2011

NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY NTNU

Prepared by:- Group 4

[GULLFAKS PART-A]

[**THE TASK WAS TO DEMONESTRATE AN UNDERSTANDING OF THE CHALLENGES RELATED TO PRODUCTION WITH PRESSURE DEPLETION AND ACQUIFIER SUPPORT.]**

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Project report – Part A

I. Introduction

The Gullfaks area is located in the Norwegian sector of the North Sea, in block 34/10, Approximately 175 km northwest of Bergen, see *Appendix 1*. The seven fields in the Gullfaks area are found in sandstones of early and middle Jurassic age, 1800 – 4000 m subsea. Reservoir quality is generally very high, with permeability ranging from tens of mD to several Darcys depending on layer and location. The Gullfaks Main field is over pressured, with an initial pressure of 310 bar at datum depth of 1850 m below mean sea level, and a temperature of 70 degrees C. The oil is under saturated, with a saturation pressure of approximately 245 bar, depending on formation depth and location. The GOR ranges between 90 and 180 Sm 3 /Sm 3, with stock tank oil gravity around 860 kg/m 3 . Structurally, the field is very complex and can be divided into three regions the so called 'Domino Area' with rotated fault blocks in the west, and a Horst area in the east; in between is a complex 'Adaptation Zone', characterized by folding structures. The north-south faults that divide up the field have throw up to 300 meters. In the western part the faults slope typically around 28 degrees downward to the east, whereas in the eastern horst they slope 60-65 degrees downwards to the west. The field is further cut by smaller faults, with throws of zero to few tens of meters, both in the dominant north-south as well as east-west direction. Many of these lesser faults have slopes of 50-80 degrees. This results in complex reservoir communication and drainage patterns, and is a major challenge in optimally placing wells in the reservoir.

The Gullfaks Satelites fields are Gullfaks Sør, Rimfaks, Gullveig, Gimle, Gulltopp and Skinfaks, see *Appendix 2*. Production from the first three satellites started in 1998, while Gimle came onstream in 2005 and Gulltopp and Skinfaks is scheduled to start in 2007.

The reservoir description is similar to the Gullfaks Main Field, but the fields contain more gas than oil – often with a significant gas cap. The initial pressure of Gullfaks Sør is 450 bar at datum depth of 3300 m below mean sea level (MSL) and at Rimfaks it is 410 bar at datum 2860 m MSL.

When the Gullfaks Field came on production in 1986, Statoil planned that 46% of the oil present in the field could be recovered. Today, more than 20 years later, the current plan calls for a recovery factor of 70%. The improvement is due to the technology development since then. The Gullfaks Village is part of this development, and every year the student groups are addressing new challenges related to better recovery of oil.

II. Data Analysis

Problem Statement

The GullfaksVillage 2011 has a focus on IOR on the Beta ridge on the western side of Gullfaks. The fields Gullveig, Tordis and Skinfaks are developed by sub-sea wells, while Gulltopp is a long 10 km well drilled from Gullfaks A. The Beta ridge at Gullfaks is shown on *Appendix 3*. Where there is not enough information, the group should clearly describe the assumptions made. Such assumptions should preferably be reviewed with either the advisors at NTNU or Statoil. The main purpose of Part A is to demonstrate an understanding of the challenges related to production with pressure depletion and aquifer support. Based on information provided in part A, the students shall do material balance calculations as a basis for analyzing production and pressure behavior.

Task

1. Convert all oil, gas and water volumes to reservoir conditions at 2500 m MSL TVD.

The conversions were already made.

2. Calculate the average reservoir pressure depletion at the Beta ridge.

All the calculations to calculate the average pressure are made in the excel sheet which can be found as an attachment.

3. Measured reservoir depletion in wells A-32 drilled to the Beta ridge is given. Compare this to the calculations under 2 above, and comment on reasons why there are differences between the calculated and the measured pressure.

Compressibility:

$$c_{water} = 4{,}5 \cdot 10^{-5} bar^{-1}, c_{rock} = 4{,}5 \cdot 10^{-5} bar^{-1},\ c_{total} = 1{,}0 \cdot 10^{-4} bar^{-1}$$

Volume: Initial assumed reservoir volume:

$$V_{initial} = 50 - 200 \cdot 10^{6} m^{3}$$

Pressure: Initial pressure:

$$P_{initial} = 380 bar$$

- *Procedure*

We were given the production- and injection rate of Skinfaks, Gulltopp, Gullveig, Gullfaks Vest, Vigdis, Tordis and Gullfaks hovedfelt. The flow rates included water, oil and gas.

- Formulas:

$$\Delta V = Q_{produced} - Q_{injected}$$

$$\Delta V = c \cdot V \cdot \Delta P$$

$$\Delta P = \frac{\Delta V}{c \cdot V}$$

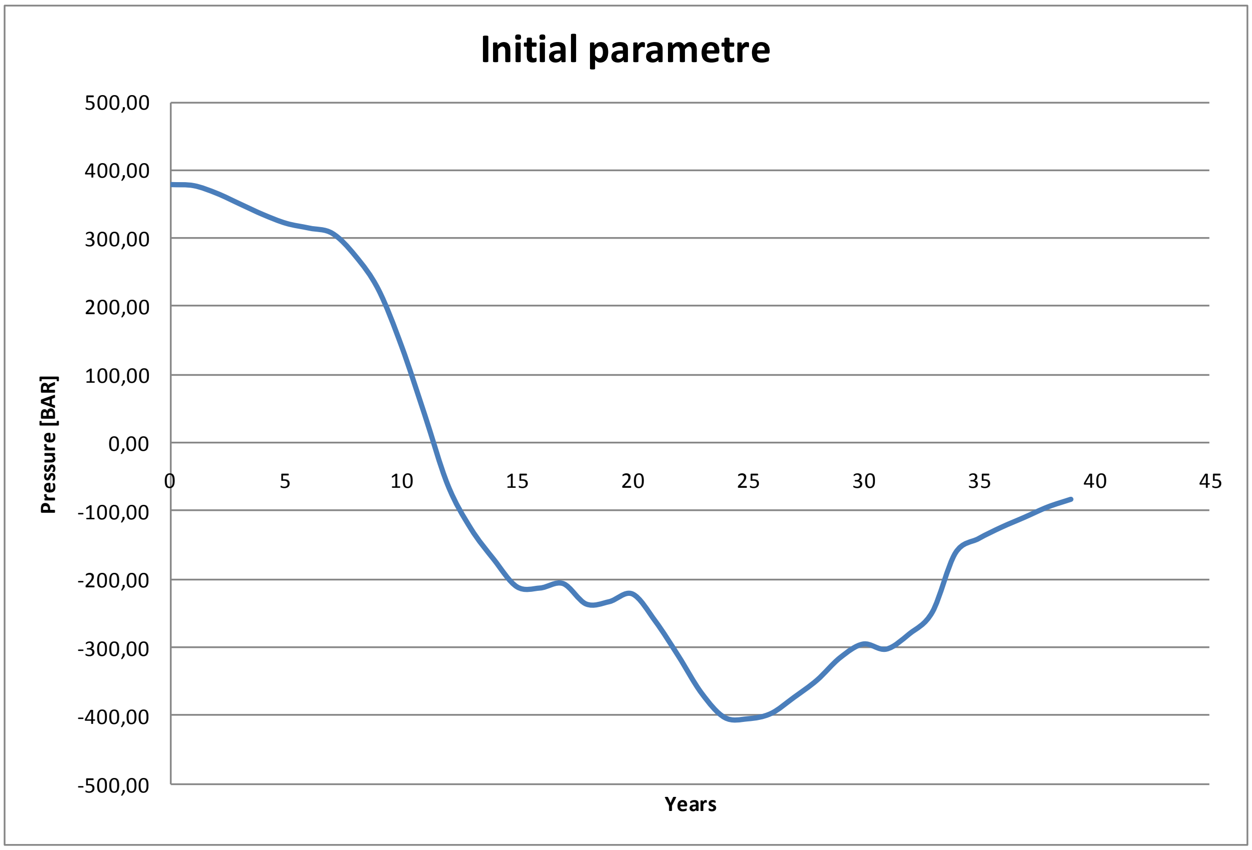
We calculated the pressure change in the reservoir due to production and injection of fluid. For comparison reason we made our calculations with different values of reservoir volume and compressibility.

Assumptions

All the fields on the Beta Ridge communicate.

Analysis and Summary

Our first pressure calculations where based on our initial data. When we plotted the pressure against time, we got negative pressure. This indicated that in reality the reservoir volume where much bigger and/or we had a huge gas cap that were affecting the total compressibility.

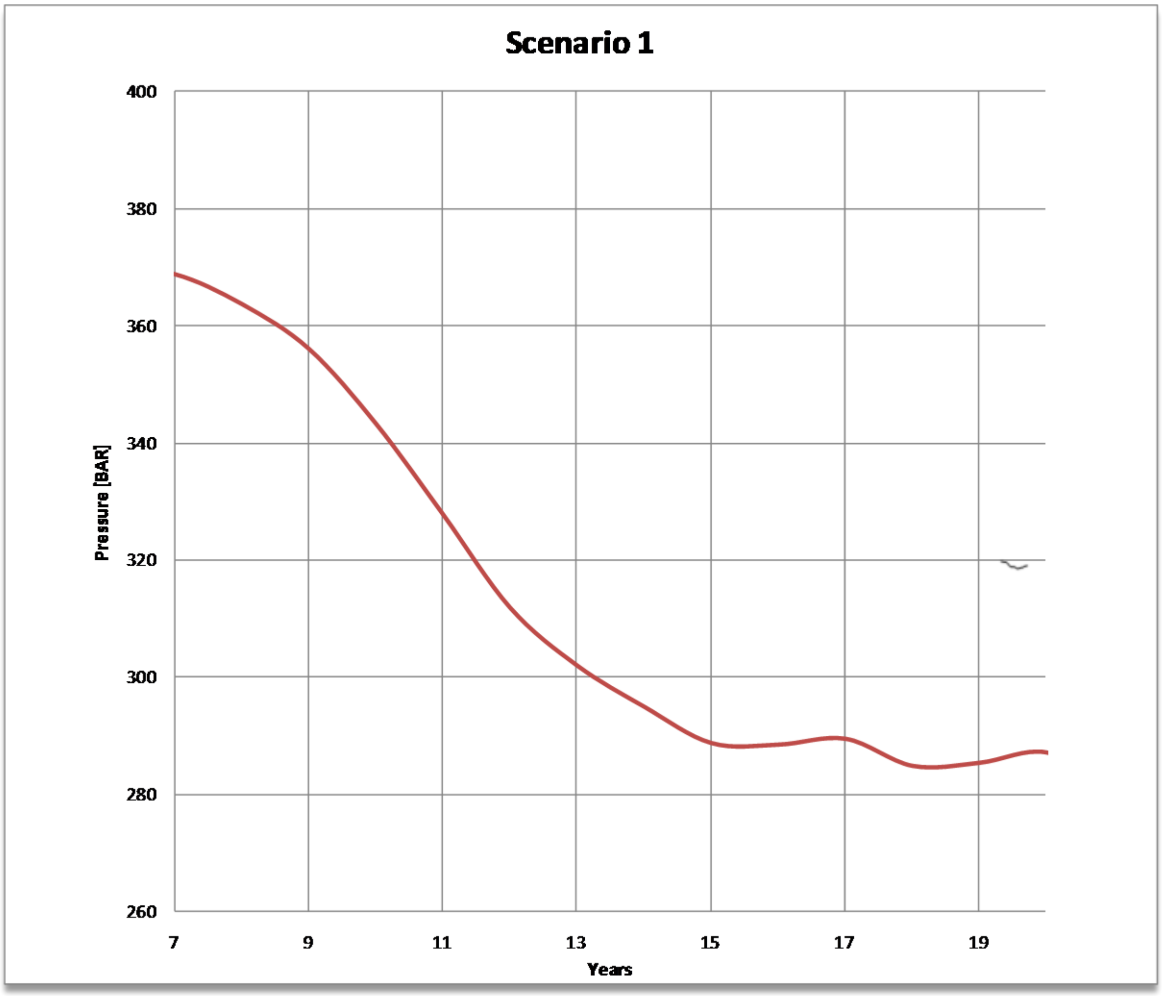


We increased the reservoir volume and changed the compressibility to get our results to match the measured one from Statoil. After some trails and errors we came up some different volumes which gave us satisfying match with the measured pressure.

Scenario 1:

Reservoir volume: $V_1 = 6,5 \cdot 10^9 m^3$

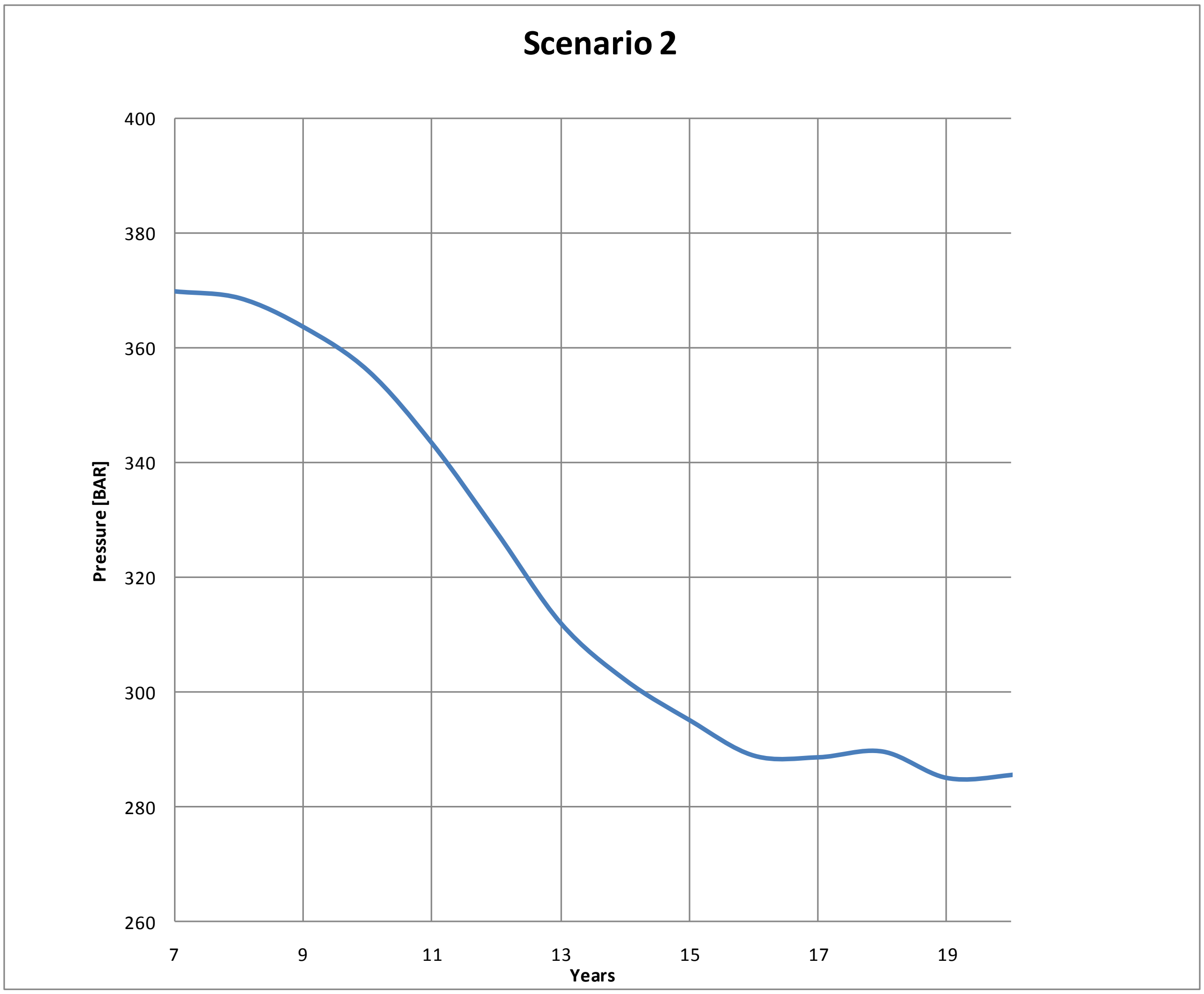
Initial compressibility



Scenario 2:

Reservoir volume: $V_2 = 3,25 \cdot 10^9 m^3$

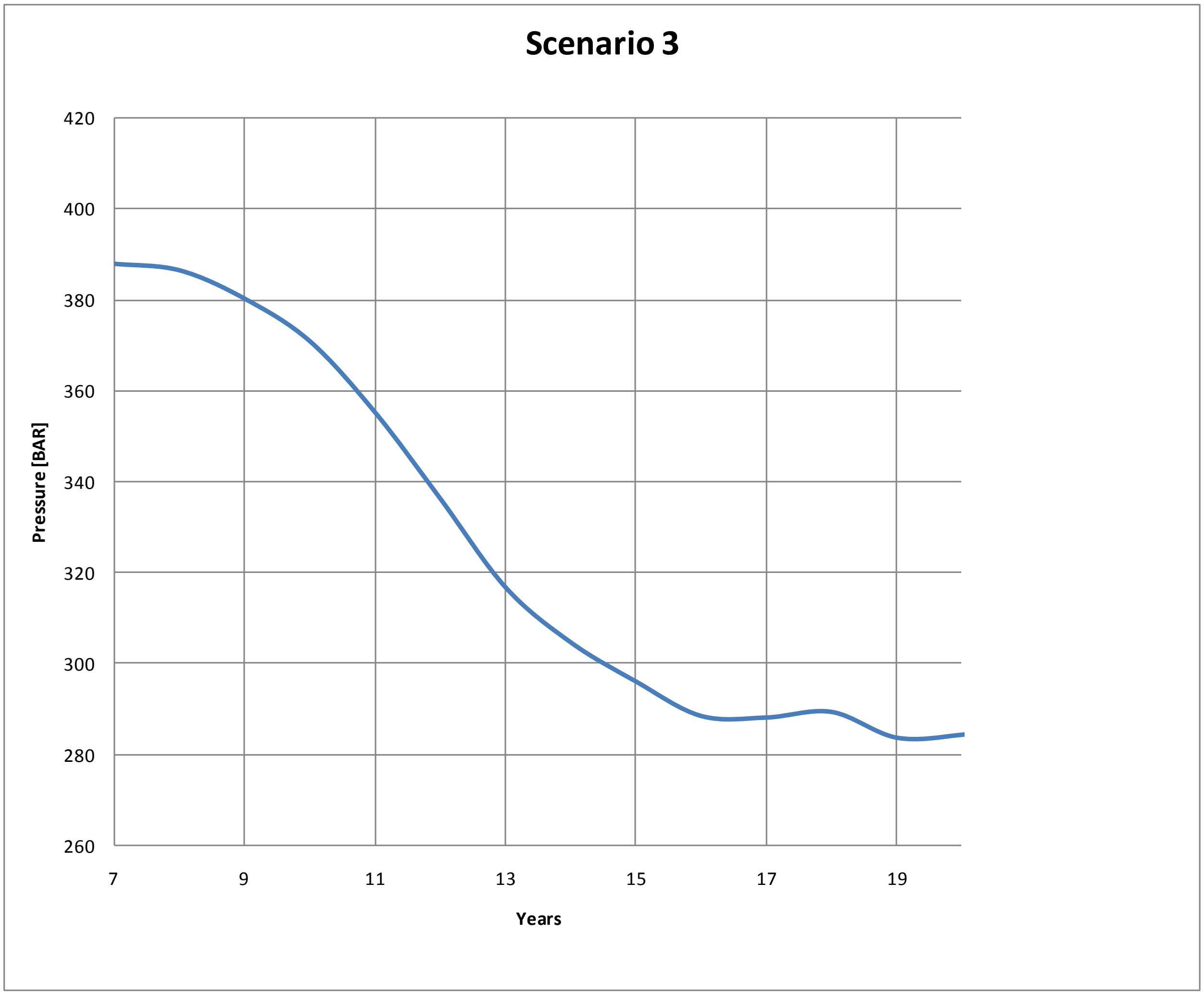
Compressibility: $c_2 = 2,0 \cdot 10^{-4} bar$



Scenario 3:

Reservoir volume: $V_3 = 5,3 \cdot 10^9 m^3$

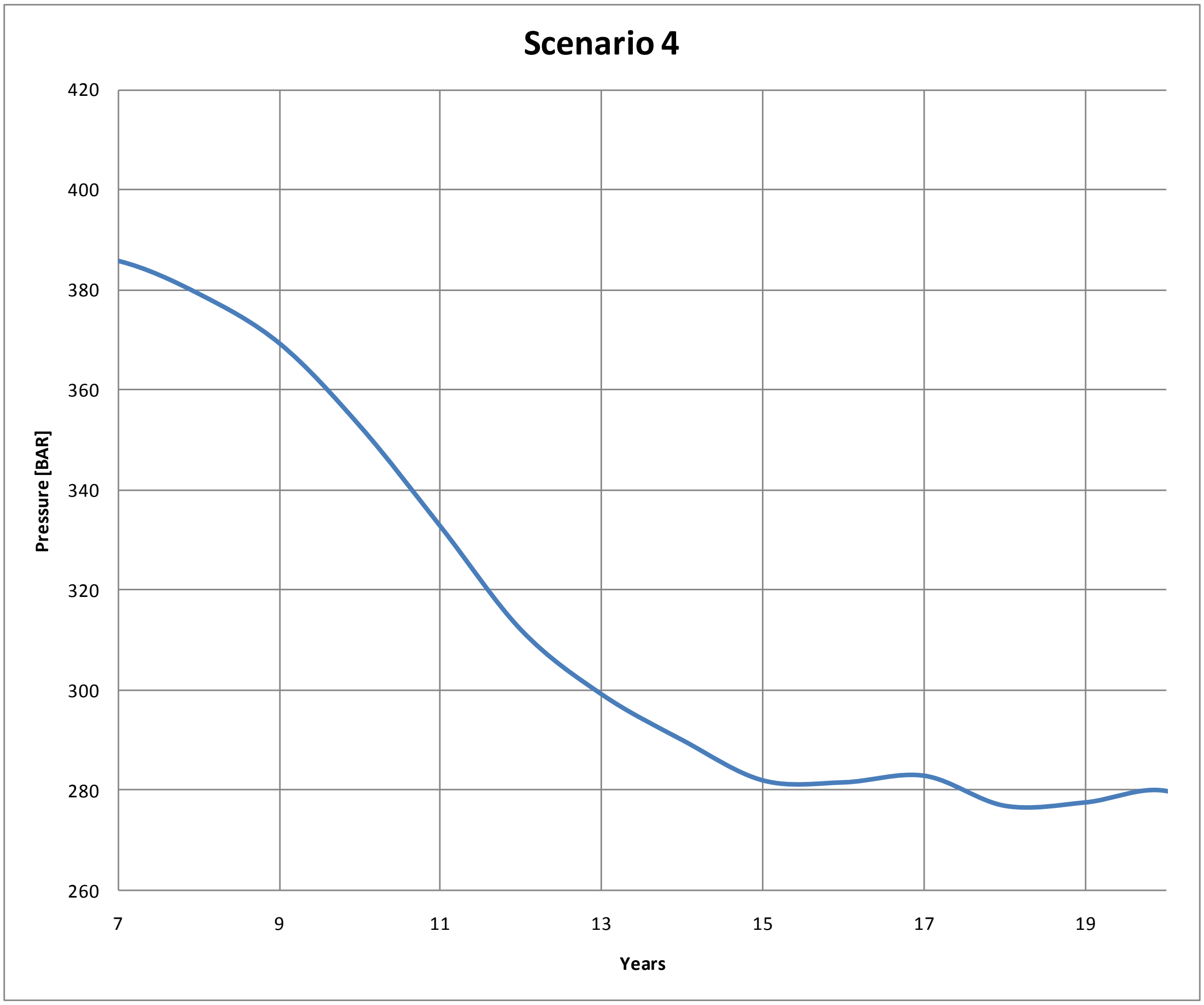
Compressibility: $c_1 = 1,0 \cdot 10^{-4} bar$



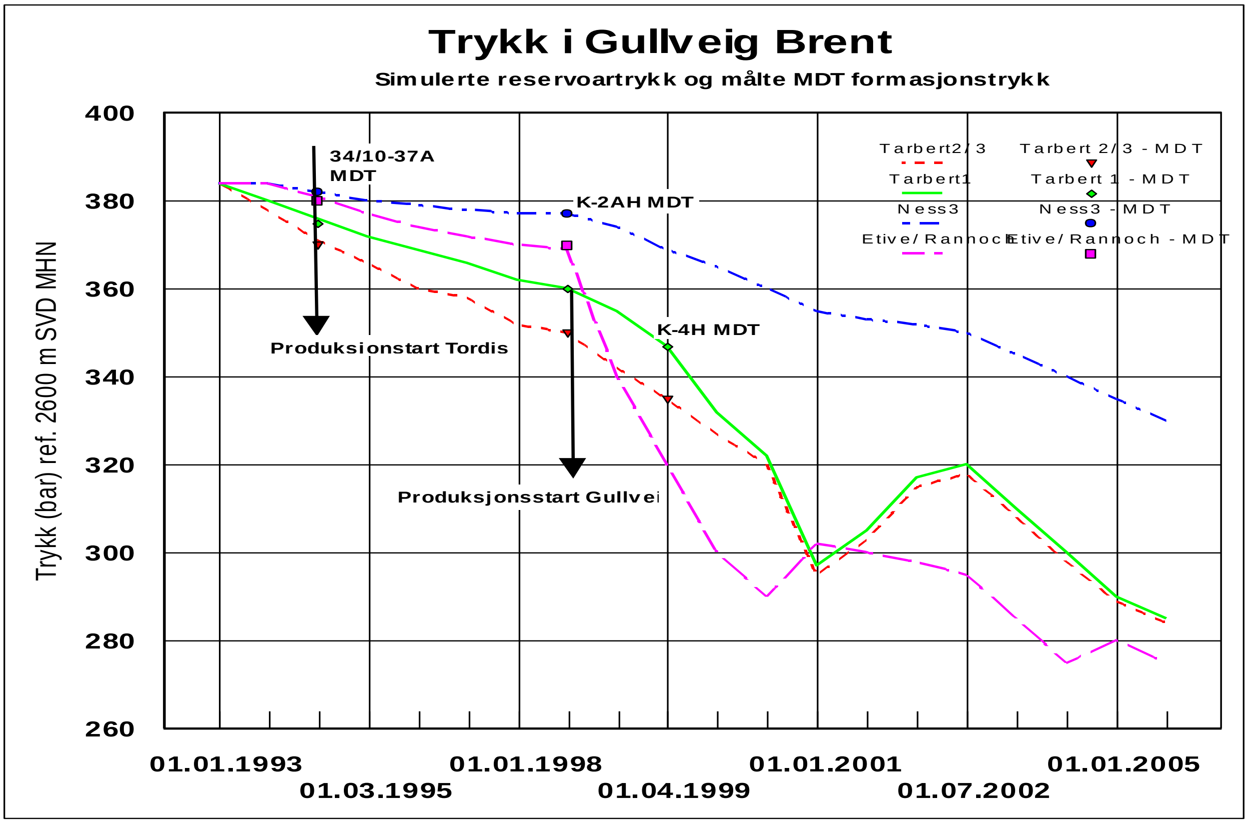
Scenario 4:

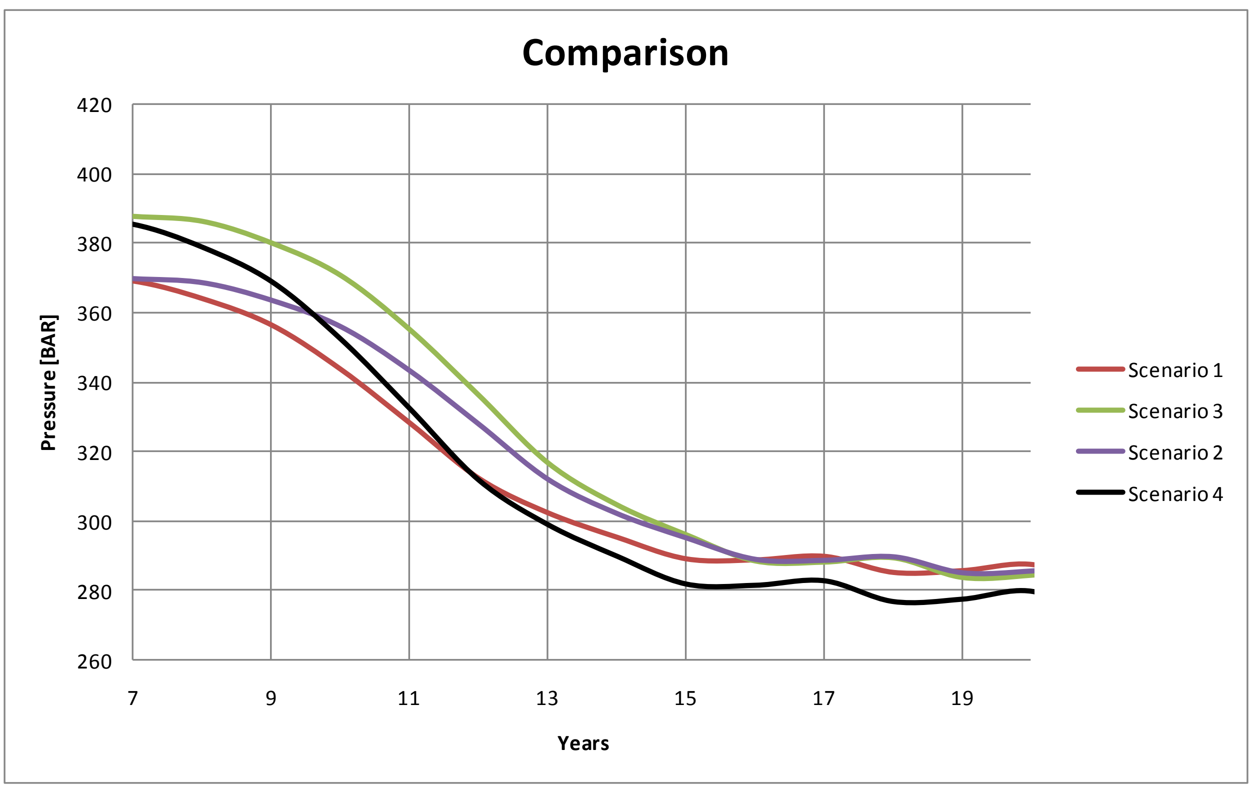
Reservoir volume: $V_4 = 2,5 \cdot 10^9 m^3$

Compressibility: $c_2 = 2,0 \cdot 10^{-4} bar$



The comparison:





Comparison of the calculated scenarios with the measured data

As our initial result varied very much from the measured data we had to change some of the parameters to make them fit the curve. From the graph it’s clear that there is something wrong either in our calculations, or the initial constant parameters. After some comparison and discussion we concluded that there where something wrong with the parameters. The results implied that we had pressure support from a larger aquifer, or that there was a gas cap of a considerable size.

We changed the reservoir volume until we had at better match with the measured pressure. We also tried to change the total compressibility to simulate a large gas cap. As we can see from our formula the pressure change is inverse proportional with both reservoir volume and compressibility. We made four main scenarios which all matched to measured data, but some better than others. The scenarios are described earlier in the document.

In scenario 1 we got a pretty good match when we used all the initial data, but increased the reservoir volume by a factor of over 30. This number is so large that we assumed that is was caused by a huge aquifer.

In scenario 2 we considered a big gas cap to be present. We doublet the total compressibility and looked at the response. This caused the Δp to get much smaller. To get the response we wanted, we had to decrease the reservoir volume from 6,5E9 m^3 to 3,25E9 m^3.

We do not know if our initial pressure is measured at the same depth as the measured pressures in Statoils graph. To get a better match with the measured data we increased the initial pressure from 380 to 400 bar. In order to get the best fit to the measured

values which will have a pressure of around 280 bar after X years, we changed the reservoir volume by trial and error.
In scenario 3 we ended up with a reservoir volume of 5,3E9 m3. And when we changed the compressibility in scenario 4, we got a volume of 2,5E9 m3

From the fig above we can see that the graph's from calculated data generally resembles quite good to the measured data as how the graph falls down. But Scenario 4 has the best logical fit.

Our results can be interpreted in several ways, but from our plot we'll have to choose scenario 3. From the production and injection rates, the assumption that all the fields on the beta rigde are in pressure communication and combined with the calculated pressure response, we assume the beta rigde to get pressure support from a relatively big aquifer. And that the pressures given to us, and from the measurements are not measured from the same depth. Another way to interpret the results is that there is a lot of gas in the reservoir and the aquifer is not as dominated as earlier assumed, but much more dominant than from the initial data.

Comparison for each scenario.

Since V scenario 1 >V scenario 3> V scenario 2 - we expect Δp scenario 1< Δp scenario 2< Δp scenario 3
Based on compressibility as C increase Δp is expected to decrease (C α 1/Δp).
Since C scenario 1 & 3 < C scenario 2 – we expect that Δp scenario 1 &3 > Δp scenario 2
From the two parameters we can decide that Δp for scenario 3 should be larger than Δp of scenario 1 & 2 and Δp of scenario 2 should be larger than scenario 1 because the change on Δp due to change in reservoir volume is larger than the case for compressibility.

4. Make an evaluation if the recovery factor for the various fields to date. How do the fields interfere with each other? Based on the production to date, what are expected recovery factors over the full production life for the fields? Why could there be differences between the different fields?

Interference between the satellite fields on the Beta ridge.

In this task we used the production/injection data provided from Statoil to see if there is any communication between the satellite fields.

Assumptions

- We assume that the pressure changes in the other fields, surrounding Gullfaks, do not affect the net flow from the Gullfaks main field to the Beta Ridge.
- The main part of the pressure support from Gullfaks Main field is given to Gullfaks Vest, Tordis and Vigdis

Procedure:

We plotted production data for the different fields to see if there was any pattern that could indicate connection between the satellite fields. Then we made a graph of the net flow rate (production rate-injection rate) from the main field. Then we could check if high production rates from the satellite fields would have an impact on the net flow from the Gullfaks main field.

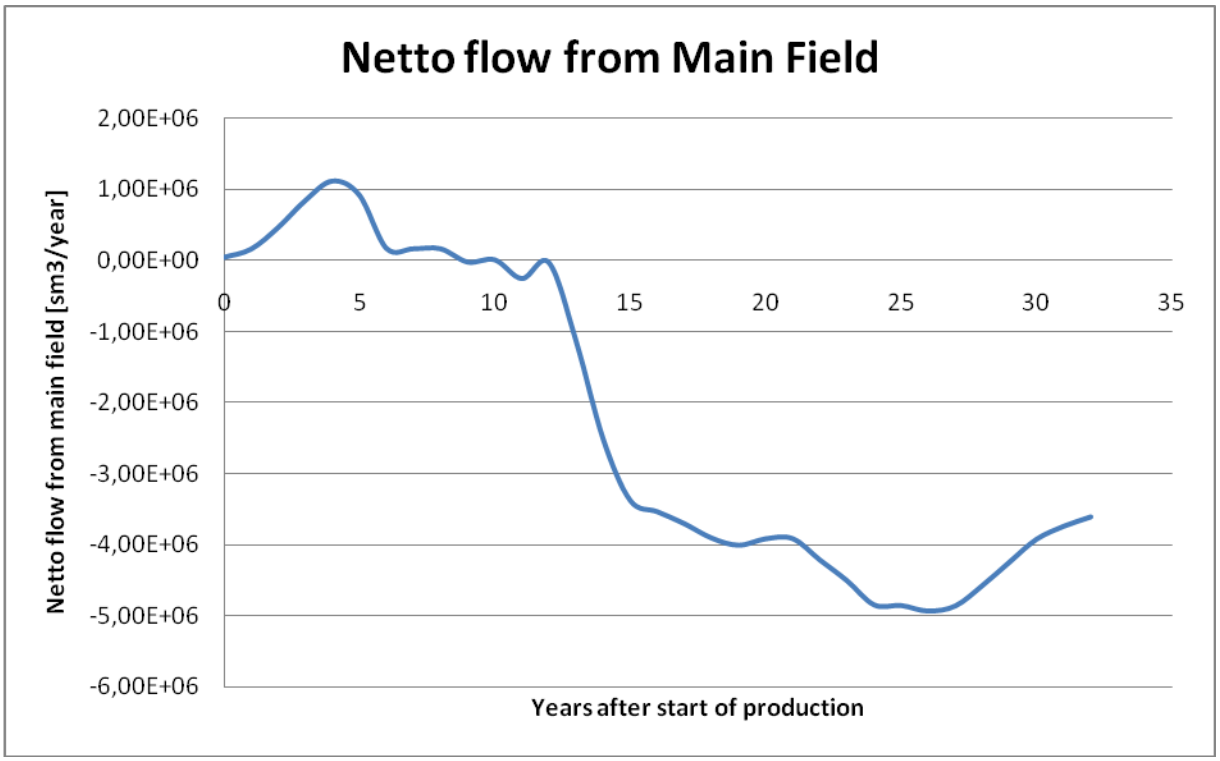
Results:

As seen from the graphs, the net flow graph becomes negative (injection from the main field) from year 9 and on. The production from Tordis and Vigdis starts at year 7 and 10, respectively, and causes the net flow graph to drop.

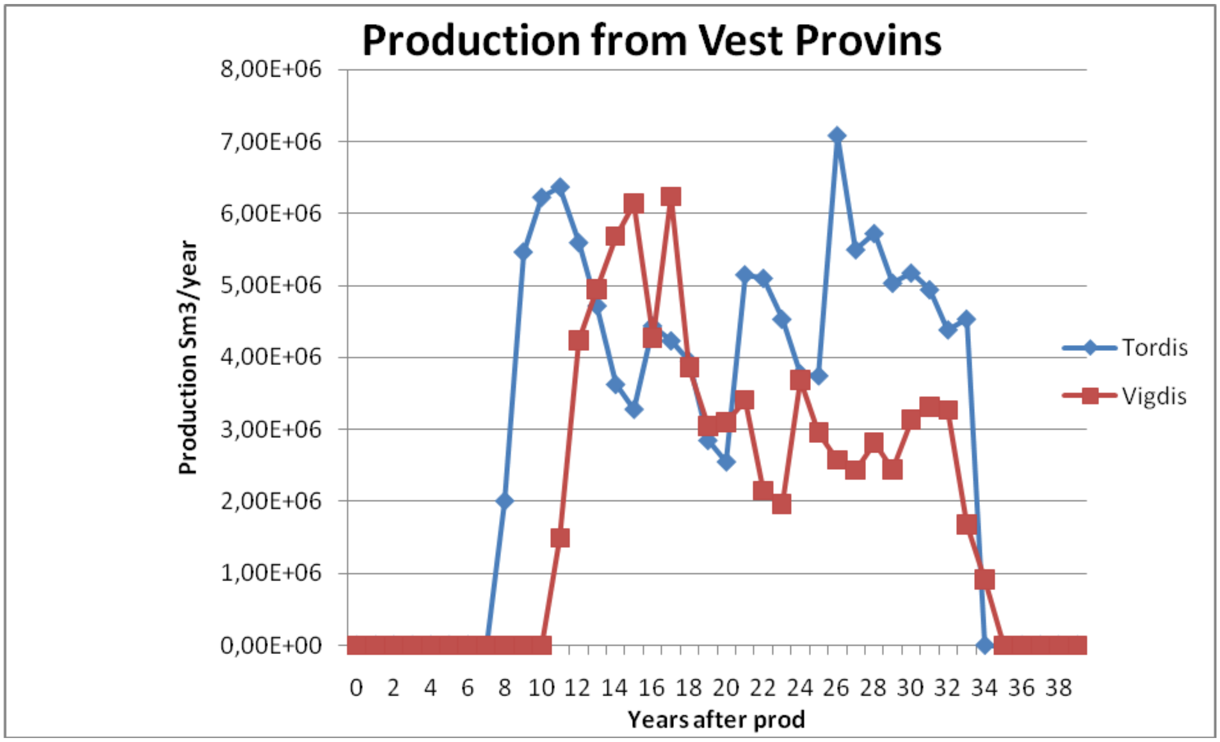
Tordis and Vigdis are affecting the flow from the Gullfaks main field, and these satellite fields are supported with the same aquifer1 as the rest of the satellite fields at the Beta Ridge. This means that there is at least some communication between the fields on the Beta Ridge.

Conclusion:

From our results we can conclude that the satellite fields are communicating with each other through the water aquifer in the Beta ridge.



[1] Statoil's Reservoir Management Plan, 2008



4. Make an evaluation if the recovery factor for the various fields to date. How do the fields interfere with each other? Based on the production to date, what are expected recovery factors over the full production life for the fields? Why could there be differences between the different fields?

Make an evaluation for the recovery factor for the various fields to date.

Assumption

Since we lack the necessary data for calculating the recovery factor for GF vest we tried to assume some value from the other fields based on

- Geographical area of the field
- Production data
- Production period

Based on the above criteria, assessment has been made and we agreed to take an assumed value for our field (GF vest) from Tordis field. From these cases we preferred geographical area of the field because we needed the rock volume of the field. Based on made assumption we calculated oil recovery factor for the field. But for the other fields we had the necessary data and we calculate the recovery factor for each field accordingly.

We just used the same recovery factor of 47 % for GF Vest and Vigdis as that of the Skinfaks because they are geographically near.

Data and calculation

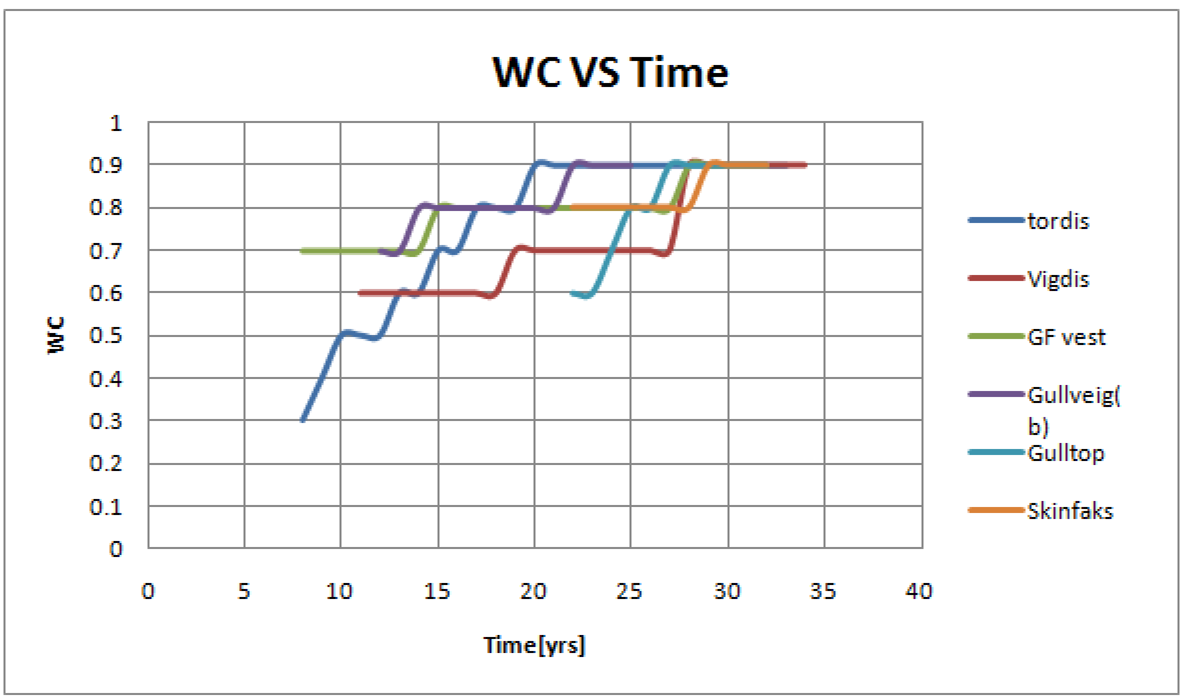
First we calculated cumulative production for each satellite fields and divide them by their respective original oil in place to find a value for oil recovery factor.

By trial and error we adjusted the WC so that we will meet the recovery percentage presented by Statoil in the management plan.

Finally we plotted the WC Vs Time[yrs] and tried to analyze them.

You can refer the attached excel sheet for the raw data and for the calculation in Appendix provided.

Data analysis and summary



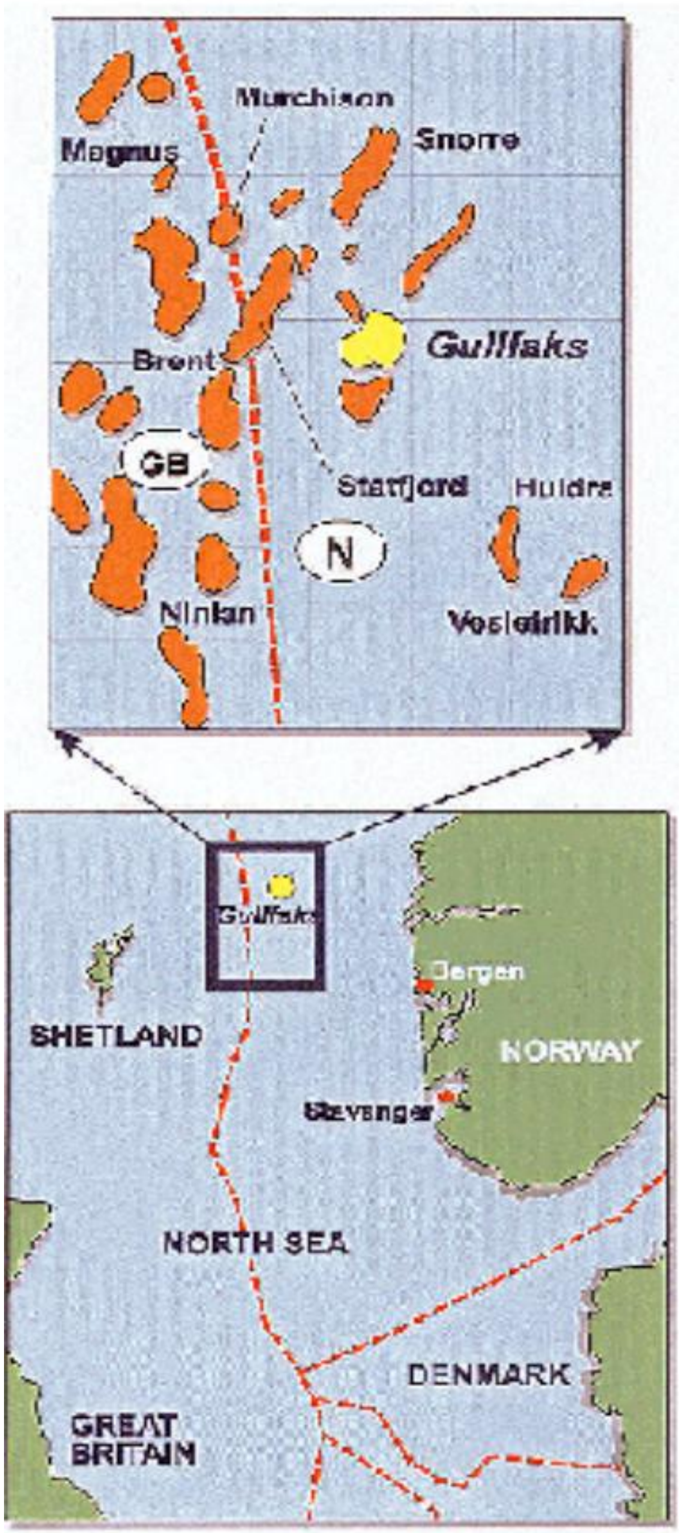
As we can see from the graphs, the water cuts are pretty high from an early stage. The average WC for the satellite fields is around 0.8, which is rater high.

Why could there be differences between the different fields?

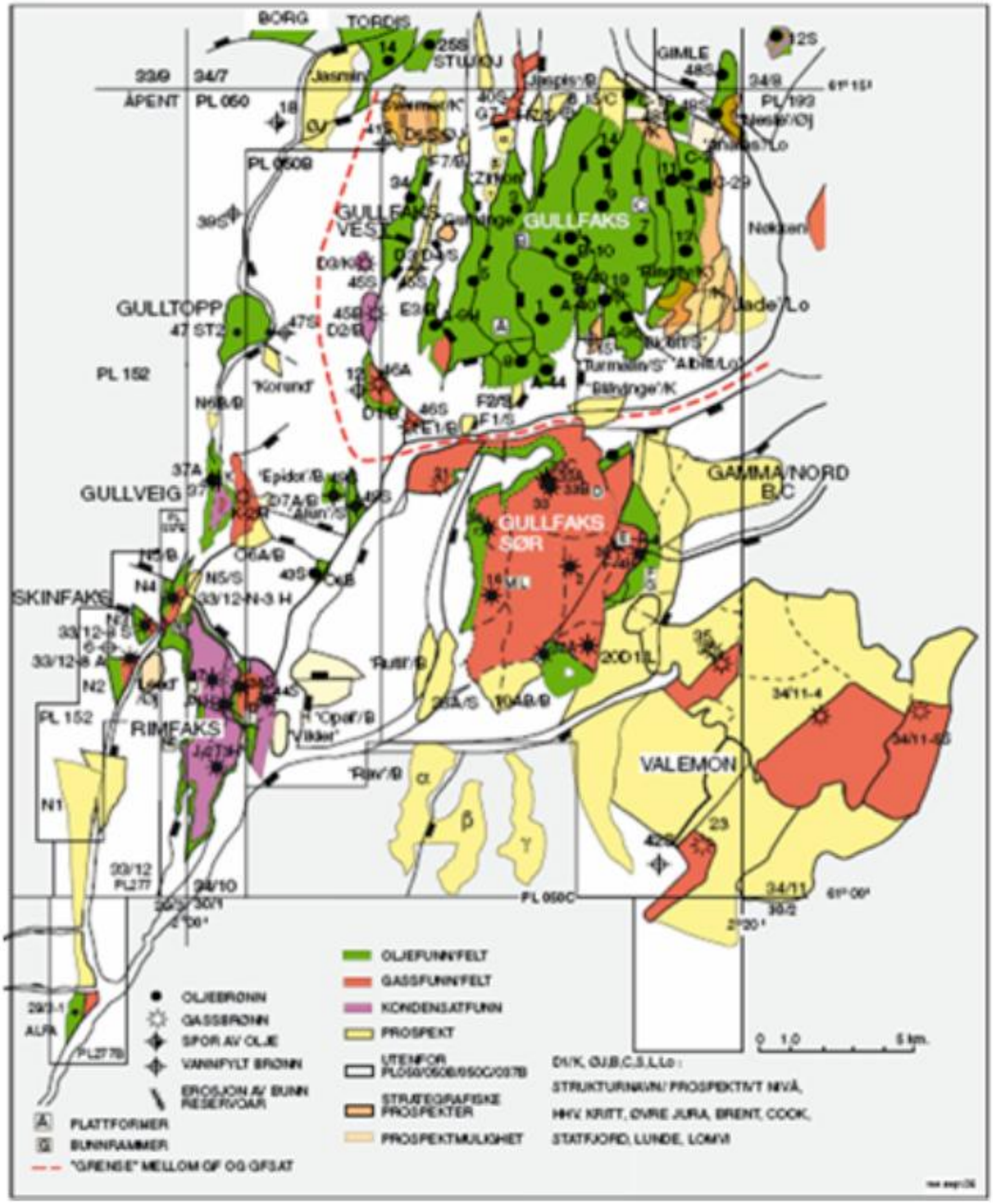
Exist great deal ways to analyze the differences among fields, in these fields we have different geological formation which have different characteristics as a porosity, permeability, mobility, compressibility, if exist or no communication between the fields and contacts between gas, oil or water that can have a great influence in results of production rate, recovery factor and amount of injection needed.

III. Appendix

Appendix 1. Geographical location of the gullfaks field



Appendix 2. Overview of the fields, discoveries and prospects in the Gullfaks area



Appendix 3. Fields and discoveries in the gullfaks area with the beta ridge marked

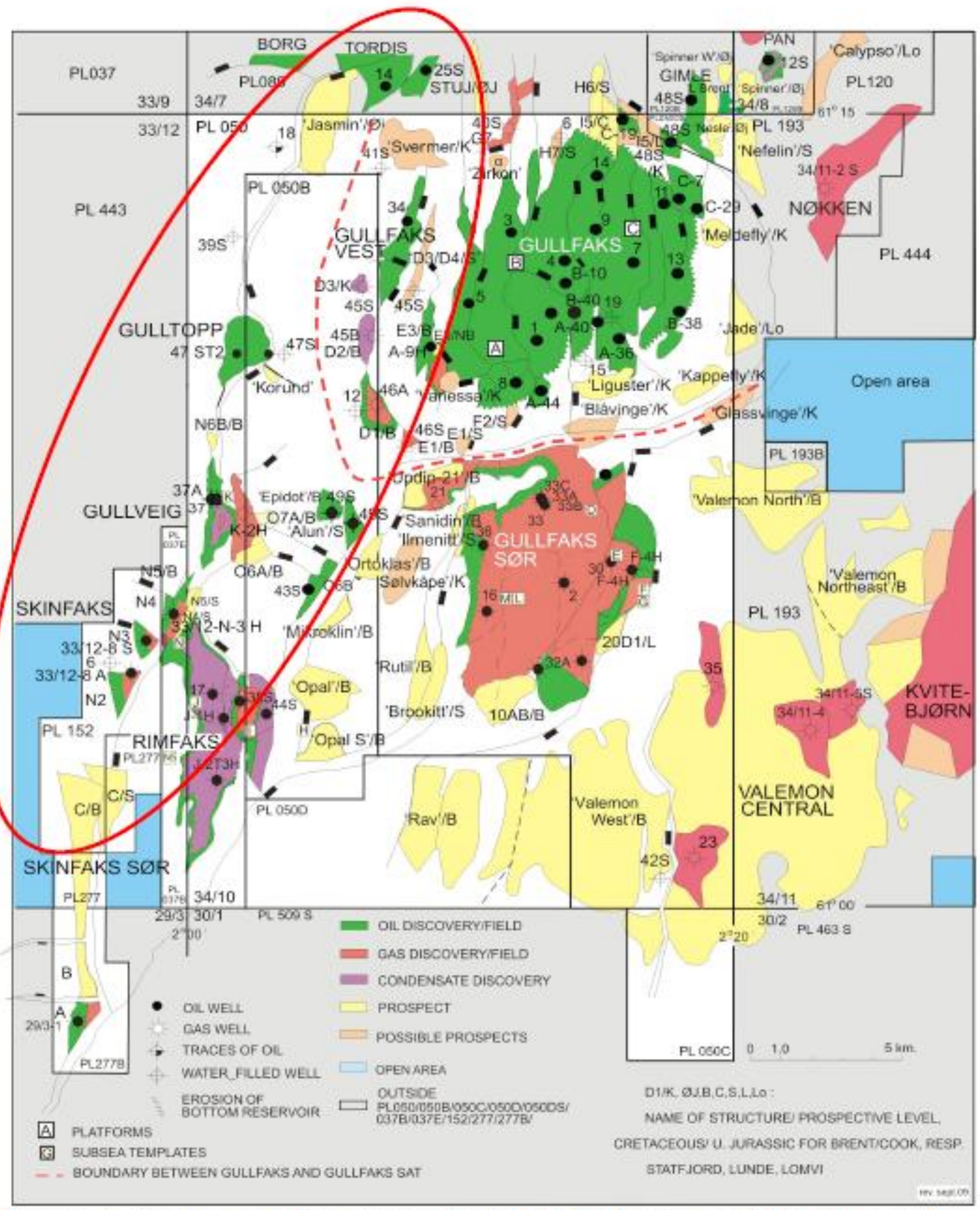


Figure 1. Fields and discoveries in the Gullfaks area with the Beta ridge marked.

III. References

- Stat Oil documents Gullfaks village 2011, https://www.itslearning.com/main.aspx