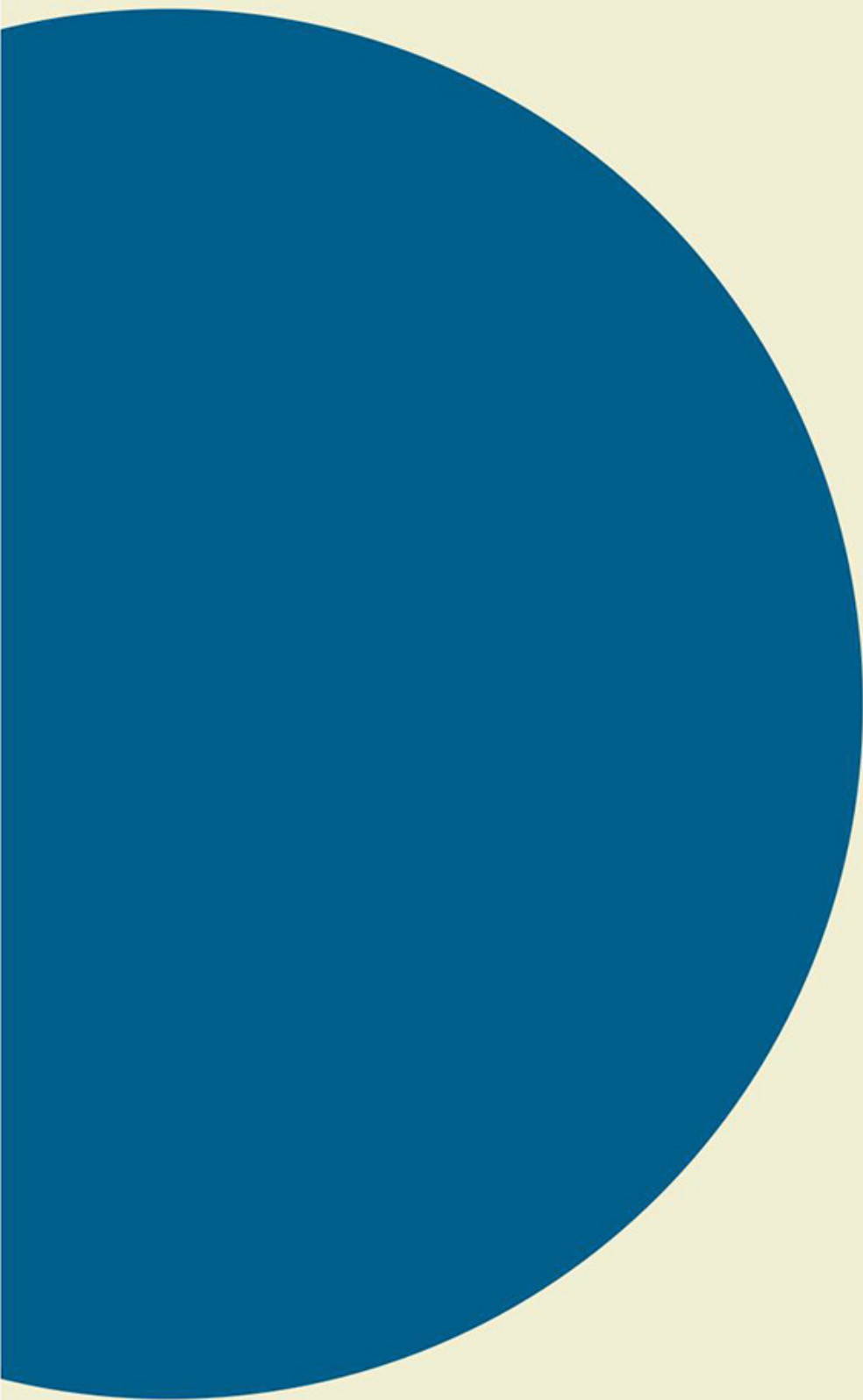


Upscaling of the Roar reservoir model

A GESTCO contribution

Peter Frykman



GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT



GEUS

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INTRODUCTION

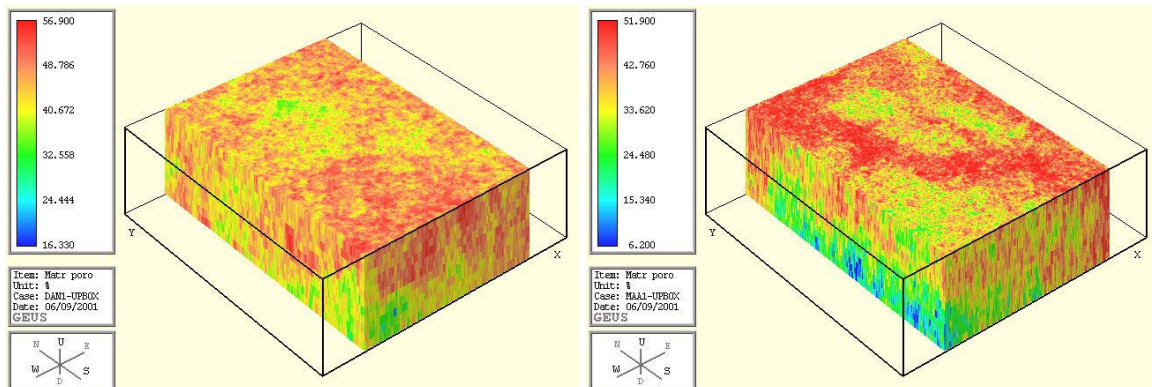
The purpose of the upscaling is to modify the very detailed geostatistical models of the Roar field reservoir units into a coarser grid that is suitable for reservoir simulation. The goal is to preserve some of the heterogeneity and the correct connectivity by an upscaling routine adapted for this.

METHOD

The input for the upscaling is the porosity models from the geostatistical modelling that used a combination of well data, seismic attributes and stochastic modelling of the porosity distribution in the Danian and Maastrichtian part of the reservoir sequence (Vejbæk 1999b; Vejbæk 1999a).

The two units are modelled separately in grids of 253x373 cells with 11 and 14 layers respectively for the Danian and Maastrichtian unit. Cell size in the model is 25 x 25 x 6 m. The upscaling is performed stepwise, starting with separate upscaling of the two units, Danian and Maastrichtian, and proceeding with a merging and further upscaling into the structural grid that is supplied by the maps for the top Maastrichtian and top Danian surfaces. The upscaling is performed with CMoS™ supplemented with a few utility programs to handle the grid calculations. The detailed input and procedures are listed in Appendix 1.

The two geostatistic models have 1,038,059 and 1,321,166 cells respectively, and the goal is to obtain a merged model with a total of between 15,000 to 40,000 cells, which is a suitable size model for a reservoir simulation study.



Figs. 1 and 2 – The original geostatistic porosity models for the Danian and Maastrichtian model boxes.

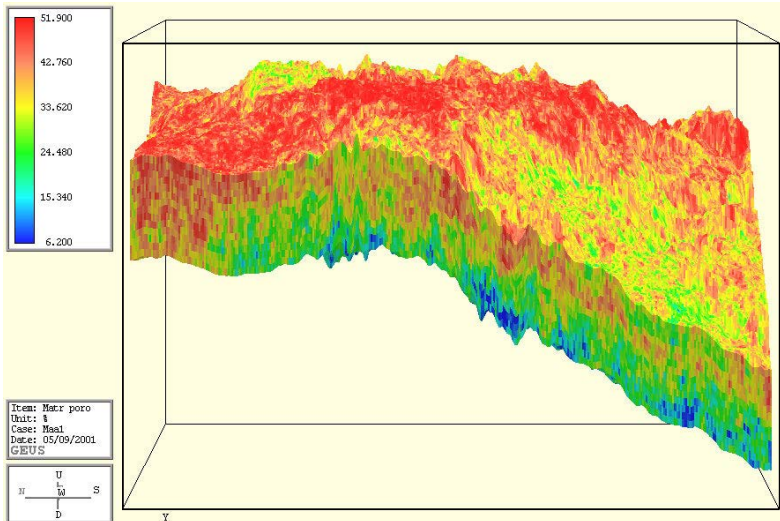
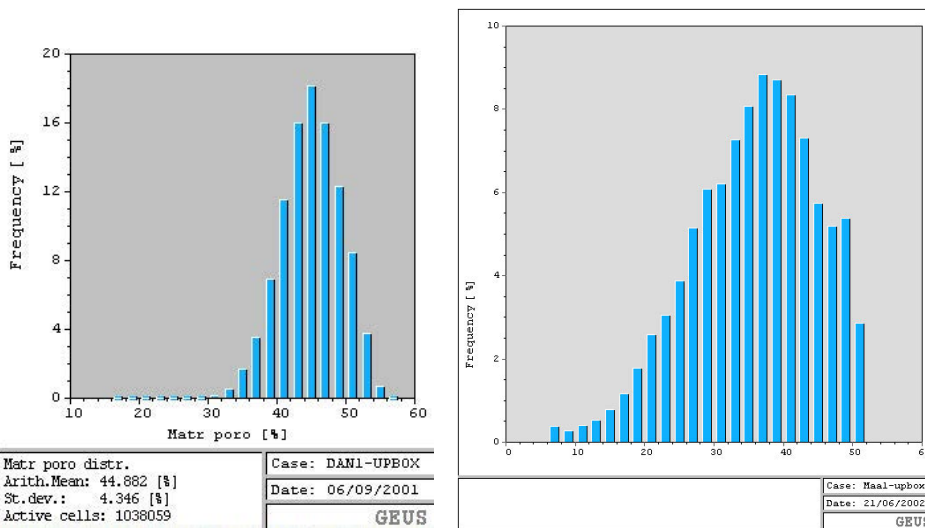


Fig. 3 – the Maastrichtian model deformed with the top-Maastrichtian map to show the correct geometry of the reservoir unit. The image shows the west face of the model.

In the geostatistic model for the Danian package it is seen that very high porosity values have been generated, with maximum values reaching nearly 57% porosity (Fig. 4). These values are deemed extravagantly high, and an alternative model has been produced by limiting the porosity to a maximum of 50.2%. The modified histogram is shown in Figure 6.



Figs 4 and 5 – Histograms of porosity in the original geostatistic models for the Danian and Maastrichtian units.

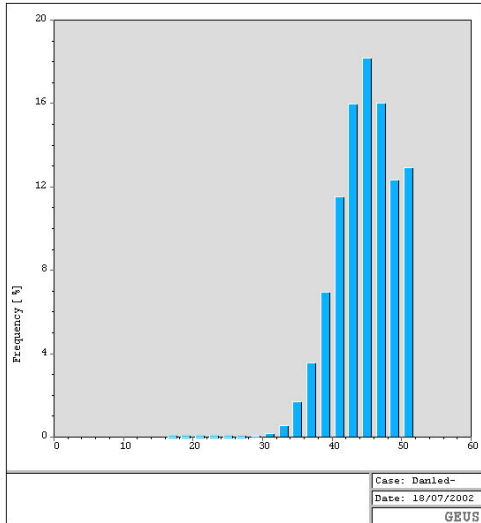


Fig. 6 – The modified porosity distribution for the Danian input model.

The porosity models are used to generate the permeability distribution by establishing a porosity/permeability relation for the two units separately. The relation is partly based on existing data from other reservoirs, since core data are sparse from the Roar field itself. The Roar data show a fair match with the Dan field derived relations (Fig. 7), although some very high permeabilities are seen in the Roar-2A well. These high values are considered abnormally high and could possibly be due to problems in the core analysis routines or originating from fractures in the plug material. These values are therefore ignored for establishing the relation as shown in Figure 7.

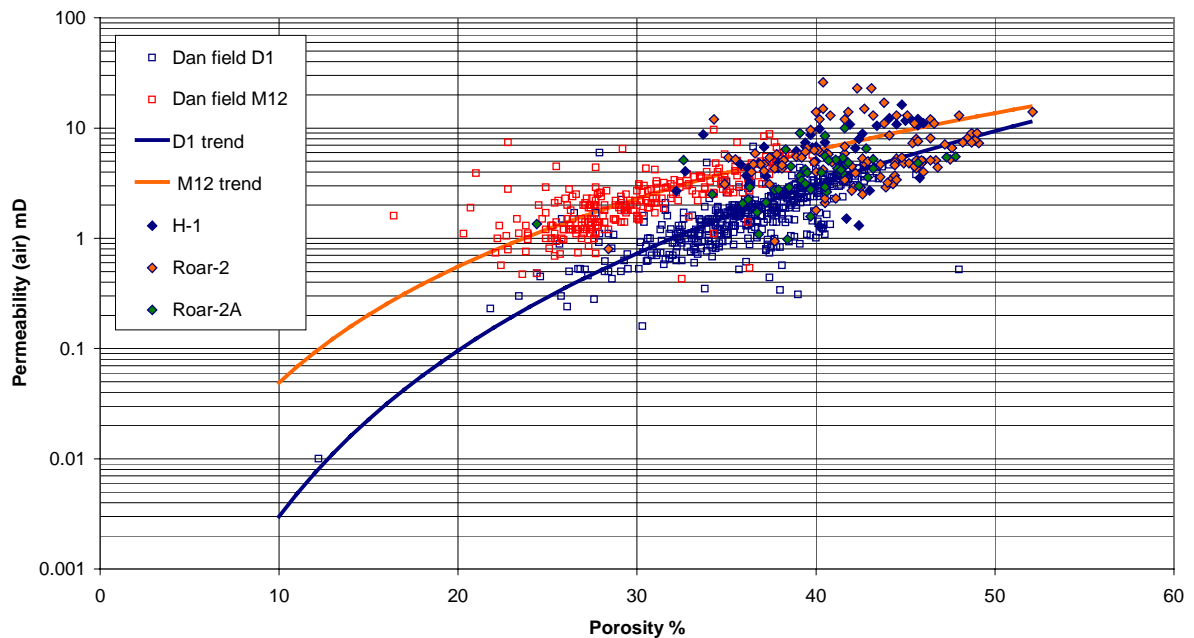
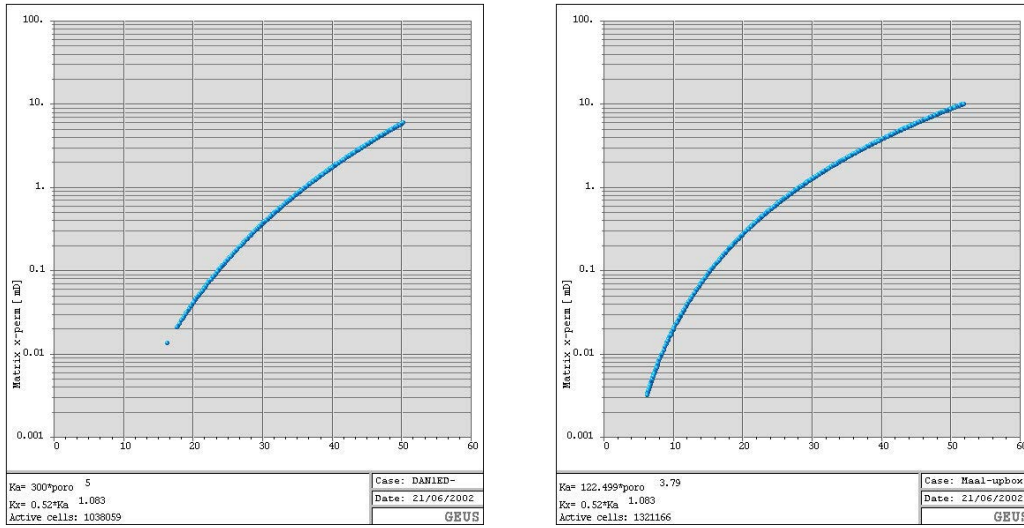


Fig. 7 – the porosity/permeability models for Danian and Maastrichtian chalk, and the core data from the three Roar wells.

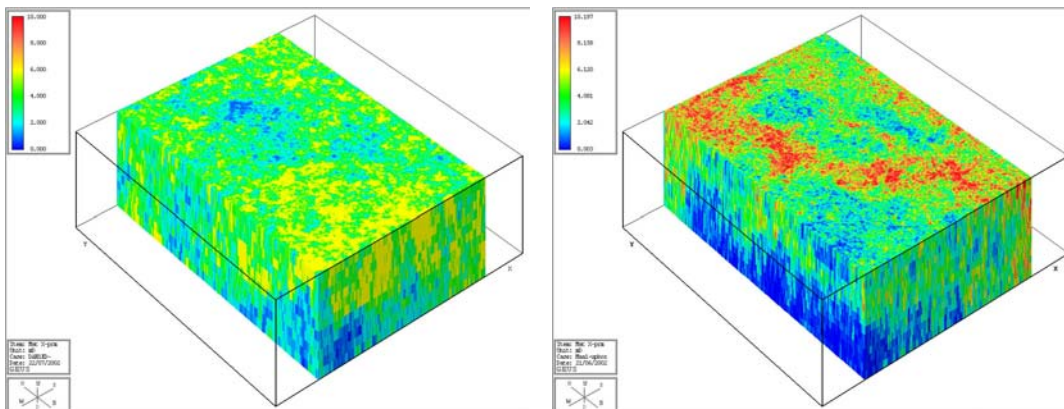
By using the modified porosity model for the Danian and the porosity/permeability relations, the fluid permeability values are generated in the upscaling program, and the relations for the input models are shown in figures 8 and 9.



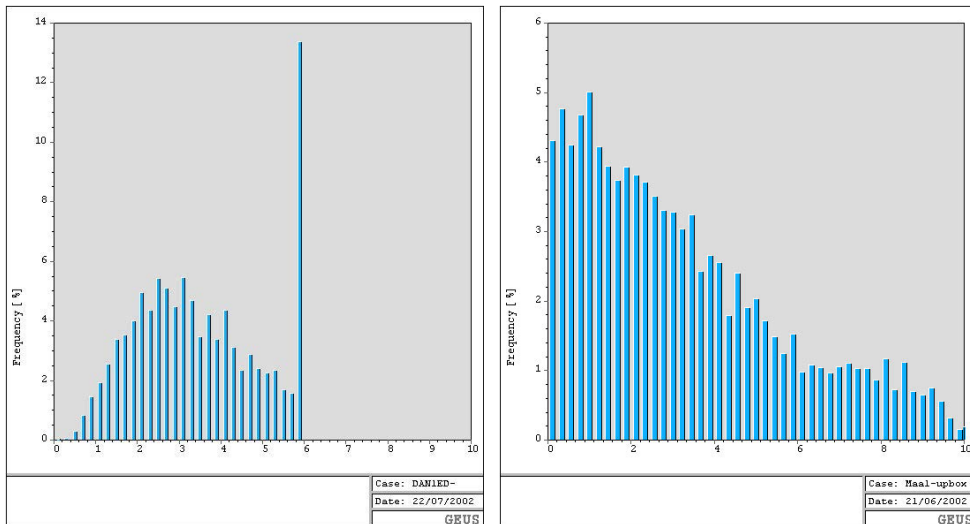
Figs 8,9 – Porosity/permeability (fluid) relations for the Danian and Maastrichtian unit in the detailed input models. The parameters for the functional relation between porosity (fraction) and permeability, and for the conversion to fluid permeability from the input of air permeability are given and summarised in Table 1.

Table 1: Porosity/permeability relation model, and conversion constants for air/fluid permeability.

Porosity (frac.) /permeability relation $k = a * \Phi^b$	a	b	Air permeability to fluid permeability relation $k_f = a * k_A^b$	a	b
Danian	300	5.0	Danian & Maastrichtian	0.52	1.083
Maastrichtian	155	3.5			



Figs. 10,11 – Permeability (fluid) models for the Danian and Maastrichtian model boxes.



Figs 12,13 – Histograms of permeability (fluid) in Danian and Maastrichtian model units prior to upscaling. The pronounced peak around 6 mD for the Danian model is due to the limiting of the porosity to 50.2 %.

Box-upscaling of the two models

This first step in the upscaling is to impose a coarser grid in the x and y direction. The change is from cells of 25x25 m to cells of 200x200 m (Fig. 14).

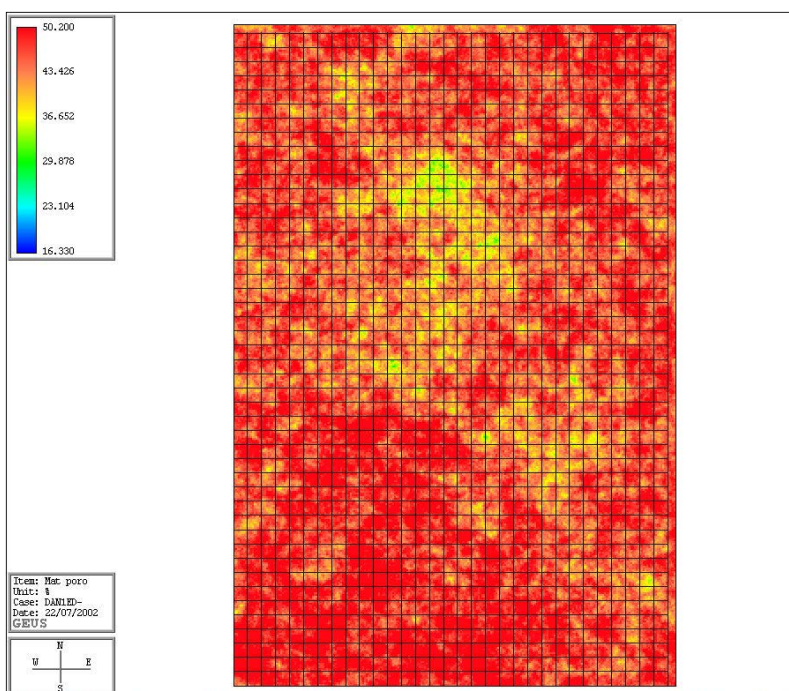


Fig. 14 – The change in grid during upscaling from 25x25 m cells to 200x200 m blocks shown for the top of the Danian model box.

The effect of the upscaling is naturally a reduction in the variance (spread) in the values and a slight change in the correlation structure as described by using the geostatistic scaling laws

(Frykman & Deutsch 2002). This is clearly seen for the Danian porosity and permeability models (Figures 15-24)

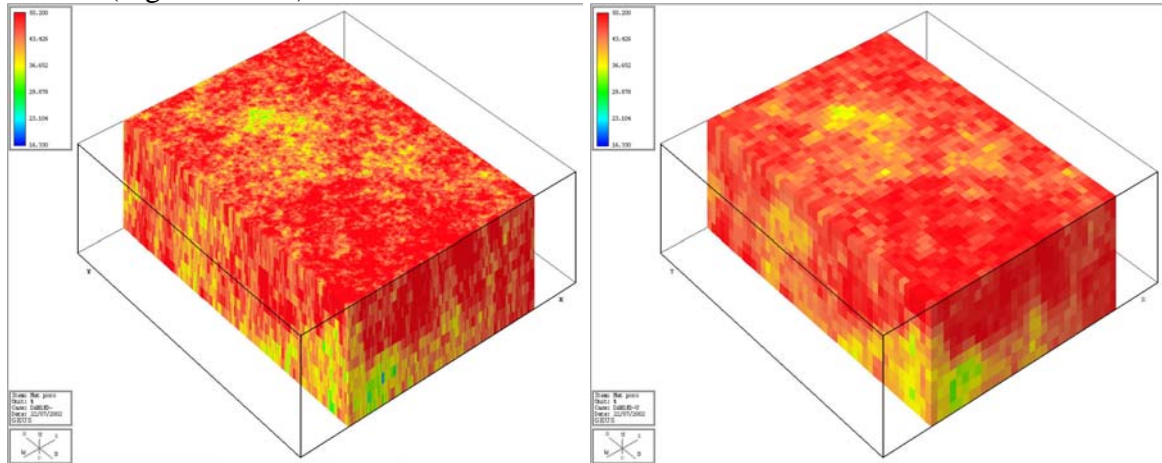


Fig. 15, 16 - The Danian porosity fine and coarse grid for comparison at top Danian level.

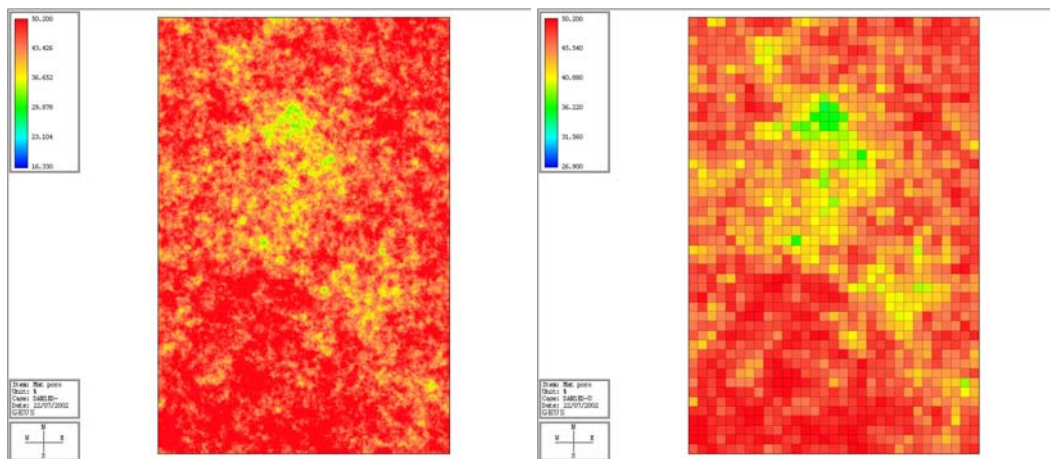


Fig. 17, 18 - The Danian porosity fine and coarse grid for comparison at top Danian level.

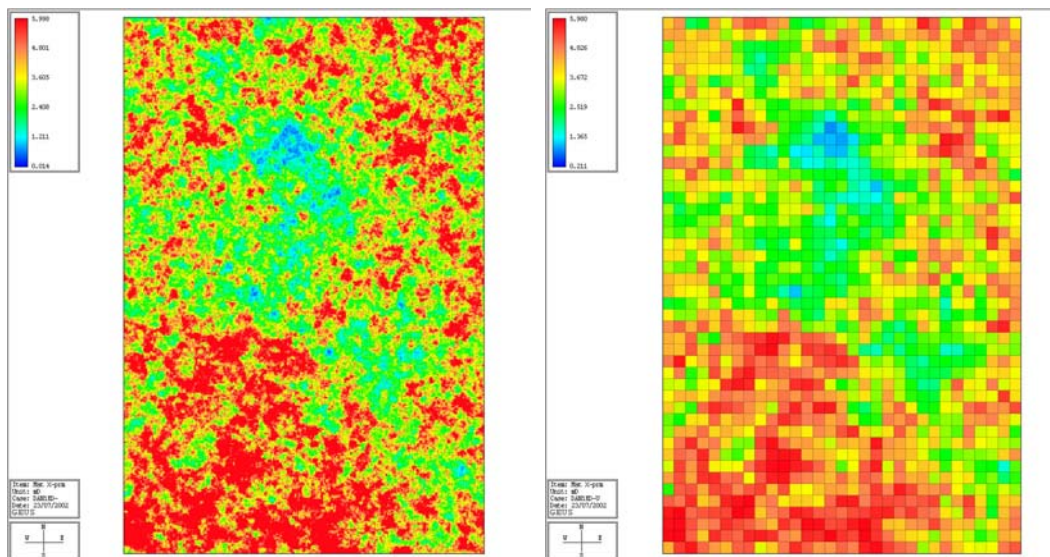


Fig. 19, 20 - The Danian permeability fine and coarse grid for comparison at top Danian level.

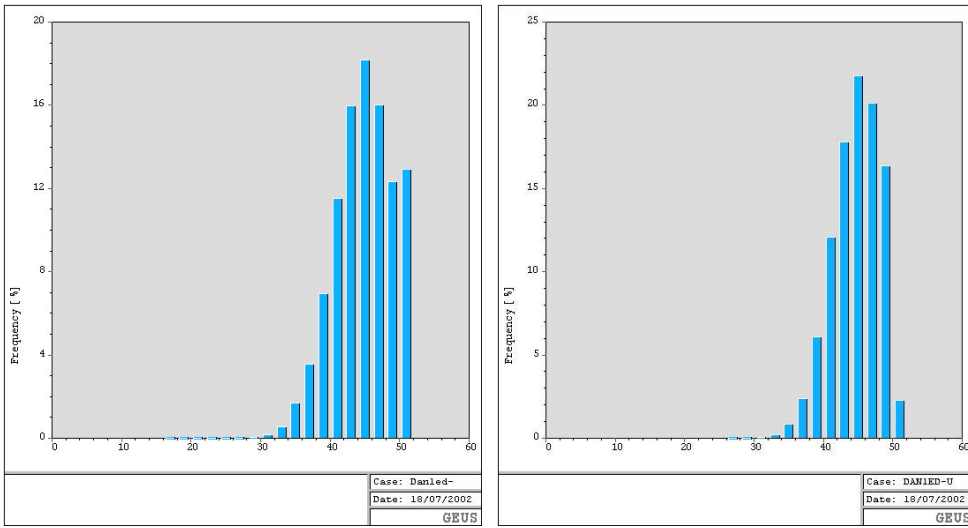


Fig. 21, 22 – Histograms for the input and the upscaled porosity in the Danian model.

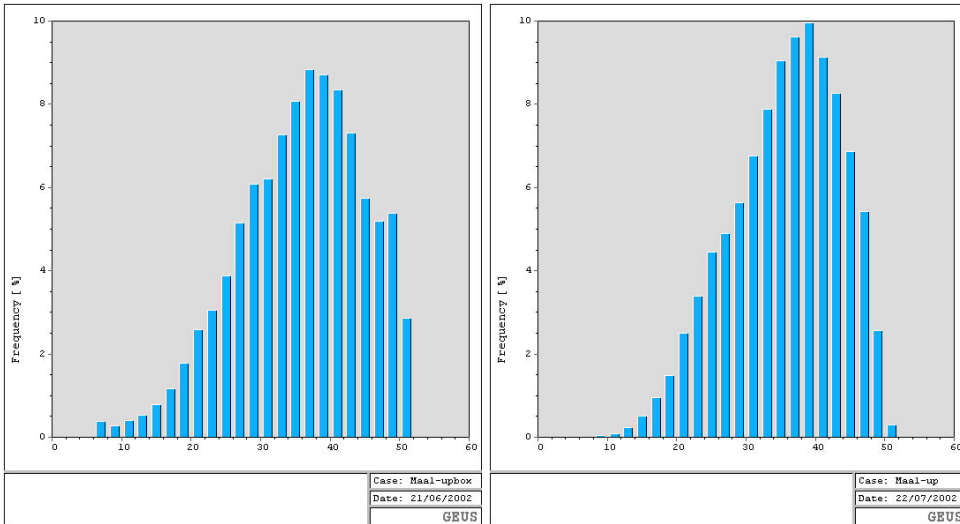


Fig. 23, 24 – Histograms for the input and the upscaled porosity in the Maastrichtian model.

Since the upscaling of the permeability is performed on a flow-based scheme, the porosity-permeability relation shows a slight spread around the original trend-line (Fig. 25)

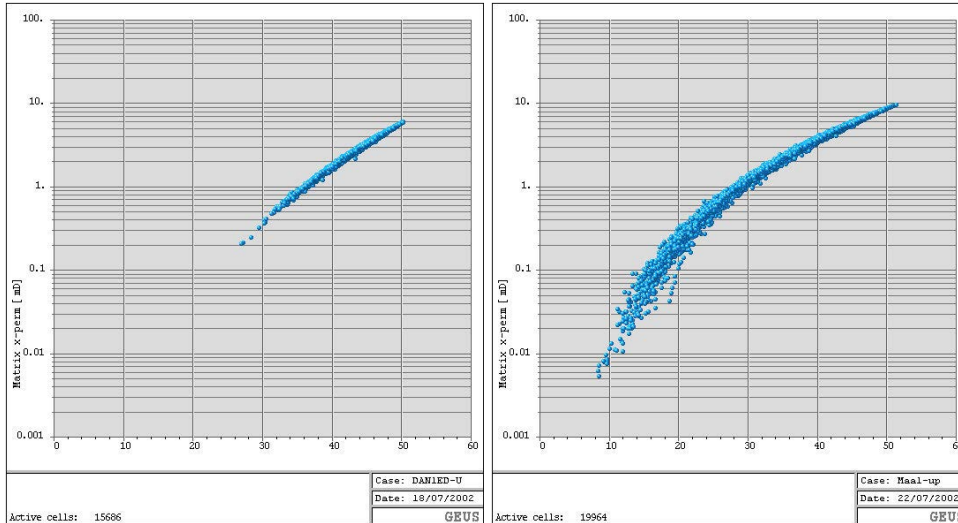


Fig. 25, 26 – Porosity-permeability relation for the upscaled models.

Merging, clipping and deformation

The two independently upscaled models are dumped and merged into a single large grid. The whole merged model is deformed with the Top-Maastrichtian structural map surface. The Top-Danian map is used to inactivate the cells above this horizon in the Danian box model. Since the upscaled model has layers with equal thickness, the variable thickness of the Danian sequence is handled by this inactivation of the top part. This implies that layering in the Danian must be assumed to conform with the top Maastrichtian structural map, if the best representation of variations is wanted.

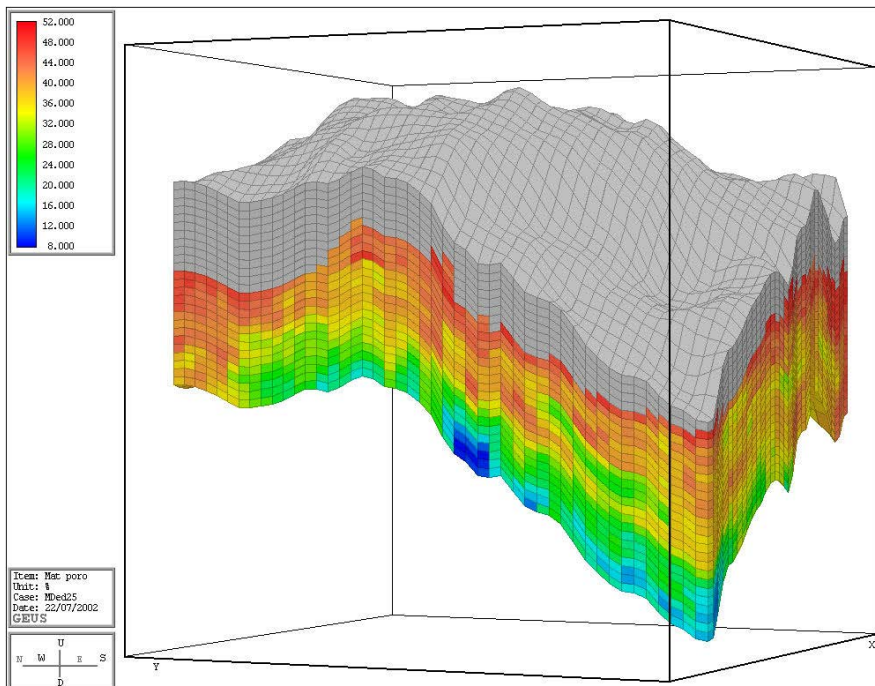


Fig. 28 - Merged models with 25 layers. The topmost 11 are the Danian, where part of the model box is inactivated where it is above the Top-Danian map surface.

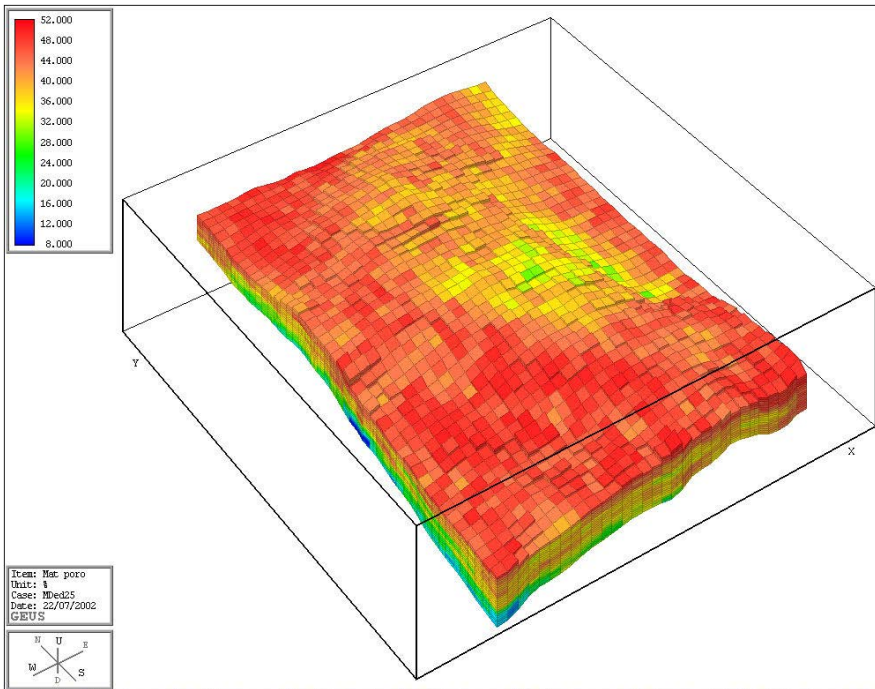


Fig. 29 – Upscaled porosity model looking down onto the true top Danian surface.

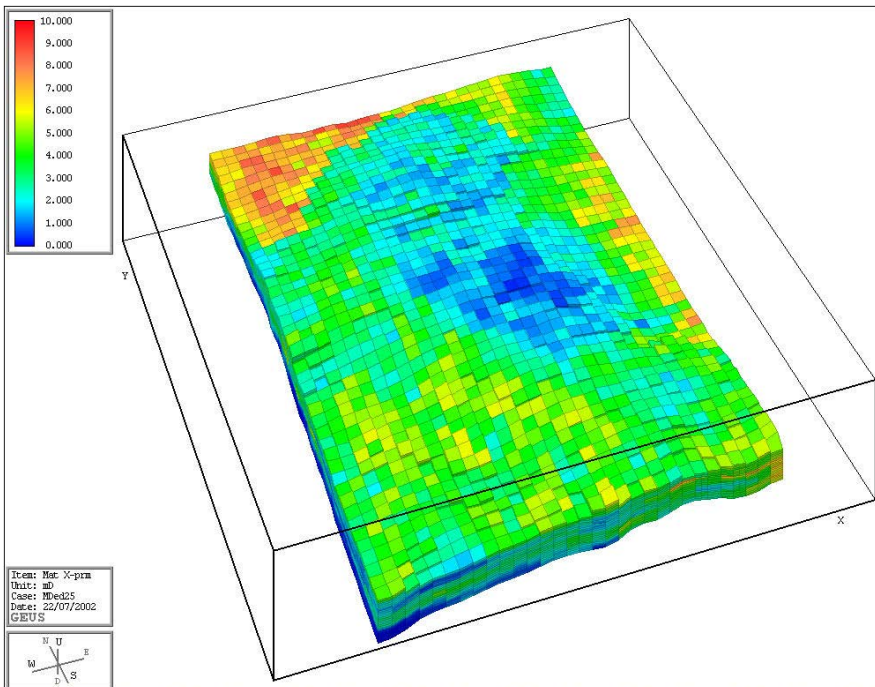


Fig. 30 – Upscaled permeability model looking down onto the top Danian surface. It is seen that the Danian has zero thickness in the NW part of the field, where the Maastrichtian high permeabilities are present.

Upscaling of final merged model

The merged model is having the original 25 layers represented, but can be upscaled to any coarse grid in the z-direction from the 25 layer model. However, the upscaling into fewer

layers in the Z direction has to account for the inactive cells in the top of the Danian model. A model for upscaling into fewer layers means that the new blocks overlap some of the inactive cells in the top part. In order to preserve the overall pore volume correctly, the porosity in the overlapping blocks is weighted according to the proportion of inactive cells.

Likewise the permeability upscaling to fewer layers create values in the top part accounting for the overlapping blocks.

The eclipse models at resolution of 25 layers has 24246 active cells, and serves as a starting porosity-permeability model input (Fig. 31).

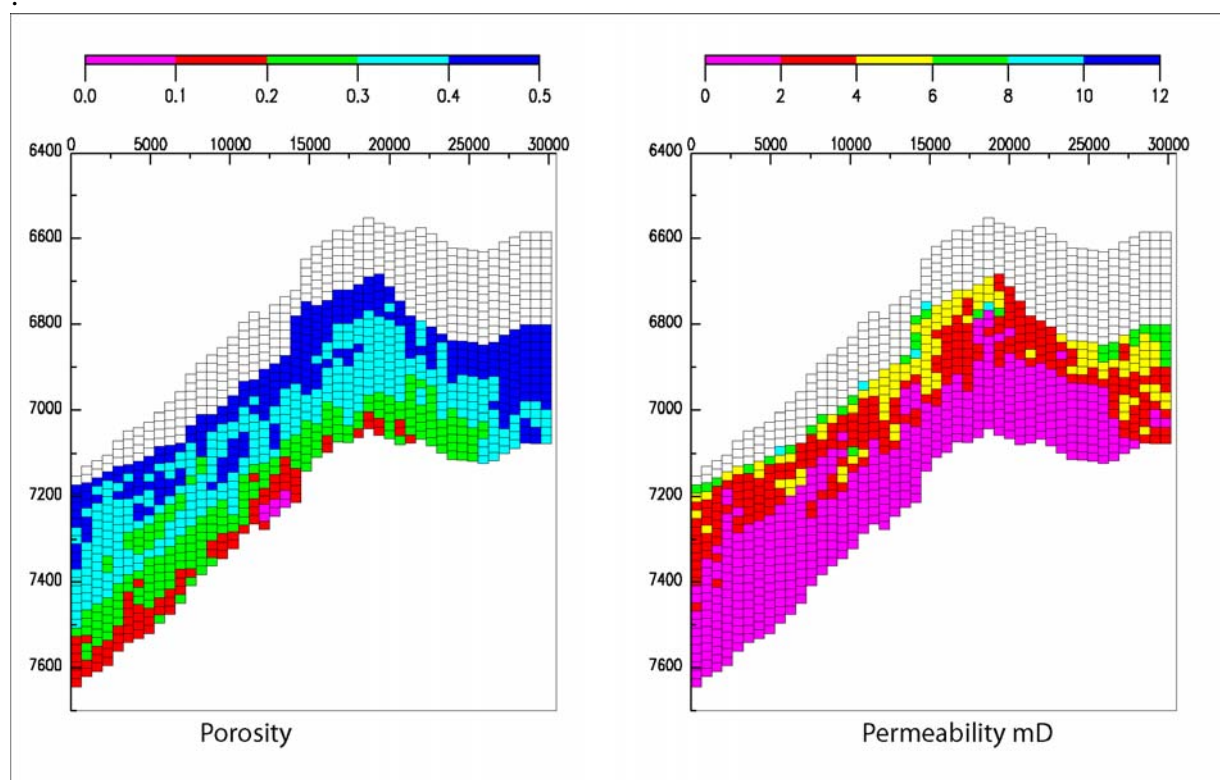


Fig. 31 – The upscaled porosity model for 25 layers in the eclipse input model.

REFERENCES

- Frykman, P. & Deutsch, C.V. 2002: Practical application of the geostatistical scaling laws for data integration. *Petrophysics* 43(3), 153-171.
- Vejbæk, O.V. 1999a: Amendment to reservoir characterization of the Roar field. Danmarks og Grønlands Geologiske Undersøgelse Rapport 60, 13 pp.
- Vejbæk, O.V. 1999b: Reservoir characterization of the Roar field. Danmarks og Grønlands Geologiske Undersøgelse Rapport 59, 64 pp.

APPENDIX 1

PROCEDURE FOR UPSCALING AND CLIPPING OF GSLIB GRIDS with CMoS and gsutilities The Roar case - Danian porosity edited to max. 50.2

Original model is 253x373 cells of 25x25 m of 6 m thickness
Danian 11 layers
Maastrichtian 14 layers
Files: Danpe1b.out, Maa1.out

New: Since the simulated porosity values in the Danian model exceeds 50%, the porosity model is modified by truncating all above 50% to a max. Of 50.2 %
New file: danpoed.out column 2

The simulation grid is at a small angle to the UTM coord system - not accounted for in the model. Corners:
SW: 600694.5, 6176498.5
NE: 606998, 6185803

Box-upscaling of the two models

Upscale Danian and Maastrichtian separately in box-format only, and only x,y upscaling.
Keep 11 and 14 layers as in original models. Dump gslib files into \gslib\

The first step in the upscaling is to impose a coarser grid in the x and y direction. The change is from cells of 25x25 m to cells of 200x200 m.

Box-upscaling

Input files for box upscaling

Dan1ed-upbox.inp

```
-----  
-- Roar data from Geus, OVV 22/8 01  
-- Danian box upscaling of x and y only  
*GRID.X.START    0  
*GRID.Y.START    0  
*GRID.Z.START    66  
--to account for the CMoS grid starts at the top of the Danian box of 66 m thickness  
*GRID.X-dim     253*25  
*GRID.Y-dim     373*25  
*GRID.Z.DIM     11*6  
-----  
-- Danian porosity and permeability  
-- porosity model danpoed.out column 2 edited to get max. 50.2 %  
-----  
*matrix.poro.file e:\tmpROAR\danpoed.out 2  
--perm left out to allow function  
*MATRIX.air.X-PERM = 300*poro**5.0  
*MATRIX.air.y-PERM = 300*poro**5.0  
*MATRIX.air.z-PERM = 300*poro**5.0
```


*block.x-dim 31*200
 *block.y-dim 46*200
 *block.z-dim 11*6

Table 1:

Porosity/permeability relation model, and conversion constants for air/fluid permeability.

Porosity (frac.) /permeability relation $k = a * \Phi^b$	a	b	Air permeability to fluid permeability relation $k_f = a * k_A^b$	a	b
Danian	300	5.0	Danian & Maastrichtian	0.52	1.083
Maastrichtian	155	3.5			

Maa1-upbox.inp

```

-----
-- Roar data from Geus, OVV 22/8 01
-- Maastrichtian upscale box x,y only
*GRID.X.START 0
*GRID.Y.START 0
*GRID.Z.START 0
--to start at the bottom of the overlying Danian box
*GRID.X-dim 253*25
*GRID.Y-dim 373*25
*GRID.Z.DIM 14*6
-----
-- Maastrichtian porosity
-----
*matrix.poro.file e:\tmproar\Maa1.out 1
--perm left out to allow function

*MATRIX.air.X-PERM = 155*poro**3.5
*MATRIX.air.y-PERM = 155*poro**3.5
*MATRIX.air.z-PERM = 155*poro**3.5

*block.x-dim 31*200
*block.y-dim 46*200
*block.z-dim 14*6

```

Upscale the matrix

Dump to gslib and cmos

First block-center should have coordinates 100.000 100.000 -81.000

Since it is at the bottom of the Maastrichtian (14 layers x 6 m = 84, minus 1/2xcellZ of 6 m = 81)

Upscale the isopach Danian map to same grid x,y

The map will be used as a "TopDanian" map later to clip the model above this level.

Dan1isoup.inp

```

-----
-- Roar data from Geus, OVV 22/8 01
-- job:
-- Danian "top" map upscaling
-----
*GRID.X-dim 253*25
*GRID.Y-dim 373*25
*GRID.Z.DIM 11*6

```

-- Depth to top (true top dan to upscale grid for clipping)

*TOP.FORMATION.DEPTH.FILE e:\tmproar\isodan.dat

*block.x-dim 31*200

*block.y-dim 46*200

*block.z-dim 1*12

Upscale the matrix

Dump to gslib

66 m has been added to the topMaa map to get a top-Danian-model map with the same shape.
tmaahzcor-66.dpt

Upscale the TopDanian-model-box-map tmaahzcor-66.dpt to same grid x,y as other models

This map will be used to deform the Top-Danian surface with the TopMaa structural map, so the whole model is having the correct structural geometry prior to clipping of the topmost part of the danian model.

Dantma66up.inp

-- Roar data from Geus, OVV 22/8 01

-- job:

-- Danian model top map tma-66 upscaling

*GRID.X-dim 253*25

*GRID.Y-dim 373*25

*GRID.Z.DIM 11*6

-- Depth to top (true top dan to upscale grid for clipping)

*TOP.FORMATION.DEPTH.FILE e:\tmproar\tmaahzcor-66.dpt

*block.x-dim 31*200

*block.y-dim 46*200

*block.z-dim 1*12

dump to gslib Dan1isoupU.gsl

- 1. Merge gslib dumps Dan1ed-U.dat and Maa1-upboxU.dat (first Maa then Dan to have gslib top to bot sequence) in textpad editor to MaaDaned.dat**
- 2. Check for zero porosity or permeability values, replace zero perm. with 0.01**
- 3. CLIPGRID (in gsutil\bin) of MaaDaned.dat with Dan1isoupU.gsl isopachfile to MaaDaned.datc by modifying column 11 to missing value 999.9 for the inactive cells. Clipgrid requires "cut from base"=1 and "keep blank cells"**
- 4. Check for any zero porosities/permeabilities in MaaDaned.datc.**
- 5. Replace the 999.9 in column 12 with 0.0 for inactive.**
- 6. Input data from MaaDaned.datc to cmos, and use the upscaled Dantma66upU.dpt map to deform the full merged model, including the inactive cells above the true top-Danian map.**
- 7. Decide how many layers are used for the upscaling (25 in original model)**

```

-----
-- Roar data
-- Maastrichtian+danian
-----
*GRID.X.START 0
*GRID.Y.START 0
*GRID.X-dim 31*200
*GRID.Y-dim 46*200
*GRID.Z.DIM 25*6
-----
-- Depth to top danian model box (topMaastricht-66)
-----
*TOP.FORMATION.DEPTH.FILE Dantma66upU.dpt
-----
-- Danian porosity and permeability. Realization 1 (High)
-----
*matrix.poro.file maadaned.datc 7
*MATRIX.X-PERM.FILE maadaned.datc 8
*MATRIX.Y-PERM.FILE maadaned.datc 9
*MATRIX.Z-PERM.FILE maadaned.datc 10
*active.cells.file maadaned.datc 11

*block.X.START 0
*block.Y.START 0
*block.x-dim 31*200
*block.y-dim 46*200
*block.z-dim 25*6

```

1. For the upscaling is needed to exclude the inactive cells.
2. Dump upscaled grid into ..\CMOS\ , ..\gslib\, and ..\ecl\
3. For eclipse dump select Field or Metric units
4. File names:
 - MD6u25UM.Out dated 12-09-02 is the 25 layer model in Metric units. And contains the original model with very high porosities.
 - MDed25UM.Out dated 21-06-02 is the 25 layer model in Metric units with the edited porosities for the Danian part.