Geo-Energy and subsurface processes

Exam 27.01.2023

Exam Hall 4, 15.00-17.00h

Name: Student ID:

Q1 CO_2 storage volumes (25P)

Am anticline structure offshore the Netherlands has been identified as a potential CO_2 storage site. The reservoir has a thickness of 100 m and based on an area-depth graph the bulk rock volume within the anticline has been calculated to be 210 million m^3. The reservoir is a good aeolian sandstone with a N/G ratio of 0.92 and a porosity of 26%. After CO_2 injection the residual water concentration will be likely 15%. Under reservoir conditions (82°C and 35 MPa) the compressibility factor for CO_2 is 0.55 and the gas expansion factor can be calculated using the following formula:

$$E = \frac{P \times T_s}{P_s \times Z \times T} \quad \text{(Eq. 1)}$$

Where P and T are reservoir pressure and temperature, P_s and T_s are pressure and temperature at standard conditions (288.15 °K and 1.01325 bar), and Z is the gas compressibility factor.

Calculate the amount of CO_2 that can be stored within this anticline structure.

Pore volume: 210 10^6 m^3 * 0.92 *0.26*(1-0.15) = 42 697 200 m^3 (10P)

Gas expansion factor E = (351 * 288.15)/(1.01325*0.55*355) = 101.140/197.837 = 511 (10P)

Amount of CO_2: 42 697 200 m3 * 511 = 21.818.269.200 m3 = 21.8 *10^9 m3 (5P)

Q2 CO_2 storage pressures (25P)

The amount of CO_2 that can safely be stored in the anticline is dependent on pressures within the reservoir. You know the following about the reservoir pressures: The lithostatic gradient is 25 MPa/km, and the gas gradient for CO_2 is at reservoir conditions around 7 kPa/m. The hydrostatic gradient is 10 kPa/m, but the reservoir is 15 MPa overpressured. A colleague wants to know if you can also store H_2, which has a gas gradient of 1.4 kPa/m, in the same reservoir. He also provides the envelope for leak of pressures.

Use Figure 1 (hand out!) to draw on the pressures relevant for the safety of the storage site.

Is the storage site secure of CO_2 storage? Can you also store hydrogen safely?

Spill point and top of reservoir identified: 2 P

Hydrostatic gradient drawn: 2P

Overpressured hydrostatic gradient correctly drawn: 5P

CO_2 gradient drawn: 5P

H_2 Gradient drawn: 5P

CO_2 safe and H_2 not. 6P

See attached pdf for solution.

Figure 1: Depth-Pressure profile of the storage site.

Q3 CO_2 storage leakage (20P)

A company decides to store CO_2 in the anticline structure (independent of your previous assessment). They fill the reservoir to spill with CO_2 and all looks good. But then suddenly CO_2 is lost from the reservoir. As there are no indications for fracturing of the caprock, it is assumed that the leakage occurs due to failure of the capillary sealing function of the caprock. The capillary pressure P_c acting on the caprock at the top of the reservoir can be calculated as follows:

$$P_c = P_{CO2} - P_{brine} \quad \text{(Eq. 2)}$$

Where P_{CO2} is the pressure the column of CO_2 and P_{brine} the hydrostatic pressure. Use the pressure data from Question 2 to calculate the capillary pressure at the top of the reservoir.

The capillary pressure is also a function of the wettability behaviour between CO_2 and the rock:

$$P_c = \frac{2\,IFT\ \times cos\theta}{r} \quad \text{(Eq. 3)}$$

Where IFT is the interfacial tension (mN/m) and θ is the contact angle, and r is the pore-throat radius of the caprock. At reservoir conditions the interfacial tension for CO_2 is 30 mN/m and the contact angle is 50°.

As capillary leakage occurs, what is the minimal pore throat radius in the caprock?

PC at top of reservoir:

Thickness of gas column: 450 m, difference in gradient 3kPa/m. Overpressure at top of reservoir: 450 * 3 kPa = 1350 kPa = 13.5 bar = 1.35 MPa 10P

r = (2 * 0.03 N/m * 0.642787) / (1350 *10^3 Pa) = 0.038567 / 1.350.000 = 2.8568 *10^-8 m = 0.02856 micro meters 10P

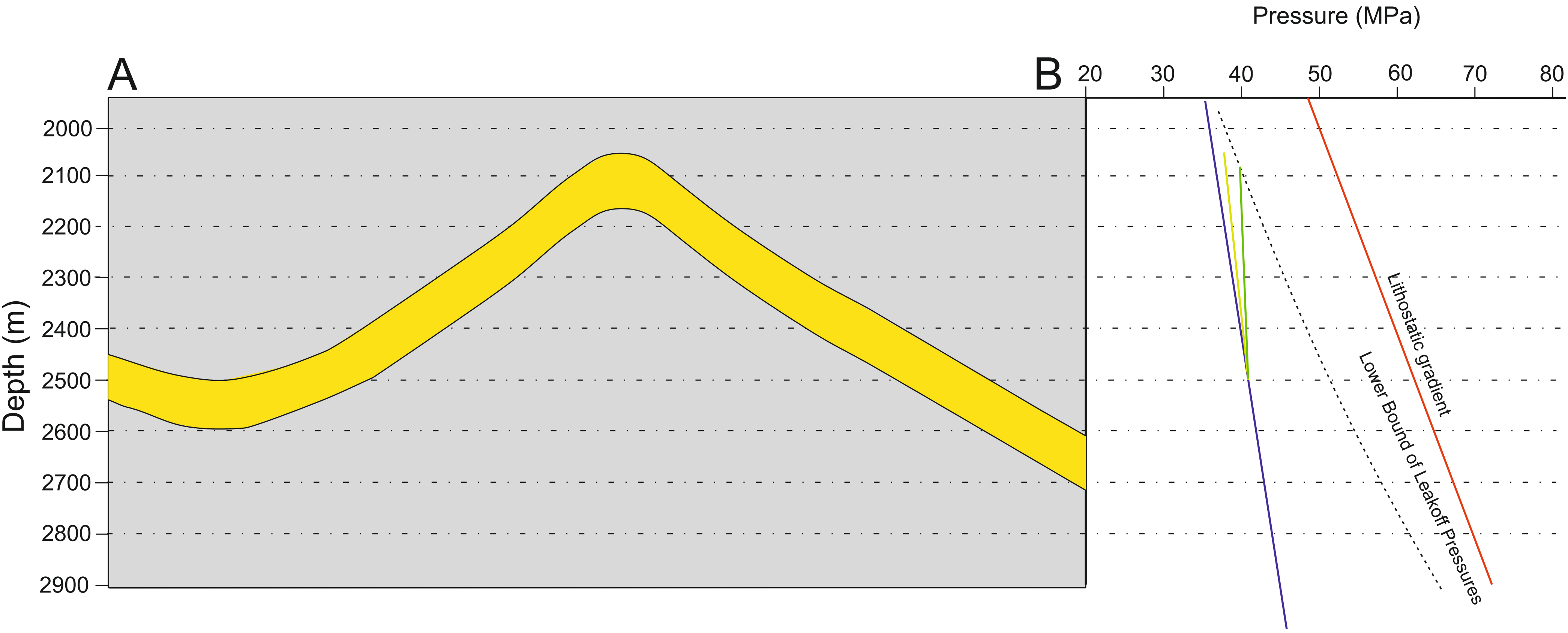
Q4 True or False (15P)

1. The inclination of the paleo-magnetic field is related to the paleo-longitude.
2. The velocity of elastic waves, caused by an induced earthquake at reservoir level, decreases significantly when they reach the shallow soil interval at around 50m below the surface.
3. Salt structures are better determined on gravity profiles than on magnetic profiles.
4. The heatflow of geothermal energy is predominantly caused by the cooling of the planet earth.
5. Onshore subsurface storage of CO_2 is generally seen as the preferred option over offshore storage.
6. The density logging tool contains a radio-active source.
7. The expansion factor for gas is a function of the water saturation in the reservoir.
8. The concept of 'accomodation space' in stratigraphy is determined by subsidence.
9. The Carbonate Compensation Depth is determined by the amount of CO_2 dissolved in ocean waters.
10. Most seismicity occurs at intraplate locations.

Q5 Essential components of a subsurface storage site (15P)

What are the three essential components of a subsurface storage site in porous media? Name and describe the role of each component and give an example.

Reservoir, Seal, Trap


Pressure (MPa)
A
B
20
30
40
50
60
70
80
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
Depth (m)
Lithostatic gradient
Lower Bound of Leakoff Pressures