LOGISTICS REPORT
OF A DIGHEM^{V} SURVEY
AND A FIXED-WING MAGNETIC /
RADIOMETRIC / VLF SURVEY
FOR

AUSTRALIAN MAP SHEET

KING RIVER AREA, NT
ARNHEM LAND WEST JV

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ABSTRACT

This report describes the logistics and results of a DIGHEM^{V} airborne geophysical survey and a fixed-wing magnetic, radiometric and VLF survey carried out for over the King River Area near . Total coverage of the helicopter survey block amounted to km. The survey was flown from 1996. Total coverage of the fixed-wing portion of the survey amounted to 15 694 line kilometres and was flown from the 20th August to the 14th September 1996. A VLF test area of 83 line kilometres was flown prior to the main fixed-wing portion of the survey over an area known as Beatrice.

The purpose of the survey was to detect zones of conductive mineralisation and to provide information that could be used to map the geology, structure and radiometric character of the survey area. This was accomplished by using a DIGHEM^{V} multi-coil, multi-frequency electromagnetic system, high sensitivity Caesium magnetometers, a four channel VLF receiver and a 256 channel spectrometer. The information from these sensors was processed to produce maps which display the magnetic, radiometric and conductive properties of the survey area. A GPS electronic navigation system, utilising a UHF link, ensured accurate positioning of the geophysical data. Visual flight path recovery techniques were used to confirm the location of the helicopter where visible topographic features could be identified on the ground.

CONTENTS

1. INTRODUCTION

An airborne geophysical survey was flown for in two sections, over the King River Area, located near . A DIGHEM^V electromagnetic / magnetic survey was flown from the 1996 and a fixed-wing magnetic / radiometric / VLF survey was flown from the 20th August to the 13th September 1996. The data were later merged for presentation as final products. The survey area can be located on Australian map -sheet .

Survey coverage consisted of approximately line-km of DIGHEM^V data and 15 694 line kilometres of magnetic / radiometric / VLF data. Flight lines were flown in an azimuthal direction of 0 / 180° with a line separation of 100 metres for the DIGHEM^V survey and 200 m for the magnetic / radiometric / VLF survey. Tie lines were flown orthogonally to the traverse lines with a spacing of 2000 m for the DIGHEM^V survey and 1500 m for the magnetic / radiometric / VLF survey. A test area of VLF, named Beatrice was flown prior to the main fixed-wing portion of the survey and amounted to 83 line kilometres.

Ancillary equipment consisted of magnetometers, radar altimeters, video cameras, analogue and digital recorders and electronic navigation systems. The DIGHEM^V instrumentation was installed in an turbine helicopter (Registration) which was provided by Helicopter Resources Ltd. The helicopter flew at an average airspeed of 100 km/h with an EM bird height of approximately 30 m. The magnetic / radiometric / VLF instrumentation was installed into a Rockwell Shrike Aerocommander 500S (Registration VH - WAM). The aircraft flew at an average of 220 kilometres per hour, with a sensor height of 80 metres.

Section 2 provides details on the survey equipment, the data channels, their respective sensitivities and the navigation / flight path recovery procedure. Noise levels of less than 2 ppm are generally maintained for wind speeds up to 35 km/h. Higher winds may cause the system to be grounded because excessive bird swinging produces difficulties in flying the helicopter. The swinging results from the 5 m^2 of area which is presented by the bird to broadside gusts.

In some portions of the survey area, steep topography may have forced the pilot to exceed normal terrain clearance for reasons of safety. It is possible that some weak conductors may have escaped detection if bird height exceeded 120 m. In difficult areas where near-vertical climbs were necessary, the forward speed of the helicopter was reduced to a level which permitted excessive bird swinging. This problem, combined with the severe stresses to which the bird was subjected, may give rise to aerodynamic noise levels which are slightly higher than normal. Where warranted, reflights were carried out to minimise these adverse effects.

2.a SURVEY EQUIPMENT - The DIGHEM^{V} System

This section provides a brief description of the geophysical instruments used to acquire the survey data:

2.a1 Electromagnetic System

Model: DIGHEM^{V}

Type: Towed bird, symmetric dipole configuration operated at a nominal survey altitude of 30 metres. Coil separation is 8.1 metres for 400 Hz, 900 Hz, 5500 Hz and 7200 Hz, and 6.3 metres for the 56 000 Hz coil-pair.

Coil orientations/frequencies:

Horizontal coplanar	/	400 Hz
Vertical coaxial	/	900 Hz
Vertical coaxial	/	5500 Hz
Horizontal coplanar	/	7200 Hz
Horizontal coplanar	/	56000 Hz

Channels recorded:
5 inphase channels
5 quadrature channels
2 monitor channels

Sensitivity:
0.06 ppm at 400 Hz
0.06 ppm at 900 Hz
0.10 ppm at 5500 Hz
0.10 ppm at 7200 Hz
0.30 ppm at 56 000 Hz

Sample rate: 10 per second

The electromagnetic system utilises a multi-coil coaxial / coplanar technique to energise conductors in different directions. The coaxial coils are vertical with their axes in the flight direction. The coplanar coils are horizontal. The secondary fields are sensed simultaneously by means of receiver coils which are maximum coupled to their respective transmitter coils. The system yields an inphase and a quadrature channel from each transmitter-receiver coil-pair.

2.a2 Survey Magnetometer

Type: Optically pumped Caesium vapour

Sensitivity: 0.01 nT

Sample rate: 10 per second

The magnetometer sensor is towed in a bird 20 m below the helicopter.

2.a3 Base Station Magnetometer

Model: G856

Type: Digital recording proton precession

Sensitivity: 0.1 nT

Sample rate: 1 each 5 seconds

A digital recorder is operated in conjunction with the base station magnetometer to record the diurnal variations of the earth's magnetic field. The clock of the base station is synchronised with that of the airborne system to permit subsequent removal of diurnal drift.

2.a4 Barometric Altimeter

Manufacturer: A.I.R.
Type: Digital Recording Barometric Altimeter
Sensitivity: 0.3 m

2.a5 Radar Altimeter

Manufacturer: Honeywell/Sperry

Type: AA 220

Sensitivity: 0.3 m

The radar altimeter measures the vertical distance between the helicopter and the ground. This information is used in the processing algorithm which determines conductor depth.

2.a6 Analogue Recorder

Manufacturer: RMS Instruments

Type: DGR33 dot-matrix graphics recorder

Resolution: 4 x 4 dots / mm

Speed: 1.5 mm / sec

The analogue profiles are recorded on chart paper in the aircraft during the survey. Table 2-1 lists the geophysical data channels and the vertical scale of each profile.

Table 2-1. The Analogue Profiles

Channel Name	Parameter	Scale units/mm	Designation on digital profile
1X9I	coaxial inphase (900 Hz)	2.5 ppm	CXI (900 Hz)
1X9Q	coaxial quad (900 Hz)	2.5 ppm	CXQ (900 Hz)
2P4I	coplanar inphase (400 Hz)	2.5 ppm	CPI (400 Hz)
2P4Q	coplanar quad (400 Hz)	2.5 ppm	CPQ (400 Hz)
3P7I	coplanar inphase (7200 Hz)	5 ppm	CPI (7200 Hz)
3P7Q	coplanar quad (7200 Hz)	5 ppm	CPQ (7200 Hz)
4X5I	coaxial inphase (5500 Hz)	5 ppm	CXI (5500 Hz)
4X5Q	coaxial quad (5500 Hz)	5 ppm	CXQ (5500 Hz)
5P5I	coplanar inphase(56000 Hz)	10 ppm	CPI (56 kHz)
5P5Q	coplanar quad (56000 Hz)	10 ppm	CPQ (56 kHz)
ALTR	altimeter	3 m	ALT
MAGC	magnetics, coarse	20 nT	MAG
MAGF	magnetics, fine	2.0 nT	
CXSP	coaxial spherics monitor		CXS
CPSP	coplanar spherics monitor		CPS
CXPL	coaxial powerline monitor		CXP
CPPL	coplanar powerline monitor		CPP

2.a7 Digital Data Acquisition System

Manufacturer: RMS Instruments

Model: DGR 33

Recorder: RMS TCR-12, 6400 bpi, tape cartridge recorder

The digital data are used to generate several computed parameters. Both measured and computed parameters are plotted as "multi-channel stacked profiles" during data processing. These parameters are shown in Table 2-2. The resistivities at 10, 20, 30 and 40 mm up from the bottom of the digital profile are respectively 1, 10, 100 and 1000 ohm m.

2.a8 Tracking Camera

Type: Panasonic Video

Model: AG 2400 / WVCD132

Fiducial numbers are recorded continuously and are displayed on the margin of each image. This procedure ensures accurate correlation of analogue and digital data with respect to visible features on the ground.

2.a9 Navigation System (RT-DGPS)

Model: Sercel NR106, Real-time differential positioning

Type: SPS (L1 band), 10-channel, C/A code, 1575.42 MHz.
Sensitivity: -132 dBm, 0.5 second update

Accuracy: < 5 metres in differential mode,
± 50 metres in S/A (non differential) mode

The Global Positioning System (GPS) is a line of sight, satellite navigation system which utilises time-coded signals from at least four of the twenty-four NAVSTAR satellites. In the differential mode, two GPS receivers are used. The base station unit is used as a reference which transmits real-time corrections to the mobile unit in the aircraft, via a UHF radio datalink. The on-board system calculates the flight path of the helicopter while providing real-time guidance. The raw XYZ data are recorded for both receivers, thereby permitting post-survey processing for an accuracy of approximately 5 metres.

Although the base station receiver is able to calculate its own latitude and longitude, a higher degree of accuracy can be obtained if the reference unit is established on a known benchmark or triangulation point. The GPS records data relative to the WGS84 ellipsoid, which is the basis of the revised North American Datum (NAD83). Conversion software is used to transform the WGS84 coordinates to the system displayed on the base maps.

2.a10 Field Workstation Software

Manufacturer: Dighem

Model: FWS: V2.65

Type: 80586 Pentium PC

A portable PC-based field workstation is used at the survey base to verify data quality and completeness. Flight tapes are dumped to a hard drive to permit the creation of a database. This process allows the field operators to display both the positional (flight path) and geophysical data on a screen or printer.

2.b SURVEY EQUIPMENT - Magnetic / Radiometric / VLF System

2.b1 Airborne Magnetometer

Model: GR822A Caesium vapour optical absorption magnetometer sensor mounted in
a Stinger.
Resolution: 0.001 nanoTesla
Sensitivity: 0.001 nanoTesla
Compensation: AADC
Sampling Rate: 0.1 second (nominally 7 metres)
Recording: Digital to tape and displayed on aircraft chart recorder.

2.b2 Base Station Magnetometer

Sensor: G856 Proton Precession magnetometer.

Recording:	Internal memory (backed up daily)
Sensitivity:	0.1 nanoTeslas
Sampling Rate:	6.0 seconds

The base station magnetometer was run during flying hours to monitor the diurnal field. The sensor was placed in a suitable position that minimised the effects of high magnetic gradients and man-made interference. The base station location was located approximately 300 m from the Oenpelli airport.

2.b3 Gamma-Ray Spectrometer

Model:	Exploranium GR 820 System (spectrum stabilised)
Crystal Volume:	33 litres (NaI crystals - Thallium activated)
Channels:	256 channel conversion
Sample Rate:	1.0 second (nominally 65 metres)

Windows:	Total Count:	0.41 - 2.81	MeV
	Potassium (K40):	1.37 - 1.57	MeV
	Uranium (Bi214):	1.66 - 1.86	MeV
	Thorium (T1208):	2.41 - 2.81	MeV
	Cosmic:	3.00 - 6.00	MeV

Recording: The four defined windows and one cosmic channel were displayed on the aircraft chart recorder. These data, spectrometer live time and all of the raw channels representing the gamma-ray spectrum above 0.4 MeV were recorded on digital tape.

2.b4 Altimeters

Radar Altimeter:	
Type:	Sperry AA210
Accuracy:	+/- 1.5%
Sampling Rate:	1.0 second

Barometric Altimeter:	
Type:	Rosemount 1241M4
Sensitivity:	0.66 mV per foot
Range:	0 - 15 000 feet
Sampling Rate:	1.0 second

Temperature	
Type:	Rosemount 22000 Series sensor mounted externally away from direct sunlight
Accuracy:	Temperature 0.6°C +/- 0.55

The aircraft radio altitude was recorded on digital tape as well as displayed on the aircraft chart recorder. The recorded value was the average of the altimeter output during the previous second so that the value used in terrain correction procedures is not a spot value.

2.b5 Video Tracking System

Equipment:	Panasonic WVDC132
	Lens DP.5BSNDA.1

Sony XV - M304 Monitor

The video tape is synchronised with the geophysical record by a digital fiducial display which is recorded on the video tape and displayed on the bottom left of the video screen. Times are recorded from the digital information provided by the data acquisition system. Video is recorded in VHS - PAL format.

2.b6 Positioning / Navigation Equipment - DGPS

GPS Equipment:	Ashtech Ranger XII GPS and antennae with Omnistar Satellite real-time DGPS
Recording:	Digital to tape, once per second for both systems
GPS Base Station:	Ahstech Ranger XII

2.b7 Data Acquisition System

Model:	RMS Instruments DAS - 8
Equipment:	Digital recording on DC - 300 data cartridges in an RMS Instruments TCR - 12 tape cartridge recorder

2.b8 Analogue Chart Recorder

Model: RMS GR33 Thermal Dot Matrix Printer
Chart Speed: Selectable
Chart Width: 12 inches (31 cm)
Recorded data:
- Total magnetic field (fine and coarse scales)
- Magnetic field fourth difference - noise monitor
- Radar altitude
- Barometric altitude
- Five channels of corrected radiometric data
- Fiducial

Scales: Selectable

2.b9 VLF receiver

A Herz Industries Totem 2A was used to measure the total field and quadrature component of each of two VLF stations operating in the range 15,000-30,000 Hz. The VLF stations to be received were:

Station No.1: Holt
Station No.2: Japan

It is acknowledged that VLF results may have been poor owing to weak, irregular or non-existent transmitted fields.

2.c CALIBRATION PROCEDURES

2.c1 Magnetometer System Calibrations

The following tests were conducted before the survey.

i)	Manoeuvre Test	to minimise aircraft manoeuvre noise.
ii)	Parallax Test	to determine magnetometer / camera parallax.
iii)	Heading Test	to monitor the variation in magnetometer response with variation in aircraft heading.

2.c2 Spectrometer System Calibrations

The following tests were be conducted:

i) Pre and Post Flight Source Checks: Thorium and uranium hand sample checks were run on the gamma-ray spectrometer before and after each days flying. Each hand sample was computed by the acquisition system and the data were recorded by the RMS printer. Samples were positioned in the same place relative to the crystals every day and the aircraft was parked in the same position for each check. The spectrum of each hand sample and the background spectrum was accumulated and plots of both the raw spectra and background corrected spectra were recorded by the RMS printer.

ii) Background Determination: Radiometric backgrounds to be subtracted from the spectrometer data were determined from the cosmic channel according to equations established from prior high altitude testing.

iii) Height Attenuation: Height attenuation coefficients have been previously determined for the system being used as installed in the aircraft.

iv) Resolution: System resolution was determined from a spectral plot before the commencement of the survey and at intervals of one week using a TI-208 source.

A test line was flown at survey altitude for 5 kilometres before and after each flight and the data were recorded in analogue and digital mode.

In-flight recording of temperature was carried out by the operator at regular intervals during each flight.

3. PRODUCTS AND PROCESSING TECHNIQUES

The following products are available from the survey data. Those which are not part of the survey contract may be acquired later. Most parameters can be displayed as contours, profiles or in colour.

3.1 Resistivity

The apparent resistivity in ohm m can be generated from the inphase and quadrature EM components for any of the frequencies, using a pseudo-layer halfspace model. A resistivity map portrays all the EM information for that frequency over the entire survey area. This contrasts with electromagnetic anomaly maps which provide information only over interpreted conductors. The large dynamic range makes the resistivity parameter an excellent mapping tool.

3.2 Total Field Magnetics

The aeromagnetic data are corrected for diurnal variation of the earth's magnetic field using the magnetic base station data. The clock of the base station was synchronised with that of the airborne system to permit this removal of the diurnal.

The International Geomagnetic Reference Field (IGRF) 1995 model (updated for secular variation) was removed from the levelled total field magnetics. Finally an arbitrary datum of 2000 nT was added back. This procedure ensures that the residual magnetic contours will match contours from any adjacent surveys which have been processed in a similar manner.

3.3 Multi-channel Stacked Profiles

Distance-based profiles of the digitally recorded geophysical data are generated and plotted by computer. These profiles also contain the calculated parameters which are used in the interpretation process. These are produced as working copies prior to interpretation and are presented in the final corrected form after processing and interpretation.

Table 3.1: The Multiparameter Profiles

Channel Name	Observed parameters	Scale: units/cm
Mag and alt		
cmag	coarse magnetics	100 nT
fmag	fine magnetics	10 nT
alt	bird height	50 m
Processed amplitude data		
4xsp	Atmospheric noise monitor	1000 ppm
56ki	Horizontal coplanar coil pair; 56 000 Hz inphase	100 ppm
56kq	Horizontal coplanar coil pair; 56 000 Hz quadrature	100 ppm
720i	Horizontal coplanar coil pair; 7200 Hz inphase	100 ppm
720q	Horizontal coplanar coil pair; 7200 Hz quadrature	100 ppm
550i	Vertical coaxial coil pair; 5500 Hz inphase	50 ppm
550q	Vertical coaxial coil pair; 5500 Hz quadrature	50 ppm
900i	Vertical coaxial coil pair; 900 Hz inphase	25 ppm
900q	Vertical coaxial coil pair; 900 Hz quadrature	25 ppm
400i	Horizontal coplanar coil pair; 400 Hz inphase	25 ppm
400q	Horizontal coplanar coil pair; 400 Hz quadrature	25 ppm
50Hz	50 Hz Powerline monitor	1000 ppm
Apparent Depth	**(of the calculated half-space)**	
idif	Inphase difference	50 ppm
qdif	Quadrature difference	50 ppm
56k	56 000 Hz	25 ppm
7200	7200 Hz	25 ppm
400	400 Hz	25 ppm
Apparent Resistivity	**(of the calculated halfspace)**	
56k	56 000 Hz	1 cm / decade
7200	7200 Hz	1 cm / decade
400	400 Hz	1 cm / decade

3.4 Contour and Colour Map Displays

The geophysical data are interpolated onto a regular grid using a modified Akima spline technique. The resulting grid is suitable for generating contour maps of excellent quality. The grid cell size is usually 25% of the line interval.

Colour maps are produced by interpolating the grid down to the pixel size. The parameter is then incremented with respect to specific amplitude ranges to provide colour "contour" maps. Colour maps of the total magnetic field are particularly useful in defining the lithology of the survey area.

3.5 Office Processing System

Hardware: UNIX workstation network and peripherals (SUN and DEC equipment)
Multi density 9 track tape transports
Exabyte/DAT/QIC150 tape transports
High speed printers
Calcomp AO Thermal Plotter

HP A0 Colour Designjet Plotter

Software: GEOTERREX developed GMAPS software
ERMapper image processing software
VISION PC image processing software

3.6 Survey Products

1. Preliminary Products

@ 1 : 000 scale
Residual magnetic contours (blackline on paper)
Potassium count colour image (colour image on paper)
Uranium count colour image (colour image on paper)
Thorium count colour image (colour image on paper)
Digital Terrain Model (colour image on paper)
@ 1 : 25 000 scale
Preliminary Resistivity maps, 7200 Hz and 56 000 Hz (colour images with blackline contours on paper)

2. Final Products

FULL SURVEY BLOCK:

DIGITAL PRODUCTS:

- *Gridded data*

Final residual magnetics, 1st Vertical Gradient of residual magnetic field and Reduced-To-Pole of residual magnetic field
Final Digital Terrain Model
Final levelled Total Count (cps) & K, U and Th (%,ppm, ppm respectively)

MAP PRODUCTS:
Final residual magnetics @ 1 : 50 000 (blackline contours on film and colour image on paper with blackline contours, laminated)
Final residual magnetics Reduced-To-Pole @ 1 : 50 000 (blackline contours on film and colour image on paper with blackline contours, laminated)
Final residual magnetics @ 1 : 100 000 (colour image with blackline contours on paper, laminated), 5 copies
Final residual magnetics Reduced-To-Pole @ 1 : 100 000 (colour image with blackline contours on paper, laminated), 5 copies
Final levelled Total Count (cps) & K, U and Th (%,ppm and ppm respectively) maps @ 1 : 100 000 (colour images on paper, laminated)

DIGHEM SURVEY BLOCK ONLY:

DIGITAL PRODUCTS:

- *Gridded data*

Final residual magnetics, 1st Vertical Gradient of residual magnetic field and Reduced-To-Pole residual magnetic field data
Final Digital Terrain Model
Final processed/levelled resistivity data for 5500 Hz, 7200 Hz and 56 000 Hz
Final levelled Total Count, K, U and Th (cps) and K, U and Th (%,ppm and ppm respectively)

- *Located Data*

Final residual magnetics
Final processed/levelled data for all 5 frequencies in-phase and quadrature data and calculated resistivity data for 5500 Hz, 7200 Hz and 56 000 Hz

Digital terrain data, radar altimeter data and barometric altimeter data
Final levelled Total Count, K, U and Th (cps) and K, U and Th (%,ppm and ppm respectively)
MAP PRODUCTS:
Final Flightpath @ 1 : 25 000 (blackline on film)
Final calculated resistivity data for 5500 Hz, 7200 Hz and 56 000 Hz @ 1 : 25 000 (colour images on paper with blackline contours, laminated)

FIXED-WING MAGNETIC / RADIOMETRIC / VLF SURVEY BLOCK ONLY:

DIGITAL PRODUCTS:
- *Gridded data*

Final residual magnetics, 1st Vertical Gradient of residual magnetic field and Reduced-To-Pole residual magnetic field data
Final Digital Terrain Model
Final levelled Total Count, K, U and Th (cps) and K, U and Th (%,ppm and ppm respectively)
Final VLF Total Field data
- *Located Data*

Final residual magnetics
Final Digital Terrain Model
Final levelled Total Count, K, U and Th (cps) and K, U and Th (%,ppm and ppm respectively)
Final VLF1 and VLF2 Total Field data and VLF1 quadrature, VLF2 quadrature
Atmospheric noise and 50 Hz Powerline noise monitor data, Barometric altimeter and Radar altimeter data

MAP PRODUCTS:
Final Flightpath @ 1 : 50 000 scale (blackline on film)

BEATRICE PROJECT (VLF TEST AREA):

DIGITAL PRODUCTS:
- *Gridded data*

Final residual magnetics
Final VLF Total Field data
Final levelled Total Count, K, U and Th (cps) and K, U and Th (%,ppm and ppm respectively)
- *Located Data*

Final residual magnetics
Final Digital Terrain Model
Final levelled Total Count, K, U and Th (cps)
Final VLF1 and VLF2 Total Field data, VLF1 quadrature and VLF2 quadrature
Barometric altimeter data and Radar altimeter data

MAP PRODUCTS:
Final Flightpath @ 1 : 25 000 (blackline on film)
Final residual magnetics @ 1 : 25 000 (blackline contours on film and colour image on paper with blackline contours, laminated)
Final levelled Total Count & K, U and Th (cps) maps @ 1 : 25 000 (colour images on paper, laminated)

OTHER PRODUCTS:
DIGHEM Multi-channel stacked profiles
Survey report
Analogue chart records
Flight path video cassettes
Note: Other products can be produced from existing survey data if requested.

4. SURVEY RESULTS

4.1 General

Wide bedrock conductors or flat-lying conductive units, whether from surficial or bedrock sources, may give rise to very broad anomalous responses on the EM profiles. These broad conductors, which more closely approximate a half space model, will be maximum coupled to the horizontal (coplanar) coil-pair and are most evident on the resistivity parameter. Resistivity maps, therefore, may be the most valuable maps, in areas where broad or flat-lying conductors are considered to be of importance. Contoured resistivity maps are included with this report. The data provided from these maps may be used to discriminate structural anomalies from discrete, possibly ore-carrying anomalies.

Excellent resolution and discrimination of conductors was accomplished by using a fast sampling rate of 0.1 sec.

Resistivity lows which occur near the ends of the survey lines (ie., outside the survey area), should be viewed with caution. Some of these could be due to aerodynamic noise, ie., bird bending, which is created by abnormal stresses to which the bird is subjected during the climb and turn of the aircraft between lines. Such aerodynamic noise is usually manifest on the coaxial inphase channel only, although severe stresses can affect the coplanar inphase channels as well.

4.2 Magnetics

Caesium vapour magnetometers were operated at the survey base to record diurnal variations of the earth's magnetic field. The clock of the base station was synchronised with that of the airborne systems to permit subsequent removal of diurnal drift.

The background magnetic level has been adjusted to match the International Geomagnetic Reference Field (IGRF) for the survey area. The IGRF gradient across the survey block is left intact. This procedure ensures that the magnetic contours will match contours from any adjacent surveys which have been processed in a similar manner.

The total field magnetic data have been presented as contours on the base maps using a contour interval of 2.5, 25, 250 nT. The maps show the underlying magnetic properties of the rock units underlying the survey area.

There is some evidence on the magnetic map(s) which suggests that the survey area has been subjected to deformation and/or alteration. These structural complexities are evident on the contour maps as variations in magnetic intensity, irregular patterns especially in the 5500 Hz resistivity, and as offsets or changes in strike direction. Some of the more prominent linear features are also evident on the topographic base map.

If a specific magnetic intensity can be assigned to the rock type which is believed to host the target mineralisation, it may be possible to select areas of higher priority on the basis of the total field magnetic data. This is based on the assumption that the magnetite content of the host rocks will give rise to a limited range of contour values which will permit differentiation of various lithological units.

The magnetic results, in conjunction with the other geophysical parameters can provide valuable information which can be used to effectively map the geology and structure in the survey areas.

4.3 Resistivity

Resistivity maps, which display the conductive properties of the survey area, were produced from the 7200 Hz and 56 000 Hz coplanar data and from the 5500 Hz coaxial data. The maximum resistivity values for are are 6000, 8000 and 30 000 ohm m for frequencies 5500, 7200 and 56 000 HZ respectively. These cut-offs eliminate the meaningless higher resistivities which would result from very small EM amplitudes. The minimum resistivity value is 0.000017 times the frequency. This minimum resistivity cut-off eliminates errors due to the lack of an absolute phase control for the EM data. Many resistivity lows may be related to bedrock features, rather than conductive overburden.

In areas where EM responses are evident primarily on the quadrature components, zones of poor conductivity are indicated. Where these responses are coincident with magnetic anomalies, it is possible that the inphase component amplitudes have been suppressed by the effects of magnetite. Most of these poorly-conductive magnetic features give rise to resistivity anomalies which are only slightly below background. If it is expected that poorly-conductive economic mineralisation may be associated with magnetite-rich units, most of these weakly anomalous features will be of interest. In areas where magnetite causes the inphase components to become negative, the apparent conductance and depth of EM anomalies may be unreliable.

It is often difficult to assess the relative merits of EM anomalies on the basis of resistivity. It is recommended that an attempt be made to compile a suite of geophysical "signatures" over areas of interest. A complete assessment and evaluation of the survey data should be carried out by one or more qualified professionals who have access to, and can provide a meaningful compilation of, all available geophysical, geological and geochemical data.

5. BACKGROUND INFORMATION

This section provides background information on parameters which are available from the survey data. Those which have not been supplied as survey products may be generated later from raw data on the digital archive tape.

5.1 ELECTROMAGNETICS

DIGHEM electromagnetic responses fall into two general classes, discrete and broad. The discrete class consists of sharp, well-defined anomalies from discrete conductors such as sulfide lenses and steeply dipping sheets of graphite and sulphides. The broad class consists of wide anomalies from conductors having a large horizontal surface such as flatly dipping graphite or sulfide sheets, saline water-saturated sedimentary formations, conductive overburden and rock, and geothermal zones. A vertical conductive slab with a width of 200 m would straddle these two classes.

The vertical sheet (half plane) is the most common model used for the analysis of discrete conductors. The conductive earth (half space) model is suitable for broad conductors. Resistivity contour maps result from the use of the second model. A later section entitled **Resistivity Mapping** describes the method further, including the effect of using it on anomalies caused by discrete conductors such as sulfide bodies.

5.1.1 Conductor Analysis

The conductance value is a geological parameter because it is a characteristic of the conductor alone. It generally is independent of frequency, flying height or depth of burial, apart from the averaging over a greater portion of the conductor as height increases. Small anomalies from deeply buried strong conductors are not confused with small anomalies from shallow weak conductors because the former will have larger conductance values.

Conductive overburden generally produces broad EM responses which may not be shown as anomalies on the EM maps. However, patchy conductive overburden in otherwise resistive areas can yield discrete anomalies for conducting clays which have resistivities as low as 50 ohm m. In areas where ground resistivities are below 10 ohm m, anomalies caused by weathering variations and similar causes can have any conductance grade.

The presence of sphalerite or gangue can result in ore deposits having weak to moderate conductances. As an example, the three million ton lead-zinc deposit of Restigouche Mining Corporation near Bathurst, Canada, yielded a well-defined , low grade conductor. The 10 percent by volume of sphalerite occurs as a coating around the fine grained massive pyrite, thereby inhibiting electrical conduction.

Faults, fractures and shear zones may produce anomalies which typically have low conductances. Conductive rock formations can also yield anomalies. The conductive materials in such rock formations can be salt water, weathered products such as clays, original depositional clays, and carbonaceous material.

A further interpretation can be presented on an EM map by means of line-to-line correlation of anomalies, which is based on a comparison of anomaly shapes on adjacent lines. This provides conductor axes which may define the geological structure over portions of the survey area. The absence of conductor axes in an area implies that anomalies could not be correlated from line to line with reasonable confidence.

Since discrete bodies normally are the targets of EM surveys, local base (or zero) levels are used to compute local anomaly amplitudes. This contrasts with the use of true zero levels which are used to compute true EM amplitudes. Local anomaly amplitudes are shown in the EM anomaly list and these can be used to compute the vertical sheet parameters of conductance and depth.

5.1.2 The Thickness Parameter

DIGHEM can provide an indication of the thickness of a steeply dipping conductor. The amplitude of the coplanar anomaly (eg., CPI channel on the digital profile) increases relative to the coaxial anomaly (eg., CXI) as the apparent thickness increases, ie., the thickness in the horizontal plane. (The thickness is equal to the conductor width if the conductor dips at 90 degrees and strikes at right angles to the flight line.) This report refers to a conductor as thin when the thickness is likely to be less than 3 m, and thick when in excess of 10 m. For example, in base metal exploration in steeply dipping geology, thick conductors can be high priority targets because many massive sulfide ore bodies are thick, whereas non-economic bedrock conductors are often thin. The system cannot sense the thickness when the strike of the conductor is sub-parallel to the flight line, when the conductor has a shallow dip, when the anomaly amplitudes are small, or when the resistivity of the environment is below 100 ohm m.

5.1.3 Resistivity Mapping

Areas of widespread conductivity are commonly encountered during surveys. In such areas, anomalies can be generated by decreases of only 5 m in survey altitude as well as by increases in conductivity. The typical flight record in conductive areas is characterised by inphase and quadrature channels which are continuously active. Local EM peaks reflect either increases in conductivity of the earth or decreases in survey altitude. For such conductive areas, apparent resistivity profiles and contour maps are necessary for the correct interpretation of the airborne data. The advantage of the resistivity parameter is that anomalies caused by altitude changes are virtually eliminated, so the resistivity data reflect only those anomalies caused by conductivity changes. The resistivity analysis also helps the interpreter to differentiate between conductive trends in the bedrock and those patterns typical of conductive overburden. For example, discrete conductors will generally appear as narrow lows on the contour map and broad conductors (eg., overburden) will appear as wide lows.

The resistivity profiles and the resistivity contour maps present the apparent resistivity using the so-called pseudo-layer (or buried) half space model defined by Fraser (1978)[1]. This model consists of a resistive layer overlying a conductive half space. The depth channels give the apparent depth below surface of the conductive material. The apparent depth is simply the apparent thickness of the overlying resistive layer. The apparent depth (or thickness) parameter will be positive when the upper layer is more resistive than the underlying material, in which case the apparent depth may be quite close to the true depth.

The apparent depth will be negative when the upper layer is more conductive than the underlying material, and will be zero when a homogeneous half space exists. The apparent depth parameter must be interpreted cautiously because it will contain any errors which may exist in the measured altitude of the EM bird (eg., as caused by a dense tree cover). The inputs to the resistivity algorithm are the inphase and quadrature components of the coplanar coil-pair. The outputs are the apparent resistivity of the conductive half space (the source) and the sensor-source distance. The flying height is not an input variable, and the output resistivity and sensor-source distance are independent of the flying height. The apparent depth, discussed above, is simply the sensor-source distance minus the measured altitude or

[1] Resistivity mapping with an airborne multicoil electromagnetic system: Geophysics, v. 43, p.144-172

flying height. Consequently, errors in the measured altitude will affect the apparent depth parameter but not the apparent resistivity parameter.

The apparent depth parameter is a useful indicator of simple layering in areas lacking a heavy tree cover. However, little quantitative use has been made of negative apparent depths because the absolute value of the negative depth is not a measure of the thickness of the conductive upper layer and, therefore, is not meaningful physically. Qualitatively, a negative apparent depth estimate usually shows that the EM anomaly is caused by conductive overburden. Consequently, the apparent depth channel can be of significant help in distinguishing between overburden and bedrock conductors.

The resistivity map often yields more useful information on conductivity distributions than an EM map. In comparing resistivity maps with EM maps, keep in mind the following:

(a) The resistivity map portrays the apparent value of the earth's resistivity, where resistivity = 1/conductivity.

(b) The EM map portrays anomalies in the earth's resistivity. An anomaly by definition is a change from the normal and so the EM map displays anomalous areas (i) over narrow, conductive bodies and (ii) over the boundary zone between two wide formations of differing conductivity.

The resistivity map might be likened to a total field map and EM anomaly maps to a horizontal gradient in the direction of flight[2].

5.1.4 Reduction of geologic noise

Geologic noise refers to unwanted geophysical responses. For purposes of airborne EM surveying, geologic noise refers to EM responses caused by conductive overburden and magnetic permeability. It was mentioned previously that the EM difference channels (ie., channel idif for inphase and qdif for quadrature) tend to eliminate the response of conductive overburden. This marked a unique development in airborne EM technology, as DIGHEM is the only EM system which yields channels having an exceptionally high degree of immunity to conductive overburden.

Magnetite produces a form of geological noise on the inphase channels of all EM systems. Rocks containing less than 1% magnetite can yield negative inphase anomalies caused by magnetic permeability. When magnetite is widely distributed throughout a survey area, the inphase EM channels may continuously rise and fall, reflecting variations in the magnetite percentage, flying height, and overburden thickness. This can lead to difficulties in recognising deeply buried bedrock conductors, particularly if conductive overburden also exists. However, the response of broadly distributed magnetite generally vanishes on the inphase difference channel idif. This feature can be a significant aid in the recognition of conductors which occur in rocks containing accessory magnetite.

5.1.5 EM Magnetite Mapping

The information content of DIGHEM data consists of a combination of conductive eddy current responses and magnetic permeability responses. The secondary field resulting from conductive eddy current flow is frequency-dependent and consists of both inphase and quadrature components, which are positive in sign. On the other hand, the secondary field resulting from magnetic permeability is independent of frequency and consists of only an inphase component which is negative in sign. When magnetic permeability manifests itself by decreasing the measured amount of positive inphase, its presence may

[2] The gradient analogy is only valid with regard to the identification of anomalous locations.

be difficult to recognise. However, when it manifests itself by yielding a negative inphase anomaly (eg., in the absence of eddy current flow), its presence is assured. In this latter case, the negative component can be used to estimate the percent magnetite content.

A magnetite mapping technique was developed for the coplanar coil-pair of DIGHEM. The technique yields a channel which displays apparent weight percent magnetite according to a homogeneous half space model.[3] The method can be complementary to magnetometer mapping in certain cases. Compared to magnetometry, it is far less sensitive but is more able to resolve closely spaced magnetite zones, as well as providing an estimate of the amount of magnetite in the rock. The method is sensitive to 1/4% magnetite by weight when the EM sensor is at a height of 30 m above a magnetitic half space. It can individually resolve steep dipping narrow magnetite-rich bands which are separated by 60 m. Unlike magnetometry, the EM magnetite method is unaffected by remanent magnetism or magnetic latitude.

The EM magnetite mapping technique provides estimates of magnetite content which are usually correct within a factor of 2 when the magnetite is fairly uniformly distributed. EM magnetite maps can be generated when magnetic permeability is evident as negative inphase responses on the data profiles.

Like magnetometry, the EM magnetite method maps only bedrock features, provided that the overburden is characterised by a general lack of magnetite. This contrasts with resistivity mapping which portrays the combined effect of bedrock and overburden.

5.1.6 Interpretation in conductive environments

Environments having background resistivities below 30 ohm m cause all airborne EM systems to yield very large responses from the conductive ground. This usually prohibits the recognition of discrete bedrock conductors. However, DIGHEM data processing techniques produce parameters which contribute significantly to the recognition of bedrock conductors. These are the resistivity and depth channels for each coplanar frequency.

The EM difference channels (idif and qdif) eliminate most of the responses from conductive ground, leaving responses from bedrock conductors, cultural features (eg., telephone lines, fences, etc.) and edge effects. Edge effects often occur near the perimeter of broad conductive zones. This can be a source of geologic noise. While edge effects yield anomalies on the EM difference channels, they do not produce resistivity anomalies. Consequently, the resistivity channel aids in eliminating anomalies due to edge effects. On the other hand, resistivity anomalies will coincide with the most highly conductive sections of conductive ground, and this is another source of geologic noise. The recognition of a bedrock conductor in a conductive environment therefore is based on the anomalous responses of the two difference channels (idif and qdif) and the resistivity channels. The most favourable situation is where anomalies coincide on all channels.

The apparent depth channels, which give the apparent depth to the conductive material, also help to determine whether a conductive response arises from surficial material or from a conductive zone in the bedrock. When these channels rise above the zero level on the digital profiles (ie., depth is negative), it implies that the EM and resistivity profiles are responding primarily to a conductive upper layer, ie., conductive overburden. If the depth channels are below the zero level, it indicates that a resistive upper layer exists, and this usually implies the existence of a bedrock conductor. If the low frequency depth channel is below the zero level and the high frequency apparent depth is above, this suggests that a bedrock conductor occurs beneath conductive cover.

[3] Refer to Fraser, 1981, Magnetite mapping with a multi-coil airborne electromagnetic system: Geophysics, v. 46, p. 1579-1594.

5.1.7 Recognition of culture

Cultural responses include all EM anomalies caused by man-made metallic objects. Such anomalies may be caused by inductive coupling or current gathering. The concern of the interpreter is to recognise when an EM response is due to culture. Points of consideration used by the interpreter, when coaxial and coplanar coil-pairs are operated at a common frequency, are as follows:

1. Channels CXP and CPP monitor 60 Hz radiation. An anomaly on these channels shows that the conductor is radiating power. Such an indication is normally a guarantee that the conductor is cultural. However, care must be taken to ensure that the conductor is not a geologic body which strikes across a power line, carrying leakage currents.

2. A flight which crosses a "line" (eg., fence, telephone line, etc.) yields a center-peaked coaxial anomaly and an m-shaped coplanar anomaly. When the flight crosses the cultural line at a high angle of intersection, the amplitude ratio of coaxial/coplanar response is 4. Such an EM anomaly can only be caused by a line. The geologic body which yields anomalies most closely resembling a line is the vertically dipping thin dyke. Such a body, however, yields an amplitude ratio of 2 rather than 4. Consequently, an m-shaped coplanar anomaly with a CXI/CPI amplitude ratio of 4 is virtually a guarantee that the source is a cultural line.

3. A flight which crosses a sphere or horizontal disk yields center-peaked coaxial and coplanar anomalies with a CXI/CPI amplitude ratio (ie., coaxial/coplanar) of 1/4. In the absence of geologic bodies of this geometry, the most likely conductor is a metal roof or small fenced yard. Anomalies of this type are virtually certain to be cultural if they occur in an area of culture.

4. A flight which crosses a horizontal rectangular body or wide ribbon yields an m-shaped coaxial anomaly and a center-peaked coplanar anomaly. In the absence of geologic bodies of this geometry, the most likely conductor is a large fenced area. Anomalies of this type are virtually certain to be cultural if they occur in an area of culture.

5. EM anomalies which coincide with culture, as seen on the camera film or video display, are usually caused by culture. However, care is taken with such coincidences because a geologic conductor could occur beneath a fence, for example. In this example, the fence would be expected to yield an m-shaped coplanar anomaly as in case #2 above. If, instead, a center-peaked coplanar anomaly occurred, there would be concern that a thick geologic conductor coincided with the cultural line.

6. The above description of anomaly shapes is valid when the culture is not conductively coupled to the environment. In this case, the anomalies arise from inductive coupling to the EM transmitter. However, when the environment is quite conductive (eg., less than 100 ohm m at 900 Hz), the cultural conductor may be conductively coupled to the environment. In this latter case, the anomaly shapes tend to be governed by current gathering. Current gathering can completely distort the anomaly shapes, thereby complicating the identification of cultural anomalies. In such circumstances, the interpreter can only rely on the radiation channels and on the camera film or video records.

5.2 MAGNETICS

In some geological environments, an EM anomaly with magnetic correlation has a greater likelihood of being produced by sulphides than one that is non-magnetic. However, sulfide ore bodies may be non-magnetic (eg., the Kidd Creek deposit near Timmins, Canada) as well as magnetic (eg., the Mattabi deposit near Sturgeon Lake, Canada). The same principle applies to kimberlite mapping.

The magnetometer data are digitally recorded in the aircraft to an accuracy of 0.01 nT for Caesium magnetometers. The digital tape is processed by computer to yield a total field magnetic contour map.

When warranted, the magnetic data may also be treated mathematically to enhance the magnetic response of the near-surface geology, and an enhanced magnetic contour map is then produced.

Any of a number of filter operators may be applied to the magnetic data, to yield vertical derivatives, continuations, magnetic susceptibility, etc. These may be displayed in contour, colour or shadow.

6. CONCLUSIONS AND RECOMMENDATIONS

This report provides a description of the survey results and describes the equipment, procedures and logistics of the survey.

The various maps included with this report display the magnetic, radiometric and conductive properties of the survey area. It is recommended that the survey results be reviewed in detail, in conjunction with all available geophysical, geological and geochemical information. Particular reference should be made to the computer generated data profiles which clearly define the characteristics of the individual anomalies.

Interpreted conductors and radiometric anomalies defined by the survey should be subjected to further investigation, using appropriate surface exploration techniques. Anomalies which are currently considered to be of moderately low priority may require upgrading if follow-up results are favourable.

It is also recommended that image processing of existing geophysical data be considered, in order to extract the maximum amount of information from the survey results. Current software and imaging techniques often provide valuable information on structure and lithology, which may not be clearly evident on the contour and colour maps. These techniques can yield images which define subtle, but significant, structural details.

APPENDIX

LIST OF PERSONNEL

The following personnel were involved in the acquisition, processing, interpretation and presentation of data, relating to a DIGHEM^{V} airborne geophysical survey carried out for , near .

Mick Drewett, Michael Hallett   Survey Supervisors / Crew Chiefs
    Geophysical Operators
, G. Archer   Pilots
Doug Morrison   Data quality control supervisor
    Data Processor

The survey consisted of line km of DIGHEM^{V} coverage, flown from the to the of 1996 and 15 694 line km of magnetic / radiometric / VLF survey, flown from the 20th August to the 14th September 1996. An additional test VLF area of 83 line kilometres was flown.

All personnel are employees of Geoterrex Pty Ltd, except for the pilots who are employees of .