MT Acquisition Best Practices: Survey Design and Field Procedures

Alan G. Jones

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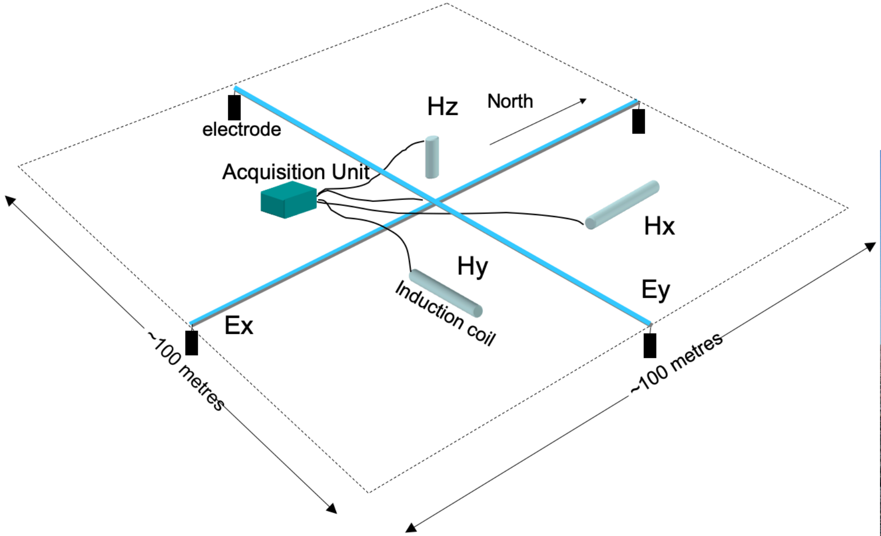

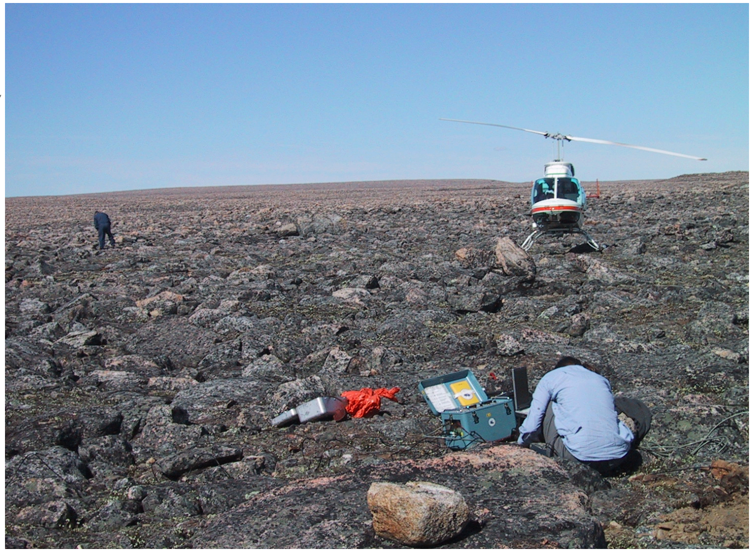

Take-away message

It all begins in the field!

…and there is a lot of lore (and some fables) about best practice!

The common truth though is that if you collect poor quality data you will be fighting to improve it in the lab through processing, then suffer the consequences during analyses and inversions, and end up with a model with poor resolution.

You will spend 10x as much time in the lab as it would have cost to collect higher quality data by taking your time in the field and being more focussed on quality acquisition.

I have seen poor data acquired particularly by academics. Generally, the major MT contractors do a consistently better job.

Survey Design

Overarching question is:

- Why are you doing the survey???
  - Before you go into the field spend time thinking about this.
  - The answer to that question defines the instruments to use, the station spacing, the frequencies of primary interest, recording time, recording time of day, etc.
- Theoretical aspects
  - many of which you can control
- Practical aspects
  - some of which you have less (or no) control over

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Survey Design – Theoretical aspects

<u>From an academic perspective:</u>

- What overarching question are you trying to address? (Usually articulated in your proposal for funding.)

<u>From an exploration perspective:</u>

- Do you wish to <u>detect</u> or <u>delineate</u>?
  - Detect: As few stations as necessary
  - Delineate: As many stations as you can afford! *(Perhaps don't need all 5 components?)*
- If going into brownfields area, you know a lot about the likely conductivity structures…
- If going into a greenfields area, you know a lot about the <u>types</u> of structures you want to find…
  - Size of deposit
  - Deposit target/rocks
  - Host rocks

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Survey Design – Theoretical aspects

MT is an awful lot easier than CSEM for Survey Design. You don't have to think about the source (unless you are in auroral or equatorial regions).

Undertake a theoretical design study to assess:

1. Frequency range of measurements to optimally image your "target"
    - Are the AMT or MT deadband responses crucially important to detection/resolution?
    - What is the lowest frequency (shortest period) that you need? → time of acquisition
2. Station spacing
    - Wide spacing for detection. Tight spacing for delineation
3. Types of measurements to make
    - Do you need all 5 components, or is it sufficient to measure only inline-E fields (EMAP or MIMDAS or Titan24) for example?

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Audio-magnetotellurics (AMT) for steeply-dipping mineral targets:

Importance of multi-component measurements at each site

Alan G Jones

Geological Survey of Canada

Gary McNeice

Geosystem Canada

Society of Exploration Geophysicists 72nd Annual Meeting

Salt Lake City, October 6-11, 2002

Objective

Understand the response to a typical Canadian ore body in terms of EM *fields*, rather than in terms of *responses*

Efficient and effective survey design

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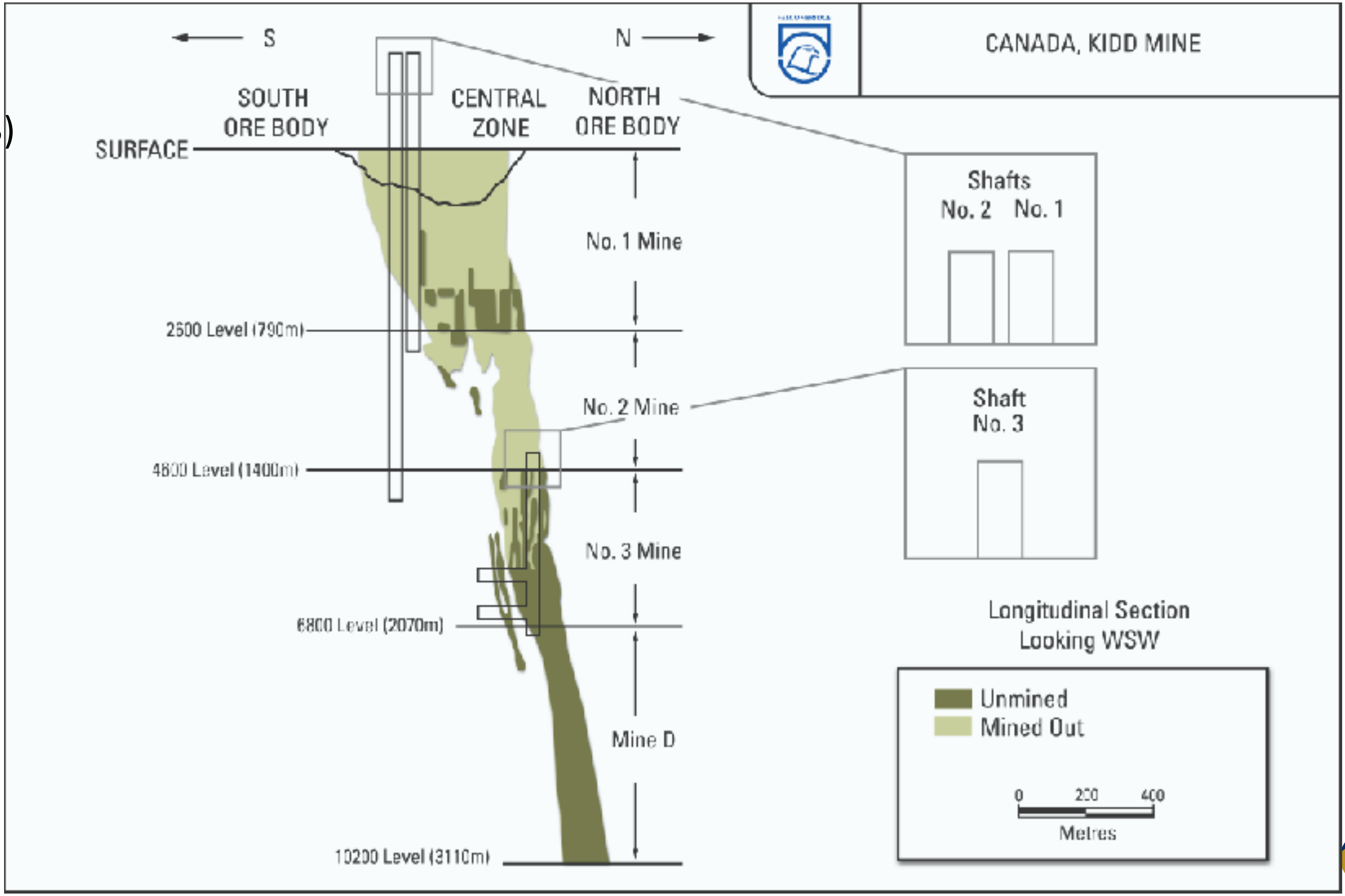
Representative Body: Kidd (Creek) Mine (world's deepest Cu-Zn-Ag mine)

Image taken from Falconbridge's web site in 2002

One of the world's largest VMS deposits

Falconbridge
→ Xtrata (2006)
→ Glencore (2013)



The bottom of No.4 shaft at Kidd Creek Mine D is 3,012 m below the surface, 2,733 m below sea level, currently the deepest accessible non-marine point on Earth.

(Deeper mines in S.A., to 4 km, but they start from ca. 1,500 m.)

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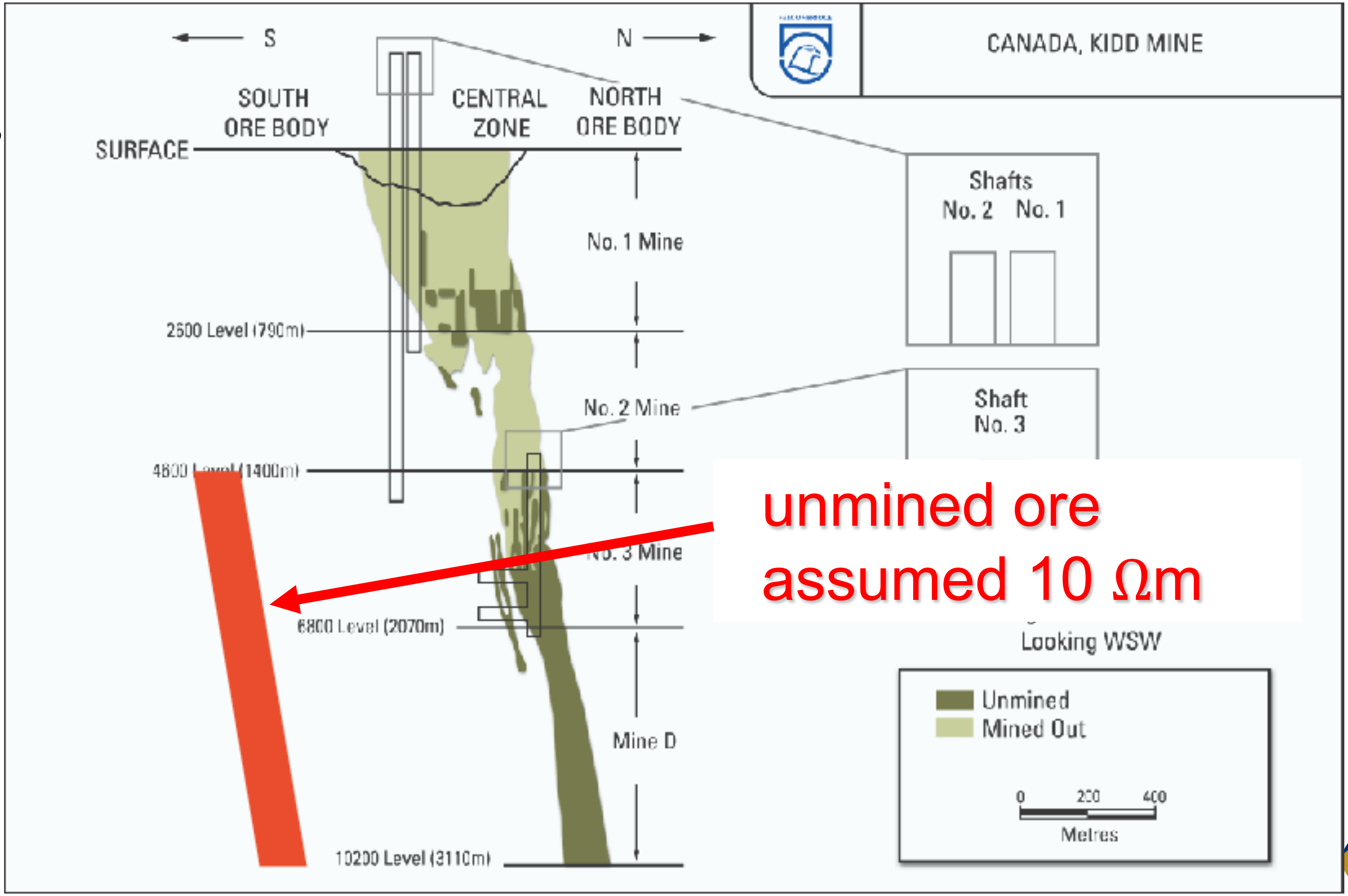

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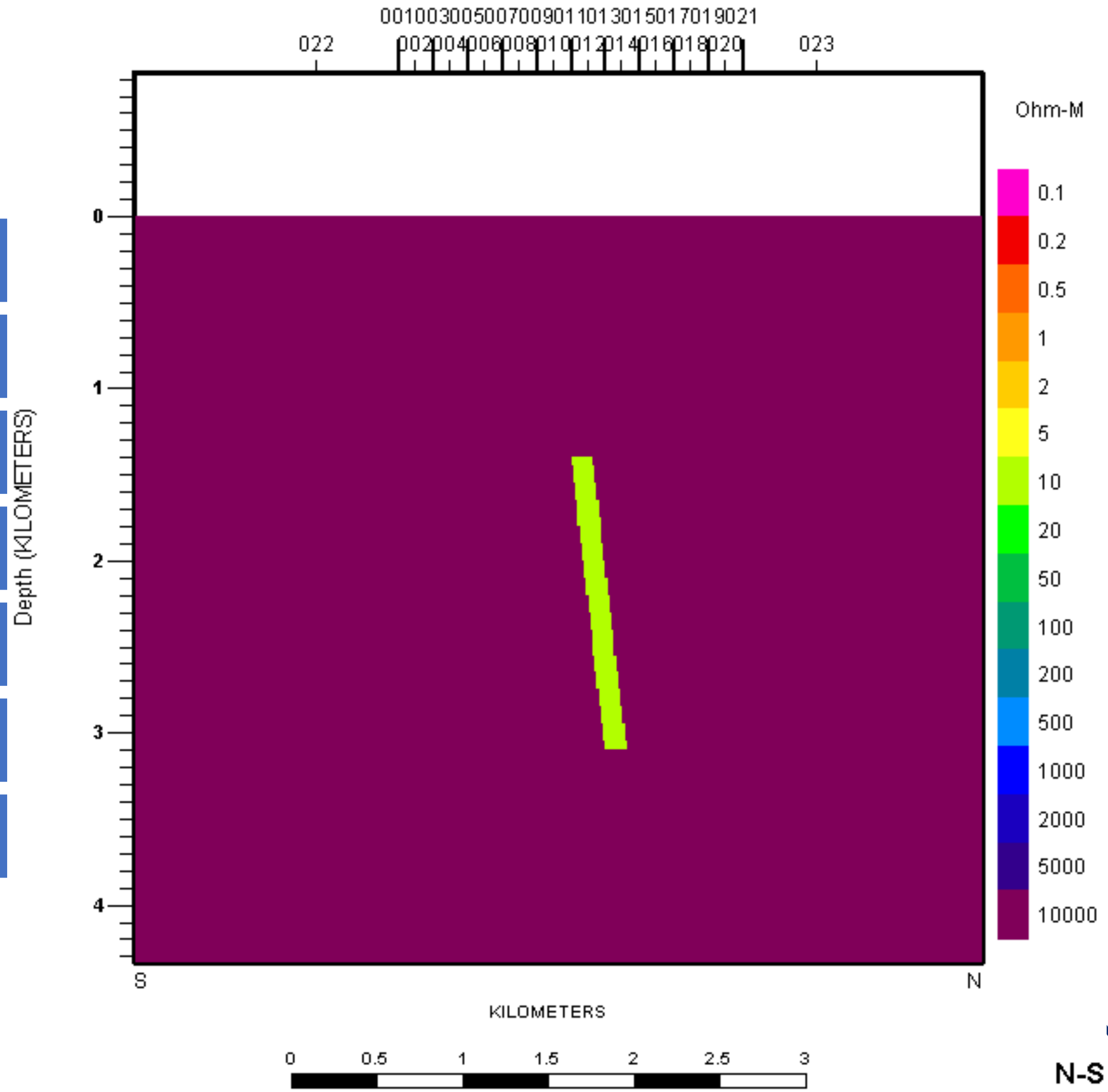
Numerical 2-D model: Kidd Creek

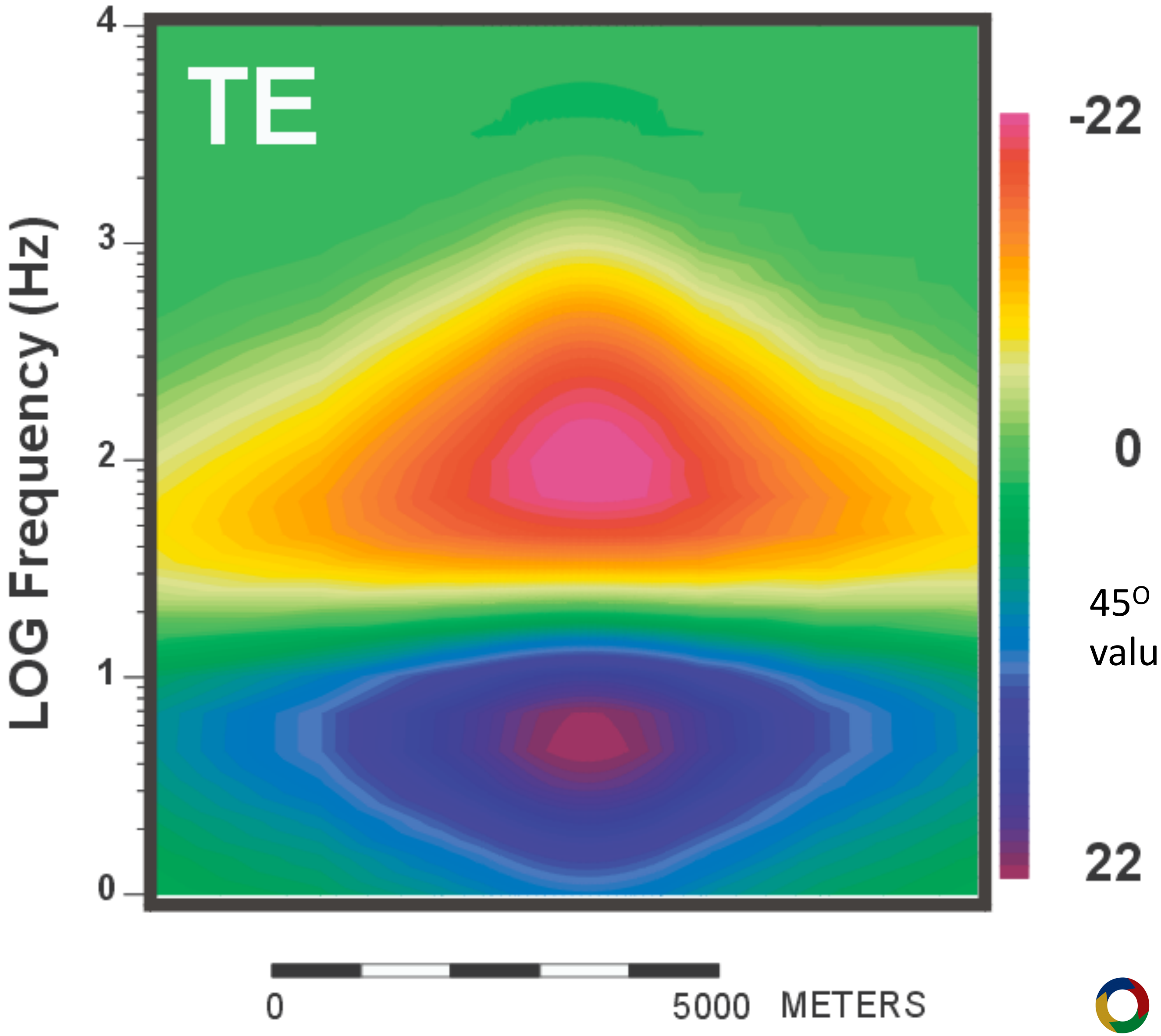
- Body:10 Ωm
- top: 1.4 km
- bottom: 3.1 km
- width: 100 m
- dip: 83°
- Host: 10,000 Ωm
- Sites: 100 m spacing



MT responses: TE phases

Strong (symmetric) TE response to the body

A -22° anomaly at 100 Hz and a +22° anomaly at 6 Hz



45° half-space value subtracted

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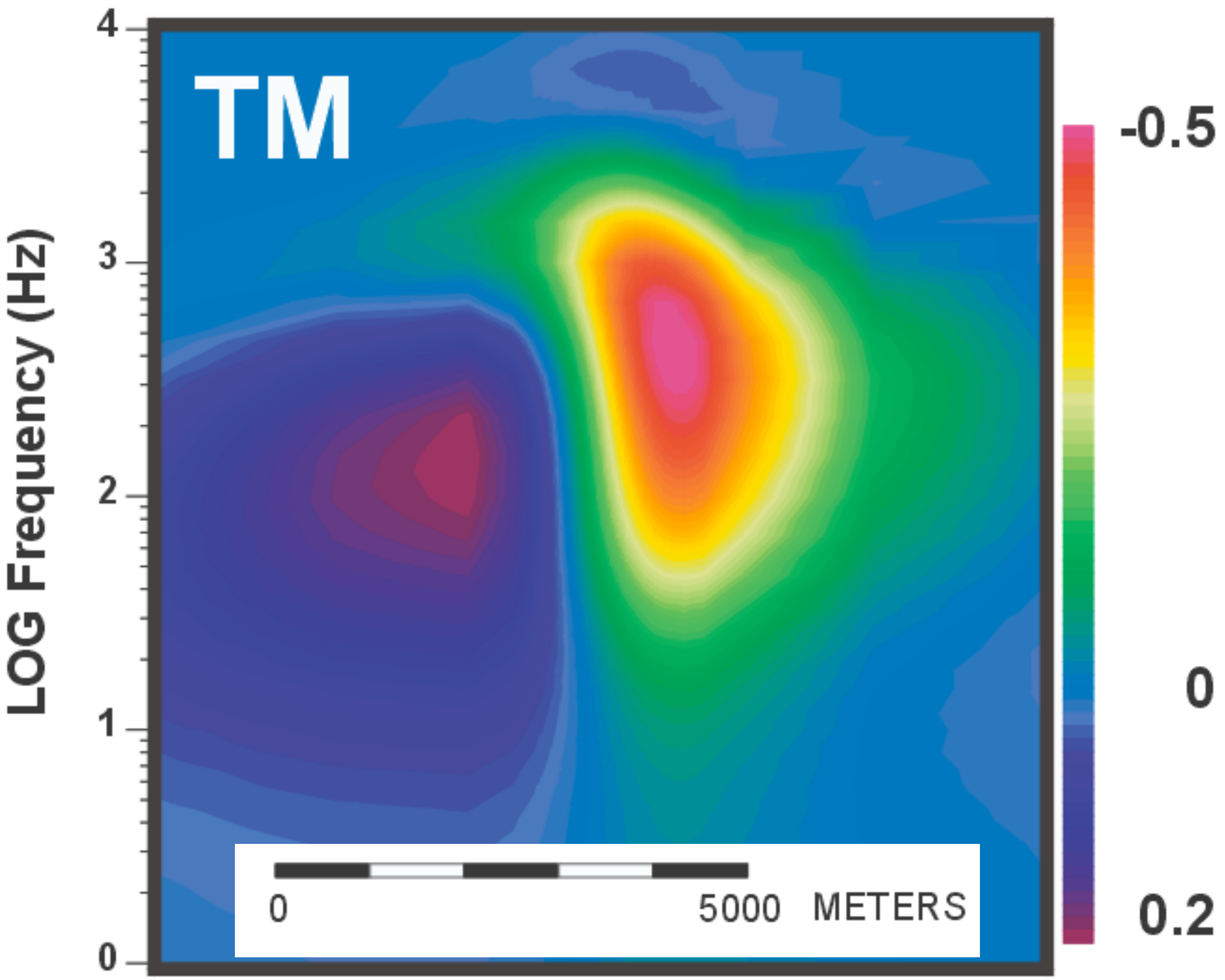
MT responses: TM phases

VERY weak (asymmetric) TM response to the body

A –0.5^{O} anomaly at 600 Hz and a 0.2^{O} anomaly at 150 Hz

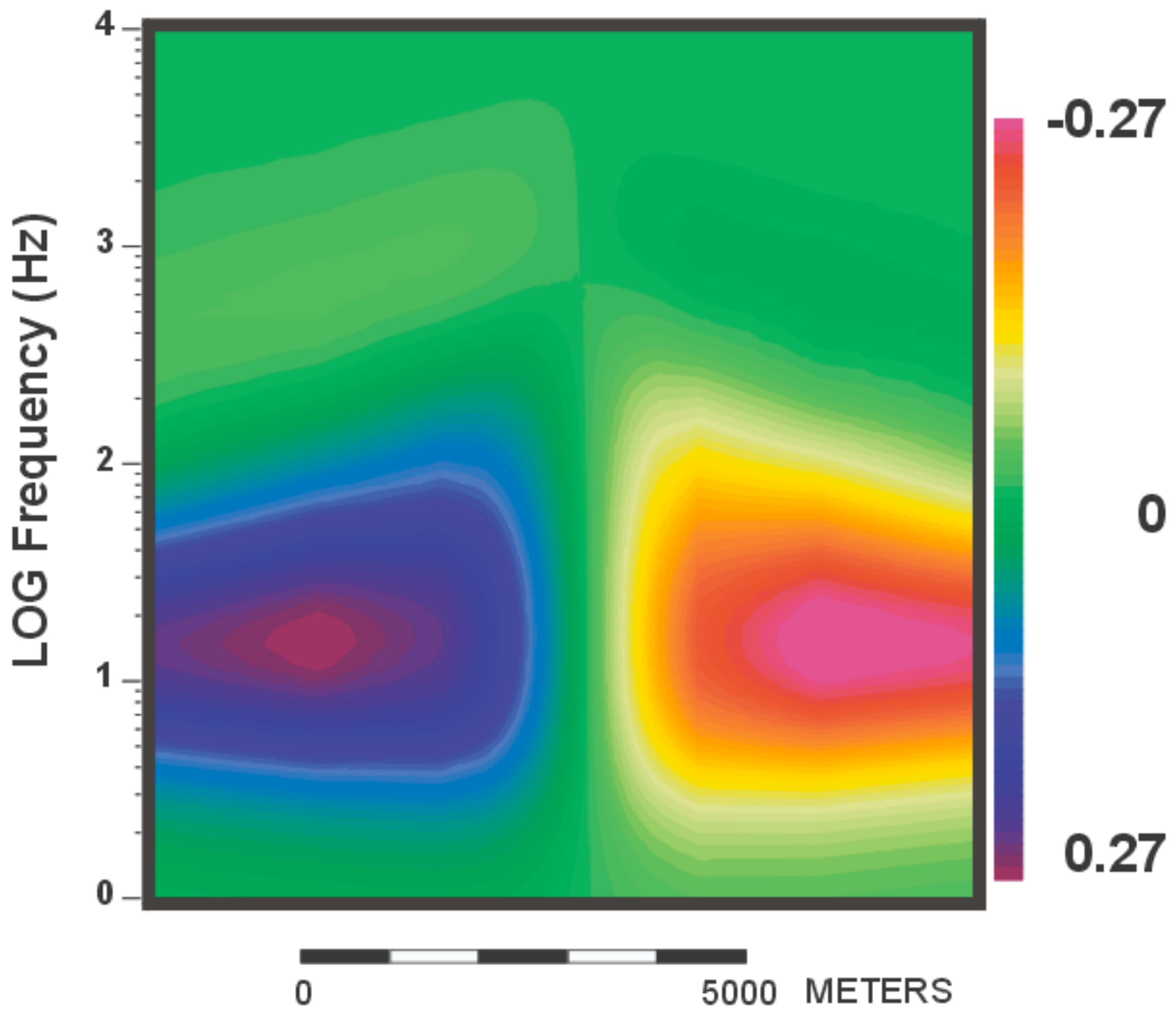


-> In-line E-fields (EMAP-like) insensitive to body!

TF responses: TZ-Real

Strong (symmetric) tipper response

A ±0.27 response at 20 Hz at distances of 2.5 km from the body

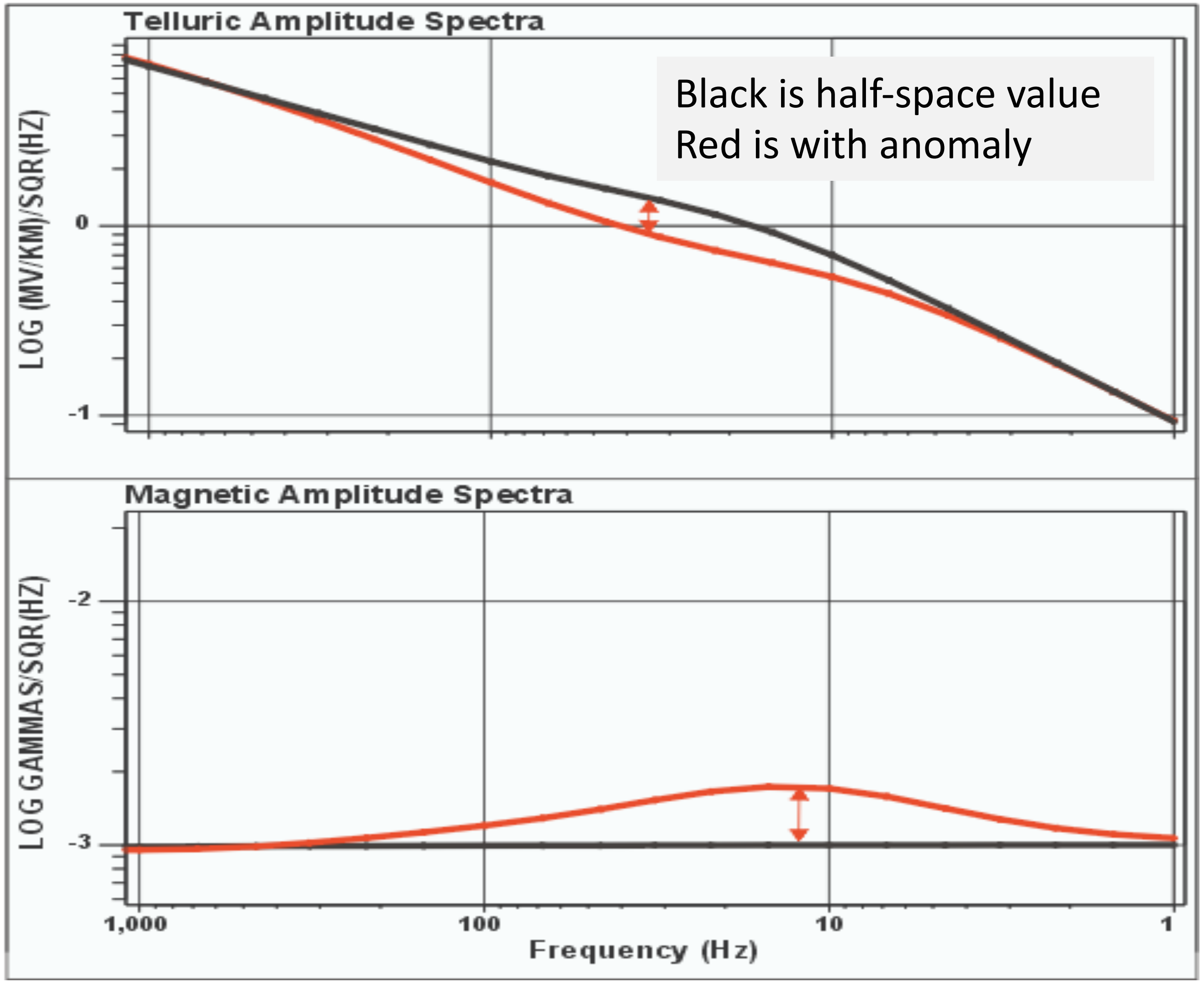


-> *Superior lateral sensitivity than in TE responses!*

TE fields at central site

Parallel E-field (Ex) shows maximum anomaly (28%) at 33 Hz.

Perpendicular H-field (Hy) shows maximum anomaly (74%) at 12 Hz



-> Greater MT response due to Hy (3/4) than to Ex (1/4)

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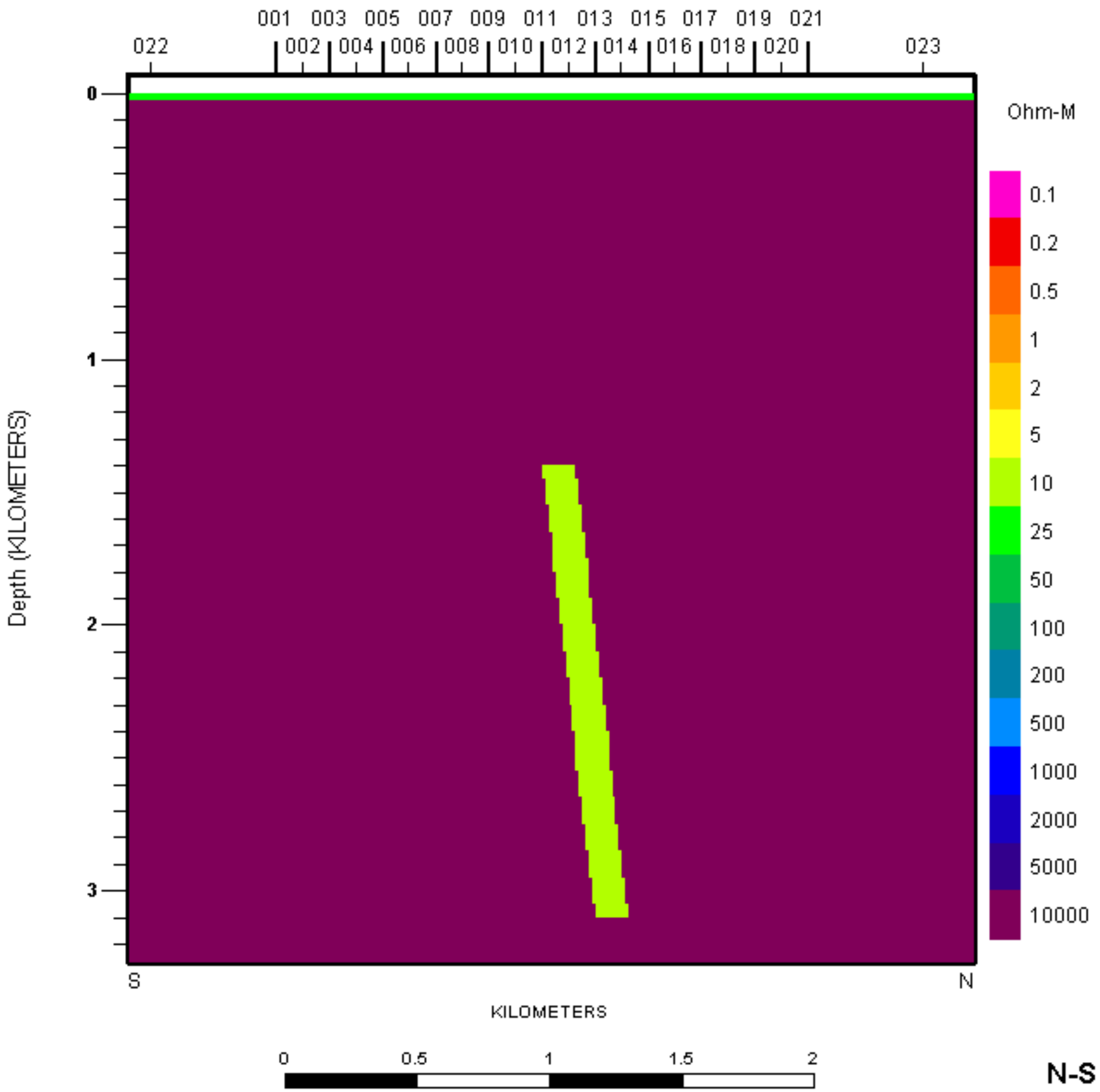
Overburden: 30 m of 25 Ω.m

How will overburden affect the fields?

30 m of 25 Ωm (1.2 Siemens)

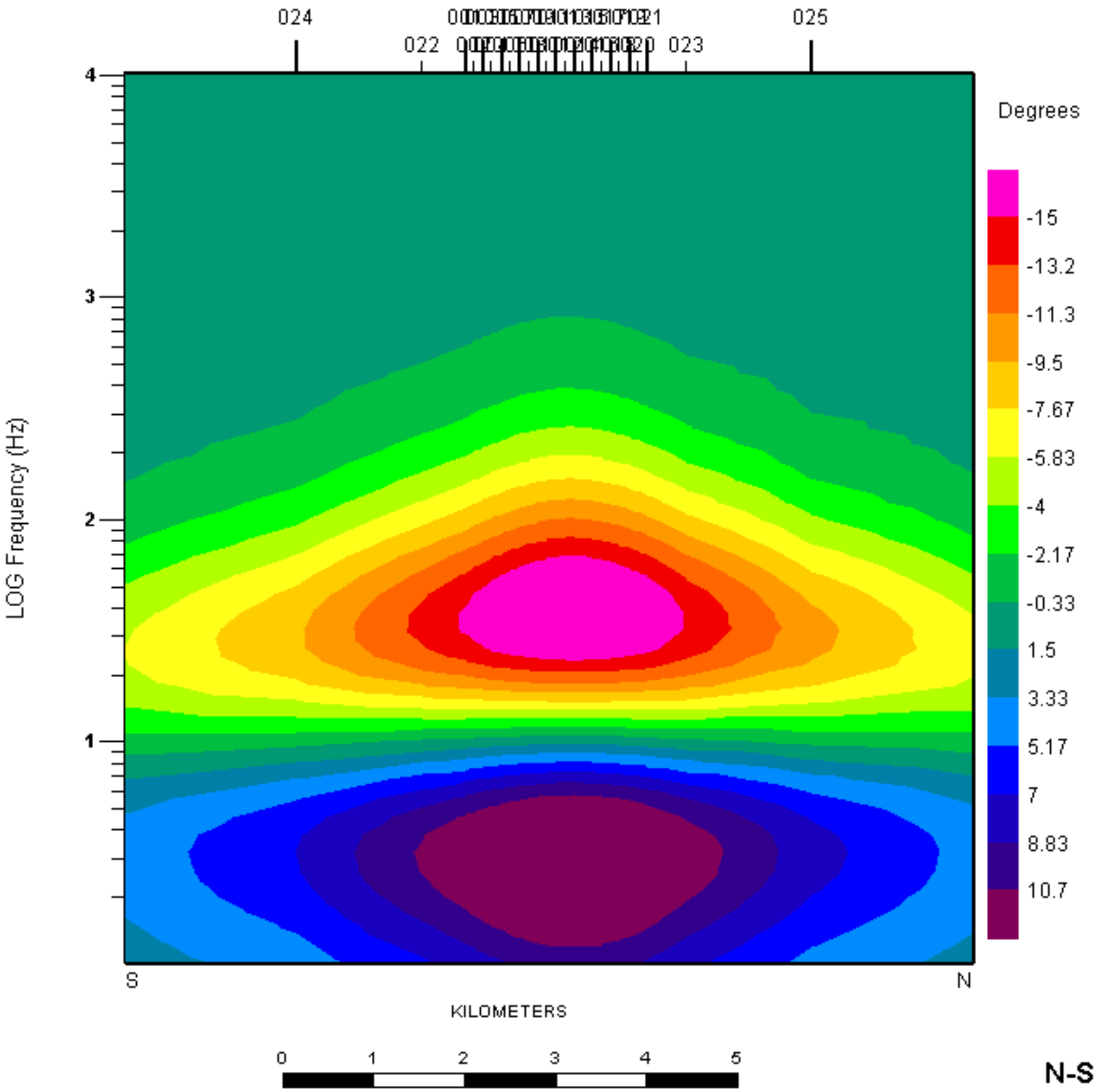


N-S

Overburden: TE phases

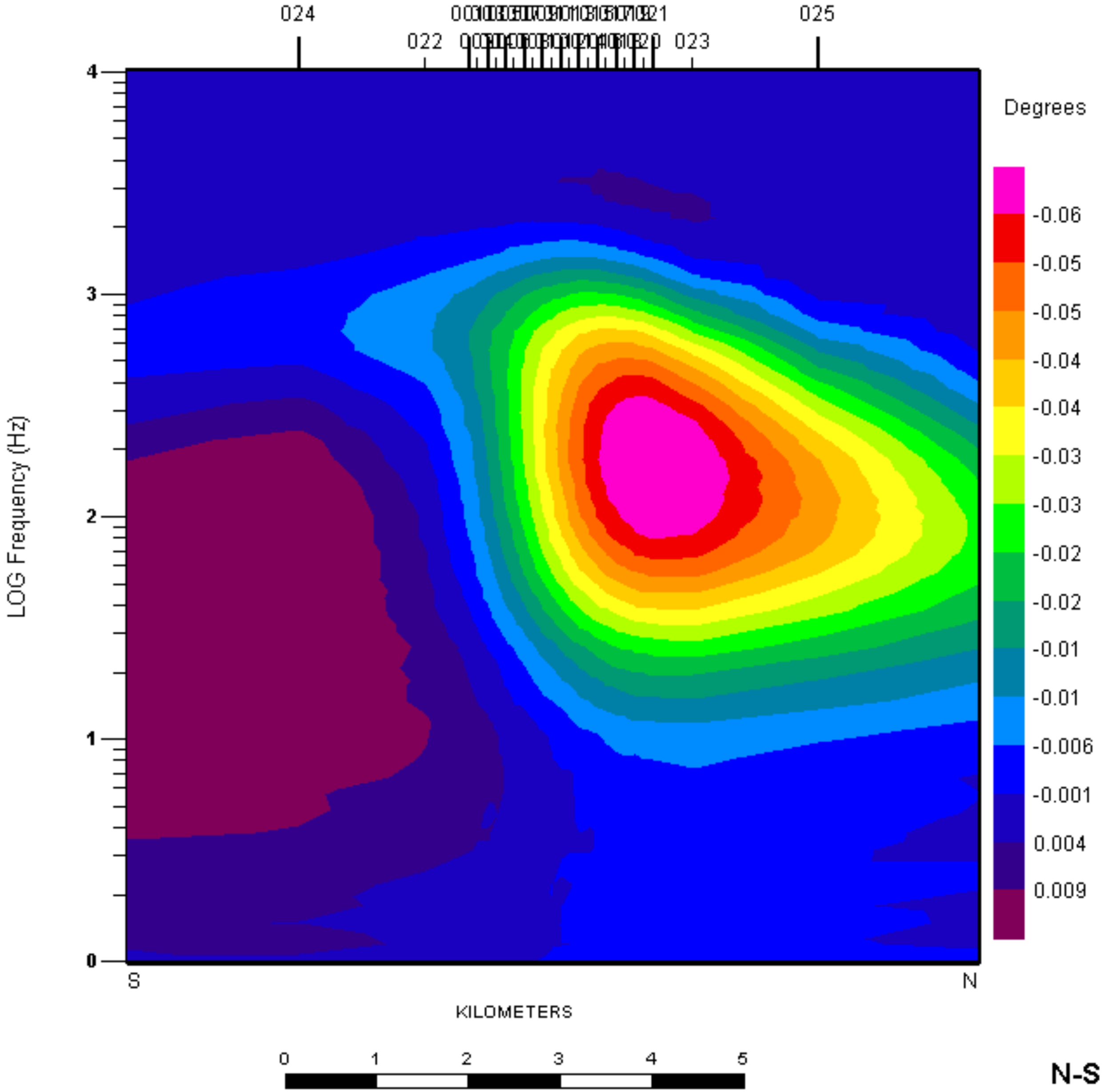
TE phase anomaly reduced to $+15^{O}/-11^{O}$ from $\pm22^{O}$

Both anomalies moved down in frequency



Overburden: TM phases

TM phase anomaly below 0.1^{O}!

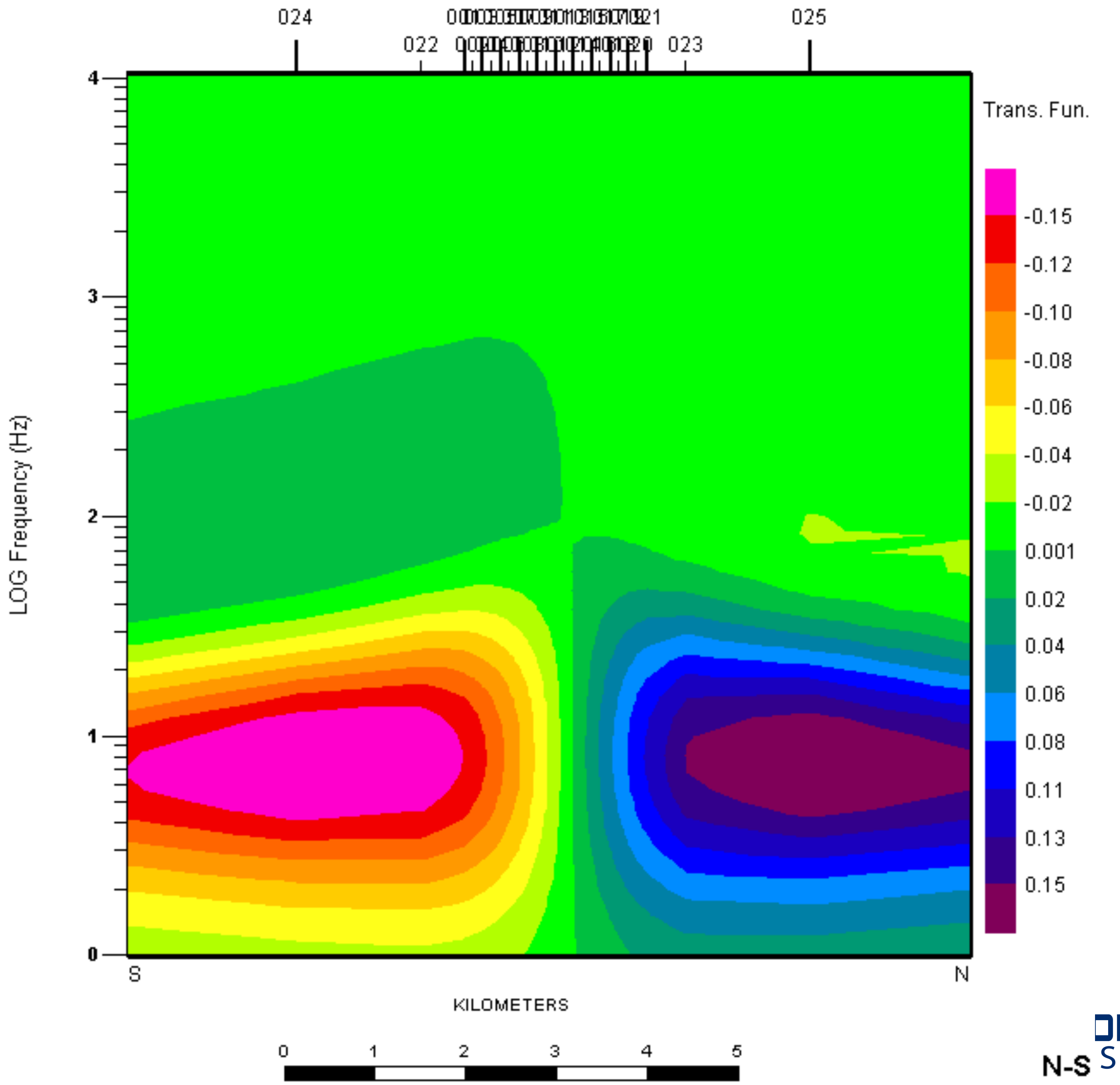


N-S

Overburden: TZ-Real

Still observable strong tipper response

A ±0.15 response at 9 Hz at distances of 2.5 km from the body



N-S

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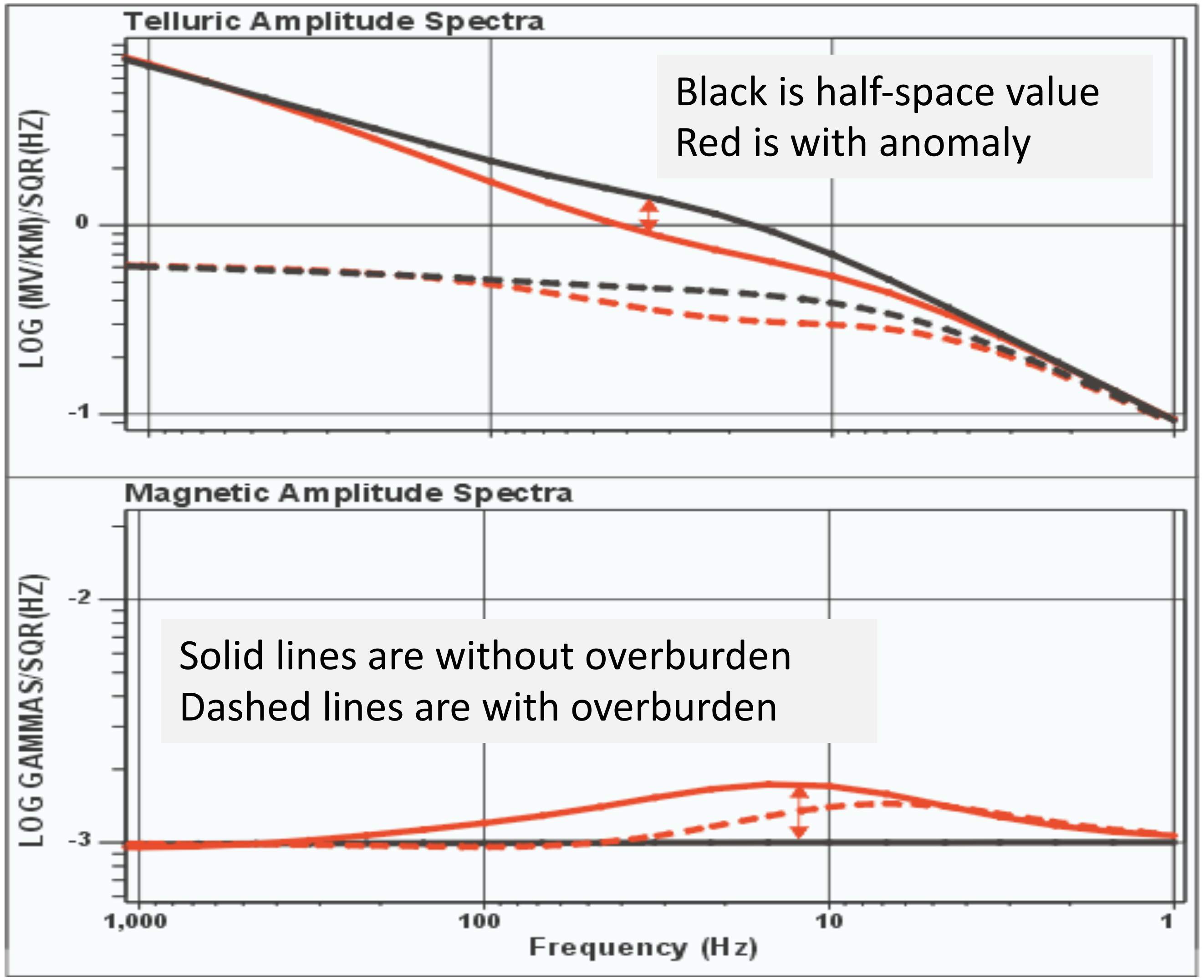
TE fields at central site

Fields at freqs >10 Hz strongly attenuated

Maximum Ex anomaly shifted down to 15 Hz, and maximum Hy to 6 Hz (into MT dead-band)



-> Need very broad frequency range of acquisition

Conclusions – Kidd Creek

Steeply-dipping, electrically-thin, mineralized targets pose a problem for AMT detection and delineation

No measurable TM-response!

Strong TE and TF responses

For TE, in 2-D most of anomalous response in (lower frequency) across-strike magnetic field (Hy) rather than in (higher frequency) along-strike electric field (Ex)

For TF, have greater lateral detection and sensitivity than TE, but at lower frequencies

-> *Measure all 5-components at each site !!!*

-> *Conduct survey design !!!*

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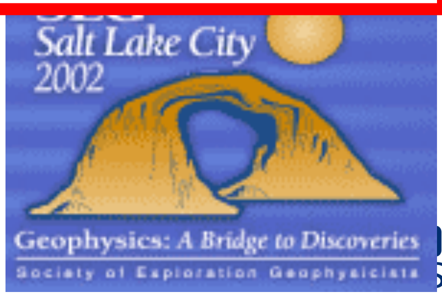
DEEP ELECTROMAGNETIC IMAGING OF THE BATHURST No. 12 DEPOSIT:

GEOPHYSICS, VOL. 72, NO. 2 (MARCH-APRIL 2007); P. F85–F95, 12 FIGS., 1 TABLE.
10.1190/1.2437105

Electromagnetic imaging of a complex ore body: 3D forward modeling, sensitivity tests, and down-mine measurements

Pilar Queralt[1], Alan G. Jones[2], and Juanjo Ledo[1]

Society of Exploration Geophysicists
72nd Annual Meeting, Salt Lake City
October 6-11, 2002



Main objectives

Methodology:

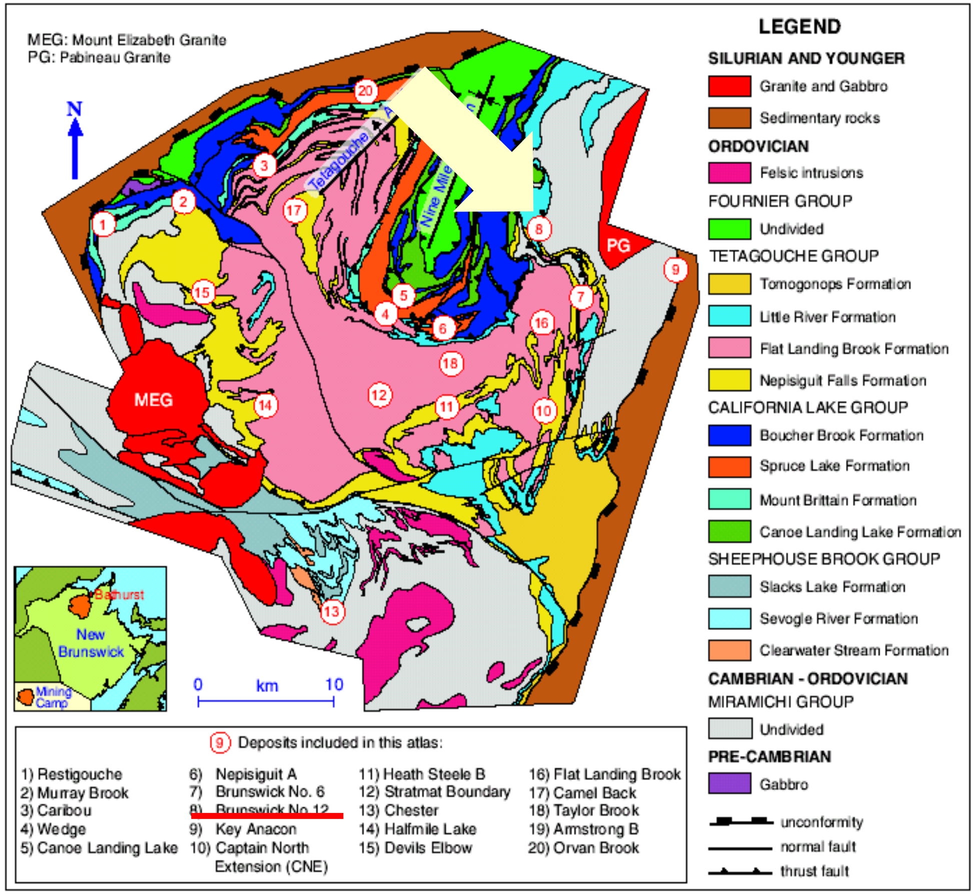
- Construct a realistic 3-D model
- Study of AMT responses of 3-D structures

Application:

- Experimental design of AMT survey for detecting and delineating conductive target ore bodies within resistive host background

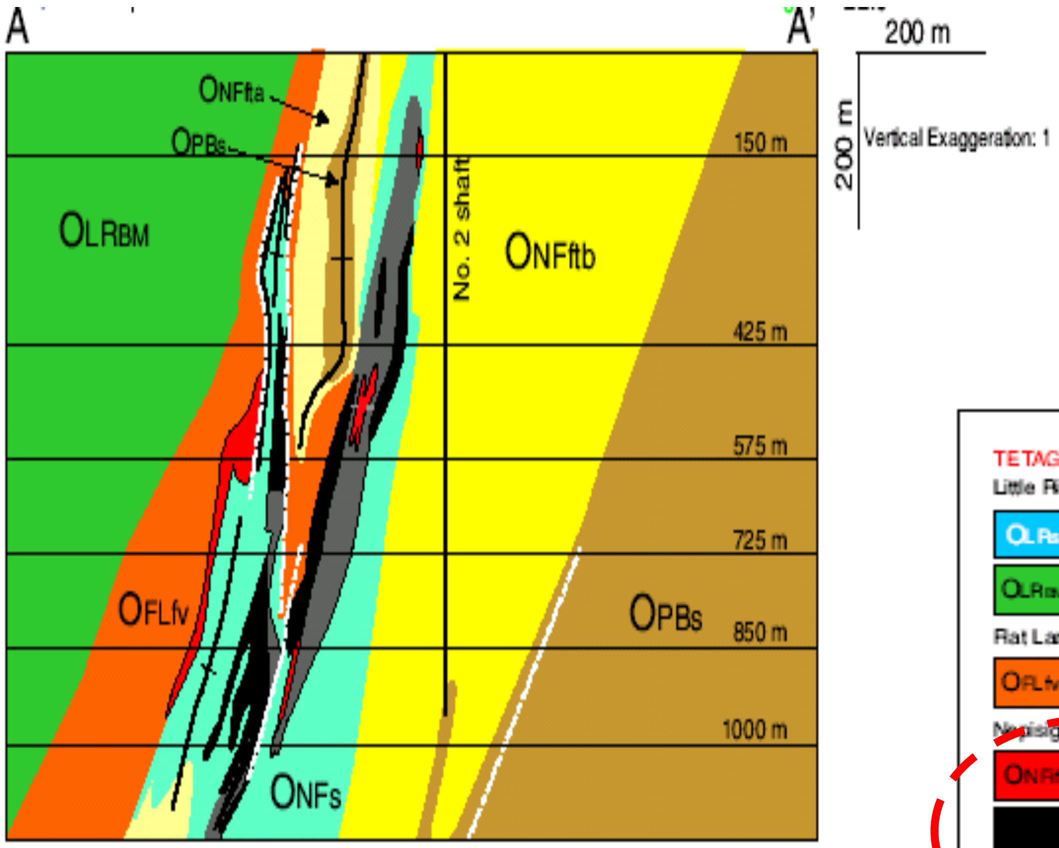
Brunswick n.12 deposit, Bathurst mining camp (New Brunswick, Canada)

- *Complex geometry of the ore bodies -> a realistic body*
- *The biggest deposit in this mining camp*
- *Rich geological and geophysical information*

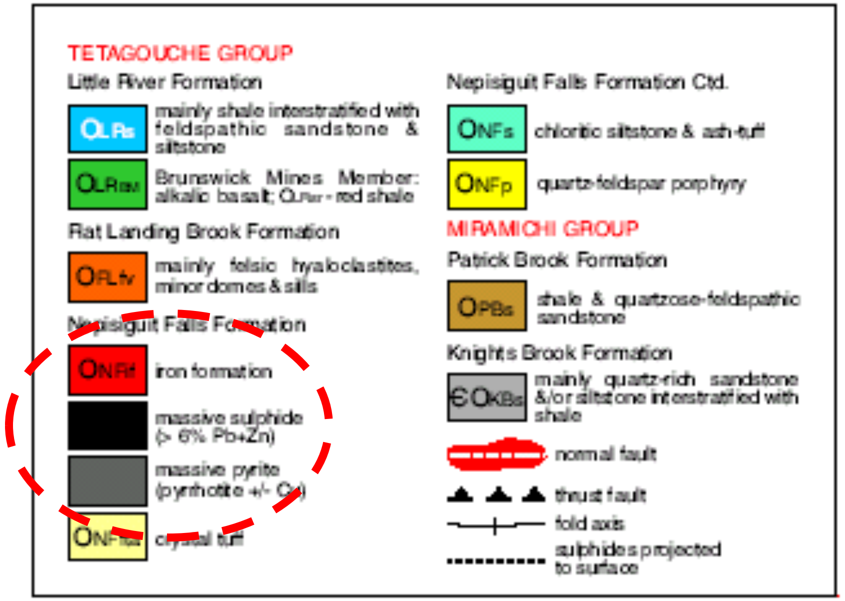


Brunswick n.12 deposit

GEOLOGICAL SECTION A-A’



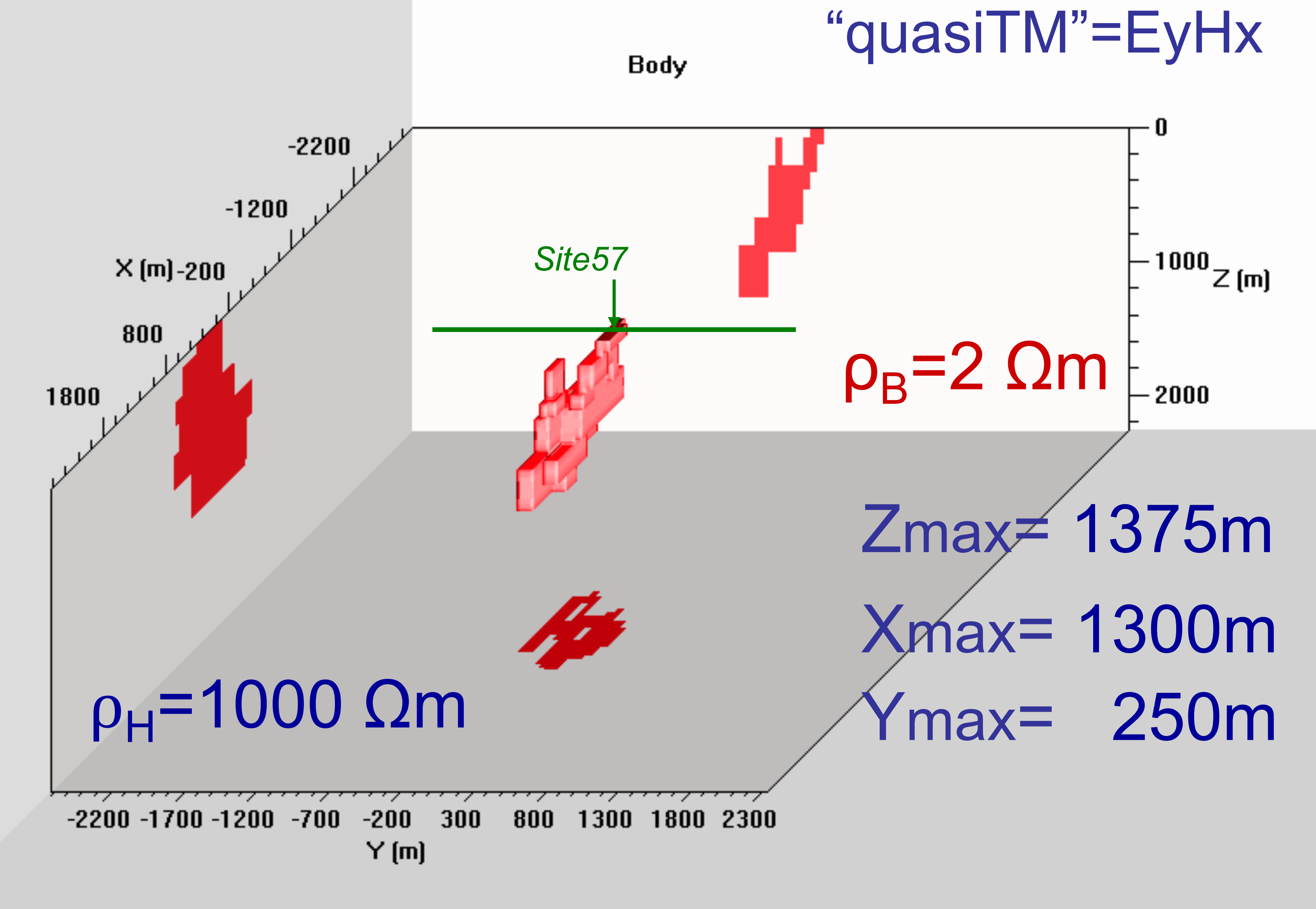
GEOLOGICAL LEGEND



MPLETE MT
OLUTIONS

Outline of the 3-D body

“quasiTE”=ExHy
“quasiTM”=EyHx



ρ_B=2 Ωm

Zmax= 1375m
Xmax= 1300m
Ymax= 250m

ρ_H=1000 Ωm

Dip angle: 80^0 X:Y=4:1 - 5:1

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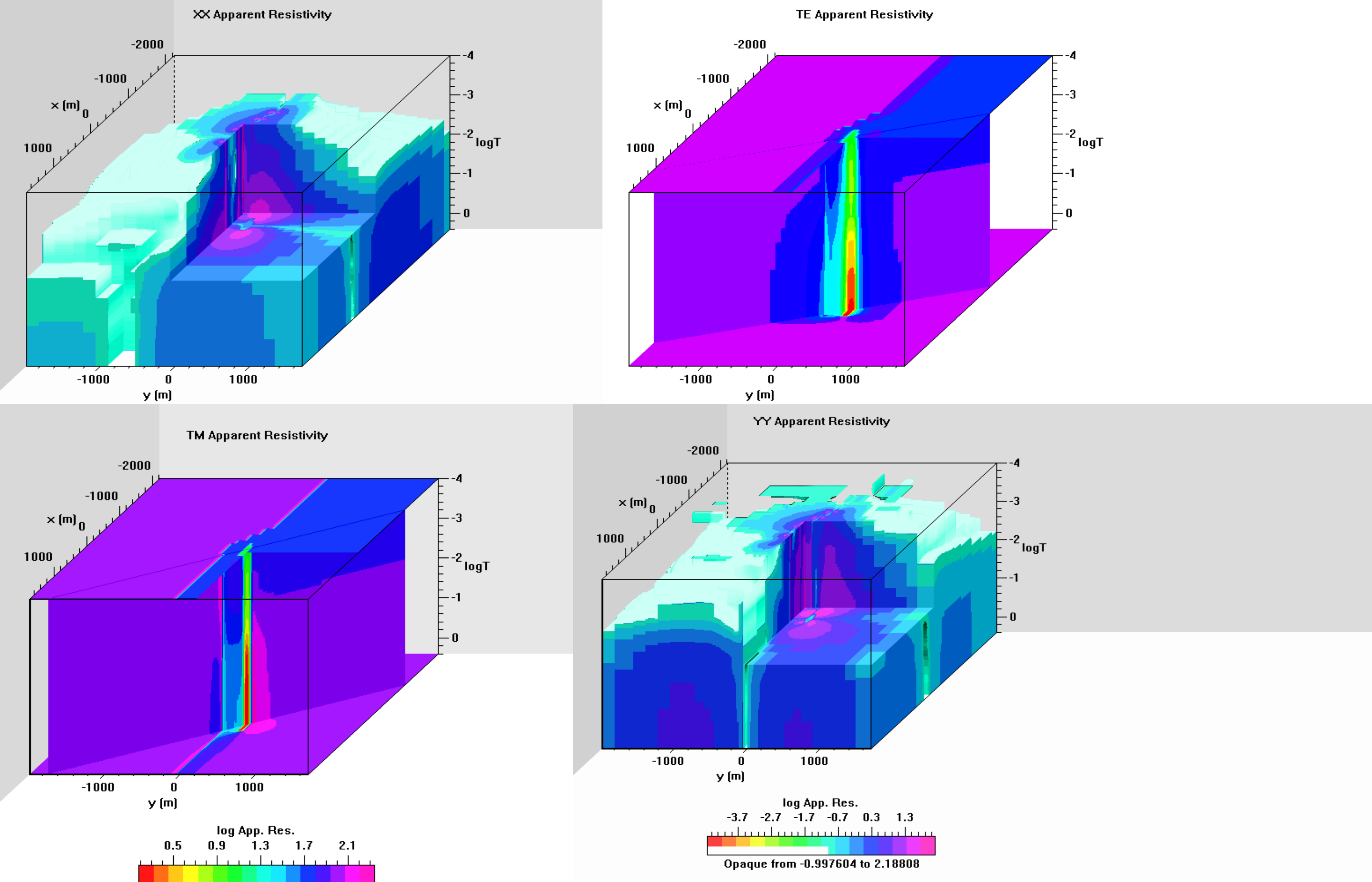
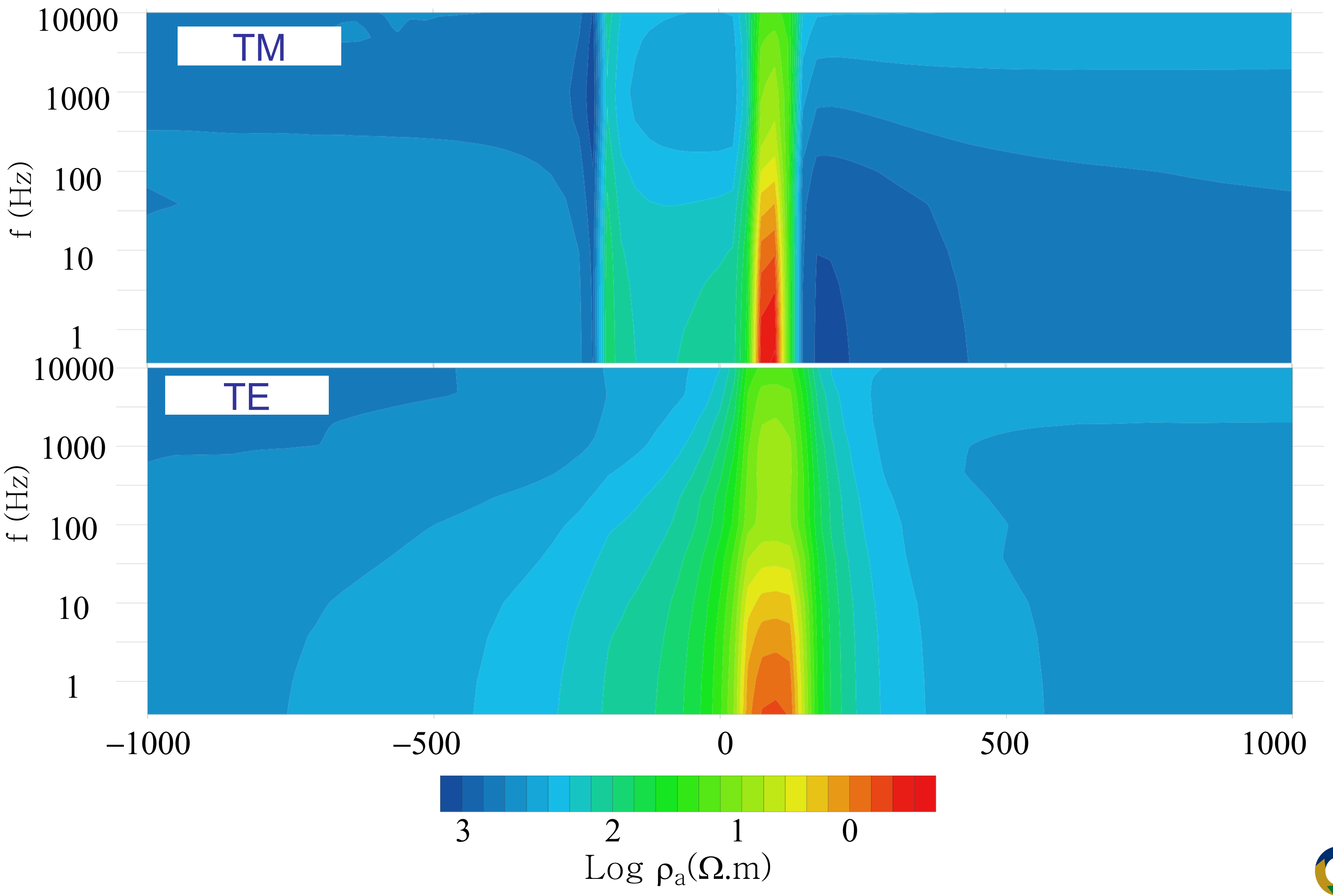
3-D modelling

- Mackie et al. (1999, 2001)
- Mesh size 99x86x50 $\Delta x = 12.5$m
- 10^4 Hz – 3.8 10^{-1} Hz , 11 frequencies
- 1.5 Gb RAM, 48 h. *SUN ULTRA*
- Generated synthetic data for inversion by adding 1% noise and scatter


XX Apparent Resistivity
TE Apparent Resistivity
TM Apparent Resistivity
YY Apparent Resistivity
x (m)
y (m)
logT
-2000
-1000
0
1000
-4
-3
-2
-1
log App. Res.
0.5
0.9
1.3
1.7
2.1
-3.7
-2.7
-1.7
-0.7
0.3
Opaque from -0.997604 to 2.18808

"2D" Model responses – Apparent Resistivity



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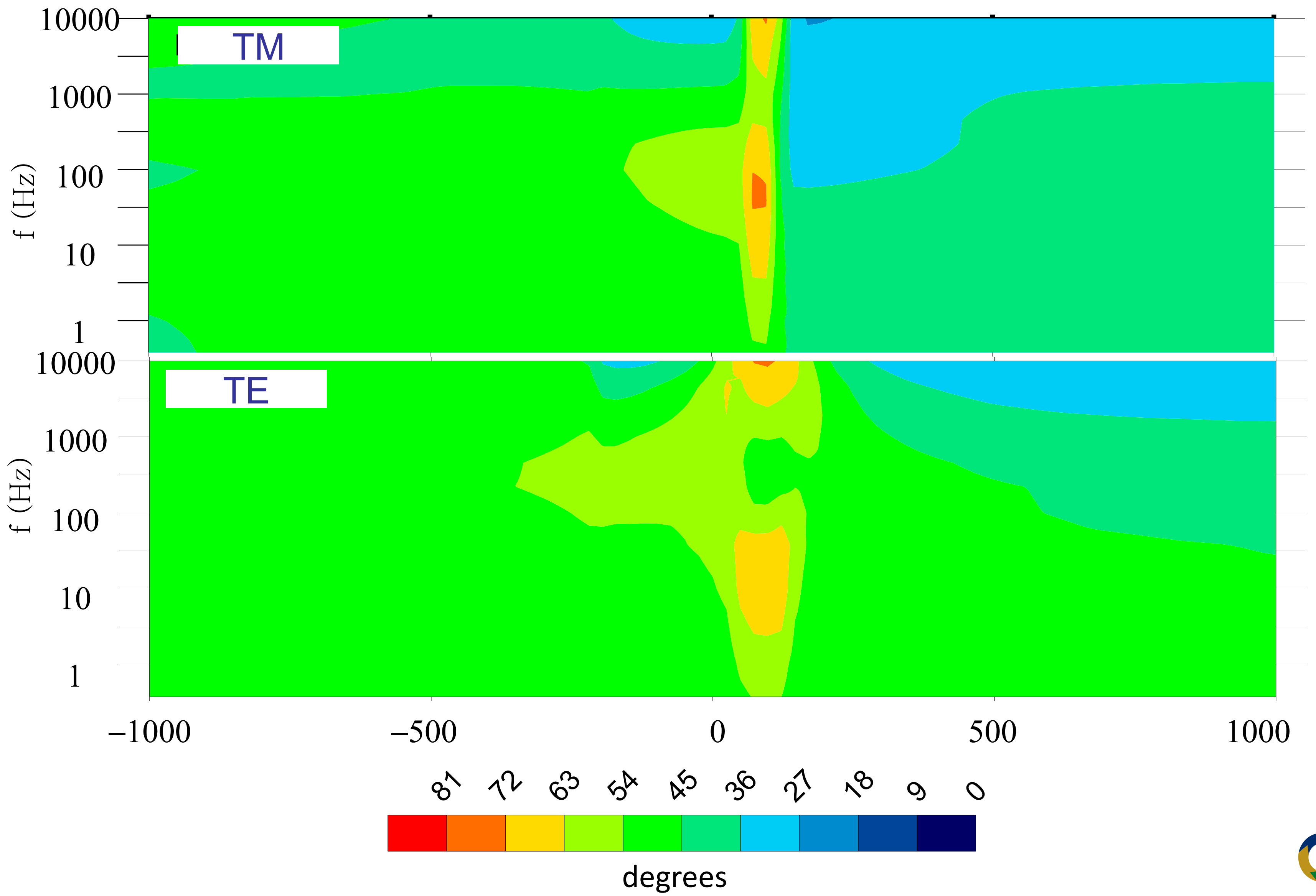
“2D” Model responses – Phases



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Conclusions – Bathurst

- The whole frequency range of AMT is required to detect and to delineate the geometry of the 3D body (Need very high quality AMT "dead-band" responses!)

- 2-D inversion can be considered for all the "quasiTM" data, but only for the high frequency "quasiTE" data.

- The "quasiTE" behaviour in the 3-D responses is very different from the 2-D case, and is highly sensitive to the length of the strike.

- For this 3-D body the anomalous horizontal magnetic field components are small compared to the 2-D model. Most of the anomalous response is in the electric field components.

  → *To optimise data acquisition, stationary magnetic sensors and multiple electric field measurements can be considered*

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Survey Design – Practical aspects

- What magnetometers are best for imaging your target?
- What electrodes should you use?
- Do you need to record AMT deadband (5 kHz – 800 Hz) or MT deadband (8 Hz – 10 s) or very low (< 0.001) frequencies?
- What will the cultural noise likely be like?
- Where should the remote be sited?

Survey Design – Practical aspects

- What magnetometers are best for imaging your target?
  - Answer depends on the frequencies that are best for imaging your target
    - Coils for high frequencies > 0.001 Hz (1,000 s)
    - SQUIDS not in common use in MT, but are used for e.g. airborne EM
    - Ring-core fluxgates for long periods > 1,000 s

Coil design is a trade—off between:

1. lots of turns over a large magnetically permeable core (=greater sensitivity at low freqs) and large eddy currents in the core (=high frequency noise), against
2. a smaller core with fewer coils (=lower sensitivity at low freqs) and low eddy currents in the core (=lower noise at high freqs)

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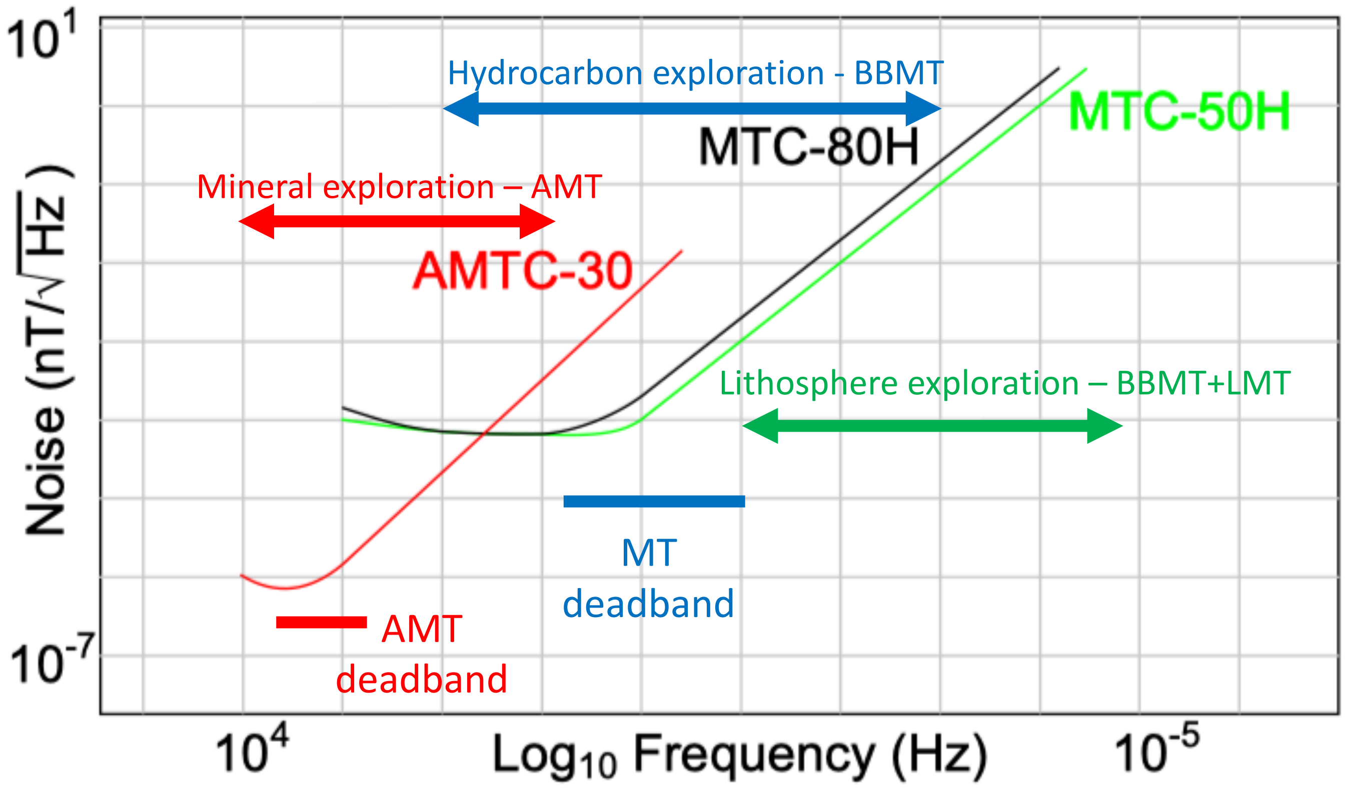
Survey Design – Practical aspects

- What coils are best for imaging your target?

Examples of Phoenix's conventional coils:



AMTC-30 *for* AMT, CSAMT, FDEM
- 82 cm x 6 cm dia., 3 kg
- Frequency range:
  10 000 Hz to 0.1 Hz

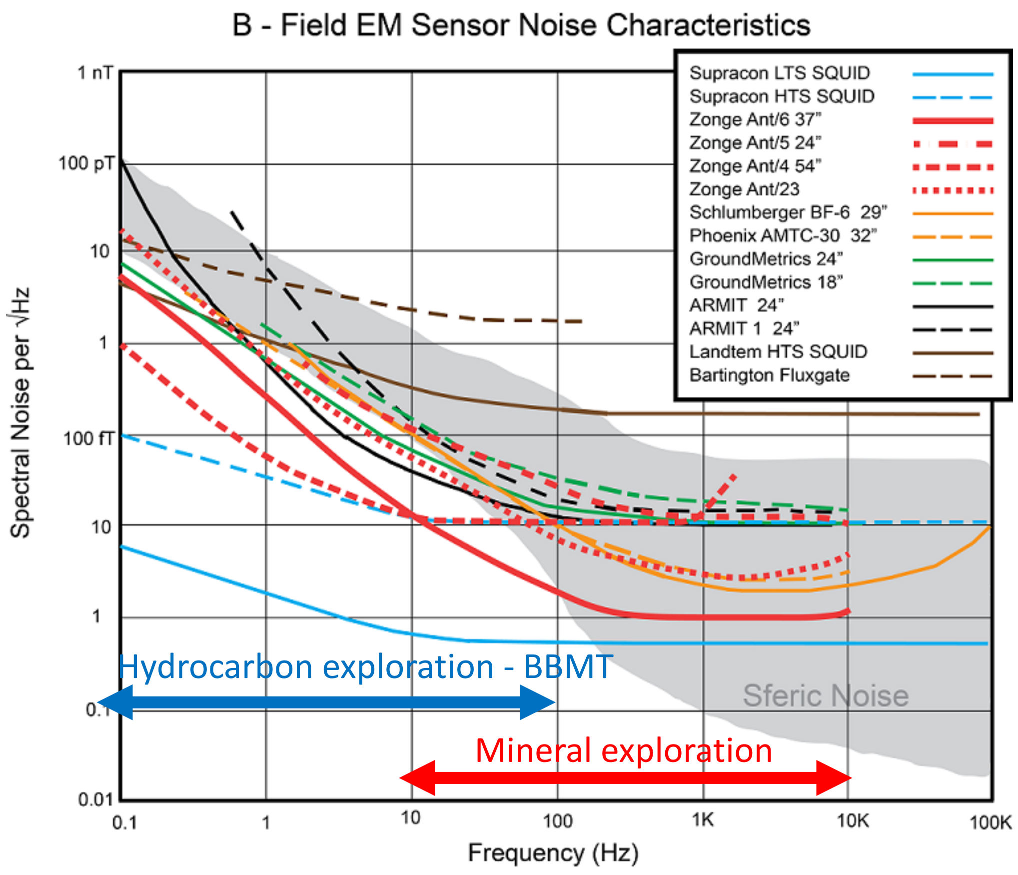
MTC-80H *for* MT
- 97 cm x 6 cm dia., 5 kg
- Frequency range:
  400 Hz to 10 000 seconds

MTC-50H *for* MT
- 144 cm x 6 cm dia., 8.2 kg
- Frequency range:
  400 Hz to 50 000 seconds

Survey Design – Practical aspects

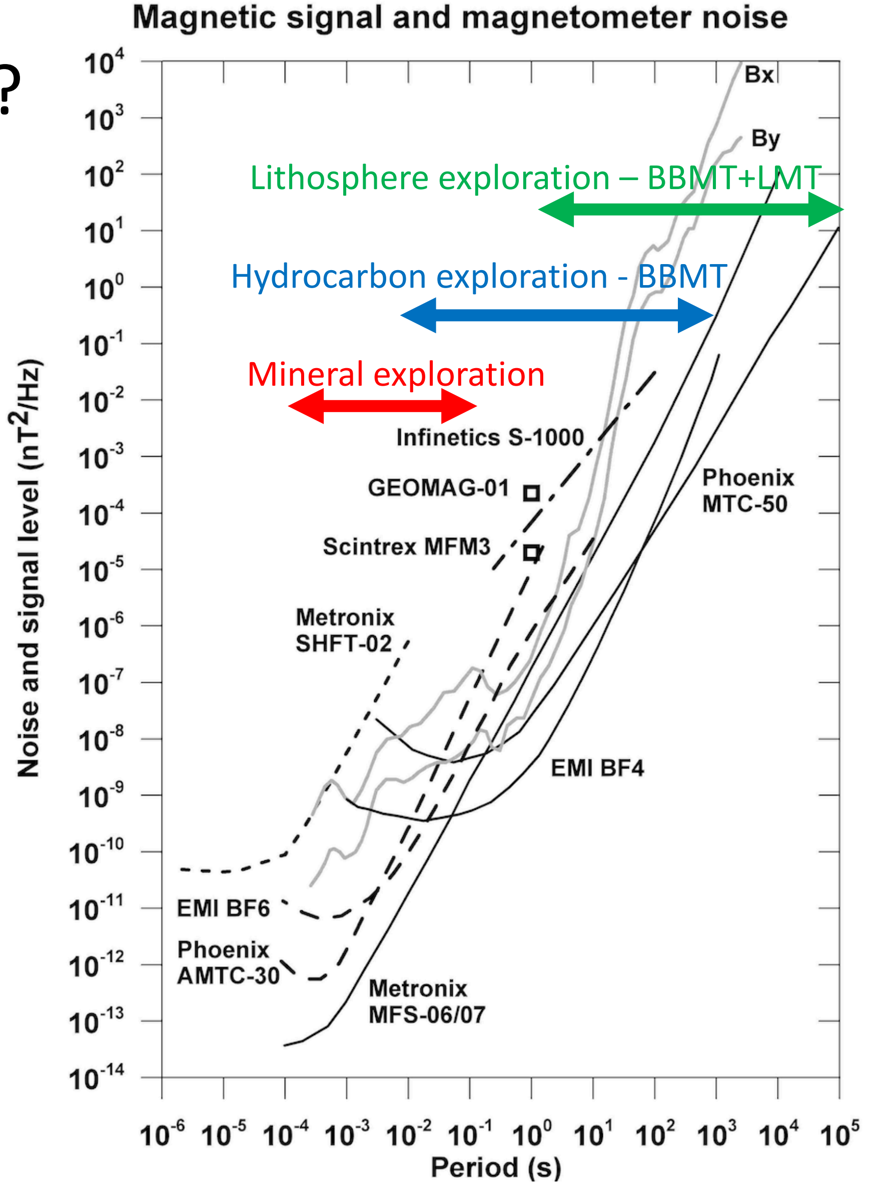
- What coils are best for imaging your target?

Comparisons in the literature of various coils



← Discovery Intl. PDAC 2013

Ferguson (2012) →



Survey Design – Practical aspects

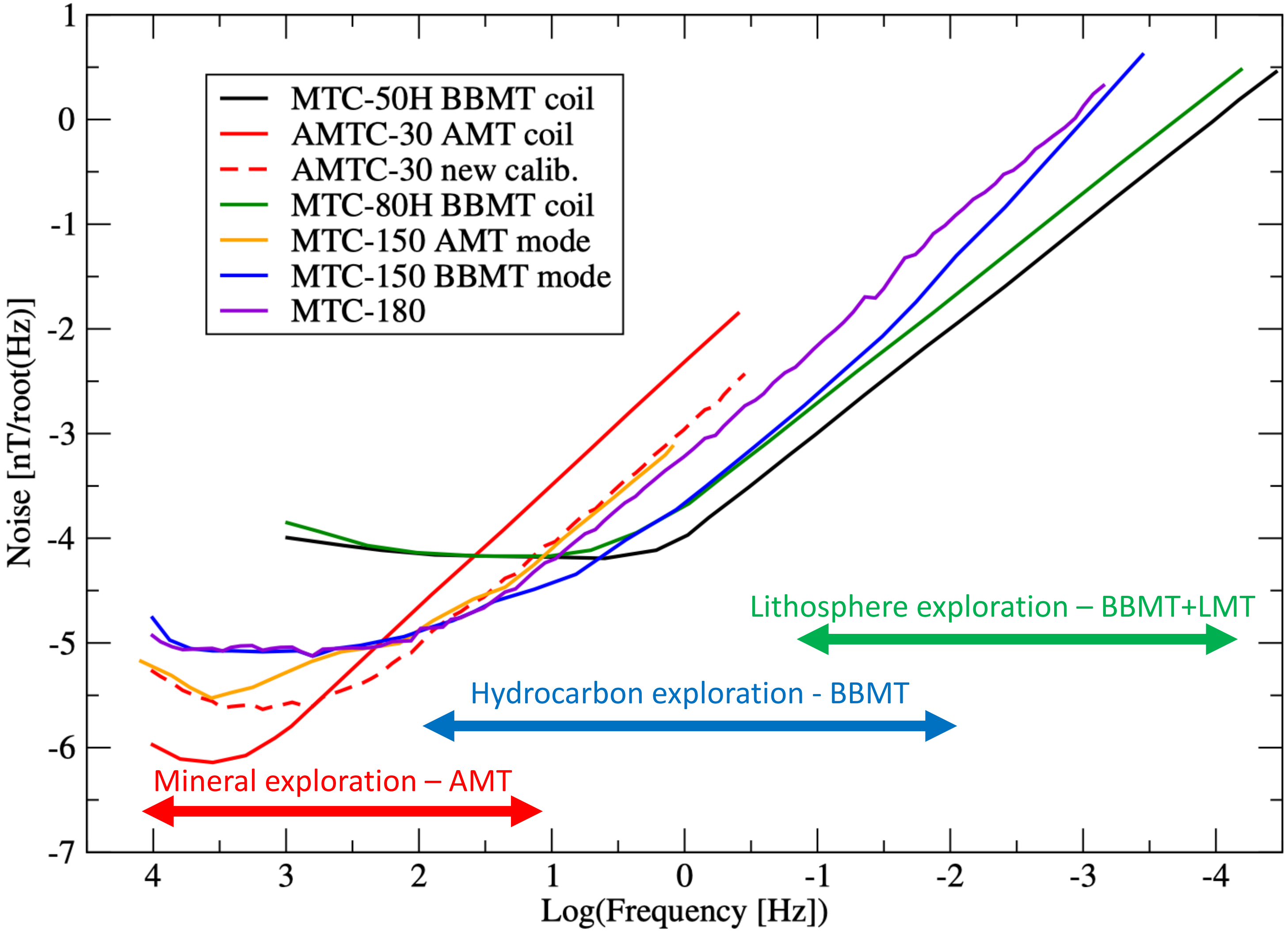
- What coils are best for imaging your target?

Hybrid coils appearing:

MTC-150/MTC-180

- Not as good at high freqs > 200 Hz
- Not as good at low freqs < 3 Hz
- Superior in the band 200 – 3 Hz

Advantage is one coil not two. Both AMT and BBMT can be done in one overnight recording



Survey Design – Practical aspects

- What electrodes should you use?
  - Answer depends on the frequencies that are best for imaging your target
    - Metal plates/rods for high frequencies > 100 Hz
    - Capacitive electrodes/antennas for very high frequencies >300 Hz
    - Non-polarizing electrodes for low frequencies < 100 Hz
    - Active electrodes at low frequencies < 300 Hz for very high contact resistance

Survey Design – Practical aspects

- What electrodes should you use?
  - Metal plates/rods for high frequencies > 100 Hz

- Advantages:
  - Low cost
  - Low maintenance
  - Quick to deploy
- Disadvantages:
  - May still have polarization charge noise even at high freqs

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Survey Design – Practical aspects

- What electrodes should you use?
  - Capacitive electrodes/antennas for very high frequencies >300 Hz

- Advantages:
  - Quick to deploy

- Disadvantages:
  - Low signal:noise possible up to 1 kHz

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Survey Design – Practical aspects

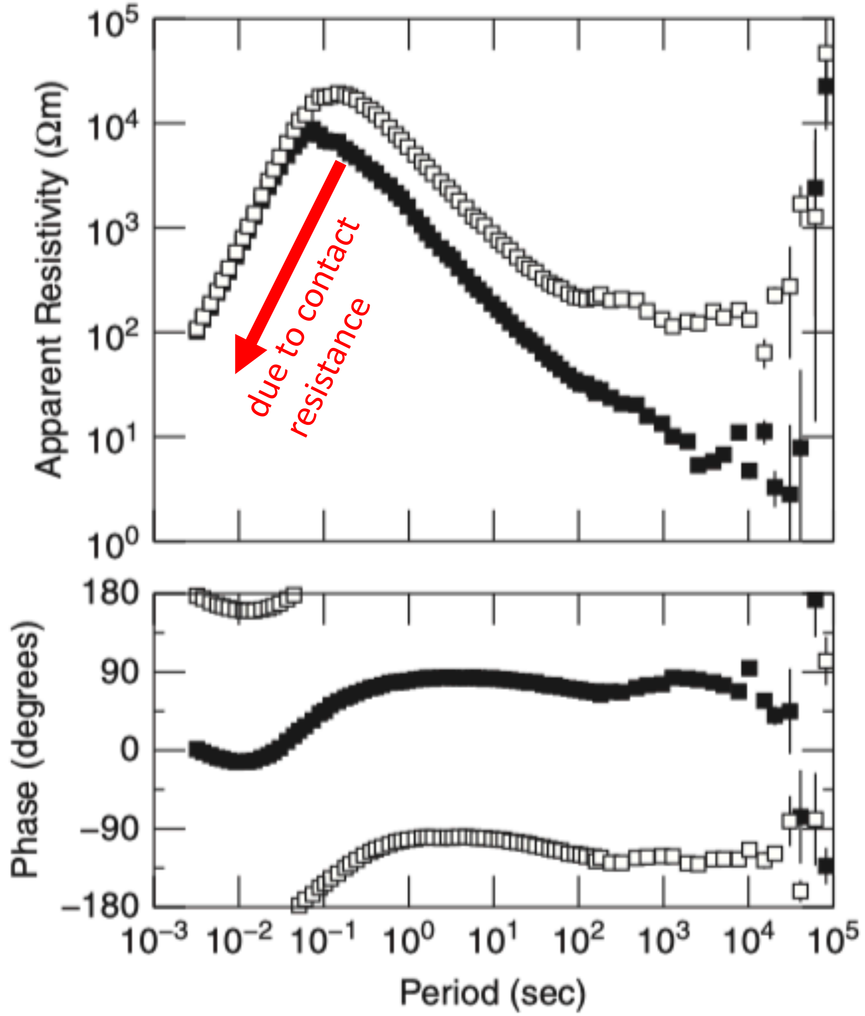
- What electrodes should you use?
  - Non-polarizing electrodes for low frequencies < 100 Hz
- Advantages:
  - Very low noise for BBMT and LMT applications
- Disadvantages:
  - Slow to deploy – need to dig a deep hole
  - Expensive
  - Need maintenance between sites and between surveys
  - Need maintenance during acquisition (hole has to be kept wet)

Number your electrodes!!!

Survey Design – Practical aspects

- What electrodes should you use?
  - Active electrodes at low frequencies < 300 Hz for very high contact resistance (John Stodt pre-amplifiers)
    - The problem is when the contact resistance approaches the input impedance of the receiver – that sets up an RC circuit and attenuates the high frequencies
- Advantages:
  - Can be used in very resistive areas – glaciers, snow cover, exposed rock
- Disadvantages:
  - Expensive
  - Need a second cable with power to the electrode for the pre-amp

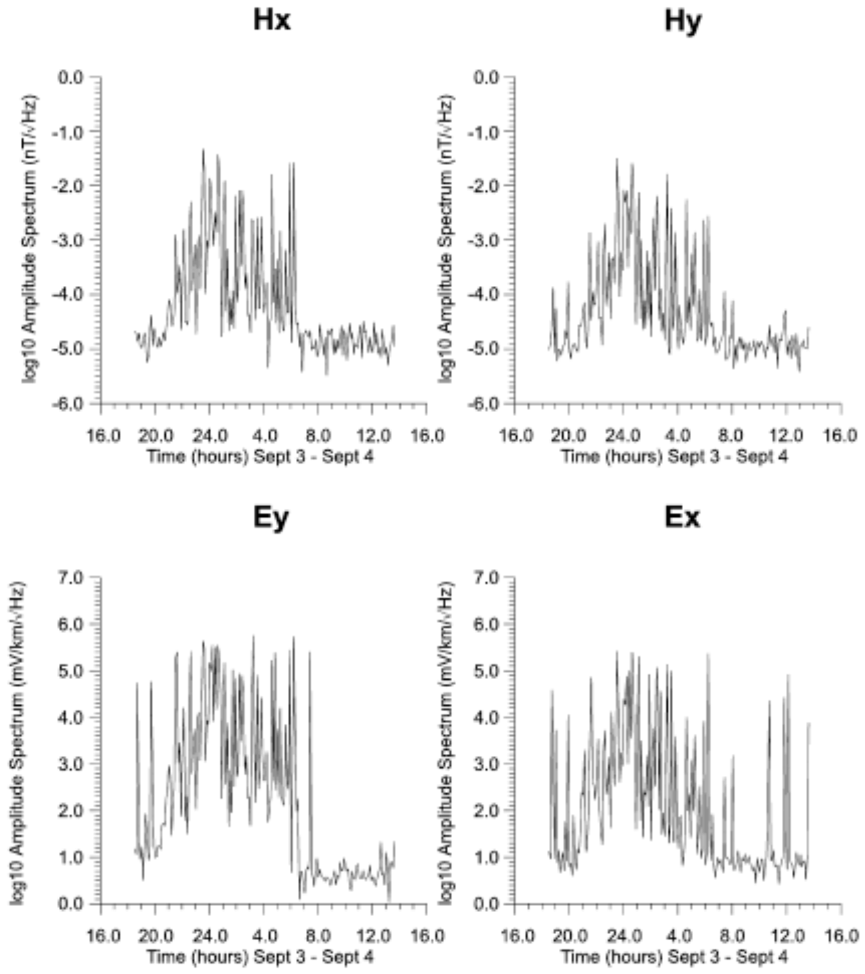
Station on Baffin Island with 2 MΩ contact resistance



Survey Design – Practical aspects

- Do you need to record AMT deadband (5 kHz – 800 Hz) or MT deadband (8 Hz – 10 s) or very low (< 0.001) frequencies?

For either of these, you will need to plan for overnight acquisition. Yes, you only need 10 mins of AMT data, but it's getting the right 10 mins! Daytime atmospheric attenuation of the propagating EM fields means virtually no signal at AMT deadband frequencies.



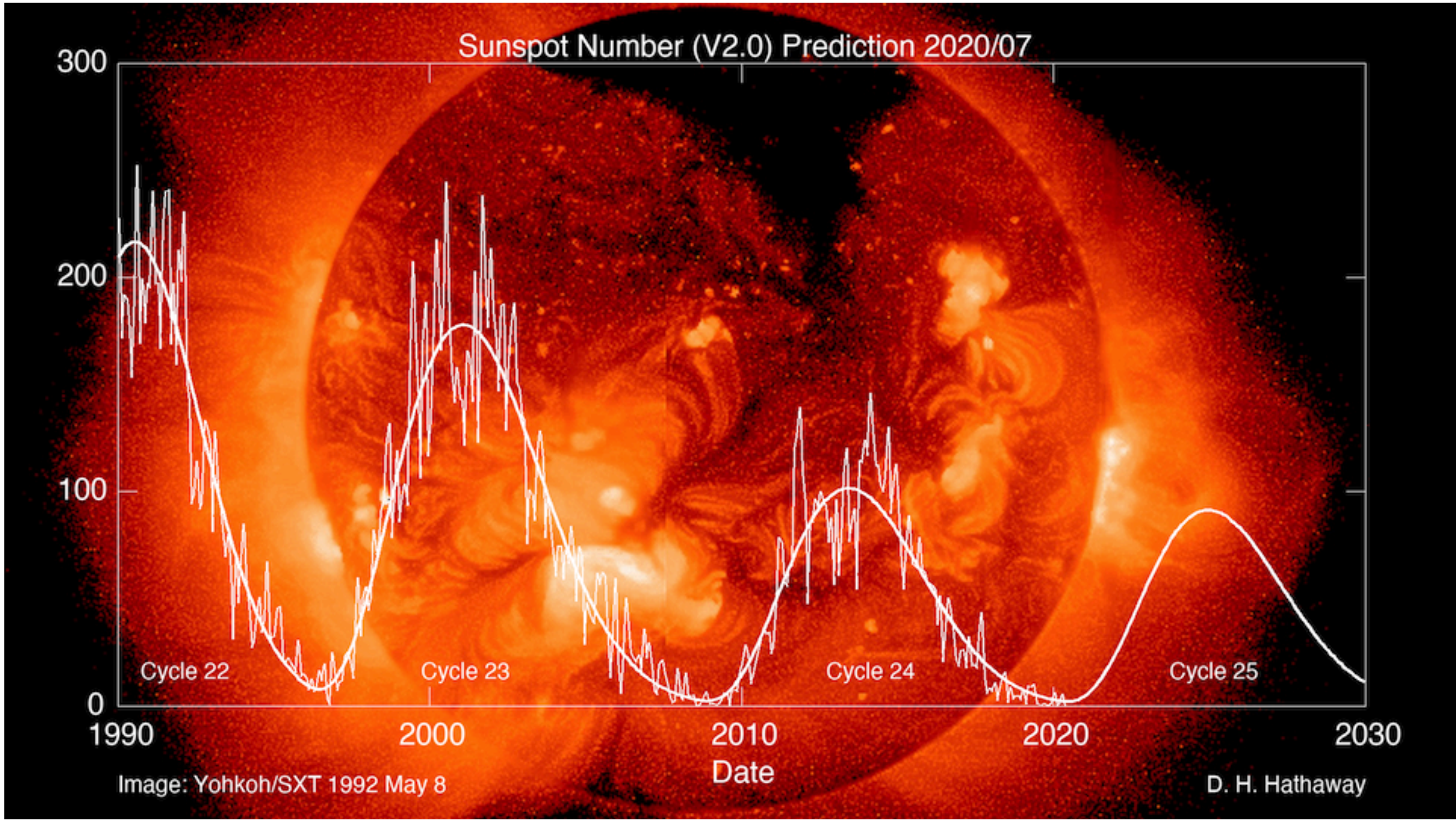
24h of 1 kHz spectral amplitude at a site near Sudbury, Canada Garcia & Jones (2002)

Survey Design – Practical aspects

- Do you need to record AMT deadband (5 kHz – 800 Hz) or MT deadband (8 Hz – 10 s) or very low (< 0.001) frequencies?

For BBMT data at freqs <8 Hz (Schumann resonance) then you do have to think about the solar cycle

Good news is that we look to be at the low, and activity will increase for the next few years



Survey Design – Practical aspects

- What will the likely cultural noise be like?

- Dirty powerlines? Unstable main harmonic and/or broad side-lobes
- DC trains?
- Mining power at 1/3 of main power frequency?
- Wells?
- Pipelines carrying DC noise generated tens to hundreds of km away
- Pipelines with cathodic protection
- Cow fences – analogue worse than digital
- Radar

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Noise Solutions - Cultural

- Avoid or minimize
- Filters remove much of 60Hz/harmonics
- Record at off peak
- Request that noise be "turned off"
- Use remote reference at whatever distance necessary
- Robust or other processing

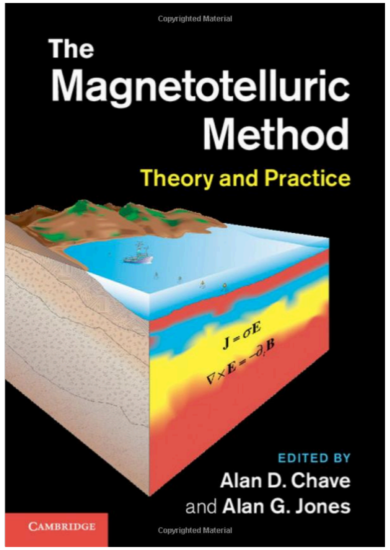
Noise Solutions - Natural

- Bury coils
- Ensure E-lines are close to ground
- Protect cables from animals – sprays
- Monitor gear in high-traffic areas
- Stop recording/disconnect during severe thunderstorms
- Shift recording schedule to avoid storms/people/animals

Survey Design – Practical aspects

- Where should the remote be sited?
  - The answer depends on frequencies of interest and cultural noise.
    - If AMT then should be within 25 km
    - If BBMT then can be much further away (1,000 km)
  - If there is the potential for correlating noise over long distances, think of using two remotes

MT Acquisition –Ferguson (2012)!!!



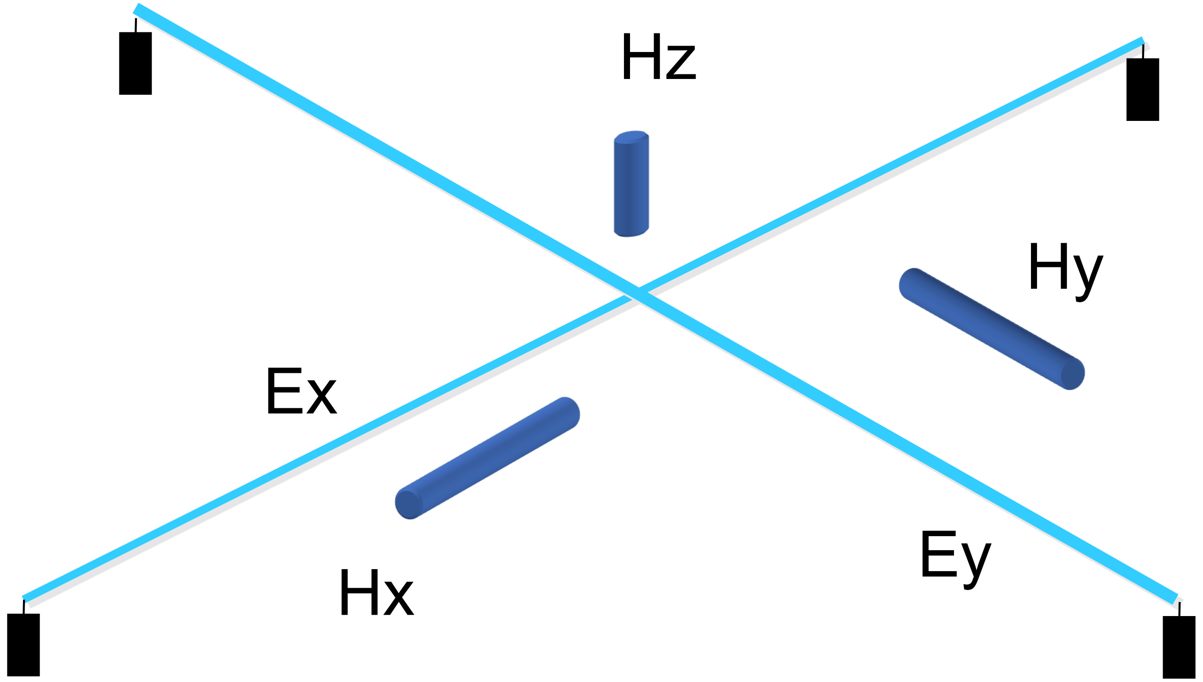
Ferguson, I. J. (2012), Instrumentation and field procedures, in *The Magnetotelluric Method: Theory and Practice*, edited by A. D. Chave and A. G. Jones, pp. 421-479, Cambridge University Press, Cambridge, UK.

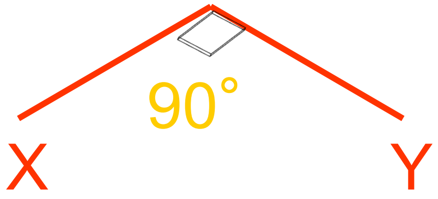
MT Acquisition

- Normally, record five channels at each station
  - Ex Ey Hx Hy Hz
  - Hz is harder to acquire (needs a deep hole!)
  - Recording the time series; processing will convert data to frequency domain
- Best statistically if x and y directions are orthogonal
- Orientation does not usually matter - x and y can be any direction
- But best if one axis is along the strike of the target conductor

MT - Five components

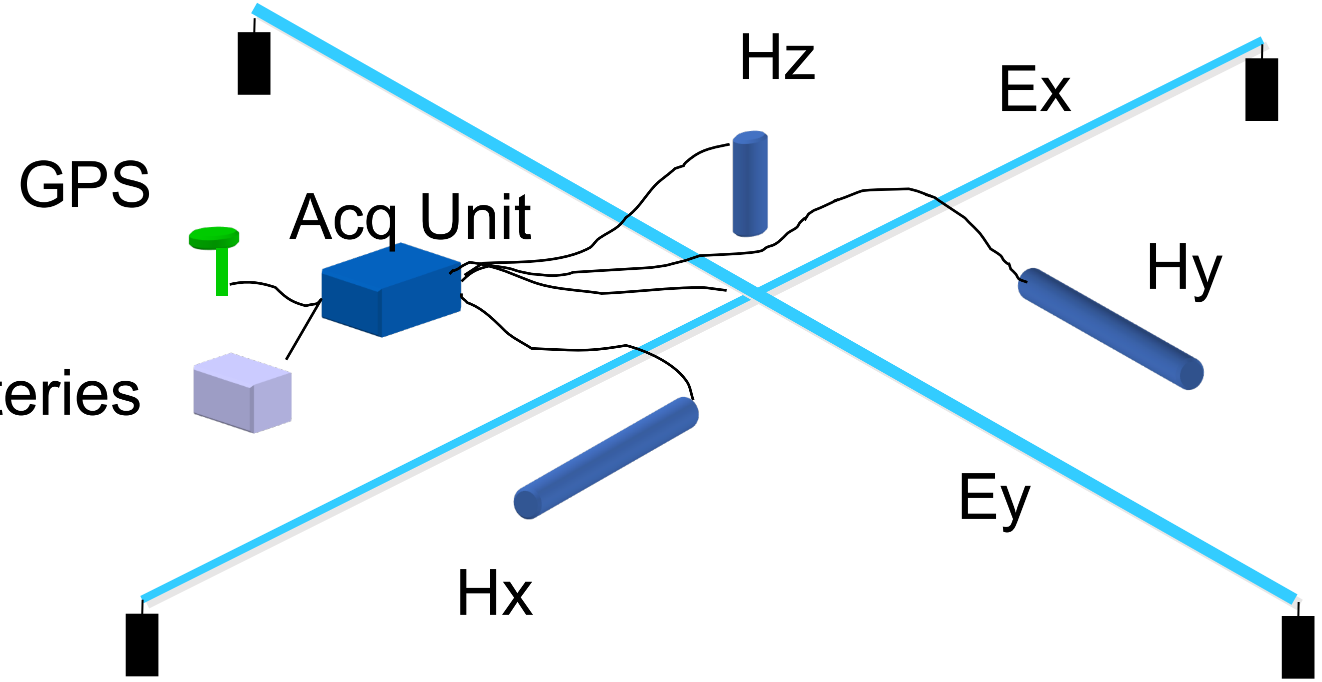
Place each of the coils in a different quadrant so no cross-talk between them

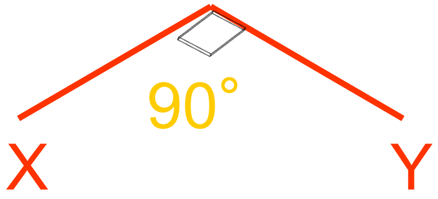




MT - Five components

Wire to acquisition unit with straight lines trying not to cross wires over each other. If you have to, do it at 90^{o}.





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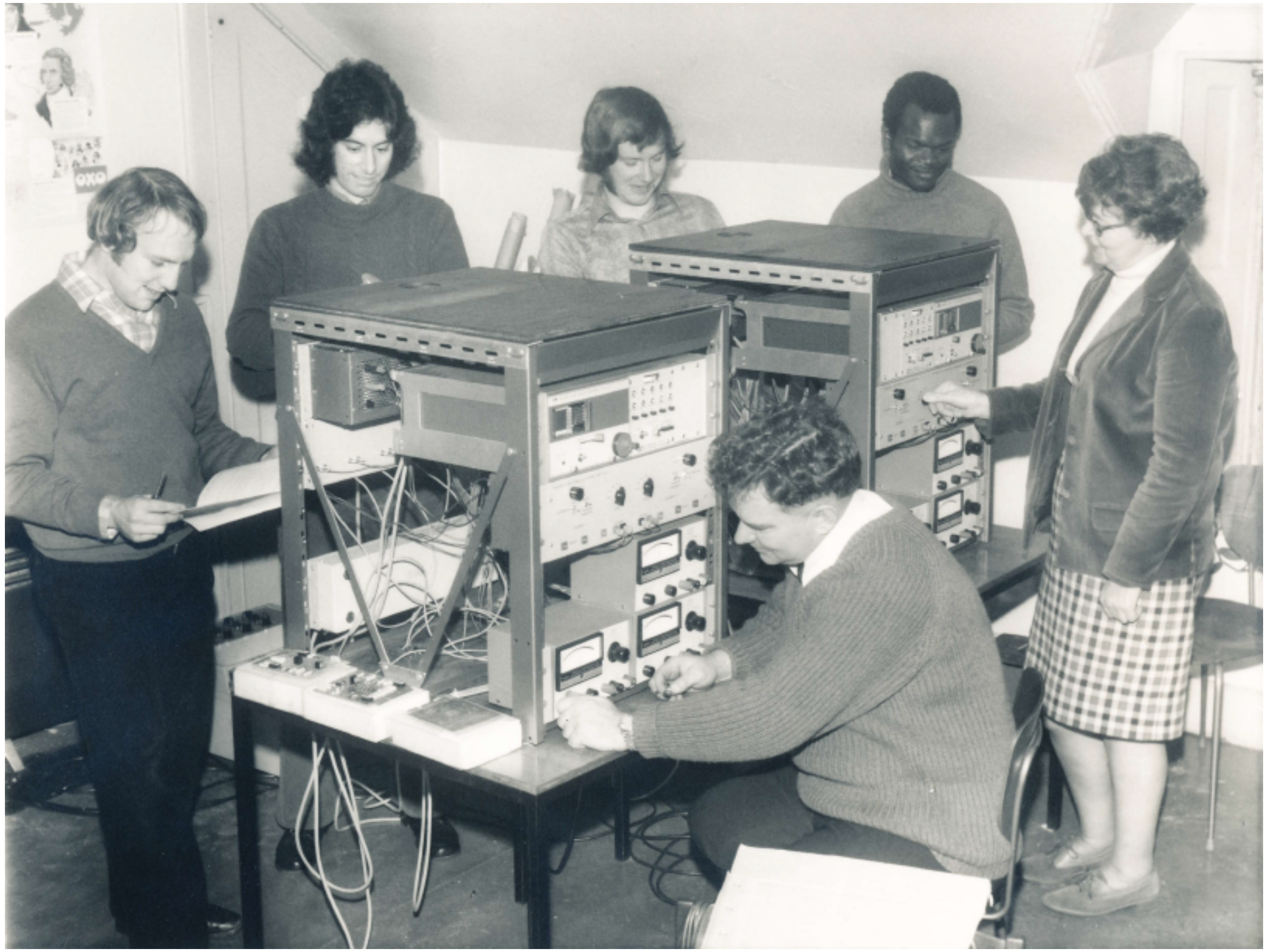
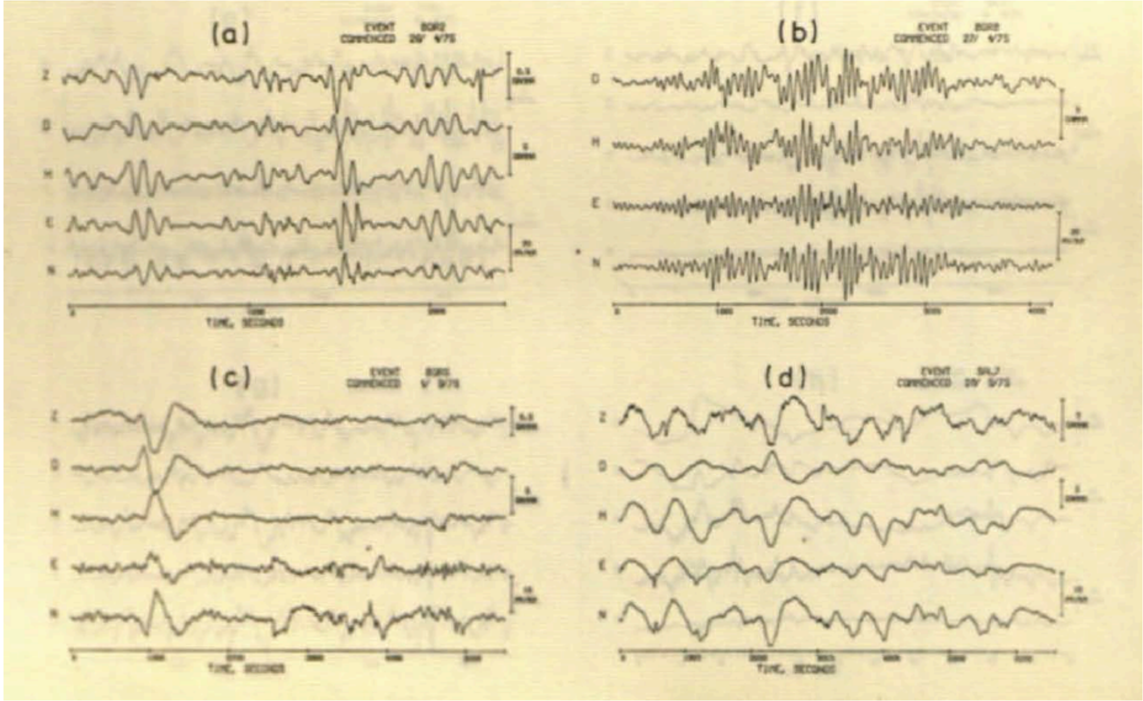
MT – the early days

Technological developments slow during 1950s to 1970s…



Edinburgh MT systems – 1972 vintage
Dr. Rosemary Hutton on right



Events recorded on paper
and hand digitized (by Jones)

COMPLETE MT SOLUTIONS

State of the Art MT Systems 1

- Low weight (5kg);
- Low power consumption (0.6A)
- Wide frequency range (DC to 30 KHz)
- Wide dynamic range (120db, 32-bit A/D)
  - better S/N; less risk of saturation
- Internal recording
  - (32MB flashcard, 1GB hard disk)
- Recording schedule downloaded from PC
- Latest innovation has recorders accessible through cell phone network

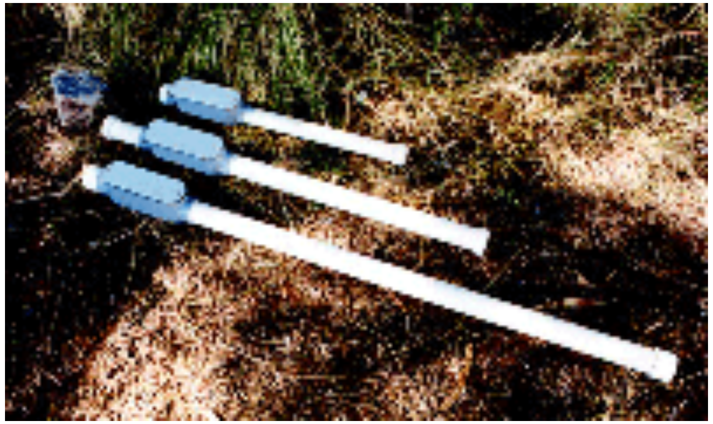
SOLUTIONS

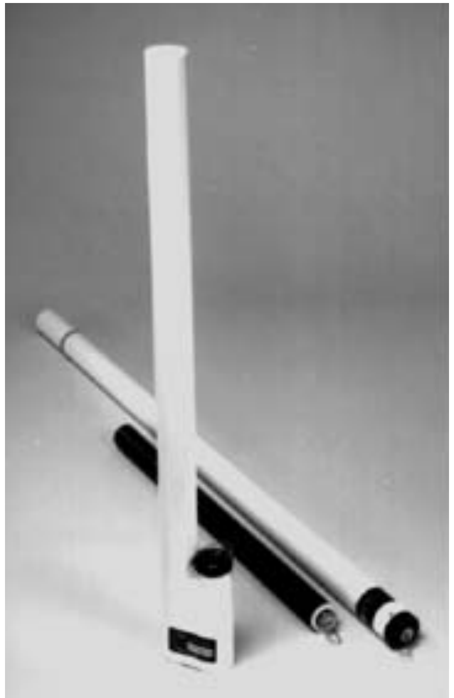
State of the Art MT Systems 2

- GPS-synchronized (130ns accuracy)
  - no cables or radios
- 2 to 8-channel units, all independent
- High reliability (ISO9001 std), etc.
- Fast set-up and deployment
  - increased production
- Operating from -40 to +75C; waterproof;
  - lightning protected

COMPLETE MT SOLUTIONS

Coils





Coils - installation

- Buried to stabilize
  - deeper for MT deadband
- Avoids wind noise
- Must be placed away from large tree roots – roots couple wind to ground movement
- Orientation within 1 or 2°
- Should be as level as possible
- Make sure coil cable buried, or held down every 0.5m, if recording MT deadband

COMPLETE MT SOLUTIONS

Hz – vertical coil

- Buried vertically as deep as possible

Coil tripods?

- Quicker deployment of magnetometers, esp. for AMT use
- Never been a fan of them
  - Tried the Metronix one in 1989…
- Too much sensitivity to wind and ground motion, even at high freqs.

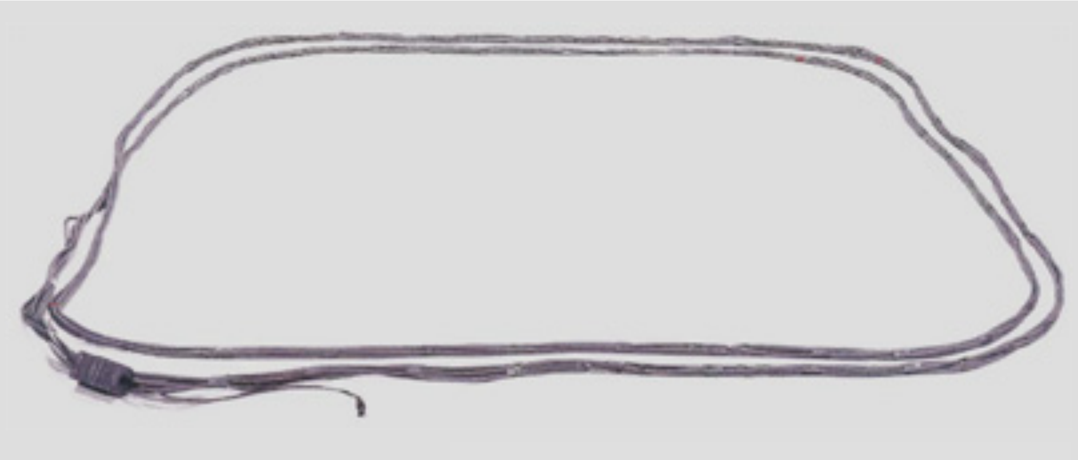
What might be feasible is an ARMIT-like tri-axial magnetometer system for AMT use – has close to the same specs as AMT-30 coil

For lower freqs for BBMT use then will need to shield it from wind vibration

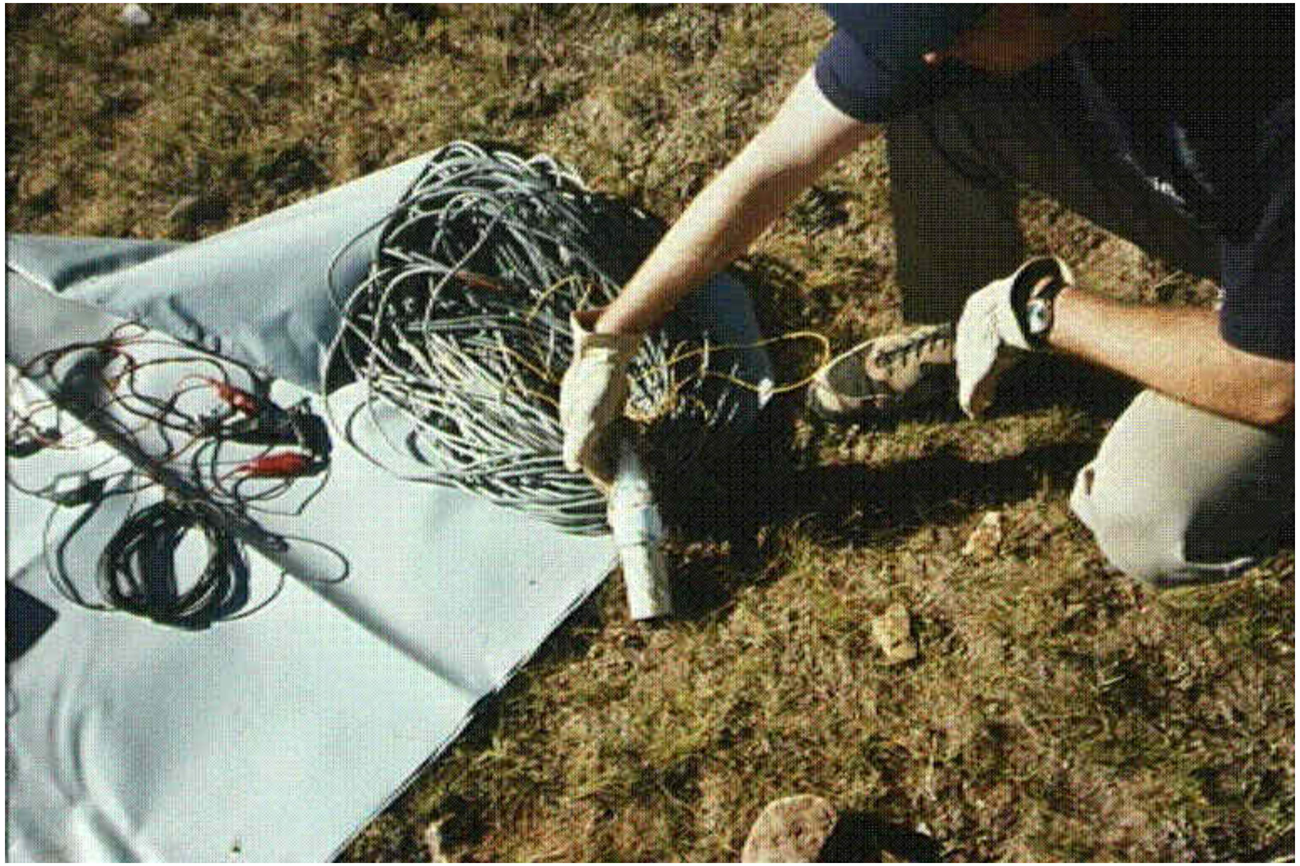
COMPLETE MT SOLUTIONS

Hz – horizontal air loop

- Easier to install than a vertical coil
- MUST be held down every 0.5m
- Only good for AMT frequencies – poor data for freq < 10 Hz.



Electrode with cable



COMPLETE MT SOLUTIONS

Polarizing solid metal Electrodes

- Can have high contact resistance
- A metal rod of length *L*, diameter *a*, in a half-space of ρ will have an intrinsic Faradaic contact resistance *R* of ➔

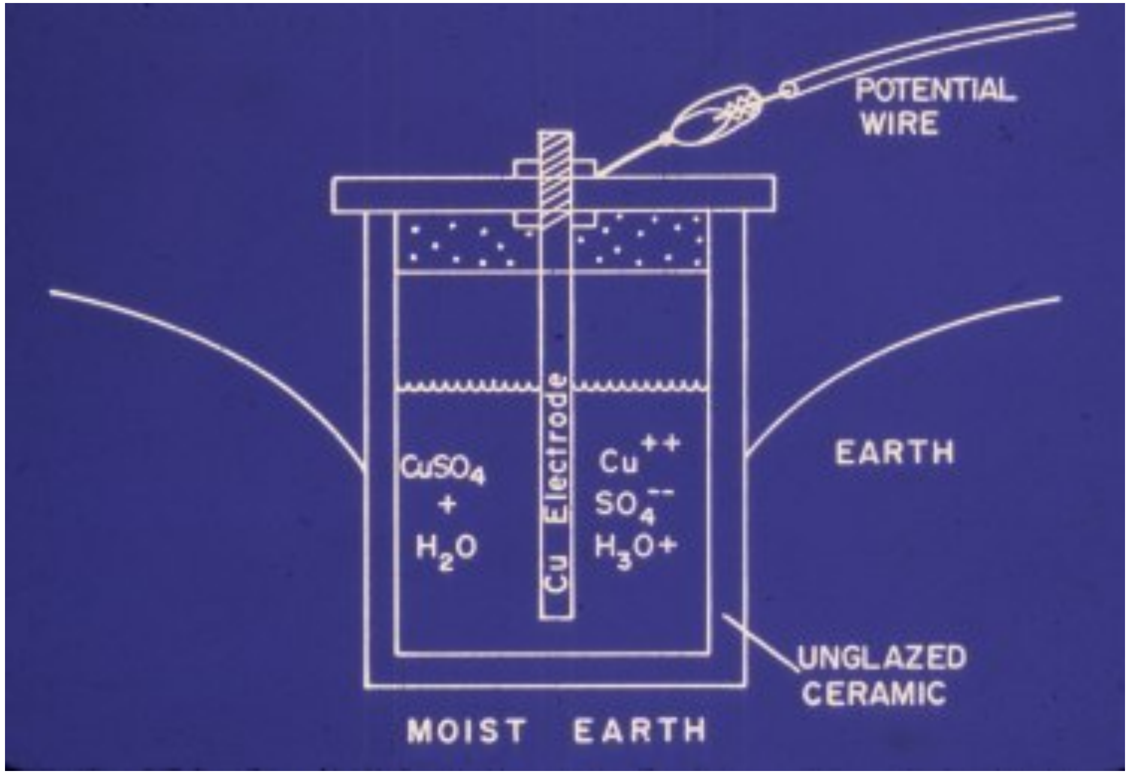
$$R = \frac{\rho}{2\pi L}\left[\ln\left(\frac{2L}{a}\right) - 1\right]$$

- A 1cm dia. rod buried 50 cm in 1,000 Ωm will have *R* = 1,150 Ωm
- If buried in dry sand of 5,000 Ωm then R = 5,750 Ωm
- If poor contact then this will dramatically increase

See Ferguson (2012) for more detailed discussion

COMPLETE MT SOLUTIONS

Non-polarizing Electrodes

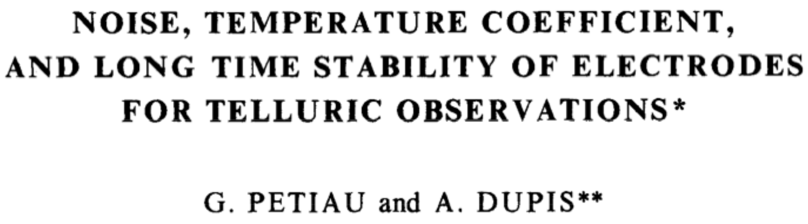


Geophysical Prospecting, 1980, 28, 792–804.

A metal and its salt – no polarization charges can build up

- Cu-$CuSO_4$ – cheapest, highest noise
- Pb-$PbCl_2$ – medium priced, medium noise
- Ag-AgCl – lowest noise, most expensive, used for marine applications

Comparison of a number of electrode designs and performance in Petiau and Dupis (1980)



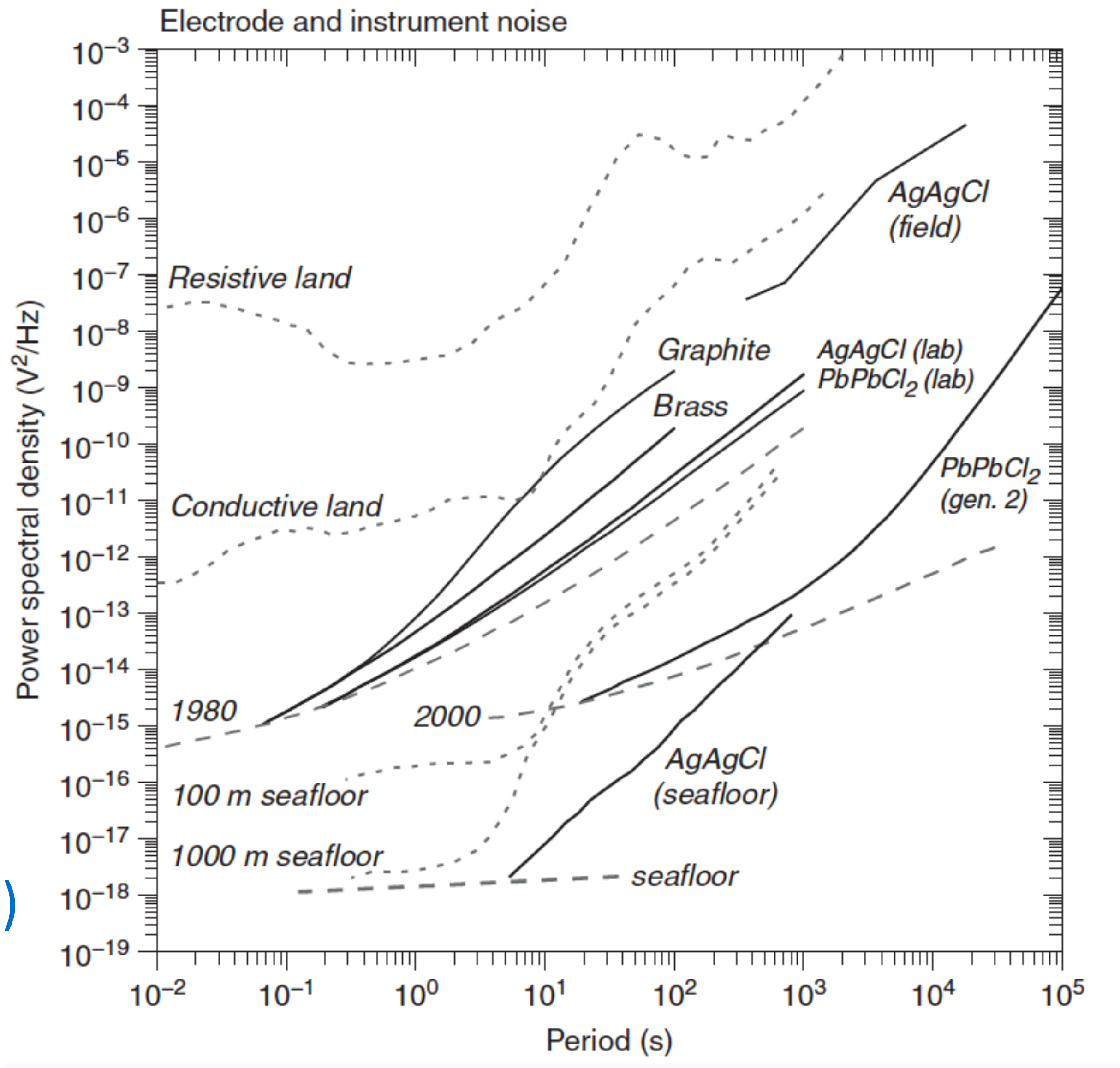
COMPLETE MT SOLUTIONS

Electrodes – noise levels

Solid lines are typical noise levels of various types of electrodes

Dashed lines are typical minimum signal levels

Ferguson (2012)



Electrodes

Pot buried for stability

- Need to stabilize for temp
- Need low contact resistance
- Generally less than 1 KΩ
- Important for long recordings
- Can use NaCl water, saltwater or bentonite-type mud slurry to reduce contact resistance

JUST BE AWARE OF ALL OF THE ELECTROCHEMICAL BOUNDARIES YOU ARE SETTING UP! Each one can introduce noise

- Boundary between the metal (Pb) and its salt electrolyte ($PbCl_2$)
- Boundary between the ($PbCl_2$) salt electrolyte and the (NaCl) mud slurry
- Boundary between the (NaCl) mud and surrounding rock

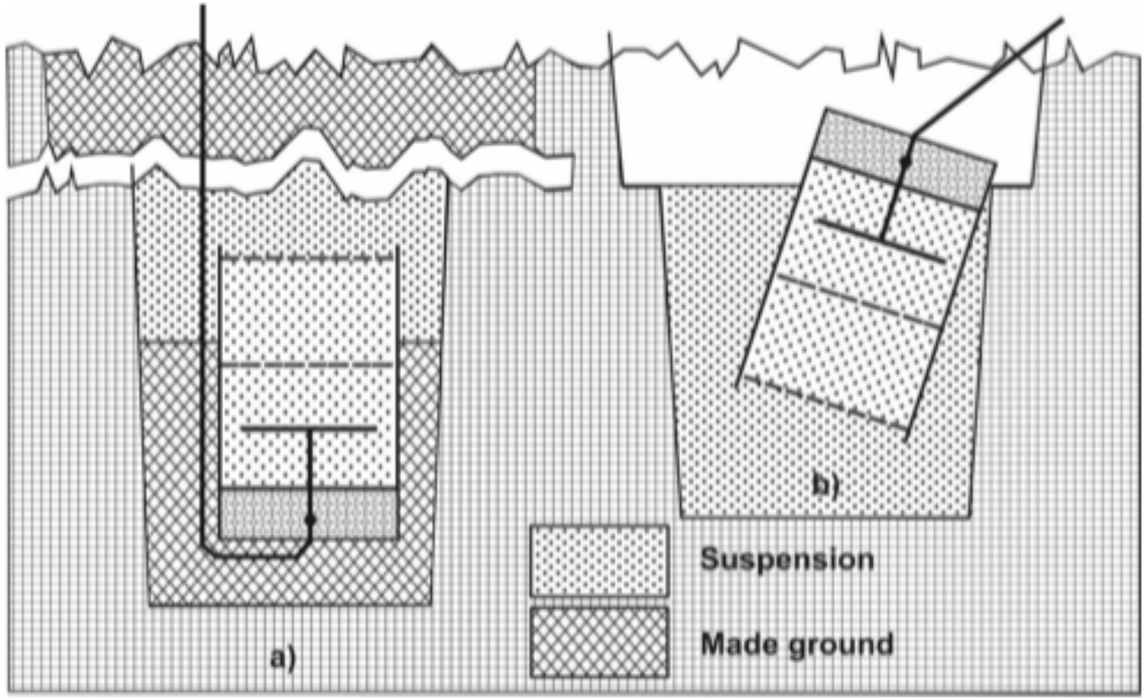
COMPLETE MT SOLUTIONS

Electrodes

If very dry ground (eg dry sand), then use the “Russian bucket” method

Place electrode upside-down in a bucket, then fill the bucket with a mud slurry.

The electrode “face” then becomes the top of the bucket, so this requires a deep hole to avoid thermal variations or drying out



COMPLETE MT SOLUTIONS

How can a Non-polarizing Electrode go bad?

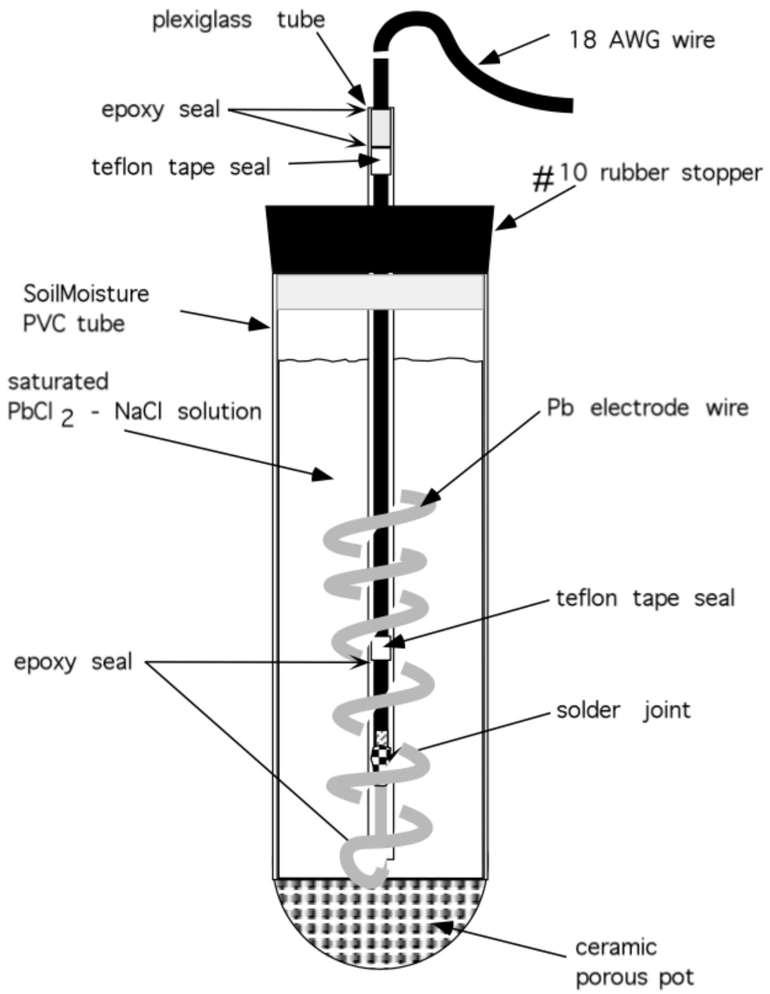


Figure B1. Diagram of Pb-$PbCl_2$ electrode

If the electrolyte is allowed to become too dry, or if “old”, then salt can precipitate onto the metal electrode

When this happens, the electrode becomes noisy due to polarization charges, and can act as a capacitor and build up charge.

The sign of this happening is if the electrode has a large DC value (>20 mV is considered a “bad” electrode)

COMPLETE MT SOLUTIONS

E-Lines

- Need to be known length
- Need to be straight line (between endpoints) – this avoids inductive effects due to Hz
- Azimuth within 1°
- Use compass or other means to “shoot in”

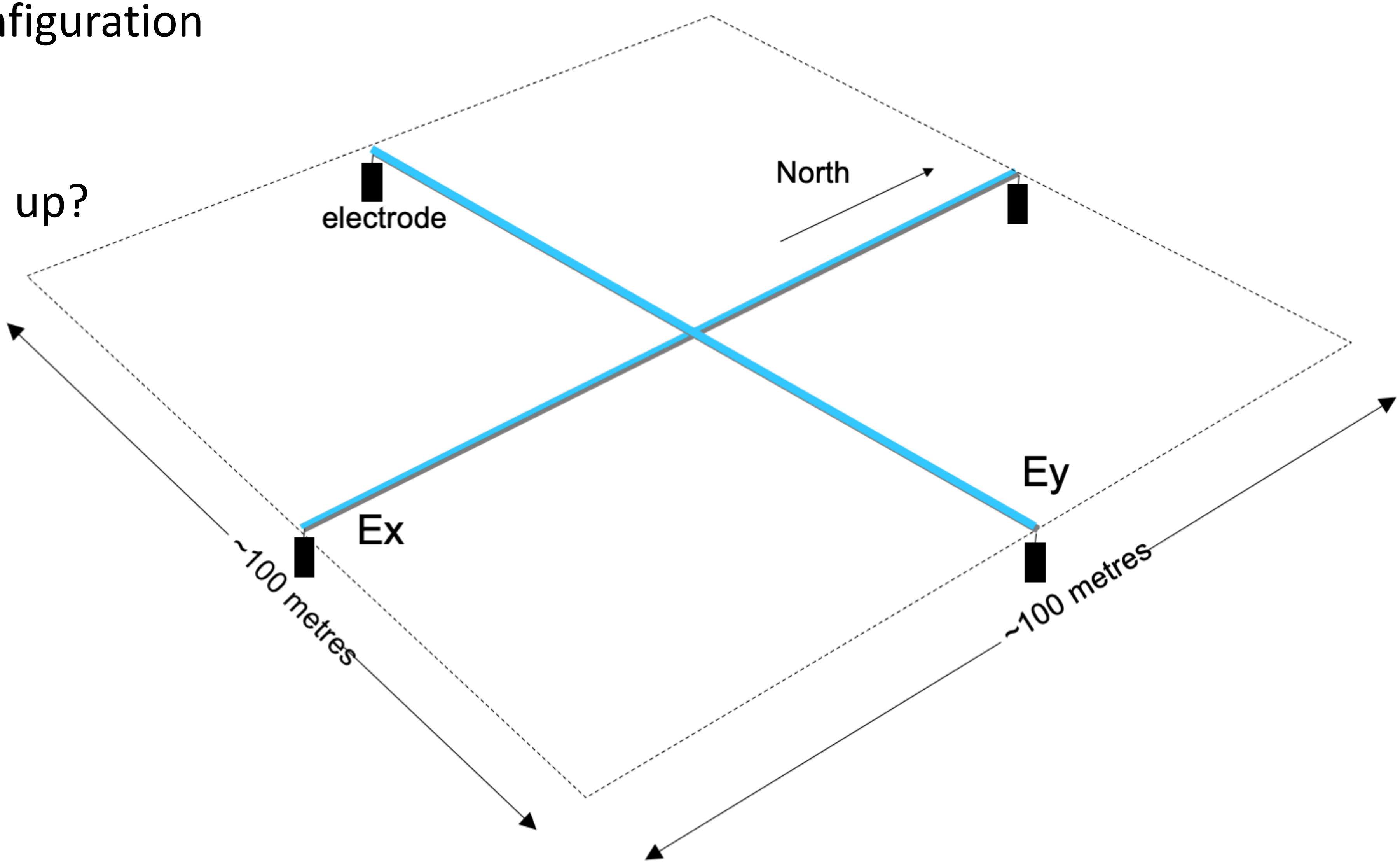
- Best wire to use is co-axial cable, with the shield open at the electrode and attached to the receiver ground at the receiver – forms a Faraday cage reducing induction pickup noise on the wire

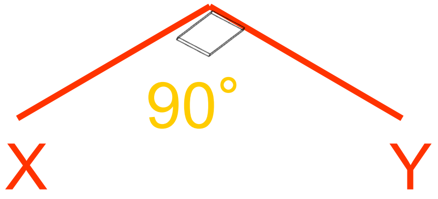
Electrode array configurations

Conventional configuration

X-array

How is this wired up?



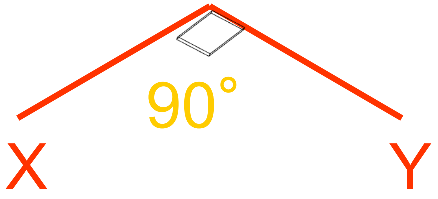


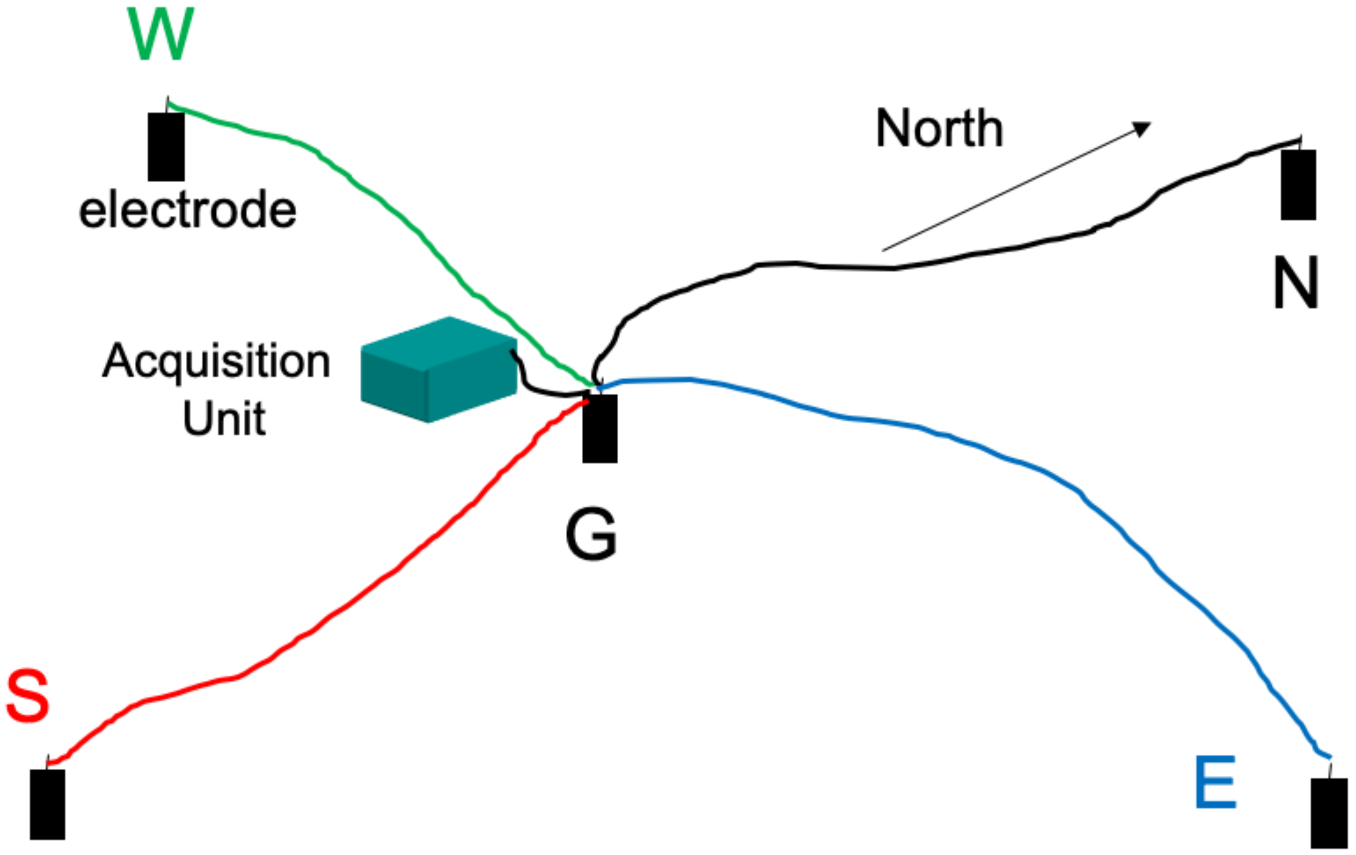
Electrode array configurations

Conventional configuration
X-array

All electrodes referenced to the system ground G

System ground MUST BE A LOW NOISE ELECTRODE AND BE VERY WELL INSTALLED!!! Otherwise the receiver may “float” and you get noise when it discharges. But noise on G doesn’t matter.

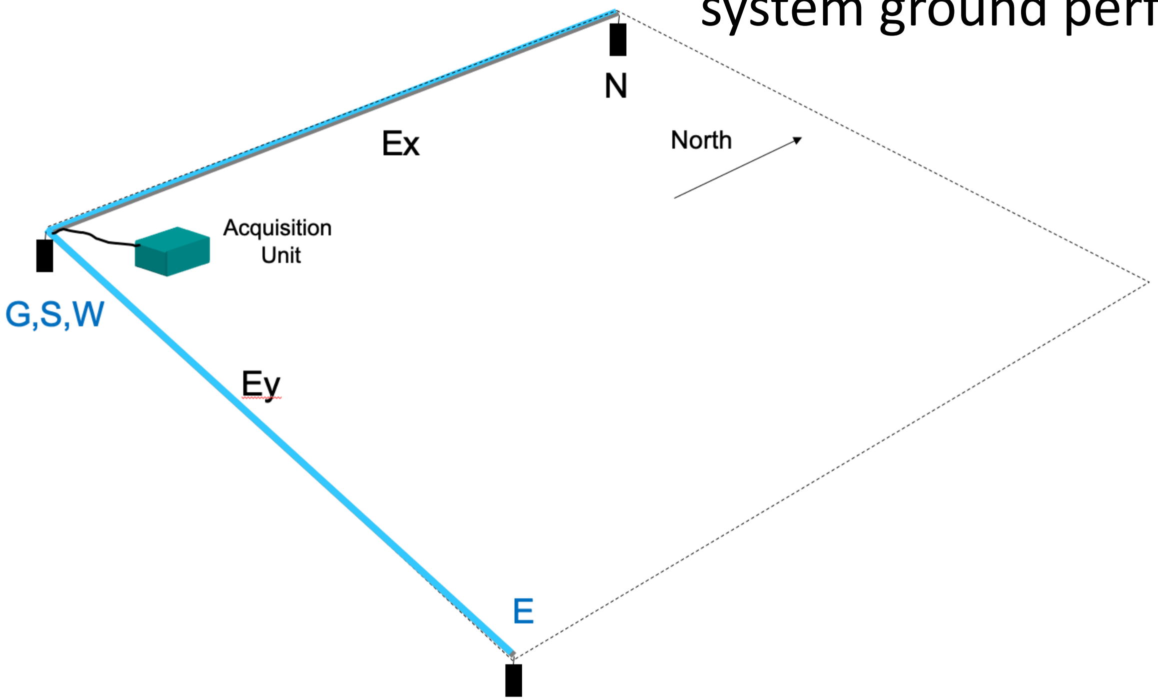




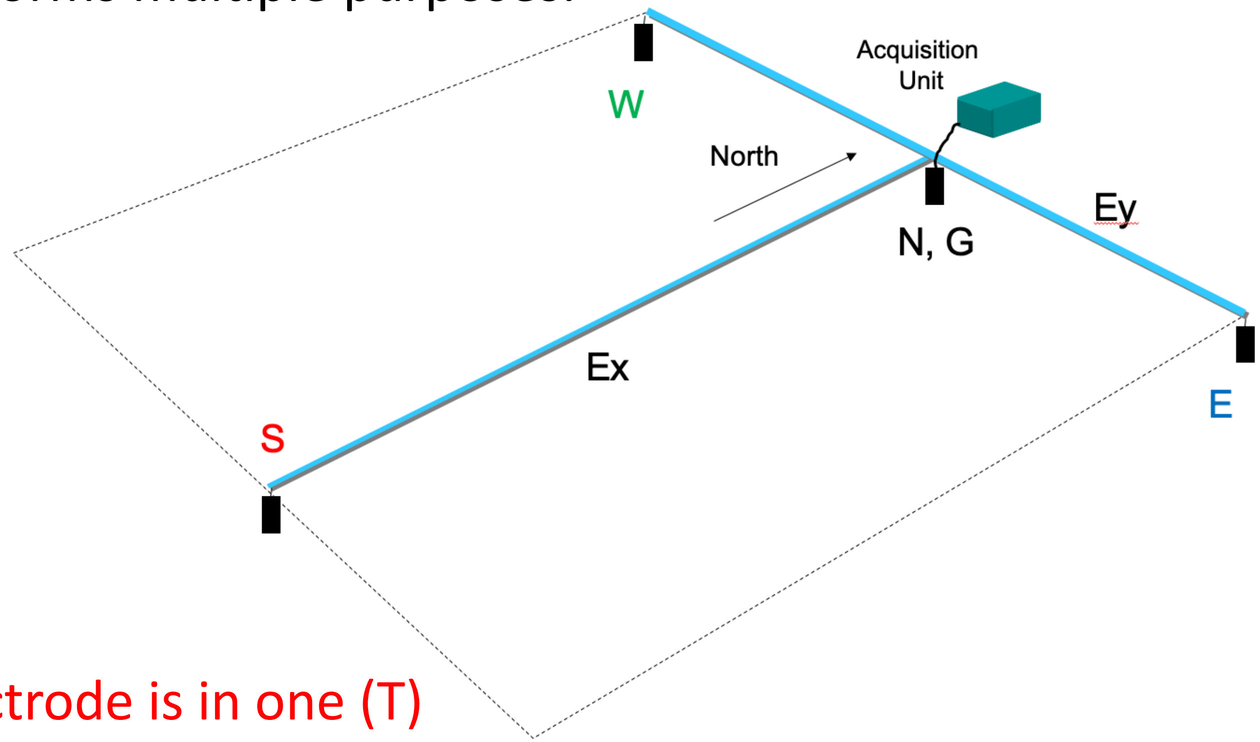
Electrode array configurations

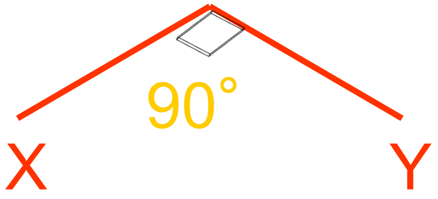
Both of these are quicker to install as less electrode holes to dig. But in both of them the system ground performs multiple purposes.

L-array



T-array





Any noise on the G electrode is in one (T) or both (L) time series. If in both (L) then correlated (ExEy) noise → can lead to problems in impedance estimation

COMPLETE MT SOLUTIONS

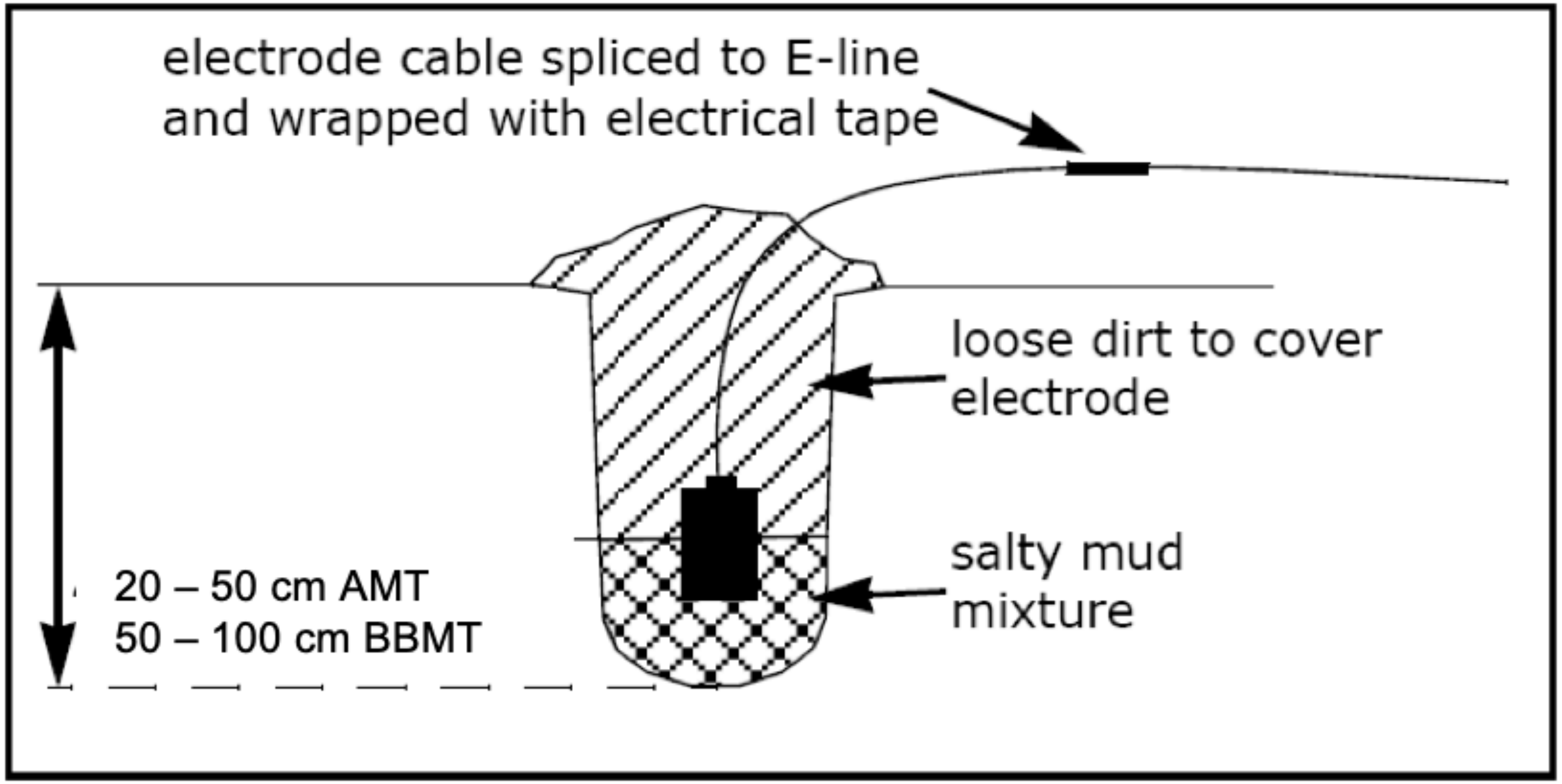
Splice electrode to E-line

Splice the end of the electrode wire to the E-line

MAKE SURE BOTH ARE CLEAN!!! Cut wire back if necessary

Do NOT use connector plugs!

Wrap splice with electrical tape and ensure no possibility of water getting in



E-lines

What is wrong with this picture???

COMPLETE MT SOLUTIONS

E-lines

What is wrong with this picture???

E-lines not help down every 0.5m to reduce wind-noise pickup

COMPLETE MT SOLUTIONS

Checking electrodes – beginning and end of acquisition at each site

- DC measurement – for electrode state
  - Measure the DC voltage between pairs of electrodes – N to S, E to W. Look for high DC levels >20-30 mV. Usually a sign of a bad electrode. Isolate which electrode by performing N to G, S to G, etc., and replace
- AC measurement – for AC noise source
  - Measure AC voltage between pairs of electrodes. Gives level of AC noise. Should be <50 mV or might saturate (although modern 24-bit systems less likely to)
- Resistance measurement – for grounding
  - Measure QUICKLY the resistance between pairs of electrodes – This is an active measurement and can polarize the electrodes so be quick and perform forward and reverse. Should be < 1 kΩ for AMT, < 10 kΩ for BBMT.
  - Best to use an analogue multimeter – far lower current used

COMPLETE MT SOLUTIONS

Power Supply

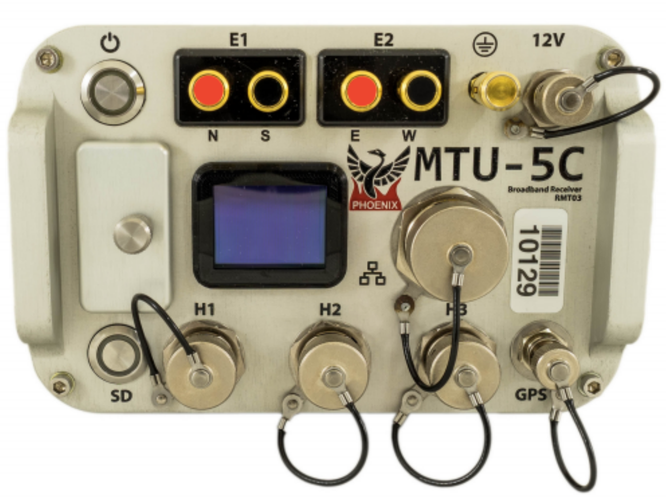
- Normally 12V batteries (as for a vehicle)
- Replaced and recharged every day
- Can be recharged with solar cells

Receiver/Recorder

- Receives all sensors via cable
- Main job is to digitize the time series
  - Digitizing rate depends on band
  - ~64 Hz for lower frequencies
  - ~512 to 2048 for higher frequencies
- Contains gain, filters, amplifiers, etc.
- All data (time series) is stored in memory

Receiver/recorder

Phoenix



Metronix ADU

COMPLETE MT SOLUTIONS

Recording unit with batteries

- Batteries are normally swapped out each day
- Recharged over night
- Possible to use solar cells to recharge

COMPLETE MT SOLUTIONS

Remote Reference

- Stations are coordinated by GPS timing signals
- Very accurate and very important
- Allows for stations to be great distances apart
- Almost always – H field is usually used for reference
  - More stable; less noise usually than E-field
  - Exception is the AMT dead-band – better to use an e-field for remote referencing

GPS

- May be difficult in certain localities to receive good gps signal

Conclusions

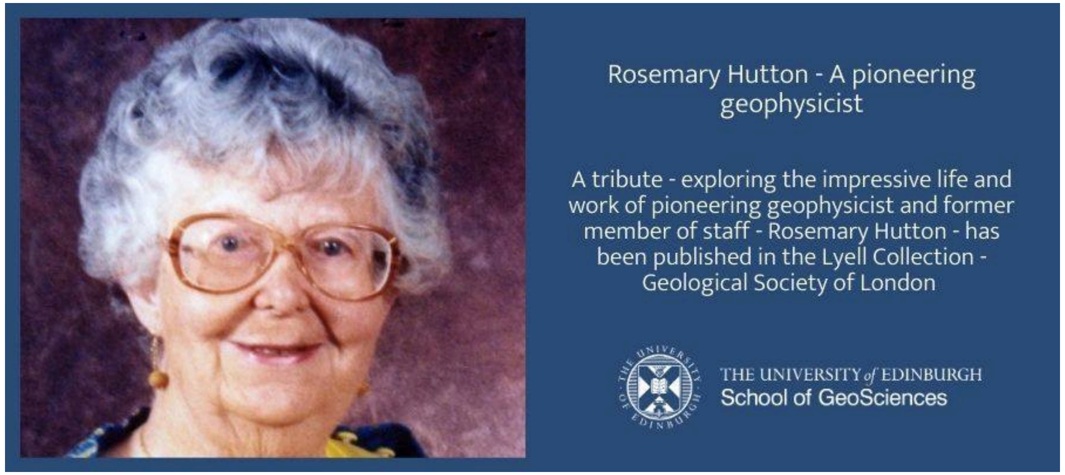
- MT data acquisition is not easy to do
- It requires at least the same diligence, care and attention as subsequent processing, analyses and inversions
- Consider EVERYTHING – electrodes, electrode lines, coils, coil cables, receiver, GPS, remotes
- Do NOT rush the fieldwork. Far better to spend more time in the field than 10x that time in the lab trying to resuscitate poor data

Acknowledgements

A number of people have mentored me on my journey through magnetotellurics since 1974…

Some of them in particular showed me how to perform high quality fieldwork with attention to every detail:

- Rosemary Hutton (U Edinburgh)
- Ron Kurtz (GSC)
- John Booker (UW)
- George Elliot and Gerry Graham (Phoenix)



COMPLETE MT SOLUTIONS