

# WHAT ARE WE MEASURING?

ASEG Workshop on Airborne Electromagnetics  
Perth  
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Southern Geoscience Consultants



**SOUTHERN GEOSCIENCE**  
CONSULTANTS

# “WHAT ARE WE MEASURING?” OUTLINE

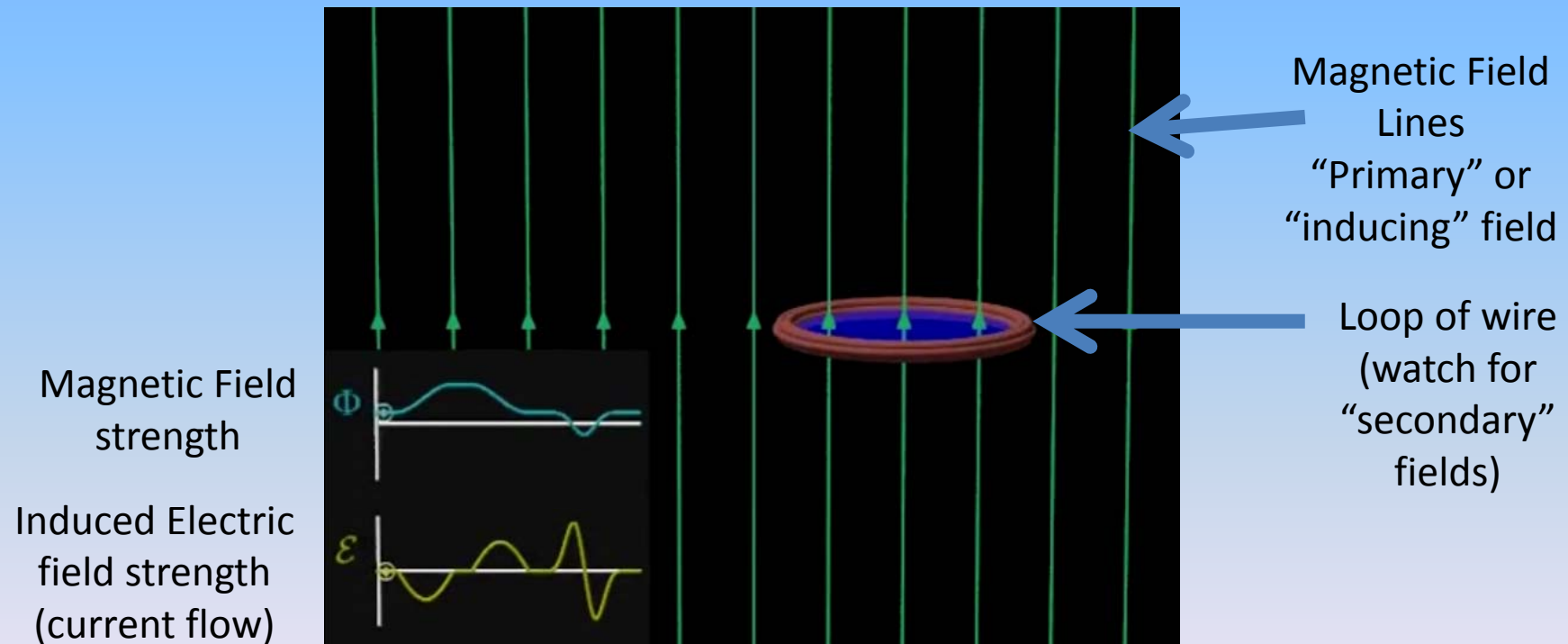
- Electromagnetic Induction
- EM Survey technique
  - Frequency and Time Domain
  - Natural and Active Source
- Conductivity of Rocks
- Survey Signal Sources
  - Conductive Earth
  - Confined Conductors
  - Ground Polarisation
  - SPM

# INDUCED FIELDS

Technique is an application Faraday's Law described with Maxwells equations

## Faraday's Law of Induction

A changing magnetic field induces a current in a conductor

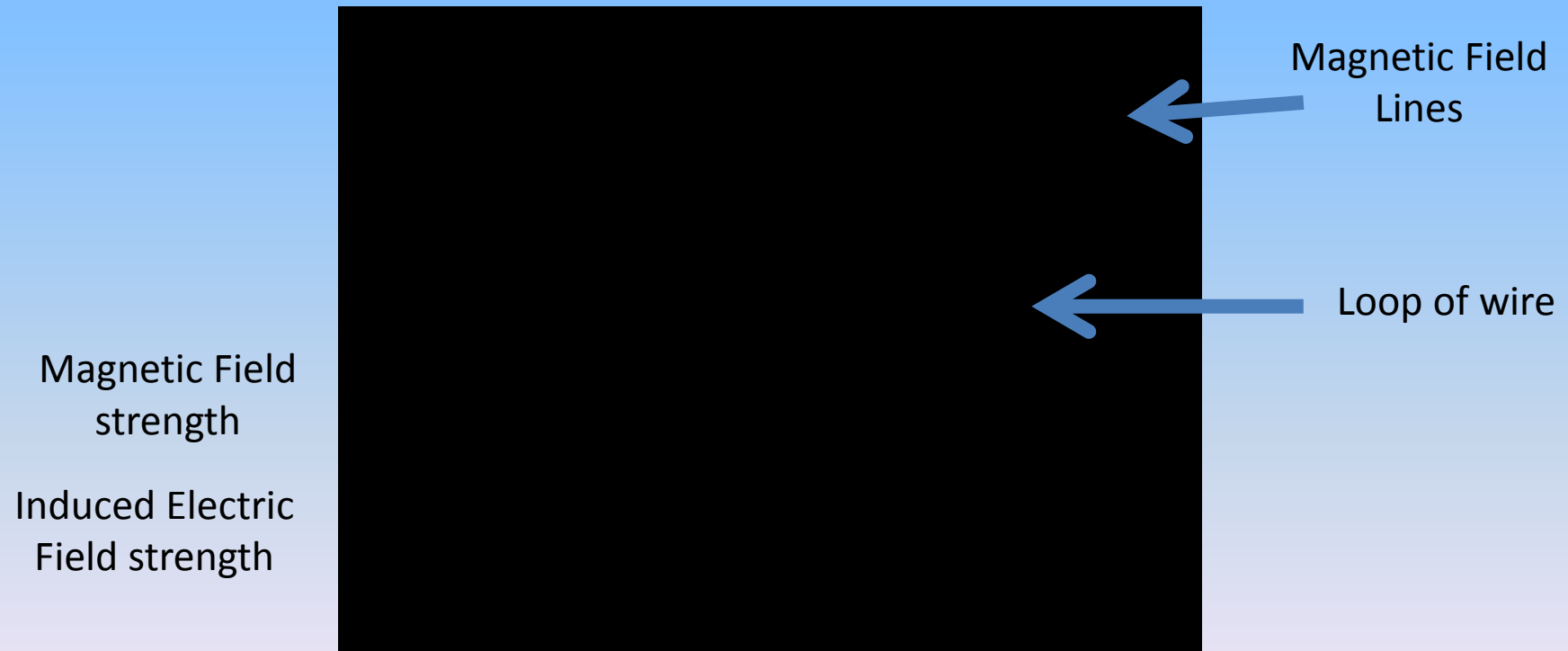


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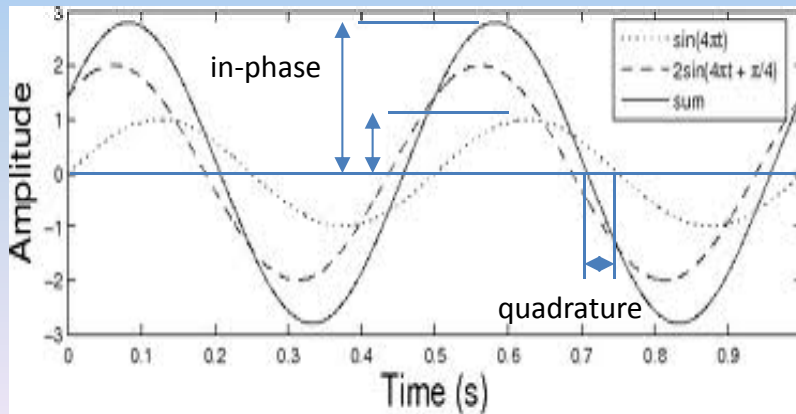


# AEM SURVEYING – FREQUENCY AND TIME DOMAIN

Measurements are completed in either

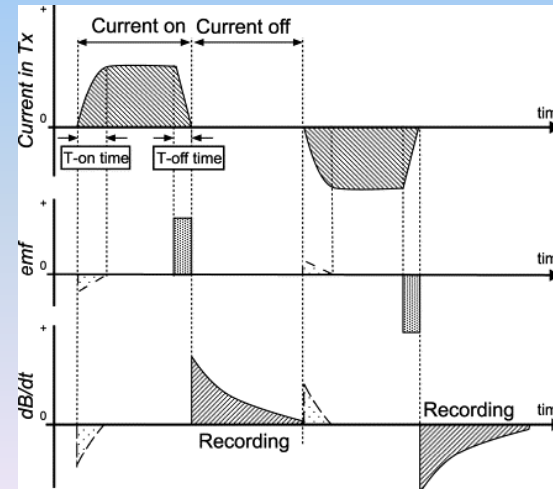
## “FREQUENCY DOMAIN”

- Measurements are of a limited number of frequencies (e.g. 5)
- Secondary field is described as an amplitude (“in-phase”) and phase difference relative to the energising field (“quadrature”)



## “TIME DOMAIN”

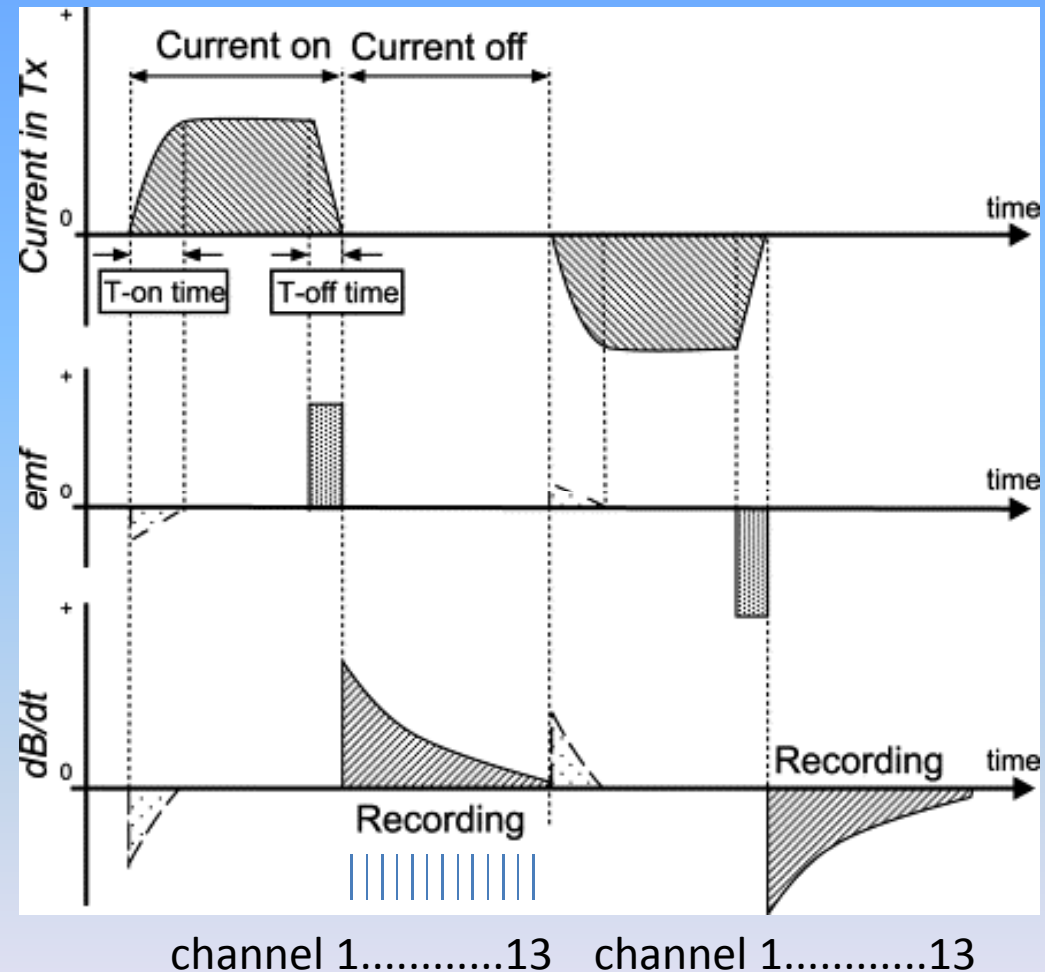
- Current is turned on and off
- Energisation of the ground occurs as the current is turned on and off
- Measurements are normally made of the decaying magnetic field after the primary current /magnetic field is off.



# EM SURVEYING – FREQUENCY AND TIME DOMAIN

Each frequency measured in a Frequency Domain survey has the same information as a single channel in a time domain survey

..... So there is much more conductivity information in any time domain EM reading than a FDEM reading .



# EM SURVEYING

Our energising fields for AEM surveys can be artificial or natural

## NATURAL SOURCE

- Lightning
- Sprites
- Solar wind – Magnetosphere interactions

## ACTIVE SOURCE

- Current in a wire with aircraft (FD & TDEM)
- VLF transmitters (submarine communication) - FD

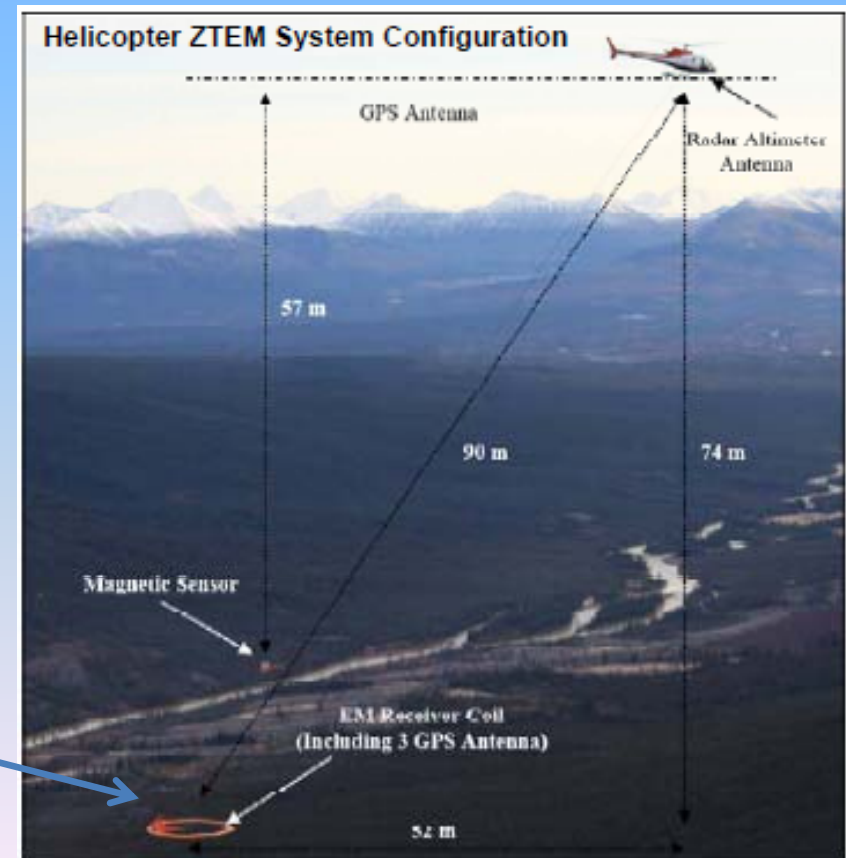


# EM SURVEYING – NATURAL SOURCE

- Aircraft travels with a large coil sensor measuring the magnetic field at many (e.g. 5) different frequencies
- A stationary remote sensor measures the horizontal and vertical fields at the same frequencies
- The lower the frequency the deeper the information
- Inversion is often required to establish correct depths.

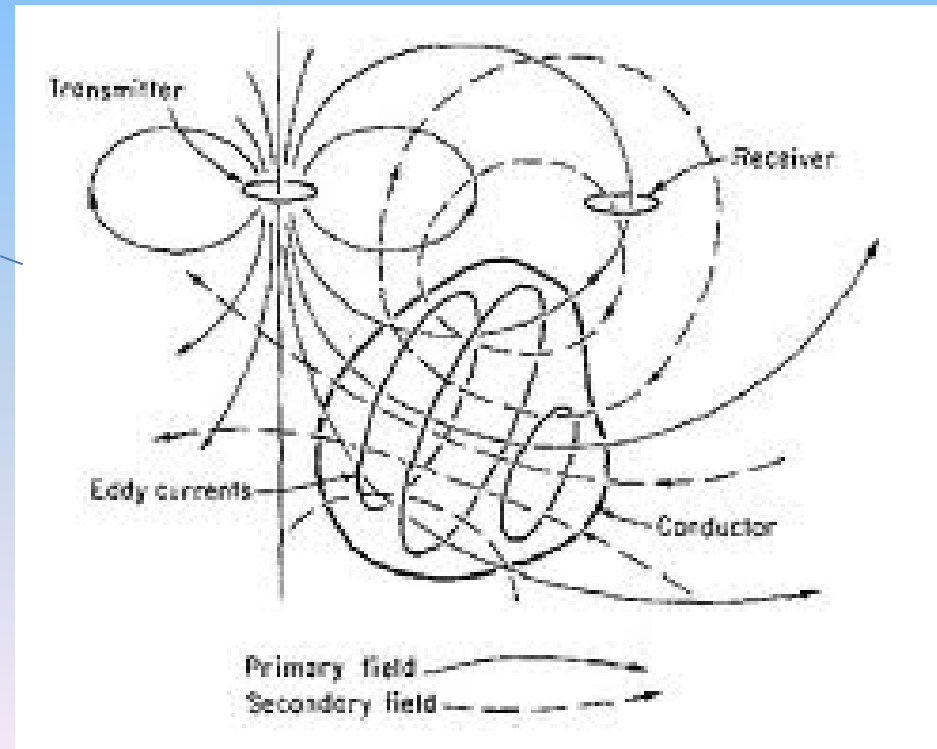


Stationary sensor Exchange for "AIRMT"



# EM SURVEYING – ACTIVE SOURCE

- Aircraft travels with a wire loop/coil with varying current (“transmitter”) which generates a large magnetic field.
- A second coil of wire is used as the sensor (“receiver”) measure the changing field from currents induced in the earth (and primary field if it is on)
- Receiver is always towed by the aircraft and may be in or outside of the transmitter loop, above, or below it.
- Transmitter can be towed (all HEM systems) or wrapped around nose, wings and tail of an aeroplane.

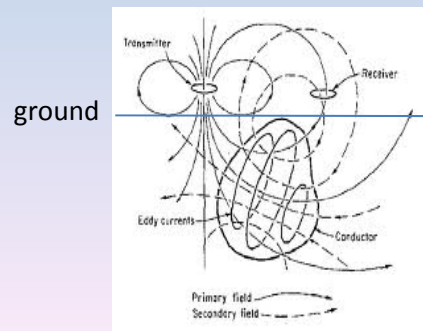


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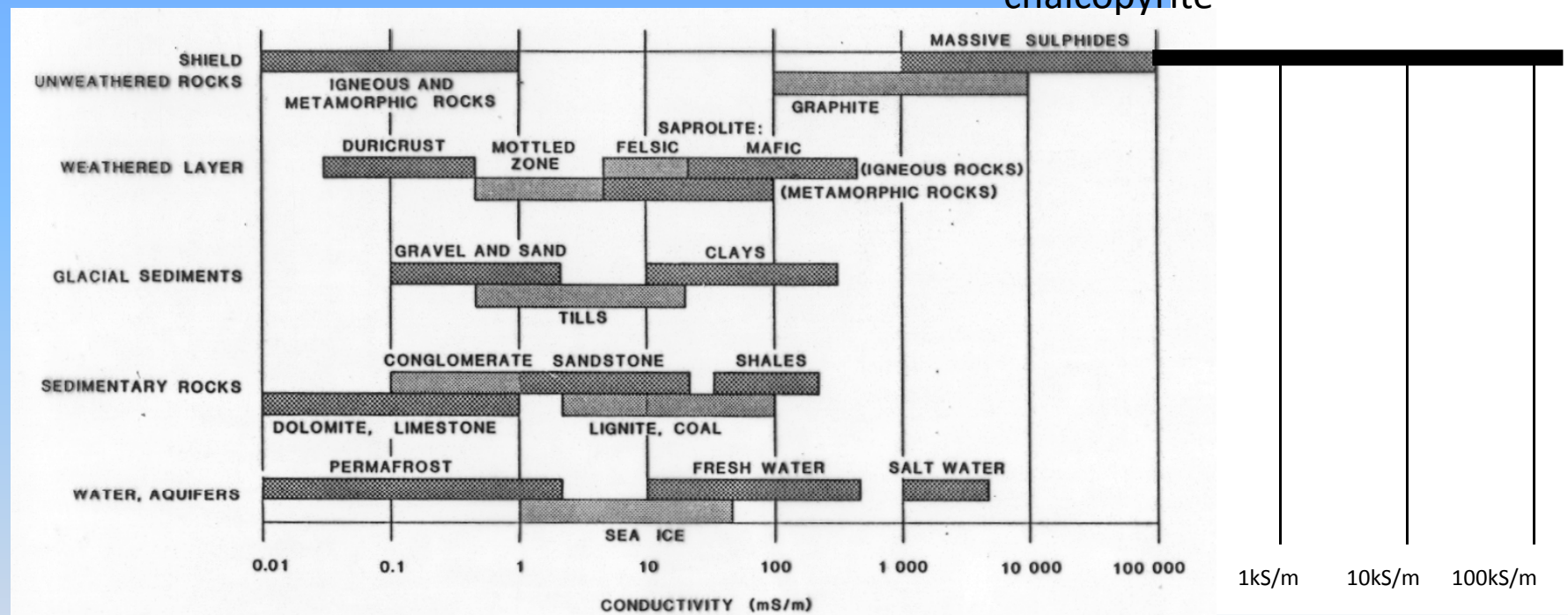
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# AEM SURVEYING CONDUCTIVE EARTH

chalcocite  
pyrite      pyrrhotite →  
chalcopyrite



After Palaky, massive sulphide range expanded

- Property we can measure is **conductance** (S) = conductivity (S/m) x thickness (m)

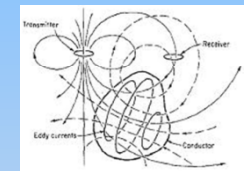
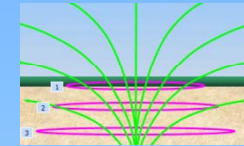
# EM SURVEYING SIGNAL SOURCES

Our transmitter signal fields (electric and magnetic) interact with the earth in a number of ways some of which we want and some of which we don't:



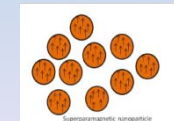
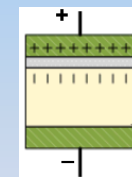
## WHAT WE WANT

1. Galvanic Currents: Inductive response from the ground (mapping, groundwater)
2. Vortex Currents: Inductive response from discrete conductors (for Ni/Cu/Fe ore targets)



## WHAT WE DON'T WANT

1. Ground polarisation effects
2. Superparamagnetic effects
3. Noise (Spherics, Powerlines)



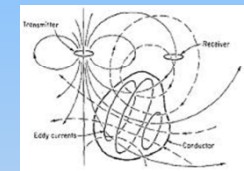
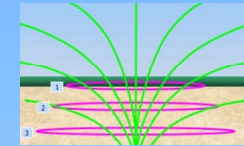
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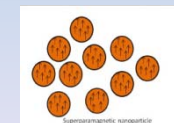
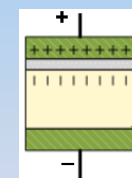
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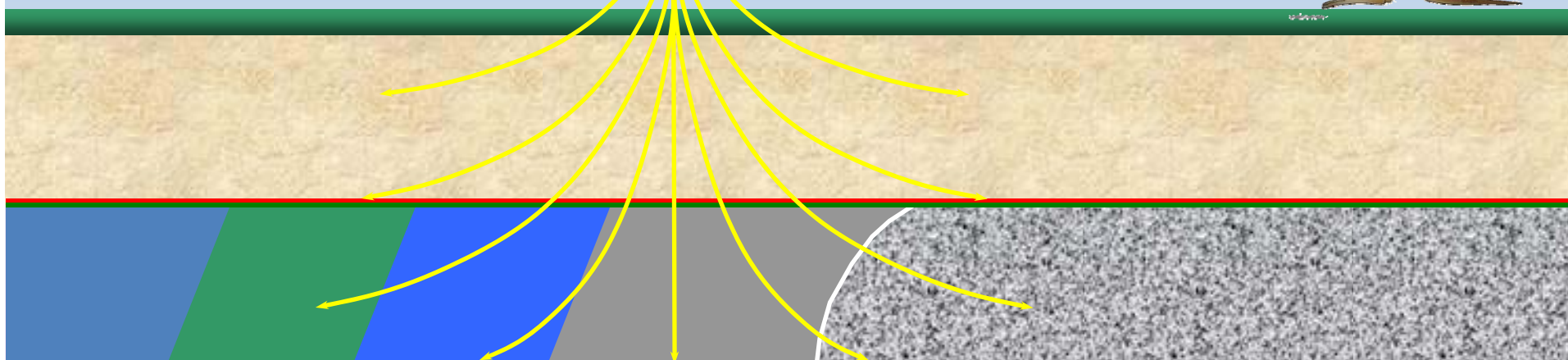
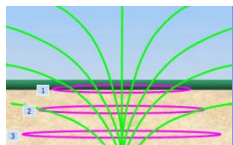
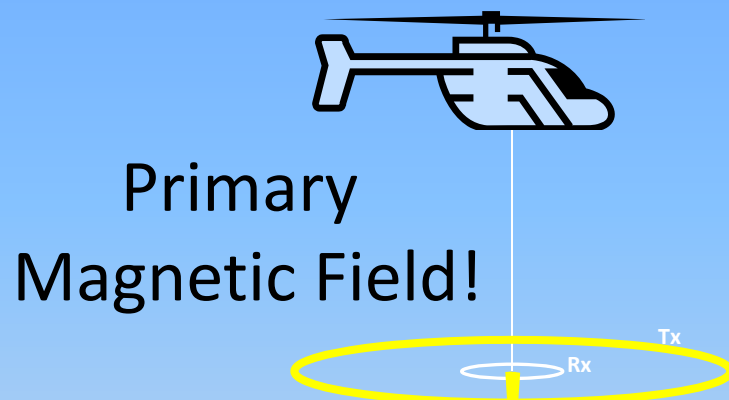


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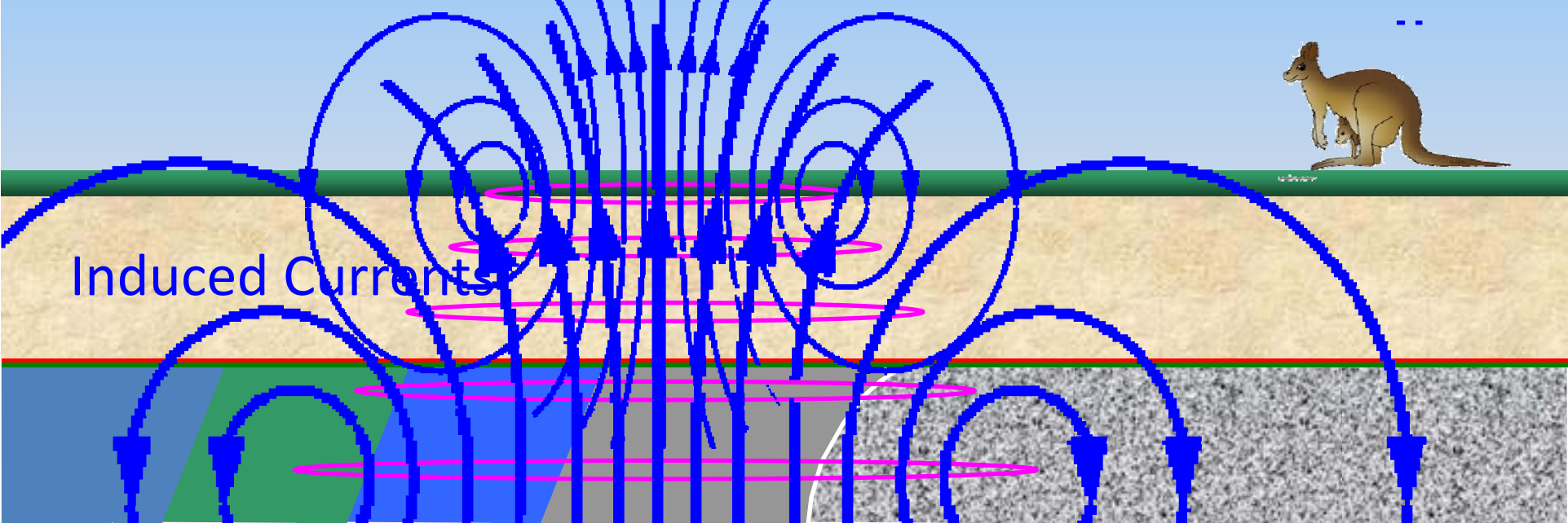
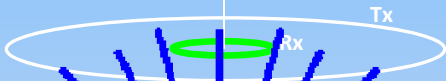
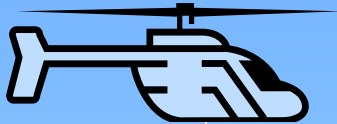
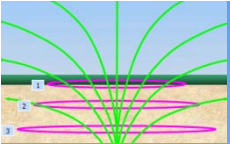
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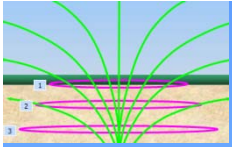


# SIGNAL SOURCES CONDUCTIVE HOST ROCKS



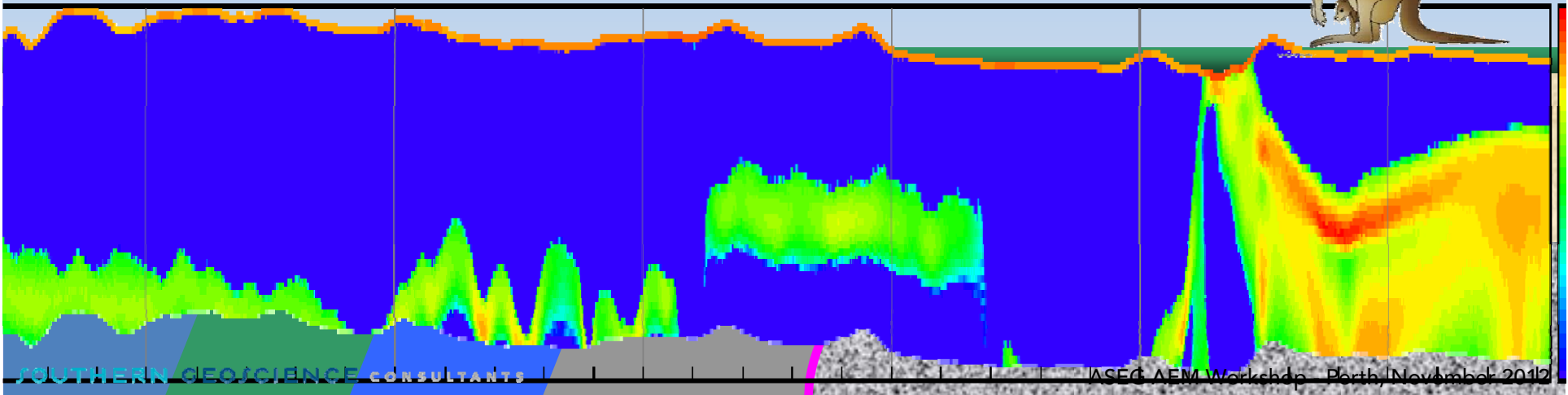
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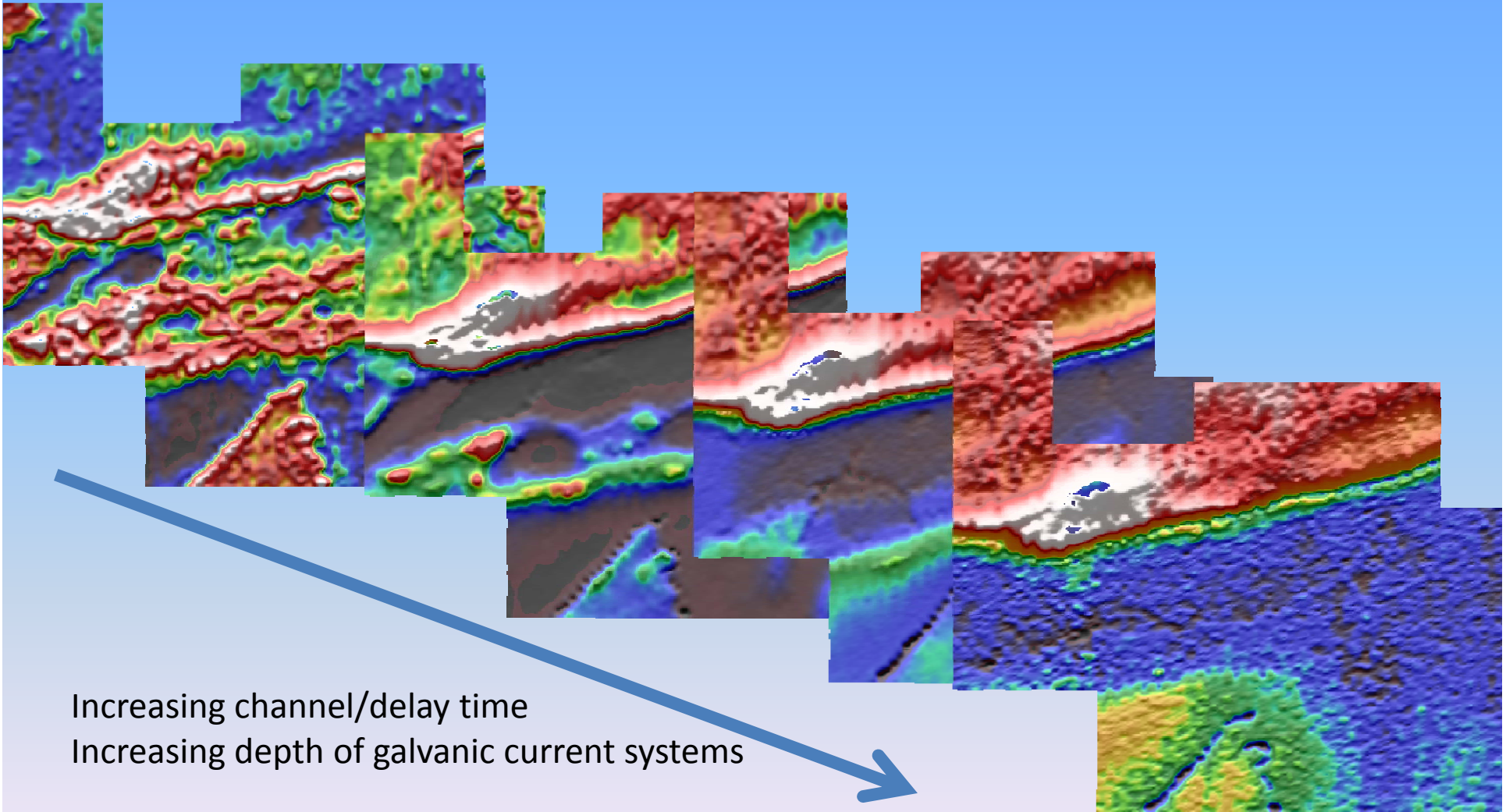
# SIGNAL SOURCES CONDUCTIVE HOST ROCKS

- These currents move down rapidly in resistive ground and slowly in conductive ground.
- The rate that the signal drops off can be used to map the conductivity of the earth – basis of Conductivity Depth Inversions.
- When the geology is layered and there are no lateral changes CDIs can map the earth very well.
- When the geology is not layered (eg: dipping strata, faults, folds, channels) the assumptions of the CDIs fail and so does the reliability of the inversions.
- 3D inversions are now possible but these are still slow and expensive.



# COMBINATION OF HOST AND CONFINED CONDUCTIVE RESPONSES

3km  
↔



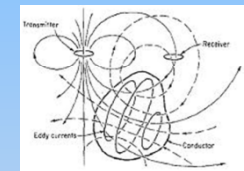
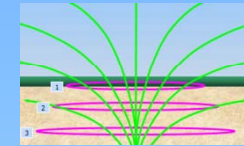
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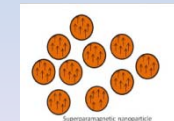
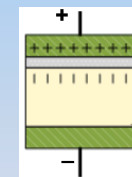
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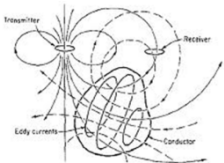
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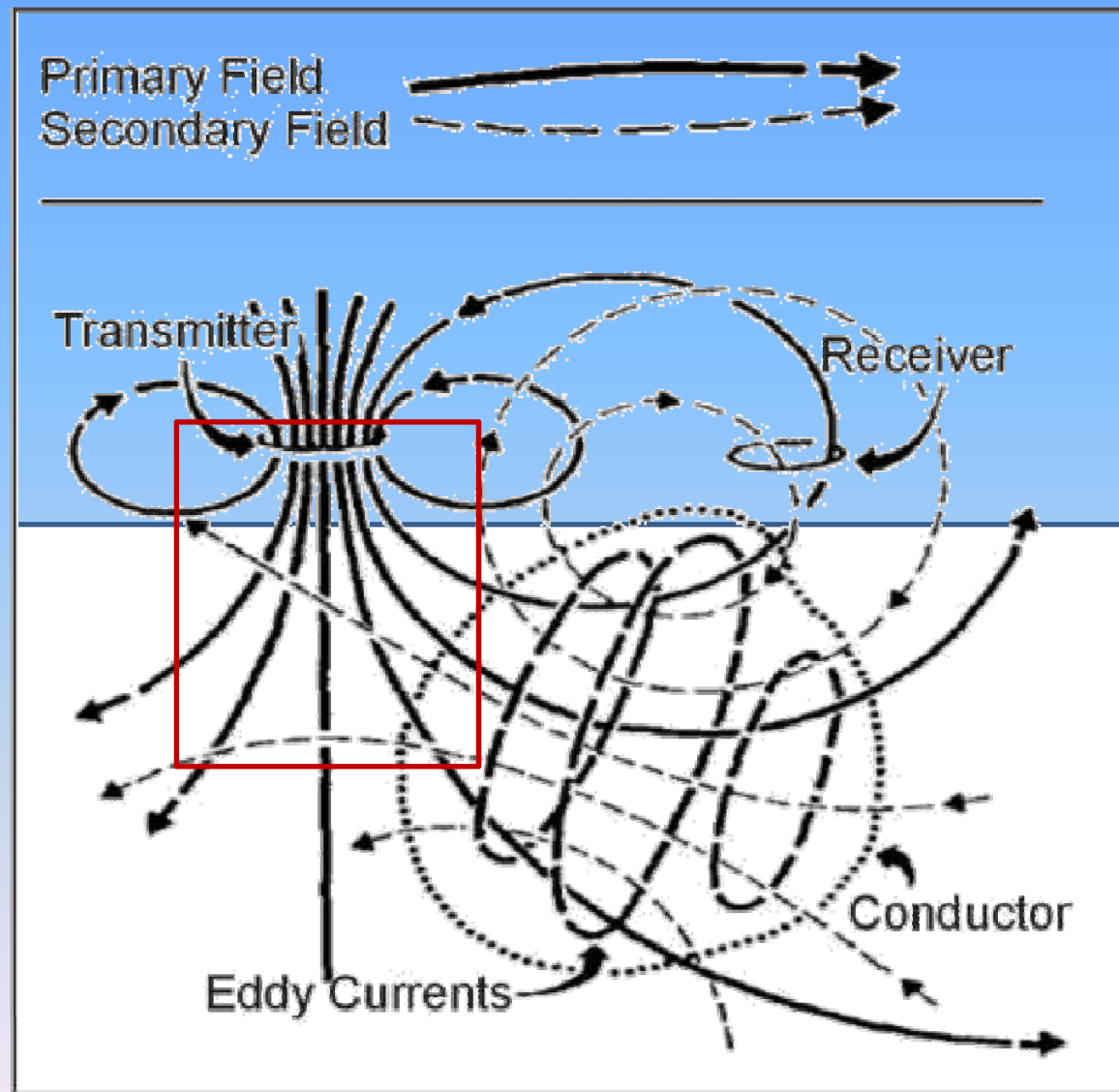
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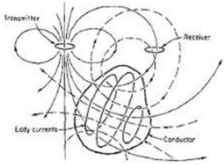




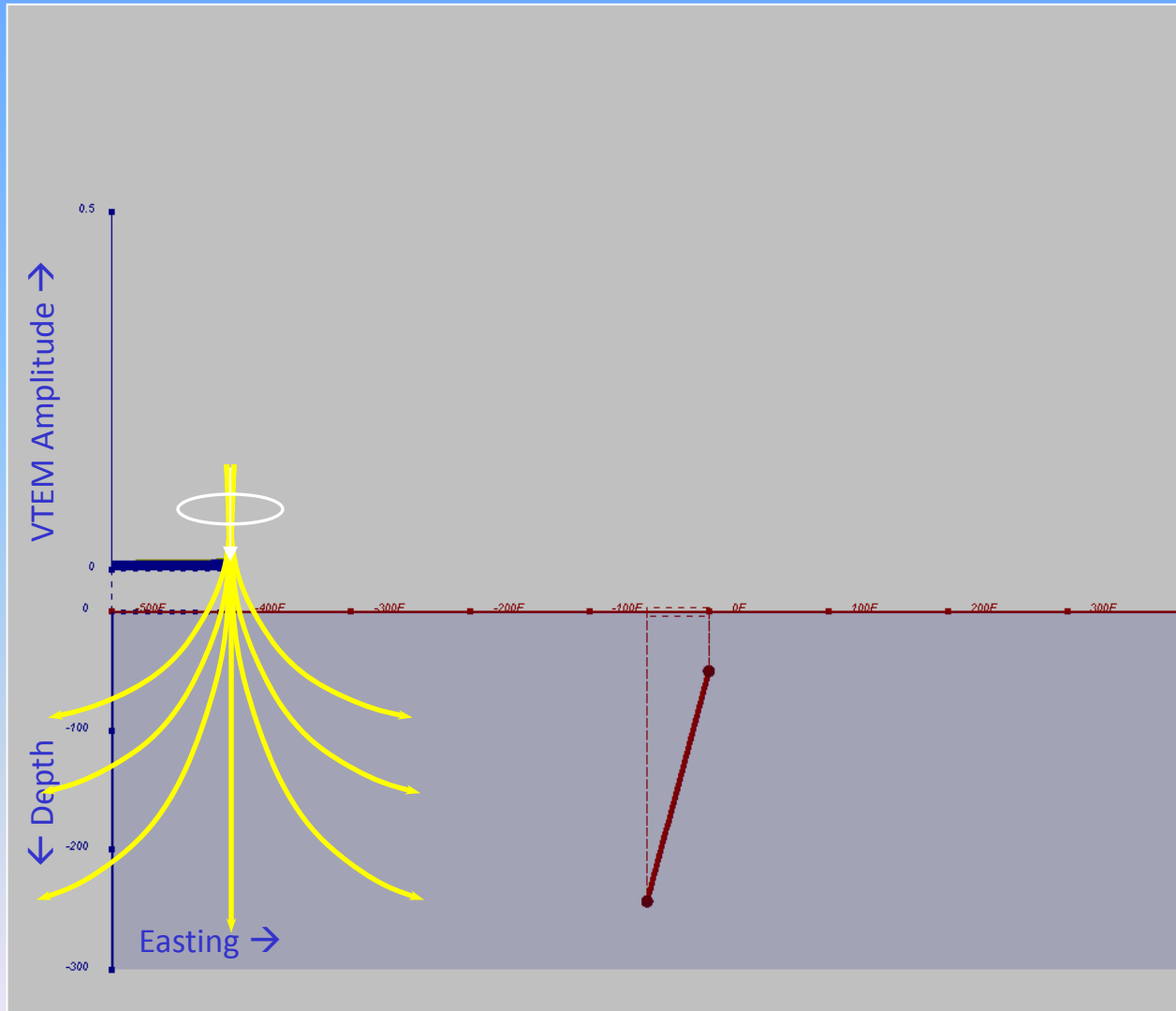
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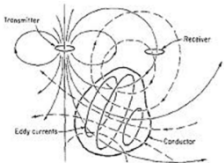
- Current induced in discrete conductors termed “Vortex” currents
- Commonly modelled using a rectangular thin plate
- Main anomaly is normally not over centre of conductor



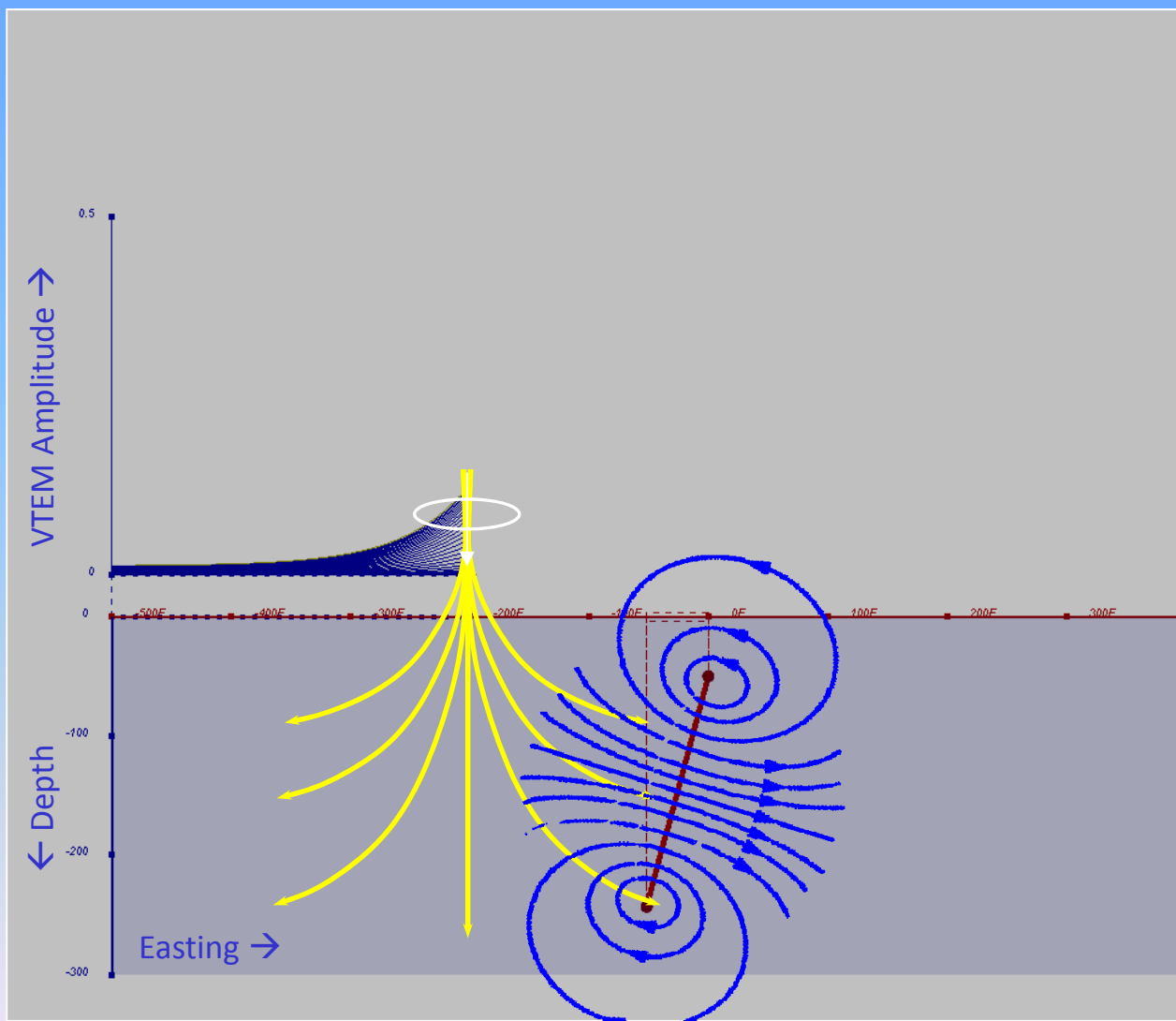


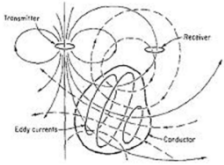
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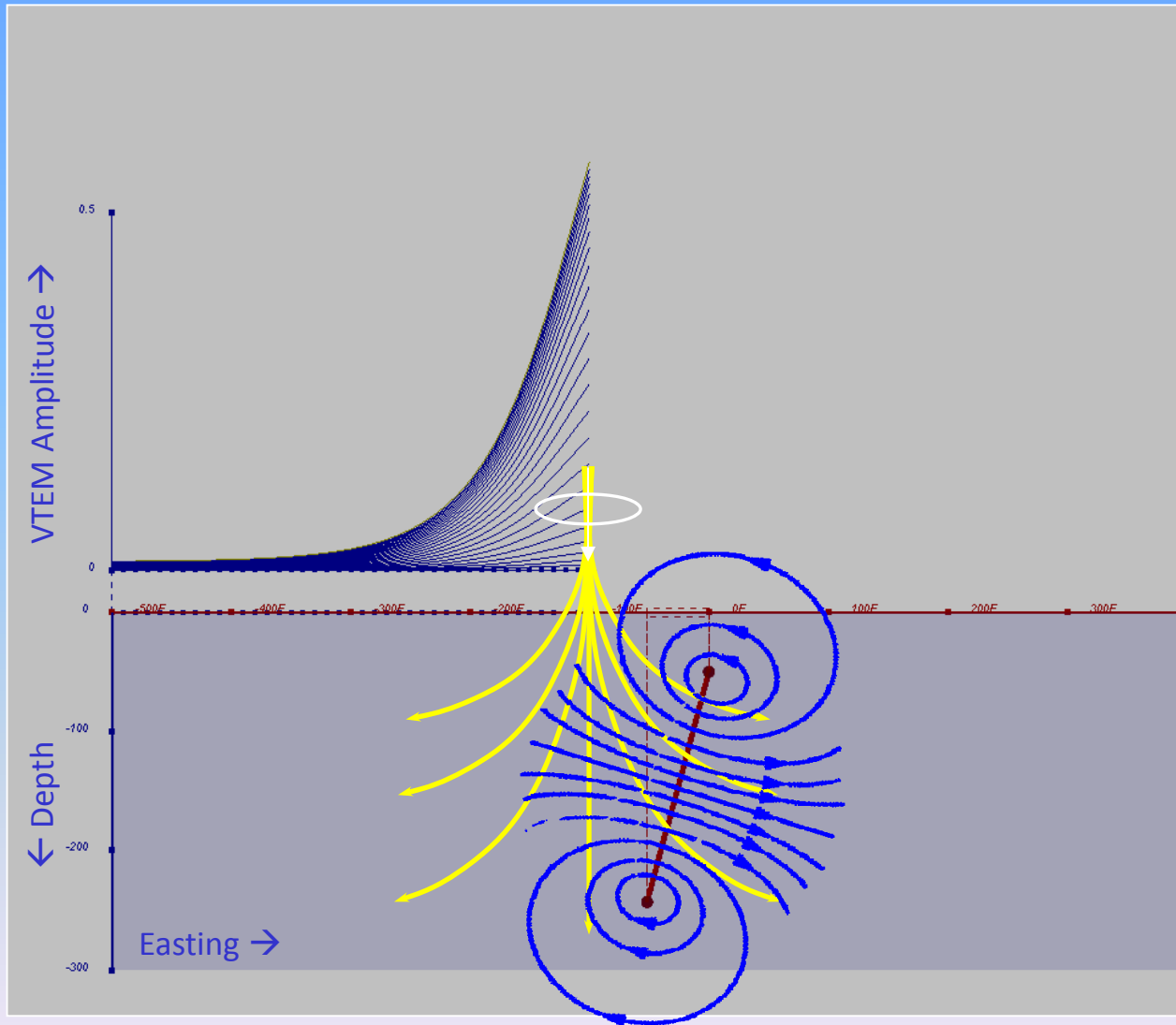


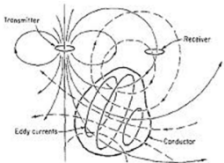
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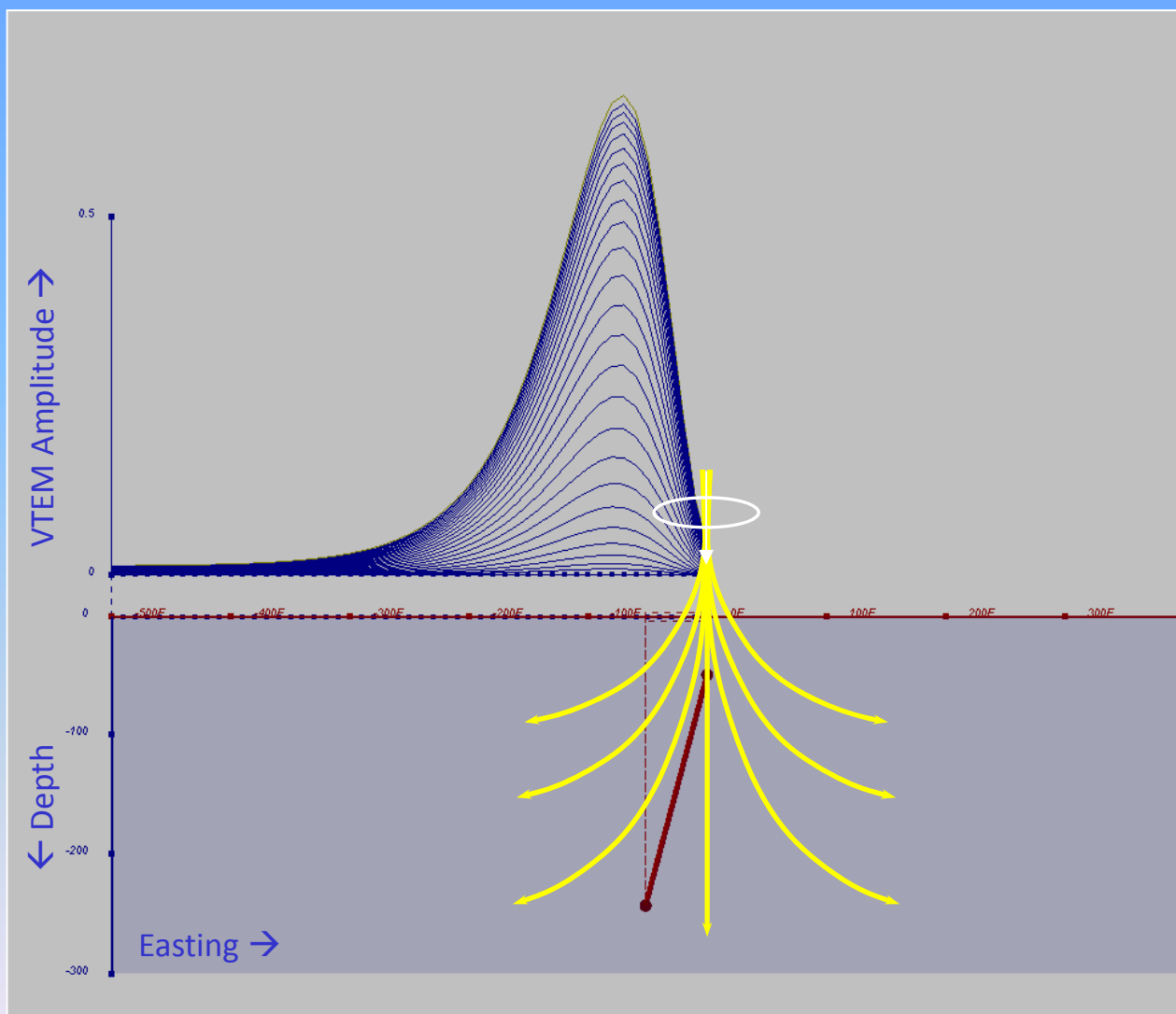


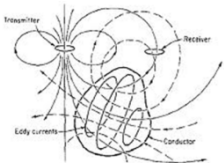
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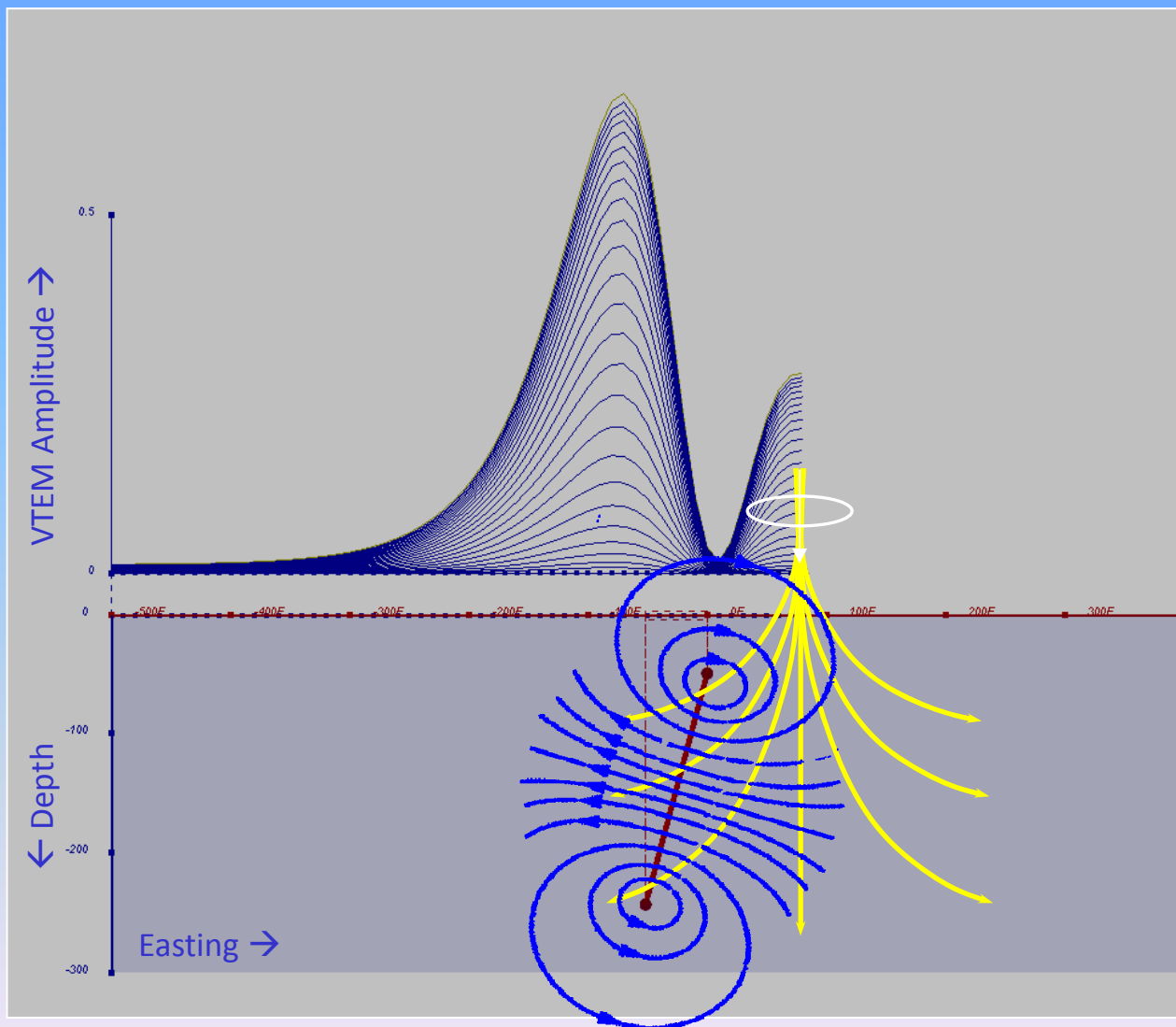


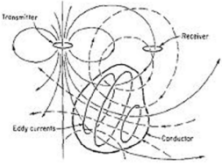
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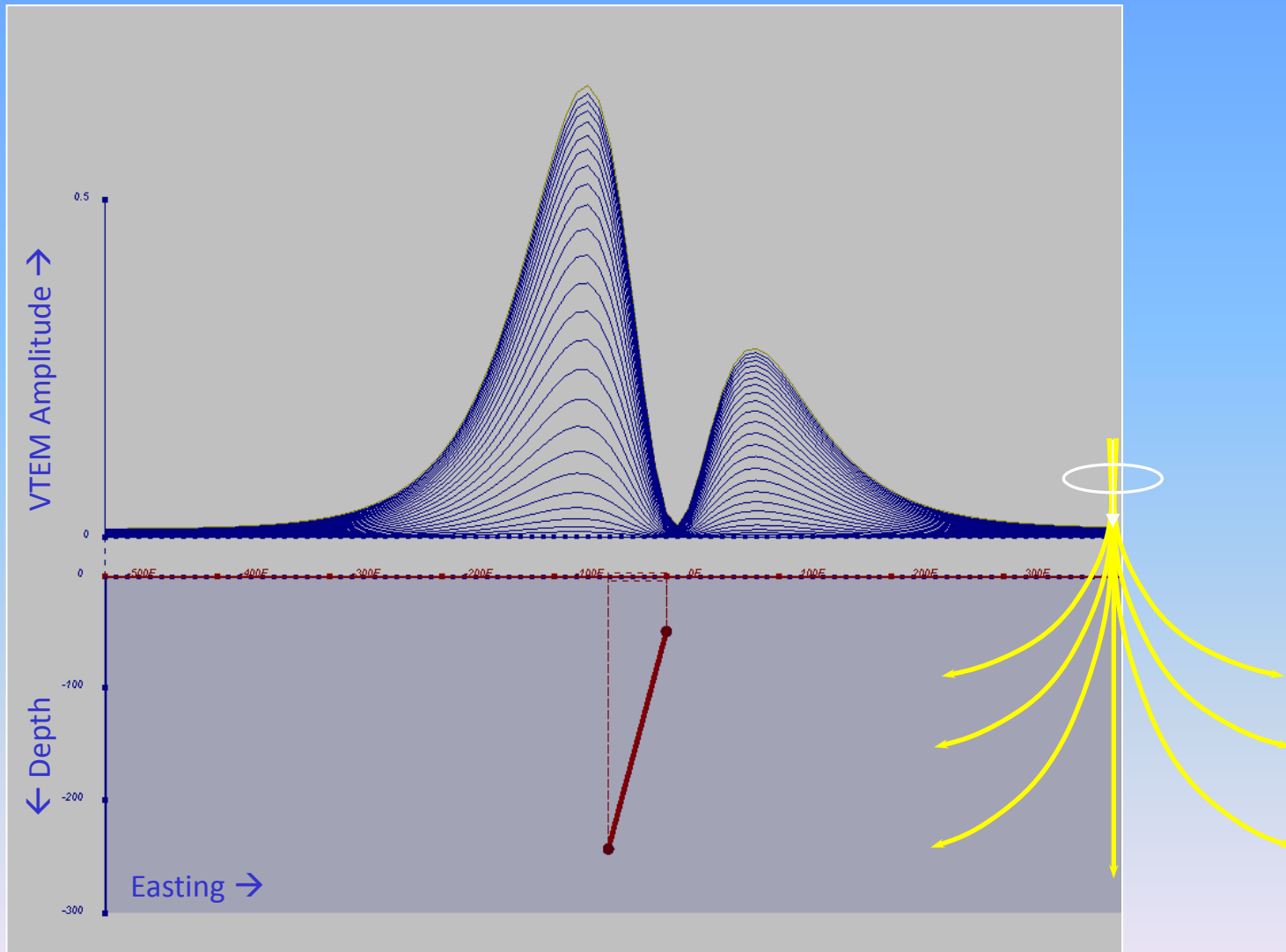


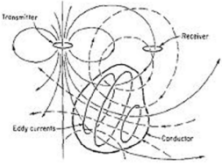
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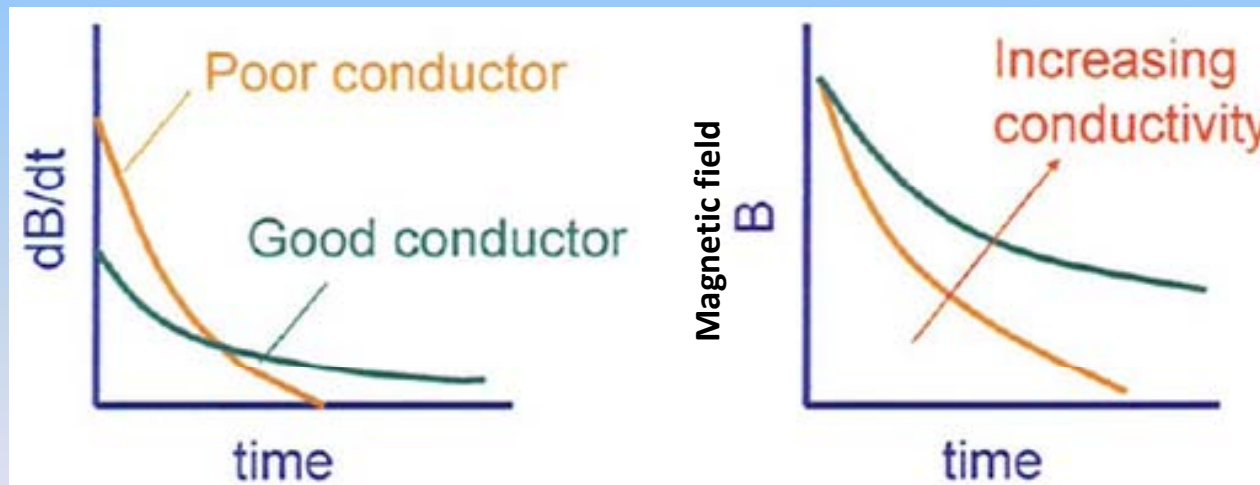


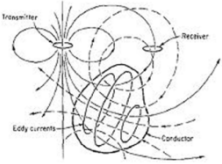


# SIGNAL SOURCES DISCRETE CONDUCTORS

- Currents are induced on the surface of the conductor and collapse in to the centre with time
- Rate of collapse inwards and current decay slow with increasing conductivity
- For extremely conductive bodies the current decay is so slow that the signal is below noise levels for coils sensor.
- Several systems offer a “B field” response

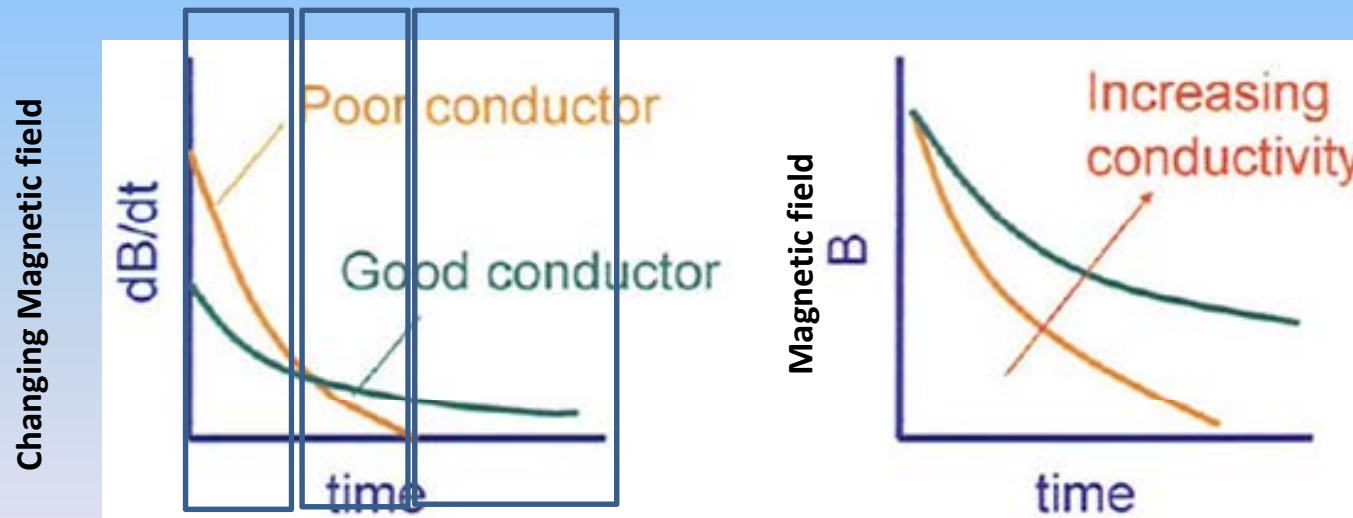
Changing Magnetic field



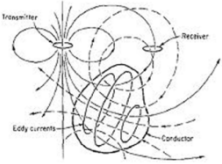


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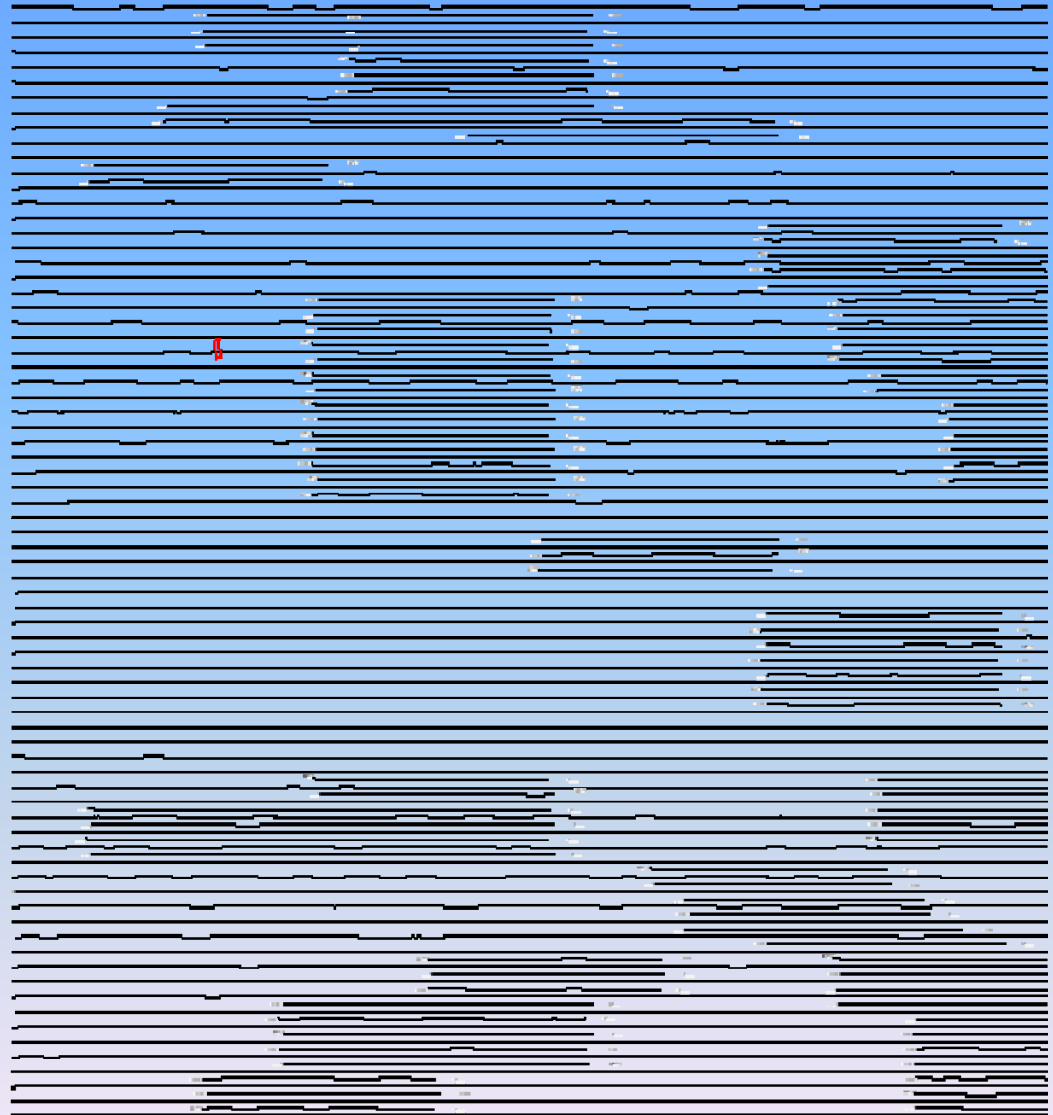


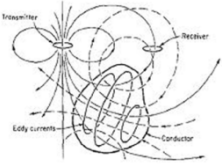
“Early”, “Mid”, “Late”, times or channels



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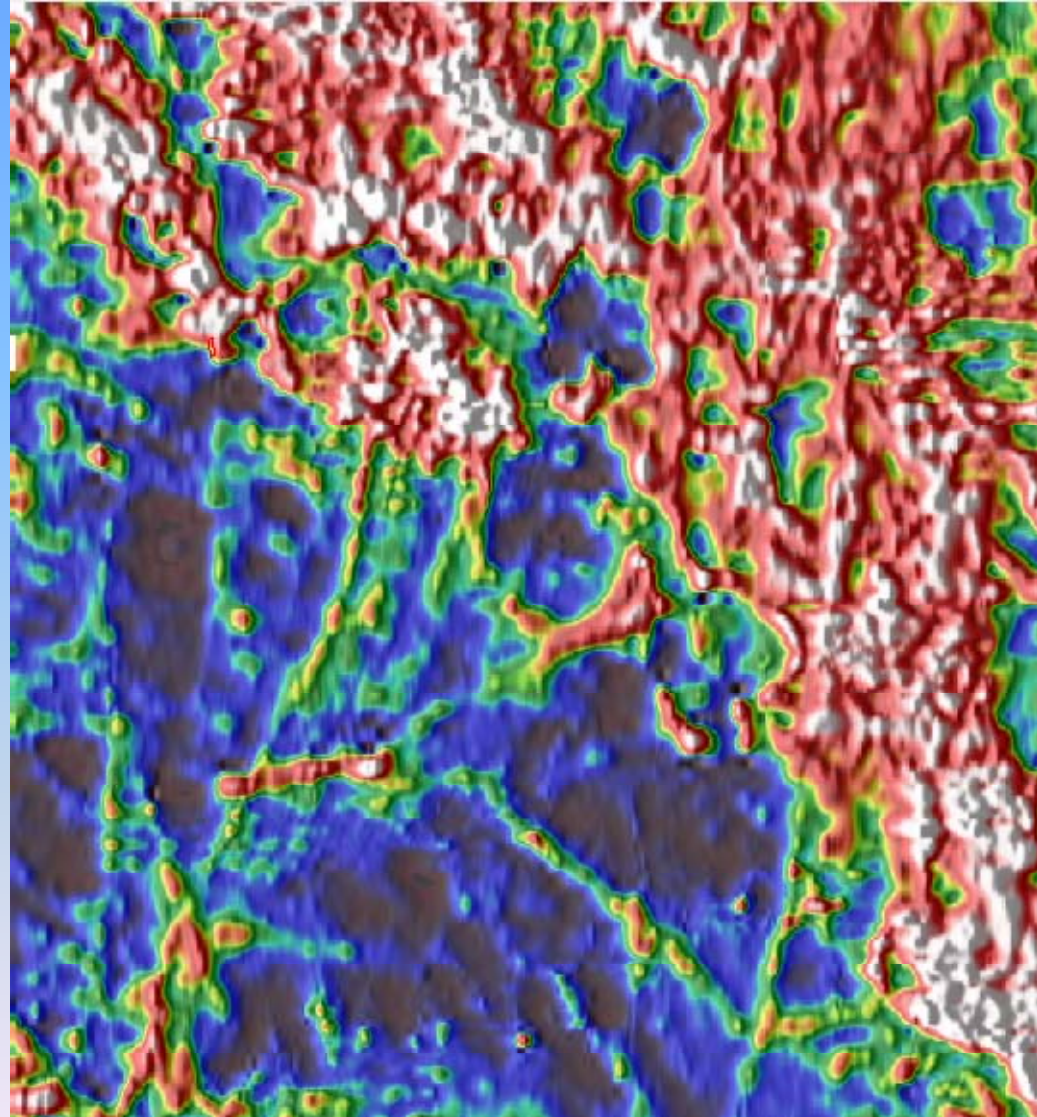
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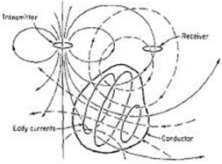


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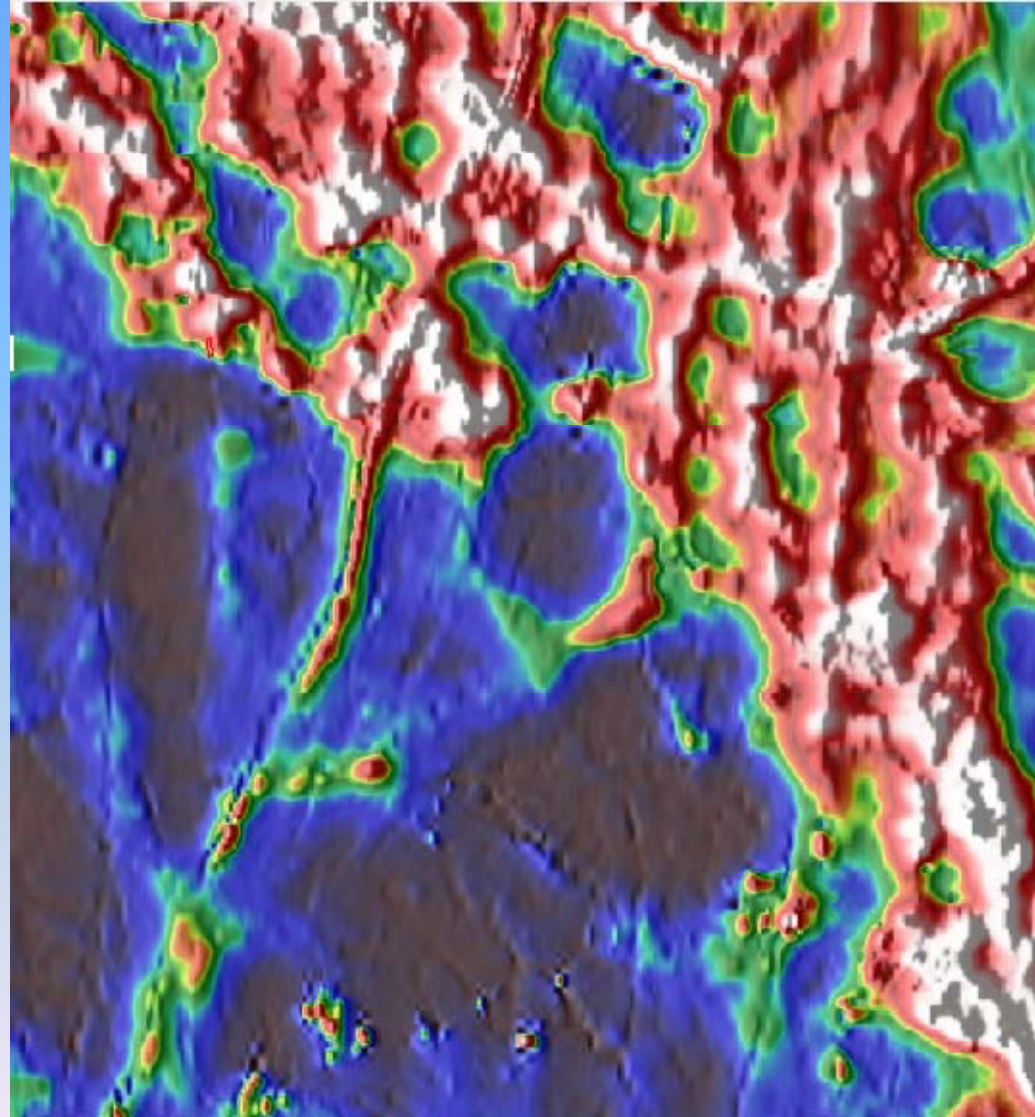


Ch 16

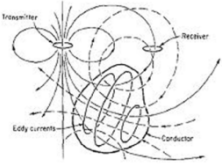


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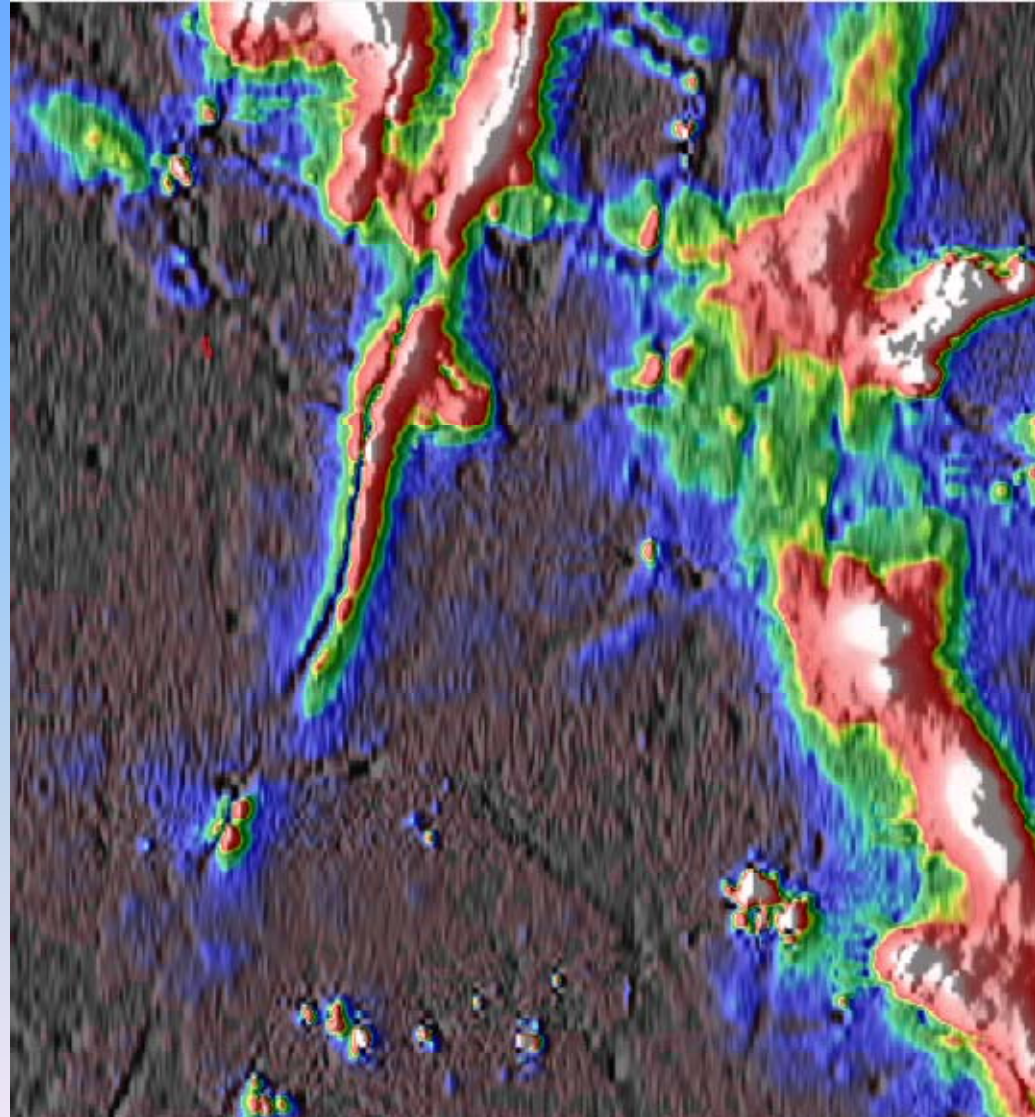


Ch 25



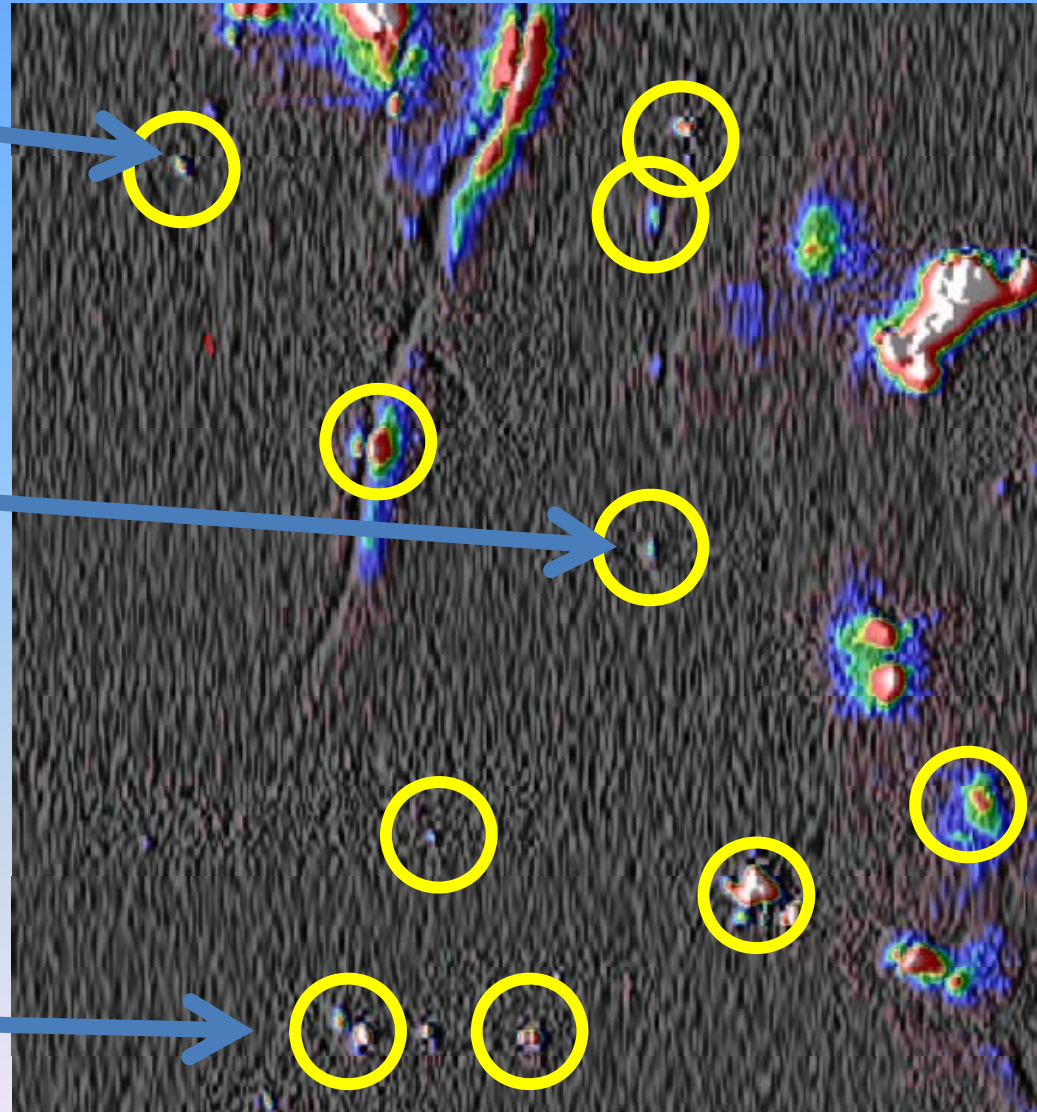
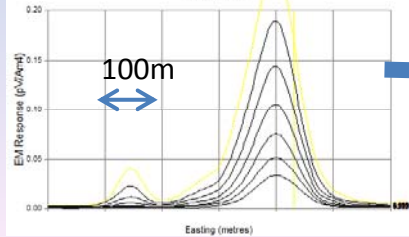
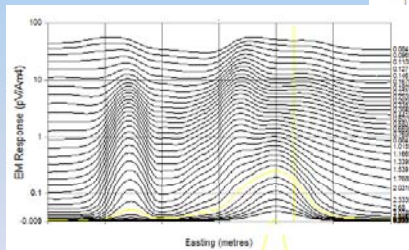
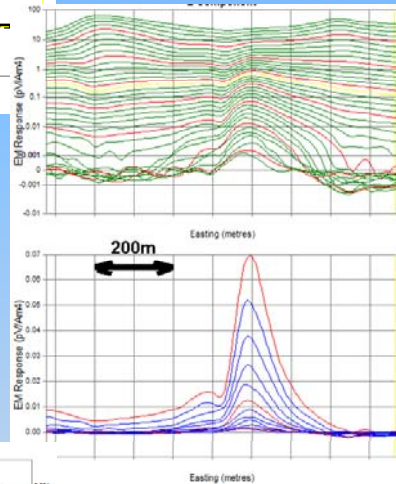
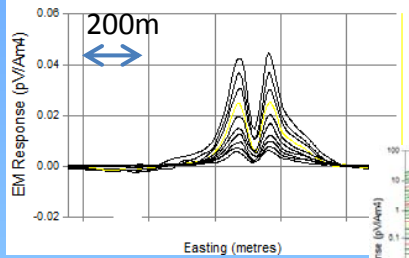
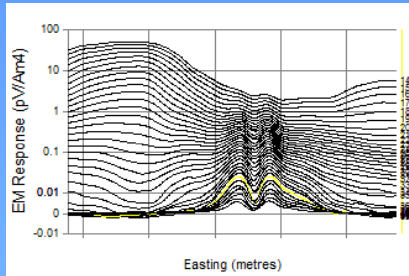
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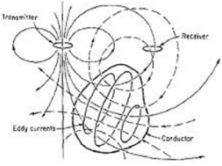


Ch 35

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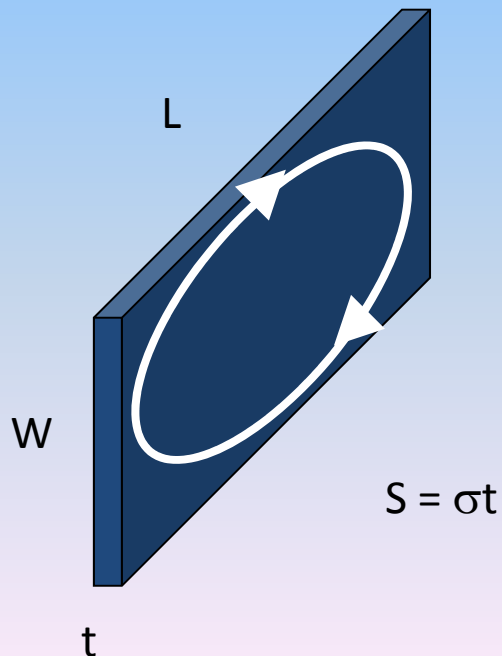


Ch 45

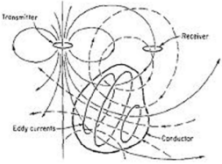


# SIGNAL SOURCES DISCRETE CONDUCTOR TIME CONSTANT

- A discrete conductor's time constant is a measure of the rate of decay of the induced currents
- For thin plate is mostly function of conductivity, thickness and dip extent
- Can be useful for influencing first pass follow-up priority



- $\tau(\text{ms}) \cong S(\text{Siemens})W(\text{km})$
- Parameters of current vortex
  - L: strike length or largest dimension
  - unimportant
  - W: intermediate dimension, measure of interaction distance between forward and return currents in target
  - t: thickness
  - S: conductance

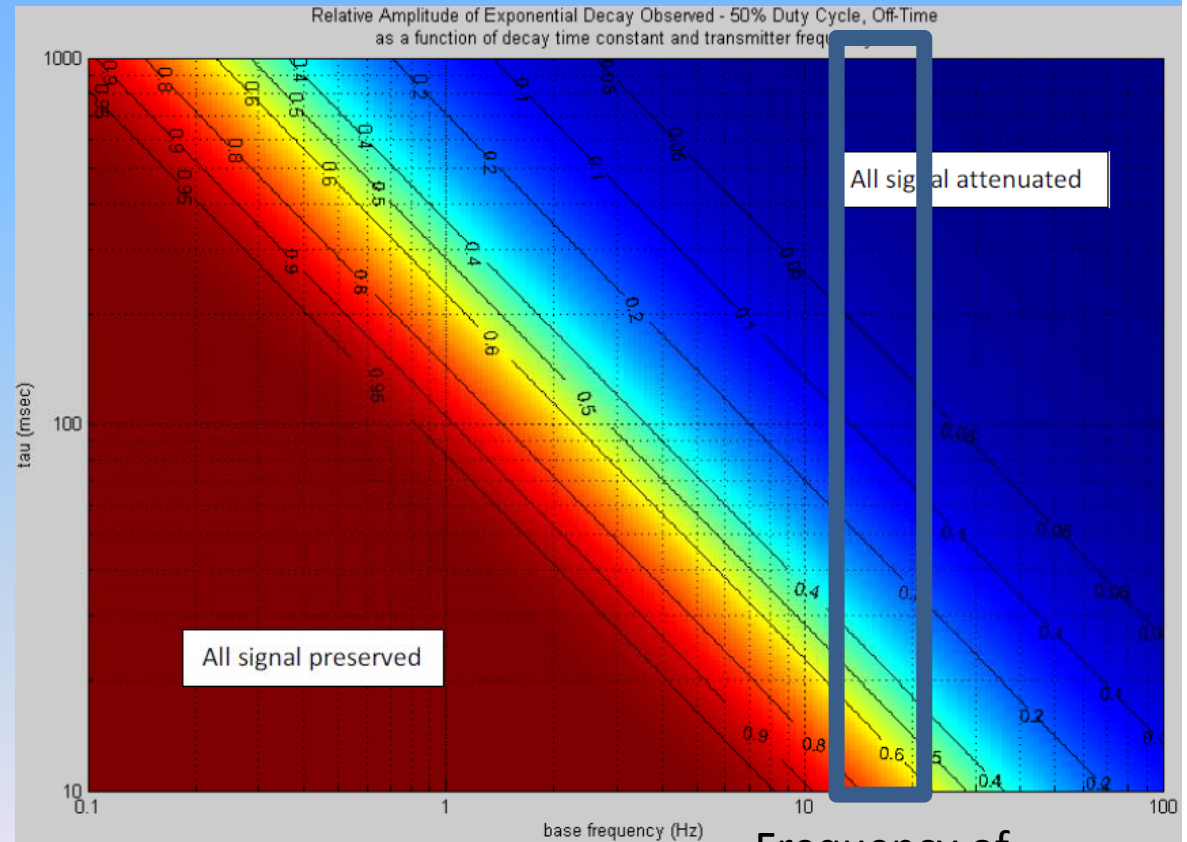


# SIGNAL SOURCES DISCRETE CONDUCTOR HIGHLY CONDUCTIVE TARGETS

– YOU WILL NOT DETECT EVERYTHING

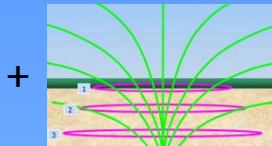
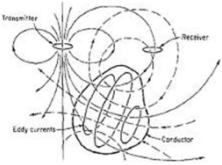
- The Base frequency effects the anomaly amplitude of conductive bodies
- Time constant are underestimated in AEM data
- Targets with high time constant may remain undetected with AEM systems
- On time measurements help

Fortunately most ore bodies have some parts that aren't highly conductive

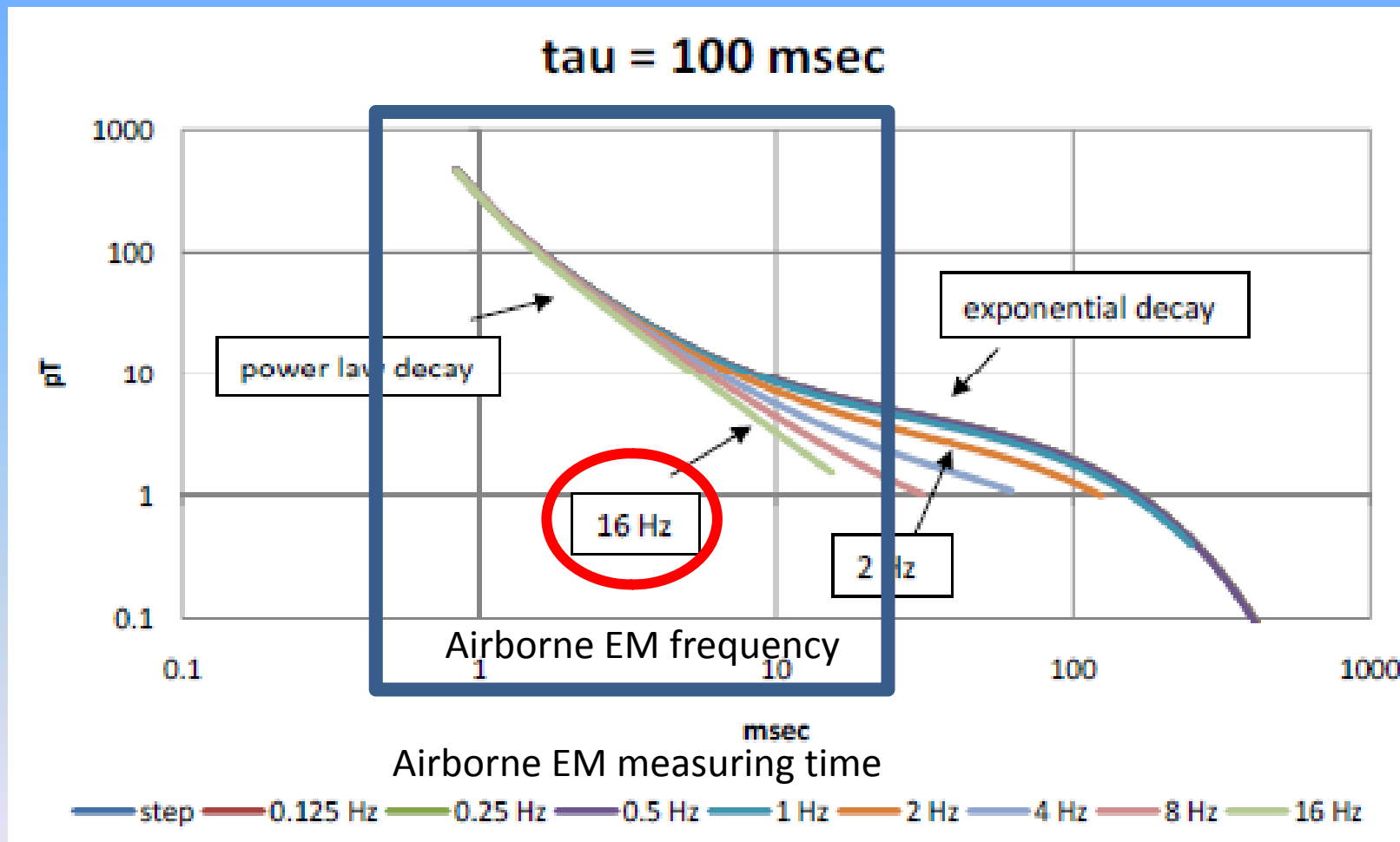


Frequency of  
AEM Systems

t



# SIGNAL SOURCES DISCRETE CONDUCTOR HIGHLY CONDUCTIVE TARGETS



t

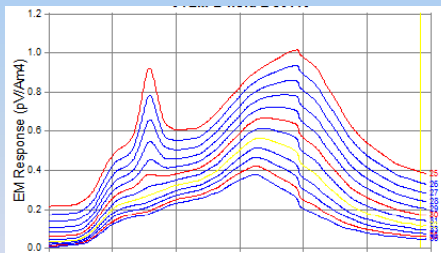
AEM System Frequencies

**SIGNAL SOURCES**  
**DISCRETE CONDUCTOR**  
**HIGHLY CONDUCTIVE**  
**TARGETS**

Early times

- Example of suppression of conductor with high time constant

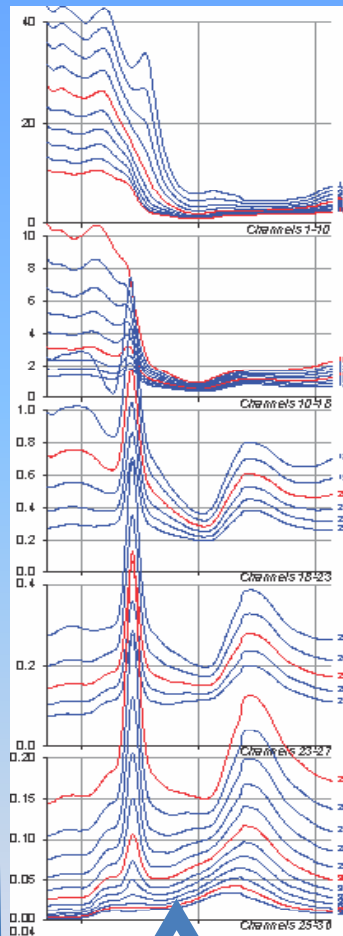
**AEM System**  
**B field calculation**



undetected

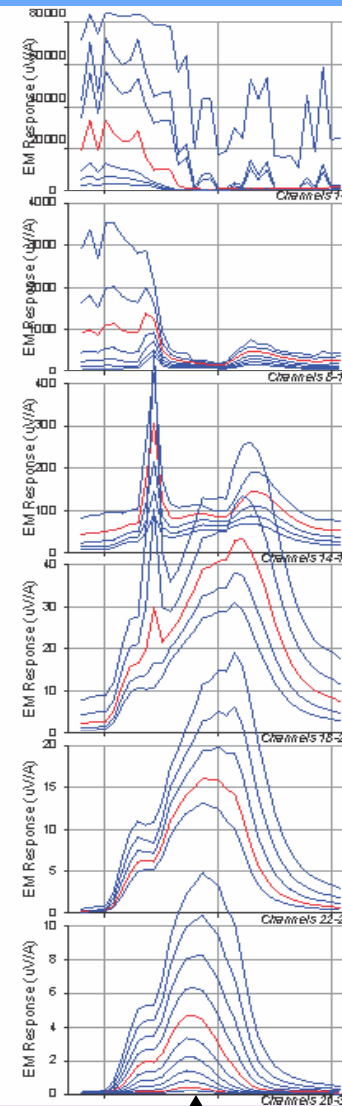
Latest times

**AEM System**  
**dB/dt**



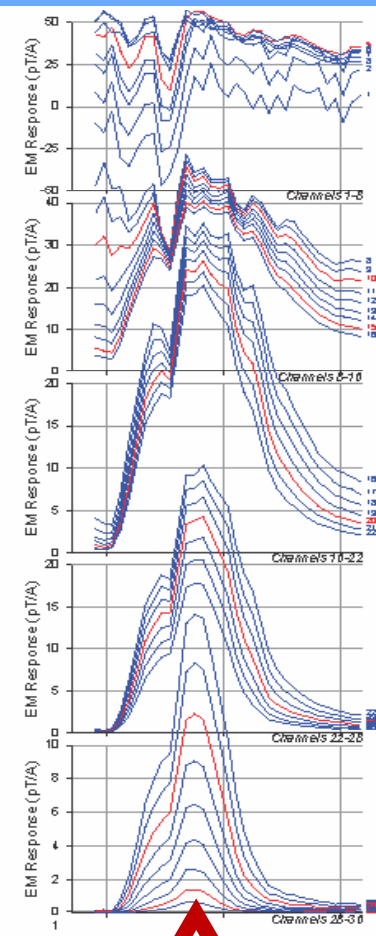
undetected

**Ground Coil**  
**dB/dt**



Detected in late times

**Ground Fluxgate**  
**B field**



dominates all decay

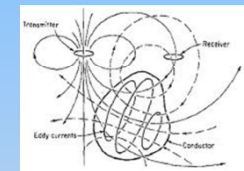
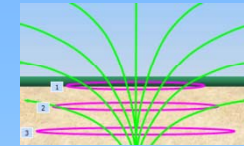
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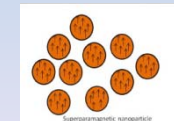
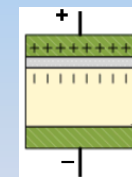
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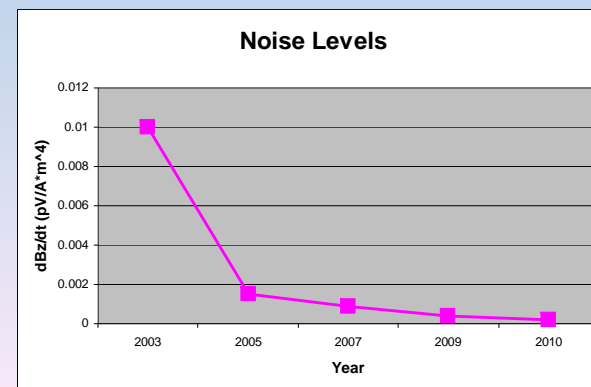
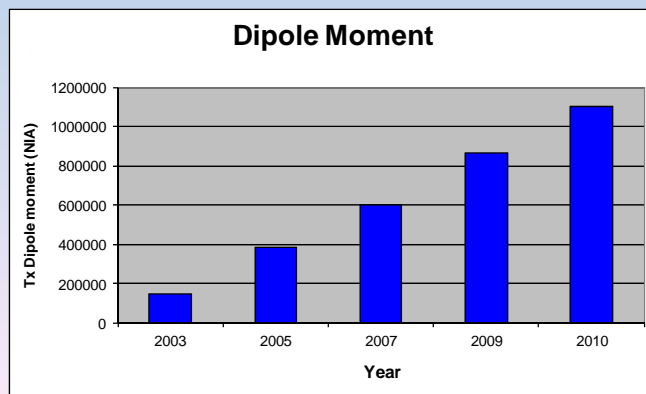
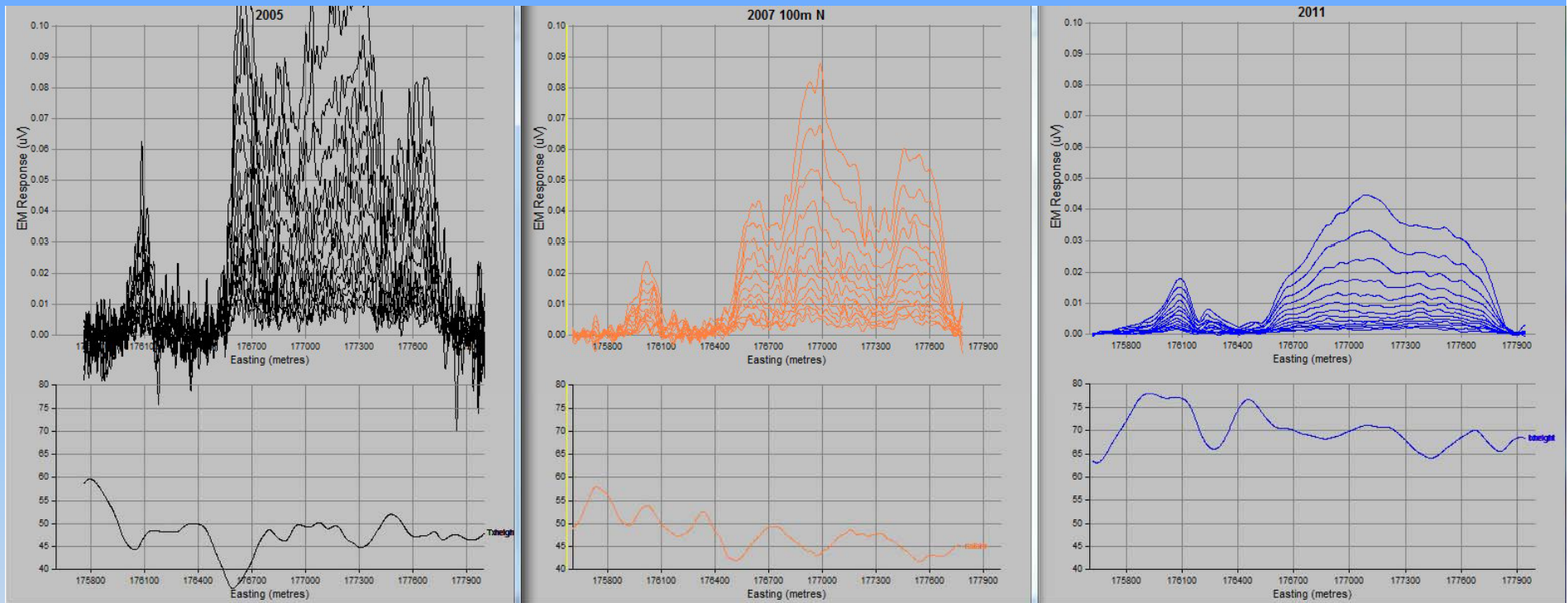


## WHAT WE DON'T WANT

1. **Ground polarisation effects**
2. Superparamagnetic effects
3. Noise (Spherics, Powerlines)



# SIGNAL SYSTEMS SOURCES IMPROVEMENT



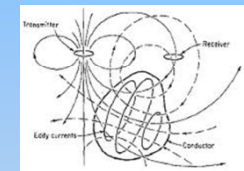
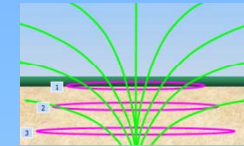
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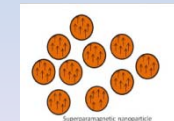
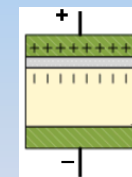
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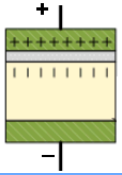
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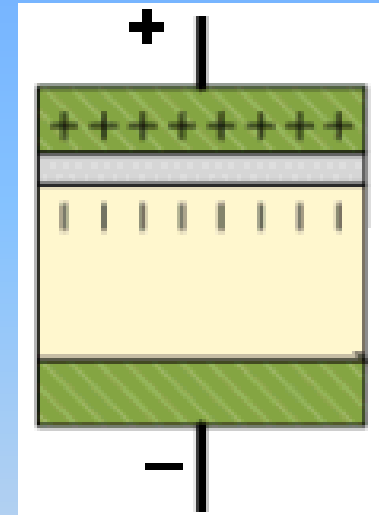


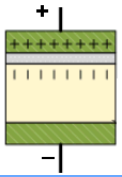
# EM SURVEYING GROUND POLARISATION

Be afraid.....

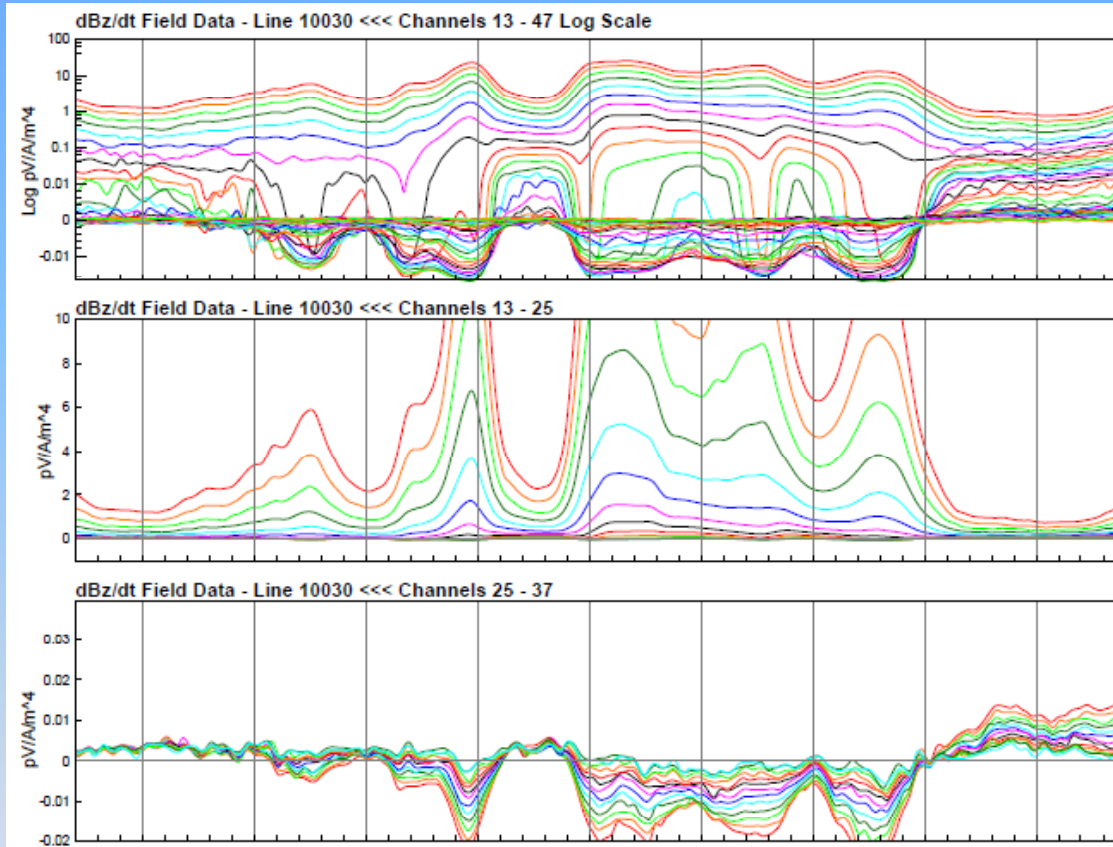
Frequency dependent conductivity variations and IP anomalies

- Caused by the strong electric fields (ie: near surface) from the transmitter loop
  - Electric fields charge up the ground like a capacitor.
  - Like capacitors the ground then discharges
  - In reality a very complex process
- 
- Same parameters as measures by IP surveys
  - Causes are most commonly clays, graphitic units, faults, and (uncommonly) disseminated sulphides
  - Complex anomalies from even simple geometries. Cannot be intuitively interpreted.
  - Easily identified as negative anomalies but these may not be present or may be offset from source.
  - Very difficult to model using any software.
  - Particularly dominating of signal in resistive areas.





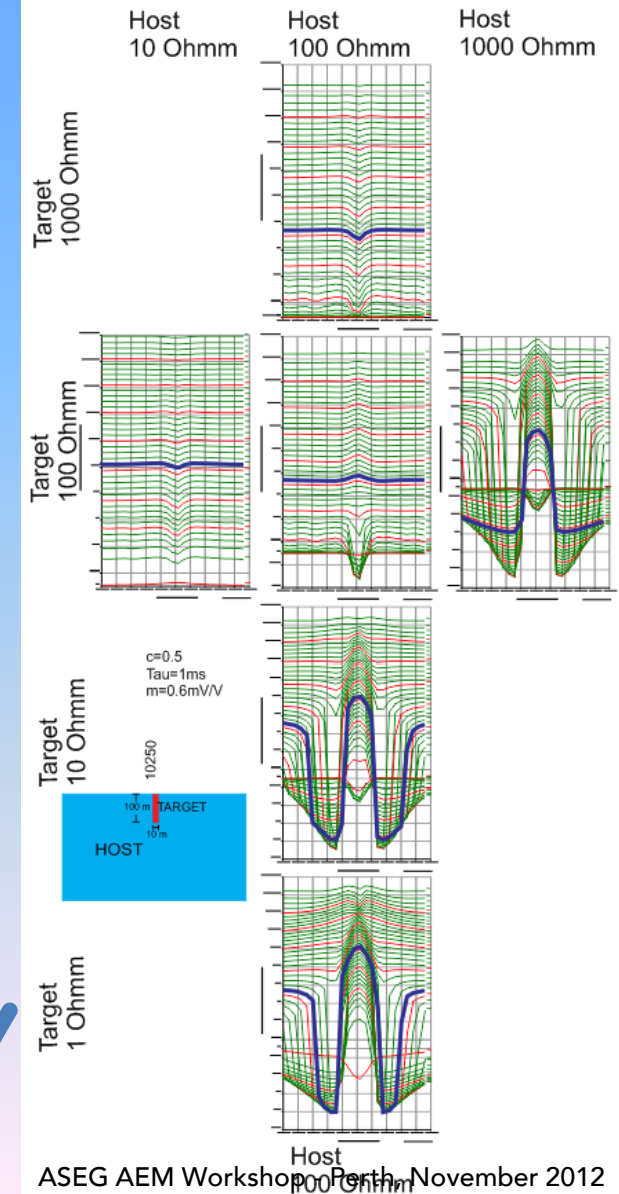
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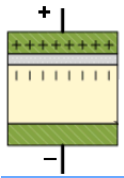


500m

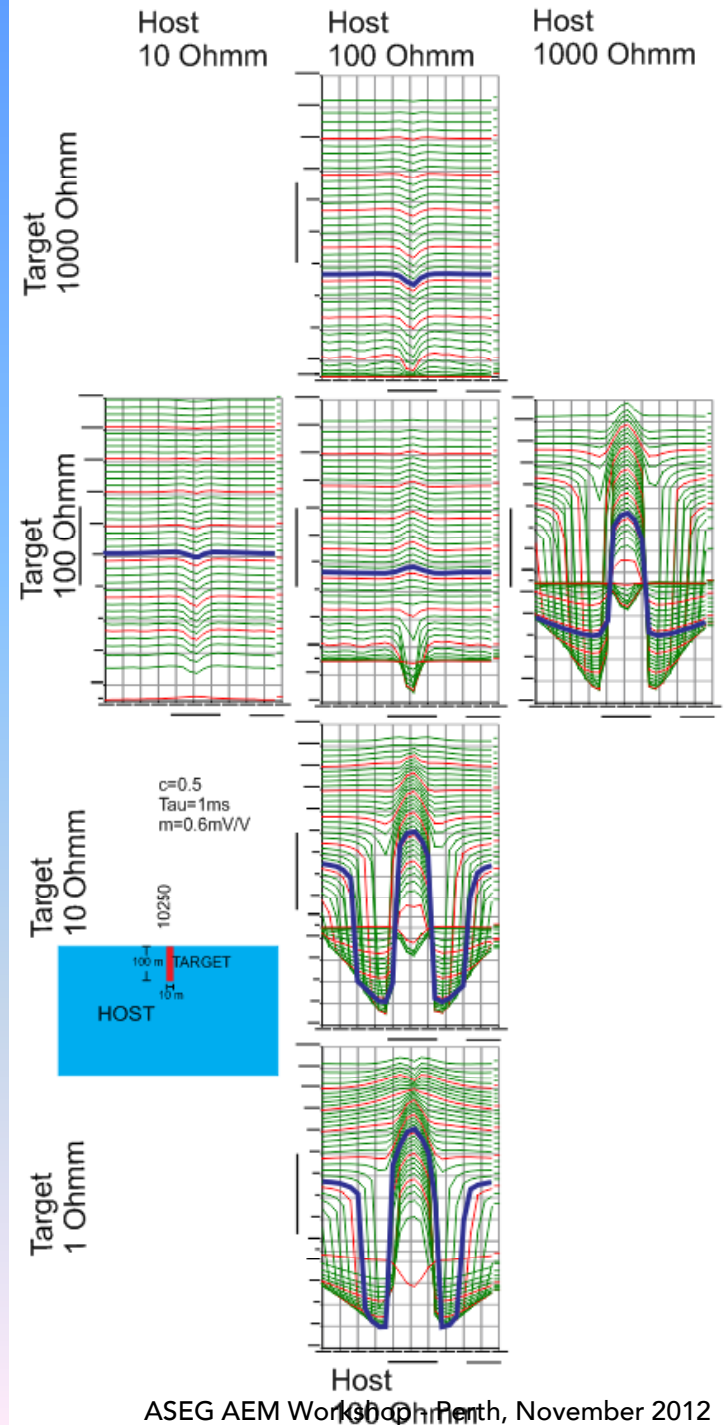
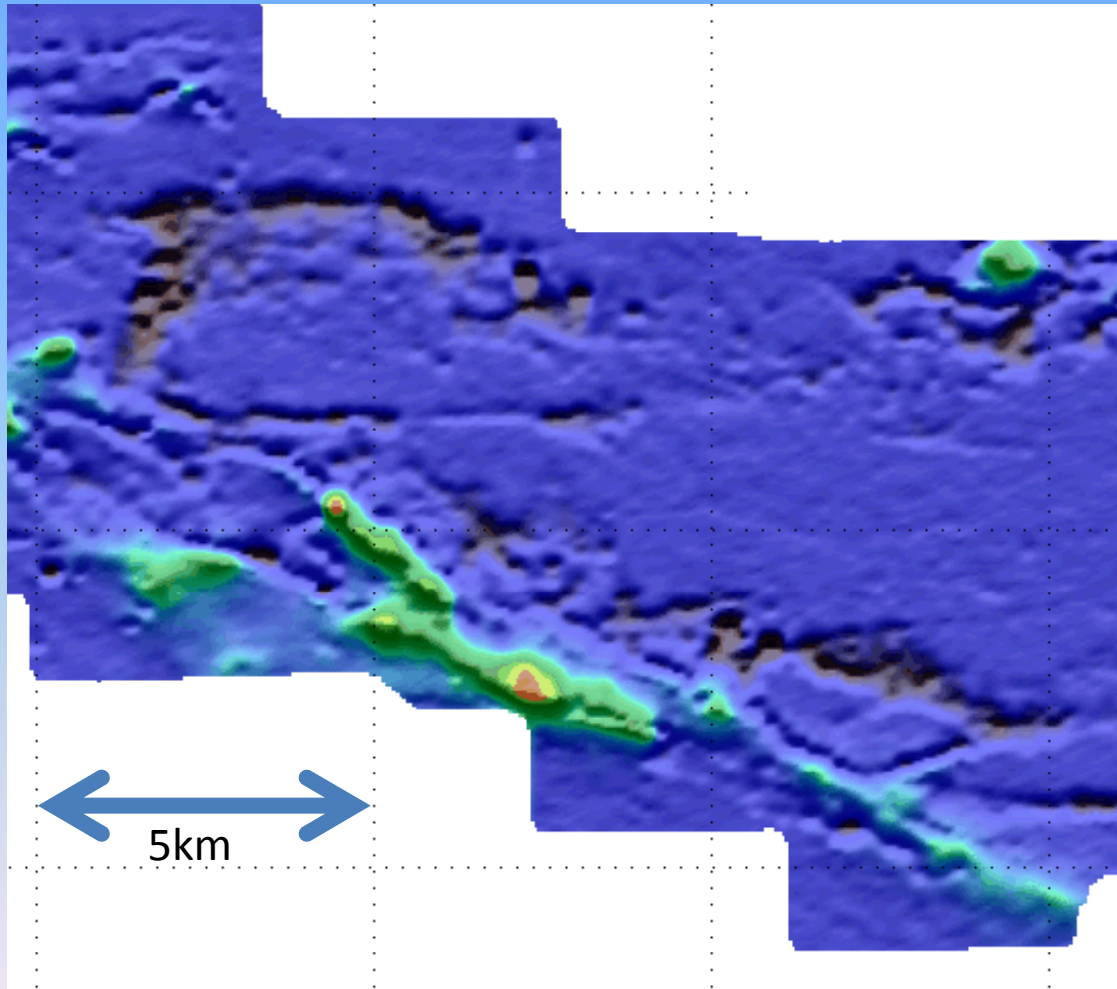
Increasing Conductivity of Chargeable body

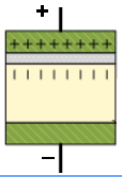
Increasing Conductivity Host



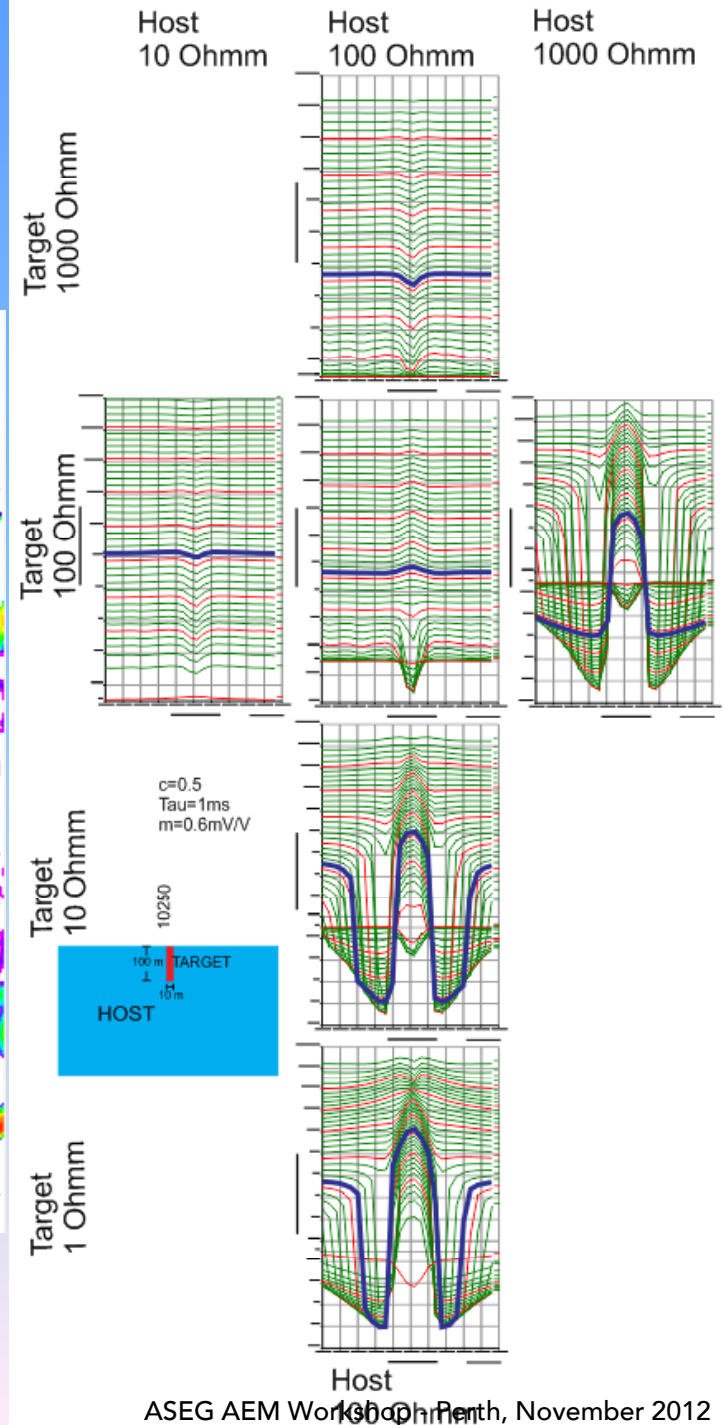
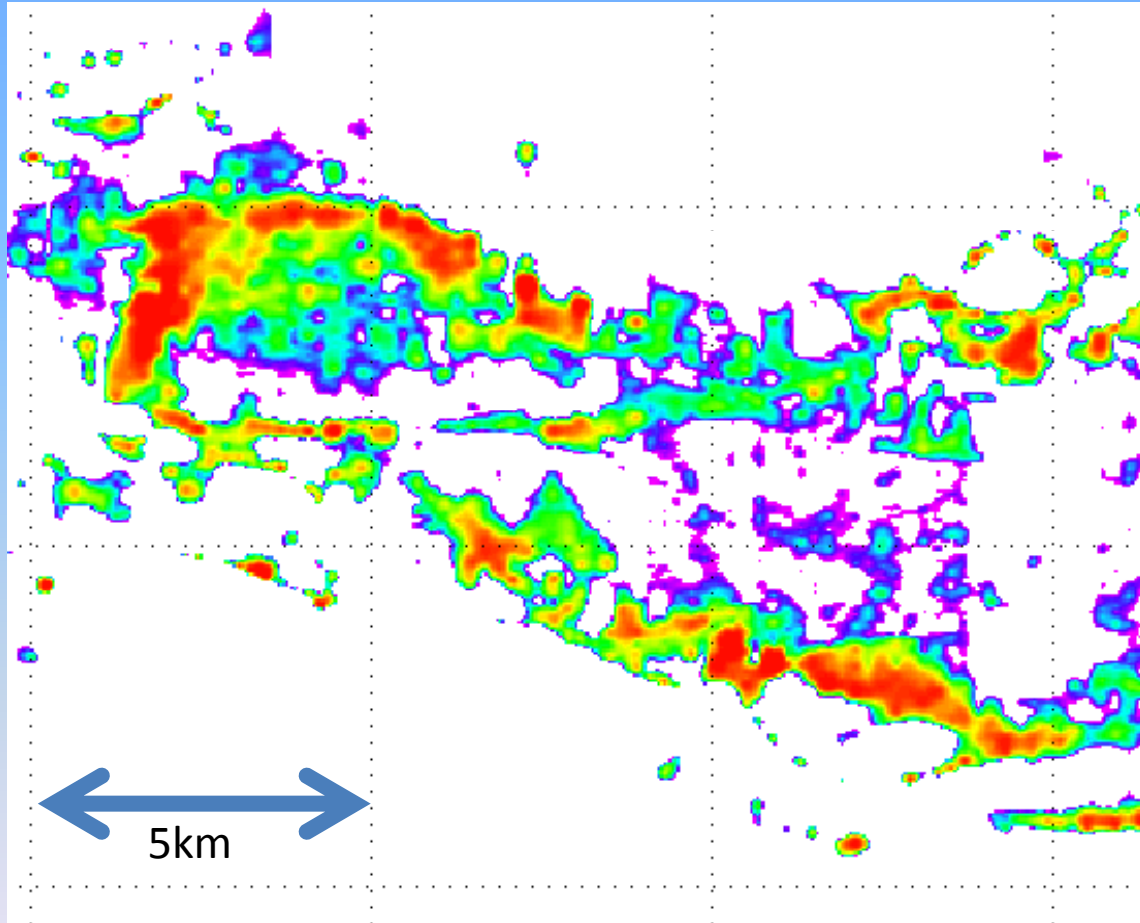


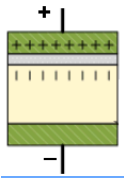
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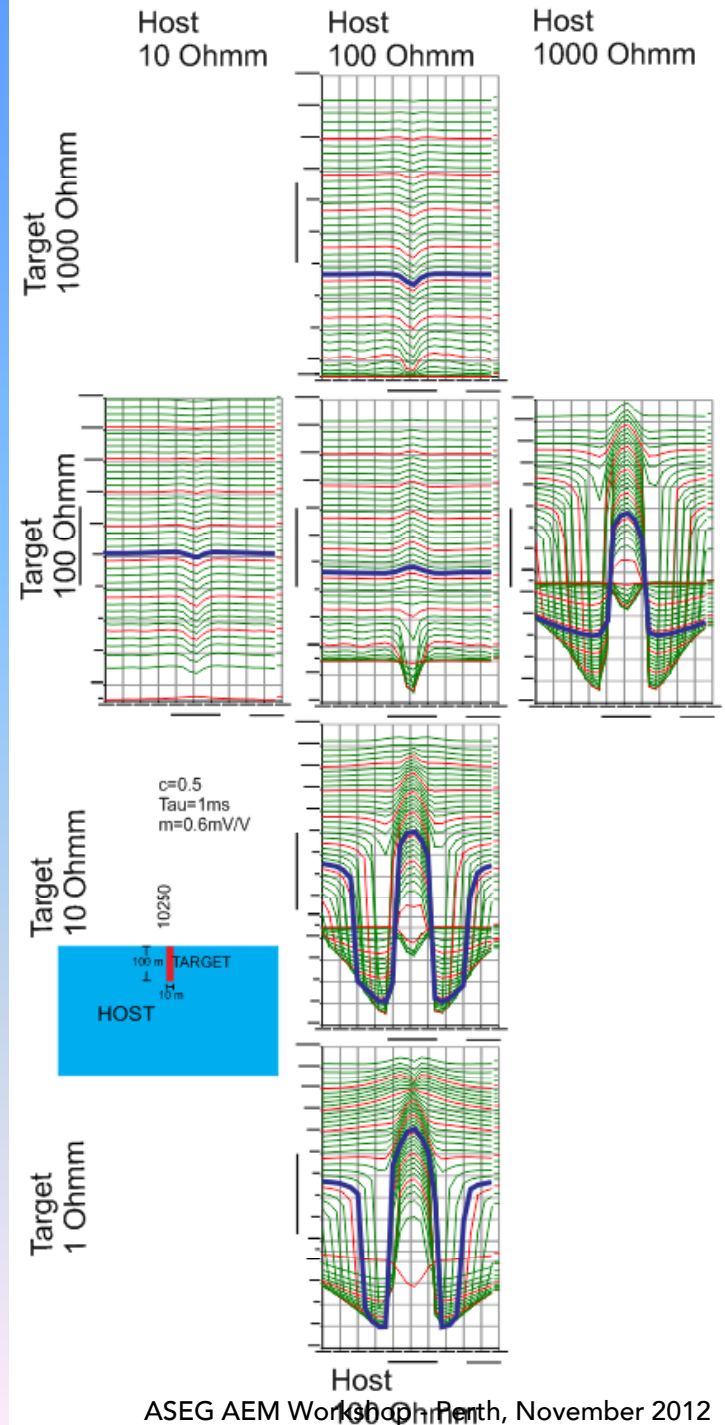
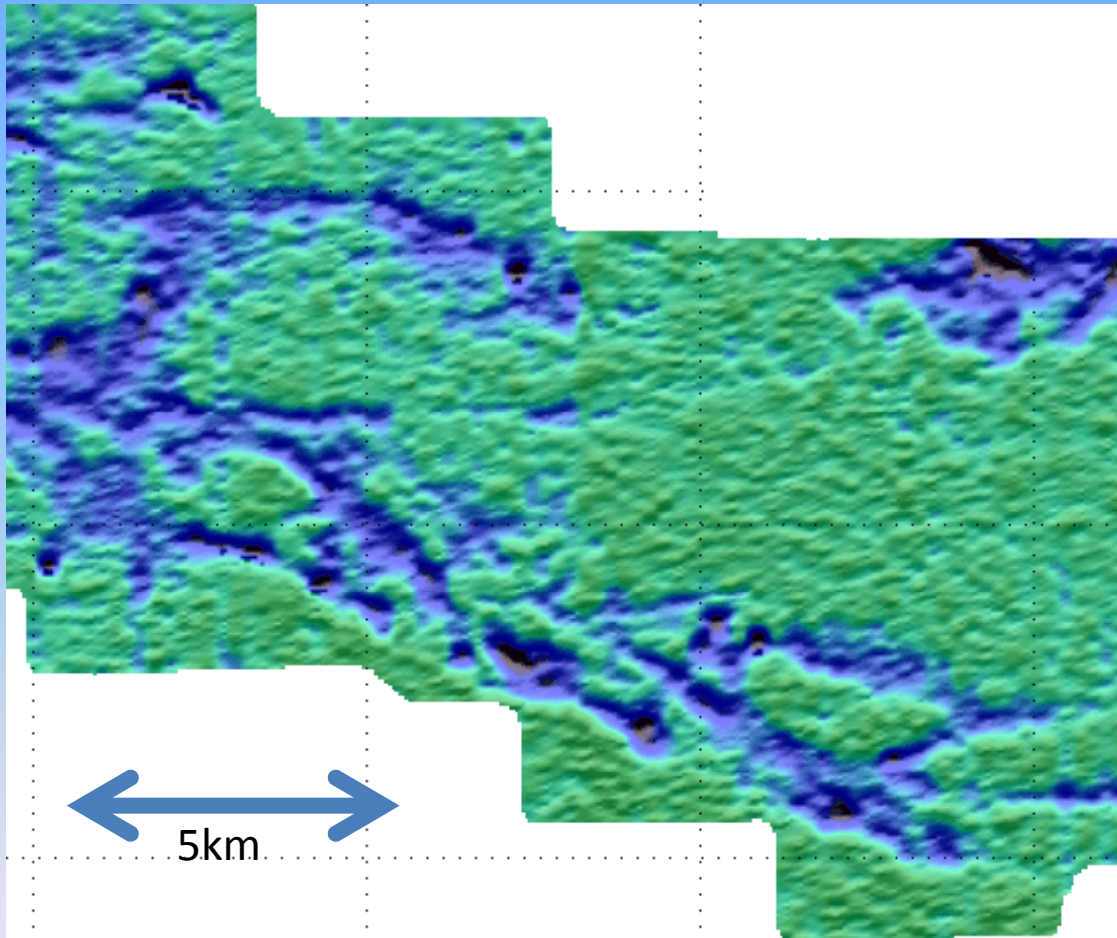


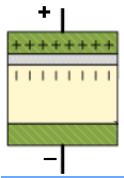
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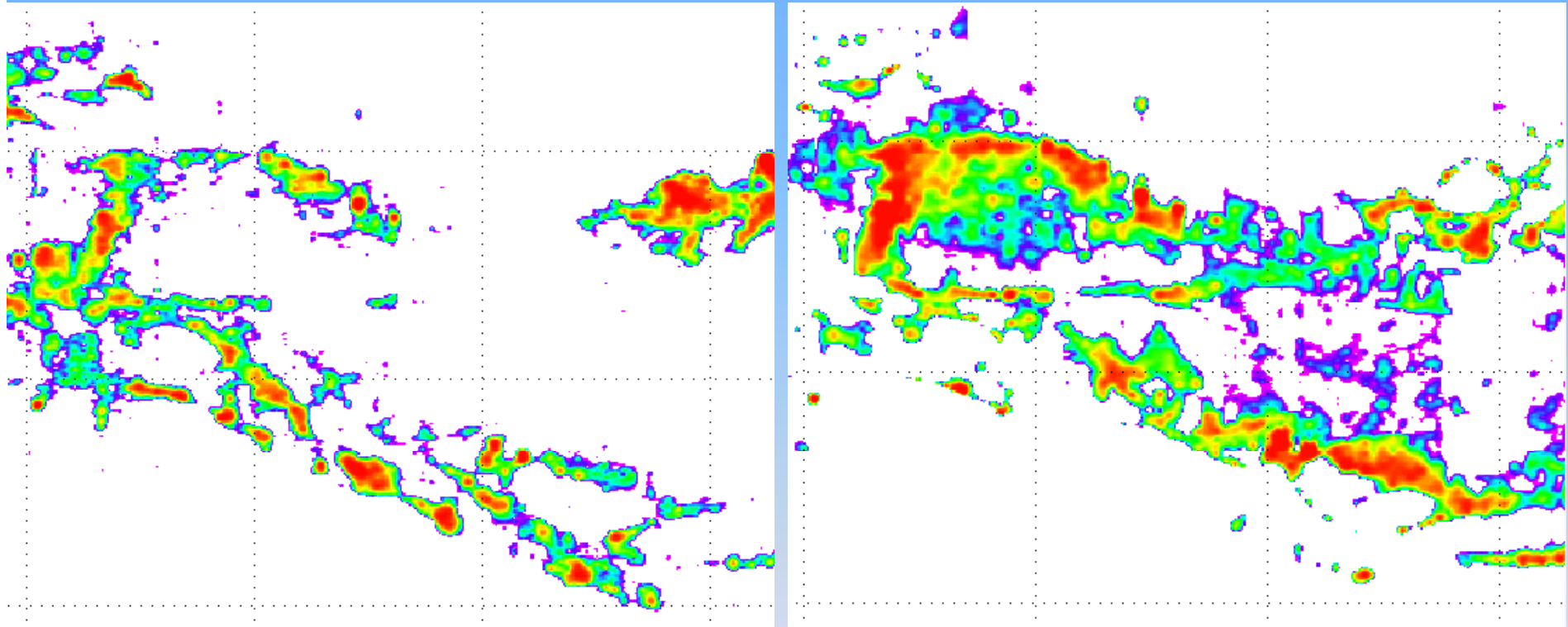


# EM SURVEYING GROUND POLARISATION





# EM SURVEYING GROUND POLARISATION



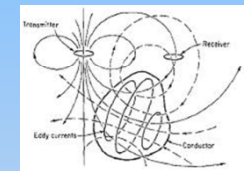
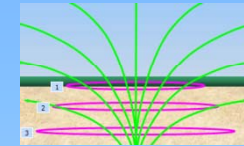
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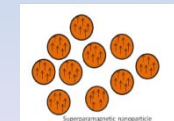
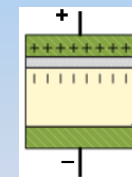
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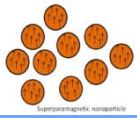
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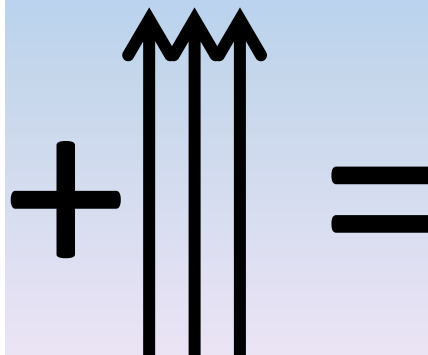
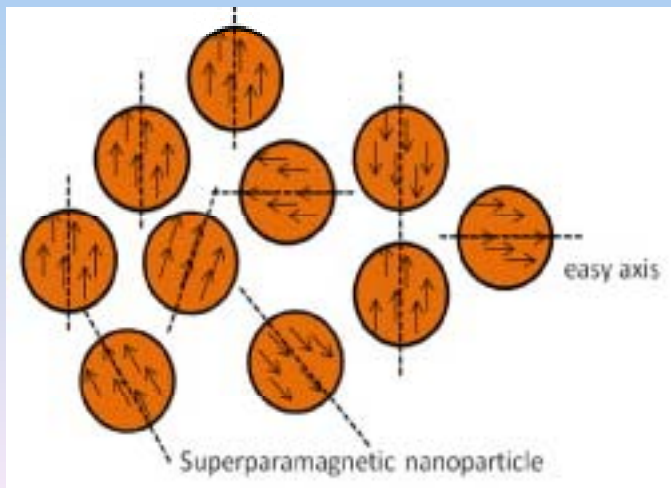


# EM SURVEYING SUPERPARAMAGNETISM

aka. “SPM” or “Magnetic Viscosity”

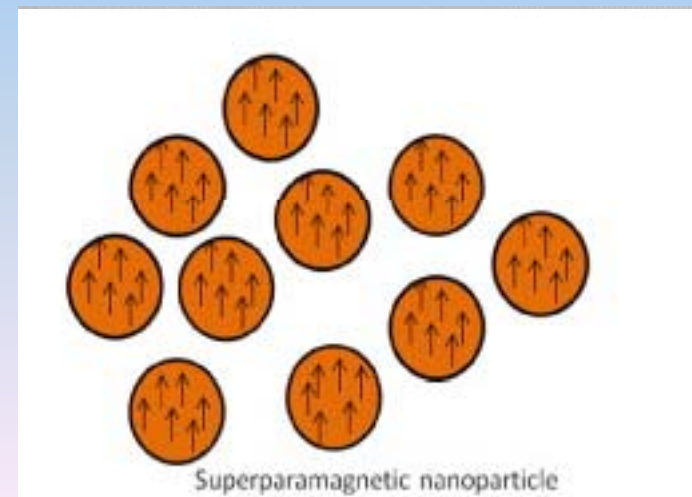
- Magnetic state of very fine grained iron oxides. Normally they are what we commonly call non-magnetic.
- Detectable by systems with very high signal and low noise (VTEM, Helitem, Spectem)
- Caused by the transmitters strong magnetic field briefly aligning the magnetic particles creating a “secondary field” which then decays when magnetic field is turned off.
- Key difference between decays is the decay rate (“Power Law” vs “Exponential” decay)

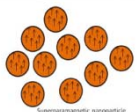
No applied field



Strong Magnetic  
field

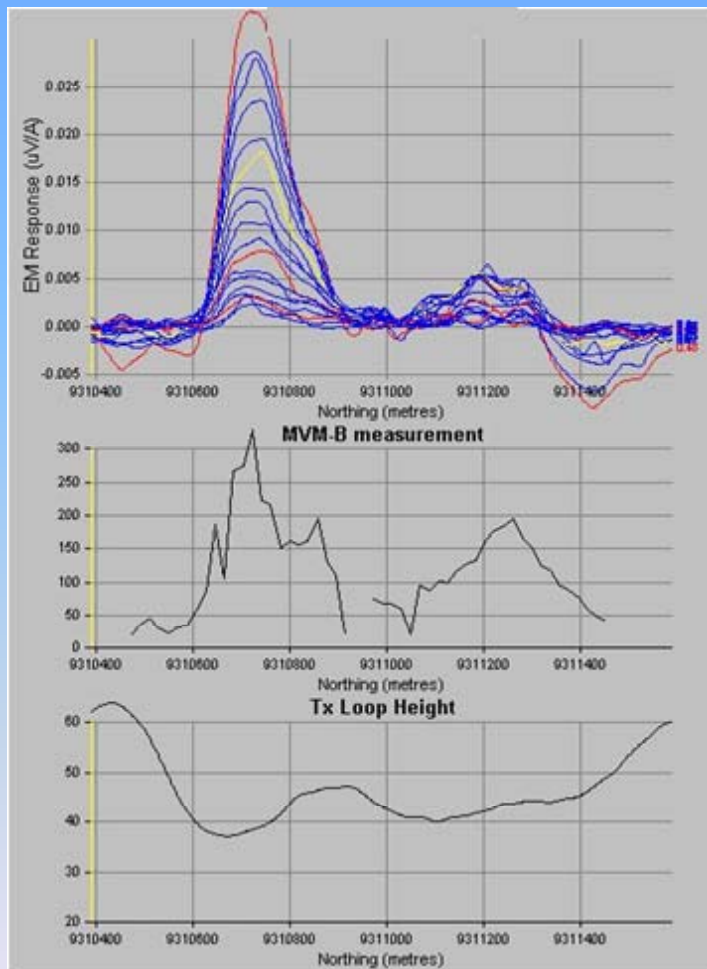
With applied field





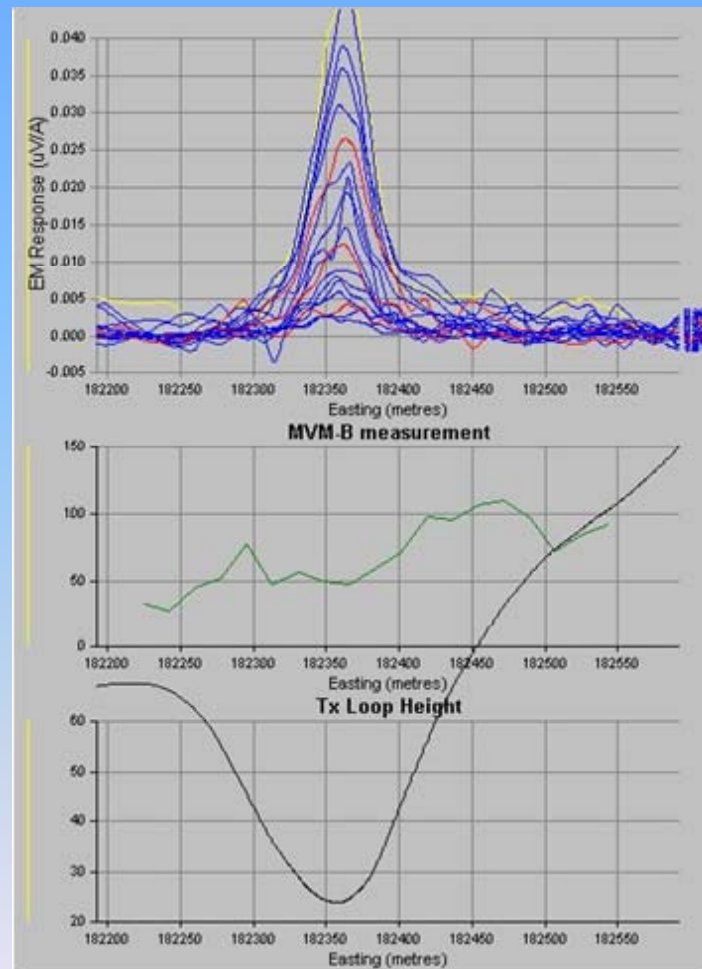
# EM SURVEYING SUPERPARAMAGNETISM

Late time AEM data  
Soil measurement  
Flying height

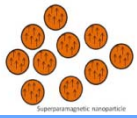


AEM Anomaly due to SPM anomaly

Late time AEM data  
Soil measurement  
Flying height



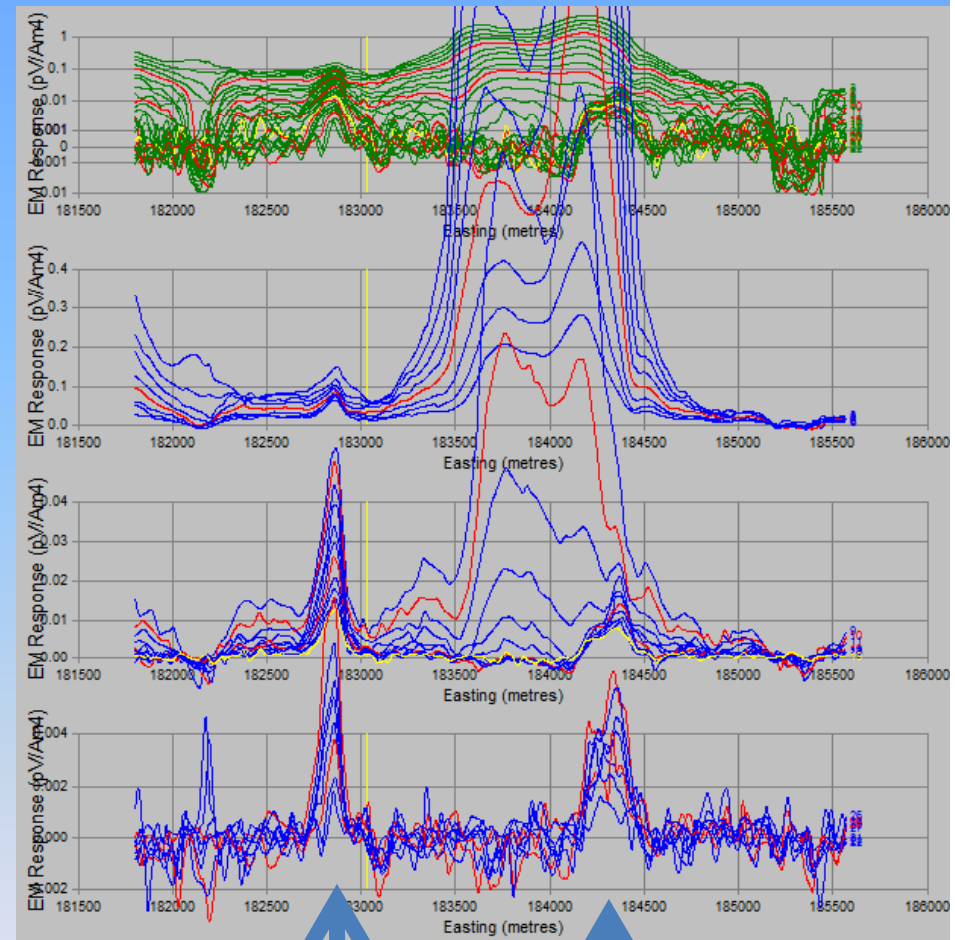
AEM Anomaly due to low flying height  
over ground with moderate SPM



# EM SURVEYING SUPERPARAMAGNETISM

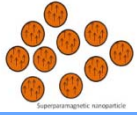
## BAD NEWS

- Anomalies often have similar sizes and shapes as orebody signatures
- Difficult to identify decay type in AEM data



Real  
conductor  
100m deep

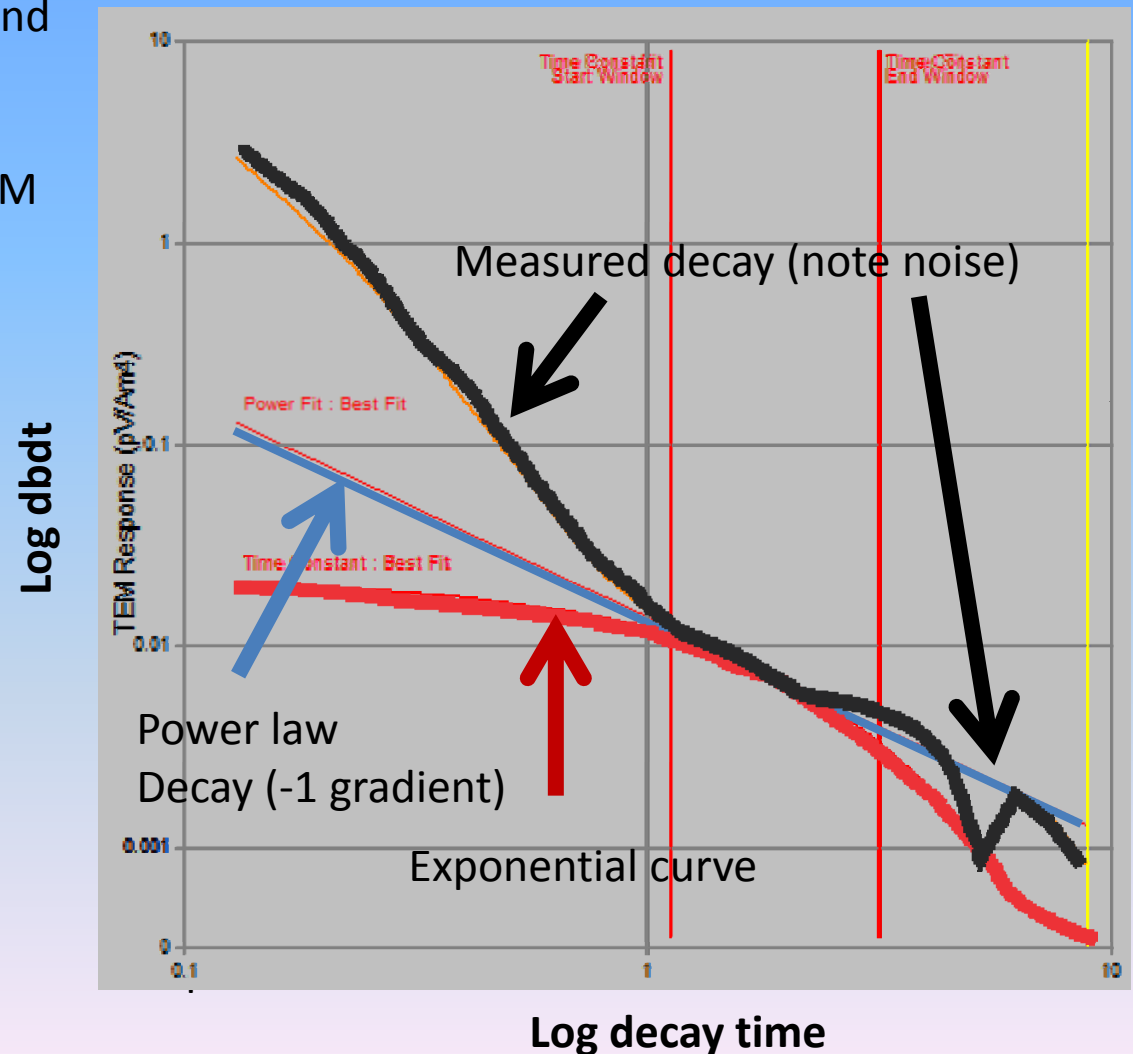
SPM at surface



# EM SURVEYING SUPERPARAMAGNETISM

## BAD NEWS

- Anomalies often have similar sizes and shapes as orebody signatures
- Difficult to identify decay type in AEM data





# EM SURVEYING SUPERPARAMAGNETISM

## BAD NEWS

- Anomalies often have similar sizes and shapes as orebody signatures
- Difficult to identify decay type in AEM data (high base frequency)

## GOOD NEWS

- Easy to confirm with ground EM measurements
- Can be normally quickly and cheaply confirmed with soil measurements (unless deep source such as palaeochannel)



Sample Sensor



Field Sensor



Core Probe Sensor



Data Acquisition Unit

# ACKNOWLEDGEMENTS

- Ken Witherly (Condor Consulting)
  - Jim Macnae (RMIT)
  - Andrew Duncan (EMIT)
  - Jean Legault (Geotech)
- + Many people who kindly paste info on the net!