AEM2023

8th International Airborne Electromagnetics Workshop

EXPERT GEOPHYSICS

*from innovations to discoveries*

# Passive and active airborne electromagnetics – separate and combined technical solutions and applicability

**Alexander Prikhodko, Andrei Bagrianski, Petr Kuzmin, Andrew Carpenter**

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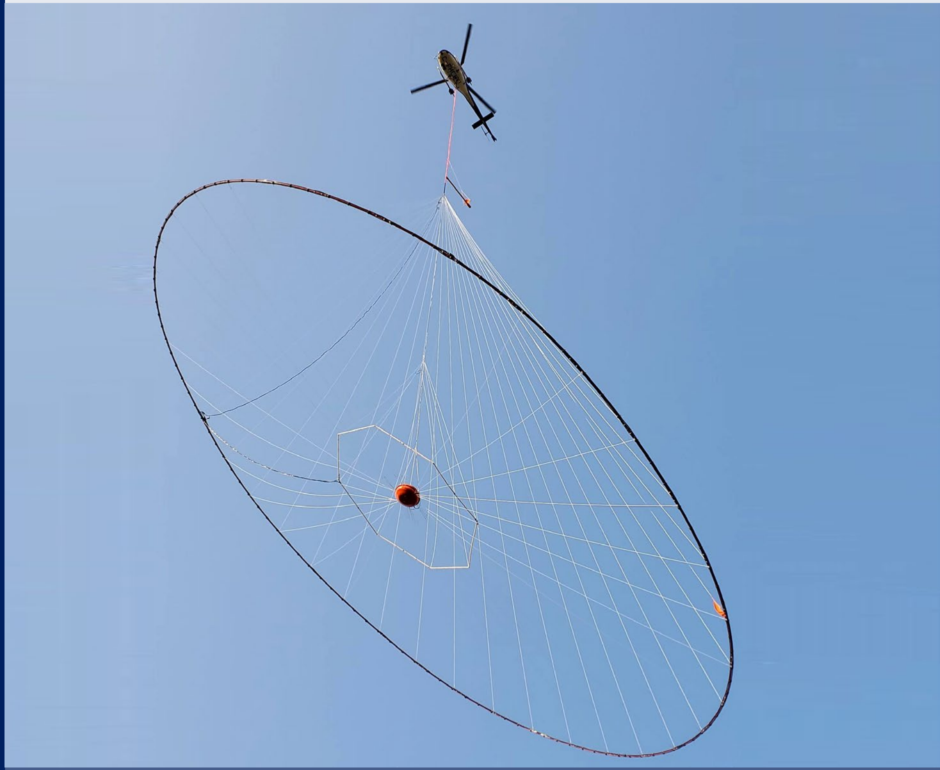

# Presentation Outline

- Pros and Cons of ‘passive’ and ‘active’ airborne EM methods
- The basis and advantages of natural energy
- Field examples

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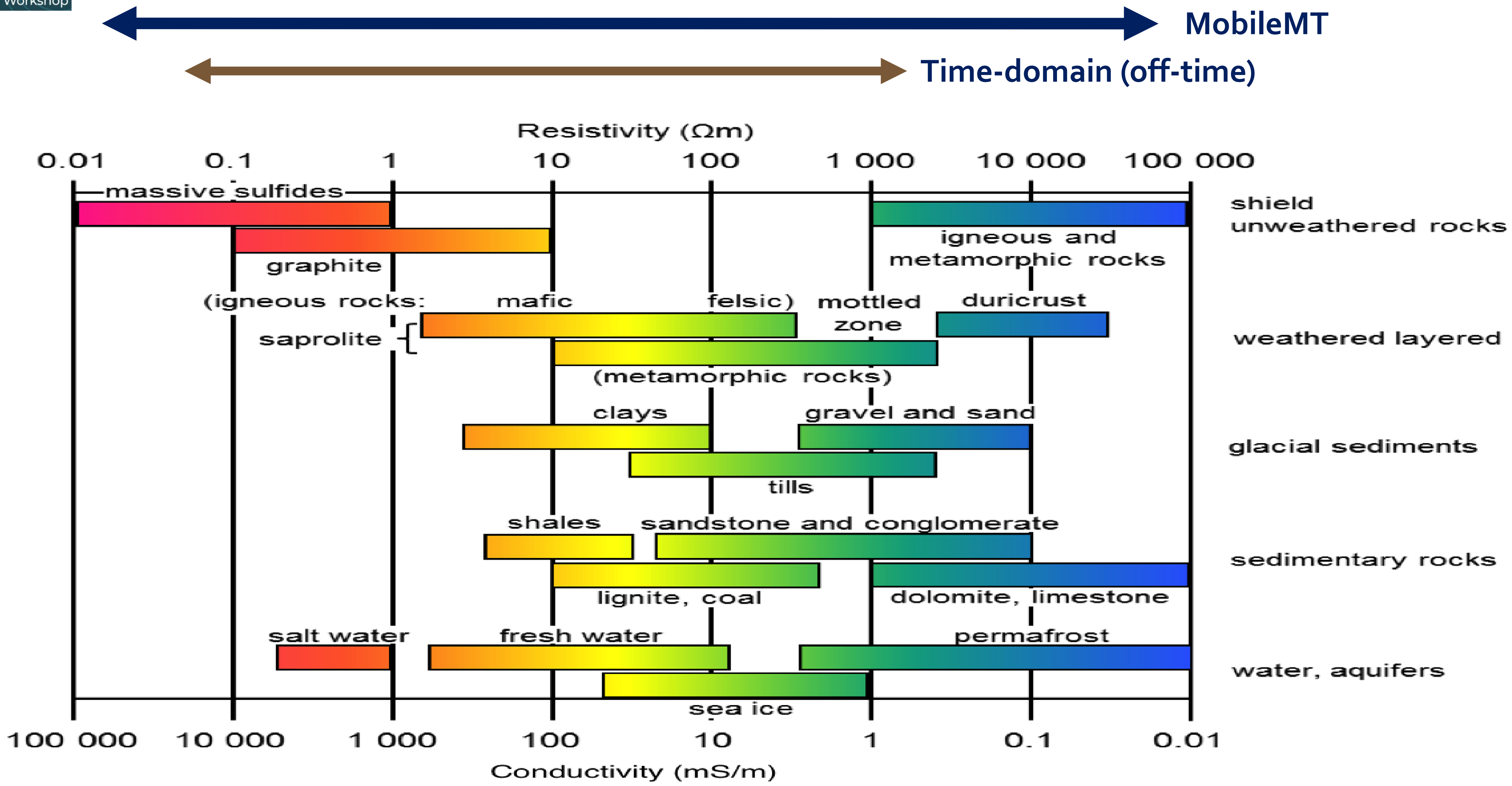
# AFMAG vs. airborne time-domain

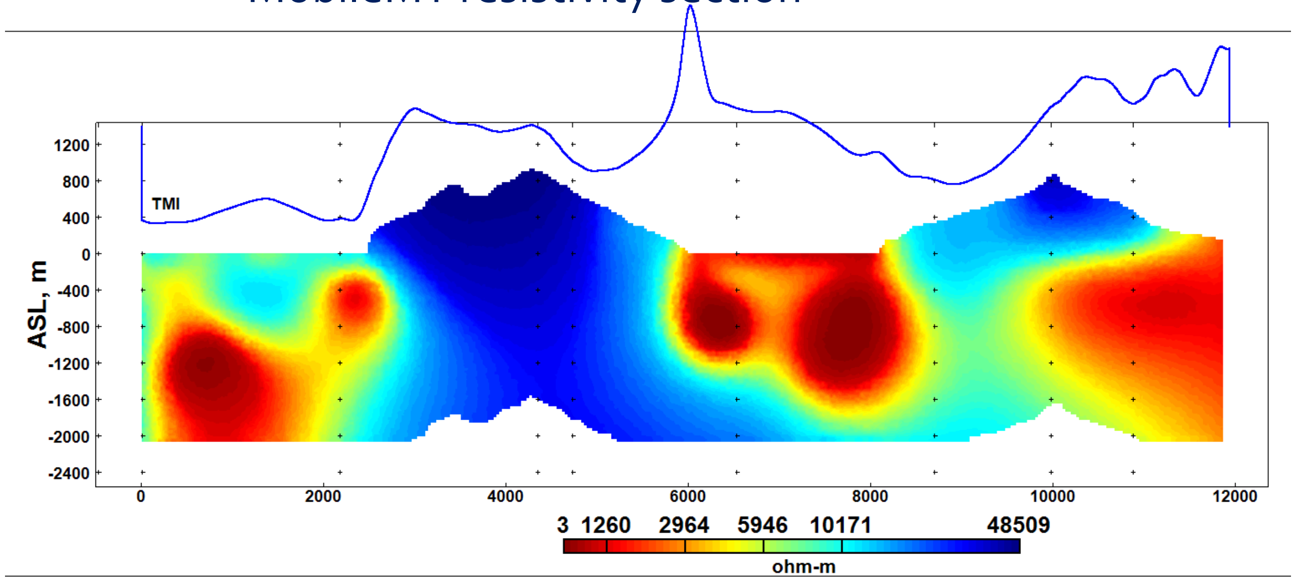
| AFMAG (Passive field) | ATDEM |
|---|---|
| Variations of natural fields are susceptible to seasonal and diurnal influence and depend on weather and geographical position | Stable, controlled and well-described primary field |
| Depth of investigation always exceeds controlled source methods' capabilities in several times | Limited depth of investigation and critically low in conducive environments |
| Signal detectability in a wide range of resistivity | Signal detectability in a limited range of resistivity |
| Non-inductive parasitic signals are not observed | IP and SPM effects often distort the inductive signal and create pseudo-anomalies |
| Negligible dependence on terrain clearance in a wide range | Highly sensitive to terrain clearance |

# RANGE OF RESISTIVITY DETECTION AND DIFFERENTIATION



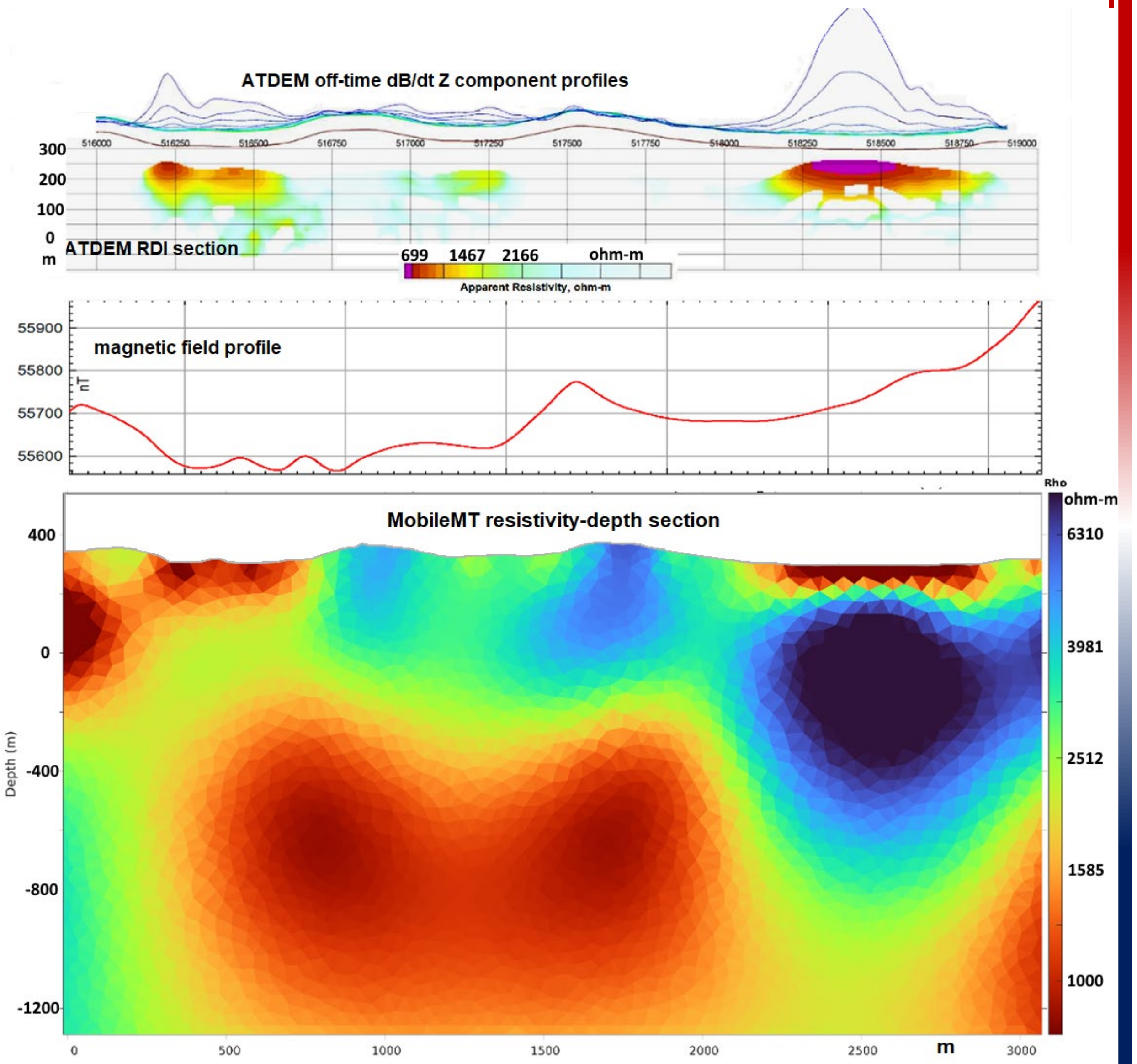
# Resistivity range field examples (vs. airborne time-domain, ATDEM)

## Greenland
## MobileMT resistivity section



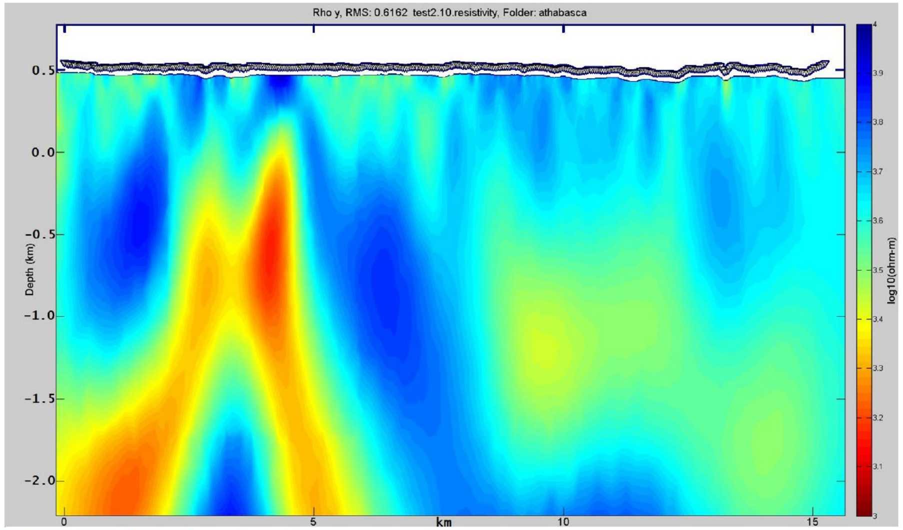

**Blind resistivity range for ATDEM**

## Northern Ontario

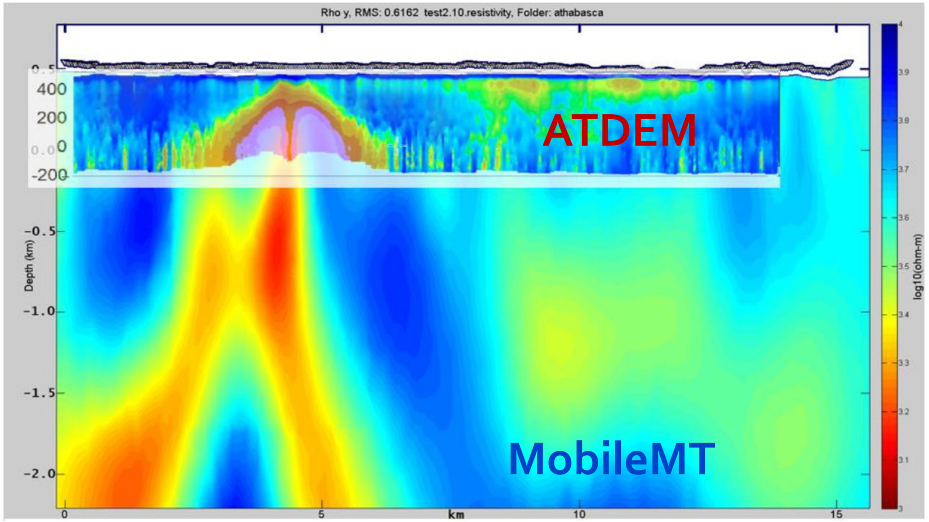


# DOI
## Athabasca Basin

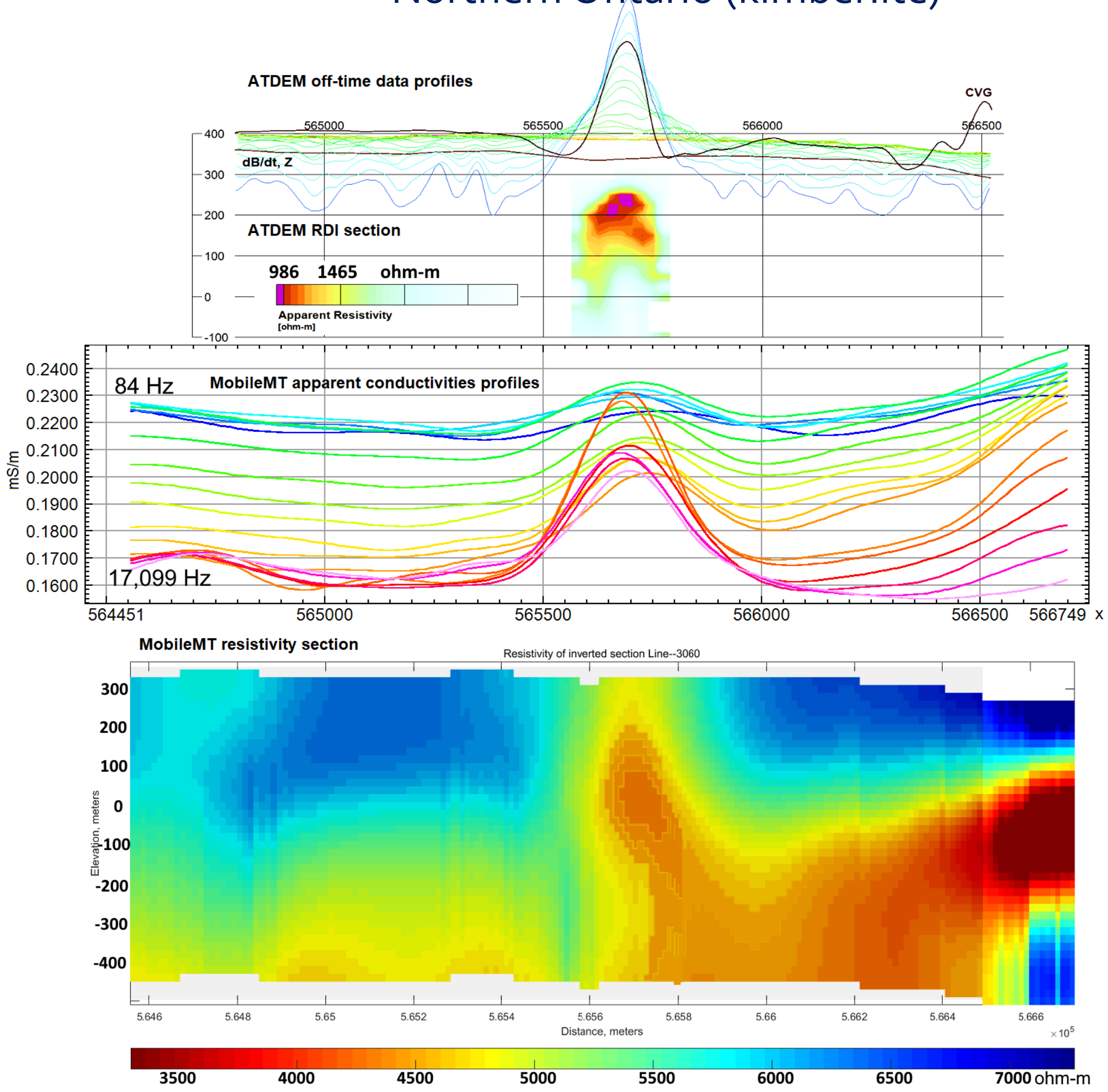
**MobileMT section**




**MobileMT with a time-domain system section**



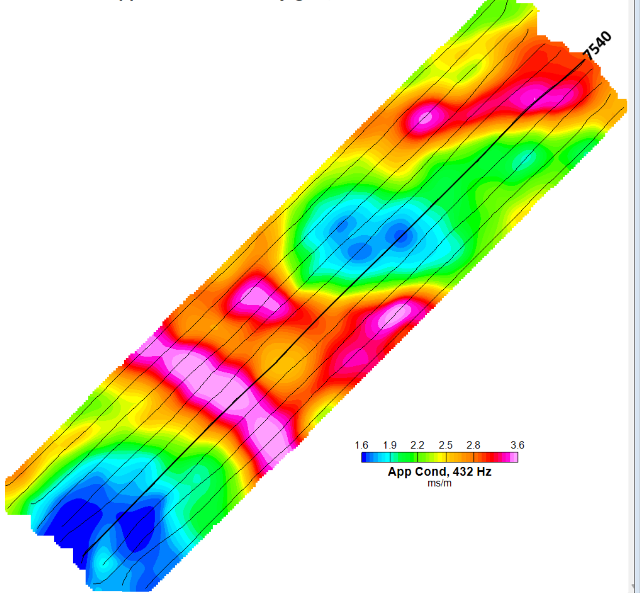

# ATDEM IP effect
## Northern Ontario (kimberlite)



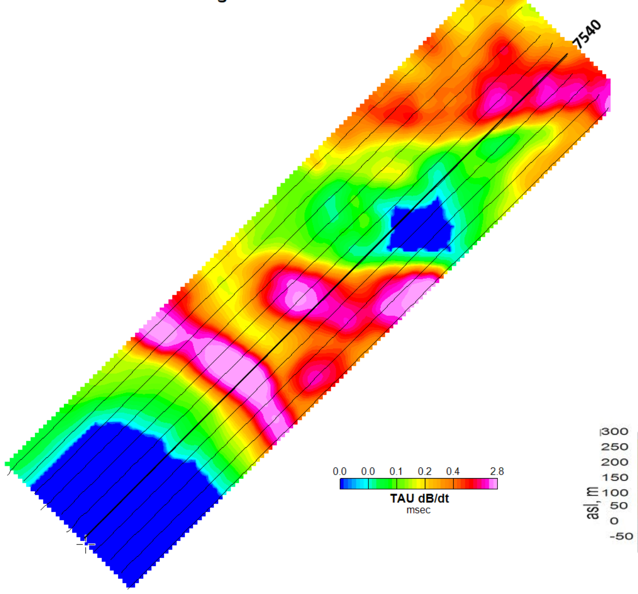
# DOI

## Cochrane, Northern Ontario

MobileMT apparent conductivity grid, 432 Hz

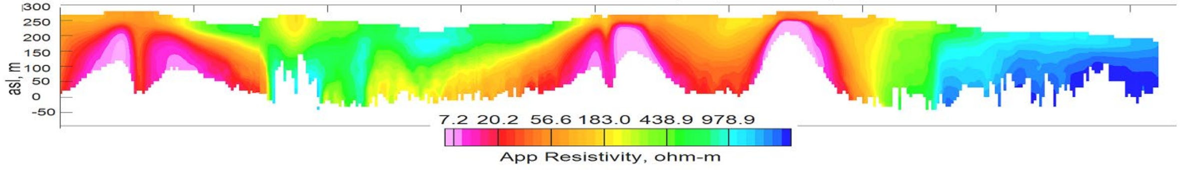


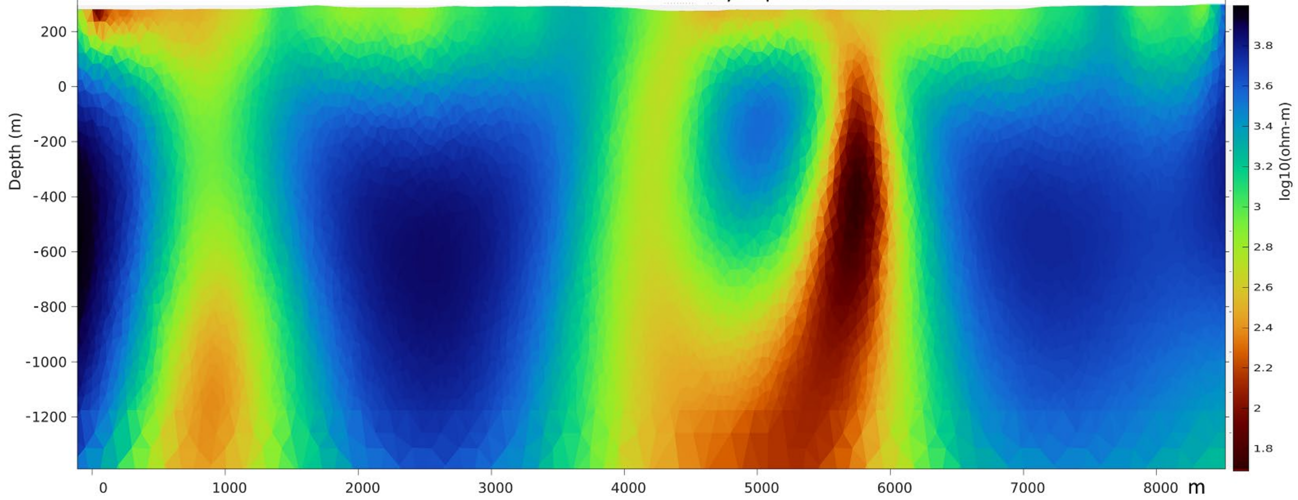

time-domain TAU dB/dt grid




NE **L7540**

airborne TDEM resistivity-depth section (RDI)



# Previous investigations of extracting AFMAG data from streamed time-domain data




SEG International Exposition and 86th Annual Meeting

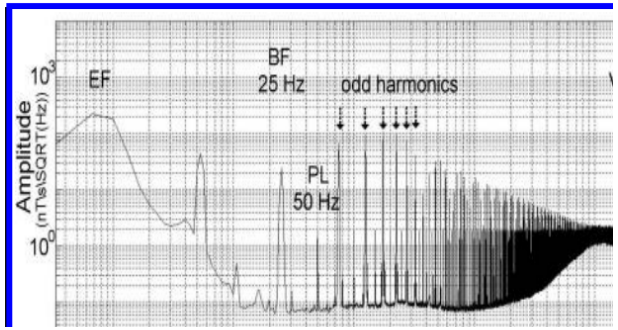
## Reprocessing streaming MEGATEM data for square-wave EM, VLF and AFMAG responses

*Daniel Sattel*, EM Solutions and Eric Battig, BHP Billiton*

**Summary**

The recording of raw or streaming EM survey data, as done by CGG during MEGATEM surveys, allows for the reprocessing of the active-source EM data and the extraction of passive EM responses. The analysis of MEGATEM data acquired in 2013 in South America demonstrates that valuable information is gained from these reprocessing steps.

During square-wave processing, the recorded EM response to the actual waveform is replaced by the EM response to a square-wave, derived via deconvolution/c frequency-domain. Results of the square MEGATEM data show that the early-tir more accessible than in the original interpretation of shallow conductivity stru





SEG International Exposition and 88th annual Meeting

## Modeling sferic signals extracted from active-source AEM data

*Daniel Sattel*, EM Solutions and Eric Battig, BHP*

**Summary**

Radio atmospheric signals or sferics are broadband electromagnetic impulses generated by lightning discharges. The recording of raw or streamed data, as done by CGG during MEGATEM surveys, allows for the extraction of sferic signals, inadvertently recorded during AEM surveys. The spectral processing of individual sferics, excluding periods of background noise between sferic events, allows for the extraction of AFMAG and VLF data in the frequency range 25 Hz - 25 kHz, including good signal in the AMT dead band (1-5 kHz).

The recording of the three-component AEM data allows for the vector processing of sferic responses, including the derivation and modeling of the tipper data. Conductivity

amplitude, w AMT dead b (Labson *et al*

The recording the magnetic for the deriva and 3D inver data set acqu derived tippe noise level th as ZTEM (I receiver coils information expected to c from the activ

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https://doi.org/10.1080/08123985.2021.1882846

## Processing of passive EM fields acquired during active-source airborne EM surveys

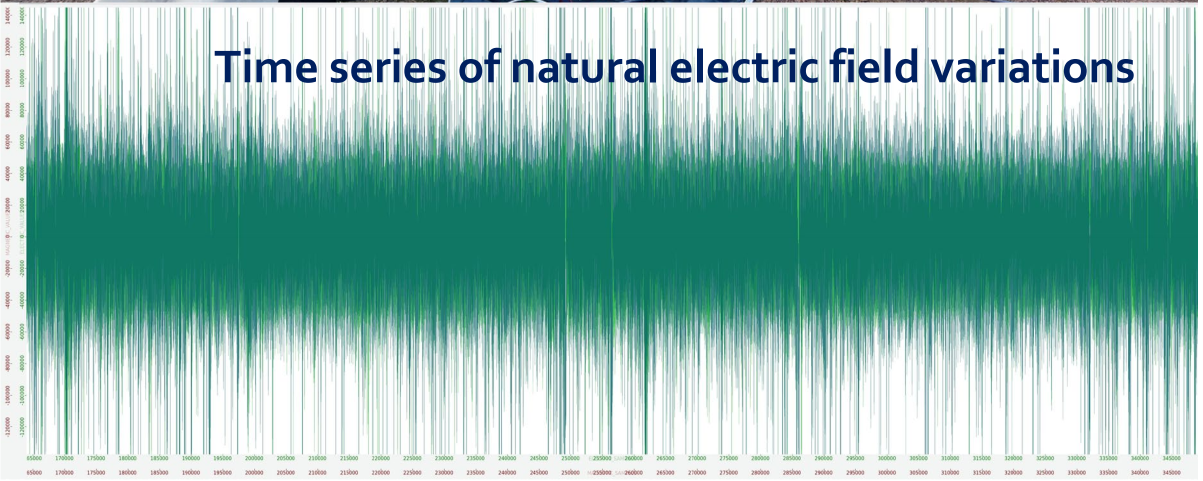
Daniel Sattel[a] and Eric Battig[b]*

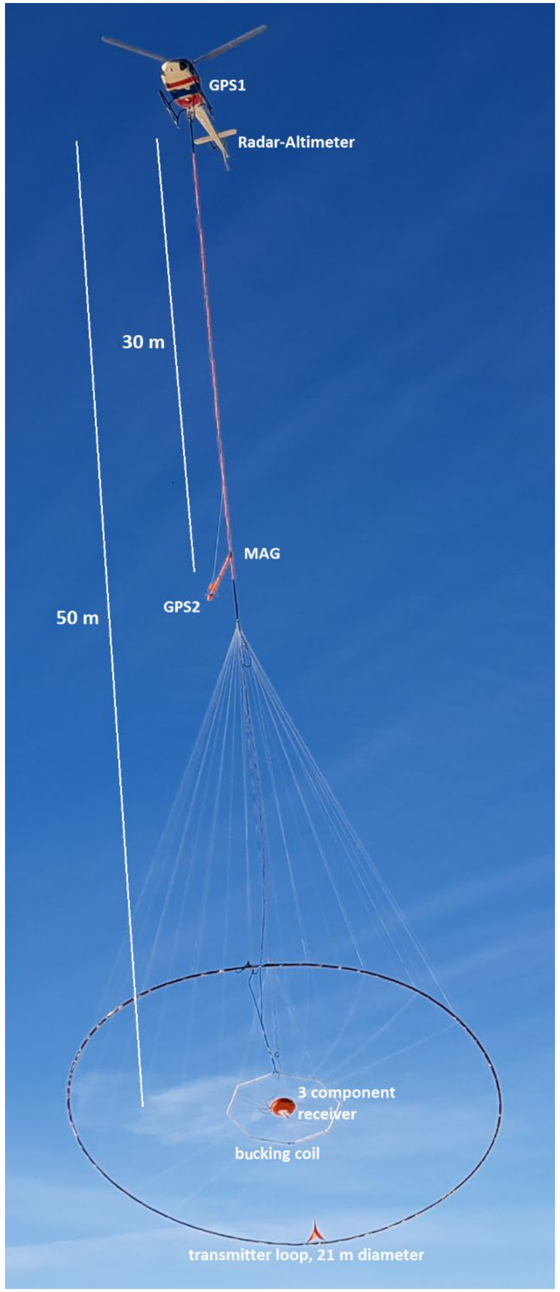
[a]EM Solutions LLC, Golden, CO, USA; [b]BHP, Brisbane, Australia

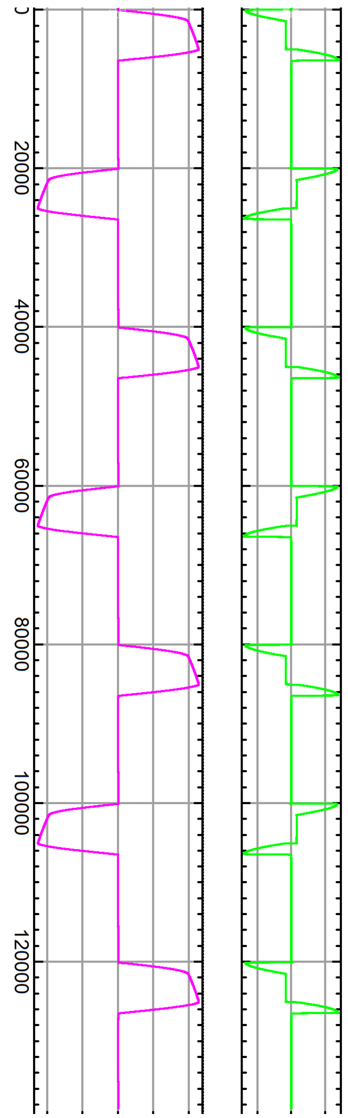
**ABSTRACT**

The recording of raw or streamed airborne electromagnetic (AEM) data, as done by CGG during MEGATEM surveys, allows for the extraction of passive EM signals also present, but not normally processed. These include (1) powerline responses, (2) responses in the very low frequency (VLF) range due to radio transmissions and (3) natural-source audio-frequency magnetic (AFMAG) and VLF responses in the frequency range 25 Hz–25 kHz extracted from individual atmospheric electrical discharges (sferics). The latter approach manages to extract good signal in the audio-frequency magnetotelluric (AMT) dead band (1–5 kHz) for one of the discussed data sets. The recording of the three-component AEM data allows for the vector processing of these passive EM responses, including the derivation and modelling of the vertical-to-horizontal magnetic field ratio (tipper) data. Conductivity information can be derived from the tipper data with an apparent conductivity transformation and, more rigorously, with 2D and 3D inversions that take into account the terrain's topography. The extraction and modelling of passive EM responses is demonstrated on two data sets. A powerline apparent-conductivity grid derived from a MEGATEM survey near Timmins, Canada indicates conductivity structures similar to those in the corresponding active-source EM data. VLF and AFMAG responses derived from South American MEGATEM data show a strong correlation to topography. These data were successfully modelled with 2D and 3D inversions, and the derived shallow conductivity structures confirm and complement the information extracted from the active-source EM data.

# TargetEM time-domain system with the combination of the electric field base station

# AFMAG data processing



The combination of magnetic and electric field variations allows using the concept of the admittance tensor introduced by Thomas Cantwell in 1960 as $\boldsymbol{Y = H/E}$ (Jones, 2017) and, ultimately, the calculation of apparent conductivities corresponded to different frequency bands:

$$\boldsymbol{\sigma(\omega) = \mu\omega|Y^2|},$$

where **μ** is the magnetic permeability of free space and **ω** is the angular frequency.

Having magnetic and electric field data variations measured in different relative orientations and in different relative directions, magnitudes of total ***H*** and ***E*** vectors independent of the sensors' spatial attitudes are calculated at the same frequency and time as

$$|\boldsymbol{H(f)}| = \sqrt{(\boldsymbol{Hz(f)^2 + Hx(f)^2 + Hy(f)^2})},$$

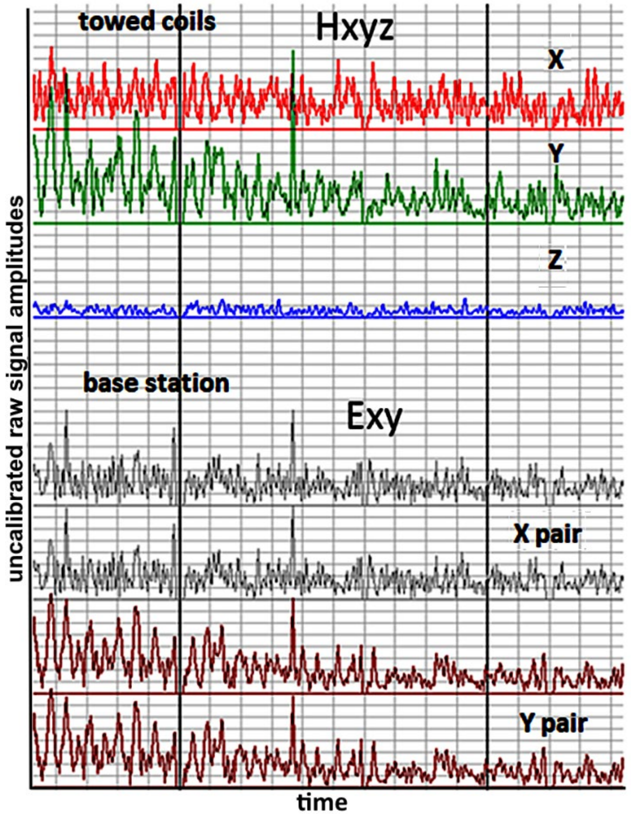
$$|\boldsymbol{E(f)}| = \sqrt{(\boldsymbol{Ex(f)^2 + Ey(f)^2})},$$

where ***f*** is frequency.

The vector components ***H***(f) and ***E***(f) are compared, and the attitude-invariant properties of the relating tensors calculated

The relation between the two vectors ***H***(f) and ***E***(f) can be expressed through the 3x2 matrix tensor (**T**):

$$\begin{bmatrix} Hx \\ Hy \\ Hz \end{bmatrix} = \begin{bmatrix} Txx & Txy \\ Tyx & Tyy \\ Tzx & Tzy \end{bmatrix} \begin{bmatrix} Ex \\ Ey \end{bmatrix}$$

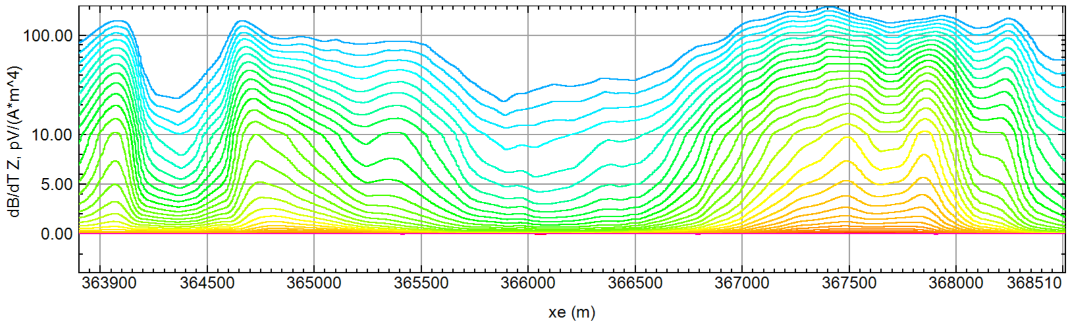


# TargetEM data (Western Australia)

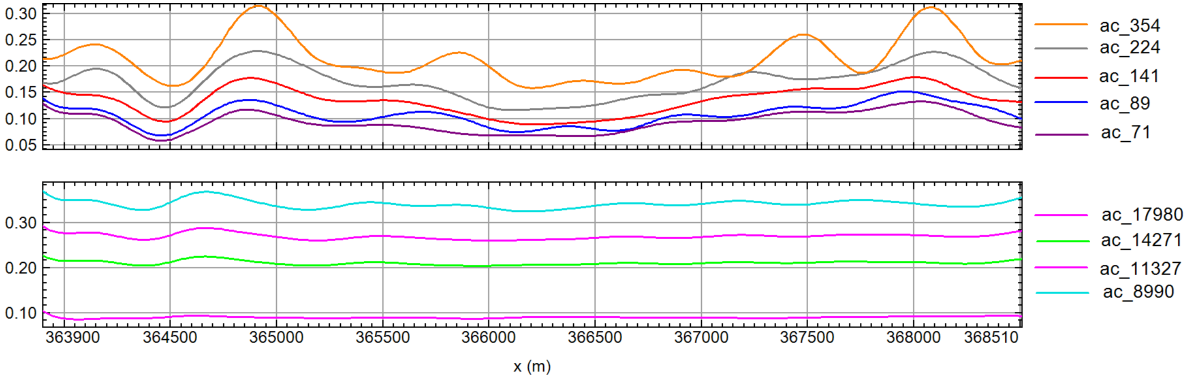


## LINE 1210

TDEM dB/dt, Z

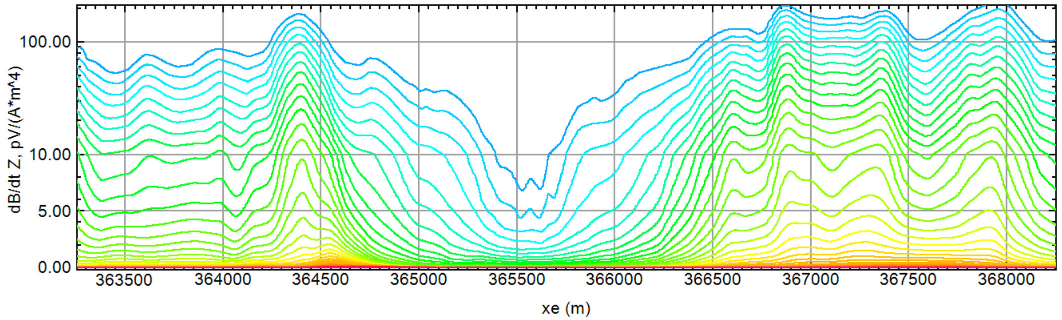



AFMAG, apparent conductivity (transmitter off)

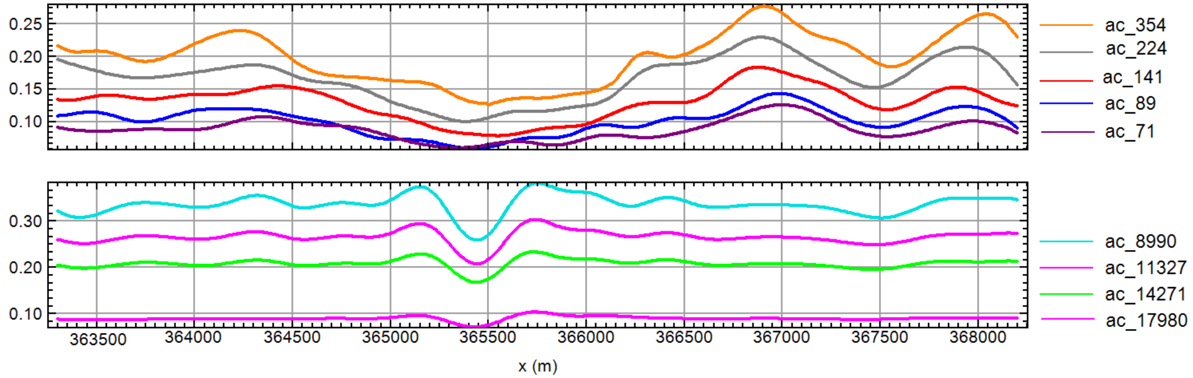



## LINE 1240

TDEM dB/dt, Z



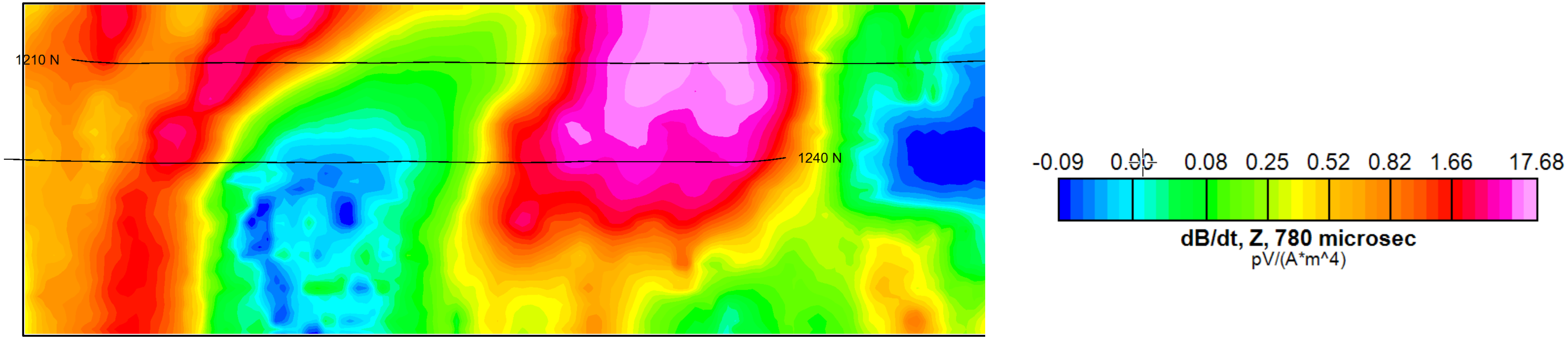

AFMAG, apparent conductivity (transmitter off)



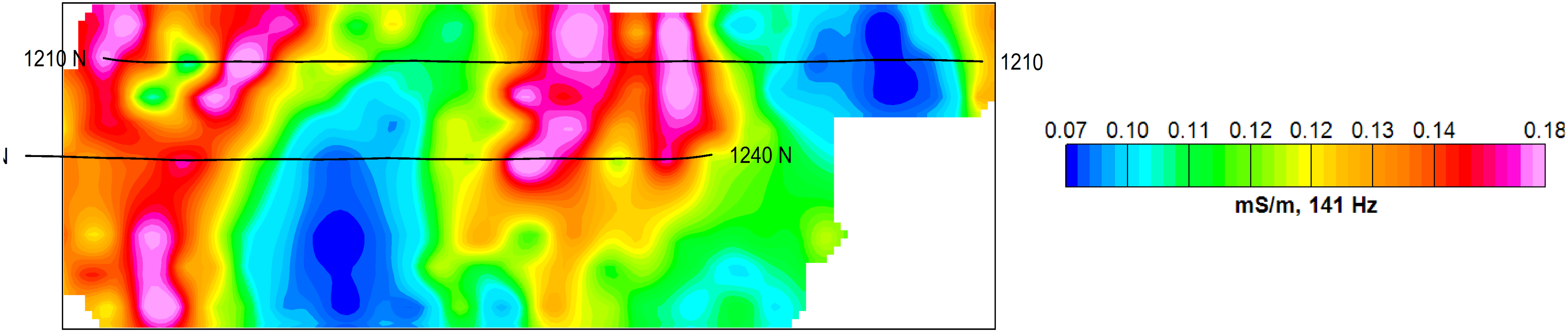
# TargetEM data (Western Australia)



## TDEM dB/dt data grid




## AFMAG apparent conductivity grid (Tr off)



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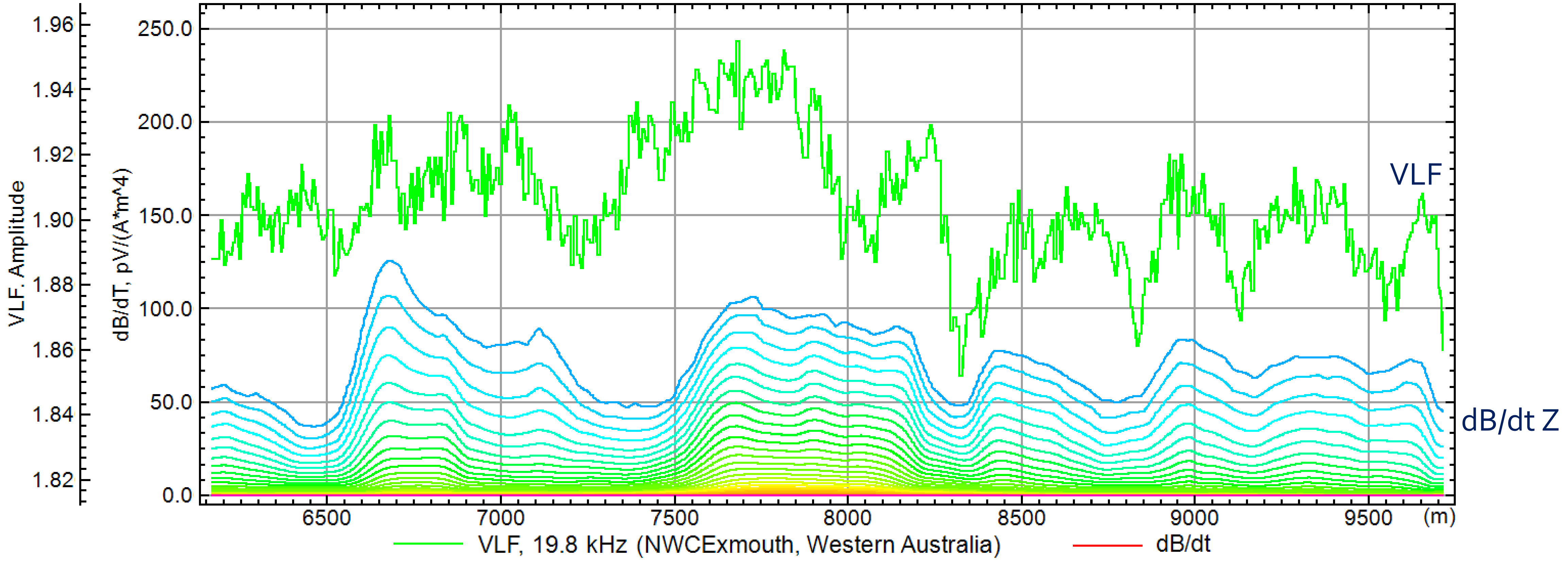
VLF amplitude (**19.8 kHz**) extracted from TargetEM time-series data recorded **during transmitting field ON** at 25 Hz base frequency

Kalgoorlie in Western Australia

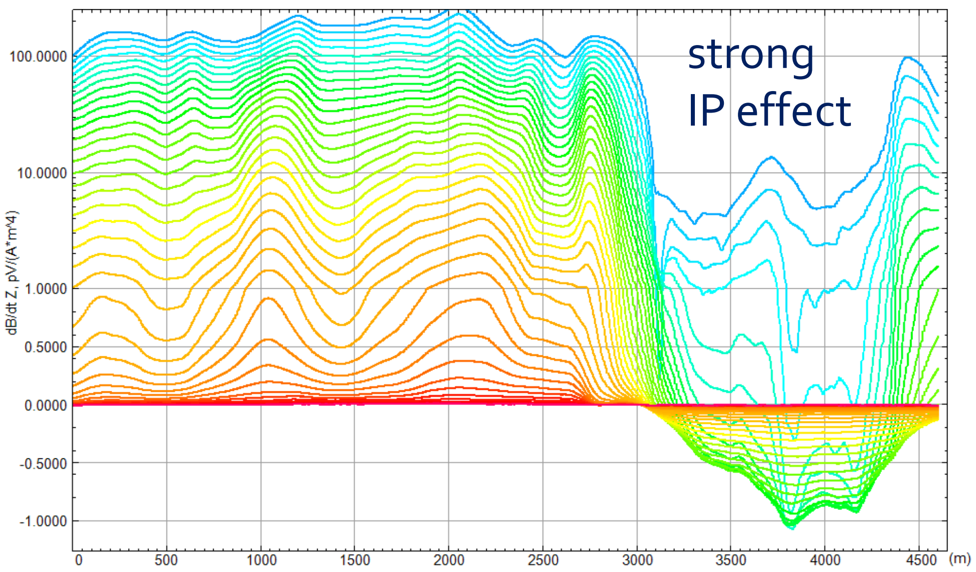


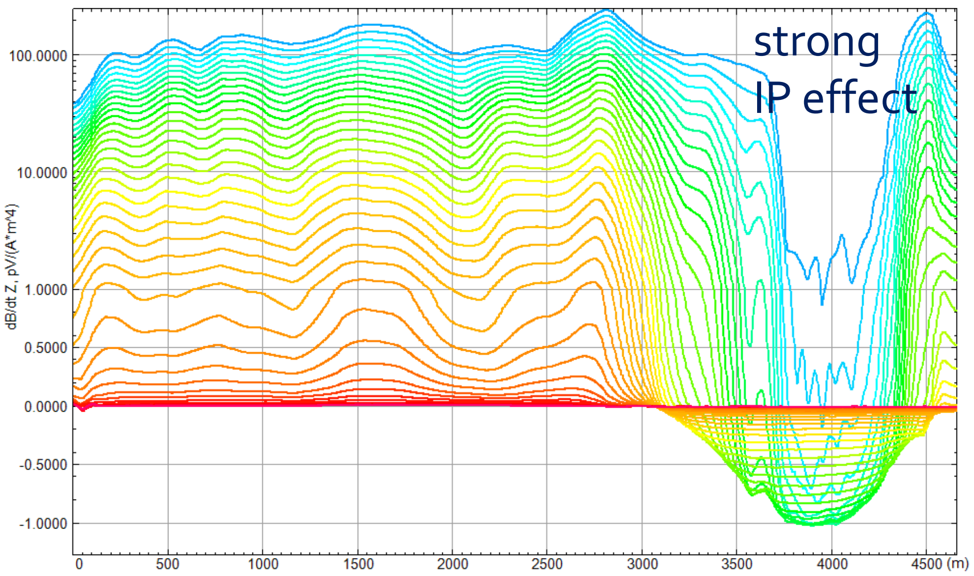
# Western Australia (TargetEM)



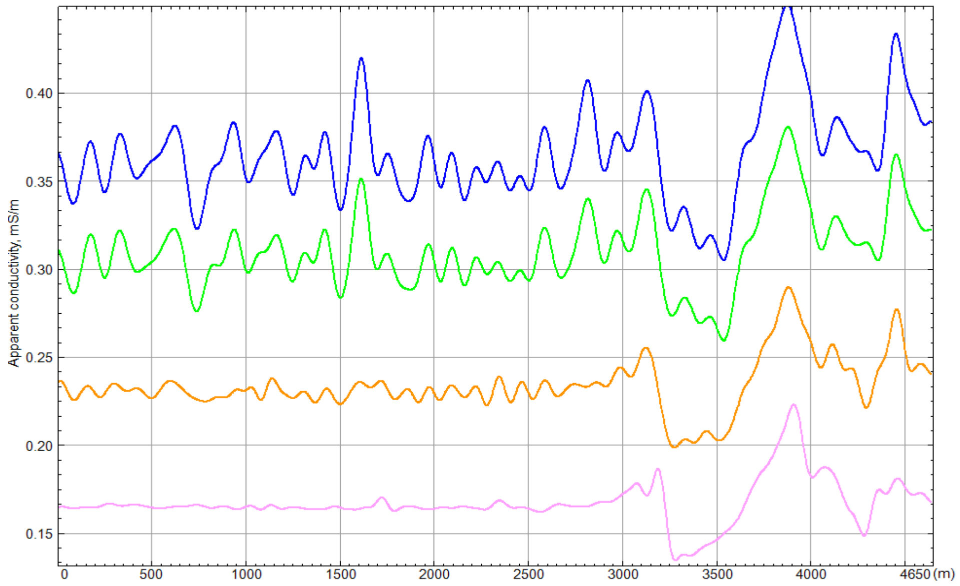
Line 2820

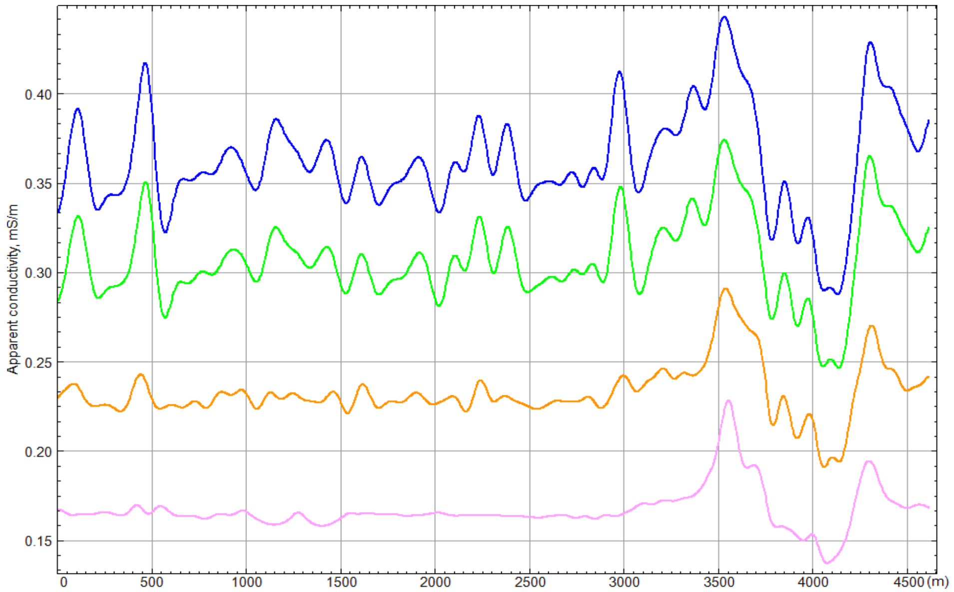
Line 2840




TDEM. dB/dt, Z



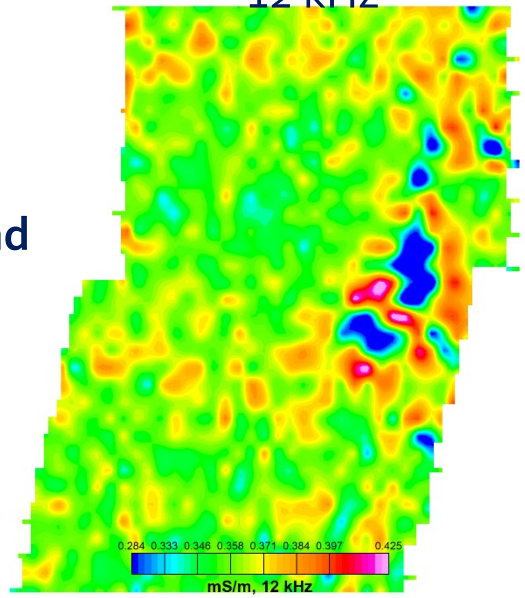

AFMAG, Tr ON app. Cond., 12-18 kHz

# Western Australia (grids, TargetEM)

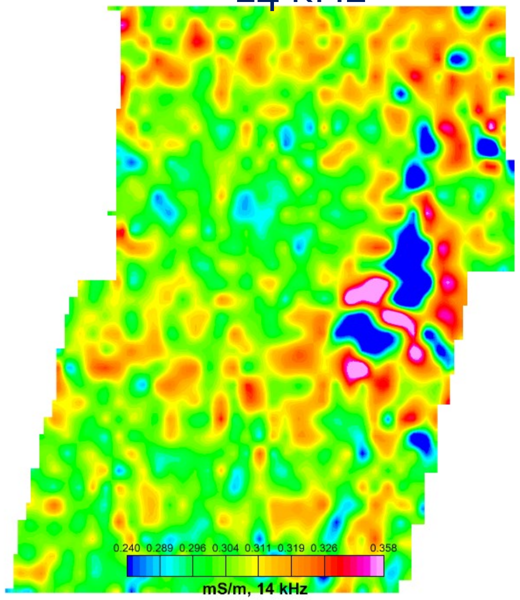


**AFMAG**
**App cond**
**Tr ON**

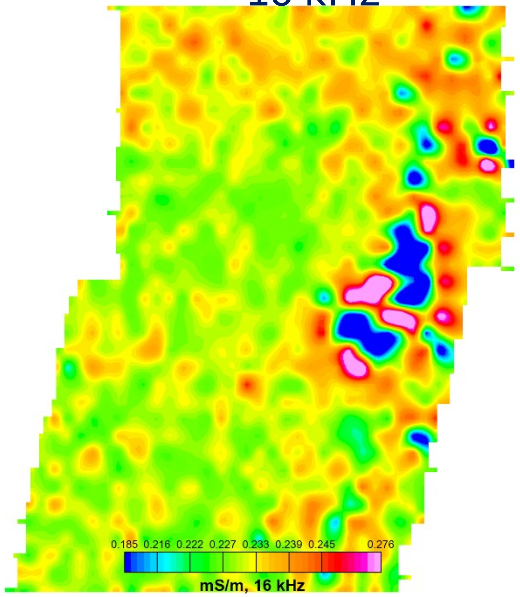
12 kHz



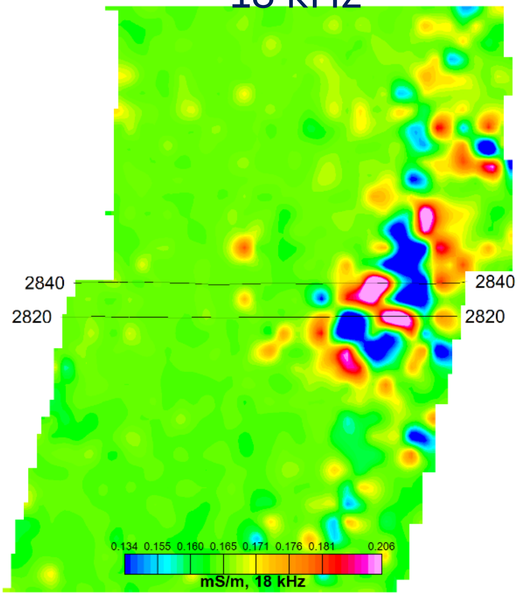

14 kHz




16 kHz

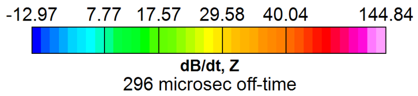


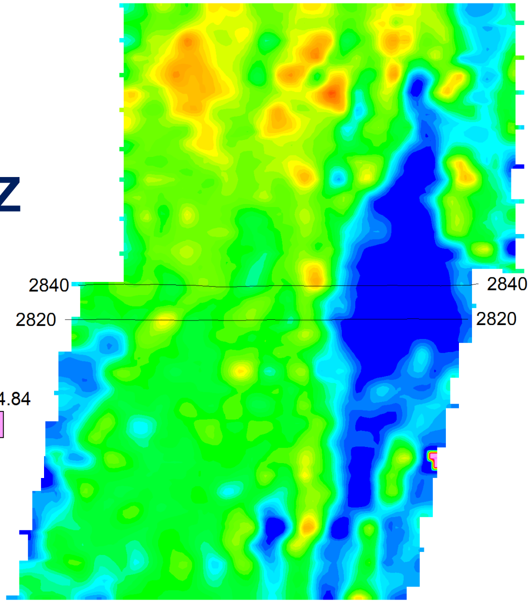

18 kHz




# Western Australia

**TDEM, dB/dt, Z**
**296 microsec**



# Conclusions



Natural field AFMAG and complimentary VLF radio-field data can be a valuable addition to the active source time-domain EM data, especially with simultaneous recording.

Natural field AFMAG data is valuable in filling the gaps when the time-domain method is limited: at mapping highly resistive geological terrains, in detecting superconductors, during surveys in rugged relief conditions, and at parasitic effects appearance (IP and SPM);

Combining streamed time series recordings over survey lines and recordings from a synchronized reference base station provides quality natural and radio field electromagnetic data.

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Acknowledgments:

ESTRELLA RESOURCES

KALGOORLIE MINING ASSOCIATES PTY LTD

Tr Transition Metals

PROMISELAND exploration