SPECTREM AIR LIMITED

CSIRO EARTH SCIENCE AND RESOURCE ENGINEERING (CESRE)

SPECTREM SURVEY
OF THE CSIRO – BRYAH BASIN AREA

October 2012

KEYWORDS

BRYAH BASIN SURVEY, AUSTRALIA, CSIRO EARTH SCIENCE and RESOURCE ENGINEERING (CESRE), SPECTREM, Airborne, Electromagnetic, Magnetic, Radiometric

SUMMARY

SPECTREM AIR LIMITED surveys were flown for the CSIRO over the Bryah Basin area. The main purpose of the surveys was mainly to stimulate mineral exploration by mapping the very conductive carbonaceous/graphitic/BIFS/iron rich sediments which are present under the regolith or at depth in this area. Another purpose was to better understand regional water resources.

Because of the very conductive and relatively thick sediments that were present in parts of the survey area, the SPECTREM data had to be re-processed by fitting a sum of exponentials to the full waveform data.

The surveys indicated that the CSIRO would be able to gain a better understanding of the subsurface structure of the very conductive sediments by a 1D or 2D inversion of the exponentially re-processed data.

CONTRIBUTORS

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Peter Leggatt

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CIRCULATION LIST

Copies of this report have been sent to:

- Yusen Ley – Research Scientist – CSIRO Earth Science and Resource Engineering, Australia
- SPECTREM's Archive

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LIST OF FIGURES

INTRODUCTION

Between the 24th-27th June 2012, SPECTREM Air Limited conducted an airborne electromagnetic, magnetic and radiometric survey over the Bryah Basin area of Australia for CSIRO Earth Science and Resource Engineering (CESRE).

The general location of the survey is shown in Figure 1.

Details of the survey can be found in Appendix 1. The system specifications are presented in Appendix 2 and the standard SPECTREM Air data processing stream is described in Appendix 3.

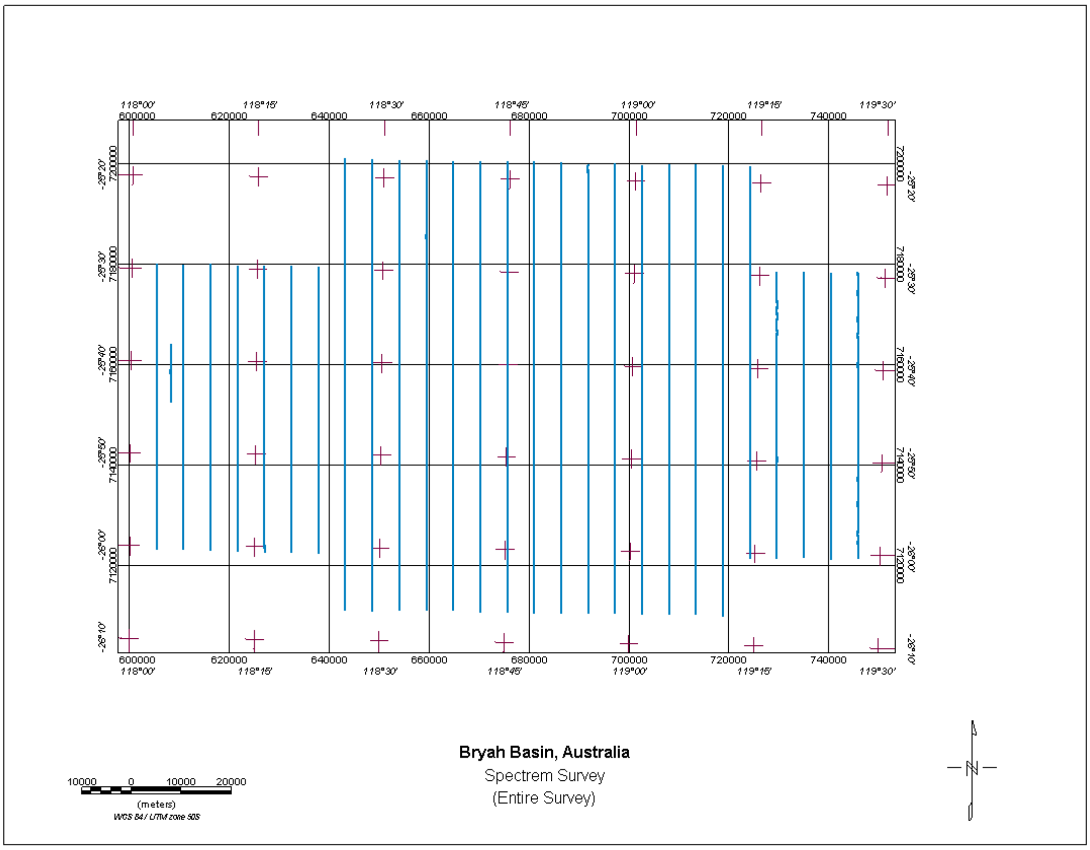


Figure 1 - Survey Location Block

In the following, a map of the total magnetic field (Figure 2) and of the conductivity Tau Z, (Figure 3) is shown on pages 7 and 8 respectively.

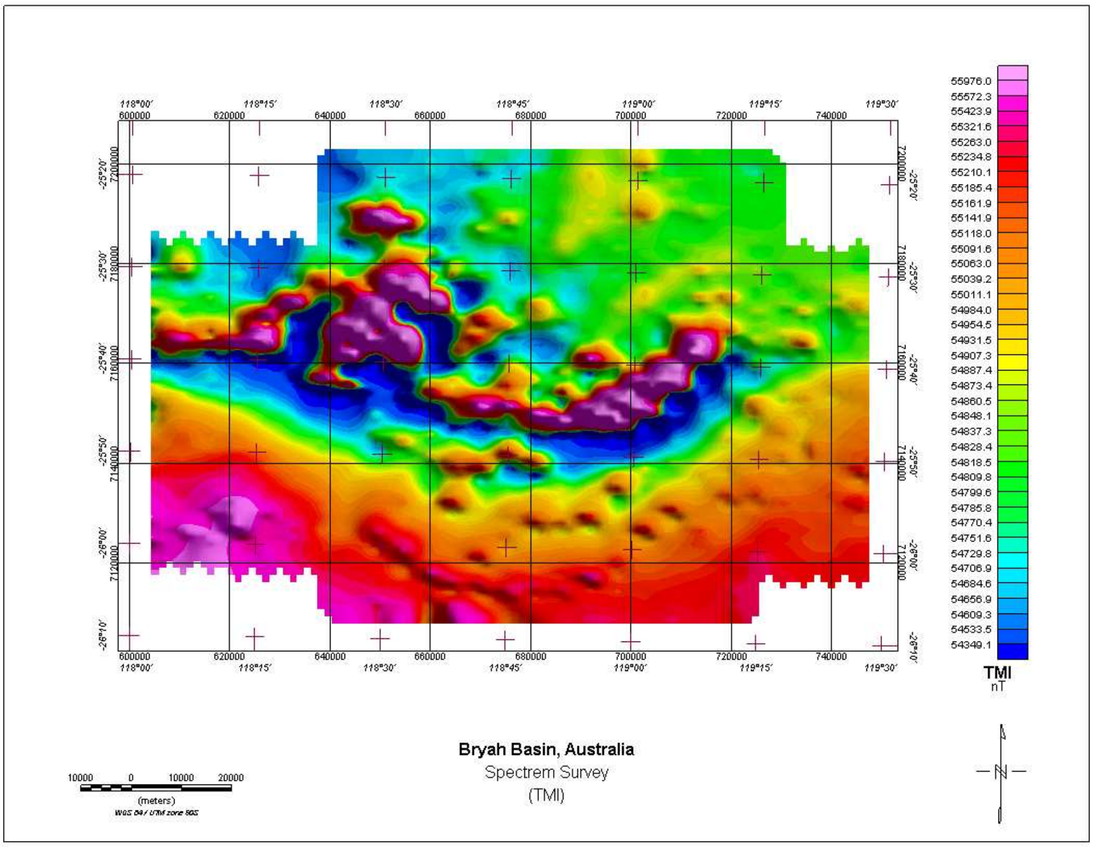


Figure 2 - Image of the Total Field Magnetic Intensity

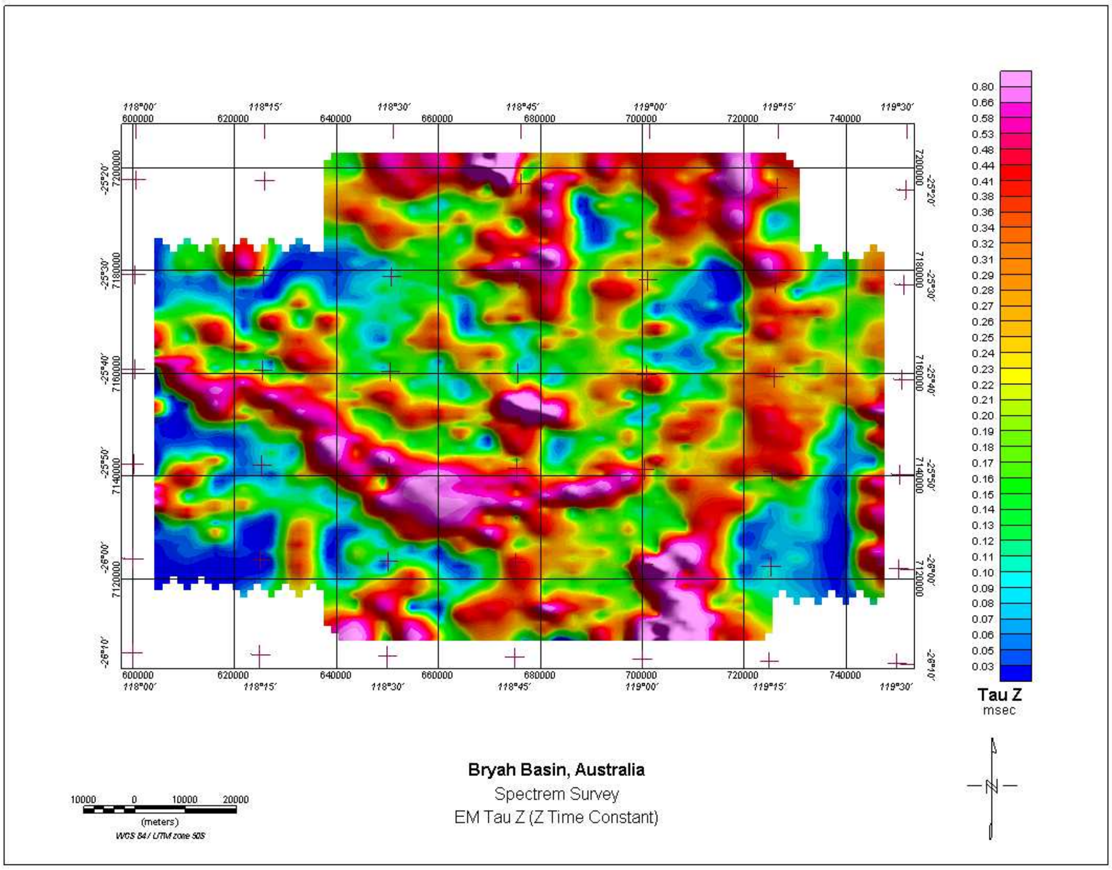


Figure 3 - Image of the EM Tau Z (Z Time Constant)

2 AEM INTERPRETATION OF THE BRYAH BASIN AREA

Conductivity-depth images (CDI's) were generated for all the flight-lines in the Bryah Basin area. An in-house CDI program written by Peter Leggatt (Appendix A) was used to generate the CDI's and to interpret the regolith-thickness. This program draws a line on the CDI's when the conductivity falls below a predetermined value. This line can be manually edited in places where the program does not estimate the regolith-thickness correctly. Where the regolith was thin and/or resistive, this line usually required editing.

Note that the interpreted regolith-thickness would include mainly weathered or fractured rock and transported cover. In the cases where conductive sedimentary members were present from the surface the interpreted regolith-thickness would include these as well.

On most of the Bryah Basin flight lines relatively thick and very conductive horizontal or dipping sedimentary members were present at moderate to deep depths below the surface. These are probably carbonaceous or graphitic sediments very closely associated with the BIFS or iron rich sediments present in this area. Some of the BIFS or iron rich sediments could of course be conductive as well. We therefore did not include these deeper and very conductive carbonaceous or BIFS/ iron rich sediments in the interpreted regolith-thickness.

A regolith-thickness map was then made from these edited lines on the CDI's. This map together with the CDI's would be very useful for interpretation purposes and for assessment of ground water resources.

Another set of CDI's were generated using the EM Flow program. Comparison of the in-house CDI's and the EM Flow CDI's show fair agreement.

The 1D inversion programs run by the CSIRO appear to give better results than our in-house CDI's and the EM Flow CDI's. It is therefore recommended that they rather be used for interpretation purposes.

Because of the very conductive and relatively thick sedimentary members that were present in many areas of the Bryah Basin region it was clear that in these areas the standard SPECTREM processing does not properly separate the secondary signal from the ground from the primary transmitted signal of the aircraft. Peter Leggatt therefore re-processed the data by fitting a Sum of Exponentials to the full decay waveform as described herewith: (Note that all SPECTREM data is measured in the On Time.)

Appendix A

The standard processing of the 10 channel single digitiser rate 25 Hz data is to assume the secondary signal due to the rapid switch of the transmitter from positive to negative has entirely decayed away by the middle of the tenth window (16.6536 milliseconds). While this is normally true, it is not so for parts of the very conductive CSIRO-Integra areas.

The problem was (partly) corrected by fitting the following function to the full decay waveform:

$Y = A + Be^{-t/dl} + Ce^{-t/d2}$

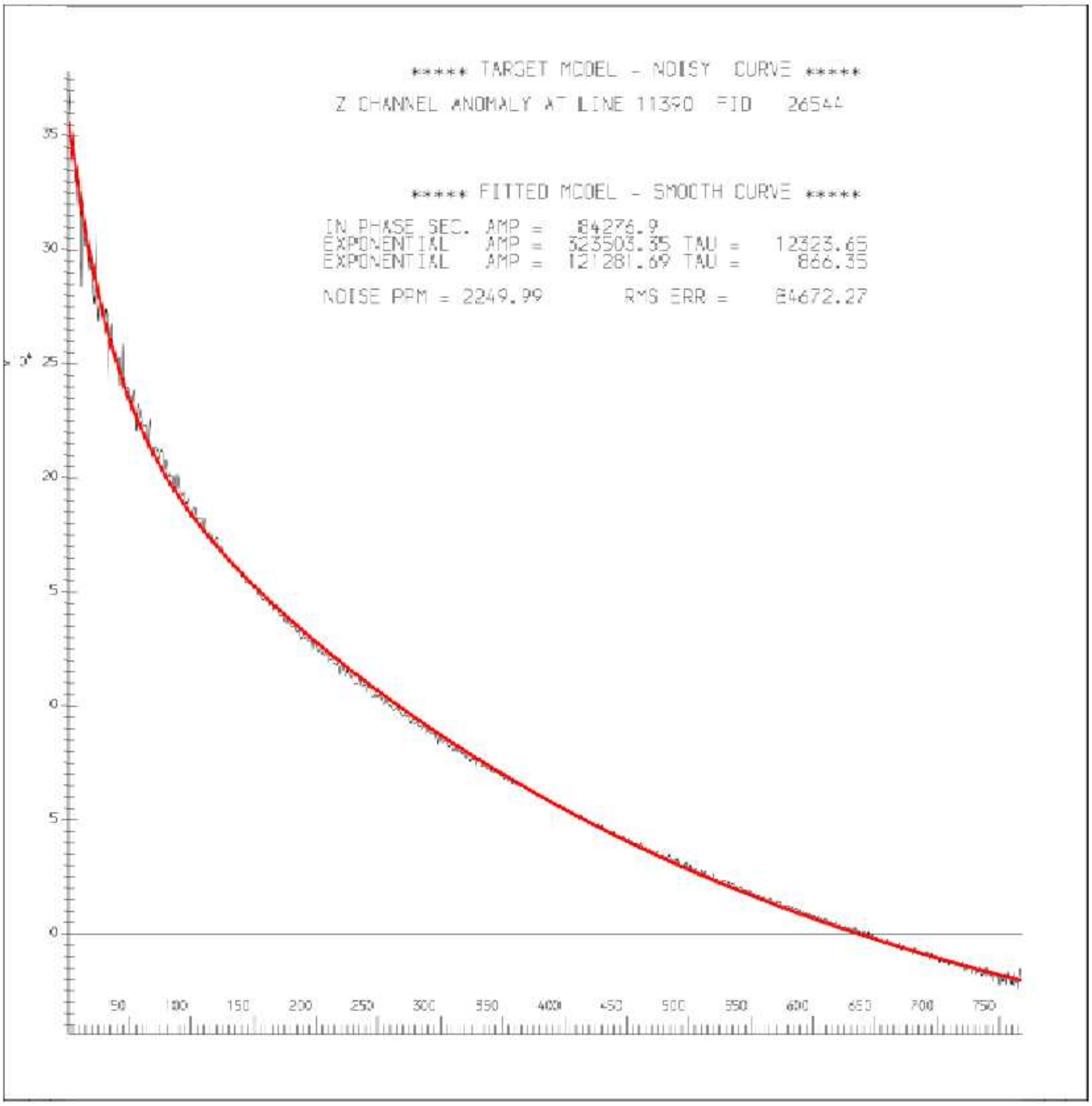
Y is the amplitude of the decay curve at delay time t.

A, B, C and the two decay constants d1 and d2 being the parameters computed by the fitting program.

The principle value obtained from the program is the parameter A which is the portion of the secondary signal erroneously disregarded by the standard processing. The correction to the original data is then to add the value A to the 10 secondary windows (including window 10 which was originally zero) thus adding an extra secondary channel. The value A is then also subtracted from the original estimate of the primary signal.

Some of these ‘corrections’ were larger than 87000 PPM (see fitted X channel decay curve below and note the good fit to the model). A further product of the fit is the two decay constants d1 and d2 of which the larger is saved in the output. Time constant values as high as 14 milliseconds were obtained for this exponentially re-processed data.

One problem with the exponential decay fitting of the data occurs when the transmitter height is too low over extremely conductive surface layers. The calculated Z channel amplitudes at the earliest delay times can then be smaller than those at slightly later delay times. The software is currently being modified by Peter Leggatt in order to correct the exponentially re-processed Z channel data for these cases.



From the X and Z channel profile data all the good conductors in the survey area were picked and parameterized using a 300 x 300m dipping plate model. Because nearly all the good conductors were relatively thick sedimentary members, the plate model was not a good model to use for quick interpretation purposes. However it does give representative conductivity-thickness products (conductance) and reasonably good conductor dips and depth estimates. The dips and depth estimates should be particularly useful for interpreting the subsurface structure of the conductive sediments.

The Bryah Basin area is probably a favourable area to explore for iron ore deposits. We do not know enough about the geology in this area to understand what the association could be between the very good sedimentary conductors and possible iron ore deposits. For this reason we graded the good conductors on the AEM anomaly map mainly in terms of the interpreted conductance values.

The CDI's were examined carefully at all the good conductor locations in order to confirm the local structure of the good conductors and ensure that the conductor parameters interpreted from the profile data were representative. If required from the CDI's, a map can very easily be generated of the depth to the top of all the good sedimentary conductors in this Bryah Basin area.

Many of the sedimentary conductors had dips steeper than 30 degrees. For the thicker conductors with dips steeper than 30 degrees, 2D or 2.5D Modeling or Inversion programs should rather be used for more detailed interpretation.

Appendix 1: Survey Details

2.1 Logistics

The specific details of the survey were as follows:

Base of operations	Kalgoorlie (Western Australia)
Flying Dates	24^{th}-27^{th} June 2012
Survey type	Electromagnetic, magnetic, radiometric, terrain
Aircraft type	DC3 – TP67
EM Base Frequency	25 Hz
Nominal aircraft altitude	90 m
Nominal aircraft speed	60 m/s
Acceptable Kilometres flown:	2025 Line kilometres
Nominal flight-line spacing	5500 m
Nominal flight-line direction:	0 degrees
Nominal tie-line spacing	n/a
Nominal tie-line direction:	n/a

2.2 Production Report

A copy of the production report is enclosed:

CSIRO-Bryah Basin - Production Report.xls

2.3 Datum

All coordinates provided in this report, in maps and in processed digital data-sets have the following datum parameters.

Datum	WGS 84
Projection	UTM Zone 50S

2.4 Survey Area Coordinates

The corner coordinates of the survey areas were:

Bryah Basin coordinates	Easting (m)	Northing (m)
(entire area)		
	598979	7104730
	751148	7104730
	751148	7207614
	598979	7207614
	598979	7104730

3 APPENDIX 2: SYSTEM SPECIFICATIONS

SPECTREM simultaneously takes electromagnetic, total field magnetic and radiometric measurements. Both the electromagnetic and magnetic sensors are towed behind the aircraft in "birds" while the radiometric crystals are installed inside the cabin. The geometry of the system and other system specifications are listed below.

3.1 EM system

Transmitter height above ground	91 m
Tx – Rx vertical separation	41 m (nominal value)
Tx – Rx horizontal separation	121 m (nominal value)
Transmitter coil axis	Vertical
Receiver coil axes	X : horizontal, parallel to flight direction; Z: vertical
Current waveform	Square wave
Base frequencies	25 Hz
Transmitter loop area	420 m^2
RMS current	960 amperes
RMS dipole moment	400 000 $A.m^2$
Digitising rate @ 25Hz	38 400 Hz / component
Recording Rate	5 Hz
Number of windows	9 per component
Window distribution	Pseudo-binary

Window Times 25Hz

Window Number	**Window Start (ms)**	**Window End (ms)**	**Window Centre (ms)**	**Window Width (ms)**
1	0.0260	0.0260	0.0260	0
2	0.0521	0.0781	0.0651	0.0260
3	0.1042	0.1823	0.14325	0.0781
4	0.2083	0.3906	0.29945	0.1823
5	0.4167	0.8073	0.6120	0.3906
6	0.8333	1.6406	1.23695	0.8073
7	1.6667	3.3073	2.4870	1.6406
8	3.3333	6.6406	4.98695	3.3073
9	6.6667	13.3073	9.9870	6.6406
10 (Primary Field)	13.3333	19.9740	16.6536	6.6667

3.2 Magnetic system

Bird height above ground	72 m
Bird location	19 m below and 41 m behind center of aircraft
Sensor	Scintrex CS-2 Sensor with SPECTREM Counter/Sync
Recording Rate	5 Hz
Sensitivity	0.01 nT
Resolution	0.1 nT

3.3 Positioning system

Sensor	Novatel RT-20 GPS receiver with Fugro Omnistar differential
Recording Rate	5 Hz

3.4 Other sensors

Radar Altitude	Collins with 5 Hz sampling with 0.3 m resolution
Laser Altitude	Riegl with 5 Hz sampling with 0.03 m resolution
Barometric Pressure	Rose Mount with 1 Hz sampling
Temperature (OAT)	PT-100 RTD with 1 Hz sampling
Analogue Chart Recorder	RMS GR-33

4 APPENDIX 3: DATA PROCESSING

The EM data were processed in Johannesburg using Oasis Montaj and proprietary software as per SPECTREM SOP 5.

4.1 Electromagnetic Processing

4.1.1 Aircraft Processing

Some of the most important EM data processing was carried out on the aircraft as it acquired the data. The first processing stage was stacking the data to 512 samples. The data was then deconvolved to remove system response and transformed to a square wave. A square transmitter waveform was chosen as a periodic approximation of the step response.

In the next stage of processing the data was binned into 8 channels or windows. As the SPECTREM system makes its measurement while the transmitter is switched on, it is necessary to separate the primary (transmitted) field from the (induced) secondary field. The assumption is made that the induced field will have decayed to a minimal amount at the time the last channel is sampled. As the last channel only measured the primary field, it can be subtracted from the other channels to separate the secondary field. Hence there are actually 8 channels with geological information in the final data.

4.1.2 Profile data

The spikes in the line data have been removed using a 3 point Naudy filter. The line data have also been drift corrected and micro-levelled. The drift is particularly noticeable on the later time channels and has been applied to channels 4 to 8. This is an iterative process, with the assumption that there is a constant drift on a single line. This is reasonable if the lines are short. The processing steps are:

- The channel data are clipped retaining the data in the resistive areas where the response should be close to zero.
- The average of the clipped data is then calculated and subtracted from the channel data.

The steps are then repeated, refining the correction.

Decorrugation and micro-levelling has been applied to all the channels to reduce small residual errors that have not been corrected through the drift correction method.

4.1.3 Apparent Conductivity

The apparent conductivity was calculated from its channel amplitudes and the aircraft height. An apparent conductivity is the conductivity of a half space that would produce an amplitude equivalent to the measured response. It is useful in providing a physically sensible unit and partially compensates for aircraft ground clearance variations. The unit for apparent conductivity is milliSiemens/meter.

4.1.4 Grids

The data were gridded using a Minimum Curvature. System lag was corrected before gridding.

A decorrugation filter was applied to reduce the herringbone effects created by geometrical asymmetry inherent in AEM systems

4.1.5 Magnetic Processing

The leveling processing included:

- Tie-line levelling
- Decorrugation
- Micro-levelling

4.1.6 Tie-line Levelling

Tie line levelling is used to remove the diurnal variation and errors due to instrument drift, both are assumed to vary slowly over time.

Tie-line levelling is an iterative process:

- Calculate the mis-closures at the crossover points of the tie and traverse lines. The mis-closure is the difference between the magnetic value on the tie line and the traverse line. The mis-closures are weighted by the gradient of the total field at the crossover point.

$$Weight = 1 / e^{(0.1 \times gradient)}$$

- The error is approximated by a piecewise polynomial as a function of time along a flight and then along a tie line.

These steps are repeated until a good fit has been obtained.

4.1.7 Decorrugation

This is a grid based operation designed to reduce the residual errors that the tie-line leveling does not remove. These are due to inaccuracies in the crossovers, localised diurnal activity, and local altitude variations.

Elongated anomalies with the following characteristics are removed:

- 2 times the line spacing perpendicular to the line direction
- 2 times the tie line spacing parallel to the line direction
- small dynamic range

4.1.8 Micro-levelling

Applies the corrections made to the grid to the profile data and thereby enhances the line data by removing the final residual errors. The micro-levelled data are then gridded. The lag correction is 40m.

4.2 DEM processing

Initially, the GPS height and the radar altimeter channels are visually inspected and any spikes or discontinuities are removed. A Low Pass or Naudy Filter is then applied to both channels. The GPS height channel is then gridded and the resultant grid is checked. Due to the nature of the GPS data, it is normally necessary at this stage to perform some degree of decorrugation on the grid with the corrections then written back to the database.

The radar altimeter channel is then subtracted from the corrected GPS height channel in the database and the resultant channel is gridded and verified.

4.3 Radiometric Processing

The processing of the radiometric data uses the full 256 channel spectra for most of the corrections. This processing allows us to use the information from the full spectrum to enhance the regions of interest in the spectrum, namely, potassium, uranium and thorium.

5 APPENDIX 4: DELIVERABLES

5.1 Digital Products and Maps

Grids / Profile Data

(Grids supplied in Geosoft and MapInfo format)

	Grids *(Digital)*	**Line Data**	**Maps** *(Paper)*
EM Data			
EMX1 to EMX8 / EMZ1 to EMZ8	Y	Y	-
Tau Z	Y	Y	Y
Anomaly Map	-	-	Y
Bedrock Elevation	-	-	-
Regolith Thickness	Y	Y	Y
TF Magnetic Data			
TFMI	Y	Y	Y
Terrain			
DEM	Y	Y	-
Radiometric Data			
TC, K, U, Th	Y	Y	-
CDI Data			
CDI Data - Individual Lines (selected profiles)	-	Y	-

5.2 Report

- This anomaly selection and logistics report.

5.3 EMPick Databases

- EMPick databases in MS Excel format (copy attached in section 8.1 of this report)

6 APPENDIX 5: AEM ANOMALY SELECTION

Interpretation of AEM data should follow two approaches, one using profile data for EM anomaly selection and the other using gridded data to produce images for secondary interpretation.

6.1 Electromagnetic Anomaly Selection

The EM profiles were interpreted using the EmPick software developed by SPECTREM. Anomaly selections were made on the basis of anomaly shape, decay characteristics and magnetic correlation. Interpreting profile data is important as it contains detail that is lost in the later, grid based and secondary interpretation.

Conductor Parameterisation and Classification

The EM anomaly interpreter picks and parameterises all EM anomalies of interest in a survey area using a SPECTREM proprietary software suite called EmPick. Using EmPick, the physical location of the electromagnetic conductor can be recorded, and various parameters associated with the conductor can be assigned. These parameters include an anomaly grade, the conductivity-thickness product of the conductor, its mid-time (window 4) residual X channel amplitude, its estimated depth below ground surface, its dip with respect to the nominal survey direction, and the magnitude of its associated magnetic anomaly.

The anomaly shapes recorded by the SPECTREM electromagnetic system can be classified into three types - cultural, surficial and bedrock.

Cultural conductors are man-made conductors such as fences, power-lines, buried pipes and other metal structures. These give rise to anomalies if they form closed conducting loops, either by being well grounded in a conducting environment, or due to their physical geometry. Cultural conductors can be flagged as such in EmPick in order to reduce the possibility of following these up in the field.

Surficial conductors are flat-lying conductors which occur on or just beneath the ground surface. They generate anomalies which are characteristically broad, of poor conductivity, and large in amplitude. Examples are Quaternary cover and conductive regolith.

Bedrock conductors are typically steeply-dipping narrow targets of high conductivity situated in a relatively resistive host environment. Strike length may be considerable. These conductors present an interpretative problem in selecting from a large number of bedrock anomalies those which are more likely to be due to economic base metal mineralisation. Anomalies which are seen as more favourable are given a higher grade.

EM Anomaly Grading

An anomaly grading scheme has been devised to assist in prioritising which anomalies should first be considered for ground follow-up. This grading scheme is essentially geophysical, being a cumulative assessment by the interpreter of the likelihood of a particular anomaly being a prospective sulphide target. Anomaly grade takes cognisance of such features of the anomaly as its peak shape (width and amplitude), its conductivity-thickness product (CTP) and its magnetic association.

SPECTREM EM anomalies are graded A, B, C or D, with grade A anomalies being the most favourable.

Complications of Anomaly Interpretation

In the grading process, small, discrete conductors were given a better grade than larger bodies, which were assumed to be lithological. Lithological conductors are generally formational (i.e. composed of a particular stratigraphic unit), with extended strike lengths, broader anomalies, and moderate to large electromagnetic responses. However the conclusion should not be drawn that larger conductors are definitely not mineralised. A sulphide body's response may also be masked by nearby lithological or surficial conductors.

The anomaly picking process is used to directly detect sulphide. This is not the only method through which SPECTREM should be applied. It is important to remember the geological mapping capabilities of the system, which are covered in the Data Imaging section.

Estimated Conductor Depth

Caution needs to be taken when using the depth estimates provided in the EM anomaly listings. EmPick uses as its reference model a 300m by 300m wire loop conductor, which bears little resemblance to a body of appreciably different dimensions, such as a larger sulphide. For this reason, depth estimates reported by EmPick are slightly unreliable for bodies of dimensions very much greater than 300m by 300m (reported depths are too shallow) and very much less (reported depths are too deep).

7 APPENDIX 6: SOFTWARE VERSIONS

SpecDAS acquisition	1.16
Spectrem processing - SDALOG	1.06
Spectrem processing - SDASPEC	4.01
Spectrem processing - LEVEL	1.03
Autopick	EMPICK 1.05
Geosoft	6.3 (30) HF2
CDI	1.00

8 APPENDIX 7: ANOMALY LISTING

These are the EM anomalies interpreted through EmPick. They are stored digitally in a Microsoft Excel Worksheet stored in the report directory on the CD. The columns for the anomaly listing are:

Line #	line number
Fiducial	fiducial number
Lag	lag in fiducials applied to anomaly peak position before plotting
Head	heading of line
NomH	nominal survey heading
UTM X	X coordinate
UTM Y	Y coordinate
Type	model type, C=culture, ?=possible culture, P=probable culture,
CTP	Conductivity thickness product in Siemens
X4	EMX4 residual amplitude (PP2T, parts per 2000 of primary field)
Depth	depth calculated for a 300m X 300m plate with the same response
Dip	dip of conductor (degrees)
Dip dir	dip direction of conductor
Strike	strike of conductor
Grade	EM anomaly grade, assigned by interpreter
Mag	Residual magnetic anomaly in nT

8.1 CSIRO Bryah Basin Survey Project – Anomalies List –Bryah Basin Area

Bryah_Basin_anomalies.xlsx