPS2 unit via a radio modem feed. Height above ground of the frame was obtained from the two laser altimeters mounted on the frame via the radio modem. There was also a backup radar altimeter used in the helicopter. Through SkyMap the pilot could also monitor the frame tilt and groundspeed to ensure the best possible data was obtained.

10 Altimeters

Laser Altimeter:	LaserAce IMHR 300
Reflectorless Range:	2 – 150 m
Accuracy:	0.2 m
Resolution:	0.1 m

11 References

Fullagar, P.K., and Reid, J.E., 2001, EMax conductivity-depth transformation of airborne TEM data: Expanded Abstracts, Australian Society of Exploration Geophysicists 15th Conference, Brisbane.

Fullagar, P. K., Reid, J. E., and Pears, G., 2008, Advances in EMaxAir conductivity-depth imaging of airborne TEM data: Conference presentation, 5th international conference on airborne electromagnetics, Haikko Manor, Finland, 28-30 May 2008.

Appendix A Survey Specifications

A.1 Groundspeed

The mean survey groundspeed for the survey was 74.7km/h. Average values were calculated for each line: these ranged from 47.8km/h to 96.1km/h.

A.2 Terrain clearance

The mean terrain clearance for the survey was 41.1m. Average altitudes for each survey line ranged from 29m to 52m.

A full report of line statistics is attached (SK850WD Line Statistics.xls).

Appendix B Transmitter current waveform measurements

Transmitter current waveforms were measured on the ground on 29th August 2008.

The current turn on was measured using a Fluke 80i-100s current clamp and PicoScope ADC212 digital oscilloscope.

The turnoff was measured using a custom-built pickup coil (serial number Pickup 01) and a PicoScope ADC212 digital oscilloscope. The pickup coil measures the time rate of change of current.

Current turnon and (dI/dt) turnoff data have been processed using WaveFormInv, an inversion code written by Niels Christensen of the University of Aarhus. WaveFormInv reconstructs the waveform from the I (turnon) and dI/dt (turnoff) measurements, and generates a piecewise linear approximation to the waveform.

The piecewise linear waveforms are given below and are supplied with this report in ASCII format files (*.wfn). The waveforms are normalized by peak current such that a normalized current of 1 corresponds to the peak transmitter current.

The *.wfn files contain two header lines, followed by the waveform data (two columns). The first column of the waveform data is time in seconds (time zero = start of current switch off), and the second column is normalized current.

Figure B1 shows an example of the high and low-moment waveforms measured using the Fluke current clamp.

Figure B2 shows an example of the measured high moment turn on waveform.

Figure B3 shows an example of the measured high moment turn-off ramp.

B.1 Piecewise approximation to high moment current waveform

Time zero is the start of current turnoff. Normalised current is actual current normalized by peak current.

29th August 2008

Time (sec)	*Normalised current*
-1.000e-002	0.000e+000
-8.386e-003	4.568e-001
-6.380e-003	7.526e-001
-3.783e-003	9.204e-001
0.000e+000	1.000e+000
3.960e-007	9.984e-001
7.782e-007	9.914e-001
1.212e-006	9.799e-001
3.440e-006	9.175e-001
1.981e-005	4.587e-001
3.619e-005	7.675e-003
3.664e-005	3.072e-003
3.719e-005	8.319e-004
3.798e-005	1.190e-004
3.997e-005	0.000e+000

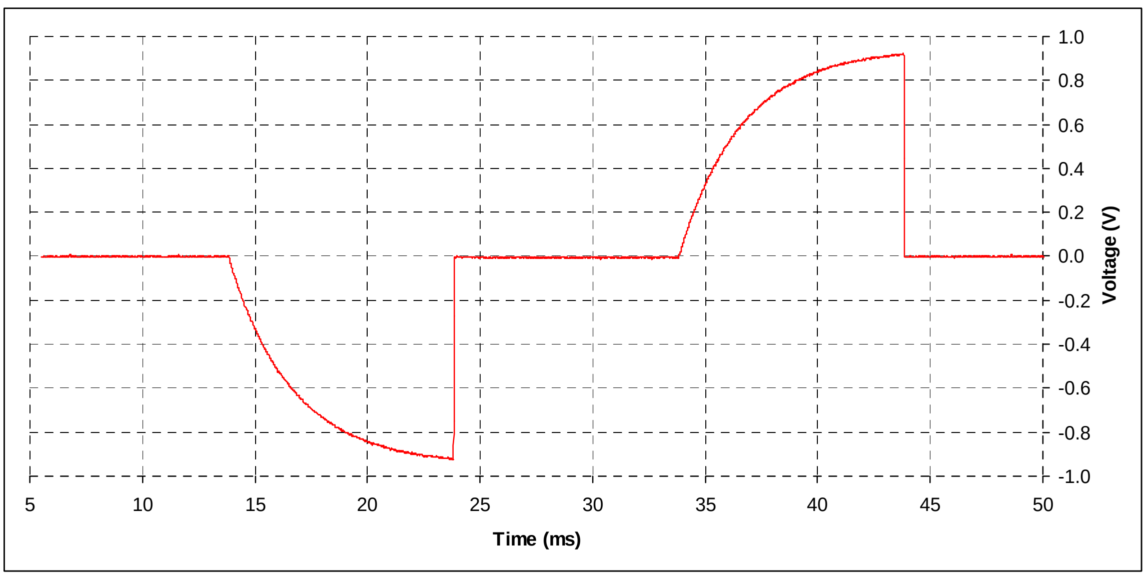

Figure B1: High moment current waveform measured on 29th August 2008. Horizontal axis is time in ms. Vertical axis shows voltage measured using a current clamp (1 V = 100 A).

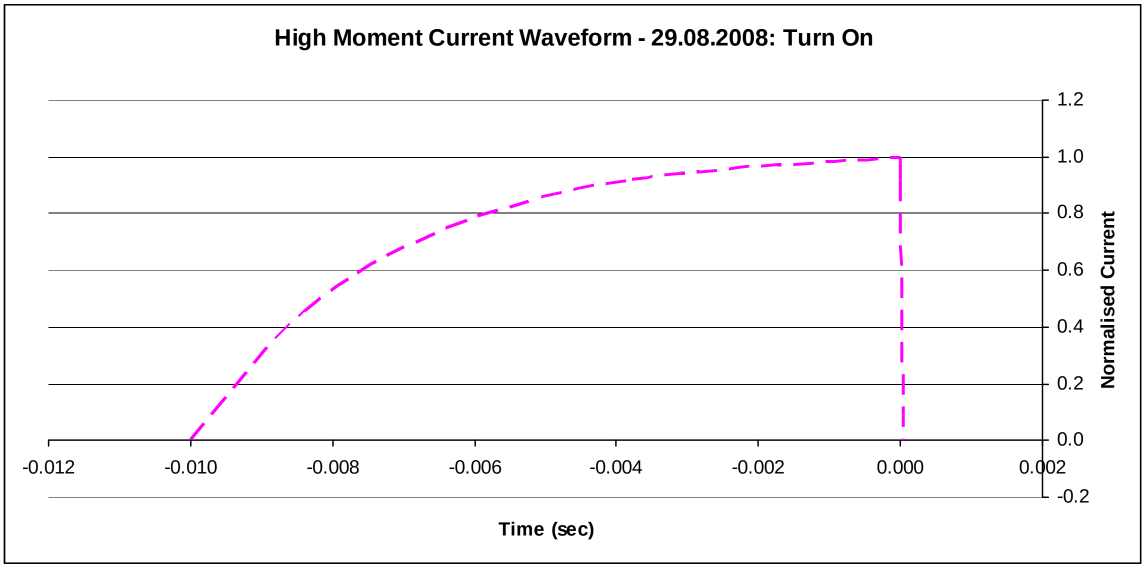

Figure B2: Piecewise approximations to high moment current turn-on measured on 29th August 2008.

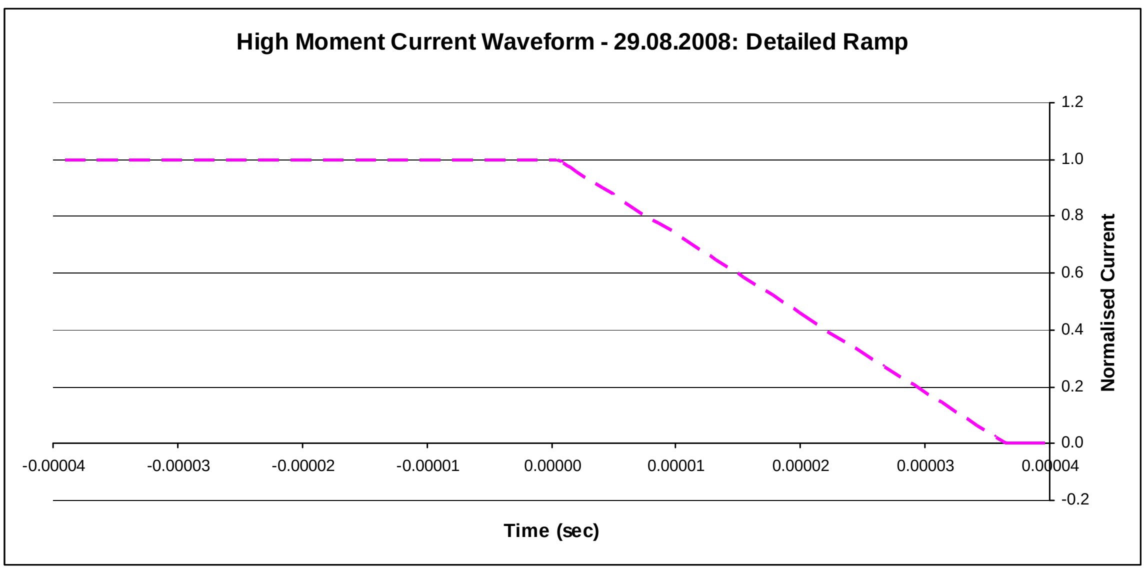

Figure B3: Piecewise approximations to high moment current turn-off measured on 29th August 2008.

Appendix C High altitude test

High altitude tests were conducted at the start and end of the survey.

Plots of the mean and standard deviation of the response at each channel are provided in Excel spreadsheets supplied with this report. All flights conducted met Geoforce quality control standards.

Plots of the mean channel amplitudes in the Excel spreadsheets show a nominal noise level for the high and low-moment data as an orange dashed line. This nominal noise corresponds to10 nV/m^2 (voltage normalized by receiver area) at a delay time of 1 ms, which is a typical expected noise level for the SkyTEM system. When converted to survey EM units of V/(A.turns.m^4) this noise level becomes 7.96e-13 V/(A.turns.m^4) for low-moment data and 8.38e-14 V/(A.turns.m^4) for high-moment data.

Note that laser altimeter data is null for all high altitude tests as the maximum range of the altimeters employed was 300 m.

Appendix D Header for field-processed high moment SkyTEM data

Column	Field	Start column	End column	Format	Null value	Description	Units	Sign convention
Column 1	Fid	1	7	I6	999999	Fiducial	n/a	
Column 2	Line	8	16	I8	99999	Line Number	n/a	
Column 3	Flight	17	27	F10.1	99999999.9	Flight number	n/a	
Column 4	DateTime	28	44	F16.10	99999.9999999999	Decimal days since midnight, December 31st, 1899	days	Greenwich mean time
Column 5	Date	45	54	I9	99999999	Date (yyyymmdd) - GMT	n/a	Greenwich mean time
Column 6	Time	55	65	F10.3	999999.999	Time (hhmmss.000) - GMT	n/a	Greenwich mean time
Column 7	TiltX	66	73	F7.3	999.999	Tilt of frame from horizontal in flight direction	degrees	Nose up +ve
Column 8	TiltY	74	81	F7.3	999.999	Tilt of frame from horizontal perpendicular to flight direction	degrees	Starboard side up +ve
Column 9	LasAlt	82	89	F7.1	99999.9	Laser altitude of Tx loop centre (average of lasers 1 and 2)	metres	
Column 10	DEM	90	97	F7.1	99999.9	Digital terrain model: (GRS80 Ellipsoid)	metres	
Column 11	CURR	98	104	F6.2	999.99	Peak transmitter current	Amperes	
Column 12	NORTH	105	114	F9.1	9999999.9	Northing (MGA52/GDA94)	metres	
Column 13	EAST	115	123	F8.1	999999.9	Easting (MGA52/GDA94)	metres	
Column 14	GPSALT	124	130	F6.1	999.9	GPS Elevation of Tx loop centre: (GRS80 Ellipsoid)	metres	

Column 15	GDSPD	131	136	F5.1	999.9	Ground speed	km/hr	
Column 16	Z1	137	150	E13.5	1.00000E+33	Normalised voltage Z-component Channel 1	V/(A.turns.m^4)	Z positive up; X positive opposite to flight direction
Column 17	Z2	151	164	E13.5	1.00000E+33	Normalised voltage Z-component Channel 2	V/(A.turns.m^4)	
Column 18	Z3	165	178	E13.5	1.00000E+33	Normalised voltage Z-component Channel 3	V/(A.turns.m^4)	
Column 19	Z4	179	192	E13.5	1.00000E+33	Normalised voltage Z-component Channel 4	V/(A.turns.m^4)	
Column 20	Z5	193	206	E13.5	1.00000E+33	Normalised voltage Z-component Channel 5	V/(A.turns.m^4)	
Column 21	Z6	207	220	E13.5	1.00000E+33	Normalised voltage Z-component Channel 6	V/(A.turns.m^4)	
Column 22	Z7	221	234	E13.5	1.00000E+33	Normalised voltage Z-component Channel 7	V/(A.turns.m^4)	
Column 23	Z8	235	248	E13.5	1.00000E+33	Normalised voltage Z-component Channel 8	V/(A.turns.m^4)	
Column 24	Z9	249	262	E13.5	1.00000E+33	Normalised voltage Z-component Channel 9	V/(A.turns.m^4)	
Column 25	Z10	263	276	E13.5	1.00000E+33	Normalised voltage Z-component Channel 10	V/(A.turns.m^4)	
Column 26	Z11	277	290	E13.5	1.00000E+33	Normalised voltage Z-component Channel 11	V/(A.turns.m^4)	
Column 27	Z12	291	304	E13.5	1.00000E+33	Normalised voltage Z-component Channel 12	V/(A.turns.m^4)	
Column 28	Z13	305	318	E13.5	1.00000E+33	Normalised voltage Z-component Channel 13	V/(A.turns.m^4)	
Column 29	Z14	319	332	E13.5	1.00000E+33	Normalised voltage Z-component Channel	V/(A.turns.m^4)	

						14	
Column 30	Z15	333	346	E13.5	1.00000E+33	Normalised voltage Z-component Channel 15	V/(A.turns.m^{4})
Column 31	Z16	347	360	E13.5	1.00000E+33	Normalised voltage Z-component Channel 16	V/(A.turns.m^{4})
Column 32	Z17	361	374	E13.5	1.00000E+33	Normalised voltage Z-component Channel 17	V/(A.turns.m^{4})
Column 33	Z18	375	388	E13.5	1.00000E+33	Normalised voltage Z-component Channel 18	V/(A.turns.m^{4})
Column 34	Z19	389	402	E13.5	1.00000E+33	Normalised voltage Z-component Channel 19	V/(A.turns.m^{4})
Column 35	Z20	403	416	E13.5	1.00000E+33	Normalised voltage Z-component Channel 20	V/(A.turns.m^{4})
Column 36	Z21	417	430	E13.5	1.00000E+33	Normalised voltage Z-component Channel 21	V/(A.turns.m^{4})
Column 37	Z22	431	444	E13.5	1.00000E+33	Normalised voltage Z-component Channel 22	V/(A.turns.m^{4})
Column 38	Z23	445	458	E13.5	1.00000E+33	Normalised voltage Z-component Channel 23	V/(A.turns.m^{4})
Column 39	Z24	459	472	E13.5	1.00000E+33	Normalised voltage Z-component Channel 24	V/(A.turns.m^{4})
Column 40	Z25	473	486	E13.5	1.00000E+33	Normalised voltage Z-component Channel 25	V/(A.turns.m^{4})
Column 41	Z26	487	500	E13.5	1.00000E+33	Normalised voltage Z-component Channel 26	V/(A.turns.m^{4})

Column 42	Z27	501	514	E13.5	1.00000E+33	Normalised voltage Z-component Channel 27	V/(A.turns.m^4)
Column 43	Z28	515	528	E13.5	1.00000E+33	Normalised voltage Z-component Channel 28	V/(A.turns.m^4)
Column 44	Z29	529	542	E13.5	1.00000E+33	Normalised voltage Z-component Channel 29	V/(A.turns.m^4)
Column 45	Z30	543	556	E13.5	1.00000E+33	Normalised voltage Z-component Channel 30	V/(A.turns.m^4)
Column 46	Z31	557	570	E13.5	1.00000E+33	Normalised voltage Z-component Channel 31	V/(A.turns.m^4)
Column 47	Z32	571	584	E13.5	1.00000E+33	Normalised voltage Z-component Channel 32	V/(A.turns.m^4)
Column 48	X1	585	598	E13.5	1.00000E+33	Normalised voltage X-component Channel 1	V/(A.turns.m^4)
Column 49	X2	599	612	E13.5	1.00000E+33	Normalised voltage X-component Channel 2	V/(A.turns.m^4)
Column 50	X3	613	626	E13.5	1.00000E+33	Normalised voltage X-component Channel 3	V/(A.turns.m^4)
Column 51	X4	627	640	E13.5	1.00000E+33	Normalised voltage X-component Channel 4	V/(A.turns.m^4)
Column 52	X5	641	654	E13.5	1.00000E+33	Normalised voltage X-component Channel 5	V/(A.turns.m^4)
Column 53	X6	655	668	E13.5	1.00000E+33	Normalised voltage X-component Channel 6	V/(A.turns.m^4)
Column 54	X7	669	682	E13.5	1.00000E+33	Normalised voltage X-component Channel 7	V/(A.turns.m^4)
Column 55	X8	683	696	E13.5	1.00000E+33	Normalised voltage X-component Channel 8	V/(A.turns.m^4)
Column 56	X9	697	710	E13.5	1.00000E+33	Normalised voltage X-component Channel 9	V/(A.turns.m^4)
Column 57	X10	711	724	E13.5	1.00000E+33	Normalised voltage X-	V/(A.turns.m^4)

						component Channel 10	
Column 58	X11	725	738	E13.5	1.00000E+33	Normalised voltage X-component Channel 11	V/(A.turns.m^4)
Column 59	X12	739	752	E13.5	1.00000E+33	Normalised voltage X-component Channel 12	V/(A.turns.m^4)
Column 60	X13	753	766	E13.5	1.00000E+33	Normalised voltage X-component Channel 13	V/(A.turns.m^4)
Column 61	X14	767	780	E13.5	1.00000E+33	Normalised voltage X-component Channel 14	V/(A.turns.m^4)
Column 62	X15	781	794	E13.5	1.00000E+33	Normalised voltage X-component Channel 15	V/(A.turns.m^4)
Column 63	X16	795	808	E13.5	1.00000E+33	Normalised voltage X-component Channel 16	V/(A.turns.m^4)
Column 64	X17	809	822	E13.5	1.00000E+33	Normalised voltage X-component Channel 17	V/(A.turns.m^4)
Column 65	X18	823	836	E13.5	1.00000E+33	Normalised voltage X-component Channel 18	V/(A.turns.m^4)
Column 66	X19	837	850	E13.5	1.00000E+33	Normalised voltage X-component Channel 19	V/(A.turns.m^4)
Column 67	X20	851	864	E13.5	1.00000E+33	Normalised voltage X-component Channel 20	V/(A.turns.m^4)
Column 68	X21	865	878	E13.5	1.00000E+33	Normalised voltage X-component Channel 21	V/(A.turns.m^4)
Column 69	X22	879	892	E13.5	1.00000E+33	Normalised voltage X-component Channel	V/(A.turns.m^4)

						22	
Column 70	X23	893	906	E13.5	1.00000E+33	Normalised voltage X-component Channel 23	V/(A.turns.m^4)
Column 71	X24	907	920	E13.5	1.00000E+33	Normalised voltage X-component Channel 24	V/(A.turns.m^4)
Column 72	X25	921	934	E13.5	1.00000E+33	Normalised voltage X-component Channel 25	V/(A.turns.m^4)
Column 73	X26	935	948	E13.5	1.00000E+33	Normalised voltage X-component Channel 26	V/(A.turns.m^4)
Column 74	X27	949	962	E13.5	1.00000E+33	Normalised voltage X-component Channel 27	V/(A.turns.m^4)
Column 75	X28	963	976	E13.5	1.00000E+33	Normalised voltage X-component Channel 28	V/(A.turns.m^4)
Column 76	X29	977	990	E13.5	1.00000E+33	Normalised voltage X-component Channel 29	V/(A.turns.m^4)
Column 77	X30	991	1004	E13.5	1.00000E+33	Normalised voltage X-component Channel 30	V/(A.turns.m^4)
Column 78	X31	1005	1018	E13.5	1.00000E+33	Normalised voltage X-component Channel 31	V/(A.turns.m^4)
Column 79	X32	1019	1032	E13.5	1.00000E+33	Normalised voltage X-component Channel 32	V/(A.turns.m^4)

Appendix E Header for CDI data

Column	Field	Start column	End column	Format	Null value	Description	Units	Sign convention
Column 1	Line	4	10	I7	9999999	Line Number	n/a	
Column 2	Easting	12	20	F9.2	999999.99	Easting (MGA52/GDA94)	metres	
Column 3	Northing	22	31	F10.2	9999999.99	Northing (MGA52/GDA94)	metres	
Column 4	Dist	34	41	F8.2	99999.99	Distance along line	metres	
Column 5	Depth	45	51	F7.2	9999.99	Depth	n/a	-ve below surface
Column 6	Cond	54	62	F9.4	9999.9999	Sharpened conductivity	mS/m	
Column 7	Elev	66	72	F7.2	9999.99	Elevation corresponding to depth in Column 5 (GRS80 Ellipsoid)	metres	
Column 8	Time	76	82	F7.2	9999.99	Delay time	µs	Start of ramp
Column 9	Alt	87	92	F6.2	999.99	Laser Altimeter	metres	
Column 10	TxElev	96	102	F7.2	9999.99	GPS Elevation of Tx loop centre: (GRS80 Ellipsoid)	metres	
Column 11	DEM	106	112	F7.2	9999.99	Digital elevation model (GRS80 Ellipsoid)	metres	

Appendix F Header for conductivity-depth slice data

Column	Field	Start column	End column	Format	Null value	Description	Units
Column 1	Line	3	9	I7	9999999	Line Number	n/a
Column 2	Easting	12	19	F8.1	999999.9	Easting (MGA52/GDA94)	metres
Column 3	Northing	23	31	F9.1	9999999.9	Northing (MGA52/GDA94)	metres
Column 4	Av0_5	34	45	E12.6	0.999990e+05	Average conductivity in depth slice 0 to 5 m below surface	mS/m
Column 5	Av5_10	48	59	E12.6	0.999990e+05	Average conductivity in depth slice 5 to 10 m below surface	mS/m
Column 6	Av10_15	62	73	E12.6	0.999990e+05	Average conductivity in depth slice 10 to 15 m below surface	mS/m
Column 7	Av15_20	76	87	E12.6	0.999990e+05	Average conductivity in depth slice 15 to 20 m below surface	mS/m
Column 8	Av20_30	90	101	E12.6	0.999990e+05	Average conductivity in depth slice 20 to 30 m below surface	mS/m
Column 9	Av30_40	104	115	E12.6	0.999990e+05	Average conductivity in depth slice 30 to 40 m below surface	mS/m
Column 10	Av40_60	118	129	E12.6	0.999990e+05	Average conductivity in depth slice 40 to 60 m below surface	mS/m
Column 11	Av60_100	132	143	E12.6	0.999990e+05	Average conductivity in depth slice 60 to 100 m below surface	mS/m

Column 12	Av100_150	146	157	E12.6	0.999990e+05	Average conductivity in depth slice 100 to 150 m below surface	mS/m
Column 13	Av150_200	160	171	E12.6	0.999990e+05	Average conductivity in depth slice 150 to 200 m below surface	mS/m
Column 14	Av200plus	174	185	E12.6	0.999990e+05	Average conductivity in depth slice > 200m below surface	mS/m

Appendix G Deliverables on CD

The following folders of data are included with this report on the provided CD. Each directory has a text file description explaining the data format of the raw files inside.

Folder Name	Data Description	File types
Current Waveform	transmitter loop current waveform check raw data	ascii
DEM_grids	gridded Digital elevation data	ers
Headers	explanation of processed EM data file structure	xls
High_altitude_tests	excel spreadsheets of high altitude em data	xls
Linefiles	start and end co-ordinates and times for flight lines	ascii
Located data	header explanation and xyz data files for processed survey data	ascii & xls
Logistics Report	Summary of field crew activity for survey	pdf
Raw Data	Raw data from SkyTEM system	ascii & binary
CDI	Apparent Conductivity Depth Profiles	Ascii & png
Images	JPEG images of EM & DEM	JPEG