EXERCISE “Bad Bentheim”

Bad Bentheim, accommodates a famous German "Kuhrort". Unfortunately the medical springs are depleting. Nevertheless, newly drilled exploration wells show highly porous sand bodies and fractured carbonate horizons in Jurassic sands and Bundsandstein formations, thus new prospects. The Delft Engineering Geological Group is asked to give an opinion on these findings, with respect to salinity, conductivity and reservoir quality of the drilled wells.
For the determination of the water salinities of the different sands, the following salinity results have to be converted to water resistivities at the formation depths e.g. formation temperatures.

- All resistivities are in ohm.m,
- FT is the formation temperature in °F or °C,
- 1 mol Na = 23 gram, 1 mol Cl = 35.5 gram).

Use table Ex.1.
At the faculty all relevant information on borehole depth and bottom hole pressures have been stored in one computer. Unfortunately, due to IT-interference this specific computer was completely formatted. Someone found in the literature the regional thermal gradients, with an average estimated gradient of G_t = 30.5°C/km. The average surface temperature is 14°C.

Questions

- For the determination of the water salinities of the different sands, the following salinity results have to be converted to water resistivities at the formation depths e.g. formation temperatures. All resistivities are in ohm.m, FT is the formation temperature in °F or °C, 1 mol Na = 23 gram, 1 mol Cl = 35.5 gram). Use table Ex.1.
- At the faculty all relevant information on borehole depth and bottom hole pressures have been stored in one computer. Unfortunately, during renovations this specific computer was stolen. Someone found in the literature the regional thermal gradients, with an average estimated gradient of Gt=30.5°C/km. The average surface temperature is 14°C. Calculate the bottom hole depths and put them in table Ex1.
- Now it is also good to know the bottom hole pressures for engineering purposes. Here the salinity and depth are needed.
- In order to get acquainted with the stability of the porous sandstones, one likes to know the effective stress (σ_p) on the grain framework. An average bulk density (σ_r) of 2.31 g/cm^3 is normal in these areas.

Table Ex.1								
Well nr	Bottom hole depth in km	Formation water salinity	ρ_f in g/cm^3	P_f in bar	P_0 in bar	ft	Rw at ft in ohm.m	σ_p in MPa
1		200,000 mg/l NaCl				212 °F		
2		100,000 ppm NaCl				122 °F		
3		50,000 ppm NaCl				130 °F		
4		50,000 mg/l Cl				122 °F		
5		100 g/l NaCl				100 °C		

A 6th well was analyzed on the ion-content of the formation water at a surface temperature of 75°F. Any other info disappeared. The ion-concentrations are:
8.000 ppm Na^+; 10.000 ppm Cl^-, 5.000 ppm Mg^{2+}; 3.000 ppm Ca^{2+}; 7.000 ppm CO_3^{2-}

- Determine the solid concentration and the equivalent NaCl concentration.
- Determine the resistivity at reference temperature and resistivity of the brine at 130°F.

1. ***Answer:***

   - Use the temperature nomograph. Assume 1g/l ~1 ppm

   *- 1gNa/l is converted to (1 +(1/23)*35.5)g NaCl/l*

2. Answer: *- use* $G_t = \frac{T_f - T_s}{D}$ *for the estimation of geothermal gradients.*

Now it is also good to know the bottom hole pressures for engineering purposes. Here the salinity and depth are needed.

3. Answer: *Salts in solution give a brine density of* $W_{water} + W_{salts}$ *per unit volume of water. Now depth multiplied by density gives a bottom hole fluid pressure (Pf) in* kg/cm^2 *or bar.*

4. Effective stress σ_p ***on the grain framework. Answer:***

$$\sigma_p = P_0 - P_f$$

P_0 *is calculated by multiplying bulk density and depth.*

(σ_p) in MPa conversion of 1 bar to 0.1. MPa.

Table Ex.1								
Well	Bottomhole depth	Formation water salinity	ρ_f	P_f	P_0	Formation Temp.	Rw at ft	σ_p
no	km		g/cm^3	bar	bar		ohm.m	MPa
1	2.82	200,000 mg/l NaCl	1.2	338	651	212 °F	0.015	31.3
2	1.18	100,000 ppm NaCl	1.1	129	272	122 °F	0.047	14.3
3	1.31	50,000 ppm NaCl	1.05	138	302	130 °F	0.08	16.4
4	1.18	50,000 mg/l Cl	1.08	127.4	272	122 °F	0.056	13.9
5	2.82	100 g/l NaCl	1.1	310	651	100 °C	0.027	34.1

5. Answer: ***The total solid concentration is:***

8.000+10.000+5.000+3.000+7.000 = **34.000 ppm**

$$Cdry_{sum} = \sum_{a=1}^{n} C_{ai}$$

***The equivalent NaCl concentration is*:**

$$C_{sum} = \sum_{a=1}^{n} M_a C_{ai}$$

The multipliers are:

8.000 ppm Na^{+}x1 = 8.000 ppm; 10.000 ppm Cl^{-}x1= 10.000 ppm; 5.000 ppm Mg^{2+}x1.39 = 6.950 ppm; 3.000 ppm Ca^{2+}x0.92 = 2.760 ppm; 7.000 ppm CO_3^{-2}x0.67. = 4.690 ppm;

Total: Csum = 32.400 ppm equivalent NaCl concentration.

The reference resistivity is calculated, using: SEE lecture notes TA3500!!!

$$R_{w75} = \left(2.74 \times 10^{-4} \times 32.400\right)^{-1} + 0.0123 = 0.125 \cdot ohm.m$$

$$R_{w75} = \left(2.74 \times 10^{-4} C_{sum}\right)^{-1} + 0.0123$$

The resistivity at 130°F is calculated, using: SEE lecture notes TA3500!!!

$$R_{wT2} = R_{w75}\left(\frac{81.77}{T_2 + 6.77}\right)$$

and

$$R_{w130} = 0.125\left(\frac{81.77}{130 + 6.77}\right) = 0.0747 \cdot ohm.m$$