FACULTY OF SCIENCE AND TECHNOLOGY

PET110

Geophysics and well logging

Continuation examination

01.09.2017

9.00 – 12.00

Tjodhallen – Kjølv Egelands hus

THE EXAM CONSISTS OF 6 PAGES (Excluding this one)

PERMITTED AIDS:

Approved calculators and dictionary.

Read the whole exam before you start, and try to answer the questions you find are the easiest first. Write in English or Norwegian. Useful formulas can be found on the last page of the exam.

Good luck!

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Problem 1

30% Sampling, aliasing and seismic waves

a) **7.5%** Figure 1 shows the frequency spectrum of a seismic trace. When sampling a seismic signal it is important to avoid the phenomenon of aliasing. Use Figure 1 to determine the largest sampling interval that can be used to sample the data without introducing aliasing. For this problem, consider the amplitude of -60 dB as virtually zero.

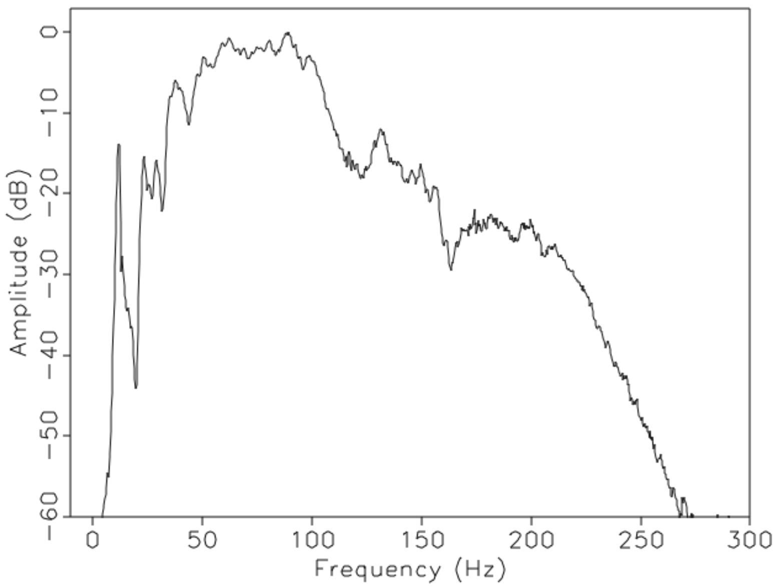


Figure 1: A frequency spectrum of a seismic trace.

b) **10%** Mention 2 reasons why the the wavelength of seismic waves generally increases with depth. Assume that the phase velocity for a P-wave travelling at the reservoir is 2500 m/s, and that the seismic signature for this P-wave has an amplitude spectrum given by Figure 1. Use this information to compute a rough estimate of the dominant wavelength of the P-wave at the reservoir.

c) **7.5%** The phase velocities of P- and S-waves can be written as a function of two elastic moduli plus the density. Write down the equations and find a new formula that describes the ratio between these velocities, and explain why the P-wave velocities are always larger than the S-wave velocities. Why is it useful to determine the Vp/Vs-ratio? How much does the Vp/Vs ratio changes if the density increases by 25% ?

d) **5%** The density of a porous rock is given by $\rho = \rho_f \phi + \rho_s(1 - \phi)$. Explain the symbols in this equation. Assume that for a reservoir rock $\phi = 0.3$ and that the density for the oil and reservoir solid minerals are respectively 700 and 2600 kg/m^3. Use this to compute the density of the reservoir rock when it is fully oil saturated and when it is fully water saturated.

Problem 2

40% Seismic methods

a) **7.5%** Draw a figure with two horizontal layers. Assume that we have a seismic source and receivers at the surface of the topmost layer, and draw the ray path of the reflected wave between the source and one receiver. Show that the traveltime for the reflected wave can be written as

$$T(x) = \frac{2}{v}\sqrt{h^2 + x^2/4} \tag{1}$$

where x is the distance between source and receiver, h is the thickness of the layer, and v is the seismic phase velocity in the layer. Assume that x is small relative to h, and compute an approximate expression for T where you take two terms in the Taylor series. Use this expression to explain what is meant by NMO-correction, and write an approximate expression for the NMO-correction.

b) **7.5%** Explain what we mean by velocity analysis, and name at least two processes within seismic processing where the velocities are important.

c) **15.0%** The traveltime equation for the critically refracted wave that travels through the layer with velocity V_2 in Figure 2 can be written as

$$T_2(x) = \frac{X}{V_2} + \frac{2Z_1 \cos\theta_{12}}{V_1}. \tag{2}$$

The traveltime equation for the critically refracted wave that travels through the layer with velocity V_3 in Figure 3 can be written as

$$T_3(x) = \frac{X}{V_3} + \frac{2Z_1 \cos\theta_{13}}{V_1} + \frac{2Z_2 \cos\theta_{23}}{V_2}. \tag{3}$$

Figure 4 shows a seismogram acquired over a layered earth. Use equations 2 and 3 together with the values in the table in Figure 4 to compute the velocities V_1, V_2 and V_3, and the thicknesses Z_1, and Z_2 to the layers.

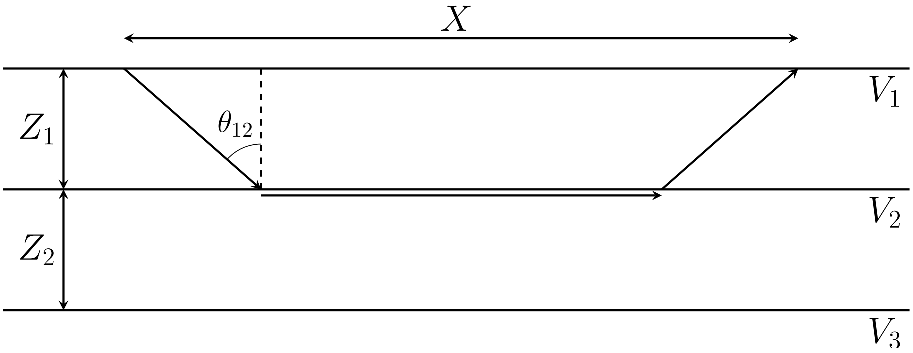


Figure 2: Problem 2c

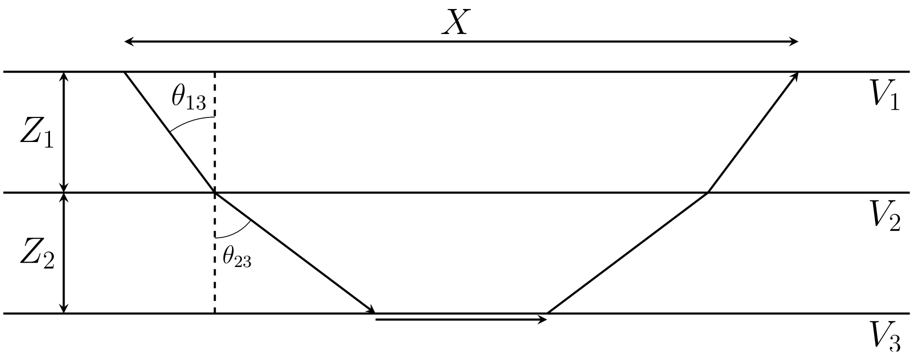
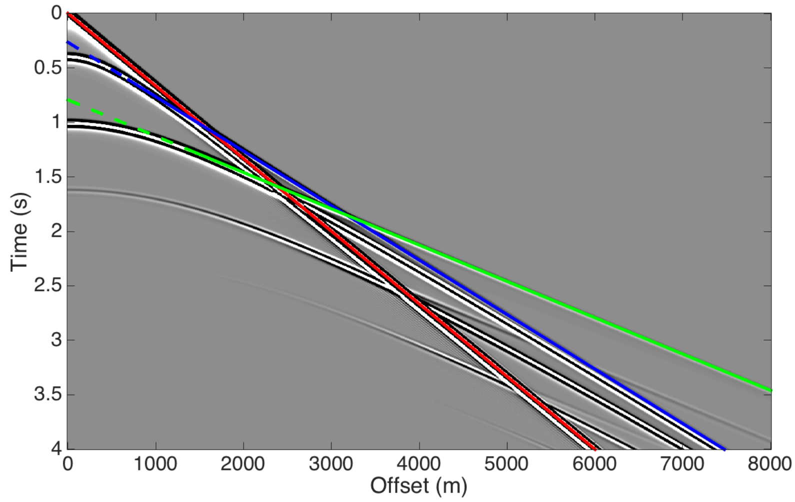


Figure 3: Problem 2c

d) **10%** Assume that the bulk modulus for a reservoir rock changes from 8 GPa to 9 GPa, and that the density changes from 2030 kg/m^3 to 2120 kg/m^3 if one changes the fluid type in the reservoir from oil to water. Compute the P- and S-wave velocities for oil and water saturated reservoir, when the shear modulus is 4 GPa. Compute also the change in the normal incidence reflection coefficient at the top of the reservoir, when oil is substituted by water. Assume that the density of the rock over the reservoir is 2000 kg/m^3 and that the velocity above the reservoir is 2000 m/s.



x[m]	dir. (red) [s]	ref.1 (blue) [s]	ref.2 (green) [s]
2000	1.3333	1.2646	1.4603
3000	2.0000	1.7646	1.7936
4000	2.6667	2.2646	2.1270
5000	3.3333	2.7646	2.4603
6000	4.0000	3.2646	2.7936

Figure 4: A seismogram acquired over a layered earth. Here "dir.", means direct wave, ref. 1, means refraction nr. 1 and "ref. 2", refraction nr. 2. Here x means source-receiver offset.

Problem 3
30% Gravity and Electric methods

a) **7.5%** The centripetal acceleration for a point mass over the surface of the Earth is given by

$$a_s = R\dot{\theta}^2 \cos\phi \tag{4}$$

Make a simple figure explaining the symbols in equation 4, and show that the angular speed due to Earths rotation around its axis is 0.0000727 rad/s. Assume that Earth is a sphere with radius 6370 km and show that the difference in centripetal acceleration between the poles and the equator is 0.034 m/s^2.

b) **12.5%** Assume that a reservoir at 2 km depth can be considered as a point mass (we assume the reservoir is small). Further assume that the reservoir is compacting due to production. The density of a porous rock can be written as $\rho = \rho_f\phi + \rho_s(1-\phi)$. Assume that the porosity in the reservoir changes from

30% to 25% due to compaction, the density of the fluids is 1000 kg/m^3 and the density of the rock is 2700 kg/m^3, and that the reservoir is a cylinder with radius and thickness of 50 m. Compute the change in the vertical component of gravity due to this compaction for $x = 0$ and $x = 2$ km ($x = 0$ corresponds to exactly above the reservoir). In this problem we assume that it is only the reservoir that changes, and not the rocks above and under the reservoir.

c) **5%** What resistivity survey method should be used if we are interested in determining the presence of an acquifer in a relatively flat region? (Select one of the choices below)

1) Vertical electrical sounding (VES)
2) Constant separation traversing (CST)
3) Vertical seismic profiling (VSP)

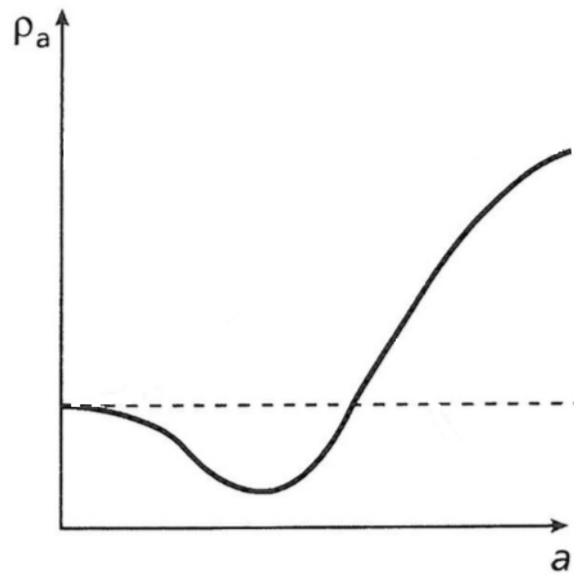


Figure 5: Problem 3d: Example of a VES resistivity measurement using a Wenner array. The plot shows the apparent resistivity (ρ_a) as function of electrode separation (a).

d) **5%** Provide a simple layered resistivity model that can be used to explain the apparent resistivty observations given in Figure 5. There is no need to give values to the resistivities, only rank the resistivities for each of the layers in your model from lowest to highest.

Formulas that can be useful:

$$\sqrt{1+x} \approx 1 + \frac{1}{2}x - \frac{1}{8}x^2 + \frac{1}{16}x^3 - \frac{5}{128}x^4 + ... \quad (x << 1)$$

$$f_{Nyq} = \frac{1}{2\Delta t}$$

$$V_P = \sqrt{\frac{\lambda + 2\mu}{\rho}} = \sqrt{\frac{k + \frac{4}{3}\mu}{\rho}}$$

$$V_S = \sqrt{\frac{\mu}{\rho}}$$

$$R_{ij} = \frac{\rho_j v_j - \rho_i v_i}{\rho_j v_j + \rho_i v_i}$$

$$T_{ij} = 1 - R_{ij}$$

$$t^2 = t_0^2 + \frac{x^2}{v^2}$$

$$\sin\theta_k = \frac{V_1}{V_2}$$

$$\sin^2\theta + \cos^2\theta = 1$$

$$\lambda = \frac{v}{f}$$

$$\omega = 2\pi f$$

$$A^{[dB]} = 20\log_{10}\left(\frac{A_1}{A_0}\right)$$

Gravitational constant:

$$G = 6.7 \times 10^{-11}\ \mathrm{m^3kg^{-1}s^{-2}}$$

Gravity anomaly due to a point mass:

$$\vec{g} = \frac{Gm}{|\vec{r}|^3}\vec{r}$$