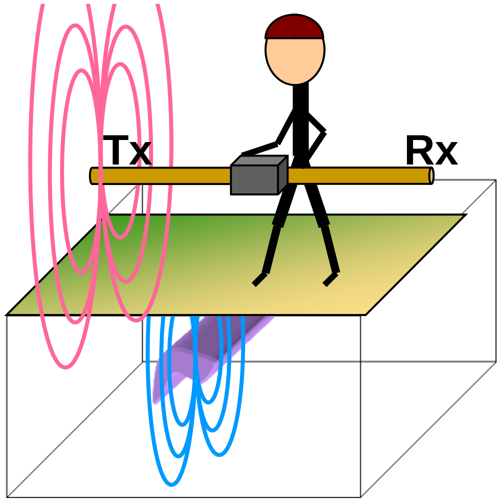
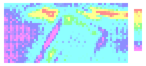
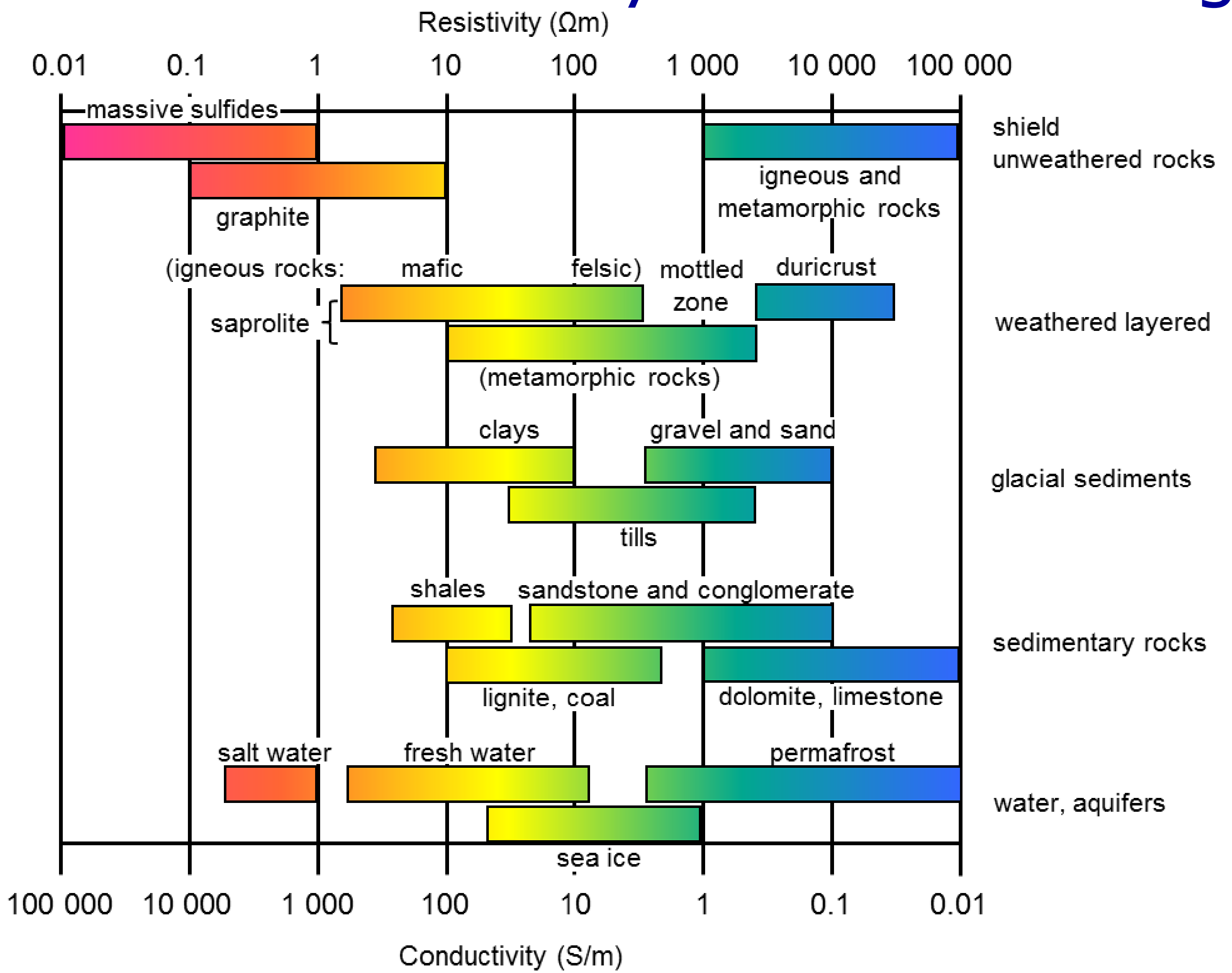
Applied Geophysics – Electromagnetics

- EM induction methods
- Amperes Law
- Faradays Law
- Basics of EM induction
- Use EM31 as a specific learning example



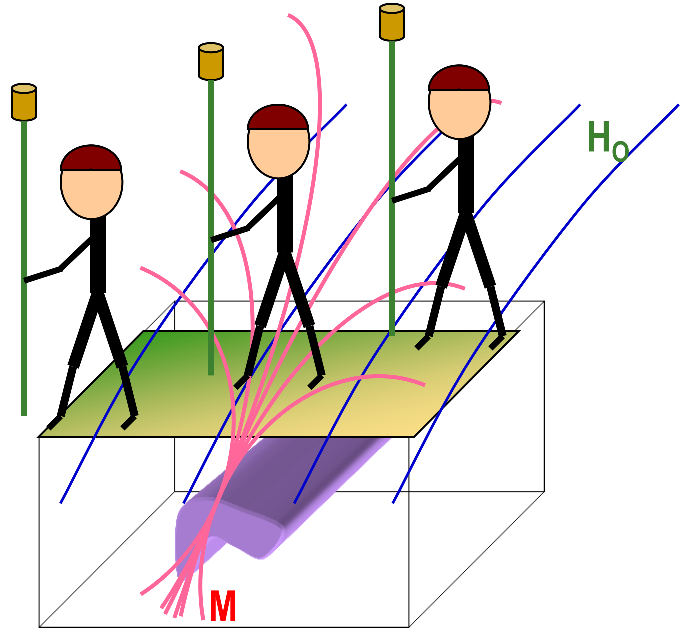


Electrical conductivity: units and range



Previous work: Magnetic induction

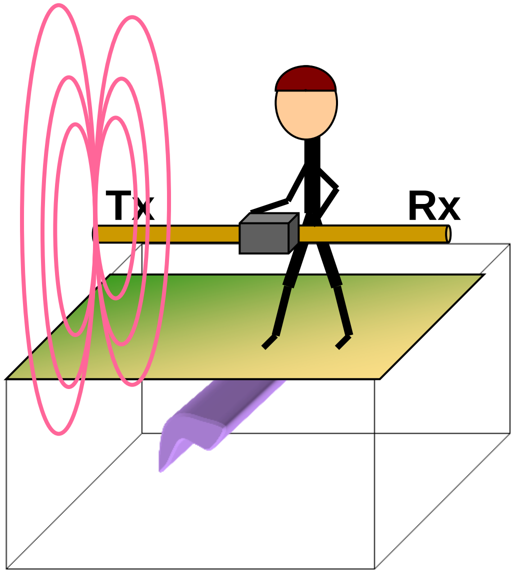
- Instrument is a sensor only
- Source is Earth's field – always present.
- Relatively uniform at survey scales
- Source field does not change with time.



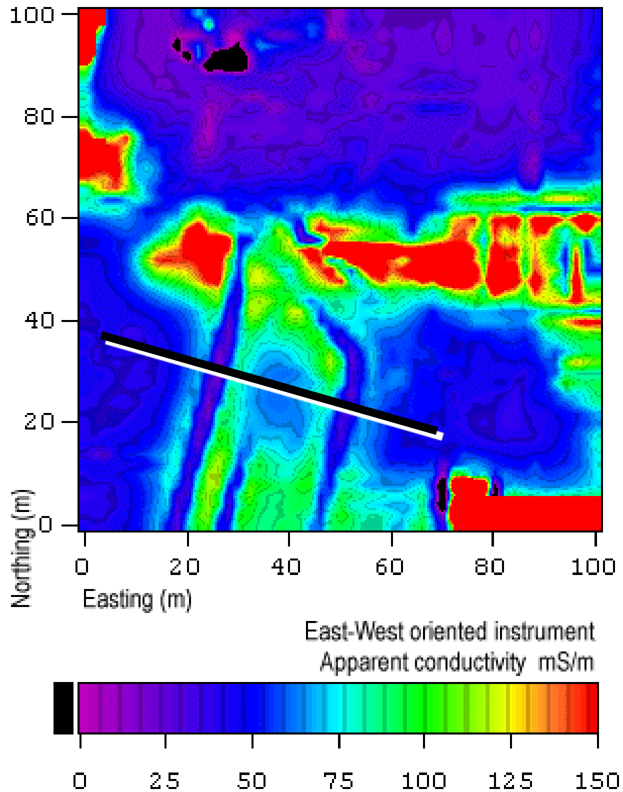
Electromagnetic induction

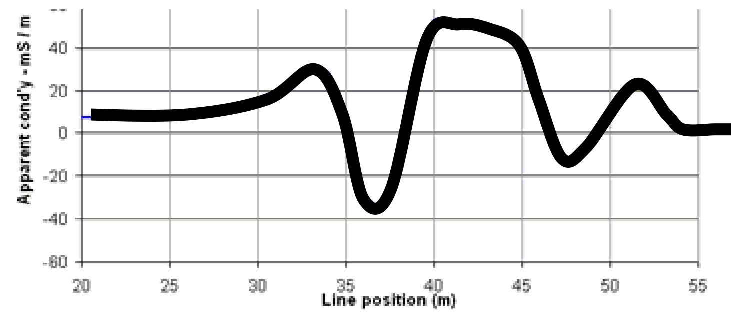
- Survey involves a transmitter and receiver
- Source field changes – it is NOT a static field
- Frequency ~ 10^1 – 10^4 Hz

(GPR is ~ 10^6 – 10^9 Hz)



EM 31 Data from Expo Site





Electromagnetics

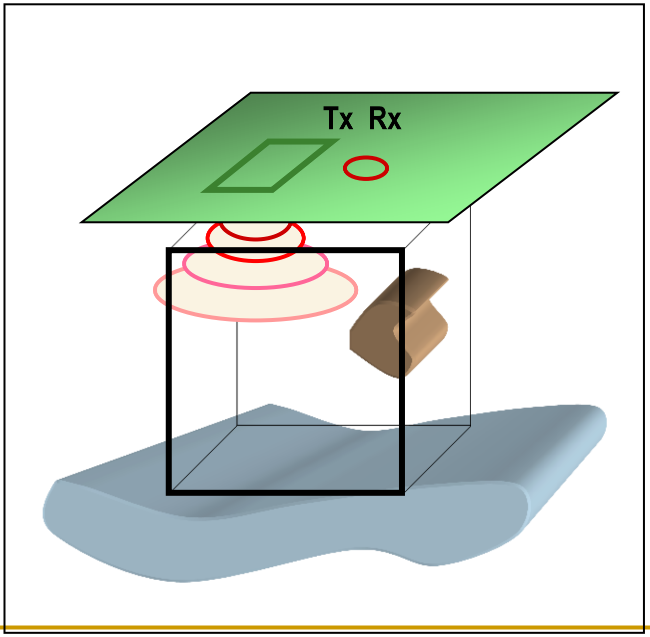
- **Faraday's Law:** A time varying magnetic field generates an electric field

$$\nabla \times \mathbf{E} = -dB/dt$$

E: electric field
B: magnetic field

Think about electric field as voltage in a circuit.
Units of E are Volts/meter

Electromagnetic induction



Electromagnetics

- **Ohm's Law:**

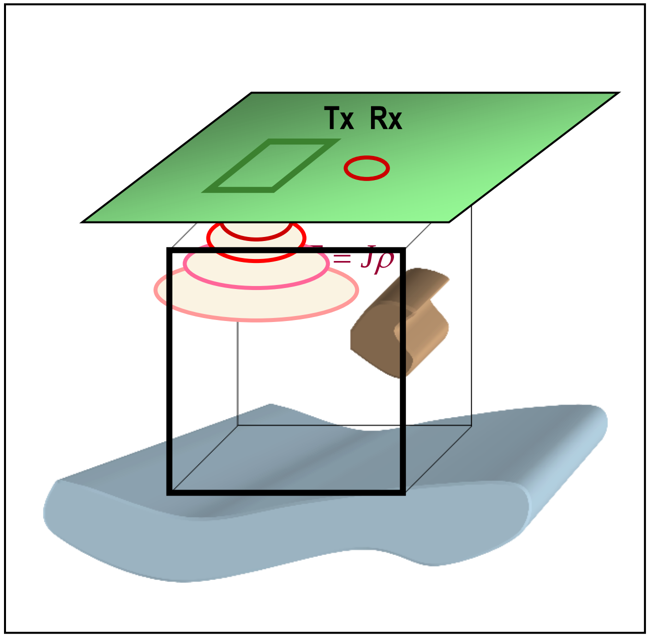
$$J=\sigma E$$

J : current density (Amp/m^2)

σ : electrical conductivity

Think about V=IR for a circuit
V: voltage (Volts)
I: current (Amperes).
R: Resistance (Ohms)

Electromagnetic induction

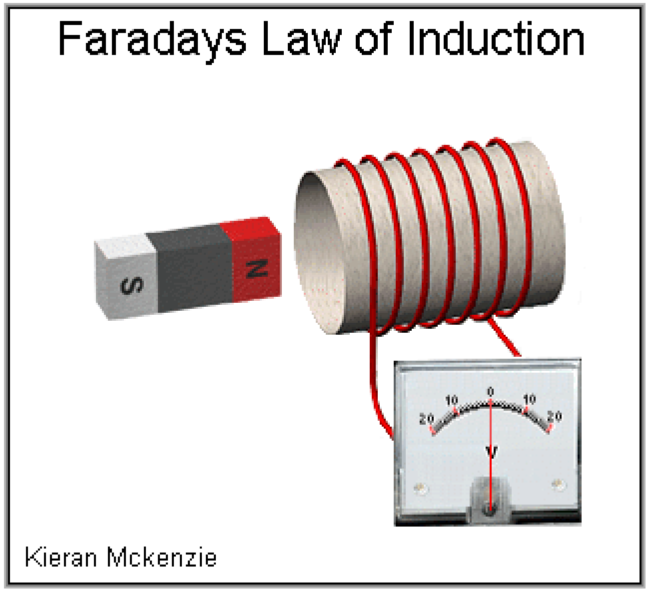


$$E = J\rho$$

$$\rho = 1/\sigma$$

EM induction

- Faraday’s law
  - Time varying magnetic fields cause electric fields
  - Electric fields produce currents in a conductor
  - Hence current flows in conductors that are near an oscillating magnetic field



Electromagnetics

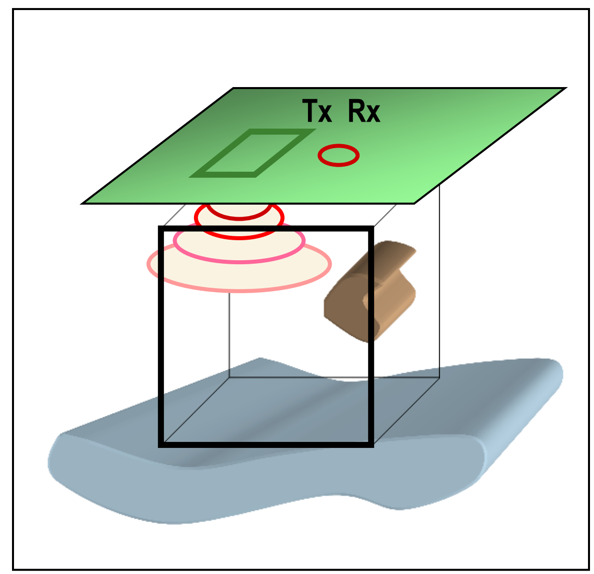
- **Amperes Law:**

  A current generates a magnetic field

$$\nabla \times \mathbf{H} = \mathbf{J}$$

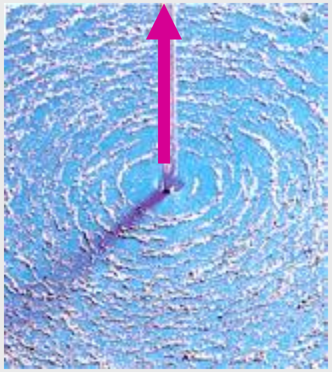
H: magnetic field
J: current source density

Electromagnetic induction



EM induction

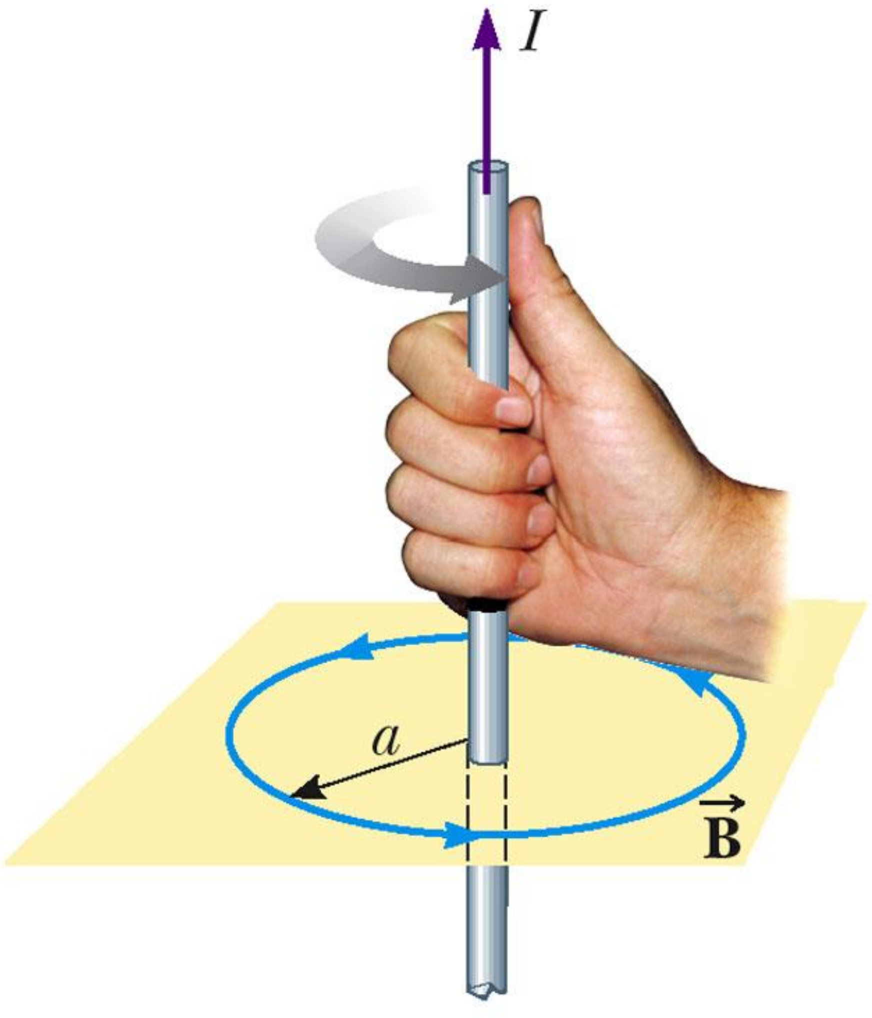
- Ampere's law -
  - Currents generate magnetic fields
  - Oscillating current will cause an oscillating magnetic field



Current in wire causes a magnetic field to sur-round it (iron filings).

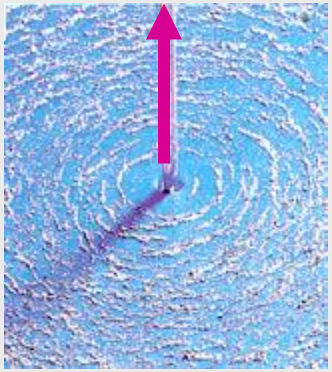
Direction of the Field of a Long Straight Wire

- Right Hand Rule
  - Grasp the wire in your right hand
  - Point your thumb in the direction of the current
  - Your fingers will curl in the direction of the field



EM induction

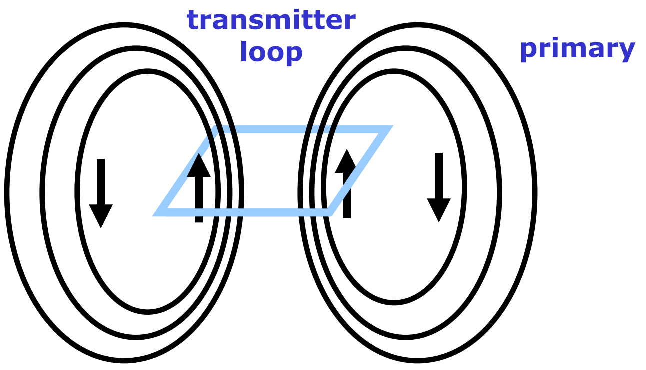
- Lens' law -
  - The direction of the induced currents will be in such a direction as to oppose any change in magnetic flux.



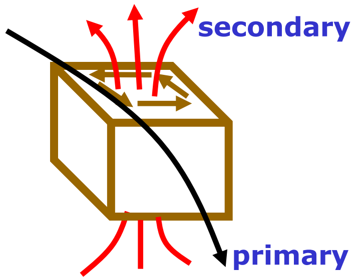
Current in wire causes a magnetic field to surround it (iron filings).

Basic principles of EM induction

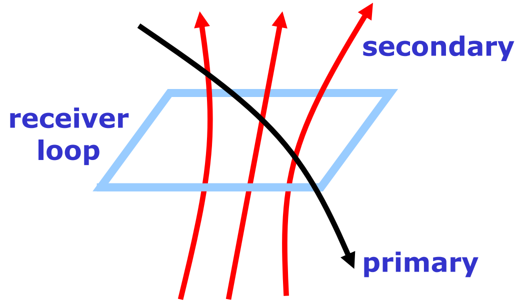
- Time-varying transmitter current generates a time-varying magnetic field



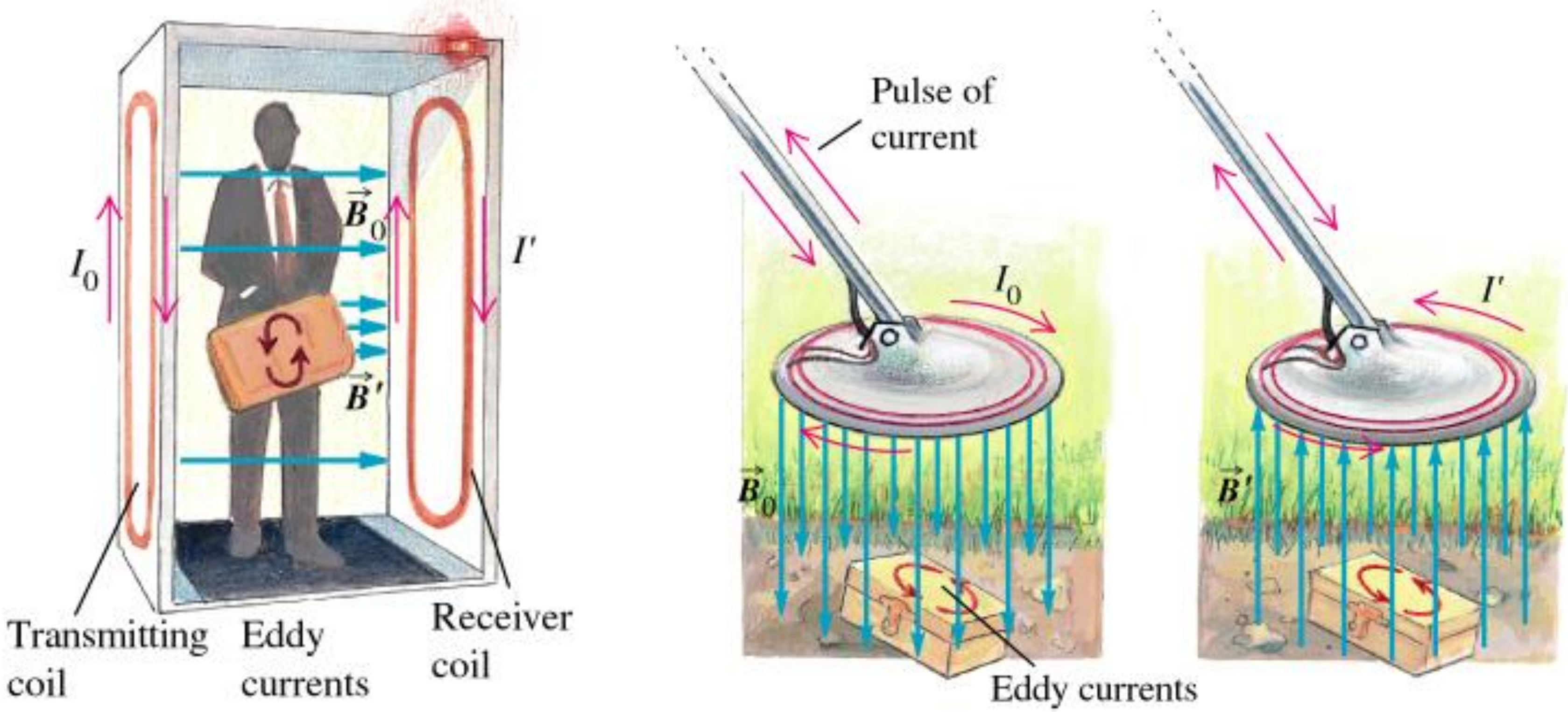
- Time-varying magnetic field generates an EMF (i.e. electric field) in the earth
- Currents are generated ($\mathbf{J} = \sigma \mathbf{E}$)



- Currents in the conductor generate magnetic fields (secondary)
- Measure the secondary fields and the primary fields of the transmitter



EM induction example: small scale



- Transmit alternating ***primary*** magnetic field
  - Induces eddy currents in conducting object
- Eddy currents produce ***secondary*** magnetic field
  - Induces current in receiver coil

Important elements

- Primary field must couple with the target
- Strength of the induced currents must be big enough to generate signal
- Need to choose which fields to measure

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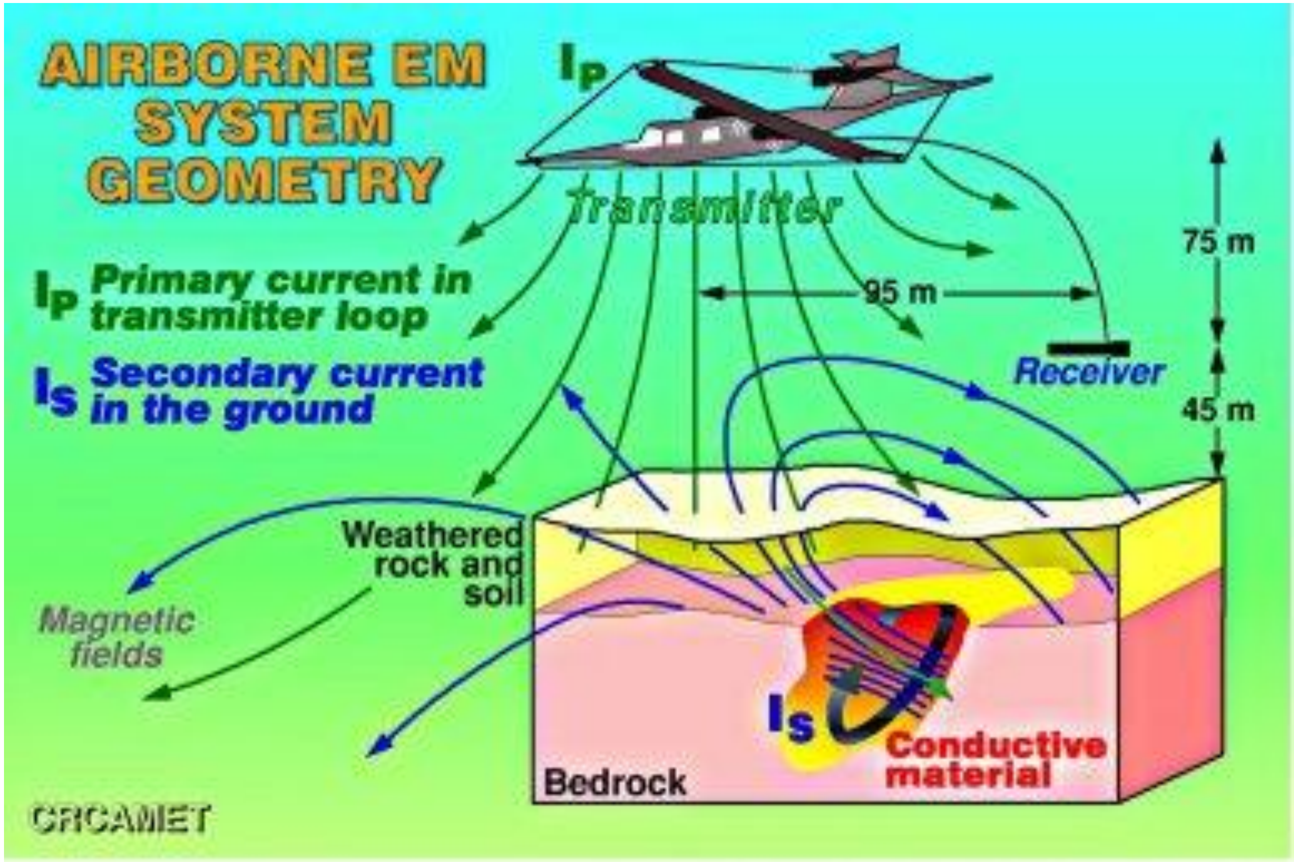
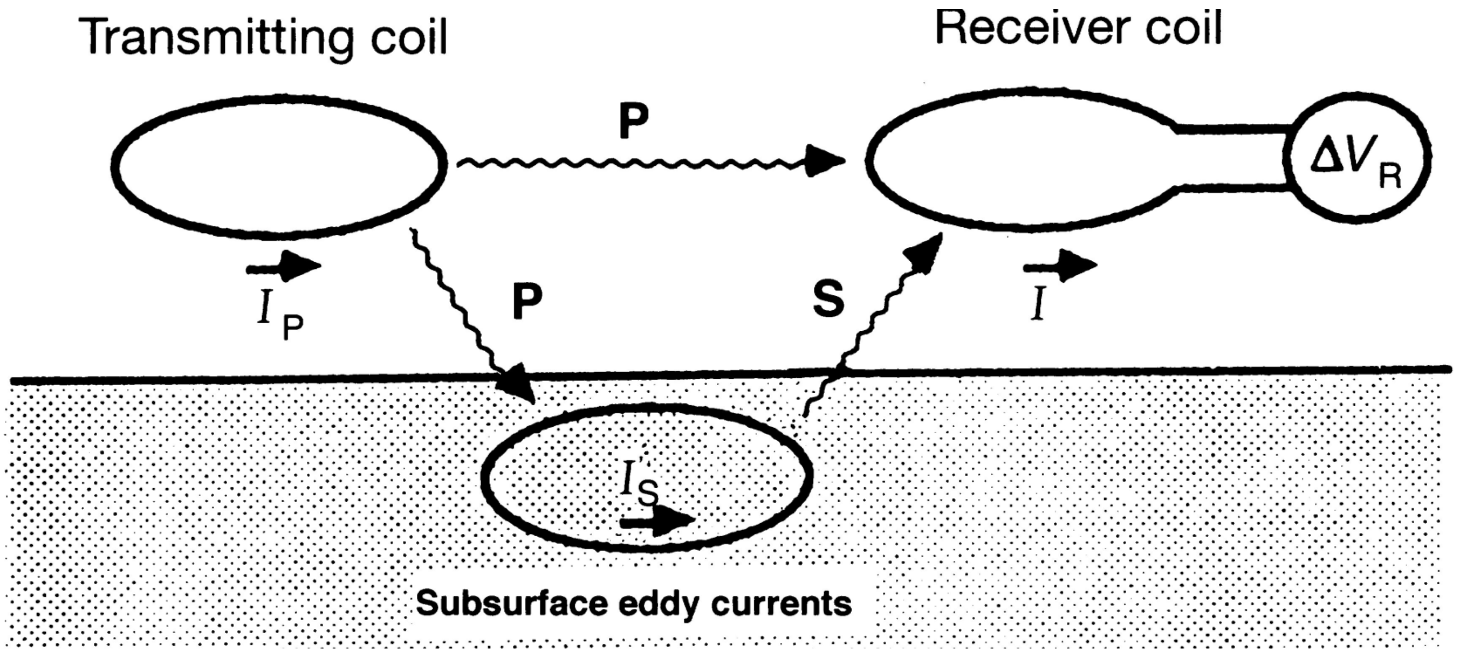
Airborne (Inductive source)



Elements of EM Induction

- Transmitter and primary magnetic field
- Magnetic flux and coupling
- Target and induced currents
- Secondary magnetic fields
- Receiver
- Data

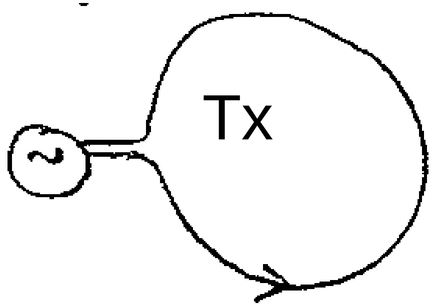
Generic EM system

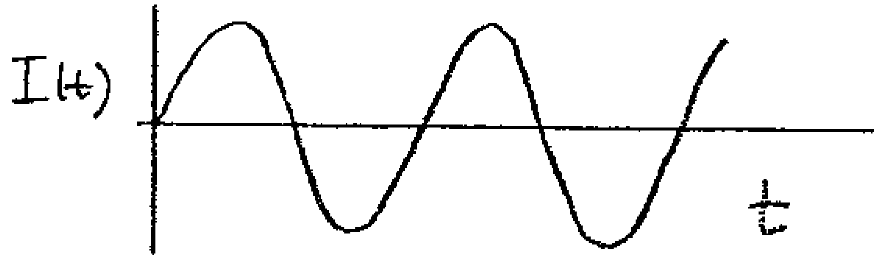


Tx: transmitter   Rx: receiver

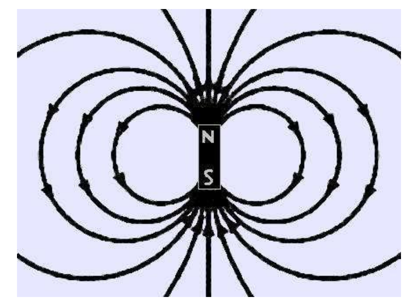
Tx, Rx, target body are represented as circuits

Transmitter





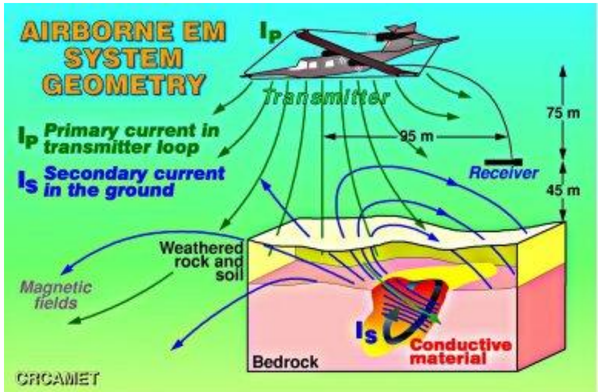
Magnetic field of a loop of current is like a magnetic dipole

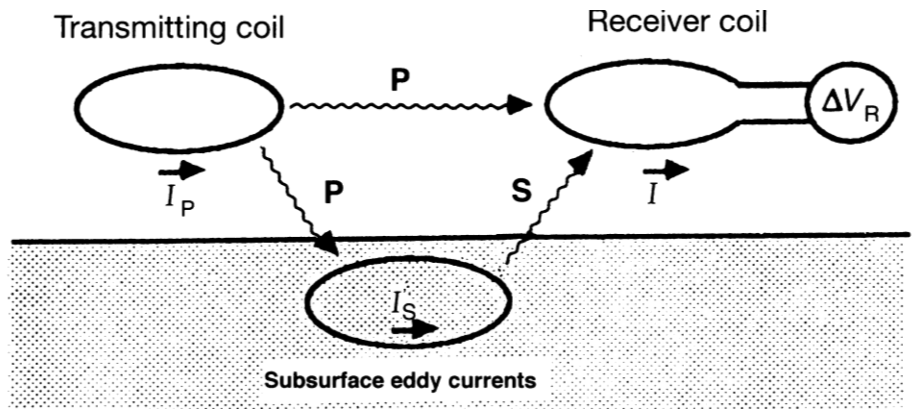


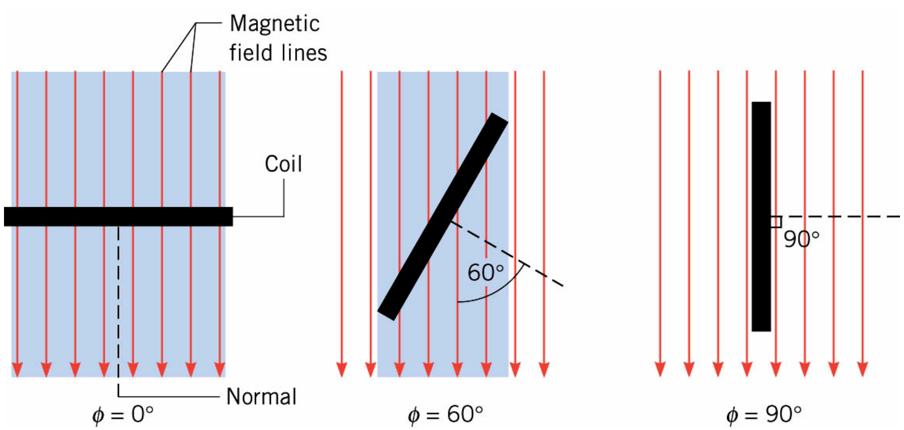
Dipole moment $m = I A$ (current x area)

Orientation of loop shows direction of primary field

Couple with the target







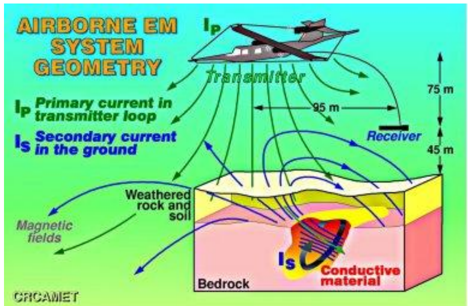
$$\phi_B = \int_{area} \vec{B} \cdot \hat{n}\, da$$

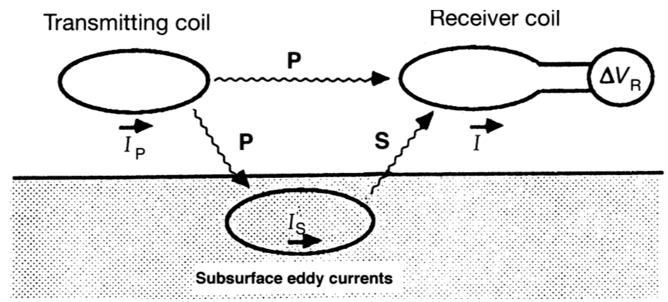
$$V = -\frac{d\phi_B}{dt}$$

Max flux

Zero flux

Induced Currents in the Target





$$\phi_B = \int_{area} \vec{B} \cdot \hat{n}\, da$$

Think of target as an electrical circuit

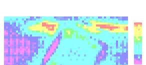
Resistance R (small R means large current)

$$V = -\frac{d\phi_B}{dt}$$

Inductance L (accounts for interaction
of currents in the target

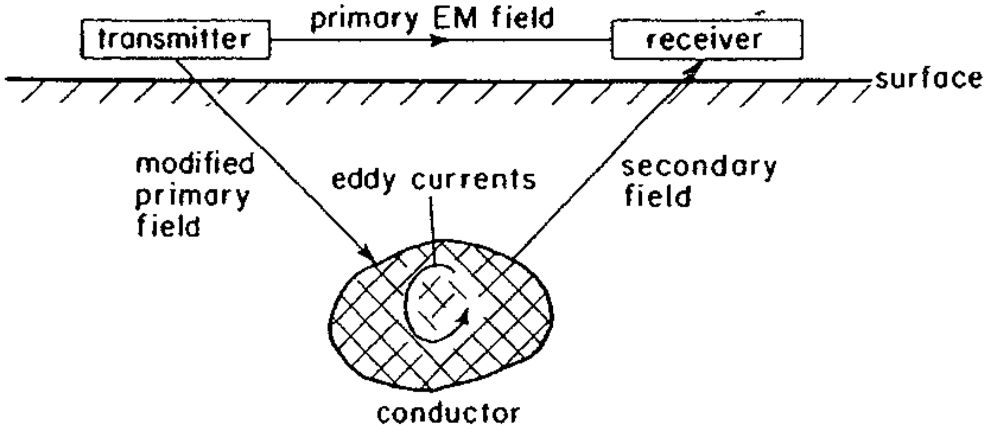
Max flux

Zero flux



Secondary Magnetic Fields

- Currents in the target generate magnetic fields
- If target is modelled by a current circuit then secondary magnetic fields are like those of a magnetic dipole.



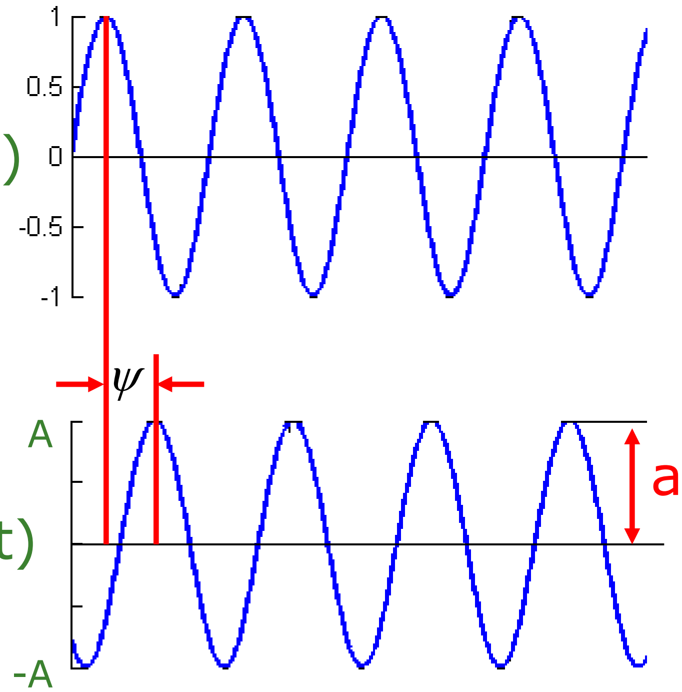
Receiver

- Receiver is a coil. A time varying flux generates a voltage.

- For some instruments Hp is known and subtracted. Then receiver measures only Hs.

Frequency domain EM data

Transmitter I(t)



$\cos(\omega t)$

Receiver V(t)

$A\cos(\omega t + \psi)$

Measure amplitude and phase (A,ψ)

Or $$A\cos(\omega t + \phi\psi) = (A\cos\psi)\cos\omega t + (A\sin\psi)\sin\omega t$$

In-phase
Real

Out-of-phase
Imaginary

Data

- Signal in receiver is harmonic (sinusoid) but not in phase with the primary.

- Decompose into portion
  - In-Phase (Real)
  - Out-of-phase (Quadrature, Imaginary)

$$\psi = \frac{\pi}{2} + tan^{-1}\left(\frac{\omega L}{R}\right)$$

$$H_s cos(\omega t + \psi) = H_s\{cos(\omega t)cos\psi - sin(\omega t)sin\psi\}$$
$$= \{H_s cos\psi\}cos(\omega t) - \{H_s sin\psi\}sin(\omega t)$$

In – phase : $\frac{H_s cos(\psi)}{H_p}$ **Out – of – phase :** $\frac{H_s sin\psi}{H_p}$

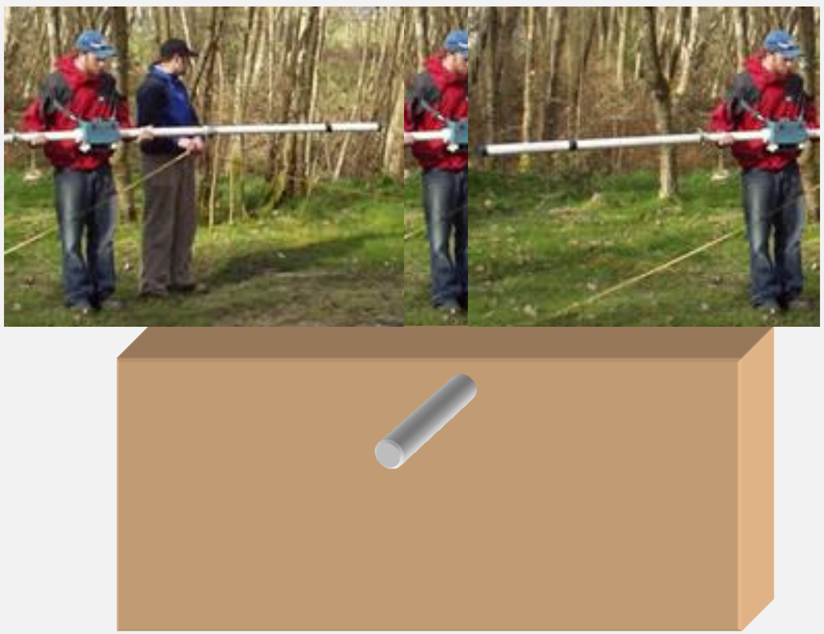
Understanding the Data

- Read the electromagnetic notes
- Learn how to understand the response of a system like the EM31 as it goes over a conductive plate.
- The first task is to work with the basic principles of EM induction and sketch out the signal caused by geometry

Effect of buried objects

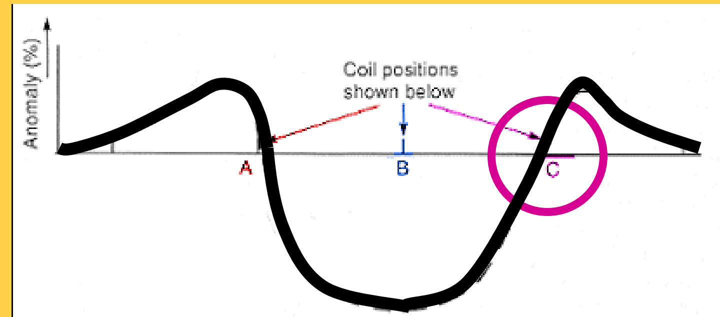
- See GPG Ch3.h.
- Source field moves with receiver.

FIELD



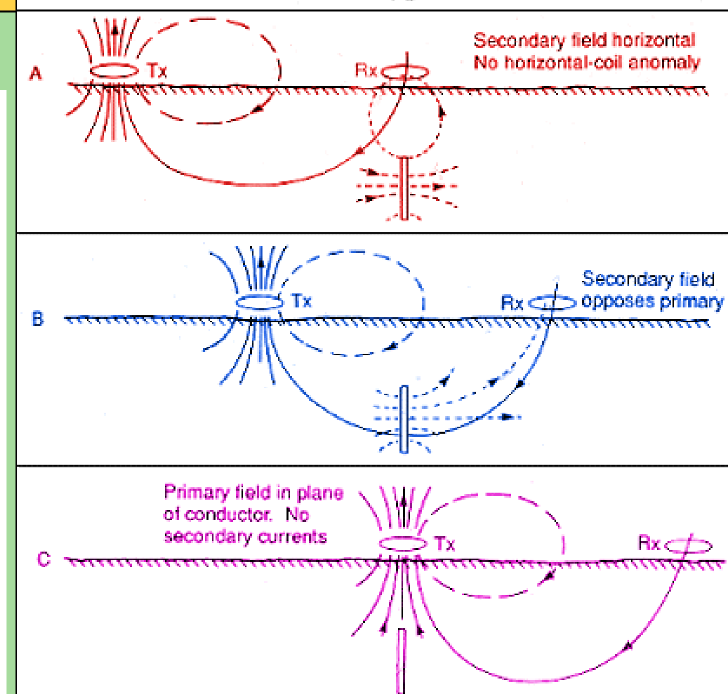
DATA

Graph measurements vs line position

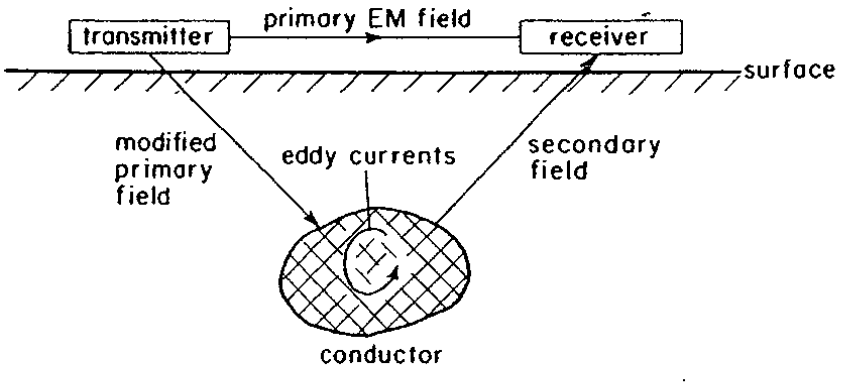


PHYSICS

Instrument, fields, and target



EM Induction: Sun

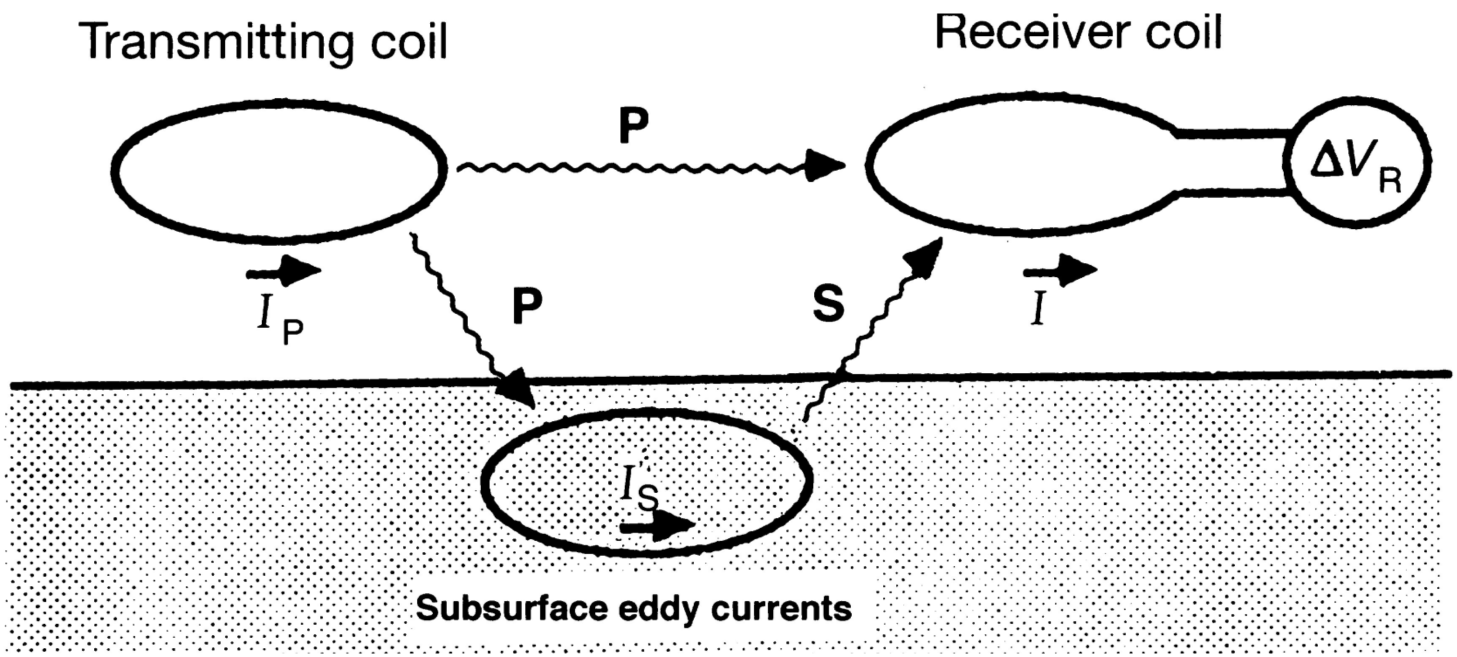


- Time varying magnetic magnetic field generates an electric field E
- J=σE (induced currents) (Coupling is important)
- Induced currents generate secondary magnetic fields
- Secondary magnetic fields are recorded at the receiver. Coupling is important.
- Receiver outputs In-Phase and Out-of-phase data

Understanding the Data

- We can now sketch the effects of geometry and coupling on an EM31 as it passes over a plate. This is essentially controlled by geometry and coupling.
- Next we'll consider the information in the in-phase and quadrature phase
- Read the EM notes
- Matlab routine to estimate the responses.
- demos.....

Earth is also a conductor



Depth of investigation depends upon

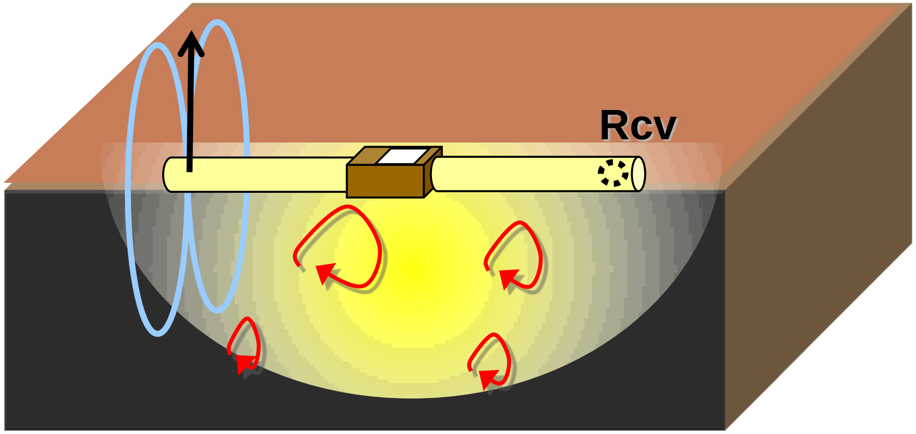
skin depth

source receiver geometry

Meaning of readings over earth

- Earth is a conductor so currents are induced everywhere.

- Reading is two numbers.



Inphase/Quadrature

The EM-31 gives two measurements called the In-phase and Quadrature

- In-phase: (also called "real")

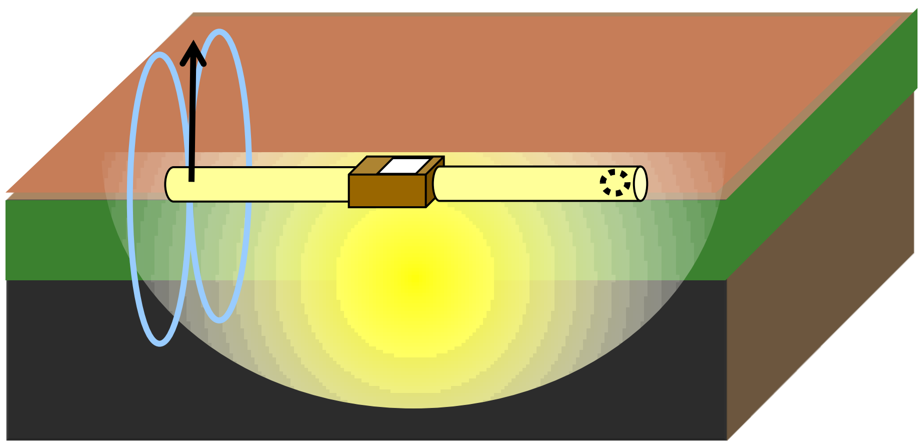
  Particularly useful for find good conductors (metal pipes, drums)

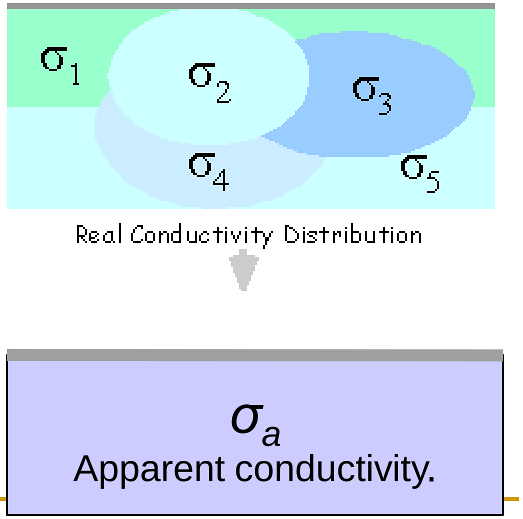
- Quadrature: (also called "imaginary" or (out of phase)

  Yields apparent conductivity (if $s>\delta$)

Implications over "real" earth

- Reading are "true" values of the ground's physical property ONLY over uniform ground.
- Therefore, result is "**apparent**" conductivity.
- Result over NON-uniform ground is a complicated weighted average of all materials.

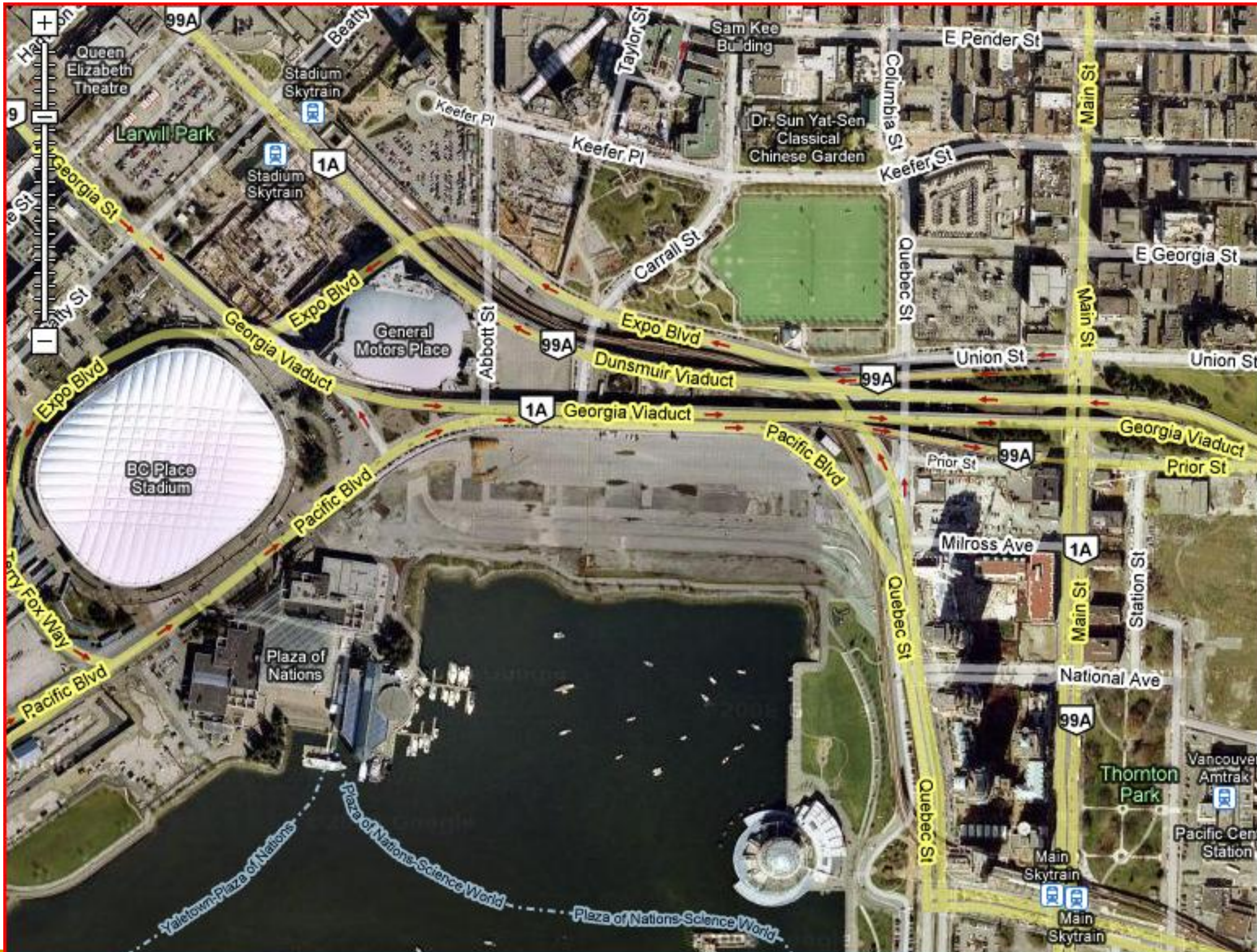




Case History Project: Expo Site

- Integrated site investigation of contaminated waste site in Vancouver

- Combines all the geophysical methods covered in EOSC 350: Magnetics, GPR, Seismic refraction and EM induction



99A
Beatty
Queen Elizabeth Theatre
Stadium Skytrain
Larwill Park
Stadium Skytrain
1A
Keefer Pl
Keefer Pl
Taylor St
Sam Kee
Dr. Sun Yat-Sen Classical Chinese Garden
Columbia St
Keefer St
E Pender St
Main St
Georgia St
Carrall St
Quebec St
E Georgia St
Expo Blvd
General Motors Place
Abbott St
Expo Blvd
99A
Georgia Viaduct
Dunsmuir Viaduct
Union St
Union St
99A
Main St
Expo Blvd
BC Place Stadium
1A
Georgia Viaduct
Pacific Blvd
Georgia Viaduct
Prior St
99A
Prior St
Pacific Blvd
Milross Ave
1A
Quebec St
Main St
Station St
Terry Fox Way
Plaza of Nations
Pacific Blvd
National Ave
99A
Thornton Park
Vancouver Amtrak
Pacific Centr Station
Quebec St
Main Skytrain
Main Skytrain
Yaletown-Plaza of Nations
Plaza of Nations-Science World
Plaza of Nations-Science World

Industrial Site

Resources

- Introduction
- Problem outline
- All text in PDF format

Contractor's report:
- ch1: Site history
- ch2: Site characteristics
- ch3: EM-31 results
- ch4: Gradient mag
- ch5: GPR results
- ch6: Seismic refraction

Additional information
- Comment: hydrocarbons
- Overlay data plots
- Flicker animations
- mag dipole applet

Outlines of survey methods
|EM-31 | GradMag | GPR |

Data spreadsheets
| em31 | seis | gradmag |

Activities

- Background tasks
- Interpretation tasks
- 2 blank site maps

Disclaimer

These geotechnical questions and geophysical problems were c
are photos and sketches of a real field site and data were gathe
to suit the teaching and learning needs of the exercises. Theref
necessarily applicable to a real field location.

The context

The field site in question is an urban area with a complex indust
construction of public space. There are many questions about th
geophysical surveys. Examples include:

- What is the thickness of the mixed fill layer (i.e. what is th
- What is the distribution of buried objects? Many objects a
small pieces of industrial trash, to railway lines, reinforced
- Can geophysics contribute any information about the exte
consists of a wide range of fill materials?
- Where is fill material dominated by wood waste, making g
- You can probably think of other questions that might be o

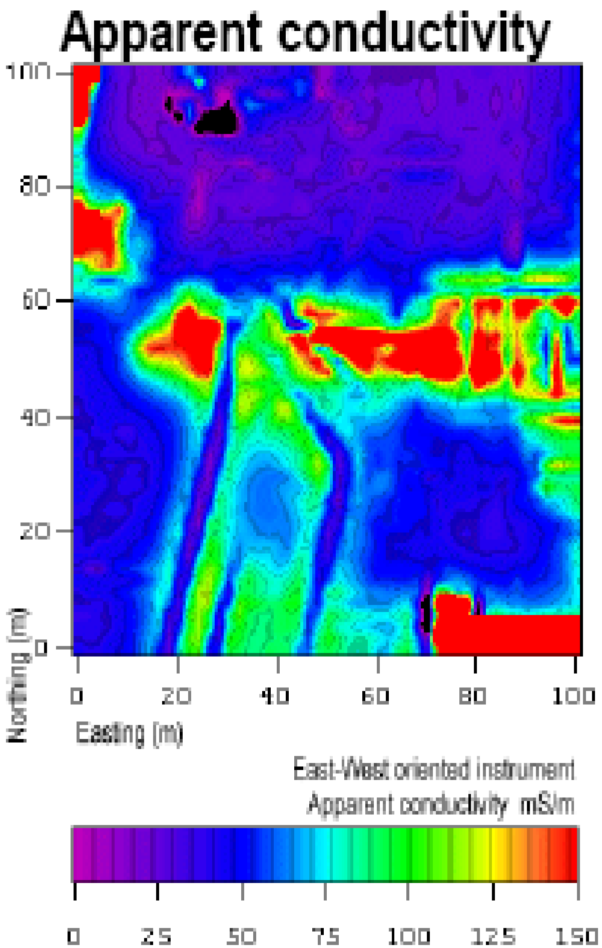
Finally, it is worth noting that the actual field site was fully reme
Ltd. (Soils and Remediation Group), May 1992. For a brief discus
information on hydrocarbons after the contractor's report

Instructions

This exercise involves using geophysics to address an environm
gradient magnetics data, and GPR results are all involved. Proce

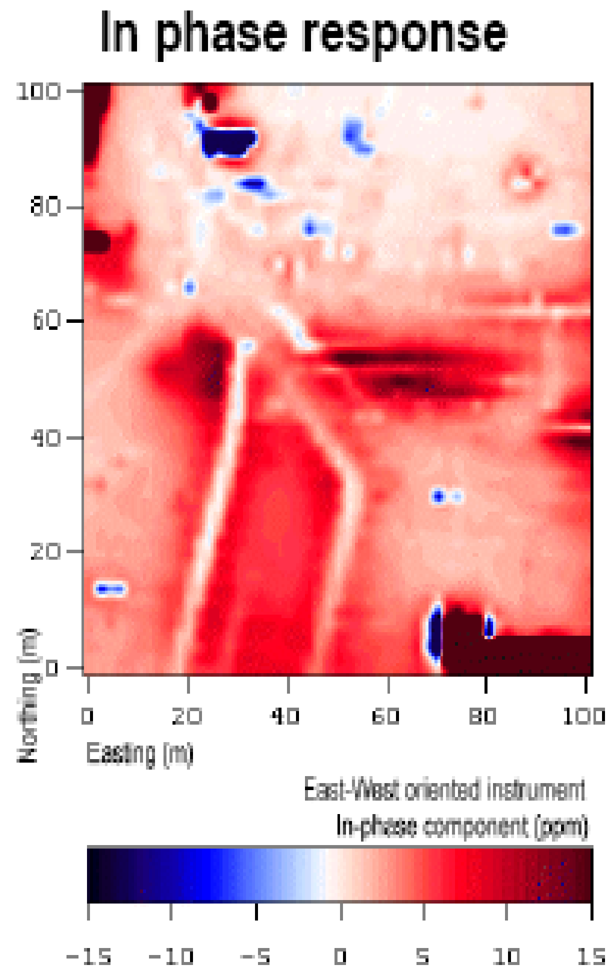
1. Read all content pages, and familiarize yourself with all th
2. You will have chosen ONE survey method to work up som

EM in phase and quad phase?



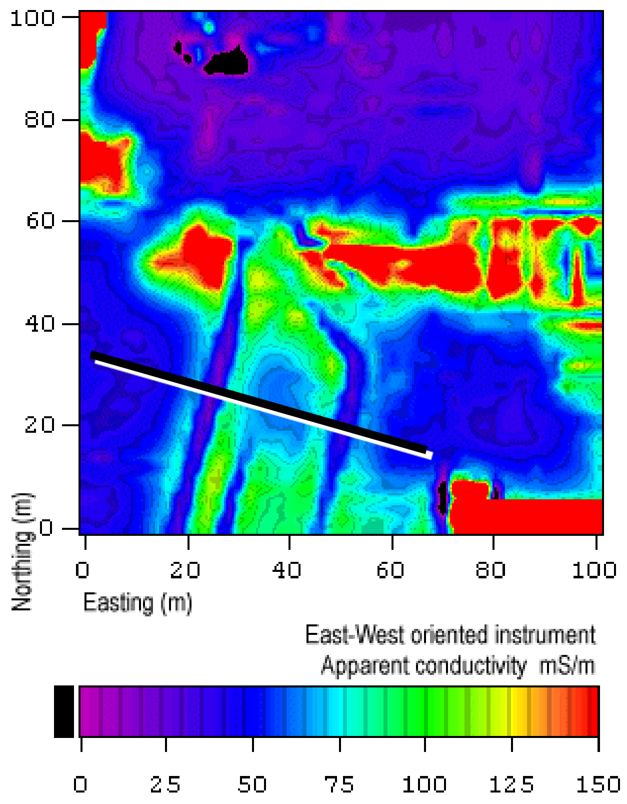
Instrument size? ~4m

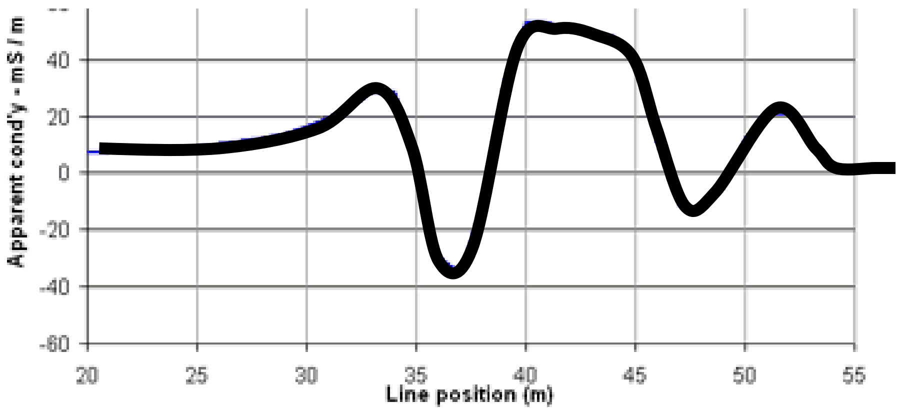
~



Effect of buried objects

- Contour plotted area data:
- Where are peak & trough patterns?
- Where are large responses?
- Where are negative responses?





EM Summary so far

- Basics of EM induction
- Sketch approximate anomalies for a simple system (EM31) that traverses a confined body
- Responses for EM31 and application

Readings for Electromagnetics

- Electromagnetics 1.0 Fundamentals
- GPG.h