

Forward Stratigraphic Modelling of Deep-Sea Sedimentary Environments: Predicting Facies Distribution in Salt Tectonics Context*

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Search and Discovery Article #41956 (2016)**

Posted December 5, 2016

*Adapted from oral presentation given at AAPG/SEG International Conference & Exhibition, Cancun, Mexico, September 6-9, 2016

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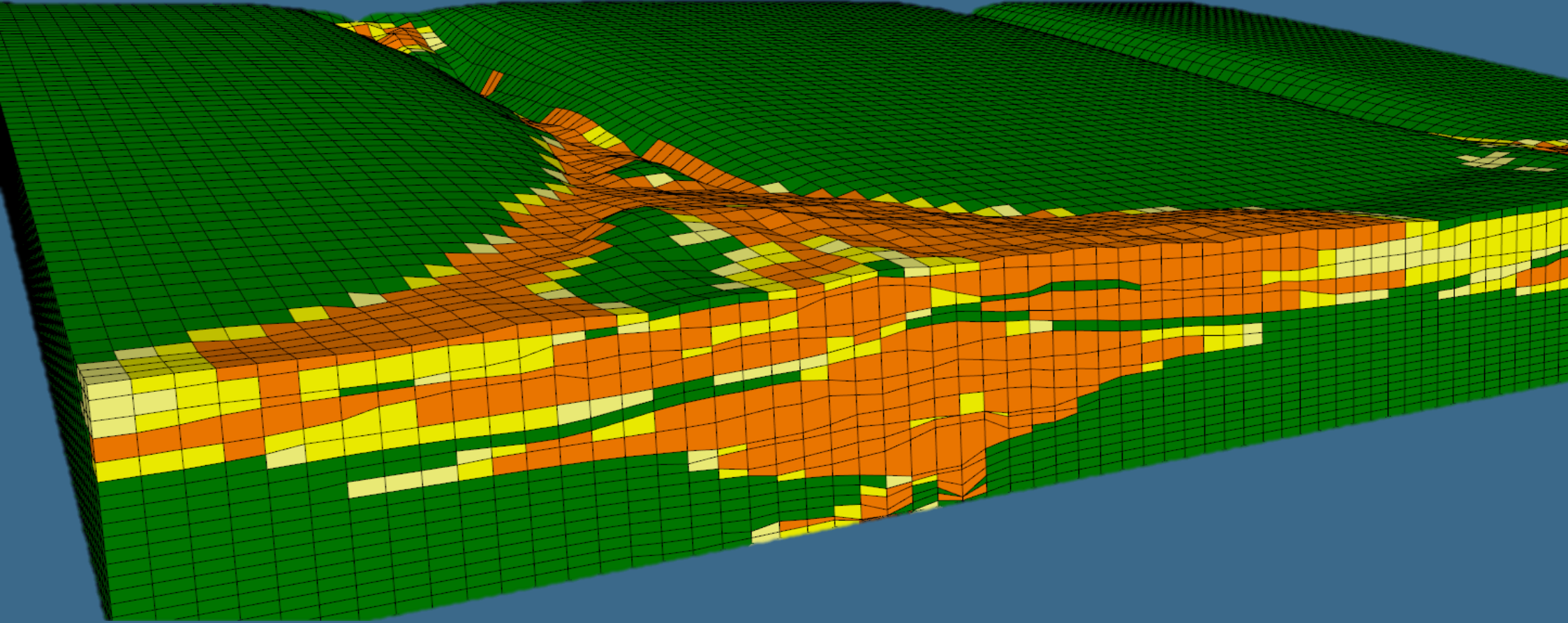
Abstract

Deep-sea sedimentary environments represent the ultimate frontier for hydrocarbons exploration, as they are associated to many technical and scientific challenges. Even if the understanding of such environments has substantially increased during the last decades supported by advances in seismic imaging techniques and deep-sea drilling, reproducing the dynamic evolution of these systems is still a major challenge. The use of innovative diffusion-based forward stratigraphic modelling approaches allows the reproduction of deep-sea sedimentary systems evolution under dynamic subsidence and uplift conditions. The modelling principles mimic the transport and sedimentation of sedimentary packages through time, steps of tens of thousands of years or more, along a continuously evolving basin-surface of hundreds of square kilometers. These sedimentary packages are transported along the system by diffusion following dynamic waterflow pathways and gravity driven creeping. Two sediment sources were used in the model: (1) a mix between lithic fine-grained sands as well as shale particles, and (2) a mix between fine-grained quartz-rich sand particles and shales.

Vertical uplift and subsidence were set as a proxy for syn-sedimentary salt kinetics, which directly impact the basin geometry. A full 4D-grid resulted from the forward stratigraphic model showing the distribution of sandstone and shale packages through time. As two mineralogically different sources have been included in the model (lithic versus quartzitic sand), it was possible to determine the preferential sediment transport route and distal accumulation related to these sources. Such results provide valuable information on the impact of the primary source composition on the reservoir quality prediction previous to any diagenetic overprint. Lithology content in cells was consequently combined with calculated environmental parameters in order to generate a sedimentary facies grid evidencing the distribution of amalgamated channel infill, overbank, stacked lobes and shales. Alternative scenarios underlining the non-uniqueness of geological models were also generated by multi-realization loops permitting consideration of the spectrum of variability linked to autocyclic processes (i.e. channel avulsions). The Forward stratigraphic modelling approach constitutes a powerful tool for predicting facies distribution in deep-sea sedimentary systems and thus a valuable contribution for reducing risks in exploration targets.

Selected References

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Forward Stratigraphic Modelling of Deep-Sea Sedimentary Environments

Predicting Facies Distribution in a Salt Tectonics Context

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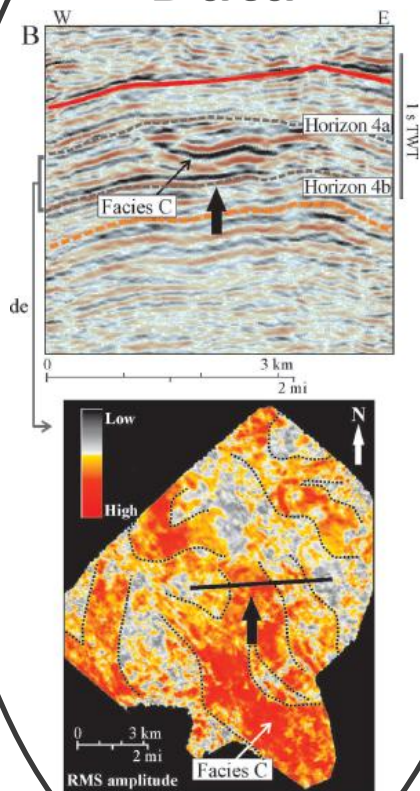
Contents

1. Objectives
2. Basin Floor Fans: Architecture, Scales & Drivers
3. Modelling Principles
4. Modelling Results
5. Uncertainties and Sensitivity
6. Conclusions

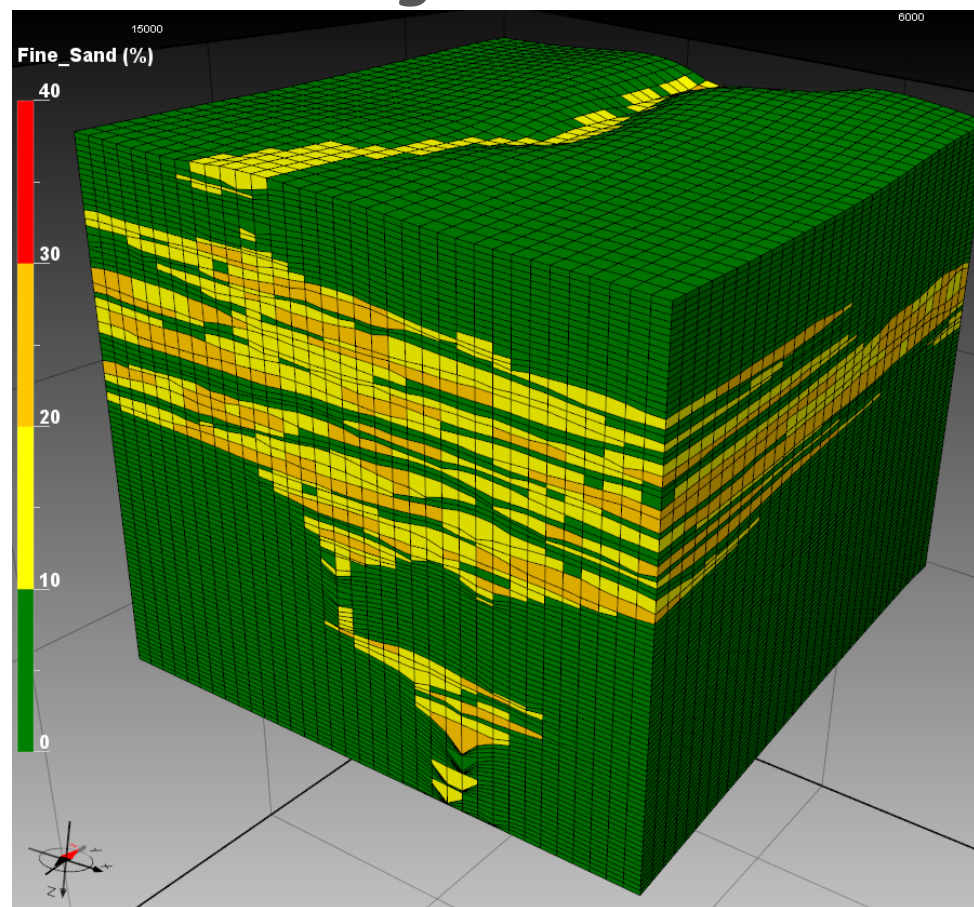
Objective

Forward Stratigraphic Modelling DionisosFlow

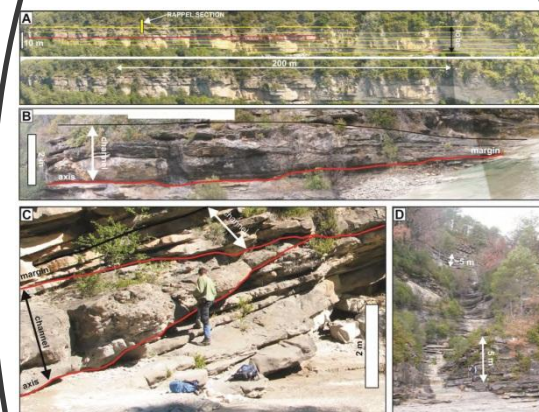
Seismic Data



McDonnell et al., 2008



Outcrop Description

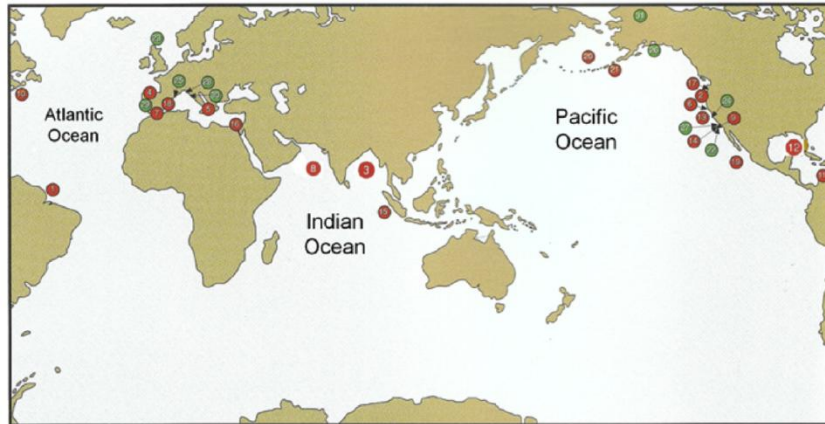


G. Gordon, 2014

*Providing a time scaled reproduction of the geometry and distribution of
sedimentary bodies in deep sea marine environments*



Submarine Fan's Distribution

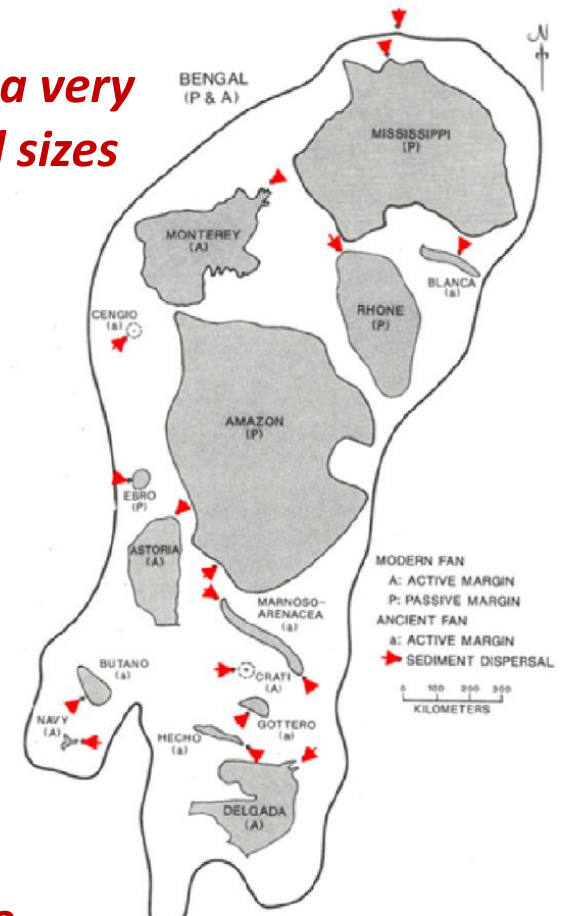


Distributed worldwide with a very high variability in forms and sizes

Modern		Ancient	
1 Amazon	12 Mississippi	22 Blanca	
2 Astoria	13 Monterey	23 Brae	
3 Bengal	14 Navy	24 Butano	
4 Cap Ferret	15 Nicobar	25 Cengio	
5 Crati	16 Nile	26 Chugach	
6 Delgada	17 Nitinat	27 Ferrello	
7 Ebro	18 Rhone	28 Gottero	
8 Indus	19 San Lucas	29 Hecho	
9 La Jolla	20 Zhemchug	30 Marnoso-Arenacea	
10 Laurentian	21 Zodiac	31 Torok-Fortress Mountain	
11 Magdalena			

(Data from Barnes and Normark, 1985)

Many examples preserved in the stratigraphic record



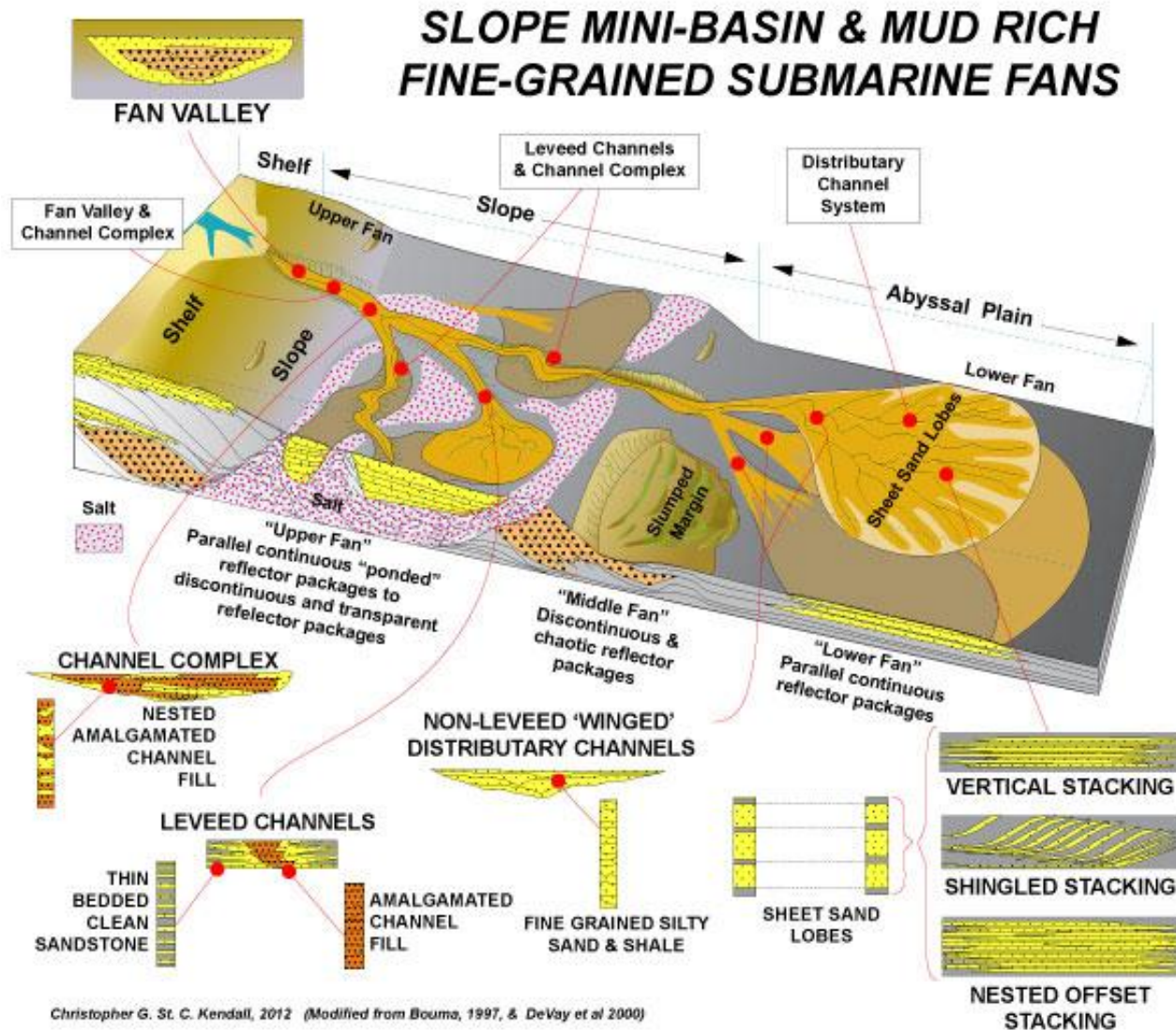
Commonly present on the submarine slope and basin floor zone

Shanmugam, 2016

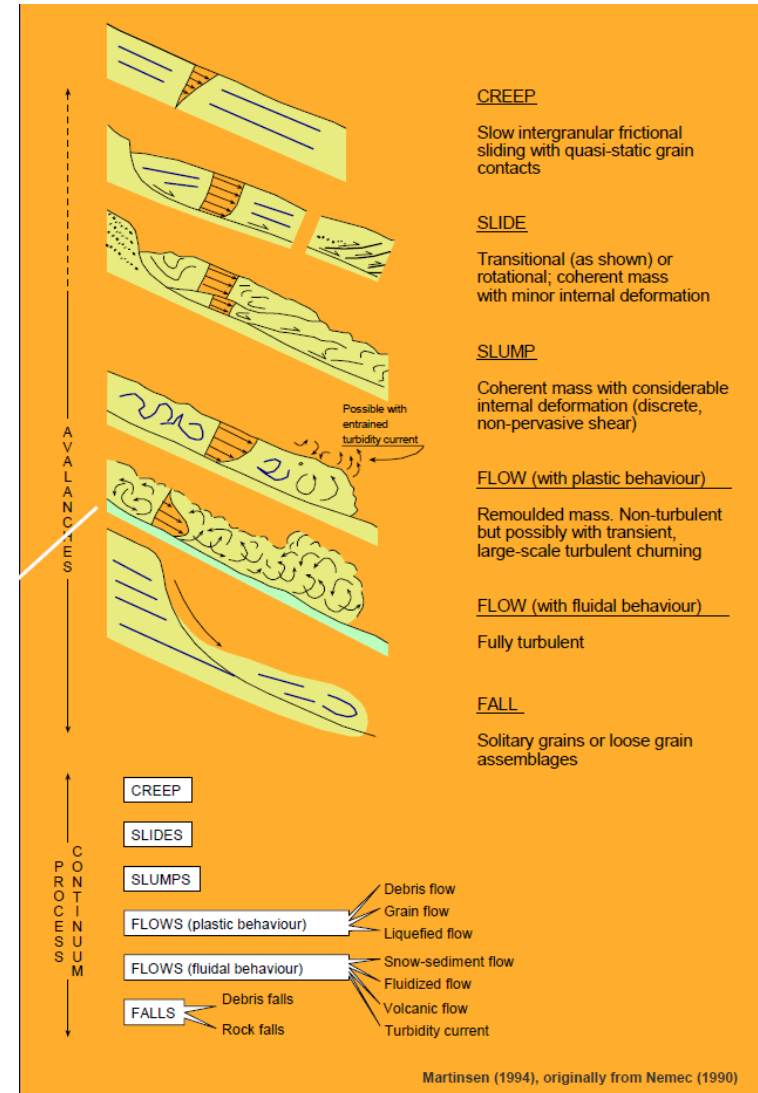


Sedimentary Processes in Deep Settings

A variety of sedimentary Processes



Kendall, 2012

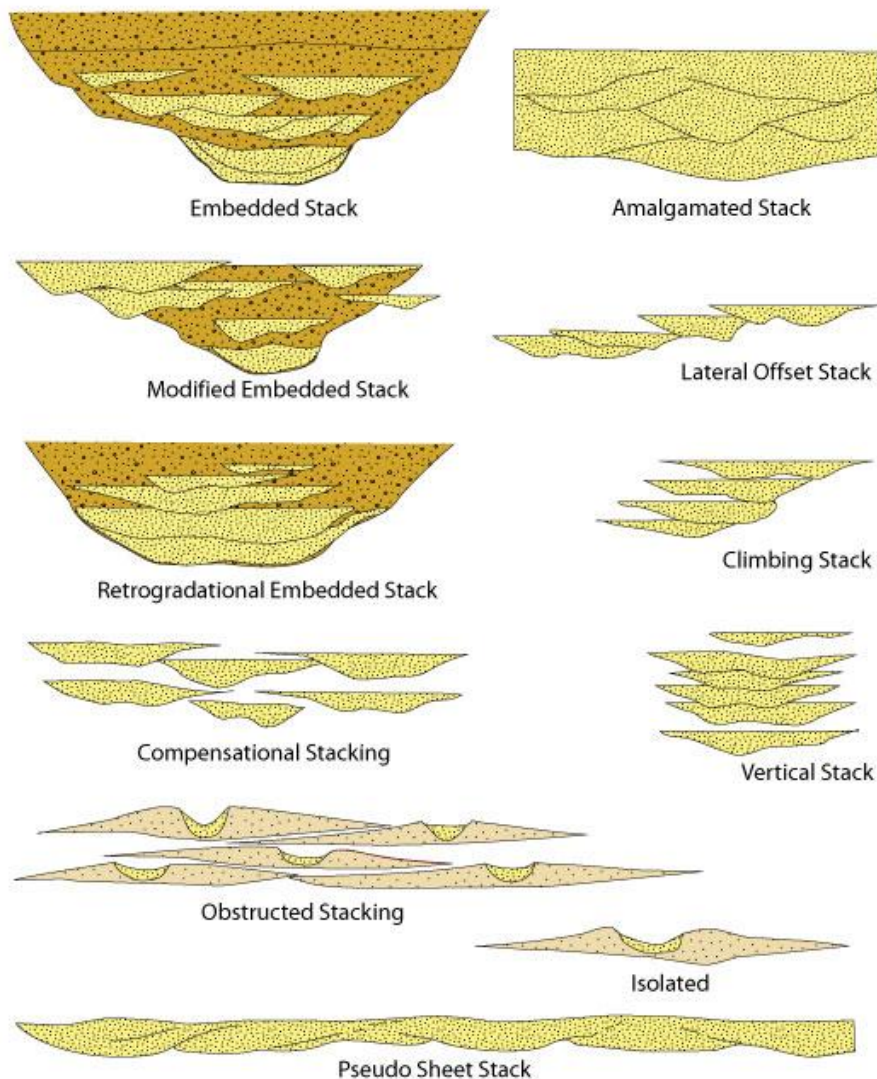


Martinsen, 2010

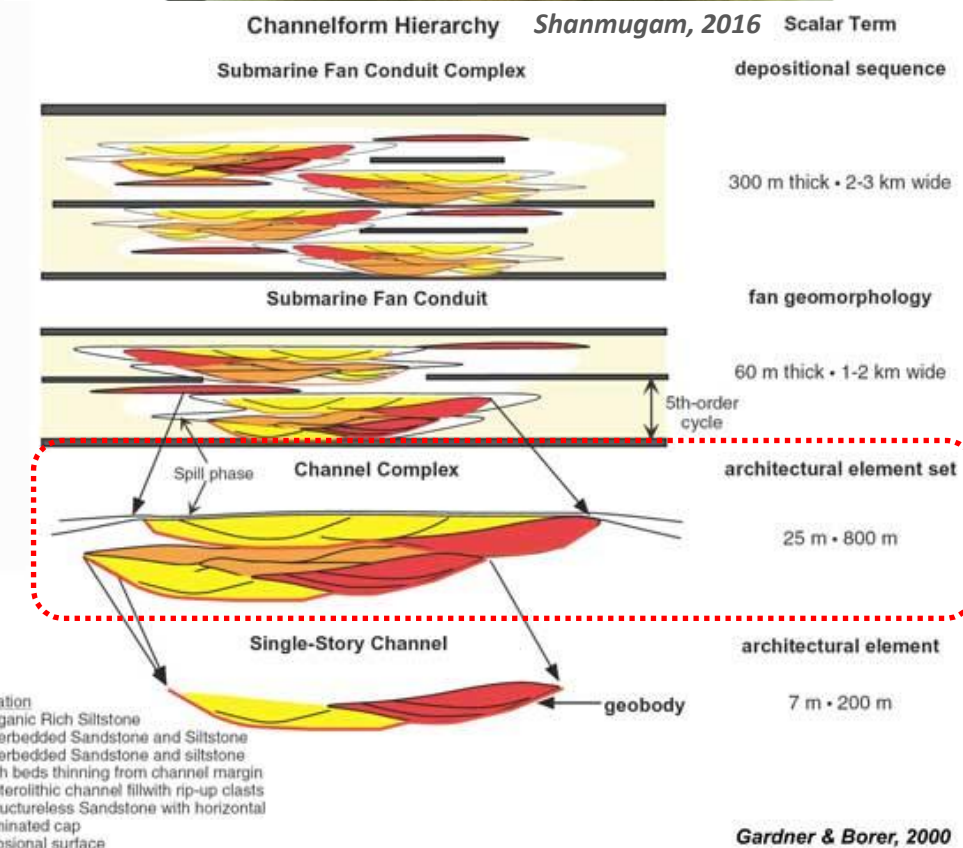
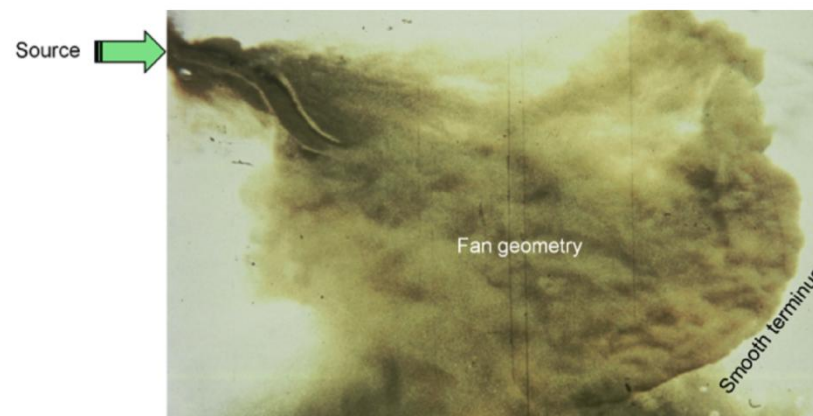


Detailed Geometries

CHARACTER OF CHANNEL STACKING

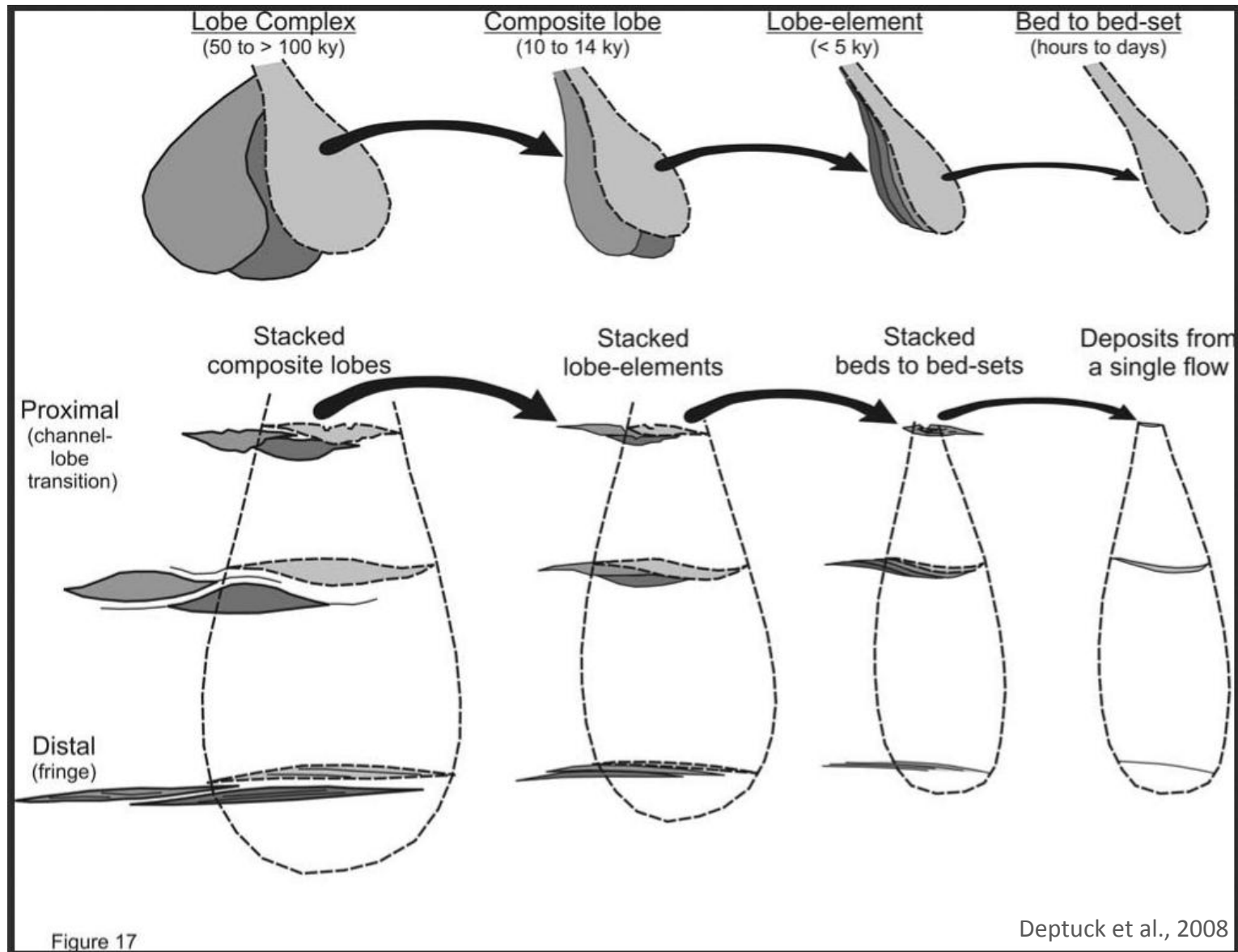


Christopher Kendall & Peter Houghton 2006





Timing & Hierarchy



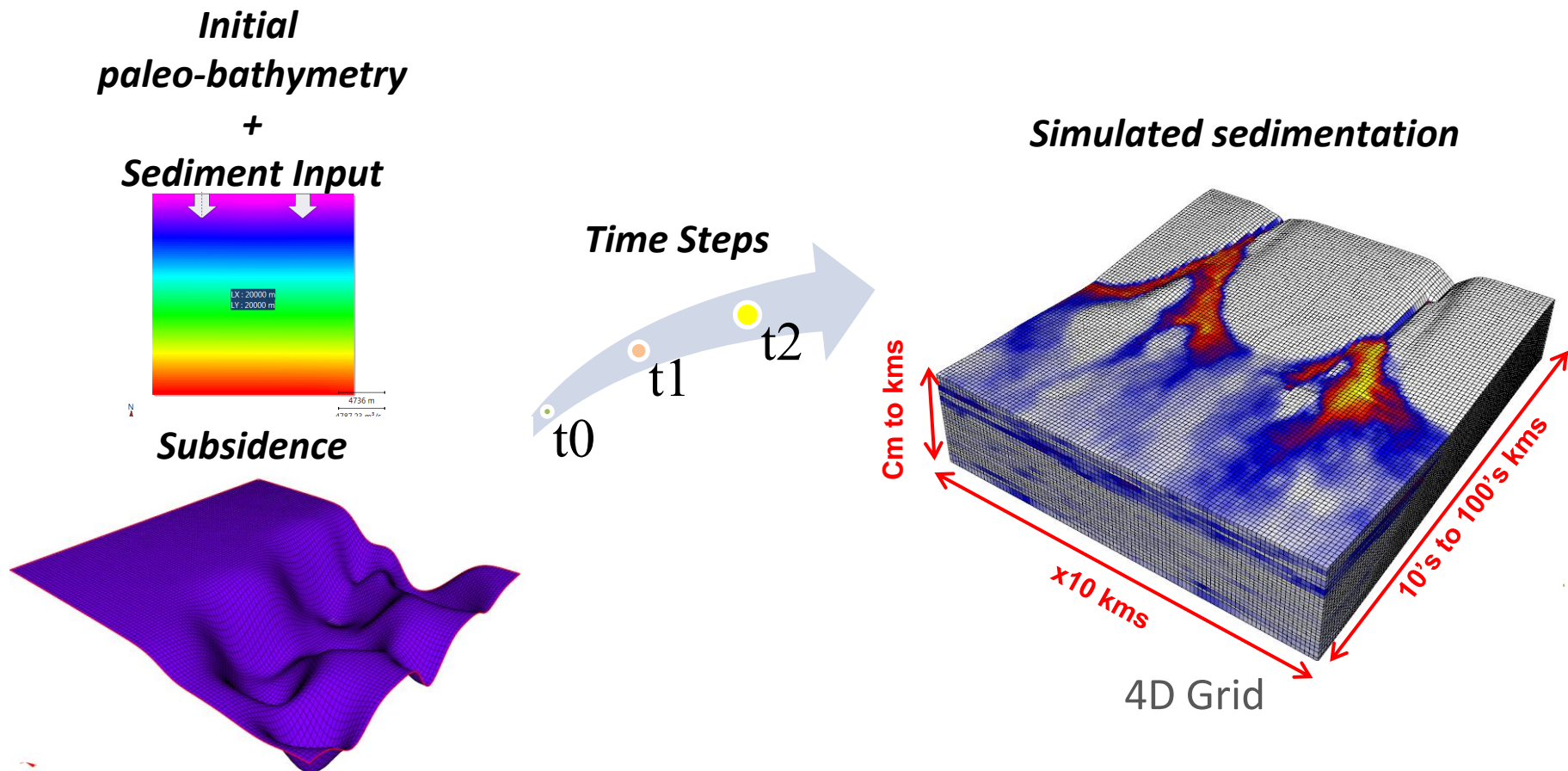


DionisosFlow – A FSM Tool

DionisosFlow is a deterministic process based tool that reproduces sedimentary transport and deposition of ***siliciclastic and carbonates***. subsidence, multiple grain sizes, eustasy, Climatic cycles , in situ production or carbonates and erosion.

Diffusive Orientated Normal and Inverse Simulation of Sedimentation

(by IFP -- Granjeon, 1997; Granjeon and Joseph, 1999).





Transport Processes – Diffusive Equation

■ *Transport is simulated through diffusive equations*

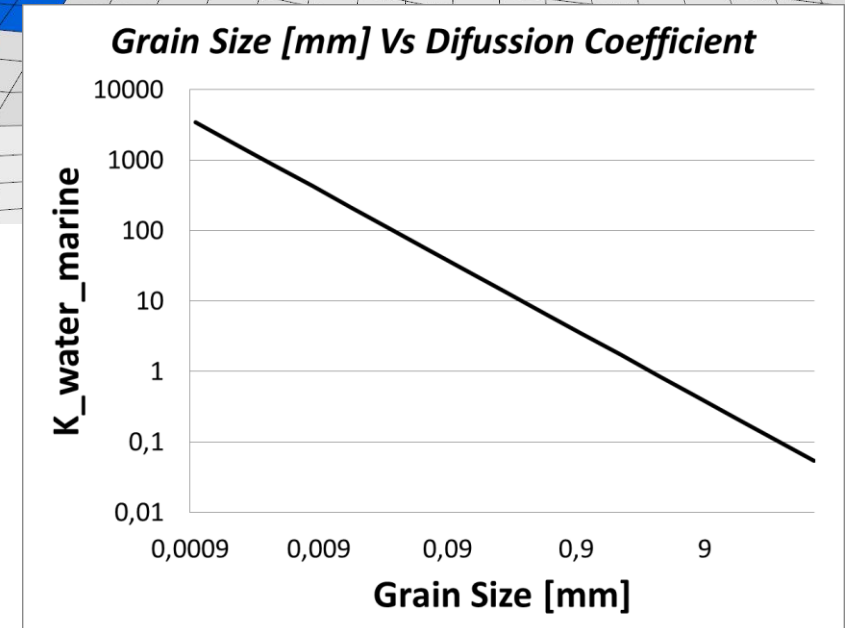
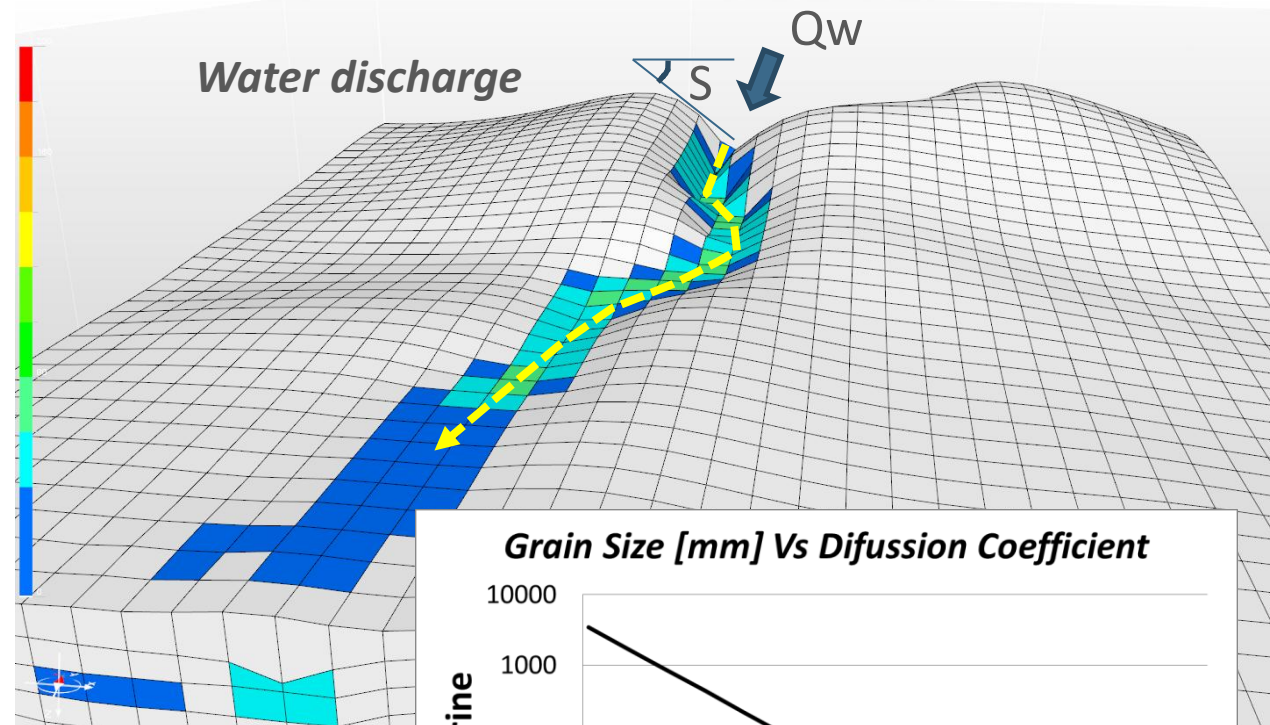
$$Q_s = K Q_w S$$

- Q_s = Sediment Load
- Q_w = Water Discharge
- S = Depositional Slope
- K = Diffusive Coefficient

■ Drivers

- Slope
- Sediment Load
- Water discharge
- Gravity

Particles move through the system transported by water and gravity at a velocity constrained by its diffusion coefficient



Hawie and Marfisi in prep,

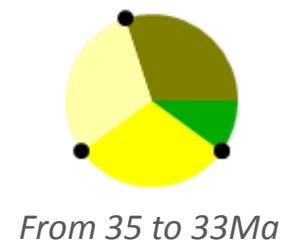
Model Building (1/2)

Model Specifications:

- 20km*20km extension
- 200m*200m cell size
- Simulation time steps: 20kyrs and 50 kyrs
- Time span simulated: 5Ma, from 35 to 30Ma

Two sources of sediments, located North

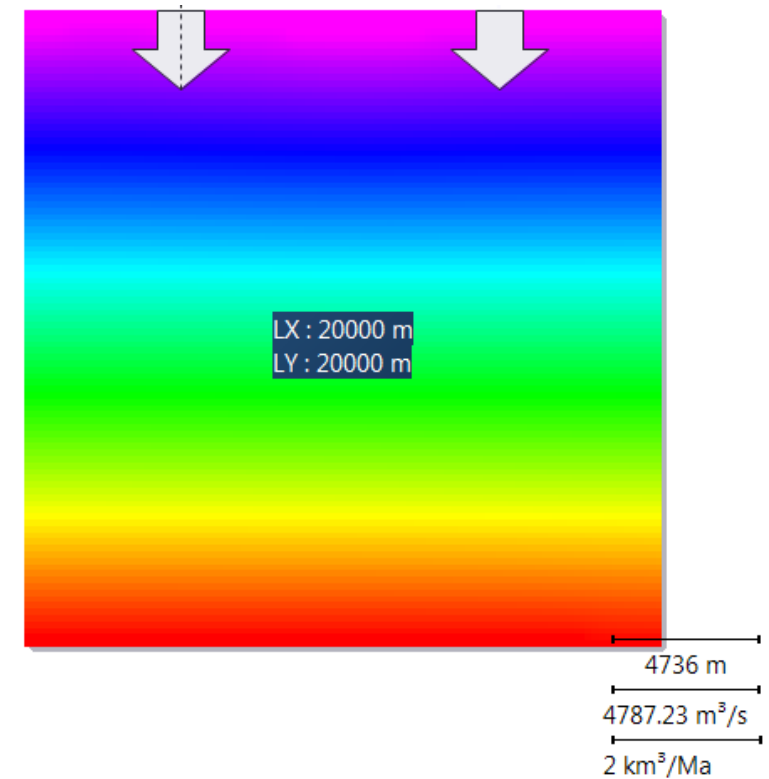
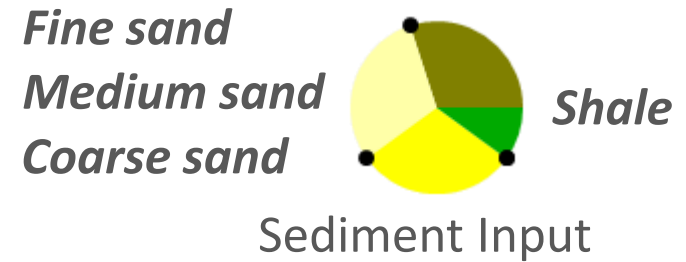
- 5 classes of sediments:
 - Shale
 - Fine Sand
 - Medium Sand
 - Quarzitic Medium Sand
 - Coarse Sand



From 35 to 33Ma



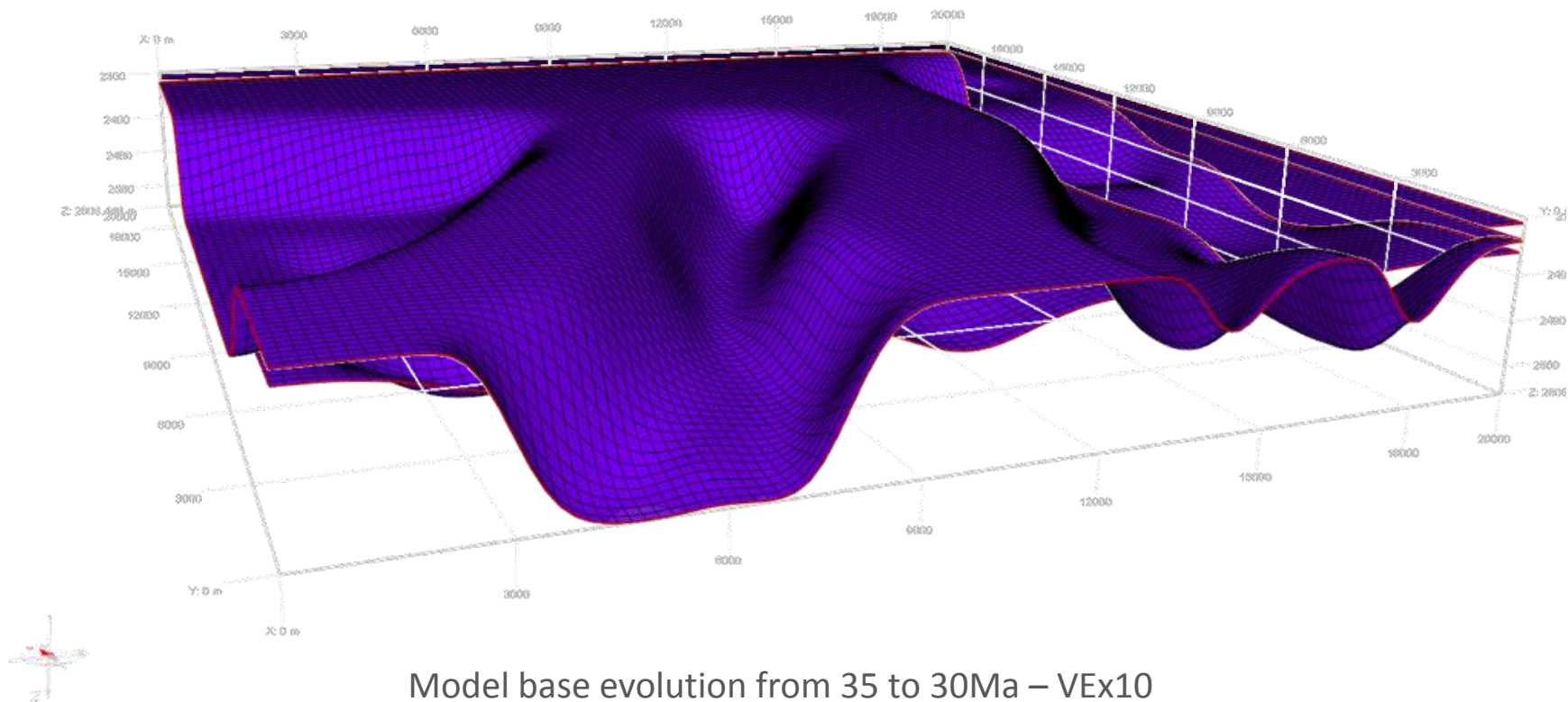
From 33 to 30Ma





Model Building (2/2)

- Long-term flow + short term events (climatic cycles)
- **Salt deformation** and its impact on sedimentation was simulated

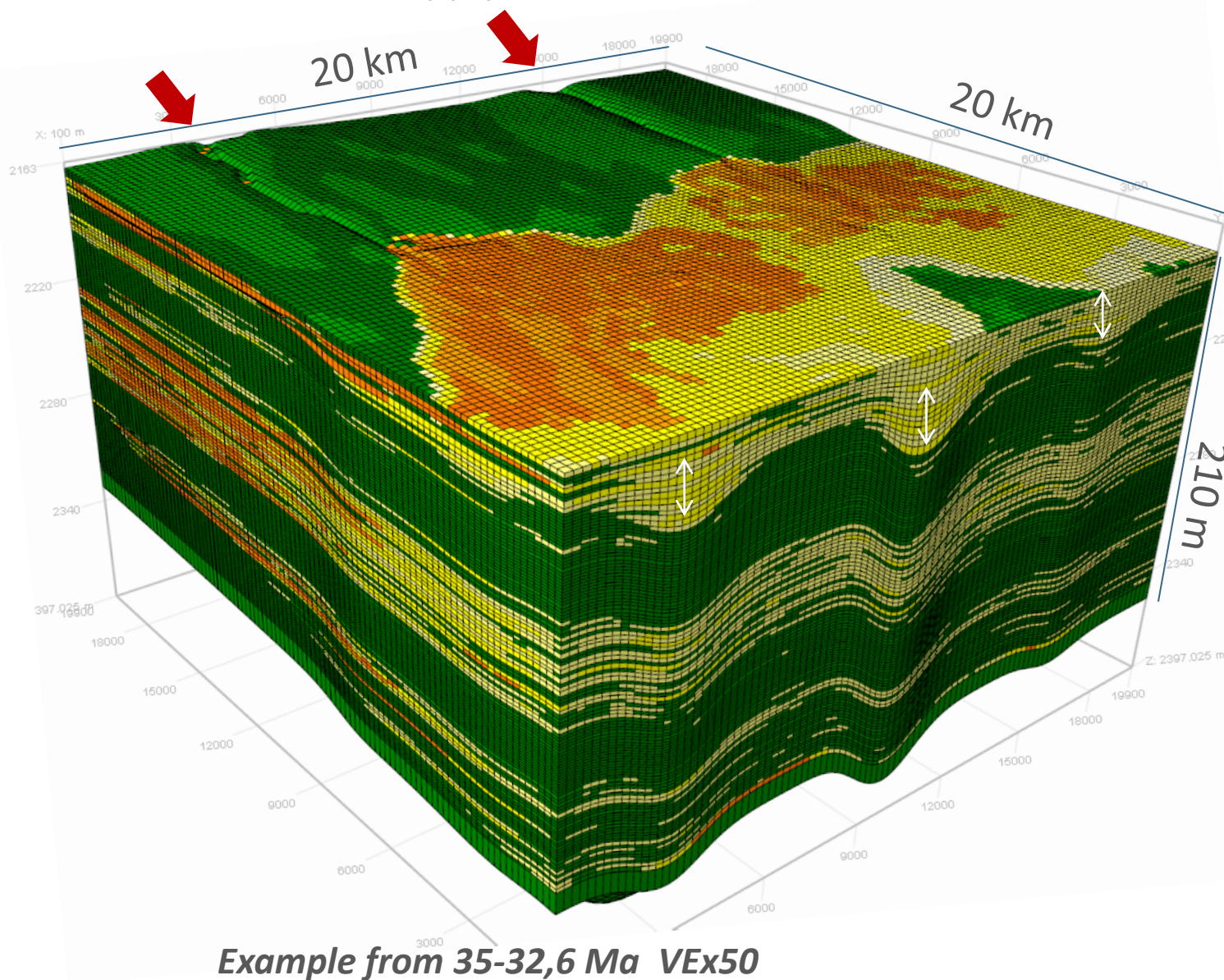


Model base evolution from 35 to 30Ma – VEx10

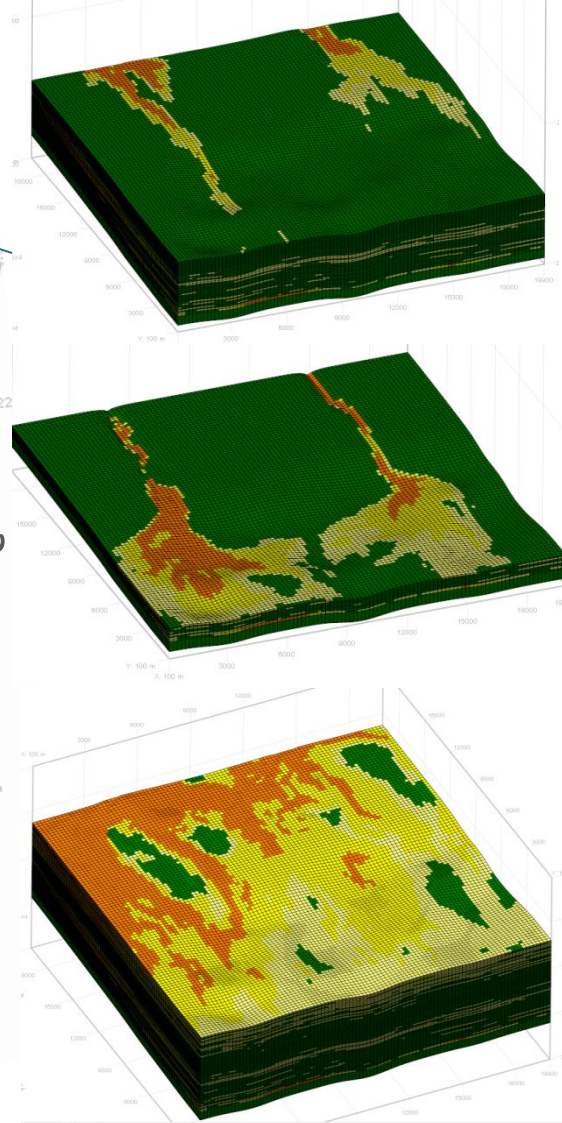


Overall Facies Model

Climatic Variations on Supply +/- 50%



Sediment Supply

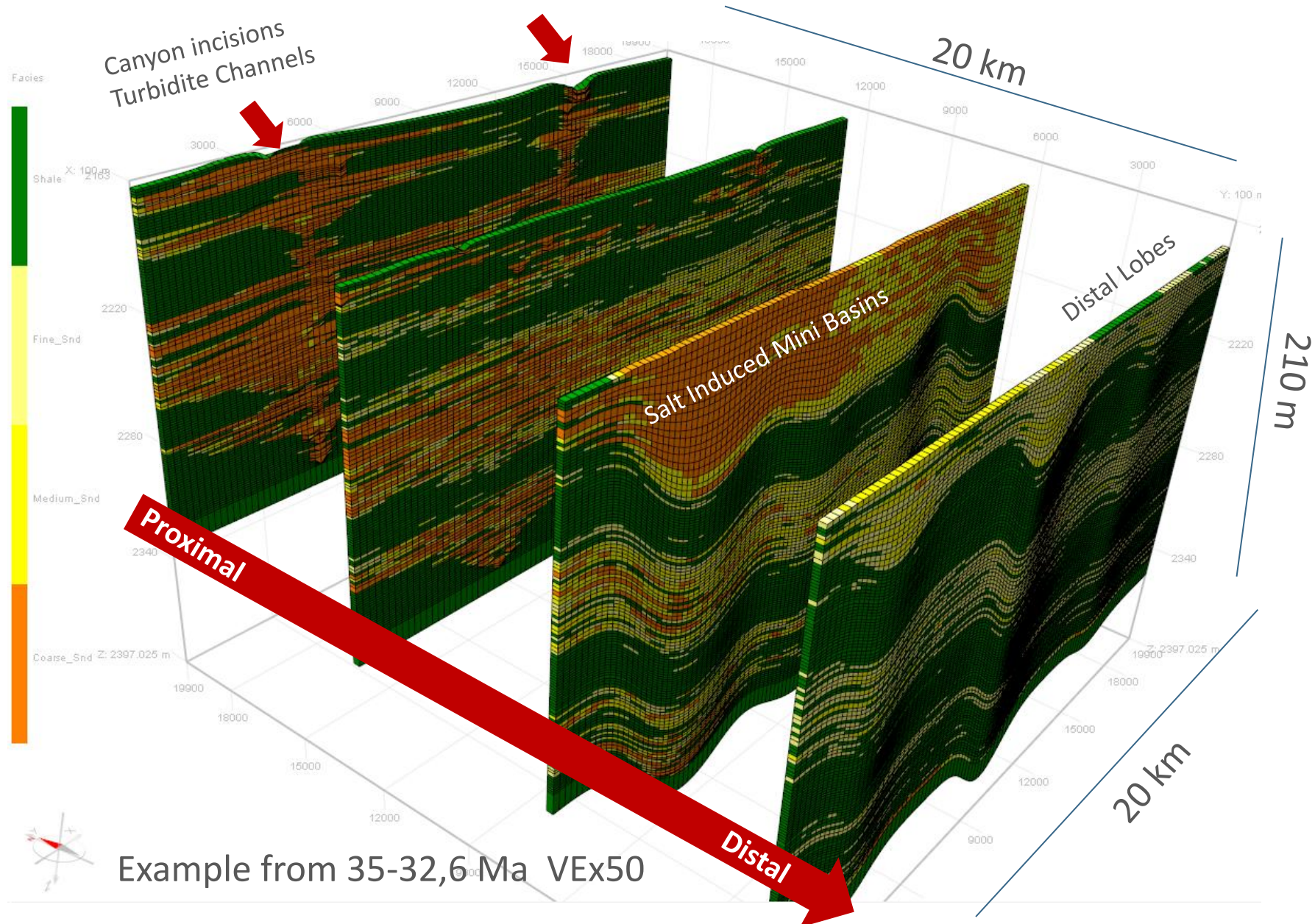


Low

High



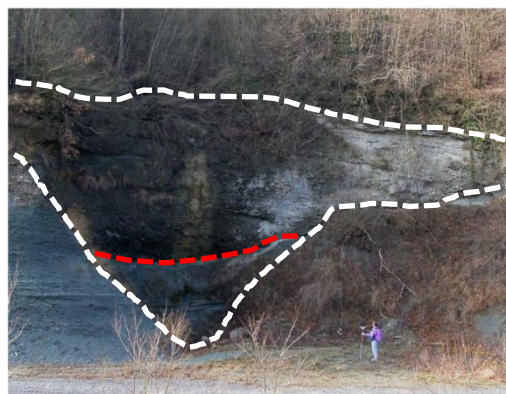
Overall Facies Model & Geometries



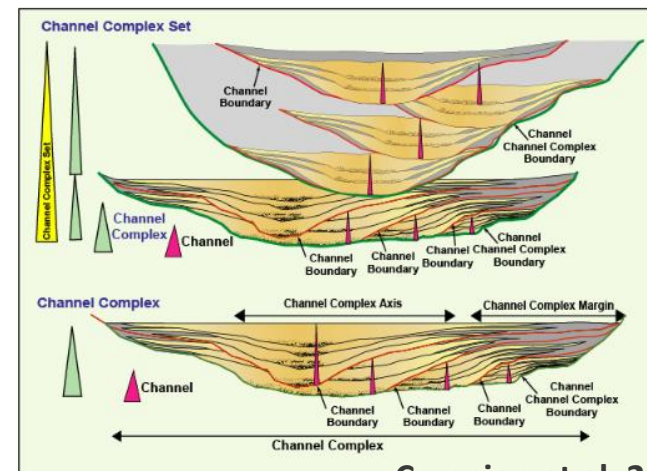


Channel Stacking Patterns

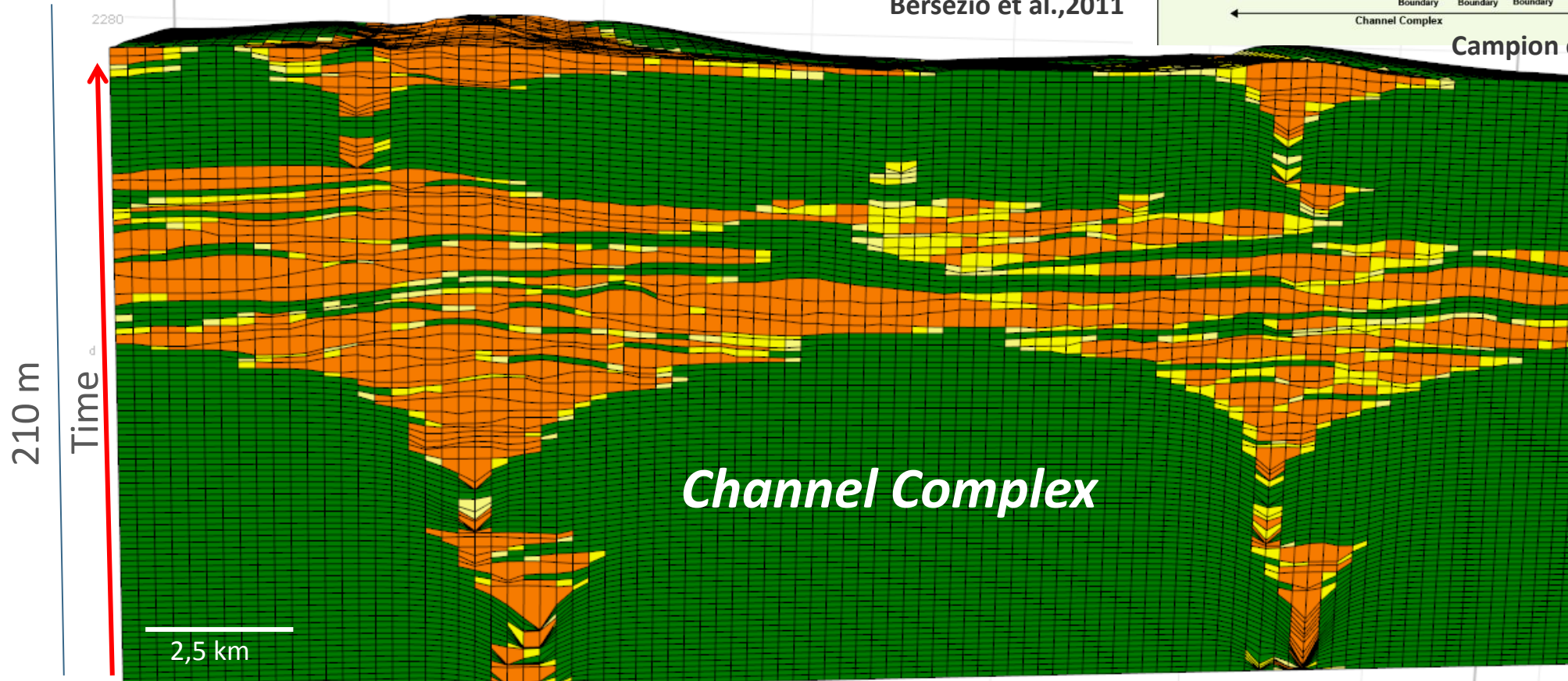
Example from 35-32,6 Ma VEx50



Bersezio et al., 2011



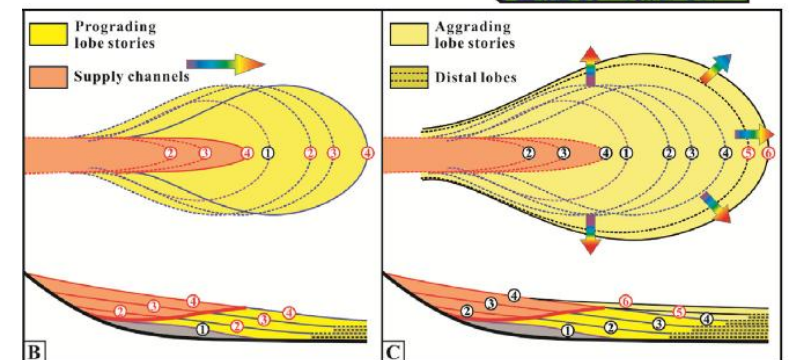
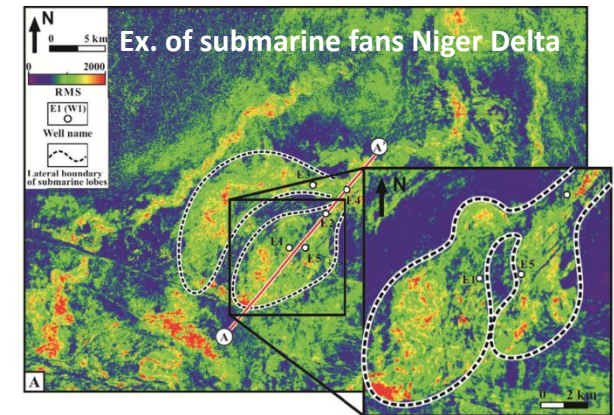
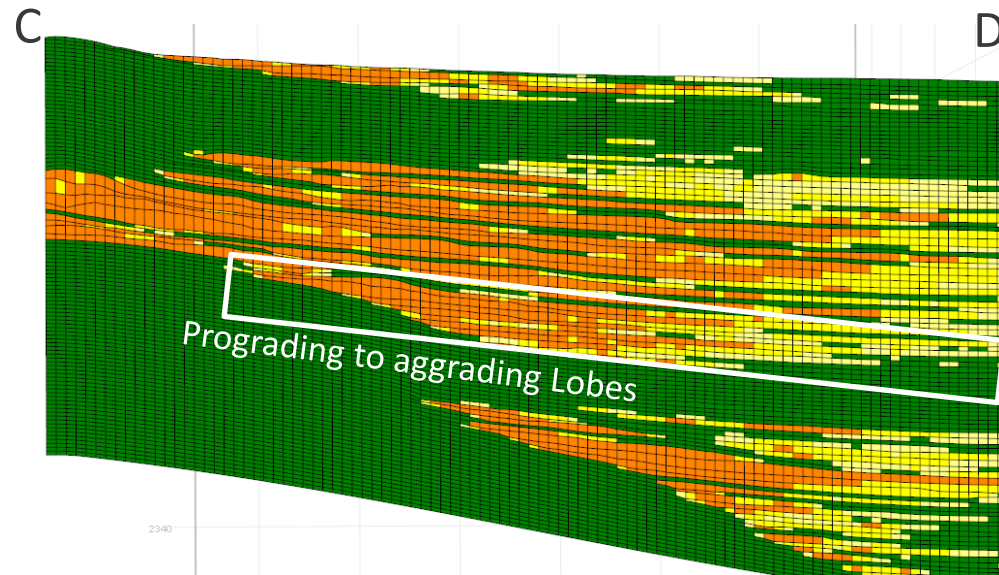
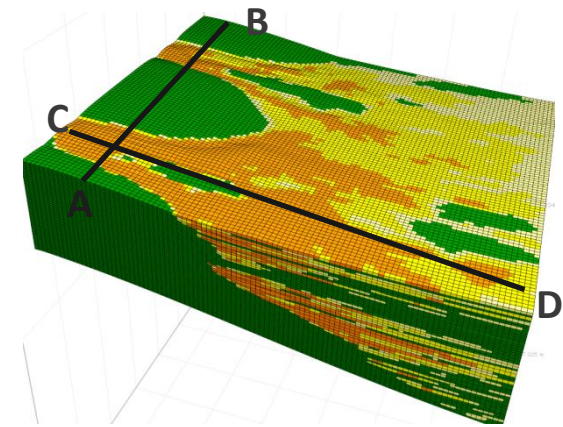
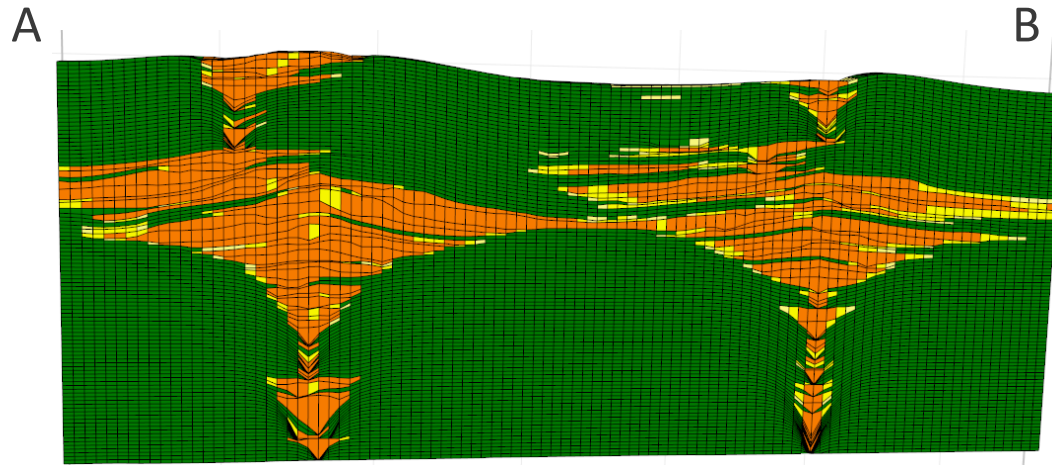
Campion et al. 2011,



Channel Complex



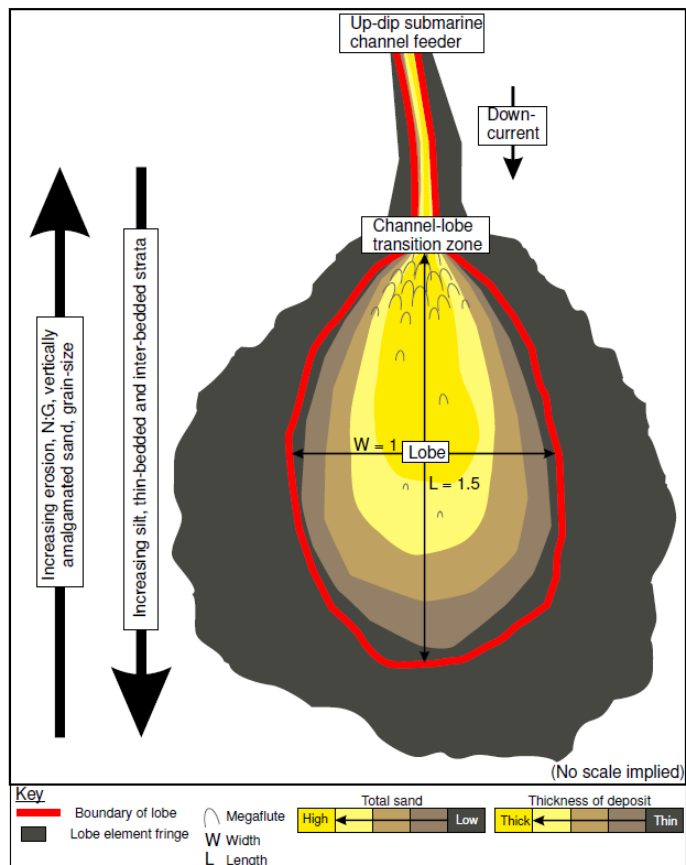
Channel & Lobe Architecture



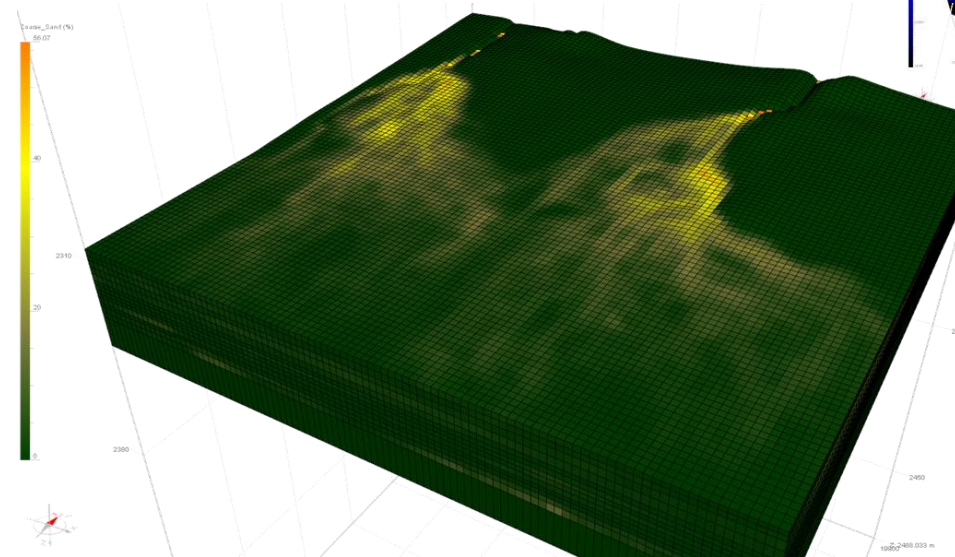
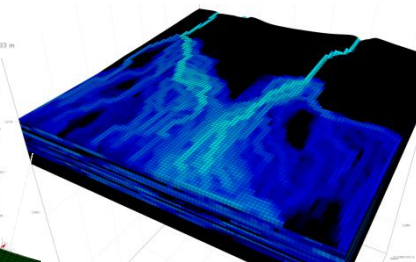
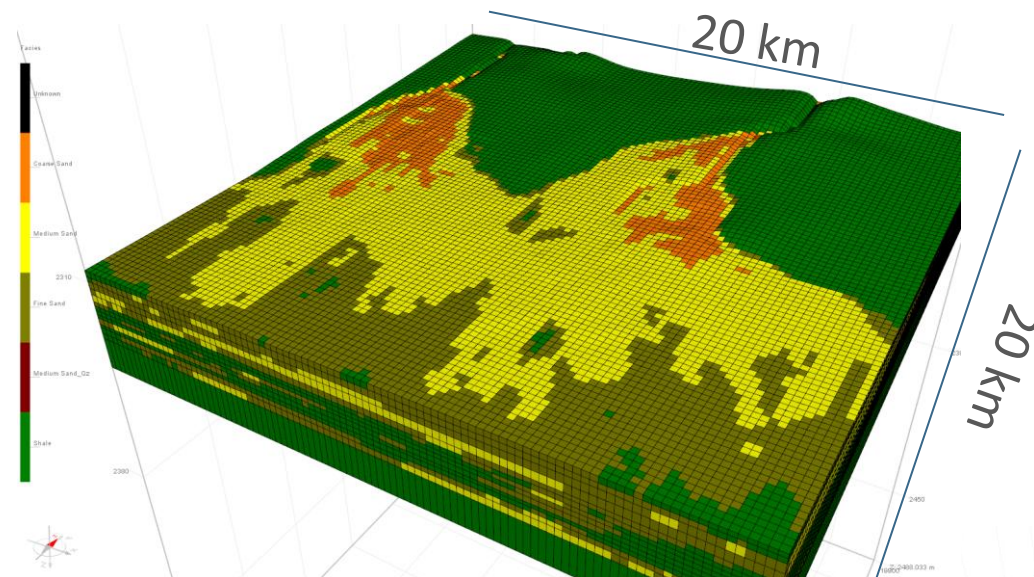
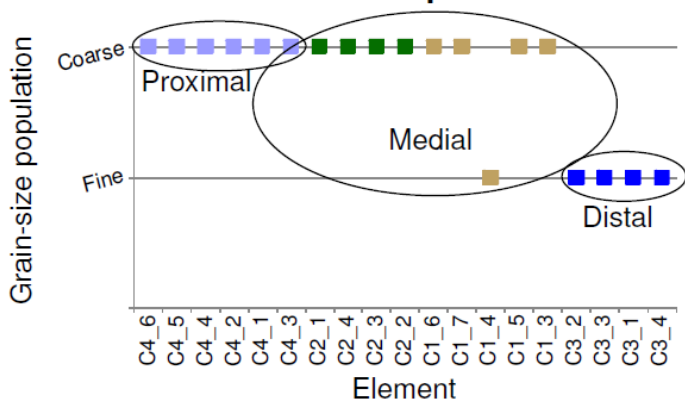
Zoom on Channel- Lobe complex VEx50



Channel & Lobe Granulometry



Grain-size Population



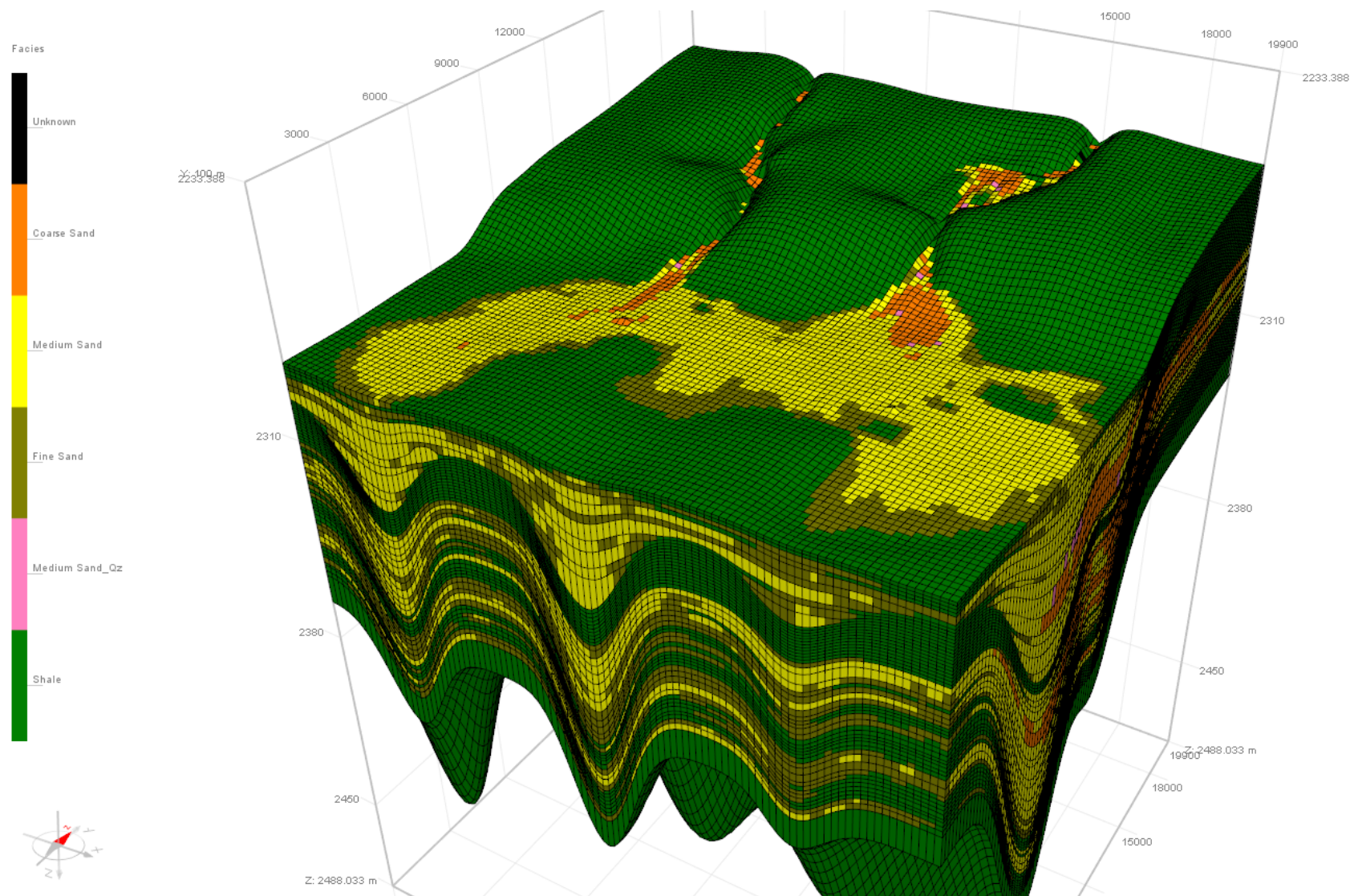
VEx100



Impact of Salt Deformation



Time step of 50kyrs

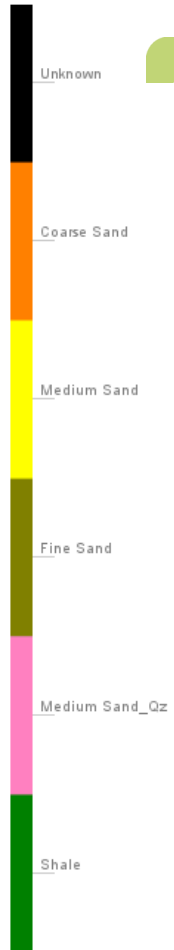


VEx100

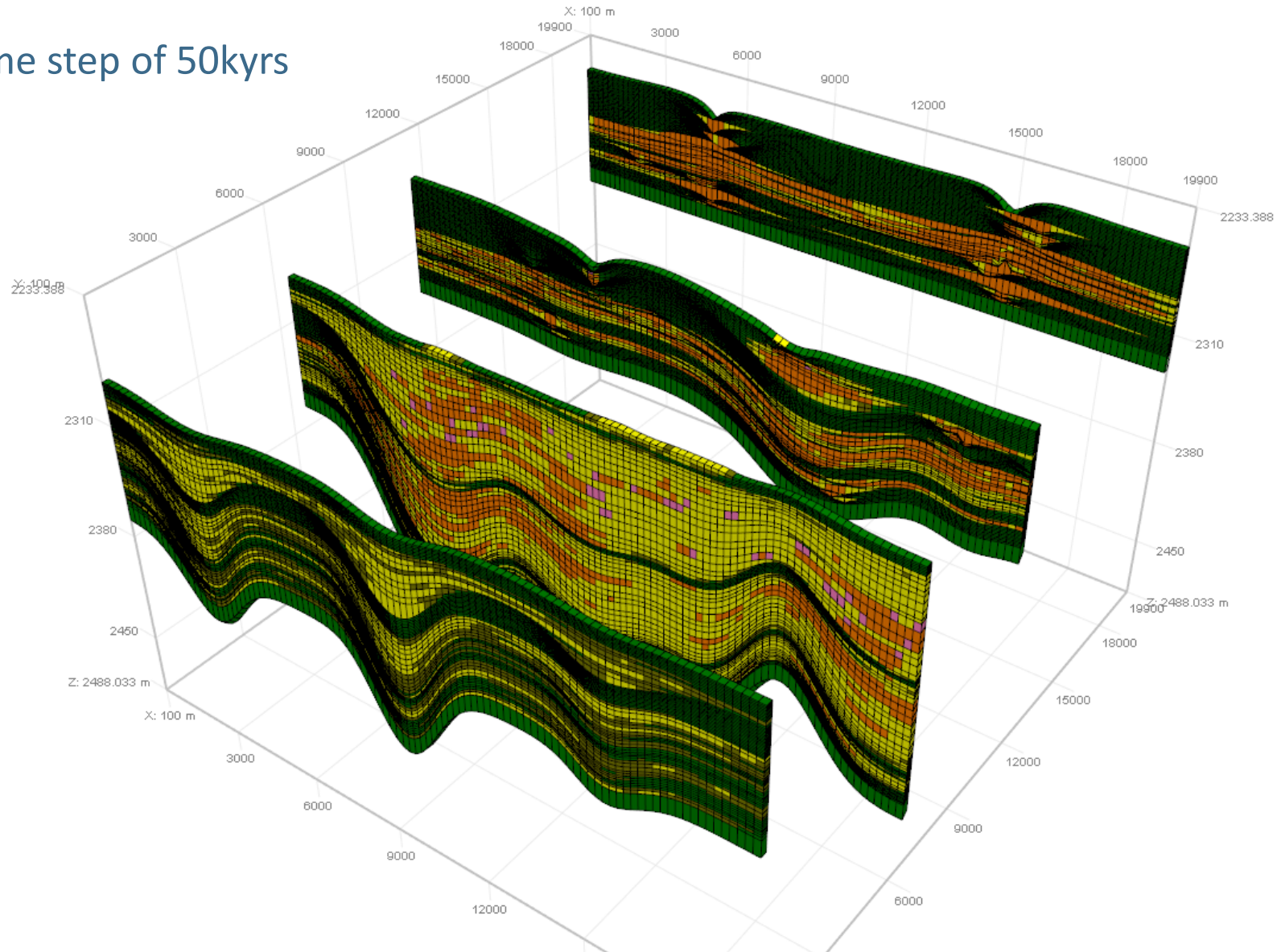


Impact of Salt Deformation

Facies



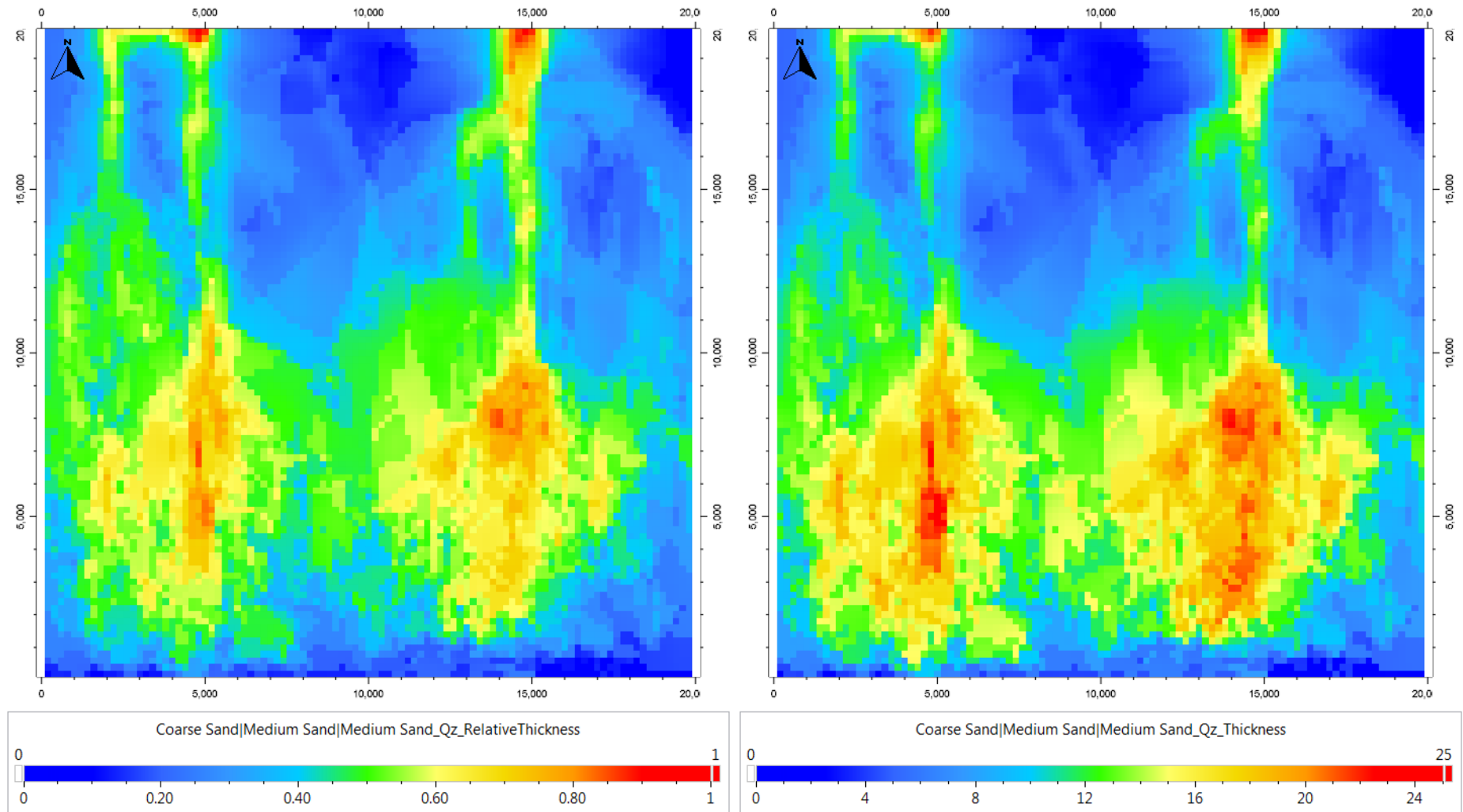
Time step of 50kys





Thickness & NTG Maps (1/2)

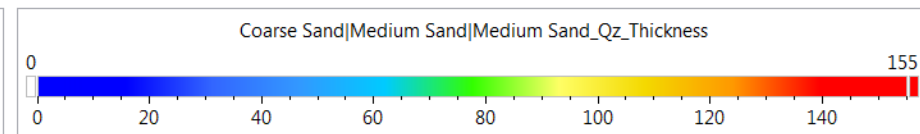
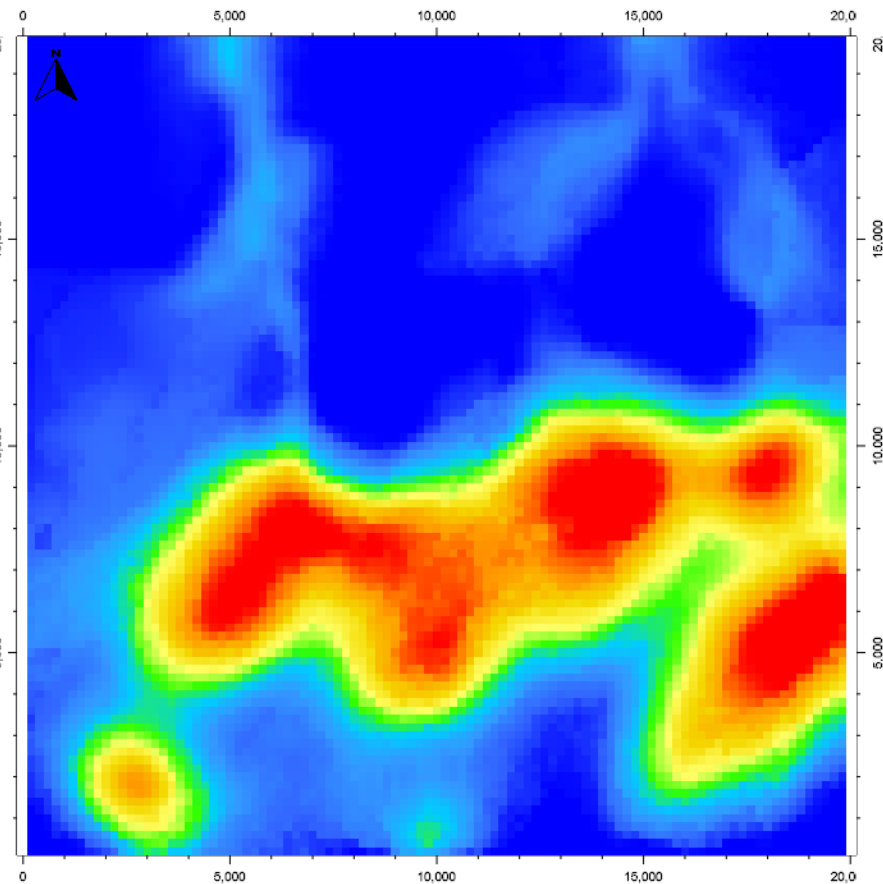
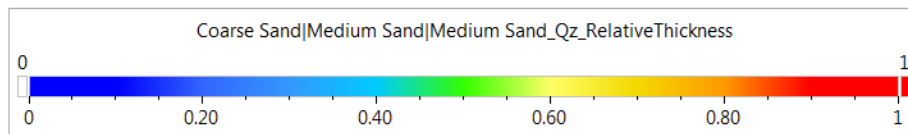
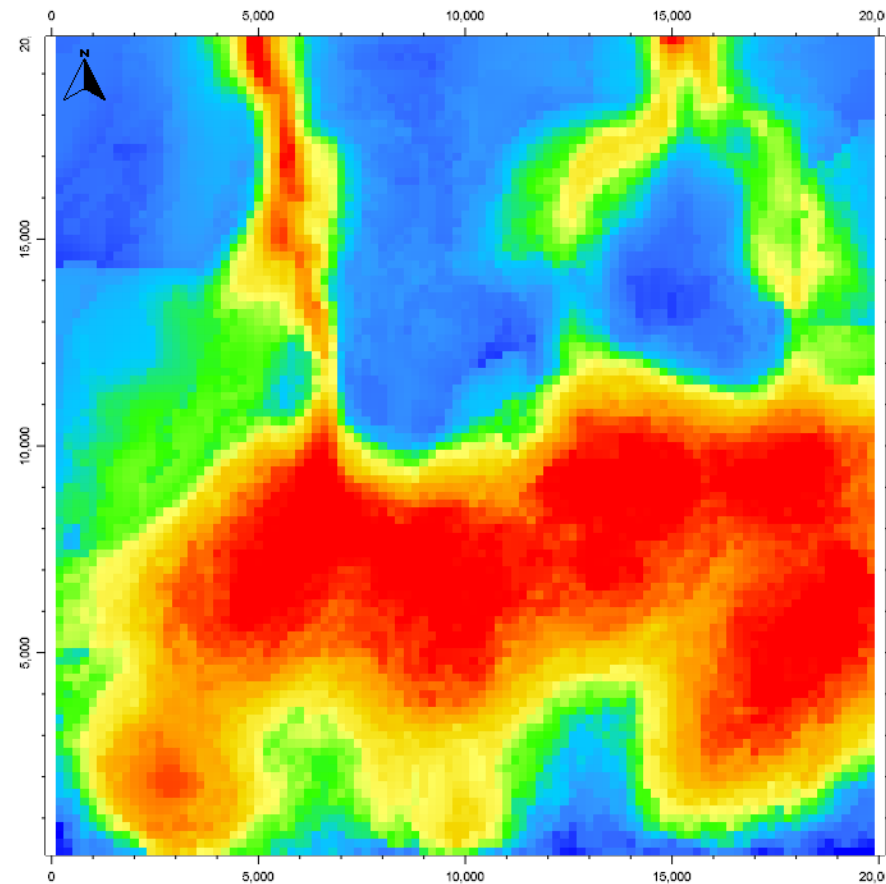
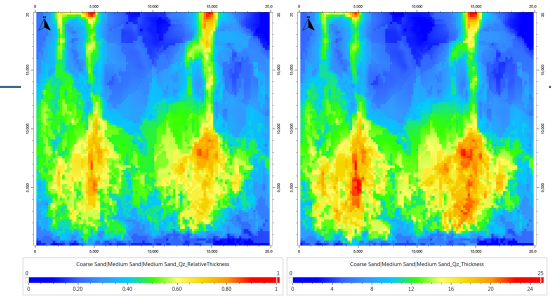
■ Pre-Salt (35 to 34Ma): {medium + coarse sand}





Thickness & NTG Maps (2/2)

Post-Salt (34 to 32Ma): {medium + coarse sand}



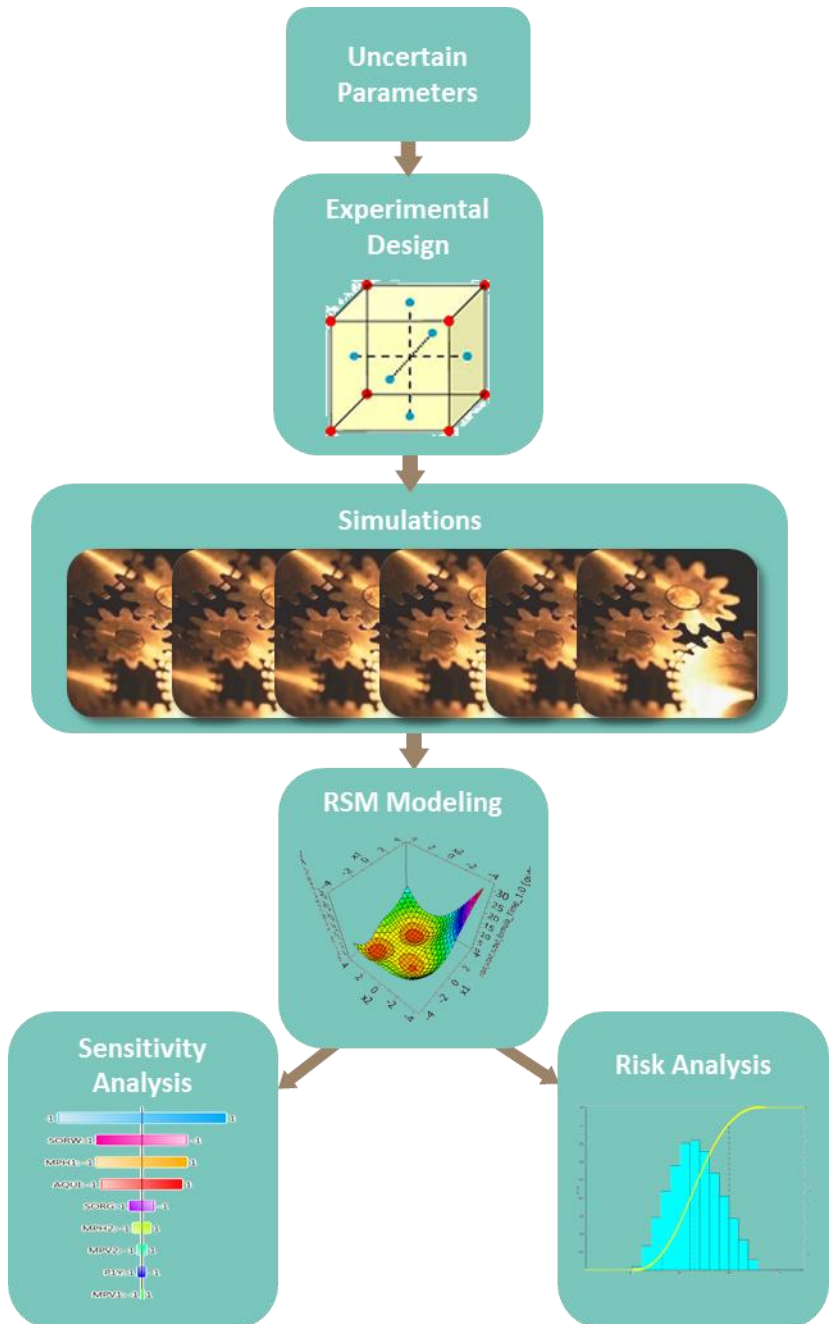
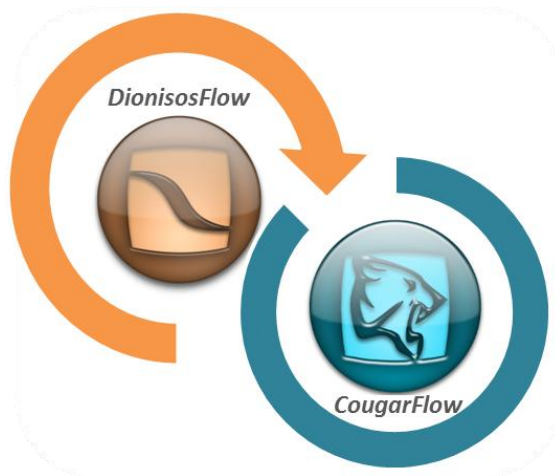


Automated Multi-Realization

CougarFlow coupling allows:

- Generating of alternative scenarios by varying some input parameters according to an Experimental Design.
- To assess the impact of main influential parameters on thickness and texture calibration.
- **Sensitivity Analysis**

➔ It allows the analysis of uncertainties on input parameters and their influence on simulation results

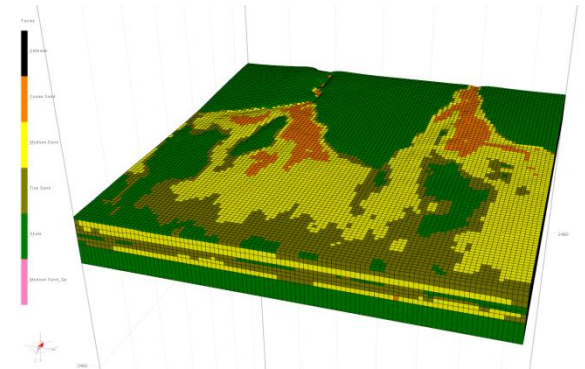




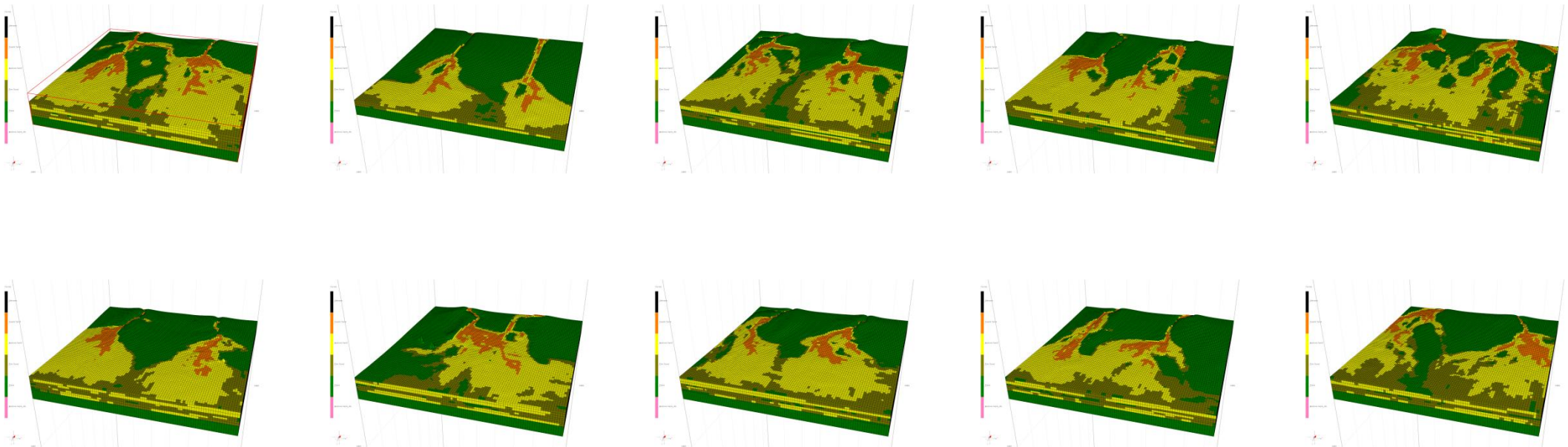
Uncertainties & Experimental Design

3 uncertain parameters

- Fluvial discharge through time (+/- 20%)
- Sediment supply for both sources (+/- 20%)
- Proportion of qz sand in both sources from 33Ma (+/- 20%)

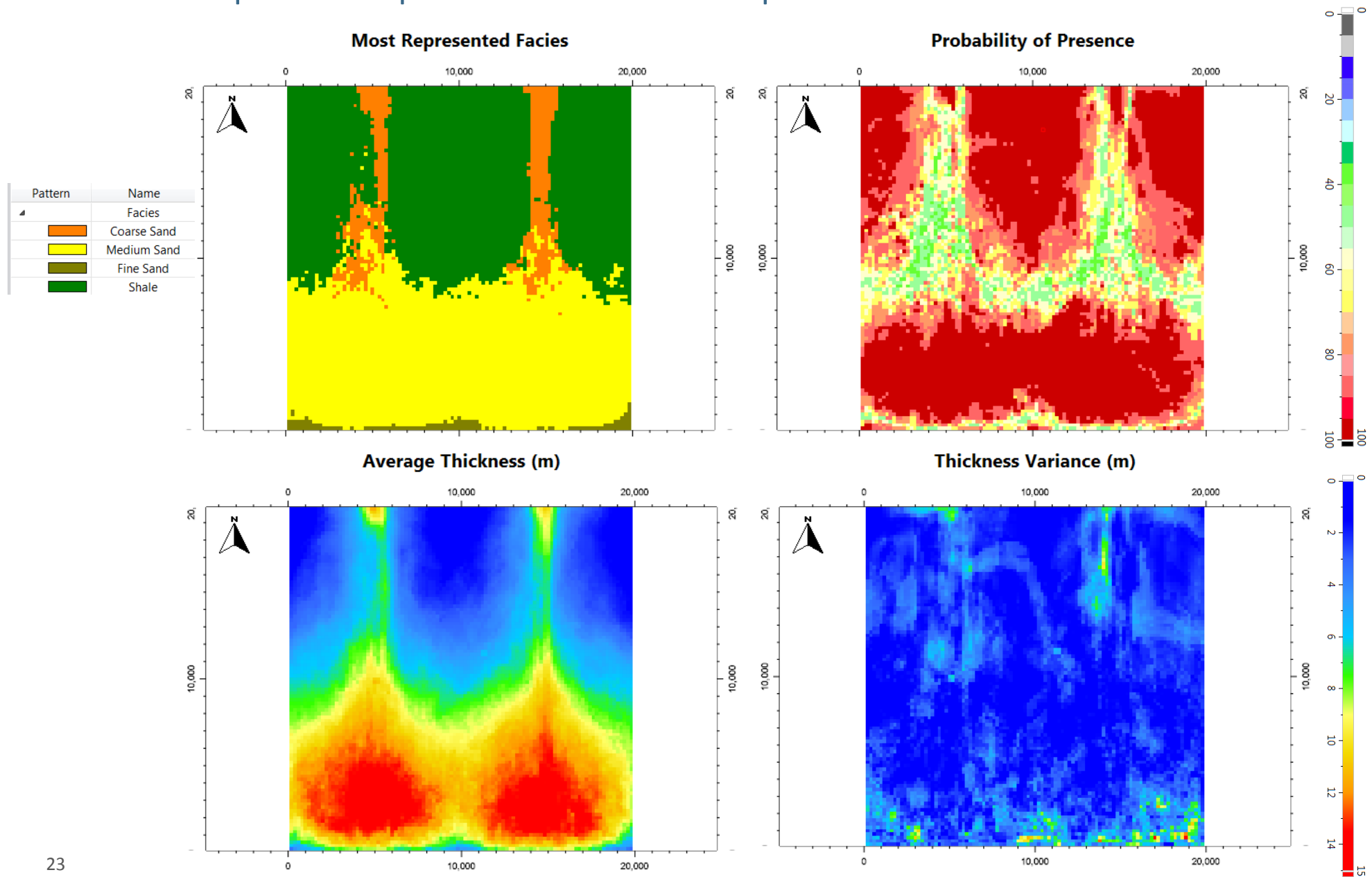


Total of 11 simulations to cover the entire uncertain domain



Sensitivity Maps

Example for the pre-salt deformation sequence:





Conclusions

- Deformation history and sediment supply are the main controls on the sand facies distribution in deep-sea environments.
- Well defined laterally constrained channel complexes are related to periods of decreasing sediment load (ie. Transgressive?)
- High sediment load periods lead to sand rich and laterally extended channel and lobes complexes (ie. Lowstand – highstand?)
- Multi-realizations generated using ranges of values for the input parameters allow to have alternative models to test sensitivity and reducing uncertainties on results.



Thank You for your attention!

