

APEGBC Examination

94 - GL - A3; Applied Geophysics

Dec, 2005

Time: 3.0 hrs.

Candidate Name: _____

Notes:

- Many questions are multiple choice, some are short answer, a few require a sentence or two, and some require a simple sketch or a little math. There are no essays.
- Marks for each question are given in brackets next to the question number. Use these as a guide for the amount of time to spend on each question. There are a total of 90 marks in the whole exam.
- If only a short answer is needed, do not spend time writing paragraphs. Single words or letters for multiple choice questions will be adequate.
- Don't forget that the marker must be able to read your writing!
- Be sure to show your work if any mathematics or arithmetic is necessary. A collection of equations and constants that might be useful is provided on the last page of the exam.
- Please hand this examination paper in with your work booklet.
- If the question asks for sketches, draw carefully and include graph axis and labels.
- Closed book, non-communicating calculator permitted.

Read each question carefully. The single most common cause of errors in exams of this type is that candidates do not read the questions carefully and completely. It is unfortunate to lose marks simply because the question was not answered fully. Good luck.

Part I: General aspects of applying geophysics (13 marks)

Physical properties are the key to making useful connections between geophysical results and geological or geotechnical information. Here are six multiple choice questions about physical properties.

1. (0.5) How are electrical resistivity and conductivity related?
 - a. Conductivity is the complex form of resistivity
 - b. Resistivity is the reciprocal of conductivity
 - c. Resistivity and conductivity are the same quantity
 - d. Resistivity will be twice the value of conductivity
2. (0.5) Which of the following does NOT affect electrical resistivity:
 - a. Hydraulic permeability
 - b. Amount of clay in the material
 - c. Magnetic susceptibility
 - d. Type of fluid in the pore space
3. (0.5) Dielectric permittivity is a property that describes ...
 - a. how easily charges bound to molecules are moved by an electric field.
 - b. how easily fluids flow through a geologic formation.
 - c. the rate at which electromagnetic signals lose their energy as they propagate into the ground.
 - d. the phase shift, or storage of energy, when an oscillating electric field is applied.
4. (0.5) Poisson's ratio (the ratio of transverse strain over longitudinal strain) can be derived from
 - a. Surface wave velocity
 - b. S-wave velocity alone
 - c. P-wave velocity alone
 - d. S-wave and P-wave velocities
5. (0.5) Because liquids have no shear rigidity, ...
 - a. S waves can not propagate through liquids.
 - b. P waves can not propagate through liquids;
 - c. Surface waves can not propagate through liquids.
 - d. At least two of the above are true.
6. (0.5) Magnetic susceptibility ...
 - a. is the strength of the permanent magnetization of a material.
 - b. describes how easily material acquires magnetization when a magnetic field surrounds it.
 - c. describes how easily an object will be detected by a magnetic survey.
 - d. is the strength of Earth's magnetic field.
 - e. is a value that is related to Earth's magnetic field.

7. (1) Ten quantities commonly encountered in geoscience work are: a) electrical conductivity; b) GPR attenuation; c) IP & complex resistivity; d) dielectric permittivity; e) magnetic susceptibility; f) density; g) porosity; h) seismic velocities; i) acoustic reflectivity and j) poisson's ratio. Identify two of these quantities that can be derived from other quantities in the same list.
8. (4) Copy the following table and fill in the blanks. The first row is completed for you as an example. Be as specific as possible. DO NOT use the same physical property twice.

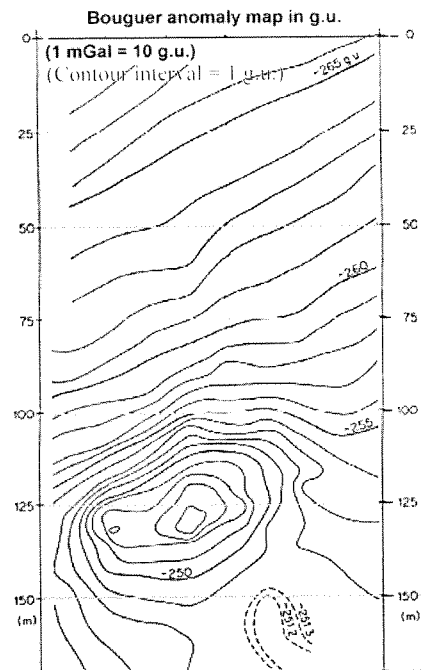
Geological or geotechnical task	One relevant physical property	One way in which the target is associated with the physical property	Corresponding Geophysical survey type
Find voids that are expected to be within 20m of the surface.	density	Voids will have a negative density contrast compared to the surrounding materials.	gravity
Locate steel under-ground storage tanks at an abandoned industrial site.			
Measure thickness of overburden over bedrock along lines at a new dam site.			
Identify the depth at which an aquifer becomes saline at a few locations.			
Map thickness of gravel (less than 5m) deposited upon clay near a river.			

9. (3) Imagine a harbour that has had heavy industrial activity on its shores for over a century. The municipality is embarking upon a project to characterize, then clean up contaminated sediments in this harbour. Such a project might include the following steps:
- i. Establish the current and historical basis for concern about the problem area;
 - ii. Determine what physical properties are associated with the contaminated zone, and whether they will be detectable remotely using practical survey methods;
 - iii. Outline the likely extent (laterally and vertically) of contamination;
 - iv. Design a mitigation procedure;
 - v. Carry out the necessary mitigation steps;
 - vi. Confirm that all contamination has been removed, and that the necessary standards are met.
- a. Which of these steps might usefully employ geophysics? There are more than one.
 - b. For each of the steps you mentioned in (a), outline one way in which geophysics might be applied.
10. (2) Investigations of subsurface materials and structures can be made with invasive techniques (drilling, trenching, etc) and non-invasive techniques (geophysics). Answer each of the following with a couple of sentences each:
- a. Describe one of many differences between information provided by invasive techniques and information provided by geophysical surveys.
 - b. Describe one way in which geophysical work will reduce the cost of an engineering or exploration project. You can use an example if that would help.

Part II: Gravity (Ch 2) (10 marks)

11. (0.5) If a buried ore body has density of 2.8 g/cc and surrounding rocks average 2.5 g/cc what value would be used to calculate the response at the surface?
- a. 2.5g/cc
 - b. 2.8g/cc
 - c. 5.3g/cc
 - d. 0.3g/cc
 - e. -0.3g/cc

12. (0.5) The so-called “free air anomaly” is not often used for land-based surveys because
- It is too complicated to compute.
 - It does take into account the effects of topography.
 - It is too expensive to make gravity measurements from the air.
 - It is only used when an ocean is near by.
 - There are no international standards by which to calculate this anomaly.
13. (2) Prove numerically that the latitude correction must be included if you measure gravity 20m further north than your base station (which is at 50 degrees latitude) when using a gravity metre with a sensitivity of 0.01 mgal.
14. (2) Consider the acquisition of a gravity profile at some location near Vancouver.
- If an identical survey were done 10 km further north, would raw (uncorrected) gravitational acceleration be **Larger, Similar** or **Smaller**?
 - If an identical survey were done at 100 m higher elevation, would raw (uncorrected) gravitational acceleration be **Larger, Similar** or **Smaller**?
 - If an identical survey were done with a 100 m cliff rising up a few metres away, would raw (uncorrected) gravitational acceleration be **Larger, Similar** or **Smaller**?
 - If an identical survey were done with a 100 m cliff dropping of into a valley a few metres away, would raw (uncorrected) gravitational acceleration be **Larger, Similar** or **Smaller**?
 - If an identical survey were done in the winter instead of in the summer, would raw (uncorrected) gravitational acceleration be **Larger, Similar** or **Smaller**?
 - If an identical survey were done near the beach at low tide instead of at high tide, would raw (uncorrected) gravitational acceleration be **Larger, Similar** or **Smaller**?
15. Consider the map of gravity data in the figure to the right.
- (2) Sketch a graph showing data along a line profile that runs from top to bottom through the centre of the main anomaly. Label both axis, and note the units.
 - (1) On this anomaly profile, sketch the regional trend (or regional gradient) upon which the target’s anomaly is superimposed.
 - (1) What is the amplitude of the residual anomaly after removing the regional trend? Note whether you are using mGal or g.u. units.
 - (1) Estimate a depth to the centre of the zone that has anomalous density.



Part III: Magnetism (Ch 3) (13 marks)

16. (0.5) Magnetic susceptibility ...
- is the strength of the permanent magnetization of a material.
 - describes how easily material acquires magnetization when a magnetic field surrounds it.
 - describes how easily an object will be detected by a magnetic survey.
 - is the strength of Earth’s magnetic field.
 - is a value that is related to Earth’s magnetic field.
17. (0.5) The best definition of “magnetization” is that it is the density of ...
- magnetic poles within the material.
 - aligned magnetic dipoles within the material.

- c. oscillating charges within the material.
- d. magnetic dipoles within the material.

18. (0.5) What do proton precession and alkali vapour instruments measure?

- a. Total magnetic field strength
- b. Vector components of magnetic field (X, Y, Z)
- c. Inclination, Declination and field strength
- d. Vertical gradient of magnetic field strength
- e. Magnetic susceptibility

19. (0.5) The "total field magnetic anomaly" can be best described as:

- a. A map of the amplitude of Earth's magnetic field.
- b. A map of the distribution of magnetic material.
- c. A map of the vertical component of the measured magnetic field.
- d. A map of the horizontal component of the measured magnetic field.
- e. A map of the component of the measured magnetic field that is aligned along the direction of Earth's magnetic field.

20. (0.5) At mid-latitudes, part of the magnetic anomaly over a buried magnetic feature is negative. This is because

- a. some portions of the induced field point down.
- b. Earth's vector field has a downward component.
- c. some portions of the induced field are in the opposite direction to Earth's field.
- d. the regional field has to be removed.

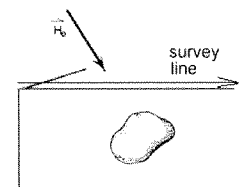
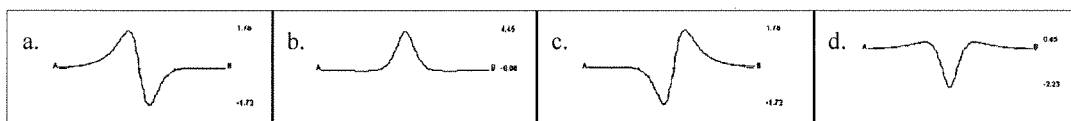
21. (0.5) Which of the following situations CAN be corrected using data gathered at a base station?

- a. (i) Magnetic storms and (ii) regional trends
- b. (i) Regional trends and (ii) geologic features larger than the survey area.
- c. (i) Diurnal variations and (ii) magnetic storms
- d. (i) geologic features larger than the survey area and (ii) diurnal variations.

22. (0.5) Which of the following is NOT likely to be a source of noise during a field survey?

- a. Belt buckles or other metal on the surveyor
- b. Fields from man-made electromagnetic and DC (direct currents) sources
- c. Above ground features like buildings and vehicles
- d. Significant pedestrian traffic near the survey

23. (0.5) Which of these four profiles will be recorded along the survey line shown to the right?



24. (0.5) Which of the following data processing techniques can be used to emphasize the edges of anomalous zones?

- a. Upward continuation.
- b. Reduction to the pole.
- c. Vertical gradient.
- d. Removal of regional fields.

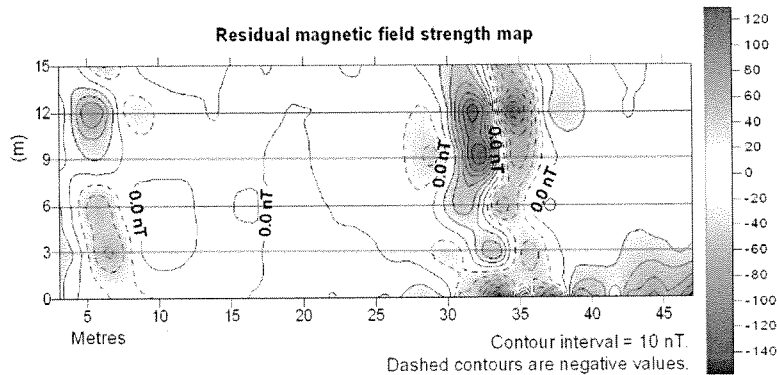
25. (1) What is the difference between induced magnetization and remanent magnetization? A couple of sentences is all that is required.

26. (1) Is magnetic surveying a good choice for finding buried voids within limestone?

- a. Yes or no,
- b. Why or why not?

27. (1) What is the one mineral that has by far the strongest influence on the susceptibility of rocks?

28. The total field magnetic anomaly measured over a small field site at a latitude of approximately 45 degrees North is shown in the figure below. The objective was to find buried steel utility pipe lines. Basic processing was applied to separate the residual anomaly from the regional trend, mainly because of the large response to a building that was within 10 metres of the bottom right corner.



- a. (2) Sketch a graph of the data along the left-right line labelled “12”.
- b. (1) On your graph’s X-axis place a dot showing where under the line you expect the centre of the target to be.
- c. (1) Sketch lightly what you expect this anomaly would look like if the identical survey had been carried out at the Earth’s magnetic north pole.
- d. (1) Assume the target can be approximated as a buried horizontal cylinder. Using your estimated response at the pole, provide an initial estimate for the depth to the centre of the pipe AND show how you obtained this estimate.
- e. (0.5) Interpretation such as we have done assumes that the anomaly is caused entirely by magnetization induced in the target by Earth’s field. What is the other type of magnetization that can affect the anomaly, but which is difficult to interpret especially when man-made metal objects are the target?

Part IV: Seismology: (Ch 4) (24 marks)

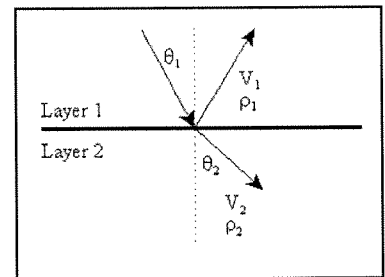
Basics (4)

29. (0.5) Consider the figure showing seismic ray paths at an interface between geologic layers with two velocities. If the incident angle θ_1 is 30° , what is the departure angle of the reflected ray?

30. (0.5) When seismic refraction signals are being observed what angle is θ_2 ?

31. (0.5) Write down the relation between θ_1 and the velocities of the two layers.

32. (0.5) Seismic surveys involve recording seismic signals that are affected by interfaces between layers where acoustic impedance changes. Acoustic impedance is the product of what two physical properties?
 _____ and _____.

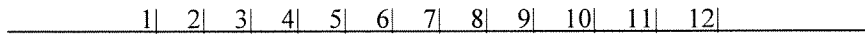


- 33. (2) Draw a sketch of a 2-layer earth; that is sketch 2 horizontal layers over basement.
 - a. Add to the sketch one shot location and 12 geophones. The geophones are 1m apart and the shot offset is 3m.
 - b. On this sketch, show carefully the raypath for a direct arrival seen on the first geophone.

- c. Also show the raypath for a signal that reflects off the basement seen at the 6th geophone. Assume each layer's velocity is higher than the layer above it.
- d. Finally, show the ray path for a signal that refracts along the first interface and is seen at the 12th geophone.

Refraction (8)

- 34. (1) For seismic refraction surveys, how are first arrivals from a single refracting horizon on a "T-X" plot used to obtain velocity of the layer beneath the horizon?
- 35. (1) A simple 12-geophone seismic refraction survey is set up looking like the sketch below:



Reproduce this sketch, and show where you would place a minimum number of shot points if you needed to interpret a single layer that is dipping gently from left to right under the survey line.

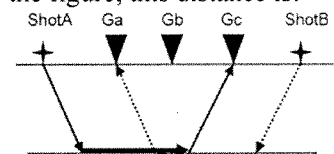
- 36. (1) Make a sketch of the T-X data you might expect if the top layer is thinner at the left end. This is meant to be qualitative only - we want to see the general shape of the T-X data plot.
- 37. (2) Imagine that you need to determine whether a break in the T-X curve's slope is caused by detection of a second interface, or whether it is due to a single layer over a basement that has a lateral velocity change.
 - a. What should you do in the field?
 - b. Describe the result that will show you have in fact detected a second layer?
- 38. (1) Match the task with the simplest appropriate refraction survey interpretation method. Just list the number and it's corresponding letter in your answer booklet.

task	refraction survey interpretation method
1. Interpret dipping interfaces	A. Plus-minus method
2. Interpret flat lying interfaces	B. Generalized Reciprocal Method (GRM)
3. Interpret mild variations in dip along an interface.	C. Intercept time from a single shot survey.
4. Interpret mild variations in dip along an interface and lateral variations in velocity within the top layer	D. Intercept time from a forward and reverse shot survey.

- 39. (0.5) Refraction surveying can not inform us about layer 2 when
 - a. V_2 is more than V_1 .
 - b. The interface between two layers is not flat
 - c. The second layer's velocity (V_2) is less than the first layer's velocity (V_1).
 - d. There are more than 2 layers.

- 40. (0.5) In the GRM method, a variable distance called "XY" is important. Based upon the figure, this distance is:

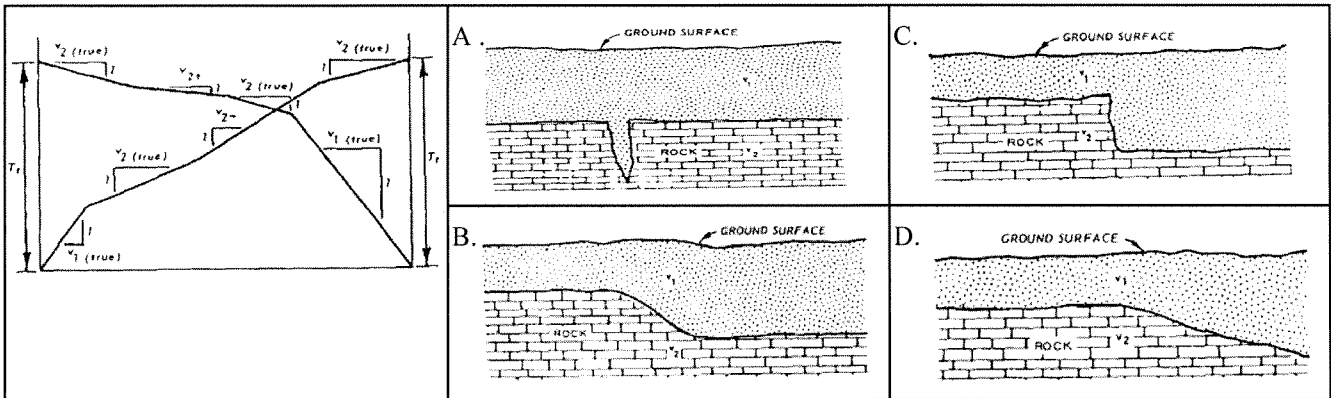
- a. ShotA \rightarrow Ga.
- b. ShotA \rightarrow Gc.
- c. Ga \rightarrow Gc.
- d. Ga \rightarrow Gb or Gc \rightarrow Gb.



- 41. (0.5) A saturated or weathered zone on top of bedrock may be difficult to image with refraction because:
 - a. It's velocity may be lower than the overlying material.
 - b. It may be so thin that refractors from it's top and it's bottom may not both be visible as first arrivals

- c. It's velocity and/or thickness may be so variable that time-distance information will be difficult to interpret.
- d. All of these are true.

42. (0.5) Which model of the subsurface is most likely to be imaged by the time-distance data set shown?
 a. A b. B c. C d. D

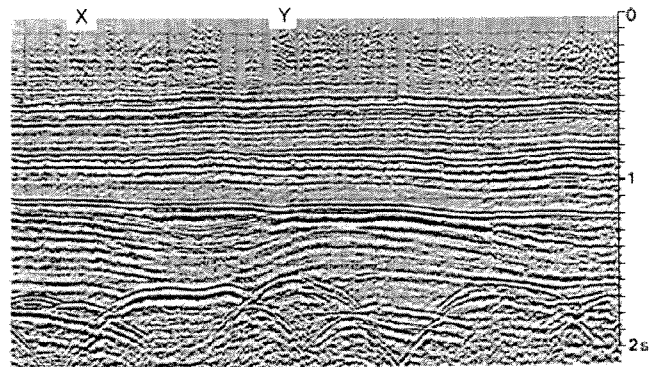


Reflection (12)

- 43. (2) Imagine that Layer 1 is a sandy overburden in which seismic waves will travel at 1400m/s and Layer 2 is a more compacted fluvial sand with a velocity of 1500 m/s. This interface may be very clear geologically but it would be difficult to see with a seismic reflection survey. Show that this is true by finding out what the amplitude of the reflected seismic waves will be as a percentage of incident waves. Assume that both layers have the same density.
- 44. (1) Imagine a seismic reflection survey with one shot and a string of geophones. As the offset between source and receivers increases, the two way travel time for reflections increases. If travel time is plotted as a function of offset, what is the shape of the curve that is generated?

45. The figure to the right is a seismic reflection section after standard processing has been completed.

- a. (1) On your exam paper, sketch or trace from this figure the two principle horizontal reflectors visible on this section.
- b. (1) Add the more complicated reflecting horizon which includes valley-shaped features.
- c. (1) Circle any two locations where valley-shaped features are evident.
- d. (1) What additional data processing step could usefully be applied to enhance the image of these types of features?
- e. (1) On the far right edge of the section, what is the zero-offset two way travel time to the horizon with synclinal features?
- f. (2) Estimate depth to the horizon with synclinal features if $V_1=2100\text{m/s}$, $V_2=2500\text{m/s}$, $V_3=2700\text{m/s}$, $V_4=3600\text{m/s}$.



- 46. (1) Multiple choice - Pick ALL that apply. Which of the following situations would make it necessary to consider a seismic reflection survey rather than a seismic refraction survey?
 - a. There will be minor changes in dip along the primary interface.
 - b. There is expected to be a low velocity layer.
 - c. Thin layers are expected.

- d. Steep dipping structures like faults are expected.
- e. Topography is moderate, but access is not a problem.

47. (1) Many seismic reflection jobs are designed to ensure the "fold" of the survey is greater than 1. Explain why surveyors go to the trouble of collecting such "redundant" data.

Part V: SP, DC Resistivity and IP methods (CHs 5, 6) (12 marks)

48. (1) Most geophysical surveys involve measurements that respond to variations in a physical property of the ground. In what way are SP (spontaneous or self potential) surveys different from this?

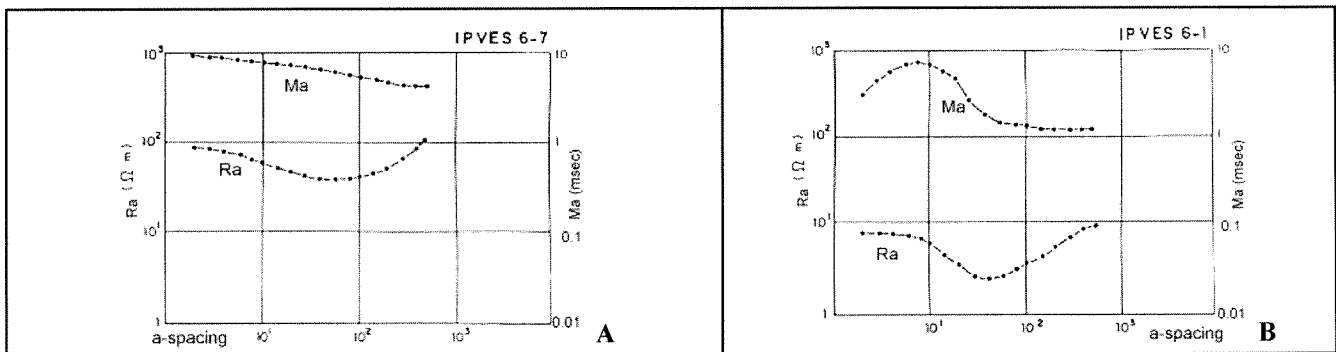
49. (1) Identify one geological or geotechnical task that might be addressed using SP survey techniques.

50. Imagine that you have been asked to confirm the presence of salt water intruding into an aquifer used for drinking water on one of the Gulf Islands. A well in a nearby property has fresh water down to 30m and salt water below that. There is only one geologic unit and it's resistivity with fresh water is 25 Ohm-m while it's resistivity with salt water is 0.8 Ohm-m. The water table is at the surface. The property you are working on has no well, so you will use DC resistivity survey.

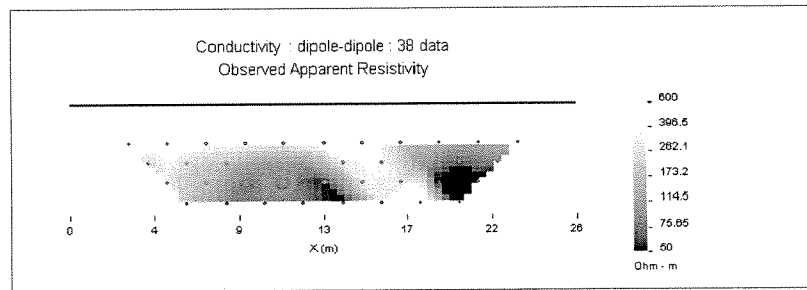
- a. (0.5) What type of DC resistivity survey would be most appropriate for this task?
- b. (2) Make a rough sketch of the raw data you might expect to acquire with this survey. Assuming the smallest "a" spacing = 1m and the largest "a" spacing = 200m. Don't worry about details. You will get full marks if you sketch the right curve shape, if the axis of your graph are appropriate (and have proper labels), and if values on these axis are the right order of magnitude.
- c. (1.5) If you would like to estimate the porosity of the rock containing the fresh water aquifer, what parameters would be needed, and how would they be used to obtain a value? Don't do the calculation, simply explain what parameters are needed and how to use them.

Below are plotted resistivity and IP soundings recorded at two locations, **A** and **B**. Each sounding includes a resistivity sounding curve labelled "Ra" and an IP sounding curve labelled "Ma". These are similar to the data sets discussed in the text (P.V. Sharma, 1997) in Figure 6.37.

51. (1) Outline one aspect of useful geological information that might be obtained from the chargeability curves which could not be obtained from the resistivity curves alone.



52. The next figure shows a pseudosection of resistivity data gathered over a trench that was back-filled with construction grade gravel. The material surrounding the trench is a more resistive soil, and the entire region is saturated with water. There is a conductive zone of unknown origin evident under the last 4m of the survey line. For this survey the a-spacing was 2m, and data were gathered at n = 1, 2, 3, 4.



- a. (1) At what line position in metres is the centre of this trench?
- b. (0.5) Does there appear to be resistive overburden on top of the back-filled trench?
- c. (1) How can you tell?
- d. (1.5) Using the apparent resistivity shown for the right-most data value at $n=4$, what would the value of the voltage measurement have been if the current used was 1 Amp? (Hint, note from the figure what array type was used in the survey).
- e. (1) Pseudosections are now a rather out dated presentation option. What type of processing is commonly applied to 2D resistivity surveys to obtain more useable images?

Part VI: Electromagnetic methods (Ch 7) (8 marks)

53. (1) DC methods involve injecting current into the ground with one pair of electrodes and measuring the resulting voltages with a second pair electrodes. In contrast to that, what is the physical process underlying electromagnetic methods? (Only a couple of sentences should be needed.)
54. (2) The equations describing propagation of electromagnetic (EM) fields involves a parameter called the complex wave number or the propagation parameter. It can be written as $k^2 = \sqrt{\mu\epsilon\omega^2 - i\omega\mu\sigma}$. The parameters are magnetic permeability, dielectric permittivity, conductivity, and frequency ($\omega=2\pi f$).
 - a. Is this propagation parameter purely complex for high or low frequencies?
 - b. Propagation is controlled mainly by conductivity under what conditions of frequency?
 - c. Propagation is controlled mainly by dielectric permittivity under what conditions of frequency?
 - d. Which situation (b. or c. above) is the case for most EM methods, other than GPR?
55. (3) For electromagnetic methods there is never any specific “depth of investigation” because the strength of EM signals decays smoothly as a function of depth.
 - a. Name, and explain, the concept commonly used to characterize the depth to which useful EM signals can be expected to penetrate.
 - b. Use this concept to estimate whether the two scenarios listed here will result in useable signals from the given target buried in the host rocks specified. Be careful of units!
 - i. An EM survey using a signal of 24,000 Hz, when host rock conductivity is $\sigma = 0.5$ S/m, and the target is at a depth of 8 metres.
 - ii. An EM survey using a signal of 440 Hz, when host rock resistivity is $\rho = 10$ Ohm - m, and the target is at a depth of 25 metres.

56. (1) Match the three categories of EM methods on the left to the appropriate conceptual framework on the right

1. Continuous wave field methods	A. Measures secondary electric and magnetic fields across a broad spectral range.
2. Transient field methods	B. Measures phasor components of secondary EM fields at a fixed or multiple frequencies.
3. Magnetotelluric methods	C. Measures the rate of decay of secondary EM fields

57. (1) Identify two (of several) characteristics that distinguish a “terrain conductivity metre” from a more general purpose frequency domain loop-loop, or “Slingram”, system.

Part VII: GPR (Ch 8) (10 marks)

58. (0.5) Identify the most significant component in the ground that affects bulk values of dielectric permittivity of geologic materials.

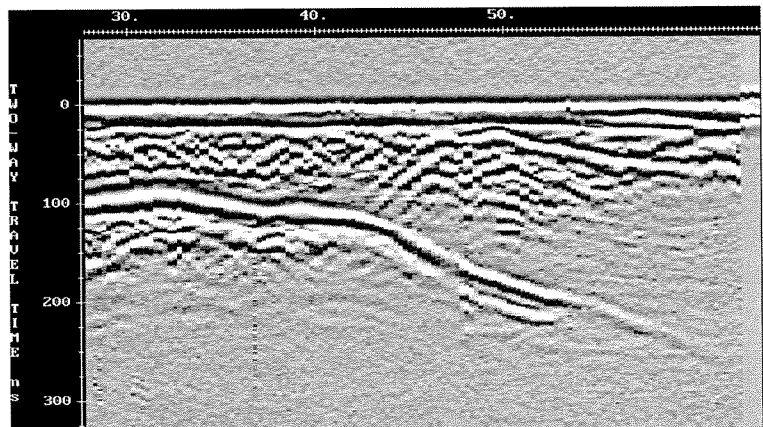
59. (0.5) What is the maximum value of dielectric permittivity in earth materials, AND what material has that value?

60. (2) Respond **True** or **False** to the following four questions:

- The velocity of GPR signals is dependent mainly upon the electrical resistivity of the ground.
- The strength of signals echoed from subsurface boundaries depends upon the change in dielectric permittivity across the boundary.
- Similarly to seismic reflection data, a complicated sequence of data processing must be applied to GPR data.
- The vertical (thin layer) resolution of GPR data varies with the system’s centre frequency.

61. The GPR data set below was plotted with no extra processing. Horizontal axis is in metres and vertical axis is in two-way travel time in nanoseconds. The line starts on a school’s soccer field that was built on top of an ancient peat bog, crosses the soccer field’s boundary at the 50m mark, and ends in deciduous woods that have grown up on the margins of the field.

- (1) Provide one geological interpretation for the reduced penetration depth at right end of the line.
- (2) What is the likely depth to the main echo under the left end of the line if the relative dielectric permittivity is estimated to be $\epsilon_r = 10$?
- (2) Show that the velocity you used in the previous part is NOT reliable IF the ground’s conductivity in that area is 1000 milli-Siemens per metre, and you used a 100Mhz antenna. There are a couple of steps, and you must watch your units, but all necessary relations are given on the last page of this exam.
- (2) Copy the figure’s axis into your exam booklet without the data. Then sketch the following interpretations:
 - The surface.
 - The base of back fill (gravel) that was used to level the soccer field.
 - The interface between forest organic soils and backfill.
 - One (of several) possible “objects” which could be a drainage pipe, or a boulder in the gravel backfill.



62. (0) Please state the amount of time it took to complete this exam. Thank you.

Some relations that might be useful:

Snell's law: $\frac{\sin \theta_1}{v_1} = \frac{\sin \theta_2}{v_2}$. Seismic impedance, $Z = \rho V$, and $T = \frac{2Z_1}{Z_2 + Z_1}$, $R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$.

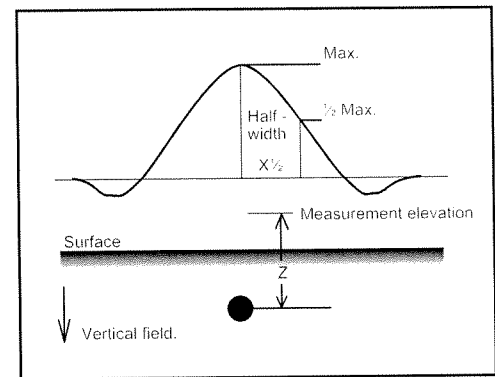
Refraction: depth $Z = \frac{t_i V_1 V_2}{2\sqrt{V_2^2 - V_1^2}}$, $x_{crit} = \frac{2zV_1}{\sqrt{V_2^2 - V_1^2}}$, $x_{cross} = 2z\left(\frac{V_2 + V_1}{V_2 - V_1}\right)^{\frac{1}{2}}$

Seismic velocities (m/s):

air	330
water	1500
saturated sand	1200 - 1900
granites and gneisses	5000 - 6200
limestones and dolomites	3400 - 6000

Halfwidth rules for magnetic & gravity anomalies:

The distance between the sensor and the centre of a buried sphere causing the magnetic or gravitational anomaly can be estimating using the measured anomaly halfwidth defined in the figure to the right. If the target is a magnetic sphere, depth is related to halfwidth as $Z \approx 2X_{1/2}$. If the target is a horizontal magnetic cylinder, the relation is $Z \approx 1.75X_{1/2}$. For a spherical **gravitational** anomaly, $Z \approx 1.3X_{1/2}$.



Skin depth: $\delta = [2 / (\mu_0 \sigma \omega)]^{\frac{1}{2}} \approx 500(1 / \sigma f)^{\frac{1}{2}}$

Archie's law: $F = \rho / \rho_w = a \phi^m$

Apparent resistivity formulae:

Wenner array: $\rho_a = 2 \pi a V/I$
 Schlumberger array: $\rho_a = \pi n(n+1)a V/I$
 Dipole - Dipole array: $\rho_a = \pi n(n+1)(n+2)a V/I$
 Pole - Dipole array: $\rho_a = 2 \pi n(n+1)a V/I$

GPR:

$V_{gpr} \approx \frac{c}{\sqrt{\epsilon_r}}$ where $c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$. The approximation holds so long as $\sigma / \epsilon \omega \ll 1$.

$\mu = \mu_0 \mu_r$, and $\mu_0 = 4 \pi \times 10^{-7}$ $\epsilon = \epsilon_0 \epsilon_r$, and $\epsilon_0 = 8.854 \times 10^{-12}$ $c \sim 300 \text{ m}/\mu\text{s}$ $\omega = 2 \pi f$

Gravity:

Maximum gravitational response to a sphere: $g = GM / (z^2)$; where M is the sphere's mass, and z is the distance to the sphere's centre. $G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg s}^2$. The mass is of course the sphere's density contrast times it's volume, where a sphere's volume is $4/3\pi r^3$.

Gravity reduction factors in units of mGals are:

- $\Delta g_l = 0.811 \sin(2a)$ mGal/km north of reference (a is latitude at reference).
- $\Delta g_f = 0.3086 h$ mGals/m (h is metres above reference).
- $\Delta g_B = 0.04191 \rho h$ mGals/m (h in metres above reference, ρ is density in g/cc).

For depth to a spherical gravitational target see the note and the "halfwidth" figure above.