Geophysics 424 A1 Final exam
Electromagnetic and Potential field methods

Date : Monday April 23rd 2012, 9 am – noon
Location CCIS L1-029
Instructor : Dr. Martyn Unsworth
Time allowed : 3 hours
Total points = 127

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 will be distributed

Question 1 : Resistivity of rocks (Total = 16 points)

A crystalline rock contains graphite in aligned cracks.

The volume fraction of graphite is V

The graphite has a resistivity of ρ_g and the rock matrix has a resistivity of ρ_r

Consider a cube that is 1 m x 1m x 1m.

(1a) Derive an equation for the resistance of the cube when electric current flows **parallel** to the cracks. Consider $0 < V < 1$ **(3 points)**

(1b) Derive an equation for the resistance of the cube when electric current flows **normal** to the cracks. Consider $0 < V < 1$ **(3 points)**

(1c) Sketch these resistance values on a graph for the **range** $0 < V < 1$
Assume that $\rho_g = 0.1\ \Omega\text{m}$ and $\rho_r = 1000\ \Omega\text{m}$
Give numerical values for $V = 0$, 0.5 and 1 **(4 points)**

(1d) Calculate the resistance predicted by Archie's Law. Plot on the graph.
Assume that $\rho_g = 0.1\ \Omega\text{m}$ and $\rho_r = 1000\ \Omega\text{m}$
Give numerical values for $V = 0$, 0.5 and 1 **(4 points)**

(1e) Comment on how Archie's Law compares to the curves you plotted in (1c) **(2 points)**

Question 2 : Ground-penetrating radar (Total = 12 points)

GPR is being used to study the subsurface structure shown below.

A metal pipe is buried at a depth d = 4 m and horizontal location x = 0 m

Velocity in the soil = v_1 = 0.1 m / ns

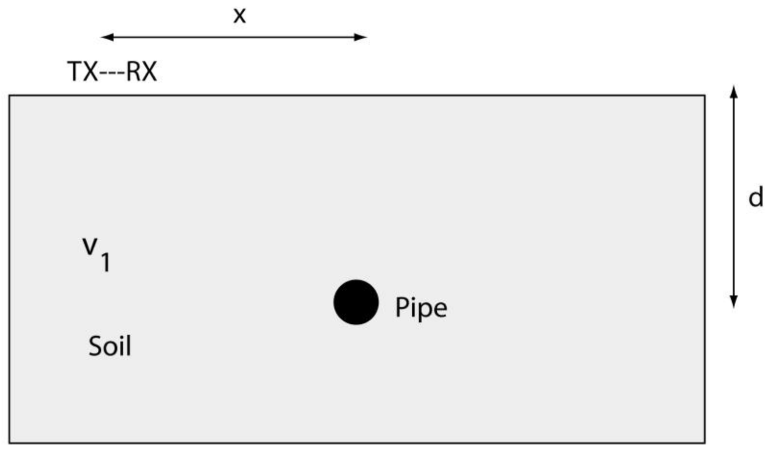
Radar frequency is 200 MHz and TX-RX distance is 1 m

(2a) On the graph below, sketch the **travel times** for the air wave and ground wave at the RX **(4 points)**

(2b) The TX-RX are located at a distance x from the pipe. Derive an equation for the travel time of a signal **diffracted** from the pipe. Assume that the TX and RX are coincident. **(2 points)**

(2c) Add the travel time for the diffracted signal to the graph **(3 points)**

(2d) Calculate the moisture content of the soil (θ_v) **(3 points)**



Question 3 : Magnetotellurics (Total = 11 points)

An MT instrument records 5 channels of data with a sample rate of 320 Hz.

Each data sample takes 16 bytes of disk space and 36 hours of data are recorded.

A 24-bit analogue to digital converter is used with a full-scale range of 4 V

Explain you answer to each of the following.

(3a) What will be the **highest frequency** that can be obtained from these data? **(2 points)**

(3b) What will be the **lowest frequency** that can be obtained from these data? **(2 points)**

(3c) What is the **weakest electric field** that can be detected? **(3 points)**

(3d) What is an **anti-alias** filter? Describe the filter that would be needed in this example? **(4 points)**

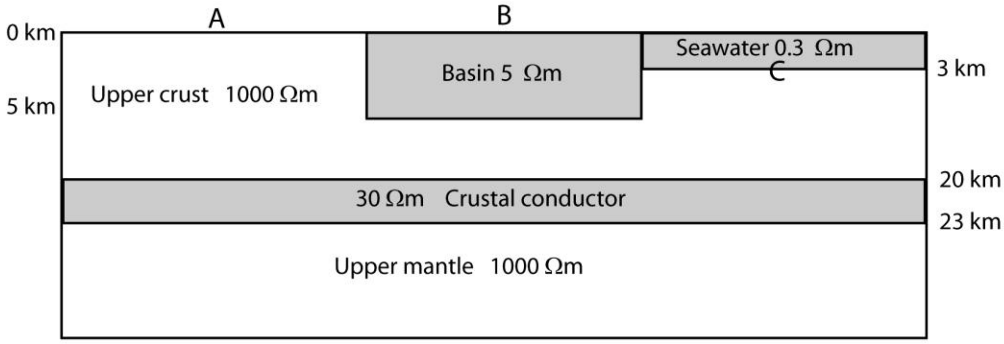
Question 4 : Marine CSEM methods (Total = 10 points)

(4a) How does frequency domain marine controlled source EM exploration measure variations of resistivity with depth? **(2 points)**

(4b) Explain the geometry used in **broadside** and **inline** configurations in marine CSEM. Include a diagram in your answer. **(2 points)**

(4c) How are these configurations used to detect **hydrocarbon reservoirs**? Describe the physics and include a diagram of measured data in your answer. **(6 points)**

Question 5 : Magnetotellurics (Total = 19 points)



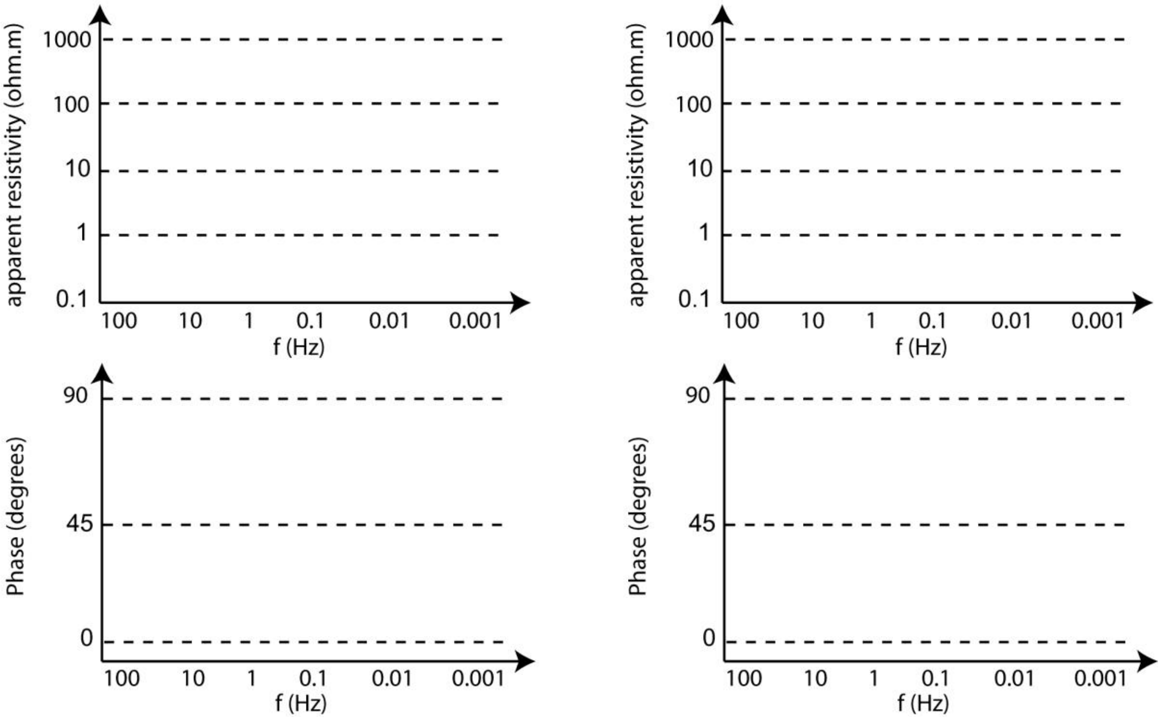


Figure above shows the crustal resistivity structure of a coastal area.

Stations A and B are onshore

Station C is on the seafloor where the seawater is 3 km deep.

(5a) Sketch the apparent resistivity and phase curves at stations A and B on the **left** hand graph. Be quantitative where possible. **(11 points)**

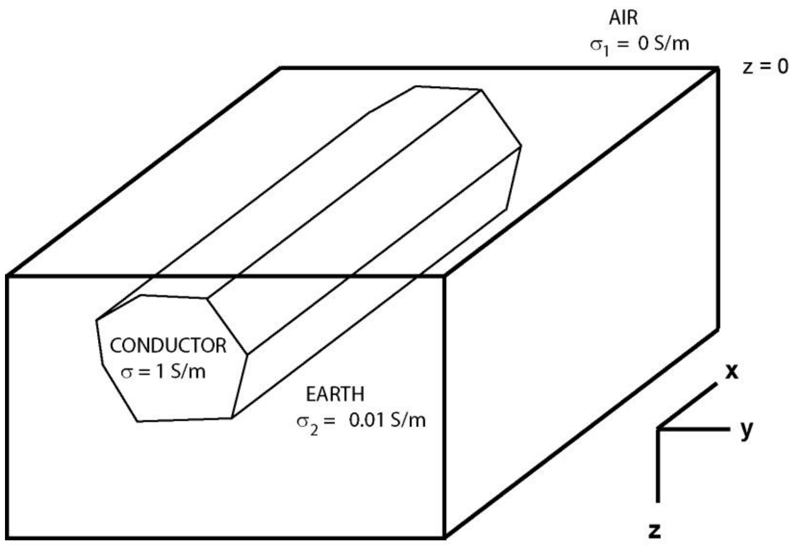
(5b) Sketch the apparent resistivity and phase curves at station C on the **right** hand graph. Be quantitative where possible. **(8 points)**

Note : Assume that an EM signal will not be detectable after travelling 3 skin depths

Question 6 : Maxwell's Equations (Total = 23 points)

An MT survey is being carried out at a location, where the Earth has a 2-D conductivity structure that is invariant in the *x*-direction.

The EM fields have an angular frequency ω, and time variation $e^{i\omega t}$



(6a) Expand Maxwell's equations for the six components of the electromagnetic field (E_x, E_y, E_z, B_x, B_y and B_z) in the frequency domain. **(8 points)**

(6b) These six equations simplify over a 2-D Earth structure. Derive a differential equation for the TM mode in terms of B_x (y,z). Explain any assumptions you have made **(7 points)**

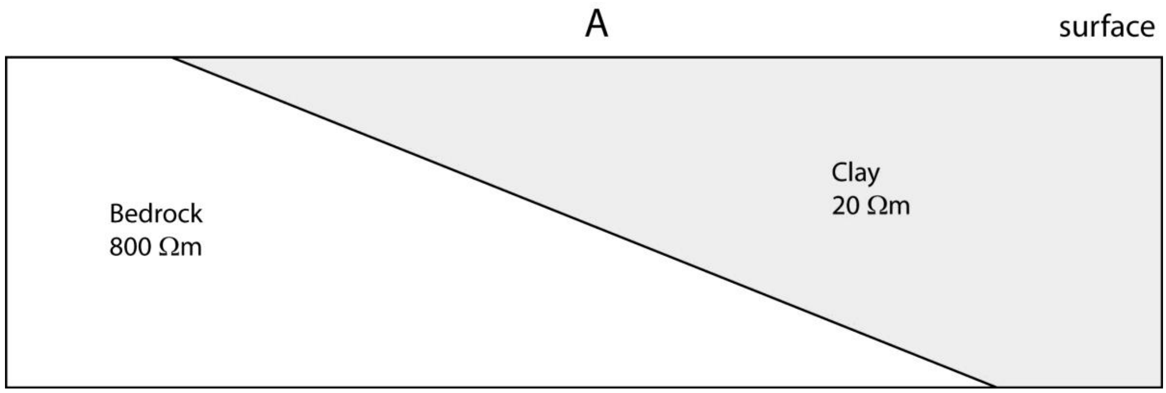
(6c) Consider a point on the surface of the Earth at z = 0

The vertical electric fields above and below the surface are E_z^1 and E_z^2
The electrical conductivity above and below the surface are σ_1 and σ_2

Derive a relationship between E_z^1 and E_z^2 **(4 points)**

(6d) Consider the case when $\sigma_1 = 0$ S/m and $\sigma_2 = 0.01$ S/m
Show that for the TM mode, B_x(y) at z = 0 is constant for all values of *y*
(4 points)

Question 7 : Frequency domain EM methods (Total = 13 points)



Am EM34 survey takes place where a clay layer overlies bedrock.

The basement outcrops on the left and has a resistivity of 800 Ωm.

The clay layer is very thick on the right and has a resistivity of 20 Ωm

TX-RX separation was 10 m and frequency was 6.4 KHz.

TX and RX placed on ground to make measurements.

(7a) Prove that for a 20 Ωm halfspace, the near-field approximation is valid **(3 points)**

(7b) At 'A', the instrument measures an apparent resistivity of 240 Ωm in the vertical dipole mode. How thick is the clay layer? **(5 points)**

(7c) At 'A', calculate the apparent resistivity that would be measured in horizontal dipole mode. Comment on your answer. **(5 points)**

Question 8 : Time domain EM methods (Total = 22 points)

A time domain survey is using a sawtooth transmitter waveform.

The primary magnetic field is shown on the next page in figure (A)

The ore body (a conductor) behaves as an **inductor and resistor in series**.

(8a) Define the **mutual inductance** between two electric circuits **(3 points)**

(8b) The secondary voltage induced in the conductor is shown in B.

Explain how the secondary voltage is related to the primary magnetic field. **(2 points)**

(8c) Sketch the time variation of the **secondary current**.

Show both GOOD and BAD conductors on same graph. **(6 points)**

(8d) Sketch the time variation of the **secondary magnetic field** at the RX.

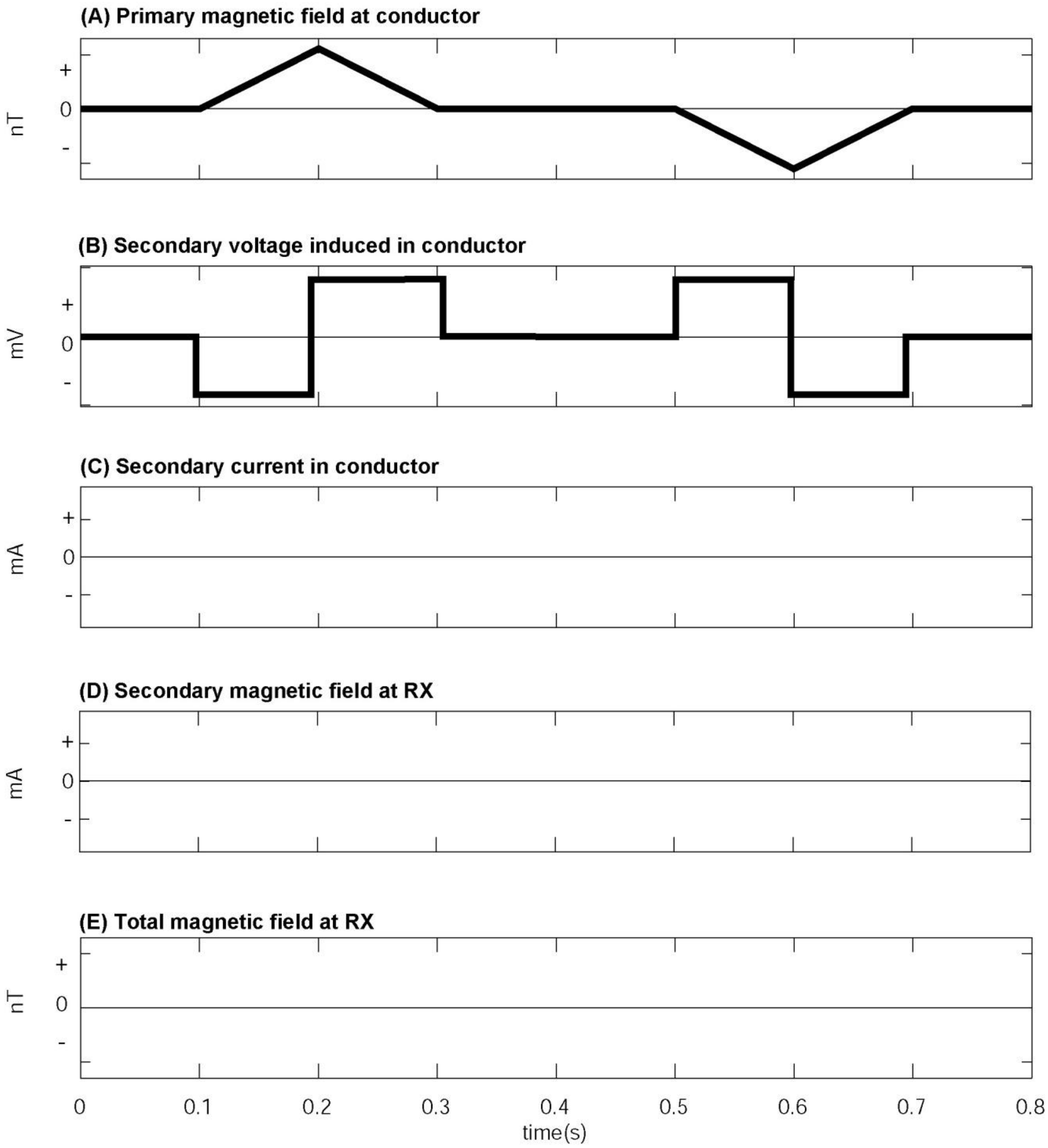
Show both GOOD and BAD conductors on same graph. **(5 points)**

(8e) Sketch the time variation of the **total magnetic field** at the RX

Show both GOOD and BAD conductors on same graph. **(6 points)**

Your answer will be **qualitative** in (8c) - (8e).

Briefly explain how you obtained your answer in each case.


(A) Primary magnetic field at conductor
nT
+
0
-
(B) Secondary voltage induced in conductor
mV
(C) Secondary current in conductor
mA
(D) Secondary magnetic field at RX
mA
(E) Total magnetic field at RX
nT
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
time(s)