Geophysics 424 A1   Final exam
Electromagnetic and Potential field methods

Date : Tuesday April 23rd 2013, 9 am – noon
Location CCIS L1-029
Instructor : Dr. Martyn Unsworth
Time allowed : 3 hours
Total points = 109

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 formula sheet will be distributed

Question 1 : Maxwell's Equations (Total points = 18)

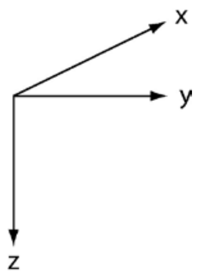
A low frequency electromagnetic (EM) wave is vertically incident on the Earth's surface.

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 = 0.001 S/m

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

Displacement current can be ignored



(1a) Use Maxwell's equations to show that in the Earth the electric field (E_x) satisfies the following partial differential equation

$$\frac{\partial^2 E_x}{\partial y^2} + \frac{\partial^2 E_x}{\partial z^2} = iw\mu\sigma E_x$$ **(7 points)**

(1b) Consider a **non-plane wave** whose amplitude varies with 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

$$\frac{d^2 E_x(z)}{dz^2} + k_a{}^2 E_x(z) = 0$$ and derive a value for k_a

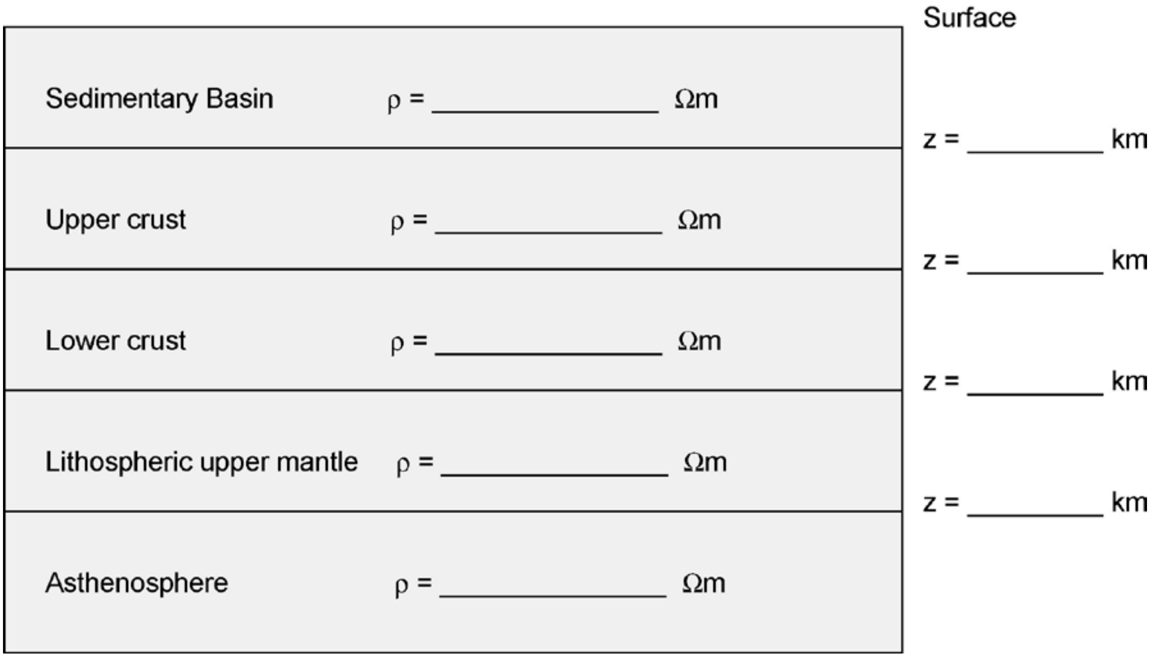
(6 points)

(1c) MT measurements show that the non-planar nature of the wave can be observed at periods greater than 200 s. What value of λ does this require?

(5 points)

Question 2 : Magnetotellurics (Total = 15 points)

(a) The figure below shows a section through the continental lithosphere. It is not drawn to scale.



(2a) Label **approximate depths** for each interface.

(2b) Label **typical resistivity** values (nearest factor of 10).

(2c) What is the **physical cause** of the observed resistivity in each layer?

(15 points)

<u>Question 3 : Magnetotellurics (Total = 14 points)</u>

An AMT survey is taking place at a mine where a mineralized zone is located at a depth of 1 km.

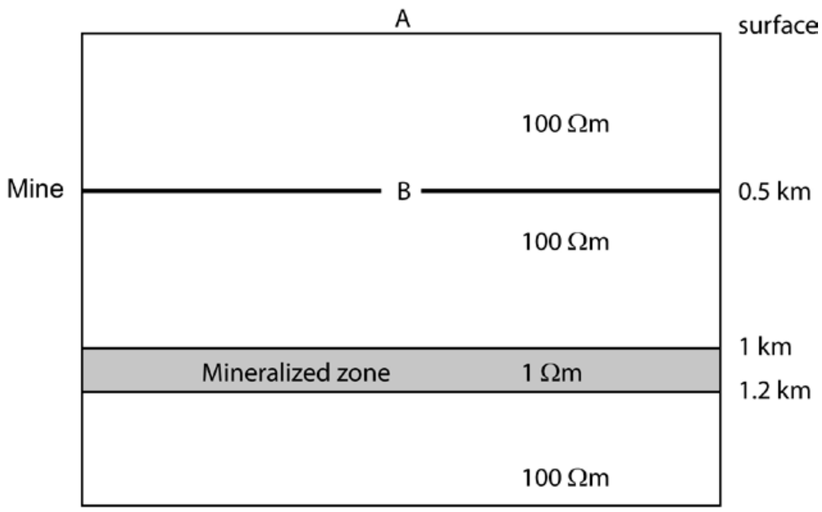
An AMT system is used that can record data in the frequency band 10000 – 1 Hz

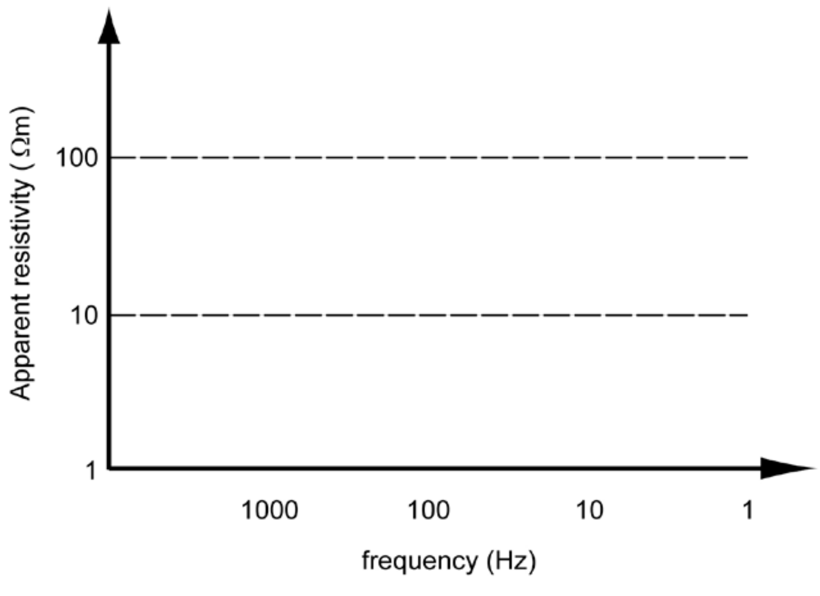
(3a) Sketch the apparent resistivity curve that would be measured at 'A' **(4 points)**

(3b) The instrument was then deployed in a mine tunnel at a depth of 500 m. Sketch the apparent resistivity curve that will be measured at 'B'. **(5 points)**

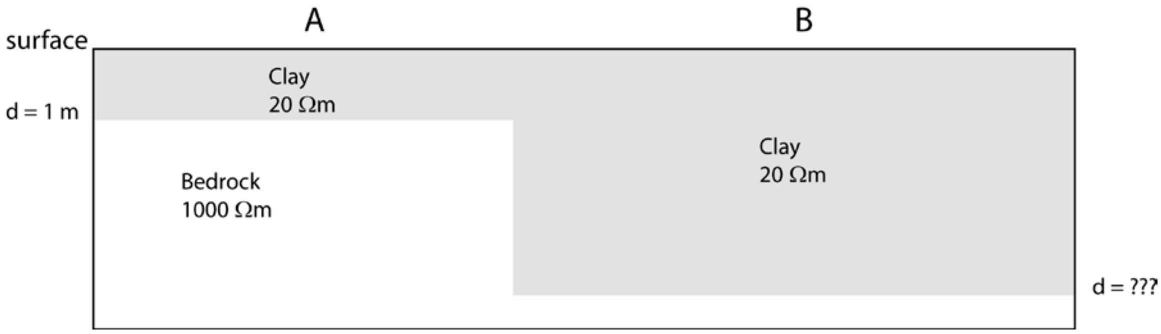
(3c) What type of sensor is used to measure the magnetic field in an AMT survey? **(1 point)**

(3d) What **sample rate** and **recording time** would be needed to collect AMT data in this frequency range? **(4 points)**





Question 4 : Frequency domain EM methods (Total = 13 points)



An EM31 survey takes place where a clay layer (resistivity = 20 Ωm) overlies granitic bedrock (resistivity = 1000 Ωm)

TX-RX separation was 3 m and frequency was 9.1 KHz.

(4a) At location 'A', the clay layer is 1 m thick. What apparent conductivity will the instrument read in **vertical dipole mode** when placed on the surface? **(3 points)**

(4b) Repeat part (4a) if the instrument is carried 1 m above the surface at 'A'.**(4 points)**

(4c) Comment on the difference between your answers to 4a and 4b **(2 points)**

(4d) The instrument is then moved to 'B' where the depth of the clay layer is unknown. The instrument reads an apparent conductivity = 0.02 S/m in vertical dipole mode when carried 1 m above the ground.

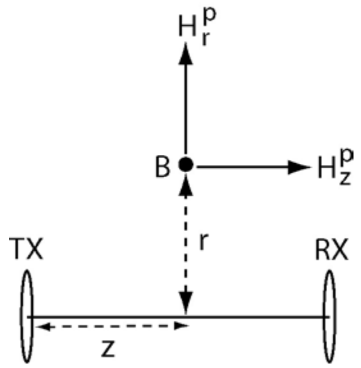
How thick is the clay layer? **(4 points)**

Question 5 : Controlled source EM measurements (Total points = 34)

A frequency domain electromagnetic (EM) system with co-axial transmitter (TX) and receiver (RX) is mounted on a bird that is flown beneath a helicopter.

- 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

The **primary magnetic field** components at point B are given by:



$$H_r^p = 3I\,A\,r\,z \,/\, 4\pi(r^2+z^2)^{\frac{5}{2}}$$

$$H_z^p = IA\,(2z^2 - r^2) \,/\, 4\pi(r^2+z^2)^{\frac{5}{2}}$$

(5a) Which **component** of the total magnetic field will the RX measure?

(2 points)

(5b) The in-phase component of the total magnetic field is required to be **accurate** to 10 ppm. No noise is present in the secondary magnetic field.

What is the minimum **distance change** in TX-RX separation that will be required to meet this specification?

(5 points)

(5c) What is the minimum **angular rotation** of the RX that can be tolerated for the in-phase component of the data to be accurate to 10 ppm? Give your answer in **degrees.**

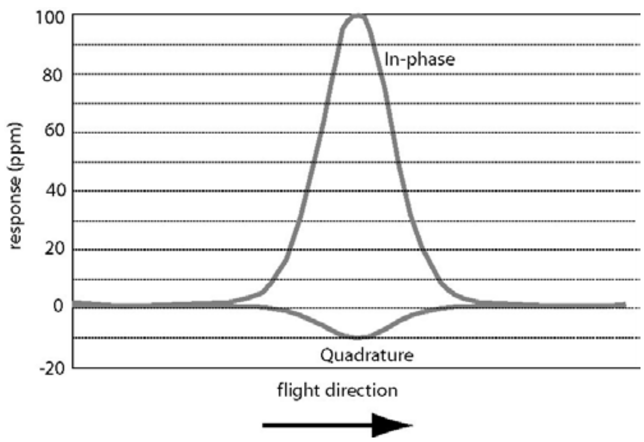
(4 points)

(5d) "*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 physics.

(8 points)

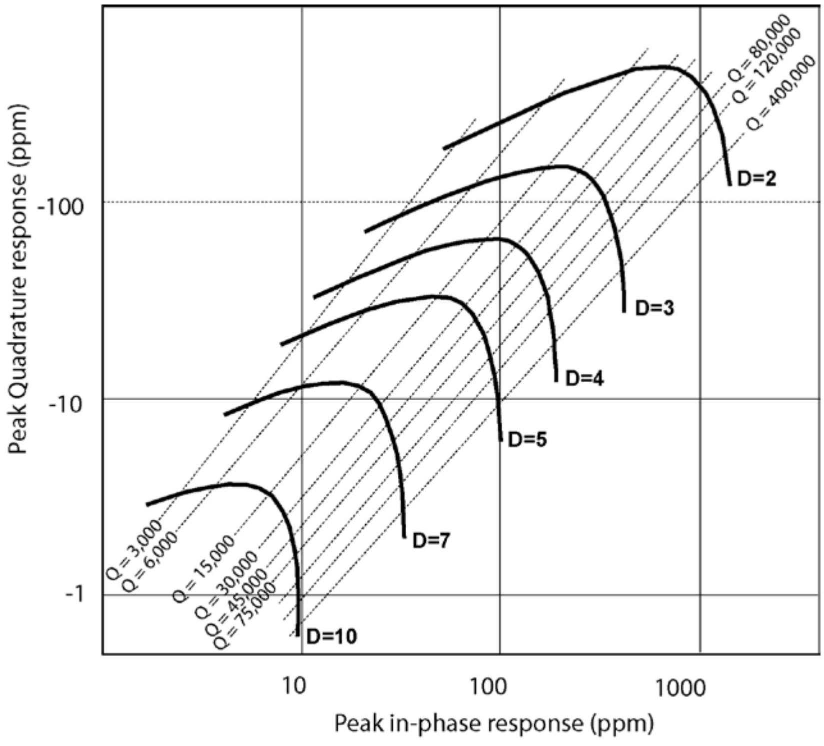
(5e) The EM system was flown across a **vertical conductor** and the following response was obtained.



Using the **characteristic curves** shown below, determine as much as possible a about the target. List all the assumptions you make. **(10 points)**

(5f) A vertical conductor has a conductance of 4 S. At what maximum depth can it be detected by this system? **(5 points)**

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

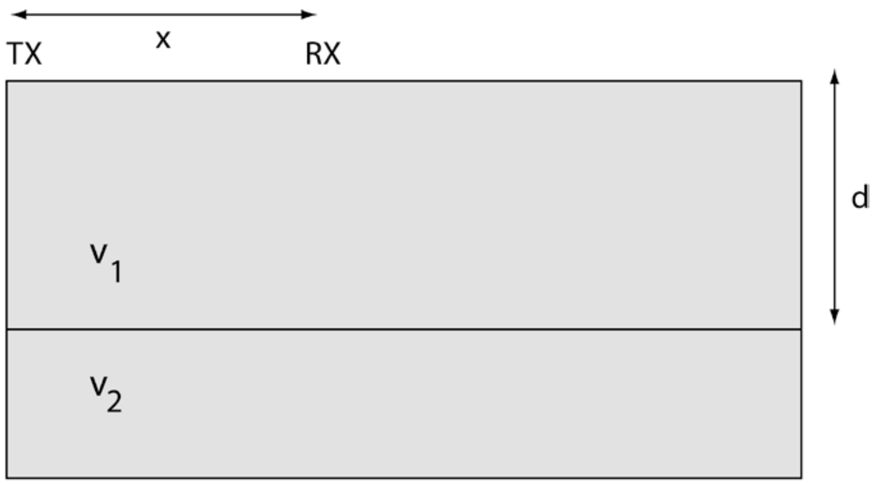


Response parameter, Q = $\sigma W f$ Depth parameter, D = H / L

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

Question 6 : Ground-penetrating radar (Total = 15 points)

GPR is being used to study the subsurface structure shown below.
A reflector is located at a depth *d*
Velocity in the Earth is v_1 above the reflector and v_2 below
Radar frequency is 200 MHz and TX-RX distance is x m
The transmitter is fixed and the receiver is moved.



(6a) Derive an expression for the **direct wave** travelling in the ground from transmitter to receiver. **(2 points)**

(6b) Derive an expression for the travel time for a **reflected wave** when the transmitter (TX) and receiver (RX) are separated by a distance *x*. **(3 points)**

(6c) Sketch these two travel time curves on the figure above. **(3 points)**

(6d) GPR travel times for the reflection are listed in the table below.
Calculate v_1 and d
Graph paper is available if needed

(5 points)

x (m)	T(ns)
1	76.0
2	79.1
3	83.9
4	90.1
5	97.6

(6e) Calculate the moisture content of layer 1 (θ_v) **(2 points)**