DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE **RAPPORT 2020/43**

Capture, Storage and Use of CO_2 (CCUS)

3D static reservoir model of the Hanstholm structure (Part of Work package 6 in the CCUS project)

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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Preface

Late 2019, GEUS was asked to lead research initiatives in 2020 related to technical barriers for Carbon Capture, Storage and Usage (CCUS) in Denmark and to contribute to establishment of a technical basis for opportunities for CCUS in Denmark. The task encompasses (1) the technical potential for the development of cost-effective CO_2 capture technologies, (2) the potentials for both temporary and permanent storage of CO_2 in the Danish subsurface, (3) mapping of transport options between point sources and usage locations or storage sites, and (4) the CO_2 usage potentials, including business case for converting CO_2 to synthetic fuel production (PtX). The overall aim of the research is to contribute to the establishment of a Danish CCUS research centre and the basis for 1–2 large-scale demonstration plants in Denmark.

The present report forms part of Work package 6 and focuses on producing a numerical 3D reservoir model of the Gassum Formation, which is to be used further in the analyses of dynamic capacity and injectivity.

Contents

Dansk sammendrag

Til brug for den efterfølgende dynamiske reservoir analyse af Gassum Formationen i Hanstholm strukturen af bl.a. kapacitet og injektivitet er der fremstillet der en 3D reservoirmodel. Den opbygges fra en strukturel model som anvender den eksisterende kortlægning til at afgrænse model volumenet, og tilføjes indhold i et regulært netværk som afspejler arkitekturen og den rumlige fordeling af sandlegemer og porøsitetsværdier.

Afgrænsningen af toppen af reservoiret udgøres af det forud eksisterende kort over toppen af Gassum Formationen, idet den nyeste kortlægning er foregået forskudt for model arbejdet og ikke er blevet indarbejdet. Det betyder også at væsentlige elementer i en reservoirmodel, f.eks. mulige forkastninger, ikke er beskrevet i det anvendte kort som er baseret på et mangelfuldt data grundlag.

Den interne arkitektur og fordelingen af sandlegemer og porøsiteter bygger ligeledes på et manglende data grundlag, idet Hanstholm strukturen ikke har repræsentative boringer til at oplyse om disse forhold. Geometrierne og porøsitetsfordelingerne er derfor kun konceptuelle, og er baseret på data fra nærtliggende boringer og formodningen om en analogi hentet fra tolkningerne udført i Thisted strukturen ca. 40 km sydøst for Hanstholm strukturen. Som følge af den forsimplede model for Hanstholm er der ikke forsøgt at opstille forskellige scenarier.

Den leverede reservoir model skal betragtes som en version 0, idet ingen lokale data med tilstrækkelig informationsindhold er indbygget. Integration af de nyeste tolkninger på de eksisterende data vil bidrage til en opdatering, men en afgørende øgning af sikkerheden i modellen forudsætter ny indhentede seismiske data og en boring, som kan tilføje lokal og detaljeret viden om geometrier og indhold.

Summary

As preparation for the dynamic reservoir analysis, a 3D static model with properties for facies and effective porosity is produced for the Hanstholm structure – the potential site for CO_2 storage. The structure is not drilled with a representative well, and the seismic data as well as the coverage are of mediocre quality. Therefore, analogue concepts from the Thisted structure and a regional interpretation have been used for facies and porosity patterns.

The geological model and the interpretations of the depositional environments deliver the basis for deciding the best method in the reservoir modelling to reflect relevant patterns and architecture of the reservoir. The geological model is mainly based on interpretations on the dataset from the Thisted structure with five drilled wells considered to be a close analogue, supplemented with information from regional structural data and from other wells in the region penetrating the Gassum Formation.

Based on the geological model and the interpretations of the depositional environments and thereby of the size, shape, and overall architecture of porous sedimentary bodies, the modelling methods have been designed to reflect all this by a combination of facies modelling and subsequent petrophysical property modelling.

The presented reservoir model should be regarded as a version 0 model, since no local data with sufficient information are incorporated. The integration of the most recent interpretations reported in other parts of this project will support an update, but a decisive improvement will be depending on new data from seismic investigations and drilling of a well, supplying local and detailed data on geometries and properties.

Introduction

In the context of the present CCUS 2020 project it is important to keep in mind that the current investigations supplying additional data and new information for designing advanced reservoir models of both the Havnsø and the Hanstholm structures have been performed in parallel to the modelling activity. Therefore, the present model versions have incorporated only limited new input and are mainly based mainly on existing data and interpretations. The most important aspect is that the work reported here shows the full chain of data analyses, data input, model design, uncertainty treatment etc. as well as transfer to dynamic investigations with injection simulation; all steps being necessary for contributing to a valid assessment of a storage complex. The present version_0 will be updated to a version_1 based on the expected future planned integration of the delivered results from the seismic, stratigraphic and petrophysical studies (reported from the various project teams). In the event that newly acquired seismic and well data will be available in the future it will be mandatory to update to a version_2.

The importance and relevance of producing this version_0 model is primarily to establish the work flow and that the model building competencies are in place, and also for the constructed reservoir model to serve as a tool for illustrating the 3D architecture of a storage formation to serve as an educating element and inspiration for improvements.

Previous work

The informal name Hanstholm structure is used for an offshore domal closure at Gassum Formation level situated approximately 35 km northwest of the city of Hanstholm (Fig. 1). The water depth at the site of the structure is approximately 30 m.

This report describes the implementation of a 3D static reservoir model of the Upper Triassic – Lower Jurassic sequence including the sandstones of the Gassum Formation in the Hanstholm structure. Part of the introduction is extracted from the earlier work within GESTCO (Christensen, 2000), a European Community supported research project (Geological storage of CO_2 from fossil fuel combustion), and mainly from Larsen, Bidstrup & Dalhoff (2003). Other sources include the work carried out in other projects such as DYNAMIS (LeGallo, 2008) and in NORDICCS (Lothe 2015).

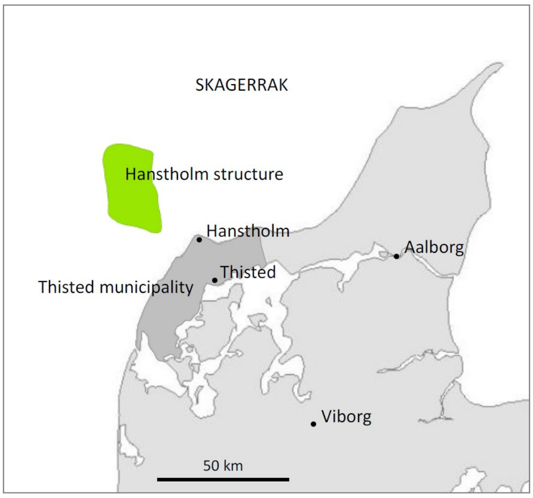

Figure 1. *Map showing the position of the Hanstholm structure.*

The EU 6th Framework Programme project DYNAMIS (2006–2009) (LeGallo 2008) constructed the first static geomodel based on the very sparse input data. The injection simulation injected 100 Mtons over a 30-year period with 4 wells distributed in the reservoir, but maximum capacity was not quantified.

The NORDICCS project (2011–2015) produced the Nordic CO_2 storage atlas. In this project the existing DYNAMIS geomodel with minor updates was used for simulating injection in 7 wells distributed over the Hanstholm structure (Lothe et al. 2015). The updated saturation functions were derived from Canadian clastic reservoir sands. The simulations arrived at a total injection over 40 years of 1170 Mtons CO_2 without optimizing for the maximum capacity.

The overall conclusions from these previous projects are indicating significant uncertainties in several input parameters for analysis of the Gassum Formation in the Hanstholm structure and its storage potential.

1. The top reservoir map has not been updated since 1991 and has very little information on structural features.

2. The structure is undrilled except for a flank well (Felicia-1) which is deemed unrepresentative based on structural position.

3. The well log suites in the nearby wells and potential analogues are lacking modern logs for quality petrophysical interpretations.

4. The depositional architecture is complex as the location was influenced by contemporary salt movements and the depositional units are spanning a wide range of facies probably representing fluvial, estuary, tidal, nearshore and shelf deposits with high variability.

5. Core material and therefore special core analysis for e.g. relative permeability and capillary pressure functions are lacking.

6. Data and core material for the local caprock section is lacking.

7. Actual site-specific data on temperatures, salinity, formation pressure, leak-off pressure, hydraulic tests, are all absent.

The results of the current analyses of the Hanstholm structure and the stratigraphic correlation between the Thisted structure and the Hanstholm structure are not incorporated into the present reservoir model as the work is conducted in parallel. The modelling is therefore based mainly on the previous work, and since the Hanstholm model is at a larger and coarser scale than e.g. the Havnsø model, the facies modelling is simplified and shows only a generalized facies pattern for a nearshore/coastal system. The lack of input also implies that it is difficult to set up a relevant spectrum of more detailed model scenarios, and therefore only one model version is produced for the Hanstholm structure.

Seismic data and map material

The map for the Top Gassum surface at Hanstholm is fairly uncertain due to limited seismic data at the time where the map was produced. The map for the Top Gassum Formation is based on the limited seismic data available during a mapping campaign with published versions (Japsen & Langtofte, 1991). (File used: Top_UnitE2_Gassum_Depth-anm.DAT).

The Top Gassum Map from the 2D seismic mapping has been imported into Petrel. Uniform thickness of 104 m in the reservoir within the model area has been assumed based on data from the nearest wells J-1 and K-1. No faults are included in the gridding of the 3D model, as the existing map has no information on such structural features.

Guided by the deepest closing contour, a model area was decided with size 35.4 x 41.6 km (Fig. 2).

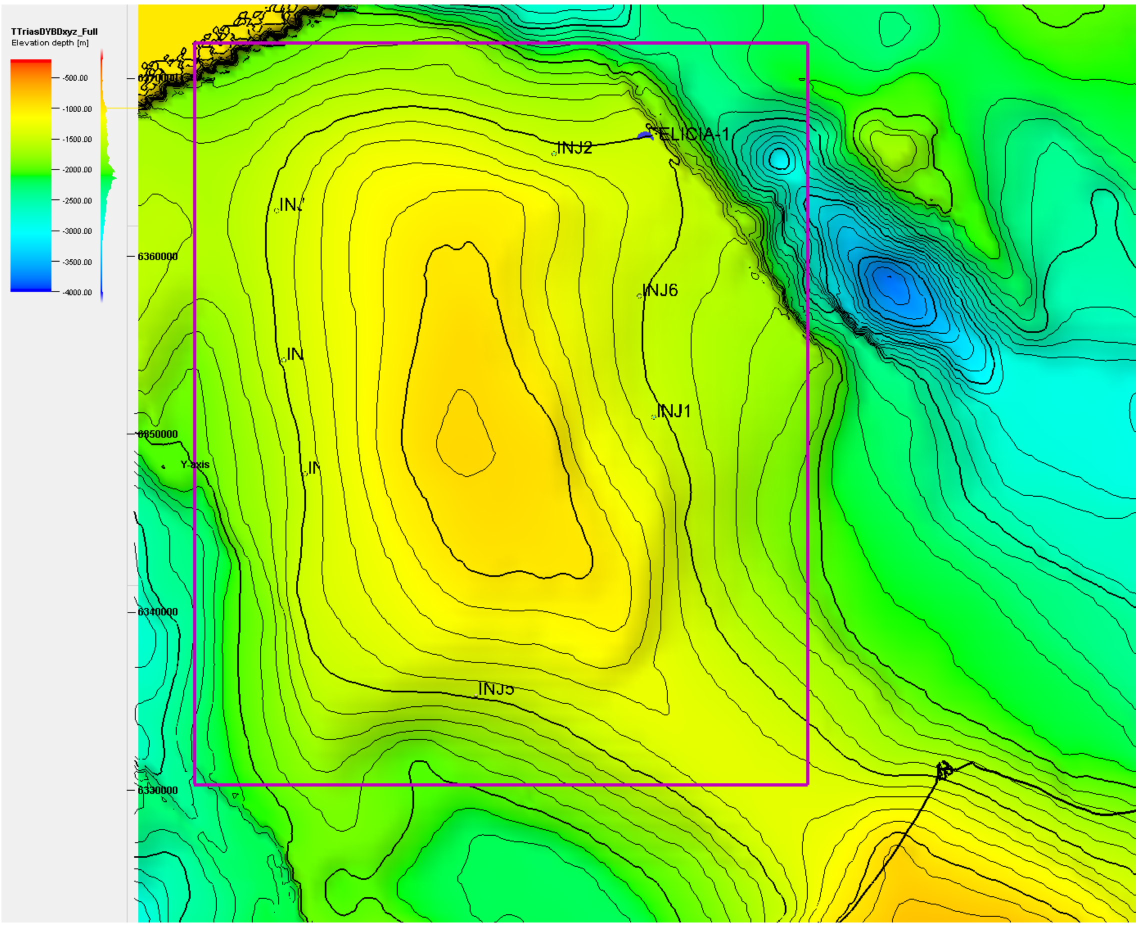

Figure 2. Map showing the Top Gassum surface in the region of Hanstholm with model size 35.4 x 41.6 km indicated.

Well data

The structure as such has not been drilled. Well information is extrapolated from the nearby Felicia-1, J-1 and K-1 wells (Figure 3). It should be noted however, that Felicia-1 is drilled at the crest of a rotated fault block, and additionally shows an extraordinary large thickness of the Gassum Formation and a thick mudstone in the middle part, which could reflect structural and topographic influence from the nearby salt pillow during deposition and thereby an association with a rim syncline (Fig. 3) . This may result in marked differences in reservoir properties between the well and the undrilled structure. Due to the well Felicia-1 considered not being representative of the main reservoir units on the structure, the well J-1 some 30–40 km to the NE has been used as a template for the sand/shale sequence and for guiding the N/G ratio in the reservoir model. The Felicia-1 well is correlated to the sequence in the J-1 well, and only the upper third of the Gassum Fm is regarded as comparable to the typical Gassum Fm section.

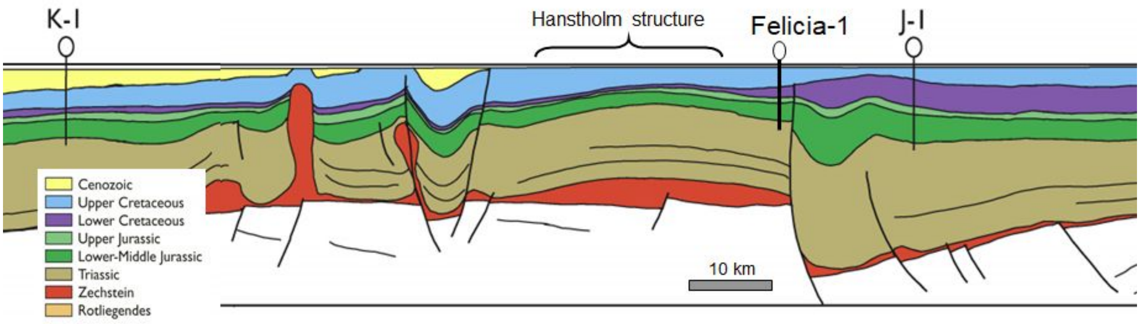

Figure 3. Geo-section SW–NE across the Hanstholm structure. The Gassum Fm occupies the uppermost part of the lightbrown Triassic layer.

Other wells in the region of interest are the wells drilled at the geothermal plant of Thisted where 5 wells – one cored – reach into the Gassum Formation and the more distant wells of Vedsted-1, Børglum-1 and Flyvbjerg-1, where sparse core material is available from all three wells (Fig. 4). The geological modelling at Thisted (Hjuler et al. 2013, 2014) was designed for a finer resolution and is therefore not directly transferable to the Hanstholm modelling work.

Additional information from well logs and core material is under interpretation and will be added as a future analogue for use in the Hanstholm geological model.

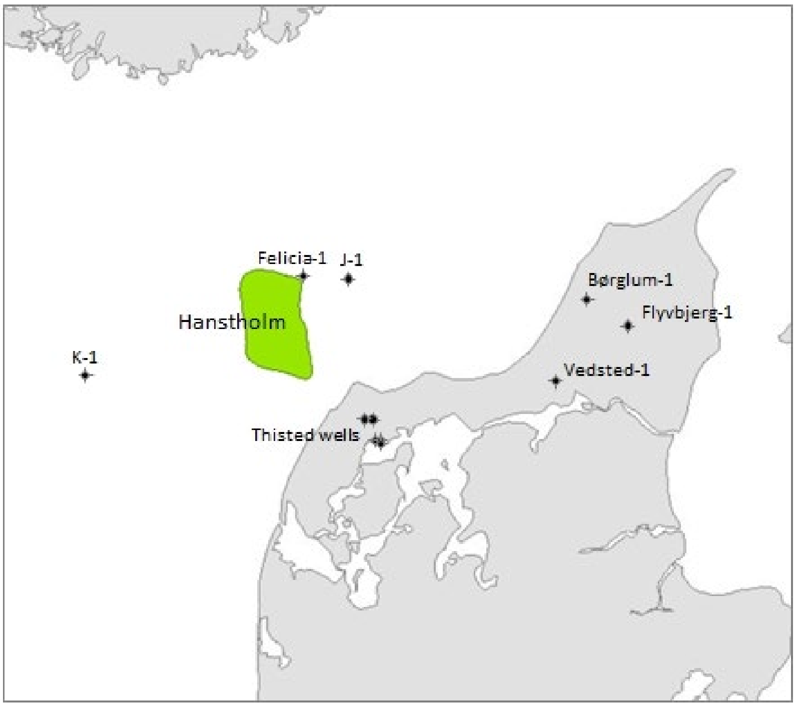

Figure 4. Map with the wells in the region around the Hanstholm structure.

The caprock section is the shale in the Fjerritslev Fm, and as a potential secondary caprock the overlying carbonates in the Chalk Group (Fig. 5)

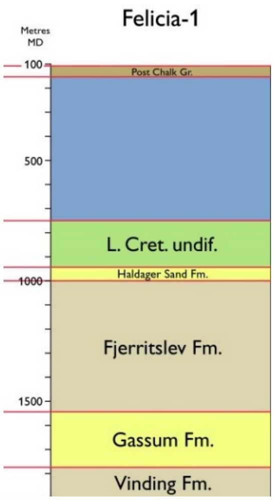

Figure 5. Stratigraphic column for Felicia-1 showing the very thick caprock section of the Fjerritslev Formation and the Chalk Group (blue) as a potential secondary caprock.

Porosity calculations

The lack of coverage and reliable well log data for interpretation of porosity in the first stage of the work has resulted in the use of only target histograms for simulation of a porosity model for the sand and shale facies.

From the sparsely available evaluated log suite the PHIE is the most appropriate porosity to apply for flow calculations, and is therefore used in the porosity modelling.

Construction of well log input for pseudo-well

For the facies modelling the wells Felicia-1 and the synthetic pseudo-well Top-1synt are included (Fig. 6). Due to the well Felicia-1 not being considered representative of the main reservoir units on the structure, the well J-1 has been used as a template for the sandstone/shale sequence and for guiding the Net/Gross ratio in the main part of the reservoir model.

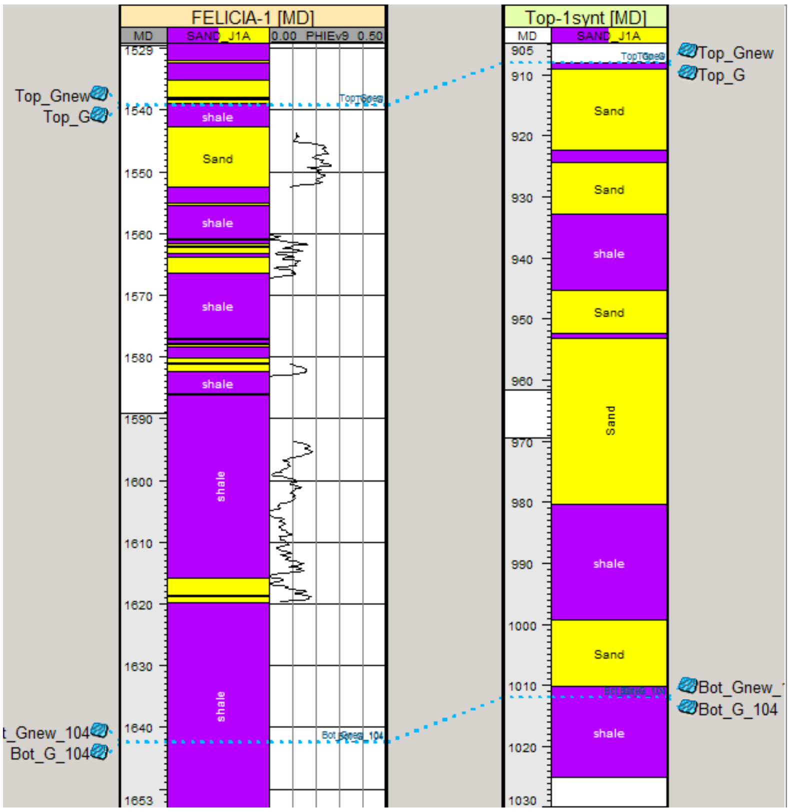

Figure 6. Well sections for Felicia-1 and the constructed pseudo-well Top-1synt for the reservoir section. The porosity log (PHIE) in Felicia-1 is incomplete due to problems with caving in the well bore and therefore only unreliable logging data is available for many intervals.

Reservoir model

Specification of the depositional control

For the single model scenario for the sandstone proportions in the reservoir, we select the 41% from the pseudo-well data.

For directionality we install an elongation of the sedimentary sandstone bodies with direction NW-SE.

This is inspired by the suggested depositional pattern for the nearshore sandy deposits. The direction is intended to reflect the possible coastline orientation as illustrated in Fig. 7. The simple elongated sandstone body geometry used is a coarse representation of the combined nearshore/coastal belt of a variety of sand facies, and is therefore a very generalised pattern. Therefore, only one scenario is produced at the moment.

The next update of the geomodelling will incorporate a more detailed analysis of the development of the depositional environment in the Gassum Fm as well as investigate the outcome of several equally possible geological scenarios.

Figure 7. Tentative illustration of the paleogeography during deposition of the Gassum Fm. It only illustrates a snapshot of the configuration during a short time interval as the position of the coast varied significantly through geologic time.

Design of reservoir model

The primary input for the reservoir model is the Top Gassum map, which is imported in Petrel (v2017). The map is copied for use as the bottom reservoir. A uniform thickness of 104 m is used for the Gassum reservoir model. The caprock is not included in the model but is installed during the flow simulation.

The maps are installed as model horizons in a regular grid with areal cells of 200x200 m and 2 m thick cells in the reservoir.

The position for the pseudo-well is chosen near the top point of the structure in the model area (Fig. 8).

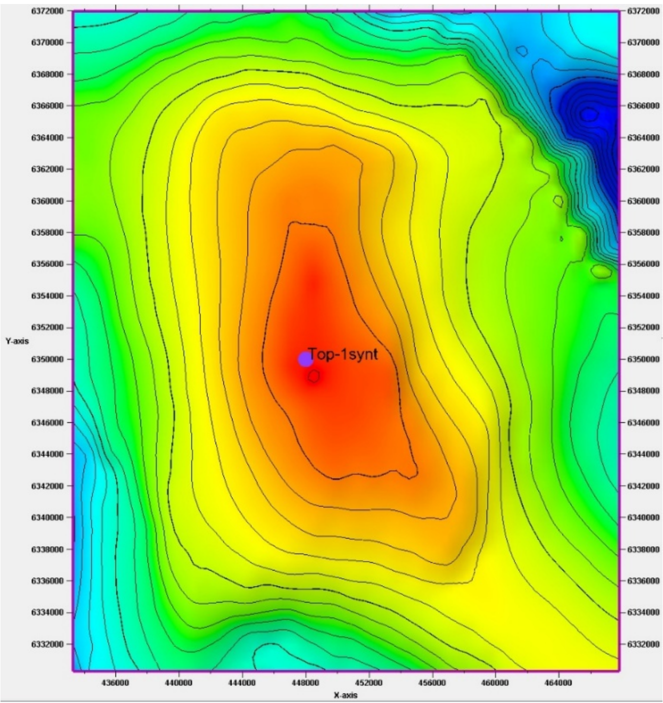

Figure 8. Map of the top Gassum Fm in the model area. The wellhead is placed at UTM 448000, 6350000. For simplicity KB=0. The well penetrates the Top_Gassum at 908.00 m TVDSS. The structure has its apex at 898 m TVDSS.

The local information in the pseudo-well on Facies and porosity PHIE is upscaled into the model grid. For the facies is used “most of” criterium, and for the porosity simple averaging on the well data which is given in 0.15 m increments.

The model workflow involves as the two first steps an object model overlain with a petrophysical model. The object model is using bodies of elongated ellipses for the sandstone bodies, the shale is modelled as a background facies and thereby designed to be more continuous that the sandstone bodies.

The total sandstone proportion = N/G is modelled as 41% from the pseudo-well data, and as a guide for the horizontal variation of N/G we assign a N/G trend map to guide the horizontal distribution of sandstone bodies during the model calculation in order to reflect the low N/G in the NE corner around the Felicia-1 well (Fig. 9). During modelling calculations the N/G map determines the frequency of the inserted sandstone bodies in order to match the N/G throughout the model volume.

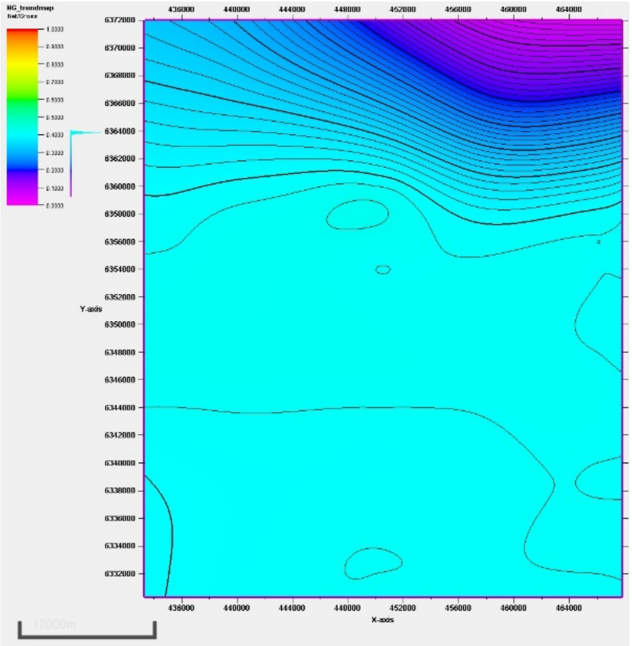

Figure 9. The N/G trendmap for guiding the modelling of the sandstone body distribution. The map reflects the low N/G around the Felicia-1 well in the NE corner, while the main part of the map shows N/G at 41% as in the pseudo-well.

For the petrophysical model of the spatial distribution of effective porosity PHIE is used the method of Gaussian random function simulation, fairly similar to the standard sequential Gaussian simulation (SGS).

Input definition for object models

The Property modelling/Facies input panels are used to describe body shape, size, directionality (Figs 10-13).

The orientation of sandstone bodies is chosen as a single value of -20 degress. The size is deterministic as 40x20 km, the thickness is described by a triangular function with mean 8 m and min-max of 4–12 (Fig. 10).

The distribution of sand bodies is guided by a N/G trend map where the area in the vicinity of the Felicia-1 well has a low N/G whereas the remaining area follows the N/G in the pseudo-well (Fig. 8).

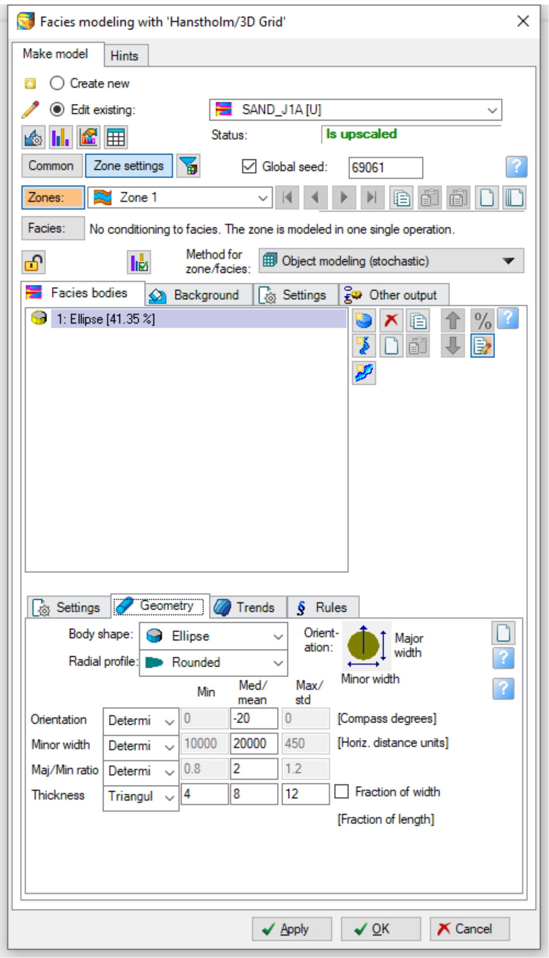

Figure 10. Geometry parameters for the sand bodies.

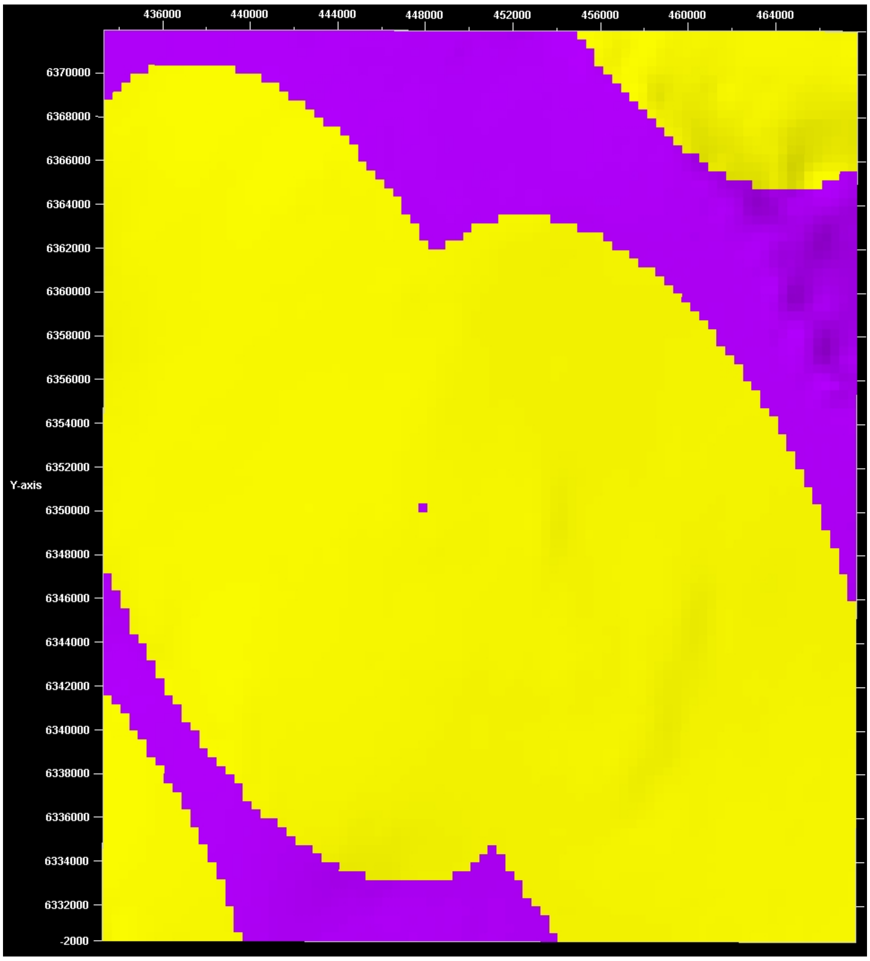

Figure 11. Layer 23 in facies model.

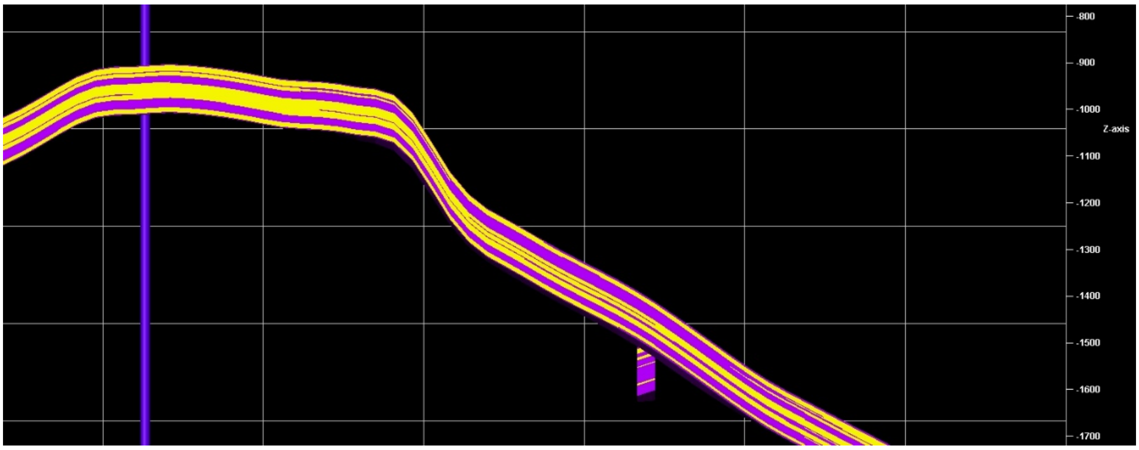

Figure 12. E–W section in facies model through the pseudo-well. Vertical exaggeration 10x.

Input definition for petrophysical models

For modelling the porosity, the input is specific for the two different facies sand and shale. The target distributions (histograms) and variograms are the main input for simulating porosity overlain onto the modelled facies.

From the sparse well data in Felicia-1 and comparison to the other wells in the region we generate two target Distributions (Fig. 13).

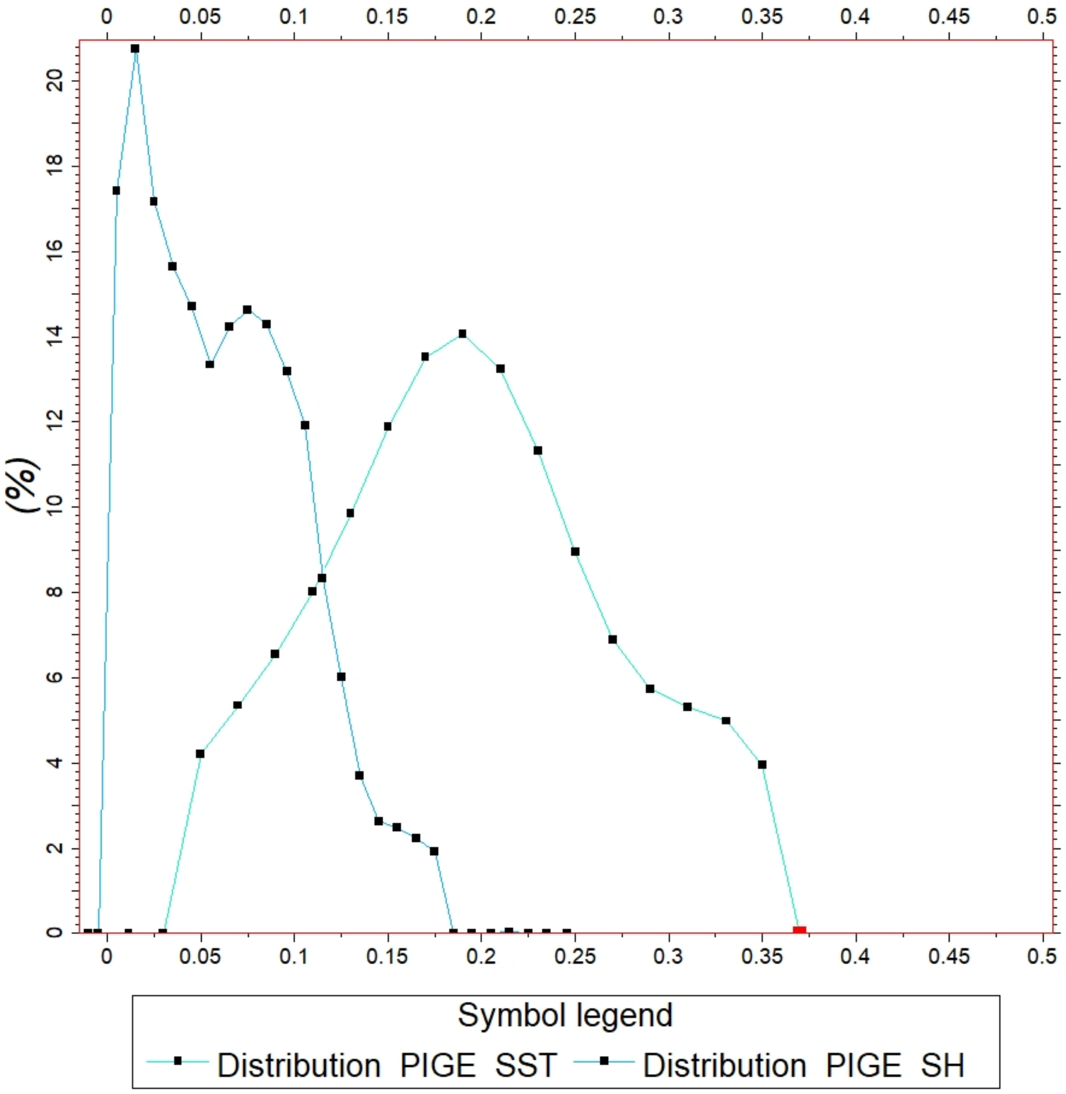

Figure 13. Histograms of porosity target distributions for shale and sandstones.

It is noted that especially the shale lithology has a large overlap with the sandstone population. This can be explained by the thresholding at a certain clay content estimate (Shale volume), allowing heterolithic intervals to be classified as shale (i.e. non-reservoir) even if they include some sandy layers, which increases the porosity estimate when interpreting the well log data.

Since some of the sandy units are assumed to be fairly homogeneous, the target histogram for porosity modelling has been extended up to 36% as the maximum value and with a fairly large overlap with the target histogram for shale porosity. The effect in the simulation is shown in Fig. 14.

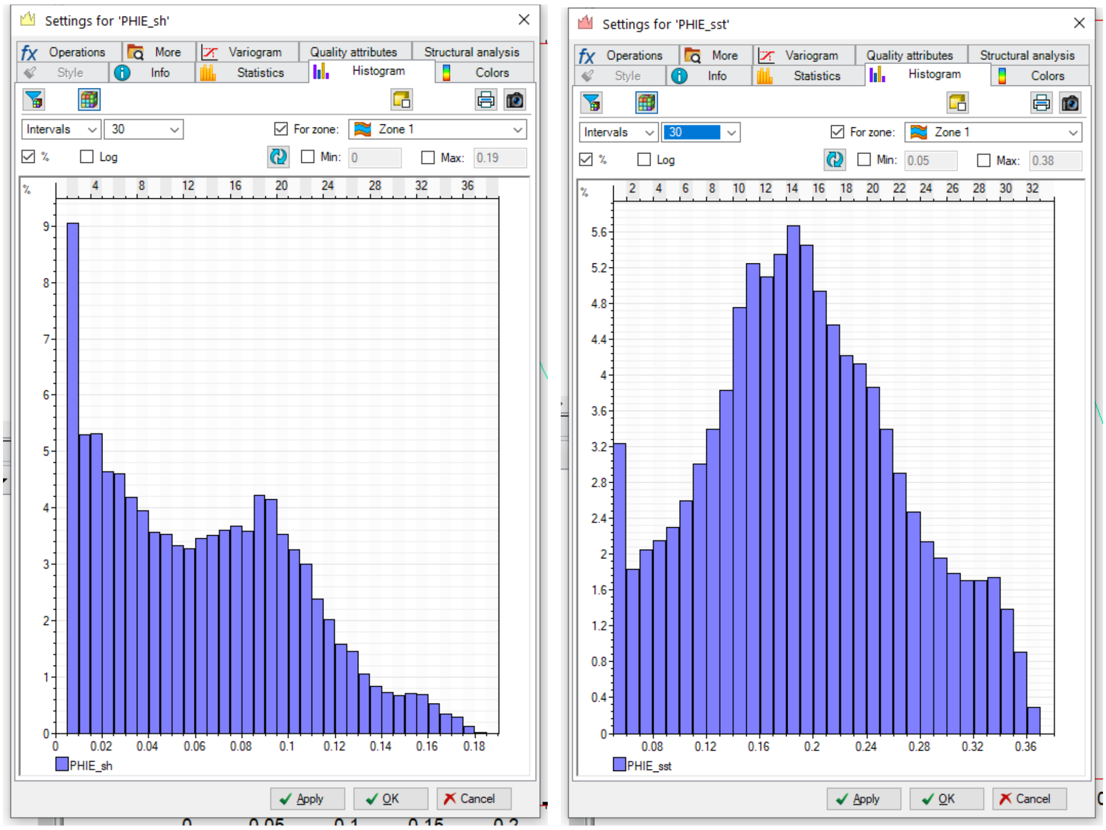

Figure 14. Histograms of simulated porosity illustrating the two populations for the shale and sandstone porosity.

The input used for the Gausssian Random Function model is describing both a target histogram for each lithology and size description by the variograms including directionality of elongated porosity regions within each of the facies simulated in the previous step.

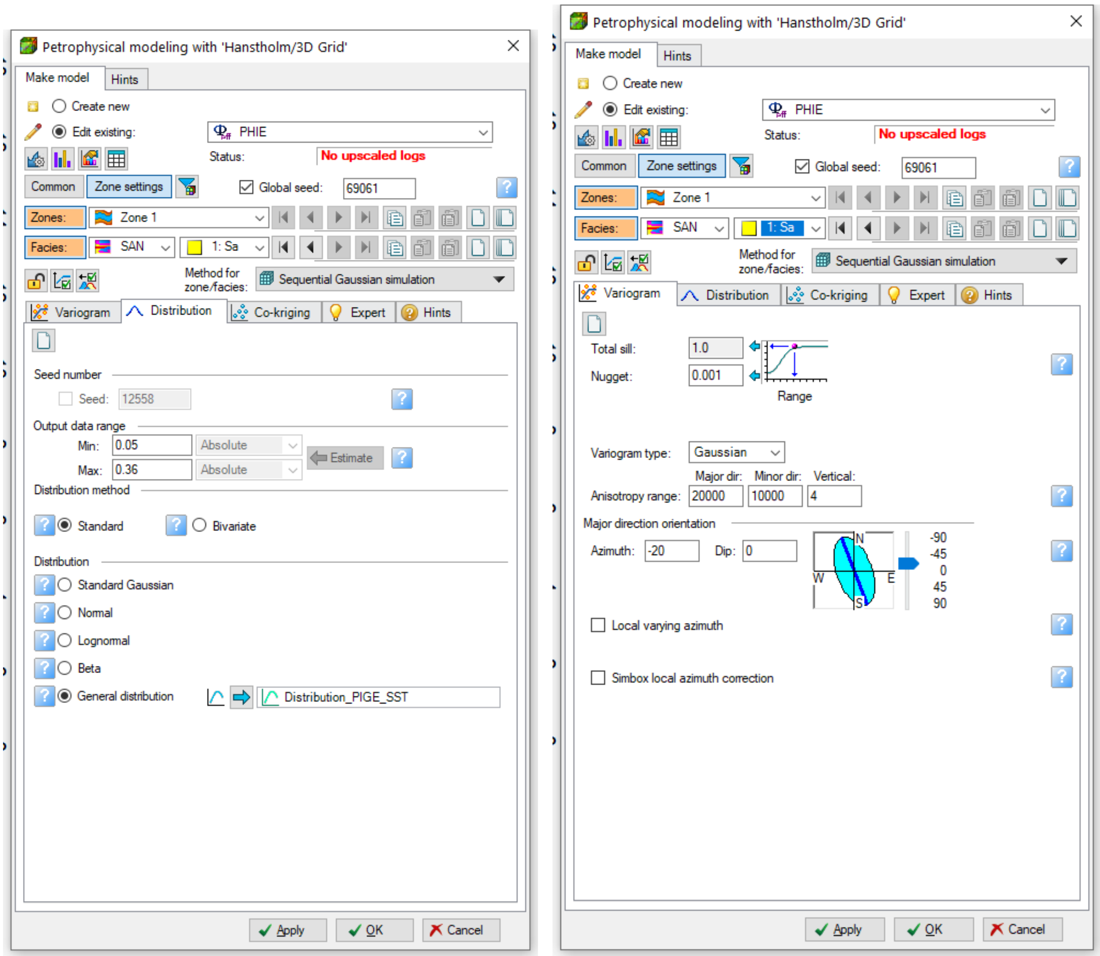

Figure 15. Input sheets for the sand porosity distribution and geometry.

Directionality of porous sandstone bodies

Within the sandstone facies we have imposed the same direction as for the facies for the porosity distribution. This is inspired by the interpretation of the general shoreline direction as described earlier.

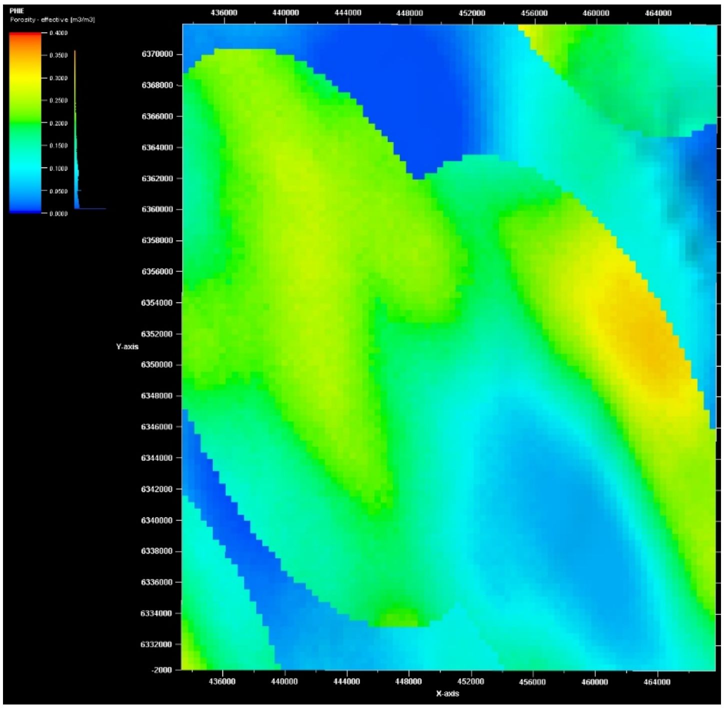

Figure 16. Porosity distribution in model, layer 23.

Recommendation for supplementary investigations and research

This chapter relates to the present state of knowledge and the uncertainties involved in establishing a reservoir model for the Gassum Formation in the Hanstholm structure. This therefore indicates where further data acquisition, research and investigations are needed to improve the modelling. Some aspects are under investigation based on existing data, some require new data for improvement, and some aspects might still be uncertain and therefore to be investigated with sensitivity studies exploring the probable ranges of the parameters under scrutiny.

Structural model

The main elements in a structural model of a storage site are: surface map of top reservoir, thickness map, and fault map.

The surface map is at present poorly defined since the available 2D seismic lines are relatively sparse and not able to locate top point of the structure neither the spill point precisely.

The thickness of Gassum Fm is not known exactly due to the same restrictions in the data background.

Faults or fracture zones are difficult to distinguish in the present seismic data set.

Therefore, a new data collection campaign is highly needed.

Facies model

The present facies model relies entirely on data from offset wells and extrapolation of the preliminary interpretations at the Thisted structure some 40–50 km to the SE. Although the overall depositional system is supported by wells outside the structure, the exact pattern of important and influential elements is very uncertain, and therefore only a simplified facies model is produced.

For obtaining a better constrain of the depositional pattern, a new seismic survey with high resolution and optimized for processing aimed at unravelling the internal texture in the Gassum Fm is necessary.

The drilling of an exploration well and obtaining quality well logs and core material would further support a better definition of the local depositional system and thereby better modelling of the sediment body geometries.

Porosity model

The present porosity model is based exclusively on extrapolation of data from the offset wells. However, the limited quality and diversity of the available well logs and the absence of core material from the Gassum Fm near the Hanstholm structure limit the interpretation of facies and depositional setting. The ongoing analysis of the data from the Thisted structure and the wells will support a more detailed model for the Hanstholm structure.

The core material is an extremely important element for the interpretation and calibration of the well logs and for the interpretation of the depositional processes that then indicate the facies patterns possible.

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