Forward Stratigraphic Modelling in Rift Basins: An Investigation of Tectonic Rates Controlling Sedimentation*

Matthieu Gravito[1], Joao Keller[2], and Julio Almeida de Carvalho[2]

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[1]Université de Strasbourg, Strasbourg, France (Matthieu.GRAVITO@beicip.com)
[2]Saudi Aramco, Saudi Arabia

Abstract

Exploration in rifting basins faces numerous industrial and scientific challenges as these basins can exhibit various depositional environments, stratigraphic and structural settings. The extreme heterogeneous facies and geometry that they present can be difficult to image and interpret even using up-to-date seismic data. Forward stratigraphic modelling (FSM) can be a solution to fully understand the role of the tectonics on the stratigraphy within these complex rift basins. FSM can predict geometry, facies, and thickness of geo-bodies while assessing the complex interaction between accommodation, sediment supply, and transport through a combined simulation of sedimentary processes. Following the FSM principles, DionisosFlow is a deterministic process-based tool that reproduces the interactions between the main mechanisms driving sedimentation and can be used in the rift environment. A series of numerical simulations were performed using the DionisosFlow stratigraphic model to simulate sedimentological processes through geological time under several different tectonic deformation rates using several subsidence maps. All other variables were kept constant during the simulations in order to test the hypothesis that the tectonic evolution of basin substratum alone can produce different patterns that can be found in sedimentary records. Furthermore, we illustrate several forward stratigraphic results with bibliographic research on regional studies in different actual and past rift basins. Our results suggest that relatively simple diffusion-based models can produce realistic results in the rift basin environment where tectonic deformation rate can have a strong influence on the heterogeneity of the sedimentary model.

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An Investigation of Tectonic Rates Controlling Sedimentation

Matthieu GRAVITO, Joao KELLER, Julio ALMEIDA DE CARVALHO

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Introduction

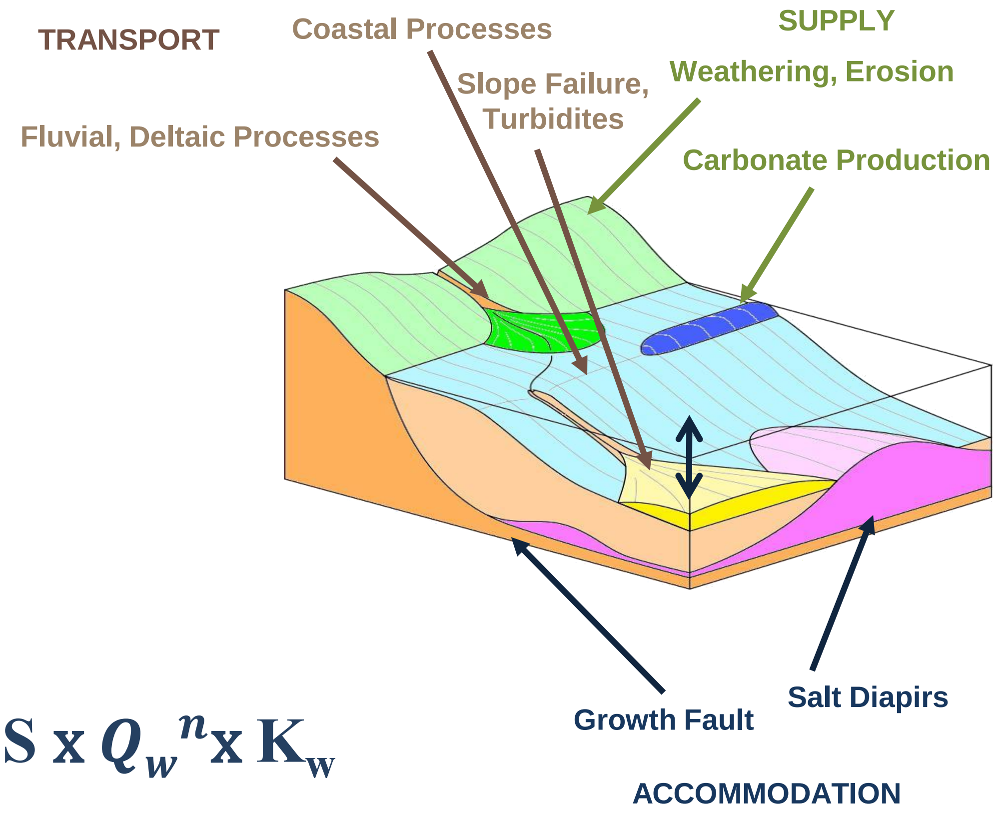
- Exploration in rift basins faces numerous operational and scientific challenges:
  - Complex structural settings
  - Difficulties to image and interpret
  - Various depositional environments
  - Extremely heterogeneous facies
  - Different stratigraphic patterns

- Forward Statigraphic Modelling can help to:
  - Validate sedimentological and stratigraphic scenarios
  - Identify geobodies locations and thicknesses
  - Check connections between geobodies

FSM Principles

- Forward simulation of sedimentary processes through geological time using **DionisosFlow** .

- **Accomodation**
  - Basin deformation history
  - Eustasy
- Sedimentary **supply**
  - Fluvial input
  - In situ marine carbonate production
- **Transport** using macro-scale sediment transport laws
  - Fluvial, deltaic and coastal processes
  - Turbidite



$$Q_s = S \times K_s + S \times Q_w^{\,n} \times K_w$$

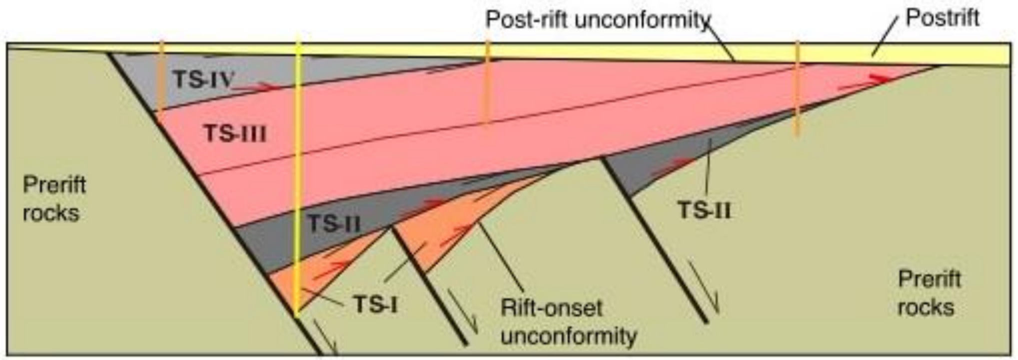
FSM Principles

- Result is a 4D grid showing:
  - Basin evolution
  - Stratigraphic architecture
  - Sediment proportions
  - Depositional environmental properties (bathymetry, water flow, wave ernergy, etc)

Background

- In rift basins, tectonic plays a major role in **accommodation creation**

- Withjack et al. (2002) identified that sequences in rift environments may be divided in **tectono-sequences**:
  - TS-I: may or may not be a syn-rift deposit
  - TS-II: Syn-rift deposit in restricted environment
  - TS-III: Syn-rift less restricted deposit
  - TS-IV: Increase of extension rate, open marine environment

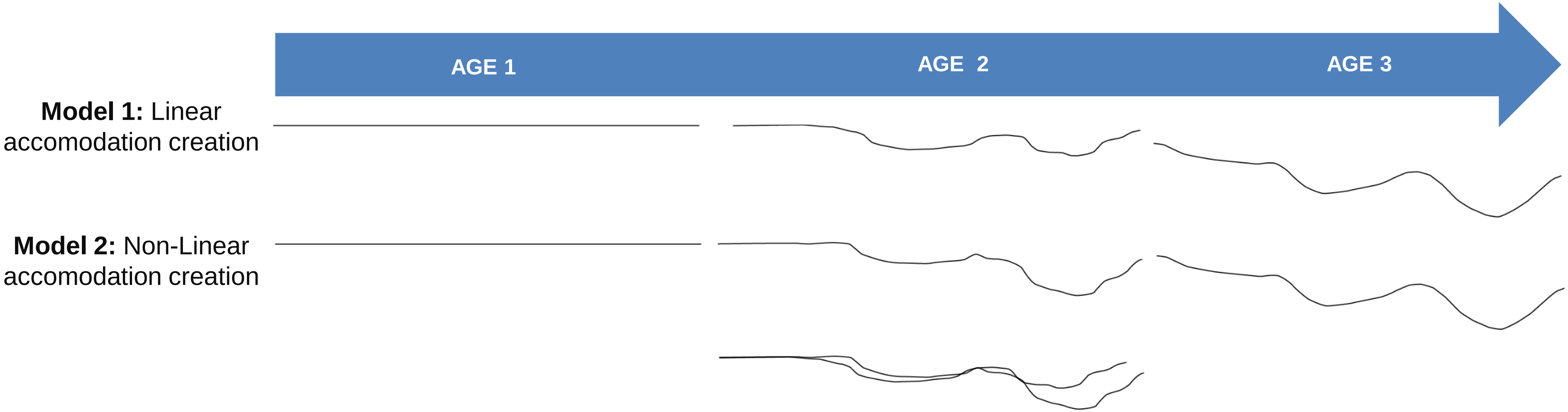


Idealized rift basin showing unconformity-bounded tectono-stratigraphic packages. (*Withjack et al., 2002*)

How do tectonics affect the type of deposition and its distribution?

Experiment

- To test the effect of tectonic on the stratigraphic pattern, two **synthetic models** that represent **pre-rift** and **syn-rift phases** were created **from several calibrated models.**
- The **total accommodation created between both models is the same**, only the timing is different. One model is **linear through time everywhere** when the other one is **compartimentalized.**



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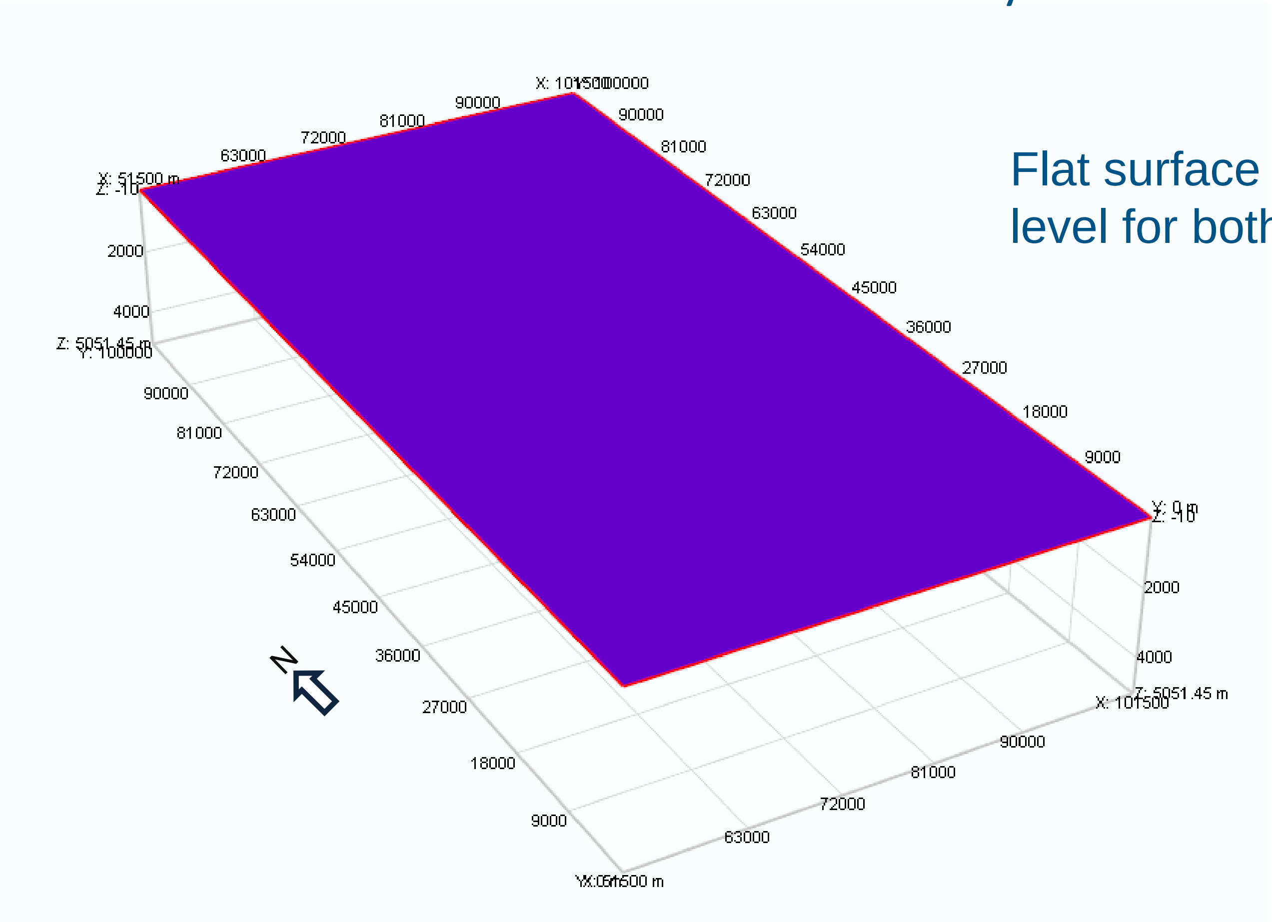
Experiment

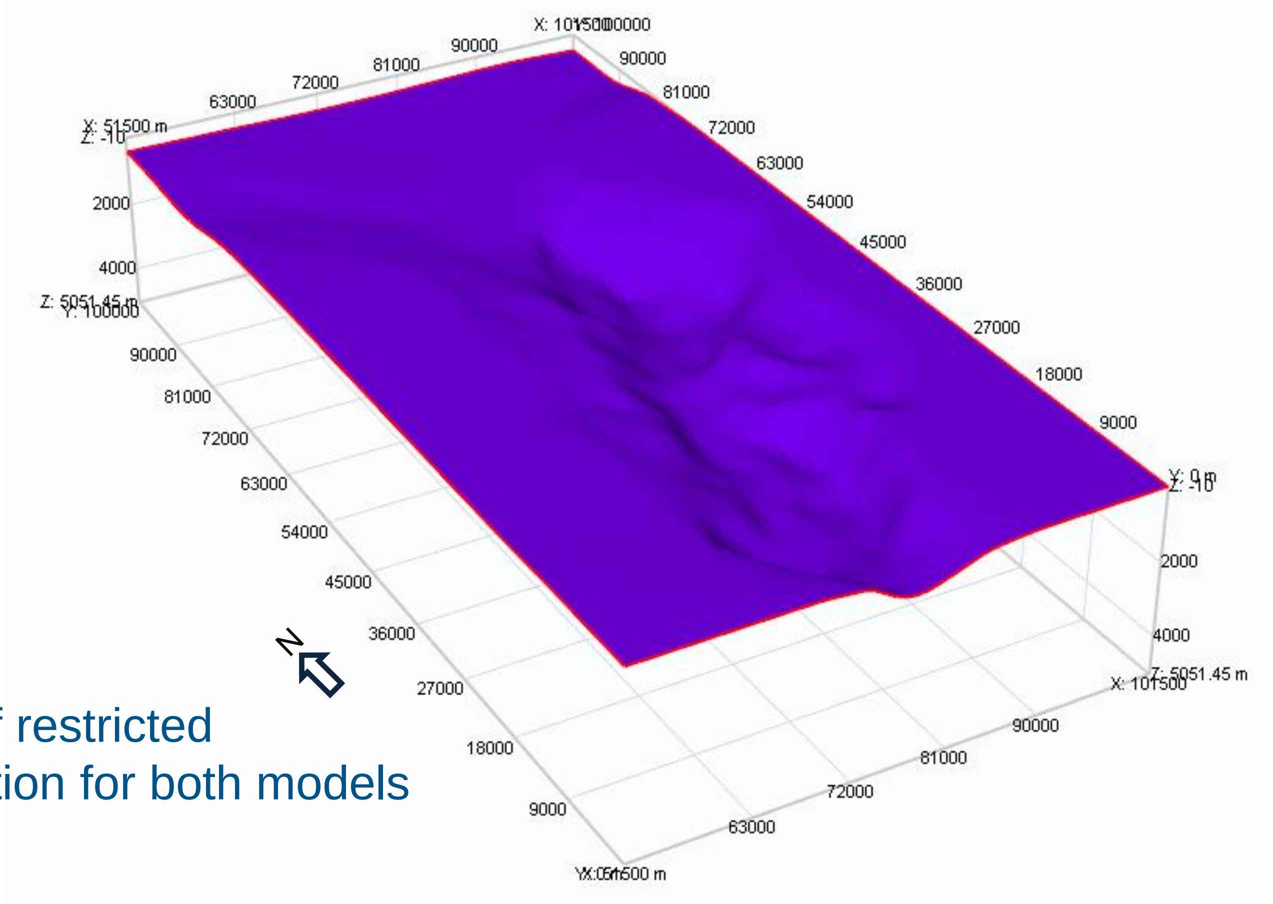
- The differences of accommodation creation will be modeled by subsidence maps:



Flat surface 5m above sea level for both models

Experiment

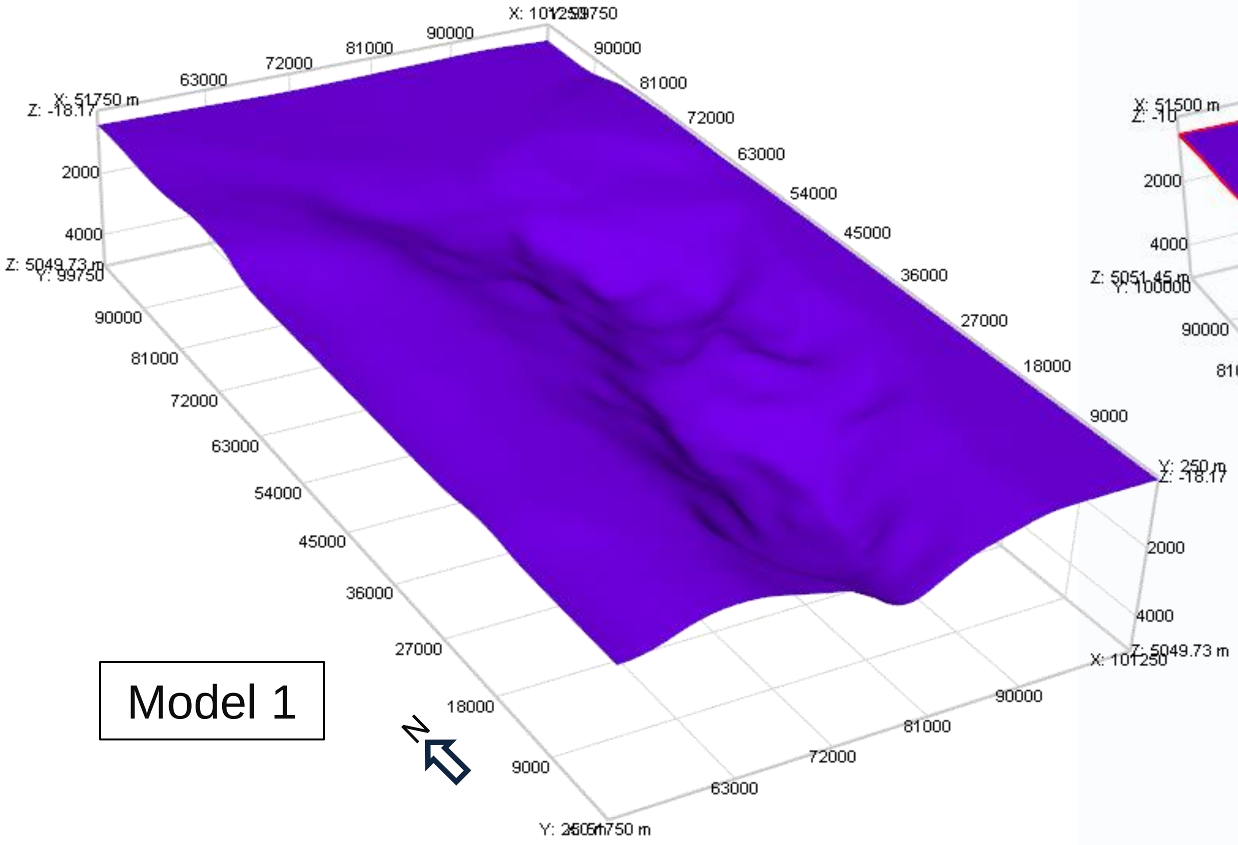
- The differences of accommodation creation will be modeled by subsidence maps:



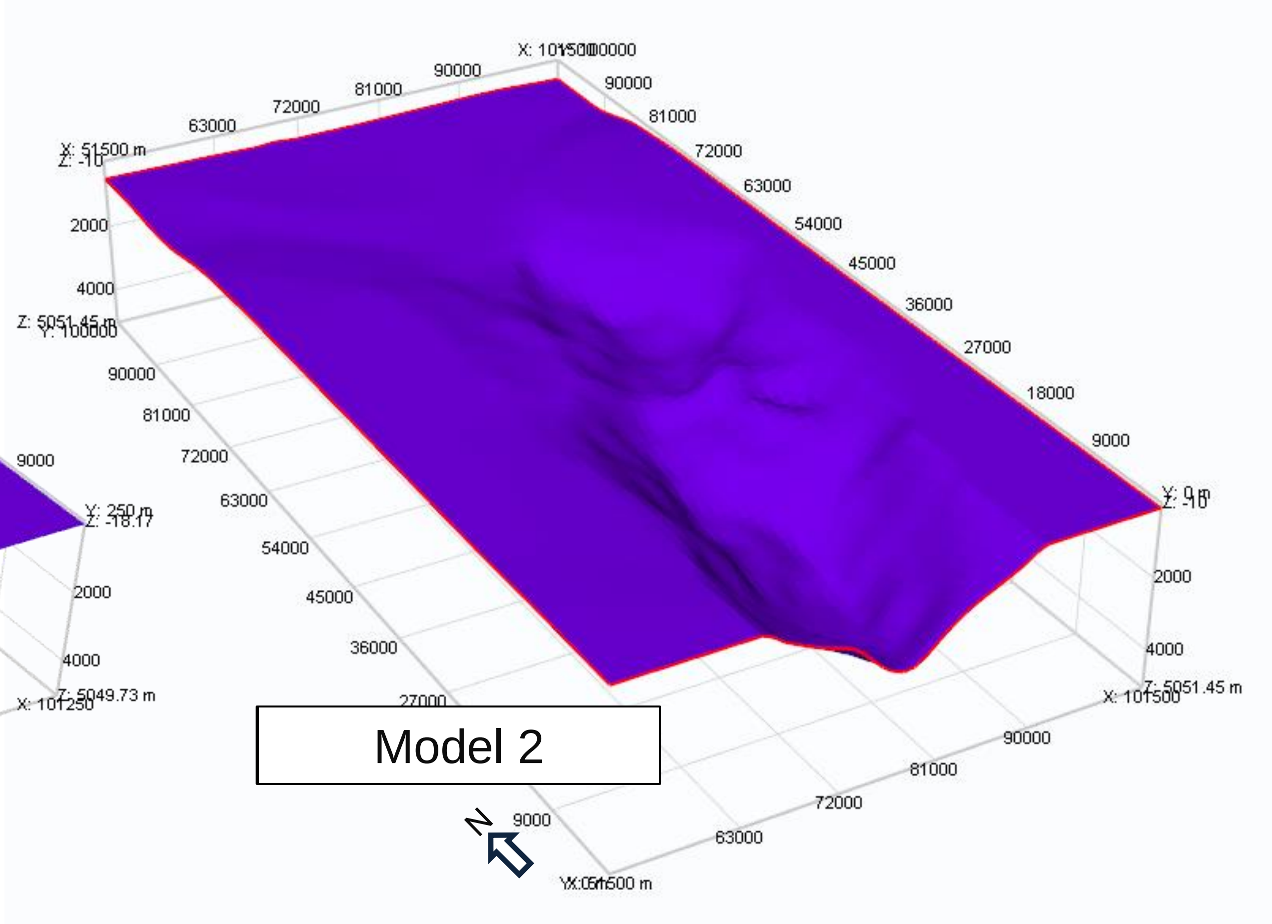
Creation of restricted accomodation for both models

Experiment

- The differences of accommodation creation will be modeled by subsidence maps:



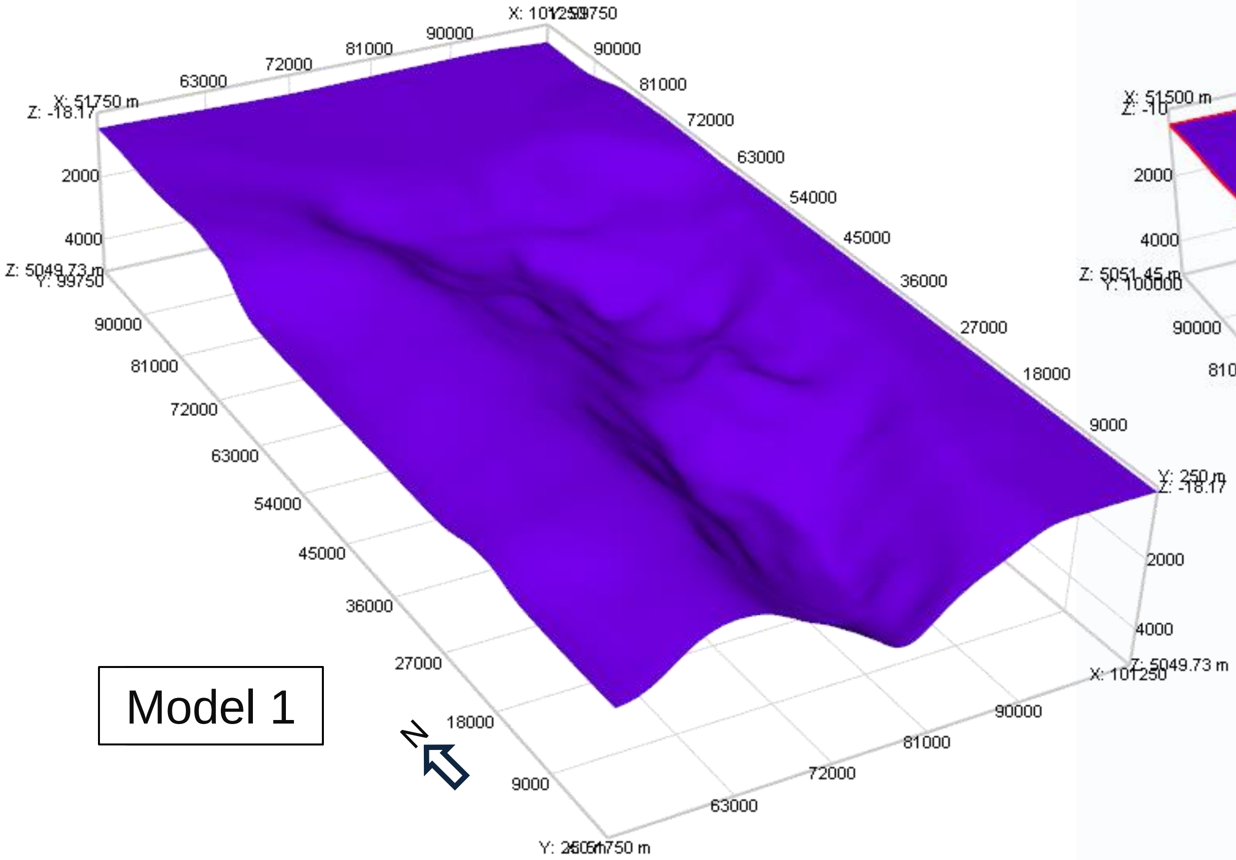
Model 1



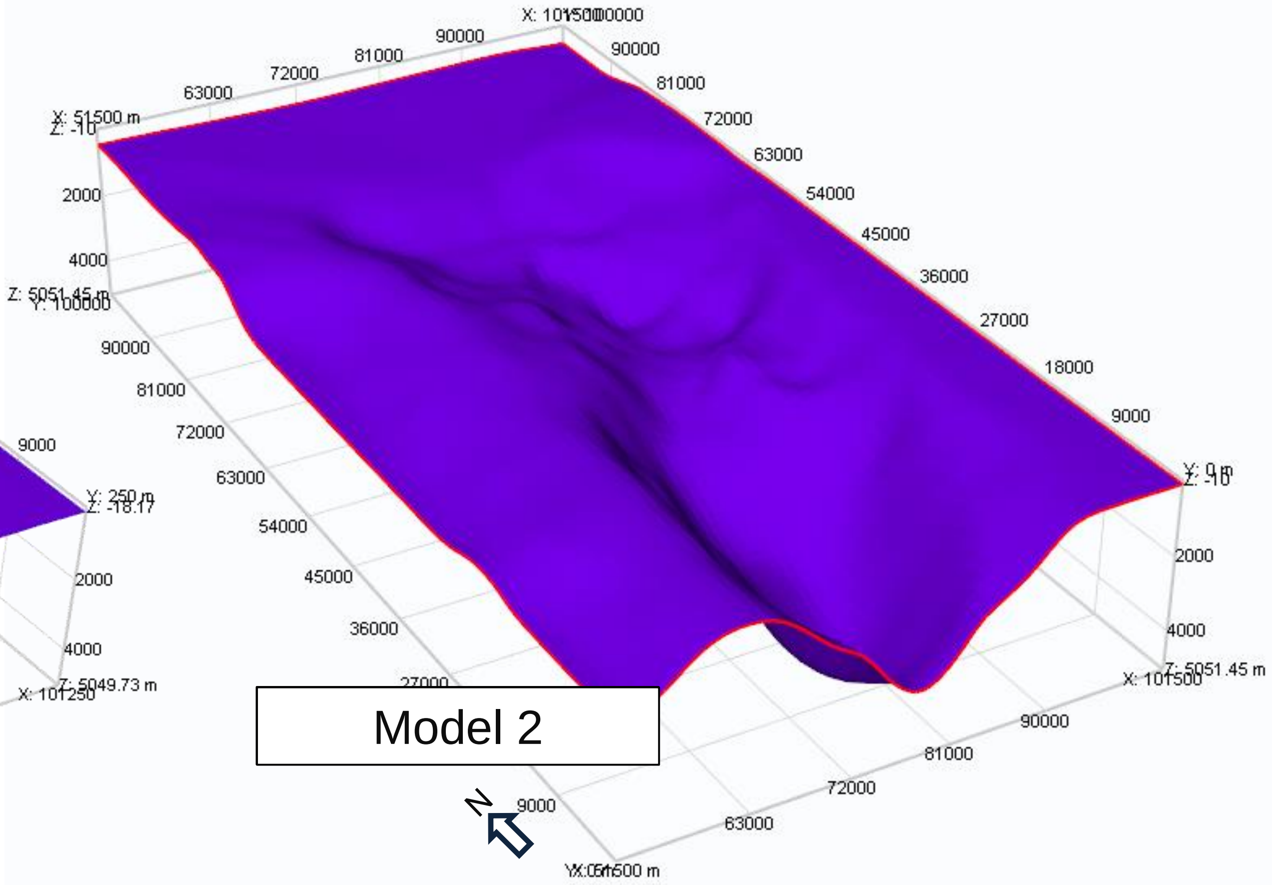
Model 2

Experiment

- The differences of accommodation creation will be modeled by subsidence maps:



Model 1



Model 2

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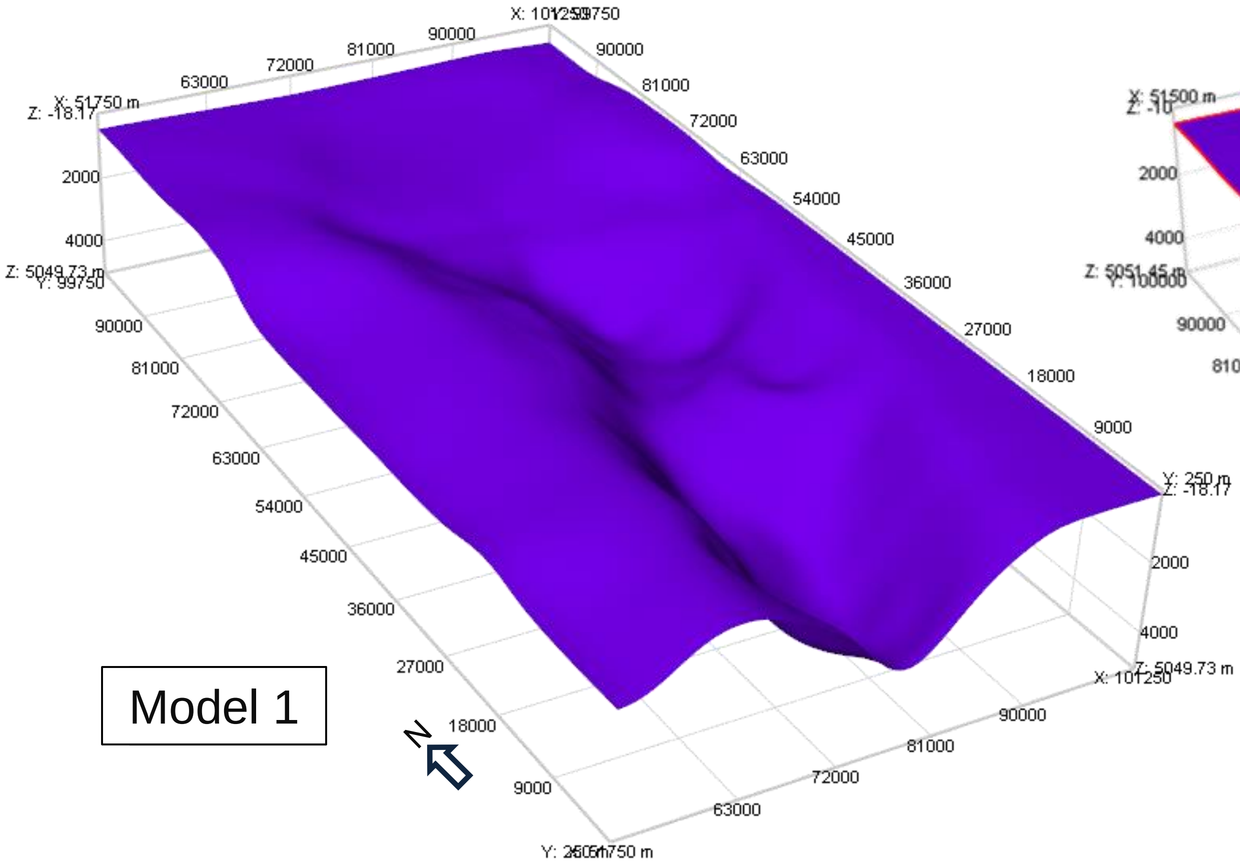
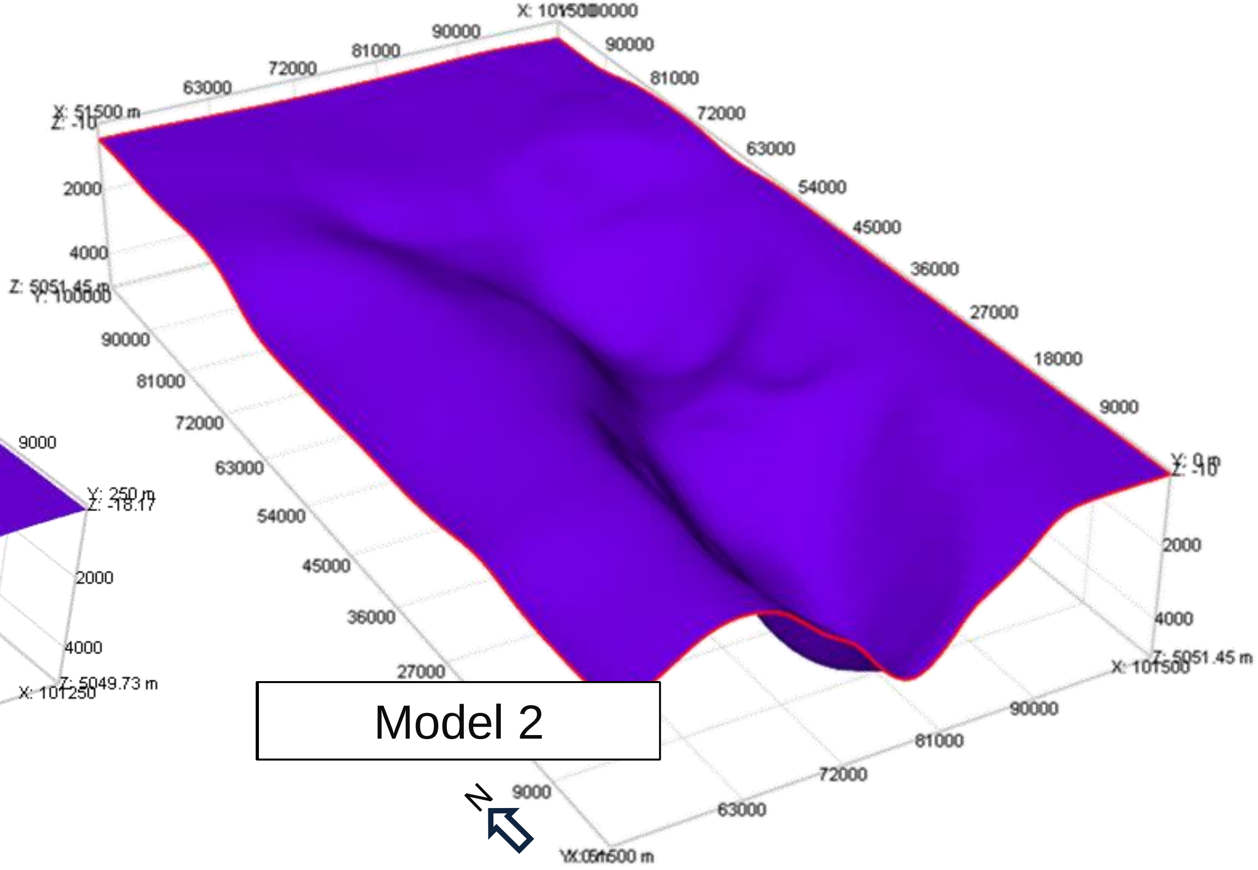
Experiment

- The differences of accommodation creation will be modeled by subsidence maps:



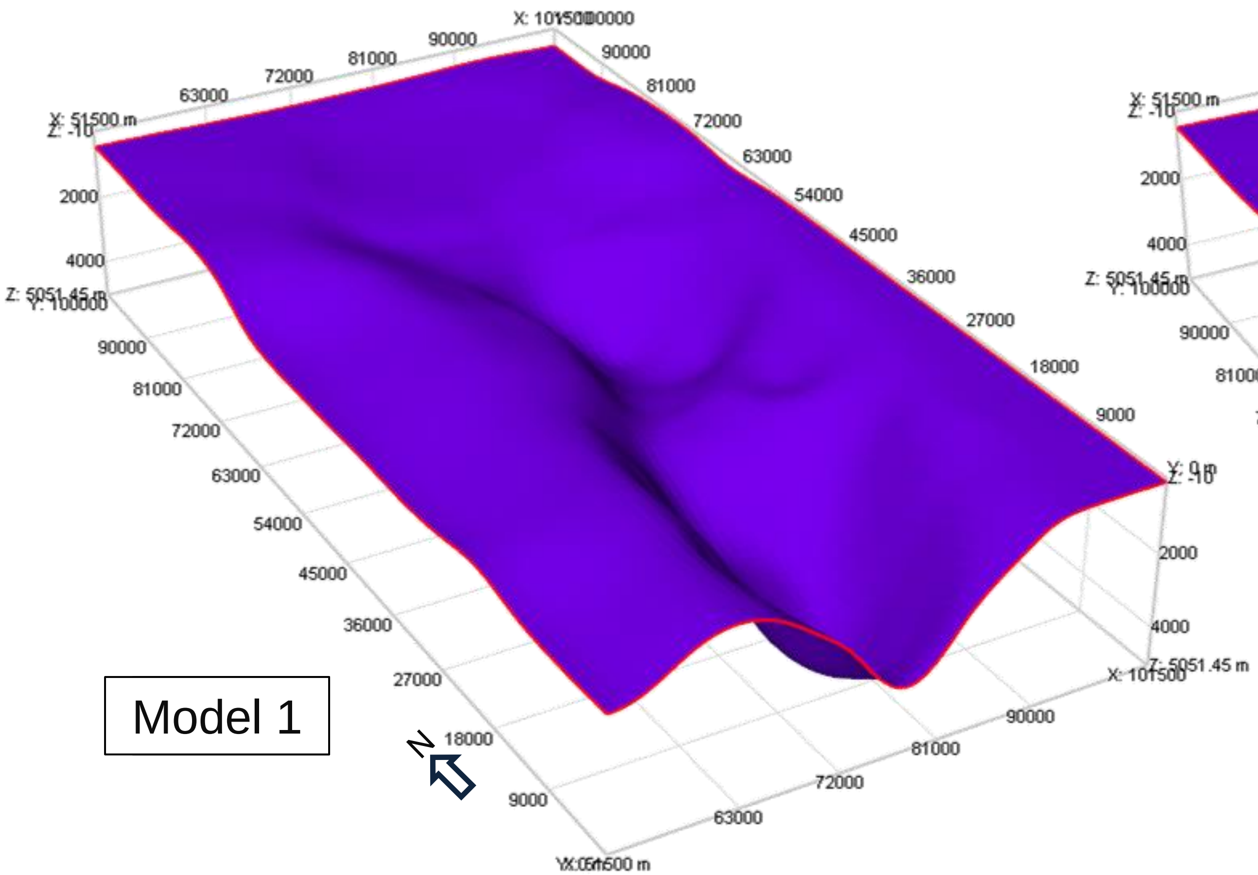
Model 1

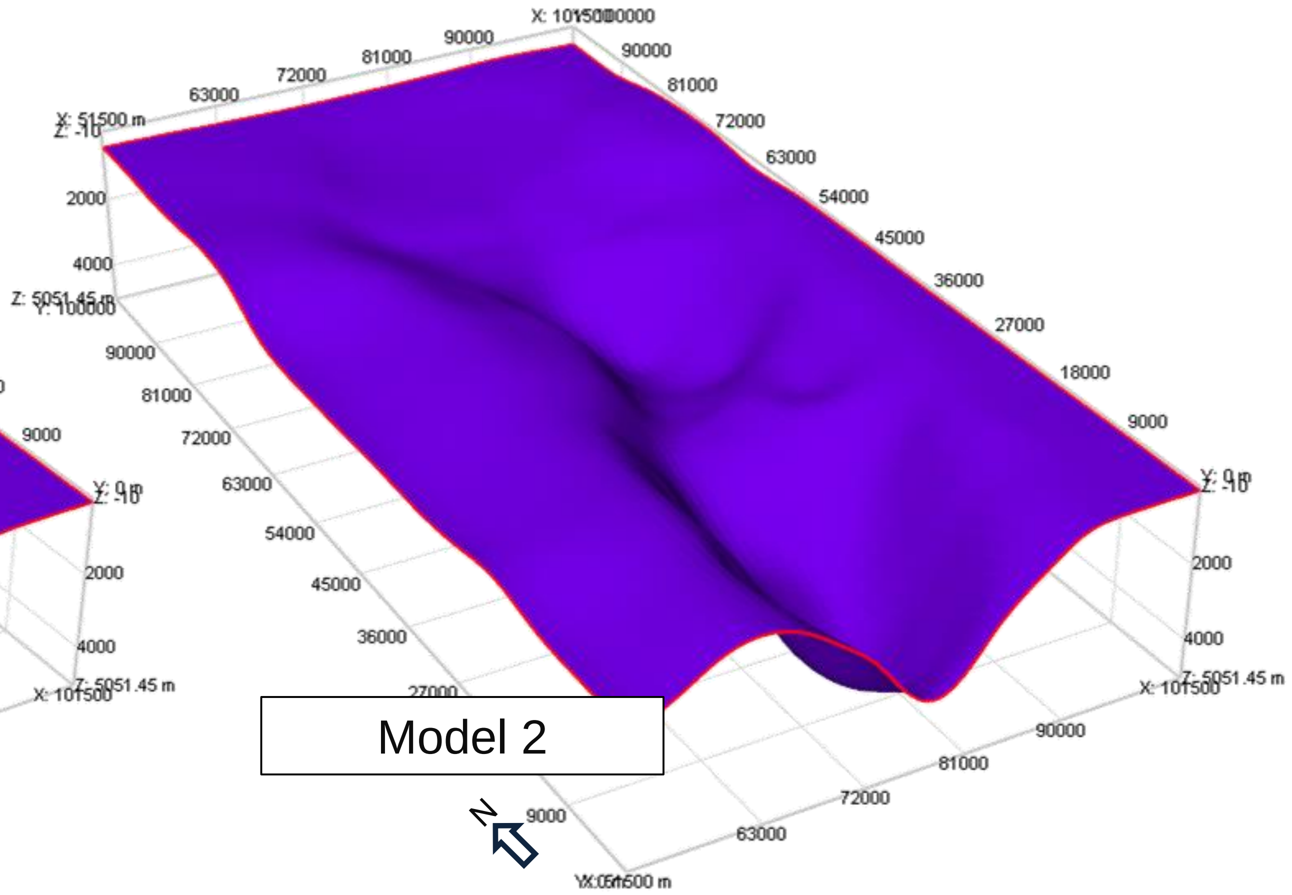


Model 2

Experiment

- The differences of accommodation creation will be modeled by subsidence maps:

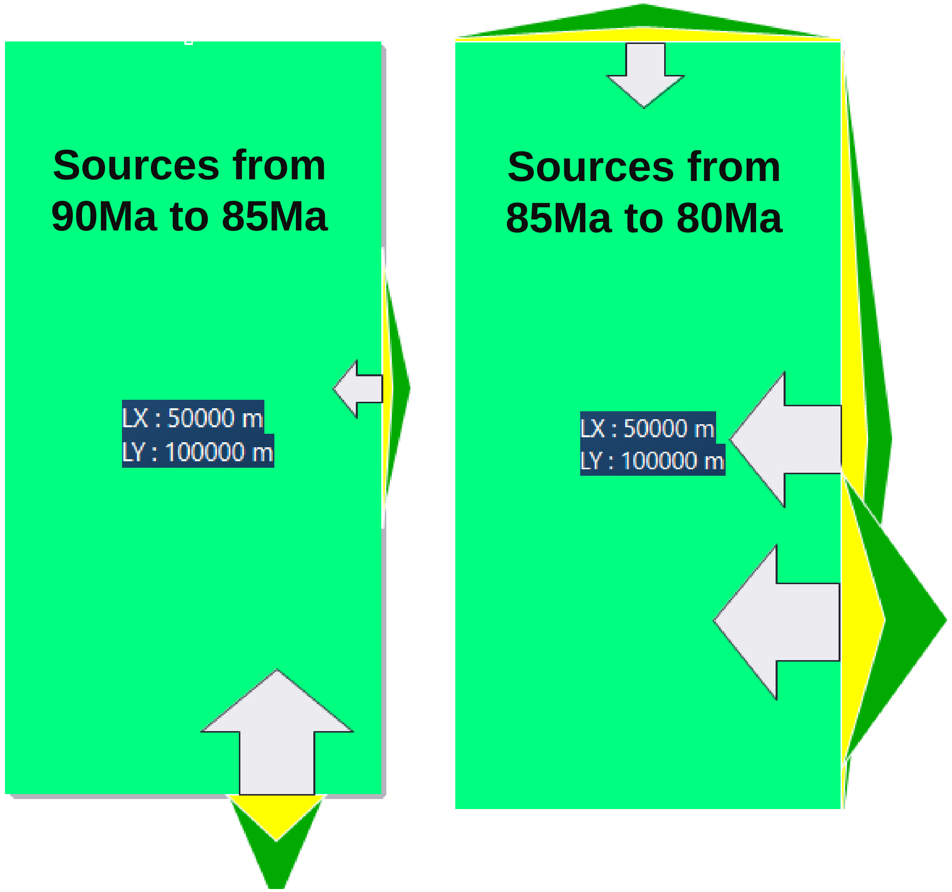




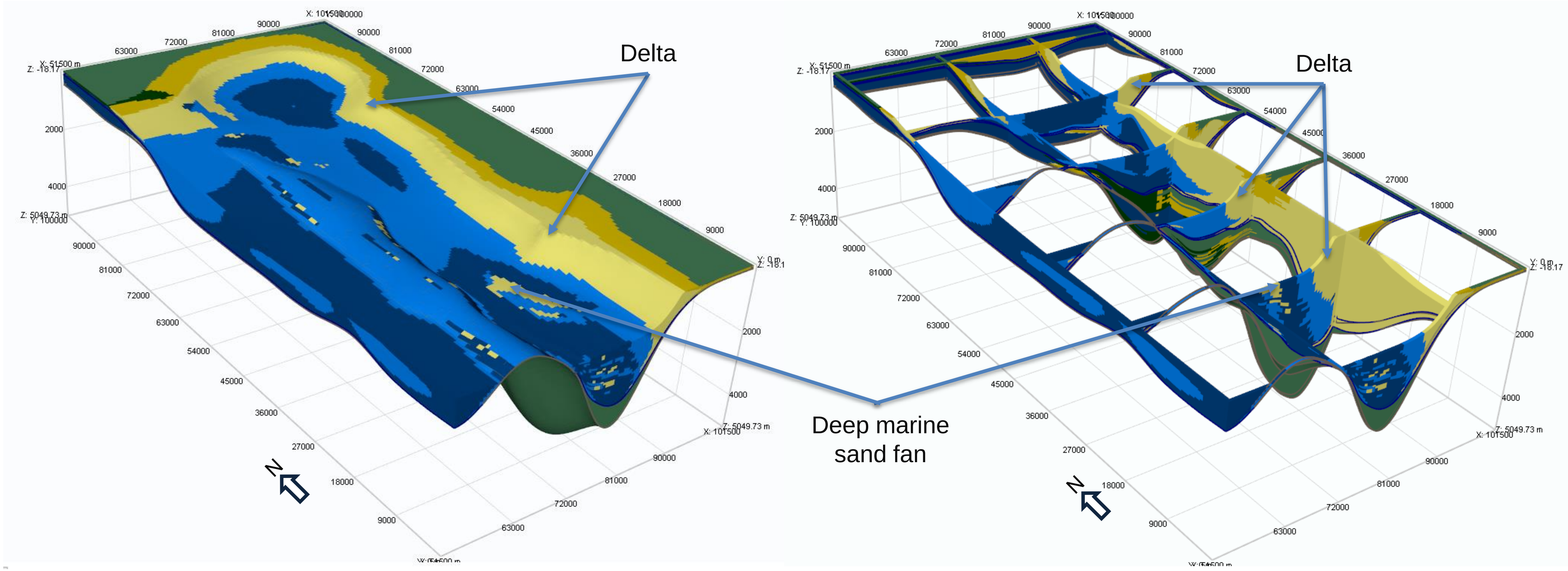
Model Setup

- Model is 50km large and 100km long with a cell size of 500m
- Other parameters are kept the same between both models:
  - Eustatic variation following **Haq curves**
  - Total Sediment supply: **350 km³/Ma**
  - Total Water discharge: **500 m³/s**
  - Same **transport coefficients**

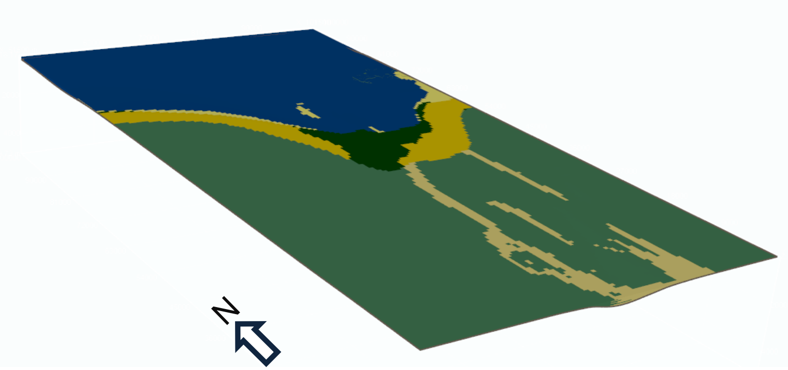
- **Time period: 10My** (between 90 and 80Ma) with an **accelera** **after 5My** of simulation.

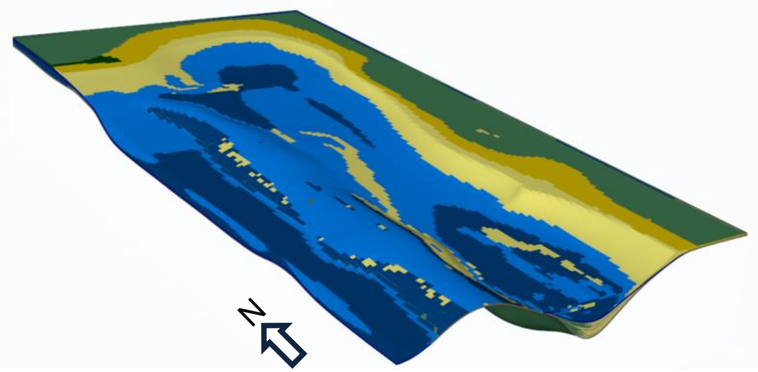


Model 1 Results

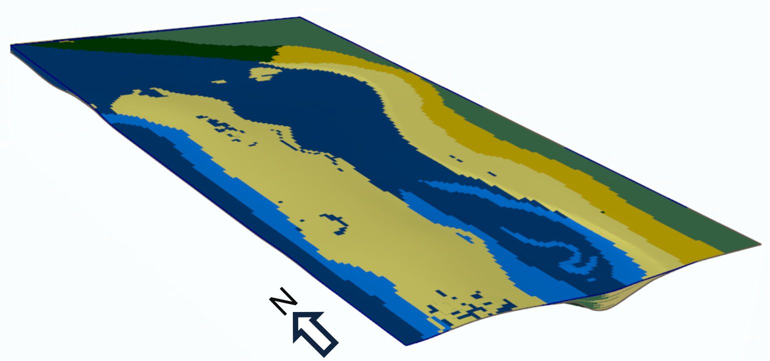


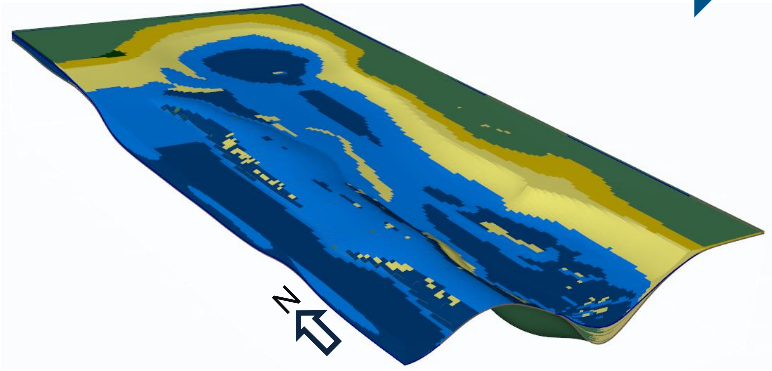
Model 1 Results



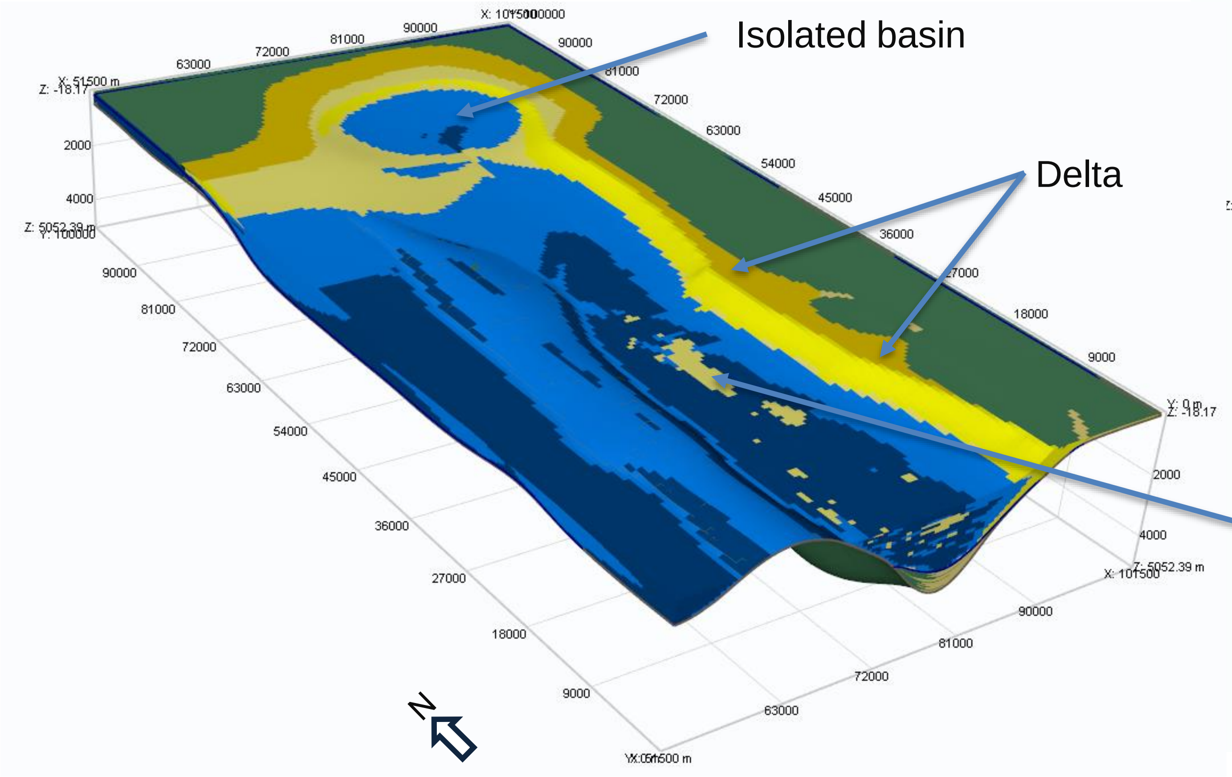


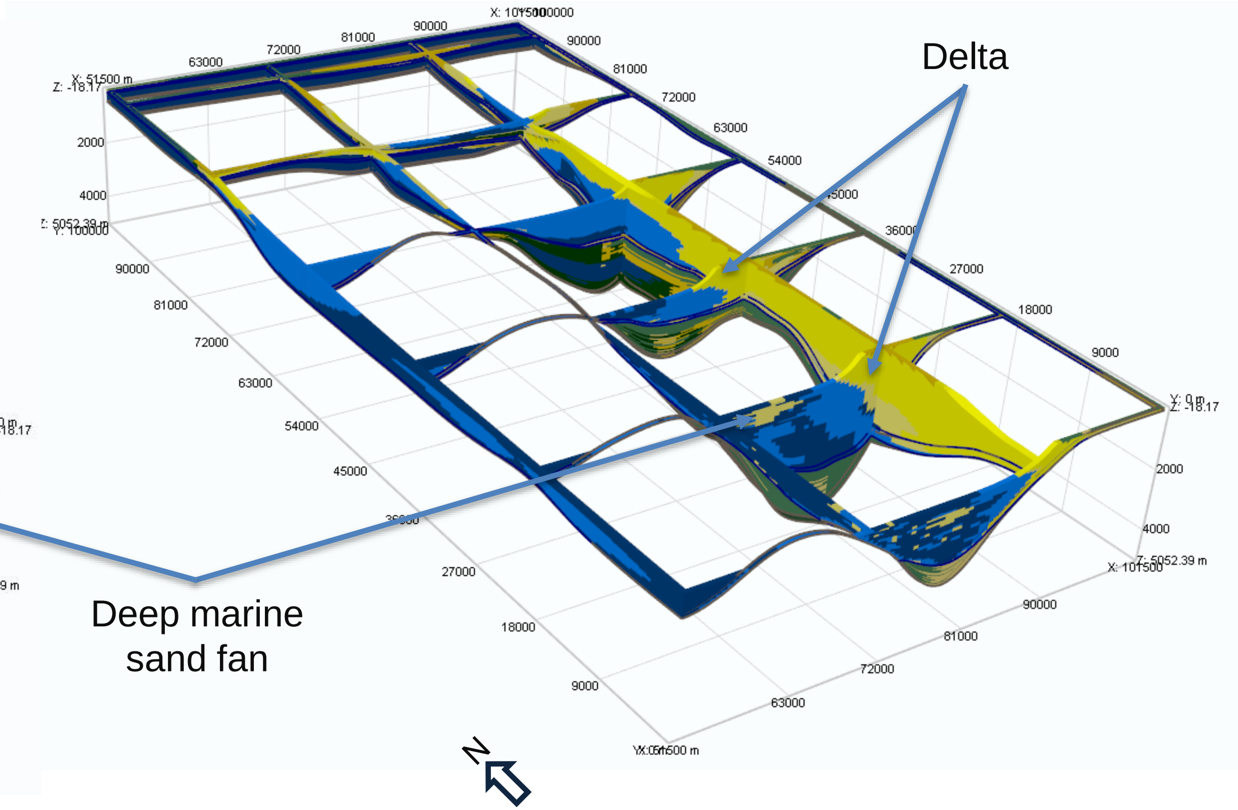
Continental environment | **Break-up all along the model** | **Closure on North and continuous subsidence**





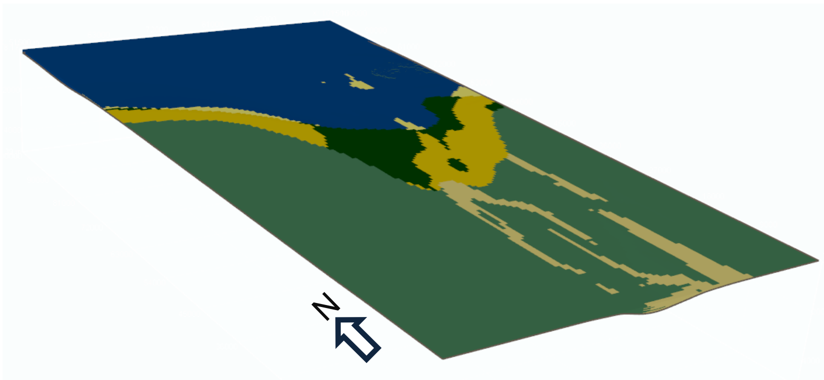
Model 2 Results

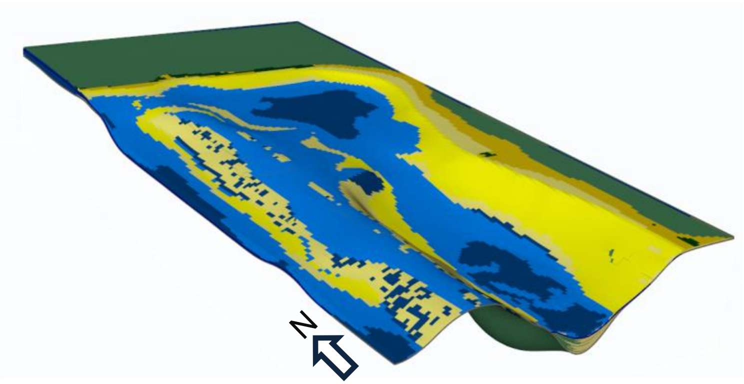


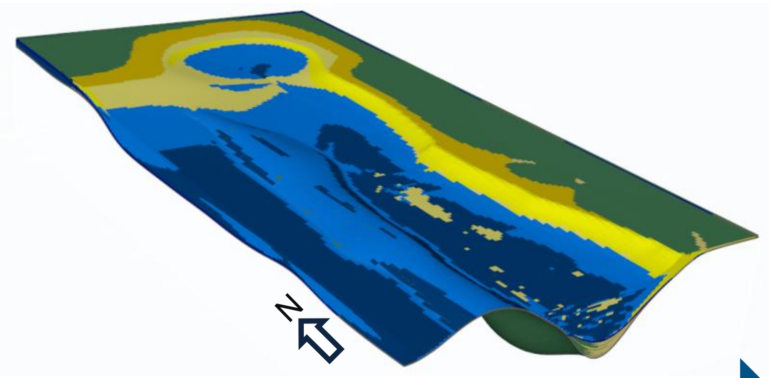


Model 2 Results

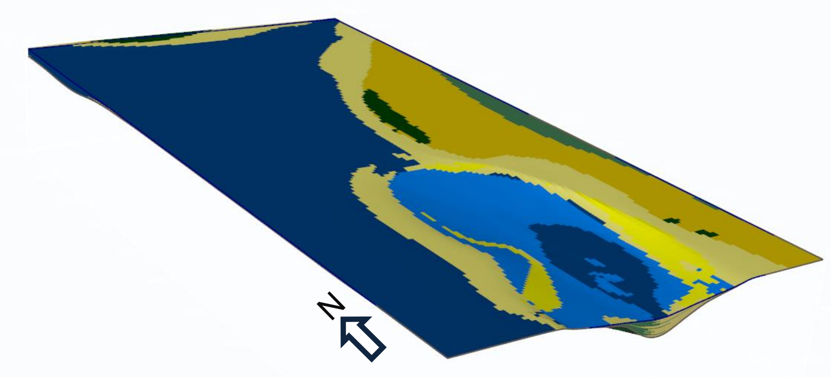
- Results of “compartimented” model

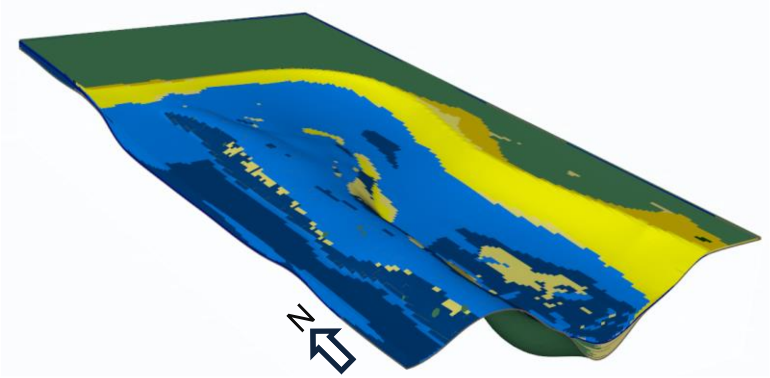






Continental environment | **Flooding and opening in the south** | **Opening in center and second graben** | **Follow-up of the opening** | **Opening of the north basin**

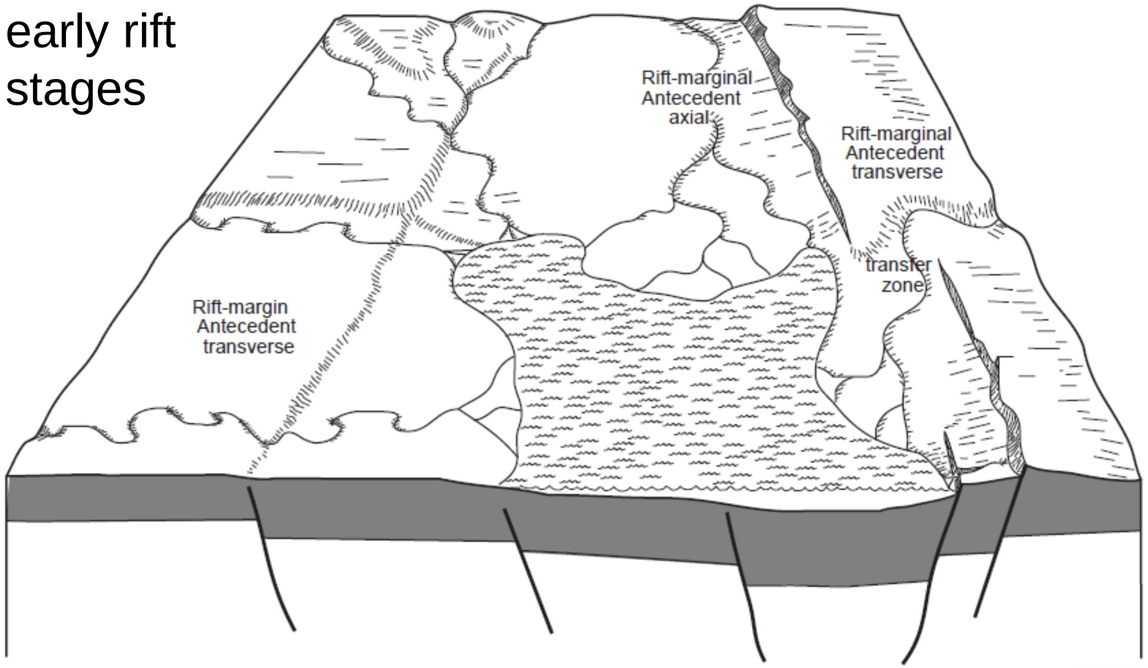




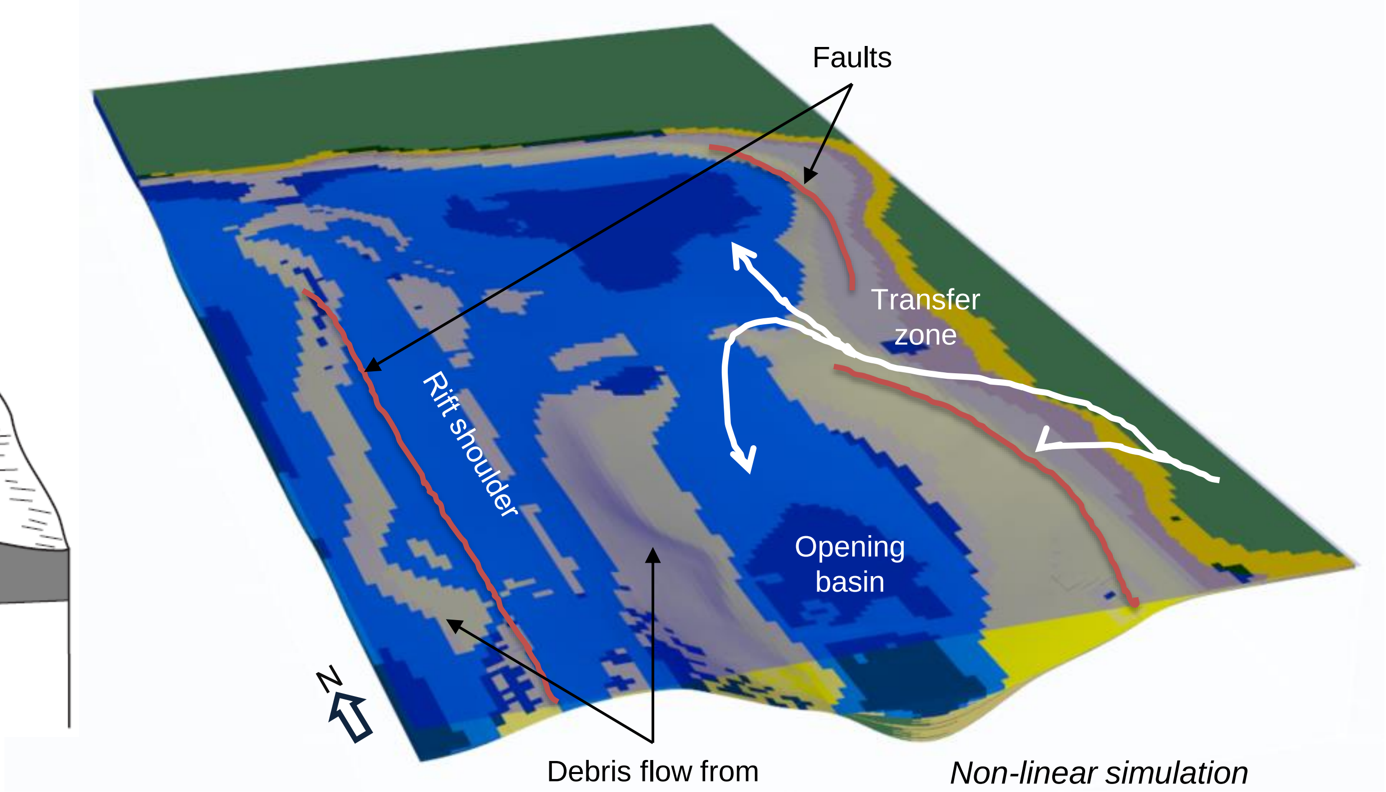
Results Analysis

- Models show classical representation of rift basins in litterature (Ravnas & Steel, Gawthorpe & Leeder):

Pre- and early rift stages



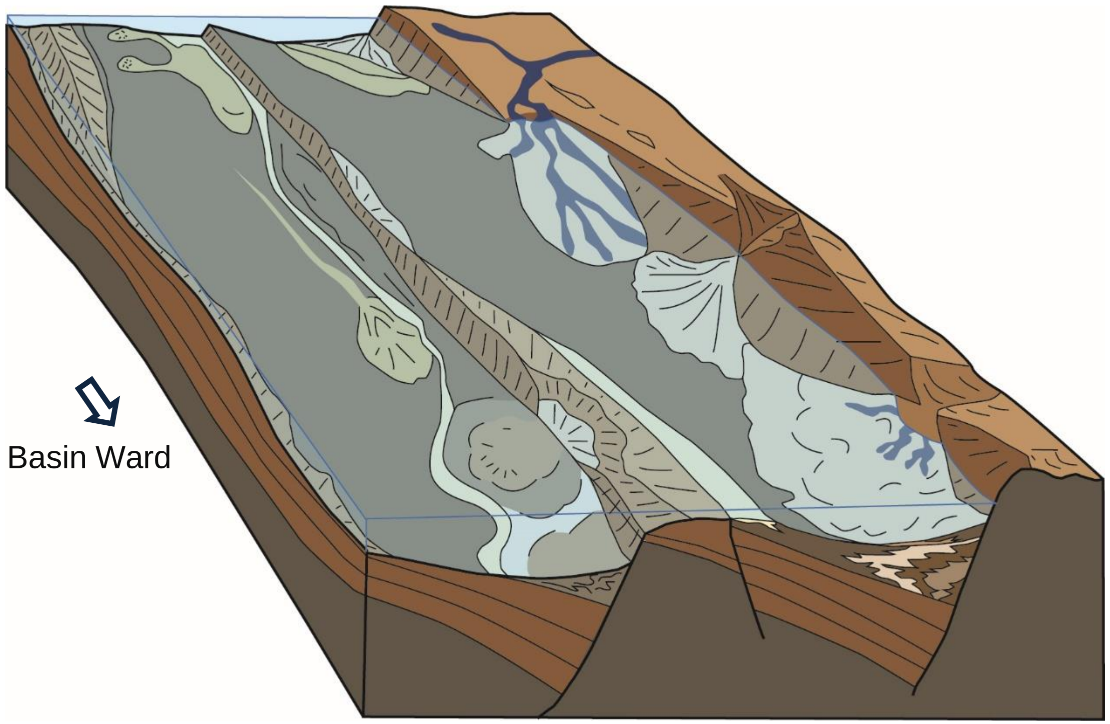
From Ravnas & Steel, (1998)



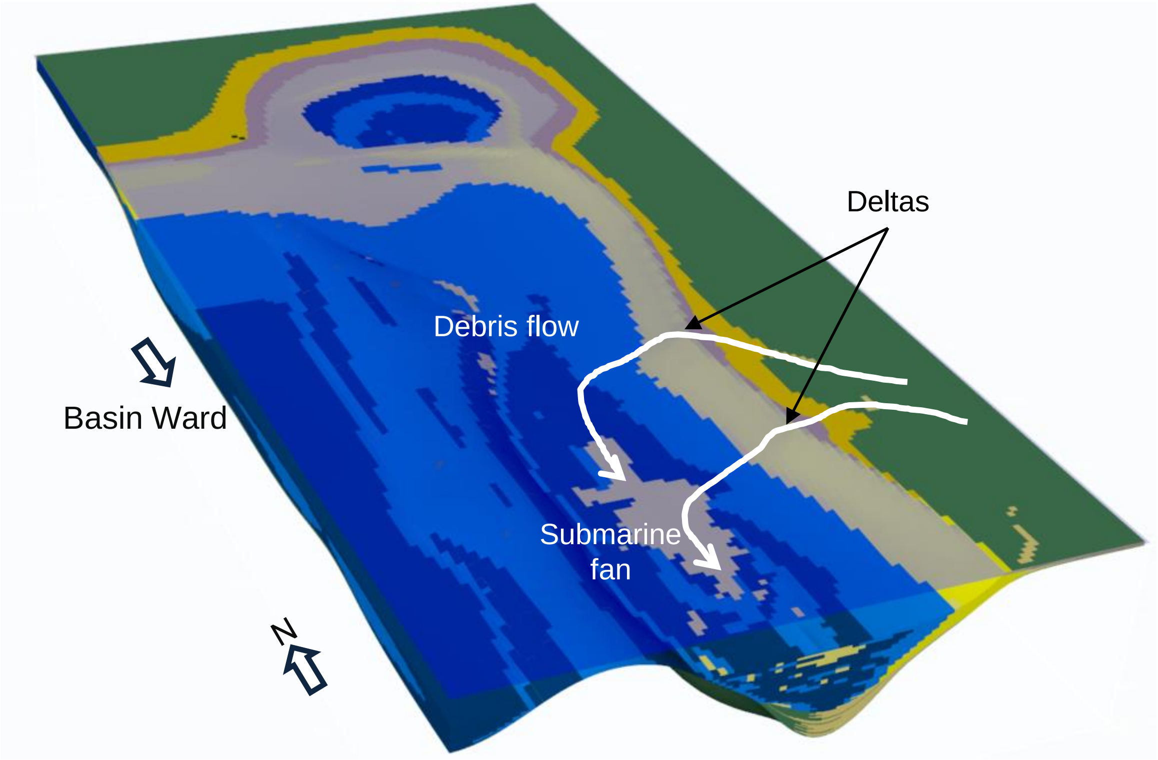
Non-linear simulation

Results Analysis

➢ Models show classical representation of rift basins in litterature (Ravnas & Steel, Gawthorpe & Leeder):



Modified from Ravnas & Steel, (1998)

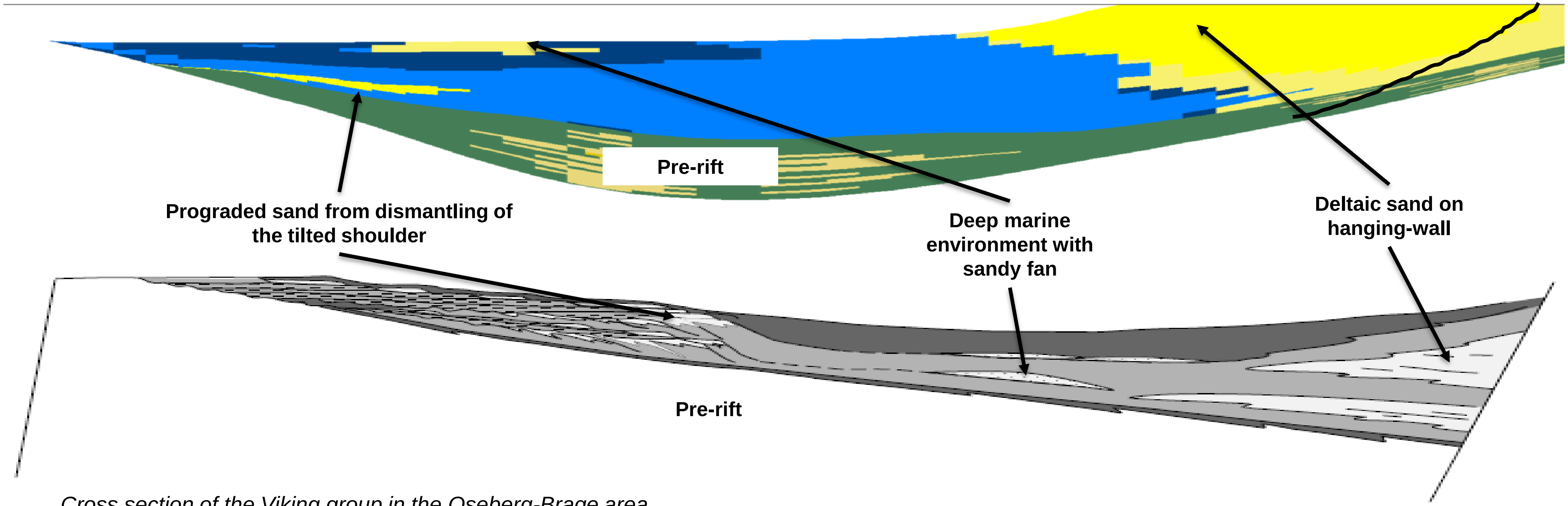


Non-linear simulation

Results Analysis

- Models show classical representation of rift basins in litterature in cross section:

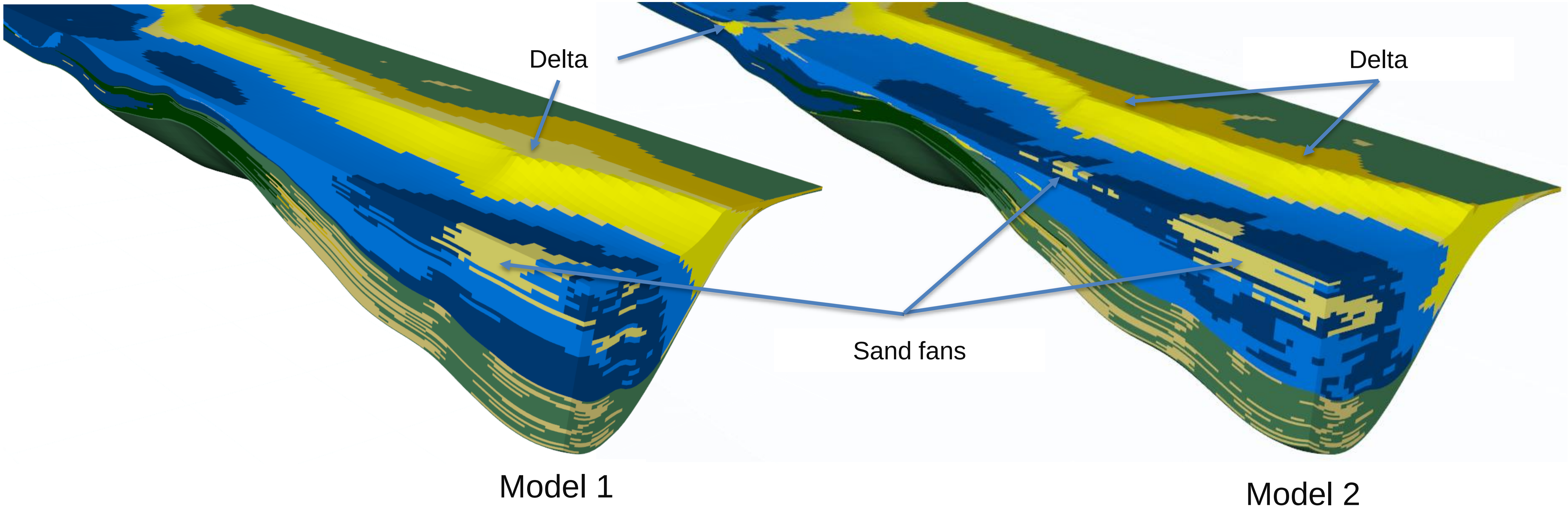
Cross section extracted of the compartimented model



Cross section of the Viking group in the Oseberg-Brage area (North Sea, Ravnas & Bondevik, 1997)

Results Analysis

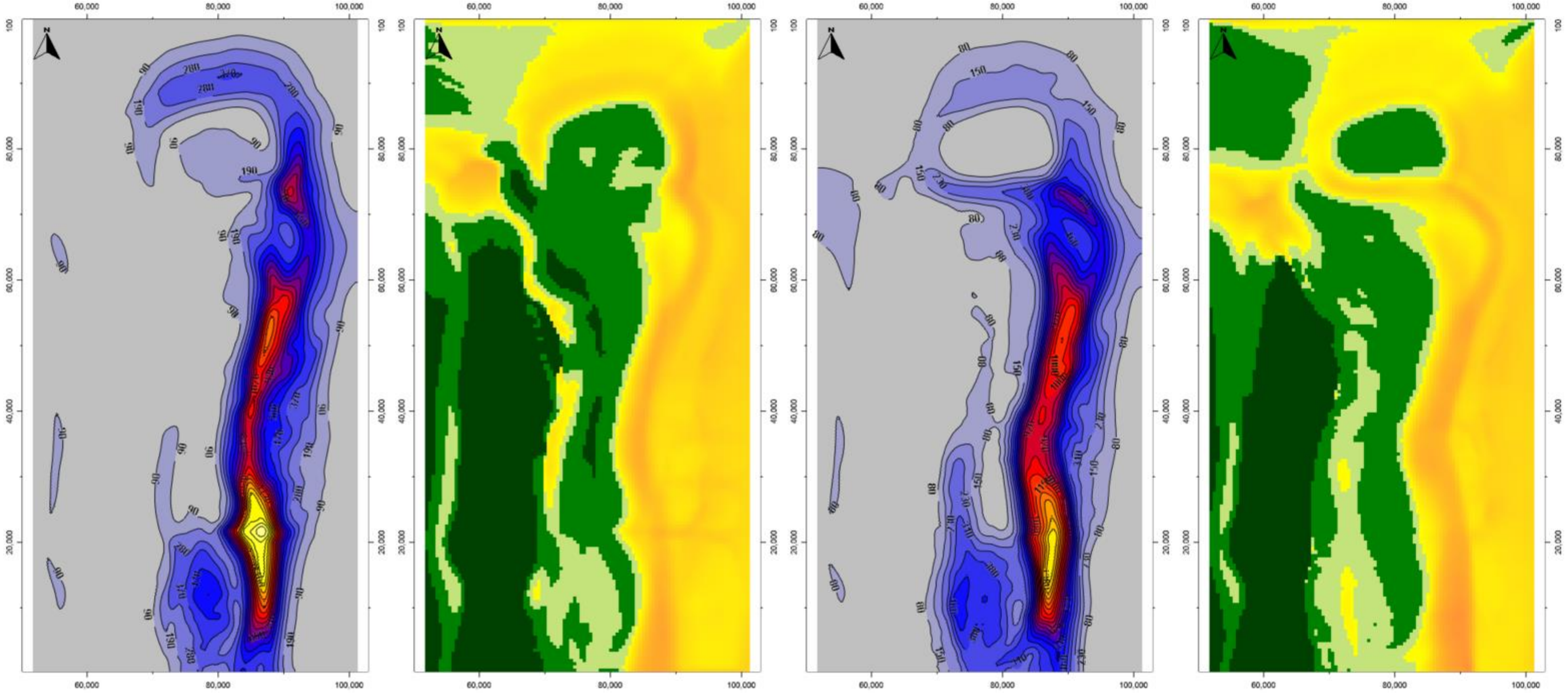
- Differences in geometry and sand distribution in both models:



Results Analysis

Model 1 – Linear case

Model 2 – Non-linear case



Sand net thickness (m)

Net to Gross (%)

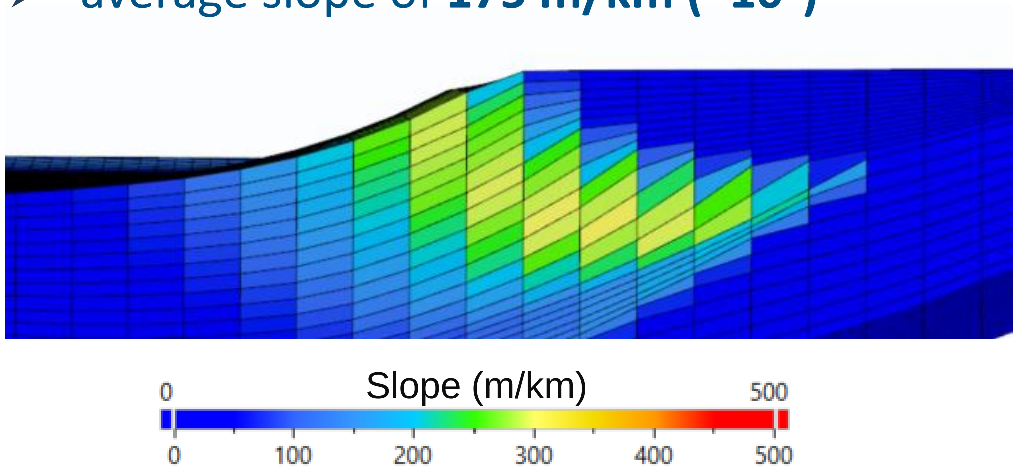
Sand net thickness (m)

Net to Gross (%)

Results Analysis

Model 1

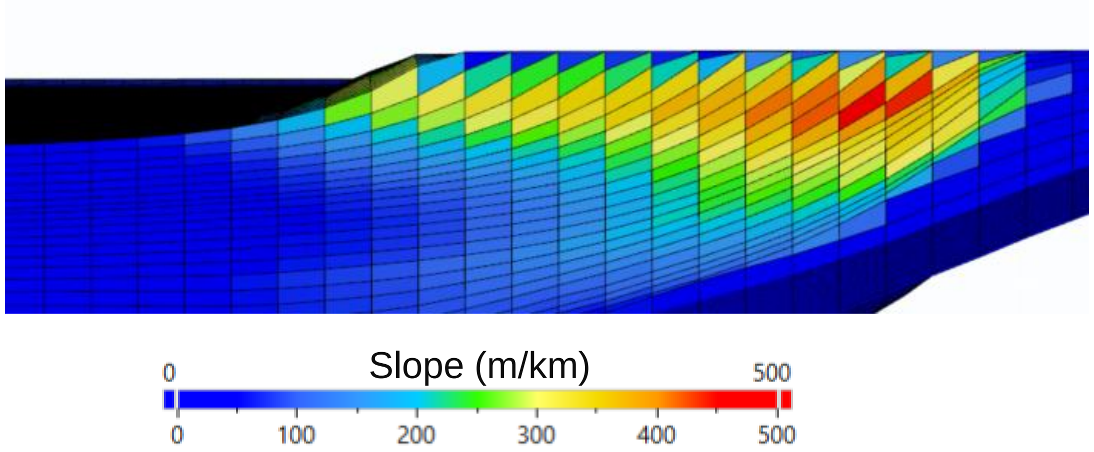
- average slope of **175 m/km (~10°)**



- Slope remains the **same through time** and signs environment of **classical delta shape**

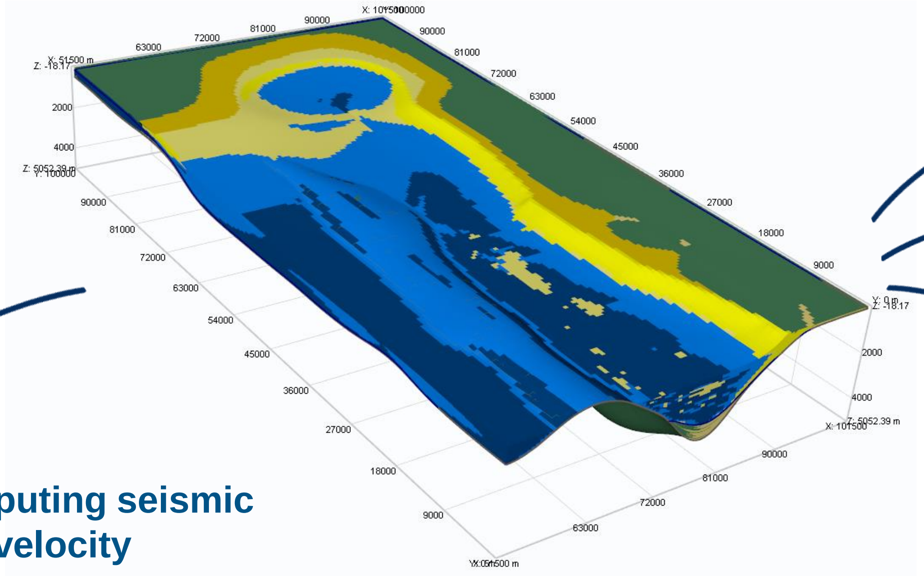
Model 2

- average slope of **400 m/km (~22°)**

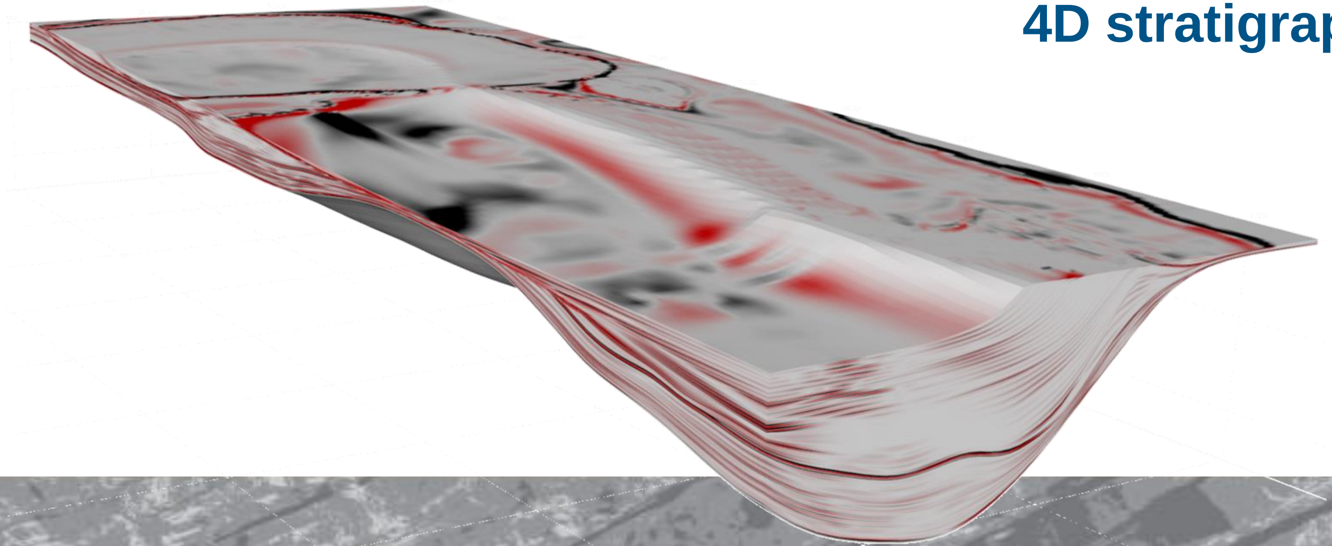


- Slope decrease through time and start with a **very steep slope** (more than 25°). This stip slope for a delta may characterize **Gilbert delta** type

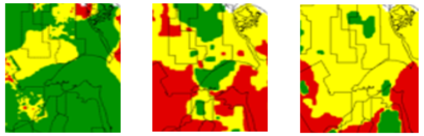
To Go Further



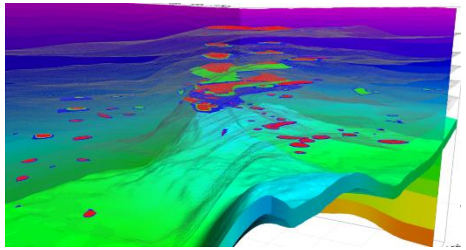
4D stratigraphic grid



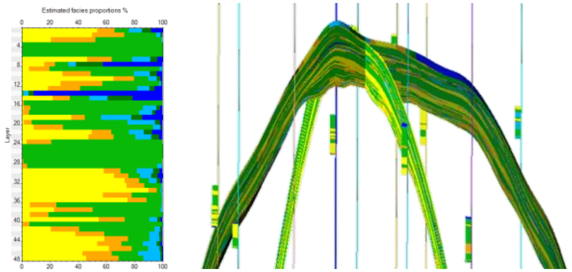
Recomputing seismic velocity



Play Risking



Petroleum System Modelling



Geomodelling & Geostatistics

Conclusion

- **Forward Stratigraphic Modeling** is a powerful too to simulate sedimentary processes and basin evolution to **derisk exploration** and more generally **predict source rock/reservoir/seal/trap presence**, distribution and body connectivity

- Our work shows that rift basins tectonics (**timing and offset of faults**) play a critical role on **stratigraphic patterns** and **reservoir distributions**:
  - The main sediment **transport is basin ward** but transport mode change according to tectonic settings
  - **Specific structures** (Raly ramp) can be modeled and lead to different **sediment pathways**
  - Change in sediment pathways induce **different sandy deep marine fans location**
  - Slope created by the fault plan influence the **type of delta created**

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THANK YOU!