Exam AESB2140: Geophysical Methods for Subsurface Characterization

03 November 2014, rooms CiTG 0.96, 1.96 and 4.99

(The answers may be in Dutch as well as English. If there are any questions about the English, please ask the exam supervisor)

Please answer on separate sheets:
- Question 1 (Logging)
- Question 2 (Resistivity method)
- Questions 3-6 (Seismic reflection method)

Allowed during exam:
- <u>Non-graphic</u> calculator
- Color pencils

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1. In this question we consider aspects of Logging

a) Which two rock properties do you need to measure using logging tools in order to link logging measurements with seismic reflection data and why? (1 point)

b) Which three rock properties do you need to measure with logging tools to calculate all elastic constants? (1 point)

c) The composite log of a section of well ZND-3 shows recordings of the gamma ray and density (see Figure 1 below). In this part of the section , at least 4 different rock types are present (maybe more). Indicate on the log by colouring the different rock types. Give depth boundaries for every rock unit and indicate using numbers 1, 2, 3, 4, etc. the different rock types. If a rock type occurs more than once give both layers then the same number. (2 points)

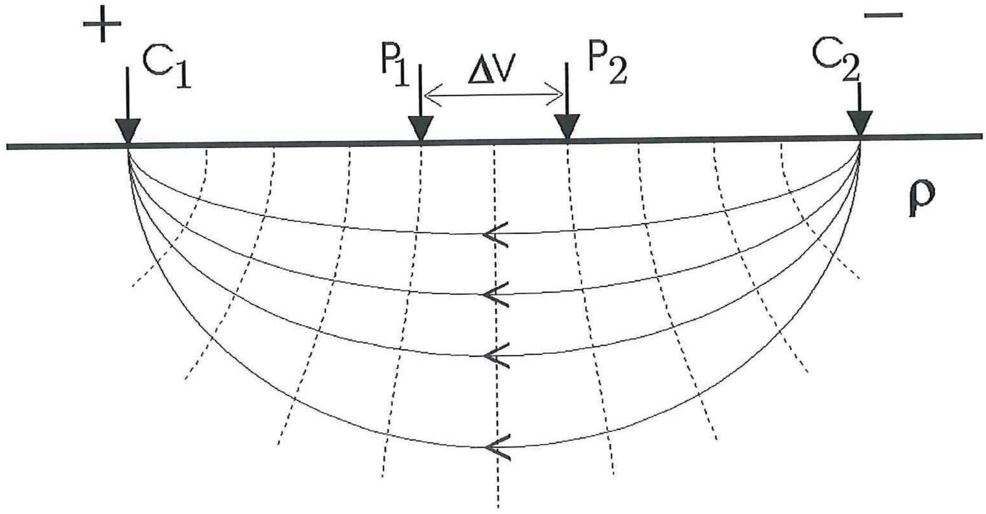
d) Also indicate the rock types you think are present and indicate reason and certainty. A table (Table 1) with rock properties is given at the end of the exam. (3 points)

e) If you have a change to run another log to better determine the rock types in question c) which tool would you run and why? (1 point)

f) Explain the concept of the Wyllie time-average equation (2 points)

(Totally 10 points)

2. Resistivity measurements are often carried out by putting electrodes in the ground at the earth surface, as shown in the figure below.



a) Assuming the resistivity ρ is constant in the subsurface, give the formula for the measured potential difference in case the distance between all electrodes is the same. (3 points)

b) The sensitivity of the resistivity measurement is determined by the electric current strength along the path from current electrode to a subsurface location where the resistivity is different than that of the surrounding medium, combined with the reverse path from the subsurface point to the potential electrode. The formula for the sensitivity function F_{3D} for the measurement involving C_1 and P_1, is given by:

$$F_{3D;11}(x,y,z) = \frac{1}{4\pi^2}\left(\frac{(x+3a/2)(x+a/2)+y^2+z^2}{(R_3^+)^3(R^+)^3}\right)$$

$$R_3^+ = \sqrt{(x+3a/2)^2+y^2+z^2}$$

$$R^+ = \sqrt{(x+a/2)^2+y^2+z^2}$$

Give the formula for the sensitivity function involving C_1 and P_2. (4 points)

c) Explain how apparent resistivity is defined for a measurement at the surface of a heterogeneous medium. (3 points)

(Totally 10 points)

3. In this question we consider the interpretation of a raw seismic record.

On the page with the figures, a seismic land record is given in Figure 2. These data have been shot with a vibratory source, correlated afterwards, and sensed with single geophones. The geophones were placed at a distance of 5 meters from each other.

a) On this record, indicate (draw coloured lines on the record and, at the end of the exam, hand it over to the exam supervisor) which event(s) can be interpreted as:

- direct/refracted P-wave (1 point)
- (direct) surface waves (1 point)
- direct air wave (1 point)
- a P-wave reflection (1 point)

b) Determine the velocity of:

- the surface waves, (1 point)
- direct/refracted P wave (1 point)

c) Indicate of what you would interpret as cultural/environmental noise. (1 point)

d) If the P-wave velocity of the subsurface is taken as the velocity of the direct/refracted P-wave arrival, what would you estimate for the depth of the reflector? (1 point)

(Totally 8 points)

4 **2.** In this question we consider the process of seismic migration of zero-offset data.

a) When we have a zero-offset section of an earth with a curved reflector, what is the angle of reflection? Define this angle, by means of a drawing. (1 point)

b) What is (zero-offset) migration? Explain the migration process itself and what needs to be known to perform it. Use an example, such as a point diffractor. (2 points)

In Figure 3 below, on the pages with figures, a depth structure is drawn on top (a). On top source and receiver positions are drawn where the source and receiver are at the same spot so this is a zero-offset configuration.

c) Based on this, draw <u>*carefully*</u> the zero-offset ray paths on this depth structure. Assume you do not get a reflection of the reflector <u>*at*</u> the surface. (2 points)

d) Based on these ray paths, draw the associated time-distance in graph (b). You can use the distance of the ray paths on graph (a) as unit (; this assumes the velocity to be constant above the reflector which is fine). (2 points)

(Totally 7 points)

3. In this question we consider the effects of the instrumentation by the use of a vibratory source.

a) How can the seismogram be written as convolution of the source signal and the impulse responses of the earth? If symbols are used, explain them! (1 point)

b) What is assumed about the impulse response of the earth, so that we can write it this way? (1 point)

c) Do these assumptions hold any time, any place? Explain your answer. (1 point)

d) When a vibratory source is used, the recorded seismogram is correlated with the input signal, i.e., the sweep. How is this correlation written in the frequency domain? Write the frequency-domain responses out in amplitudes and phases. (1 point)

e) When we use a vibratory source as seismic source, how does the wavelet (time-domain signal) look *after* correlation? Explain. (1 point)

f) When we use a sweep with frequencies of 5 to 200 Hz, how does the spectrum look *before* correlation? Give both the amplitude and phase characteristics. (1 point)

g) And how does the spectrum look *after* correlation? Give the characteristics that are different from (f), and explain your answer. (1 point)

(Totally 7 points)

4. The 1-dimensional wave equation for the particle velocity for a shear wave can be derived from two equations that have been derived from basic physical conservation laws. The latter two equations are the deformation equation and the equation of motion. They relate the particle velocity and the shear stress. The deformation equation for a shear wave is given by:

$$\frac{\partial \tau_{shear}}{\partial t} = \mu \frac{\partial v_x}{\partial z}$$

while the equation of motion for a shear wave is given by:

$$\rho \frac{\partial v_x}{\partial t} = \frac{\partial \tau_{shear}}{\partial z}$$

in which τ_{shear} denotes the shear stress (force per area), v_x denotes the particle velocity, z denotes depth, μ denotes the shear modulus, ρ denotes the mass density and t denotes time. Note that the shape of these equations is similar to the one for a compressional wave.

a) From these two equations, <u>*derive*</u> the wave equation for the *particle velocity*, assuming the shear modulus is constant. (2 points)

b) What is the solution of the particle velocity of that wave equation, so in the time domain? <u>*Prove*</u> it, by substituting it in the wave equation. (2 points)

c) What is this solution in the frequency (Fourier) domain? (1 point)

d) Based on frequency-domain solution for the particle velocity v_x, what is then the solution for the shear stress τ_{shear}? <u>*Derive*</u> it. (2 points)

e) When we look at the solutions for the particle velocity v_x and the shear stress τ_{shear}, what is the difference between the two, and how is that called? (1 point)

(Totally 8 points)