Geophysics 424 A1 Final exam
Electromagnetic and Potential field methods

Date : Tuesday December 11th 2007
Location CEB 1-23
Instructor : Dr. Martyn Unsworth
Time allowed : 3 hours
Total points = 100

Instructions

Attempt all questions.

Notes and books may ***not*** *be used.*

Calculators may be used.

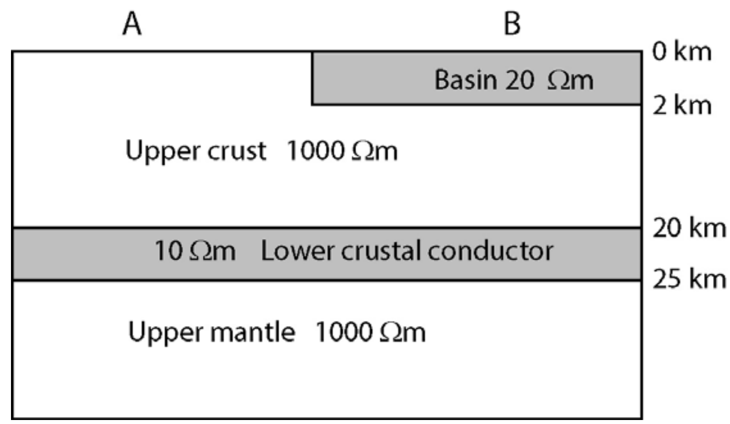
Cell phones and all other electronic devices must be switched off and stored.

All questions must be directed to the invigilator.

A separate 2 page formula sheet is available.

Question 1 : Magnetotellurics (Total = 20 points)

MT data (100-0.0001 Hz) are being used to image a lower crustal conductor. Site A is located on exposed basement rocks, while B is in a sedimentary basin.



- Sketch the MT apparent resistivity and phase data at sites ‘A’ and ‘B’. You can approximate the structure at each location is 1-D. Be quantitative where possible. **(12 points)**

- One theory suggests that the lower crust is conductive because of **interconnected** graphite films. The conductivity of pure graphite is 1000 S/m. What **volume fraction** of graphite is required to account for a bulk resistivity of 30 ohm-m? **(4 points)**

- The other theory is that saline fluids cause the low resistivity in the lower crust. The fluid distribution is not known. Assuming a fluid conductivity of 10 S/m what **range of porosities** is required to account for a bulk resistivity of 30 Ωm **(4 points)**

Question 2 : Frequency domain electromagnetics (Total = 10 points)

“A good conductor produces a secondary magnetic field that is in-phase with the primary magnetic field in a frequency domain EM survey”.

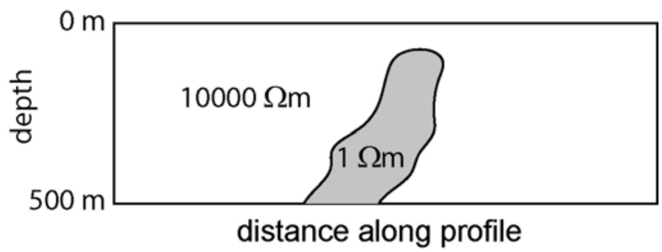
Explain this statement. Use a **phase diagram** and explain the **basic physics**.

How does this influence data collection in airborne EM surveys?

(10 points)

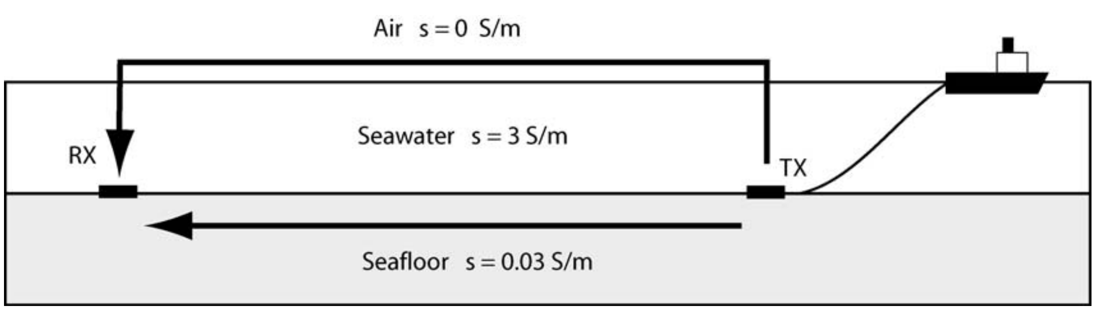
Question 3 : VLF (Total = 9 points)

VLF measurements with an EM16 are being used to locate massive sulphides. The transmitter has a frequency of 21 KHz. The VLF instrument measures the **tilt angle**.



- Sketch a map of the **ideal orientation** of the VLF profile, primary magnetic field and transmitter. **(3 points)**
- Sketch the **tilt angle** data recorded in this orientation. **(3 points)**
- What is the **maximum depth** at which the target can be detected with VLF. **(3 points)**

Question 4 : Marine CSEM (Total = 8 points)



In a marine CSEM survey, the EM signals travel diffusively from transmitter (TX) to receiver (RX) by the **two routes** shown above. In the CSEM survey shown above the seawater depth was 400 m and the transmission frequency was 4 Hz

- Estimate the TX-RX offset at which the two signals have the same strength? **(6 points)**

  Hint : Ignore geometric spreading, consider only attenuation.

- Name two commonly used types of transmitter in seafloor CSEM **(2 points)**

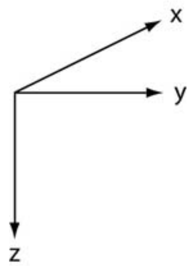
<u>**Question 5 : Maxwell's Equations (Total points = 20)**</u>

An electromagnetic (EM) wave is vertically incident on the Earth's surface.

The EM fields vary with time as $e^{i\omega t}$ with angular frequency *ω*

At this location, the Earth has a **uniform conductivity** *σ*

The electric field is **polarized** in the *x*-direction and E_x does not vary in the *x*-direction.



Magnetic permeability of ground	$= \mu = \mu_0$	$= 4\pi \, x \, 10^{-7}$	H/m
Dielectric permittivity of ground	$= \varepsilon = \varepsilon_0$	$= 8.85 \times 10^{-12}$	F/m
Electrical conductivity of ground	$= \sigma$	$= 0.01$	S/m
Frequency = f	= 1	Hz	

(a) Use Maxwell's equations to show that E_x satisfies the following partial differential equation

$$\frac{\partial^2 E_x}{\partial y^2} + \frac{\partial^2 E_x}{\partial z^2} = iw\mu\sigma E_x$$

(9 points)

State any assumptions made in your derivation.

(b) Consider a **non-plane wave** whose amplitude varies as a function of y as :

$$E_x(y,z) = E_x(z)\sin(\frac{2\pi y}{\lambda})$$

Show that in this case, the partial differential equation in (a) simplifies to an ordinary differential equation

$$\frac{d^2 E_x}{dz^2} + k_a^{\ 2} E_x = 0$$

and derive a value for k_a

(6 points)

(c) Using the numerical values listed above, estimate the **highest frequency** at which the non-planar nature of the wave will be noticed when λ = 200 km.

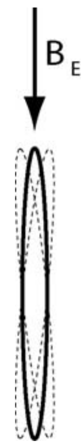
(5 points)

Question 6 : Time domain EM methods (Total points = 12)

(a) A time domain EM survey is being conducted at a location where the Earth's magnetic field is **vertical** and B_E = 50000 nT.

The x-axis receiver coil oscillates with an amplitude of 1^o at a frequency of 0.2 Hz.

What noise level does this produce in $\frac{dB_z}{dt}$?



(6 points)

(b) The transmitter has a current I = 500 amps and an area A = 100 m^2.

The noise level is that computed in part (a)

The Earth has a resistivity of 100 ohm-m?

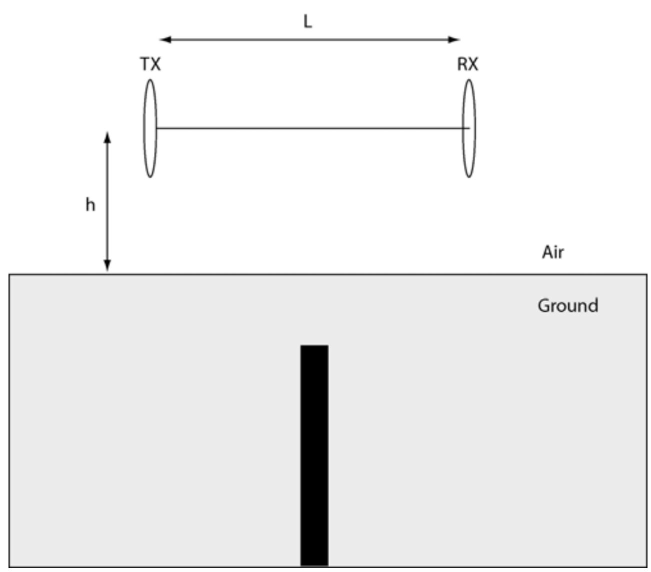
What is the **latest time** at which the transient can be observed? **(4 points)**

(c) What is **maximum depth of exploration** at this location? **(2 points)**

Question 7 : Frequency domain EM methods

A frequency domain electromagnetic (EM) system with **co-axia**l transmitter (TX) and receiver (RX) is mounted on a bird that is flown beneath a helicopter. The system has the following parameters:

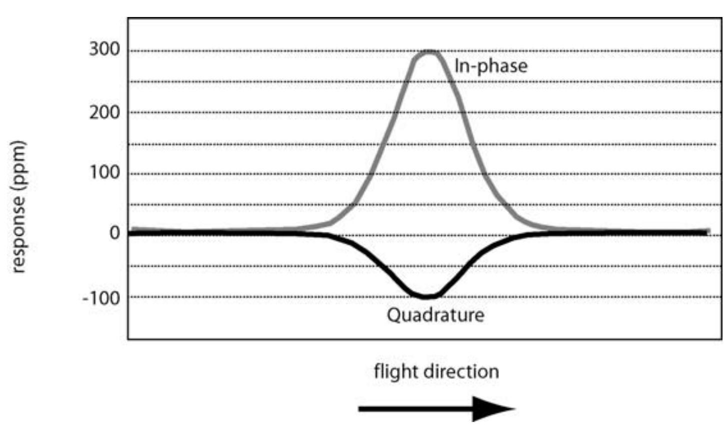
- primary field frequency, f = 20,000 Hz
- transmitter-receiver offset, L = 10 m.
- area of transmitter loop = A
- transmitter current = I
- ground clearance of TX-RX bird, h= 30 m
- noise level 10 ppm (both in phase and quadrature)



(a) The EM system was flown across a **vertical conductor** and the following responses were obtained.

Explain the shape of the **in-phase** response with a diagram showing magnetic field lines for primary and secondary magnetic fields.

(6 points)

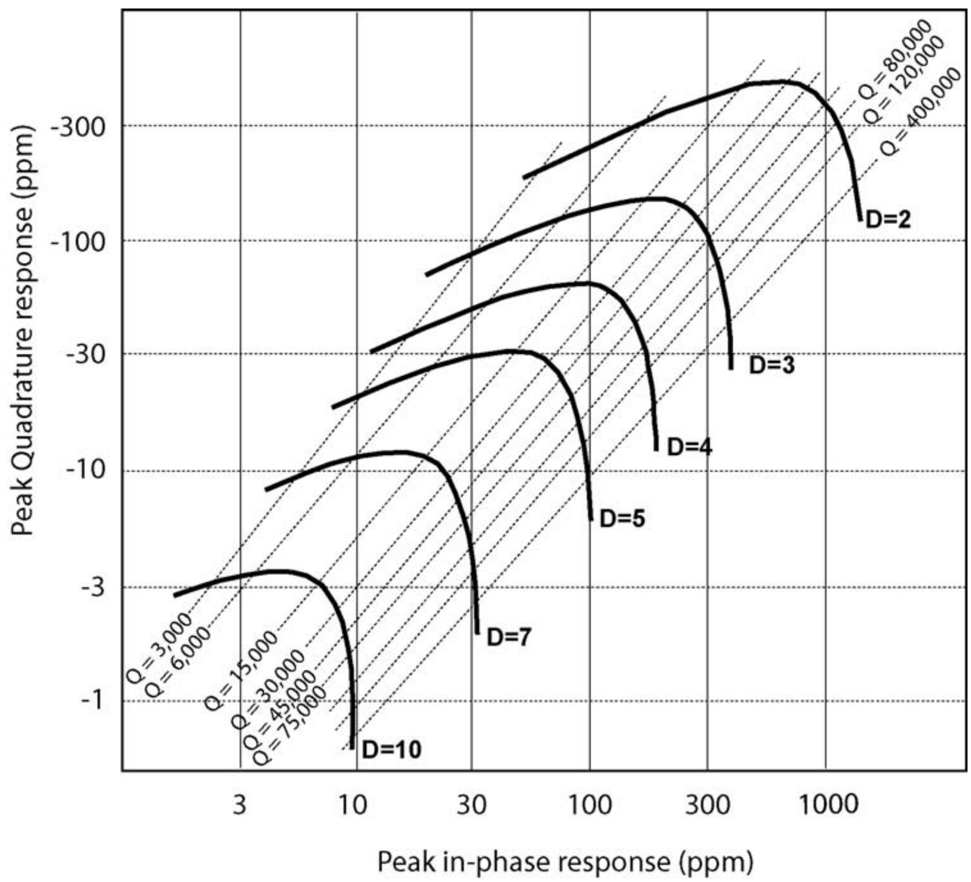


(b) Determine as much as possible about the target.

List all the assumptions you make. **(10 points)**

(c) A vertical conductor has a conductance of 4 S.
What is the maximum depth at which it can be detected by this system? **(5 points)**

Characteristic curves for co-axial TX-RX and a vertical plate



Response parameter, $Q = \sigma W f$ Depth parameter, $D = H / L$

W = width of conductor
σ = conductivity of conductor
H = depth to top of conductor below TX-RX bird
f = TX frequency (Hz)
L = TX-RX separation