Geophysics 424 A1 Final exam
Electromagnetic and Potential field methods

Date : Wednesday December 9th 2009, 2pm – 5pm
Location CEB 4-42
Instructor : Dr. Martyn Unsworth
Time allowed : 3 hours
Total points = 100

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. $\mu = \frac{\overline{v}}{E}$

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

(6 points)

(b) A brine is formed by dissolving 30 g of sodium chloride in 1 liter of water.

The brine has a conductivity of 3 S/m.

Estimate the mobility of the ions. You can assume that the sodium (Na^+) and chloride (Cl^-) ions have the same mobility

(5 points)

Useful data

Volume of 1 liter 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 : Marine EM methods (Total = 14 points)

- How does frequency domain marine controlled source EM exploration measure variations of resistivity with depth?
- In a study area, 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?
- Explain the difference of **broadside** and **inline** configurations. How are they used to detect **hydrocarbon reservoirs**? Include a diagram in your answer.

Question 3 : Frequency domain EM (Total = 26 points)

(a) 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.**

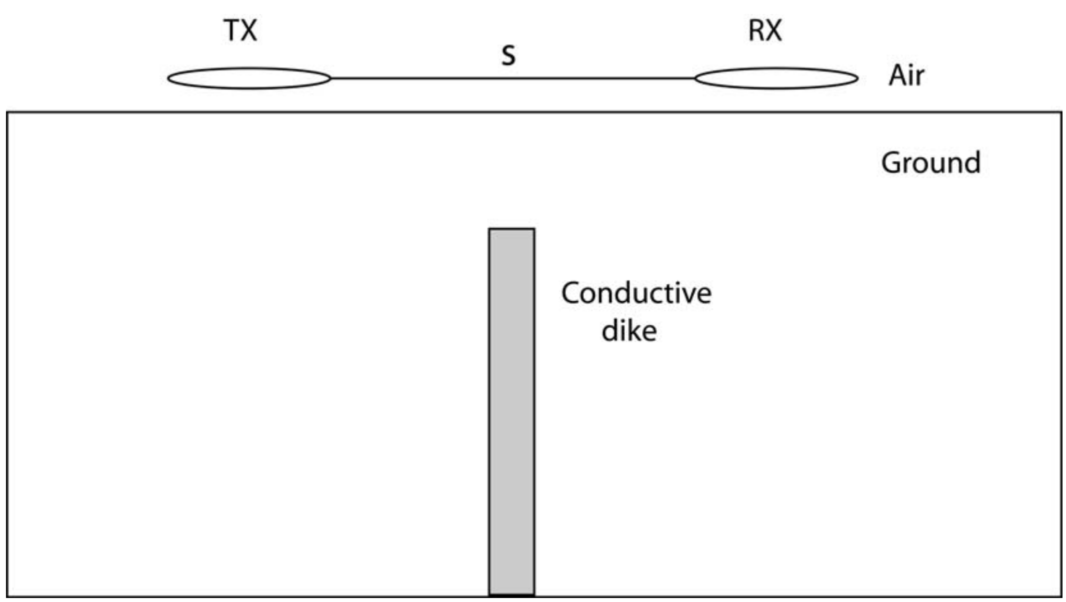
(6 points)

(b) An EM survey uses **horizontal co-planar** transmitter and receiver loops.

Consider the situation when the transmitter (TX) and receiver (RX) are located above a conductive dike.

Sketch the primary magnetic field (H^P) and **in-phase** secondary magnetic field (H^S) lines on the diagram below.

What will be the **sign** of $\frac{H^S}{H^P}$ at the receiver? **(6 points)**

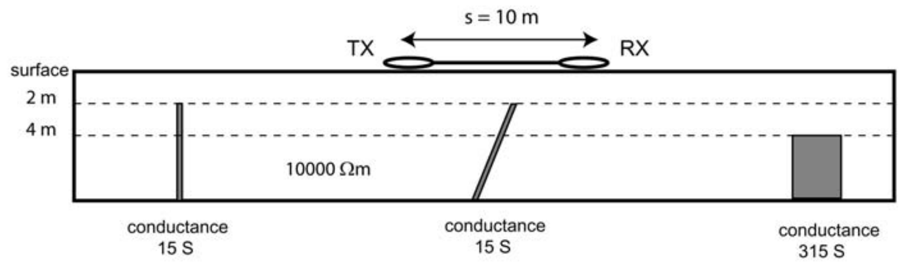


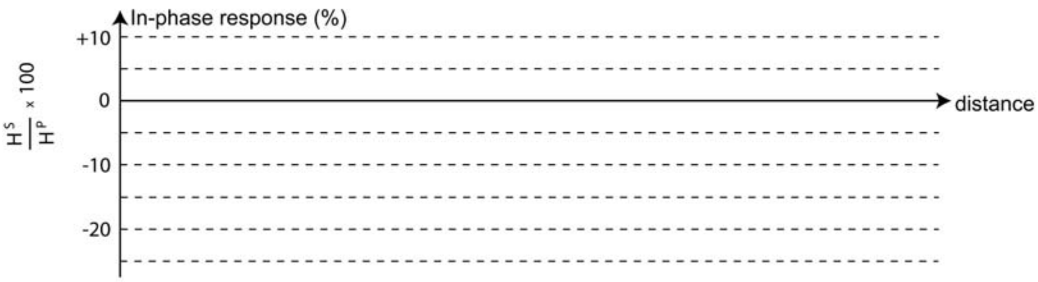
(c) The figure on the next page shows three basement conductors. Sketch the **in-phase** and **quadrature** responses along the profile that would be obtained with an EM system using a frequency of 4200 Hz

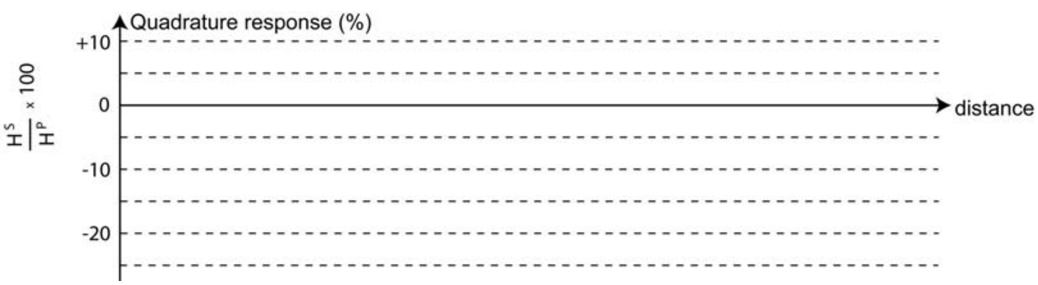
Use the **characteristic curves** to be **quantitative** where possible.

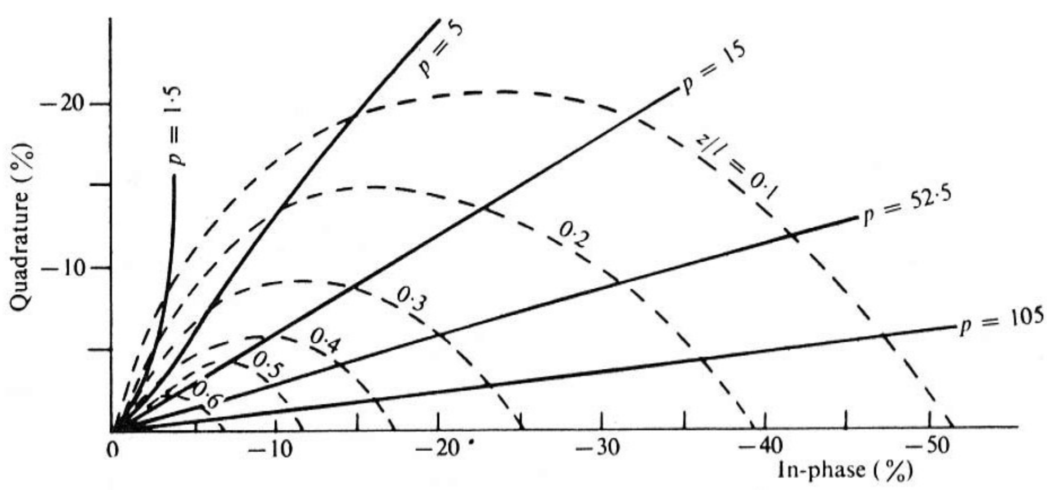
Response parameter, $p = \mu\omega\sigma Ws$ (constant on solid lines)
Depth parameter, $D = z / s$ (constant on dashed lines)

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


s = 10 m
TX
RX
surface
2 m
4 m
10000 Ωm
conductance
15 S
conductance
15 S
conductance
315 S


In-phase response (%)
+10
0
-10
-20
distance
$\frac{H^S}{H^P} \times 100$

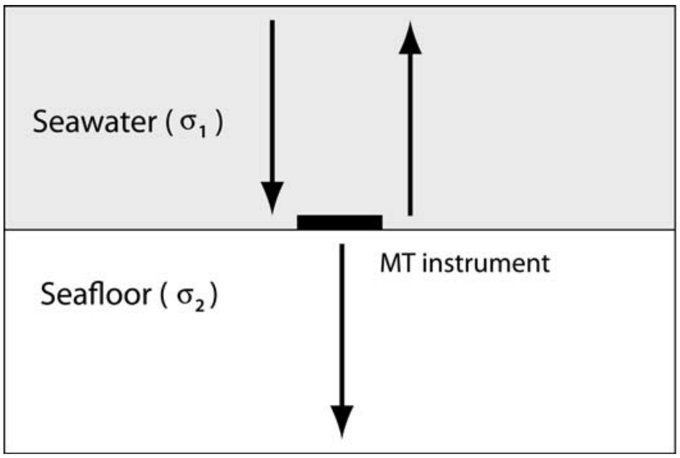

Quadrature response (%)
+10
0
-10
-20
distance
$\frac{H^S}{H^P} \times 100$


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

(14 points)

Question 4 : Maxwell's Equations (Total = 21 points)

A seafloor MT survey is being used to measure the resistivity of the seafloor.
A **plane** EM wave has an angular frequency, ω, and travels **vertically** downwards in seawater in the z-direction. The electric field is **polarized** in the x-direction.



Down going signal in seawater	$E_x(z,t) = Ae^{-k_1 z}e^{-i\omega t}$
Up going signal in seawater	$E_x(z,t) = Be^{k_1 z}e^{-i\omega t}$
Down going signal in seafloor	$E_x(z,t) = Ce^{-k_2 z}e^{-i\omega t}$

$k_1 = \sqrt{-i\omega\mu_0\sigma_1}$ and $k_2 = \sqrt{-i\omega\mu_0\sigma_2}$

(a) Use Maxwell's equations to prove that the **horizontal electric** field is continuous at the seafloor (z = 0)

(5 points)

(b) Use Maxwell's equations to show that for this plane, polarized EM signal

$$H_y(z) = \frac{1}{i\omega\mu}\frac{\partial E_x(z)}{\partial z}$$

(5 points)

(c) Derive an expression for $\frac{C}{A}$ at the seafloor in terms of σ_1 and σ_2. State any boundary conditions that you use.

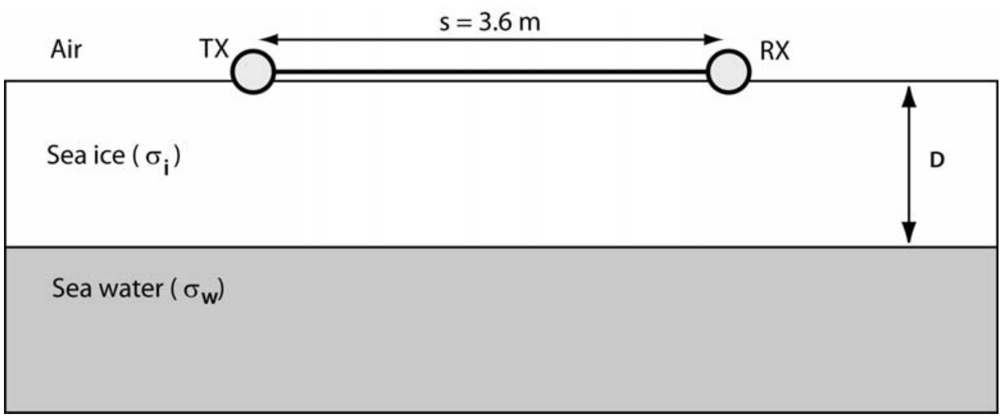
(6 points)

(d) The MT instrument measures electric and magnetic fields at a frequency ω.
At z = 0, the measured electric and magnetic fields is E_x^m and H_y^m
Derive an equation for the seafloor conductivity (σ_2) in terms of E_x^m and H_y^m

(5 points)

Question 5 : Frequency domain EM methods (Total = 17 points)

An EM31 survey is being used to measure sea-ice thickness with a frequency of 9100 Hz. The transmitter and receiver dipoles are oriented **horizontally** and placed on the ice. The sea-ice has a conductivity σ_i and the seawater has a conductivity σ_w



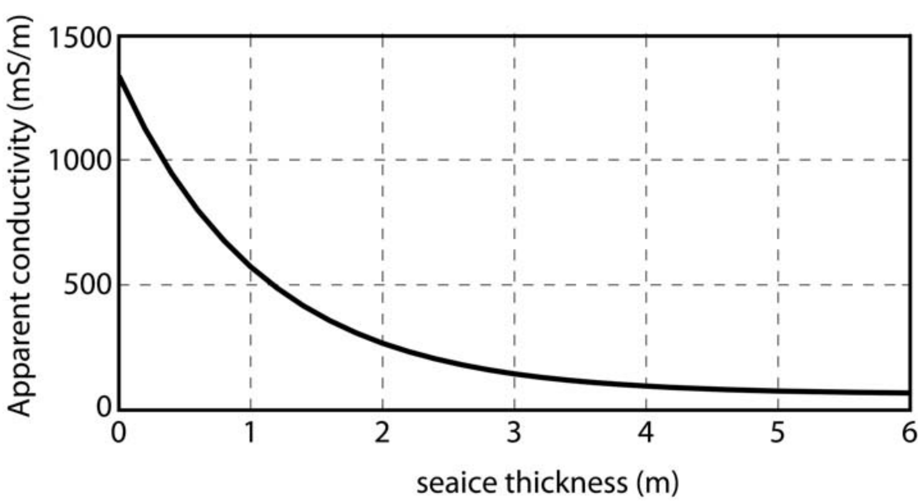
(a) Write down an equation for the **average conductivity** $\bar{\sigma}_h$ measured by the EM31.

(3 points)

(b) Studies have shown that $\sigma_i = 23$ mSm and $\sigma_w = 2600$ mS/m

Compute $\bar{\sigma}_h$ for D = 2, 3 and 4 m. Plot your results on the graph below.

(7 points)



(c) The instrument reading was 600 mS/m. Estimate the ice thickness (D) at this location from the graph you plotted in (b)

(2 points)

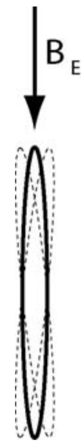
(d) The black line on the figure shows the results of a calibration test where the ice thickness was measured by coring. Compare your answer to that from (b) and suggest an explanation for any differences. **(5 points)**

Question 6 : Time domain EM methods (Total = 11 points)

(a) A time domain EM survey is being conducted at a location where the Earth's magnetic field is **vertical** and B_E = 50000 nT.

The x-axis receiver coil oscillates with an amplitude of 1^o at a frequency of 0.5 Hz.

What noise level does this produce in $\frac{dB_z}{dt}$?



(4 points)

(b) The transmitter has a current I = 100 amps, area A = 100 m^2 and 5 turns of wire (N = 5).

The noise level is that computed in part (a)

The Earth has a resistivity of 200 Ωm

What is the **latest time** at which the transient can be observed? **(4 points)**

What is **maximum depth of exploration** at this location? **(3 points)**