Geophysics 424 A1 Final exam
Electromagnetic and Potential field methods

Date : Wednesday December 15th 2010, 2pm – 5pm
Location CEB 442
Instructor : Dr. Martyn Unsworth
Time allowed : 3 hours
Total points = 102

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 : Resistivity of rocks (Total = 11 points)

(a) Electric current flows in a material that contains a single type of charge carrier.

There are n charge carriers per unit volume and each has a charge q.

The charge carriers have a mobility μ which is defined as the drift velocity per unit electric field. $\mu = \frac{\bar{v}}{E}$

Show that the electrical conductivity of the material is given by $\sigma = n\mu q$

(6 points)

(b) A brine is formed by dissolving 9 g of sodium chloride in 1 litre of water.

The brine has a conductivity of 1 S/m

Estimate the mobility of the ions.

Assume that the sodium (Na^+) and chloride (Cl^-) ions have the same mobility

(5 points)

Useful data

Volume of 1 litre of water	10^{-3} m^3
Molar weight of sodium chloride	58.4 g / mol
Avogadro's number	$6.02\ 10^{23}$
Charge on electron	$1.6\ 10^{-19}$ C

Question 2 : Ground-penetrating radar (Total = 7 points)

You are studying the structure of some layered sand deposits and the survey is required to resolve layers 50 cm thick to a maximum depth of 3 m

You have the choice of using GPR (Frequency = 100 MHz) or seismic reflection (signal frequency = 100 Hz)

The sand has the following properties

- electrical resistivity of 4000 Ωm
- radar velocity of 0.15 m/ns
- seismic velocity of 2000 m/s.

Which geophysical method will work in this case? Explain your answer.

Hint : The thinnest layer resolved has thickness = $z = \lambda/4$, where λ = wavelength

Question 3 : Magnetotellurics (Total = 10 points)

An MT instrument records 5 channels of data with a continuous sample rate of 8 Hz.

Each data sample takes 16 bytes of disk space.

The instrument has an 16 MB memory card.

(a) What will be the highest frequency recorded?

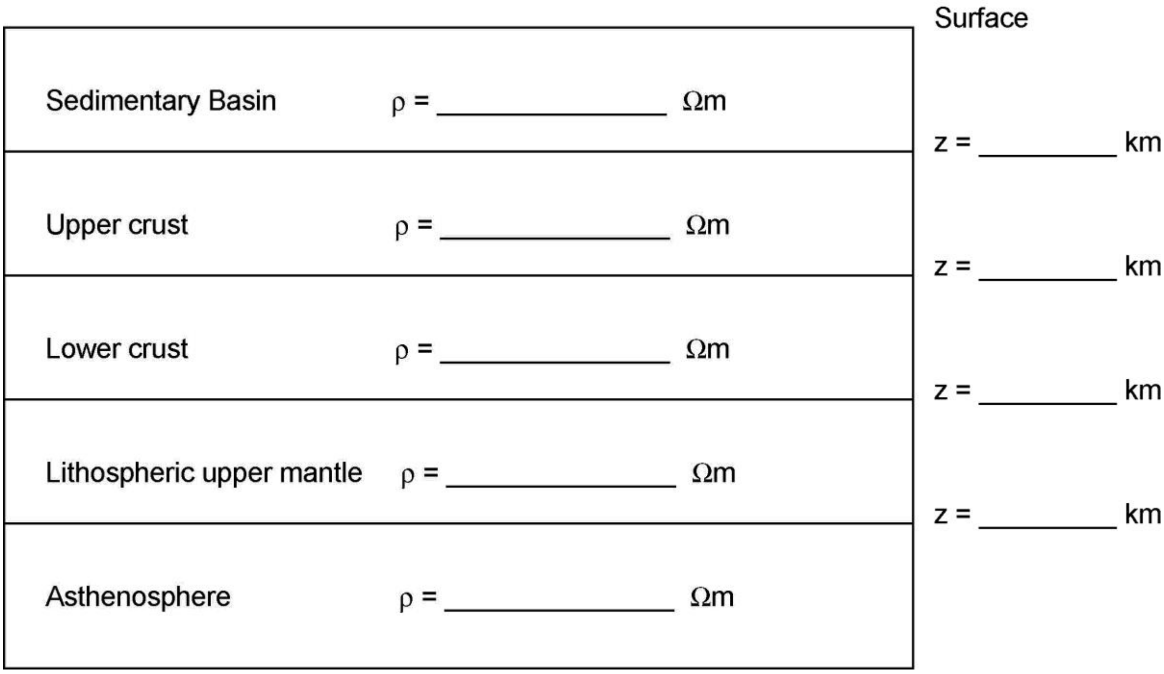
(b) How long can data be recorded before the memory is full?

(c) What will be the **lowest frequency** recorded?

(d) Give **two reasons** for burying the magnetometer in an MT survey.

Question 4 : Magnetotellurics (Total = 21 points)

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



Label **approximate depths** for each interface.

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

What is the **physical cause** of the observed resistivity values in each layer?

(15 points)

(b) Describe **two** applications of **magnetotellurics** in hydrocarbon exploration.

For each

- describe the contrasts in resistivity that make MT applicable.
- State why seismic exploration fails in each case

(6 points)

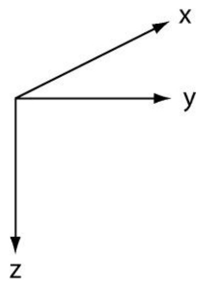
Question 5 : Maxwell's Equations (Total = 20 points)

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	$= \varepsilon = \varepsilon_0$	$= 8.85\ \text{x}10^{-12}$	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

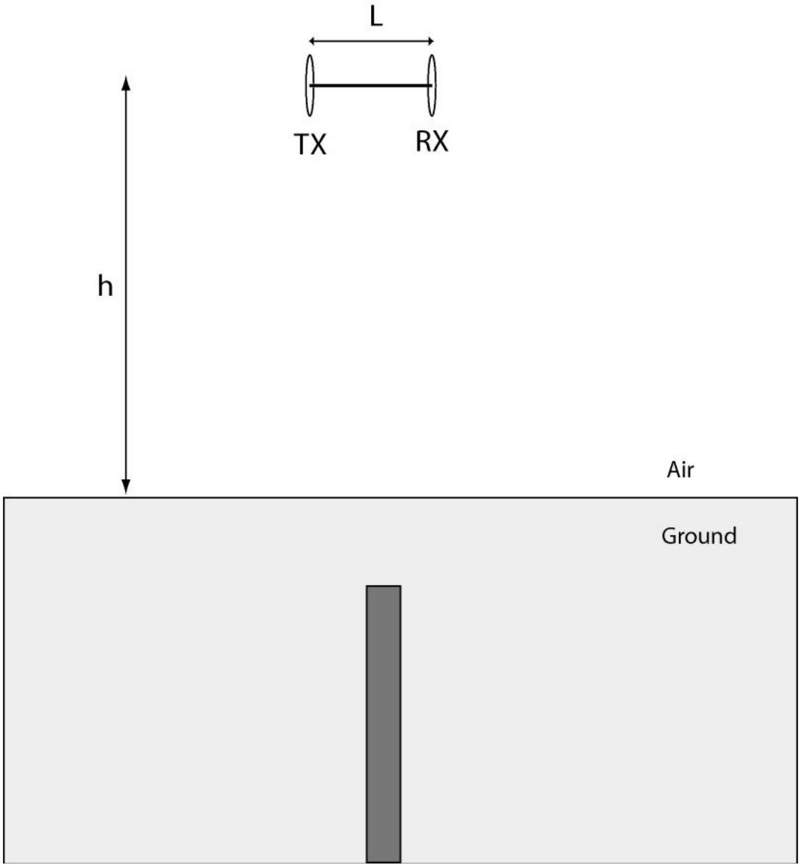
$$\frac{d^2 E_x}{dz^2} + k_a{}^2 E_x = 0$$ and derive a value for k_a

(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 $\lambda = 100$ km.

(5 points)

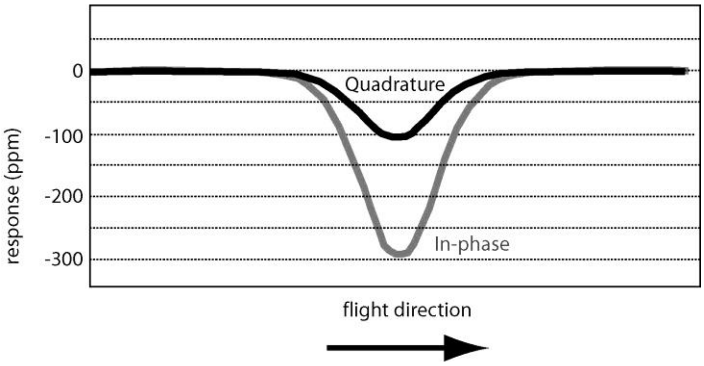
Question 6 : Frequency domain EM methods (Total = 20 points)



A frequency domain electromagnetic system with **co-axia**l transmitter (TX) and receiver (RX) is flown beneath a helicopter. The system parameters are:

- primary field frequency, f = 20,000 Hz
- transmitter-receiver offset, L = 10 m.
- 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 response (H_S / H_P) was measured.



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

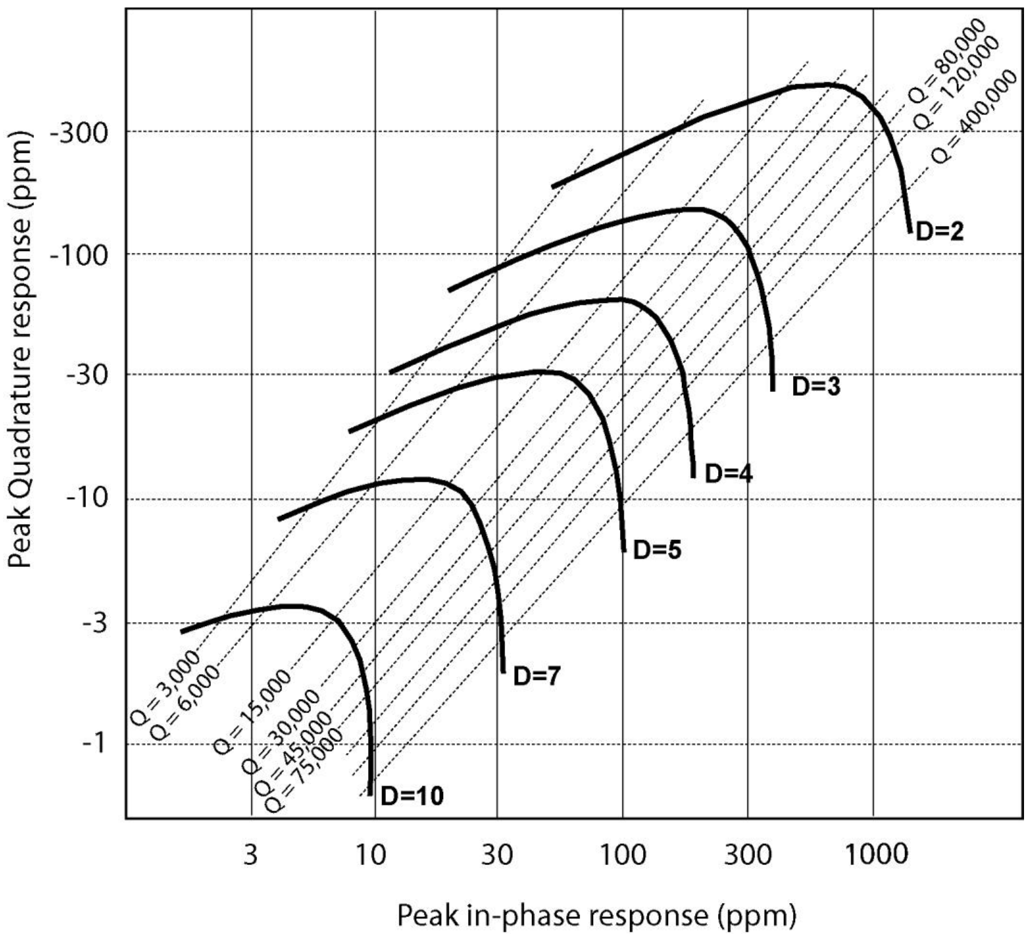
(5 points)

(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)

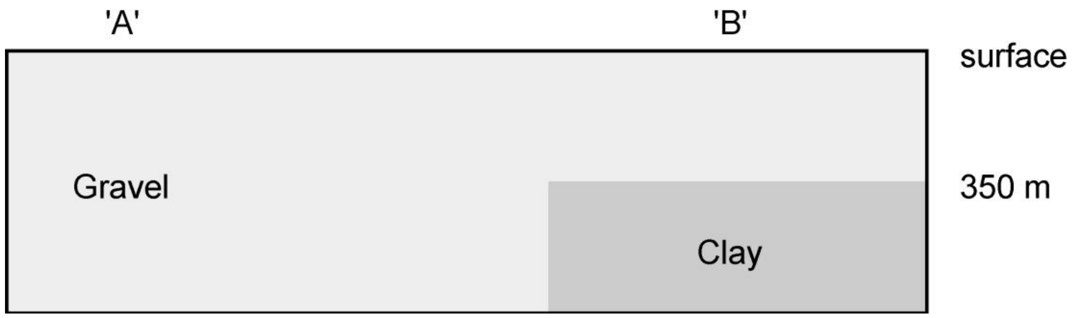
Characteristic curves for co-axial TX-RX and a vertical plate



Response parameter, Q = σWf 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 7 : Time domain EM methods (Total = 13 points)

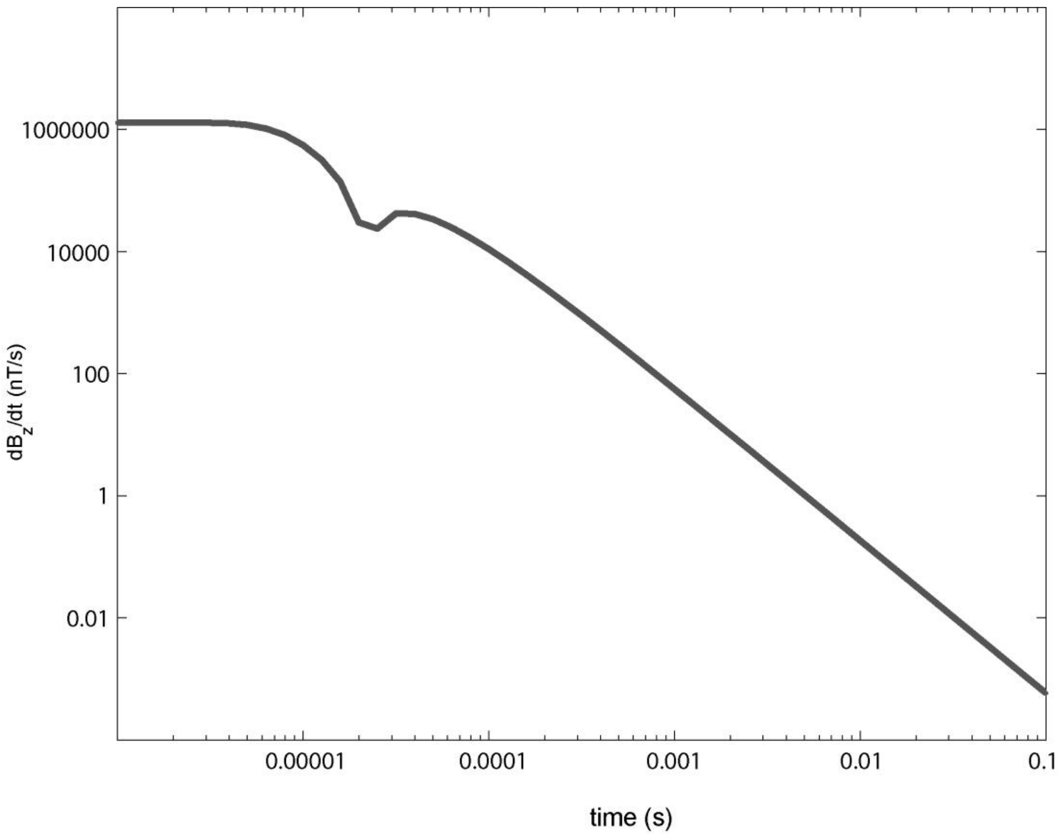


A time-domain EM system is being used to measure the resistivity during a ground water survey. The system parameters are:

Transmitter geometry	10 m x 10 m square loop
Transmitter current	I = 100 amps
Number of turns on transmitter	N = 10
TX-RX separation	r = 100 m

(a) The transient below was collected at 'A'.

Selected data values are listed in the table on the next page.



Time (s)	—— (nT/s)
0.0001	1.100e+004
0.001	5.599e+001
0.01	1.852e-001
0.1	5.883e-004

Calculate the conductivity of the gravel. Justify any assumptions you make.

(7 points)

(b) A second transient was recorded at ‘B’ where a **high conductivity clay layer** was present . Sketch the transient at ‘B’ on the graph above. Be quantitative where possible.

(6 points)