Geophysics 424 A1 Final exam
Electromagnetic and Potential field methods

Date : Monday December 18th 2006
Instructor : Dr. Martyn Unsworth
Time allowed : 3 hours
Total points = 135

Instructions

Attempt all ***three*** *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.

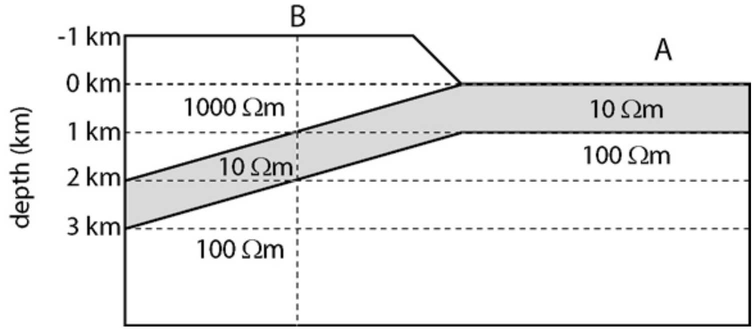
This exam has 8 pages

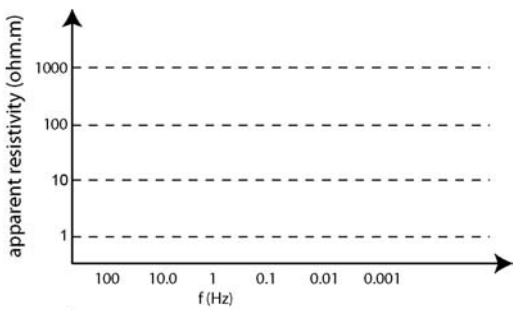
Question 1 : Applications of EM methods (Total points = 65)

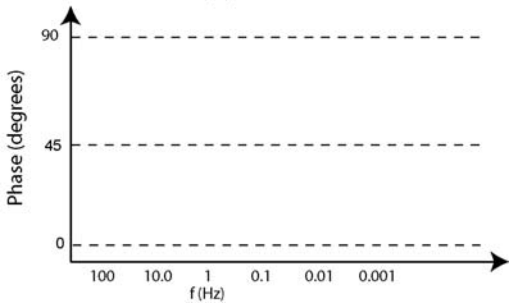
1(a) Magnetotellurics (19 points)

Broadband MT data (100-0.001 Hz) are being used in hydrocarbon exploration to determine the depth of a layer of potential reservoir rocks (shown in grey).

Station ‘A’ is at sea level, while ‘B’ is 1 km above sea level.







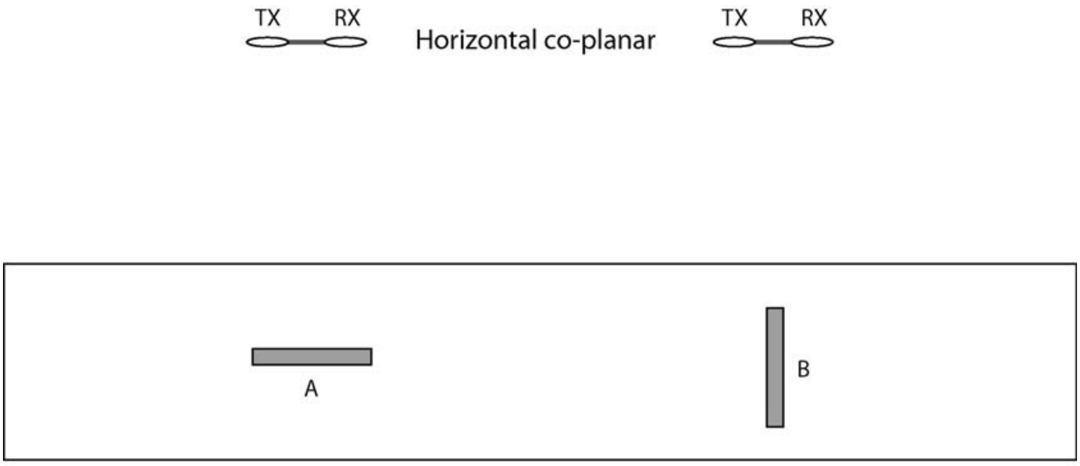
- Sketch the MT apparent resistivity and phase data at sites ‘A’ and ‘B’ on the graph above. You can approximate the structure at each location to being 1-D.

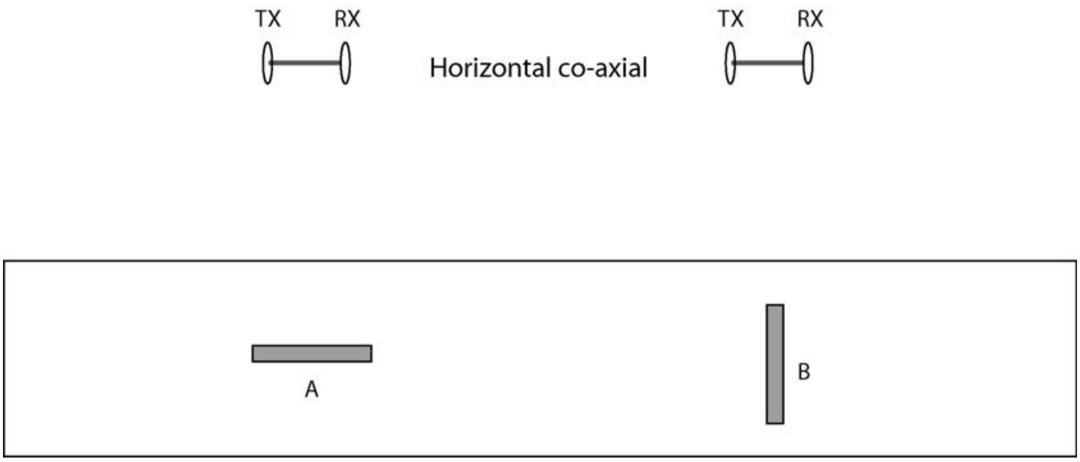
  Be quantitative where possible. **(12 points)**

- What type of magnetic sensor would be used for this survey? Briefly explain how this sensor works and what exactly is measured. **(3 points)**

- Give **two** reasons why magnetic sensors should be buried in MT exploration? **(4 points)**

1(b) Frequency domain electromagnetics (12 points)





A frequency domain EM survey is flown over two buried conductors. Two configurations of TX and RX are used. Assume that the secondary magnetic field (H^S) is in phase with the primary magnetic field (H^P).

- Sketch the **primary** and **secondary** magnetic field lines when the TX-RX is above each conductor.
- For each TX-RX geometry, which conductor (A or B) will give the biggest response in H^T/ H^p?
- Indicate if $H^T/ H^p > 1$ or $H^T/ H^p < 1$ above each conductor for the co-axial and co-planar configurations.

(12 points)

1(c) Marine magnetotellurics (6 points)

Seafloor MT data are being recorded in an area where the seawater depth varies.

The seawater conductivity is 3 S/m. The client requests that seafloor MT data is recorded in the frequency band 1-0.001 Hz.

The seafloor EM fields can be detected when they are 0.1% of the value at the ocean surface.

- What is the **maximum seawater depth** in which seafloor MT data can be recorded?

1(d) Marine Controlled Source EM (12 points)

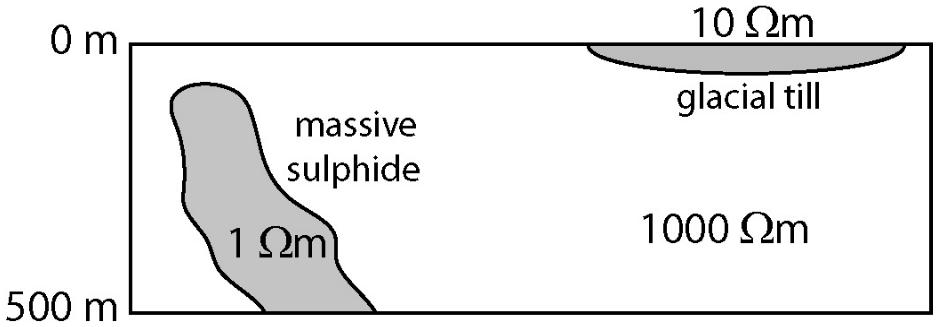
- Explain the **basic physics** of seafloor controlled source EM exploration.

- In a study area offshore Norway, the seafloor has a uniform porosity of 10% and the pore space is poorly connected. The seawater conductivity is 3 S/m. It is required to transmit EM signals over a distance of 5 km through the seafloor. What transmission frequency is needed?

- How is this technique used to detect **hydrocarbon reservoirs**?

1(e) Time domain electromagnetics (16 points)

A MEGATEM system is being used to locate massive sulphides. In the survey area there are also shallow areas of glacial till. The instrument measures the secondary voltage at 5 discrete times after the primary field is switched off.



- Sketch the data recorded as the TX and RX are flown along this transect . Clearly explain what is being measured. **(5 points)**

- How are **surface conductors** distinguished from **deeper conductors**? **(2 points)**

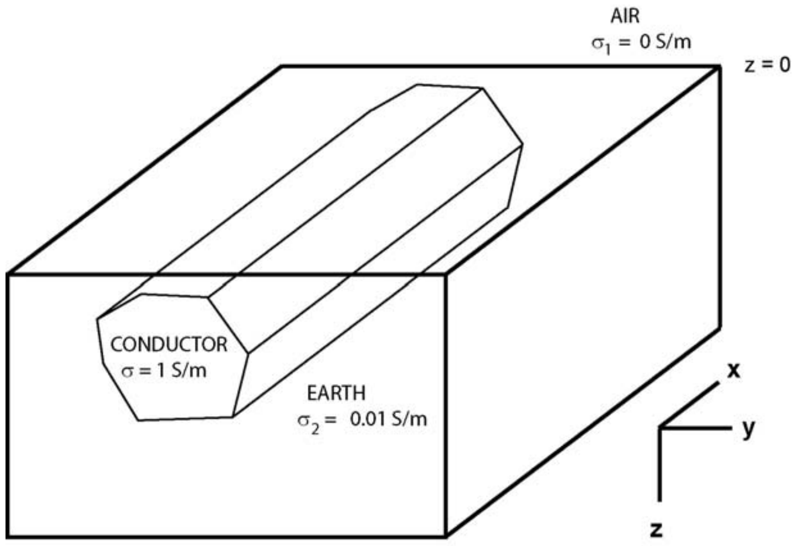
- What factors cause **noise** in the measurements? **(3 points)**

- The latest time recorded is 10 milliseconds. What is the maximum depth at which the massive sulphide can be detected? **(3 points)**

- If the data is noisy, what can be done to increase the depth of penetration? **(3 points)**

Question 2 : Maxwell's Equations (Total points = 30)

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 $e^{i\omega t}$



(a) 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.

(7 points)

(b) These six equations simplify over a 2-D Earth structure. Show that the TE mode can be described by the following equation:

$$\frac{\partial^2 E_x}{\partial y^2} + \frac{\partial^2 E_x}{\partial z^2} = iw\mu\sigma E_x$$

Justify any assumptions you have made **(7 points)**

(c) Derive a similar equation for B_x for the TM mode. **(5 points)**

(d) 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 **(5 points)**

(e) 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*

(6 points)

<u>Question 3 : Controlled source EM methods (Total points = 40)</u>

(a) "*A frequency domain, loop-loop EM system measures the mutual induction between the transmitter(TX) and the receiver(RX)*"

Explain this statement. Include a definition of mutual induction. **(6 points)**

(b) How will a conductive ore body will be detected by such a system? **(4 points)**

(c) Relative movement of the TX and RX produces noise. How can this be explained on the basis of mutual induction? **(3 points)**

(d) The figure on the next page shows three basement conductors. A ground EM survey uses horizontal co-planar transmitter and receiver loops that are 20 m apart with a frequency of 2120 Hz.

- Draw **primary and secondary magnetic field lines** for positions as the TX-RX moves over one conductor.
- Then sketch the **in-phase** and **quadrature** responses along the profile.

Use the **characteristic curves** to be **quantitative** where possible.

Response parameter, $p = \mu\omega\sigma W l$

Depth parameter, $D = z / l$

W = width of conductor,
l = TX-RX separation,
σ = conductivity of conductor
ω = TX frequency (rad /s)
z = depth to conductor

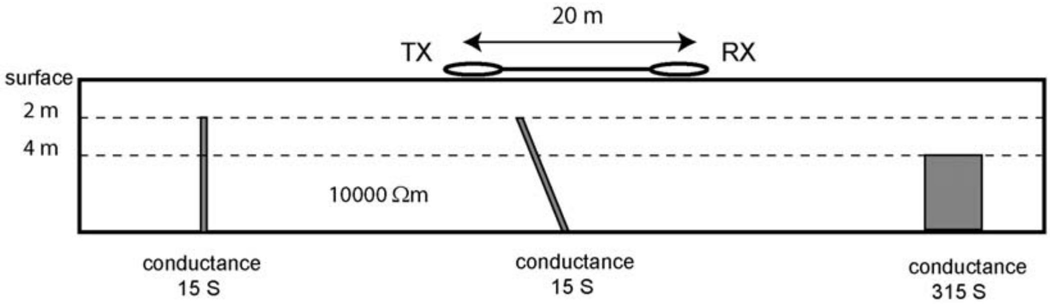
(19 points)

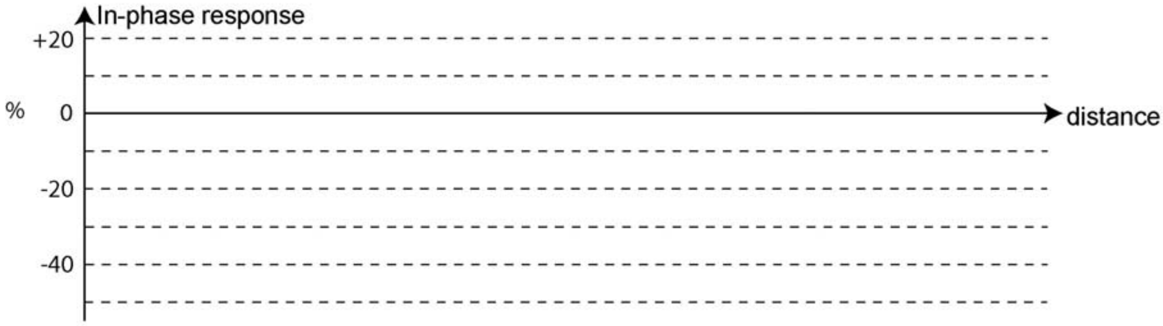
(e) The characteristic curves show that a **good conductor** generates a secondary magnetic field that is **in-phase** with the primary magnetic field.

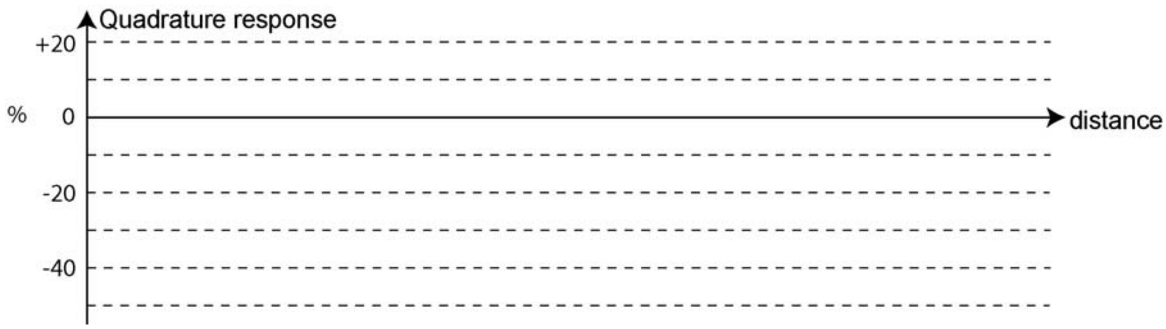
Explain the **physics** of this observation in detail.

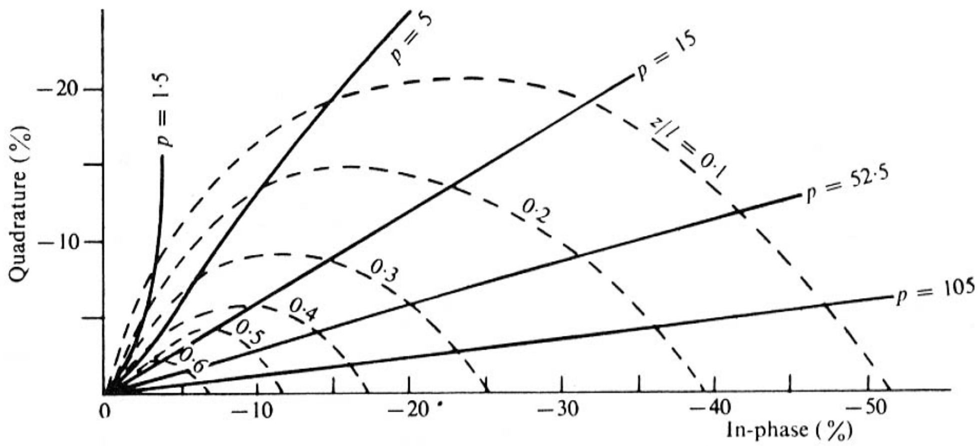
Your answer should include a **phase diagram.**

(8 points)


20 m
TX
RX
surface
2 m
4 m
10000 Ωm
conductance
15 S
conductance
15 S
conductance
315 S


In-phase response
+20
%
0
-20
-40
distance


Quadrature response
+20
%
0
-20
-40
distance


Quadrature (%)
In-phase (%)
p = 1·5
p = 5
p = 15
p = 52·5
p = 105
l/z = 0·1
0·2
0·3
0·4
0·5
0·6
−20
−10
0
−10
−20
−30
−40
−50