Geophysics 424 A1 Final exam
Electromagnetic and Potential field methods

Date : Wednesday April 23rd 2014, 9 am – noon
Location CCIS L1-029
Instructor : Dr. Martyn Unsworth
Time allowed 3 hours
Total points **116**

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 = 28 points)

A **plane** EM wave is travelling **vertically** downwards in the Earth in the *z*-direction.

The wave has an angular frequency, ω, and time dependence $e^{i\omega t}$

The electric field is **polarized** in the *x*-direction.

At this location, the Earth has the following properties

Magnetic permeability	$= \mu = \mu_0$	$= 4\pi \times 10^{-7}$ H/m
Dielectric permittivity	$= \varepsilon = \varepsilon_0$	$= 8.85 \times 10^{-12}$ F/m
Electrical conductivity	$= \sigma$	$= 0.01$ S/m
Speed of light	$= c$	$= 3 \times 10^8$ m/s

(a) Show that Maxwell's equations reduce to an ordinary differential equation for E_x

$$\frac{d^2 E_x(z)}{dz^2} = i\omega\sigma\mu\, E_x(z) \; - \; \omega^2 \mu\varepsilon E_x(z)$$

Clearly explain all assumptions made in your derivation **(8 points)**

(b) Indicate the type of **electric current** that is represented by each term on the right hand side of this equation. At a frequency $f = 10$ Hz, which term is larger? Simplify this equation by discarding the **smaller term**.

(6 points)

(c) Find a solution to the equation in (a) of the form $E_x = Ae^{kz}$ where z increases positively into the Earth. Boundary conditions require that $E_x = E_o$ at $z = 0$ m

Derive values for A and k. **(6 points)**

(d) The skin depth (δ) is defined as the depth at which $|E_x|$ has fallen to $1/e$ of the surface value. Show that

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \sim \frac{503}{\sqrt{\sigma f}} \text{ (m)}$$ **(4 points)**

(e) A VLF signal is being used to communicate with a submarine at a frequency of 10 KHz. What is the maximum depth at which signals will be detectable? The seawater has a resistivity of 0.3 ohm-m. Reception ceases when the amplitude of the electric field has been reduced to 0.01% of the surface value. **(4 points)**

Question 2 : Resistivity of rocks (Total = 13 points)

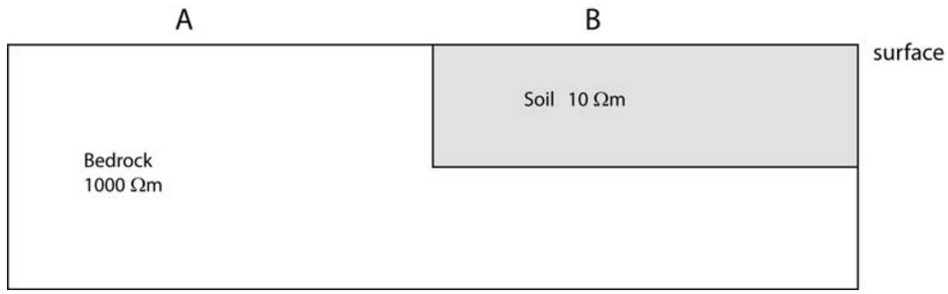
(2a) Draw a cross section through a **hydrothermal geothermal reservoir**. Explain the physical basis for each region having a high, or low, electrical resistivity.

(6 points)

(2b) What is one **limitation** of using MT to study this type of reservoir? **(3 points)**

(2c) The **lower continental crust** is often found to have a low resistivity. What are the two main explanations? Which one do you prefer - and why? **(4 points)**

Question 3 : Frequency domain EM methods (Total = 13 points)



An EM31 survey takes place where a thin layer of soil overlies bedrock

The basement outcrops on the left and has a resistivity of 1000 Ωm

The soil has a resistivity of 10 Ωm

TX-RX separation was s = 3.66 m and frequency was 9800 Hz

The EM31 is carried 1 m above the surface by Matthew Comeau

(3a) Prove that for a 10 Ωm halfspace, the near-field approximation is valid for the EM31

(3 points)

(3b) At 'A', the EM31 was used in **vertical dipole mode**? What apparent conductivity will the EM31 read? Assume that the conductivity of the air is zero.

(4 points)

(3c) At 'B' the EM31 was used in **horizontal dipole mode** and an apparent conductivity of 0.05 S/m was measured. How thick is the soil at 'B'?

(6 points)

Question 4 : Marine CSEM methods (Total = 12 points)

A marine CSEM survey takes place in deep water in a region where the seawater has a resistivity of 0.25 Ωm and the seafloor has a resistivity of 3 Ωm.

A frequency of 1 Hz is transmitted over a distance of 5 km.

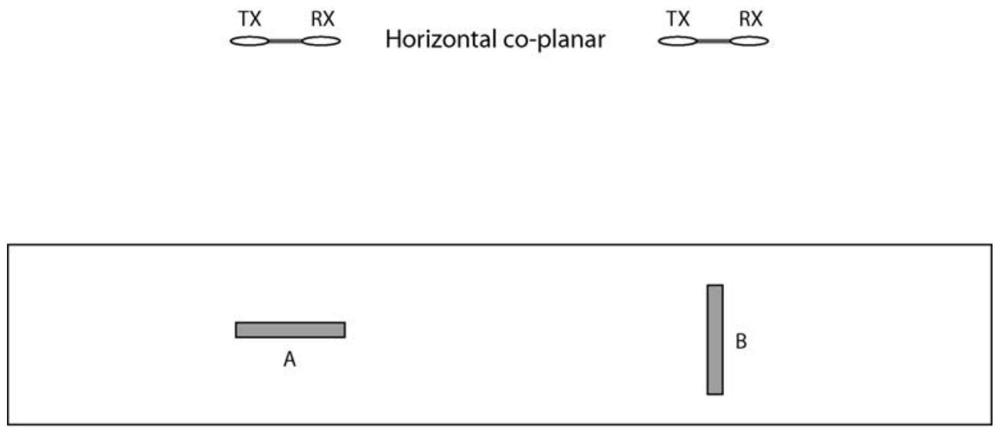
The transmitter is a horizontal electric dipole.

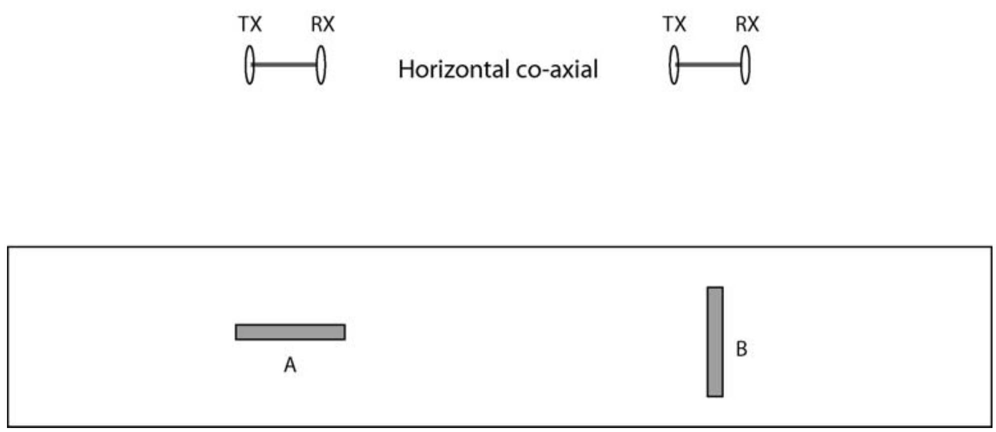
(4a) Show that this type of EM system corresponds to the **far field** **(3 points)**

(4b) Explain what is meant by **inline** and **broadside** configuration of transmitter and receivers. Include a diagram. **(4 points)**

(4c) How can a CSEM survey be used to detect a **thin hydrocarbon layer?** Include a sketch of the inline electric field as a function of distance for the cases of oil present and oil absent. **(5 points)**

Question 5 : Frequency domain EM surveys (Total = 16 points)





A frequency domain EM survey is flown over two buried conductors (A and B)

Two configurations of TX and RX are used.

The secondary magnetic field (H^S) is in-phase with the primary magnetic field (H^P).

(5a) Sketch the **primary** and **secondary** magnetic field lines when the TX-RX is above each conductor. Sketch on figure above. **(8 points)**

(5b) For each TX-RX geometry, which conductor (A or B) will give the biggest response in $|H^T / H^p|$? **(4 points)**

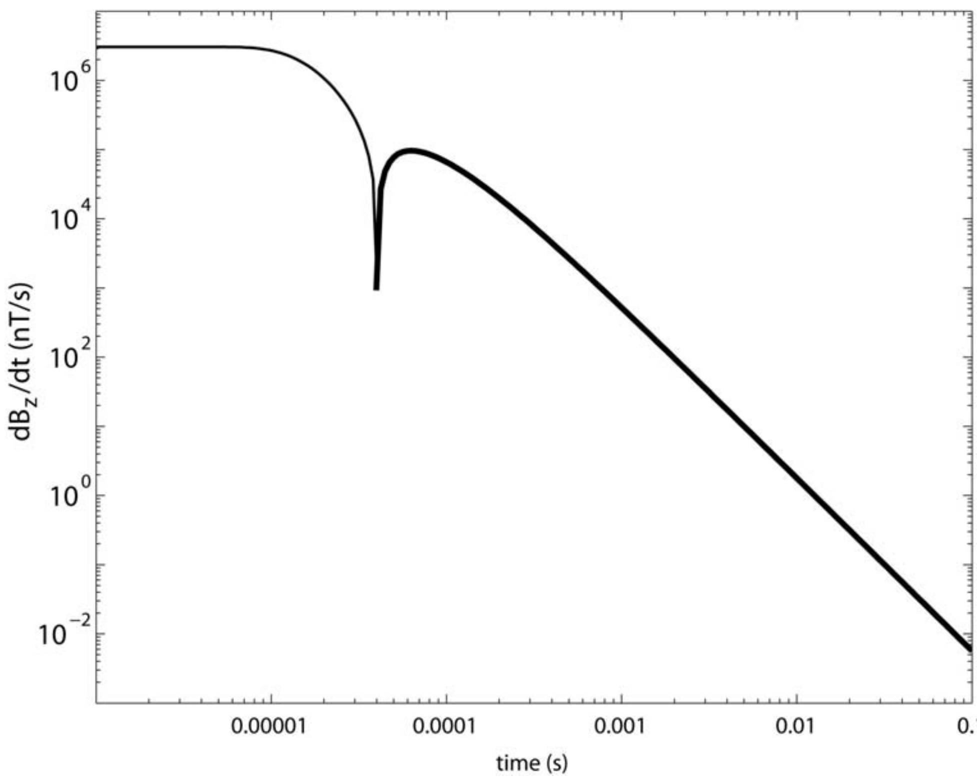
(5c) Indicate if $|H^T / H^p| > 1$ or $|H^T / H^p| < 1$ above each conductor for the co-axial and co-planar configurations. **(4 points)**

Question 6 : Time-domain EM (Total = 19 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 = 200 amps
Number of turns on transmitter	N = 20

The transient below was recorded at a station.
Thin line denotes negative values and thick line denotes positive values.
Selected data values are listed in the table.



Time (s)	$\frac{dB_z}{dt}$ (nT/s)
0.0001	66042
0.001	519.47
0.01	1.7822
0.03	0.115
0.1	0.005682

(6a) Explain the physics of time domain EM in terms of a "smoke-ring" of induced electric current. Include diagrams of the induced current and secondary magnetic fields at various times. **(6 points)**

(6b) Use the late-time decay equation to determine the gradient of $\frac{dB_z}{dt}$ as a function of time on a log-log plot?

(2 points)

(6c) Calculate the conductivity of the ground at this location. Assume that conductivity does not vary with depth. **(5 points)**

(6d) At approximately what time does the **late time equation** become valid? **(2 points)**

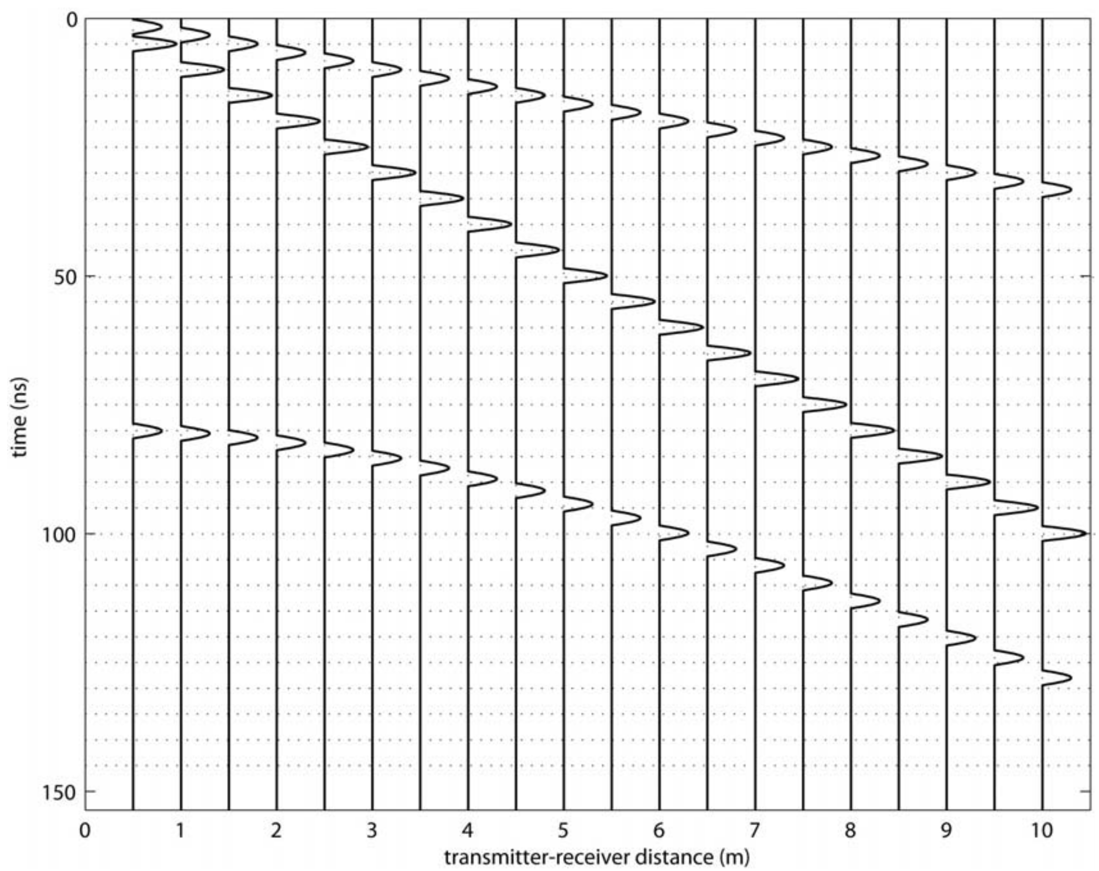
(6e) The system has a noise level of 1 nT/s and is moved to site where the resistivity is 500 ohm-m. What is the **maximum depth** that can be imaged? **(4 points)**

Question 7 : Ground-penetrating radar (Total = 15 points)

GPR is being used to detect a horizontal slab of buried concrete. The concrete is covered by a layer of soil. The radar frequency is 200 MHz

v_1 = velocity of radar wave in soil
v_2 = velocity of radar wave in concrete
d = depth of soil layer
x = transmitter-receiver distance (variable)

The data collected is shown below as a set of traces, spaced every 50 cm



(6a) Identify the **air wave** on the plot above. Confirm that it is travelling at the expected velocity **(3 points)**

(6b) Draw a diagram showing the paths taken by the other two arrivals **(3 points)**

(6c) Calculate the velocity in the soil, v_1 **(2 points)**

(6d) Calculate the depth of the layer, d **(3 points)**

(6e) Calculate the relative permittivity of the soil **(2 points)**

(6f) Calculate the moisture content of the soil (θ_v) **(2 points)**