High-Performance Stratigraphic Modeling of Shelf to Deep-Water Plays*

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Abstract

Remote and deep-water frontier areas require accurate sedimentary facies models to reduce exploration and development risks. Thanks to the seismic and wireline data acquired over the last decades, and to the recent development of big data management technologies, it is now possible to propose high tech solutions to create an image of the subsurface geology. However, despite their reservoir scale increasing potentialities, these approaches are not yet fully applicable to assess plays in frontier areas where only few data are available.

To address exploration challenges, we propose an innovative integrated workflow using the advanced numerical stratigraphic and diagenetic forward model DionisosFlow. The aim of our study was to develop and run a fast and accurate workflow combining seismic interpretation, detailed sedimentological studies of the available wireline logs and seismic data, with deterministic stratigraphic forward model and synthetic seismic modeling at an appraisal to basin scale. Geological processes, such as tectonics and flexure, evaporite/carbonate production, weathering, transport and deposition of clastic sediments, slope stability and mass transport flows, are described by long-term and large-scale physical laws, solved using fully parallel numerical schemes and high performance computing technologies (HPC). This workflow was applied on the Neogene formations of two sedimentary margins: the Amazon Mouth Basin and the Niger Delta. A series of numerical simulations were run on a HPC cluster to simulate geological processes and the Neogene evolution of the two margins and associated deep-sea fans, but also the growth of the carbonate platform on the edge of the Amazon delta. The simulation results were calibrated to the wireline and seismic data until reaching a reasonable match between simulated and interpreted sediment proportions inside each sedimentary formation. Finally, sensitivity analysis was performed.

Thanks to this integrated HPC digital workflow, we were able to illustrate that modeling sedimentary basin dynamics at a regional to an appraisal scale by simulating geological processes makes it possible to bridge the gap between geological conceptual modeling and play fairway analysis. Furthermore, this stratigraphic and seismic modeling workflow is not restricted to regional clastic system analysis in preliminary exploration phases; it may be extended to field development and appraisal stages either in clastic or mixed systems.

Reference Cited

Chauveau, B., D. Granjeon, P. Stanislas, and M. Ducros, 2017, Integration of marine organic matter deposition in a stratigraphic forward numerical model (DionisosFlow): Application on the Duvernay Formation (Canada): International Meeting of Sedimentology.

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Pitch

RESPONSIBLE
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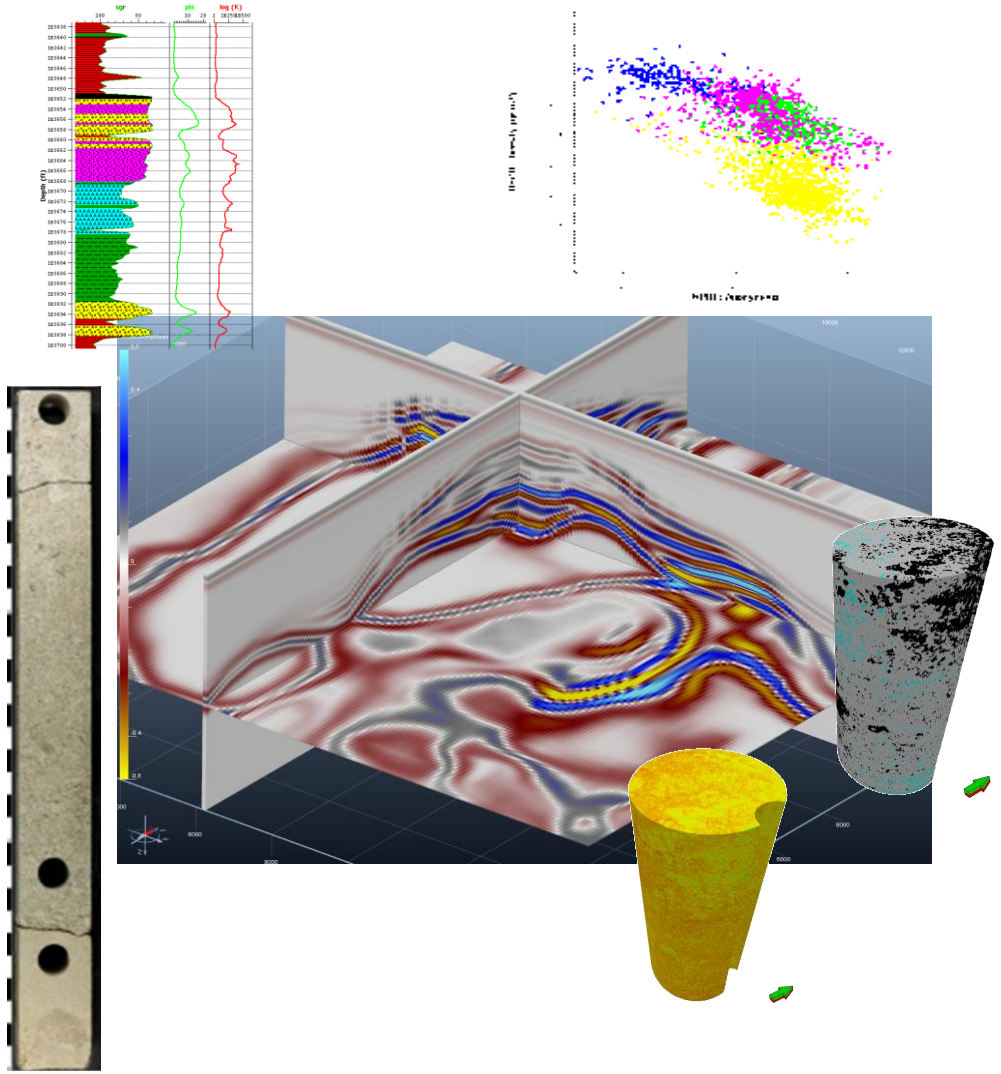
- Challenges
  - How to identify subtle stratigraphic traps in sedimentary basins ?
  - How to assess facies distribution in carbonate or clastic fields ?
  - How to link data with different resolution into a realistic and reliable geological model?
- Objectives
  - Evaluate conceptual geological models
  - Improve basin exploration and reservoir characterization
  - Facilitate true geological-geophysical-geochemical data integration

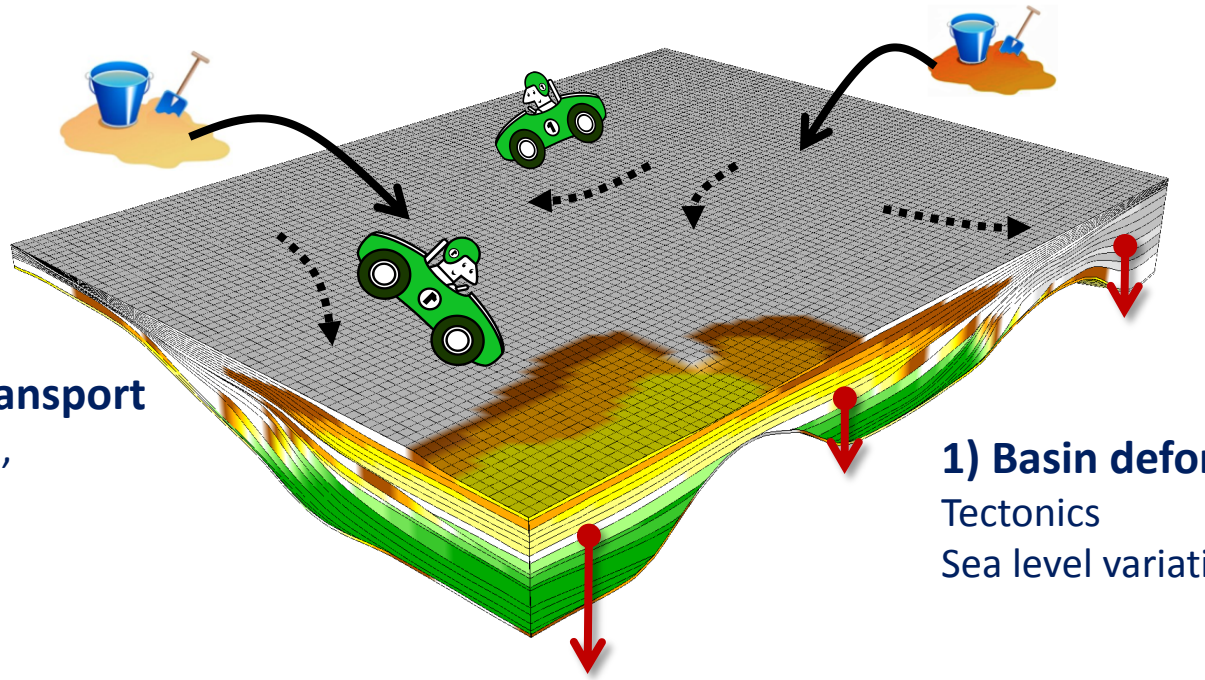


Stratigraphic Forward Modeling

- Method: Simulate sedimentary processes that formed source rocks, reservoirs and seals

2) Sediment supply
Fluvial supply,
carbonate production, ...

3) Sediment transport
Rivers, turbidites,
ocean waves, …



1) Basin deformation
Tectonics
Sea level variations, …

The Miocene Fm., Pannonian Basin (Hungary)
Studied area = 140 km x 185 km

Stratigraphic Forward Modeling

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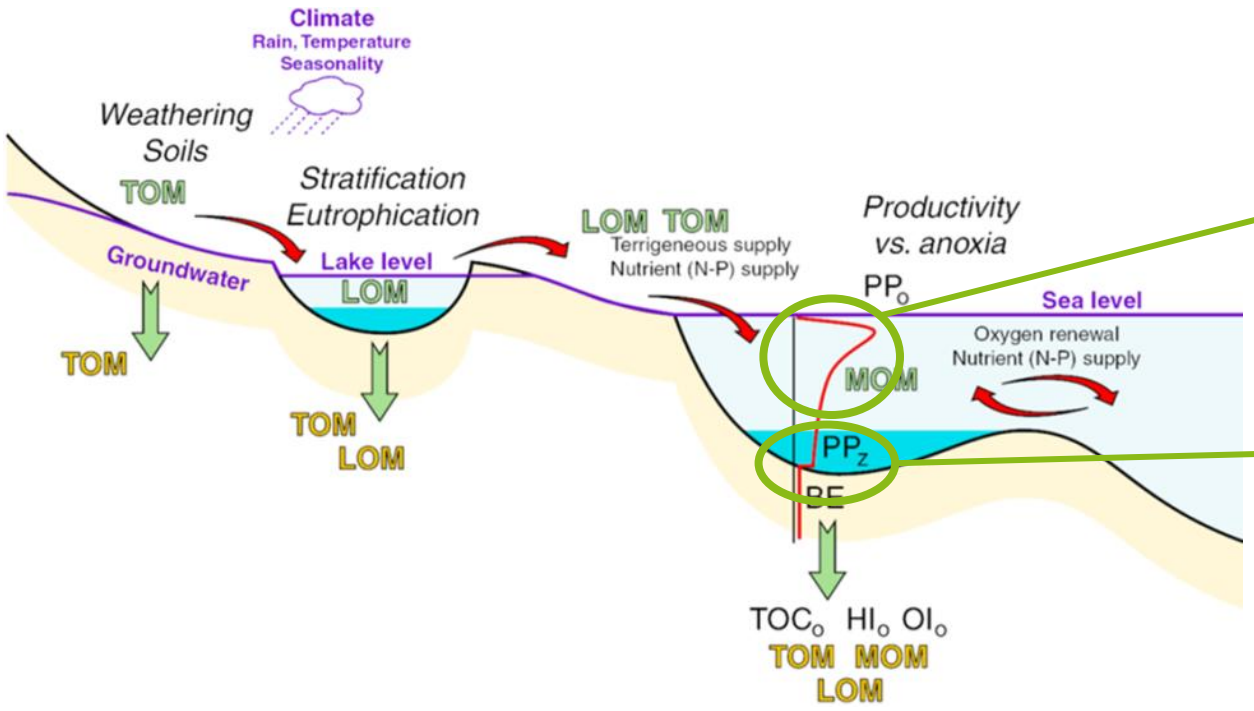
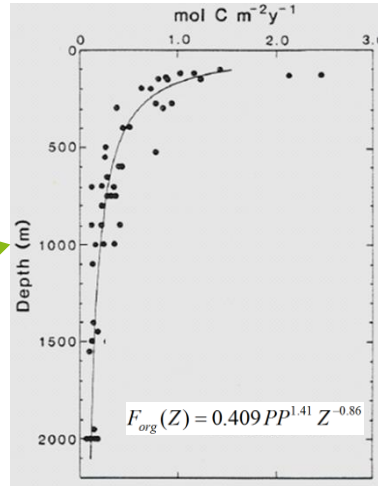
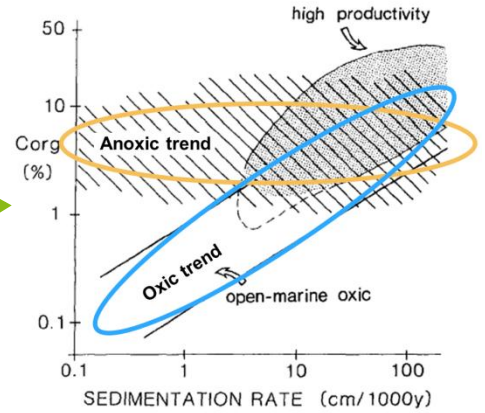
- Step 1: Development of geological process models
  - Example: primary production, transport and degradation of terrestrial, lacustrine and marine organic matters







MOM: Marine Organic Matter
LOM: Lacustrine Organic Matter
TOM: Terrestrial Organic Matter

Stratigraphic Forward Modeling

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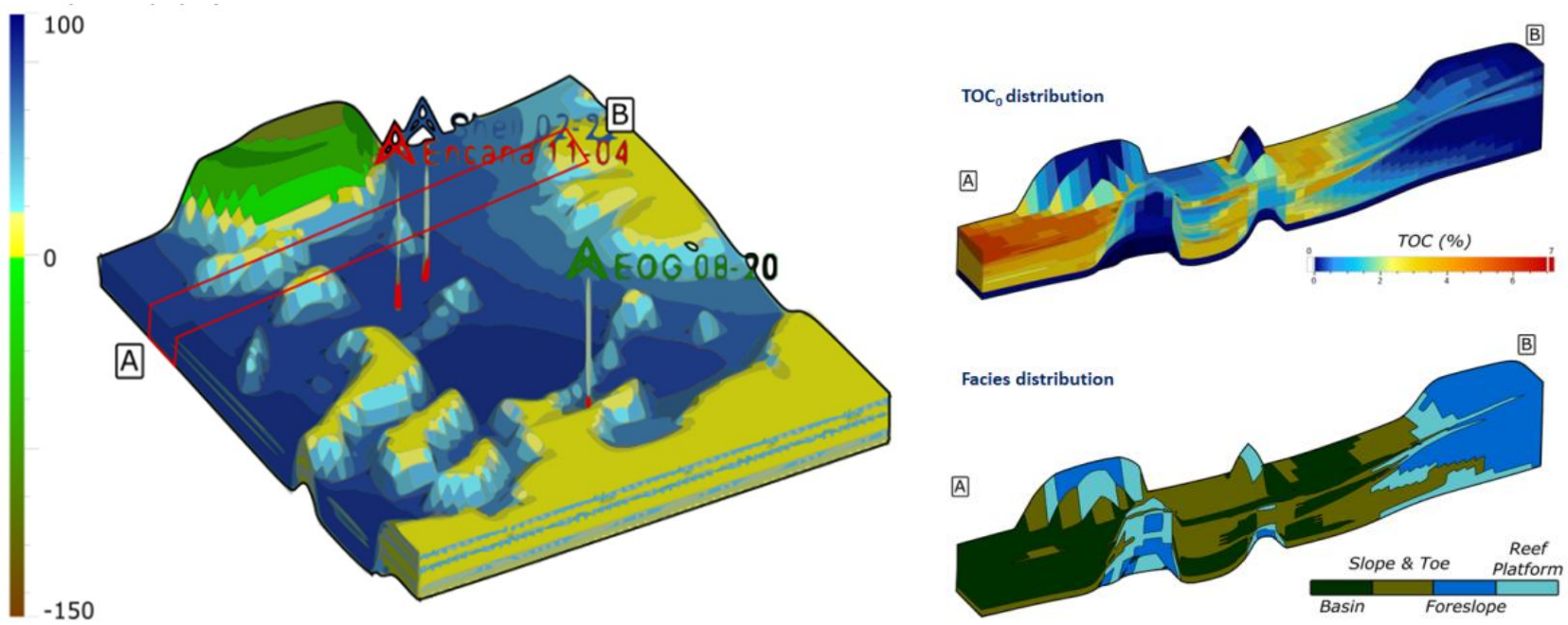
- Step 2: Calibration and validation on case studies
  - Example: Evaluation of petroleum system characteristics (Duvernay Fm., Canada)



[L= 600 km x 800 km; T=10 My] (Chauveau et al., 2017)

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Stratigraphic Forward Modeling

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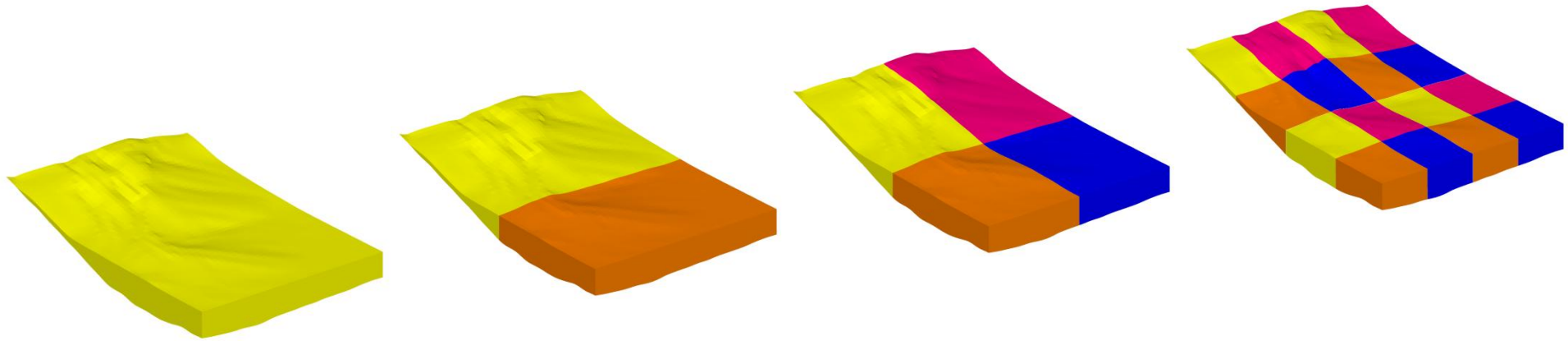
- Step 3: Development of advanced 3D finite-volume fully-parallel numerical models for high-performance computing (Arcane Platform, IFPEN-CEA)
  - Optimized numerical schemes and linear solvers
  - Tasks strategy and dynamic balancing of the processor's loads
  - Use of modern architecture such as GPU on clusters and high performance computers
    - Coming soon: adaptive mesh refinement, with dynamically refined grid over time to better control simulation cost and precision



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High-performance computing

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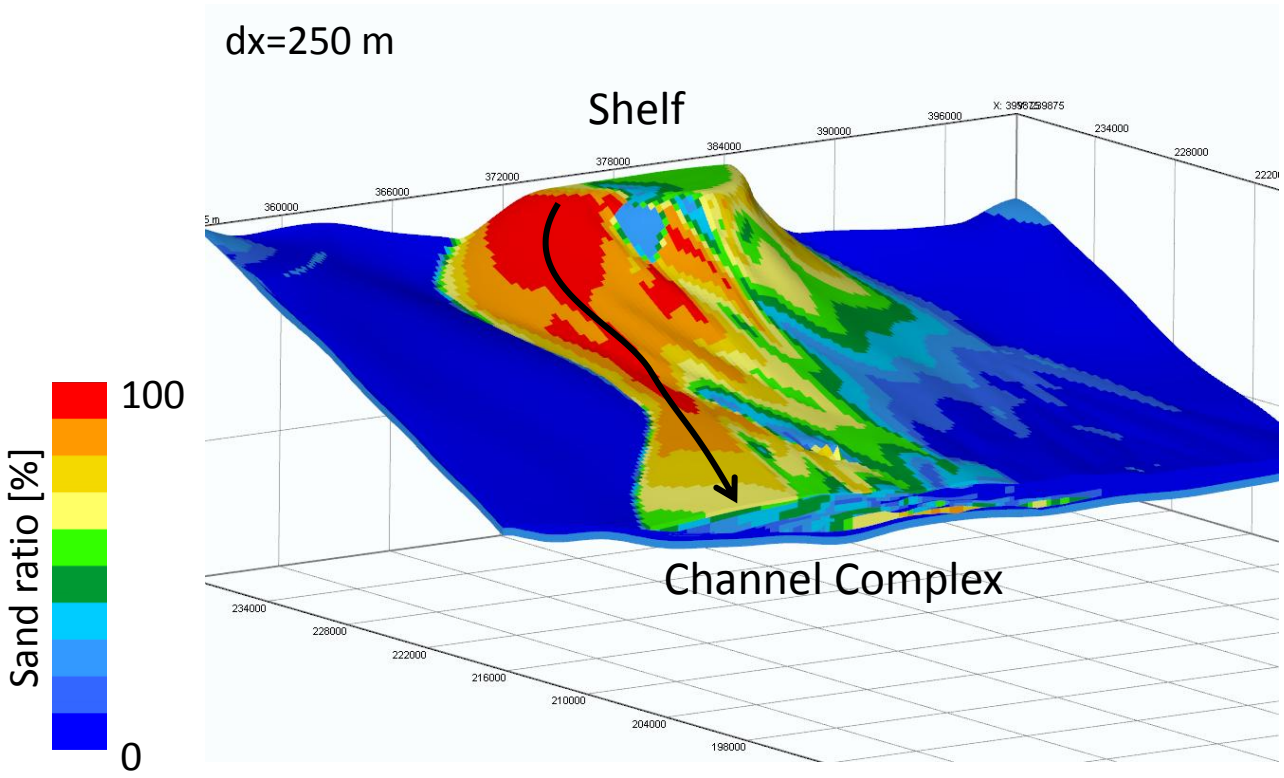
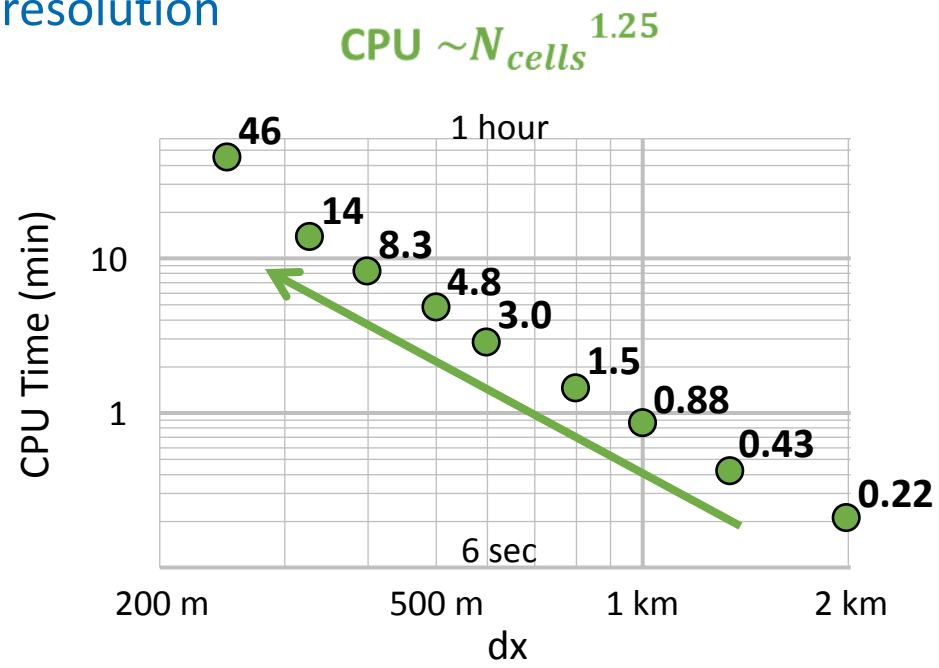
- Consistency
  - Efficiency test when using increasing numbers of cells and resolution

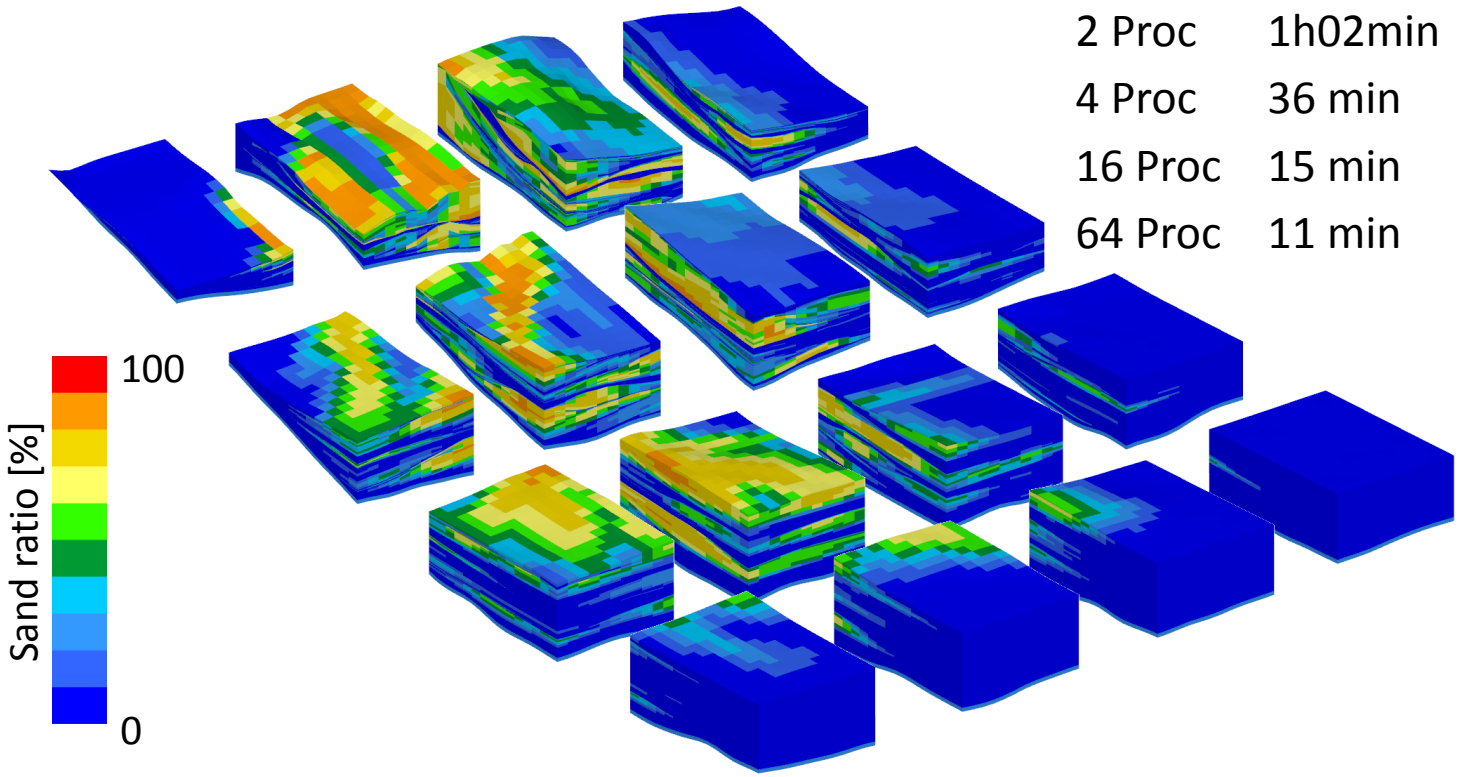


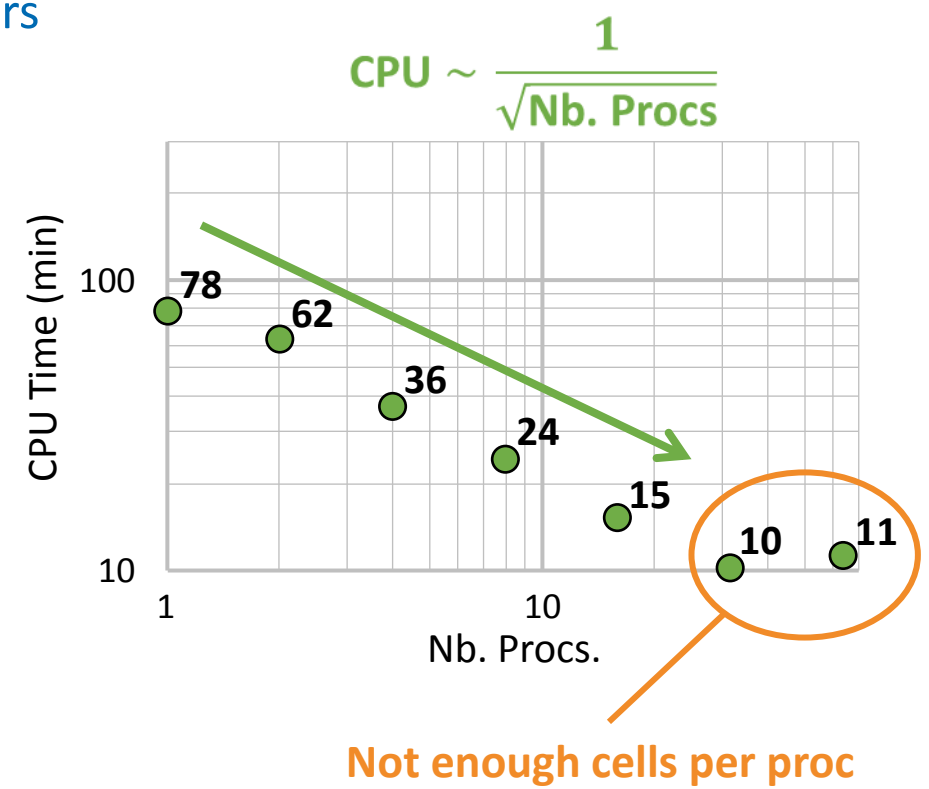


High-performance computing

- Scaling efficiency
  - Efficiency test when using increasing numbers of processors

1 Proc	1h18min
2 Proc	1h02min
4 Proc	36 min
16 Proc	15 min
64 Proc	11 min





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Results

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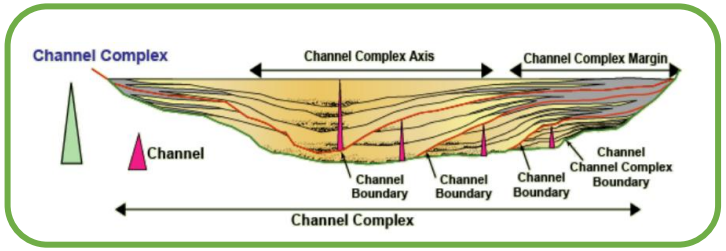
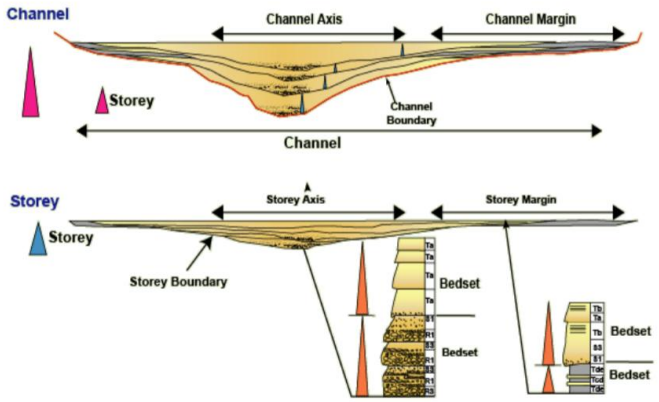
- Geological Context
  - Neogen turbiditic system (Amazon and Niger deep-sea fans)
- Data Available
  - 2D and 3D seismic
  - Wells logs and cores
  - Seismic stratigraphy and sedimentological description
- Questions
  - Assess clastic and organic facies distribution
    - Sand vs shaly lobes, marine vs terrestrial organic matter, …
  - Identify subtle turbiditic source rocks, traps and seals

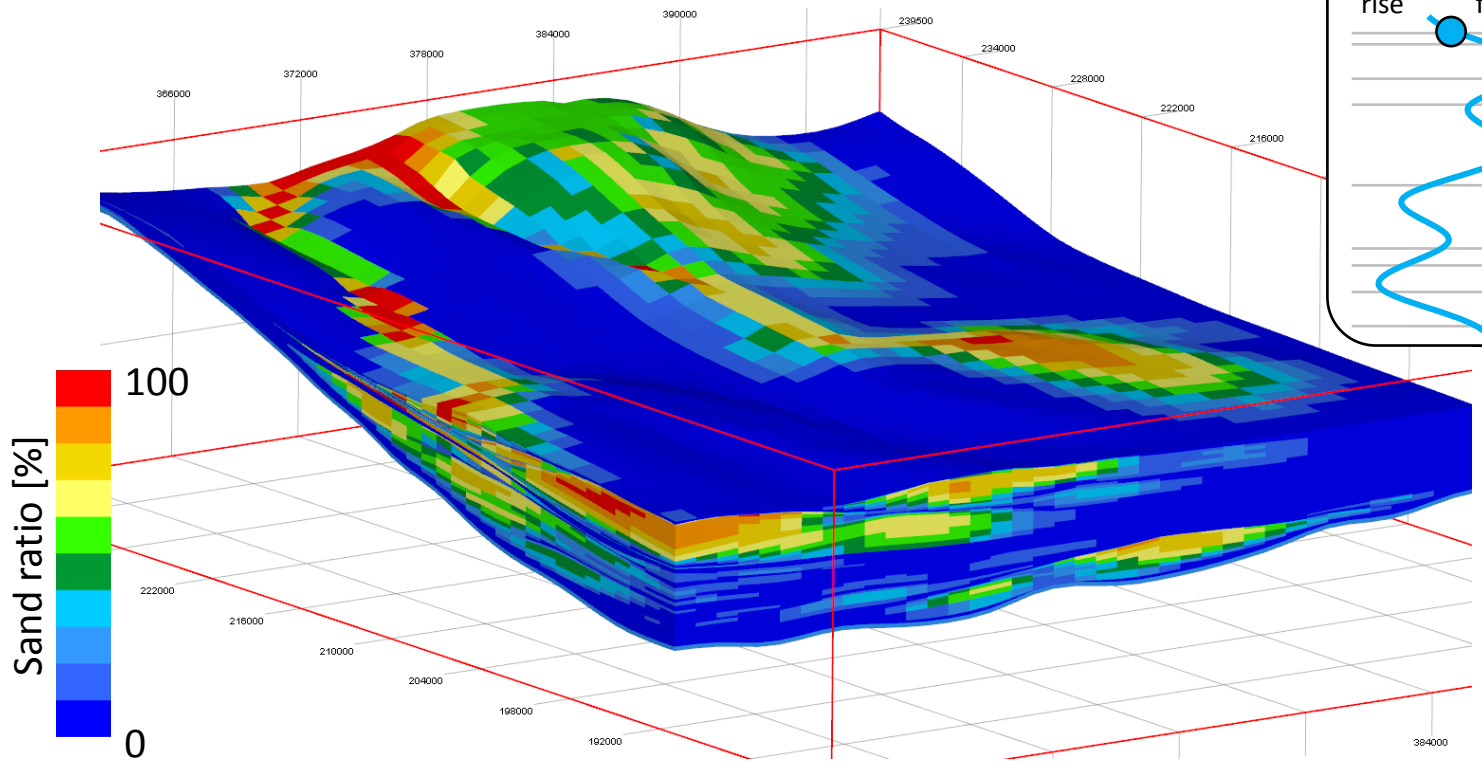
Results

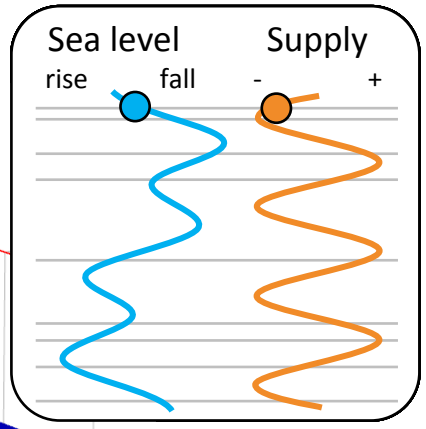
- Simulation of the stratigraphic architecture of turbiditic channel complexes, taking into account basin deformation, eustasy, but also climate variations (nutrient supply and organic matter production)





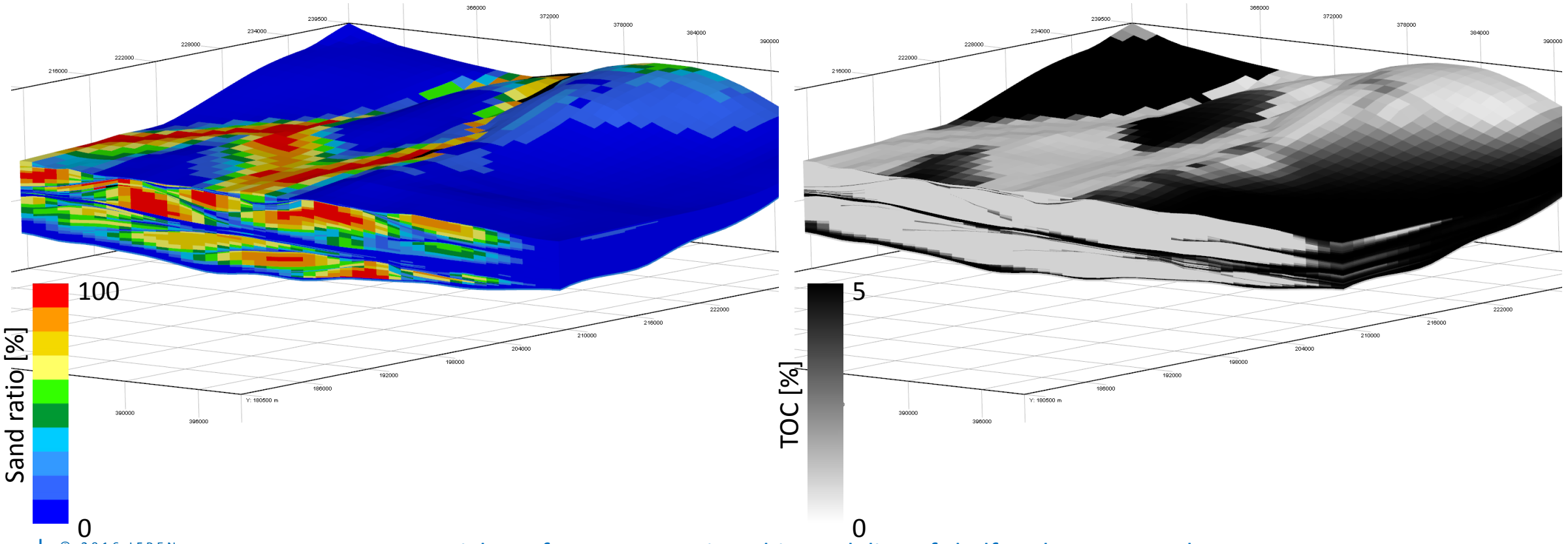
Campion, Sprague & Sullivan, 2011





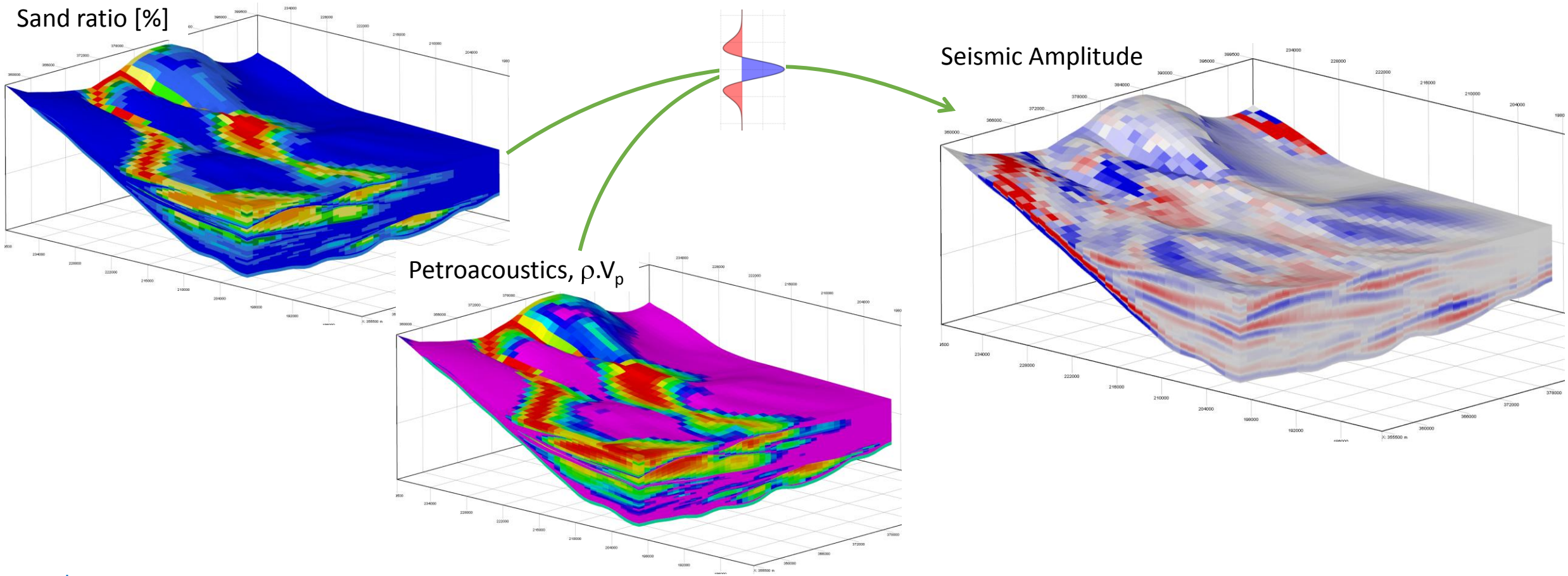
Results

- Estimation of facies (net-to-gross ratio, environment of deposition, lithology…), and organo-facies (marine and terrestrial organic matters, TOC, HI/OI)



Results

- Estimation of rock properties and simulation of 3D synthetic seismic cube



Take away message (1/2)

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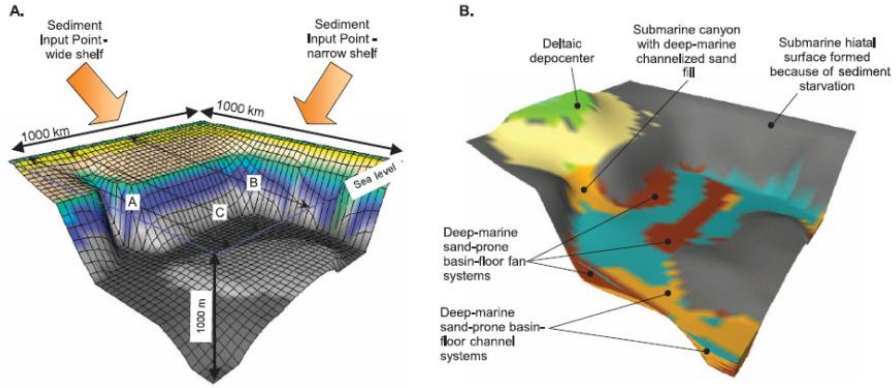
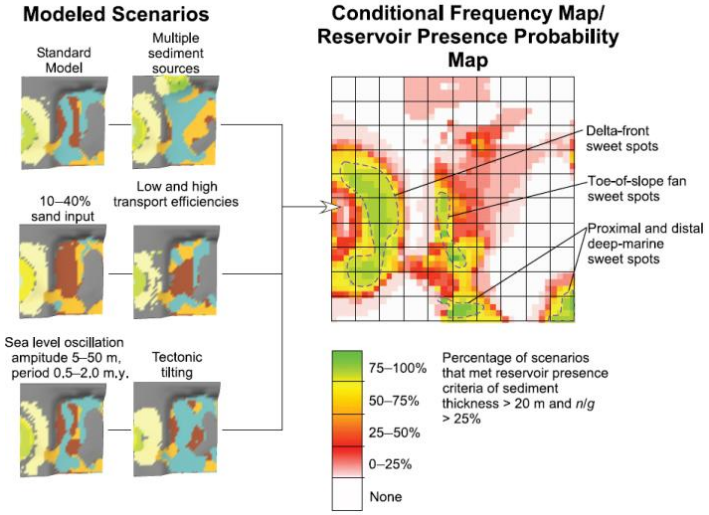
- Added-Values of Stratigraphic Forward Modelling
  - Evaluate conceptual geological models
    - Create stratigraphic models showing sedimentary sequence external and internal geometries
    - Estimate sediment distribution at basin to appraisal scales by simulating sedimentary processes
    - Appraise geological and geophysical interpretations (stromatolite / microbialite / travertine; non-unique seismic horizons…) with a process-based point-of-view
    - Assess reservoir property trends by simulating early diagenetic overprints

The Miocene Fm., Gulf of Mexico (offshore USA)

[L= 1000 km x 1000 km; T=3 My] (Burgess et al., 2006)





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Take away message (2/2)

RESPONSIBLE
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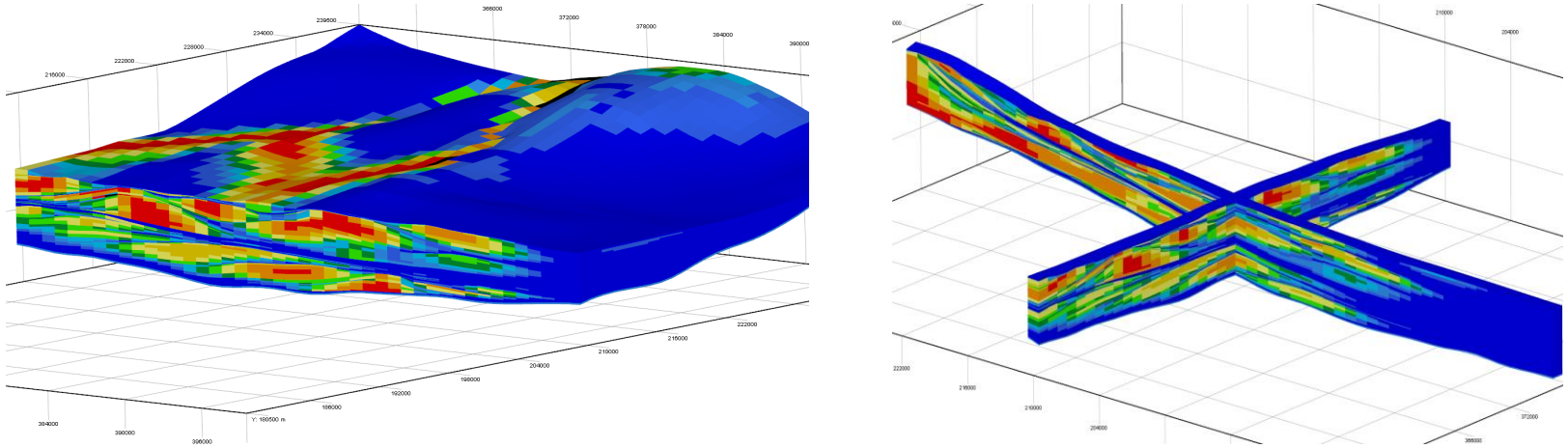
- Added-Values of Stratigraphic Forward Modelling
  - Improve basin exploration and reservoir characterization
    - Provide gross depositional environment (GDE) maps to basin modelling tools
      - HC genesis, migration and trapping, CO_2 circulation, silicification risks…
    - Condition classical geostatistical methods to get better reservoir property characterization
      - Use of geologically- and physically-consistent regional trends
  - Facilitate true geological-geophysical-geochemical data integration



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Thank you for your attention

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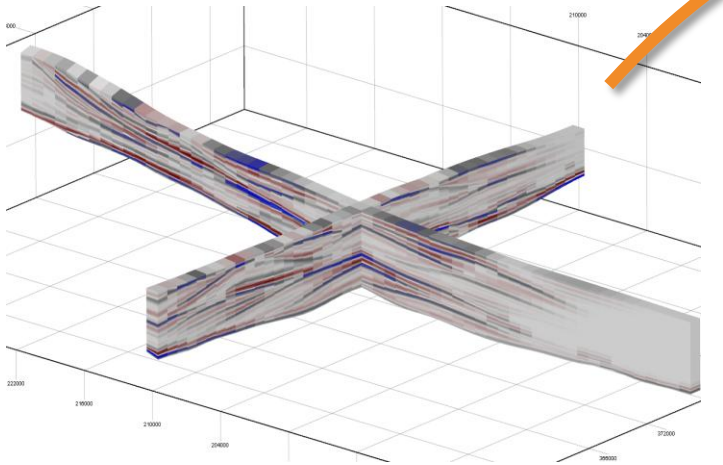
Seismic cube / Well logs

Seismic facies, net-to-gross ratio…

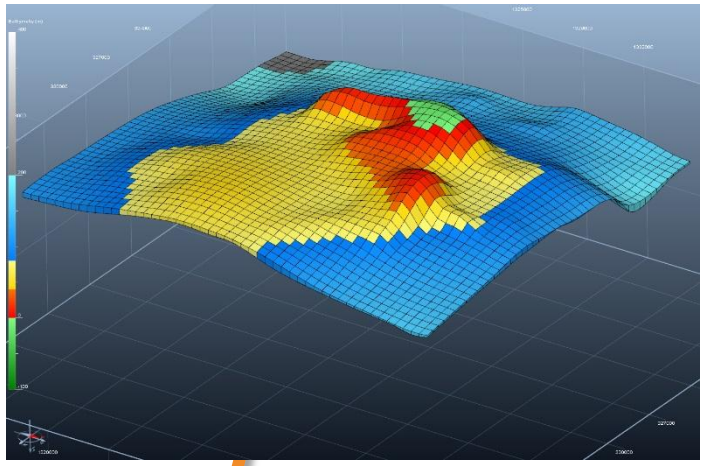


HPC

High-Performance Computing
Parallel Numerical Schemes

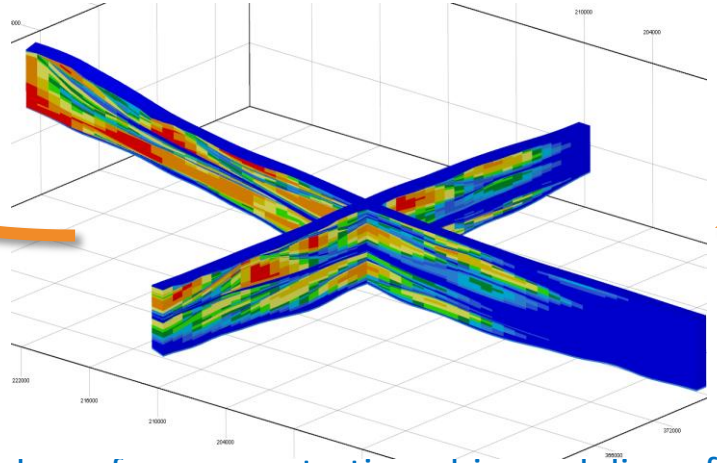
Geological Processes

Tectonics and sea level variations,
Climate, carbonate production, soil leaching, organic matter,
Ground water flow, sediment transport, early diagenesis…



Stratigraphic simulation

Sand/shale/carbonate ratio,
Environments of deposition, organofacies …



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