AARHUS UNIVERSITET

Eksamensopgave i: Geofysiske metoder

Eksamens varighed: 4 timer

Tilladte hjælpemidler: Alle pånær PC

Antal sider i opgavesættet: 11

Evt. vægtning af spørgsmål:

Examination in: Geophysical methods

Duration of examination: 4 hours

Aids allowed for the examination: All except PC

Number of pages in the examination set: 11 *(English version starts on page 4)*

If relevant, weighting of examination questions:

Data in Problem 1 (5 questions) and 2 (4 questions) were obtained by computer calculation, which explains their very simple appearance.
Note that you may fill in, tear off and hand in the table- and figure sheets as part of your solution. Remember to write your name and student ID on all submitted sheets.

Problem 1
You have just been employed at the company SeisConQuest on an investigation of a possible oil / gas field near the Somali coast. Only one reflection seismic profile is available at the site. About 50 km from the location a single well has been drilled.
Table 1 shows the three main lithologies with associated depth interval, P-wave velocity and density.

1. *Interval velocity in the first layer:* Fig. 1a and 1b show CMP-sections at the position x = 5 km and x = 20 km along the seismic profile. Two prominent reflections (marked A and B) are supposed to represent the two layer boundaries between chalk and clay (hyperbola A) and clay and sand (hyperbola B).
   Determine the rms velocity of the chalk layer from hyperbola A at the two positions. It's okay to use only two readings on each hyperbola.

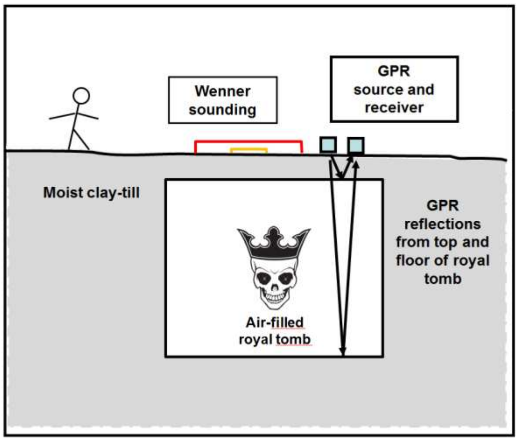
2. *Thickness of the first layer:* Fig. 2 shows the time section along the seismic profile. Again, the two main reflectors are marked by A and B. Table 2 row b shows the two-way time to reflector A for every 5 km along the profile.
   Note that two two-way times are missing: Read two-way times to reflector A at x = 0 km and 15 km and enter them in Table 2 row b.
   Calculate the depth to reflector A, using as interval velocity the average of the two velocities computed in question 1. If you have not solved questions 1, you may use the appropriate P-wave velocity measured in the drilling, see Table 1.
   Draw reflector A in the depth section in Figure 3. Note the vertical exaggeration 1:10.

3. *Interval speed in the second layer:* Consider again the CMP-sections in Fig. 1a and b.
   Determine the rms velocity between the surface and reflector B at both x = 5 km and x = 20 km. Then determine an average interval velocity of the clay layer between reflector A and reflector B at both positions.

4. *Geometry of the second layer:* Fill in the rows e, f and g in Table 2 and plot reflector B in the depth section in Fig. 3.

5. *Reflection coefficients:* The waveforms of the reflections show that reflection A swings to the negative side (left) along the entire profile, while reflection B swings to the positive side (right), except for the interval between x = 10 km and x = 15km. Explain why this is to be expected from the speeds and densities found in the well, see Table 1. Explain also why the change of sign in the reflectance of reflector B in the range between x = 10 km and x = 15 km may indicate a gas accumulation, i.e. a layer of sand where gas has replaced water as the pore fluid.

Problem 2



The company iArcheo wants to win an EU contract for the geophysical investigation of a number of large royal tombs in the Caucasus region. You have just been hired by iArcheo to make interpretation of some basic example data that iArcheo gathered at one of these royal tombs. An earlier excavation of another royal tomb revealed an almost cubic air-filled chamber with an edge length of approximately 4 meters. The left picture illustrates the target as well as two of the involved measuring methods.

1. Using a highly accurate gravimeter a gravity profile was measured with points every metre along a 25 m long profile over the royal tomb. You may assume that the gravimeter sensor was located at a height of 0.2 m above ground level, defining z = 0 m.
   Fig. 4 shows the residual anomaly after removal of the regional level. <u>Determine</u> the location (x_{tp},z_{tp}) of the center of the burial chamber (i.e. center of gravity) using the assumption that it can be modeled as a homogeneous sphere.

2. <u>Determine</u> the excess mass below the anomaly. <u>Determine</u> the volume of a tomb, if it is assumed to be air filled. Finally, <u>determine</u> the edge length, assuming that the chamber is cubic. It may be assumed that the burial chamber is surrounded by moist clayey till with a density of 1800 kg/m^3.

3. The tomb has an almost flat upper surface, which is convenient for geoelectrical sounding. Table 3 contains data measured by the Wenner configuration with electrode spacings, a, between 0.1 and 2 meters. <u>Calculate</u> the lacking apparent resistivity at a = 1 meter. <u>Draw</u> the missing data point in the loglog-plot in Fig. 5. <u>Determine</u> the resistivity of the first layer (moist clayey till in Caucasus) and the depth to the interface where the resistivity increases (the ceiling of the burial chamber).

4. iArcheo plans to use also GPR (georadar) to map the interiors of the royal tombs. As part of the preparations, you must answer the following:
   <u>What is</u> the skin depth in the rock (moist clayey till) covering the burial chamber?
   <u>Is it realistic</u> to reach the burial chamber with GPR?
   <u>Calculate</u> two-way time for a GPR reflection from the top-side of the burial chamber as determined in question 3 (if you did not find a value for the layer thickness, you may assume the layer thickness to be 1.2 meters).
   <u>Calculate</u> also the expected two-way time for reflections from the bottom of the chamber, assuming that the burial chamber is 4 meters high.
   You may assume that the dielectricity number, K, of the clayey till is 30.

Problem 3

1. The neutron log, the density log and the sonic log are used to measure formation porosity. Answer the following questions briefly:

    a. What does the neutron log measure and how is this measurement converted to porosity?
    b. What does the density log measure and how is this measurement converted to porosity?
    c. What does the sonic log measure and how is this measurement converted to porosity?

2. A homogeneous chalk reservoir of thickness 100 m is water saturated in the lowermost 30 m. Above the water zone, the formation pore space contains both water and hydrocarbons. In the water zone, porosity readings based on the density log agree very well with the neutron porosity. The matrix setting of the neutron log is chalk. Do not consider any effects of invasion. There are no clay minerals in the formation. Answer the following questions:

    a. The matrix density of chalk is 2.71 g/cm^3 and the density of the pore water is 1.1 g/cm^3. The density log reads 2.47 g/cm^3 in the water zone. What is the porosity of the chalk?

    b. In the hydrocarbon zone the density log reads 2.35 g/cm^3. The chalk porosity is exactly the same as in the water zone. What is the density of the mixture in the pore space? What could the mixture be composed of (qualitatively)?

    c. What would you expect about the neutron log reading in the hydrocarbon zonen? Would it be higher or lower than the porosity in the water zone? Why?

3. In another reservoir zone the specific elctrical resistivity of the pore water is 0.016 Ωm at reservoir temperature. The porosity is 15 %. The deep resistivity log reads 25 Ωm. Use Archie's formula to answer the following questions. It is assumed that a=1 and n=m=2.

    a. What is the water saturation?

    b. What is the hydrocarbon saturation?

4. At the same depth as I question 3, the specific electrical resistivity of the mud filtrate is 0.10 Ωm at reservoir temperature. The shallow resistivity log reads 10 Ωm.

    a. What is the water saturation of the invaded zone?

    b. Is there any reason to believe that the hydrocarbons can be produced, i.e. that they are movable?

Tabel 1 / Table 1:

	Interval [m]	P-bølgehastighed [m/s] P-wave velocity [m/s]	Massefylde [kg/m^3] Density [kg/m^3]
Kalklag / Chalk layer	0-300	2450	2350
Lerede lag / Clayey layer	300-600	1960	2040
Sandede lag /Sandy layer	600-620	2210	2090

Tabel 2 / Table 2:

a	x	0 km	5 km	10 km	15 km	20 km	25 km
b	Tovejstid til A [s] / Two-way time to A [s]		0.53	0.22		0.22	0.22
c	Tovejstid til B [s] / Two-way time to B [s]	0.72	0.72	0.72	0.72	0.82	0.82
d	Tykkelse af lag 1 (kalk) Thickness of layer 1 (chalk) [km]						
e	Tovejs-tidstykkelse for lag 2 [s] / Two-way thickness of layer 2 [s]						
f	Tykkelse af lag 2 (ler) / Thickness of layer 2 (clayey layer) [km]						
g	Dybde til laggrænse B/ Depth to boundary B [km]						

Tabel 3 / Table 3.

a [m]	I [A]	U [V]	R [Ohm]	ρ_a [Ohmm]
0.10	0.0033	0.2902	87.9	55
0.15	0.0036	0.1867	51.9	49
0.20	0.0052	0.2198	42.3	53
0.30	0.0033	0.0912	27.6	52
0.50	0.0029	0.0570	19.7	62
0.70	0.0044	0.0692	15.7	69
1.0	0.0037	0.0584		
1.5	0.0021	0.0309	14.7	139
2.0	0.0069	0.1011	14.7	184

Fig. 1a: CMP section at x = 5 km

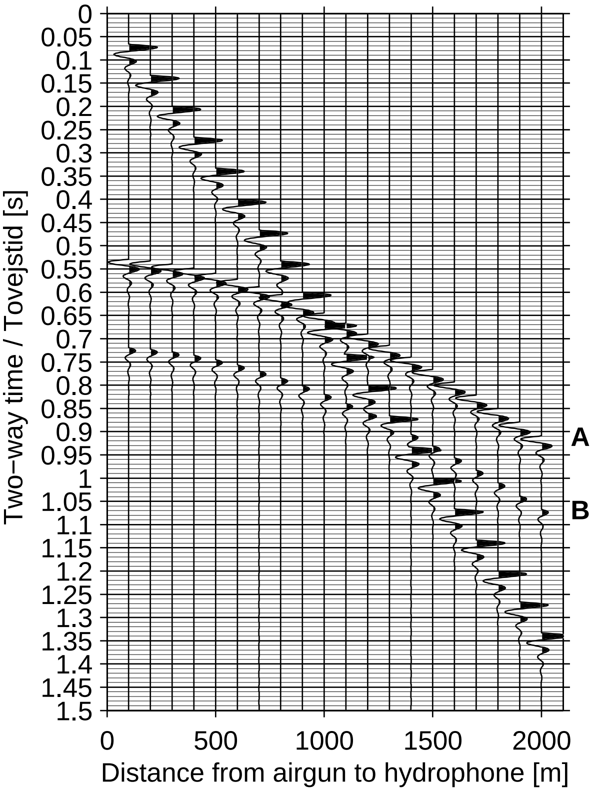


Fig. 1b: CMP section at x = 20 km

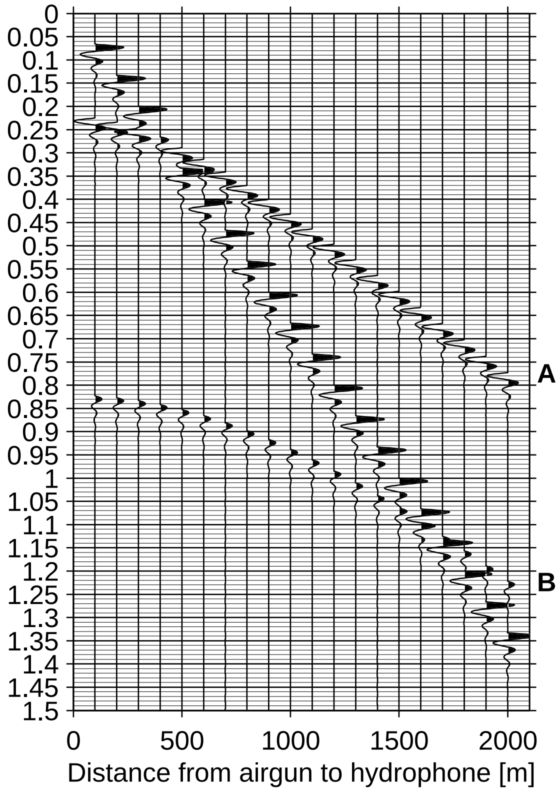


Fig. 2: Seismic section / Seismisk sektion

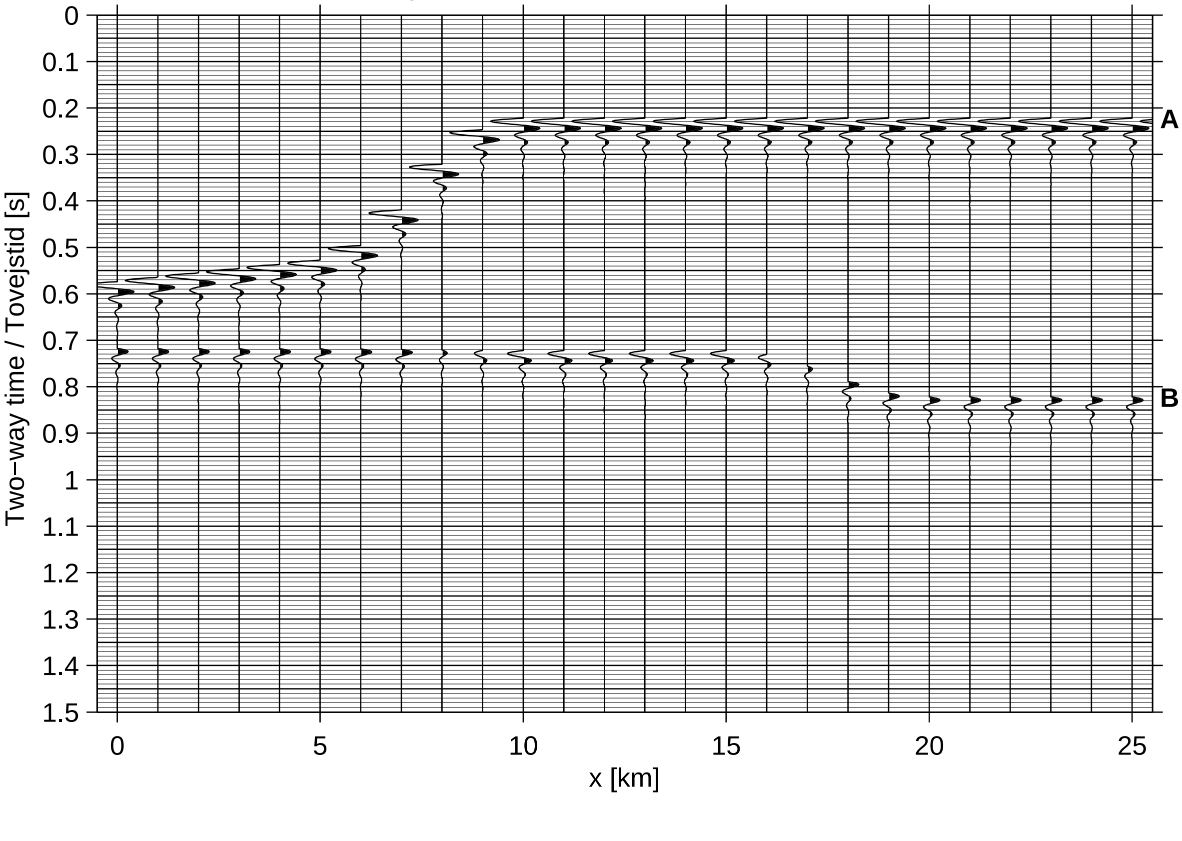


Fig. 3: Depth section / Dybdesektion

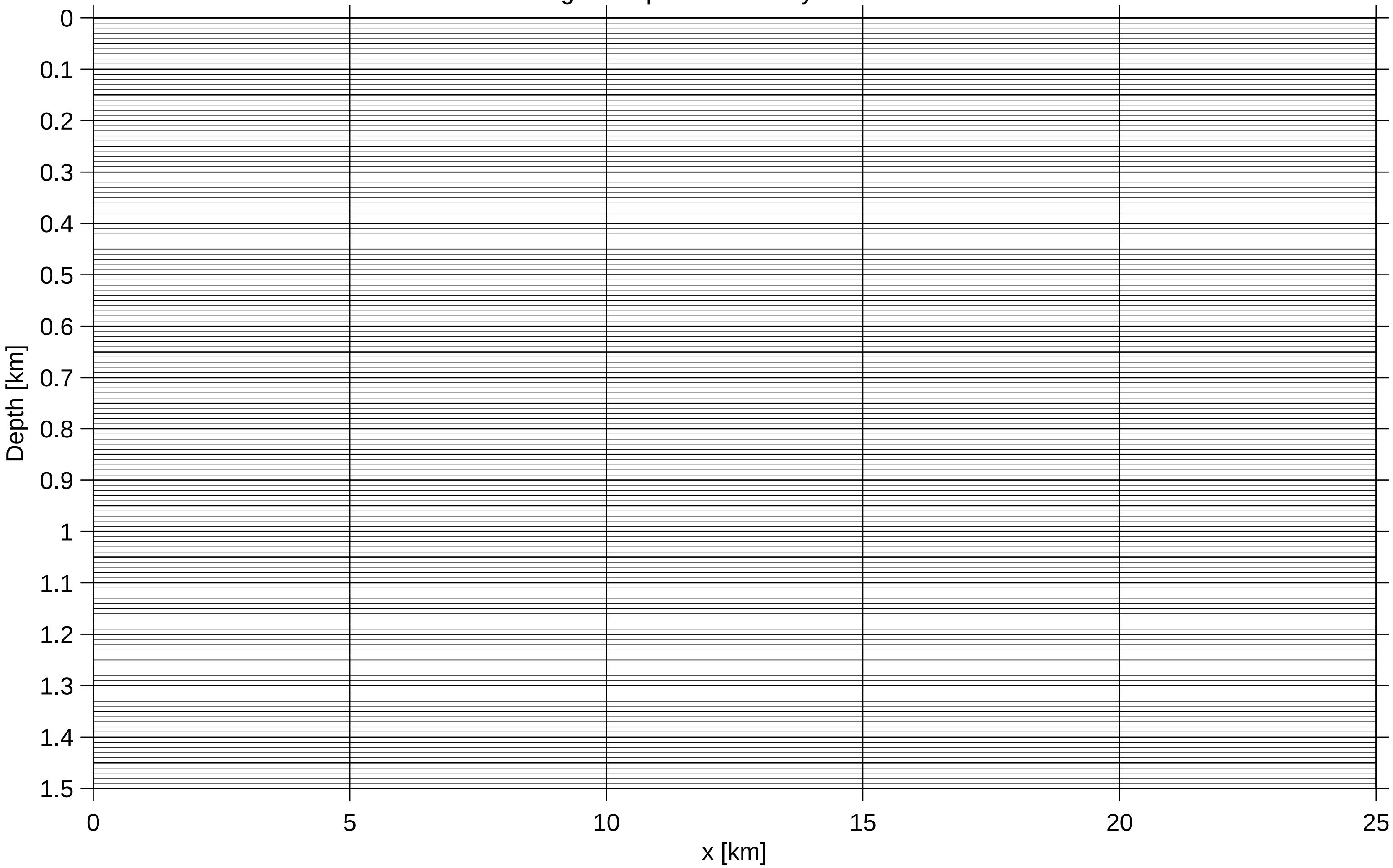


Fig. 4: Residual Bouguer anomaly /Residual Bouguer−anomali

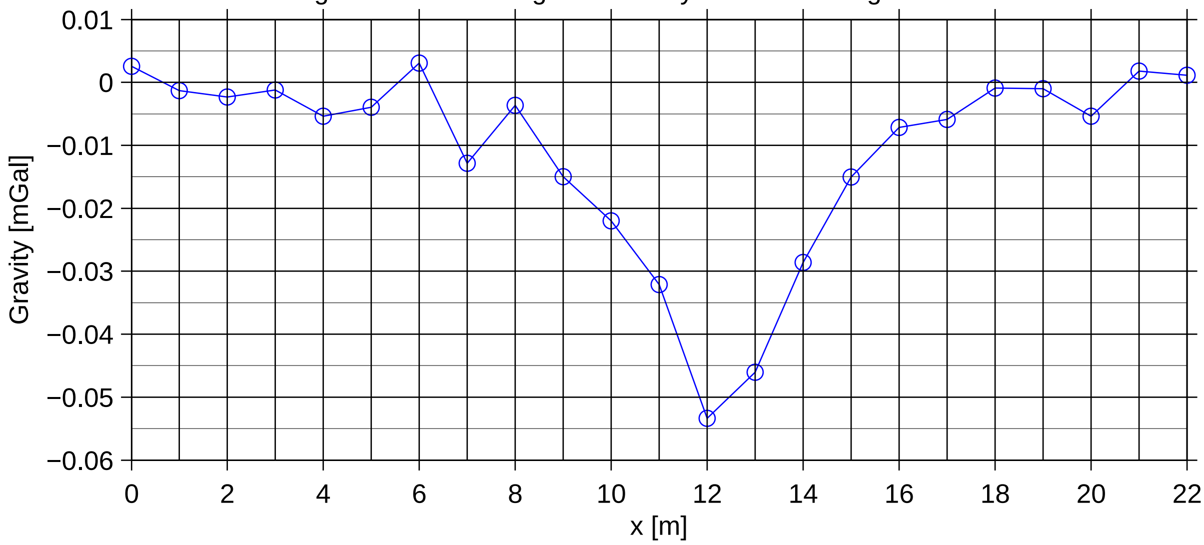


Fig. 5: Geoelectrical sounding data