Sub-Audio Magnetics (SAM)

Deep Penetration EM

Malcolm Cattach

Chief Geophysicist – Gap Geo Group

CEO – Gap Geophysics Australia

CEO – Gap GeoPak

Introduction

- We’ve picked the “low-hanging” fruit!
  - Near-surface mineral resources have “probably” already been discovered due to their relative ease of detection
- Future exploration will focus on targets under cover
  - Likely to be more subtle, deeper or more difficult targets
  - Extensive deep drilling is prohibitively expensive
  - Greater dependence on *Geophysics* to provide high quality drill targets
- Exploration Budgets are under strain
  - Currently a situation of very low commodity prices
  - Significantly reduced exploration budgets
- It is imperative that mining companies achieve *maximum* benefit from their exploration budgets in this environment.

We need to get creative with our Geophysics!

Geophysical Survey Considerations

- Viable exploration (mineable) depths
  - Typically surface -> 1000 m
  - Low grade or small deposits at significant depth are of less interest.
- Shallow Exploration (0 -> 300m)
  - Surveys benefit more from high spatial resolution
  - Significantly improves interpretability of finer geological structure
  - Reduces ambiguity of interpretation
- Deep Exploration (300 -> 1000m)
  - Deep exploration receives little guidance from surface expression
  - The deeper the orebody, *the longer the wavelength of anomalies*
  - Deeper orebodies need to be high grade or large to be viable (in our favour)
  - Statistics - Exploration success will become more dependent on achieving as much coverage for the $$ as possible.

Deep Penetration Electrical Geophysics

- Deep Penetration electrical geophysical techniques require:
  1. Larger Scale surveys
  2. Greater Sensitivity
  3. Significantly increased transmitter power (where active sources are used)
  4. More efficient acquisition (ground acquisition is very slow and expensive)
  5. Reduced Cost
- Deep Penetration Surveys are very challenging if they are to be cost-effective. They need to be:

  "Bigger, Better, Deeper, Faster, Cheaper"

- *Recent developments in the field of Sub-Audio Magnetics (SAM) have enabled us to address these various challenges.*

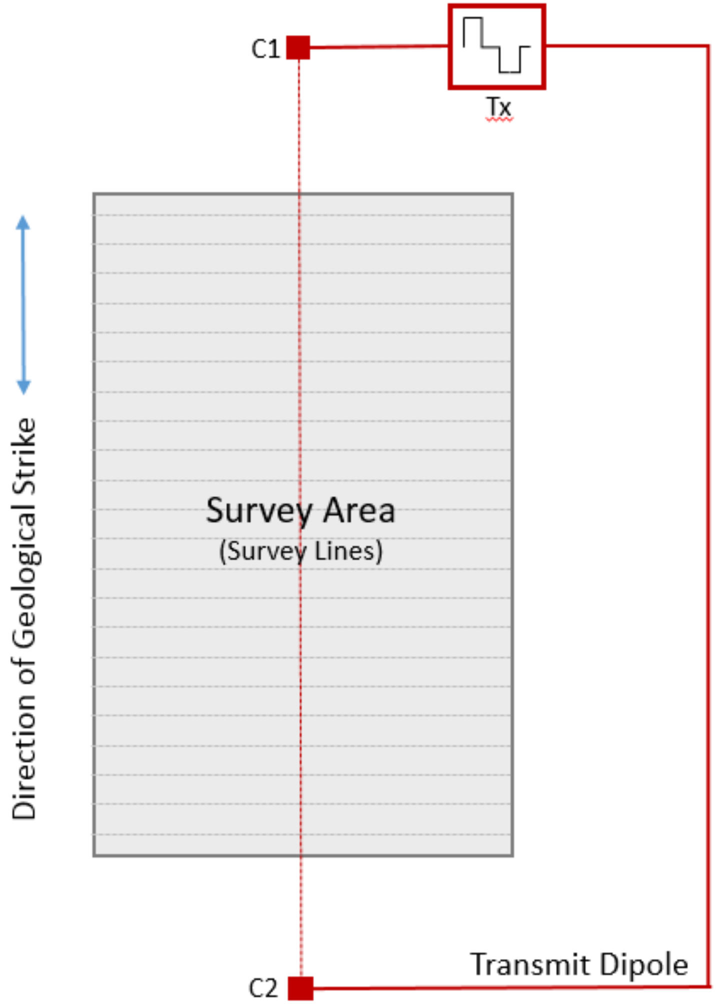
Sub-Audio Magnetics (SAM)

"Sub-Audio Magnetics is a proprietary, rapid acquisition, geophysical method which provides high spatial definition and / or deep penetration data related to both the electrical and magnetic properties of the earth"

1. Geophysical transmitter -
   - Produces an alternating electromagnetic field either through distant electrodes or through a loop
2. High performance *Cs vapour Total B-Field* magnetometer
   - Measures the earth's EM response to the Transmitted signal simultaneously with the Earth's magnetic field (Geomagnetic Field acts as a "carrier" signal)
3. Signal Post-Processing
   - Separates the EM signal from the earth's magnetic field with a Low Pass Filter
   - Extracts parameters of interest from SAM Waveform
4. Information provided depends on survey configuration but includes:
   - Total Magnetic Intensity (TMI)
   - Total Field Magnetometric Conductivity (TFMMC)
   - Total Field ElectroMagnetics (TFEM)
   - Total Field MagnetoMetric Induced Polarisation (TFMMIP)

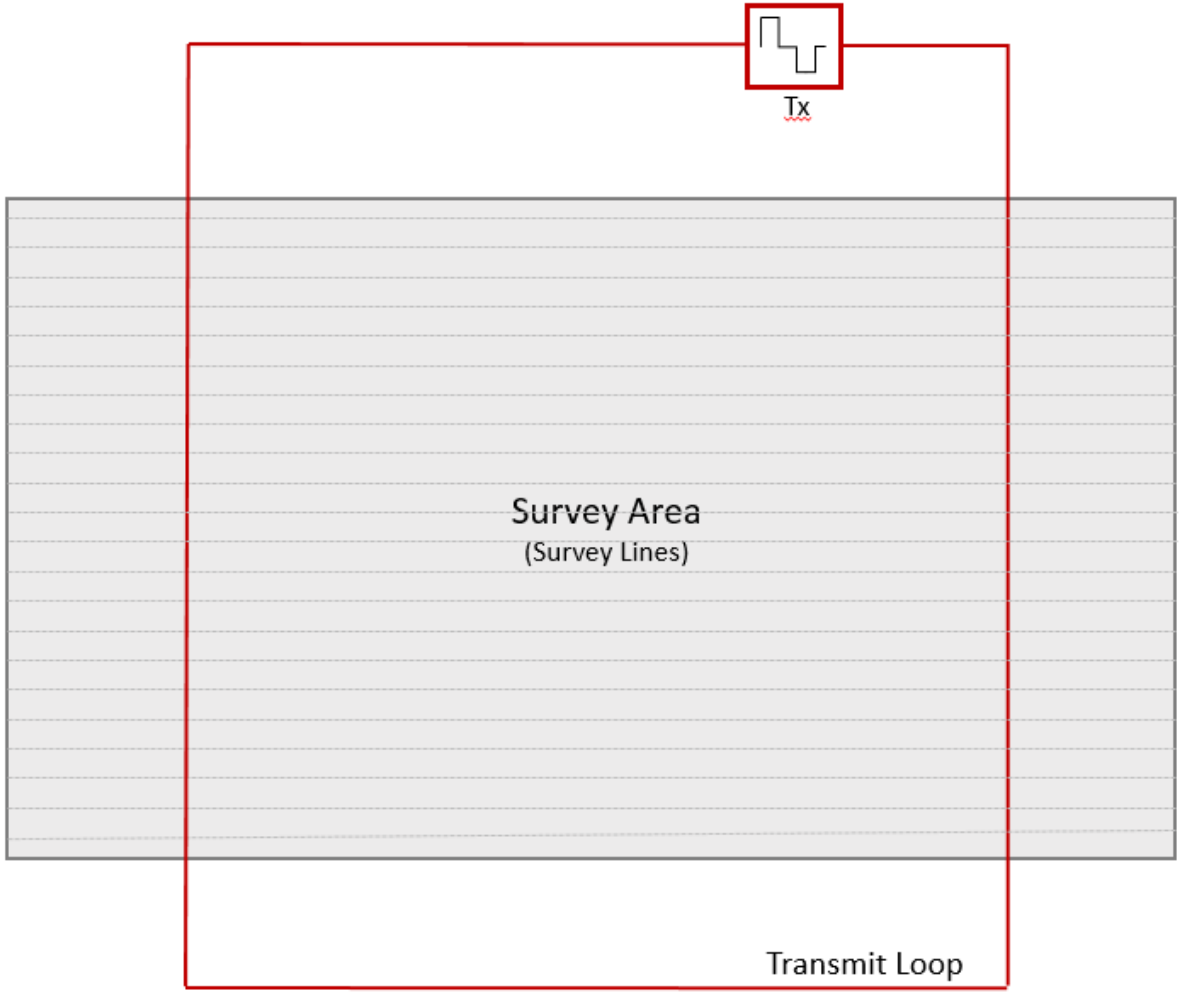
SAM Survey Configurations

Galvanic Source (MMR Mode)



*Dipole Separation typically 2-10 km

Inductive Loop (FLEM Mode)



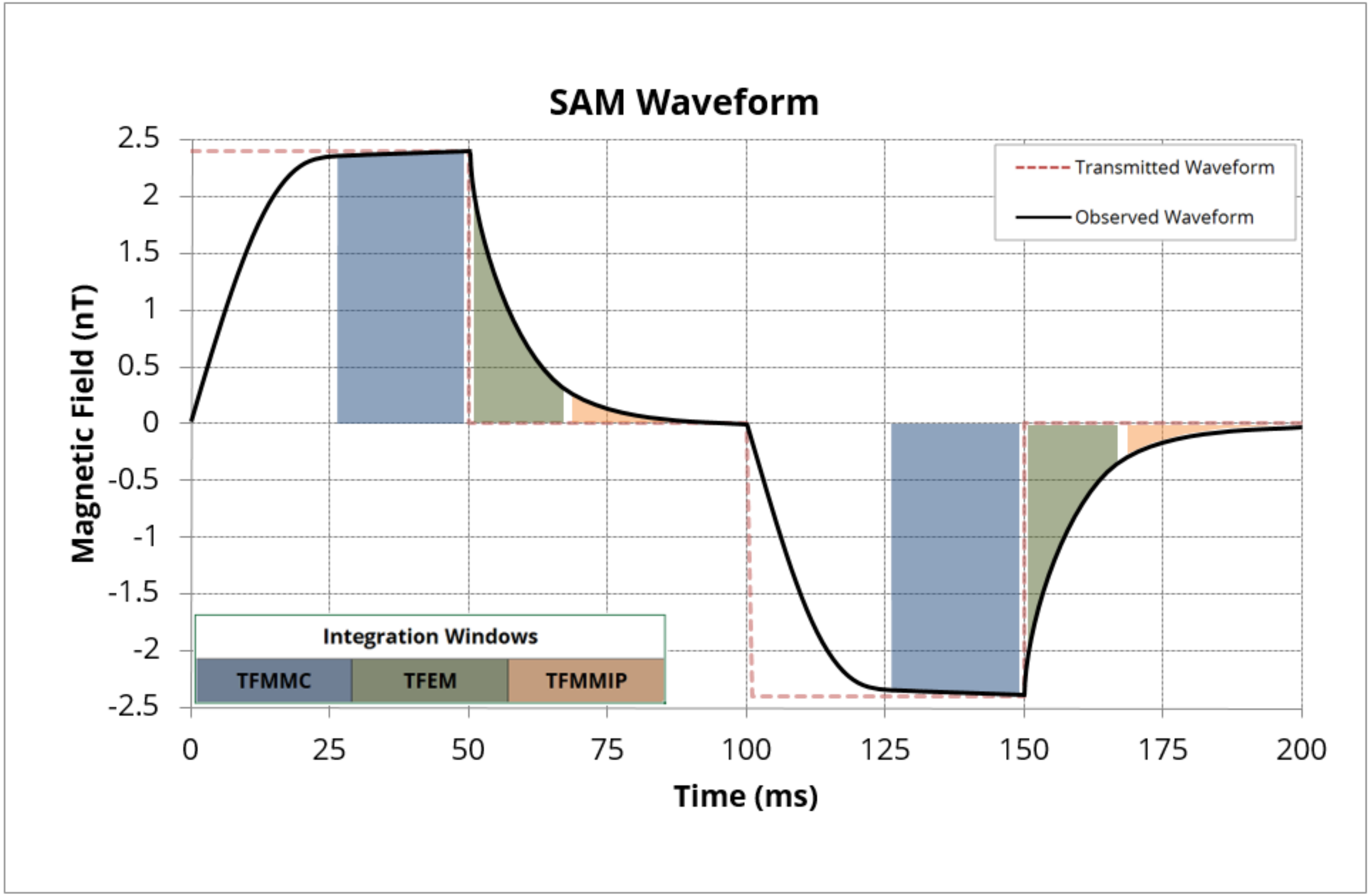
*Loop Sides typically 400 - 2500 m

Comparison of EM Sensors

Sensor	Coil	Fluxgate	SQUID	Cs Vapour
Low Frequency Performance	Poor	Good	Excellent	Excellent
High Frequency Performance	Good to Excellent	Poor	Good to Excellent	Poor
B or dB/dt	dB/dt	B	B	B
Vector or Scalar	Vector 3 Component	Vector 3 Component	Vector 3 Component	Scalar Total Field

- **Vector sensors**
  - Require levelling and orientation or orientation needs to be accurately monitored
  - Susceptible to movement (rotational noise) - need protection from the wind and vibration.
- **Scalar sensors – Make SAM Possible!**
  - No orientation required. Fairly immune to rotational noise – can be used in poor conditions.
  - Enable dynamic acquisition, high spatial definition, lower cost surveys.
  - The key to SAM has been the development of sophisticated frequency counter technology capable of extracting high precision data at high sample rates.

SAM Waveform



- Sub-Audio Frequencies
  - < 20Hz
  - 50% Duty Cycle
  - Square Wave
- TFMMC measurement
  - ON time signal
- TFEM / TFMMIP
  - OFF time signal

  (much weaker signal)

Twenty-Five Years of SAM Development

Year	Milestone
1991	Development of SAM Concept / International Patent Filed
1992 - 2002	Initial Feasibility Research (PhD); Prototype SAM Receiver (TM-4)
2003	First Prototype SAM Receiver (TM-6) was developed (with USACE)
2004	SAM TMI / TFMMR surveys fully commercialised in Australia
2005	Gap Geophysics Australia incorporated
2006	Development of TM-7 SAM Receiver (first Engineering Prototype)
2007	Development of Gap HeliMAG System
2008	Gap GeoPak incorporated to develop high powered transmitters
2009	First commercial HeliSAM / TFMMR surveys
2009	First GeoPak High Powered transmitters / SAMSON commissioned
2014	First successful TFEM trials conducted for mineral exploration ➢ SAM EM Survey - Forrestania EM Test Range, WA ➢ HeliSAM EM Survey - Lalor VMS Deposit, Manitoba
2015	Ground / HeliSAM TFEM surveys commercialised in Australia and Canada
2016	Gap Discovery JV incorporated (Gap Geophysics / Discovery International Geophysics / DIAS)

Gap Geophysics TM-7 SAM Receiver

Number of Cs Vapor Sensors	Up to 4
Sampling Rates (samples /sec)	1200, 2400, 4800, 9600
RMS noise @1200, 2400, 4800, 9600	0.02, 0.04, 0.12, 0.58 nT
Counter absolute error	0.043 nT @ 50000 nT = 0.9 ppm
Larmor measurement range	350-131000 nT (equivalent)
Real-Time Clock	Synchronized to GPS PPS

SAM – Dynamic Acquisition

- Sensor and TM-7 are mounted on non-metallic frames and separated from the instruments / acquisition system
- Typical Tx frequencies: 3.125 - 15 Hz (Walked); 1 Hz (Towed Sled)
- Sample Intervals: TMI – 0.5m; MMC – 2.0m; TFEM – 5.0m
- Acquisition rates
  - Terrestrial: Typically 15-20 km per day
  - Salt Lake: 10 km per hour
- Speed is dependent on Tx frequency, sensor elevation and magnetic noise

SAM Airborne Platforms

- Gap HeliSAM Acquisition Platform
  - Used commercially for large dipole (up to 12 km) SAM MMR surveys
  - Used for large scale SAM EM surveys.
  - Suitable for Tx frequencies >= 3.125 Hz
  - Sample Intervals: TMI – 5.0m; MMC – 20.0m; TFEM – 20.0m (dep. on Frequency)
  - Lower frequencies (1-2Hz) also possible
- Gap UAV systems are in development
  - Lightweight SAM receiver has been built
  - Platforms are technically robust and undergoing trials and certifications
  - UAV's not speed-restricted by "Dead Man's Curve"
  - Will be capable of Tx frequencies ~1 Hz.

SAMSON – Stationary Acquisition

- Most sensitive configuration – used for TFEM or TFMMIP
  - Late time noise levels < 0.005pT/A (Gap GeoPak Tx)
  - Dipole, FLEM or MLEM Modes
  - Sensor is mounted on a tripod
  - No orientation, levelling or stable platform required
  - Immune to wind and vibration
  - Low Tx frequencies – typically 0.125 to 2Hz
  - Typically 3-5 minute stations
  - Acquisition Rate – typically 8-12 stations per hour
  - Logistically simple – lightweight, no cryogenic cooling required
  - Logging time and stack time are preset in the SAMUI control software
  - Real-time Quality Control

SAMSON Surveys
Atacama Desert, Chile (Top, Middle)
Finland (Bottom)

Electrical Geophysics Data Quality

- Data quality depends partly on external factors
  - Cultural noise (50/60 Hz)
  - Telluric noise (low frequency)
  - Operator
- Where an active Tx source is used (MMR, IP or EM), two fundamental factors govern both quality and depth of exploration for the surveys:
  - The ability of the "Receiver System" to detect the very weak Secondary EM fields.
  - The ability of the "Transmitter System" to induce current flow in conductors at exploration depth.

**If the transmitter system isn't powerful enough to induce a response from the conductor, the most sensitive receiver won't detect it.*

- In recognition of this, Gap GeoPak subsidiary was established to develop a range of "High Performance" geophysical transmitters.

Gap GeoPak

- Gap GeoPak transmitters were designed to:
  - Significantly increase power output
  - Significantly increase current output (up to 10 times)
  - Include enhanced safety features which meet and exceed the modern safety requirements
  - Be compatible with commercially available instrumentation

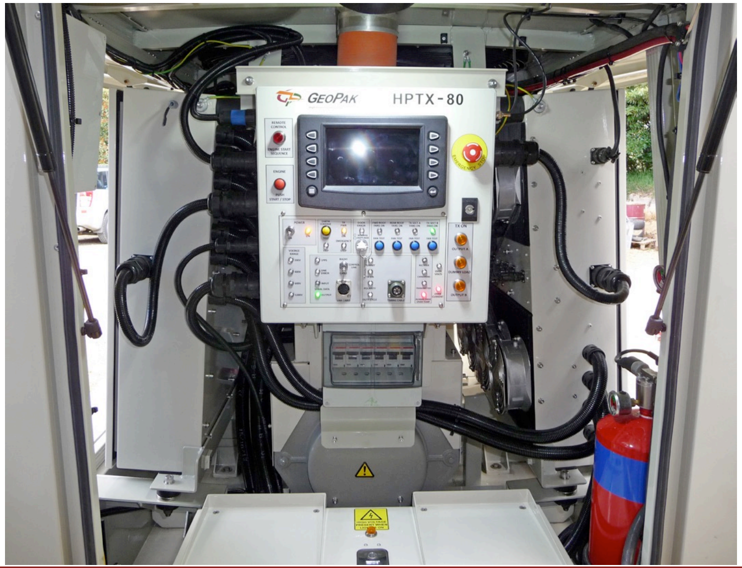
- No single transmitter is ideal for all survey requirements.
  - Need to be *optimised* for different applications.

- Depending on the application and terrain, surveys may require transmitters capable of:
  - High Power (FLEM, DHEM, MMR, IP, SAM)
  - High Voltage (IP, resistivity – galvanic surveys)
  - High Current (EM surveys), or
  - High degree of portability (difficult terrain / poor access) .

GeoPak HPTX-80

- High Power Transmitter
- Ideal for FLEM / DHEM / MMR
- Powered by Cummins 100 kW turbo-diesel engine
- Max Output Power: 80 kW
- Typical current for 800m x 800m loop: 165A (with high ampacity cable)
- ASEG Graeme Sands Award (2013)

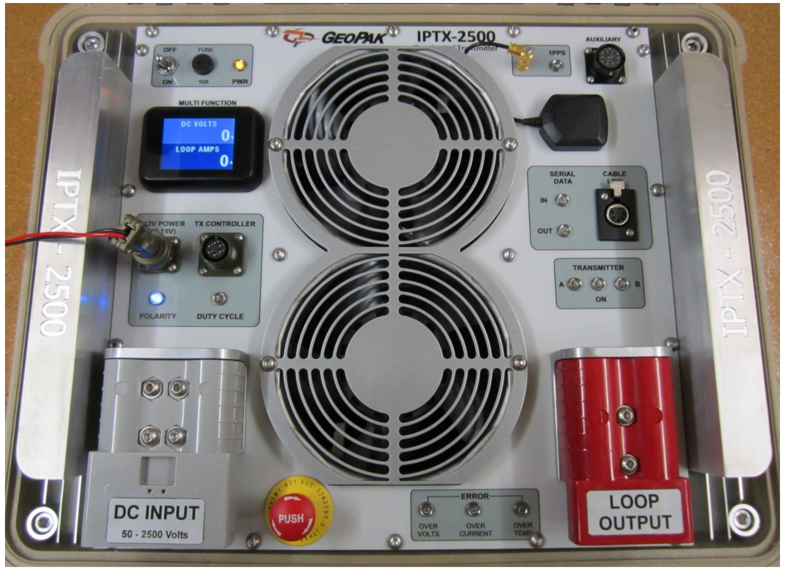
Voltage Range	Min Volts	Max Volts	Max Amps
Range 1	100	200	360
Range 2	200	400	180
Range 3	300	600	120
Range 4	600	1200	60

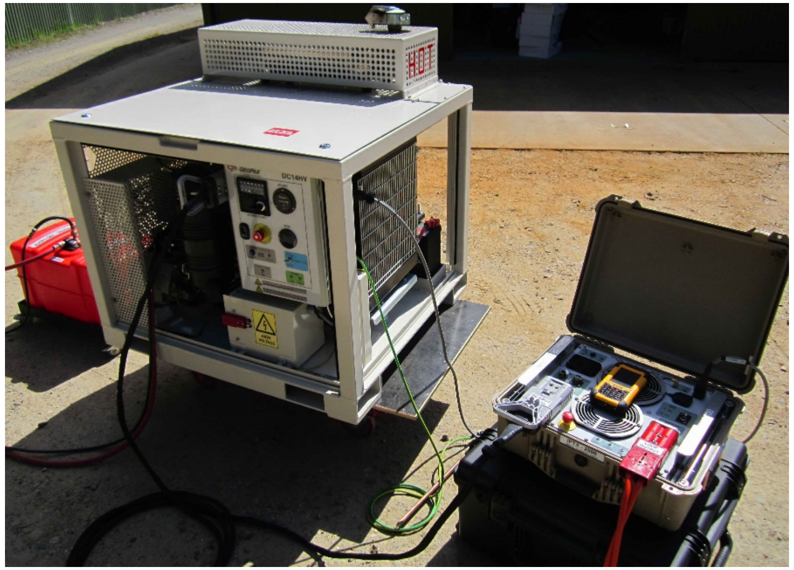


GeoPak IPTX-2500

- High Voltage Transmitter
- DC14HV (14kW) or PS30HV (30kW) power supplies now available; capable of over 100kW.
- Designed for Portability / Remote Access – (can be slung)
- Typical currents: Grounded dipole: 15-30A; Loop 20-50A

Voltage Range	Min Volts	Max Volts	Max Amps
Range 1	100	2500	50

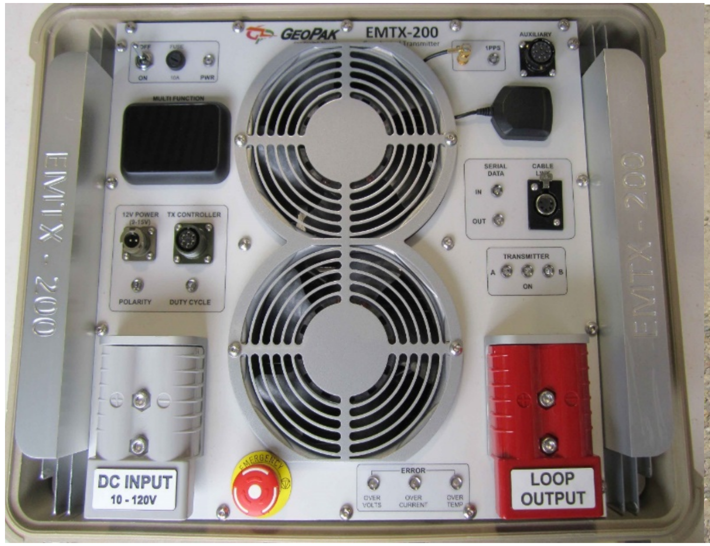




GeoPak EMTX-200

- High Current Transmitter
- DC14MV (14kW) or PS30MV (30kW) power supplies; capable of over 100 kW
- Designed for Lightweight / Portability (Ideal for MLEM)
- Typical current for 200m x 200m loop: 140A (DC14MV)

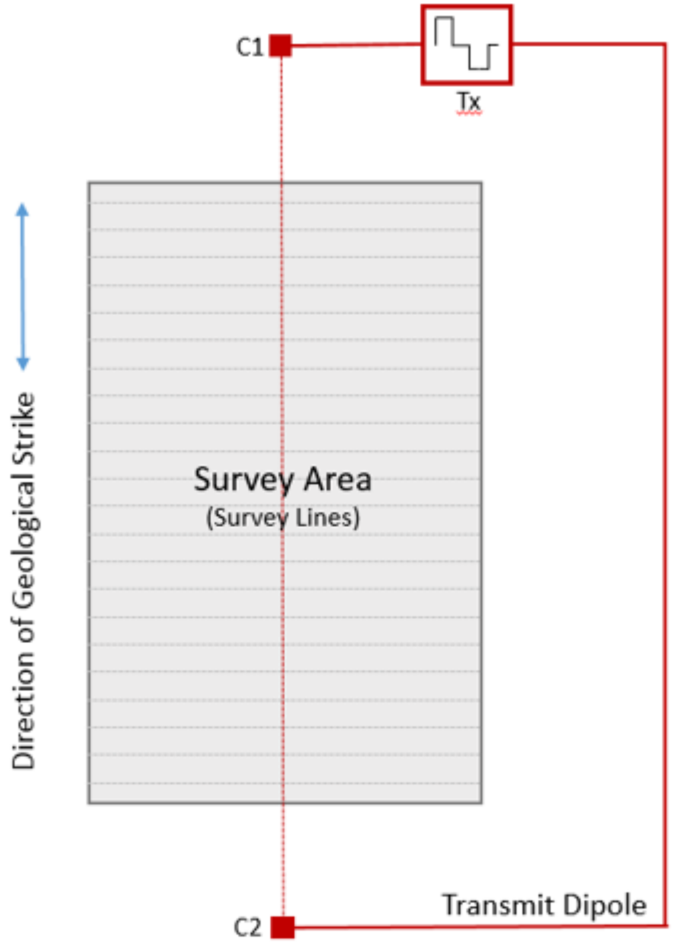
Voltage Range	Min Volts	Max Volts	Max Amps
Range 1	10	120	200




SAM MMR Surveys

- Current channelling technique suitable for mapping vertical / sub-vertical linear stratigraphy and structures
  - Rapid acquisition
  - Extremely high detail
  - Multi-parameter data sets
  - Relatively inexpensive – value for money
  - TMI / MMC data sets offer multiple, complementary views of the geology
  - Recent refinement of Galvanic Source TFEM .
- Examples
  - Polar Bear – Salt Lake Survey, WA
  - Gold Road – Yamarna Belt Survey, WA

Galvanic Source (MMR Mode)



*Dipole Separation typically 2-10 km

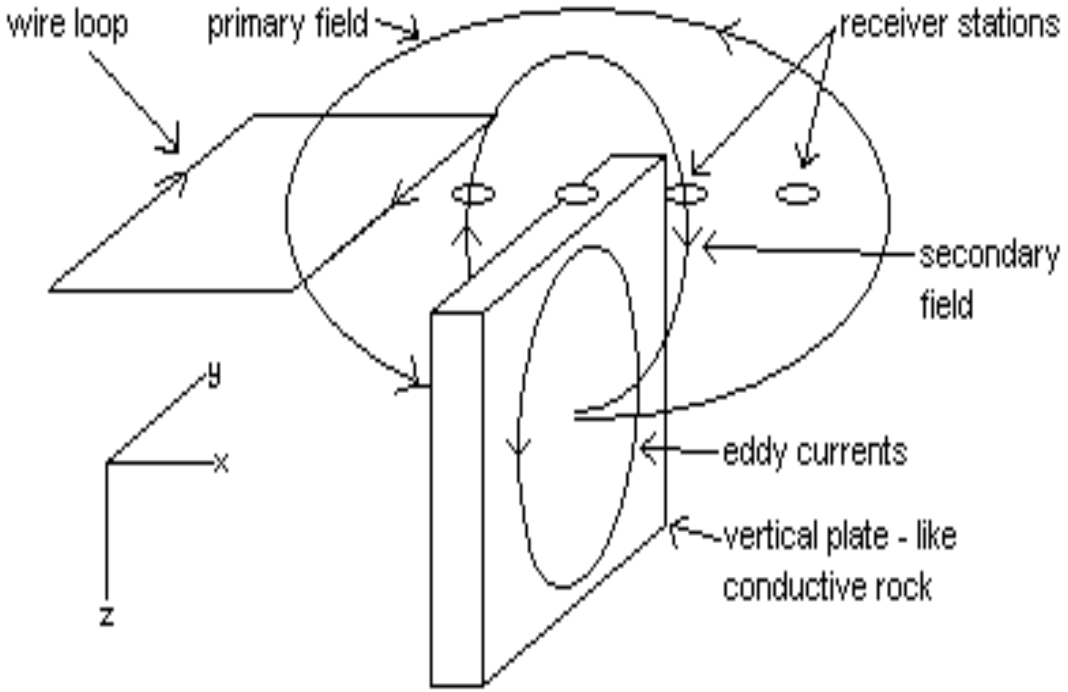
Deep Penetration Transient EM

- Transient EM (TEM) – a very successful geophysical exploration technique designed for the detection of high conductance orebodies.
- Depth penetration of TEM surveys is dependent on transmitter power, transmit frequency and instrument sensitivity.
- Depth penetration will also depend on ground conditions.
- The effective exploration depth of airborne or conventional ground TEM surveys conducted in Australia is likely to be <300m due to our conductive overburden.

**Areas previously explored with TEM should still be considered prospective at greater depth.*

Basic TEM Principles

1. A geophysical transmitter produces an alternating EM field (Primary Field) by transmitting electrical current into a wire loop.
2. The EM field induces secondary electrical current flow (eddy currents) in sub-surface conductors.
3. Eddy currents produce Secondary EM fields.
4. Secondary EM fields are measured at receiver stations by a sensitive EM Receiver as a transient decay.
5. The decays are considered diagnostic of the ground conditions.



Airborne EM

- Airborne EM is an excellent first pass survey technique as it permits:
  - Rapid survey coverage over large areas
  - Relatively low acquisition cost for the area covered.

- However, the ability of AEM to detect orebodies at depth will always be limited due to:
  - High Tx frequencies (typically 25 / 30Hz) – decays normally limited to ~ 10ms
  - Short stacking periods (80 knots = 40 metres per second)
  - Low Tx Power compared to ground EM systems

Ground Level EM

- Used as Primary exploration tool or to follow up AEM anomalies.

- Much greater depth penetration than AEM due to:
  - Low Tx frequencies (typically down to 0.125 Hz)
  - Long station occupation time
  - Significantly higher Tx power than possible with airborne acquisition

- Several drawbacks:
  - *Stationary* readings are necessary for low frequency EM
  - Surveys are consequently slow and expensive to deploy
  - Budget constraints dictate wide line spacing and station intervals
  - EM profiles are generally *spatially under-sampled* as a result.

Transmitter "Systems"

- Consist of:
  - A geophysical transmitter which transmits electrical current into:
  - A Loop consisting of one or many turns.
- Typical Loop sizes:
  - Helicopter borne EM - 20-35m in diameter (SkyTEM, VTEM).
  - Moving Loop (MLEM) – typically 200m x 200m.
  - Fixed Loop (FLEM) - 400m x 400m up to 1000m x 1000m (or more).
- Typical Tx currents
  - May be very 100's of Amps for AEM
  - 10 - 40A for conventional ground surveys.
- The Power of the Transmitter System is called the "Dipole Moment".

**Dipole Moment is a direct measure of the Primary Field's ability to persist to depth.*

Dipole Moment

Dipole Moment = NIA

where N is the Number of turns
I is the current (Amps)
A is the area of Loop (m^2)

Example – SkyTEM 512

NIA SkyTEM (512) =0.775M Am^2

(N=12 turns, I=120 A, A= 536 m^2).

High Power Heli EM System	Peak NIA (MAm^2)
SkyTEM 512	0.775
VTEM Max (GeoTech)	1.4
HeliTEM (CGG)	2.0

Tx Depth Penetration Comparison

Comparison of Dipole Moments

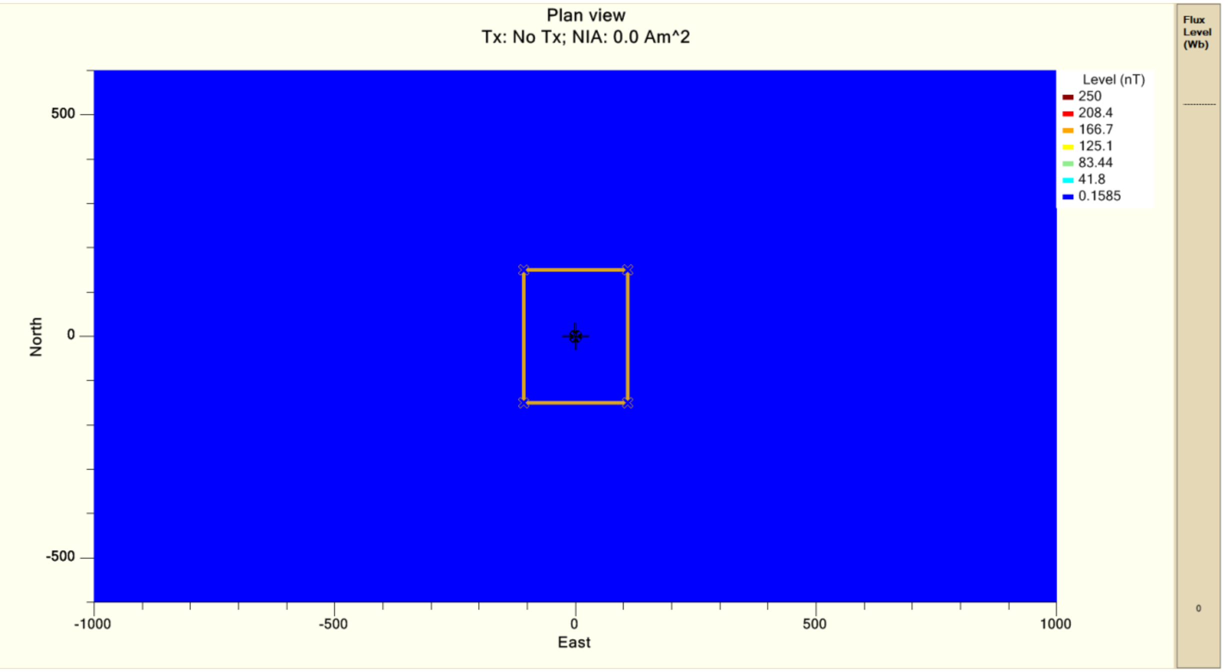
- How does Helicopter-borne EM compare with ground systems for depth penetration?
  - We can calculate the Dipole Moments for various configurations.

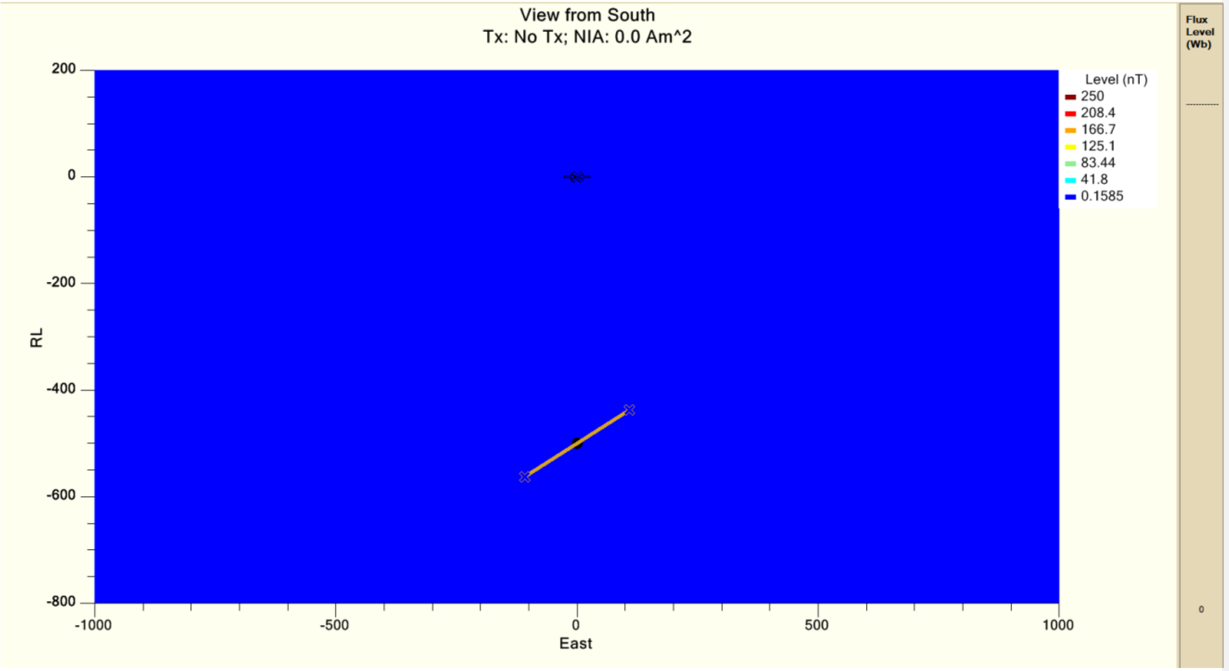
Calculation of Magnetic Flux

- The induced response of the conductor is proportional to the magnetic flux passing through it.
  - We can also calculate the magnetic flux passing though a conductor at depth, using different Dipole Moments (airborne and ground transmitter configurations).

Plate Model for Flux Calculations

Model Plate
- Width: 250m
- Length: 300m
- RL (Centre): -500m
- Dip: 30 deg





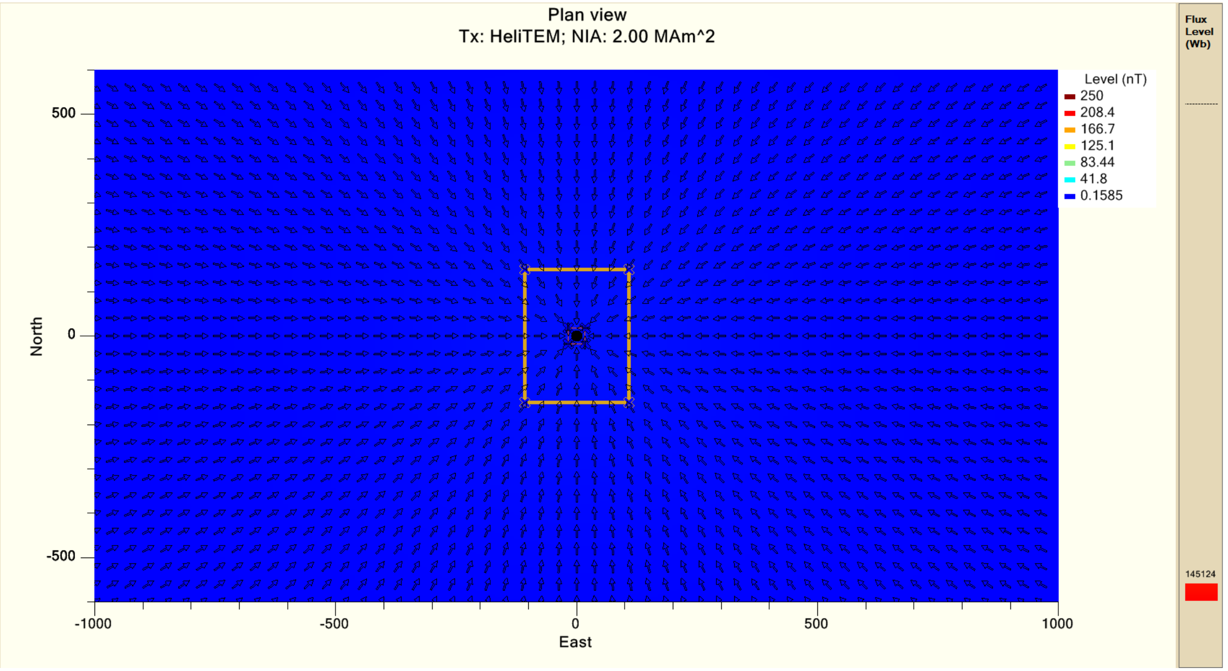
Helicopter TEM – NIA 2.0 MAm^2

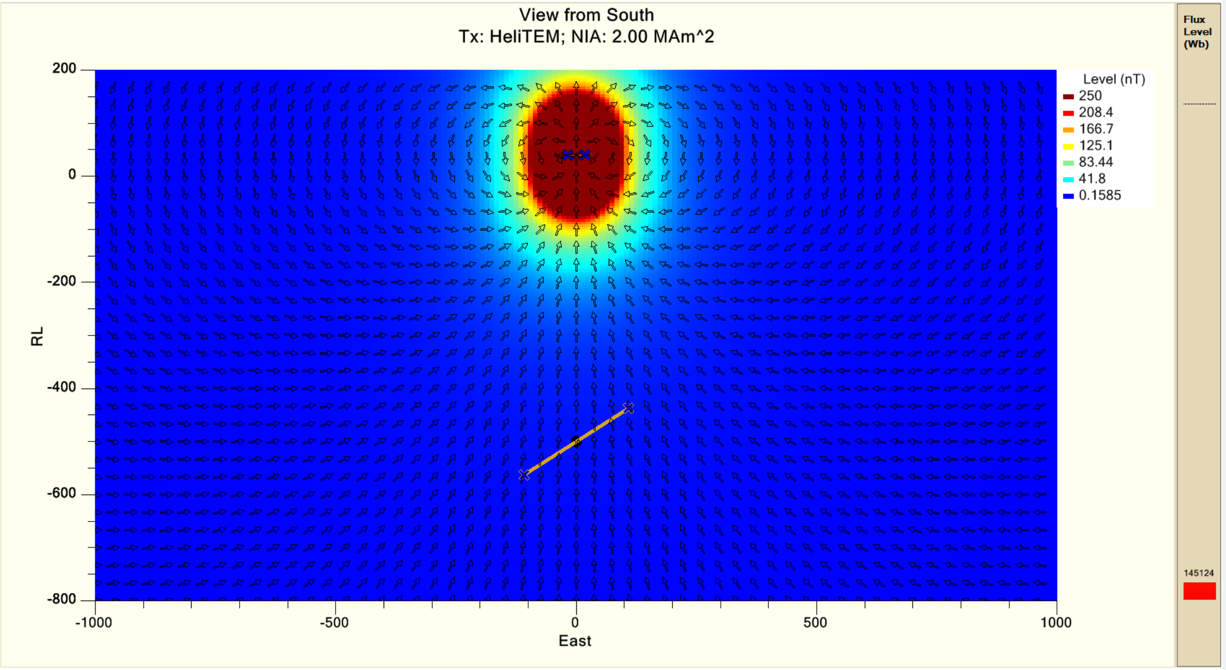
SAM

Model Plate
- Width: 250m
- Length: 300m
- RL (Centre): -500m
- Dip: 30 deg

Tx Specifications
HeliTEM
Elevation 40m

Magnetic Flux
145,124 Wb



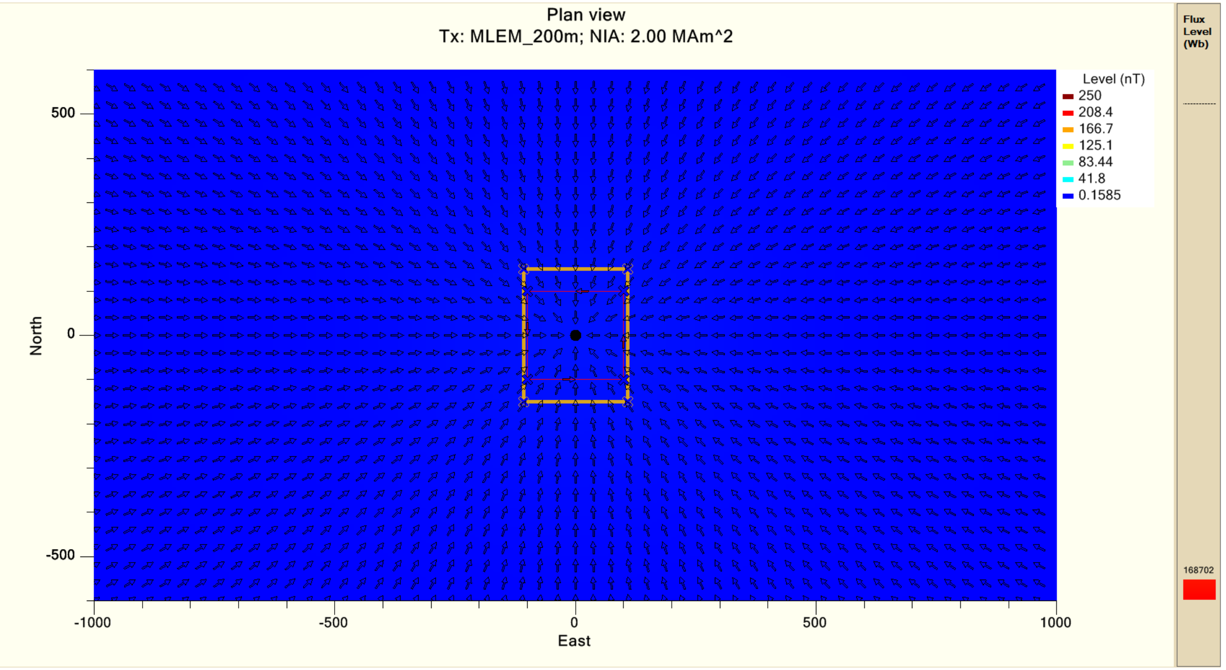


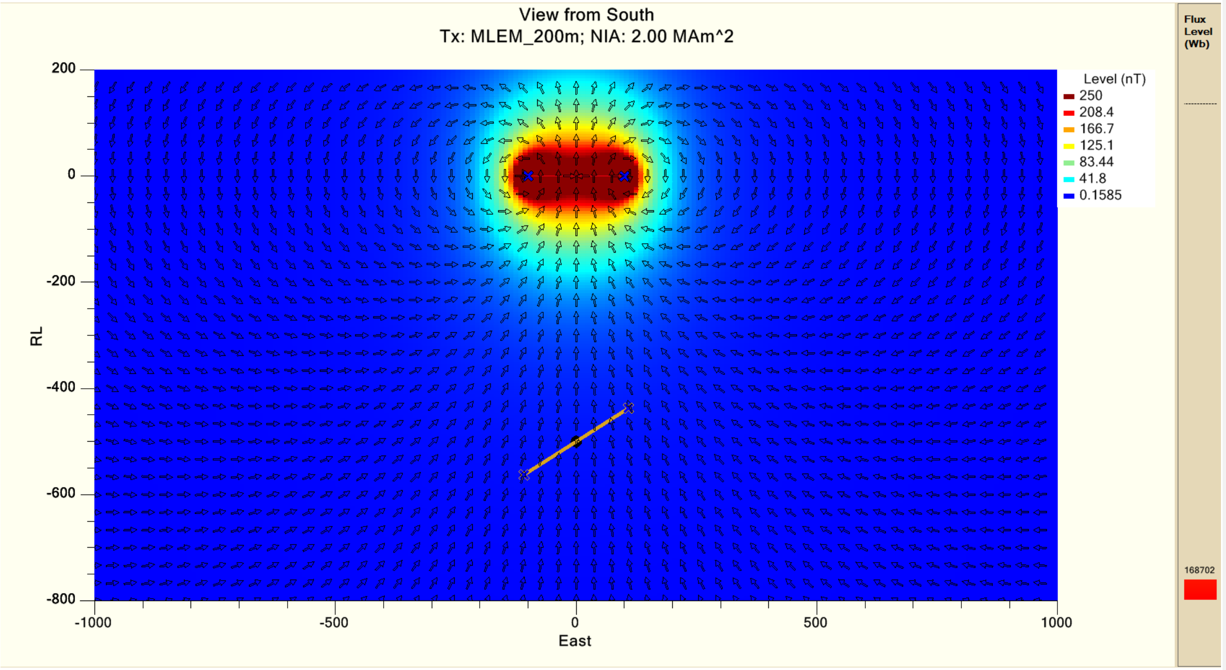
MLEM_200m - NIA 2.0 MAm^2

Model Plate
- Width: 250m
- Length: 300m
- RL (Centre): -500m
- Dip: 30 deg

Tx Specifications
High Power ZT-30
Double Turn Loop
Current: 50 A

Magnetic Flux
168,702 Wb





MLEM_400m - NIA 4.0 MAm^2

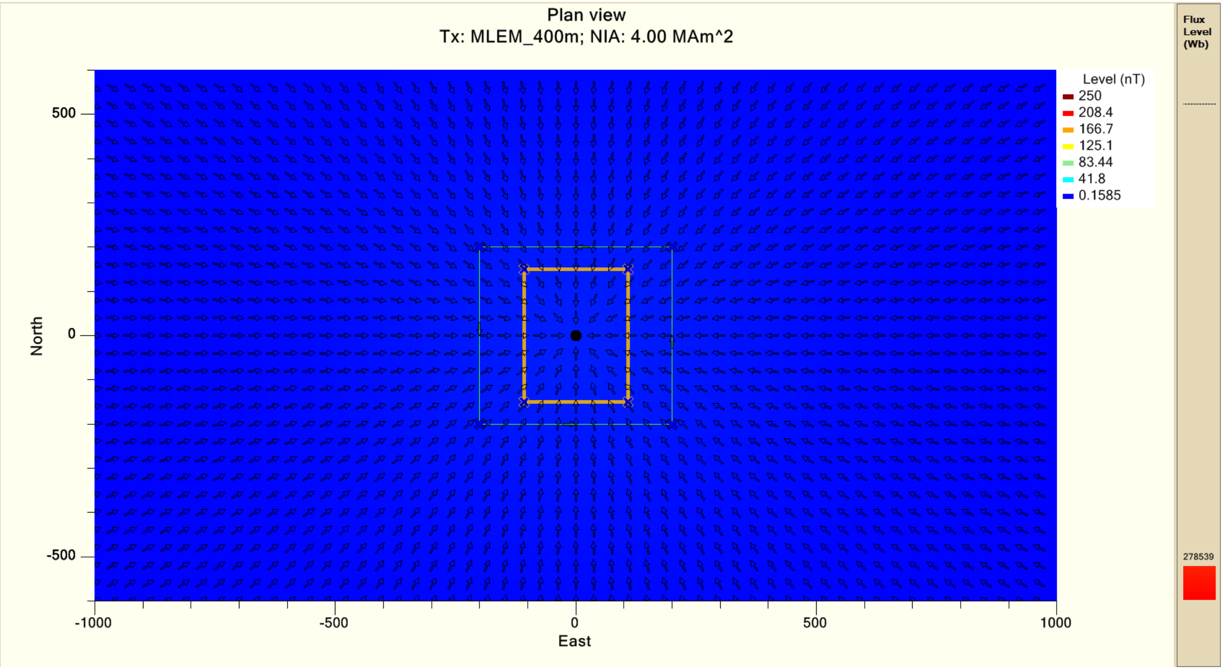
SAM

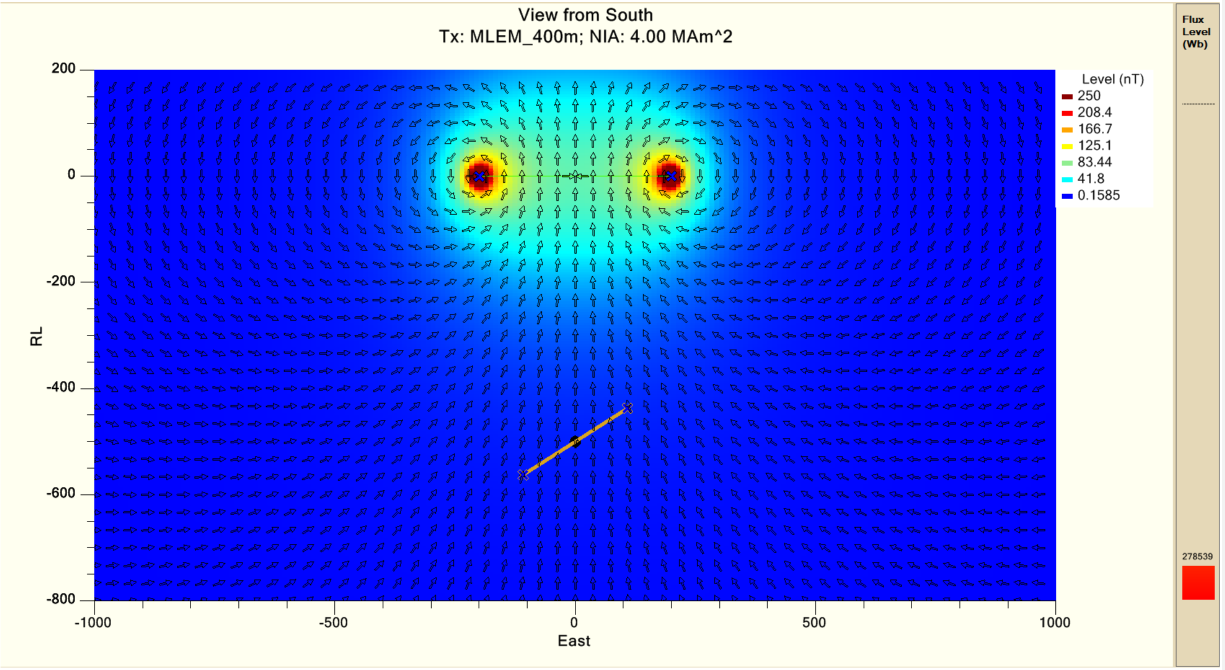
Model Plate

- Width: 250m
- Length: 300m
- RL (Centre): -500m
- Dip: 30 deg

Tx Specifications
High Power ZT-30
Single Turn Loop
Current: 25 A

Magnetic Flux
278,539 Wb





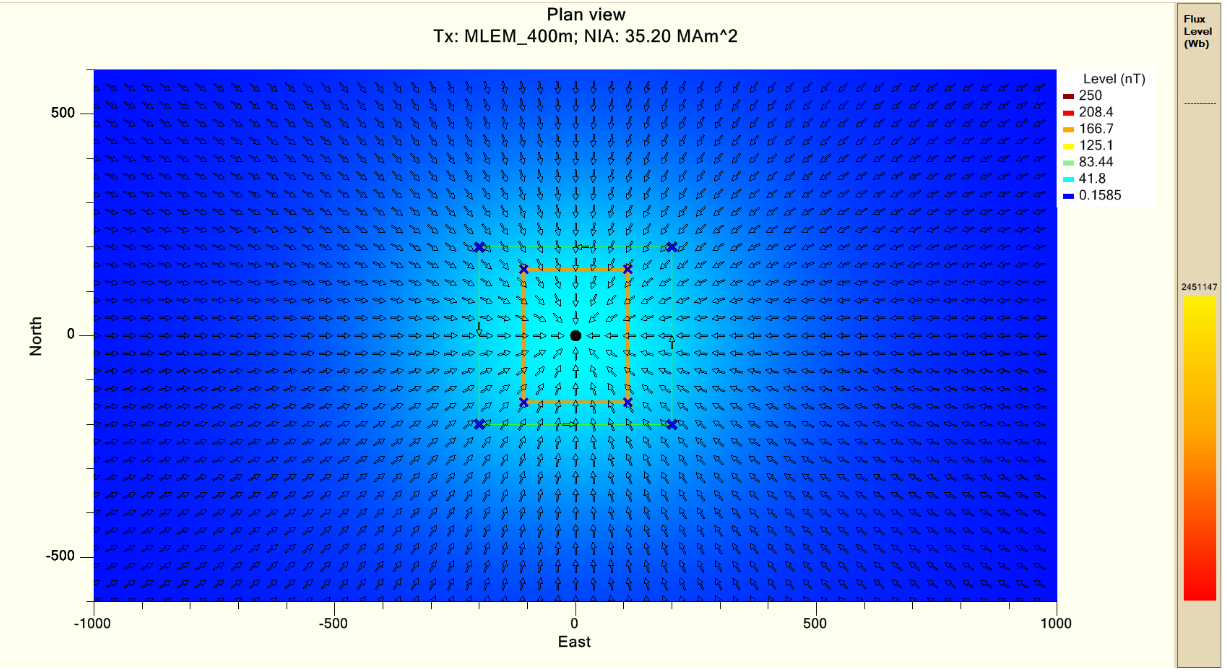
MLEM_400m - NIA 35.2MAm^2

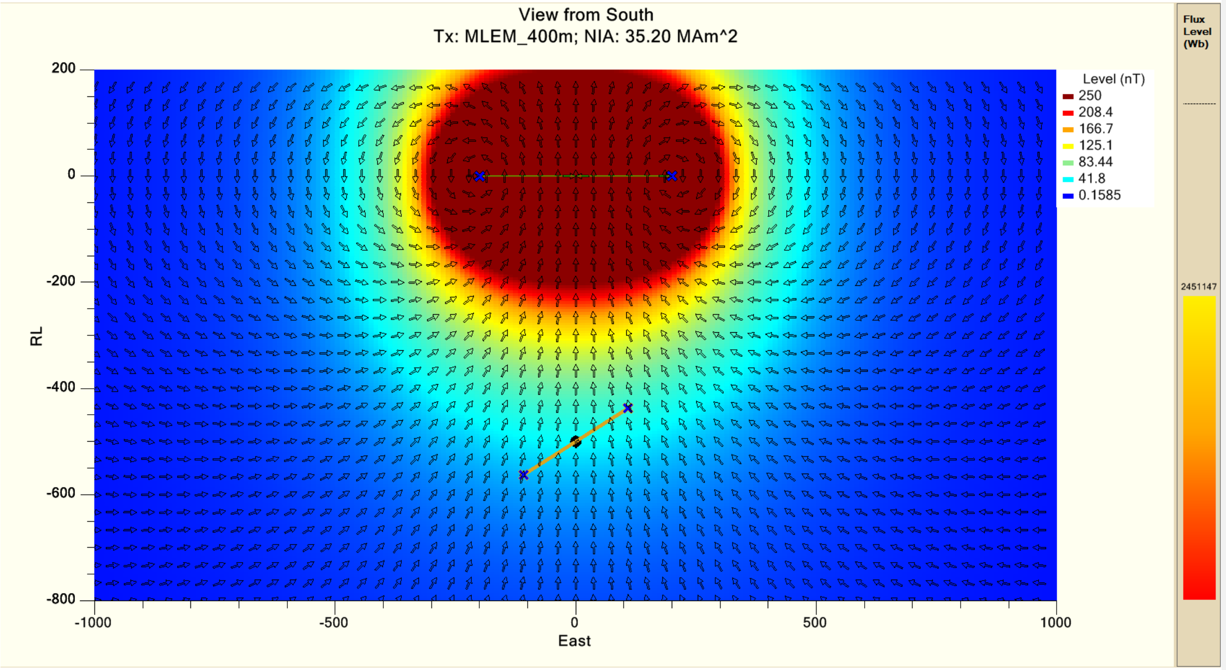
SAM

Model Plate
- Width: 250m
- Length: 300m
- RL (Centre): -500m
- Dip: 30 deg

Tx Specifications
GeoPak HPTX-70
Single Turn Loop
Current: 225 A

Magnetic Flux
2,451,147 Wb



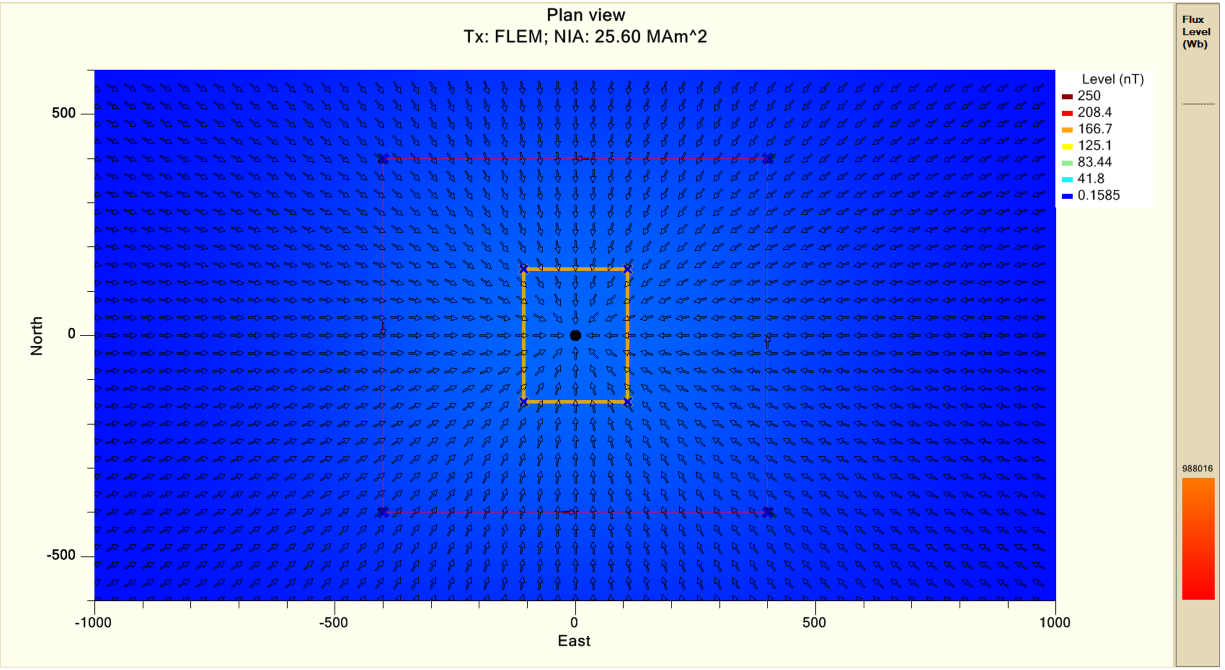


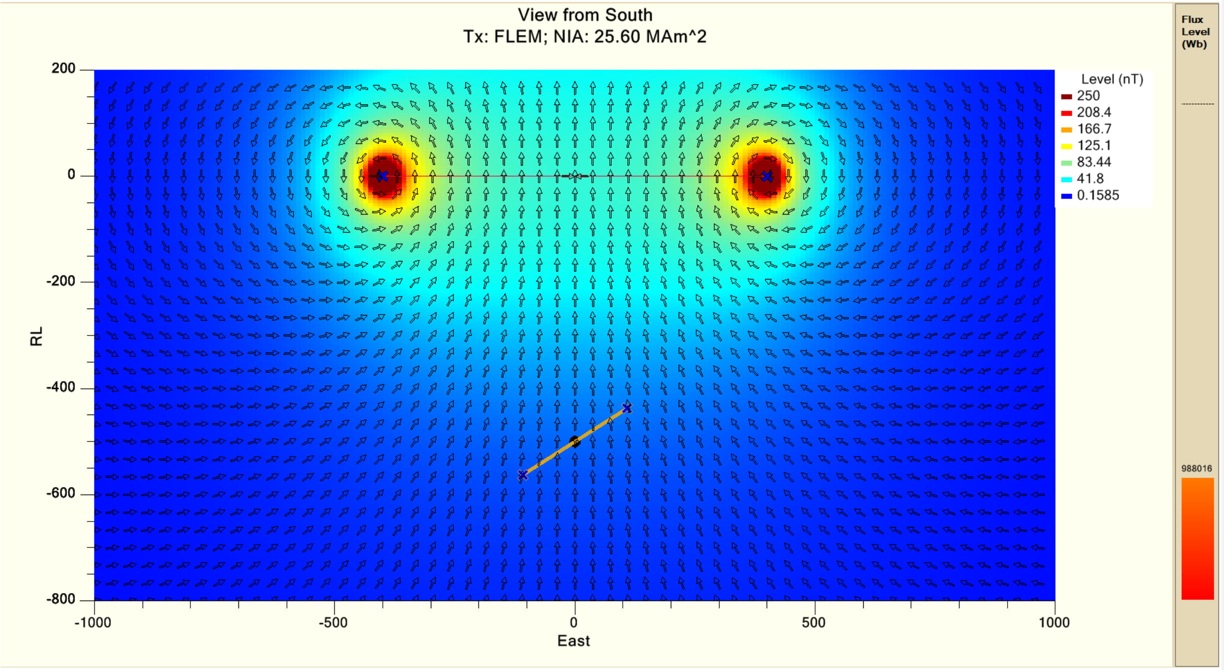
FLEM_800m - NIA 25.6 MAm^2

Model Plate
- Width: 250m
- Length: 300m
- RL (Centre): -500m
- Dip: 30 deg

Tx Specifications
Phoenix TXU-30
Single Turn Loop
Current: 40 A

Magnetic Flux
988,016 Wb





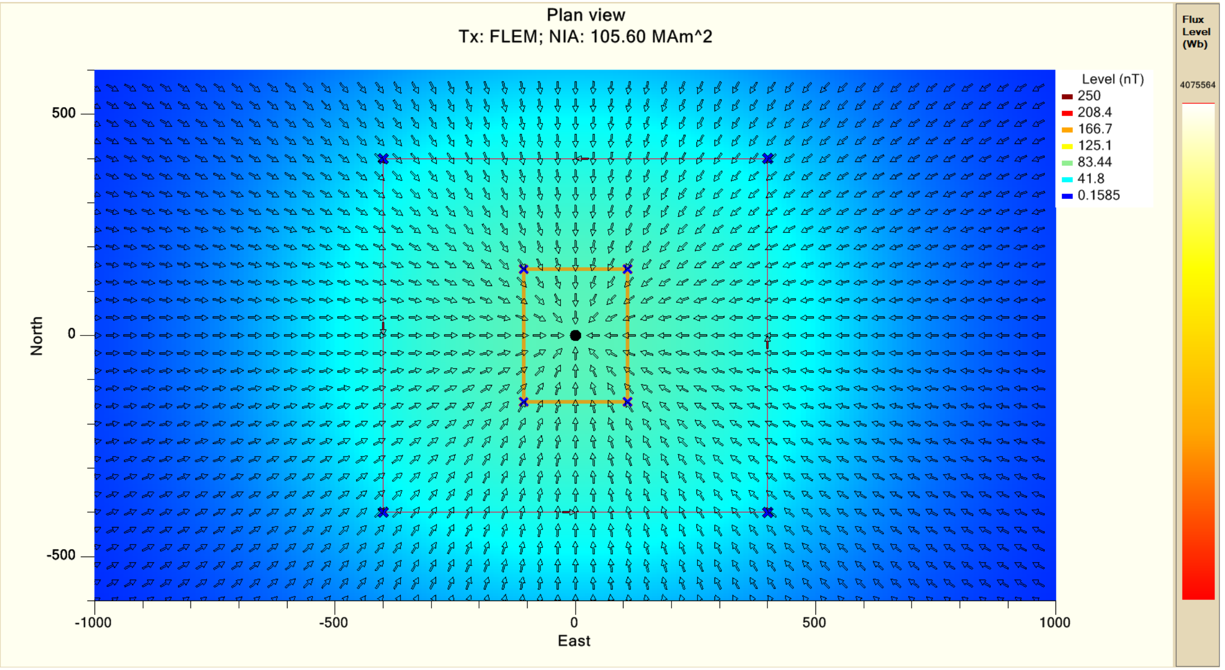
FLEM_800m - NIA 105.6 MAm^2

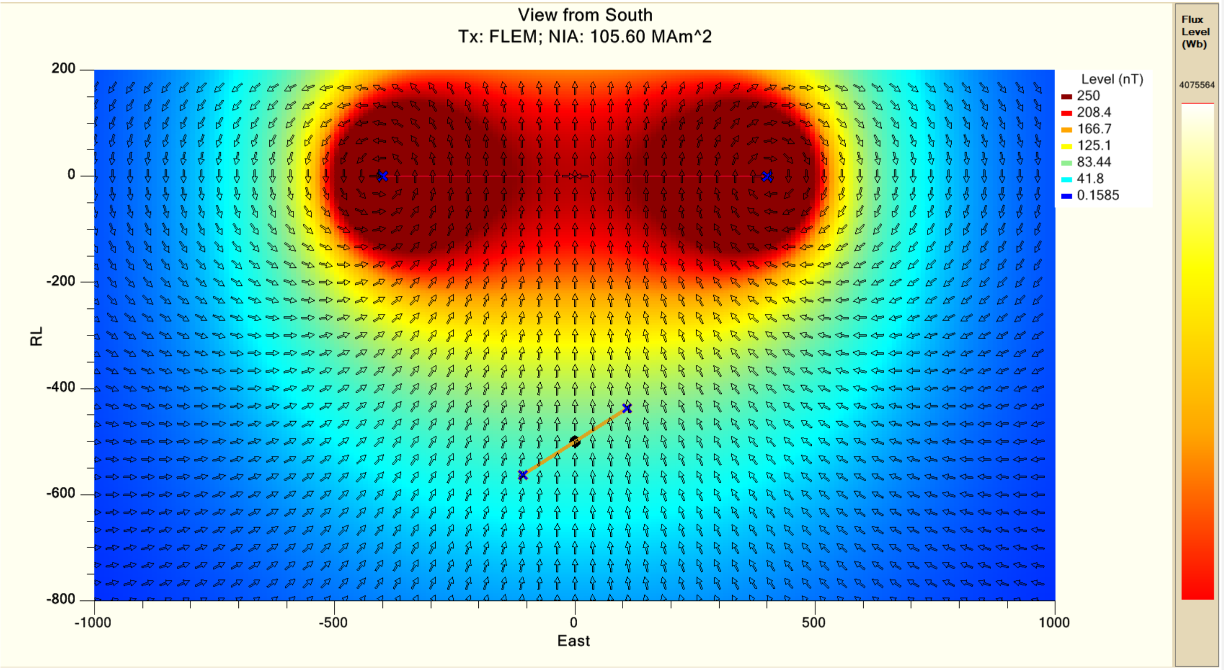
SAM

Model Plate
- Width: 250m
- Length: 300m
- RL (Centre): -500m
- Dip: 30 deg

Tx Specifications
GeoPak HPTX-70
Single Turn Loop
Current: 165 A

Magnetic Flux
4,075,564 Wb



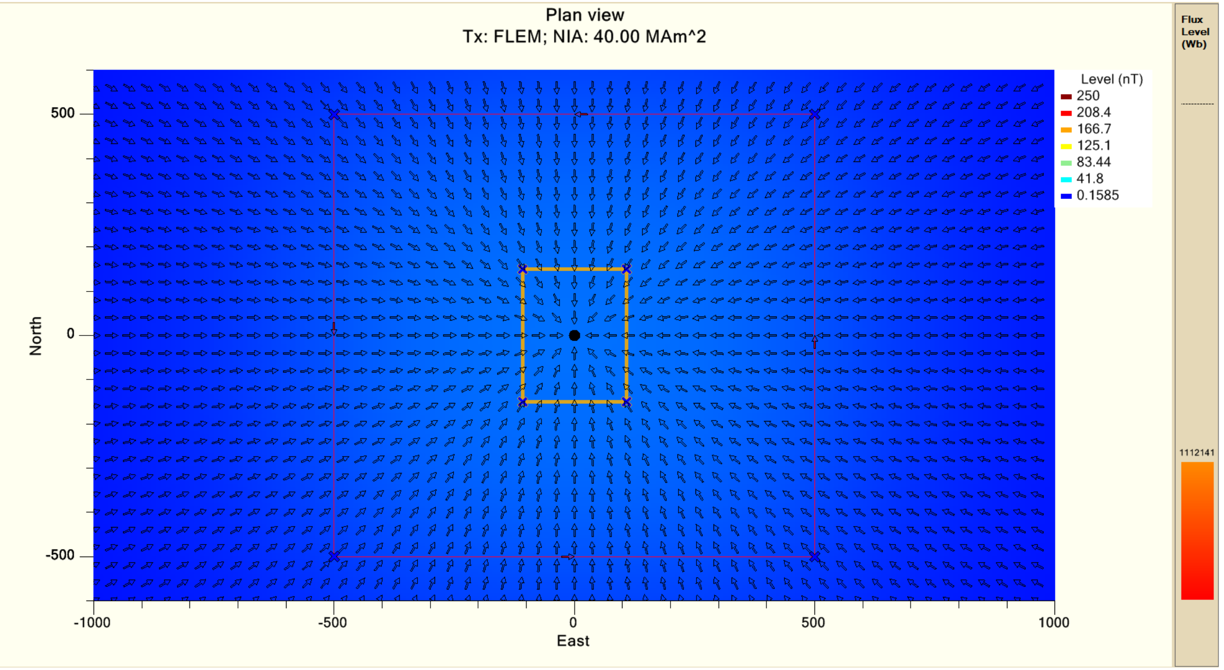


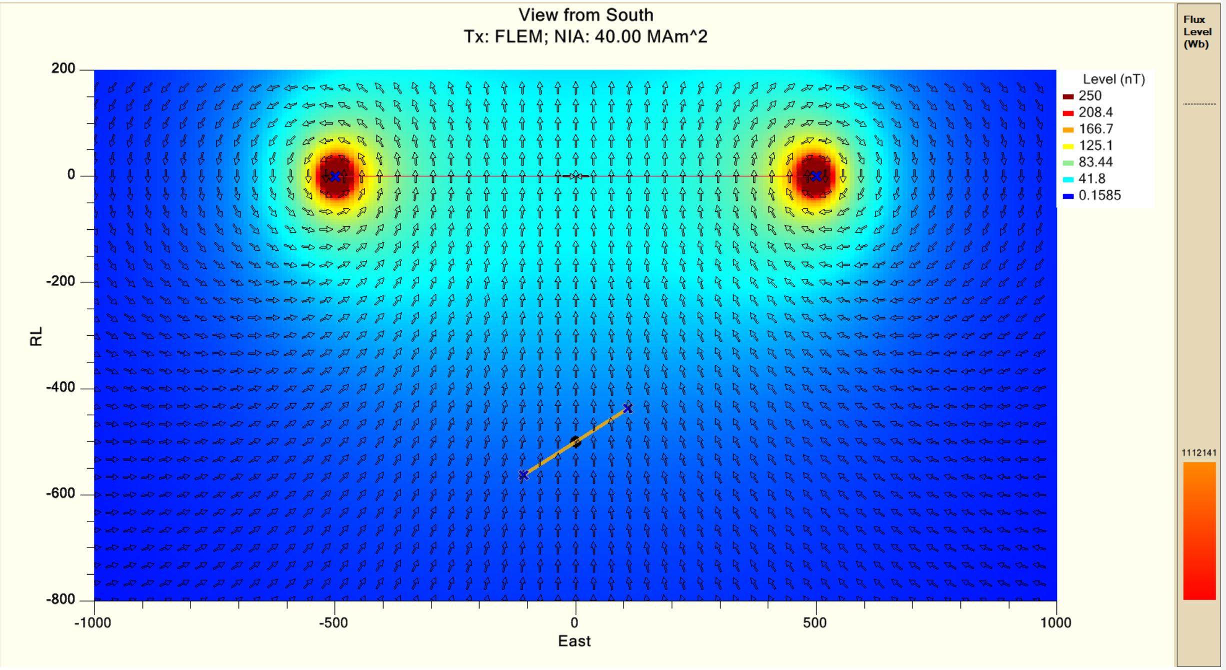
FLEM_1000m - NIA 40 MAm^2

Model Plate
- Width: 250m
- Length: 300m
- RL (Centre): -500m
- Dip: 30 deg

Tx Specifications
Phoenix TXU-30
Single Turn Loop
Current: 40 A

Magnetic Flux
834,105 Wb





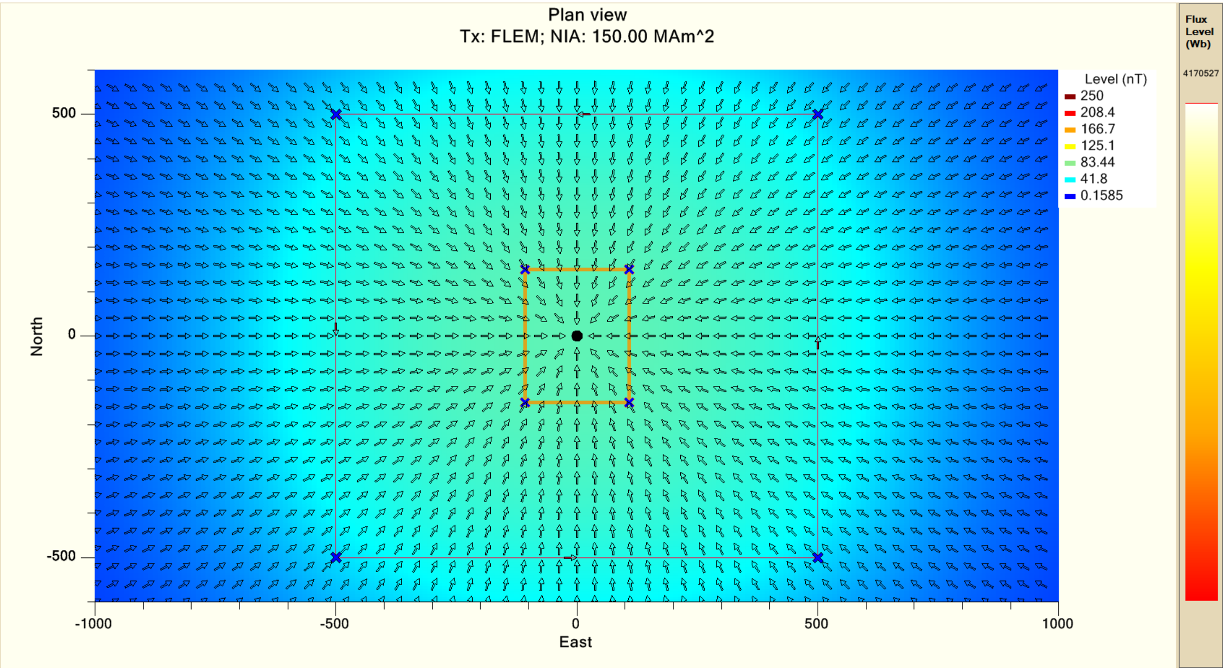
FLEM_1000m - NIA 150 MAm^2

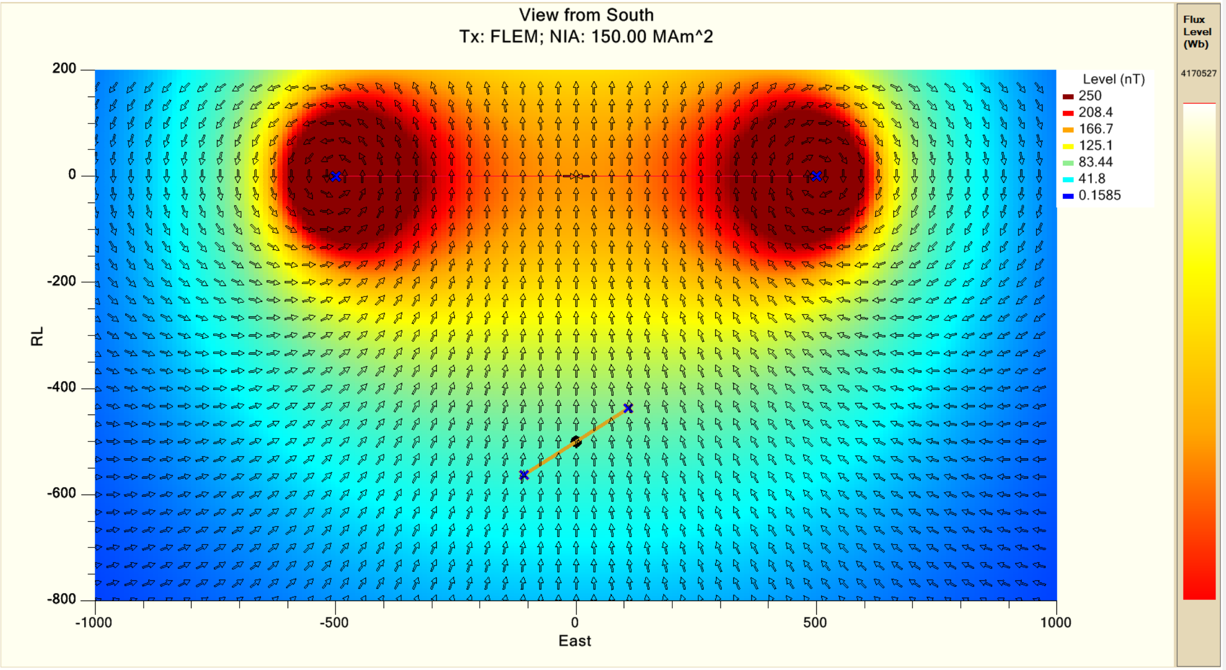
SAM

Model Plate
- Width: 250m
- Length: 300m
- RL (Centre): -500m
- Dip: 30 deg

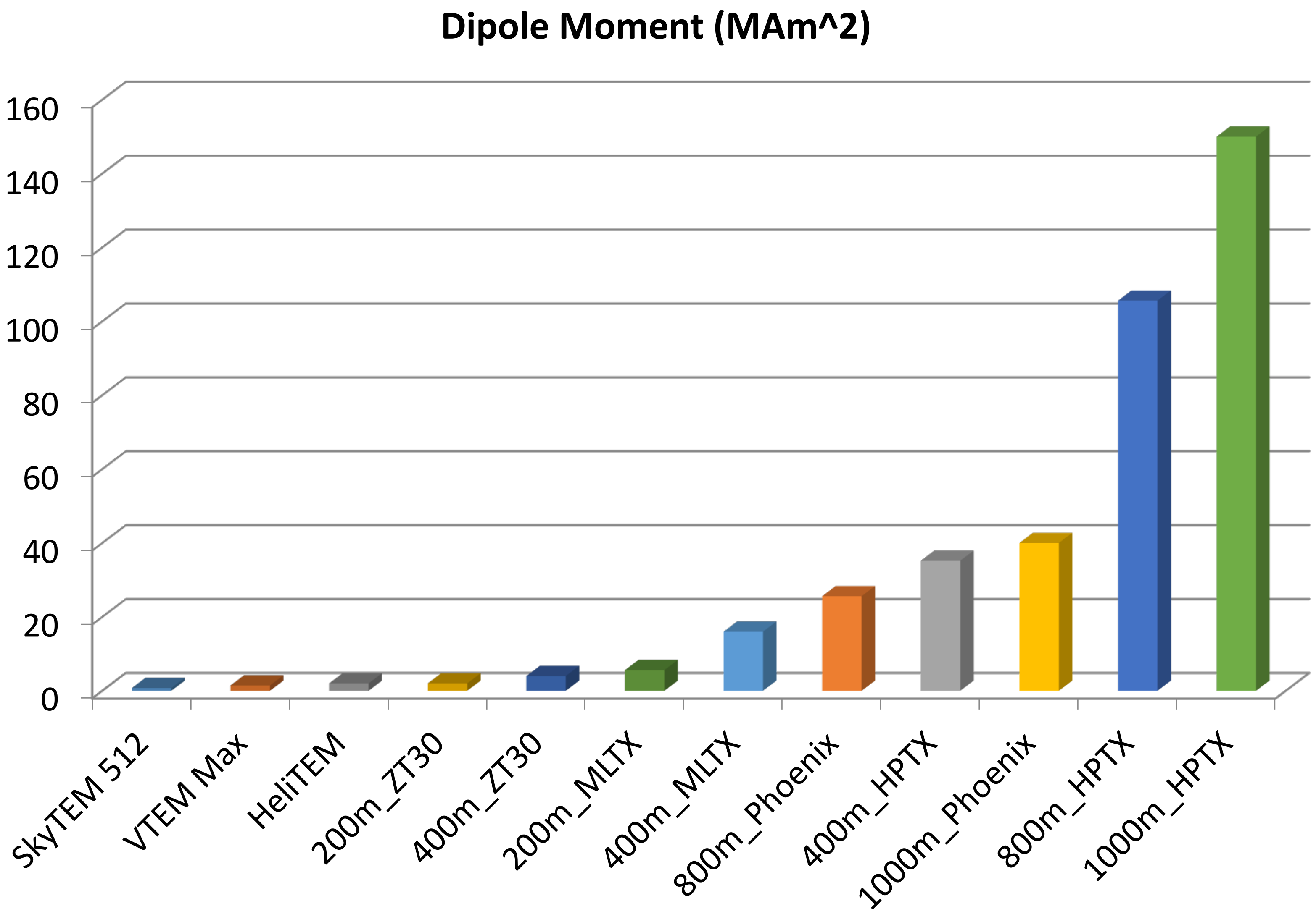
Tx Specifications
GeoPak HPTX-70
Single Turn Loop
Current: 150 A

Magnetic Flux
4,170,527 Wb

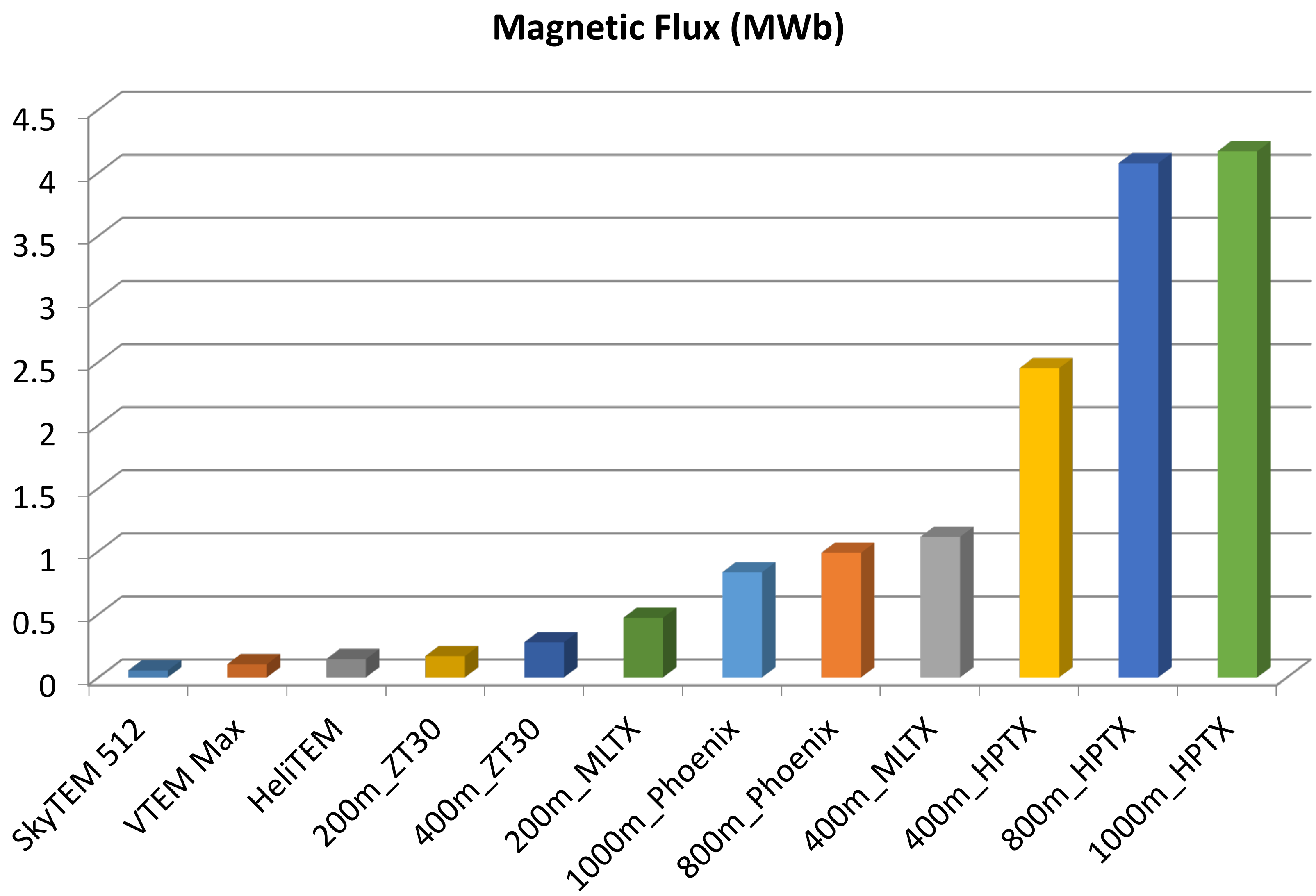




Dipole Moment Comparison



Magnetic Flux Comparison

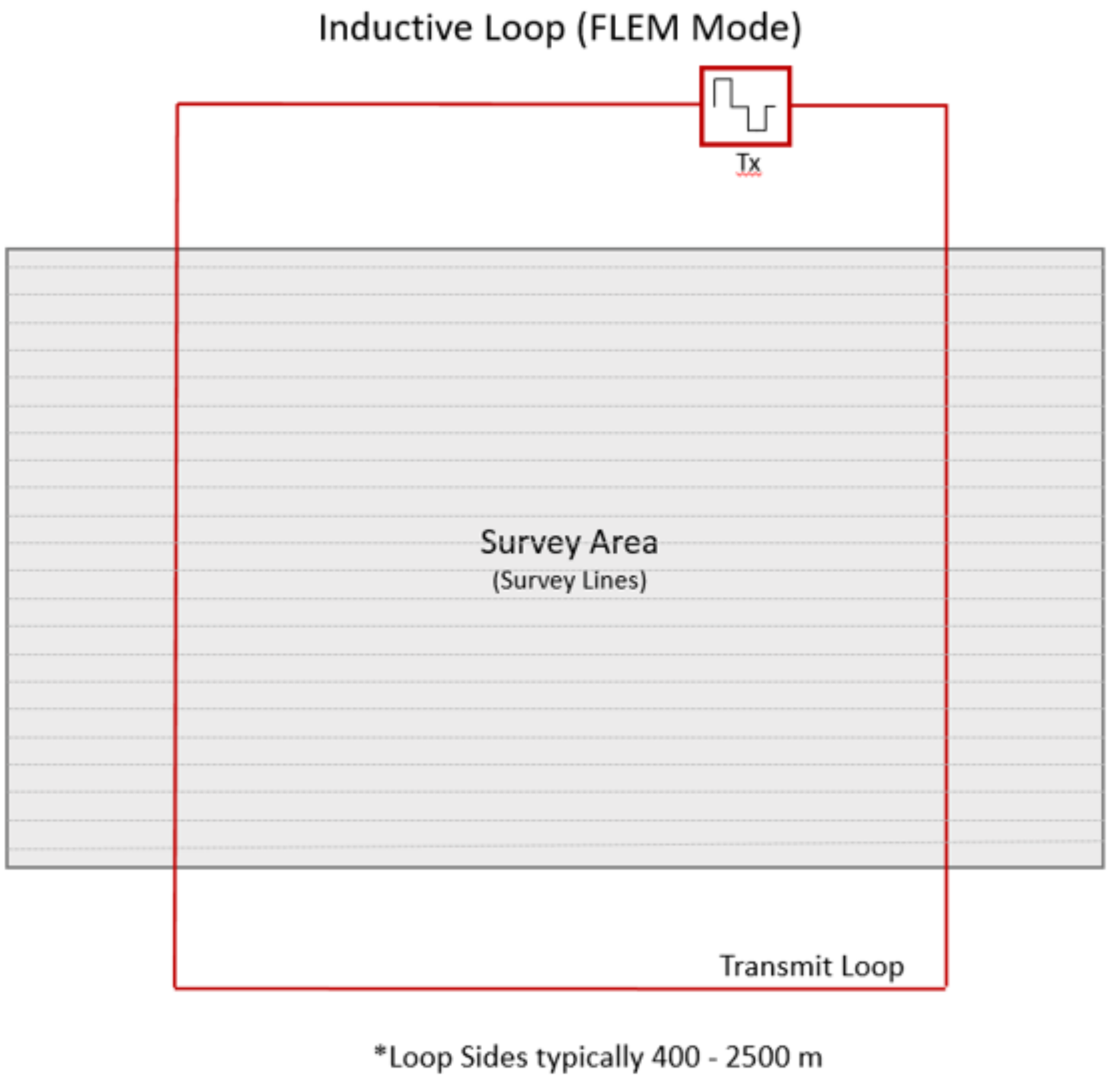


Tx Limitations of Airborne Loops

- Airborne EM is an excellent, cost effective way to cover wide areas.
- Ideally all EM would be airborne – much easier logistically.
- AEM Dipole Moments can't compare with ground Tx systems due to logistical constraint of small loops and Tx weight.
- If we therefore assume that Deep Penetrating EM will require high powered ground loops, we need to look at sensor / acquisition technology to increase productivity.
- *How applicable is SAM to Deep Penetration EM?*

SAM Inductive Loop TEM Surveys

- SAM TEM surveys have been available since 2014 and are quickly gaining recognition for:
  - Rapid acquisition
  - Extremely high detail
  - Multi-parameter data sets
  - Inexpensive – value for money
  - TFEM / TMI data sets offer multiple, complementary views of the geology
- Deep Penetration TEM Examples
  - Forrestania EM Test Range, WA
  - Lalor VMS Deposit, Manitoba



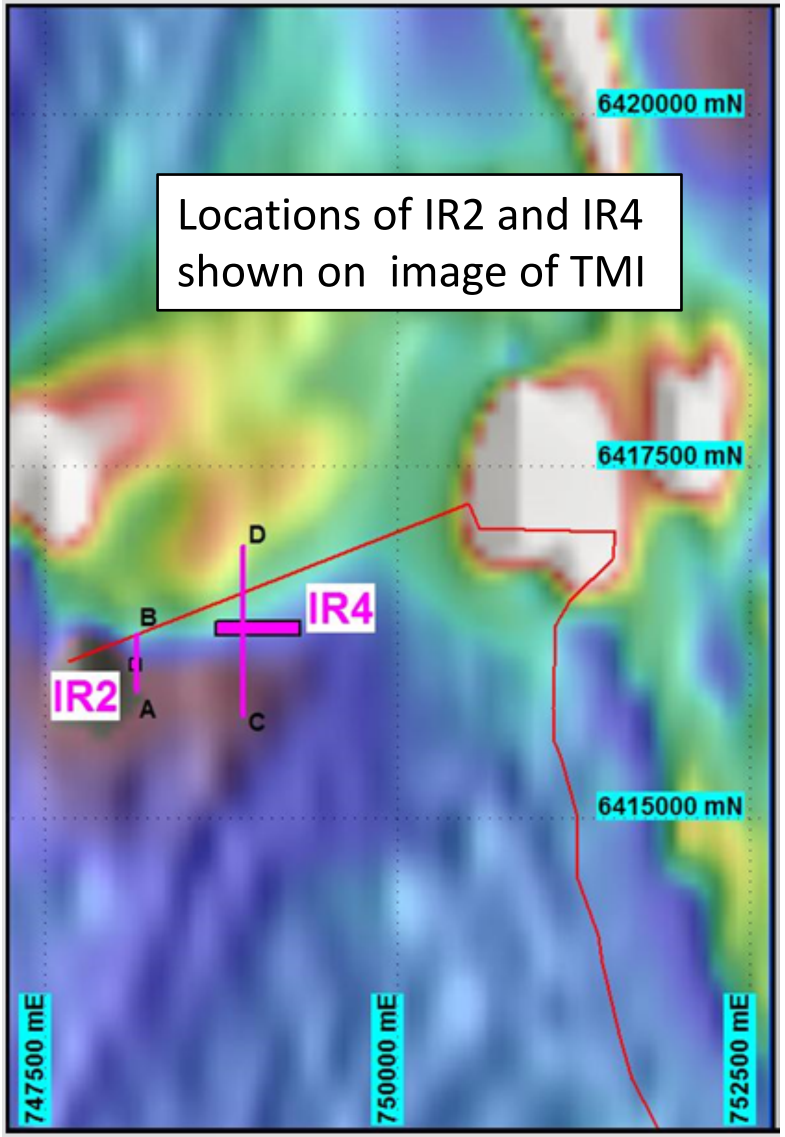
Case Study: Forrestania EM Test Range

- Situated south of Hyden in WA.
- Used for testing/trialling various electromagnetic methods (surface, airborne and downhole techniques over many years).
- In January 2014, Gap conducted a series of SAM FLEM trials at Forrestania.
- The trials were designed to
  - Determine if dynamic acquisition of high quality EM was possible at low Tx frequencies
  - Compare SAM and SAMSON FLEM survey techniques with a view to assessing the relative acquisition speed and efficiency of each survey mode.

**SAMSON was used to provide control survey data.*

Forrestania Geology

- Two bedrock conductors (IR2 and IR4).
  - Barren, semi-massive to massive sulphides (po-rich).
- Western Conductor (IR2)
  - Small - 75 x 75m
  - <100m depth
  - Dips Northward (~30-40 deg)
  - High conductance – >7000 S
  - Detected by surface, downhole and airborne EM
- Eastern Conductor (IR4)
  - Extensive in strike/plunge extent (~500-600m+) and
  - depth ~300-325m (western side) to ~400m+ (eastern side),
  - Well constrained in depth extent (~100-150m).
  - Dips northward (~30-40 deg)
  - High conductance ~5000-10000 S
  - Challenging target for surface TEM methods with small Tx loops.
  - Not detected by airborne EM

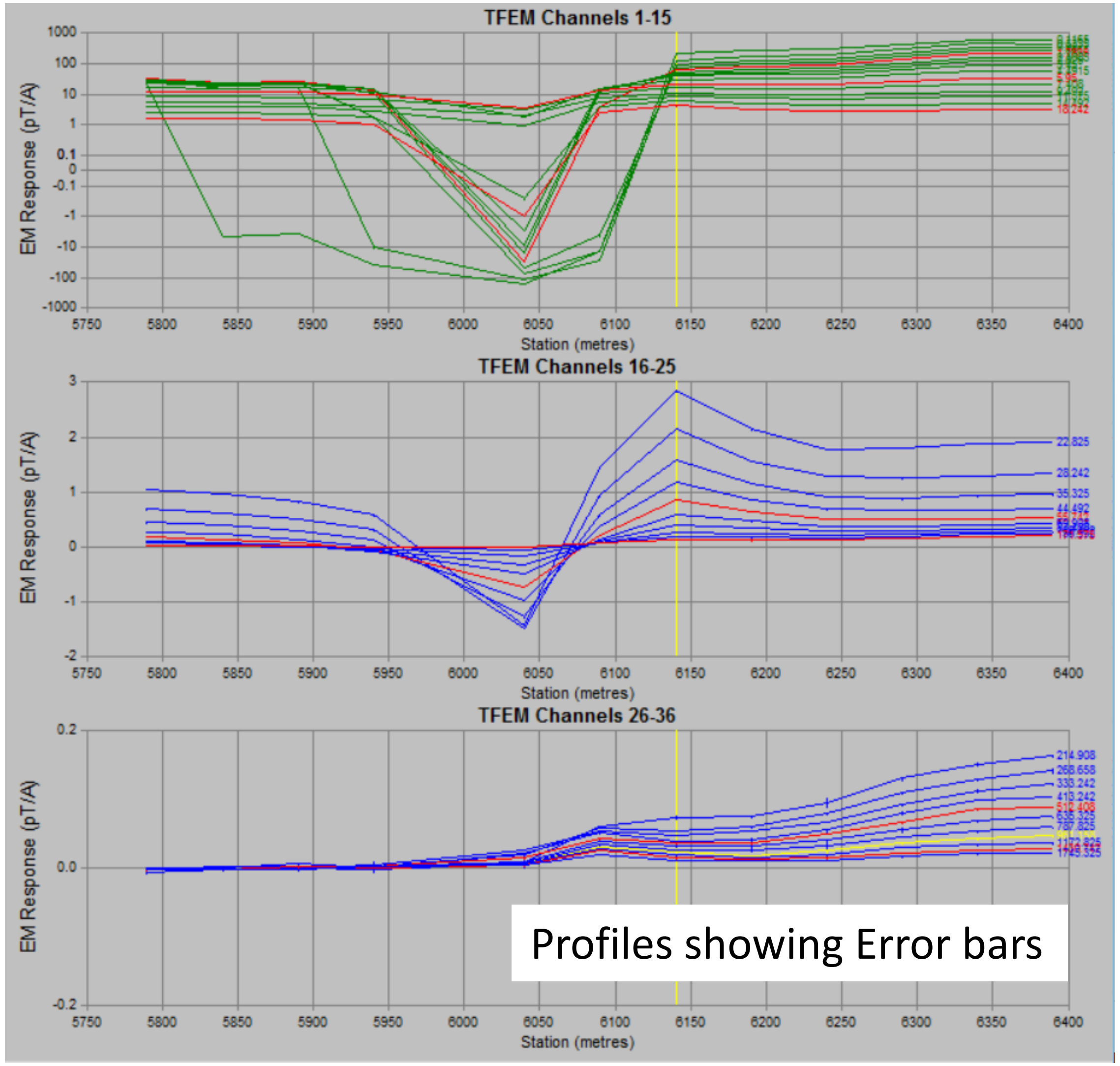


* Information sourced from www.sgc.com.au (Southern Geoscience Consultants) website

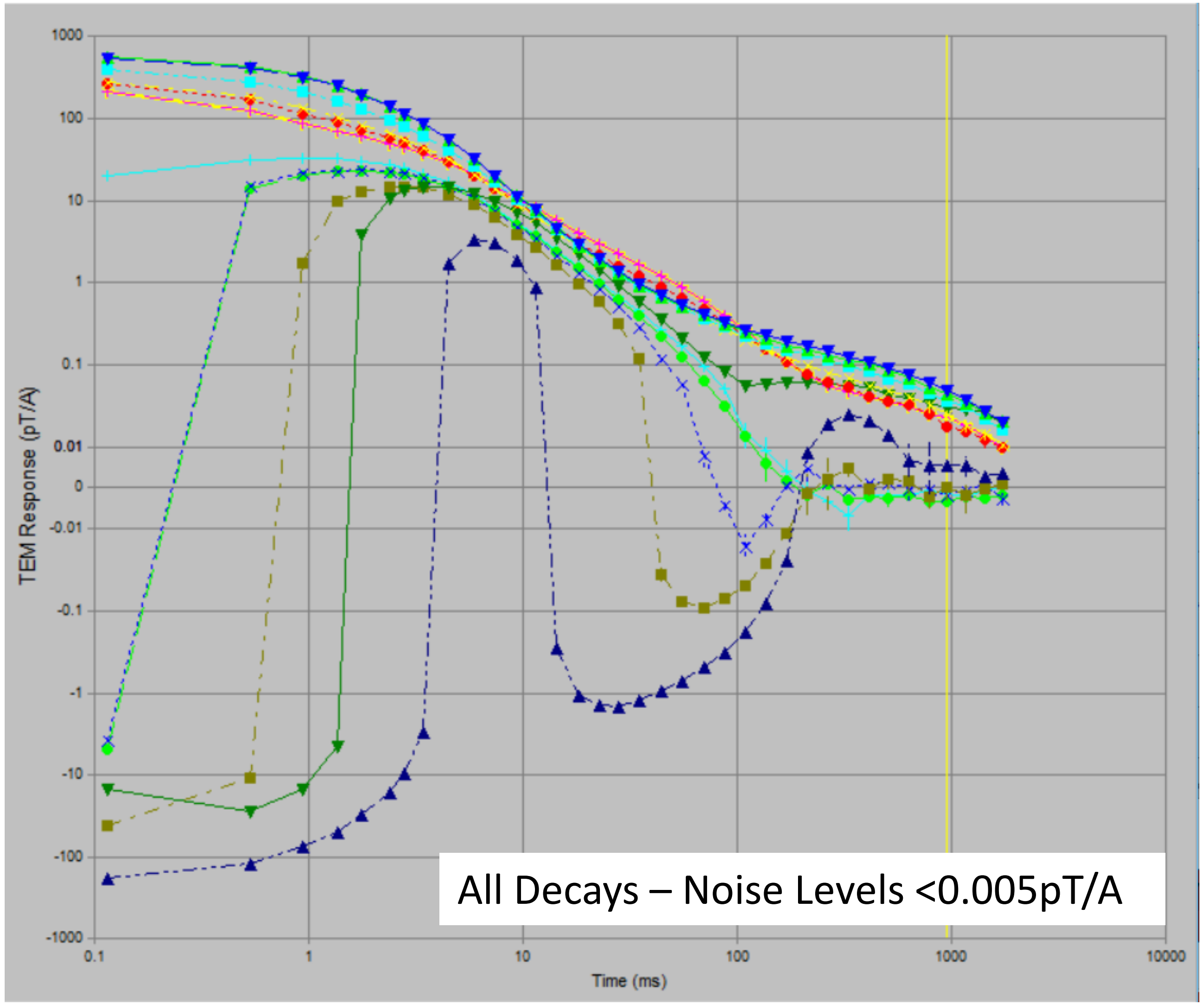
Survey Layout - FLEM

- Google Earth Image showing
  - Loops L1 and L2
  - L1 designed around IR2 (shallow conductor)
  - L2 designed for IR4 (deep conductor)
  - Planned SAMSON FLEM Lines.
- Loop configuration:
  - One turn of 35 sq mm wire (~4km).
  - Transmitter: Gap GeoPak HPTX-70
  - Current achieved: 150A.

IR2 SAMSON - Line 748050

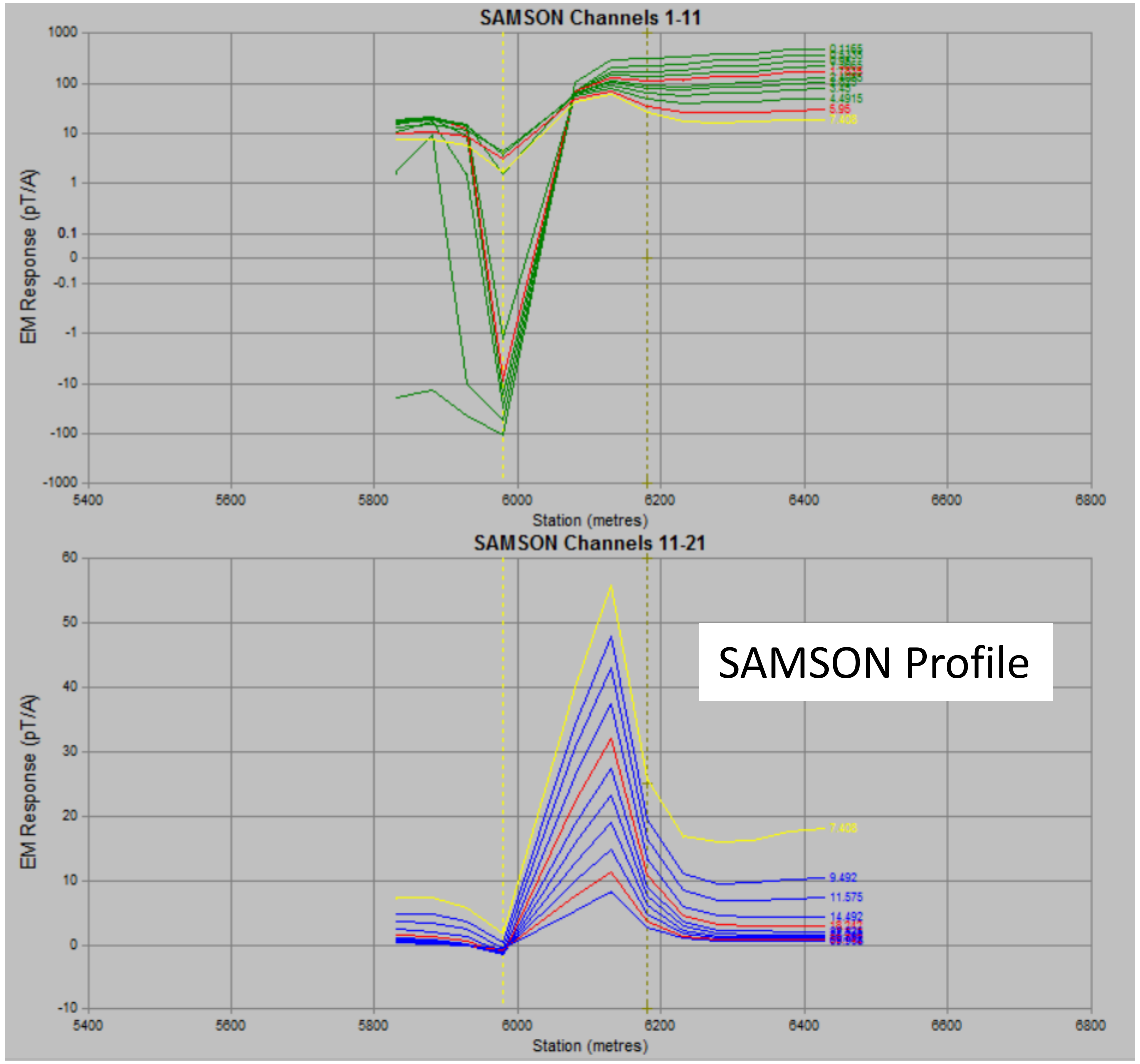


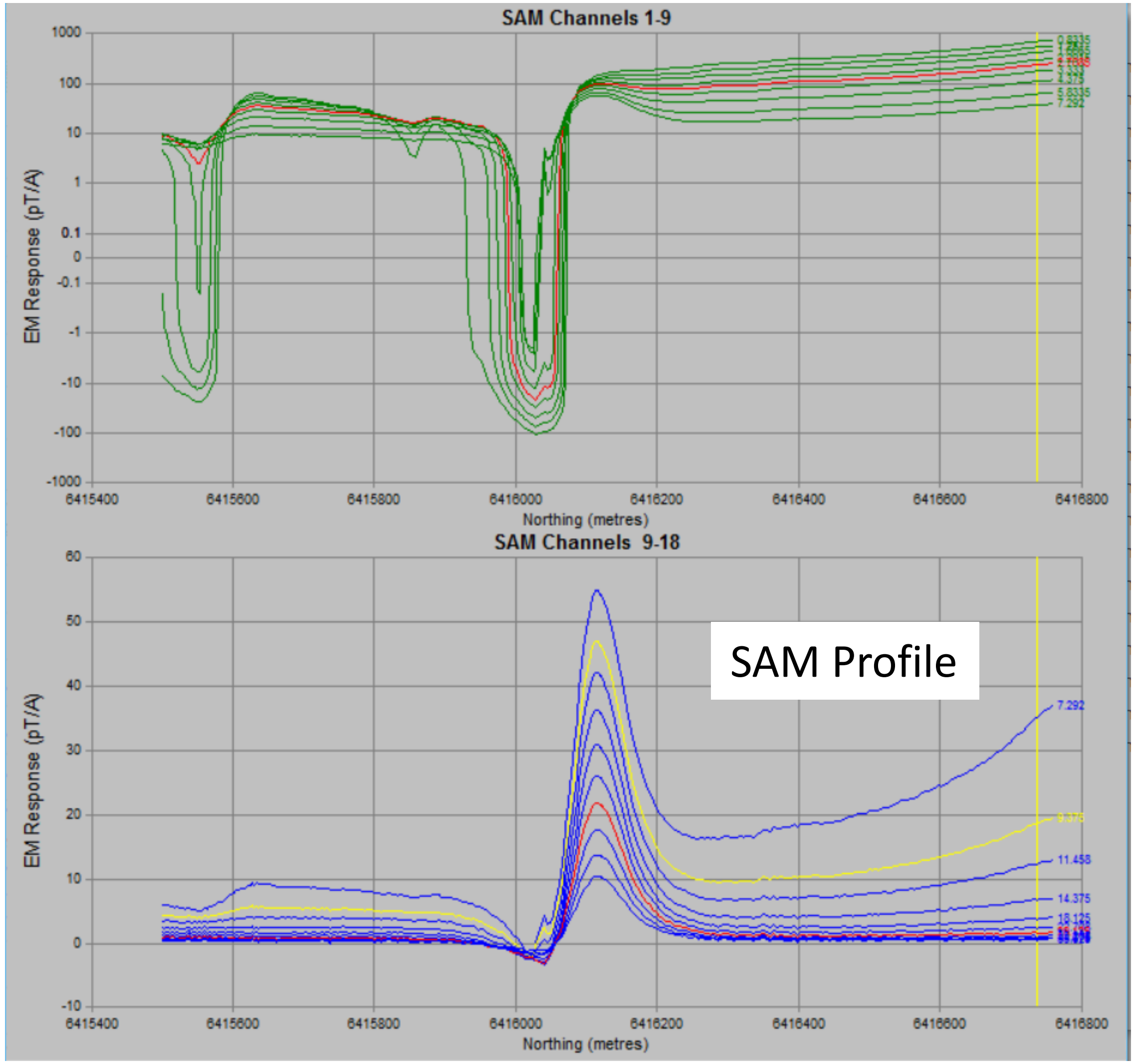
Profiles showing Error bars



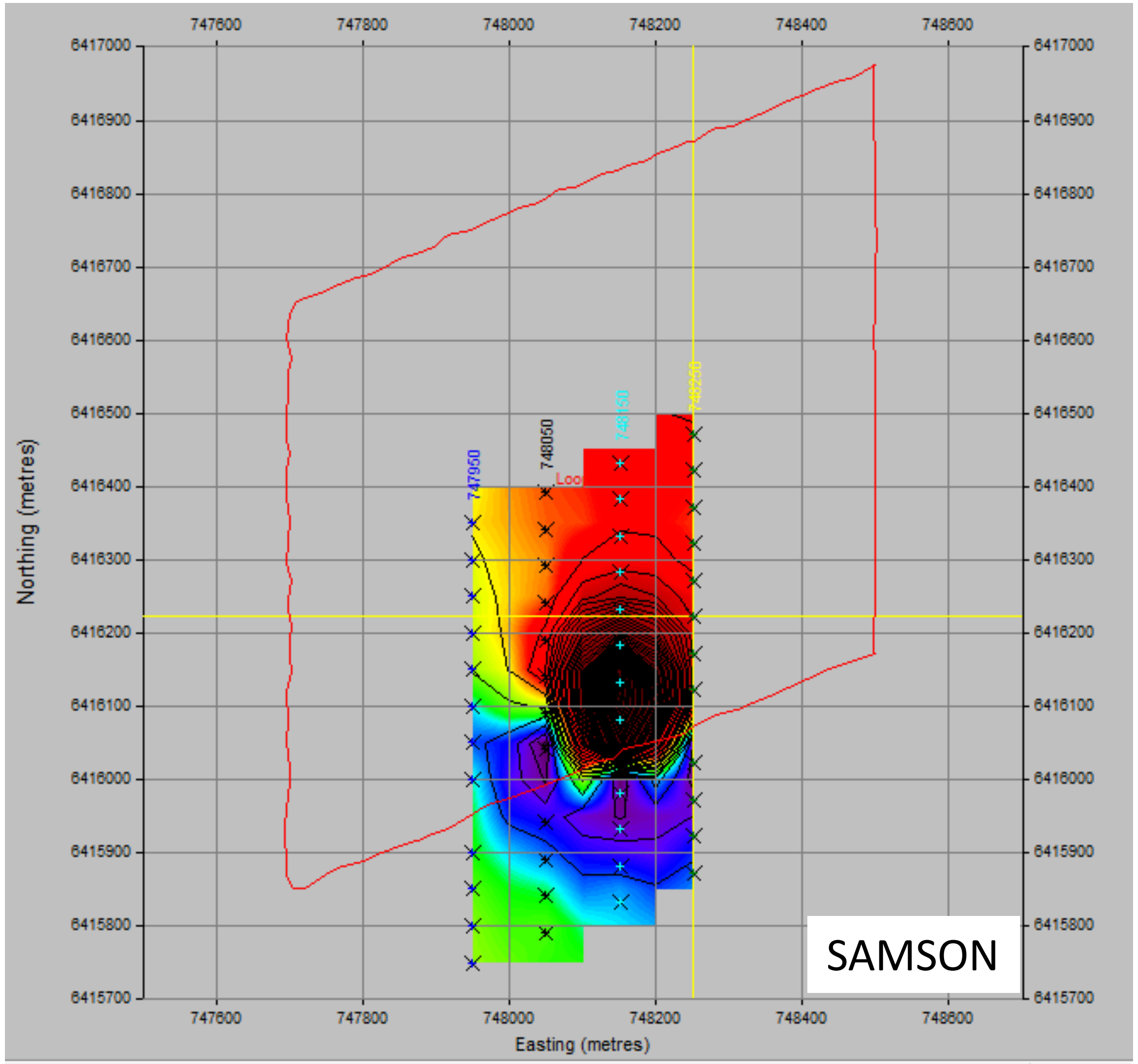
All Decays – Noise Levels <0.005pT/A

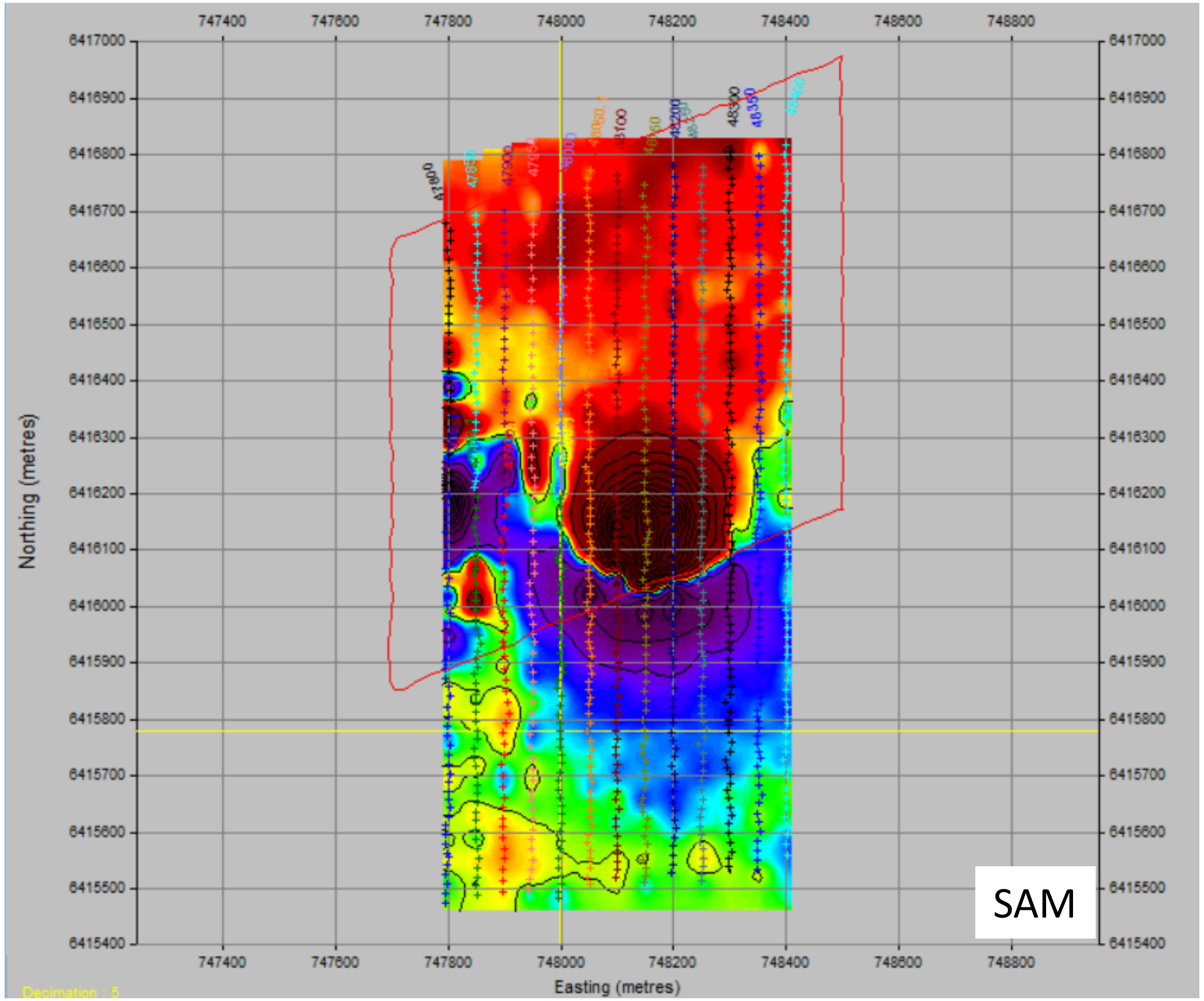
IR2 Line 748150 - SAMSON Vs SAM





IR2 TFEM - Channel 20

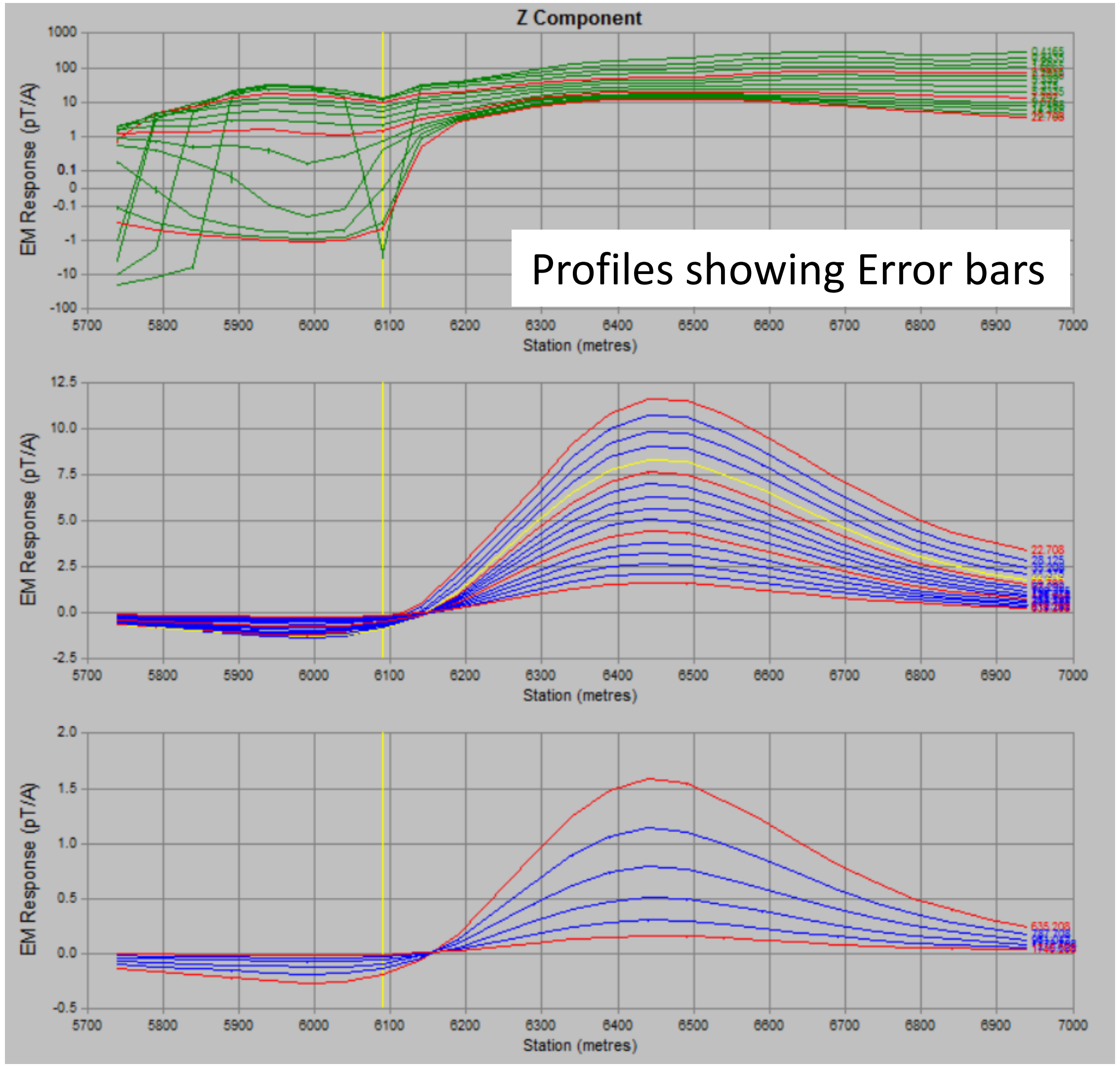


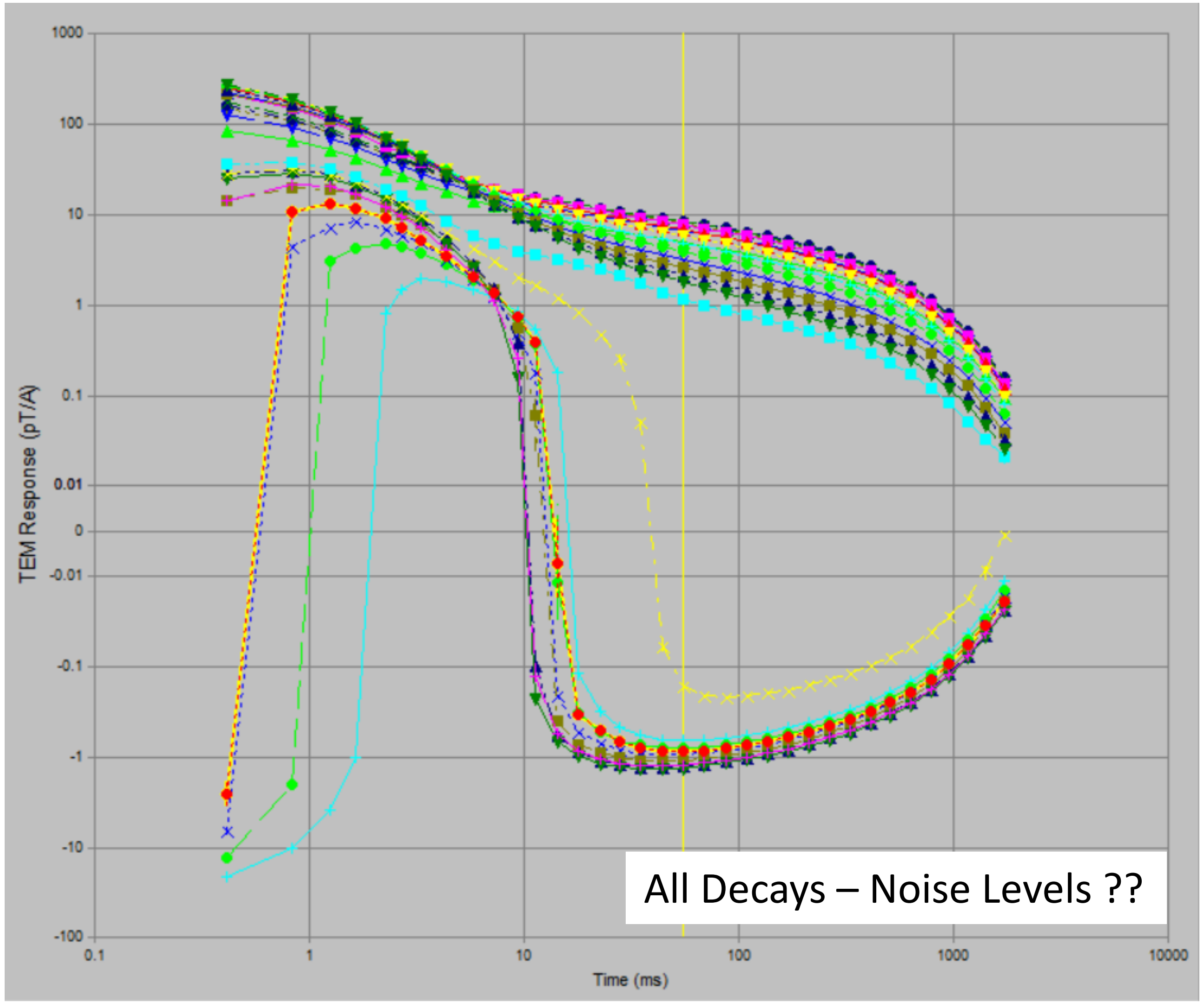


IR2 - SAMSON / SAM Survey Specs

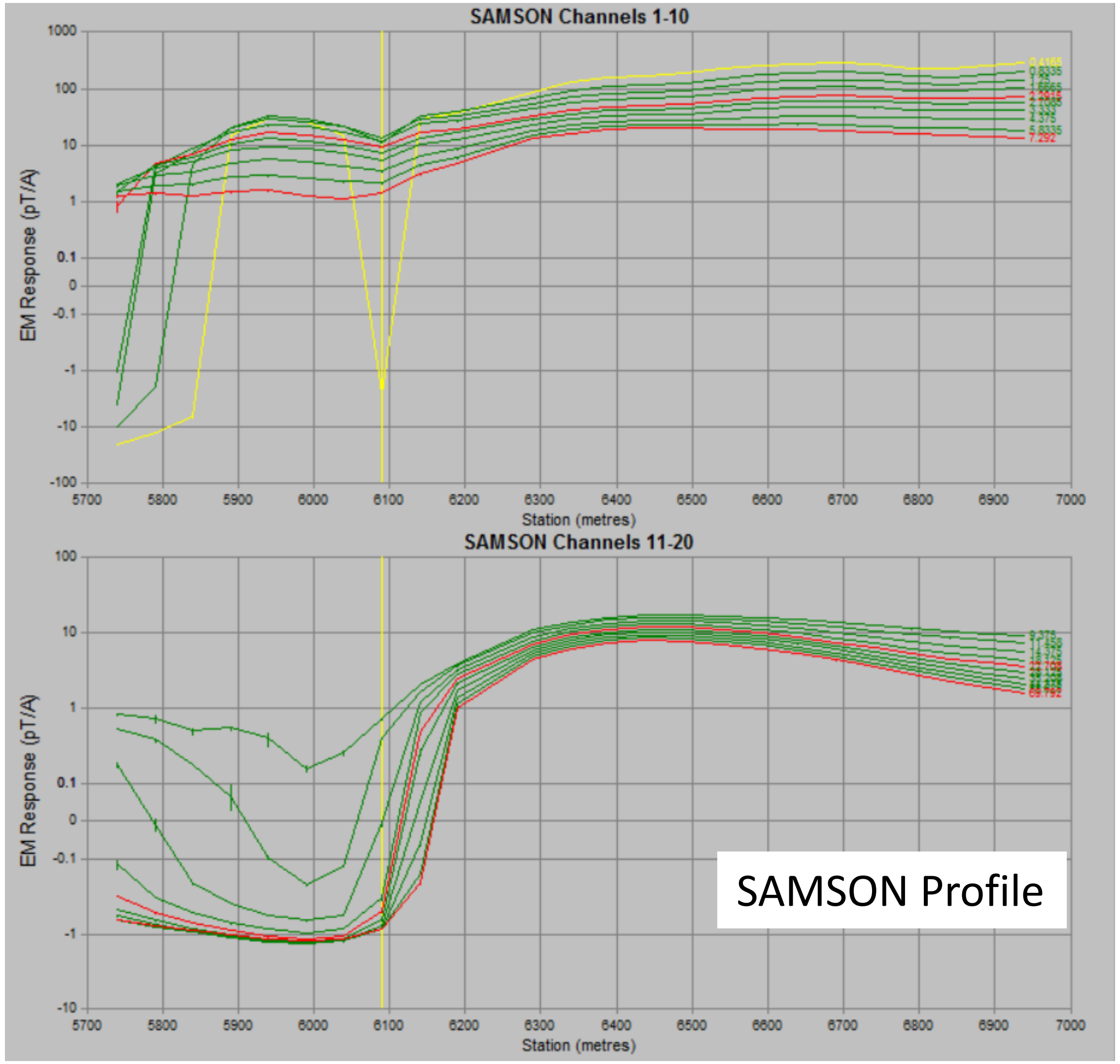
	SAMSON FLEM	SAM FLEM
Survey Mode	Stationary	Dynamic
Tx Frequency	0.125 Hz	3.125 Hz
Parameters Acquired	TFEM, TMI	TFEM, HD TMI
Line Spacing	100m	50m
Station Spacing	50m	~5m
Acquisition Time	2 x 40 half periods (5.3 min)	40 half periods (6.4 sec)
Acquisition Speed	0.4 km /hour (8 stations per hour)	4 km / hour (600 stations per hour)
Total No Stations	48	3120
Total Distance	2.2 km	15.6 km
Total Acquisition Time	6 hours	4 hours

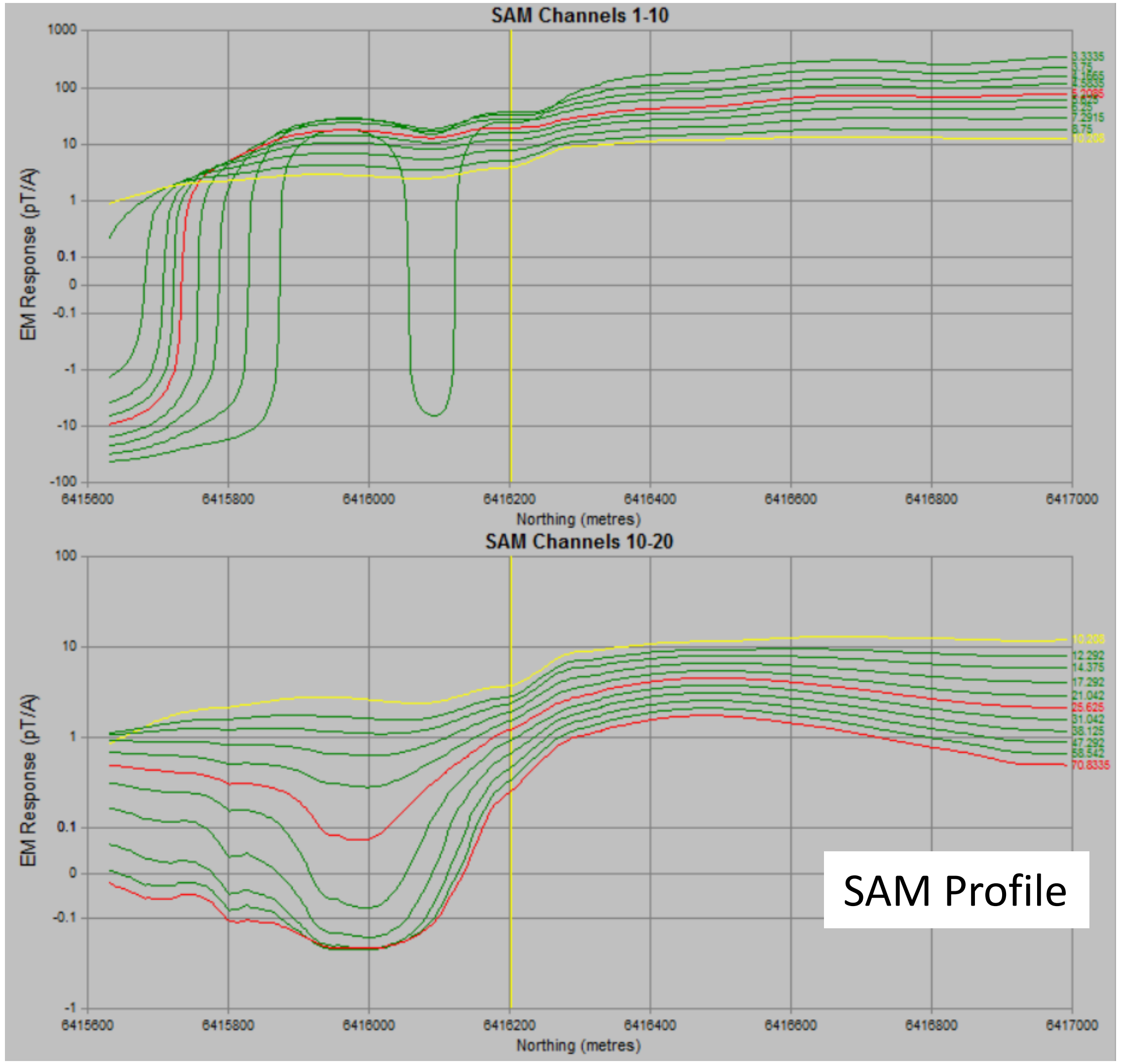
IR4 SAMSON - Line 748050



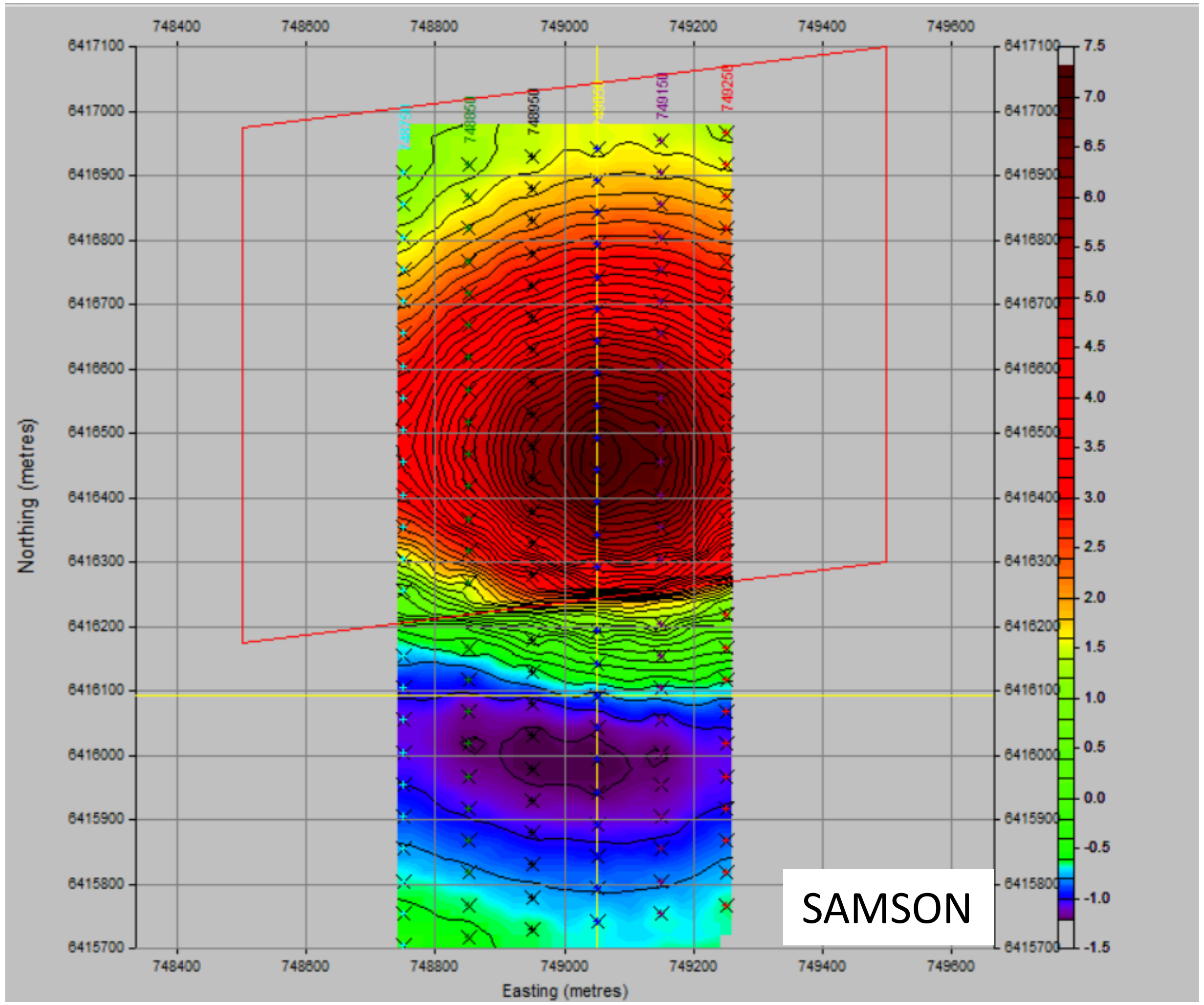


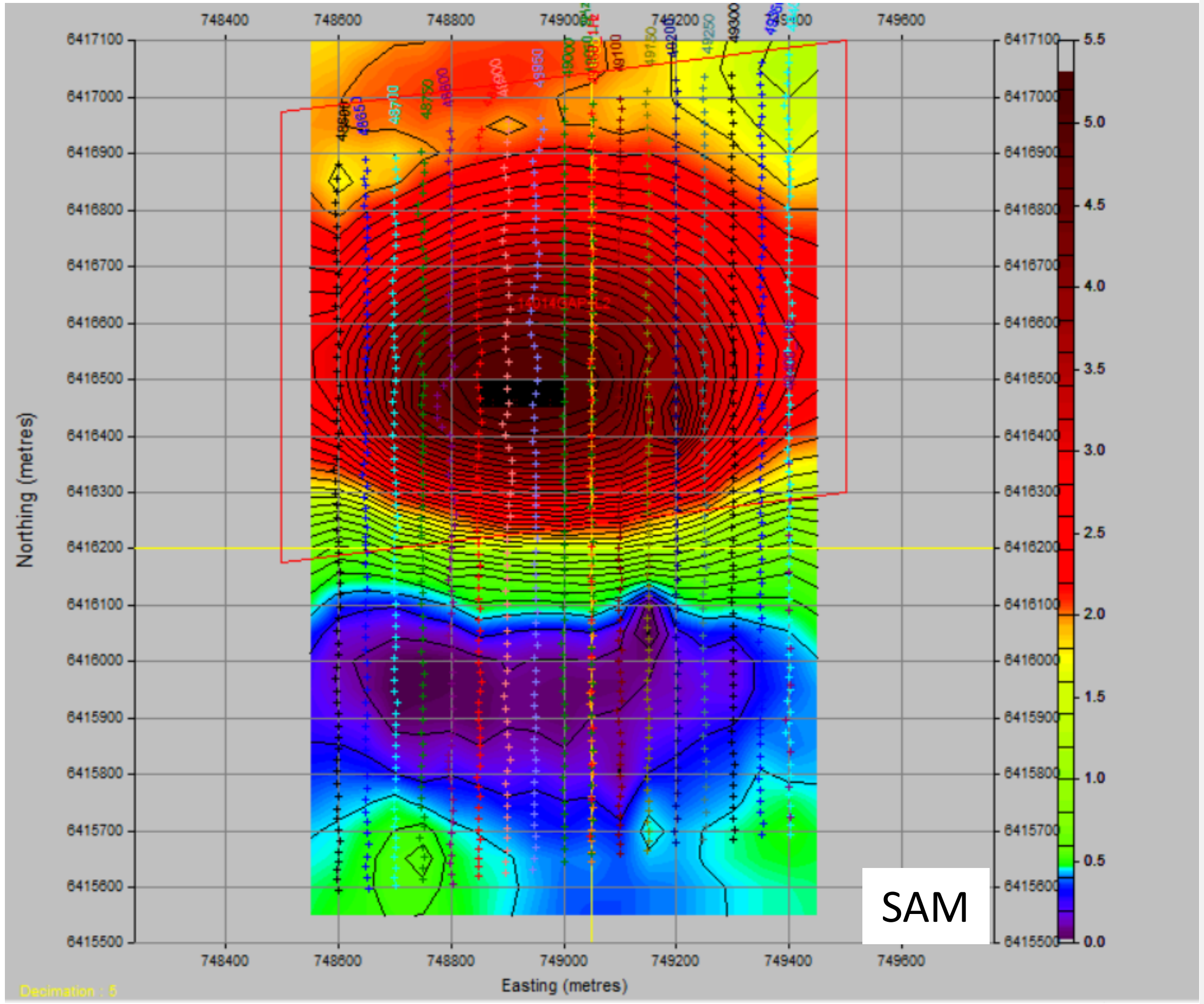
IR4 Line 749050 - SAMSON Vs SAM





IR4 TFEM - Channel 20





IR4 - SAMSON / SAM Survey Specs

	SAMSON FLEM	SAM FLEM
Survey Mode	Stationary	Dynamic
Tx Frequency	0.125 Hz	3.125 Hz
Parameters Acquired	TFEM, TMI	TFEM, HD TMI
Line Spacing	100m	50m
Station Spacing	50m	~5m
Acquisition Time	2 x 40 half periods (5.3 min)	40 half periods (6.4 sec)
Acquisition Speed	0.4 km /hour (8 stations per hour)	4 km / hour (600 stations per hour)
Total No Stations	144	4800
Total Distance	6.9 km	24 km
Total Acquisition Time	2.5 days	8 hours

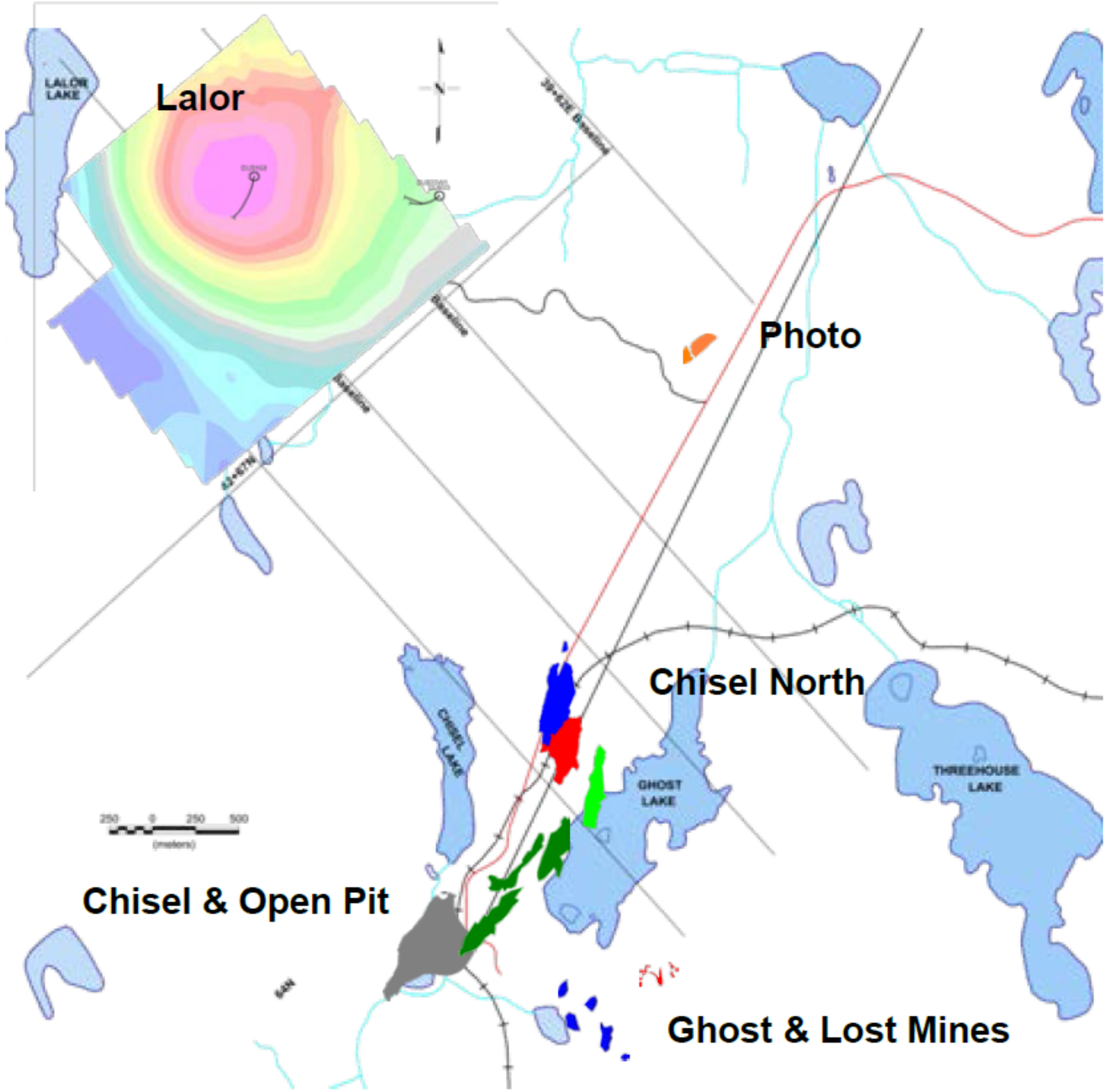
Forrestania Conclusions

- SAM FLEM was able to acquire high quality EM in significantly less time than required to acquire stationary EM:
- For example IR4:
  - 150 stations (6.9 km at 50m intervals) were acquired by SAMSON in 2.5 days
  - 4800 stations (24 km at 5m intervals) were acquired in 1 day by a one acquisition crew in SAM Mode.
  - SAM data were just as diagnostic of the presence of the deep conductor as SAMSON data.
  - SAMSON data provided late time information due to the lower transmit frequency which in this case would be beneficial for modelling.
- The trials demonstrated SAM EM as a viable rapid exploration technique using low transmit frequencies
  - Anomalies could be followed up by SAMSON or other conventional EM techniques at lower frequencies if required.

HeliSAM Case Study - Lalor VMS Deposit

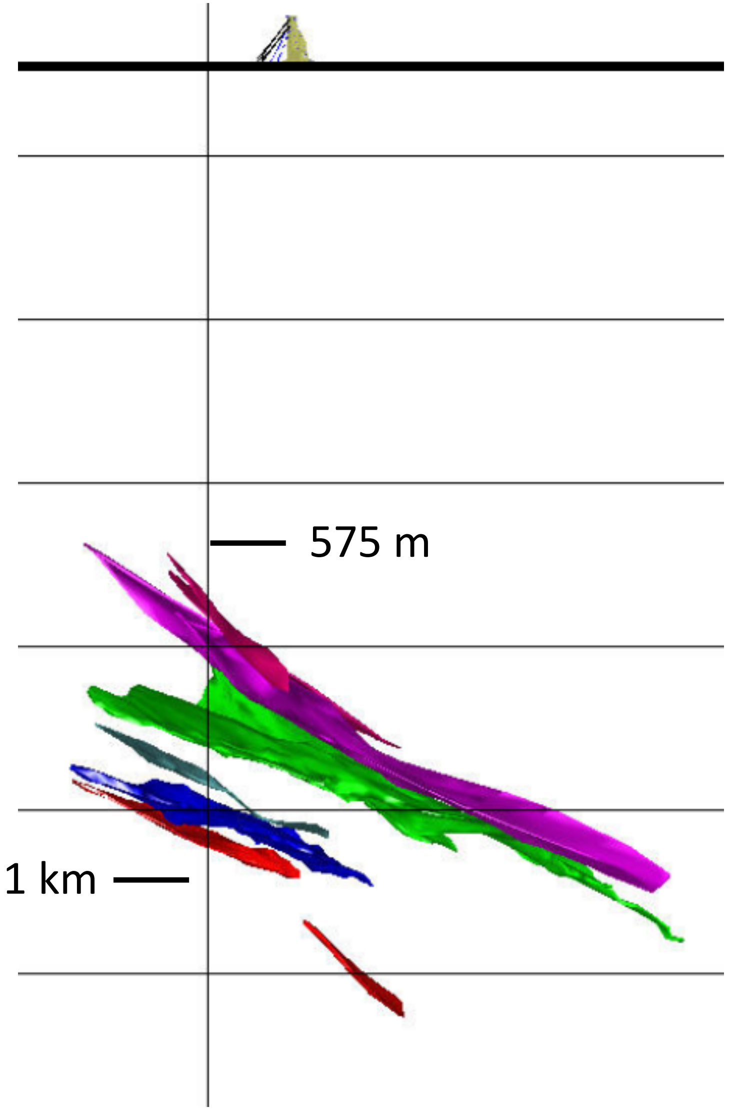
- In August, 2014, Gap Geophysics Australia in collaboration with Discovery Int'l Geophysics flew a HeliSAM test survey over the Lalor VMS Deposit, Snow Lake, Manitoba.
- Lalor is a very challenging target for Airborne EM due to its depth
- HeliSAM easily detected Lalor using:
  - inductive ground loop source
  - sub-audio frequency excitation
  - Total field airborne SAM receiver

The Lalor VMS Deposit



- Discovered by the Hudbay exploration team in 2007
  - Brownfields Exploration
  - Ground FLTEM system
  - Large multi-turn Tx loops, long stack times

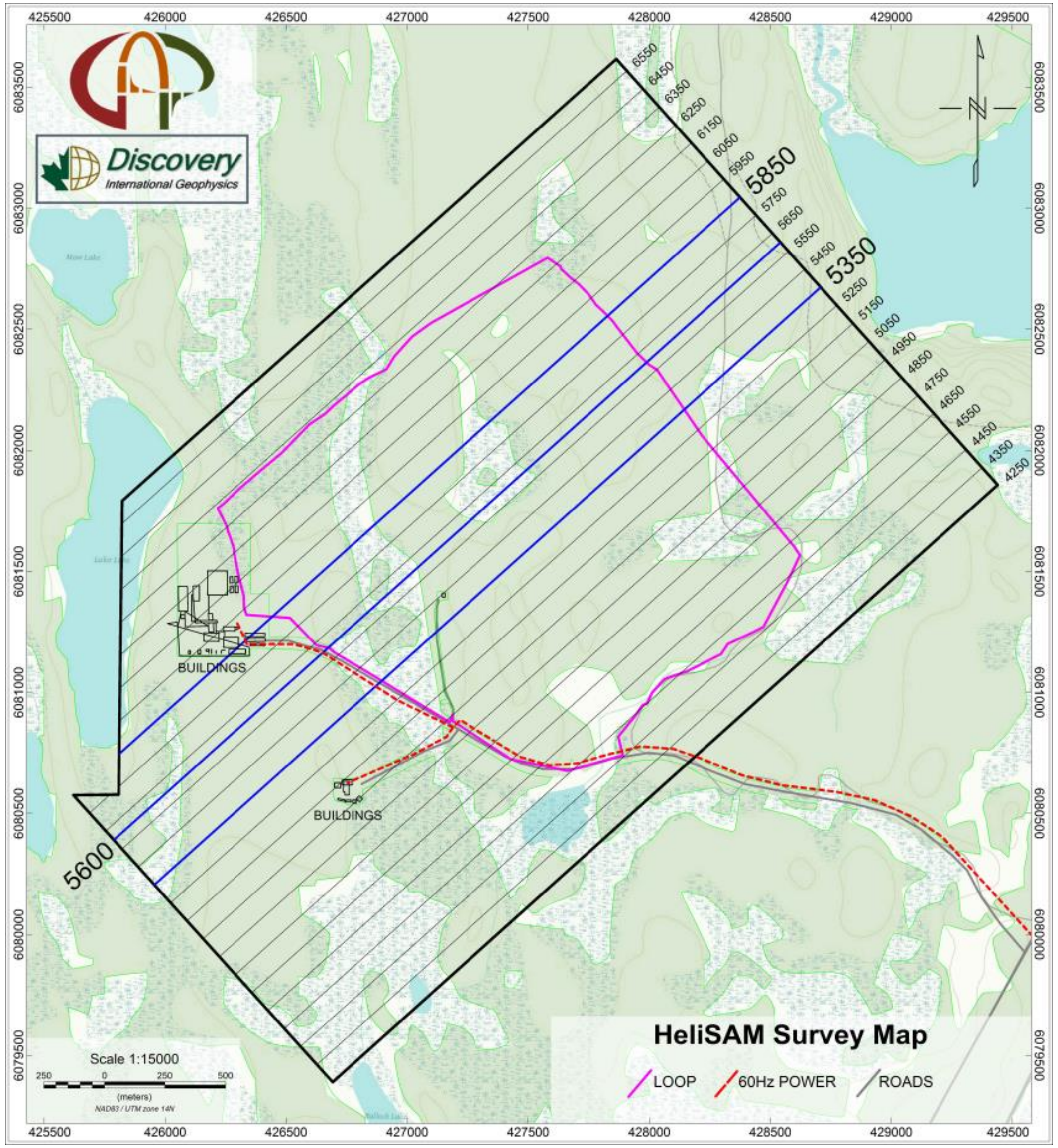
The Lalor VMS Deposit



- The largest deposit of the Snow Lake camp approaching 30 Mt, comprising:
  - Reserves - 14.4 Mt grading 1.86 g/t Au, 24 g/t Ag, 0.6 wt% Cu and 7 wt% Zn
  - Resources - 12.6 Mt grading 3.85 g/t Au, 27.3 g/t Ag, 0.9 wt% Cu and 2.3 wt% Zn
- Three zones of alteration/mineralization
  - Zinc-rich, closest to surface
  - Cu-Au rich, deepest portion
  - Au-rich, between the other two zones

**Depths are between 700 and 1500m*

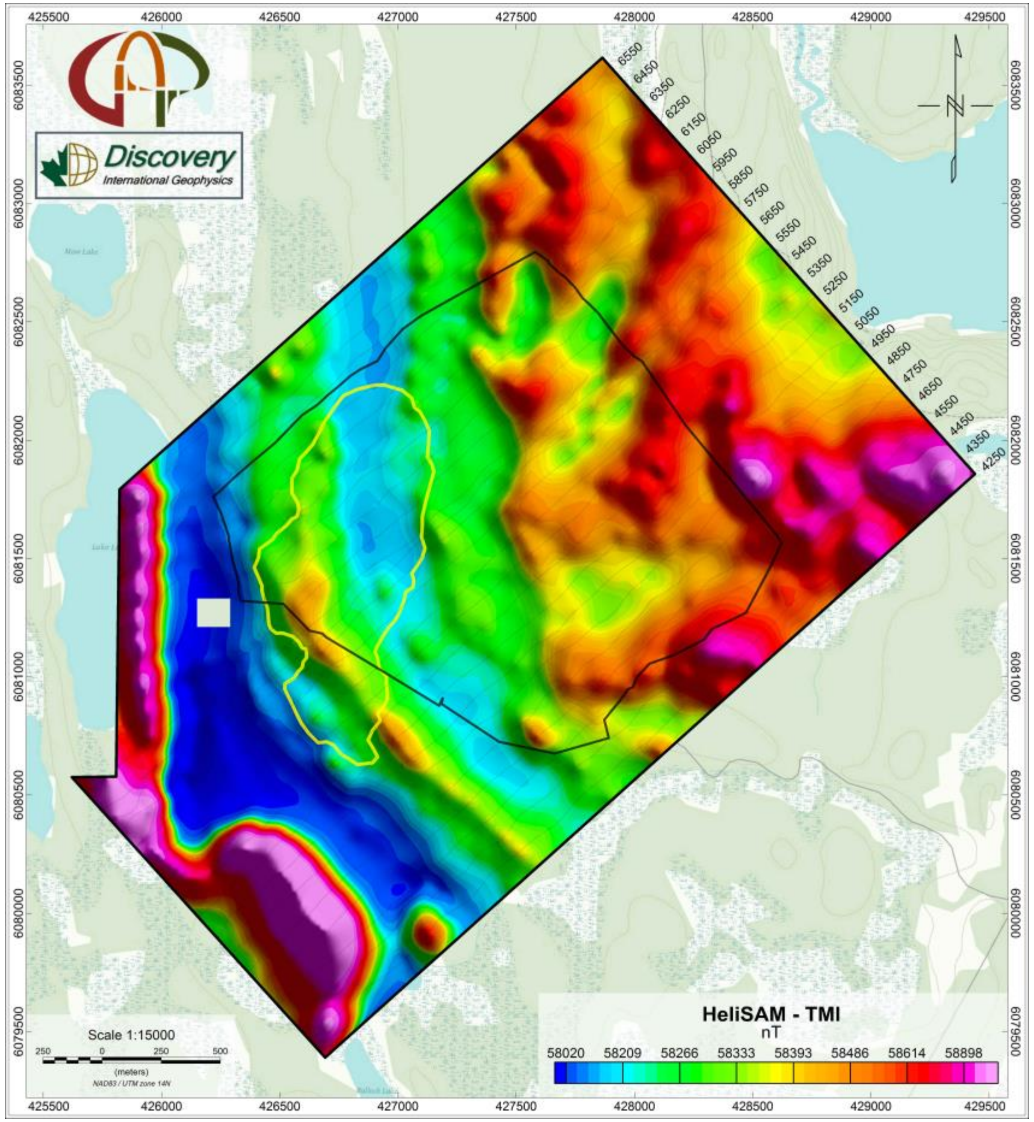
HeliSAM FLEM Survey



- Helicopter
  - Type: Robinson R-44
  - Prep and Fitout: 0.5 day
  - Training Time: 2 hours including test flights
  - Ferry Time: 1 hour
  - Survey Time: 2 hours
- Transmitter System
  - Tx: Phoenix TXU-30 with Gap Tx Controller
  - Loop: ~1.7 km x 1.7 km (already established)
  - Current: 20 amps
  - Base Frequency: 7.5 Hz
  - Magnetic Moment: 57 MAm^2
- Survey
  - Dimensions: 3.7 km x 2.4 km
  - Area: ~ 8.7 km2
  - Line spacing: 100m
  - Survey Distance: 93 line kilometres
  - Survey Speed: 50 knots survey speed

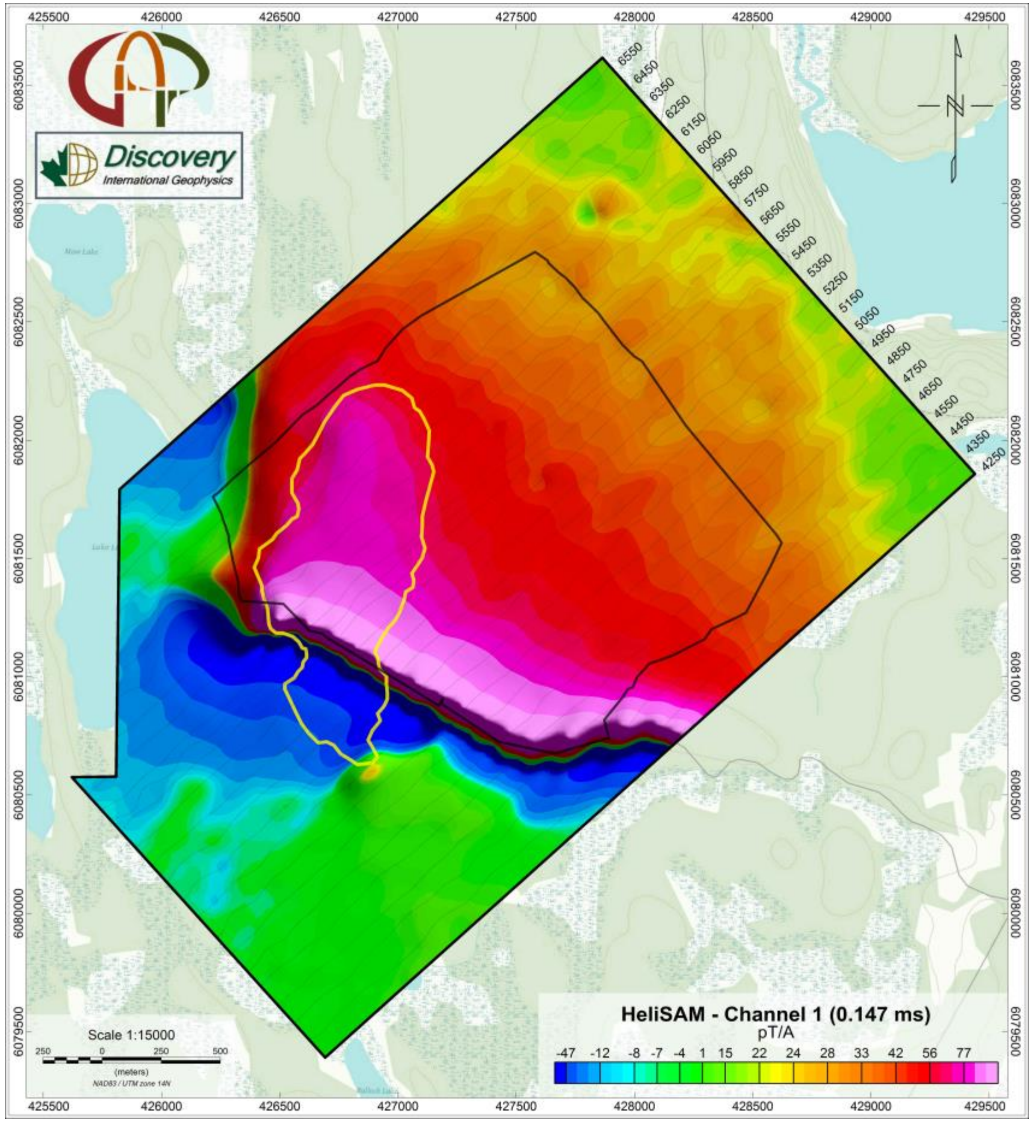
*Blue survey lines correspond with other test surveys

Total Magnetic Intensity

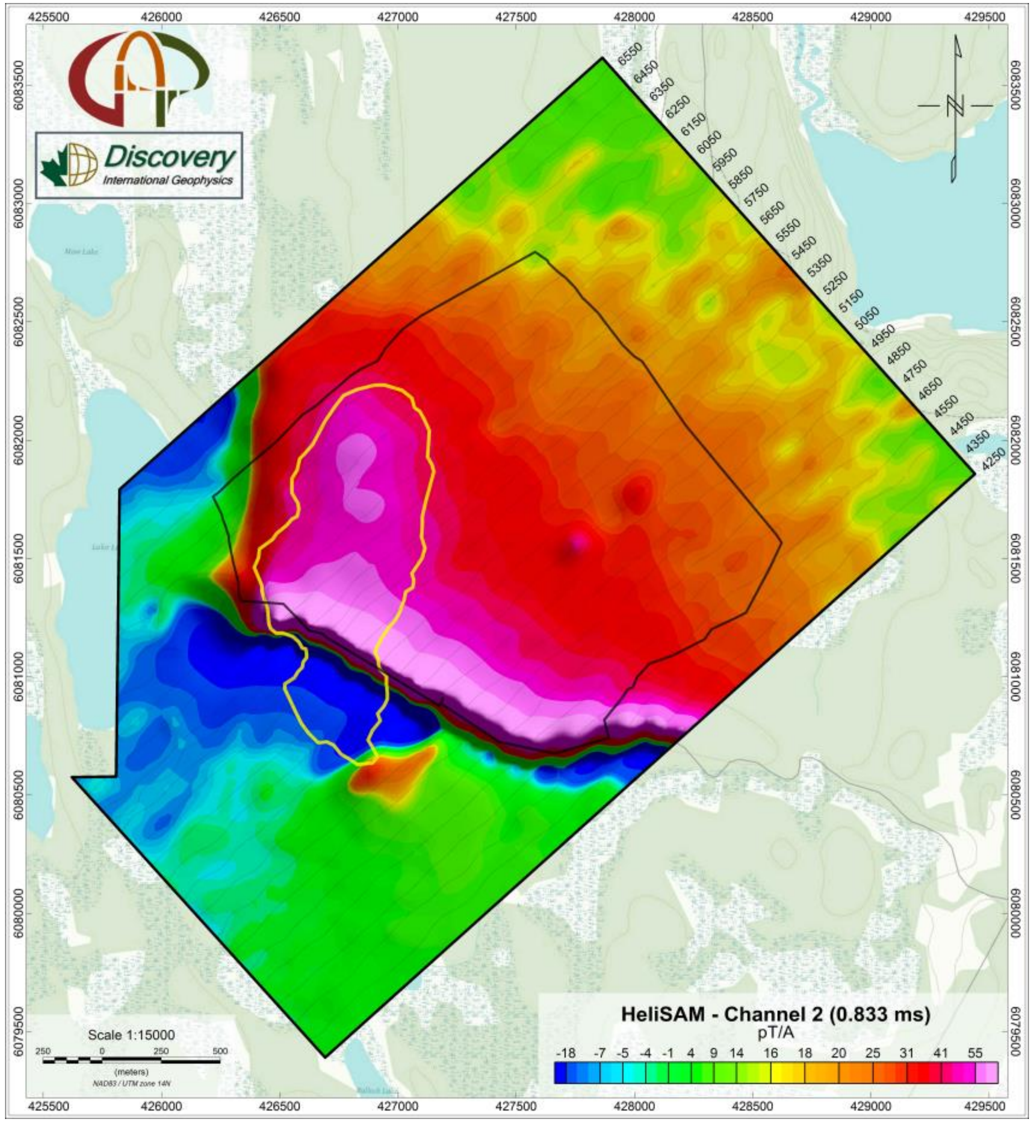


TFEM Channel 1: 0.417 ms

SAM

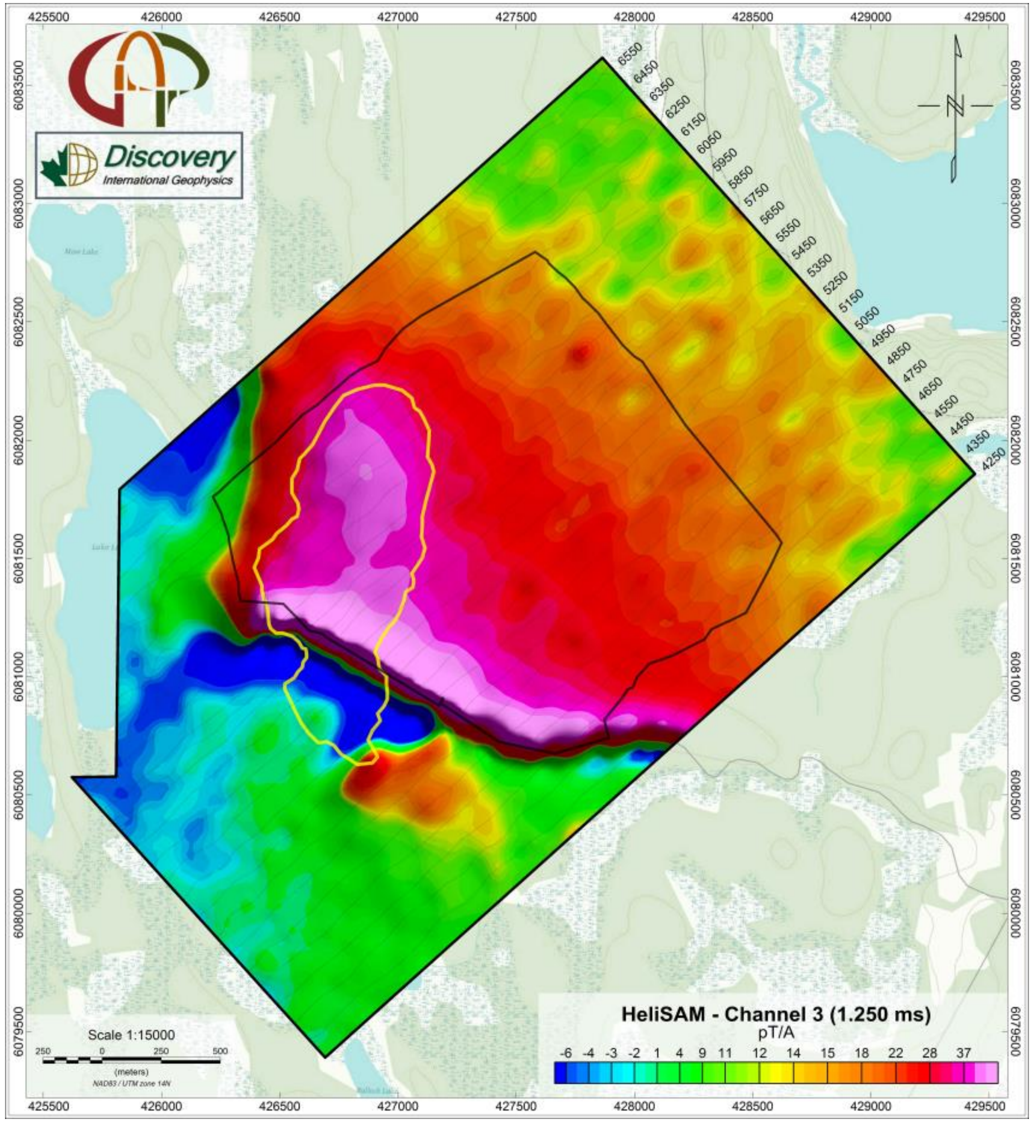


TFEM Channel 2: 0.833 ms



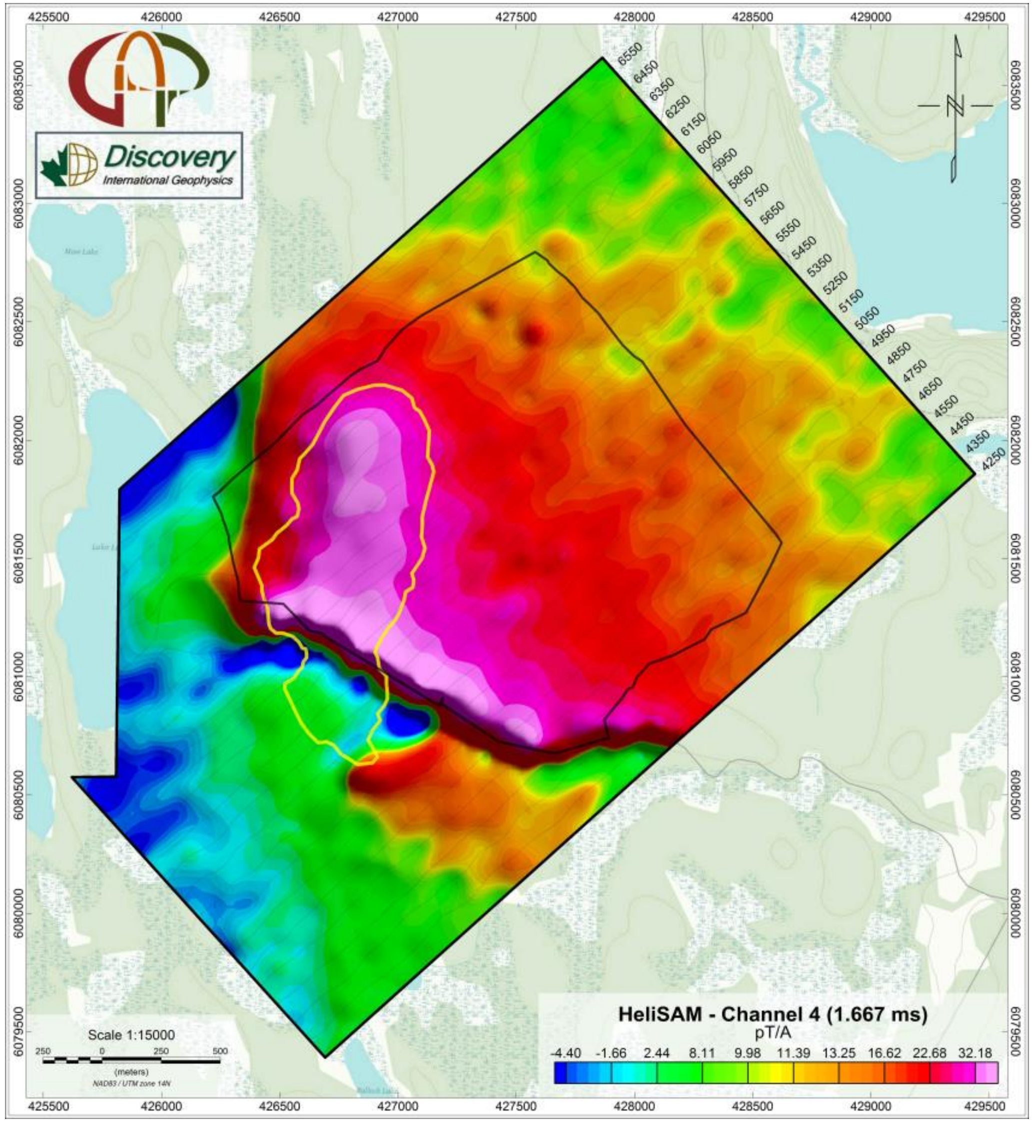
TFEM Channel 3: 1.250 ms

SAM

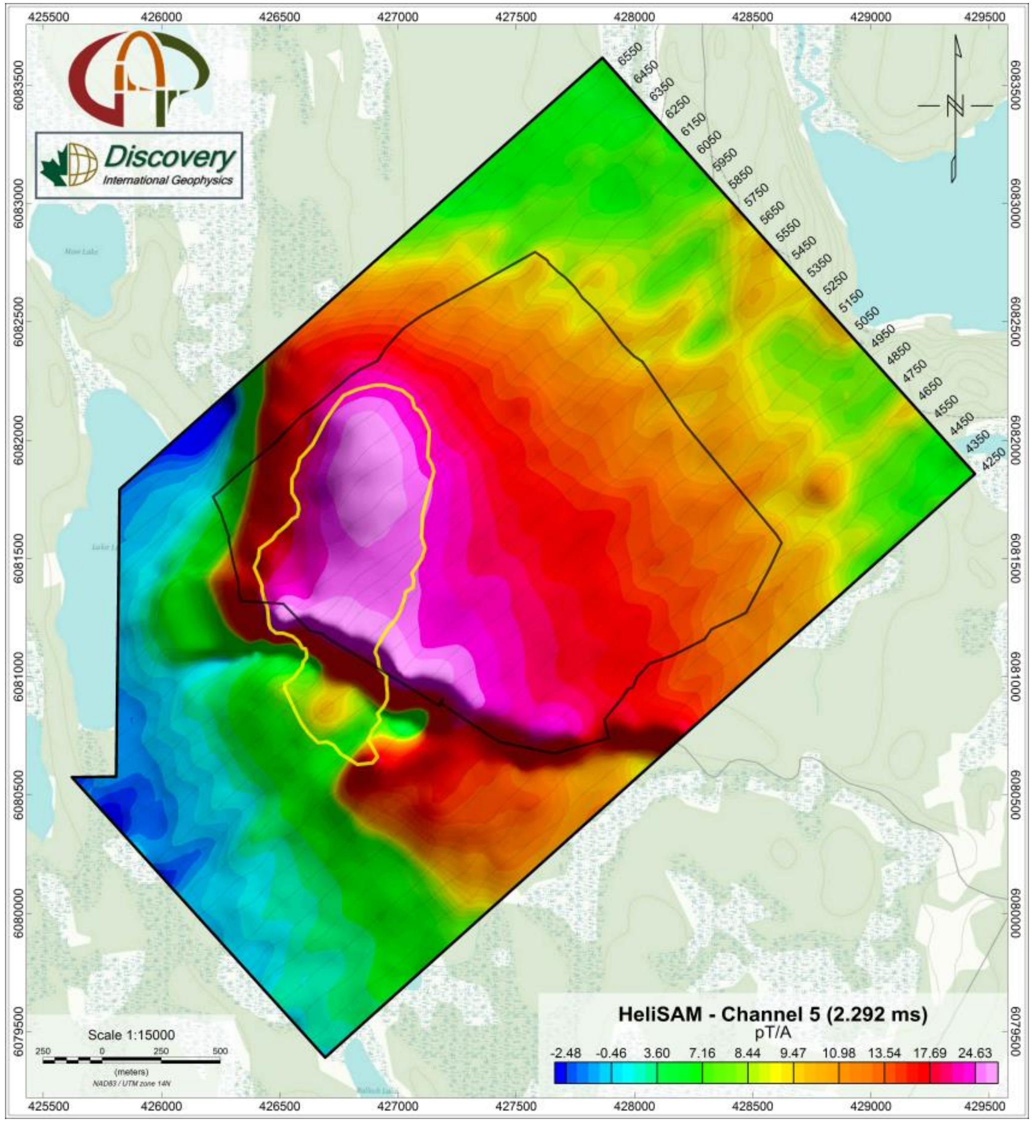


TFEM Channel 4: 1.667 ms

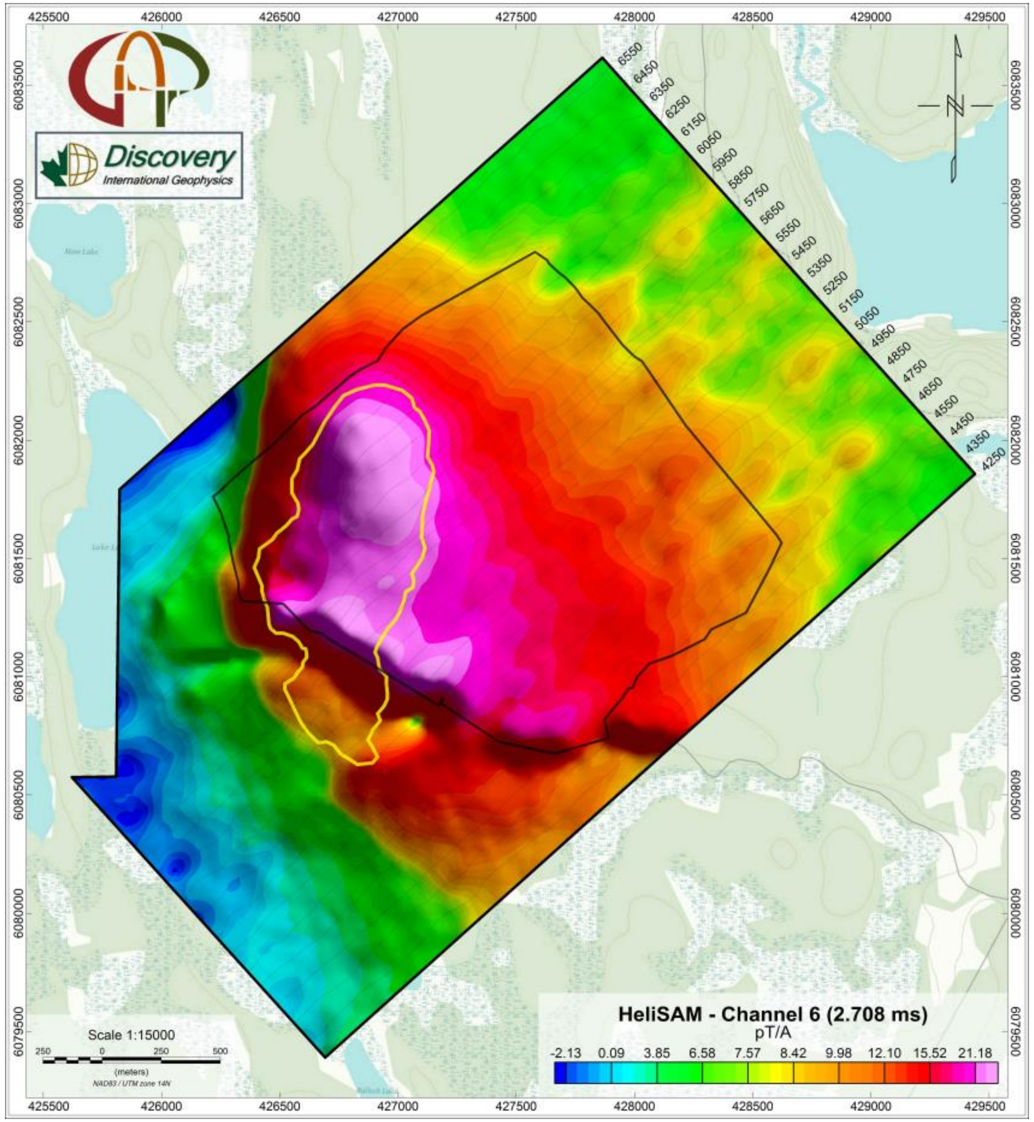
SAM



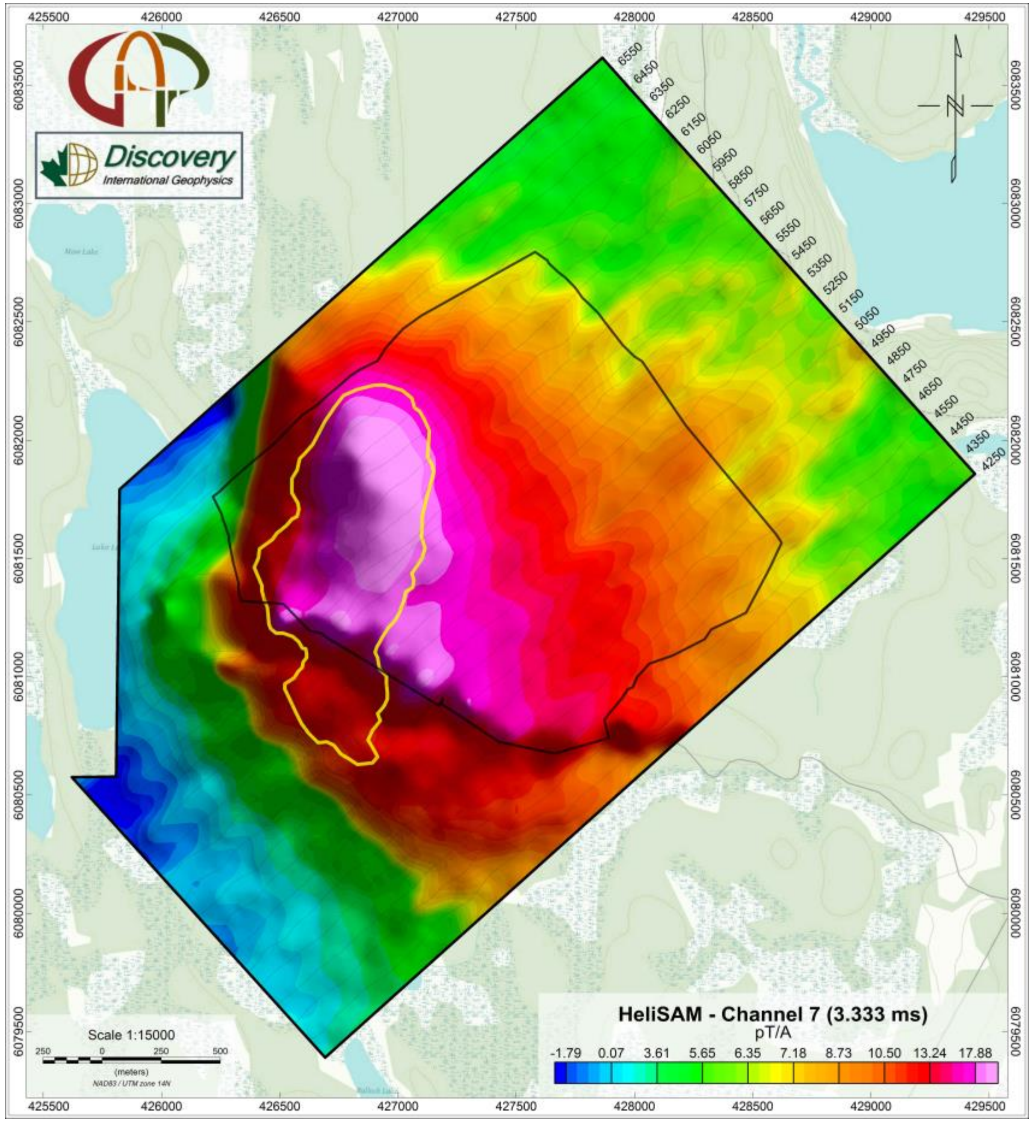
TFEM Channel 5: 2.292 ms



TFEM Channel 6: 2.708 ms

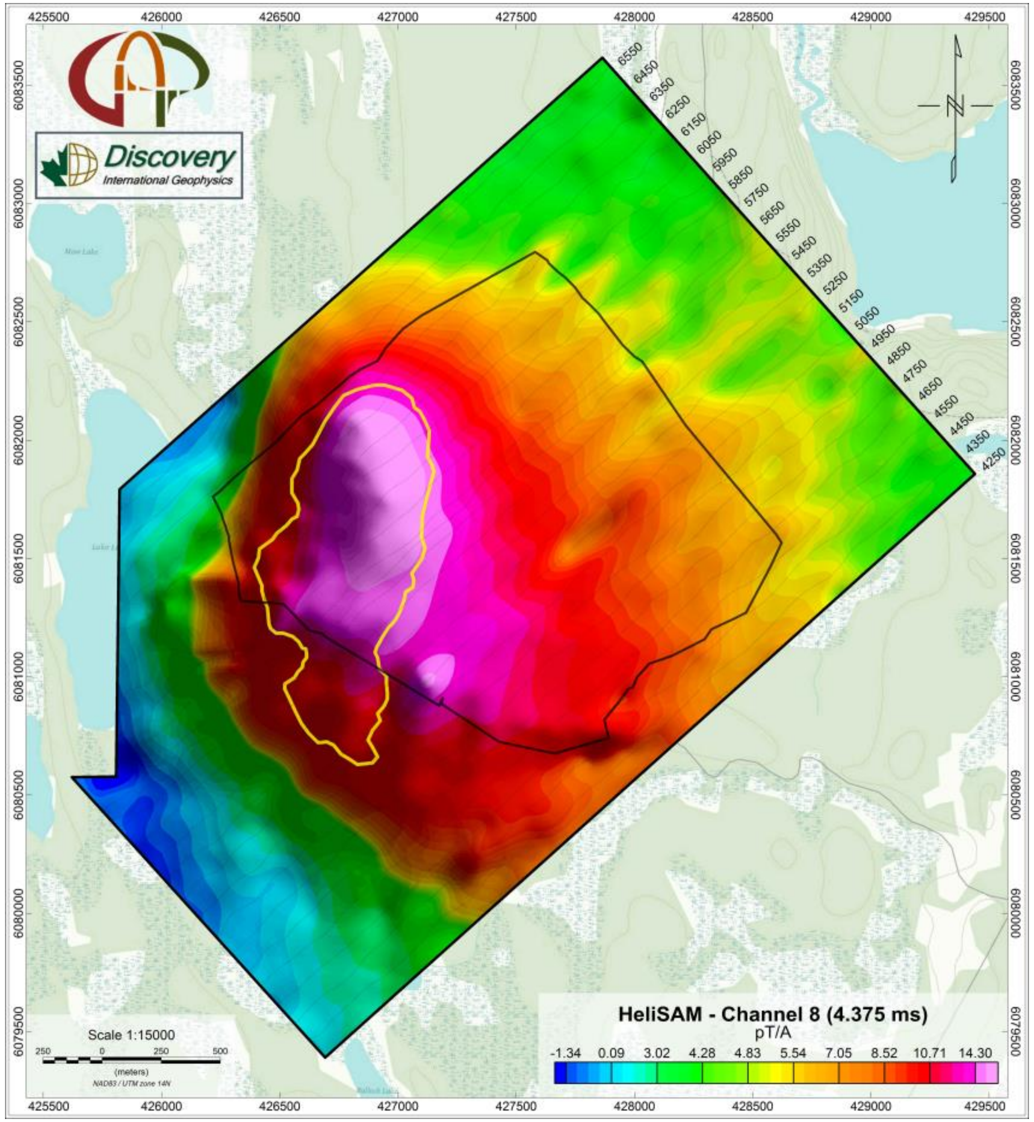


TFEM Channel 7: 3.333 ms

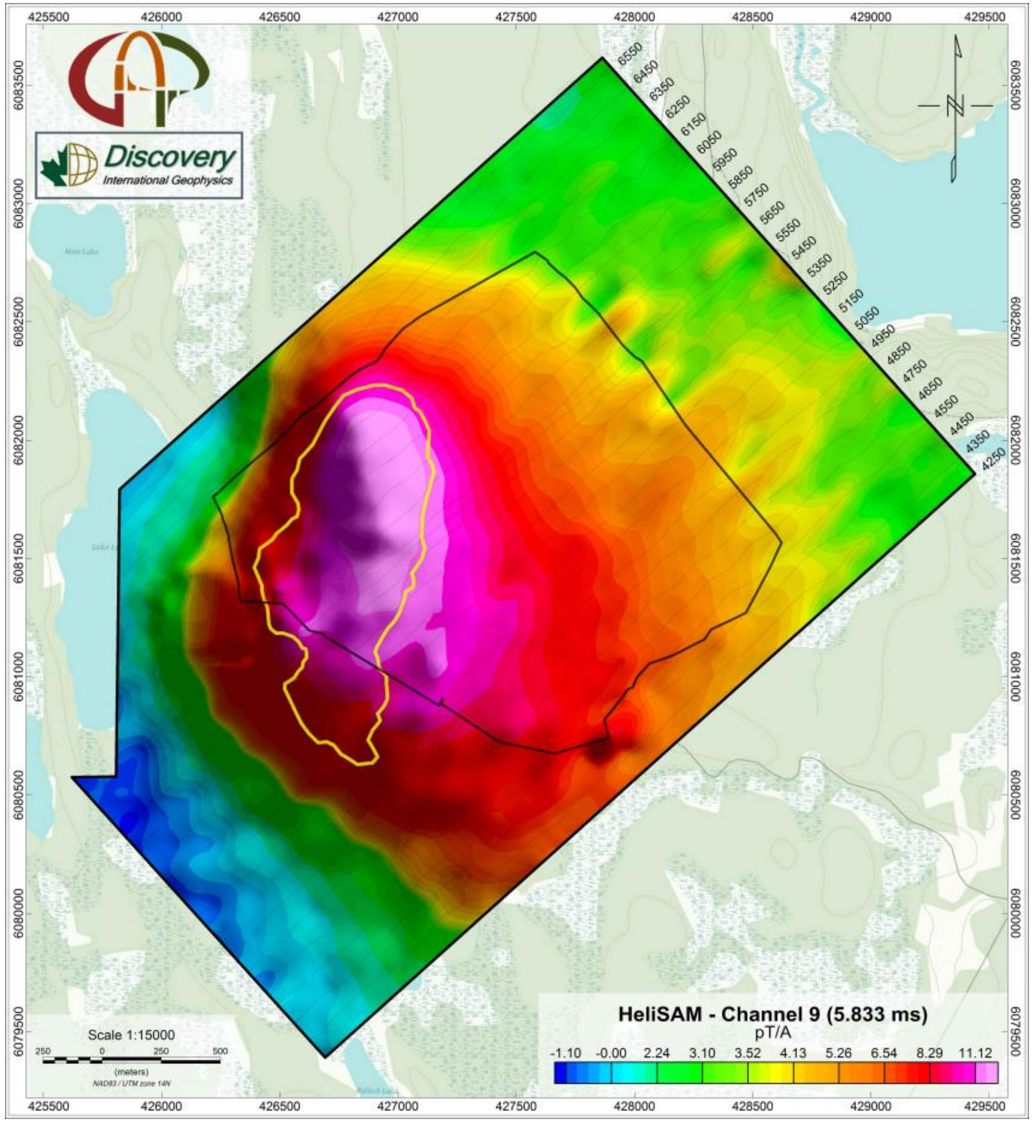


TFEM Channel 8: 4.375 ms

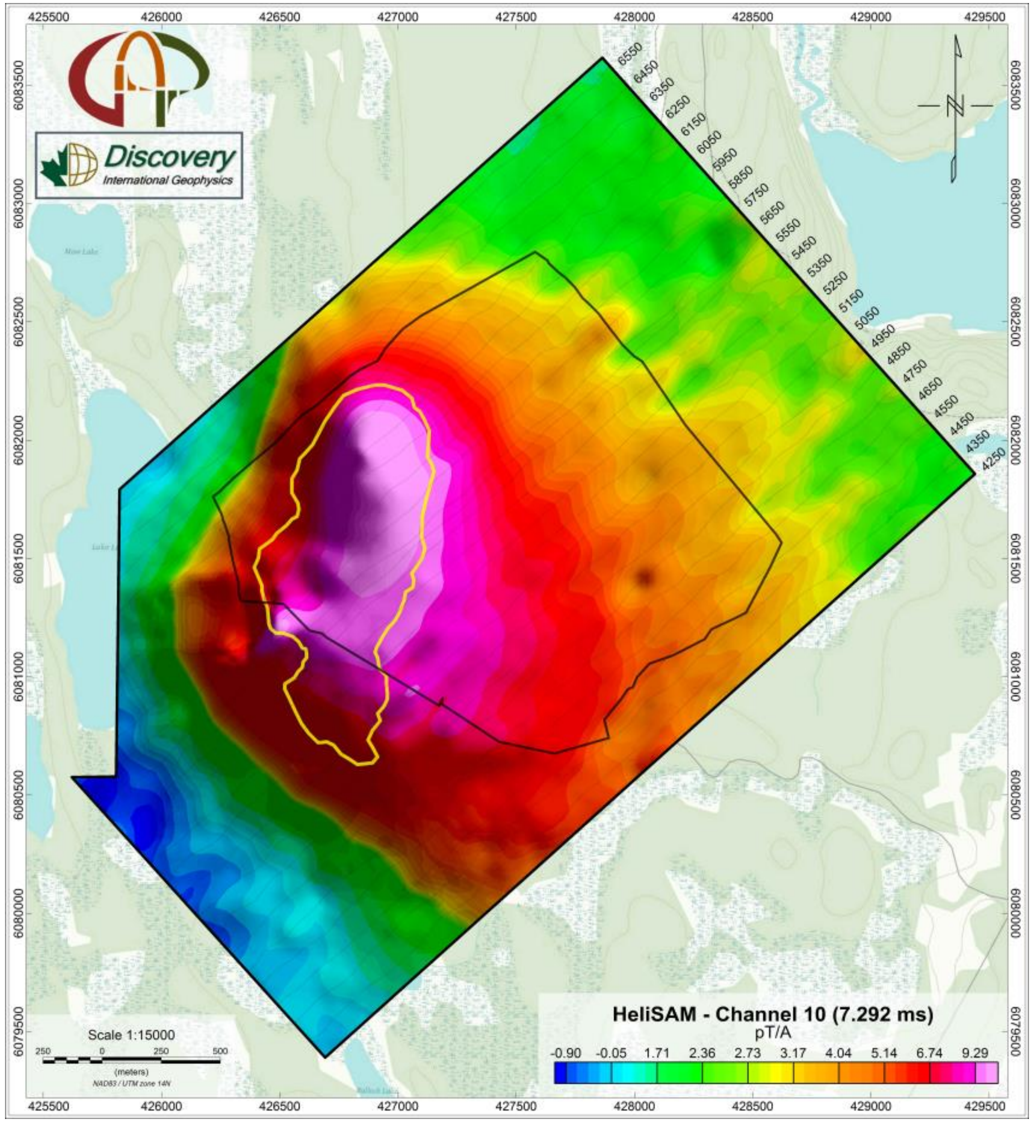
SAM



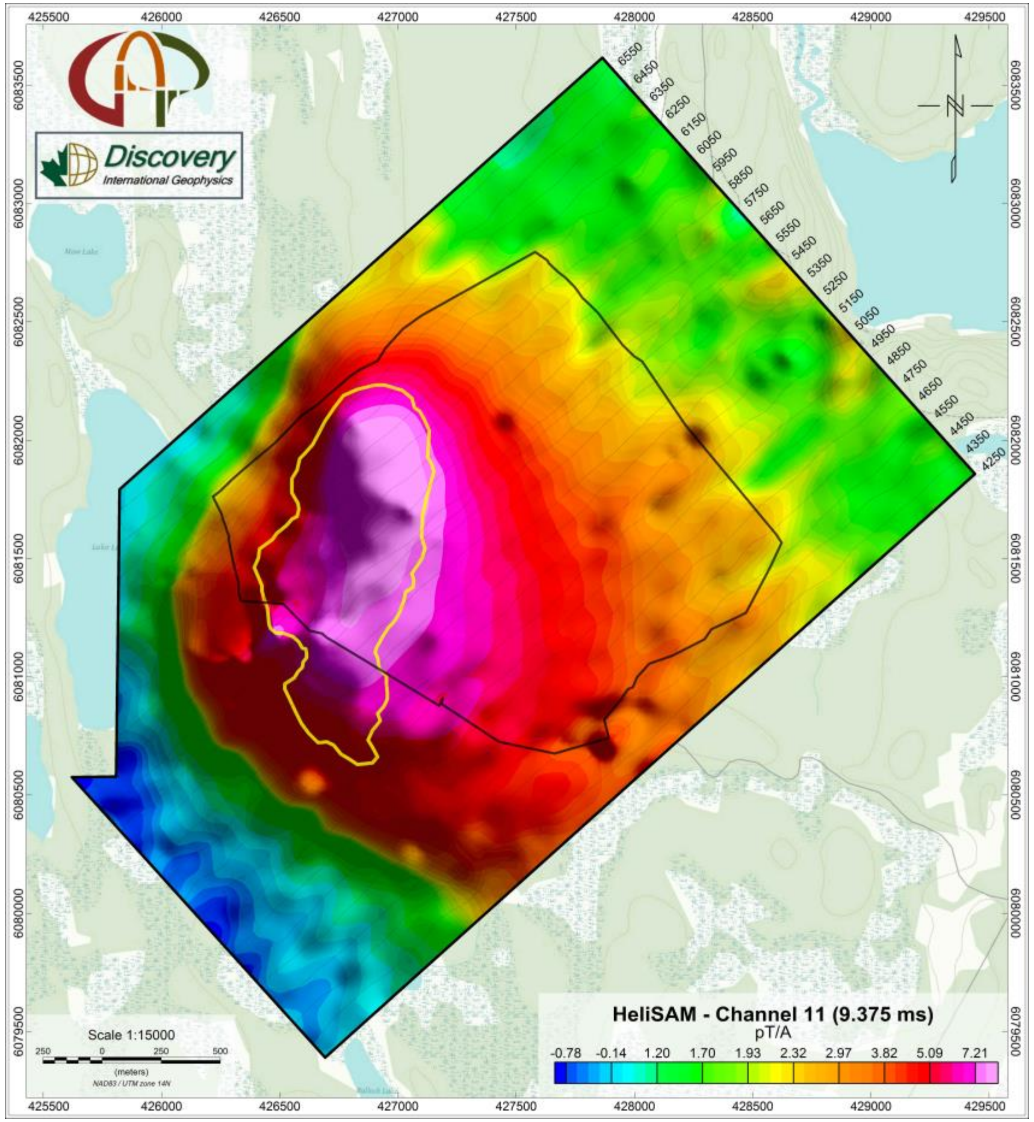
TFEM Channel 9: 5.833 ms



TFEM Channel 10: 7.292 ms

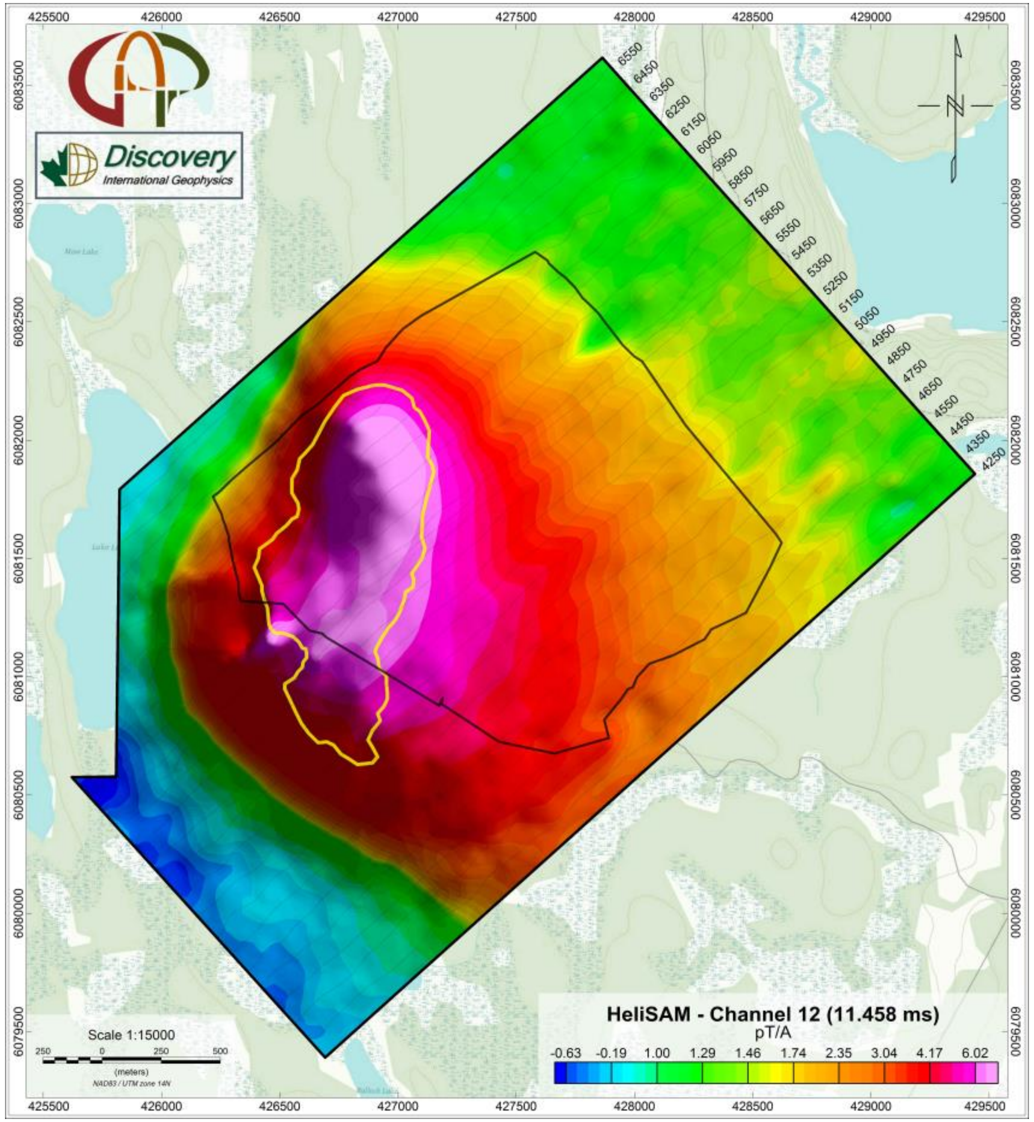


TFEM Channel 11: 9.375 ms



TFEM Channel 12: 11.458 ms

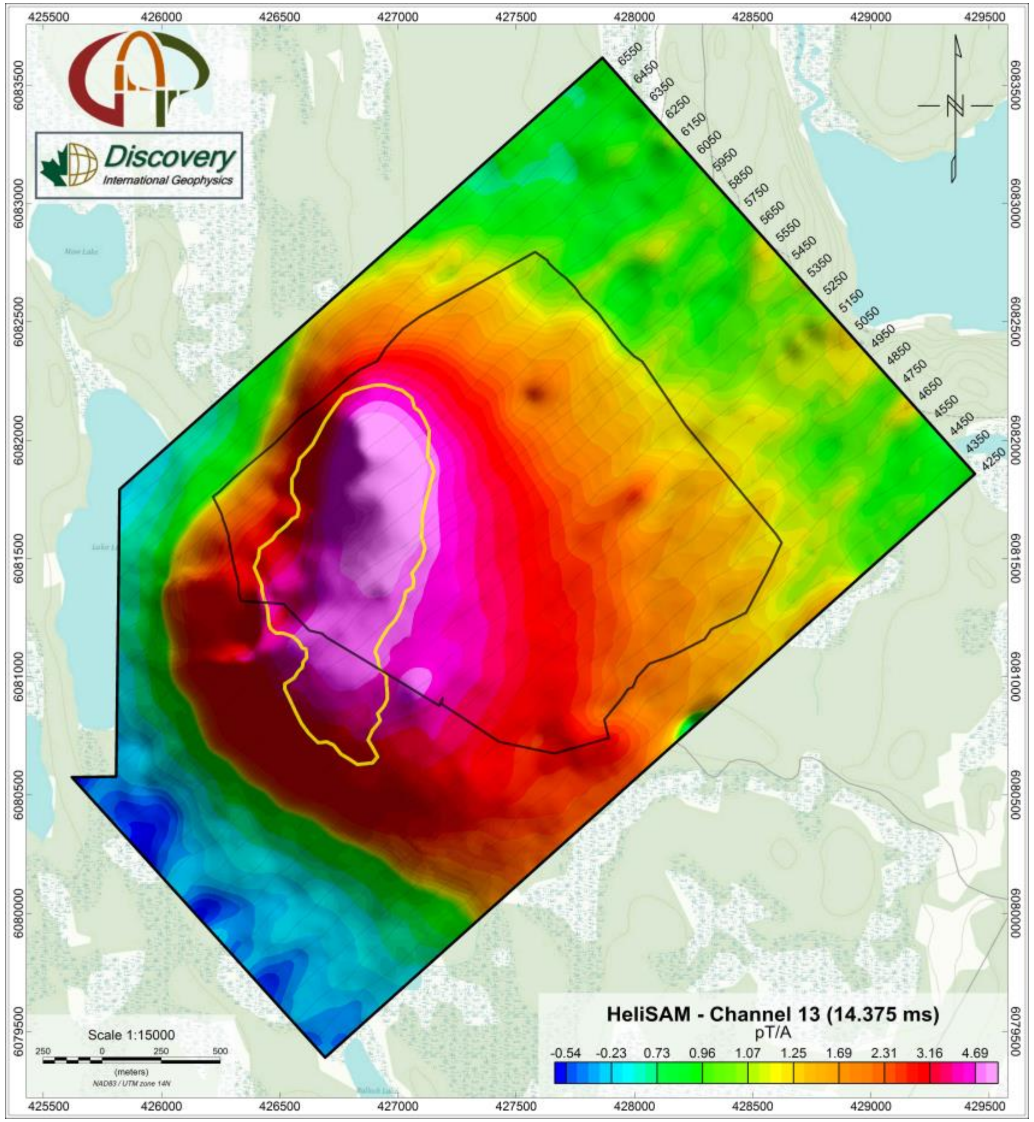
SAM



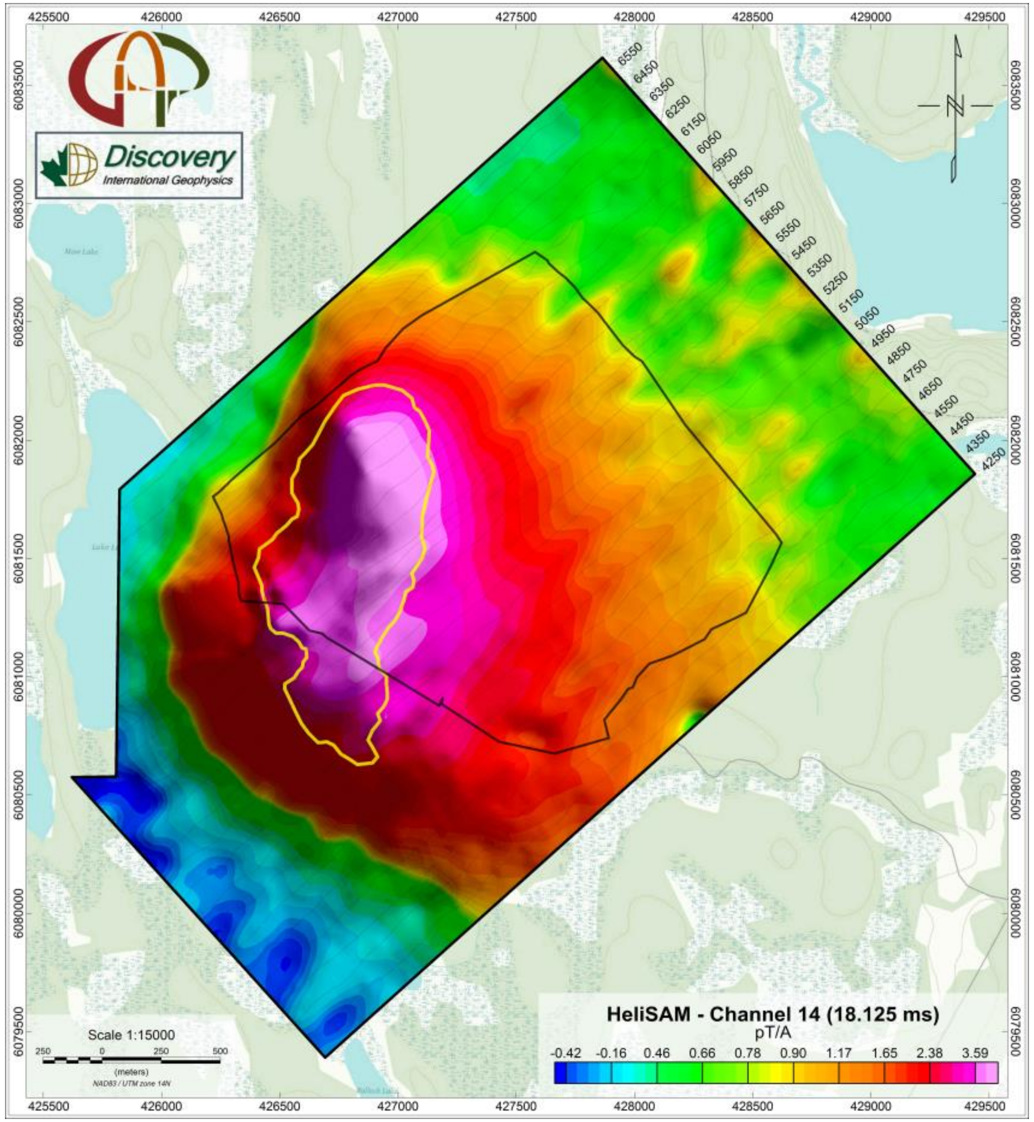
Channel 12: 11.458 ms

TFEM Channel 13: 14.375 ms

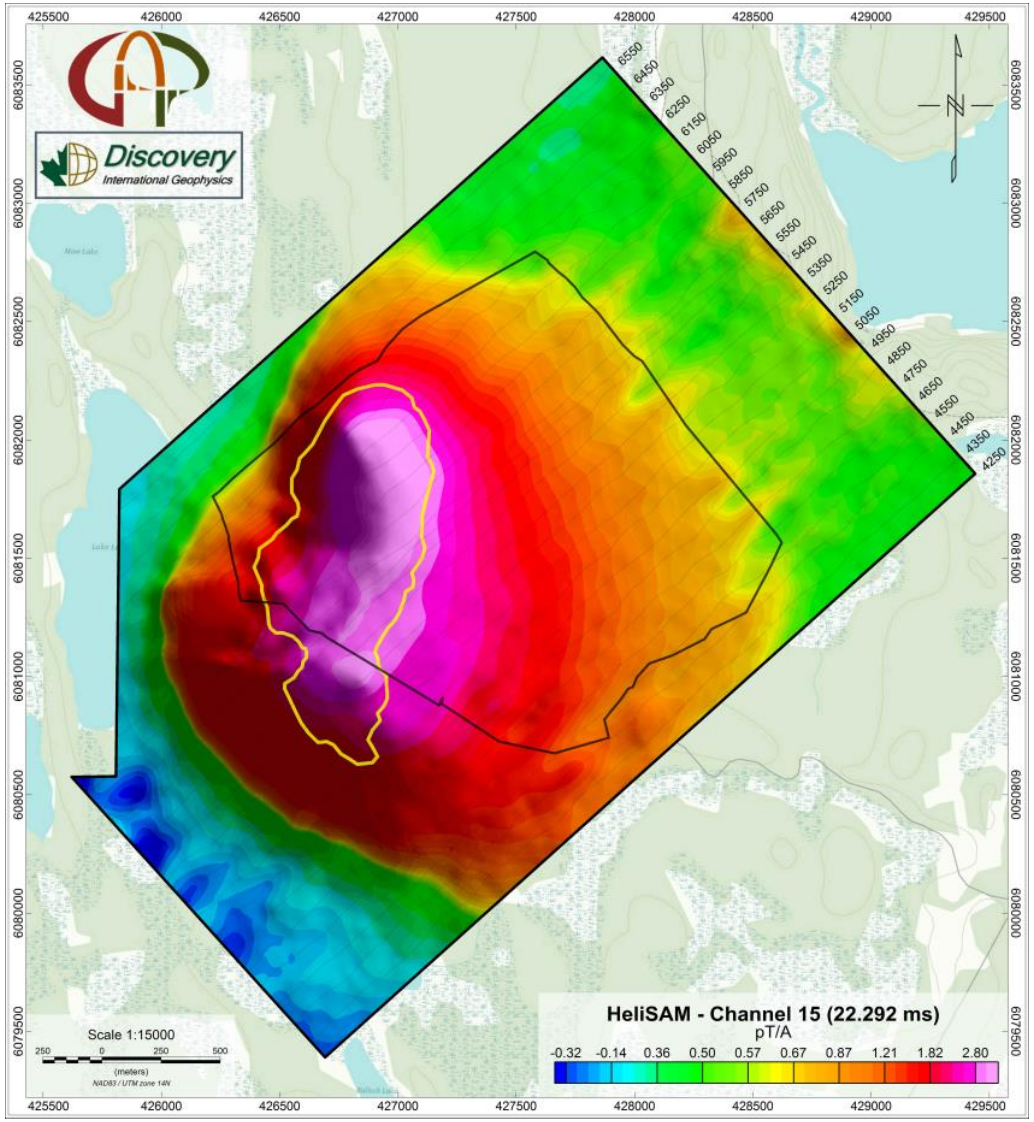
SAM



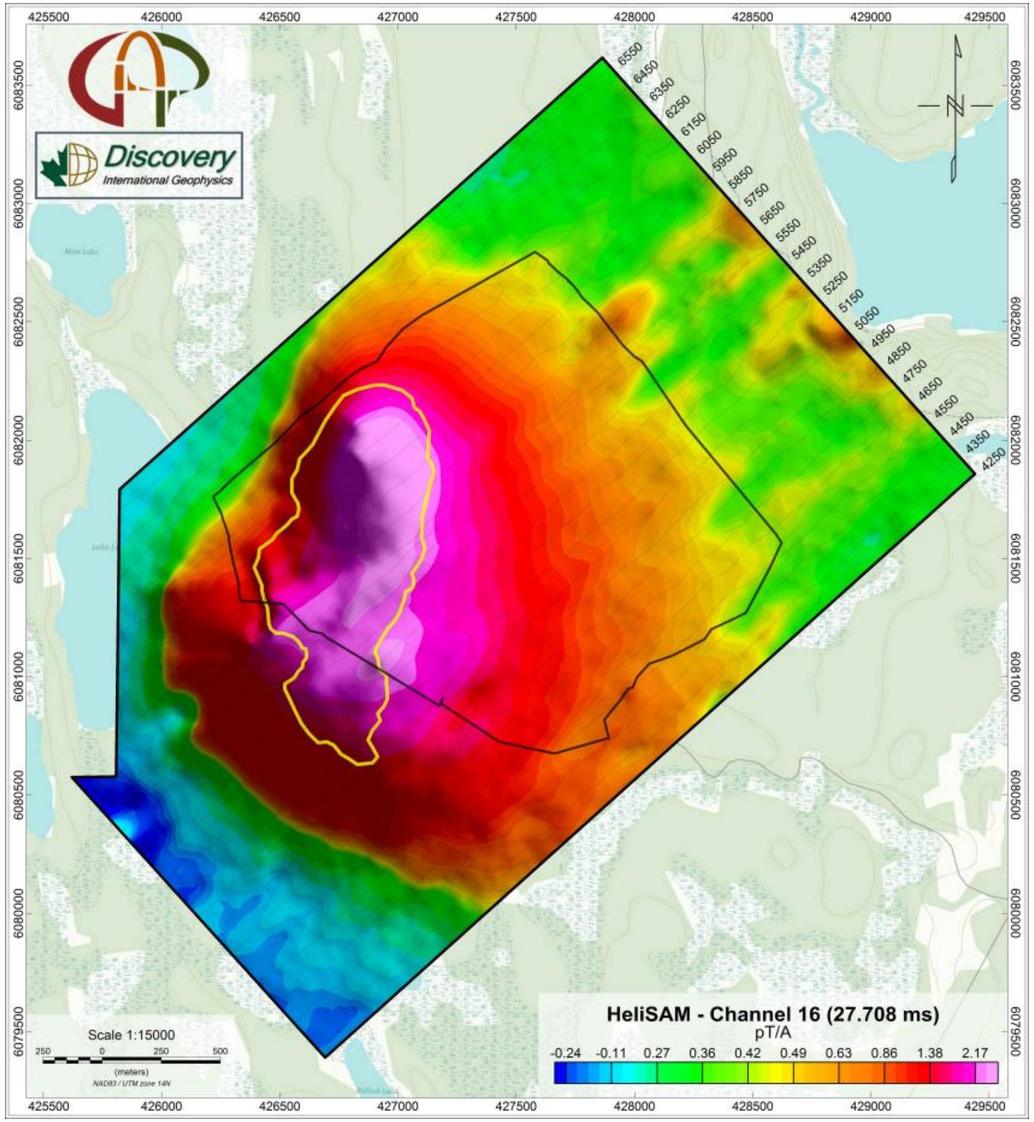
TFEM Channel 14: 18.125 ms



TFEM Channel 15: 22.292 ms



TFEM Channel 16: 27.708 ms



VPem3D inversion of Lalor TFEM

SAM

- SAM TFEM is compatible with industry standard software such as Maxwell (EMIT).
- 3D inversion of the Lalor data has been successfully accomplished by UBC (Yang and Oldenburg, to be published)

- VPem3D (Fullagar Geophysics) also promises very rapid first-pass 3D inversion in a commercially available package.

Procedure:

1. Resistive limits computed; channels 1 – 7 ignored to minimise powerline interference.
2. Compact body inversion; zero conductivity starting model
3. Editing of compact body: most conductive cells retained (conductivity > 70% of maximum)
4. Optimisation of conductivity of edited compact body

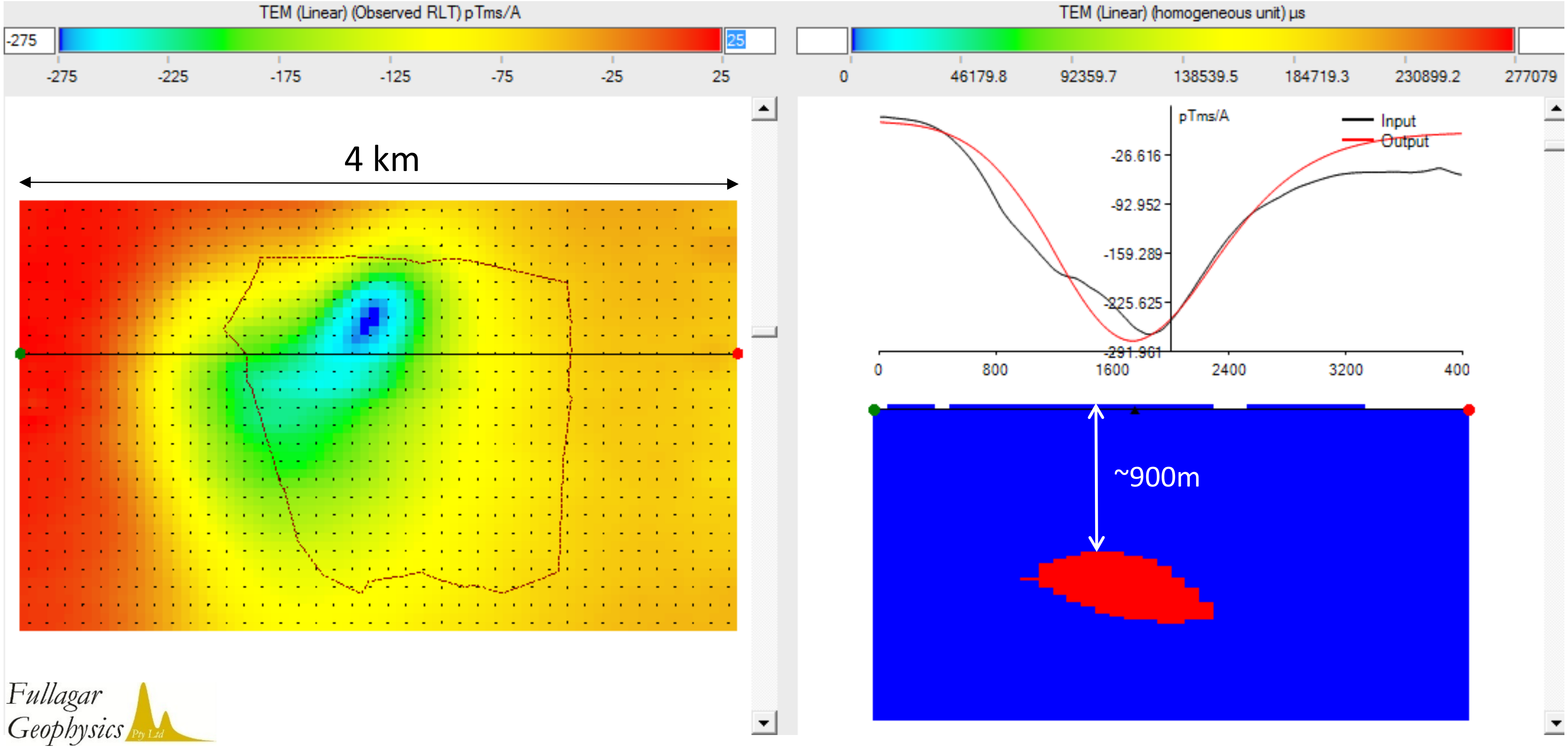
➢ Total inversion time: 7s on Dell notebook

➢ Showed good agreement with known geology

Fullagar Geophysics Pty Ltd

VPem3D inversion of Lalor TFEM

SAM



Lalor Conclusions

- 93 km of data were acquired at effectively 20m station spacing in two hours of acquisition (normally weeks at ground level with line clearing).
- The results were very significant for exploration in Canada due to the logistical issues and costs involved in surveying in such difficult environments
  - Cold – surface surveys are usually restricted to winter when the lakes are frozen.
  - Tree cover – all loops as well as survey lines require cutting prior to conducting the surveys.
- The trials demonstrated that HeliSAM could be used as a very cost-effective, rapid exploration technique for VMS deposits in Canada.

Summary

- Deep penetration EM surveys need to be larger scale than conventional surveys
  - Approach needs to be systematic
  - Survey Lines need to be longer to cover the wavelength of the anomalies from deep conductors (2-5 km).
  - Prospective areas need to be surveyed with multiple loops (to ensure coupling) and have survey overlap
  - They will require powerful transmitters, larger / heavier loops and more expensive equipment.
- *DPEM survey costs can be managed with rapid acquisition technologies such as Sub-Audio Magnetics!*

Acknowledgements

Discovery International Geophysics

Fullagar Geophysics Pty Ltd

HUDBAY

Thank You