

AN OVERVIEW OF AEM SYSTEMS – WHAT ARE YOU TRYING TO ACCOMPLISH, AND WHICH SYSTEMS ARE SUITABLE

ASEG Workshop on Airborne Electromagnetics
Perth
November 7th 2012

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Southern Geoscience Consultants



SOUTHERN GEOSCIENCE
CONSULTANTS ₁

INTRODUCTION

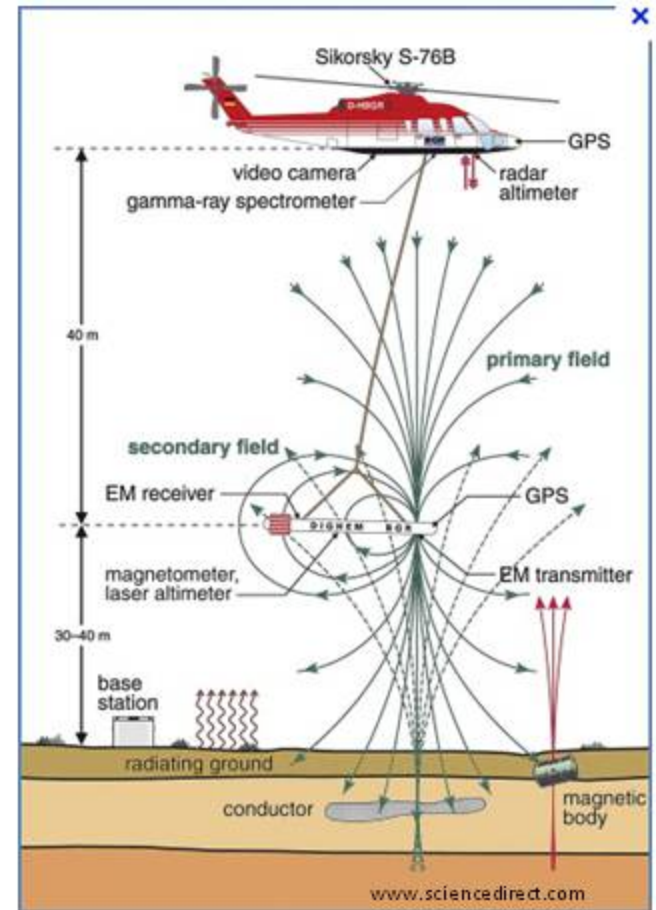
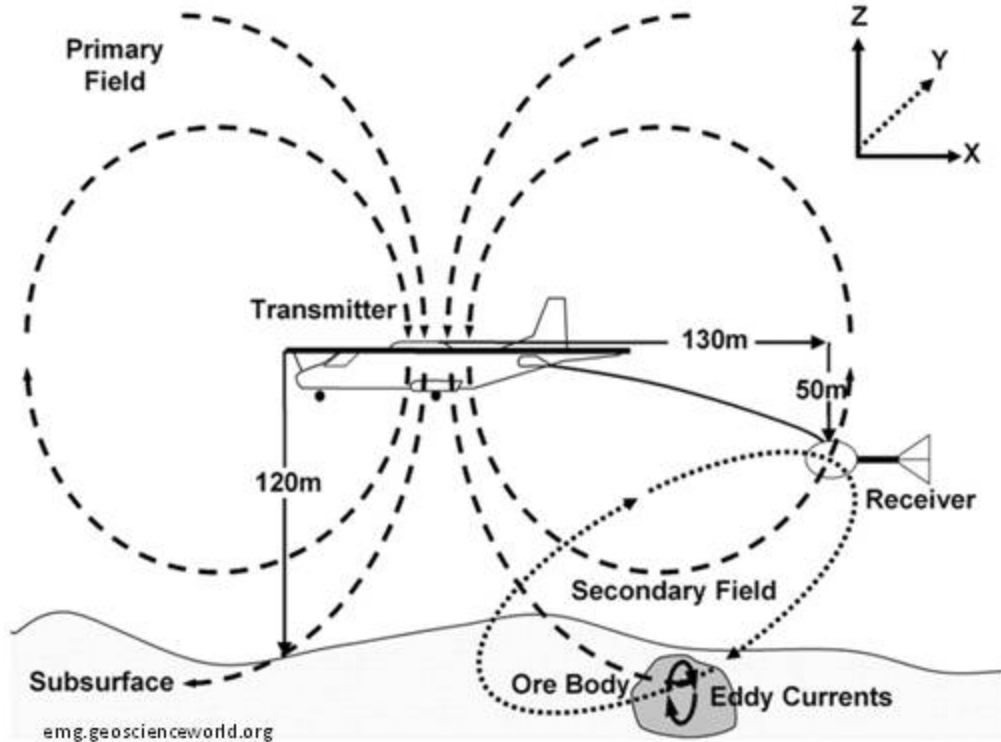
- Choosing a system - Survey Objectives
- Planning considerations
- Systems available in Australia (but applicable globally)
- Description of systems
- Advantages and disadvantages
- Approximate costs



Don't fly too low...

Yes – That's me in thinner times

BASIC PRINCIPLES OF AEM



Transmitter – large coil encircling the aircraft or suspended beneath a helicopter

Receiver – Usually within a towed “bird” or coil suspended beneath a helicopter

Electromagnetic Induction – “Eddy” or “Secondary” currents

Active versus Passive systems

SURVEY OBJECTIVES

AEM surveying has a very large number of uses

Massive sulphide mineralisation

Alteration mapping

Geological mapping

Kimberlites

Graphite

Iron ore, manganese

Groundwater

Paleochannel mapping – placer deposits, uranium, detrital iron, etc

Bathymetry

Regolith mapping

UXO

Decide what you are trying to accomplish and choose and design accordingly

SELECTING A SYSTEM AND SURVEY DESIGN

Use a system and survey specifications that match the specific objectives of the survey.

Target size and dimensions

Horizontal Spatial resolution

Conductance of target and host

Vertical resolution

Survey dimensions

Terrain

Depth of investigation

Infrastructure

SELECTING A SYSTEM AND SURVEY DESIGN - CONTINUED

Signal to noise – this is what counts

Contractors will sell you what they have

Value for money

Tie lines

Wide line spacing initially and then infill?

Follow up –Budget for this!

Fly parallel to strike?

TYPES OF AEM SYSTEMS

MOST COMMON SYSTEMS IN USE TODAY

Fixed Wing TEM Systems

Helicopter TEM systems

Helicopter FDEM systems

OTHER SYSTEMS

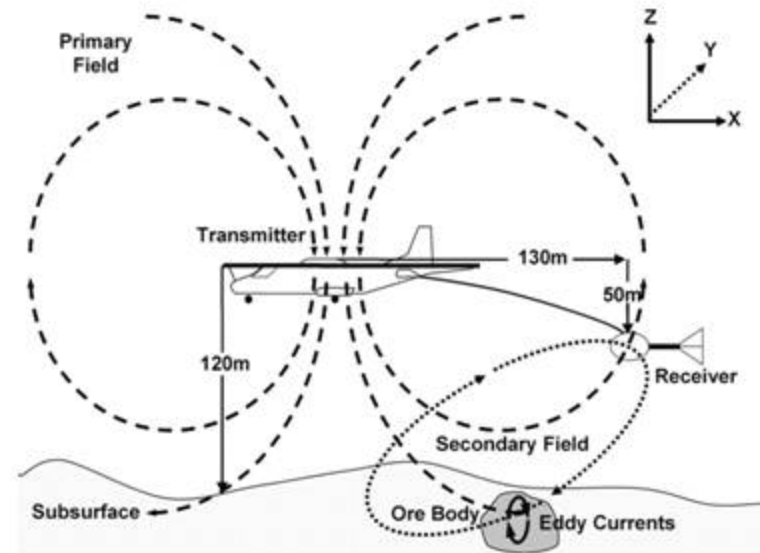
Fixed Wing Frequency Domain (FDEM) Systems

Helicopter and Fixed Wing MT Systems

Airborne VLF Systems

FIXED WING TEM SYSTEMS

- Almost exclusively Fugro (now CGGVeritas)
- Dominated market until advent of helicopter TEM
- Lower cost compared to helicopter TEM
- Large footprint
- Deep penetration
- Good coupling with steeply dipping conductors
- Lower spatial resolution
- Unsymmetrical – adds complexity to interpretation and imaging
- Needs long line lengths
- Not suitable for rugged terrain
- Needs airfield but can sustain long ferry distance



Developed originally for salt mapping by World Geoscience

CASA 212-200, Skyvan, Cessna 208

25hz or 75hz Transmitter

Peak Dipole Moment: 56000 Am²

Three component dB/dT receiver

Mainly a high resolution low cost shallow mapper

Can be used for sulphide exploration in more resistive areas



FOR

Broad bandwidth & good calibration

Good vertical resolution at shallow depths

Suited for regolith mapping, paleo-channels, groundwater, geological mapping, graphite.

Relatively low cost ~ \$90-\$100/ line km



AGAINST

Lower power and less depth penetration than competitors

Unsymmetrical response

Cessna C208 aircraft – Based in South Africa

Adaptation of **TEMPEST?**

225hz (high frequency)

TEM, magnetics and radiometrics

A set of non-negotiable datasets, offered at a low price

Indicative Cost - \$40 / line km

FOR

Relatively high resolution & good calibration

Well suited for regional geological and regolith mapping

Low cost

AGAINST

Shallow depth penetration

Unsymmetrical response



The most popular fixed wing TEM system for mineral exploration

Introduced mid 1980s - Long proven system

Dipole moment 850,000 A.m², half sine waveform 25Hz

Discoveries and successes in base metals, diamonds, uranium, coal, oil and gas, water mapping and geological mapping.

Indicative Cost : \$100-110/ line km

FOR

- Large footprint and good depth penetration
- High power - Transmitter dipole moment of 850 000 A m².
- Broadband measurement of three components (X, Y, Z)
 - Measurement of both dB/dt and B Field.
- Moderate Cost

AGAINST

- Unsymmetrical response
- Lower spatial resolution than helicopter TEM



GEOTEM on Casa 212:
Port Hedland 1990

More powerful version of GEOTEM

Not used in Australia to date

Developed 1997 for high altitude work

De Havilland Dash-7

TEM, magnetics & radiometrics

Relatively low cost for ground covered - large surveys.

Dipole moment: 2,200,000 A m², 25, 30, 75, 90Hz

Broadband measurement: X, Y, Z components

On-time measurement. dB/dt and B Field.

Indicative Cost: \$150-\$200/ line km?



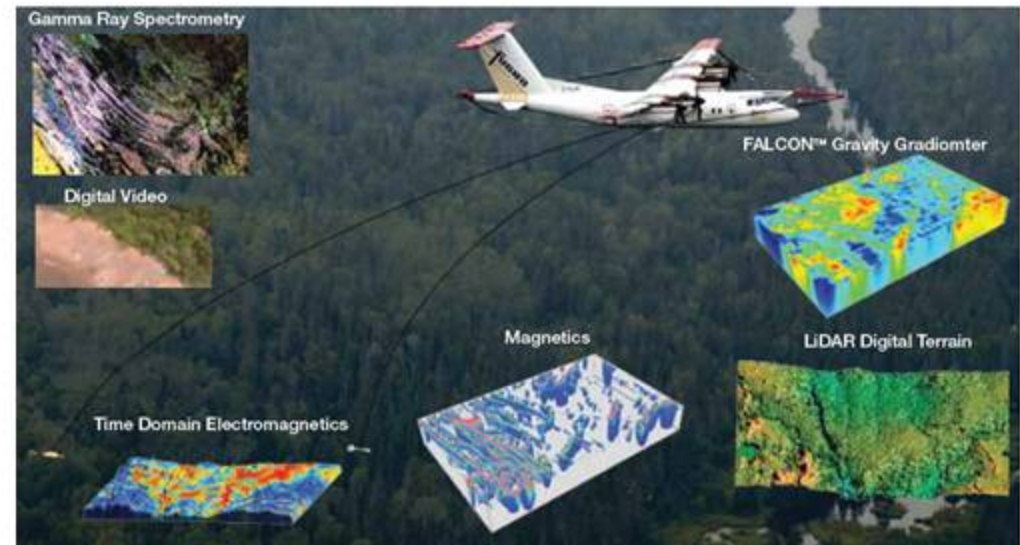
Collects simultaneous measurements of:

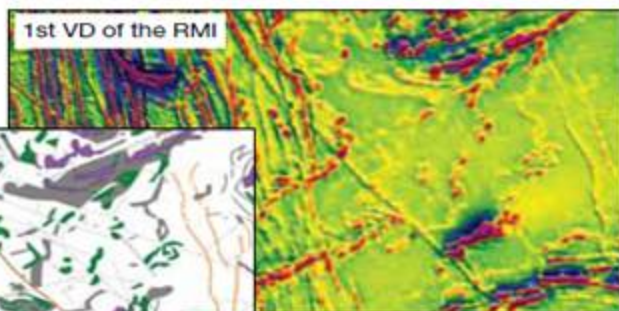
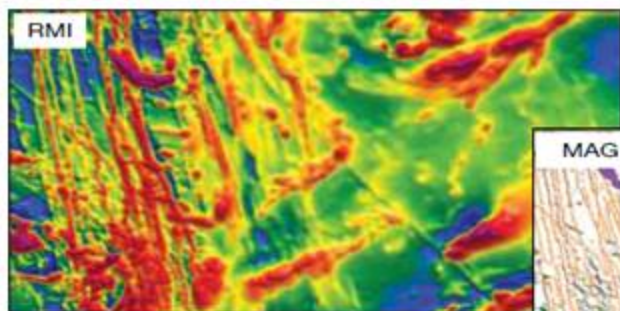
- Time Domain EM (MEGATEM or TEMPEST)
- High Resolution Magnetics
- FALCON Gravity Gradiometry
- Gamma Ray Spectrometry
- LiDAR
- Digital Video

Not in Australia as yet

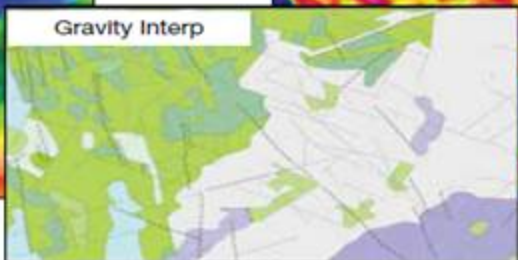
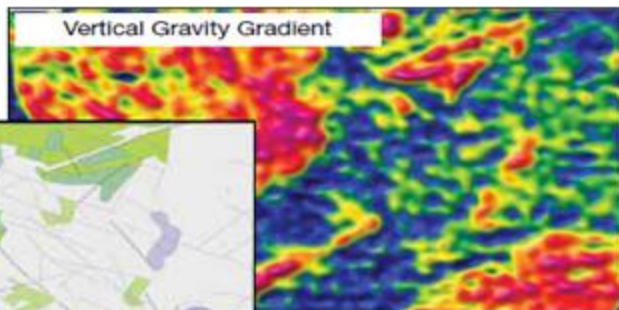
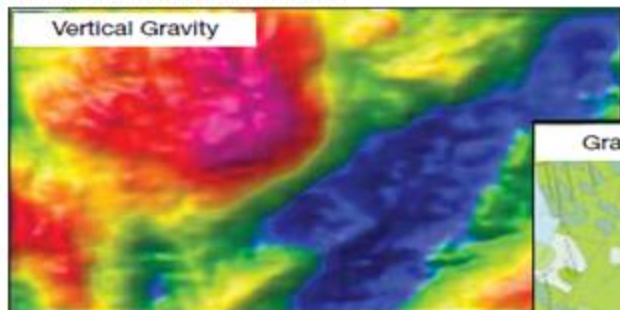
Indicative Cost: \$250/ line km (plus mobilisation....)

Currently – Multi-client survey in West Africa

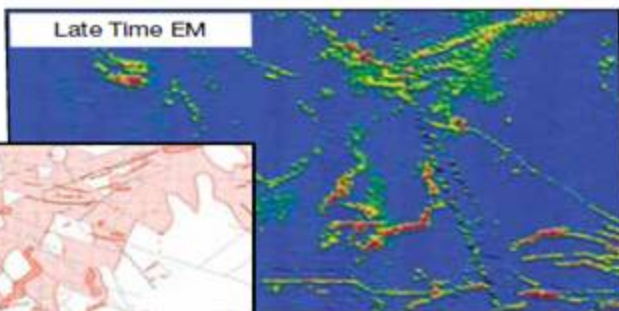
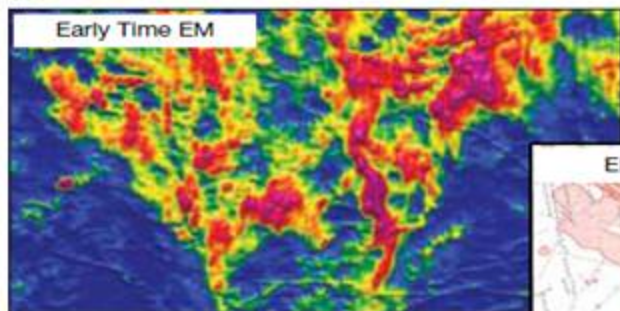




Magnetic data yields information on the geology and structure of the earth from the surface and down to deep bedrock formations and can help identify contacts, folds and faults.



Gravity data is used to identify formations based on density contrasts and can be used for large scale deep structures in oil and gas exploration down to small scale mineral and engineering applications



Electromagnetic data can give information on the geology and structure of the earth from the surface down to depths of several hundred metres and can help identify conductor axis and zones based on contrasts in conductivity.

Developed by Anglo American since 1982
 Used worldwide with a number of mine discoveries
 Commercially available without AAC strings attached
 Used in Australia and available
 Square waveform – enhances effective dipole moment
 On time measurements, Step Response -> B –
 Field X & Z components

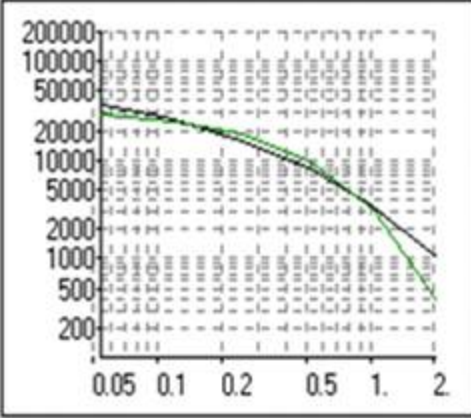
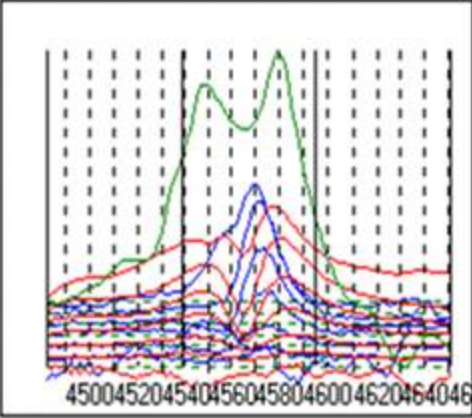


Indicative Cost: \$80-90 per line km (This includes interpretation)

Dipole Moment	420 000 Am ²
Transient Current	1000 Amps
Transmitter Duty Cycle	100 % (no off -time)
Loop Area	420 m ²
Base Frequencies	25,30,37.5,45,60,75,90 Hz
Digitization Rate	76 800 Hz /component
Square-Wave Rise Time	180 microseconds

Strong on interpretation and processing software

Decay Fit

Grade: A B C D 1 2 3 4 5 6 7 8 9 10 Redo Fit

Dip: 0 15 30 45 60 75 90 105 120 135 150 165 Depth: 28.4

Body Conductance (S):

2 2.8 4 6 10 14 20 28 40 60 100 140 200 280 400 600

O/B Conductance (S): 0.0298

Mag: No Correlation Digitize Automatically Digitize Manually Value: 0.0

Use results from:

Nomogram

Inversion

Fence

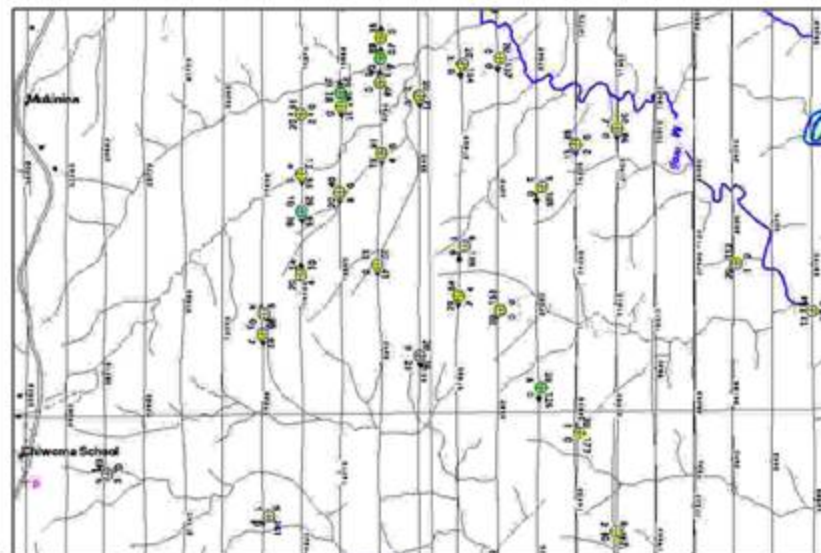
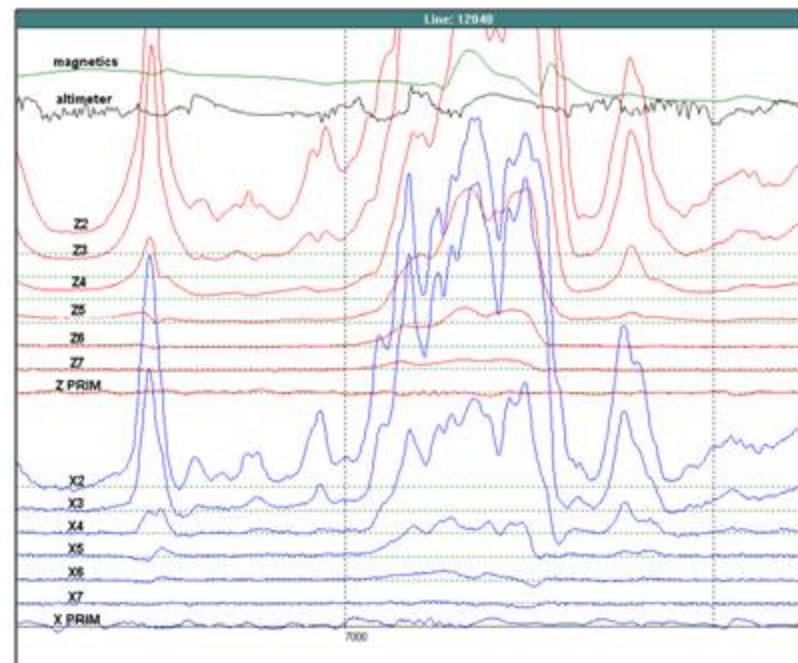
Probable Fence

Possible Fence

No Fence Visible

Invert

OK



Introduced in late 1960's - Developed by Barringer for Inco
 Major advance over the frequency domain systems in use
 Flown mainly on Catalina (PBY, Canso) aircraft
 Very successful – 70% of EM surveys flown at that time
 Credited with the discovery of tens of billions of dollars worth of ore deposits.
 Analogue system – Six channels, no digital data
 Replaced by GEOTEM (digital version of INPUT)

INPUT on Catalina – Springbok, South Africa 1975

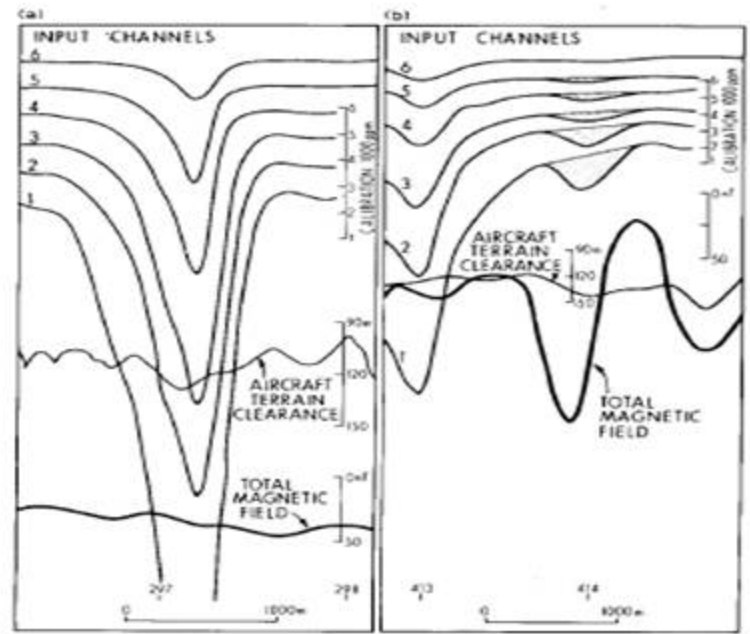
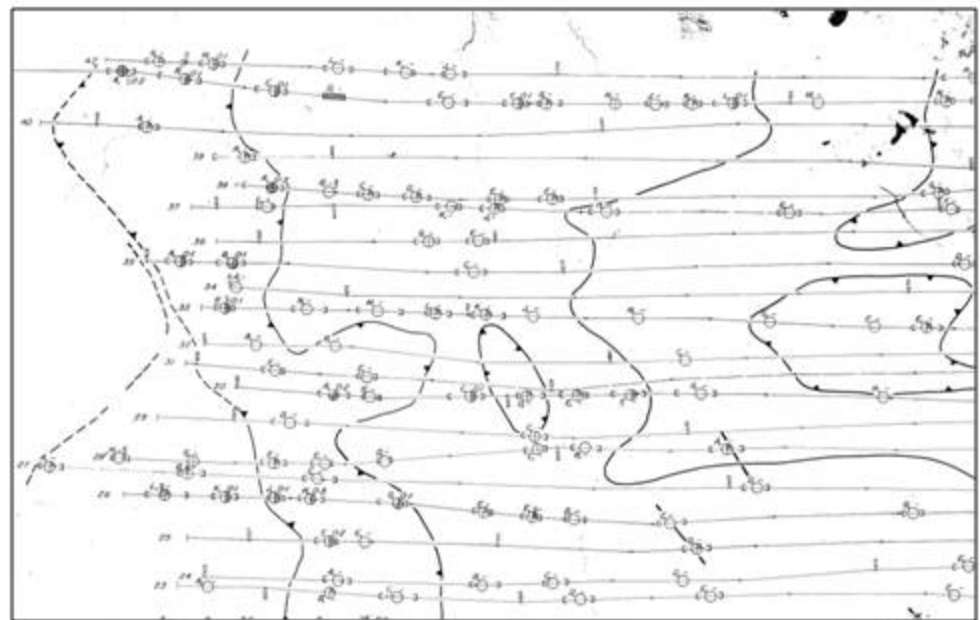
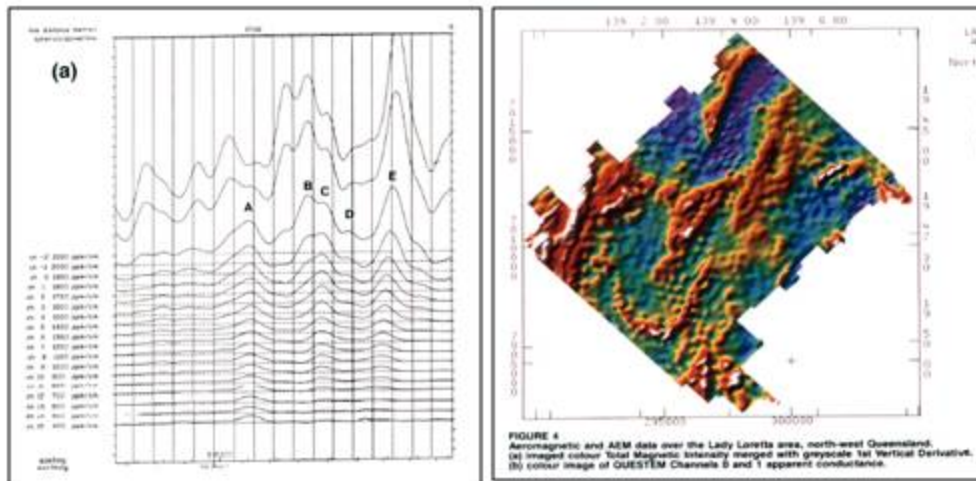


Fig 1(a) INPUT response over the Berjaya Prospect, NT.
 Fig 1(b) INPUT response (stippled) over the Gurubang Prospect, NSW.



- Introduced as a competitor to GEOTEM
- Operated by Questor Surveys until taken over by World Geoscience Corporation
- Very similar to GEOTEM at the time
- Fifteen channel dB/dt Z component data
- TX: 75Hz and 37.5Hz
- Flown mainly on Trilander and Sky Van aircraft
- Used extensively in Australia so a lot of data still around
- Not quite as good as GEOTEM (personal opinion)



QUESTEM data over Lady Loretta



FIGURE 4
Aeromagnetic and AEM data over the Lady Loretta area, north-west Queensland.
(a) Inverted colour Total Magnetic Intensity merged with grey-scale 1st Vertical Derivative.
(b) colour image of QUESTEM Channels 8 and 1 apparent conductance.

HELICOPTER TEM SYSTEMS

Introduced ~2000

Deep penetration

Symmetrical response – easier interpretation and imaging

Short line lengths (3kms usually)

Handle rugged terrain

No airfield needed

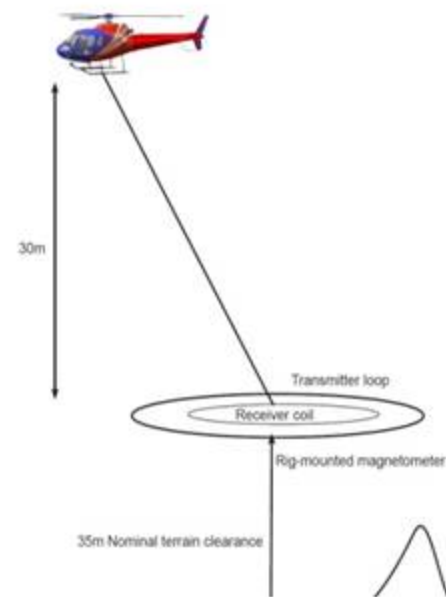
Higher cost

In House Systems: Hoistem, Newtem, Explorhem

Commercial Systems: Aerotem, Vtem, Skytem, Helitem, Reptem, Xtem

Continuing improvement in signal to noise, depth of investigation, spatial resolution, conductance aperture and discrimination.

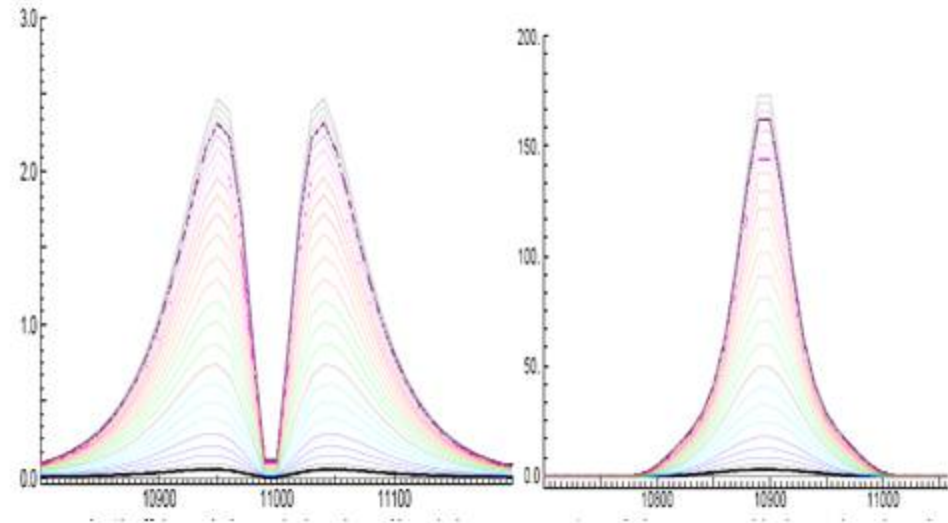
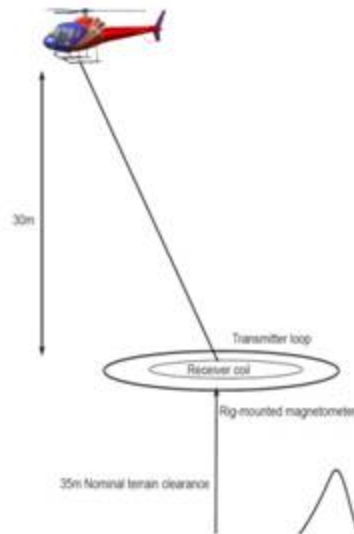
B- Field measurements, multiple components, on time measurements, full waveform, very early time resolution, etc



HELICOPTER TEM SYSTEMS

Two different array designs

VTEM, AeroTEM, HoistEM,
RepTEM, XTEM, (SkyTEM?)
In-loop where receiver coils are in
the centre of the transmitter loop.
Anomaly shapes are independent
of the flight-line direction and
symmetrical for vertical conductor.



HELITEM, NewTEM, THEM : Receiver
coils located on the towed cable
above the transmitter loop and a
short horizontal distance ahead of the
transmitter loop causing a slight
asymmetrical effect on the profiles

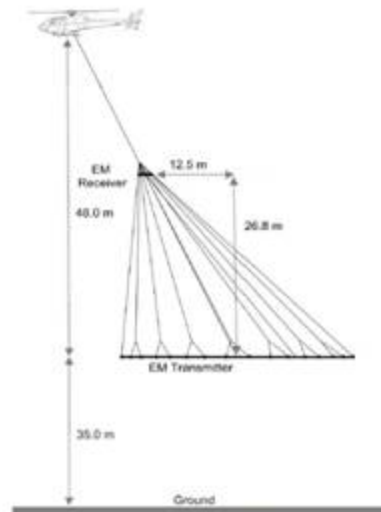
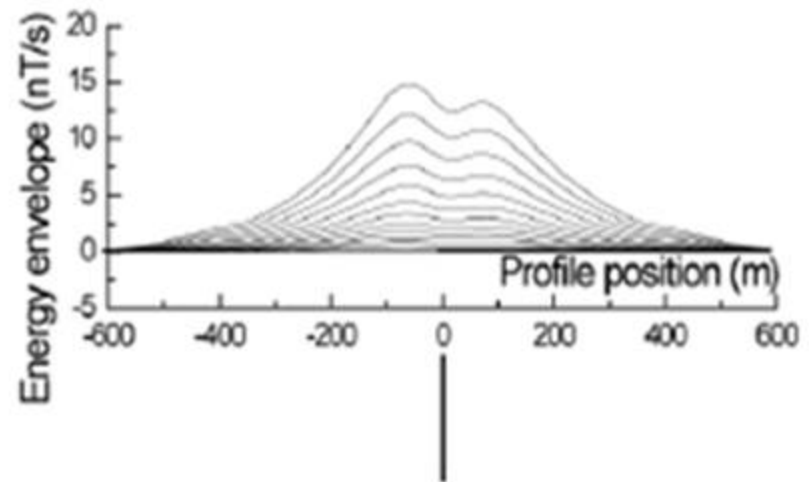


Figure 4 Geometry of the HELITEM System



- One of the first helicopter TEM systems.
- Originally developed by Normandy/ Newmont but then licensed to GPX 2001-2007.
- Now back in Newmont hands and not commercially available.

Waveform – 25% duty cycle square wave

Pulse on Time - on)	5 ms (inclusive of 1ms cosine ramp
Pulse off Time -	15 ms
Pulse Current -	320 Amps
Switch on Ramp	1 ms
Switch off Ramp	40 μ s
Tx Loop Area -	~340 m ²
Tx NIA -	108,800
Tx Frequency-	25 Hz

FOR

Lightweight and portable
(Transportable by commercial aircraft)
Symmetrical in loop system

AGAINST

Lower power than some other HTEM systems
-> Limited depth penetration
No X & Y components
No B-Field



Replaced HOISTEM

Was flown by GPX Surveys but now by Geosolutions

High bandwidth, square waveform system

Aerodynamic - flies in a stable horizontal position at low forward speeds

Good in steep terrain where other systems can struggle.

Transmitter	– 25% duty cycle square wave, 25Hz
Current -	320 Amps
Tx Loop Area -	~350 m ²
Tx NIA –	112,000
Receiver	21 Channels

FOR

Lightweight
Very portable
Low cost

AGAINST

Low power
Single component
No B-Field

Indicative Cost: \$90 - \$100 per line km



Another In loop system developed by GPX to now replace REPTM.

Four systems; Two in Australia and two overseas

Z component – dB/dt (No X & Y components)

Thirty channels

Square wave (25% duty cycle)

Tx Frequency: 25 Hz

Current: 300 amps

Tx Loop Area: 344 m²

Tx moment (NIA): 103,200 Am²



FOR

Lightweight and portable

Good early time information (shallow)

Lower cost than some others

Symmetrical in loop system

AGAINST

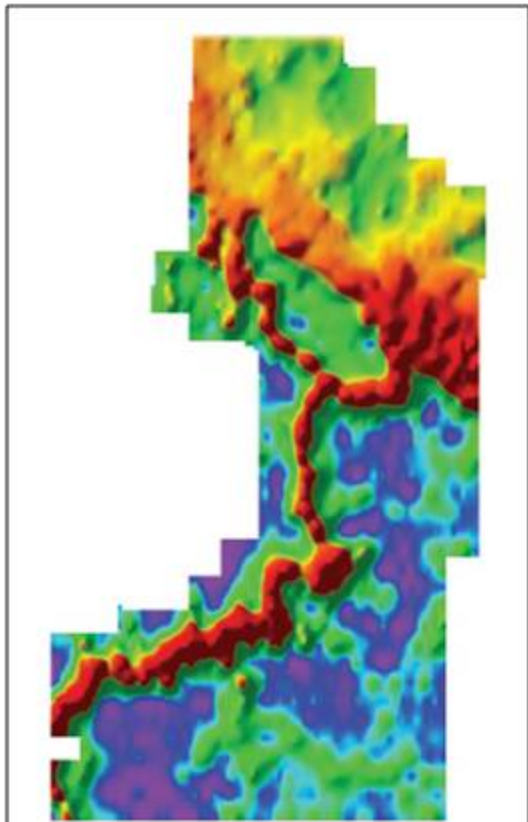
Lower power than some other HTEM systems

-> Limited depth penetration

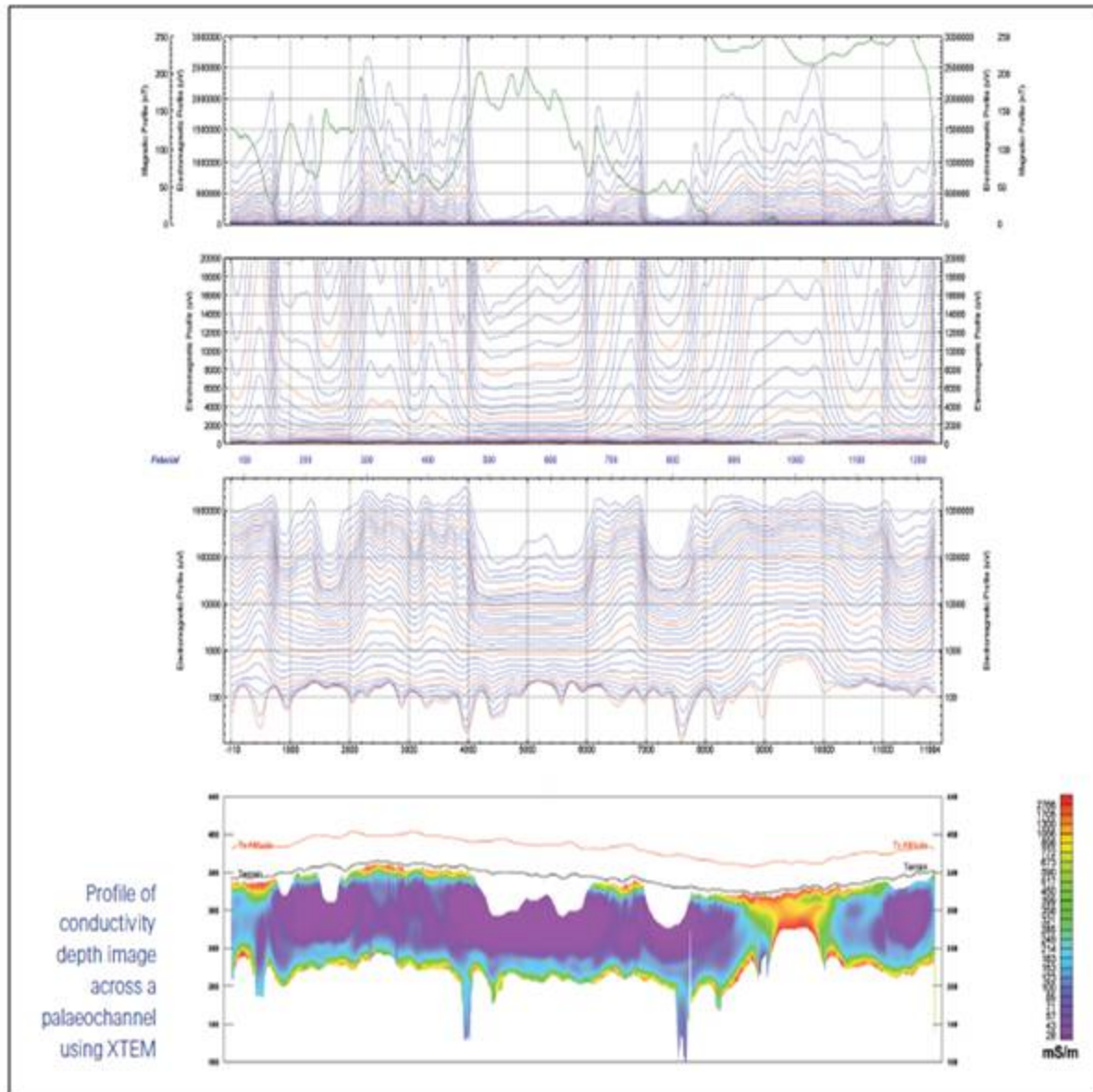
No X & Y components

No B-Field

INDICATIVE COST: \$50 to \$150/km including fuel and helicopter)



Example of conductivity depth image mapping a palaeochannel using XTEM.



Developed to compete with VTEM

Previously called HeliGEOTEM

Dipole moment 2,000,000 A.m², Half sine waveform 25Hz

dB/dT and B Field

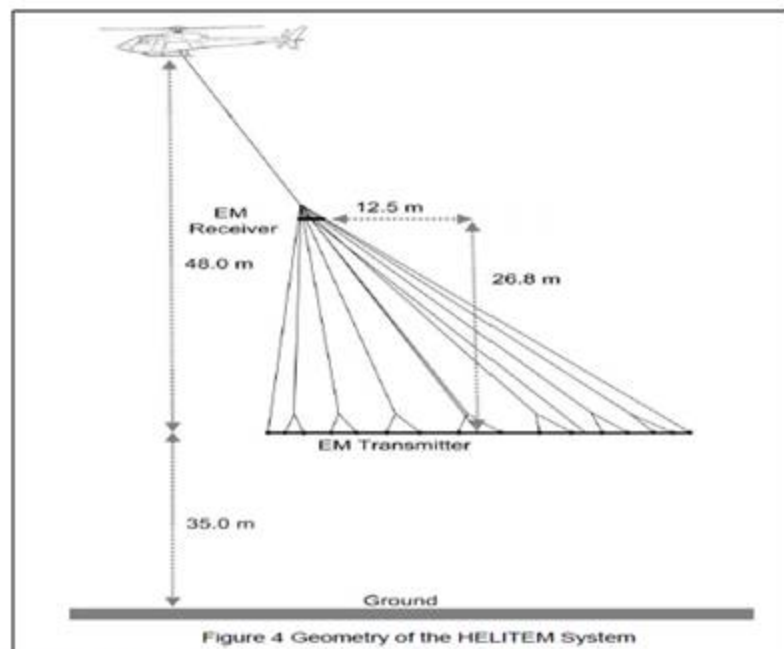
EM and Magnetics

Three Component X, Y & Z low noise receiver

Sharp turn-off for sensitivity to weak conductors

Long off-time provides sensitivity to strong and deep conductors

Can be configured with less transmitter turns to give "Lite" versions for steep terrain or lower powered helicopters



FOR

Very High power

Good three Component data helps with interpretation

Sharp turn-off -> sensitivity to weak conductors

Long off-time -> sensitivity to strong and deep conductors

On time & Off time measurements

Good B-Field data

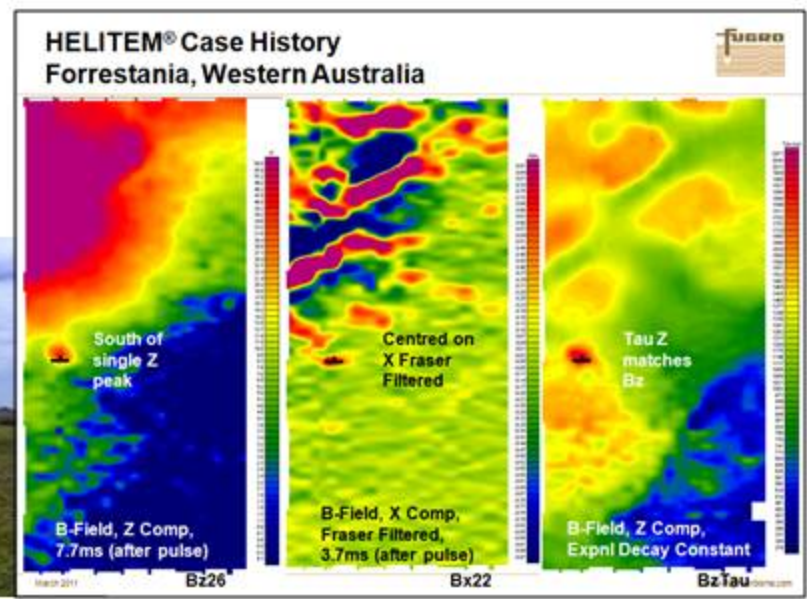
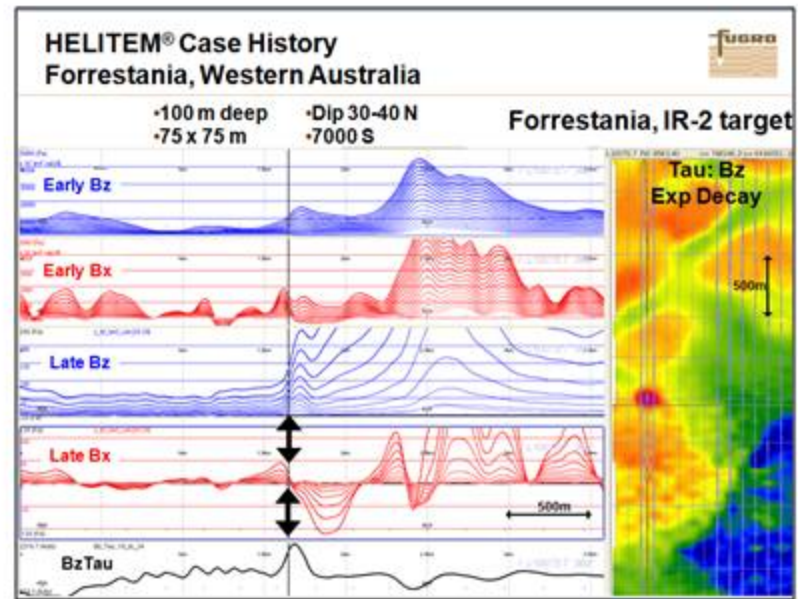
AGAINST

Not much

Slightly asymmetrical array

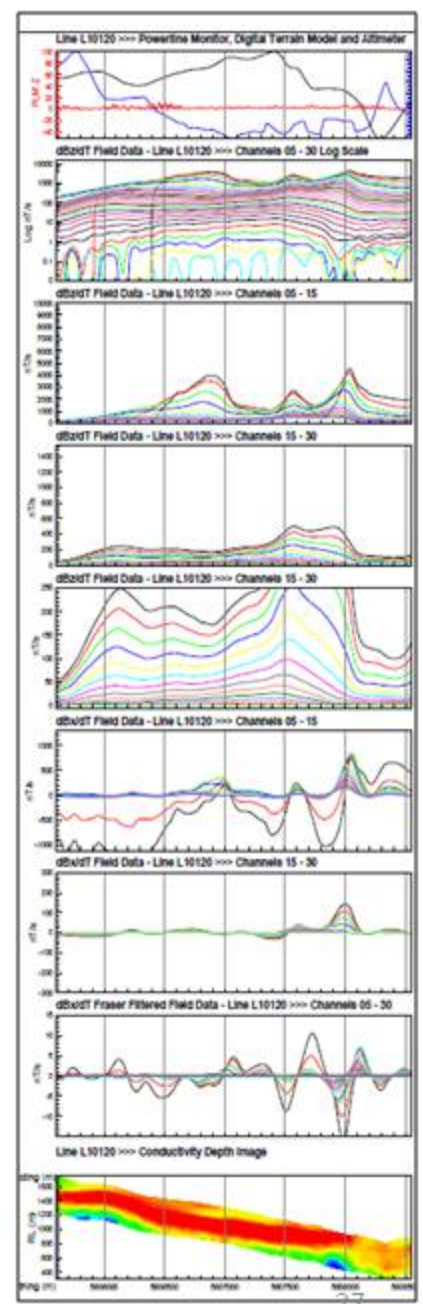
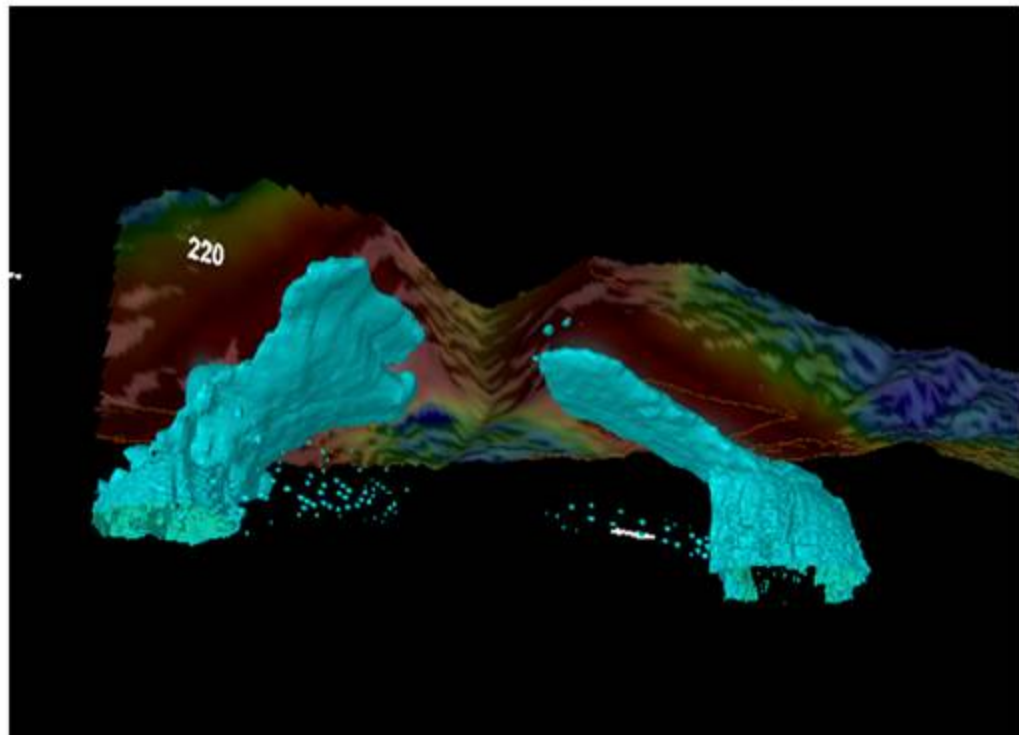
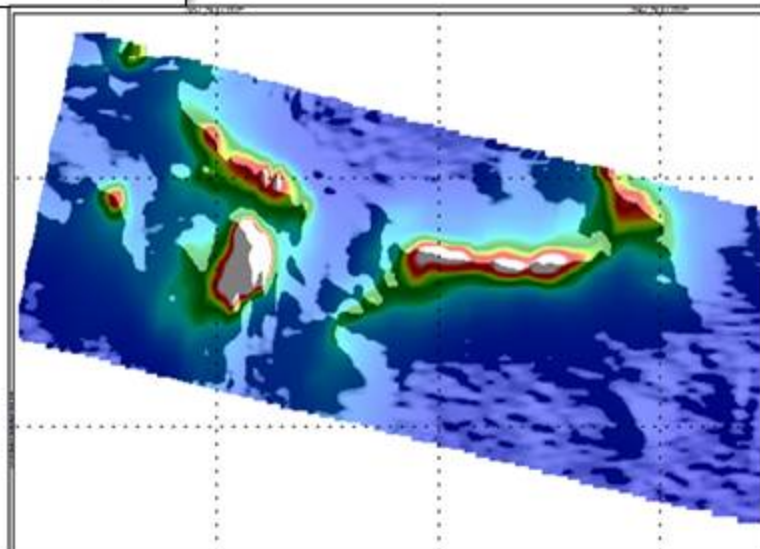
High receiver slightly degrades resolution

INDICATIVE COST: \$140 - \$160/ line km

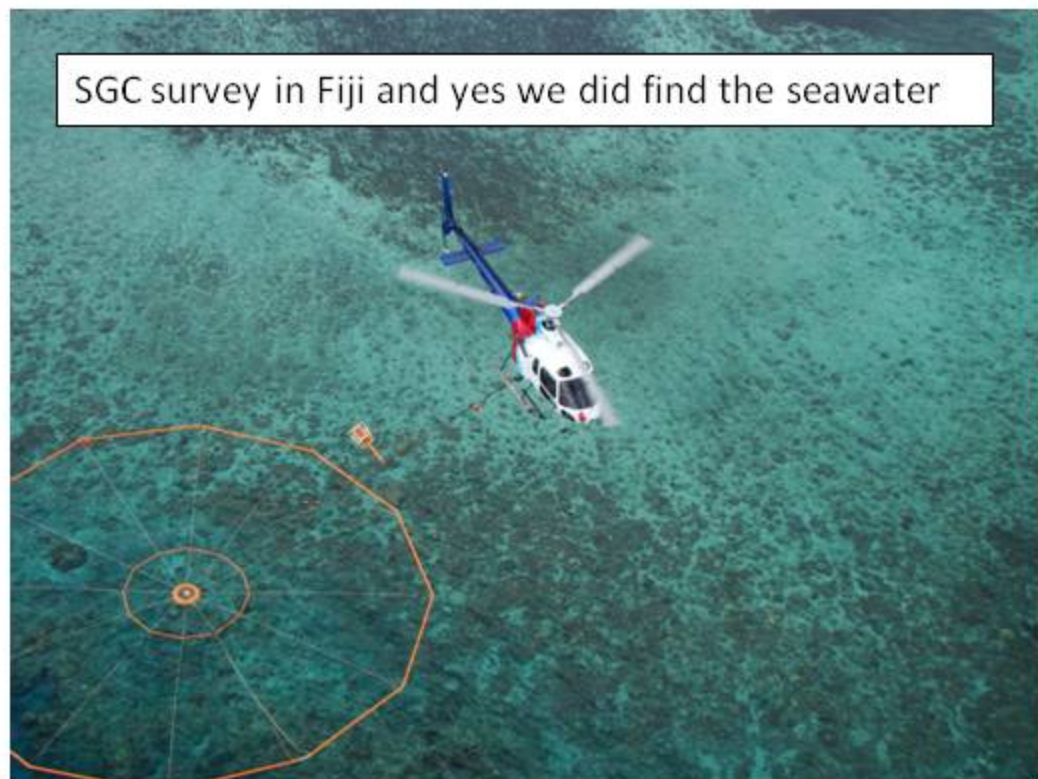


HELITEM Survey - British Columbia

Performed well in rugged terrain
 Images shallowly dipping stratigraphic
 conductors very well



- Developed in 2002
- Industry leader
- Thirty systems
- In-loop configuration – symmetrical response
- Large dipole moment up to 1000 000 A.m²
- Very low noise levels
- Full wave data acquisition introduced 2012
- dB/dT and B Field
- Three components



FOR

- High power
- High spatial resolution
- Deep penetration
- Very low noise -> High signal/noise ratio
- Wide variety of system configurations
- Good range of deliverable products

AGAINST

- Not much
- X & Y component data not as good as HELITEM?

INDICATIVE COSTS: \$140 - \$180 PER LINE KM



A multitude of different configurations with various names!

VTEM - (formerly VTEM Lite, Micro VTEM)

- Base Frequency: 25 Hz/30Hz
 - Waveform: Trapezoid
 - Peak dipole moment: **240,000 NIA**
 - Tx loop diameter: **17.6 m**
 - Tx/Rx height: 30 to 35 m
 - Tx Pulse On Time: Approx 3.5ms
 - Rx Time gates: 36/37 channels
 - Rx Sampling Range: **80 μ S to >7.5mS**
 - Typical Noise: **0.0003 pV/A/m² = 0.07 nT/s**
 - EM: dBdt and B field(*) Z component
 - Magnetics: Single sensor Cs
 - Radiometrics: Optional Spectrometer
- Applications**
 Surveys at High Altitude
 Surveys in Extreme Terrain
 Regional Reconnaissance Surveys.

VTEM^{Early Time}

- Base Frequency: 25 Hz/30Hz
 - Waveform: Trapezoid
 - Peak dipole moment: **450 - 600,000 NIA**
 - Tx loop diameter: **26 m**
 - Tx/Rx height: 30 to 35 m
 - Tx Pulse On Time: 3.5 to 7ms
 - Rx Time gates: > 45 channels
 - Rx Sampling: **21 μ S to 7mS (VTEM^{EARLYTIME} Rx)**
 - Late Time Noise: **0.0008 pV/A/m² = 0.32 nT/s**
 - Delivered Data: **Ideal Waveform Deconvolved**
 - EM: dBdt field – Z component
 - Magnetics: **Cs Sensor or Magnetic Gradient**
- Applications**
 Environmental
 Engineering
 Hydrogeology
 Shallow Mapping (bauxite etc)

VTEM^{PLUS}

- Base Frequency: 25 Hz/30Hz
 - Waveform: Trapezoid
 - Peak dipole moment: **450 - 600,000 NIA**
 - Tx loop diameter: **26 m**
 - Tx/Rx height: 30 to 35 m
 - Tx Pulse On Time: Approx 7ms
 - Rx Time gates: 36/37 channels
 - Rx Sampling Range: **80 μ S to >7.5mS**
 - Typical Noise: **0.0002 pV/A/m² = 0.08 nT/s**
 - EM: dBdt and B field- Z, X & Y component
 - Magnetics: **Horizontal Gradiometer**
 - Radiometrics: Optional Spectrometer
- Applications**
 Deep penetrating mineral surveys
 Moderately Conductive environments
 Regional Mapping

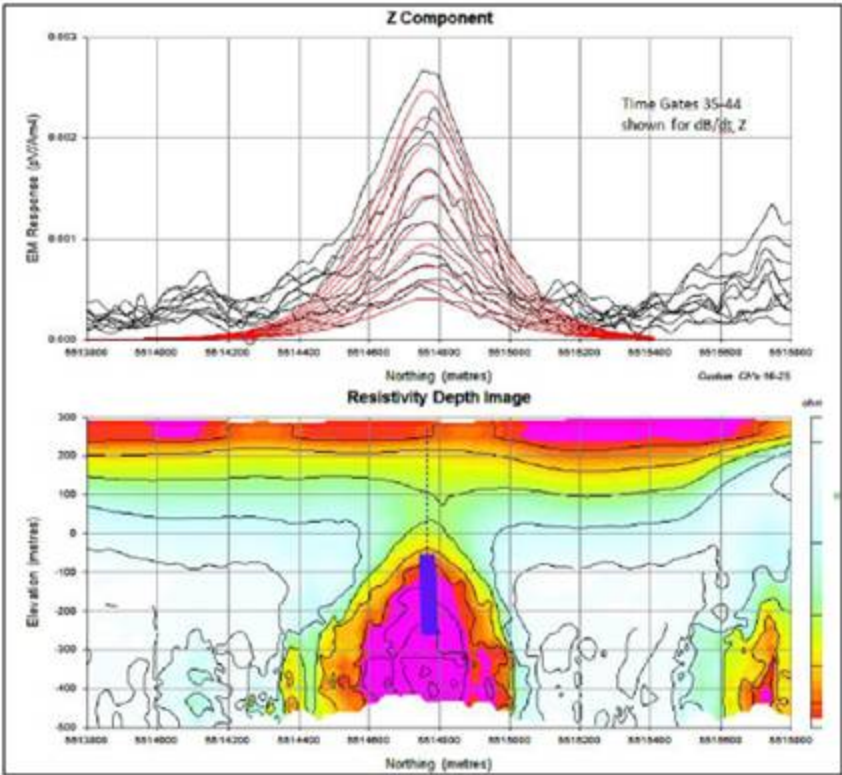
VTEM^{Full Waveform}

- Base Frequency: 25 Hz/30Hz
 - Waveform: Trapezoid
 - Peak dipole moment: **450 - 600,000 NIA**
 - Tx loop diameter: **26 m**
 - Tx/Rx height: 30 to 35 m
 - Tx Pulse On Time: 3.5 to 7ms
 - Rx Time gates: > 45 channels
 - Rx Sampling: **21 μ S to 9mS (VTEM^{PLUS} Rx)**
18 μ S to 7mS (VTEM^{EARLYTIME} Rx)
 - Late Time Noise: **0.0002 pV/A/m² = 0.08 nT/s**
 - Delivered Data: **Ideal Waveform Deconvolved**
 - EM: dBdt and B field – Z component
 - Magnetics: **Cs Sensor**
- Applications**
 Environmental
 Engineering
 Hydrogeology
 Shallow Mapping (bauxite etc)
 Base Metal Surveys/Shear zone mapping

VTEM^{Max}

- Base Frequency: 25 Hz/30Hz
 - Waveform: Trapezoid
 - Peak dipole moment: **~1,000,000 NIA**
 - Tx loop diameter: **34.6 m**
 - Tx/Rx height: 30 to 35 m
 - Tx Pulse On Time: Approx 4 ms
 - Rx Time gates: 36/37 channels
 - Rx Sampling Range: **80 μ S to >10mS**
 - Typical Noise: **0.0001 pV/A/m² = 0.09 nT/s**
 - EM: dBdt and B field- Z & X & Y component
 - Magnetics: Single sensor Cs
 - Radiometrics: Optional Spectrometer
- Applications**
 Deep penetrating mineral surveys
 Highly Conductive cover

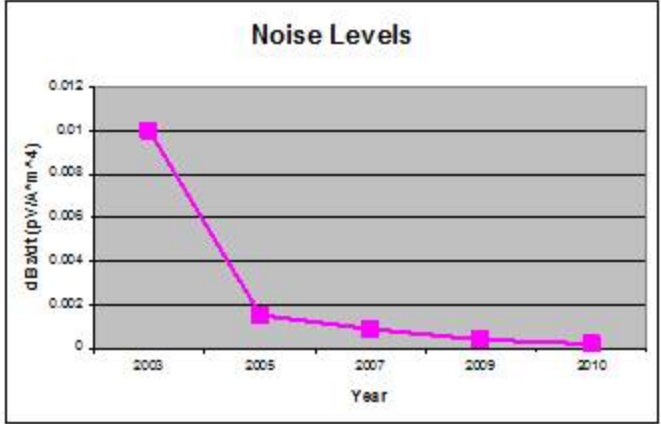
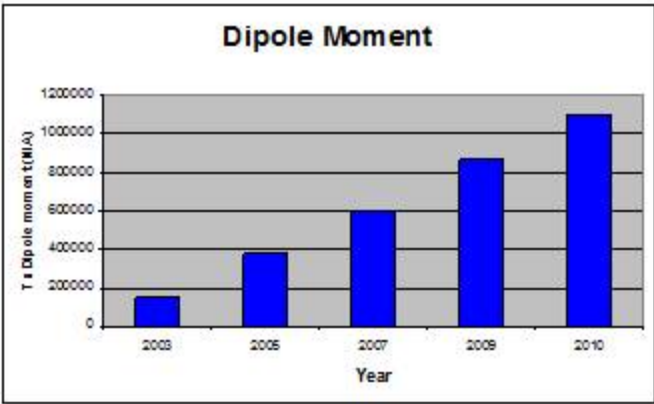
STRONG R&D - Continuing improvement 2002-2012



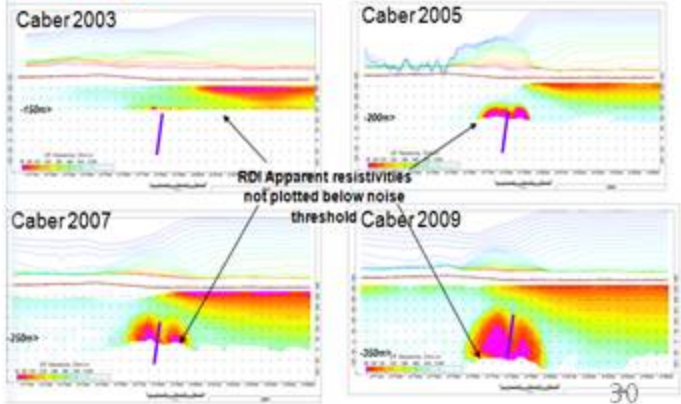
The Caber North deposit in Canada is at over 300 meters depth under conductive overburden.

It has not been detected by any airborne EM system until now

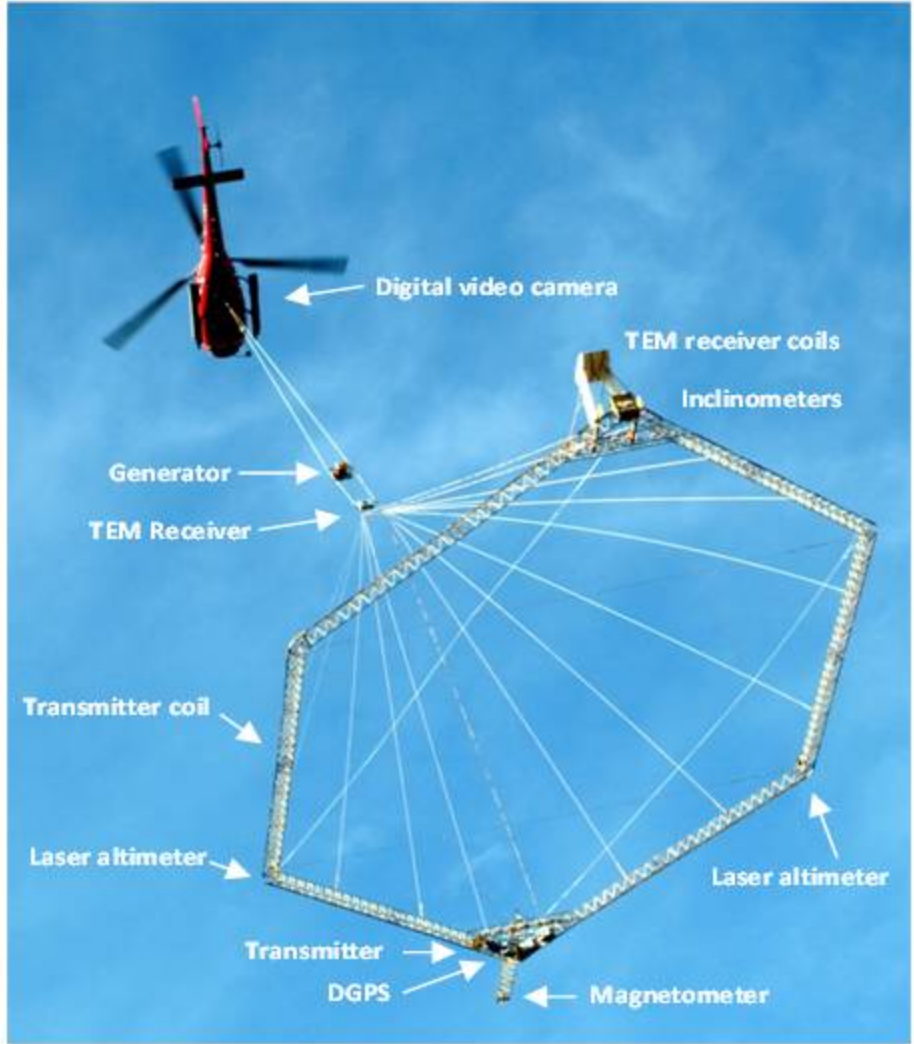
Flown October 2012 with VTEM-35 (dipole moment 1,600,000 NIA)



VTEM Improvements in Depth of Investigations due to reducing system noise and increasing S/N



- Developed in Denmark initially for water applications
- Dual square waveform gives high and low power during same flight.
- Low power - shallow mapping
- High power - deeper conductors
- Rigid frame, High drag, Slow flying
- X & Z components
- Highly controlled and calibrated



	SkyTEM ¹⁰¹	SkyTEM ³⁰²	SkyTEM ³⁰⁴	SkyTEM ⁵⁰⁸
Main applications	Environmental/Engineering/ Groundwater	Engineering/Groundwater	Groundwater/Mining exploration	Mining exploration
Description	Enables ultra-detailed near-surface resolution due to: <ul style="list-style-type: none"> The extremely fast switch-off of the transmitter current in the small 135 m² single-turn Tx loop The large system bandwidth. 	Enables very detailed near-surface resolution due to: <ul style="list-style-type: none"> The small self-inductance produced by only 2 transmitter loop turns on high moment The large system bandwidth. 	Enables detailed near-surface resolution due to: <ul style="list-style-type: none"> Relatively high system bandwidth The use of low moment Relatively high depth penetration due to: <ul style="list-style-type: none"> Damped receiver coil system giving a high SNR 4 transmitter loop turns on high moment 	Dual mode: Enables good near-surface resolution and relative large depth penetration due to the use of damped receiver coil. Single mode: The near-surface resolution remains class-leading for helicoptertime-domain EM systems, whilst simultaneously providing a very large depth penetration due to: <ul style="list-style-type: none"> More decays in the stack pr. unit time as only high moment is used A low system bandwidth providing a better SNR than dual mode
Maximum depth of penetration	100 m	200 m	350 m	450 m
First bias free gate after beginning of current termination	5.2 μ s on low moment	10 μ s on low moment	13 μ s on low moment	26 μ s on low moment
Receiver coil system embedded in the tower construction	Undamped	Undamped	Damped	Damped: <ul style="list-style-type: none"> Dual mode: 100 kHz Single mode: 10 kHz
System bandwidth	300 kHz	300 kHz	100 kHz	Dual mode: 100 kHz Single mode: 10 kHz
Transmitter modes	Dual mode: <ul style="list-style-type: none"> Low moment: 1 transmitter loop turn, 7.5 A peak current High moment: 1 transmitter loop turn, 55 A peak current 	Dual mode: <ul style="list-style-type: none"> Low moment: 1 transmitter loop turn High moment: 2 transmitter loop turns 	Dual mode: <ul style="list-style-type: none"> Low moment: 1 transmitter loop turn High moment: 4 transmitter loop turns 	Dual mode: <ul style="list-style-type: none"> Low moment: 1 transmitter loop turn High moment: 8 transmitter loop turns Single mode: <ul style="list-style-type: none"> High moment: 8 transmitter loop turns
Waveform shape	Exponential rise	Exponential rise	Exponential rise	Pseudo-rectangular
Base frequencies	Low and high moment: 175 Hz	Low moment: 175 Hz High moment: 25 Hz	Low moment: 175 Hz High moment: 25 Hz	Dual mode: <ul style="list-style-type: none"> Low moment: 175 Hz High moment: 25 Hz Single mode: <ul style="list-style-type: none"> High moment: 25 Hz or 12.5 Hz
Maximum dipole moment	7,000 NIA	65,000 NIA	138,000 NIA	500,000 NIA

FOR

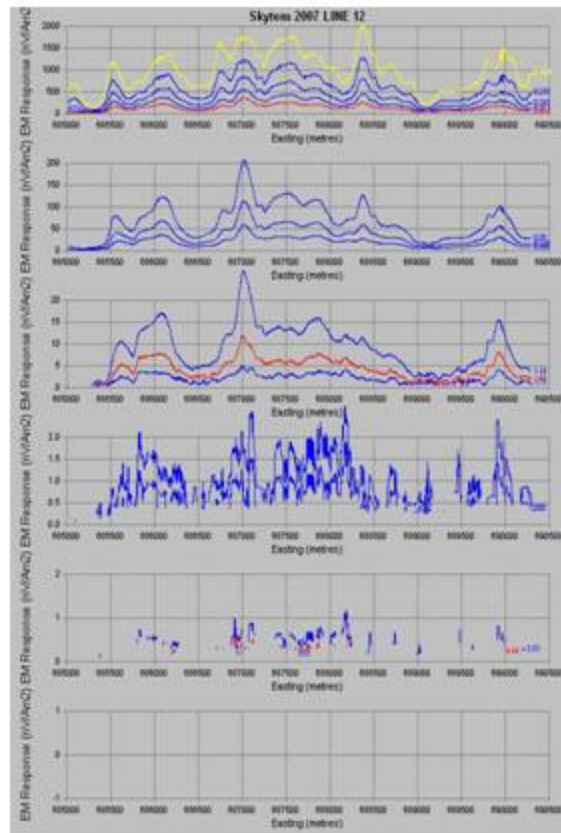
- Very high resolution for shallow mapping
- Highly calibrated
- Low noise & no drift
- Dual moment operation
- Wide system choice

AGAINST

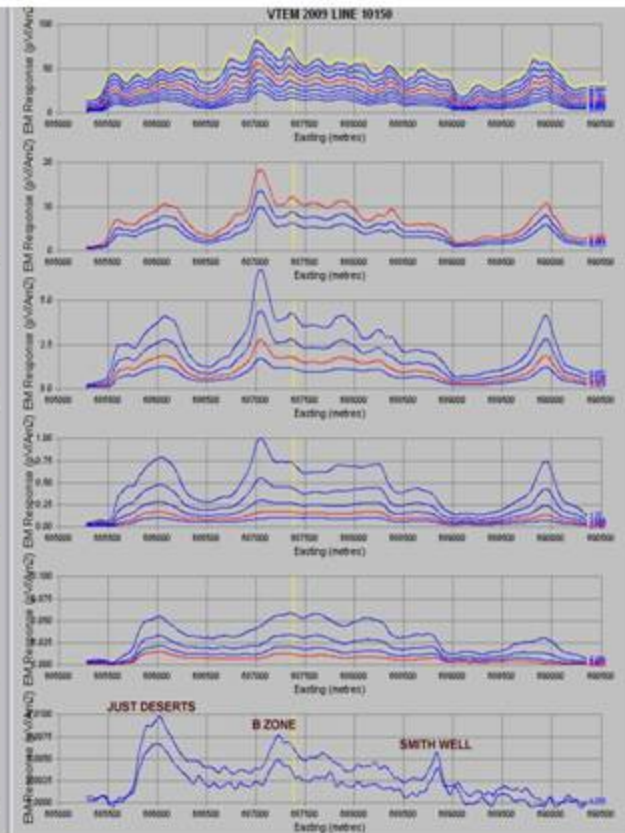
- Slow flying
- No B-Field
- Lower power than opposition

INDICATIVE COSTS: Not supplied

SKYTEM 2007

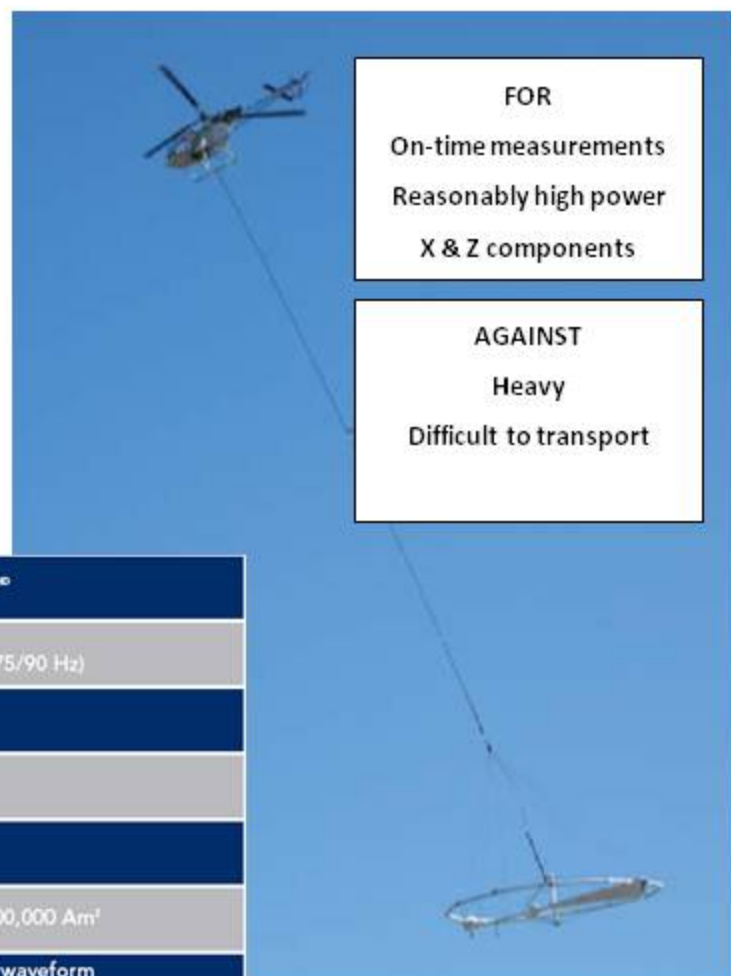


VTEM 2009



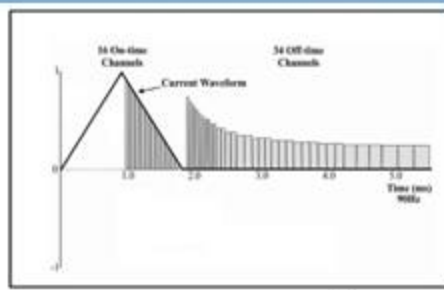
Early Skytem - low in power and penetration for bedrock conductor search
 New systems claimed to be much better

- Developed by Aeroquest, Canada. Taken over by Geotech and system retired
- Very successful in Canada
- Bought to Australia by UTS but very few if any successful surveys
- Rigid frame
- Triangular waveform → On-time measurement



FOR
 On-time measurements
 Reasonably high power
 X & Z components

AGAINST
 Heavy
 Difficult to transport



	AeroTEM II	AeroTEM IV	AeroTEM [®]
Base operating frequency:	125/150 Hz (optional 75/90 Hz)	25/30 Hz (optional 75/90 Hz)	25/30 Hz (optional 75/90 Hz)
Transmitter waveform:	Bipolar triangular pulse, 20 to 50% duty cycle		
Transmitter coil:	Vertical dipole		
Receiver coils:	Vertical Z axis plus horizontal X axis (along flight line)		
Transmitter dipole moment:	40,000 Am ²	Up to 340,000 Am ²	Up to 1,000,000 Am ²
Data output:	16 on-time channels plus 17 off-time channels for X and Z components available full waveform streaming data up to 34 off-time channels		
Output sampling rate:	10 per second - selectable		
Tow cable:	40 m	60 m	70 m
System Size (diameter):	5 m	12 m	20 m
Magnetometers:	Geometrics G823A high-sensitive Cesium sensor (.001 nT) sampled @ 10 Hz		

HELICOPTER FREQUENCY DOMAIN SYSTEMS

All helicopter-borne electromagnetic (HEM) systems used to be of this type.

Transmitting coils and receiver coils all in a “bird”

Continuous sinusoidal transmitter waveform

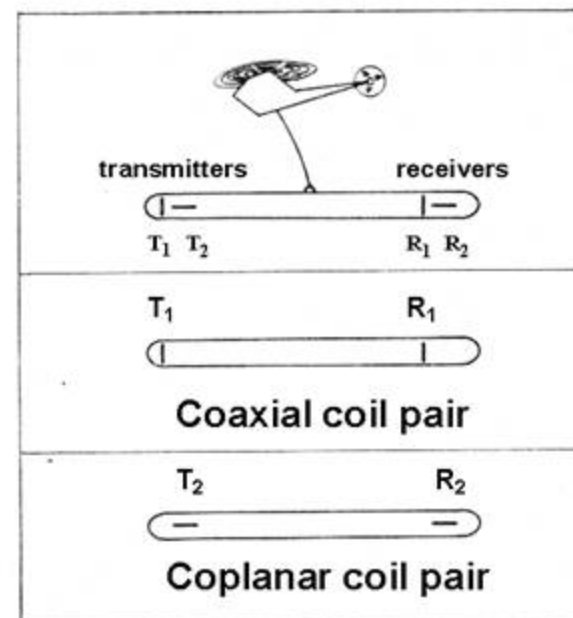
Multiple coil pairs at various frequencies

“Co-axial” Coil axes in direction of flight

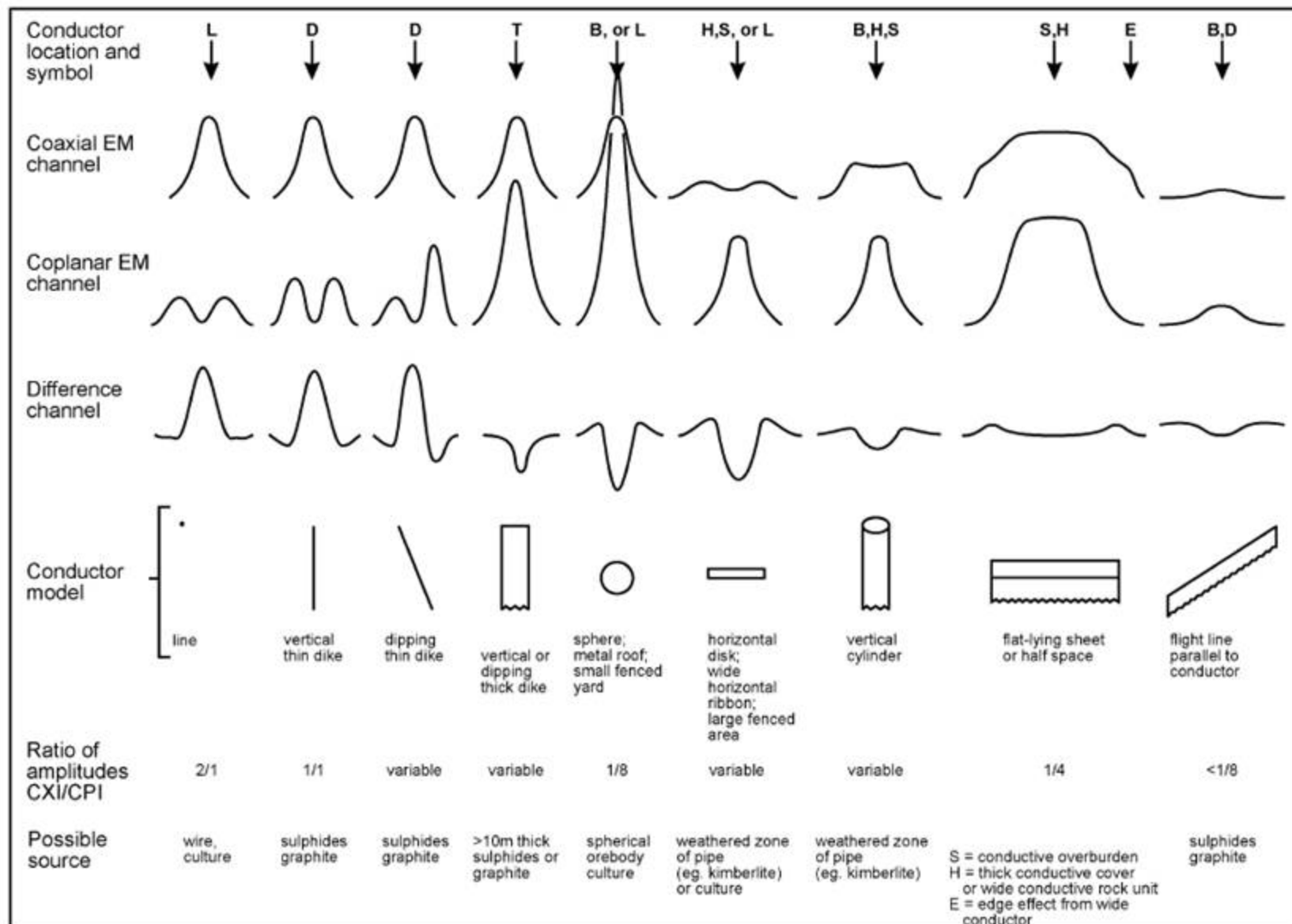
“Co-planar” Vertical coil axes

Measures the in-phase and quadrature, of the secondary field

The different coil orientations provide useful conductor geometric information



HELICOPTER FREQUENCY DOMAIN SYSTEMS



Typical HEM anomaly shapes

DIGHEM– Fugro Airborne Surveys

- Developed by Doug Fraser (& Teck) in the 1970s
- Used extensively worldwide for over forty years
- Coplanar coil pairs at frequencies of 900, 7200 and 56000 Hz
- Coaxial coil pairs at 1000 and 5500 Hz.
- Coplanar coil pairs - greatest sensitivity to the conductivity of the earth and its layering
- Coaxial coil pairs - strongest anomalies from vertical conductors, such as steeply dipping massive sulphides and cultural or human-made conductors.
- High resolution but shallow penetration compared to HTEM
- Well suited to mapping of weaker conductors such as kimberlites



FOR

High resolution
Sensitive to weak conductors
Good geometrical information

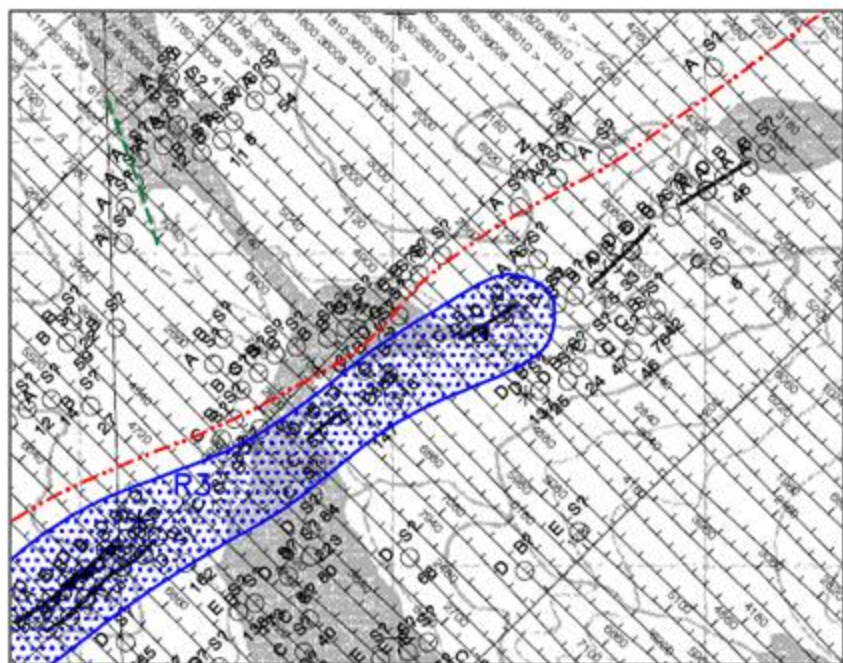
AGAINST

Low penetration
Not well suited for deep bedrock conductor search

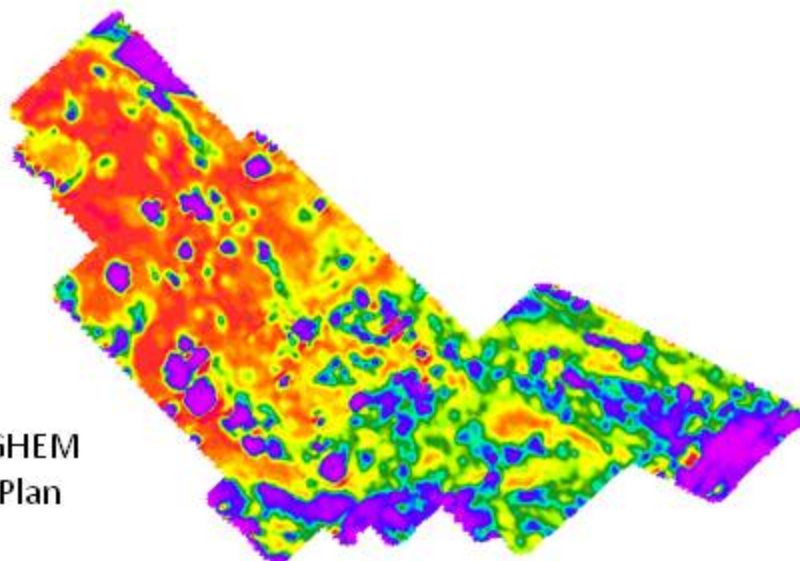
INDICATIVE COSTS: Not supplied



DIGHEM– Fugro Airborne Surveys



Typical DIGHEM Anomaly Plan



Typical DIGHEM Resistivity Plan

ELECTROMAGNETIC ANOMALIES

Grade	Anomaly	Conductance
7	●	>100 siemens
6	●	50–100 siemens
5	⊕	20–50 siemens
4	⊕	10–20 siemens
3	⊕	5–10 siemens
2	○	1–5 siemens
1	○	< 1 siemens
–	*	Questionable anomaly

Anomaly identifier	Interpretive symbol	Conductor model
●	B	Bedrock conductor
●	D	Narrow bedrock conductor ("thin dike")
⊕	S	Conductive cover ("horizontal thin sheet")
⊕	H	Broad conductive rock unit, deep conductive weathering, thick conductive cover ("half-space")
○	E	Edge of broad conductor ("edge of half space")
□	L	Culture, e.g. power line, metal building or fence
△	M	Magnetite

Standard DIGHEM Interpretation scheme

A derivative from DIGHEM

Designed more for mapping earth resistivities as well as horizontally layered geology, making it ideal for environmental and engineering applications.

Six-frequency system, with horizontal coplanar coils at 400 Hz, 1800 Hz, 8200 Hz, 40 kHz, 140 kHz, and one coaxial coil at approximately 3300 Hz

FOR

High resolution

Sensitive to weak conductors

AGAINST

Low penetration

Not well suited for bedrock conductor search

INDICATIVE COSTS: Not supplied



Developed by Geotech as a competitor to DIGHEM and sold commercially

Very similar to DIGHEM in nearly all aspects

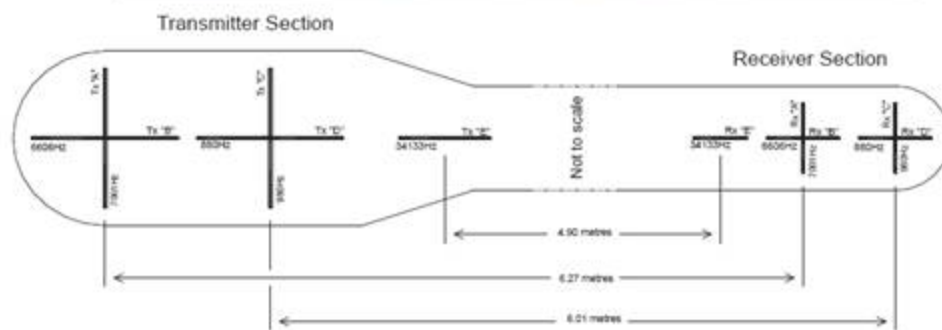
Was operated here by Geoinstruments so data is around

Not currently offered in Australia

Operated out of Canada by at least two contractors



COIL FREQUENCY	COIL ORIENTATION	COIL SEPARATION	CHANNELS
880 Hz	Coplanar	6.0 meters (19.5ft)	I, Q
980 Hz	Coaxial	6.0 meters (19.5ft)	I, Q
6.6 kHz	Coplanar	6.3 meters (20.5ft)	I, Q
7 kHz	Coaxial	6.3 meters (20.5ft)	I, Q
34 kHz	Coplanar	4.9 meters (16ft)	I, Q



Layout and dimensions of the transmitter and receiver coils in the HUMMINGBIRD EM system



FIXED WING FREQUENCY DOMAIN SYSTEMS

These were the first AEM systems developed

Relatively low powered

All on time measurements – quadrature and in-phase

Multiple frequencies

Bird or fixed receivers

Best suited to high resolution shallow penetration mapping

Currently only one commercial system but not in Australia

Digital data from GTK system available for African countries



AAC McPhar F400 system



GTK system

Not used in Australia

Vertical coplanar coils on wingtips

Developed initially as a two frequency system by the Geological Survey of Finland in 1980

Used to survey much of Finland

Used extensively on Aid Programs in Africa

Purchased by the British Geological Survey and extended to four frequencies

Now operated by Sander Geophysics of Canada

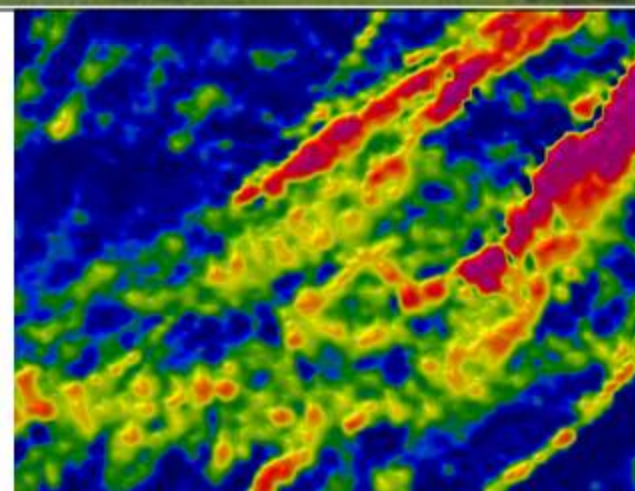


Frequencies (Hz)	912	3005	11962	24510
Tx-Rx coil spacing (m)	21.35	21.35	21.38	21.38
Magnetic moment (Am ²)	190	127	49	27

High resolution

Shallow penetration

Low power



Apparent conductivity calculated from 25 kHz EM data

AIRBORNE MAGNETOTELLURIC SYSTEMS

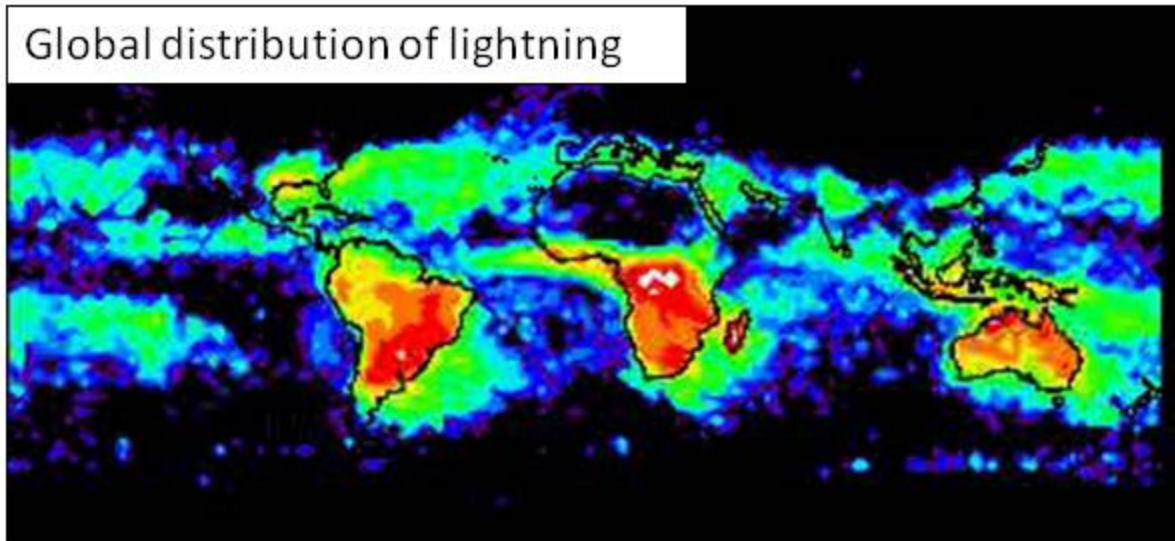
Measures magnetic fields from currents induced in conductors using lightning strikes as transmitter

Good sensitivity to lateral weak resistivity contrasts

Also sensitive to large discrete conductors conductivity such as massive sulphides but prefers long strike length features

Deep penetration – in excess of 1000m

Interpretation not easy – Ambiguity between contacts and confined conductors



ZTEM

- Natural magnetic (AFMAG EM) field measurement (30-720Hz)
- Fixed Base Station
- Airborne Z axis loop sensor that acquires vertical magnetic field data.
- Receiver loop-tilt correction via use of onboard GPS sensors
- Rx loop diameter: 7 m
- Tx/Rx height: 50 m nominal

Measures T_{zx} (in-line) and T_{zy} (cross-line) Tipper vectors

- Magnetics: Cs Sensor



AirMt

Key System Parameters

- Natural magnetic (AFMAG EM) field measurement (45-720Hz)
- **3-axis loop sensor with identical base station**
- No Receiver loop-tilt correction necessary (GPS for positioning only)
- In-Phase and Quadrature transfer functions
- Peak responses over lateral variations in resistivity structure
- Tx/Rx height: 50 m nominal

Measures rotationally invariant Amplitude Parameter (AP)

- Magnetics: Cs Sensor

Applications

Resistivity Mapping – Mineral Industry
Porphyries
Environmental
Hydrocarbon
Geothermal



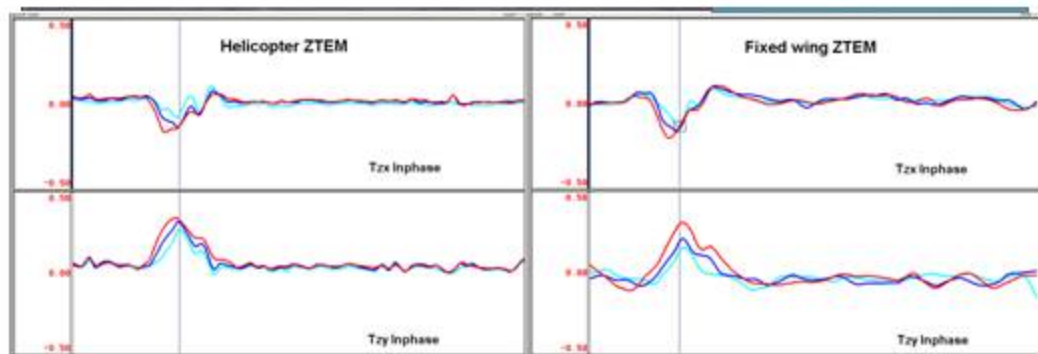
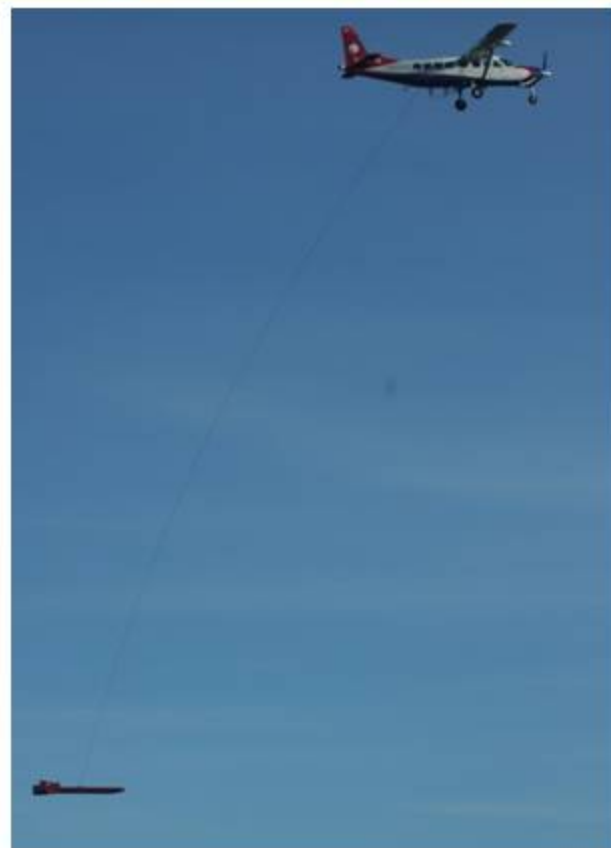
ZTEM – Fixed Wing

- Natural magnetic (AFMAG EM) field measurement (30-720Hz)
- Fixed Base Station
- Airborne Z axis loop sensor that acquires vertical magnetic field data.
- Receiver loop-tilt correction via use of onboard GPS sensors
- Tx/Rx height: 50 m nominal

- Measures Tzx (in-line) and Tzy (cross-line) Tipper vectors
- Magnetics: Cs Sensor

Applications

- Low Cost Regional Resistivity Mapping
- Porphyries
- Environmental
- Hydrocarbon
- Geothermal



Notice Excellent Repeatability between ZTEM & FW-ZTEM Results



Designed by SGC in 2006 to facilitate the testing of the performance of airborne, surface and down hole EM systems.

Site locations, results and data are available.



FORRESTANIA (85km east of Hyden): Shallow (<100m) and deep (300-400m) sulphide conductors.

Known AEM surveys

VTEM(2007)m, ZTEM(2010), HELITEM (2011), VTEM-Max (2011)

Known Ground EM surveys

FLTEM coil and HT squid, MLTEM coil and fluxgate, DHEM (coil), Fixed Loop SAMSON Total Field

NEPEAN (25km south of Coolgardie): Several shallow (90m) sub-vertical sulphide conductors

Know AEM surveys

Hoistem(2004), VTEM(2007), HeliGeotem(2008), Aerotem (Jan 2009, September 2010), XTEM (2009), VTEM (2011)

Known Ground EM surveys

MLTEM (coil & Fluxgate), DHEM (coil)

CONCLUSIONS

Airborne EM - responsible for many discoveries over last fifty years and cost effective rapid exploration method

Extremely wide range of uses for AEM - massive sulphide detection, geological mapping, paleochannel delineation, ground water exploration, bathymetry, etc.

To optimise exploration and value for money - very important to match AEM system used and survey design to survey objectives. Many mistakes are made.

Fixed wing systems -> large footprint and lower cost but with lower resolution and asymmetrical response.

Helicopter systems -> higher cost but higher resolution, symmetrical response and shorter line lengths.

Frequency domain systems best suited to shallow penetration mapping applications

Time domain systems -> high power and penetration - better at deep bedrock conductor search.

This is an exciting field of geophysics and has advanced faster than almost any other technique in mineral exploration in recent years with new systems appearing almost monthly.