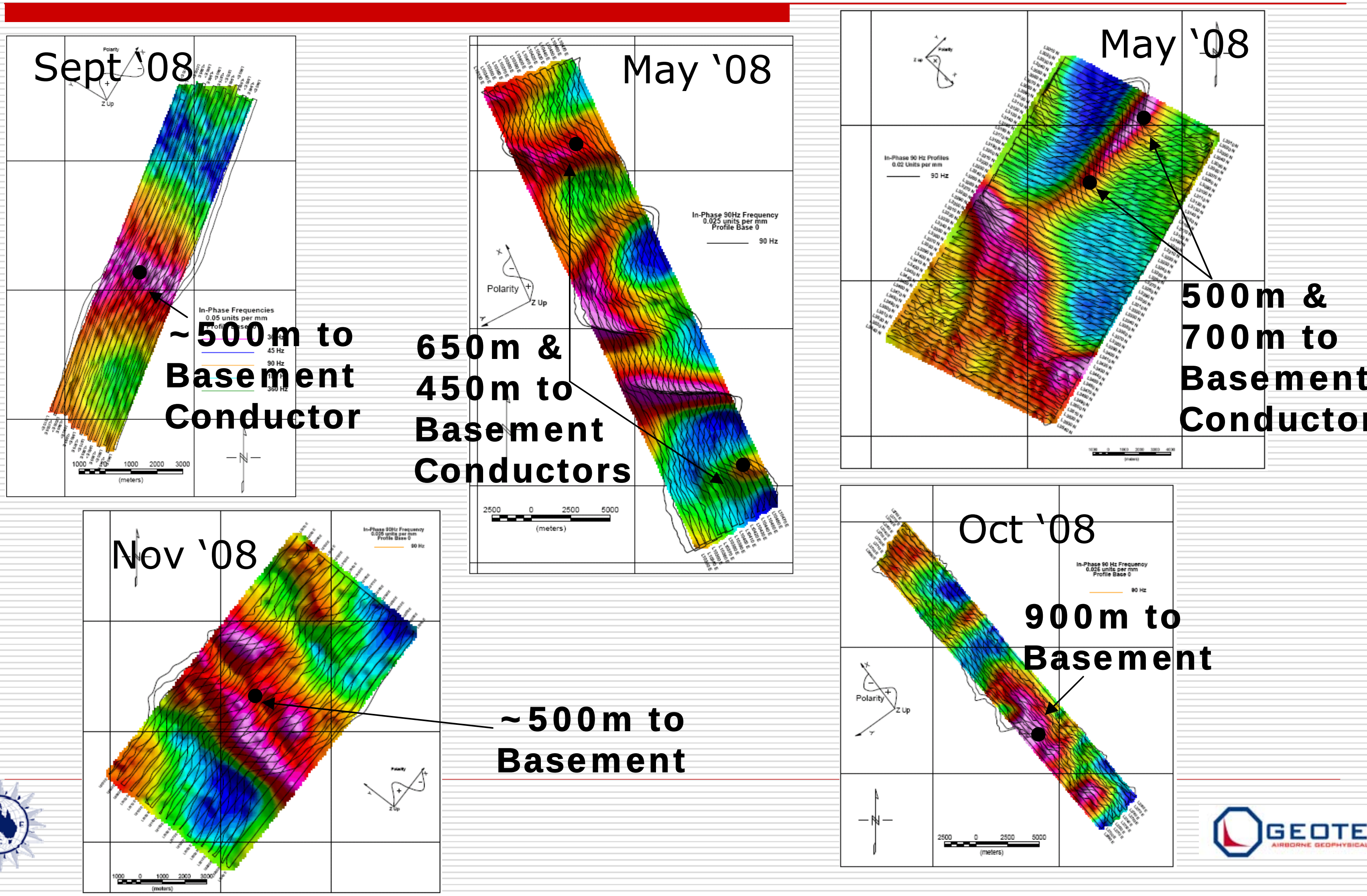
ZTEM (Airborne AFMAG) Tests over Unconformity Uranium Deposits

Presentation at ASEG '09, 20TH International Geophysical Conference and Exhibition, "Brighter, Deeper, Greener – Geophysics in a Changing Environment", February 22-25, 2009, Adelaide, AU.

By:

Bob Lo, Exploration Syndicate Inc.
Jean Legault and Biljana Milicevic, Geotech Ltd.
Petr Kuzmin, Geo Equipment Manufacturing Ltd.

Results of Athabasca ZTEM Surveys in 2008



Outline

- Introduction to AFMAG
- AFMAG development
- ZTEM development
- ZTEM modeling
- ZTEM survey results
- Conclusion

AFMAG – historical

- Ground AFMAG were used in the late 1960's by McPhar for minerals exploration.
- In spite of its many positives, poor data quality and repeatability were major impediments to its application/acceptance.
- Technique was essentially abandoned as an exploration tool as other EM techniques of using controlled transmitters were developed, proved successful and gained acceptance.

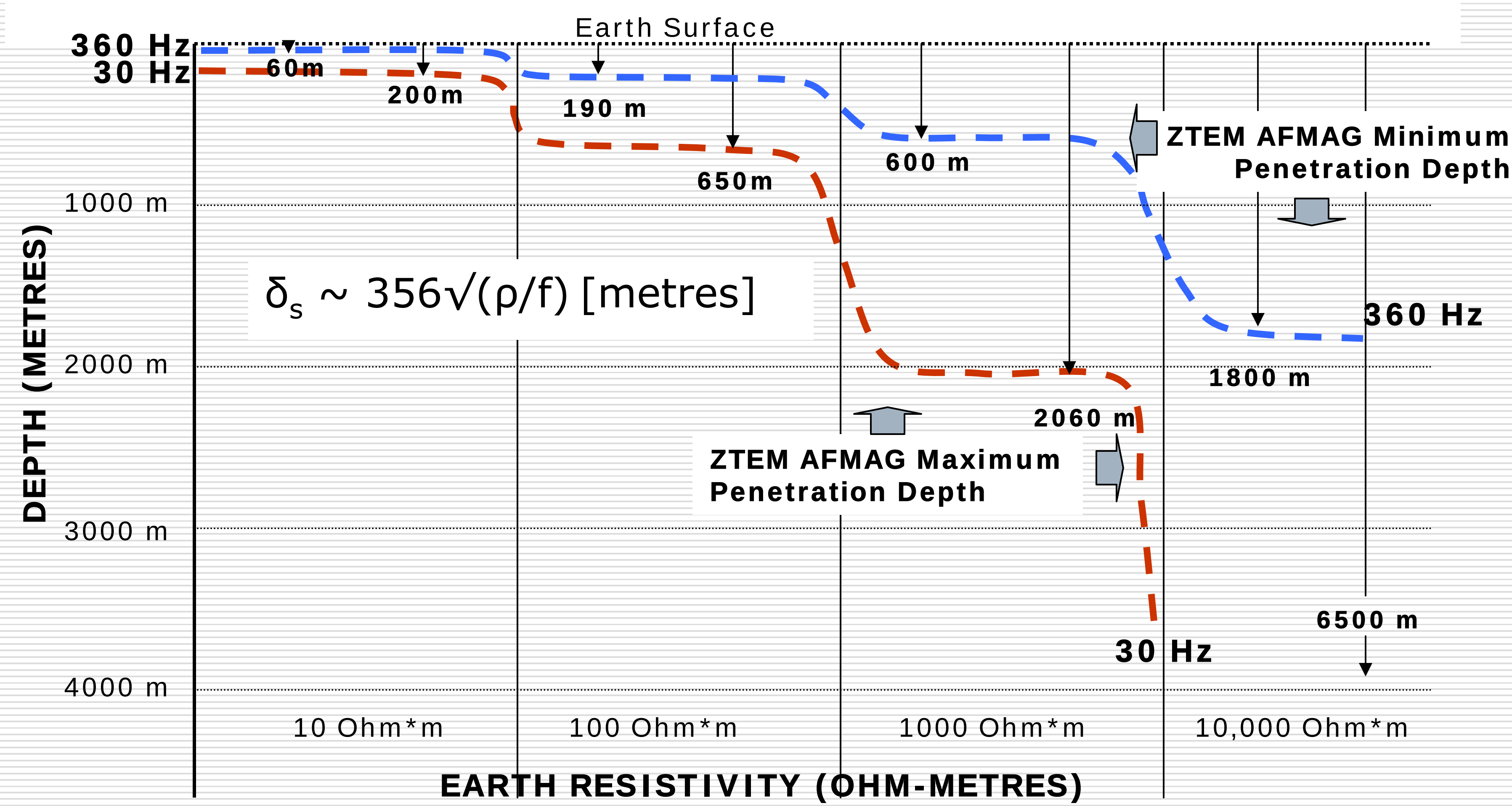
AFMAG Background

- passive EM technique – does not a have man-made transmitter
- frequency range - “audio range” Geotech’s AFMAG can operate from 22 to 2800 Hz (based on digitizing rate), but in practice we operate from 30 to 360Hz (based on signal strength).
- The source is the natural field of Earth caused by lightning strikes at a distance.
- The Earth and the Ionosphere, both conductive, acts as a wave guide to “transmit” these energies a great distance.

Source and polarization difficulties

- Source is variable – at certain times of the year (portions of the winter in North America), the source fields are relatively weak. Summer season is best, but early Spring to late Fall can have sufficiently reliable signal.
- At each moment, during the survey flight, there is a mixture of signals from different sources – creates unknown EM coupling issues.
- In practise, we can assume that the source field has wide azimuthal direction and deal with two vector components of the B primary field.

AFMAG Depth Penetration
Simplest Case: 1D Skin Depth Rule



MT PLANE WAVE SKIN DEPTHS in 1D HALF-SPACE

GEOTECH AIRBORNE GEOPHYSICAL SURVEYS

Airborne AFMAG Theory: Basic Principals

The various frequency bands are extracted digitally from the time series of the recorded components of the signal

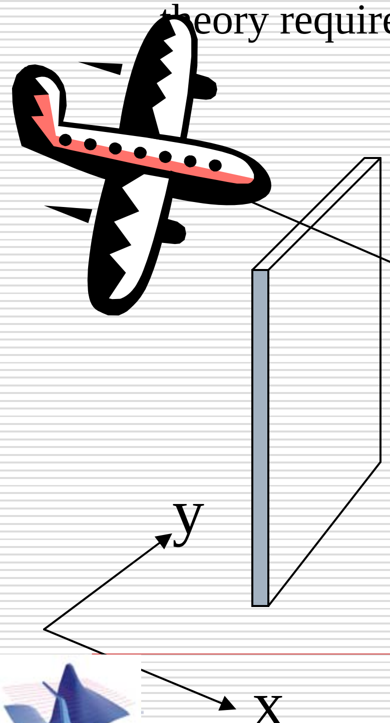
3 components of the magnetic field are measured and they are processed according to:

$$\mathbf{H_z(\mathit{f}) = T_x(\mathit{f})\, H_x(\mathit{f}) + T_y(\mathit{f})\, H_y(\mathit{f})}\quad ,$$

The vector (T_x,T_y) is referred to as the 'Tipper' vector and is determined in the frequency domain through FFT processing. This is normally done by determining transfer functions from an extended time series.

Airborne MT Theory
Basic Mode Behaviour and Physics

To understand the directional component (mode) behaviour, we assume a thin plate-like conductor model The model is perpendicular to the flight direction. For this exercise, we will assume very long strike directions. From this quasi-2D model, there are 2 basic responses. The TE response and the TM response. In airborne AFMAG, we will assume that the flight is in the X direction and the strike of the conductor is in the Y direction. EM theory requires that varying E- and H-fields are orthogonal.

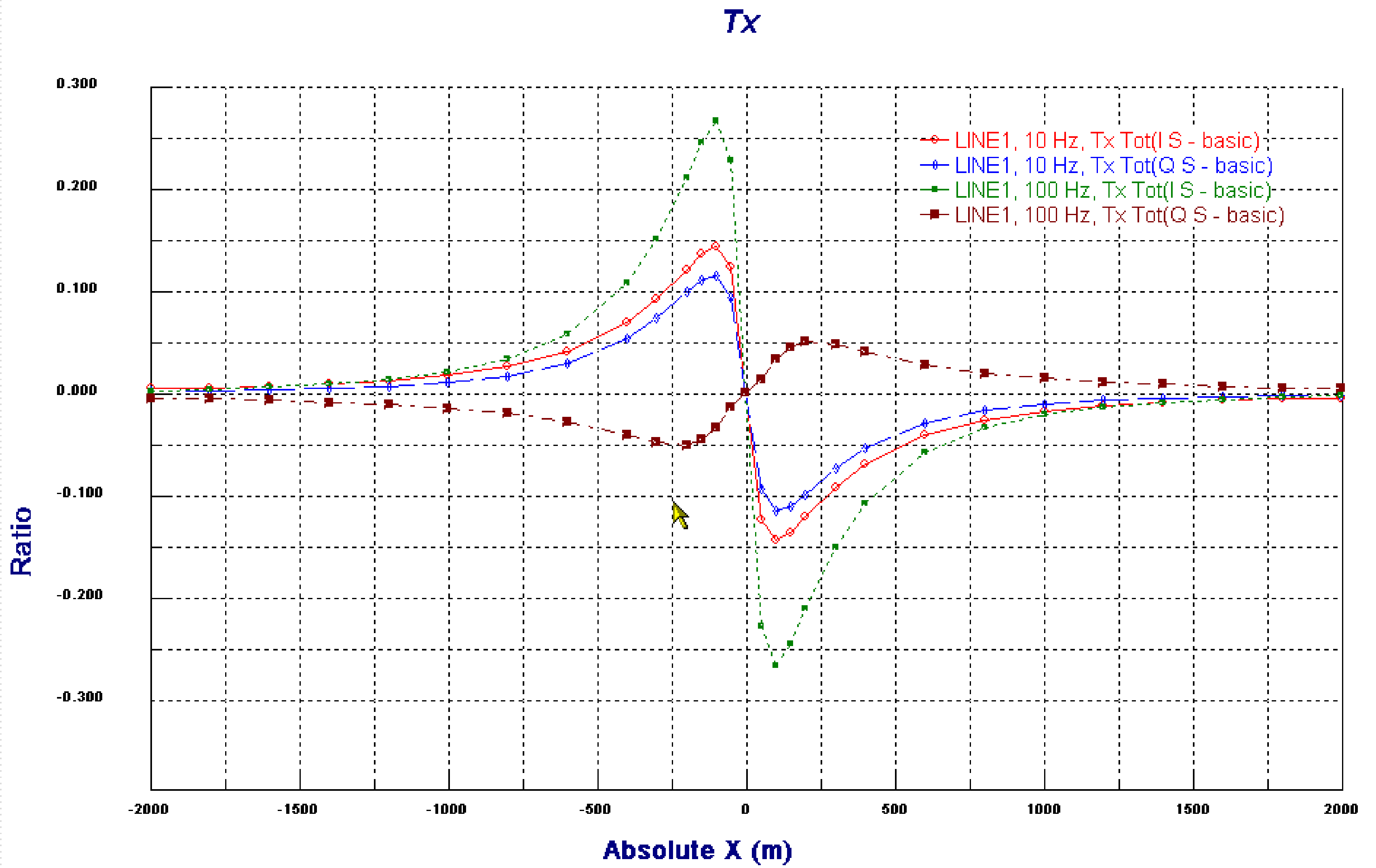


TE Mode: For the TE response, the electric E field excitation flows along strike (Y) due to current channeling and the horizontal H field (Hx) flows perpendicular to strike thus causing induction through Faraday's law. Hz is generated both from channelling and induction from Hx.

TM Mode: For this response, the electric field excitation flows perpendicular to strike generating quasi-static charges on faces and the horizontal H field (Hx) flows parallel to strike. Since, the XZ face is very small for this model, little current is induced. The charges on the faces have a small dipole moment due to the thinness of the model.

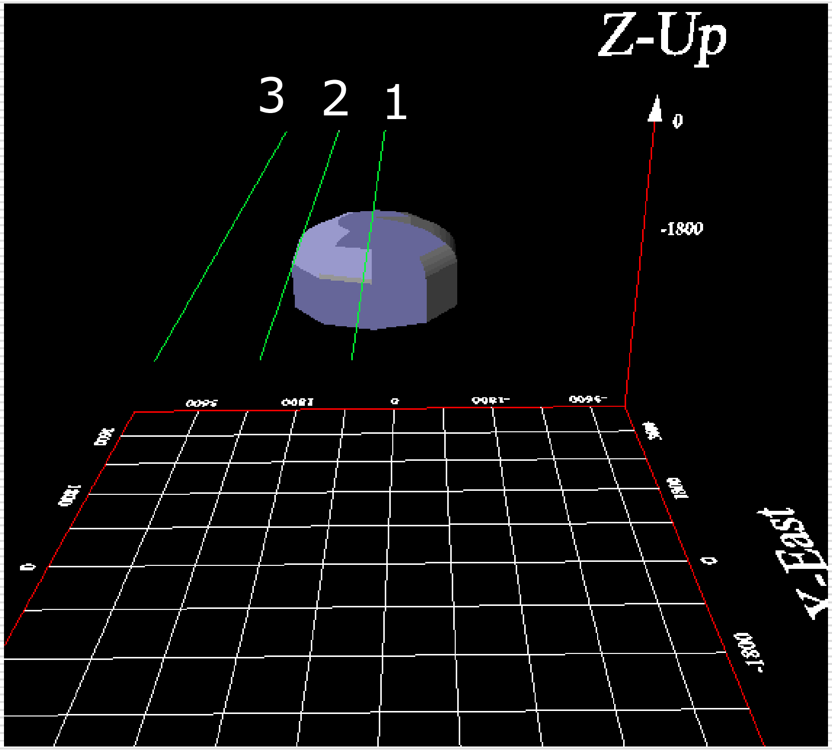
Practically speaking, for 2D or elongate 3D cross-cutting bodies, the TM mode response is weak relative to the TE mode (Hy/Hz small for 2D earth).

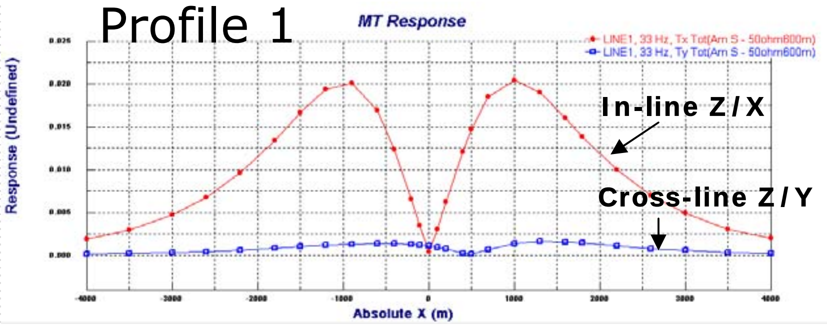
Airborne MT modeling
2D Inphase and Quadrature Response In-line Hz/Hx (TE mode) for a buried plate conductor in a moderately resistive half-space

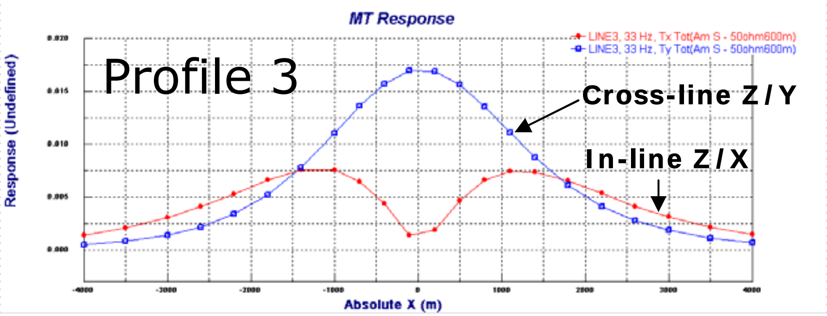


Tx) Inphase, Quad at 10 and 100Hz. Crossovers in Inphase and Quadrature.

Modelling of 3D bodies







Geotech’s AFMAG development

Geotech revisited AFMAG starting in 2000 using modern technology, and signal processing tools.

Test results using the system as shown on the right, were encouraging, but showed that the receiver coils were not sensitive enough – i.e. too small.

System in 2000

Geotech's AFMAG development

With funding and support from INCO and MIM, Geotech obtained a OMET grant to significantly upgrade the airborne AFMAG system.

New coils, suspension system, base stations, orientation sensors, numerical simulation, field trials, data processing techniques and reporting were accomplished.

Geotech also patented the system.

ZTEM – late 2006

- Onboard Hz-Hx-Hy receiver coils in AFMAG bird replaced by combination of larger single vertical aircoil and fixed base station receiver coils. New configuration called "ZTEM" (Z-Tipper EM) system.
- Early ZTEM airborne coil was 7.4 m (same size now)
- Orientation devices were accelerometers and digital compass, but these did not perform as well as expected and were changed.
- Early ZTEM had base station coils same size as airborne coil at 7.4 m,
- This proved impractical and smaller base stations were built.

GEOTECH
AIRBORNE GEOPHYSICAL SURVEYS

ZTEM base station (current)

- Base station is now smaller – about 3.5 meters square,
- braced to be perpendicular to each other,
- Internal suspension system,
- Aircore loops

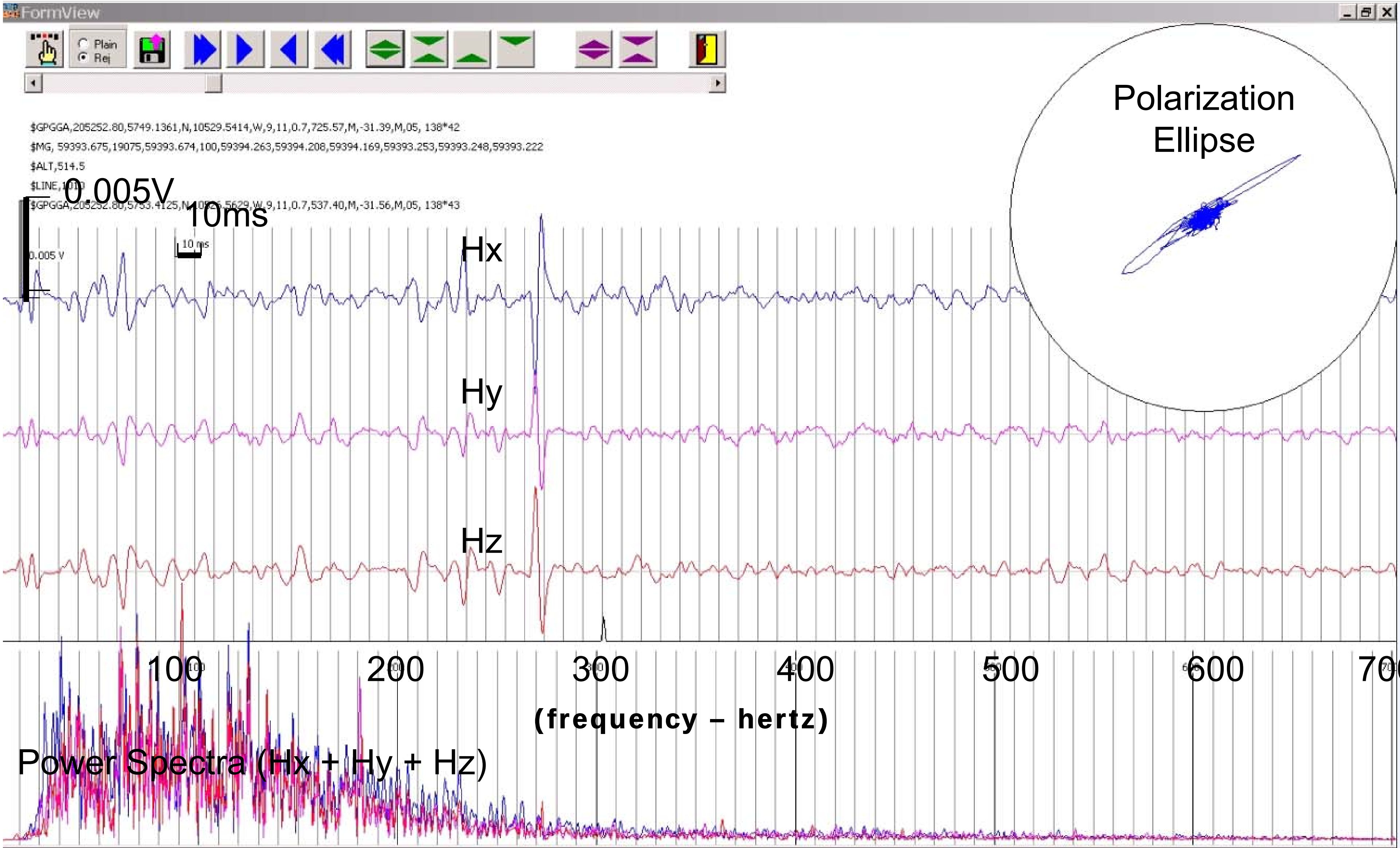
ZTEM – airborne coil

- Single axis aircoil
- Roughly 7.4 metres in diameter (about 50 times larger area than eggshell version)
- 90 metre long tow cable
- Internal suspension system
- Attitude measured by three GPS mounted on airborne coil

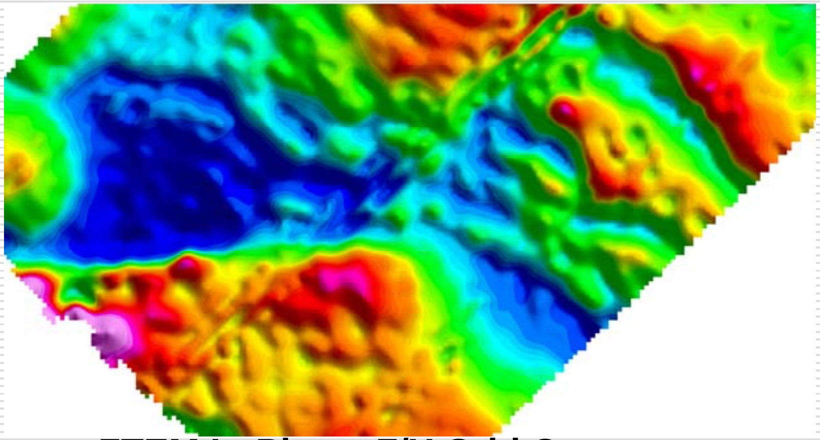
Survey Specifications

- Helicopter speed – approximately 100 km/hr
- Frequencies extracted at 0.4 second intervals (approx. 10m),
- EM sensor terrain clearance –nominally 50-100 metres (depends on terrain & geology)
- Typical extracted frequencies from the airborne and the base station coils: 32, 45, 90, 180, and 360 Hz.

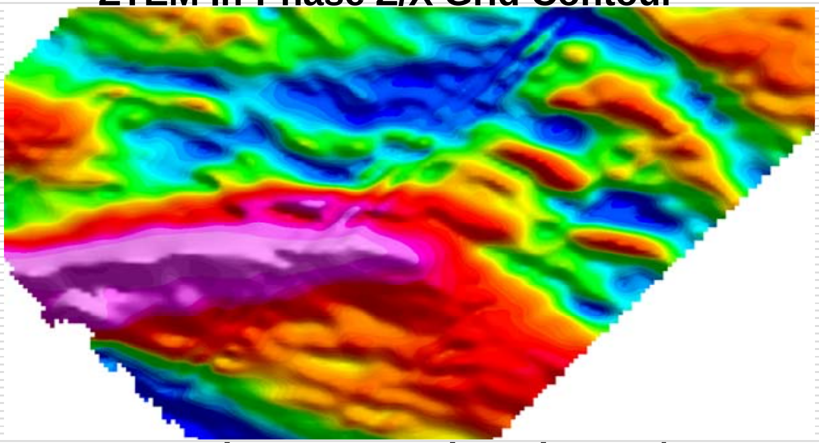
Time series from ZTEM bird & base station coils



Data Presentation



ZTEM In-Phase Z/X Grid Contour



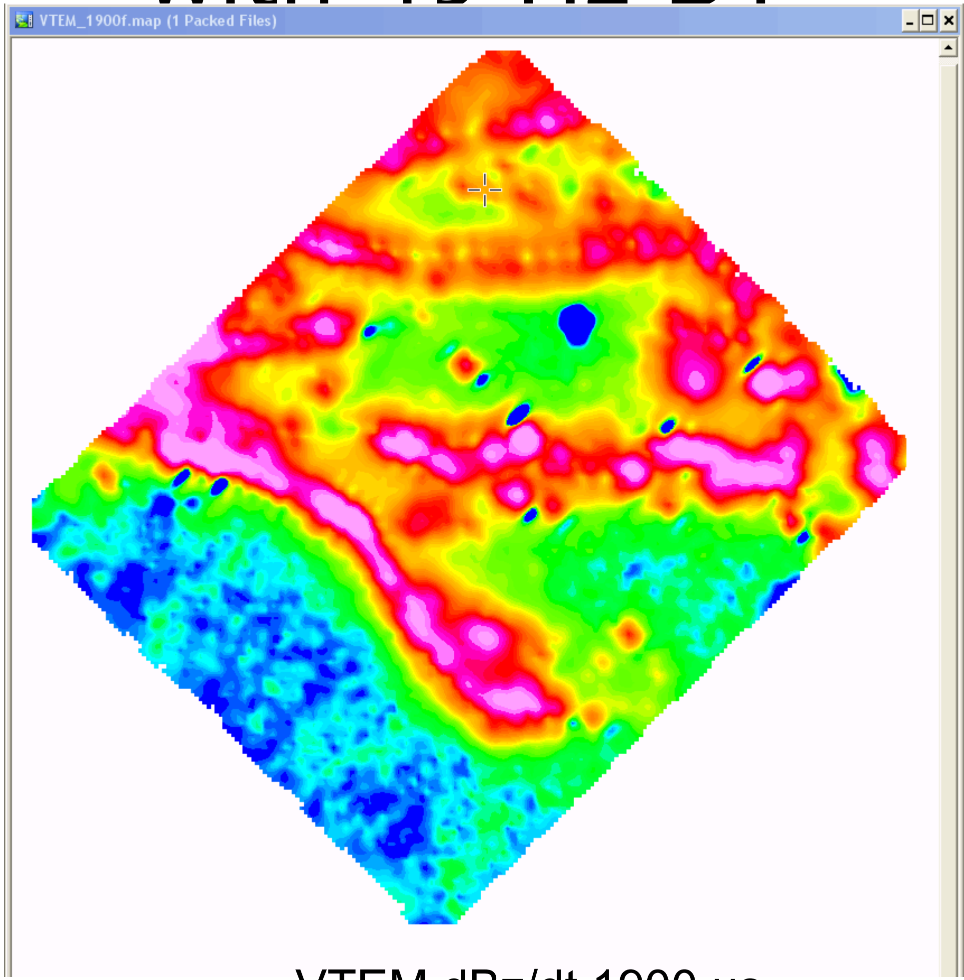
ZTEM Phase-Rotated In-Phase Z/X

- Top panel is of gridded dip angles values in the in-line direction. Conductive anomalies are located in the transition between the highs and low values.
- Bottom panel is of a phase rotated grid, such that the cross-overs are now peaks, centred over the conductive anomaly.

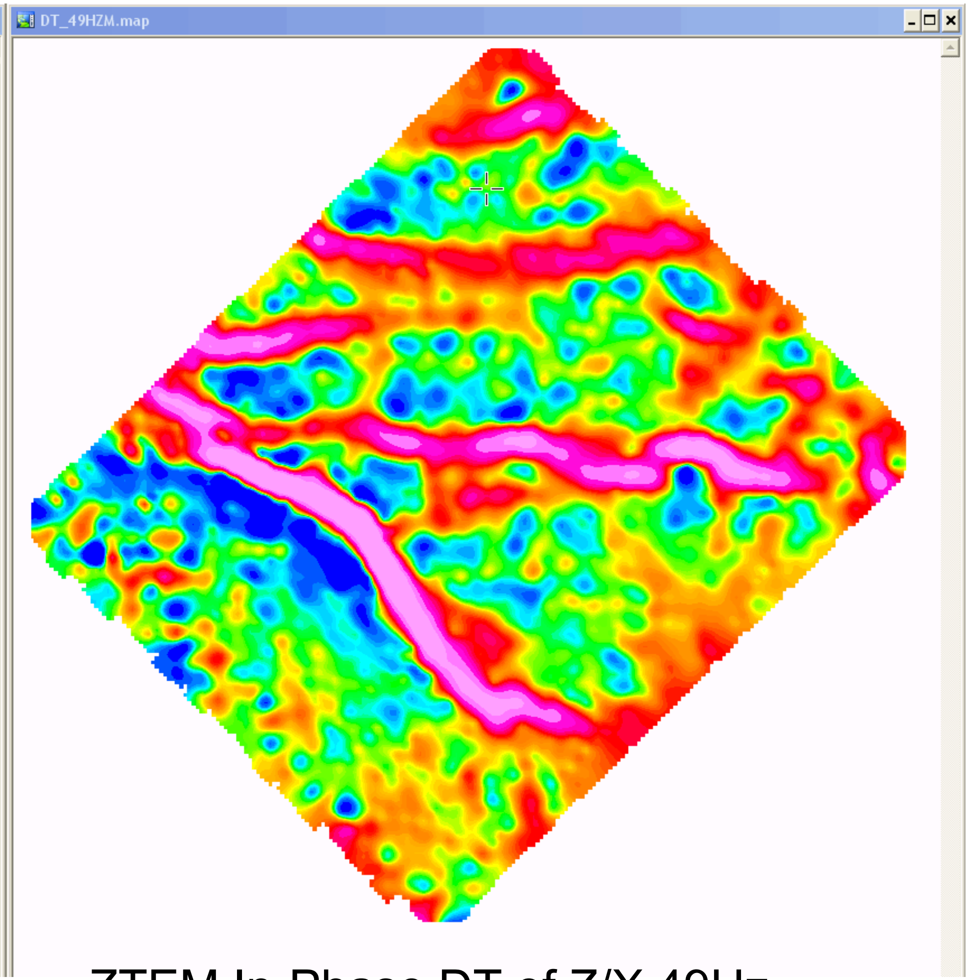
Another data presentation method

- We wished to combine the two components into one single one which was centred over the conductive anomaly – i.e. not a cross-over anomaly.
- Started presenting data in terms of DT (Total Divergence)
- DT=DIV (Z/X, Z/Y)= d(Z/X)/dx + d(Z/X)/dy
- The DT has a minima over a conductive body – so we use an inverted colour bar.

VTEM 1900µs comparison with 49 Hz DT

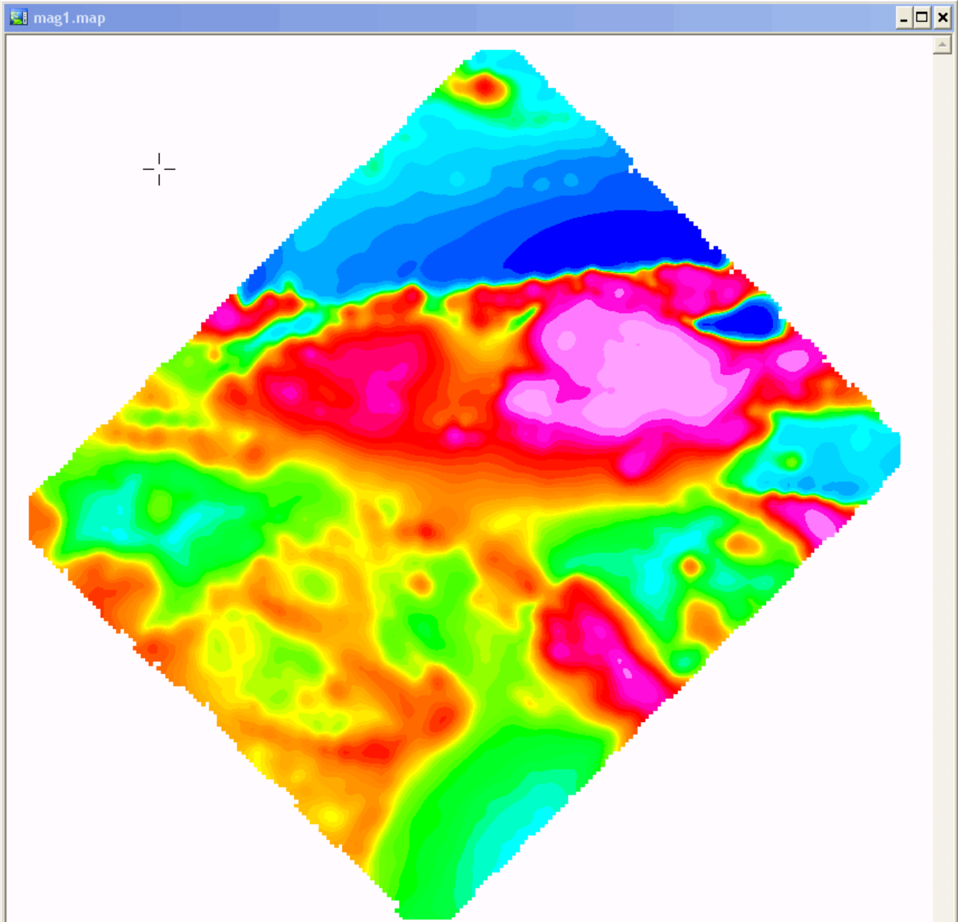


VTEM dBz/dt 1900 µs

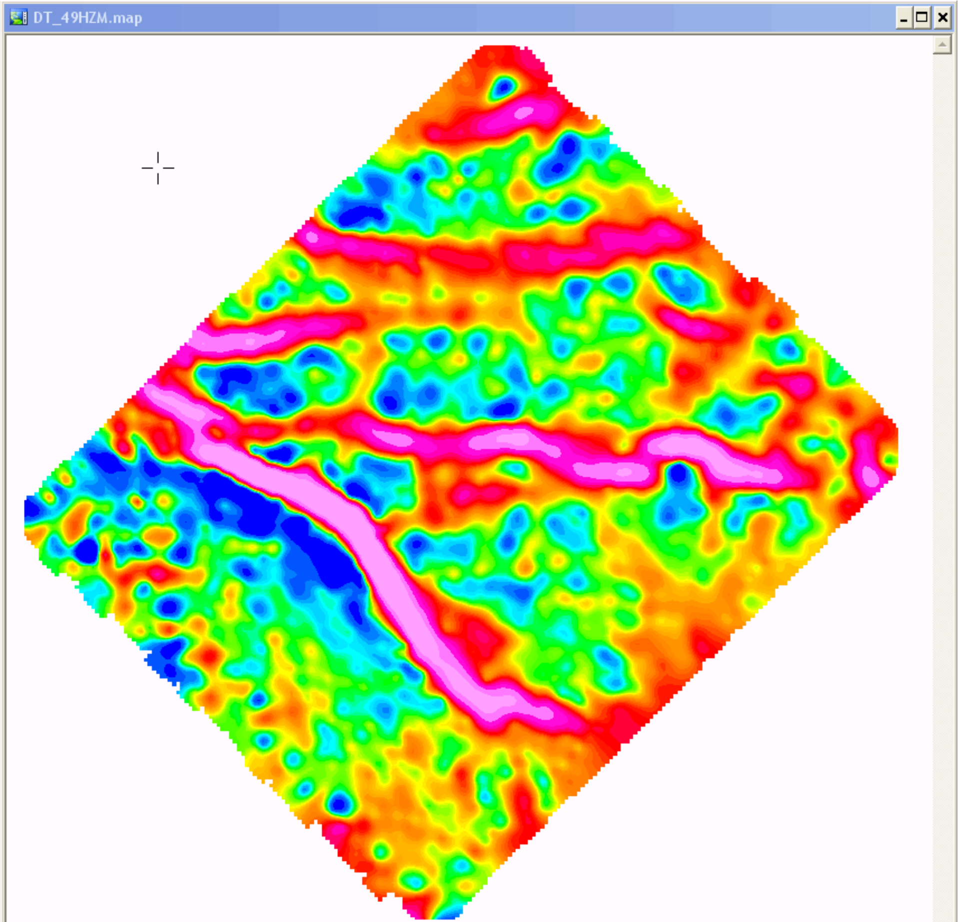


ZTEM In-Phase DT of Z/X 49Hz

TMI comparison with 49 Hz DT



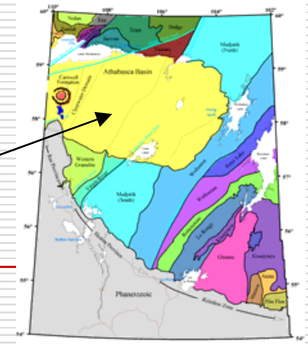
MAG TMI

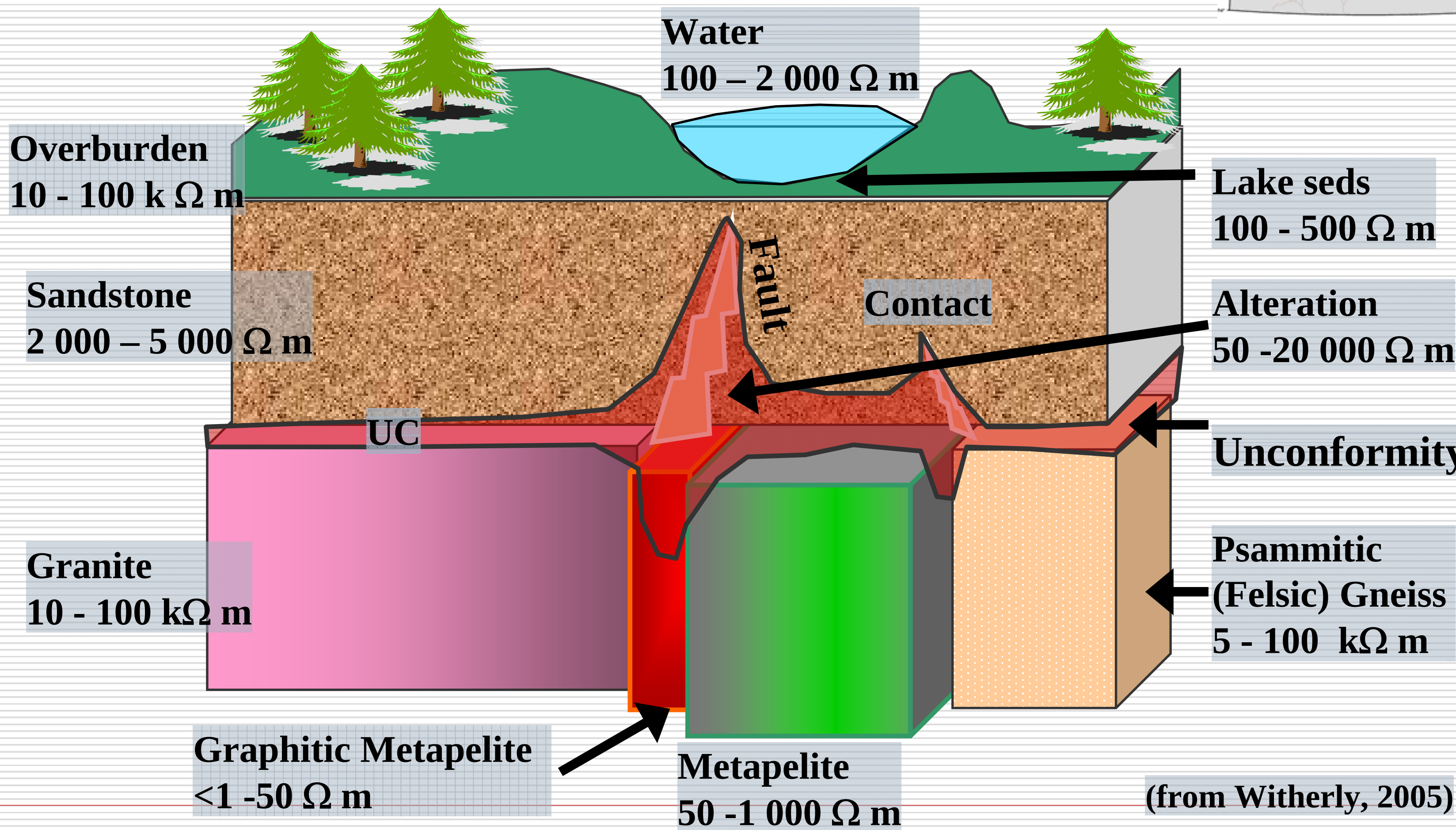


ZTEM In-Phase DT of Z/X 49Hz

Athabasca ZTEM Tests in 2008

ATHABASCA BASIN
SASKATCHEWAN
WESTERN CANADA

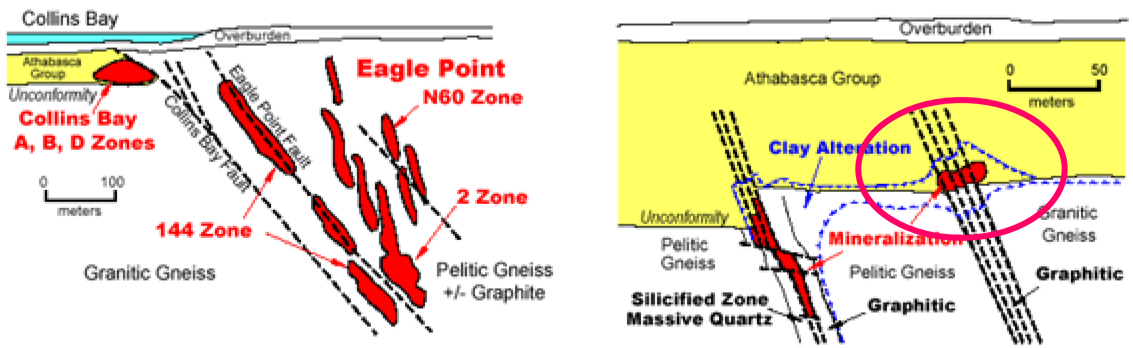




(from Witherly, 2005)

GEOPHYSICAL PROPERTY MODEL for ATHABASCA-TYPE URANIUM DEPOSITS

BASEMENT AND UNCONFORMITY HOSTED URANIUM DEPOSIT STYLES

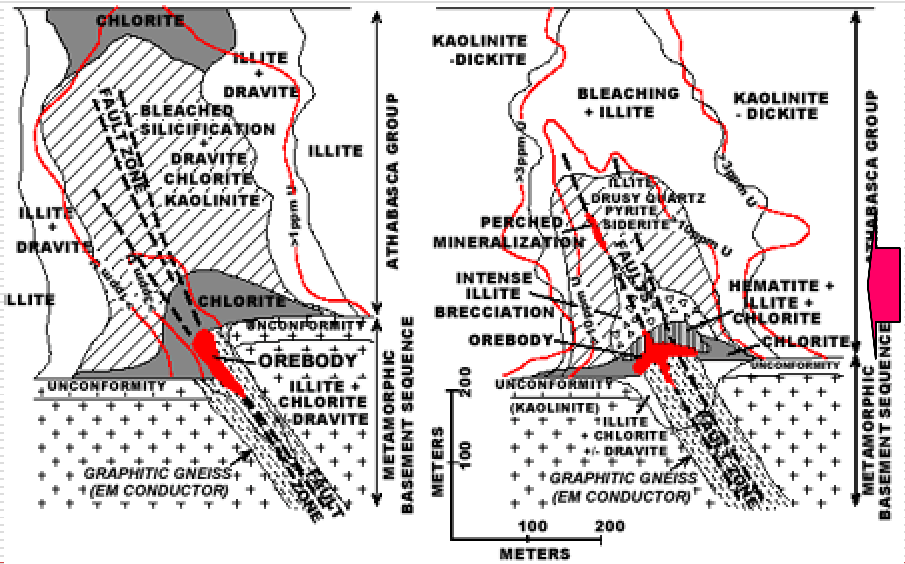


Eagle point and Collins Bay deposits *Sue deposits*

Cross sections illustrating uranium deposit styles: Deposits may be developed at the unconformity below the Athabasca sandstone (e.g. Collins Bay zones, Sue A, B) and extending into underlying basement rocks as veins and replacements (e.g. Eagle Point, Sue C).

- ***Mineralization occurs:***
  a) at unconformity,
  b) above graphite,
  c) with basement elevation change.

ALTERATION ASSOCIATED WITH UNCONFORMITY-HOSTED URANIUM DEPOSITS



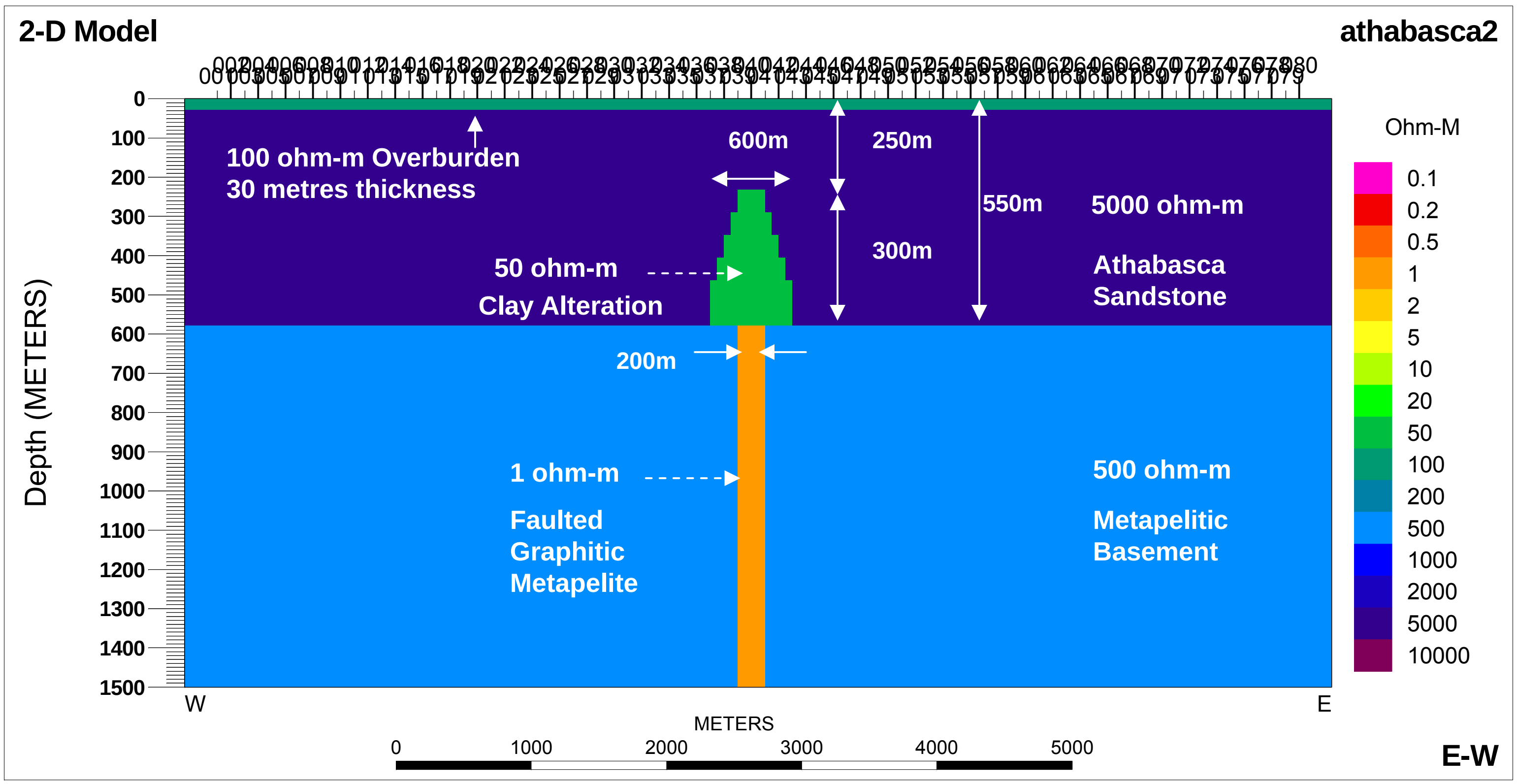
A. McArthur River/Key Lake Type **B. Cigar Lake/Midwest Lake Type**

Silicification ***Clay-Alteration***

Possible Targets:

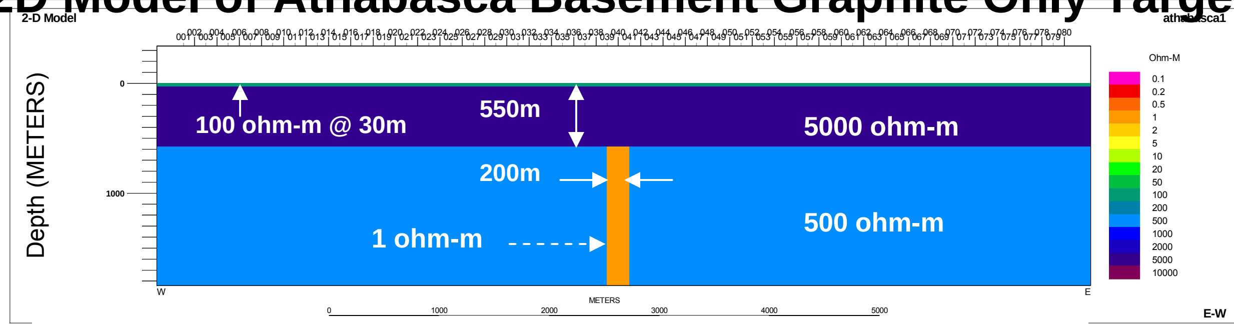
1) Alteration Zone
2) Unconformity
3) Basement Graphite
BUT
Thick Athabasca Sandstone cover requires Deep Penetration >500m

2D Forward Modeling of Athabasca ZTEM Target Responses

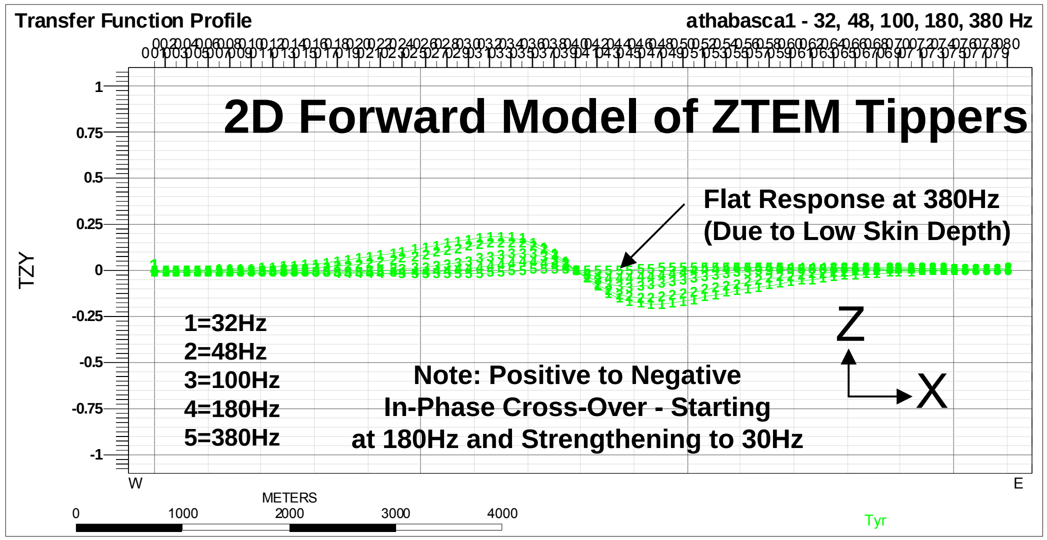


CONCEPTUAL GEOPHYSICAL MODEL OF ATHABASCA-TYPE URANIUM TARGET

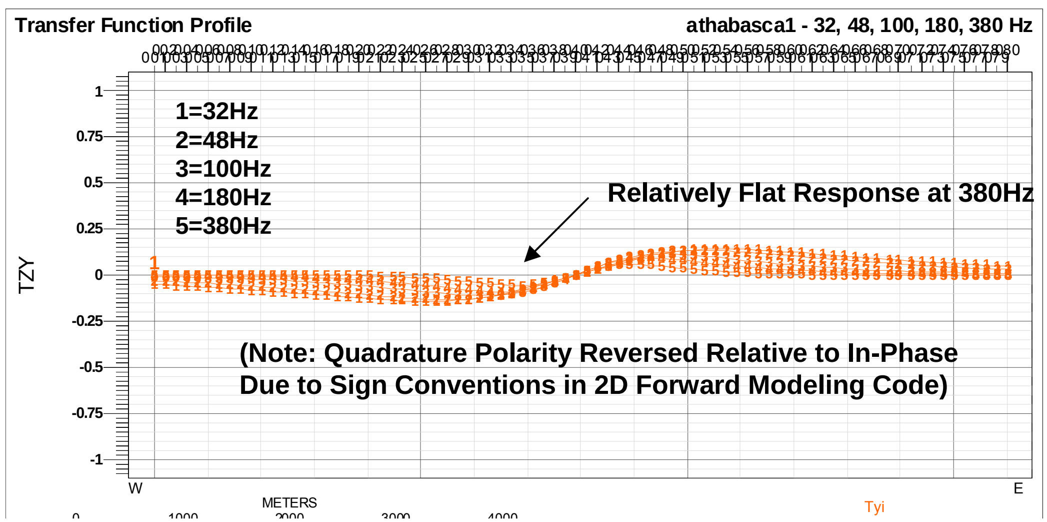
2D Model of Athabasca Basement Graphite Only Target



Hz/Hx In-Phase (%)



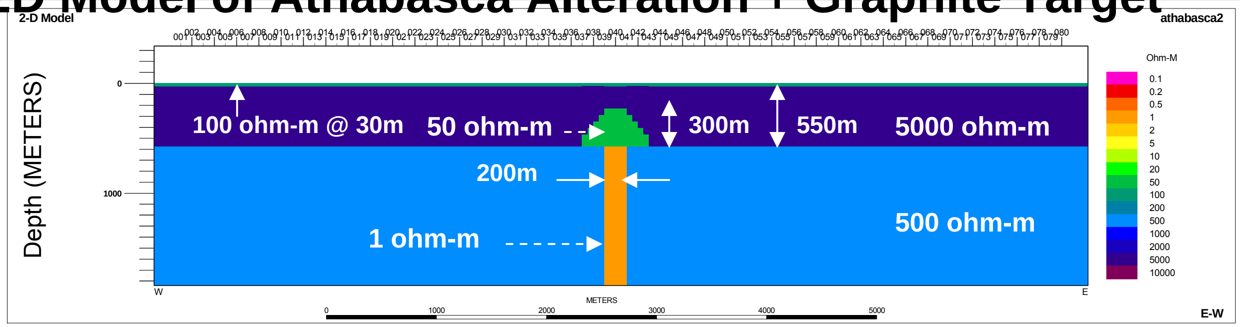
Hz/Hx Quadrature (%)



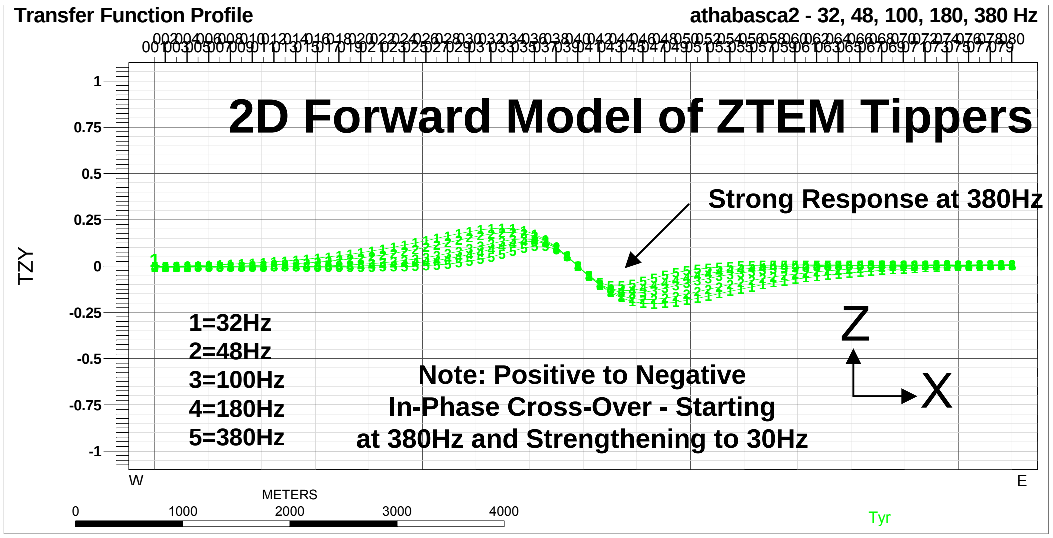
2D Forward Modeling using Known Physical Properties Provides Adequate Proof of Concept that ZTEM is is Easily Capable of Penetrating >500m of Athabasca Sandstone

GEOTECH AIRBORNE GEOPHYSICAL SURVEYS

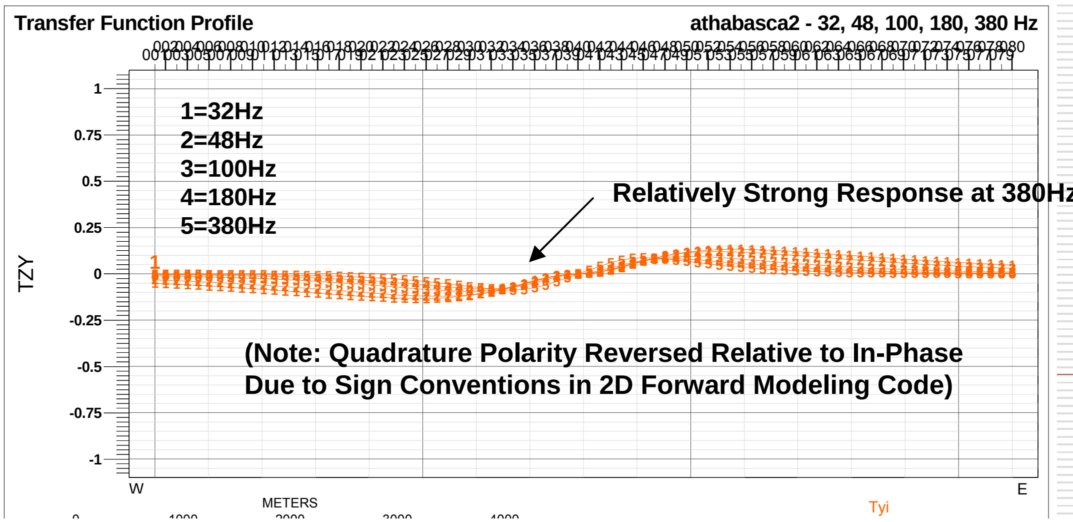
2D Model of Athabasca Alteration + Graphite Target



Hz/Hx In-Phase (%)



Hz/Hx Quadrature (%)

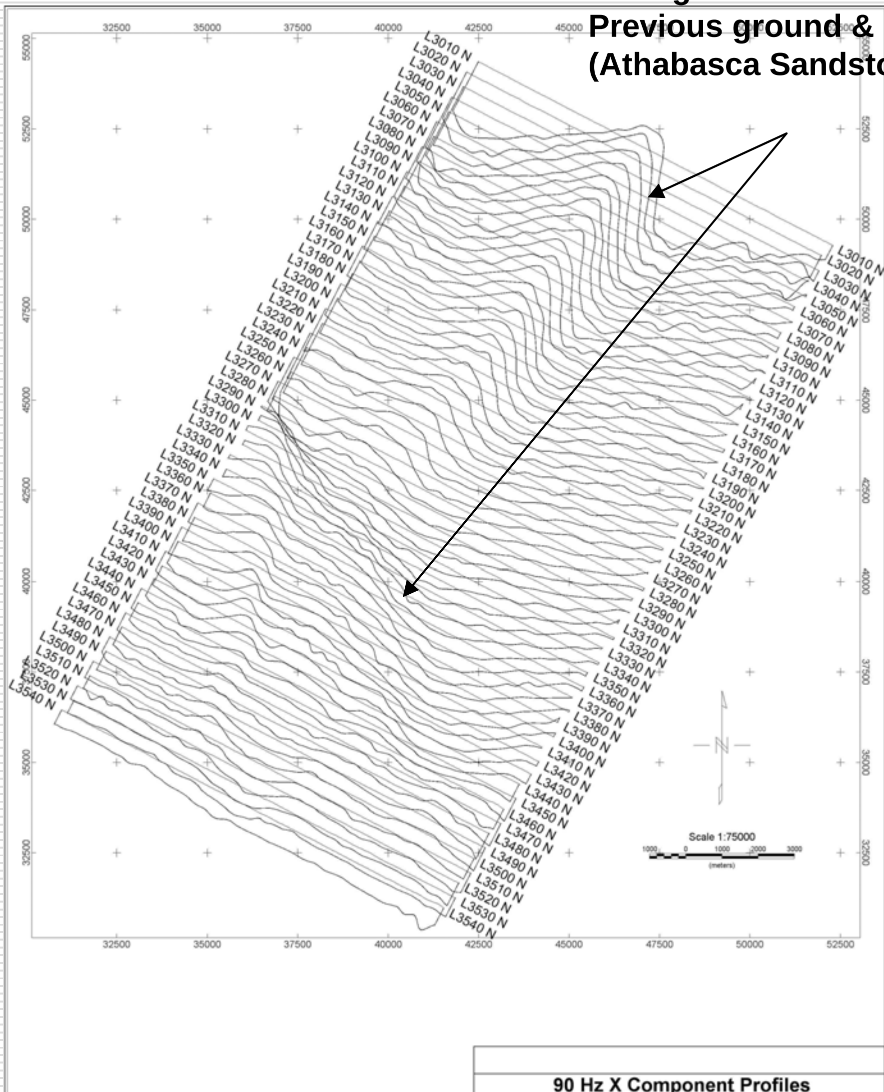


2D Forward Modeling using Known Physical Properties Provides Reasonable Proof that ZTEM should be Capable of Detecting Alteration Zone AND Basement Graphitic Conductor.

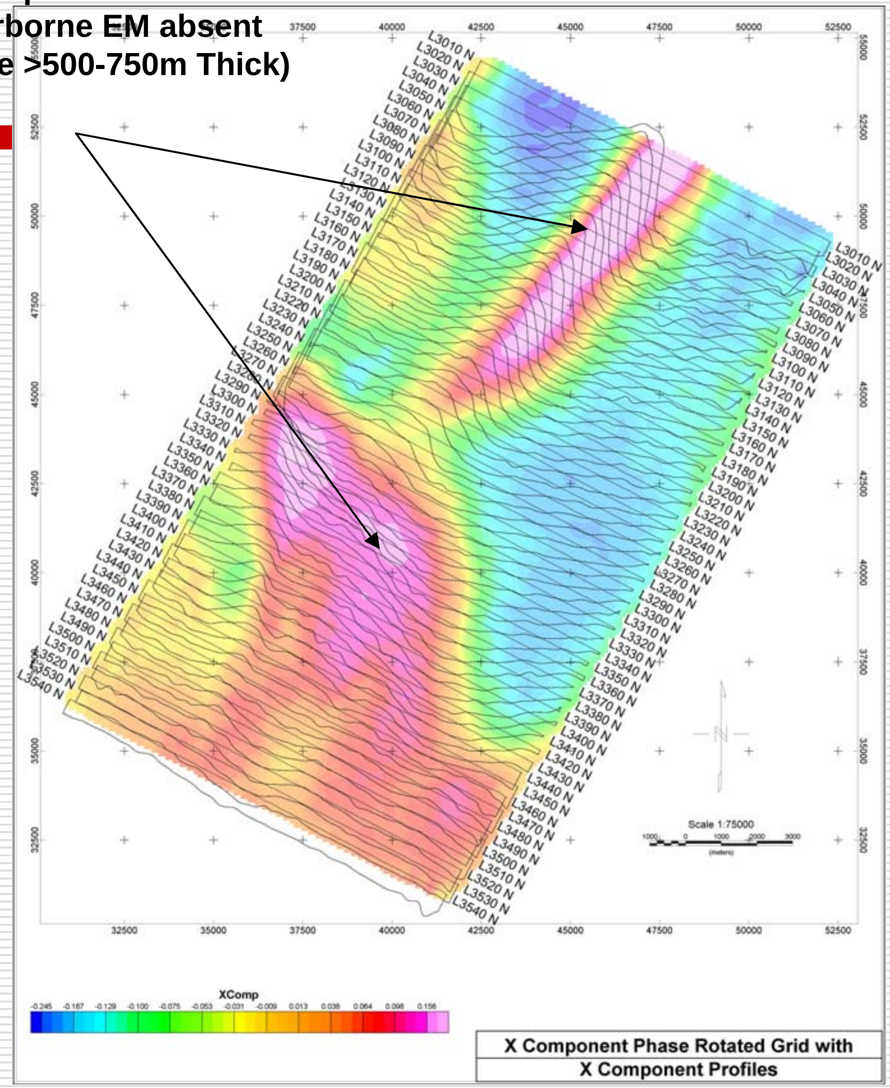
(Note: This is currently believed to be beyond capability of Airborne TDEM Systems – Only Detectible using Ground DC/IP or MT Methods)

ZTEM Tests from Athabasca Basin

Strong Cross-Over Responses where Previous ground & airborne EM absent (Athabasca Sandstone >500-750m Thick)



ZTEM 90Hz Z/X (In-line Tipper)
(Vertical Hz to Horizontal Hx Field Ratio)

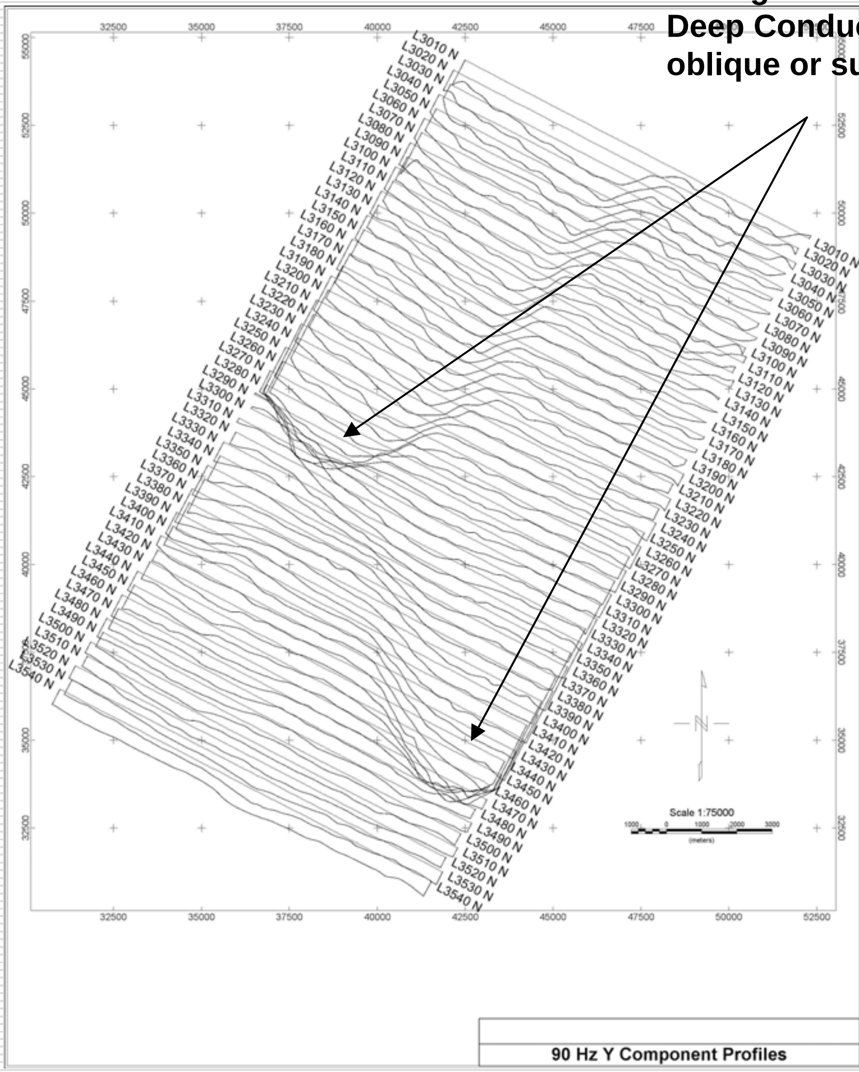


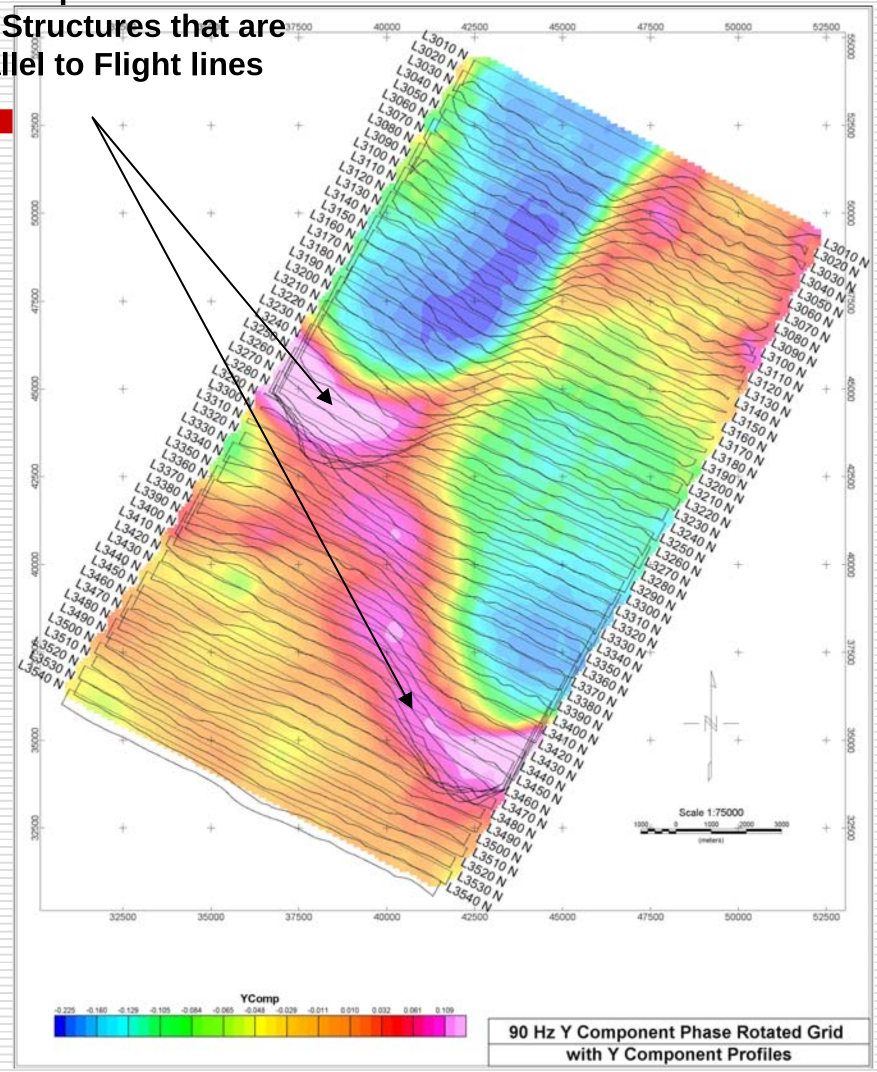
ZTEM 90Hz Z/X Profiles
over 90Hz Phase-Rotated Z/X Grid

GEOTECH
AIRBORNE GEOPHYSICAL SURVEYS

ZTEM Tests from Athabasca Basin

Strong Cross-Line Responses due to Deep Conductivity Structures that are oblique or subparallel to Flight lines





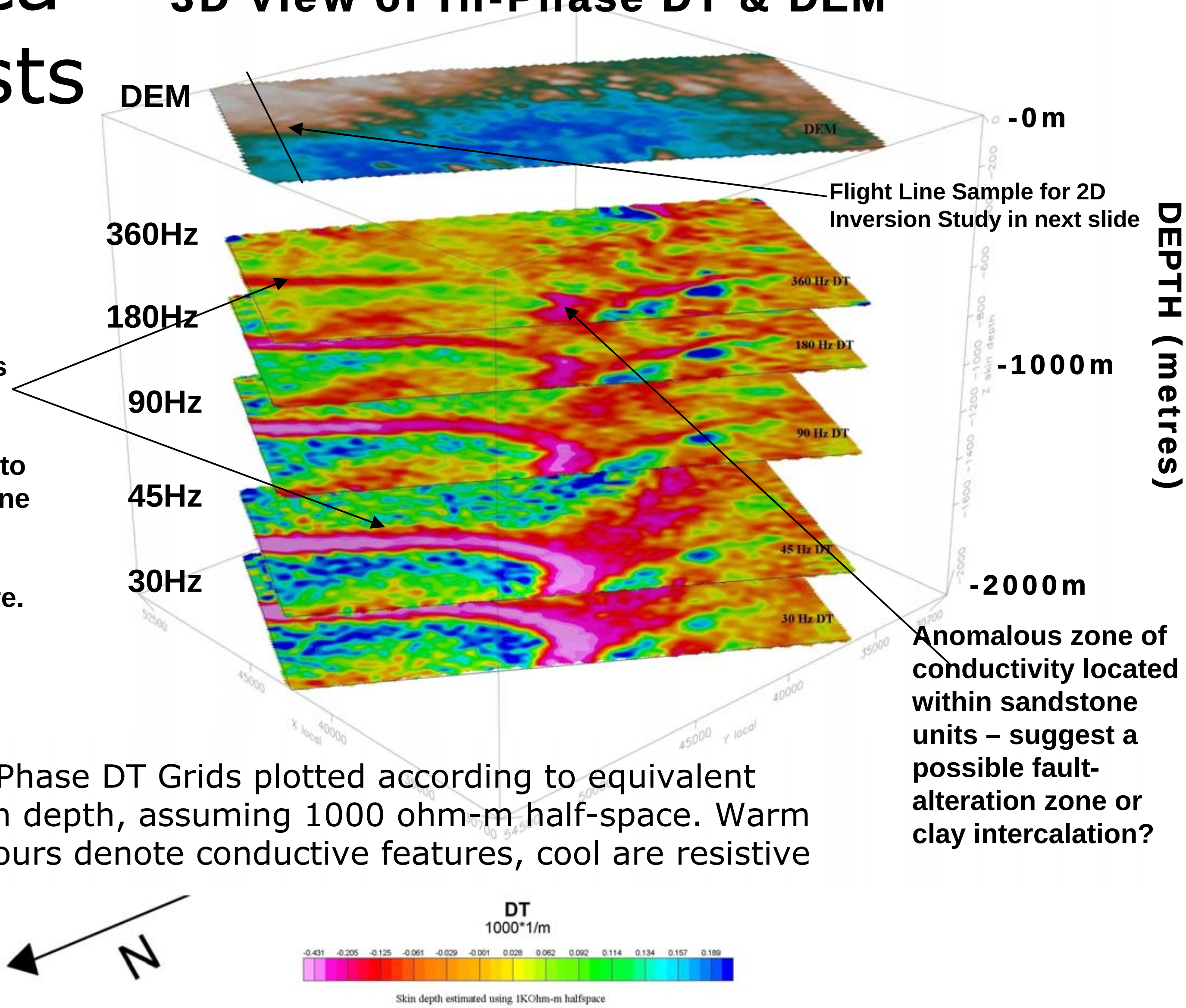
ZTEM 90Hz Z/Y (Cross-line Tipper)
(Vertical Hz to Horizontal Hy Field Ratio)

ZTEM 90Hz Z/Y Profiles
over 90Hz Phase-Rotated Z/Y Grid

GEOTECH
AIRBORNE GEOPHYSICAL SURVEYS

Athabasca Basin tests

3D View of In-Phase DT & DEM

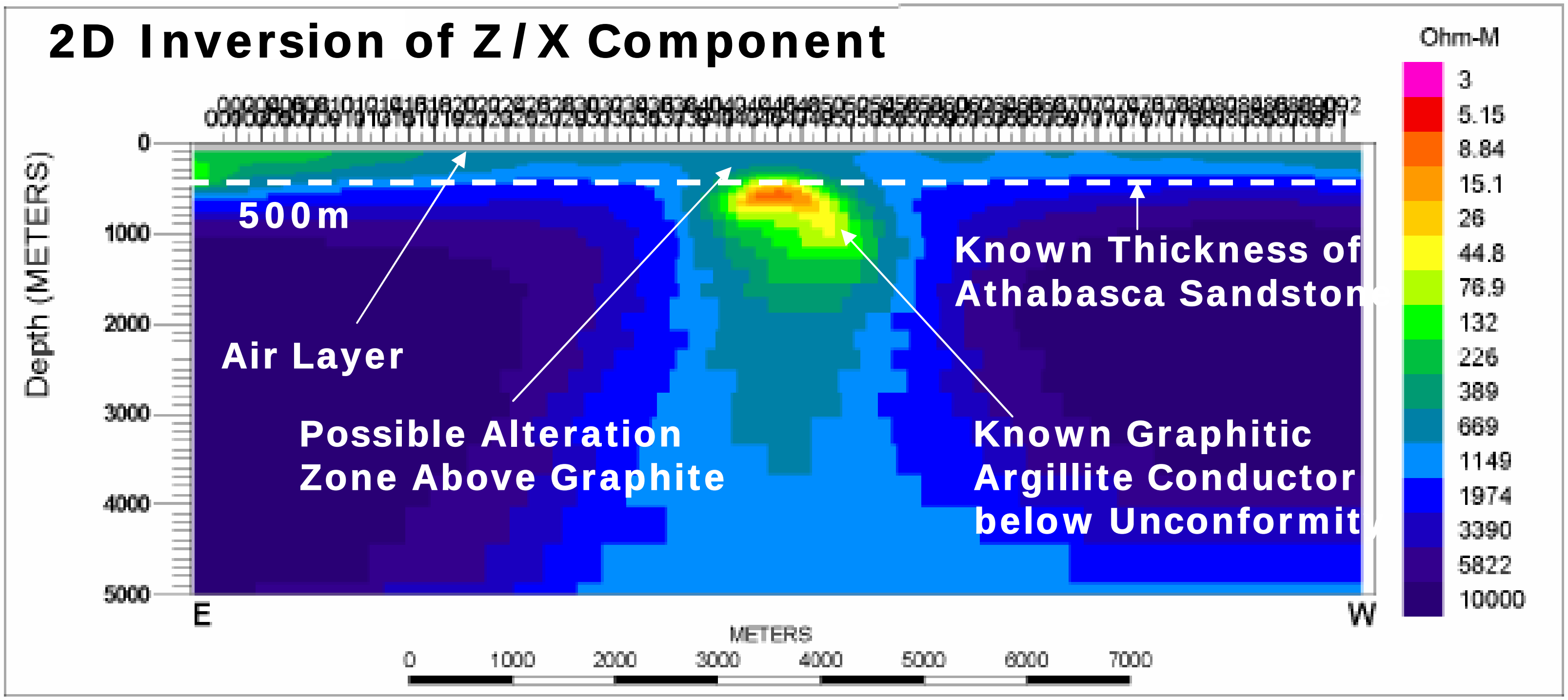


Progressively stronger linear conductive structure with increasing skin depth is consistent with basement graphitic argillite unit below progressively deeper, 500m to >750m thickness of sandstone from left-side to center of image. Arcuate shape consistent with fold structure.

Anomalous zone of conductivity located within sandstone units – suggest a possible fault-alteration zone or clay intercalation?

In-Phase DT Grids plotted according to equivalent skin depth, assuming 1000 ohm-m half-space. Warm colours denote conductive features, cool are resistive

Athabasca Basin tests



Using Zvert2d Gauss-Newton finite element code by Phil Wannamaker (U of Utah). Assumes 1000 ohm-m starting half-space model and 95m sensor elevation)

CONCLUSIONS from ZTEM Tests for Athabasca Basin targets

- Deep penetration below thick Athabasca sandstone units achieved (>450m-900m). Basement graphites & alteration zones in overlying sandstones also appear to be imaged.
- Combination of Z/X and Z/Y data provides Omni-directional structural mapping capability. Complementary information to Magnetics, Effective reconnaissance resistivity mapping tool.
- 2D Forward + Inverse Modelling demonstrates that ZTEM capability can extend from 2D plan-view space to 2 ½D Cross-sectional Interpretation.

Conclusions - general

- 360Hz to 30Hz ZTEM bandwidth provides effective 3-season survey capability in Canada (>3 seasons further south, closer to equatorial thunderstorm centers).
- But broader frequency bandwidth is a future goal, particularly at lower frequencies (down to 10Hz)
- Vertical coil towed bird system and fixed horizontal base station coil combination provide better than expected Signal-to-Noise.
- But full onboard tensor (Hx-Hy-Hz) measurement system (AirMt) is next step in Airborne AFMAG development.
- More commercial and test surveys for ZTEM and AirMt are set to commence for 2009 exploration season
- Broader applications for Porphyry, Sedex, VMS, and in particular Nickel (due to fact that ZTEM is True In-Phase method, ideal for High Conductivity Targets)

Acknowledgements

- Geotech and Mining Companies for allowing the authors to present this data.
- Phil Wannamaker, U of Utah, and Bill Doerner, Emblem Geophysics, for Zvert2D Inversion code development and inversion study.