Sleipner 2019 Benchmark Model

Supporting documentation

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Introduction

This presentation gives an explanation of how the Sleipner Reference Utsira Model (2019) was built, including input data, assumptions and workflow used. The resulting model is intended to be suitable for usage in international projects on CO_2 storage.

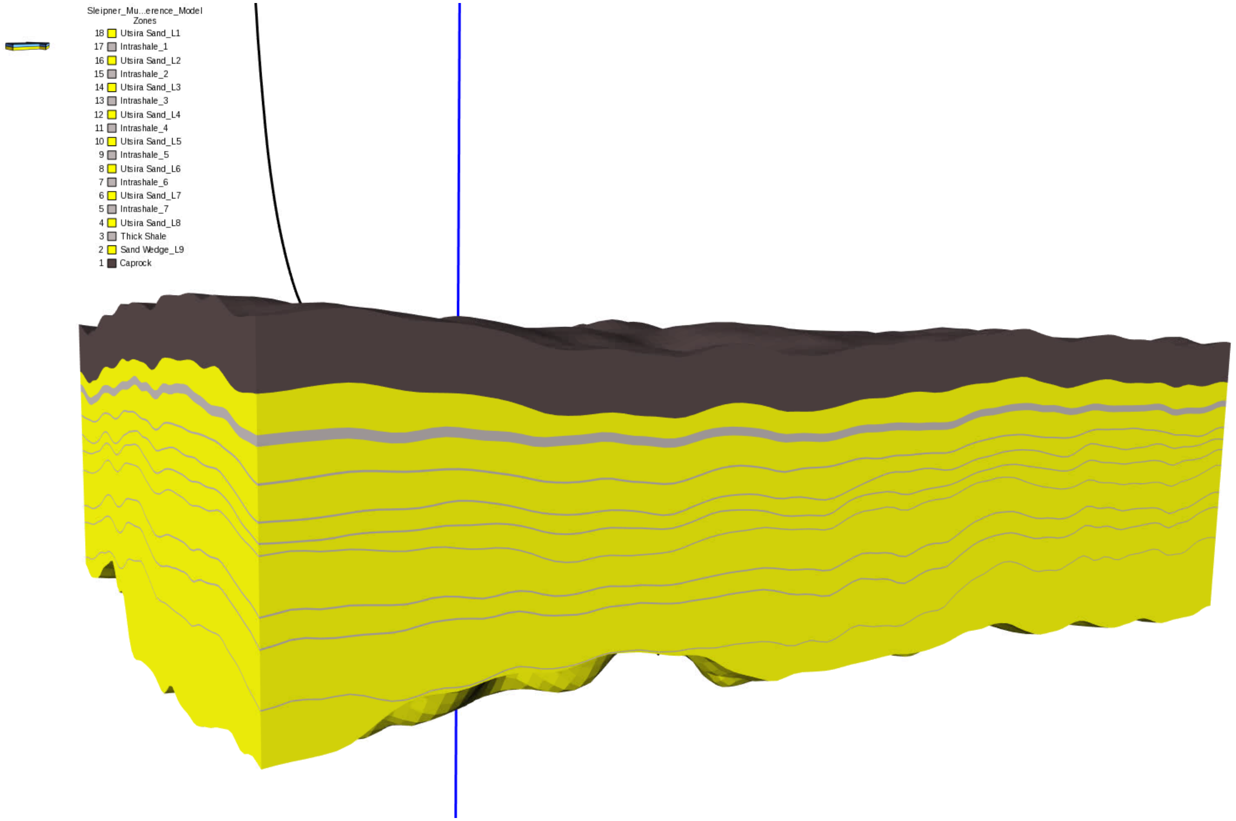
The software used was the Irap-RMS software suite under license to Equinor. Details of the software and workflows cannot be shared – rather we focus on the assumptions made.

In most cases the model was based on well data and 3D seismic surveys (up to 2010) which have also been made publicly available, but in some case non-released data was also used to help guide the model process.

Contents

The following slides explain:

- The Horizon Uncertainty Modelling (HUM) framework used and the input parameters
- The HUM output depth surfaces
- Well picks used for grid design
- Grid purpose and resolution
- Petrophysical parameters
- The package released for the CO_2 data share (CSDC) project



Horizon Uncertainty Modelling (HUM) Overview

RMS Structural modelling process that incorporates data and uncertainties from wells, thickness and/or velocities and time interpretations

The input parameters and key assumptions for the Sleipner structural model are:

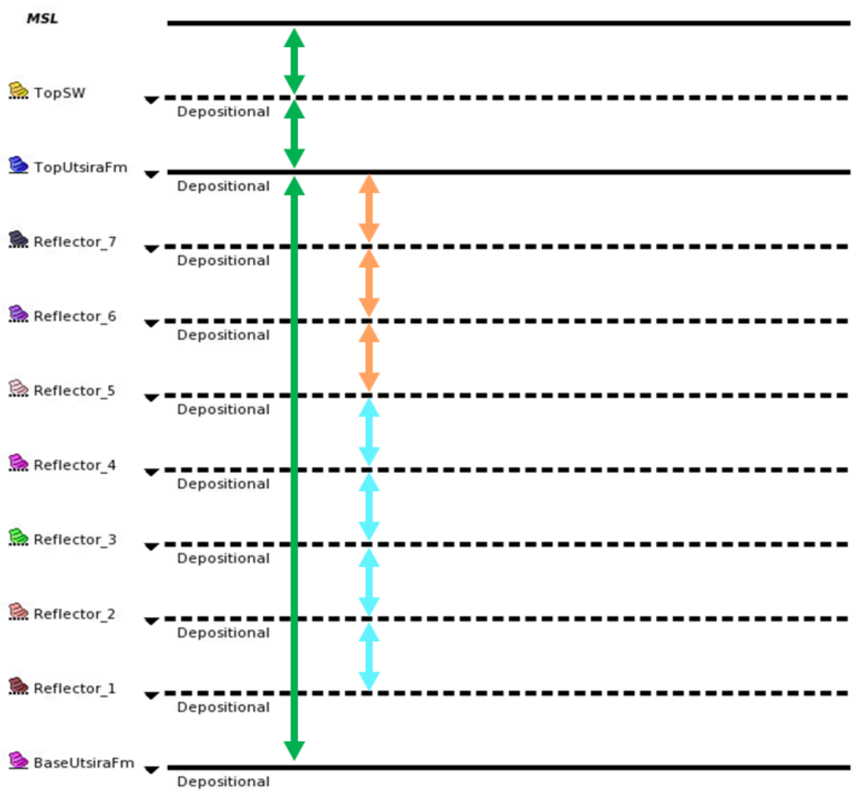
- 3 baseline seismic (1994) interpreted horizons:
  - Top Sand Wedge (SW), Top Utsira Formation and Base Utsira Formation
- 7 reflectors within the Utsira Formation interpreted post-CO_2 injection:
  - Reflectors 7, 6 and 5 which were interpreted across the seismic survey on the 2010 image data
  - Deep reflectors 4 to 1 are very difficult to interpret on any data and only possible along the extent of the plumes (based on the 2010 imaging data, except for deepest reflector 1 which was interpreted on the 2008 time-lapse seismic data) – these were incorporated based on their isochrons
- Extracted interval velocities trend maps from stacking velocities cubes pre- and post-CO_2 injection, applied according to the seismic horizons interpretations that defined each interval (as illustrated on the next slide)
- Calibrated to wells 15/9-13 and 15/9-A-16
- No faults are interpreted in the reservoir
- Confidence in the input data for the thickness/velocities are defined as higher to the interval velocities maps and lower to the isochrons (deep reflectors)
- Time interpretations consider uncertainties from well tops residuals, areas more challenging to interpret and local pull up effects caused by thin layers reflections

Horizon Uncertainty Modelling (HUM) Framework

Graphic explains surface handling logic

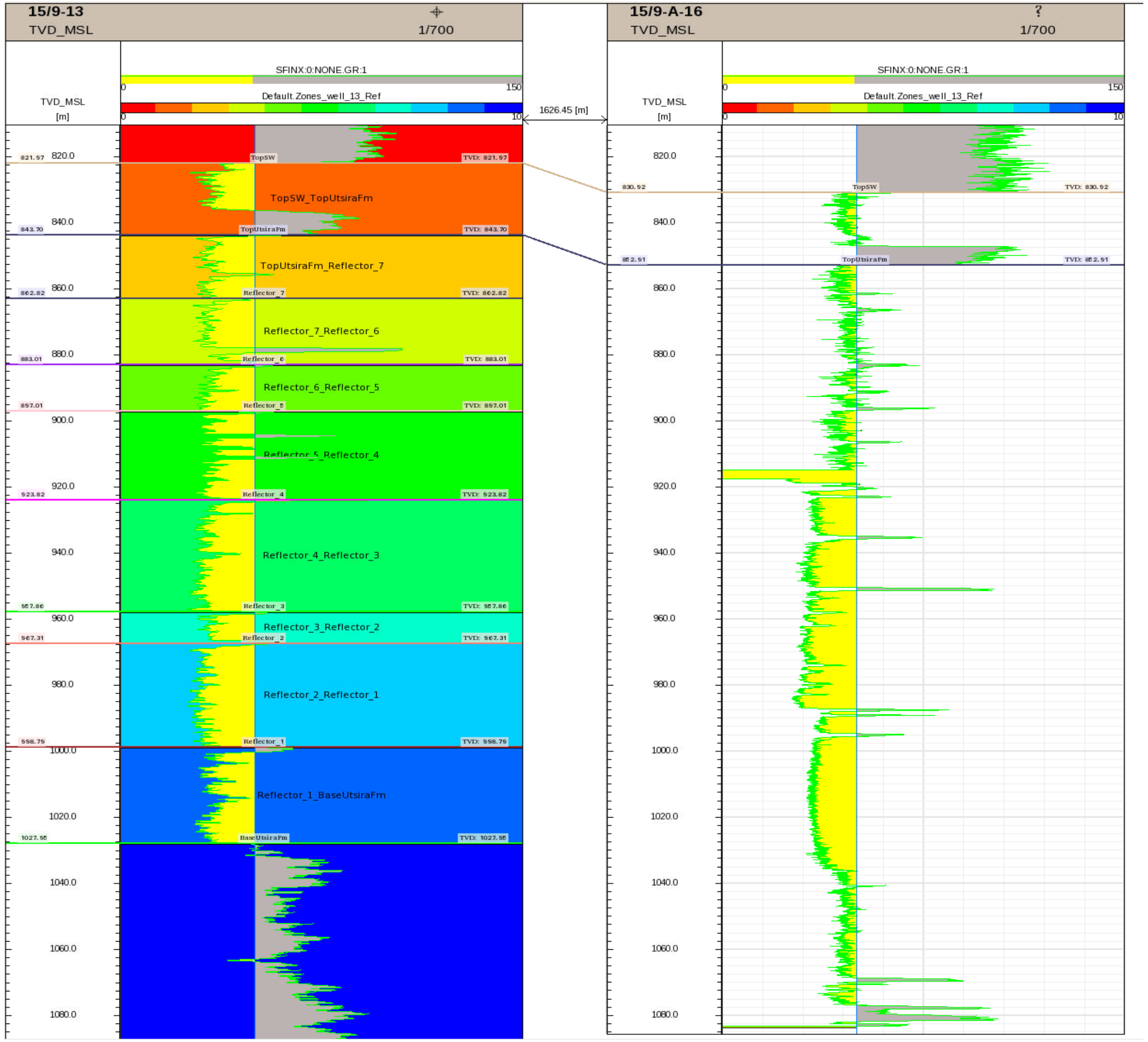
- Green arrows show intervals defined by interval velocities trend maps extracted from the 1994 stacking velocities for the baseline interpreted seismic horizons
- Orange arrows correspond to interval velocities trend maps extracted from the 2013 stacking velocities (no 2010 stacking velocities cube) for the reflectors interpreted across the survey
- Blue arrows show deep reflectors intervals defined by isochrons

- Surfaces were tied to well picks for wells 15/9-13 and 15/9-A-16, with a zone log for well 15/9-13



HUM - Well data

- Graphic shows calibration to wells picks for both wells and zone log to well 15/9-13
  - It is difficult to confidently interpret the internal reflectors within the Utsira Fm. For the well 15/9-A-16 which therefore have not been incorporated into the HUM calibration process



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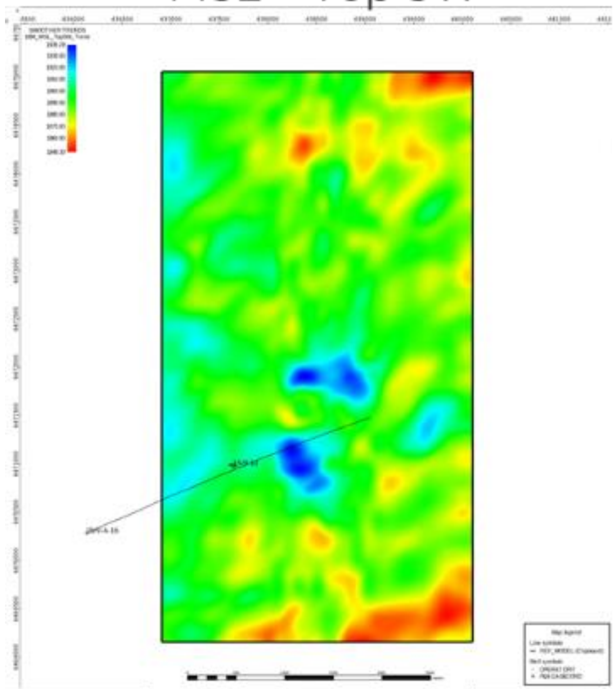
HUM - Thickness and Velocities

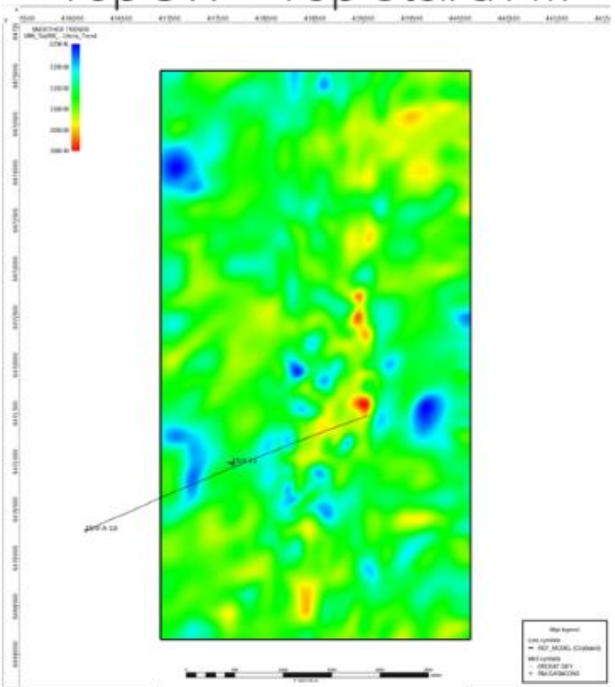
- Interval velocities trend maps from 1994 stacking velocities model – applied to intervals related to baseline interpreted horizons (Top Sand Wedge – SW, Top and Base Utsira Formation; MSL = mean sea level)

MSL – Top SW



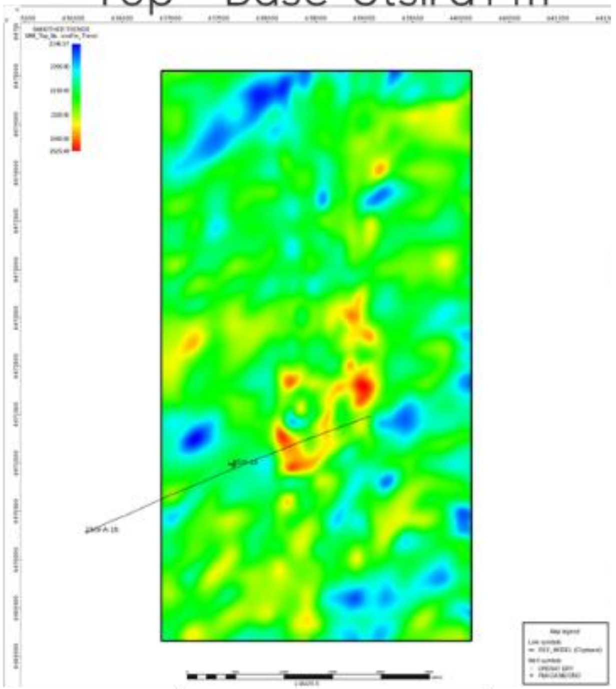
Statistics	Z	X	Y
Min	1844.51	436910.2	6469154
Max	1946.28	440110.2	6475054
Mean	1888.78	438510.2	6472104
Sum	229602400		
Std	14.45		

Top SW – Top Utsira Fm



Statistics	Z	X	Y
Min	2000.43	436910.2	6469154
Max	2256.41	440110.2	6475054
Mean	2130.77	438510.2	6472104
Sum	259019008		
Std	32.88		

Top – Base Utsira Fm

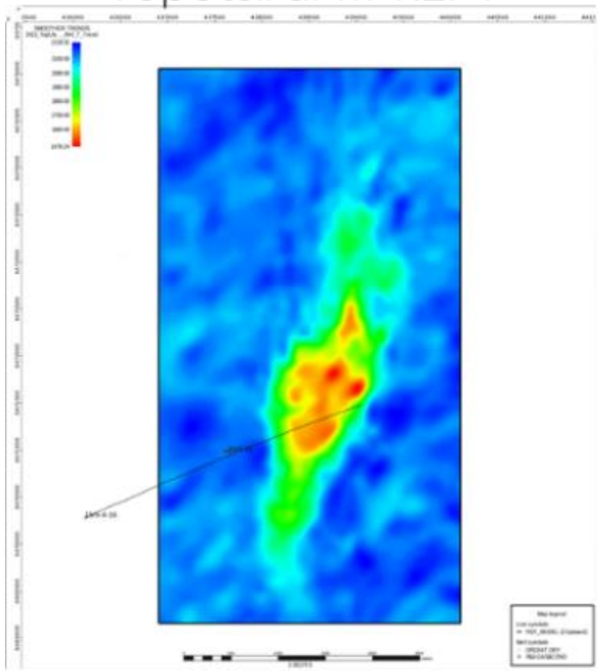


Statistics	Z	X	Y
Min	2025.49	436910.2	6469154
Max	2246.57	440110.2	6475054
Mean	2141.03	438510.2	6472104
Sum	260265184		
Std	31.93		

HUM - Thickness and Velocities

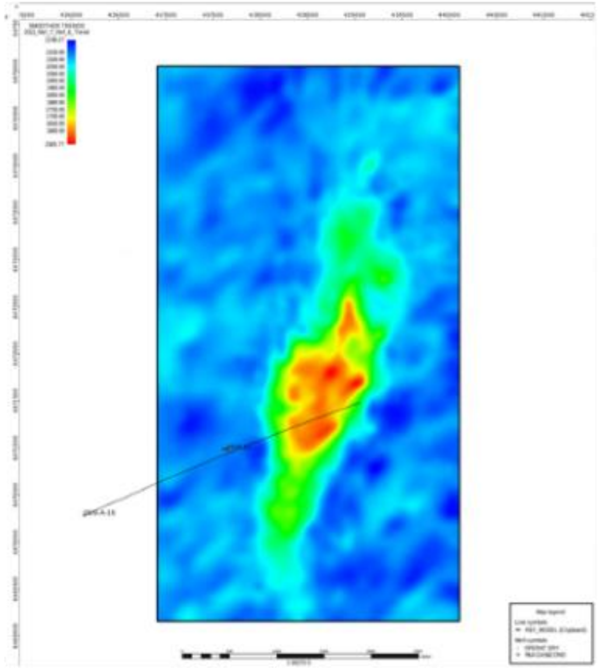
- Interval velocities trend maps from 2013 stacking velocity models – applied to intervals defined by reflectors interpreted across the survey area (Ref 7, 6 and 5)

TopUtsiraFm-REF 7



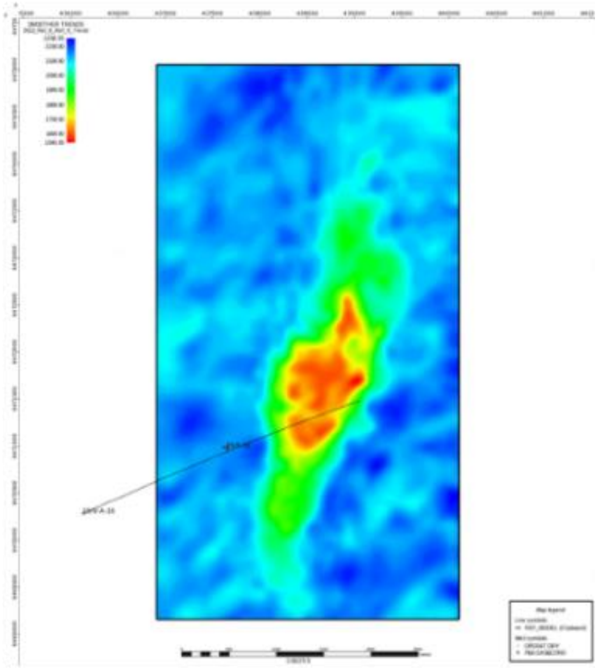
Statistics	Z	X	Y
Min	1478.24	436910.2	6469154
Max	2219.31	440110.2	6475054
Mean	2078.84	438510.2	6472104
Sum	252705776		
Std	121.62		

REF 7-REF 6



Statistics	Z	X	Y
Min	1505.77	436910.2	6469154
Max	2238.27	440110.2	6475054
Mean	2082.74	438510.2	6472104
Sum	253180352		
Std	122.33		

REF 6 – REF 5

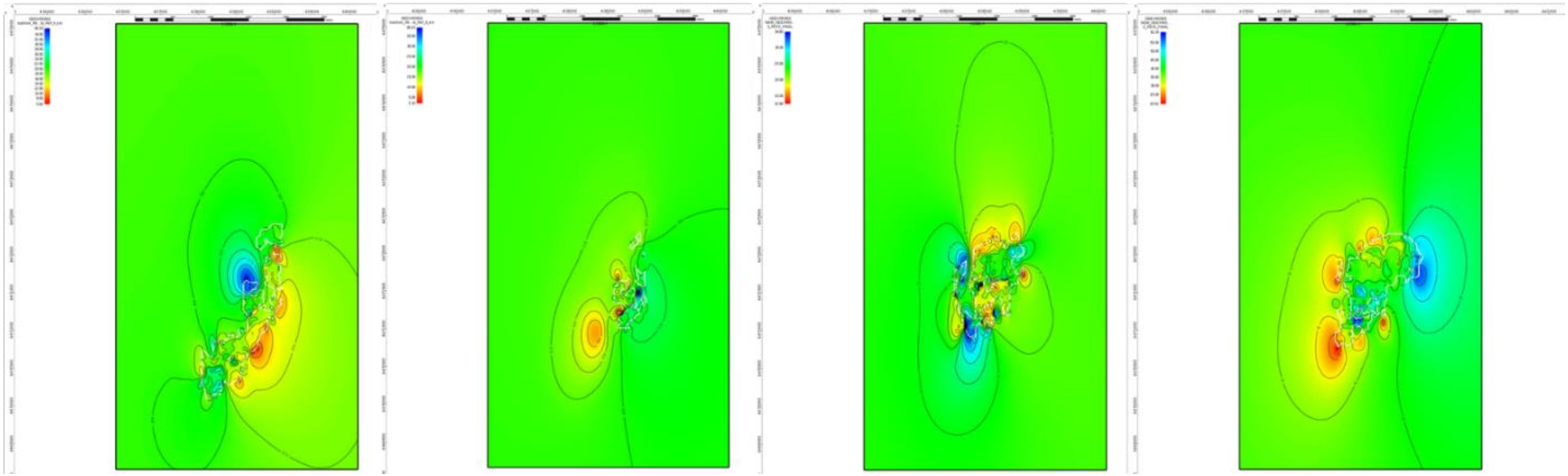


Statistics	Z	X	Y
Min	1505.77	436910.2	6469154
Max	2238.27	440110.2	6475054
Mean	2082.74	438510.2	6472104
Sum	253180352		
Std	122.33		

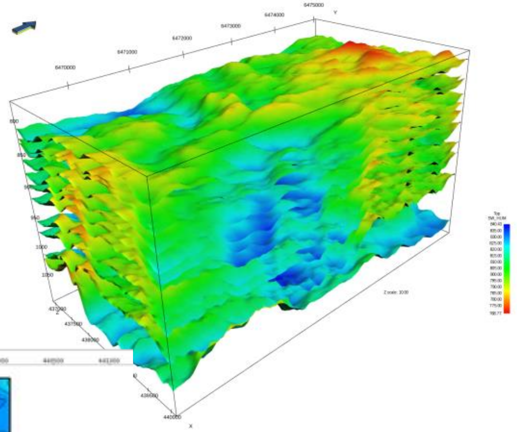
HUM - Thickness and Velocities

- Isochron maps extrapolated beyond the CO_2 plumes´ imaging areas defined for the deep reflectors intervals (Ref 4, 3, 2 and 1) – higher uncertainties were assigned to these intervals

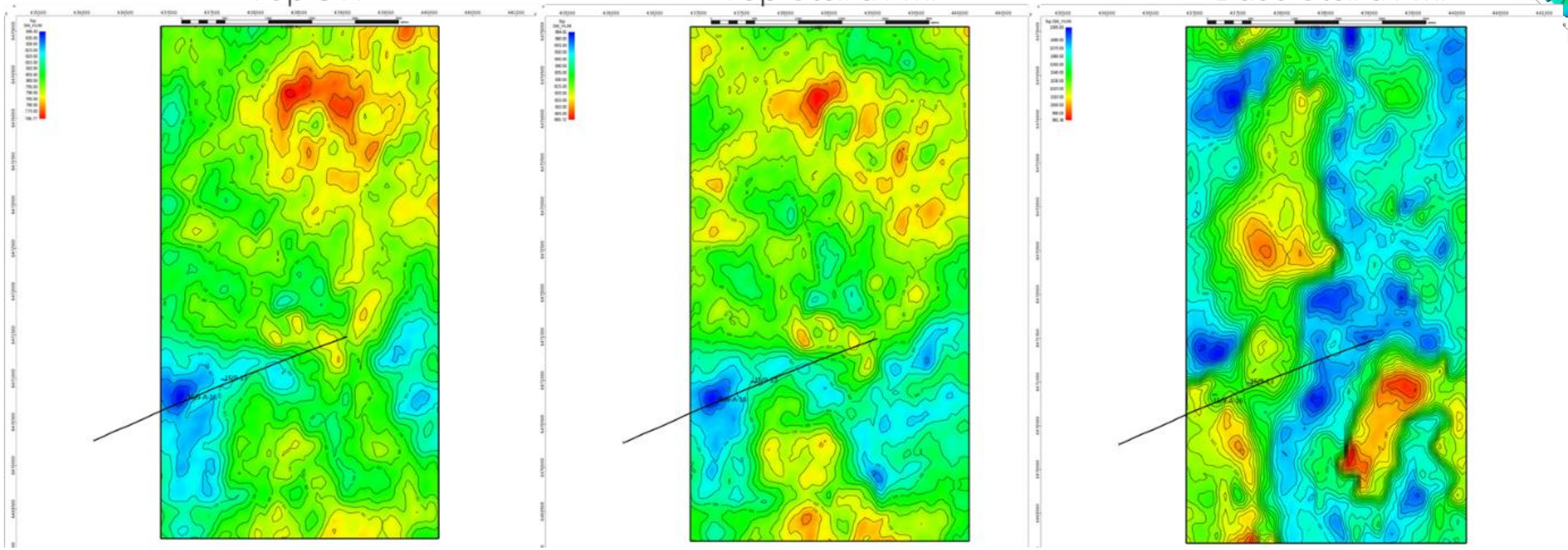
REF 5 – REF 4 | REF 4 – REF 3 | REF 3 – REF 2 | REF 2 – REF 1



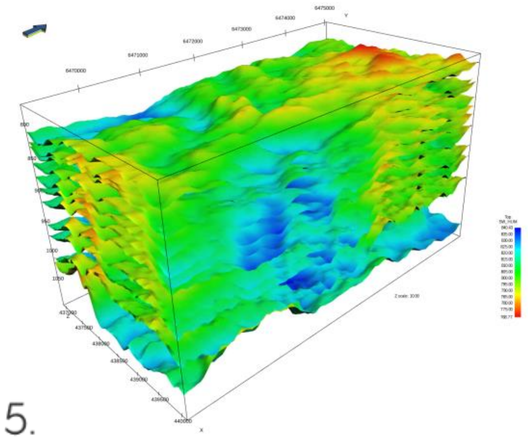
HUM – Output Depth Surfaces



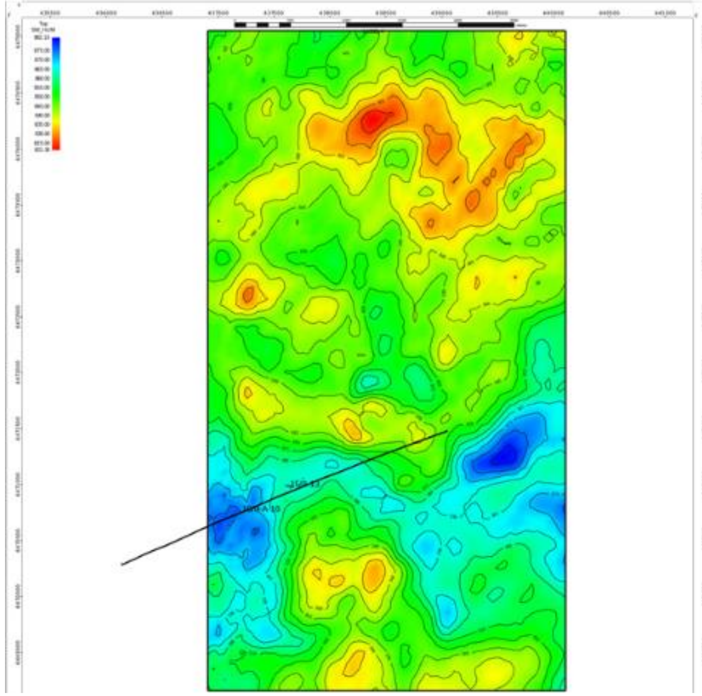
Top SW | Top Utsira Fm. | Base Utsira Fm.



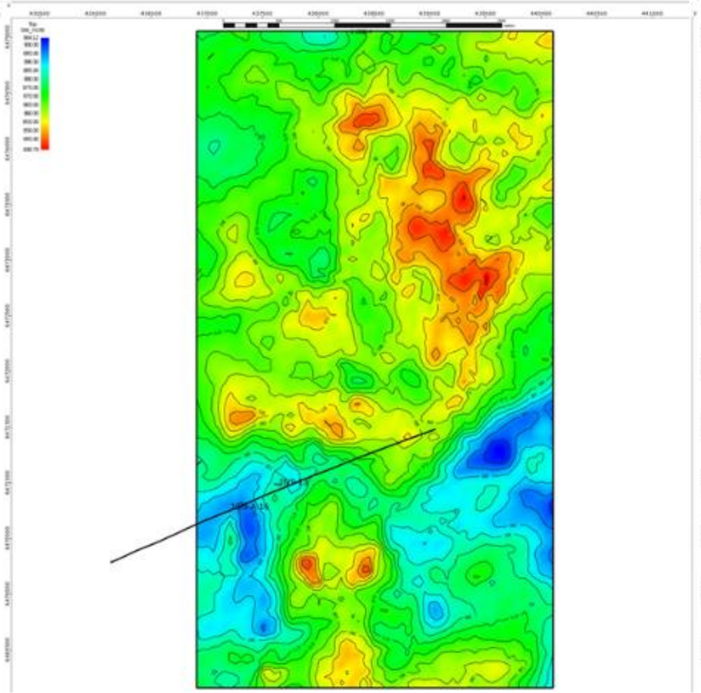
HUM – Output Depth Surfaces



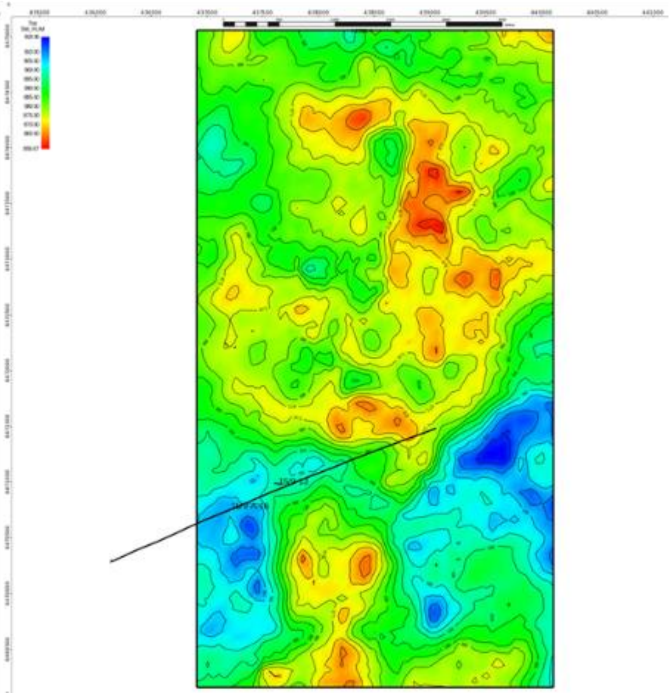
Reflector 7



Reflector 6.



Reflector 5.



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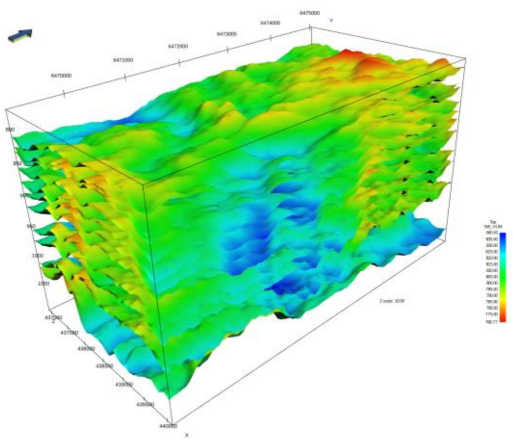
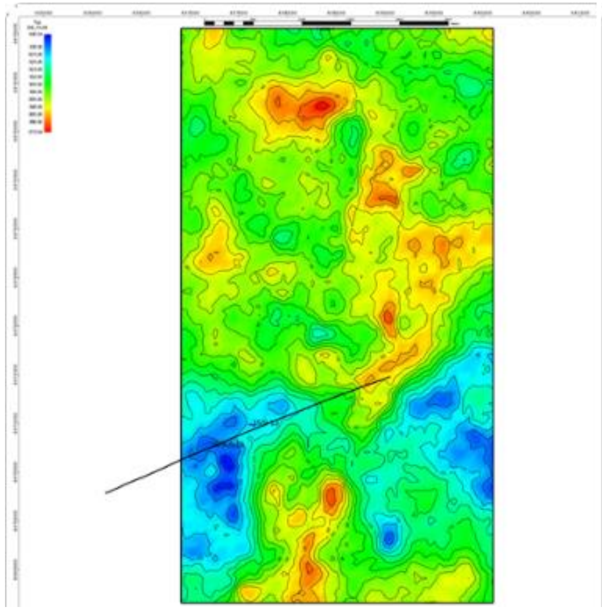
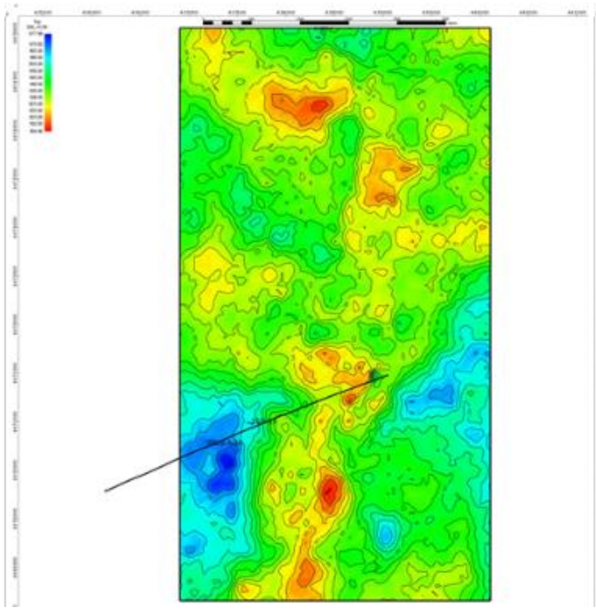


HUM – Output Depth Surfaces

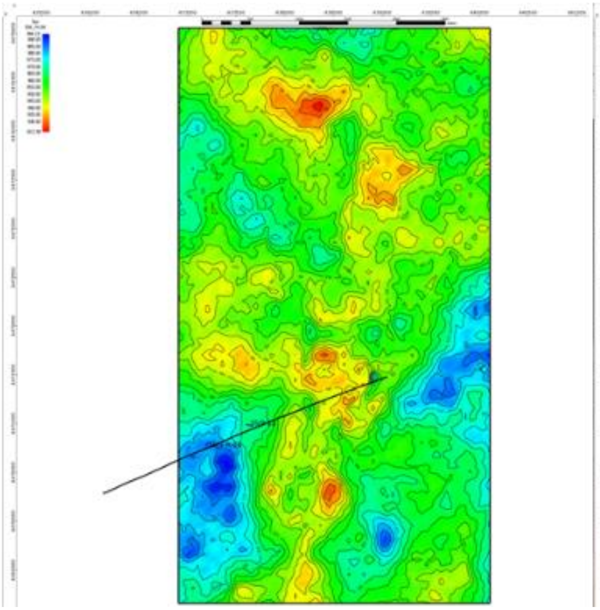
Reflector 4



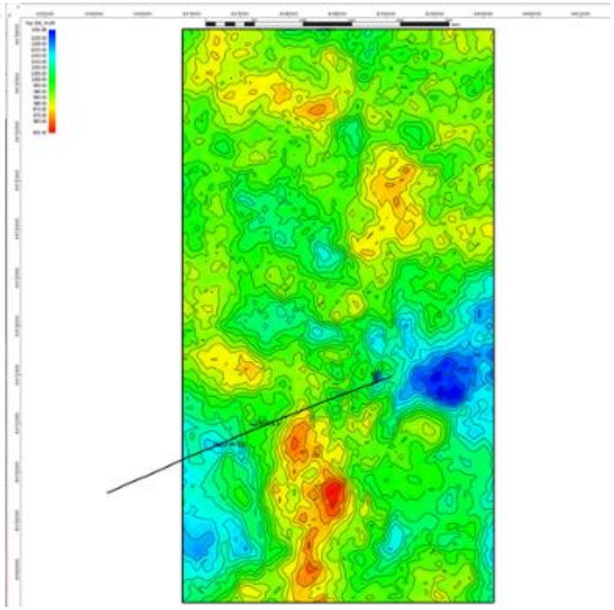
Reflector 3



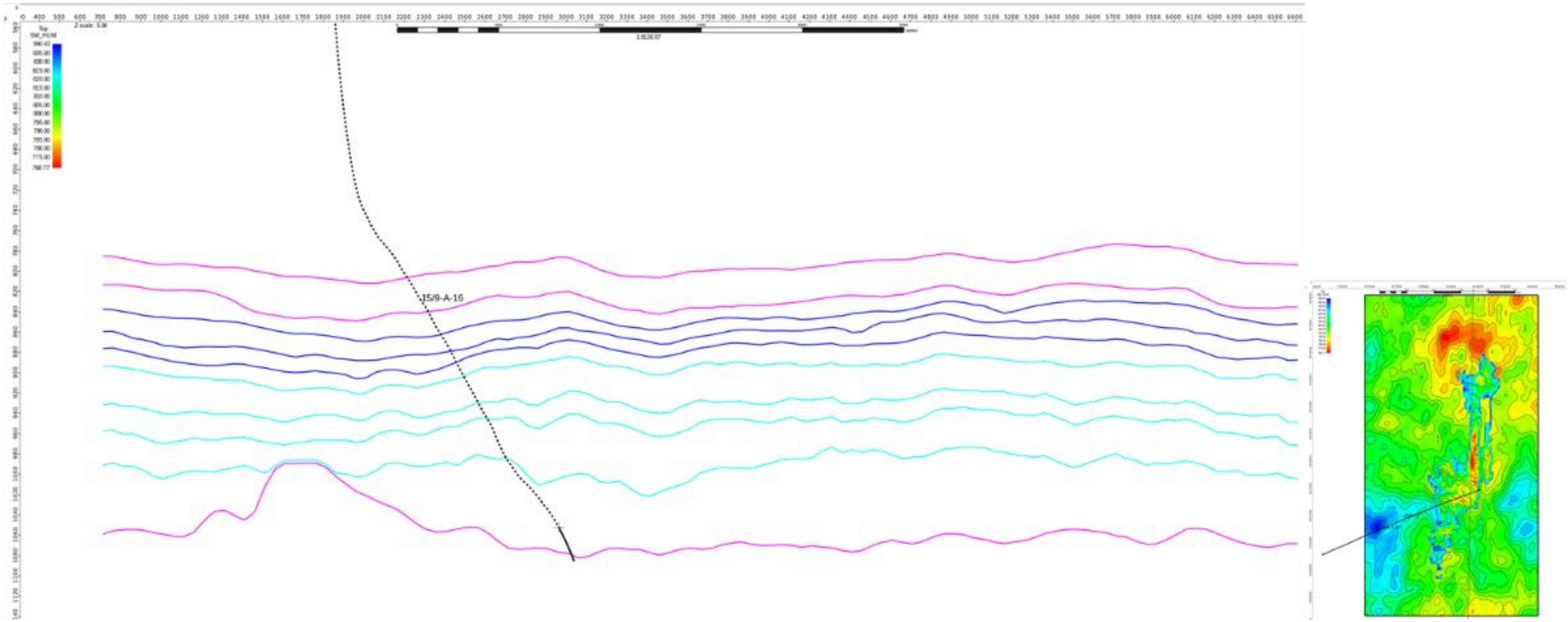
Reflector 2



Reflector 1

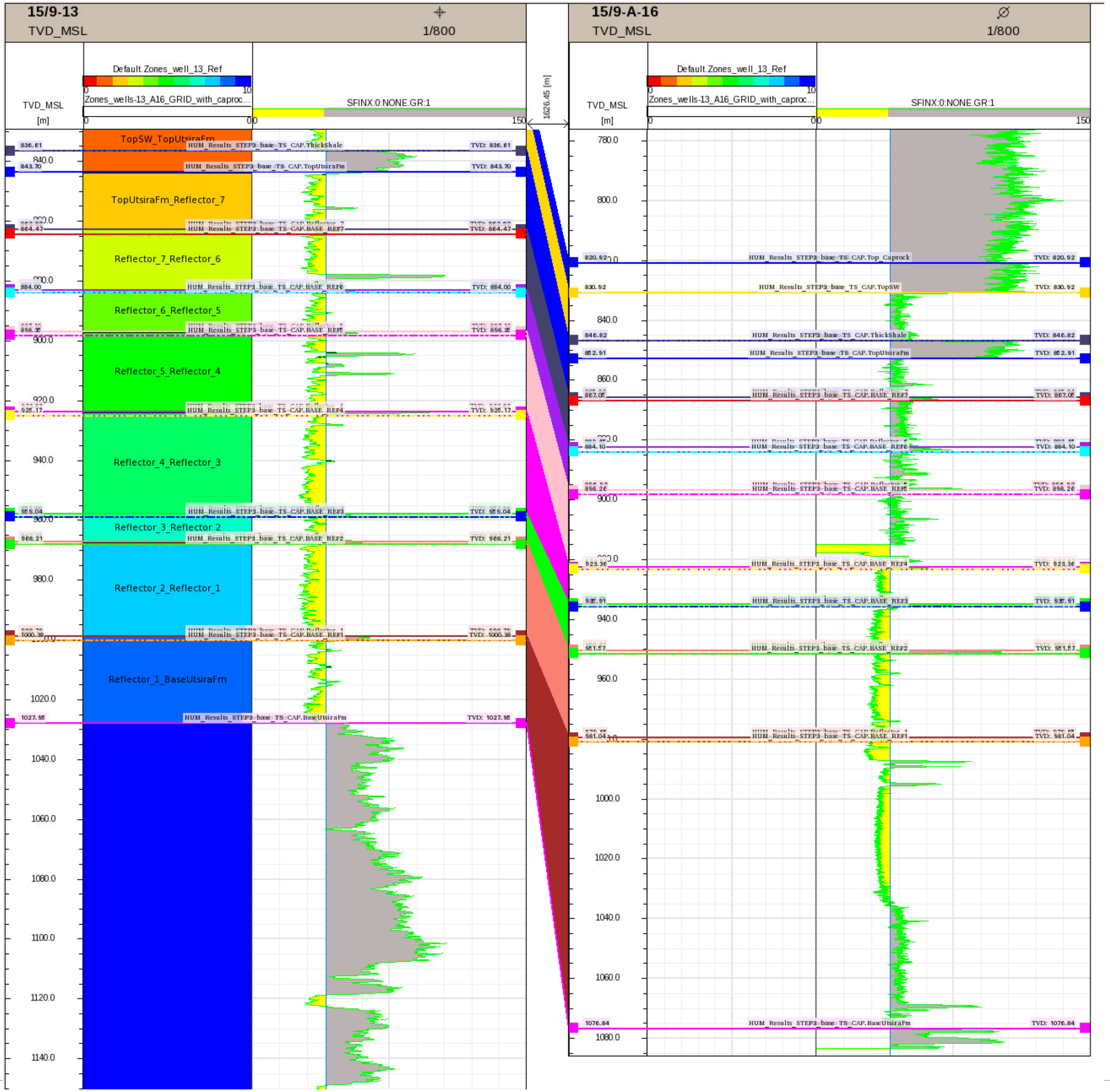


HUM – Output Depth Surfaces

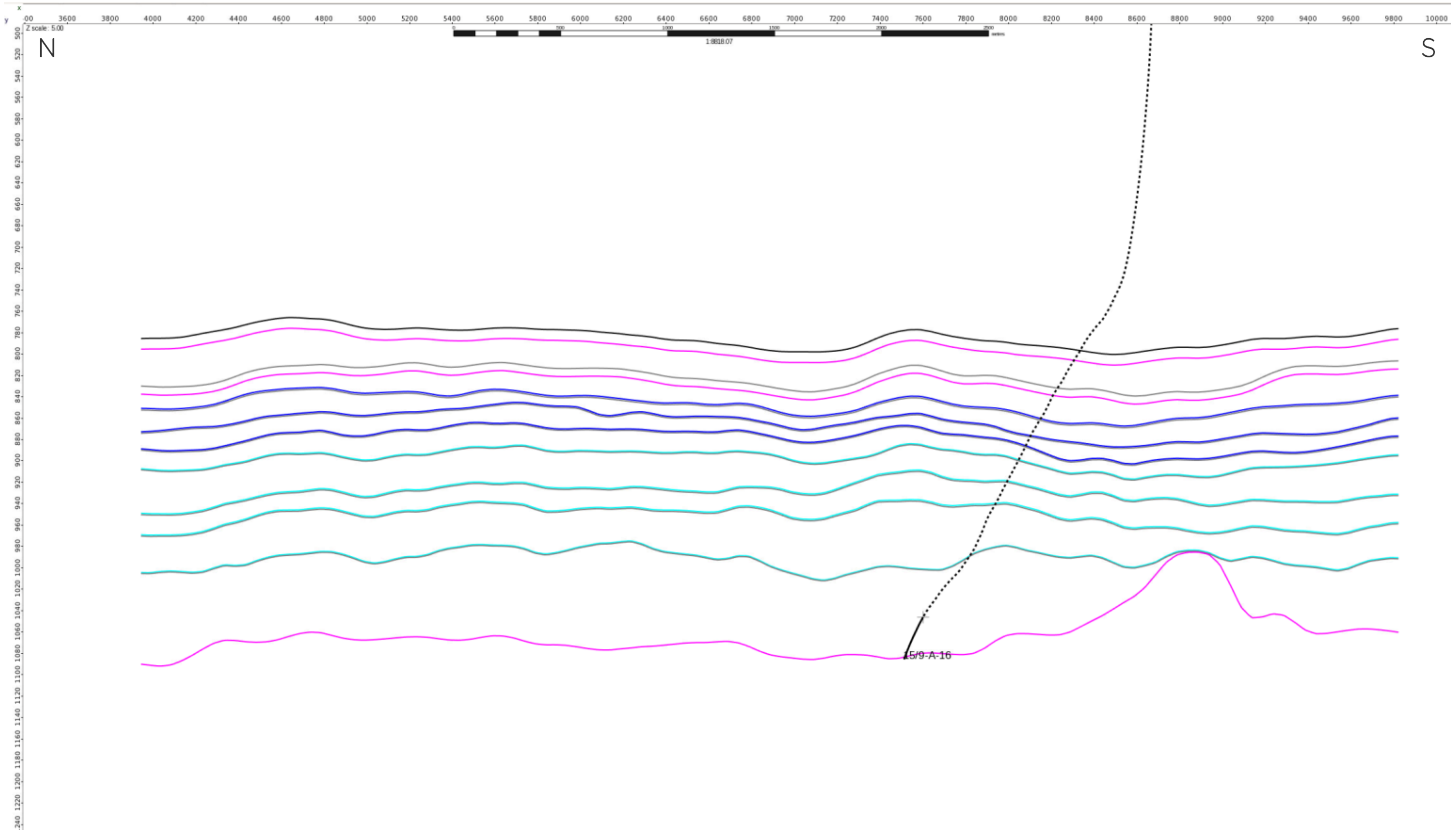


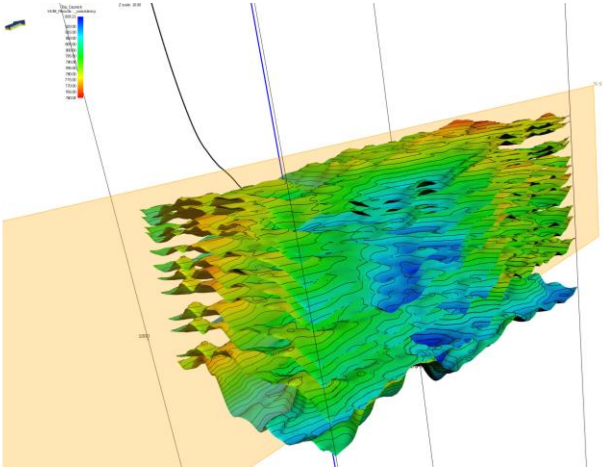
Wells picks for grid

- In RMS the surfaces need to be calibrated to the wells (wells picks and/or zone logs) prior to the grid building process, particularly since the injector well 15/9-A-16 is nearly horizontal
  - Surfaces within the Utsira Formation were adjusted to well 15/9-A-16, except for reflectors 5 and 1 due to limitations in the well adjustment functionality in RMS considering this well's inclination and proximity to well 15/9-13. Therefore these reflectors do not have corresponding GR peaks at this well
- Based on the HUM depth surfaces, base reflectors and the Thick Shale were built from the well picks with the Stratigraphic Modelling process in RMS
- Top Caprock was given 50 m constant thickness from Top SW (although it is much thicker in reality)



Depth Surfaces for grid





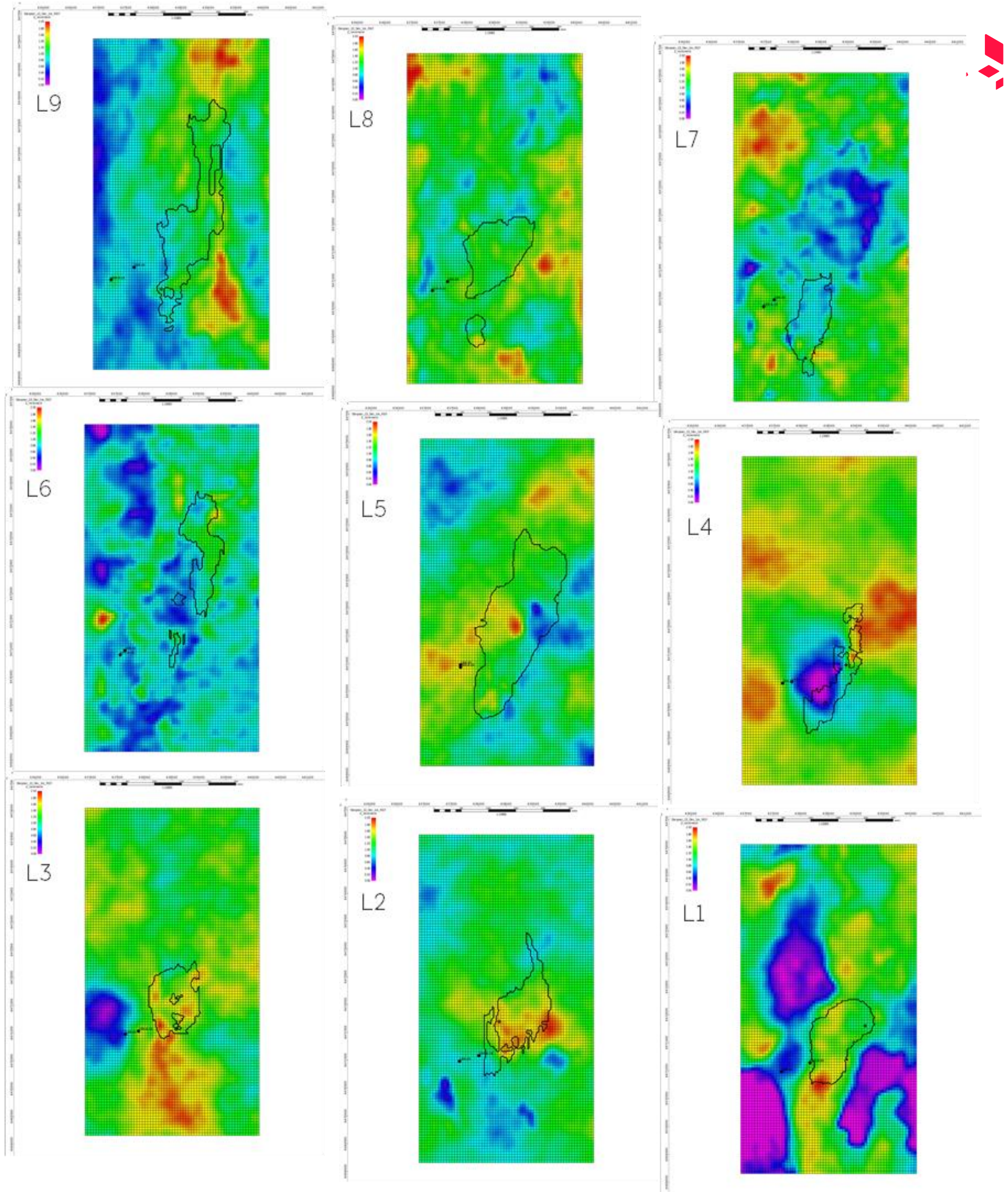
Grid Purpose and Resolution

Grid intended to be used for simulation to capture CO2 plume distribution (history match and prediction)

- Graphic shows boundary polygons for each plume layer (2010) overlain corresponding zone in the grid Z-increment property (thickness in the grid)

Grid resolution choices:

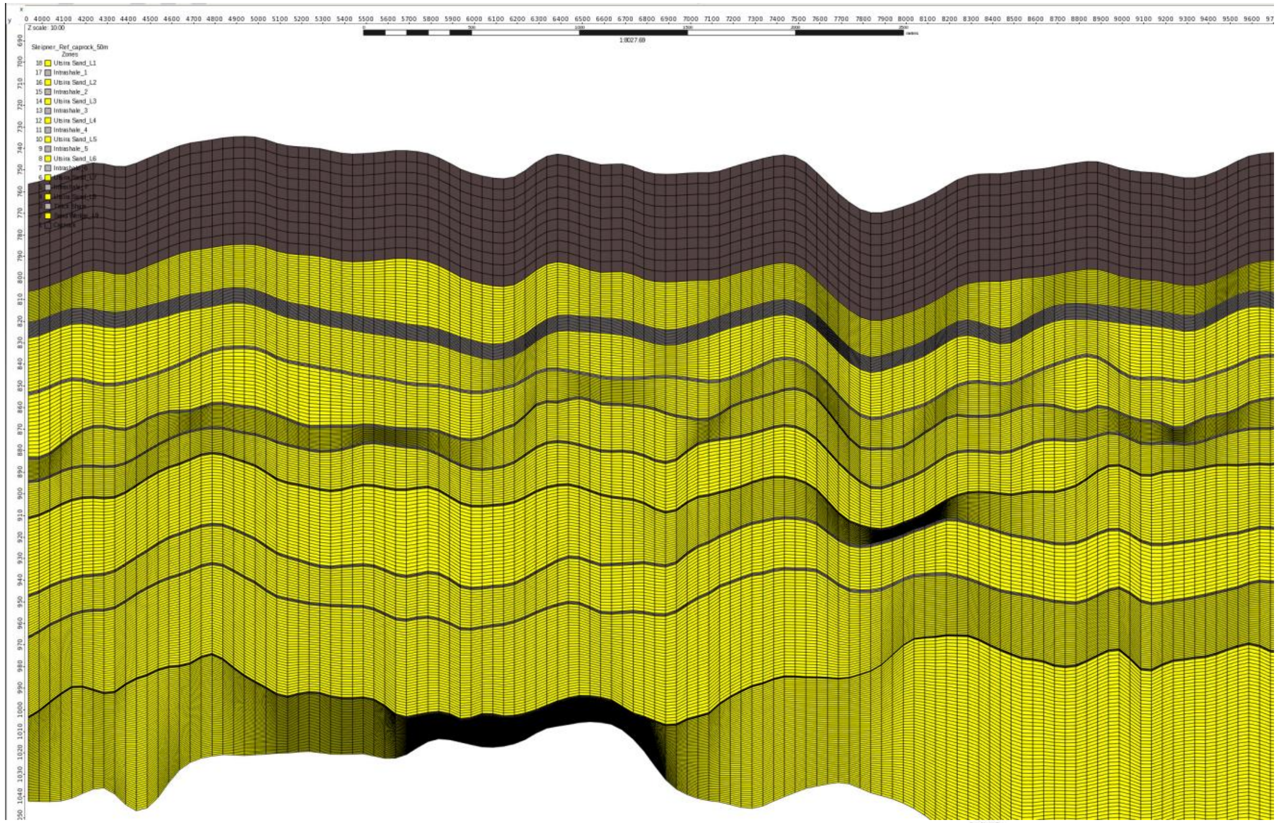
- 50 m x 50 m in X and Y
  - Seismic resolution 12.5 m
  - Smallest areas of the plumes' lateral extensions are about 100 m wide (some exceptions) so captured with 2 cells
- ~2 m thick for sandstone layers (CO2 plume layers thickness estimated ~8 to 20 m) and 5 m cell thickness in caprock
- ~0,5 m thick cells for shales baffles (that is ~1m thick layers represented vertically with at least 2 cells)
- Proportional layering scheme (least impact on flow)

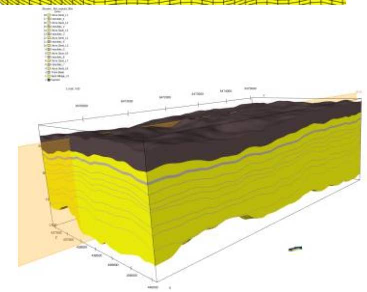


Sleipner Reference Model Grid

- Well picks constrain Thick Shale and laterally continuous shales
- 18 zones modelled:
    - 8 reservoir zones within the Utsira Fm. (L1 to L8) interbedded with 7 laterally continuous intrashale layers (~1 m)
    - Thick Shale layer (~7.6 m)
    - Sand Wedge
    - Caprock (50 m)
- Total of ~2 million cells (64x118x263)

Zone name	Number of layers
Caprock	10
Sand Wedge_L9	21
Thick Shale	16
Utsira_L8	16
Intrashale_7	3
Utsira_L7	16
Intrashale_6	3
Utsira_L6	17
Intrashale_5	3
Utsira_L5	15
Intrashale_4	3
Utsira_L4	23
Intrashale_3	3
Utsira_L3	15
Intrashale_2	3
Utsira_L2	35
Intrashale_1	3
Utsira_L1	58





Petrophysical Parameters – SPE table (2010)

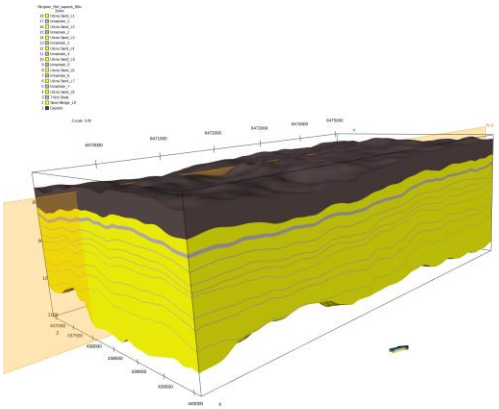
- For base case properties we used reference values from the SPE paper Singh et al., 2010.

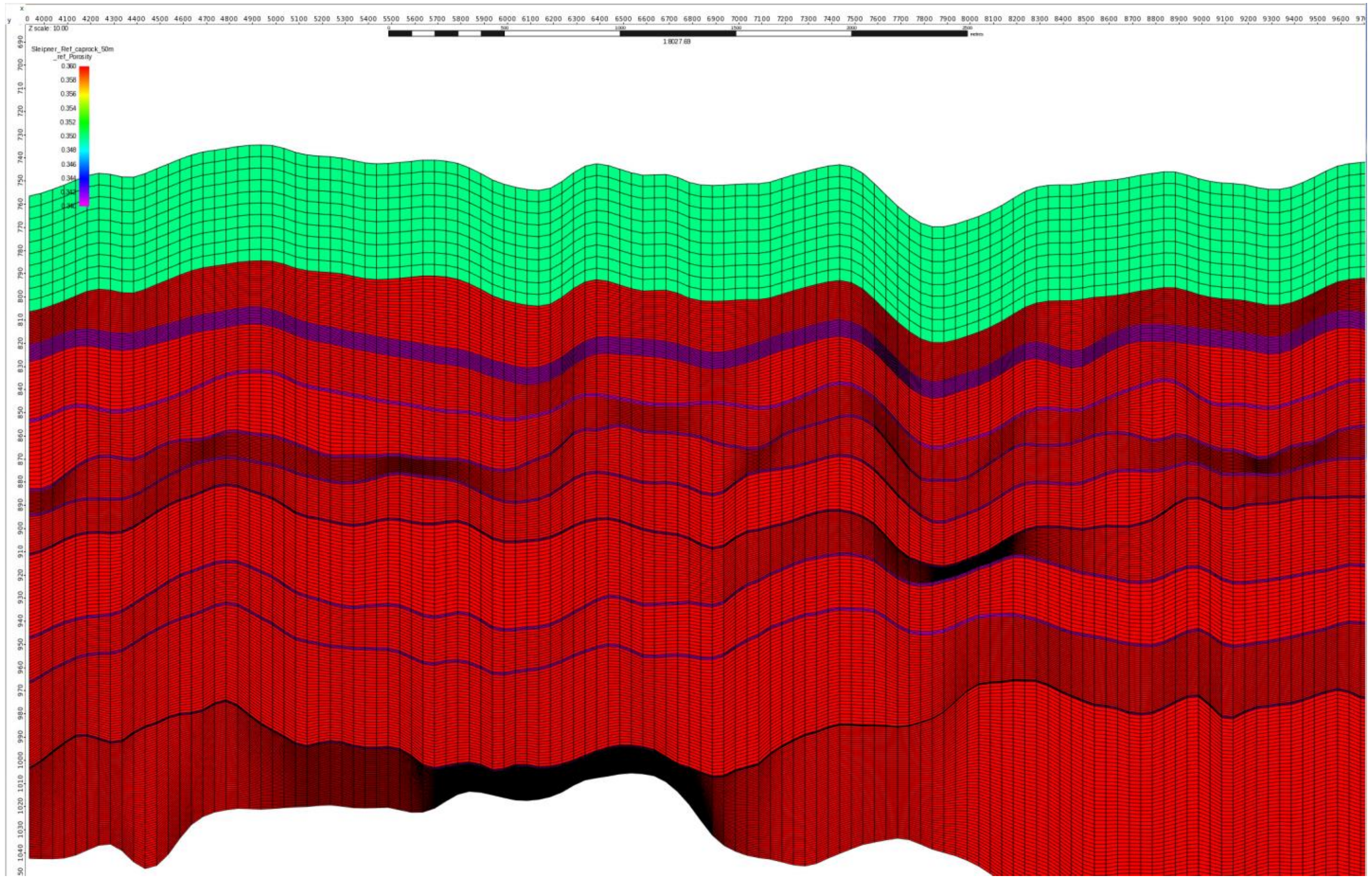
Sleipner Reference Model Input Parameters (SPE 2010)					
Model parameters	**Symbol**	**Units**	**Assumed reference case properties**	**Range**	**References and comments**
Caprock porosity	ϕ_{cap}	%	35	34-36	Springer and Lindgren (2006)
Utsira porosity	ϕ_{fmn}	%	36	27-40	Lothe and Zweigel (1999); Holloway et al. (2000)
Shale porosity	ϕ_{sh}	%	34	31-38	Zweigel et al. (2000); Yang and Aplin (2004).Porosity in shales is very uncertain and controlled by clay content and effective stress.
Caprock permeability	k_{cap}	md	0,0010	0,00075-0,0015	Springer and Lindgren (2006)
Utsira permeability	k_{xy}	md	2000	1100-5000	Lindeberg et al. (2000)
Shale permeability	k_{sh}	md	0,0010	0,00075-0,0015	Springer and Lindgren (2006). Assume same as caprock, but has a large uncertainty.

Sleipner Reference Model Grid

- Base-case Porosity is homogeneous

Model parameters	Symbol	Units	Assumed reference case properties
Caprock porosity	ϕ_{cap}	%	35
Utsira porosity	ϕ_{fmn}	%	36
Shale porosity	ϕ_{sh}	%	34

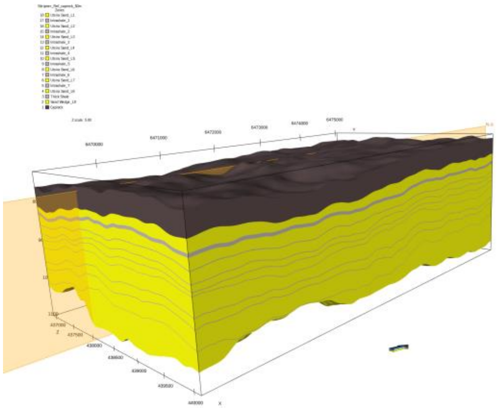


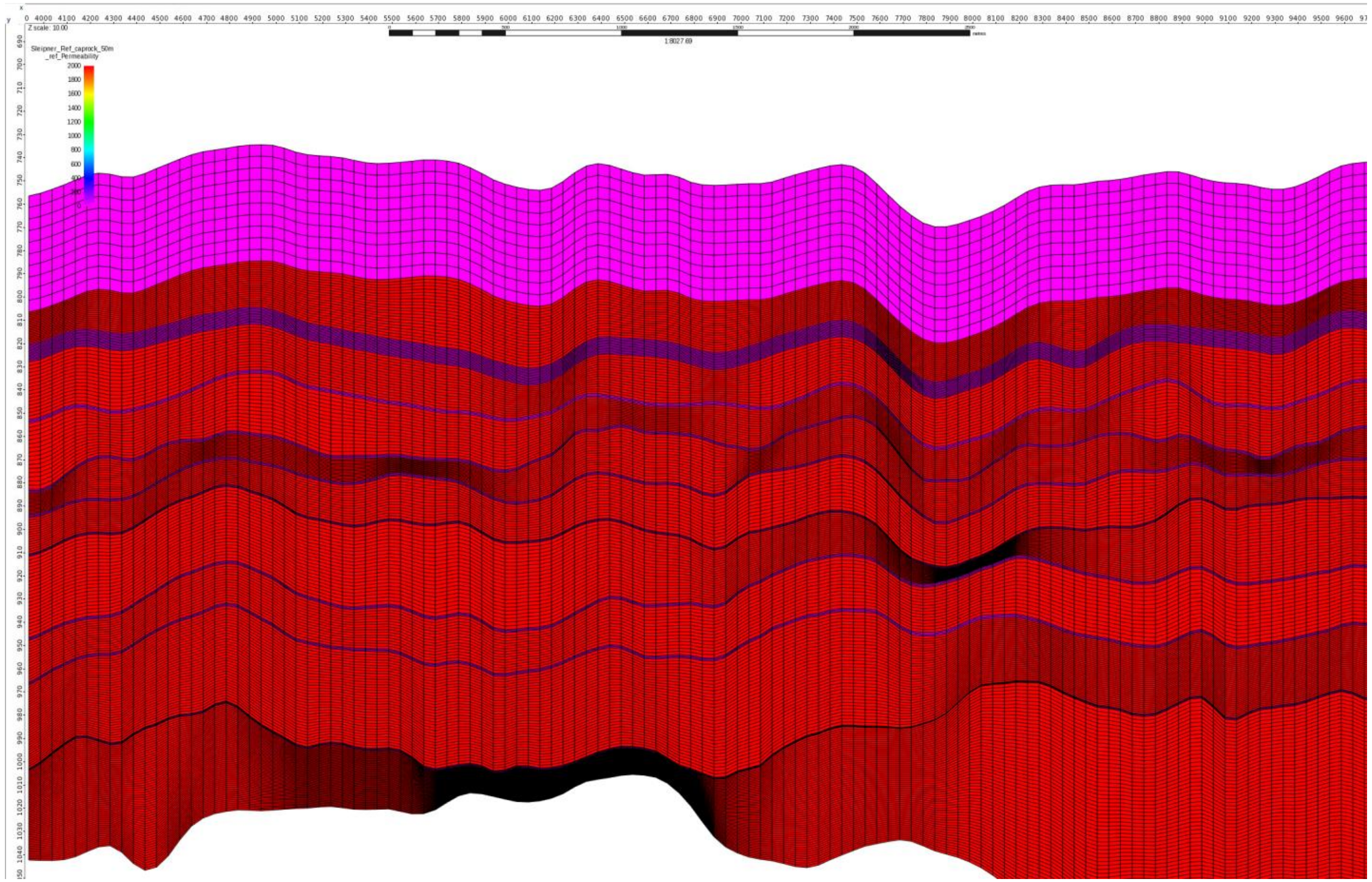


Sleipner Reference Model Grid

- Base-case Permeability in Homogeneous

Model parameters	Symbol	Units	Assumed reference case properties
Caprock permeability	k_{cap}	md	0,0010
Utsira permeability	k_{xy}	md	2000
Shale permeability	k_{sh}	md	0,0010





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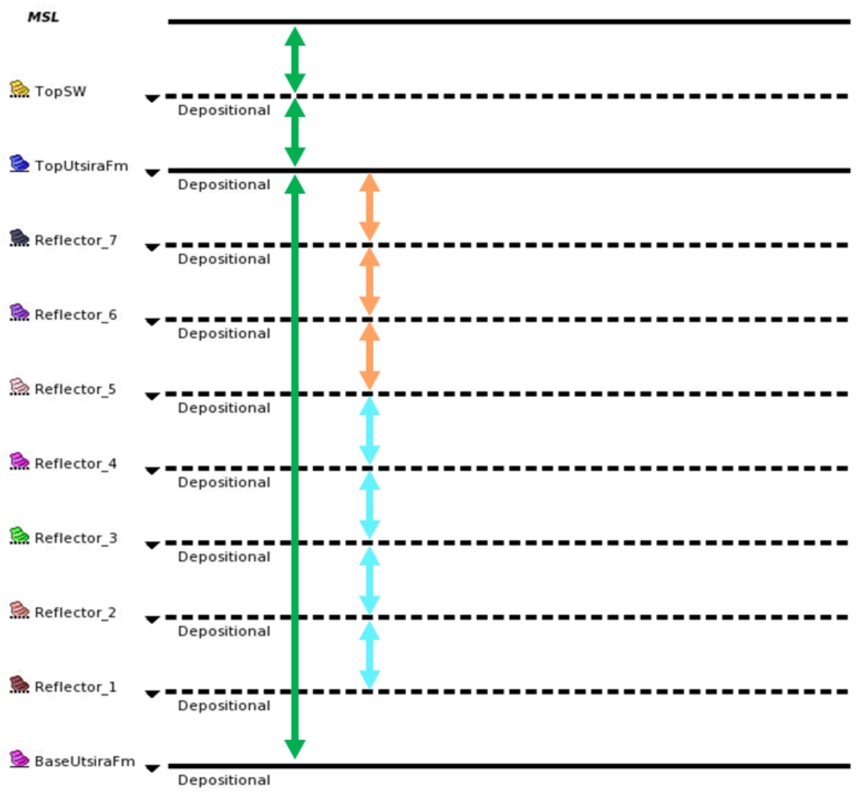
Overview of Package for CO2 data share (CSDC project)

Following items were exported to the data package:

- Wells 15/9-A-16 and 15/9-13 and logs (as previously released in 2011)
- Wells picks for the grid (includes Reflectors 7 to 1 and Thick Shale)
- Extracted interval velocity maps *(1994 INTERVALVels; ST12018_VEL_RMS_STK)*
- HUM interval velocity trends (adjusted extracted interval velocity maps for HUM)
- HUM isochrons for the deep reflectors (L4 to L1)
- Depth Surfaces for the grid (includes Caprock, Thick Shale and Base Reflectors 7 to 1)
- Sleipner Reference Model grid with porosity and permeability properties (RESCUE and ECLIPSE GRDCECL)

Folders are:

- DepthSurfaces_Grid
- Extracted_Interval_Velocity_Maps
- HUM_Interval_Velocity_Trends
- HUM_Isochrons_Deep_Reflectors
- Sleipner_Reference_Model_2019_Grid
- Wells_picks_Grid
- Wells_released_2011



Some key supporting references

- Cavanagh, A.J., Haszeldine, R.S. and Nazarian, B. (2015) The Sleipner CO_2 storage site: using a basin model to understand reservoir simulations of plume dynamics. *First Break*, 33, 61-68.
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- Yang, Y. and Aplin, A.C. (2004). Definition and practical application of mudstone porosity/effective stress relationships. *Petroleum Geoscience*. 10, 153-162.
- Zweigel, P., Lothe, A.E., Arts, R. and Hamborg, M. (2000). Reservoir geology of the storage units in the Sleipner CO2 injection case – A contribution to the Saline Aquiner CO2 Storage (SACS) project, SINTEF report.

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