Geophysics 524A1 - 424 A1 - Final exam - Fall term
Electromagnetic and Potential field methods

Date :	Friday December 18th 2015, 2-5 pm
Location	CCIS L1-029
Instructor :	Dr. Martyn Unsworth
Time allowed	3 hours
Total points	**118**

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 : Resistivity of rocks (Total = 18 points)

An ore deposit consists of crystalline rock with **sulphide minerals** in aligned cracks.

The volume fraction of sulphides in the rock is V

The sulphides have a resistivity of ρ_s 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 $\rho_s = 0.01\ \Omega$m and $\rho_r = 1000\ \Omega$m

Give numerical values of the resistance for $V = 0$, 0.5 and 1 **(4 points)**

(1d) Calculate the resistance predicted by Archie's Law for the range 0 < V < 1.

Plot the resistance on the graph.

Assume that $\rho_s = 0.01\ \Omega$m and $\rho_r = 1000\ \Omega$m

Give numerical values of the resistance for $V = 0$, 0.5 and 1 **(5 points)**

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

(3 points)

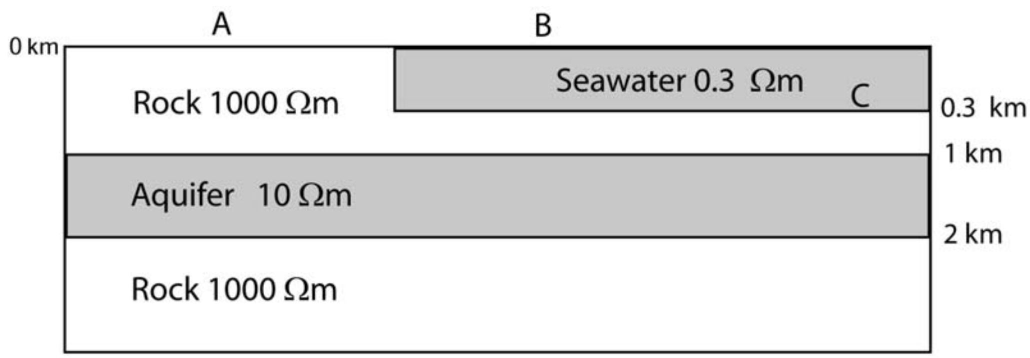
Question 2 : Magnetotellurics (Total = 18 points)

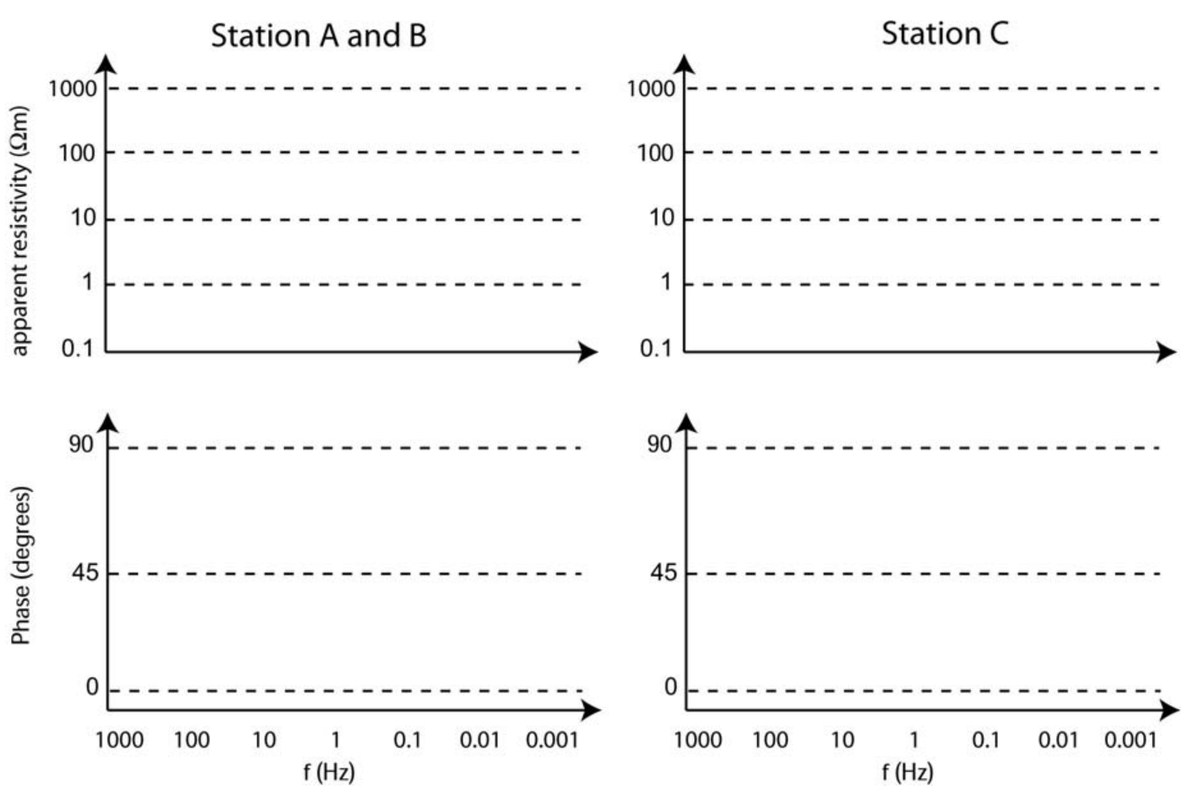
Broadband MT data (1000-0.001 Hz) are being used to image a coastal aquifer in the Canadian Arctic. Site A is located on rock, while B is located on sea ice

(2a) Sketch the apparent resistivity and phase data at sites A and B **(12 points)**

(2b) 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 1 skin depth in seawater

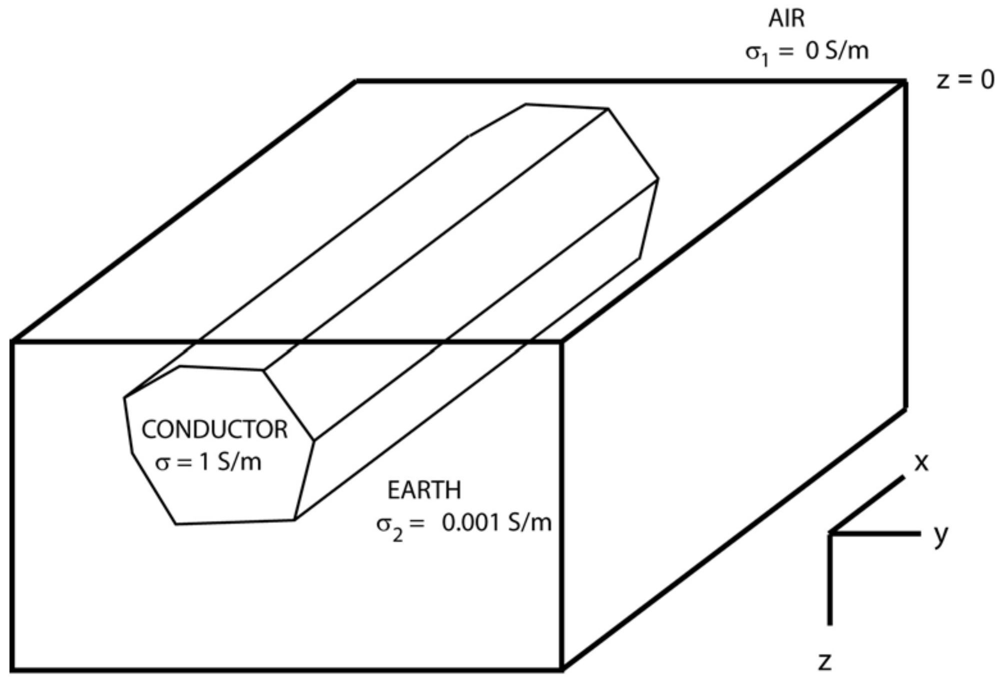




Question 3 : Maxwell's Equations (Total = 21 points)

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 $e^{i\omega t}$



(3a) 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. **(6 points)**

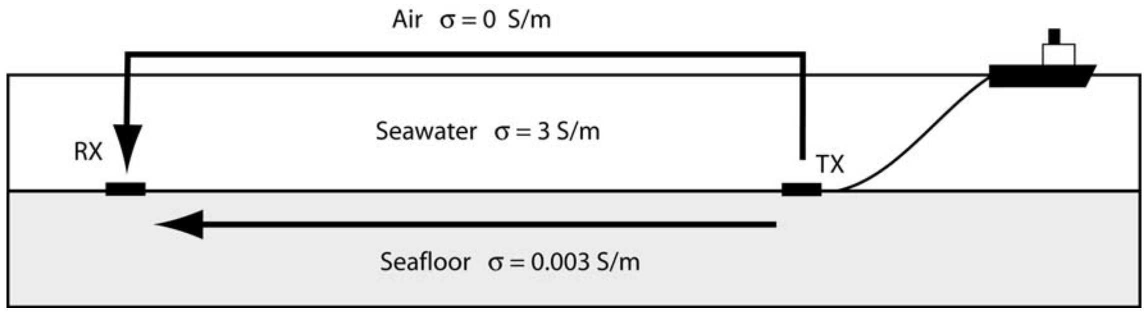
(3b) These six equations simplify over a 2-D Earth structure. Derive a differential equation for the TM mode in terms of B_x (y,z). Explain any assumptions you have made **(7 points)**

(3c) Consider a point on the surface of the Earth at z = 0

The vertical electric field 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)**

(3d) Consider the case when $\sigma_1 = 0$ S/m and $\sigma_2 = 0.001$ S/m
Show that for the TM mode, B_x(y) at z = 0 is constant for all values of *y* **(4 points)**

Question 4 : Marine EM methods (Total = 8 points)



In a marine CSEM survey, the EM signals travel diffusively from transmitter (TX) to receiver (RX) by the **two routes** shown above. In the CSEM survey shown above the seawater depth was 400 m and the transmission frequency was 4 Hz

(4a) Estimate the TX-RX offset at which the two signals have the same strength? **(6 points)**

Hint : Ignore geometric spreading, consider only attenuation.

(4b) Name two commonly used types of transmitter in seafloor CSEM **(2 points)**

Question 5 : Frequency domain EM methods (Total = 24 points)

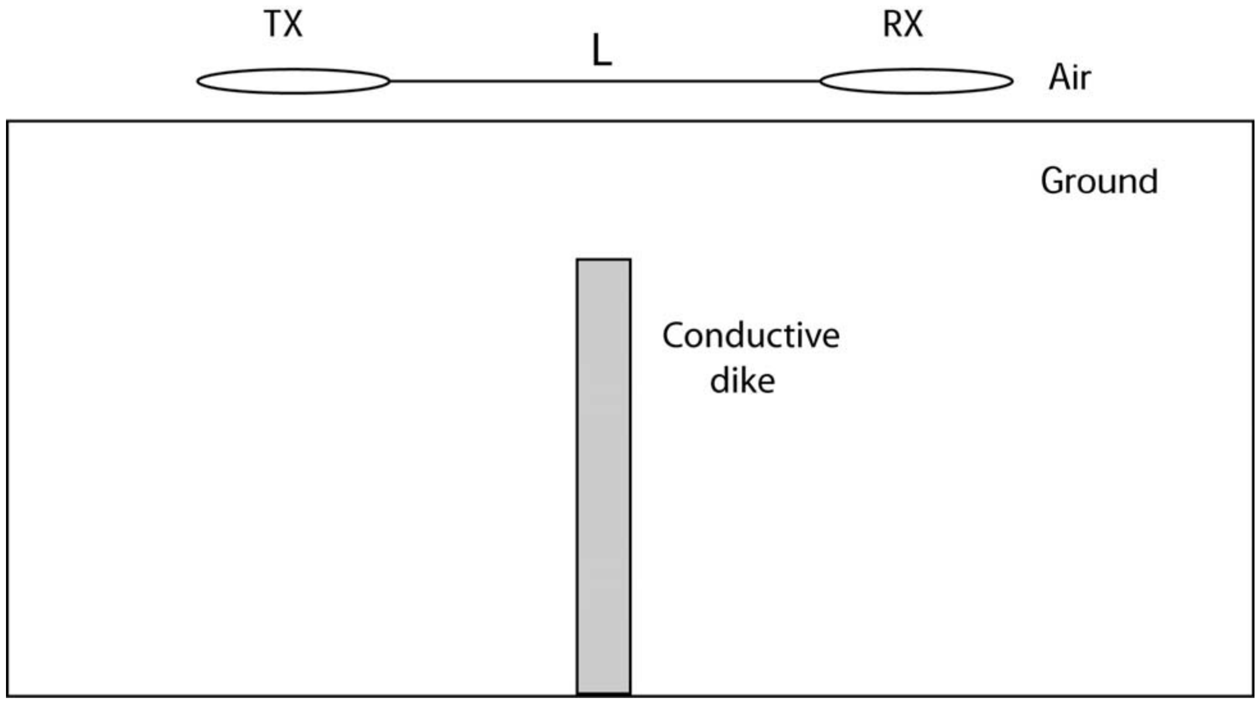
(5a) A **good conductor** generates a secondary magnetic field that is **in-phase** with the primary magnetic field. Explain the **physics** of this statement in detail.

Your answer should include a **phase diagram.** **(6 points)**

(5b) An EM survey uses **horizontal co-planar** transmitter and receiver loops as shown below. 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)**



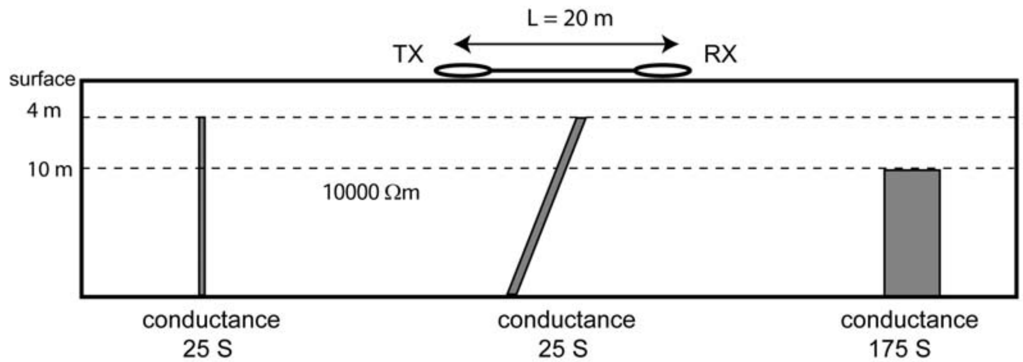
(5c) The figure on the next page shows three basement conductors.

Calculate the value of the **in-phase** and **quadrature** responses when the TX-RX system is located above each conductor. System operates at 3800 Hz **(6 points)**

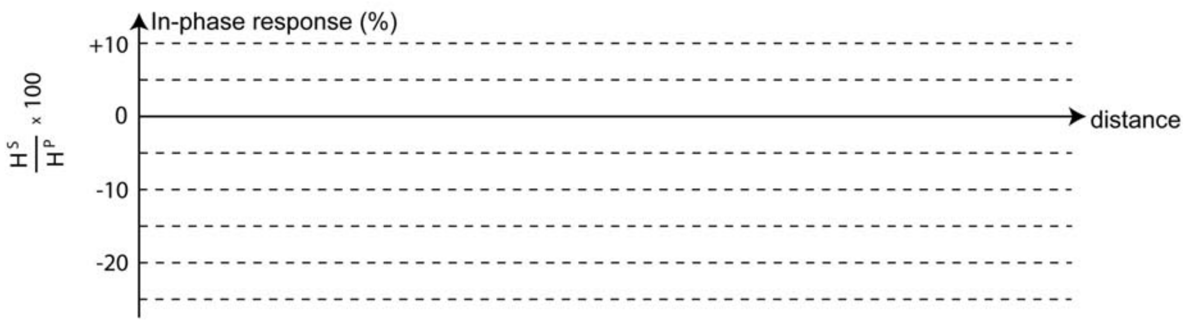
(5d) Sketch the variation of the in-phase and quadrature responses along the profile on the diagram below **(6 points)**

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

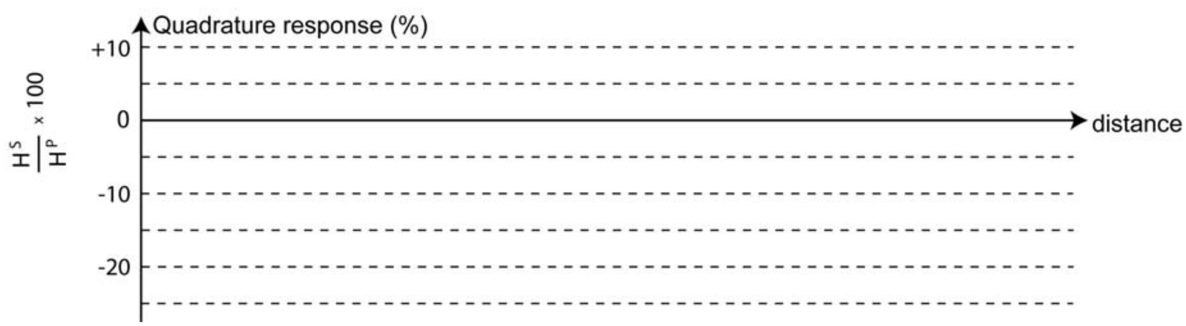
W = width of conductor
σ = conductivity of conductor
z = depth to top of conductor
L = TX-RX separation,
ω = TX frequency (rad /s)



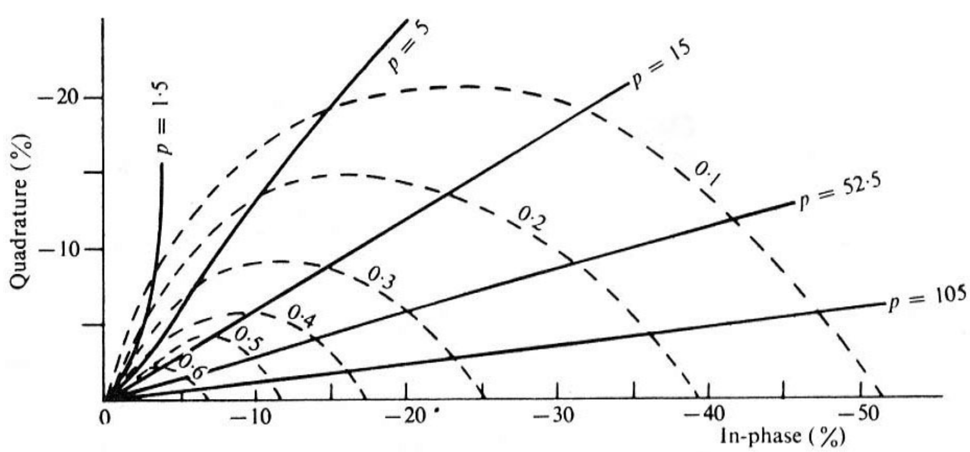
L = 20 m
TX
RX
surface
4 m
10 m
10000 Ωm
conductance 25 S
conductance 25 S
conductance 175 S



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
0·1
0·2
0·3
0·4
0·5
0·6

Question 6 : Time domain EM methods (Total = 12 points)

(6a) A GEOTEM survey is being conducted at a location where the Earth's magnetic field is **horizontal** and $B_E = 30000$ nT.

The z-axis receiver is in a towed bird that oscillates with an amplitude of 1^o at a frequency of 0.1 Hz. This receiver is a horizontal loop.

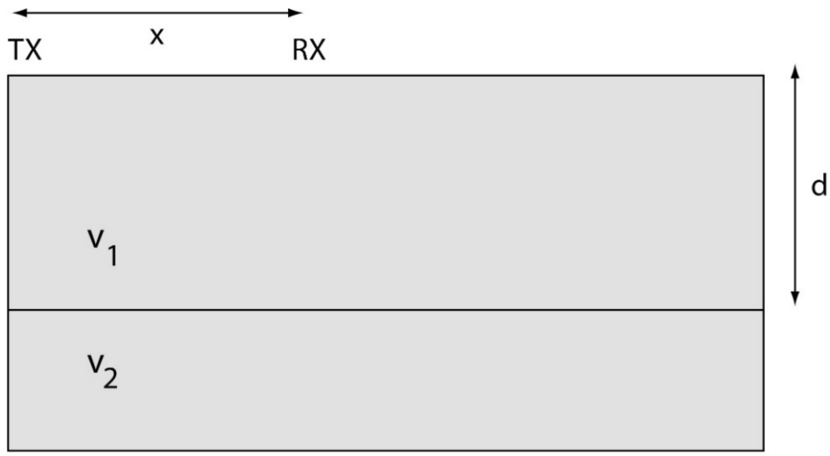
Calculate the amplitude of noise in $\frac{dB_z}{dt}$ caused by the oscillation **(6 points)**

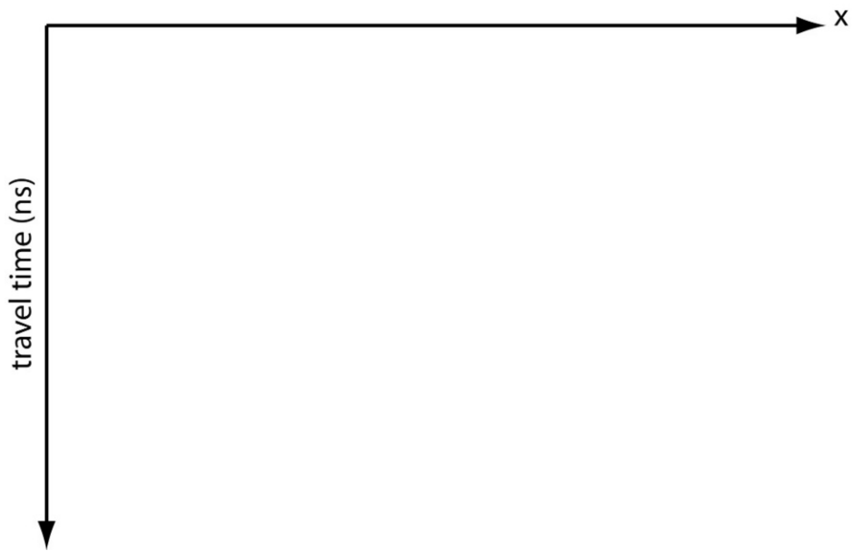
(6b) The transmitter has a current $I = 1000$ amps, area $A = 100$ m^2 and 5 turns. The noise level is that computed in part (a). The Earth has a resistivity of 1000 Ωm. What is the **latest time** at which the transient can be observed? (**4 points)**

(6c) What **depth of exploration** does this represent? **(2 points)**

Question 7 : Ground-penetrating radar (Total = 17 points)

GPR is being used to study the subsurface structure shown below.
A reflector is located at a depth *d*
Velocity in the Earth is v_1 above the reflector and v_2 below
Radar frequency is 200 MHz and TX-RX distance is x m
The transmitter is fixed and the receiver is moved.





(7a) Derive an equation for the travel time of the **air wave** when the transmitter (TX) and receiver (RX) are separated by a distance *x*.

(2 points)

(7b) Derive an equation for the travel time of the **direct wave** travelling in the ground when the transmitter (TX) and receiver (RX) are separated by a distance *x*.

(2 points)

(7c) Derive an equation for the travel time for a **reflected wave** when the transmitter (TX) and receiver (RX) are separated by a distance *x*. **(3 points)**

(7d) Sketch these two travel time curves on the figure above. **(3 points)**

(7e) GPR travel times for the reflection are listed in the table below.
Calculate v_1 and *d*

(5 points)

x (m)	T(ns)
1	34.36
2	37.27
3	41.67
4	47.14
5	53.36

(7f) Calculate the moisture content of layer 1 (θ_v) **(2 points)**