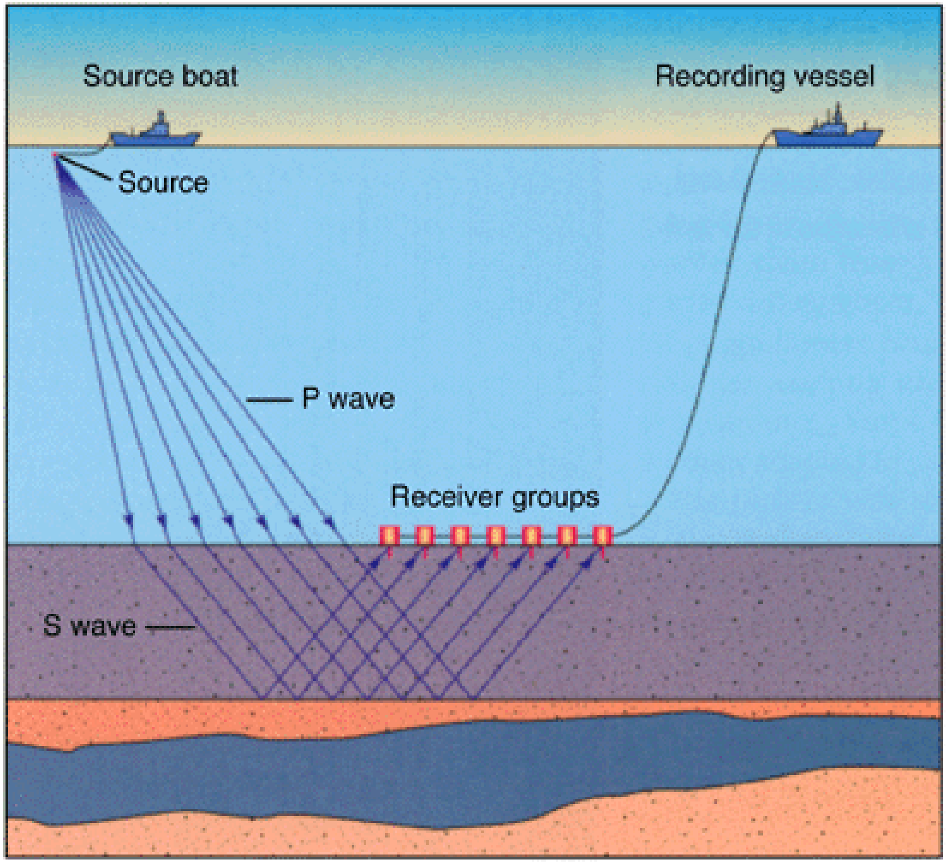
Norwegian University of Science and Technology (NTNU)

TPG4852 EIT-NORNE VILLAGE SPRING 2010

Technical Report



History Matching of 4-D seismic data

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May 2010

Acknowledgement

Kweku Engineering Minds are grateful to the entire Norne Village. Most especially, our gratitude goes to Statoil ASA for their financial, logistic and moral supports. We must also express our appreciation to the village leader, Prof. Tom Jelmert for his guidance and support on this project throughout the semester. Nan Cheng and Mohsen Dadashpour for their very much needed technical support because of our peculiar challenges on 4D seismic, Lars Høier for the good feedback and thoughts on improvment after final presentation, Per Einar Kalnæs for helping out on Eclipse, and Jan Ivar Jensen for being such a problem solver and good guide on the trip to Harstad.

Summary

This is a report about “History Matching of 4D seismic data” written in connection with the course EIT Norne Village.

The main objective is using History Matching and 4-D seismic to study the behaviour of the reservoir at different times in the order to improve eclipse model to match seismic qualitatively. We were for that purpose provided a seismic line within the E segment with the seismically determined oil water contacts (OWCs) from 2001 and 2004.

We have been able to better match the model to the seismic line we were provided with, and we also have discussed the accuracy and validity of our model. There are for instance lot of uncertainties in modelling, and our need to relocate our seismic line in the model caused us to have to introduce even more.

The changes we have made to the model when trying to History Match the OWC have been fairly simple. We have done local changes to permeability and transmissibility in different layers, and have run two different successful simulations from this.

We are quite satisfied with our results, and though this task we were given has been quite challenging, it also has proven very interesting and has been a good learning experience.

In the appendix A we have added some of the important figures and graphs in larges scale, so the readers has the possibility to see the results for them selves.

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Technical background of group members

Our group consists of 5 master members students: Andreia Tatiana de Vasconcelos Barros (Geologist, Angolan), Adeshina Adeyemi Elegbede (Civil Engineer, Nigerian), Faizan Ahmad Khan (MSRAMS, Indian), Kathrine Karlsen (Drilling Engineer, Norwegian), Kofi Tutu Addo Assuming-Gyimah (Physicist, Ghana). So, as seen above, our team includes five different nationalities and five different academic backgrounds, with all the advantages and disadvantages it brings for team work.

Figure 1: Our group. From the left: Andreia, Shina, Kathrine, Tutu and Faizan.

Introduction

In this introduction we go through the basis of our task and the Norne Field in general. References are given in the separate chapter named References at the end of the report.

The village theme was about one of the oil fields in Norway called Norne, consisting of 4 segments, but with focus only on the E-segment. The field was discovered in December 1991, oil production started November 1997 and gas production 2001, with a recovery factor estimated to be 62% and expected life time is up to 2021. The village was to develop new ideas for better reservoir characterization and improve production, proffering a practical solution that would help improve the recovery factor.

Our group project is “History Matching of 4D seismic data”, where the main objective is using History Matching and 4-D seismic to study the behaviour of the reservoir at different times in the order to improve eclipse model to match seismic qualitatively. We were for that purpose provided a seismic line within the E segment with the seismically determined oil water contacts (OWCs) from 2001 and 2004. The exact task description is shown below:

History Matching of 4D seismic data

- Understand basics of 4D seismic
- Study selected seismic line through the segment
- Qualitative comparison of oil-water contact (OWC) from the simulation model and from 4D
- Further improve the current E-segment reservoir simulation model

History Matching is the search for a mathematical solution that gives an answer to a predefined number, or series of numbers you are seeking, for example oil, water, or gas production, from a field or well. It is used to calibrate the model, predict future, increase the understanding of the reservoir, and detecting operational issues. Once a model has been History Matched, it can be used to simulate future reservoir behaviour with a higher degree of confidence.

The 4-D seismic is the term used for 3D sets with identical spatial configurations that are shot at different times for the purpose of examining the change in a reservoir over time.

History Matching and 4-D seismic data are important source of dynamic information about the reservoir. Reservoir engineers, geophysicists and geoscientists are working together on this problem, known as seismic History Matching.

Location

The Norne field is located in the blocks 6608/10 and 6608/11 on a horst block in the southern part of the Nordland II in the Norwegian Sea (Figure 2). The horst block is approximately 9 km x 3 km. It consists of two separate oil components, The Norne main structure (C, D and E segment) and the Northeast segment (G segment). 98 % of oil in place is situated at the Norne main structure. Total Hydrocarbon column (based on well 6608/10-2) is 135 m which contains 110 m oil and 25 m gas in the rocks of Lower and Middle Jurassic age of the Fangst and Båt Group.

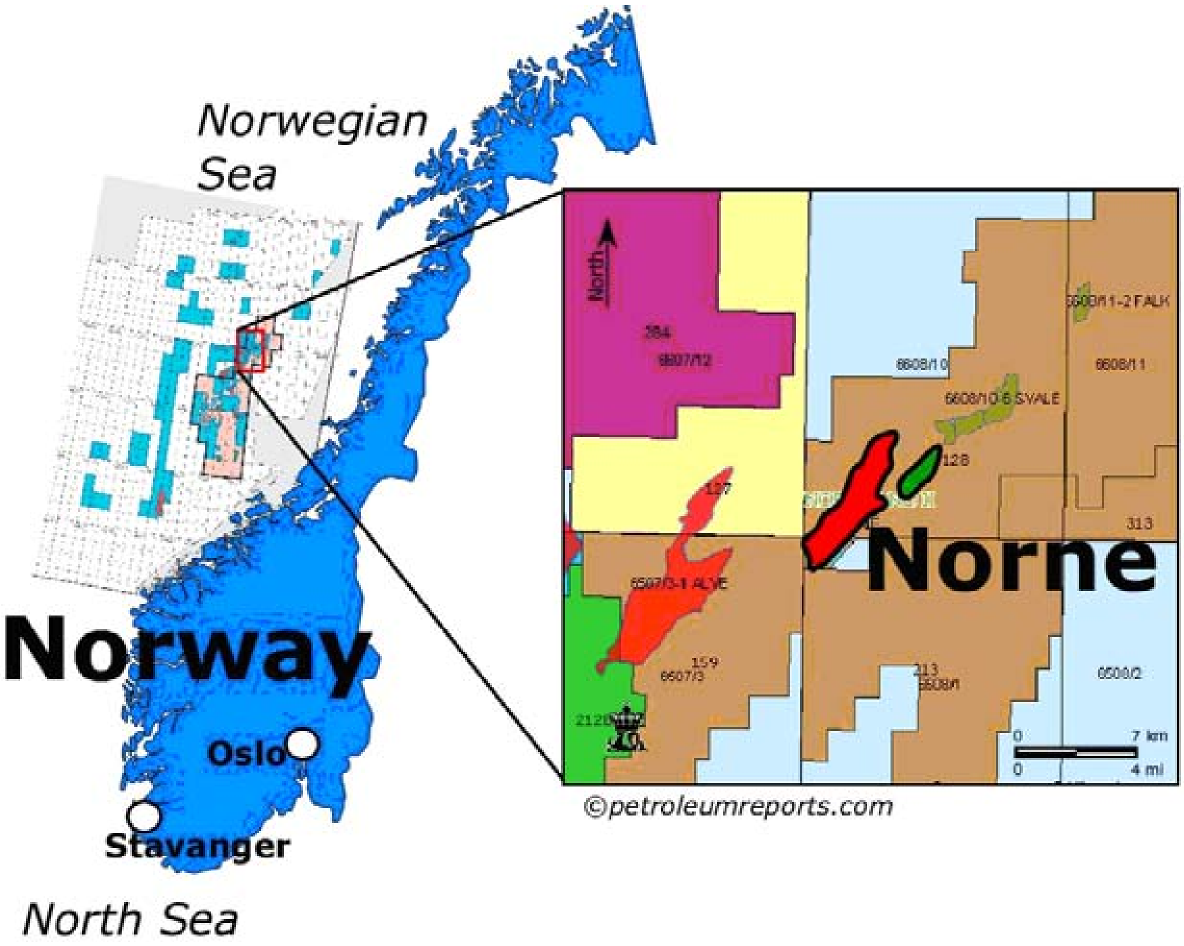

Figure 2: Location of Norne field (petroleumreports.com)

Geological description

The reservoir model is subdivided into four different formations from top to base: Garn, Ile, Tofte and Tilje (Figure 3). Hydrocarbons in this reservoir are located in the Lower-to Middle-Jurassic sandstones. The reservoir sandstones are dominated by fine-grained, and well to very well stored sub-arkosic arenites. Approximately 80% of oil is located at Ile and Tofte formation and the gas in the Garn formation.

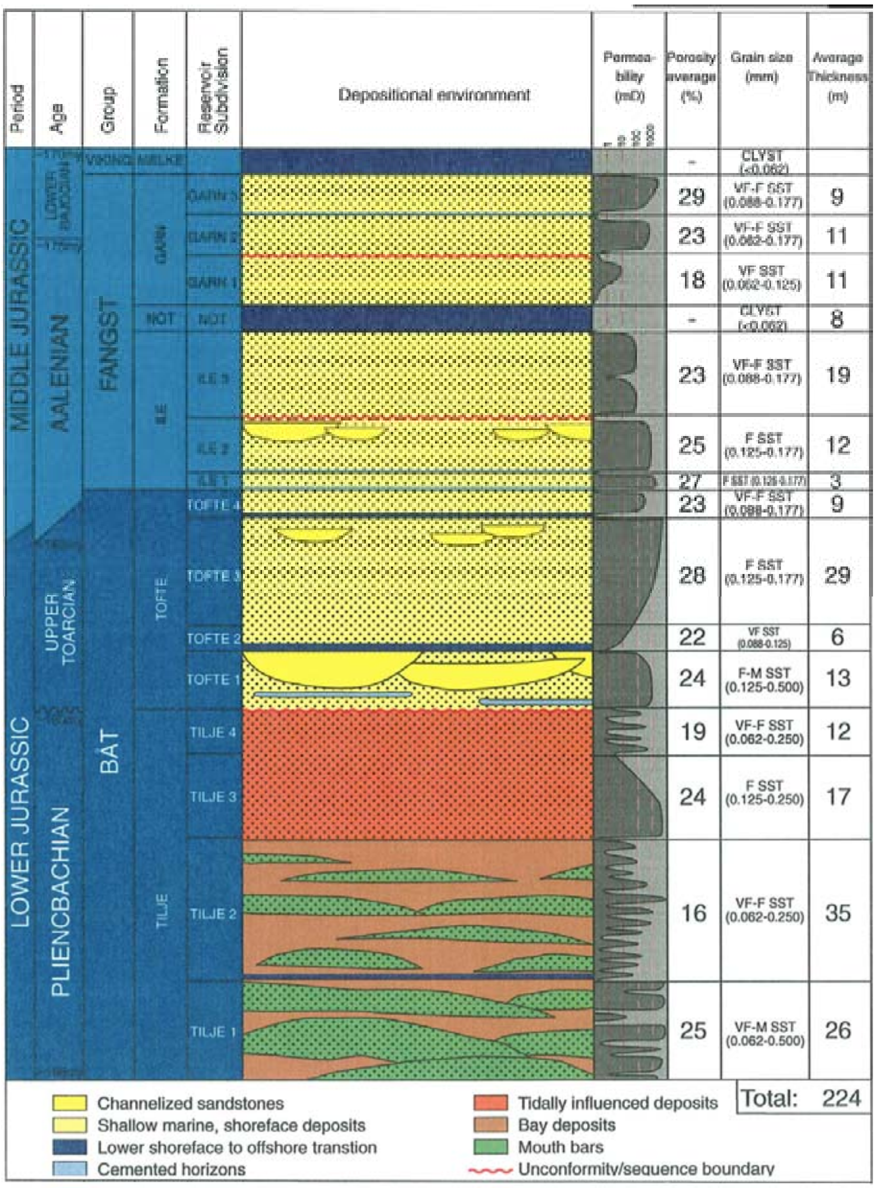

Figure 3: Stratigraphical sub-division of the Norne reservoir (Statoil Hydro, 2001)

The sandstones are buried at a depth of 2500-2700 m and are affected by diagenetic processes. Mechanical compaction is the most important process which reduces reservoir quality. Still, most of the sandstones are good reservoir rocks. The porosity is in the range of

25-30 % while permeability varies from 20 to 2500 mD and water saturation 12-43% for hydrocarbon zones.

The source rocks are believed to be the Spekk formation from Late Jurassic and coal bedded Åre formation from Early Jurassic. A source rock is a rock of high organic content, which under the right circumstances, temperature and pressure, will form oil and gas.

The cap rock which seals the reservoir and keeps the oil and gas in place is the Melke formation. The Not formation behaves as a cap rock, preventing communication between the Garn and Ile formations.

History Matching

This chapter explains the term History Matching, focusing on which parameters you often change, and also which you normally should not change. Knowing this is very important when History Matching.

History Matching is an iterative process which is defined as act of adjusting a model of a reservoir until it closely reproduces the past behaviour of a reservoir.
Mathematically, History Matching can be defined as the search for a mathematical solution that gives an answer to a predefined number, or series of numbers you are seeking, for example oil, water, or gas production, from a field or well.

We can perform History Matching By manual adjustment of the model: It gives full control, but it is Tedious repetitive. It is also an option to do computer assisted History Matching that gives automatic case setup and visualization.

These techniques use conventional grid-based simulation to compute sensitivity coefficients, which give the change in production data caused by a change in the permeability or porosity of some portion of the simulation model. Using the sensitivity coefficients, the porosity and permeability are adjusted to create a new reservoir model. When another simulation is performed using this model, a better match to the data should be obtained. If the match is still unacceptable, new sensitivity coefficients are computed and used to modify the reservoir model again. Because the sensitivity coefficients are nonlinearly dependent on the reservoir description, many iterations may be needed before a good History Match is obtained. For a finely-gridded model, there are many more matching parameters than data, and the match is non-unique.

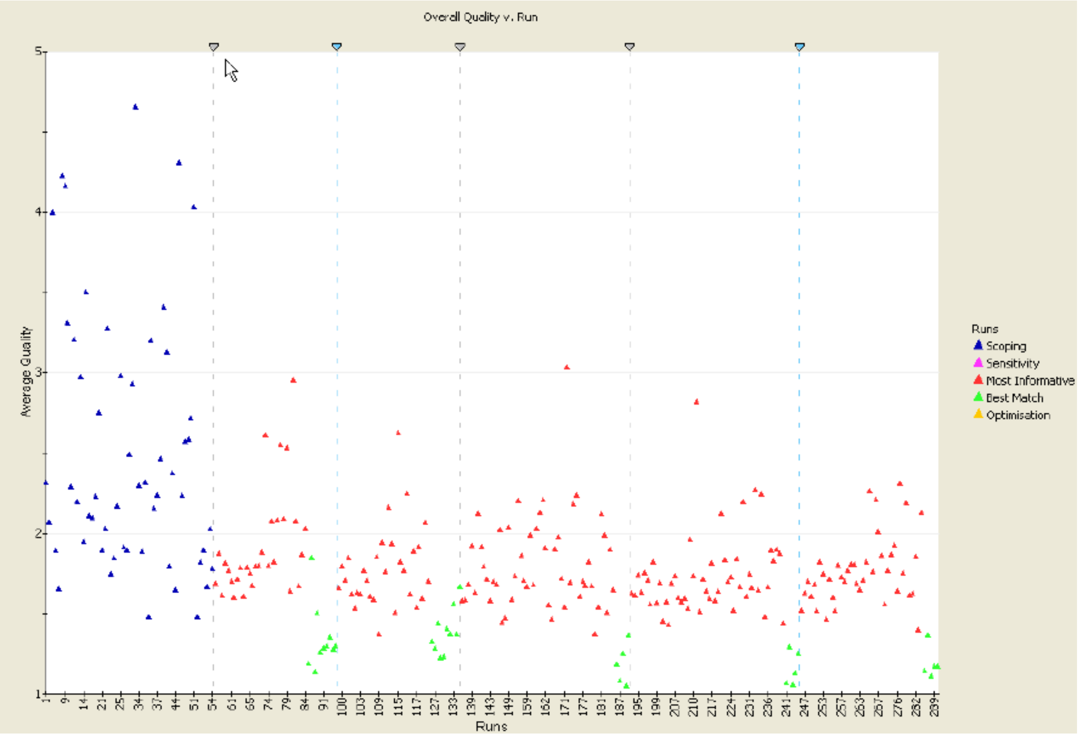

Figure 4: Example of Computer assisted History Matching. (Nan Cheng presentation, origin unknown)

We need to do Model Calibration for validating the reservoir description in order to predict the future performance with higher confidence, enhance our understanding of reservoir and its parameters, and also to detect some operational issues. Dynamic data (production data) can be an important source for information about the reservoir and should be used to update the geological model. The accuracy of the History Matching depends on the quality of the reservoir model and the quality and quantity of pressure and production data.

The challenge is to incorporate the information in dynamic data in all reservoir modeling, and to consistently span the uncertainty in predictions. Reservoir engineers search for reservoir models that match the observed dynamic data.

Choice of parameters to update

History Matching process, which is basically an optimization problem, consists on modification of reservoir properties such as porosity, permeability, relative permeability, among others, to match production data.

Determining which parameters in History Matching to change is a difficult task since a large number of parameters affect production data, and all or at least most of the parameters have some amount of uncertainty associated with them. Some reservoir parameters have a high degree of certainty based on test samples and production history while others are yet uncertain. To make the procedure efficient, parameters that have the most significant impact on the production need to be perturbed.

The following parameters are examples of parameters with a high degree of certainty:

- **Fluid properties:** Fluid properties such as viscosity, pour point, temperature etc are properties that have been obtained from inception of production; therefore, they are very certain and need no modification in History Matching.

- **Initial reservoir pressure:** This is the pressure at discovery before production takes place. The major source of initial reservoir pressure data includes drill-stem testing. This is a parameter that characterizes the entire field and has a high degree of certainty.

- **Initial water saturation:** The minimum water saturation from capillary pressure data or core analysis data is considered as an estimate of water saturation in the oil column at the time of discovery [Dandekar, 2006]. It is also a major parameter and has a high degree of certainty; hence, it just is not a probable choice for change.

- **Porosity and structure:** Rock porosity is a measure of the pore volume of the rock over its bulk volume. It can be categorized into absolute and effective porosity, where absolute porosity is the volume of connected and non connected pores as a fraction of the bulk volume of the porous rock. Porosity measurements are determined by comparing the volume before and after crushing samples. Effective porosity is the volume of interconnected pores as a fraction of the bulk volume of porous rocks. This is measured by allowing a fluid of known density to enter the pores of a dry core [Satter et al, 2007].

- **Major faults**

The following parameters are examples of what one is more likely to change, because they have a higher degree of uncertainty:

- **Transmissibility:** Transmissibility is a function of formation permeability, thickness and fluid viscosity [Satter et al, 2007]. It is a parameter that ranges between 0 to 1. A

- **Permeability:** Permeability is a property that describes the connection of pores in the rocks. It can be defined as the fluid conductivity of the reservoir rock. It can be measured by lab core analysis and log analysis, however, there is still a high uncertainty in this property due to the difference phases of fluids (water, oil and gas) present in reality and the extrapolation of core sample results to entire formation.

- **Relative permeability:** The permeability for each phase is called the effective permeability while relative permeability is the ratio of the effective permeability to one phase to the absolute rock permeability, that means to the rock permeability if this one alone fill the fills all the pores [Schmid, 1956]. Relative permeability data are typically placed at the top of the hierarchy of uncertainty because they are modified more often than other data. Relative permeability curves are often determined from core floods. As a consequence, the applicability of the final set of curves to the rest of the modelled region is always in doubt [Fianchi, 2001].

4-D seismic

This section is devoted to the field of 4-D seismic, going through every aspect from acquisition to interpretation of the final seismic line. References are listed under "References" in the end of this document.

Time-lapse (or 4D) seismic data is one of the important tools used for monitoring the Norne field. However, in order to reduce uncertainties, an integrated multidiscipline approach involving geophysics, reservoir engineering, geology and petrophysics has been successfully applied. As a result, a better History Matched reservoir model was obtained by improving the consistency between the reservoir simulator results and the observed 4D seismic data. This lead to an increased understanding of the reservoir drainage and hence contributed to the process of identifying and prioritizing infill-drilling targets at Norne.

4-D seismic is a method that involves acquisition, processing, and interpretation of repeated seismic surveys over a producing hydrocarbon field. Time-lapse seismic are seismic reflecting the reservoir changes over time.

The objective is to determine the changes occurring in the reservoir as a result of hydrocarbon production or injection of water or gas into the reservoir by comparing the repeated datasets. A typical final processing product is a time-lapse difference dataset (i.e., the seismic data from Survey 1 is subtracted from the data from Survey 2). The difference should be close to zero, except where reservoir changes have occurred.

Acquisition

Seismic analyses are divided into three parts: seismic acquisition, seismic processing and seismic interpretation.

Seismic acquisition is the artificial generation and recording of seismic data (Figure 5). A seismic source, such as a dynamite explosion, compressed air gun or vibrator unit, generates energy that travels into the Earth as vibrations passing through underground rock layers. Different types of rock filter the seismic waves and some energy returns to the surface due to refraction or reflections from at surfaces between different rock layers.

The returning seismic energy is measured by receivers, which record the seismic signals as electronic waveforms. Geophones are one type of receiver, used on land, on the sea floor or inside a wellbore (as in a vertical seismic profile) to record the seismic signal. Geophones use a moving magnet or coil, as used in some microphones, to measure small vibrations. Hydrophones are another type of receiver, used to measure changes in pressure as sound travels through water. Hydrophones are usually towed a few meters underwater inside “streamers” that are typically 3 – 6 km (abut 2 – 4 miles) long. Hydrophones can also be suspended vertically or laid on the sea floor.

Different types and configurations of receivers are used depending on local environmental conditions and the underground geological features that are to be imaged. The layout of the receivers is also designed to minimize the effect of noise that can otherwise mask the seismic signal. So long as appropriate receiver configurations are used, special computer processing techniques can be applied to the recorded data to remove noise and enhance the seismic signal.

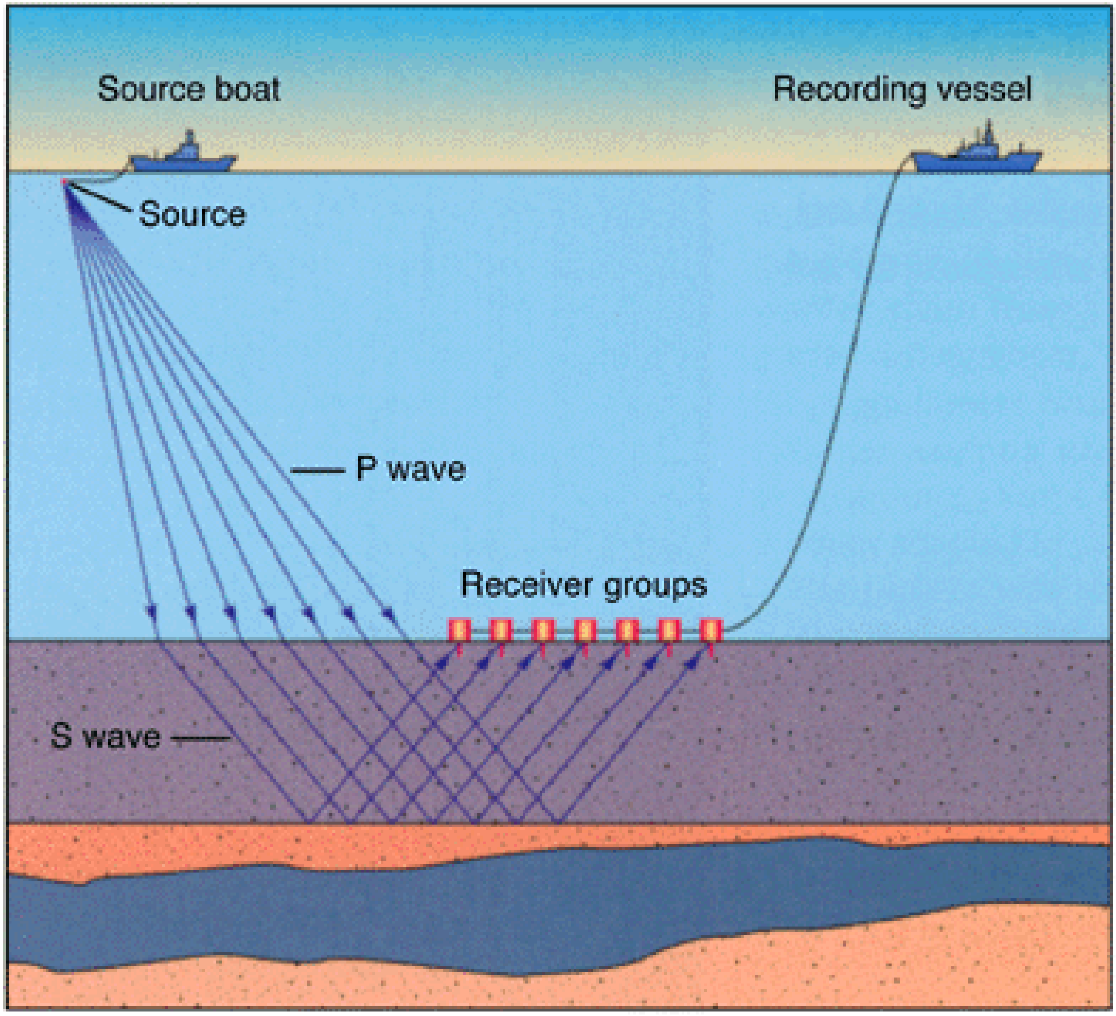

Figure 5: Schematic acquisition of marine seismic data (Schlumberger Oilfield Glossary, 2003).

Seismic marine data is acquired by a seismic vessel. The different layers in the subsurface have different properties and to be seen by the seismic energy, the acoustic impedance must be different from the surrounding layers. The acoustic impedance is given by:

$$z = v\rho$$

The difference in acoustic impedance is given by the reflection coefficient, R which is given by:

$$R = \frac{v_2\rho_2 - v_1\rho_1}{v_2\rho_2 + v_1\rho_1}$$

Where v is the p-wave velocity and ρ is the density.

Processing

For seismic acquisition represents more realistically the geological structure of the sub-surface seismic shots should be adjusted. This adjustment process is called seismic processing or imaging, is an alteration of seismic data to suppress noise, enhance signal and migrate seismic events to the appropriate location in space. Processing steps typically include analysis of velocities and frequencies, static corrections, deconvolution, normal moveout, dip moveout, stacking, and migration, which can be performed before or after stacking. Seismic processing facilitates better interpretation because subsurface structures and reflection geometries are more apparent, when all that is done, the interpretation can start. [Schlumberger]

Interpretation

Seismic interpretations are the analyses of processed images for explorations, characterization and monitoring of oil reservoirs.

The interpretation was done in seismic line from 2001 and 2004 in order to compare the difference in oil water contact (OWC) of both lines, the line choose was 1050 in the map, because may be represent with major detail the subsurface in E-Segment.

In the maps views can display traces (cross line) means that the acquisition was done in perpendicular direction of shoreline and lines (inline) means that acquisition was done in the same direction (parallel) of shoreline (Figure 6 and Figure 7).

The Map View serves both a data selection and data viewing function. In any of the algorithmic products where selection of a trace gate is required, the selection can be made interactively on the base map by dragging the cursor to describe a 2D arbitrary line or a 3D volume.

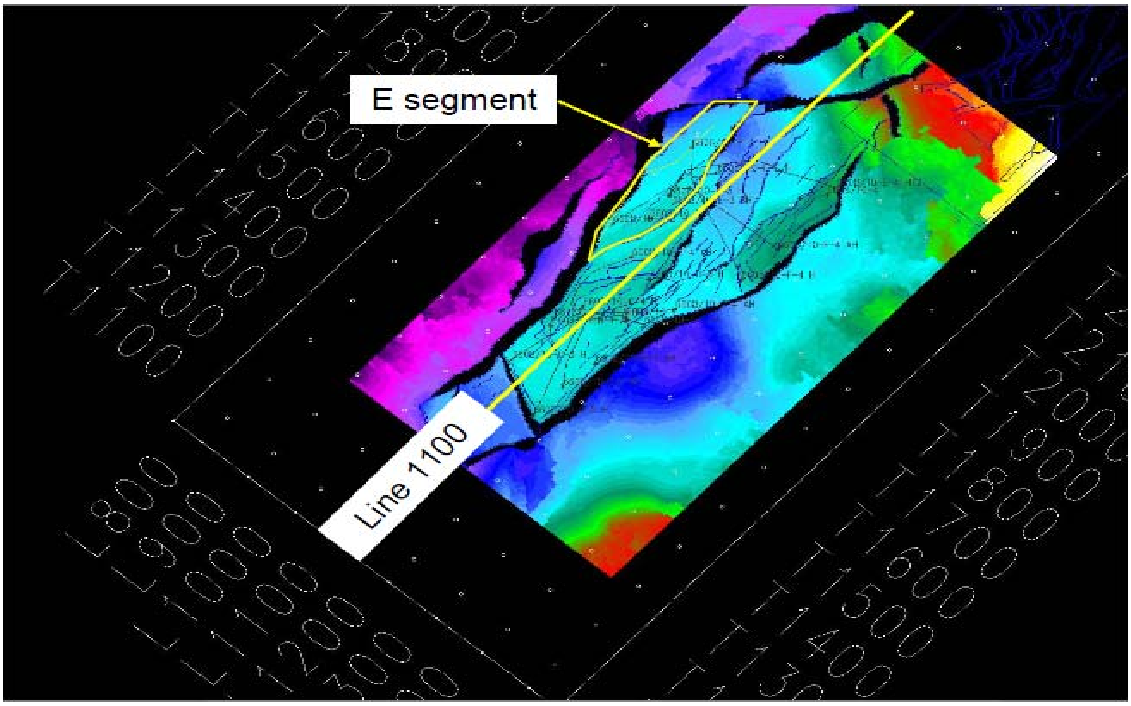

Figure 6: Map view of Norne field E-segment (provided by Tom Jelmert).

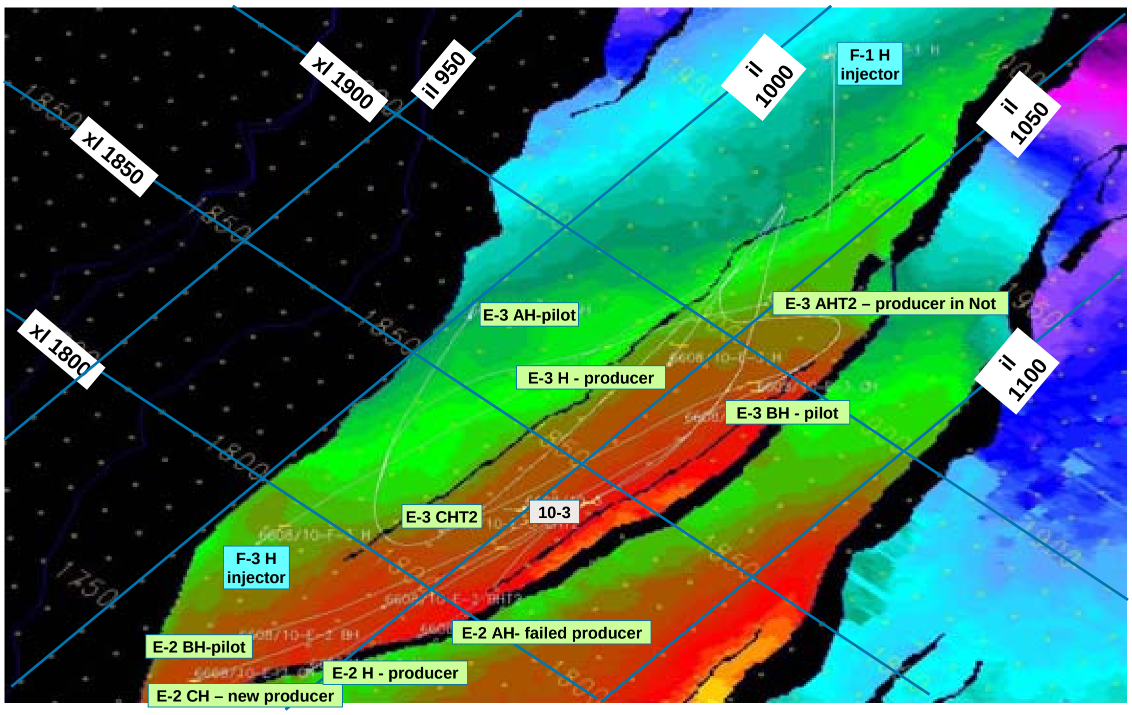

Figure 7: Study selected seismic line through the segment (provided by Tom Jelmert)

The Map View supports editing functions for horizons, including interpolation, extrapolation, and smoothing with a number of filter operators to choose from. Editing to remove unwanted points via defined polygons is supported as well.

In seismic exploration, the images are analyzed in detail by seismic interpreters seeking traces that may be indicating the presence of hydrocarbon. A flat spot is, the seismic expression of a fluid contact, and normally the fluid contact will be flat, the flat spots are wonderful indicators of hydrocarbon.

Oil water contact (OWC)

The character and colour of the reflections is also of the utmost importance and this depends on the phase and polarity of the data.

Confidence in actual seismic interpretation show improvements if it passes for several test:

- The OWC must have the correct polarity, corresponding to an increasing in impedance downwards across the interface.
- The OWC must be flat (usually, though velocity effects can cause it to be tilted in TWT and contacts are sometimes not flat in depth. Also, interference with strong bedding reflectors can cause the flat event to be broken up into a series of segments that may individually appear to be slightly tilted, although the ensemble remains flat).
- The flat event at OWC should run horizontally across inclined bedding, resulting in apparent reflector termination below it.
- Crucially, the amplitude dimming, the flat spot extent and the apparent isochore change should be consistent in map view each other and with a mapped trap. The amplitude change should follow a structural contour if it is indeed caused by a change in fluid typeat downdip edge of a trap. This is where 3-D seismic can make a big contribution. Both the amplitude map and the structural map are much more detailed than could be achieved using a grid of 2-D data, so this test is much more rigorous.

If all tests are passed, then it is possible to have a high degree of confidence in the interpretation of a fluid fill.

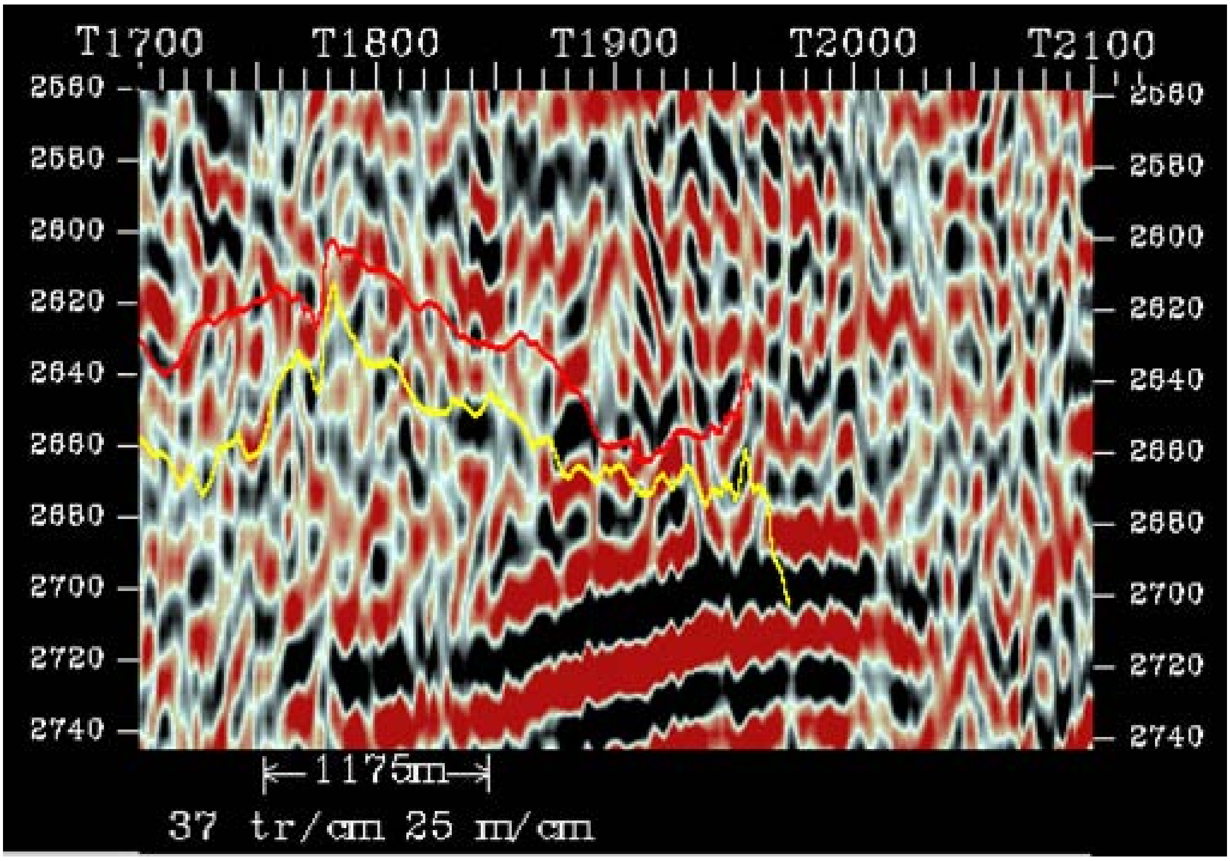

Figure 8: Interpretation of OWC at different time, line 1050 (2001-2004), Norne Field. (Provided by Tom Jelmert)

Procedure

To History Match the E-segment of Norne field model with the 4D seismic data, we were provided with seismic survey results for 2001 and 2004 as shown in Figure 8. The follows steps were taken:

- Base case simulation: We ran a simulation of the base case on both Petrel and Eclipse.
- Location of seismic line path on model: We zoomed in to E-segment of the model, calibrated it using Petrel as other applications such as GL view and Eclipse Office were not able to do this, and tried to ascertain the part of E-segment through which the seismic line crosses (at *xl 1770* to *xl 1970*) taking a cross-section of this. See below, Figure 9.

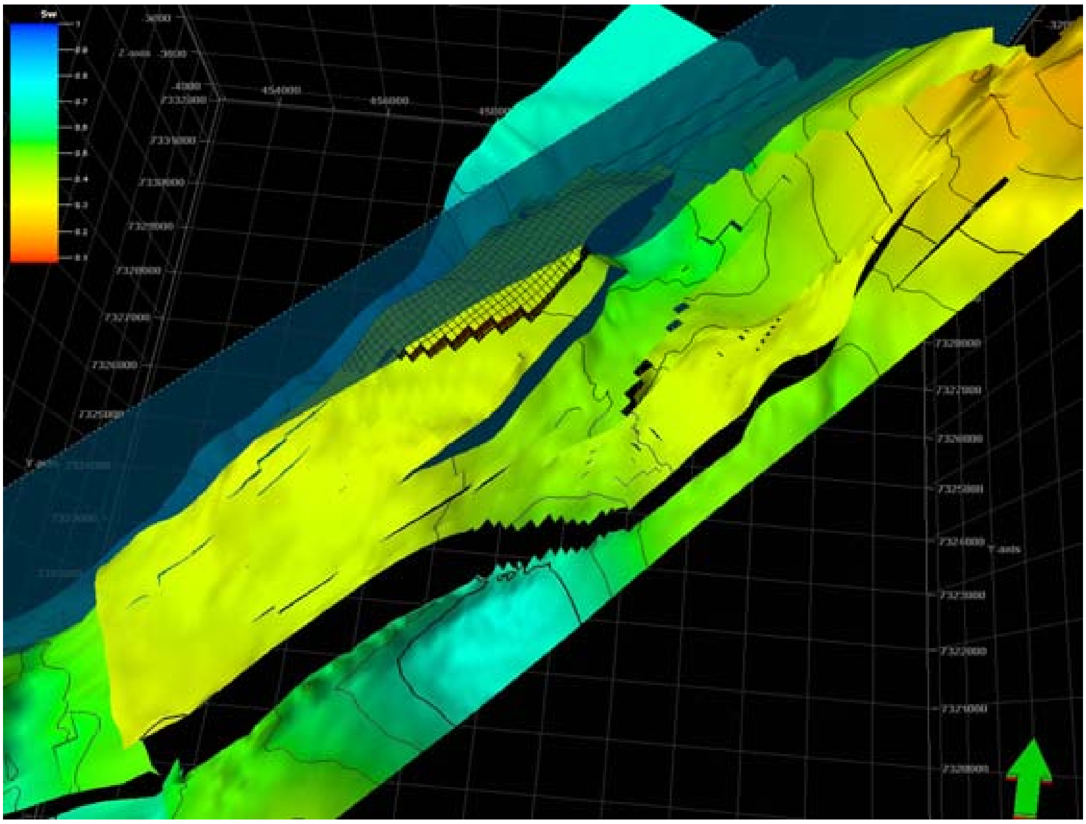

Figure 9: Relocating seismic line in Petrel

- Determination of OWC: We looked at the water saturation profiles in the months the seismic surveys were obtained in 2001 and 2004 for a balanced and validated comparison of the OWC.

- Qualitative comparison: We make a qualitative comparison of the simulation and seismic; shape, depth and how far up the water had migrated in the last 3 years.

- Understanding reservoir behaviour: We studied the locations of nearby wells to aid and validate our understanding of the reservoir; trying to know why depths water has moved up in some grid blocks relative to others.

- Finally, we try to update the model to see if we can match the simulation with the seismic.

The parameters we decided to change were two quite simple ones, because the short amount of available time. That is: Vertical permeability and vertical transmissibility.

Results and observations

In this section we look at our results and observations and explain the changes done to the model when trying to History Match it to the seismic data. The figures displayed here are obtained from our simulated models in Petrel and Eclipse office. They might be difficult to see properly because of their size, and therefore we also have them separately in "full size" in Appendix A.

Base case

The first simulation related task for our group was to do a qualitative comparison of the OWC given by seismic and the OWC obtained from the base case simulation. When running the base case in Eclipse and viewing the results in Petrel we got the following results:

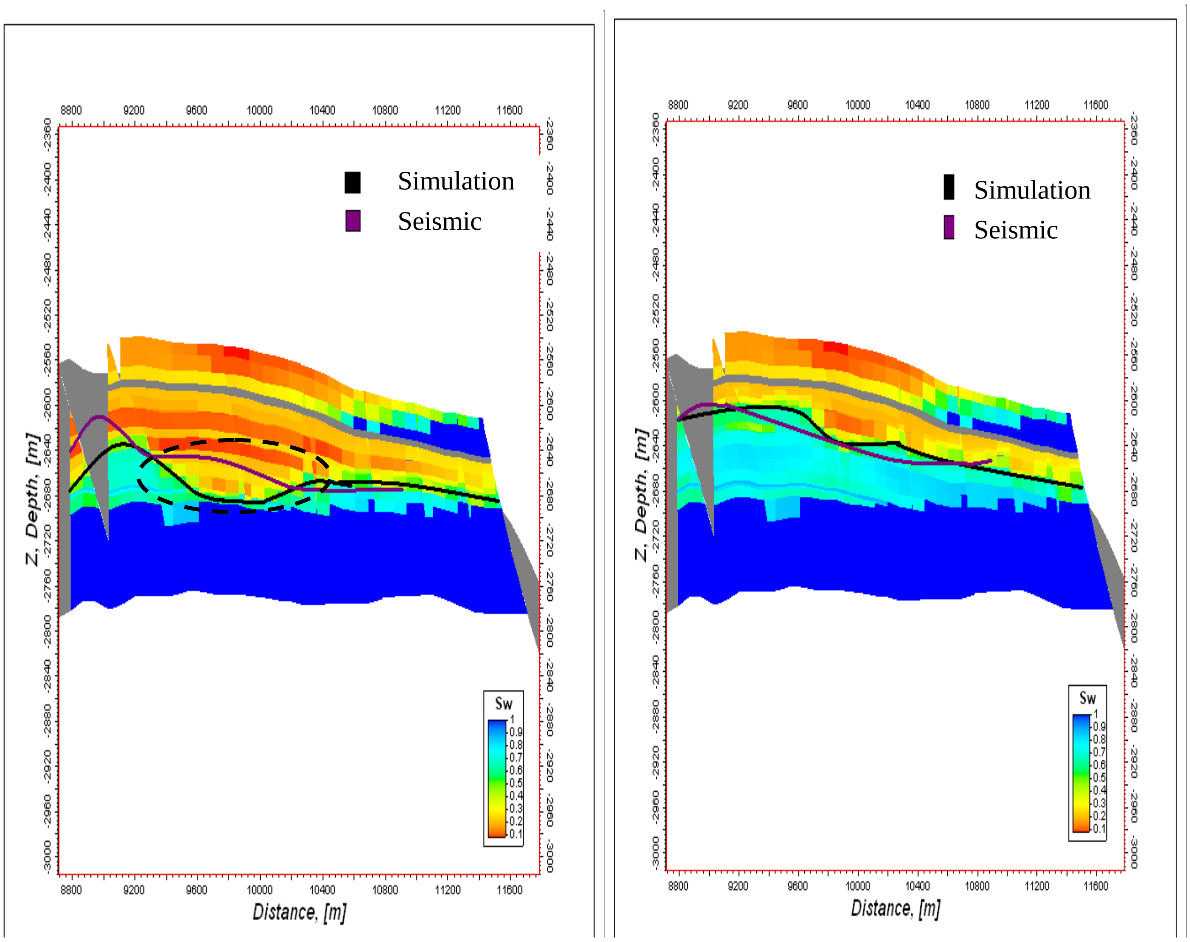

Figure 10: Comparison between obtained OWCs in 2001 (left) and 2004 (right).

The purple line represents the seismic OWC and the black one the OWC equivalent to the simulated water saturation, Sw.

To find the OWC from water saturation we have assumed the following: The dark blue colour emphasises 100% water saturated formation and the interphase between this colour and some lighter blue marks approximately the free OWC, or initial OWC before Norne started producing. For our interpretation of the new OWC developed during production we have used the green colour as boarder line, this equals a water saturation of about 40-50 %, this because of residual oil saturation. We have tried to draw a best possible line from this.

When compared to seismic, we can see several apparent discrepancies between these two, especially in 2001. On the most it is a depth difference in OWC of 30 meters. The dotted circled area to the left in Figure 10 is the area we have decided to focus on, because of the large discrepancy, but also because of well E-2H being in that area, see Figure 11. The well drainage areas are the most important once to consider because the OWC will have great impact on production, water-cut, etc. In other words, this affects economy, which is the most important parameter for further decision making and plans for field development, such as well placement, plugging, sidetracks and more.

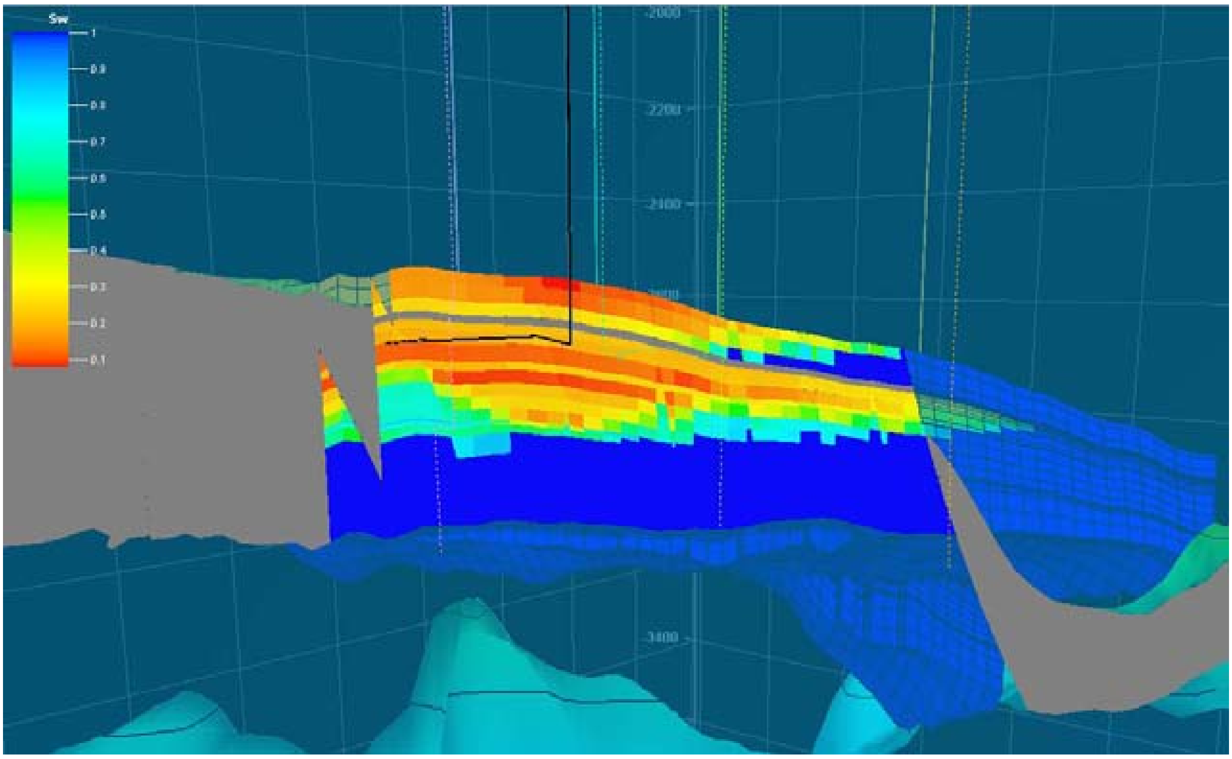

Figure 11: Intersection with well placement. E-2H is for the occasion emphasised in black.

Another observation we made from these figures was that the difference in OWC seemed to be local, that is; we could not spot a specific trend in the discrepancies between seismic and simulations, neither in the 2001, 2004 or in the difference between the 2001 and 2004.
In 2001 the simulation causes the OWC in some to be below the seismic one, while in 2004 it is the opposite. It is also just in some regions it differs, the difference is not overall. This caused us to have to do local changes when trying to update the model, and not changing whole layers or rows.

Updating the model

When comparing the seismic of 2001 with the simulation of the same period, we decided to alter some input data in order to match this year better as a first step. To raise the OWC in the simulation we have several choices as mentioned previously, but one of the easiest in this case is vertical permeability (PERMZ) and transmissibility (by MULTZ). In the cases where transmissibility already had a value of 1 the flow could not be increased further, since 1 implies full flow. When changing vertical permeability, we quickly saw that the 3 low permeability layers 18, 19 and 20 shown in pink/purple colour in , would have a great influence on saturation, and a large local increase in these layers would cause the OWC to rise in the circled area of Figure 10. From Petrel we read the grid block numbers to the blocks we wanted to change, and implemented a new section for the permeability of these in the input file. The alteration could be as simple as shown below:

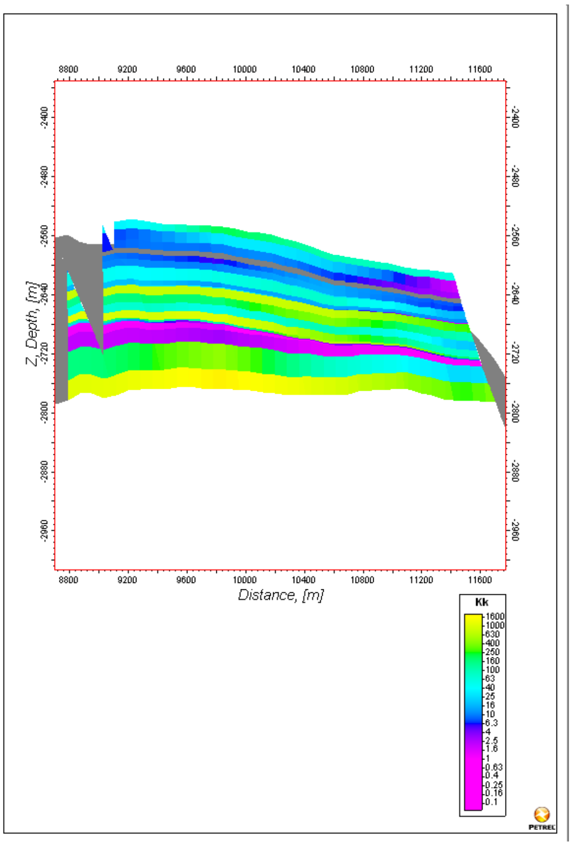

Figure 12: Vertical permeability in cross section, base case

```
EQUALS
 PERMZ  500  11  12  58  68   18   18 /
 PERMZ  500  11  12  58  68   19   19 /
 PERMZ  500  11  12  58  68   20   20 /
/
```

Figure 13: Replica of the first simple change done to simulations.

The first couple of runs we simulated when trying to update the model, did not differ at all from the base case, the values was exactly the same – and this caused us to draw the incorrect assumption that our alteration of the input file had been incorrectly done, and we spent several hour and days trying different ways of making the changes and repeating simulations hoping to see that the changes were considered by eclipse, but with no use. It was only by chance we figured out what the problem was, when Kathrine by impulse expanded the area of change to involve more grid blocks. Then the discovery was made that eclipse in fact did take the alterations into consideration, the problem had actually been that the grid blocks we told the program to change had been outside E-segment, outside the grid, and therefore the same results had appeared time after time within the segment. When the area was expanded it extended into the E-segment and changes became apparent in grid blocks on the edge of the border inside the segment.

The conclusion we drew from this was that somehow the grid in eclipse and petrel differed, causing a shift in position of the grid blocks. With this discovery and with the help from Jan Ivar Jensen and others the problem with the model was revealed, and only when you know the problem you can start figuring out solutions to fix it. So this was quite a breakthrough in the problem solving. We have not get to this day figured out a reasonable explanation of how this discrepancy on grid can occur, since both programs import the same input and grid files. It is simply beyond our understanding. However, by figuring out how much the grid had shifted in a certain direction from eclipse to petrel, we could input the new and correct numbers for the grid blocks to change in eclipse. Unfortunately it seemed that the degree of grid shift changed from time to time, as do the direction, so it proved very cumbersome to change the correct blocks.

In total we ran over 20 different simulation runs, however, because of the problem with the grids only a few of them turned out as intended. Here we will go more in depth on to of these, named first and second change (in reality probably more like 13^{th} and 22^{nd}).

First change to model

The first successful run we managed to make represent the changes apparent in Figure 13. We raised the low permeability in layers 18, 19 and 20 from values of 1-2 mD to a value of 500 mD. The below figures shows the results: Figure 14 shows the relevant layers and the rectangle of altered vertical permeability, and Figure 15 the resulting water saturations in 2001 and 2004.

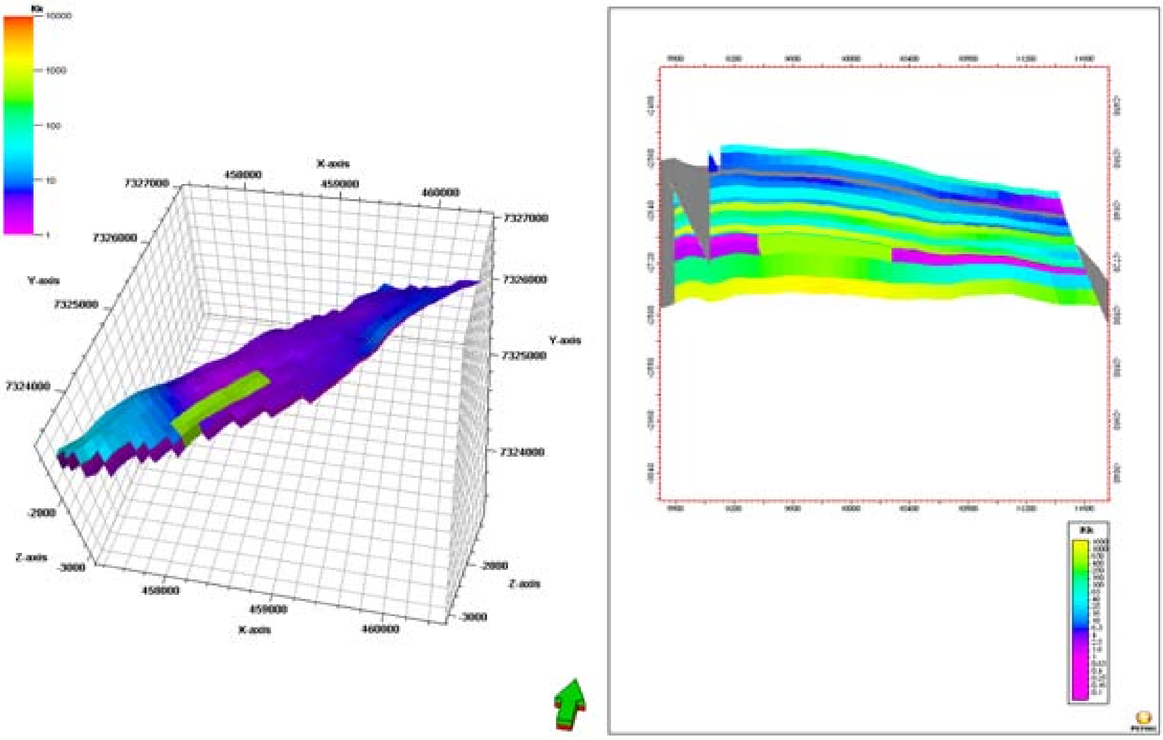

Figure 14: Vertical permeability in layer 18, 19 and 20, seen from above (left) and in the cross section (right).

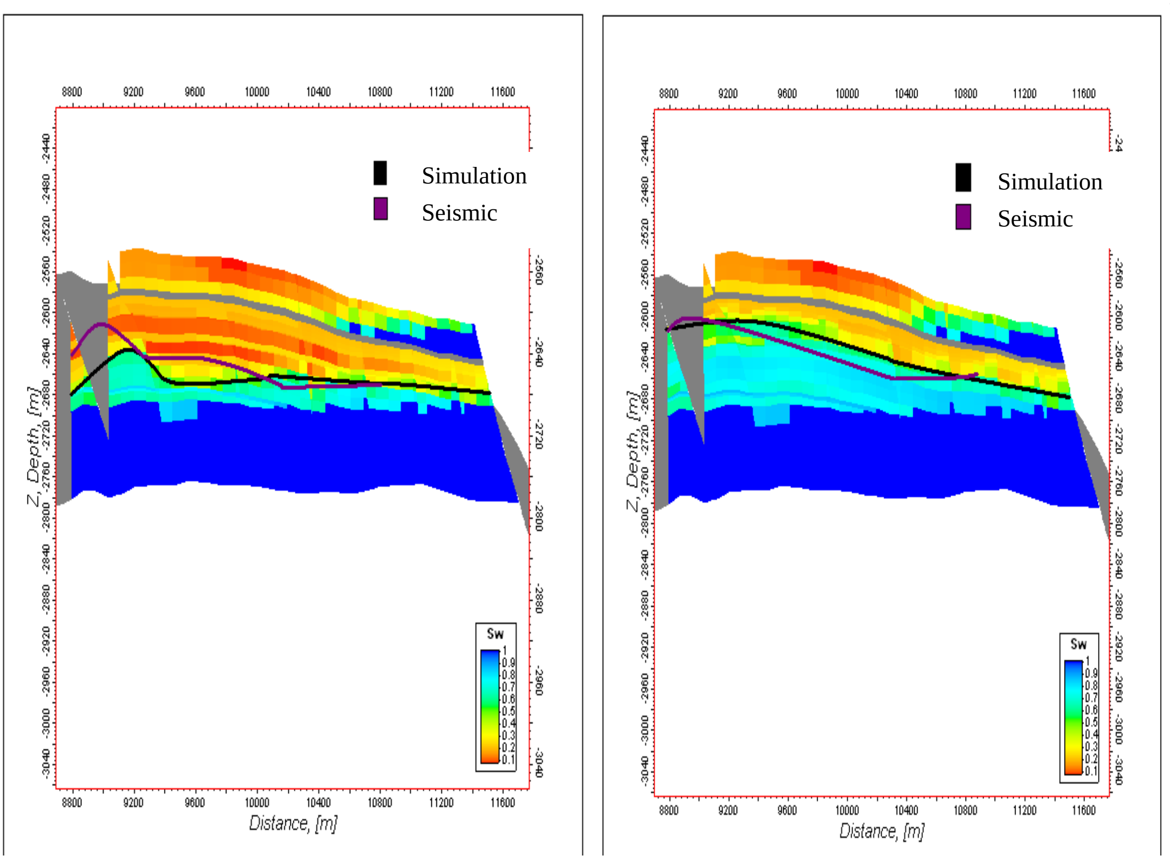

Figure 15: Water saturation profile from the first improved model. OWCs from seismic and simulation drawn in purple and black for 2001 (left) and 2004 (right).

Here we have reduced the gap in OWC in 2001 from 30 meters to 20 meters, roughly. This is a huge improvement for the 2001 case. Since any alterations done to the model will have an effect on all results, we also had to see if the changes had done the 2004 figure worse. For 2004 the trend of higher OWC in simulation becomes more general and goes over a larger area than before because we increased the vertical permeability in lower layers. In the region with most change, the OWC has raised almost 20 meters.

Second change to model

To prevent the 2004 figure to have an increased difference in seismic and simulated OWC, we decided to decrease transmissibility in layers above the problem part seen in 2001, but below the layers that differentiate in 2004. We also wanted to try to improve 2001 even more by altering the permeability and transmissibility further in the same layers as before, to raise OWC even more. The specific changes made to the input file can be seen in the textbox named Figure 16.

```
EQUALS
  PERMZ  500  11  12  57  68   18   18 /
  PERMZ  500  11  12  57  68   19   19 /
  PERMZ  500  11  12  57  68   20   20 /
/

EQUALS
  'MULTZ'  1.0  11  12  57  68   18   18 /
  'MULTZ'  1.0  11  12  57  68   20   20 /
/

EQUALS
  'MULTZ'  0.3  11  12  57  64  10  10 /
  'MULTZ'  0.3  11  12  57  64  11  11 /
  'MULTZ'  0.3  11  12  57  64  12  12 /
  'MULTZ'  0.3  11  12  57  64  13  13 /
  'MULTZ'  0.3  11  12  57  64  14  14 /
/
```

Figure 16: Excerpt of the changes to data file.

As one can see there are three main changes done in this run, the vertical permeability in low permeability layers 18, 19 and 20 has been increased locally, as before, to 500 mD, just see the previous Figure 14. The vertical transmissibility multiplier has also increased from 0 to 1 in layers 18 and 20. And to try to prevent the 2004 image to be a worse match because of these changes, the vertical transmissibility in layers 10-14 has been decreased to 0,3. All these changes in transmissibility are emphasised with the figures below:

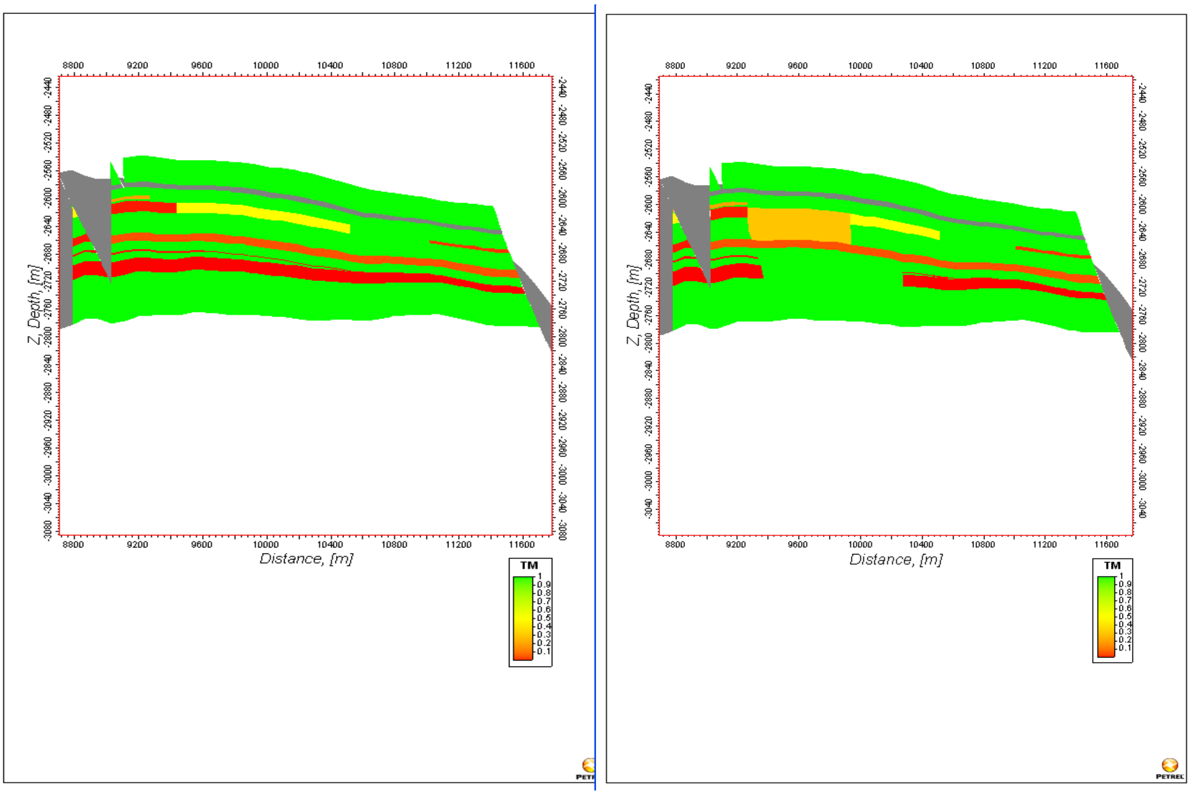

Figure 17: Changes in vertical transmissibility from base case (left) to second updated model (right). Stoplight principle: Red equals full stop, value 0. Green full flow, value 1.

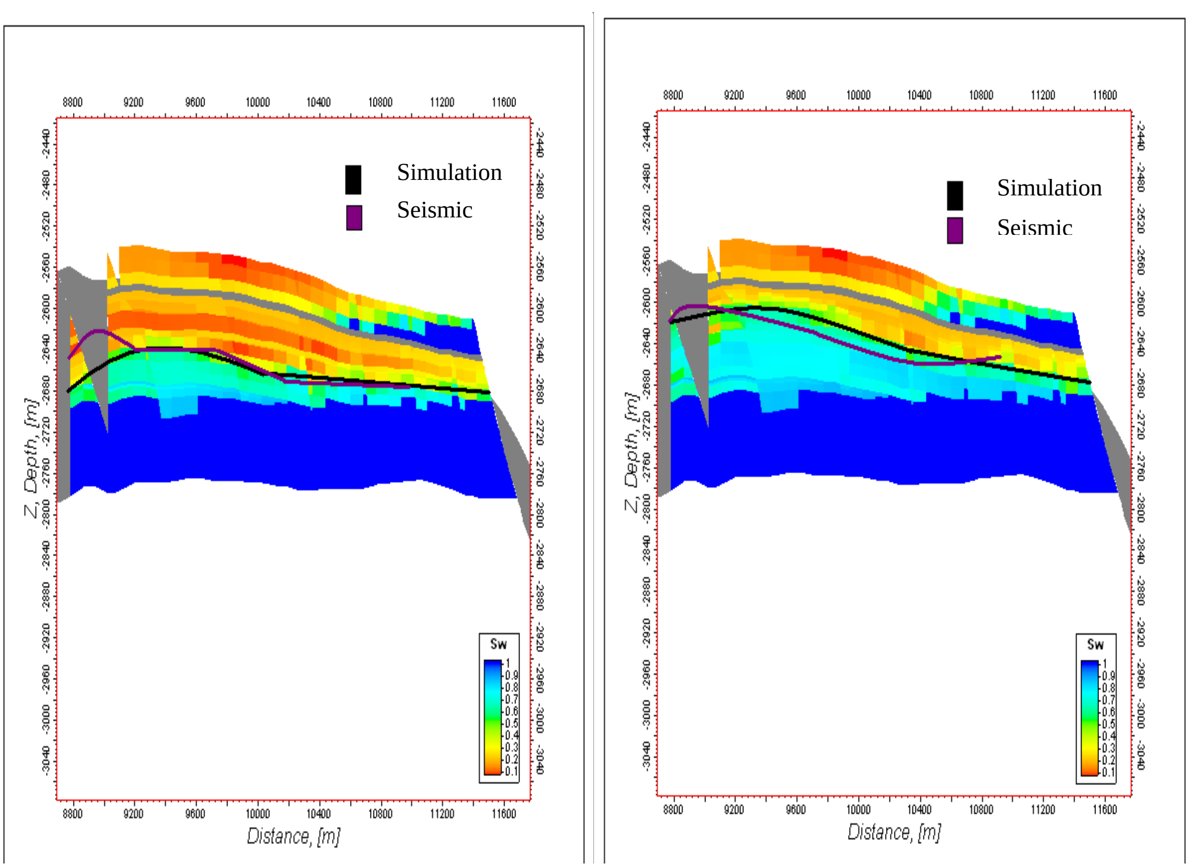

Figure 18: Water saturation profile from the second try to updated model. OWCs from seismic and simulation drawn in purple and black, respectively. The 2001 case (left) and the 2004 (right).

Again the gap seen between seismic and simulation in 2001 has shrieked, and now there is quite a good match, as little as +/- 5 meters in the focused area. The 2004 case has not differed that much from the first try on updating the model, it has certainly not become any worse – even though there were taken more serious measures to increase the 2001 OWC with great success. This is probably because of the attempt to create somewhat of boundary layers further up in the segment.

Resulting changes in other properties

It also would be interesting to see whether the other relevant and important properties such as production volume, water-cut and pressure have gone through larger changes due to the different attempts of updating the model. Perhaps the small changes that were made to improve a better OWC match with seismic has interrupted other parameters causing a mismatch somewhere else? Below we have compared base case with both the first and second case, and we have also added the history graph to see if we have improved the simulation or worsened it. The colour of graphs of all the specific cases is consistent through out; green being base case, blue implying the history, the dotted purple being our first case scenario, and finally red being the second case scenario.

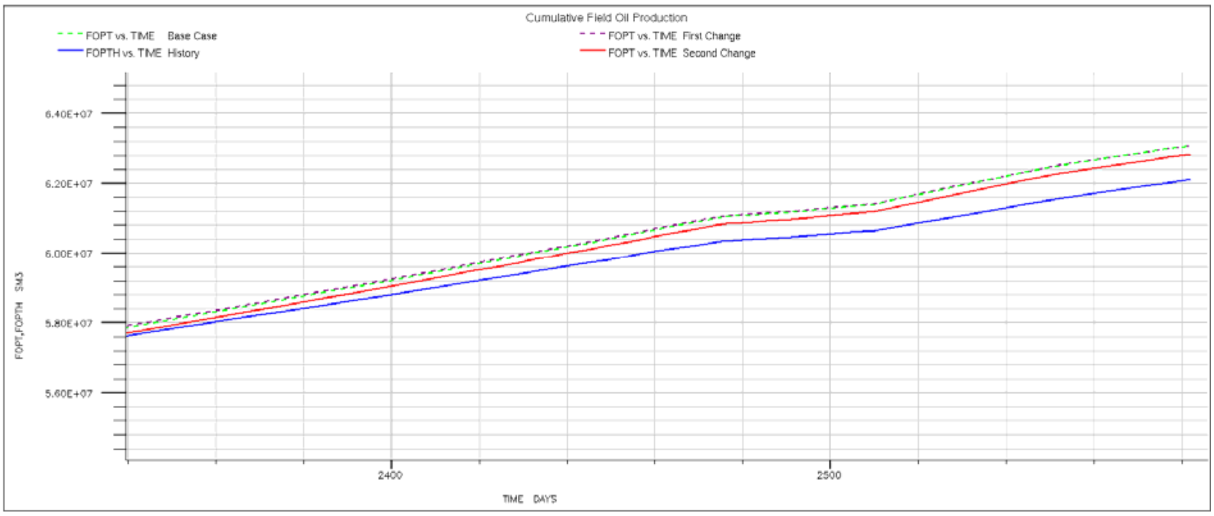

Figure 19: Cumulative Field Oil Production. Look in Appendix A.

If one look at the original graph over cumulative field oil production, the changed cases behave quite similar to the base case, and all the cases are deviating some from the production observed historically. When zooming in at the end of the graph, as shown in Figure 19, there is evident that the base case and our first changed case have as good as identical behaviour. The reason is perhaps because the very local change in permeability is not that visible looking at the whole E-segment. The changes in our second case however, have had a greater impact, and cause a decrease in production from base case of about 300 thousand Sm^3 in total until 2004. By that, our second case actually becomes a better match with the actual history than base case.

It might not seem logical that the production decreases as we improve permeability and transmissibility in the lower layers causing OWC to rise. However, at the same time we have decreases transmissibility in above layers, and that may be one of the reasons why we see a decrease. Another reason can be that some of the oil, when moving faster through the lower layers, at the same time merges to other more remote areas, where the drainage efficiency is less. We actually believe we can see such an effect, when compiling the saturation profiles in the cross section to our knowledge of where the main well in this area, E-2H is situated, see Figure 11. We observe a detectable decrease in water saturation, which implies an increase in oil saturation, in some areas a longer way from E-2H.

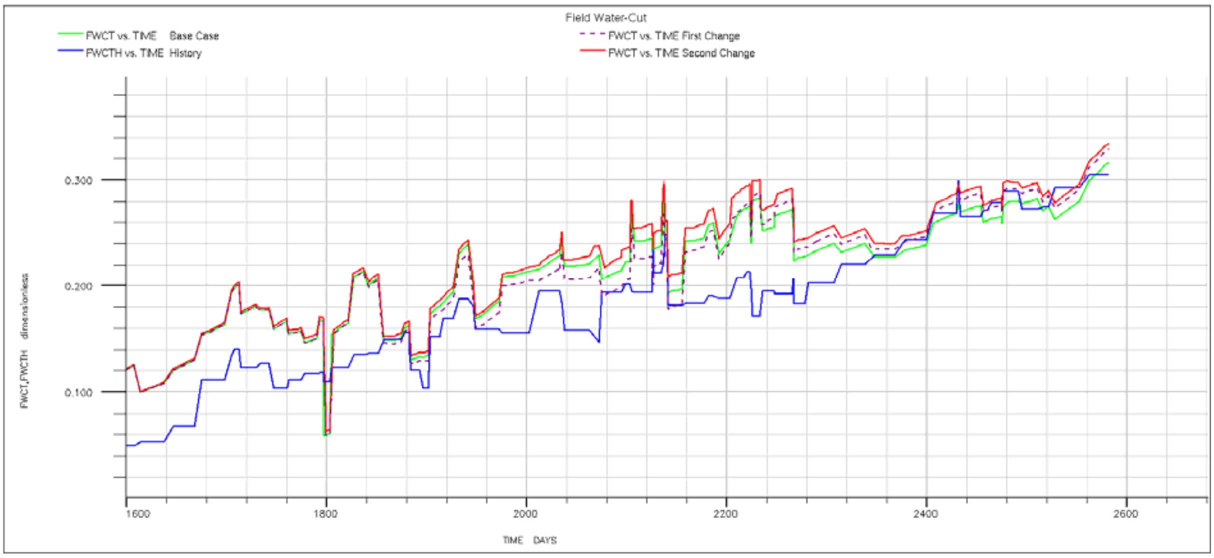

Figure 20: Field water-cut, excerption from main graph. Look in Appendix A.

The field water cut also starts out quite similar in all the cases, but as shown on the excerpt of field water-cut graph, Figure 20, they start to differ as well E-2H starts to produce a larger quantity of water. Which is no surprise since this is the only well close by to our local made changes. None of the cases manages to match the historical data in a very good way, with all having a higher water-cut than reality. Compared to the base case our first case starts off with a decrease in water-cut before the situation completely turns around in the end of 2003 and we start to have a higher water-cut than the base case. This can be explained by the increase in vertical permeability causing the OWC to rise faster while at the same time pushing the above oil in front of it. It happens to a larger extent than in the base case due to increased speed of the raising water. This makes us produce more oil at first, before this effect is reversed when the waterfront itself approaches. This can also be seen more clearly in the significant delay of water breakthrough in well E-2H, Figure 21.

The water-cut in the second case is kept at a higher, almost constant difference compared to the base case. As mentioned earlier the raise in transmissibility from 0 to 1 in the lower layers might have caused the oil to migrate to other locations. This again will cause the OWC and water front to advance even more rapidly and with grater volumes. The early breakthrough of water is seen in Figure 21.

We can also derive from these figures that the changes made to the local area has very little effect on other wells than E-2H since the differences in the field water-cut graph is consistent with the changes in the water-cut graph of this nearby well.

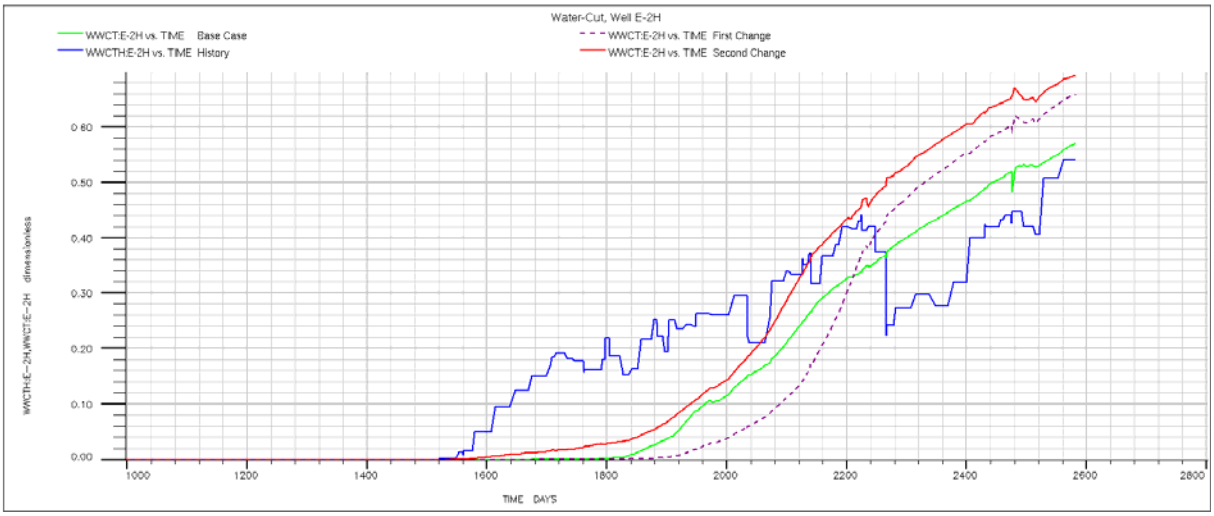

Figure 21: Water-cut, well E-2H

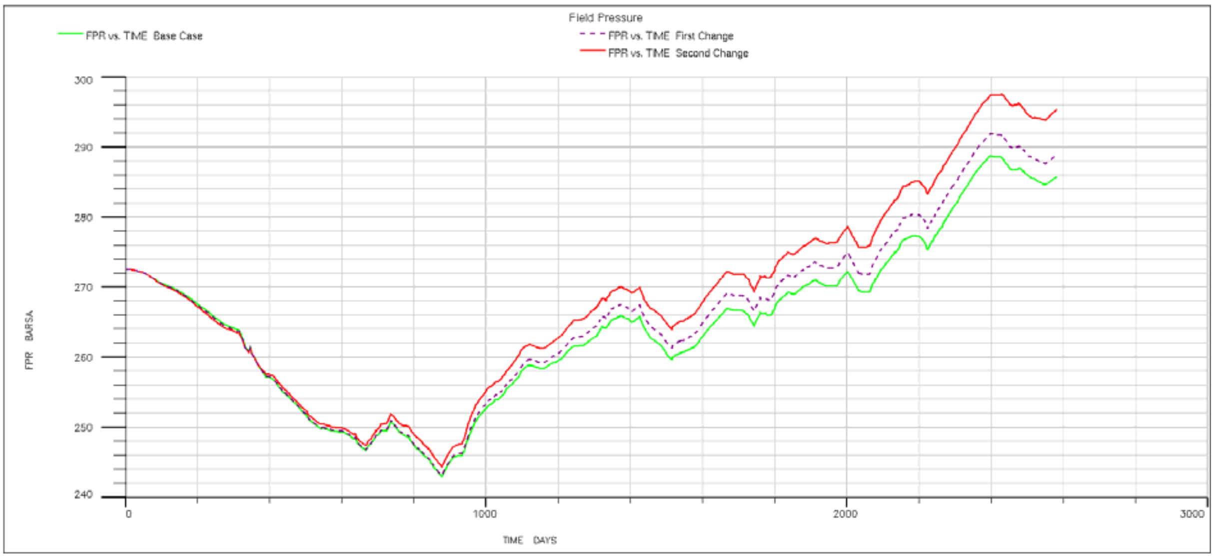

Figure 22: Field Pressure

The field pressure in Figure 22 increases in the two altered cases due to the larger and more rapid movement of water due to increased permeability and transmissibility. Not surprisingly the second case with the most rapid OWC has the highest field pressure of them all.

Discussion

The results themselves are discussed in the previous chapter. In this chapter we discuss more if our model and results are valid. We have chosen to focus on the importance of uncertainties and the critical choice in changing parameters.

Accuracy

There are lots of inaccuracies and uncertainties in our results. First off there is a great deal of inaccuracy to the model itself, even before we started to change parameters to the base case. The word "model" itself implies uncertainties: It is not the reality but merely an attempt to reproduce a coarse version of it, and that is as good as it ever going to get. Nature can not be reproduced on a computer, especially in the case of reservoir modelling when you do not really know nature behaves since whatever happens takes place several kilometres under ground. The fact that reservoirs are something that can not be directly observed and looked at, is also a reason *why* modelling is so important.

Another uncertainty with the model is that it is divided into fairly large homogenous grid blocks that are representing heterogeneous areas. In spite of the large uncertainties to reservoir models in general, the uncertainty can be reduced by constantly implementing new and better input data to match the previous history. The more data you know the better you can make the model, and the better predictions you can make. This is History Matching.

In the process with relocate the seismic line on the model, there might be hidden a mayor potential error. If our attempt of relocating has been only a little inaccurate, this can cause a shift in x-y plane between seismic and simulation that again can make spotting trends very difficult. As mentioned above, that if there had been an overall trend in how the OWC interacted between 2001 and 2004, it could have been assumed that the issue was not only local and parameters in whole layers could have been changed. For instance, if we look at the base case in Figure 10 there could have been a better match with more overall tendencies, if the seismic line had been shifted a bit to the right, causing the first "top" on the seismic OWC to be localized right above the same shaped top from simulations. There are actually not unlikely that this should have been the case, since the seismic line crosses a "smooth" and continuous border of E-segment, while the coarse grid blocks in the simulation model causes the intersection to cross over several blocks in different j-columns at the border, as seen in the figure below. This is also the reason why we get a grey area to the left in all water saturation profiles.

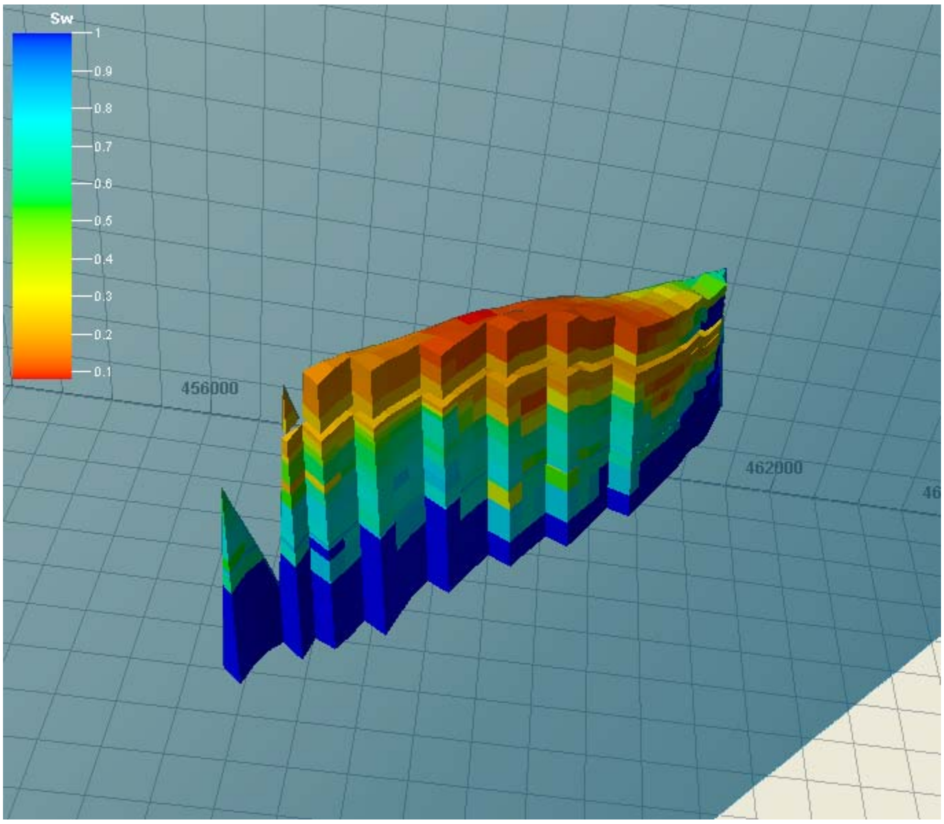

Figure 23: Cut cross section seen from the side with the inner part removed. See here uncertainties due to coarse edge.

On all the figures of OWC the OWC it self is drawn on the water saturation profile using the very simple program Paint. However, even though this might seem to have been done with not that much care and accuracy, the original drawings actually were done by hand, and with use of rollers to a large extent. So the facts that we have presented in the result and observations chapter on the OWC are not at all that incorrect as might seem on drawings. It proved quite difficult to draw smooth and spot on correct graphs by eyesight in Paint, but with trial and error and several do-overs we have managed to be as precise as can be with such a tool.

Parameters

The way we decided to make it, with making a rectangular shape area with locally changed parameters was because the intersection cuts through the x and y axis with an angle of almost

45 degree. This makes the intersection approximately where the diagonal is in this rectangle. We were very unsure if this small rectangle would be enough to see the large differences in water saturation in that area that we needed, but the changes were as the results show; quite large.

We changed the permeability from low values ranging from 2-7 mD to an even value of 500 mD. Is this reasonable in reality? A value of 500 mD is in itself not at all out of the ordinary. Having such a high permeability area locally inside low permeability layers however, is not that realistic. The low permeability layers can represent formations such as shale, and shale though it often has high porosity does not have high permeability, thus making it a bad reservoir rock. High overall or total vertical permeability for an area can be seen where you have cracks and non-sealing faults etc, but that this should happen in the quite small rectangle like we simulated is not likely. That transmissibility suddenly changes in that same rectangle, from 0 to 1, is also not that likely in reality. So, our simulations are not that good if we look at the geology and flow patterns behind the parameters them selves. This shows how important it is to have the right geological understanding of what is actually happening during modelling and simulation.

Even though our models and the changes we applied by trial and error is maybe not that realistic, the model is just a model, and to simulate what is really happening there might be a need to do something a bit unrealistic to make it fit better. These unrealistic changes can in some cases work as a substitute for other changes in other parameters that is not carried out for some reason. As long as the resulting behaviour is quite similar, there is the possibility of still getting some useful results out of the modelling.

The fact is that there is no way of knowing which model is the most correct one – as stated in the History Matching chapter. There is not one unique solution, and if a prediction is given on basis of simulations, there would be much better to give a range than a single value – that single value is going to be wrong.

When comparing behaviour we have in most cases compared our updated models to the base case by Statoil. This is a good indication of whether we have a change or not, but not necessarily the best indication whether our model is a good one. The base case Statoil model is not a standard one should try to obtain – history is. On the graphs on production volume, water-cut etc, we have also added the curve of the historic data. This is the real measure of whether the model has the potential to be good or not.

When altering a model, the mayor changes in overall field properties and field behaviour when suddenly increasing a value in an area can be greatly reduced by decreasing that same parameter in another area. This we have not worked with that much in our simulation model, but to try to keep the overall properties constant, and not getting very deviating oil production graphs for instance, are important for the History Matching. Even though the goal is to match OWC, other aspects of the model should also be taken into consideration to get the best model possible, but sometimes trying to match everything is simply not possible.

For further study

If we had more time, there are many subjects we would enjoy to dig deeper into, and thought our project is done and delivered, there are probably new village attendees next year. One is the seismic it self, to try and understand the interpretation of the seismic line. That would have been very interesting, but would also required an own group consultant since this is a whole field of study for it self. Also we would have liked to continue the simulations, and maybe simulating more advanced cases, and more realistic cases. This would cause us to dig maybe too deep, because this would really not be easy with no experience beforehand.

During the work on the model we have discovered how great a tool Petrel is. Even though we have not got the time to discover and seizing *all* the opportunities this program has to offer, it has proved very helpful, and to further explore the options would surely be a case of further study.

Conclusion

As a conclusion we can firstly state that we managed to get some results. This was not so certain just a few weeks ago due to a severe time issue. We have been able to better match the model to the seismic line we were provided with, all though the changes we made may not be the most realistic once – as discussed above. When that is said, the models are not the most *un*realistic once either. There are a lot of uncertainties in modelling, and our try to relocate our seismic line in the model caused us to have to introduce even more.

We are quite satisfied with our results; we have put so much work into the updating part of our task due to the previously explained problems with the programs, causing it to be almost obligatory. We have been working very well together as a group, and we believe that reflect upon our results.

This task we got was very interesting, but quite intimidating for us at first since none of us had any real experience with simulations and such beforehand. We have been able to learn a lot about Norne, 4-D seismic and History Matching. There has been a very steep learning curve, and lots of challenges. However, we have handled it well, and now some of the group members can rightfully brag about being able to use to some degree both the remote server, eclipse, eclipse office, GL view and Petrel. It is actually so that Kathrine is now one of the few, of both students and teachers, at this institute that knows something about how to use Petrel. When we realised that we needed to use Petrel, we had to use out own resources, friends and fellow students to figure out how the program worked and how to get started. After this course we have gotten a feel for simulations, and this knowledge we have gathered during these weeks being in Norne Village well surly be an advantage for the group members who will get a job in the oil and gas industry in the future.

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Introduction

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Figures

Appendix A: Relevant figures and graphs

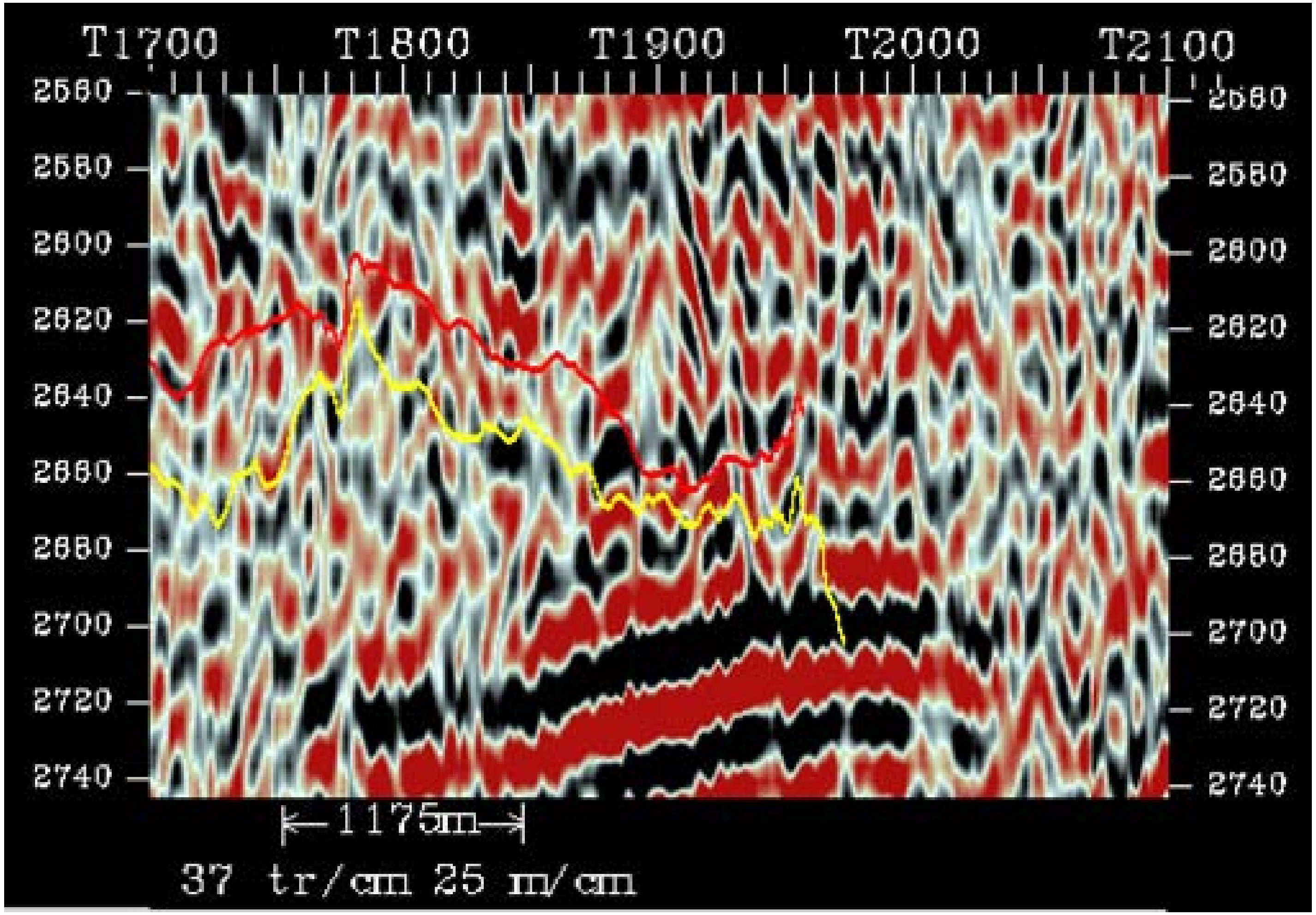


Figure 8: Interpretation of OWC at different time, line 1050 (2001-2004), Norne Field. (Provided by Tom Jelmert)

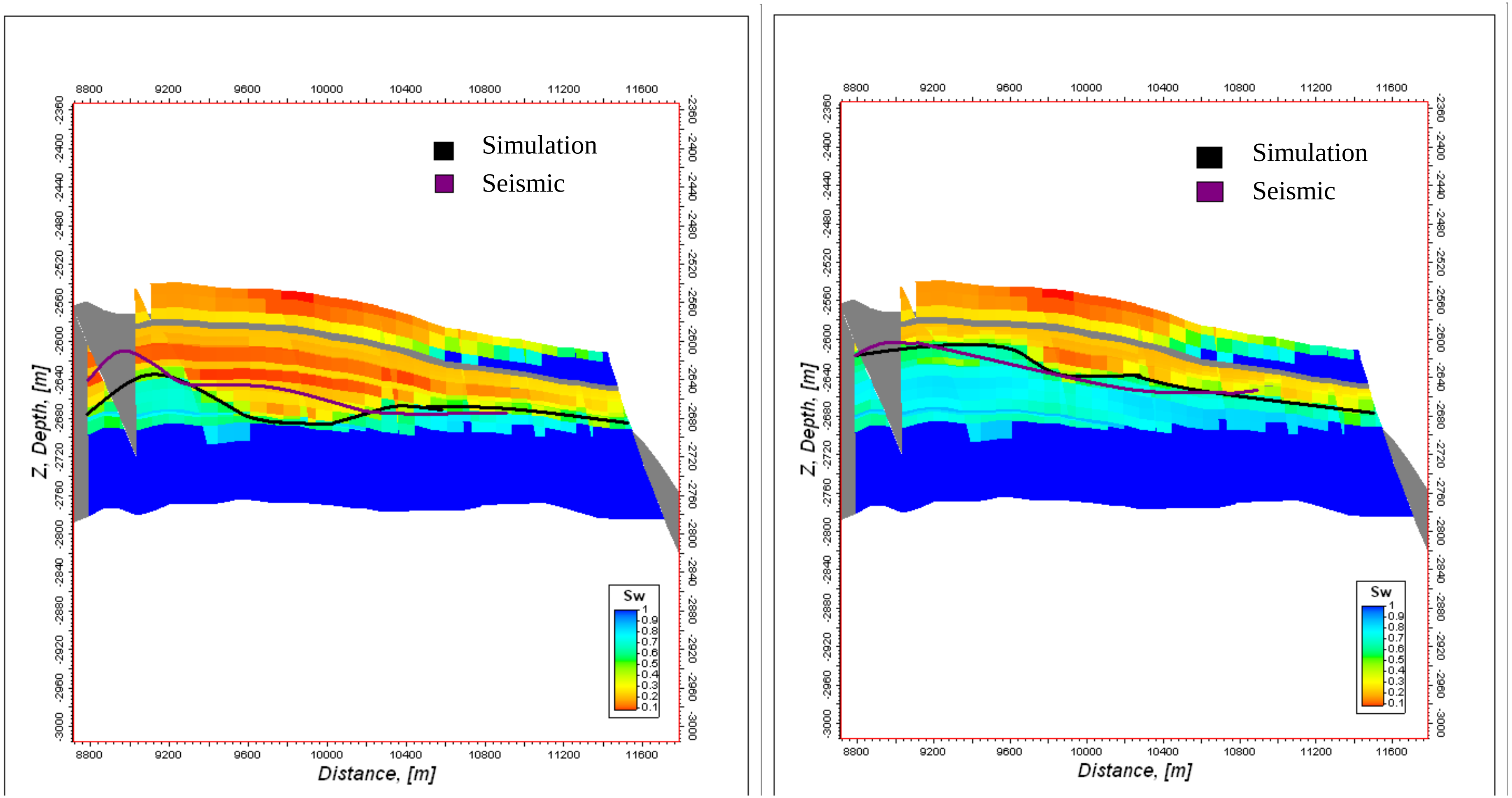


Figure 10: Comparison between obtained OWCs in 2001 (left) and 2004 (right).

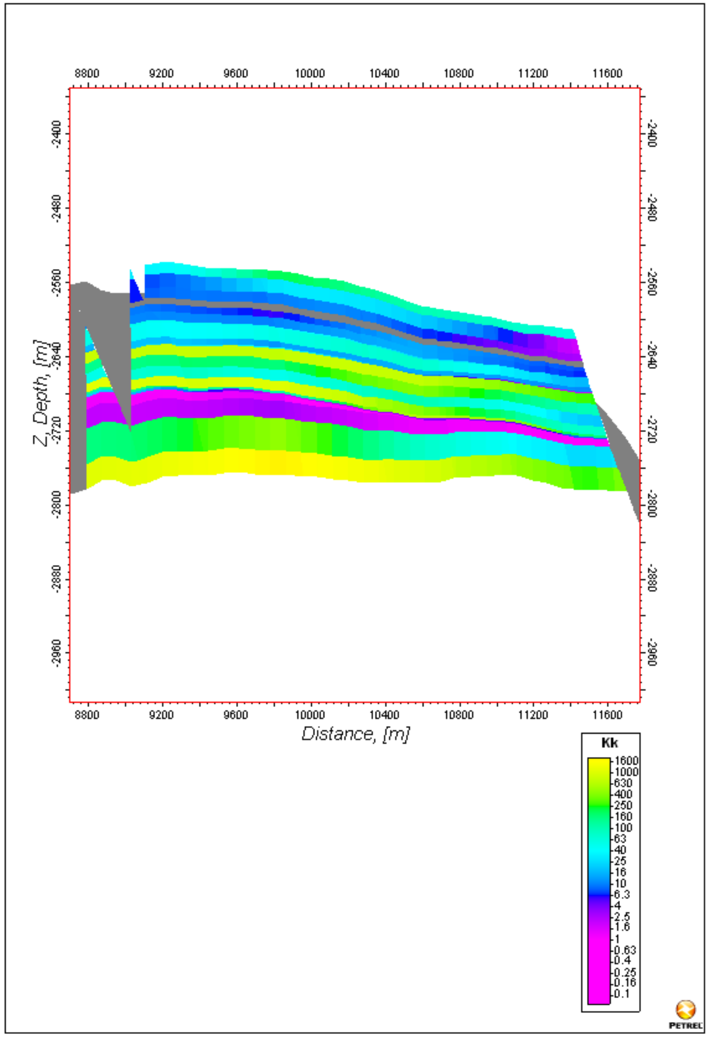


Figure 12: Vertical permeability in cross section, base case

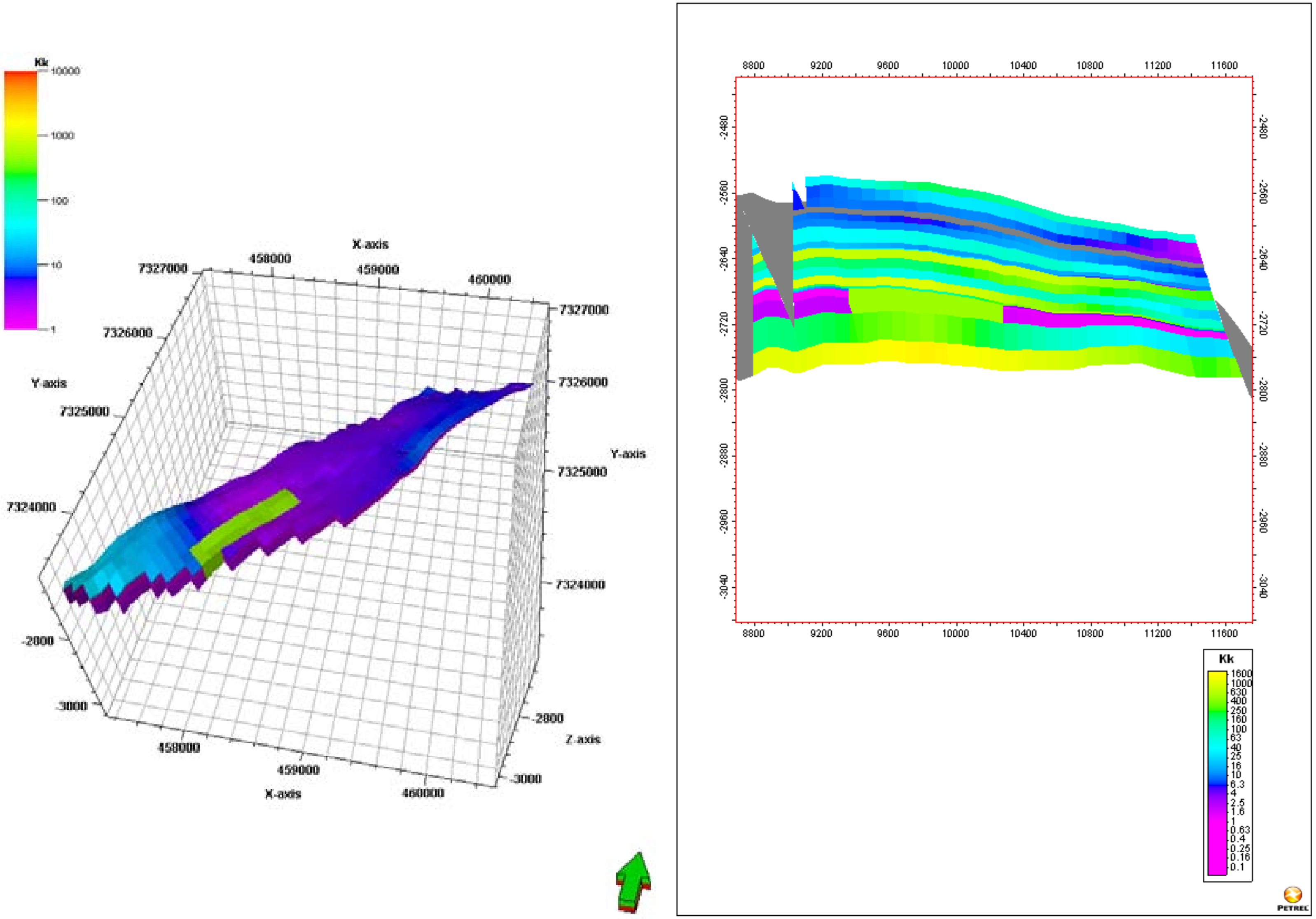
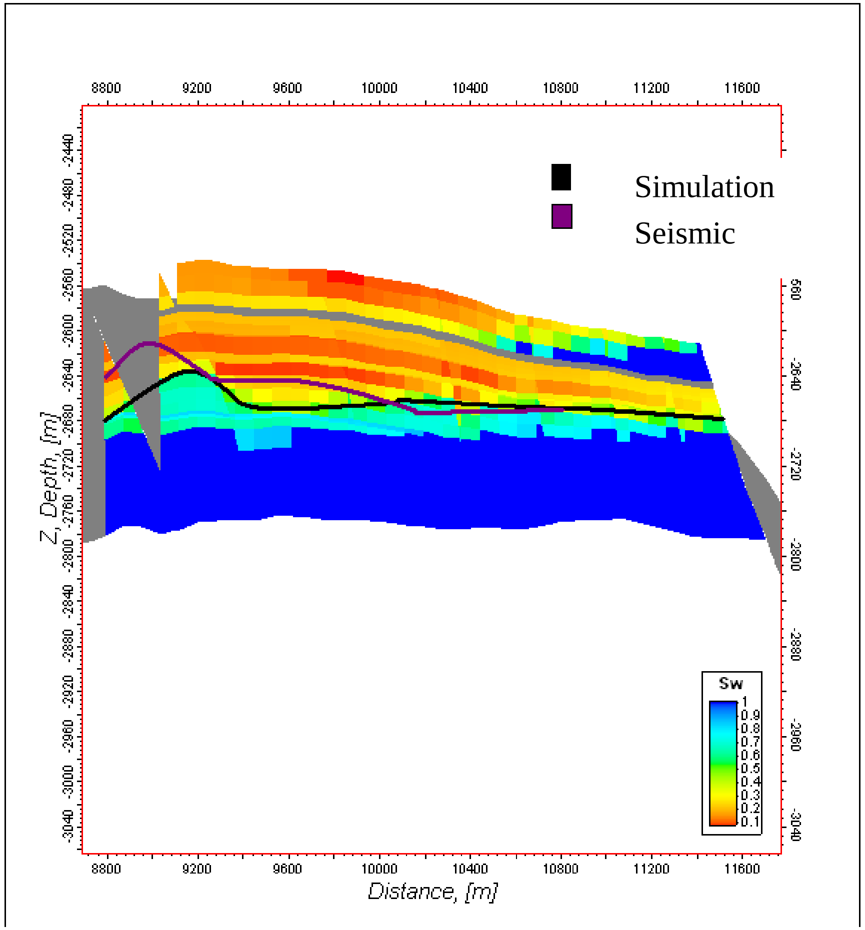


Figure 14: Vertical permeability in layer 18, 19 and 20, seen from above (left) and in the cross section (right).



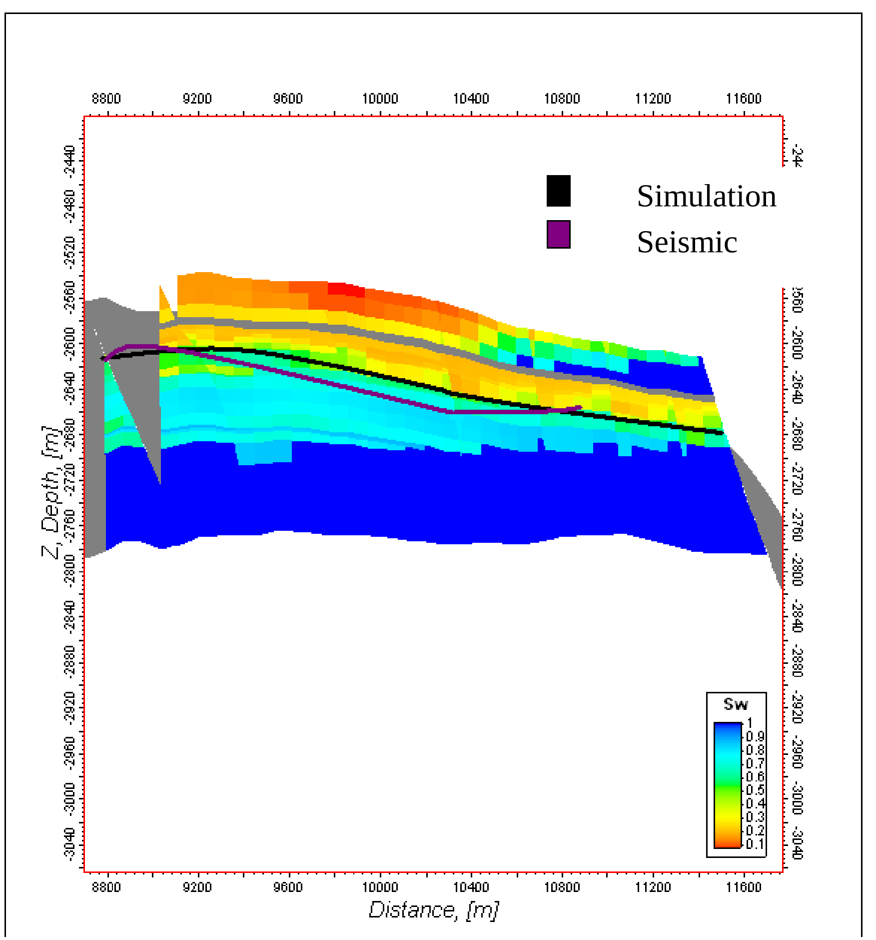


Figure 15: Water saturation profile from the first improved model. OWCs from seismic and simulation drawn in purple and black for 2001 (left) and 2004 (right).

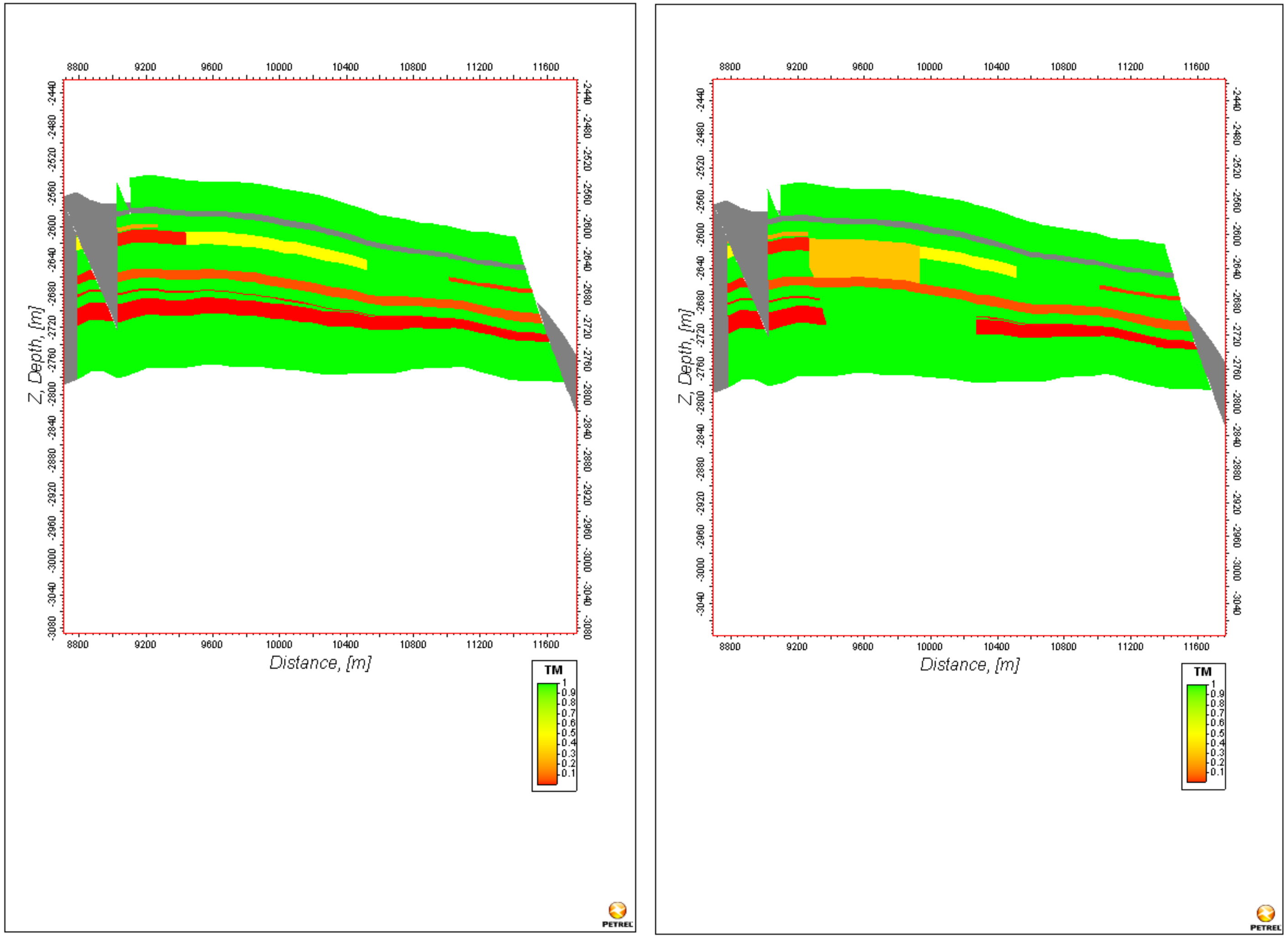


Figure 17: Changes in vertical transmissibility from base case (left) to second updated model (right). Stoplight principle: Red equals full stop, value 0. Green full flow, value 1.

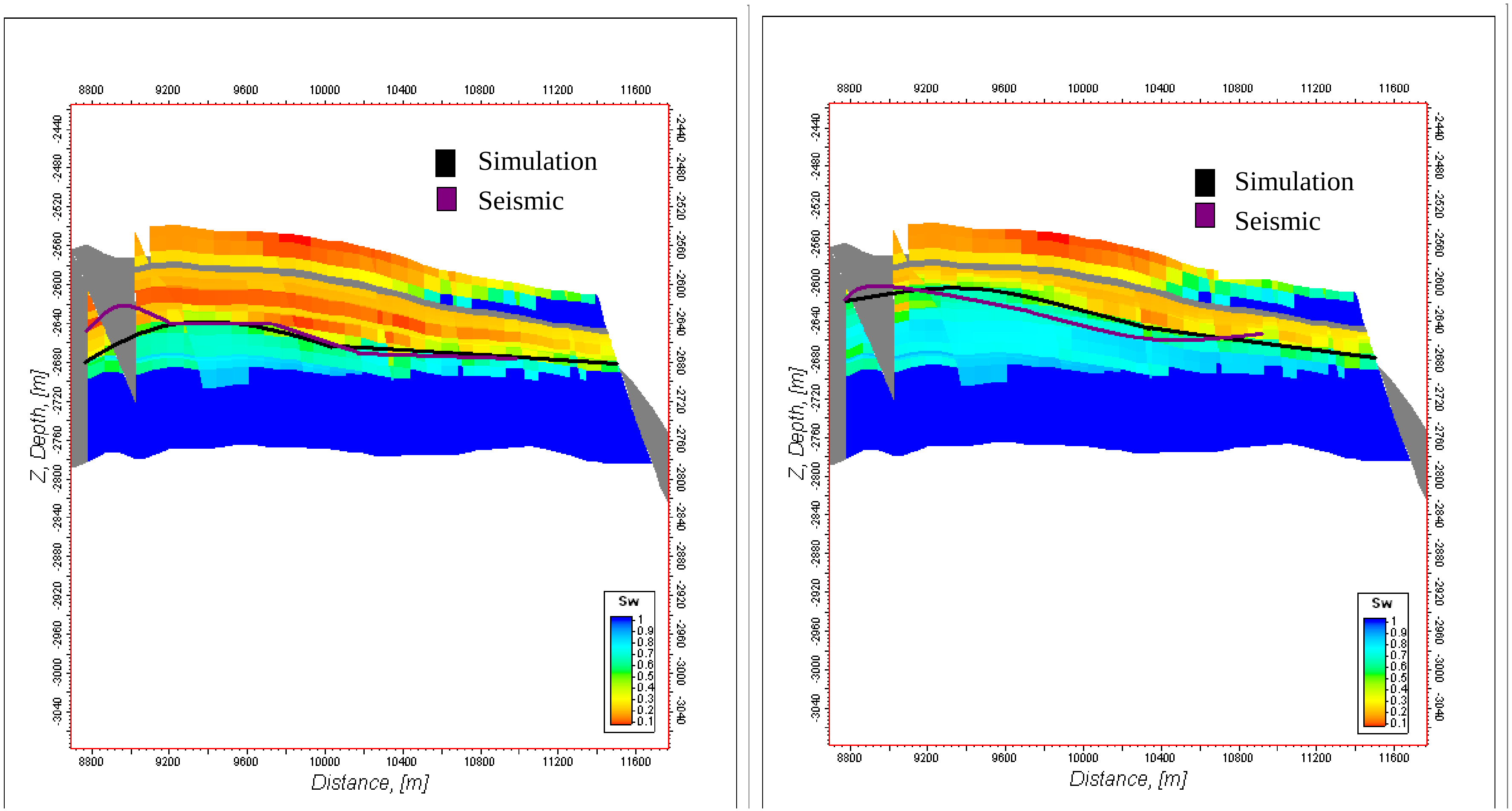


Figure 18: Water saturation profile from the second try to updated model. OWCs from seismic and simulation drawn in purple and black, respectively. The 2001 case (left) and the 2004 (right).

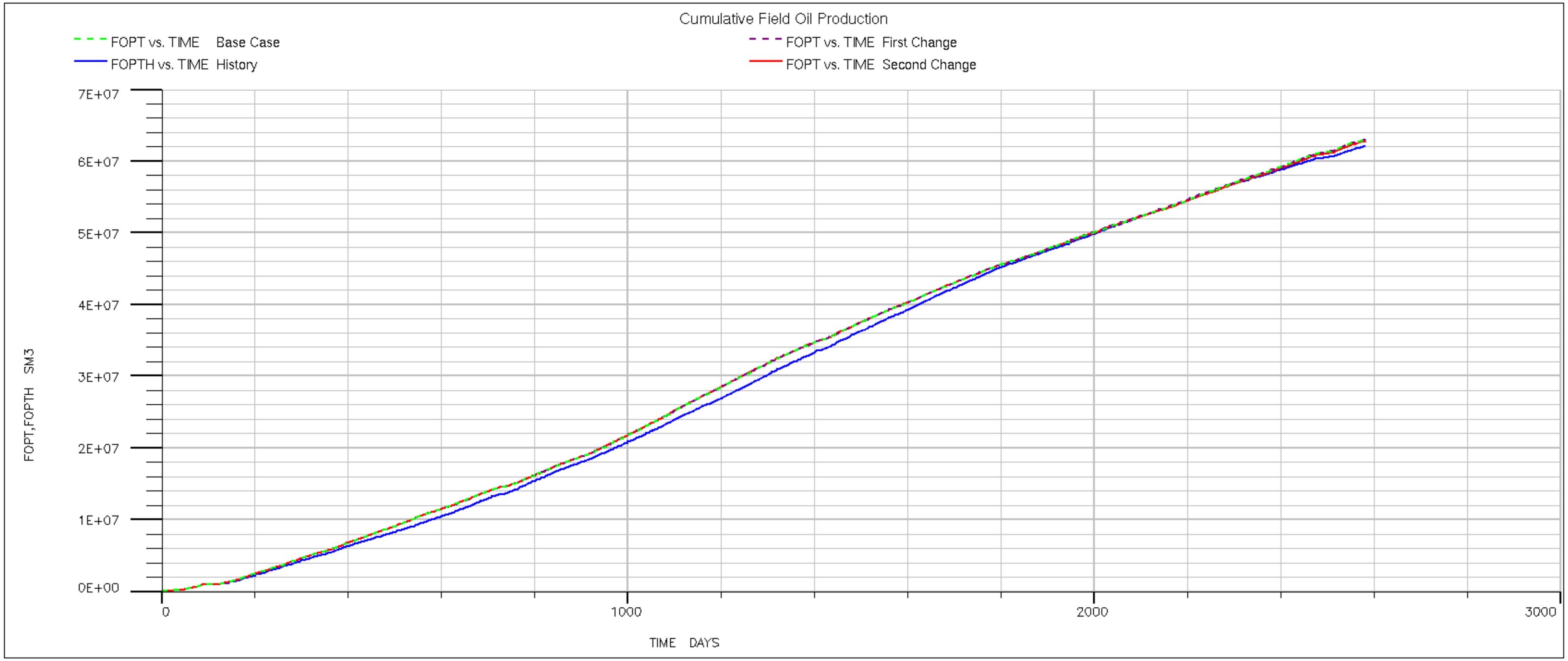


Figure 19: Cumulative Field Oil Production. Look in Appendix A.

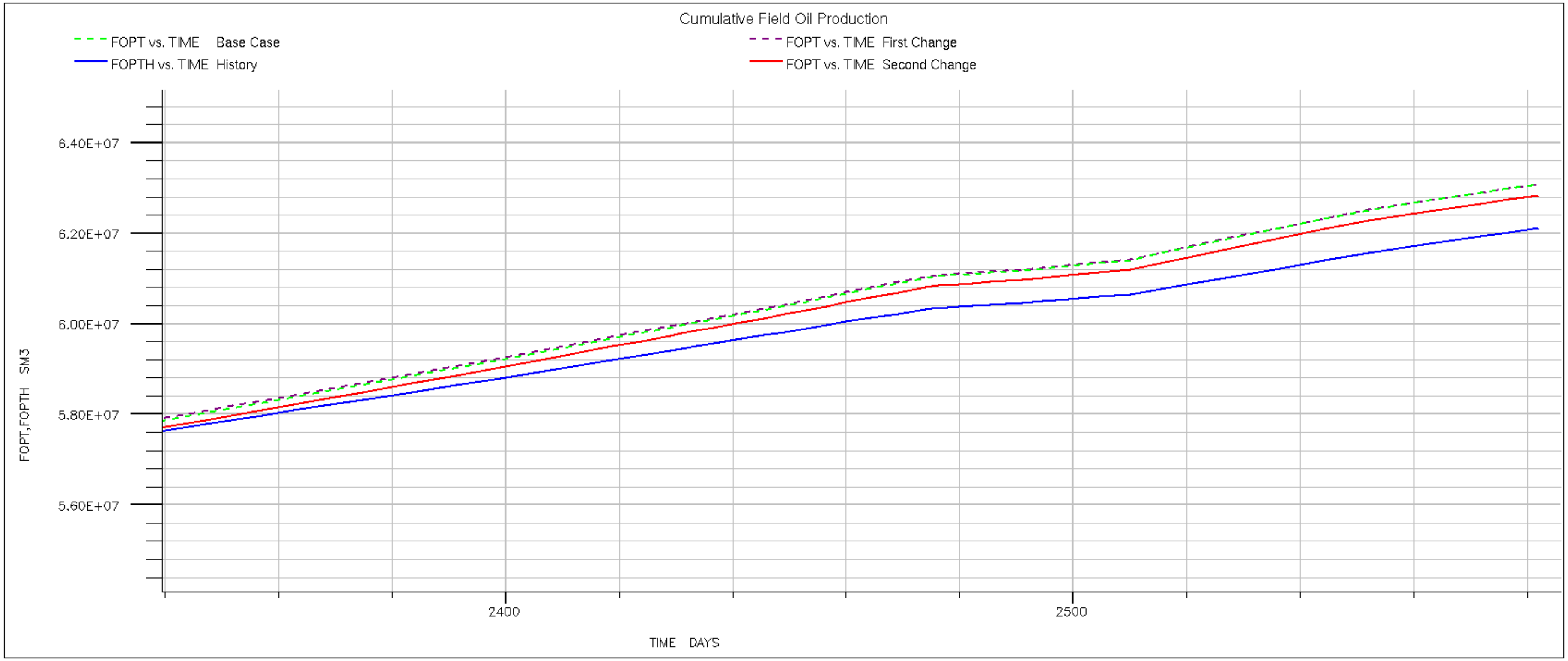


Figure 19: Cumulative Field Oil Production. Look in Appendix A. Excerption of main graph.

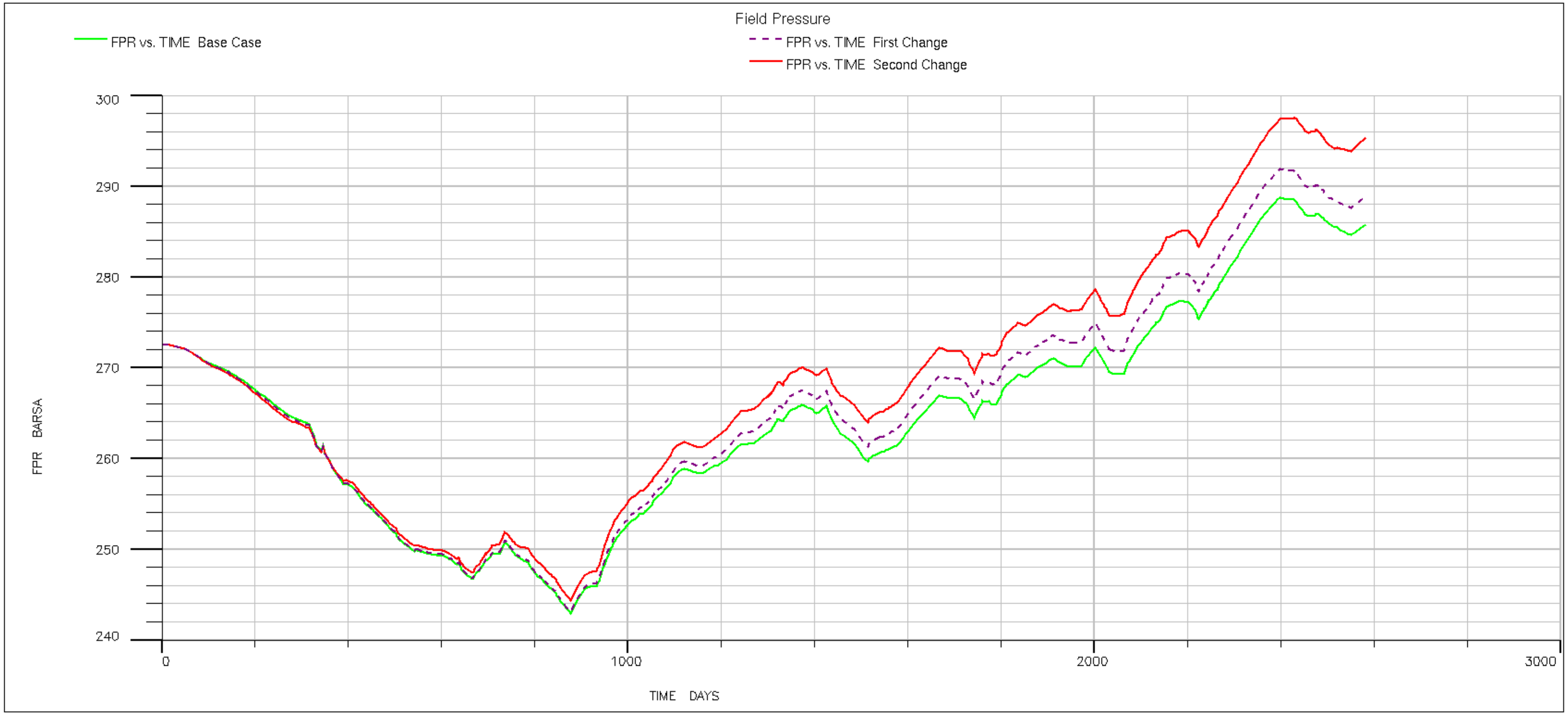


Figure 22: Field Pressure

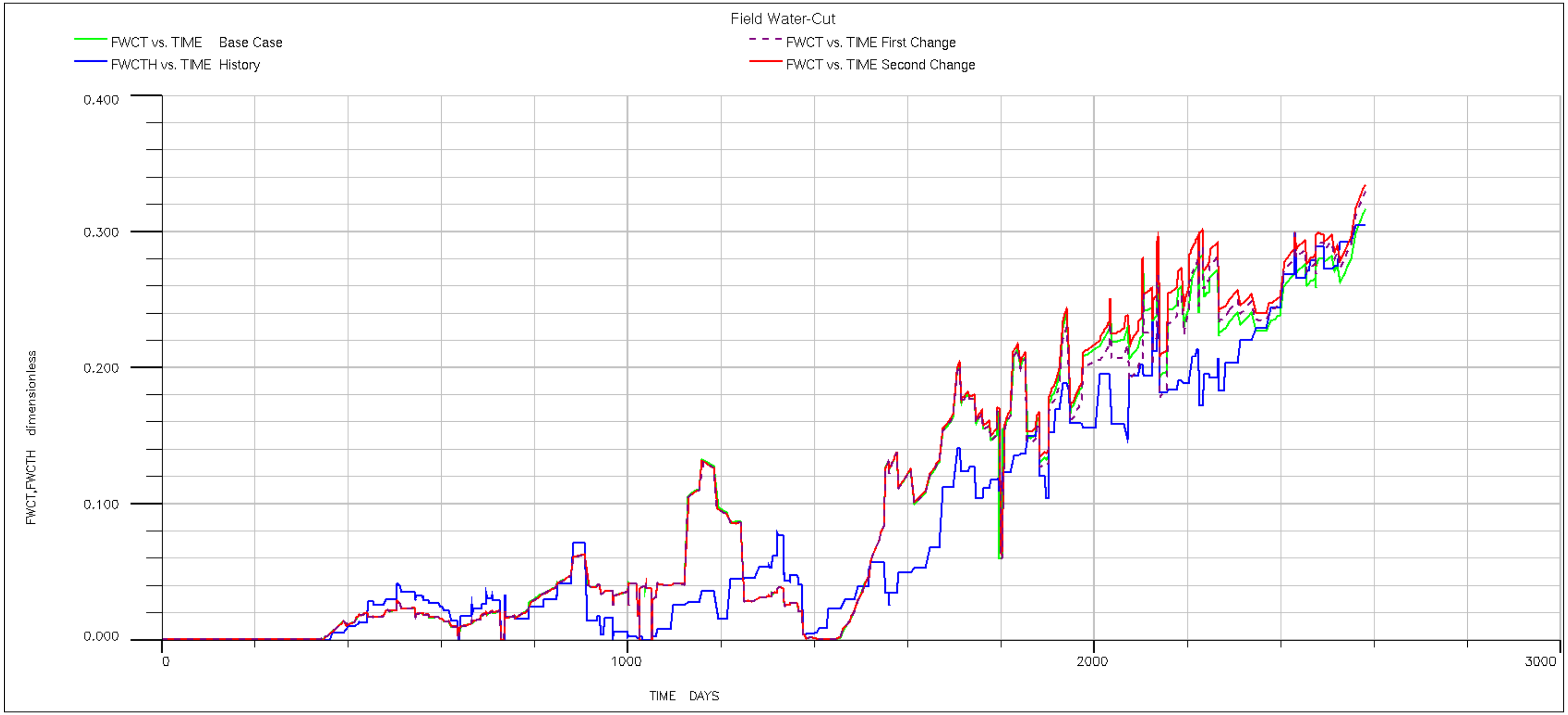


Figure 20: Field water-cut, excerption from main graph. Look in Appendix A.

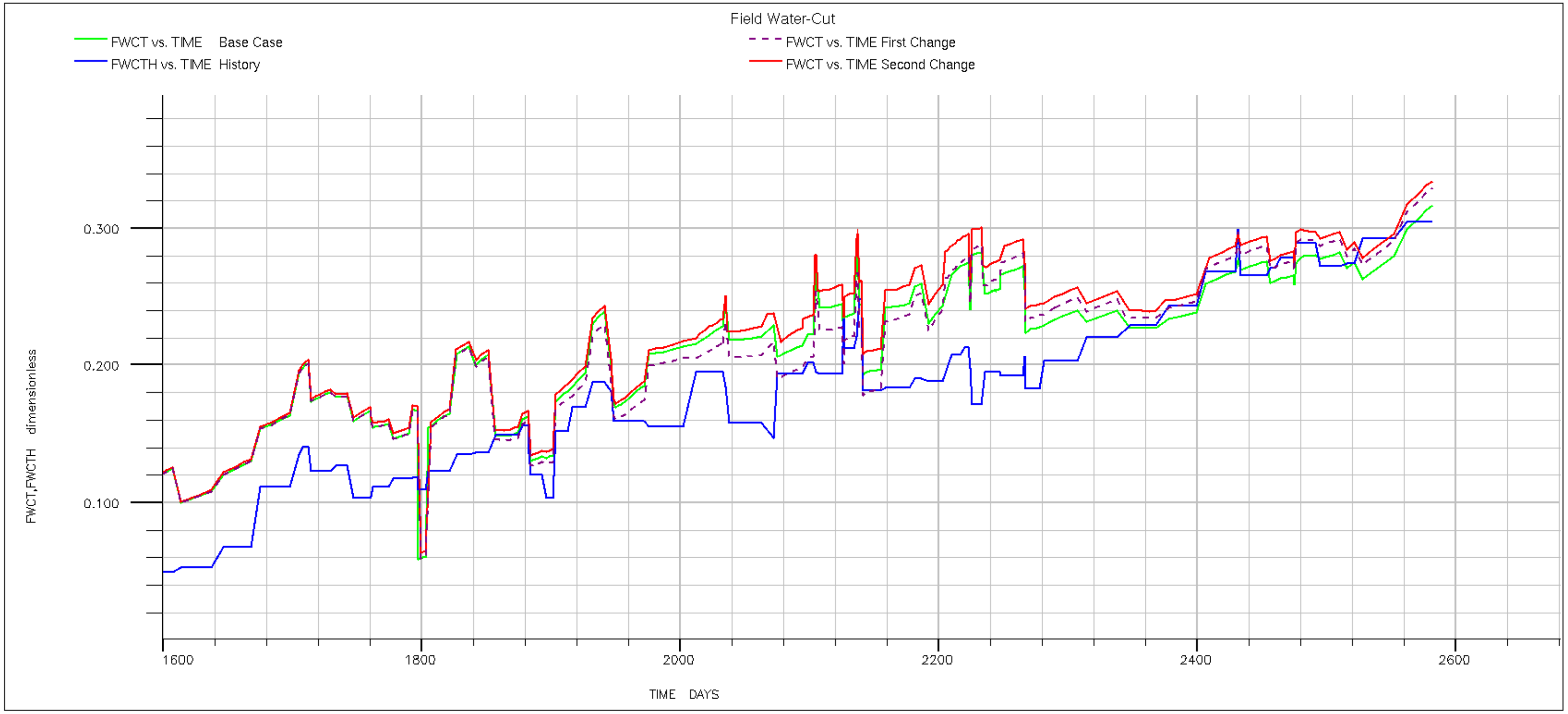


Figure 20: Field water-cut, excerption from main graph. Look in Appendix A.

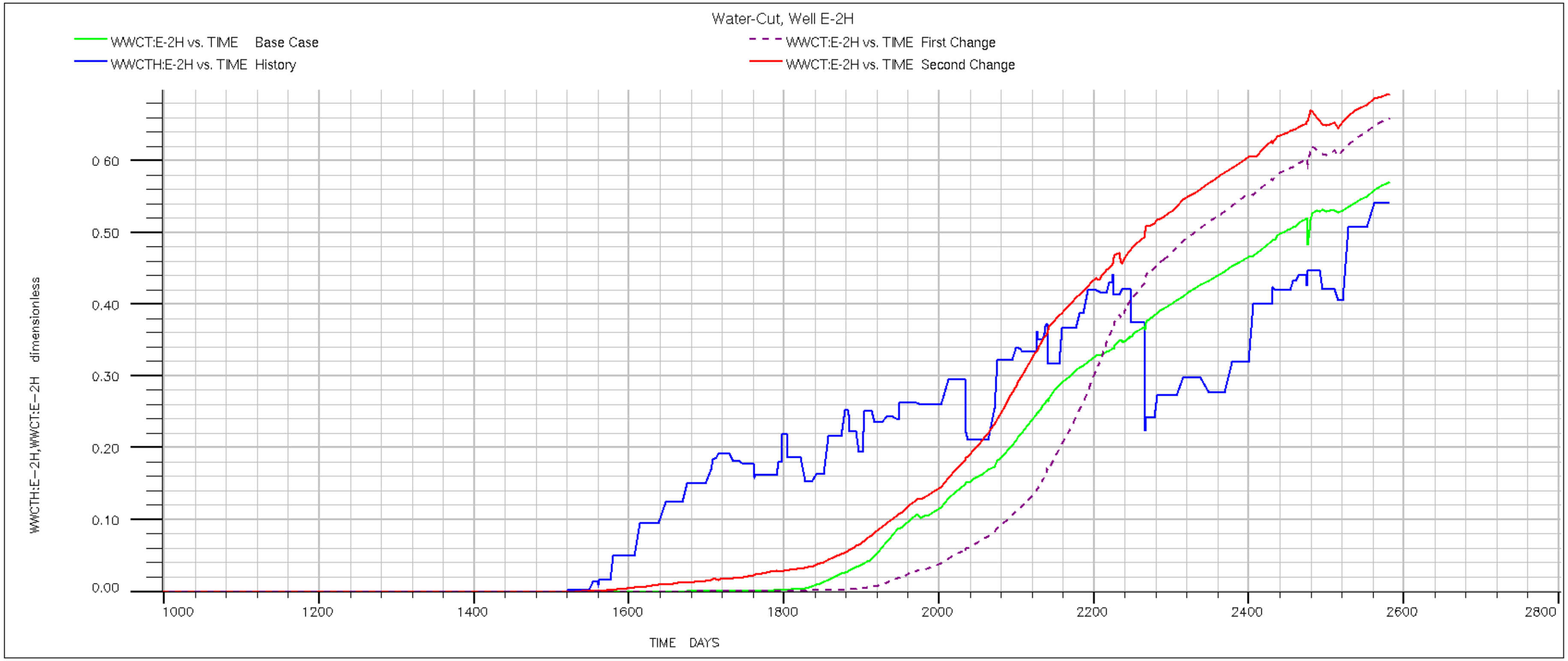


Figure 21: Water-cut, well E-2H