Geophysics 424 A1 Final exam
Electromagnetic and Potential field methods

Date : December 16 2016 2- 5 pm
Location CCIS L1-029
Instructor : Dr. Martyn Unsworth
Time allowed : 3 hours
Total points = 110

Instructions

Attempt all questions

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

Non-programmable *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

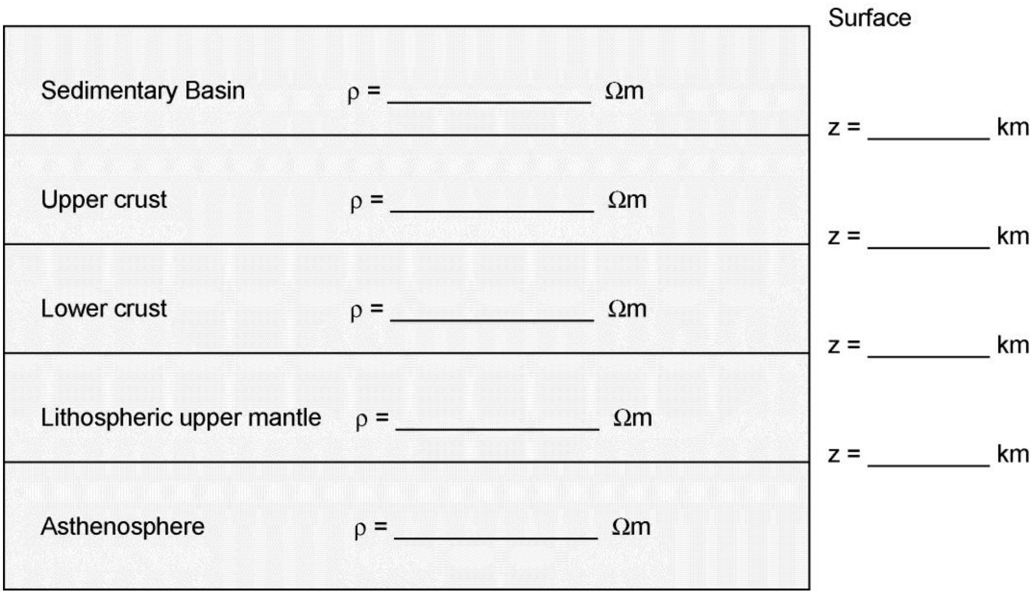
A separate formula sheet will be distributed

Name _:_ ____

Question 1 : Resistivity of rocks (Total = 14 points)

The figure below shows a section through the continental lithosphere.

It is not drawn to scale.



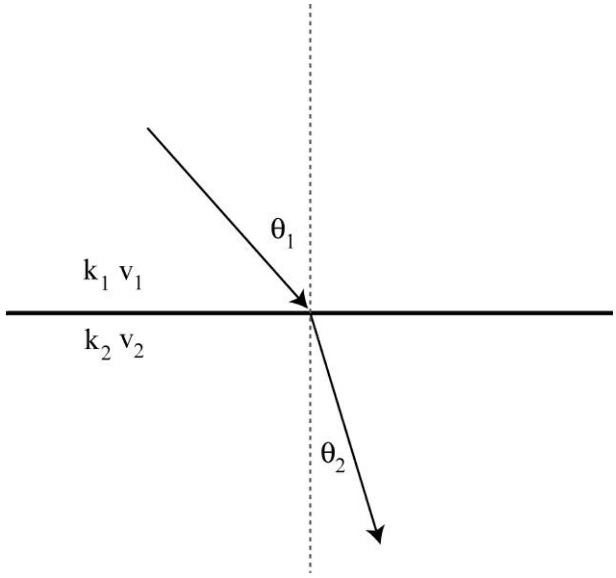
(1a) Label **approximate depths** for each interface on the diagram

(1b) Label **typical resistivity** values on the diagram (nearest factor of 10).

(1c) What is the **physical cause** of the observed resistivity in each layer?

(14 points)

Question 2 : Maxwell's Equations (Total = 15)



An electromagnetic wave has an angular frequency ω

In layer 1 it travels at velocity v_1 and at an angle θ_1 to the normal with a wavenumber k_1
In layer 2 it travels at velocity v_2 and at an angle θ_2 to the normal with a wavenumber k_2

(2a) State Snell's law. Use Snell's Law to show that $|k_1|\sin\theta_1 = |k_2|\sin\theta_2$

(5 points)

(2b) Consider the case when Layer 1 is the air, and Layer 2 is the Earth which has a conductivity of σ_2. It can be shown that

$$k_1 = \omega\sqrt{\mu_0\varepsilon_0} \quad \text{and} \qquad k_2 = \sqrt{-i\omega\mu_0\sigma_2}$$

where μ_0 is the permeability of free space, ε_0 is the permittivity of free space.

Derive an equation for θ_2 in terms of θ_1 , ω and the material properties **(4 points)**

(2c) Derive an equation for the maximum possible value of θ_2 **(2 points)**

(2d) Consider the case when σ_2 = 0.01 S/m and f = 10 Hz. What will be the maximum value of θ_2 ? **(2 points)**

(2e) How could this phenomenon be used to measure the conductivity of the Earth?

(2 points)

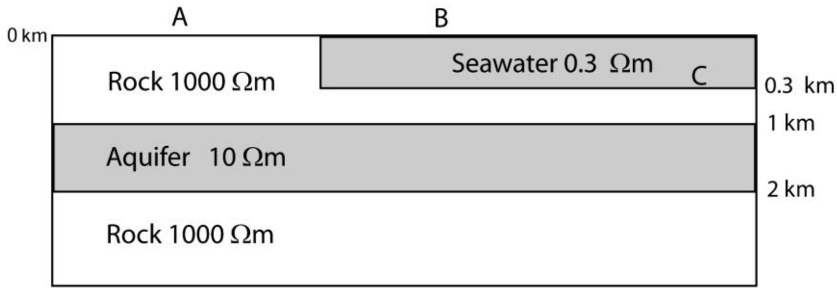
Question 3 : Magnetotellurics (Total = 18 points)

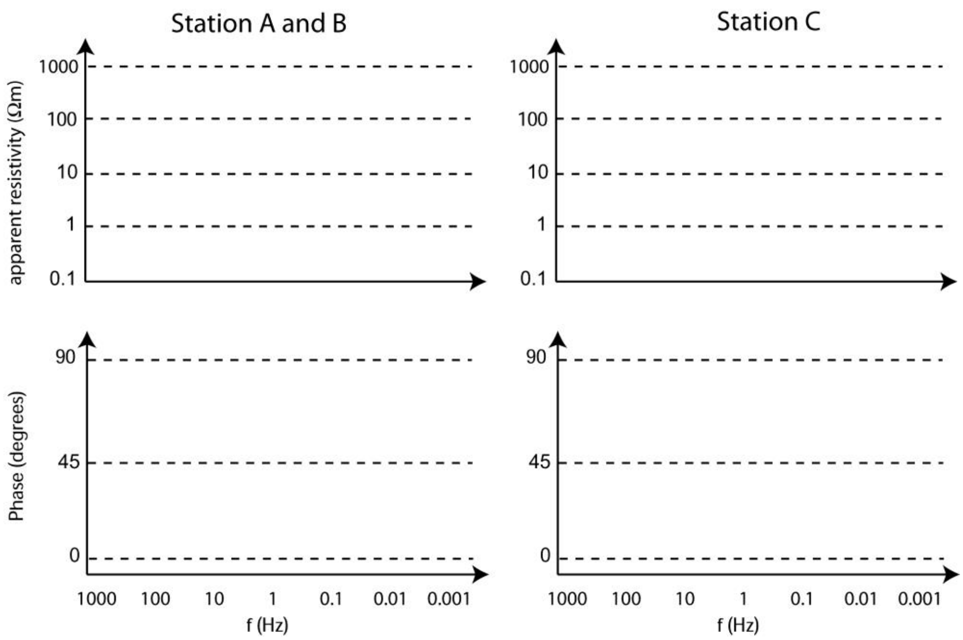
Broadband MT data (1000-0.001 Hz) are being used to image a coastal aquifer in the Canadian Arctic. Site A is located on rock, while B is located on sea ice

(3a) Sketch the apparent resistivity and phase data at sites A and B. Clearly label the data from sites 'A' and 'B' **(12 points)**

(3b) To avoid the problem of working on sea ice, the researchers returned when the sea ice had melted and placed a seafloor MT instrument at site C. Sketch the apparent resistivity that would be measured at C **(6 points)**

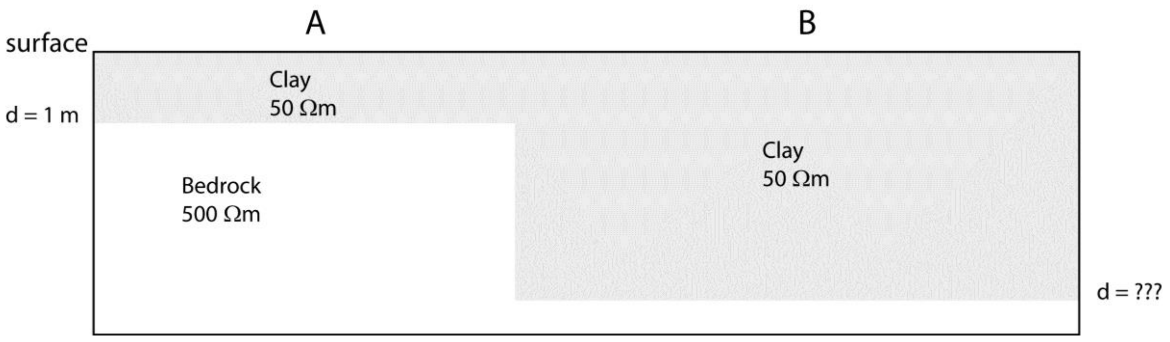
- You can approximate the structure at each location is 1-D.
- Be quantitative where possible. Ignore the resistivity of the sea ice
- Assume that EM signals can be detected after travelling 3 skin depths in seawater





DRAW YOUR ANSWER ON THE FIGURE ABOVE

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



An EM31 survey takes place where a clay layer (resistivity = 50 Ωm) overlies granitic bedrock (resistivity = 500 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 = 0.01 S/m in vertical dipole mode when carried 1 m above the ground.

How thick is the clay layer at ‘B’? **(4 points)**

Q5 : Frequency-domain electromagnetics (Total = 8 pts)

"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?

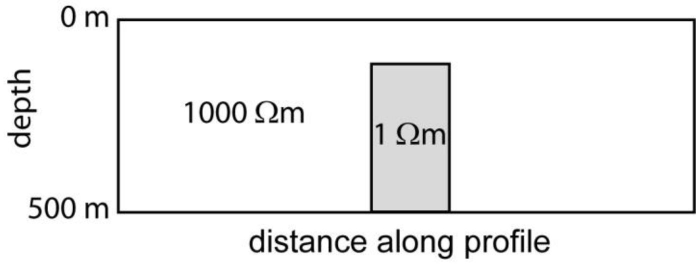
(8 points)

Question 6 : VLF (Total = 8 points)

VLF measurements with an EM16 are being used to locate an ore body.

The transmitter has a frequency of 21 KHz.

The VLF instrument measures the **tilt angle**.



(6a) Sketch a map of the **ideal orientation** of the VLF profile, primary magnetic field and transmitter. **(3 points)**

(6b) Assume the survey is performed in the ideal orientation.
Sketch the **tilt angle** data recorded along the profile shown above. **(3 points)**

(6c) What is the **maximum depth** at which the orebody can be detected with VLF? **(2 points)**

Question 7 : Time domain EM methods (Total = 20 pts)

A time domain survey is using the transmitter waveform shown on the next page.
The primary magnetic field is shown in (A)
The ore body (a conductor) behaves as an **inductor and resistor in series**.

(7a) Define the **mutual inductance** between two electric circuits **(2 points)**

(7b) Sketch the **secondary voltage** induced in the conductor in (B)
Explain how the secondary voltage is related to the primary magnetic field.
(4 points)

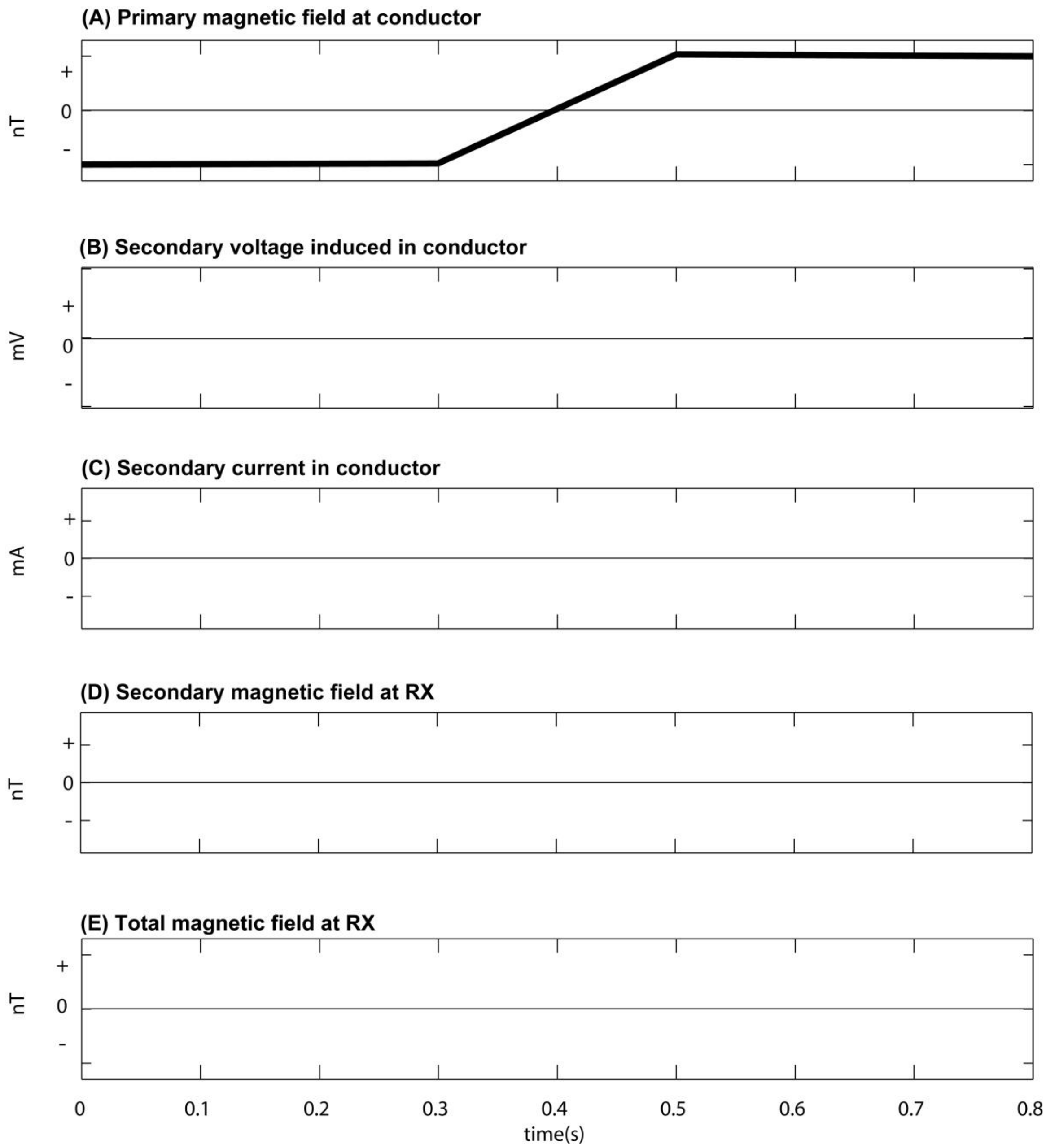
(7c) Sketch the time variation of the **secondary current** in (C)
Show both GOOD and BAD conductors on same graph. **(6 points)**

(7d) Sketch the time variation of the **secondary magnetic field** at the RX in (D)
Show both GOOD and BAD conductors on same graph. **(4 points)**

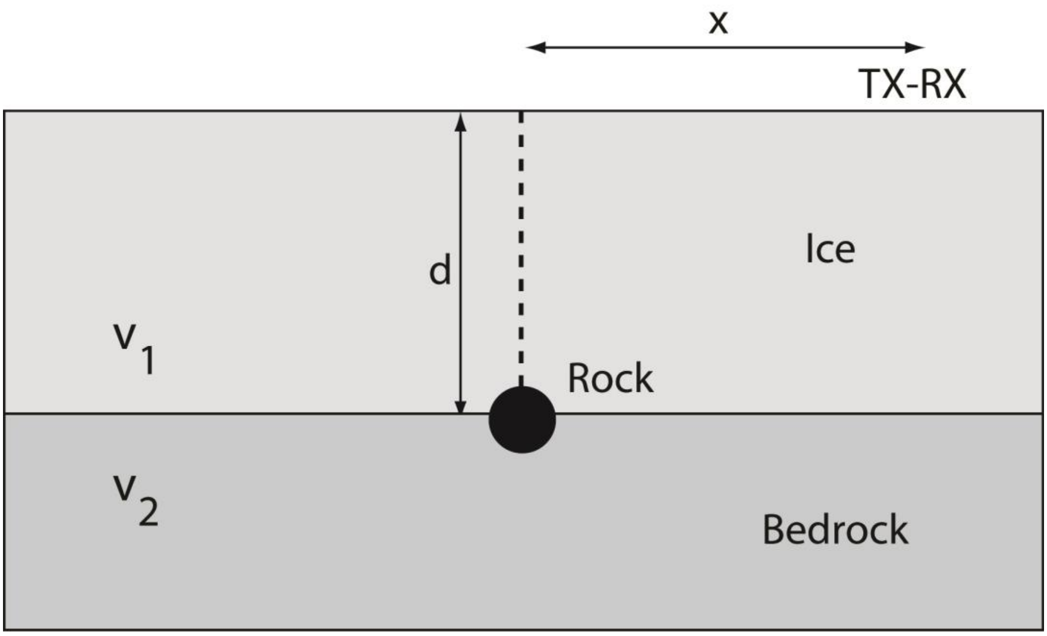
(7e) Sketch the time variation of the **total magnetic field** at the RX in (E)
Show both GOOD and BAD conductors on same graph. **(4 points)**

Your answer will be **qualitative** in (7b) - (7e).

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

Question 8 : Ground-penetrating radar (Total = 14 points)



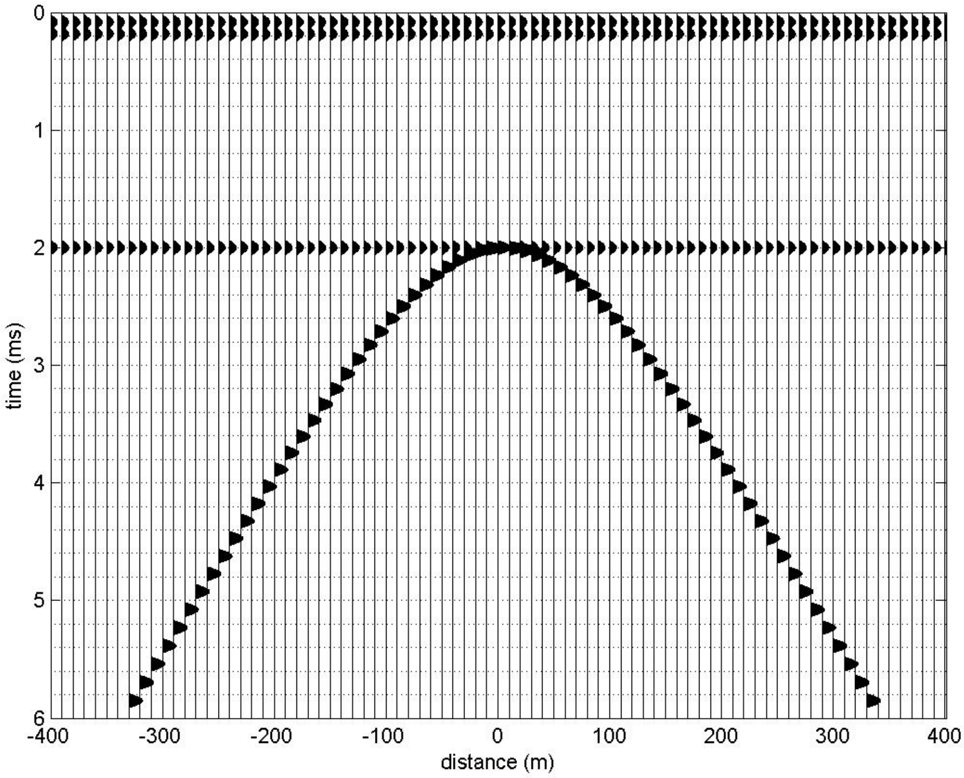
- GPR is being used to study the glacier shown above
- The radar system has a closely spaced transmitter and receiver system.
- Radar frequency is 200 MHz
- TX-RX distance is very small compared to the thickness of the ice.
- A rock is located at the base of the ice at x = 0 m and acts as a diffractor

(8a) Derive an equation for the two-way travel time of the reflection from the bed of the glacier **(2 points)**

(8b) Derive an equation for the travel time of a signal diffracted from the rock. Assume that the TX and RX are coincident. **(3 points)**

(8c) The figure below shows radar data collected on the glacier. Numerical values are also given in a table. Calculate v_1 and d **(6 points)**

(8d) Estimate the velocity in the bedrock (v_2) **(3 points)**



x(m)	arrival 1(ms)	arrival 2(ms)
-300.000	2.000	5.385
-200.000	2.000	3.887
-100.000	2.000	2.603
0.000	2.000	2.000
100.000	2.000	2.603
200.000	2.000	3.887
300.000	2.000	5.385