

PS Quantifying the Risk on Reservoir Quality with Forward Stratigraphic Modelling in Frontier Areas – Orphan Basin, Canada*

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Abstract

Forward stratigraphic modeling allows assessing the extension, thickness and quality of reservoir bodies in underexplored areas. However, most of the data used in such basins is subject to uncertainties which become critical in frontier areas where very little information is available for calibration. The potential range of input parameters variation leads to a high variability of the modeling simulation results that should be quantified to reduce the exploration risk. Traditionally, risk assessment is done performing multi-realizations with a Monte-Carlo sampling which requires a lot of time, sometimes months, when hundreds of simulations are required on a high-resolution model. To overcome these delays unaligned to the E&P industry constraints, we here present a new workflow linking forward stratigraphic modeling to a dedicated uncertainty analysis tool based on response surfaces. If the later technology is commonly used in reservoir engineering, it is quite unknown in exploration. In this approach, a set of simulations – the experimental design – is used to compute response surfaces that provide very fast estimations of the simulator outputs for any parameter values. The uncertainty study is then conducted from the response surface predictions only. A limited number of simulations is generally enough to obtain reliable estimations. The total time required to estimate the risk associated to the model uncertainties is thus drastically reduced. The Canadian passive margin is used to illustrate this workflow. The focus is made on the turbiditic sandy reservoirs of the Upper Cretaceous formation of the Orphan Basin and the uncertainties linked to its quality in terms of net to gross ratio and thickness. Only one well being available for calibration, the impact of subsidence, sediment sources supply and content, and sediment transport is analyzed to understand the influence of each parameter. A propagation is then realized to quantify the risk on the reservoir quality and the probability of presence of reservoir facies. Applied to the full reservoir unit and not only at a single well location, this approach provides relevant probability maps critical in the decision-making process.

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Gervais V., M. Ducros and D. Granjeon, 2018, Probability maps of reservoir presence and sensitivity analysis in stratigraphic forward modeling: AAPG Bulletin, v. 102/4, p. 613-628.

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Quantifying the risk on reservoir quality with forward stratigraphic modeling in frontier areas - Orphan Basin, Canada

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1. INTRODUCTION & OBJECTIVES

CONTEXT: Forward Stratigraphic Modeling (FSM) allows assessing the extension, thickness and quality of reservoir bodies in underexplored areas. However, most of the data used in such basins is subject to uncertainties which become critical in frontier areas where very little information is available for calibration. The potential range of input parameters variation leads to a high variability of the modeling simulation results that should be quantified to reduce the exploration risk.

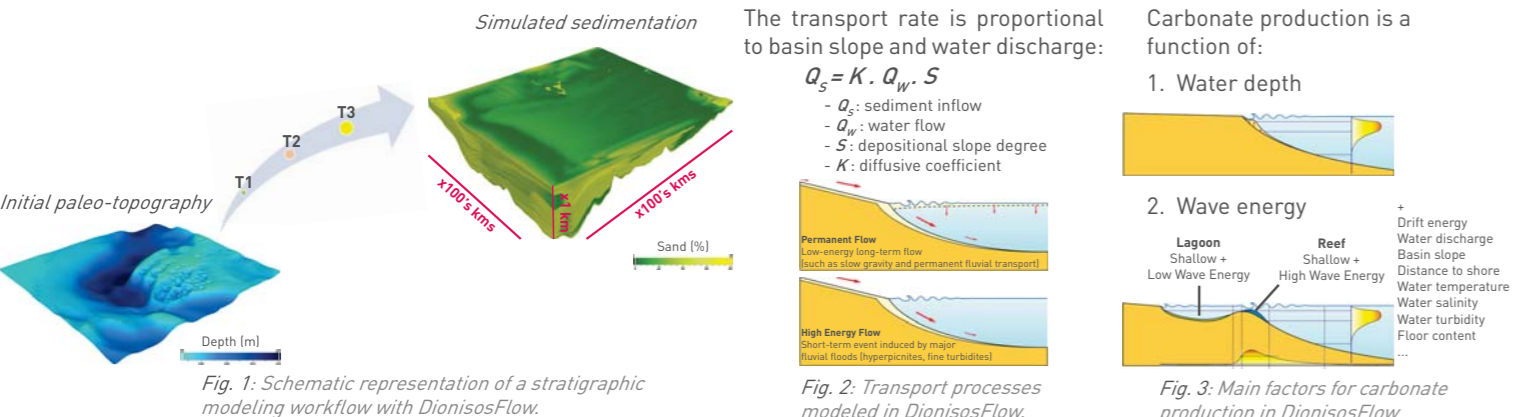
Traditionally, risk assessment is done performing multi-realizations with a Monte-Carlo sampling which requires a lot of time, sometimes months, when hundreds of simulations are required on a high resolution model. A new approach, allowing to quickly assess the risk over the entire basin, is needed.

- OBJECTIVES:**
- To properly take into account the uncertainties on the input parameters in FSM using a limited number of simulations;
 - To infer maps of parameter influence and probabilities of reservoir and seal presence;
 - To generate quantified CRS maps in a small amount of time.

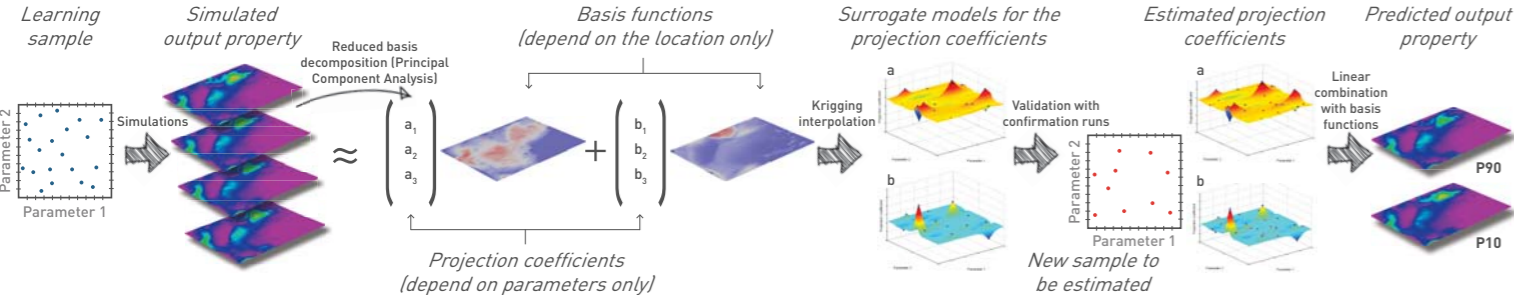
PROPOSED APPROACH: To overcome these delays unaligned to the E&P industry constraints, we here present a workflow linking forward stratigraphic modeling, performed with DionisoFlow™, to a dedicated uncertainty analysis tool based on response surfaces, CougarFlow™. The analysis is performed on the full reservoir unit and not only on a simple scalar value to provide relevant probability maps critical in the decision-making process.

2. METHODOLOGY

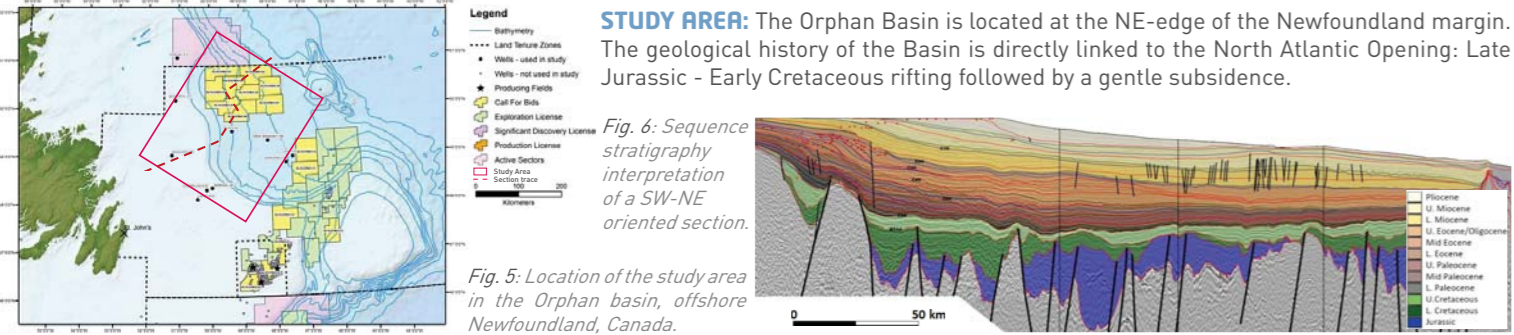
FORWARD STRATIGRAPHIC MODELING: DionisoFlow is a deterministic process based tool that reproduces interaction between the main mechanisms driving sedimentation (i.e., subsidence, bathymetry, sediment transport/in situ production, erosion, eustasy).



UNCERTAINTY ANALYSIS: Once a reference case model is manually calibrated, automated multi-realizations are performed using CougarFlow to generate several other plausible calibrated models. Distributions of output properties through space (e.g. sediment thickness in the basin) are approximated as spatial functions rather than scalars in each grid blocks and only a few surrogate models are needed to estimate each property in the entire basin.



3. GEOLOGICAL FRAMEWORK



4. INPUT PARAMETERS & CALIBRATION

DETERMINISTIC SIMULATION: The simulation time ranges from the base of Berriasian (145 Ma) to the top Oligocene (24 Ma). The time step used in the simulation is 0.1 Ma in the Tertiary (to be representative of main eustatic variations) and 0.5 Ma in the Cretaceous (lower seismic resolution). 6 seismic horizons are used to constrain the subsidence and deposited thicknesses, while 8 GDE maps allow estimating theoretical bathymetries. Calibration is done through a step-by-step process to match the well information (markers, Vshale, lithologies) and the observed thicknesses.

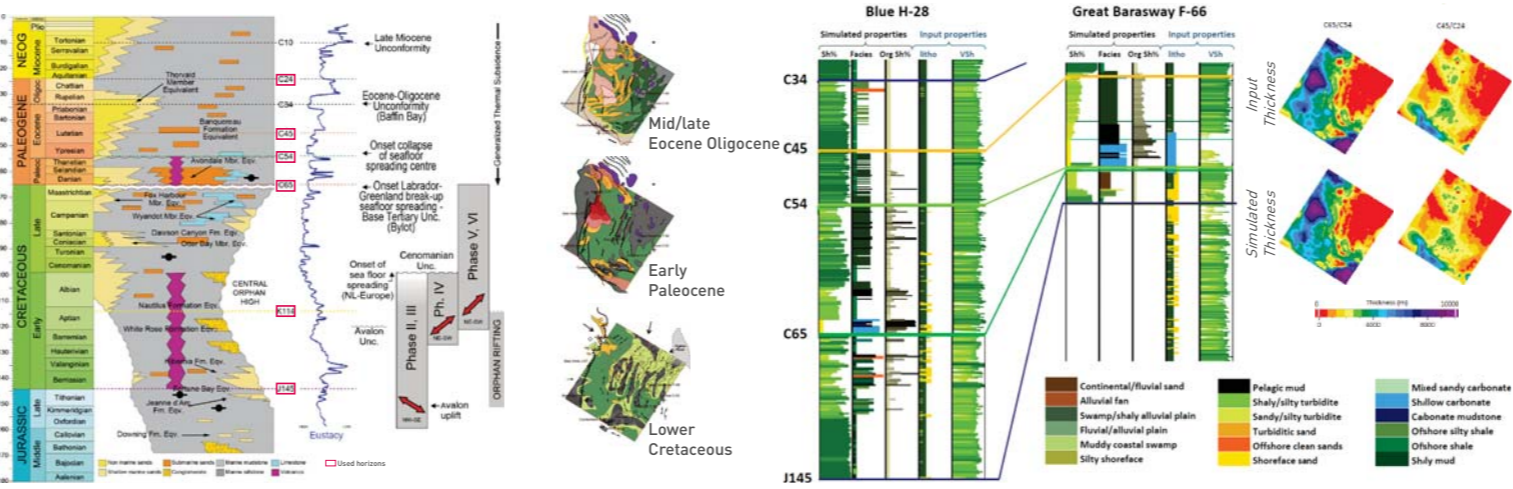


Fig. 7: Chronostratigraphic scale summarizing the geological information used to constrain the model.

Fig. 8: GDE maps used to estimate paleo-water depths.

Fig. 9: Final calibration of the model to well data and thickness maps interpreted on seismic.

5. FORWARD STRATIGRAPHIC MODELING RESULTS

PLAY DEFINITION: Four main plays (source, reservoir and seal) are identified within Cretaceous and Tertiary sequences. Several potential reservoirs, of mainly turbiditic origins, are highlighted as well.

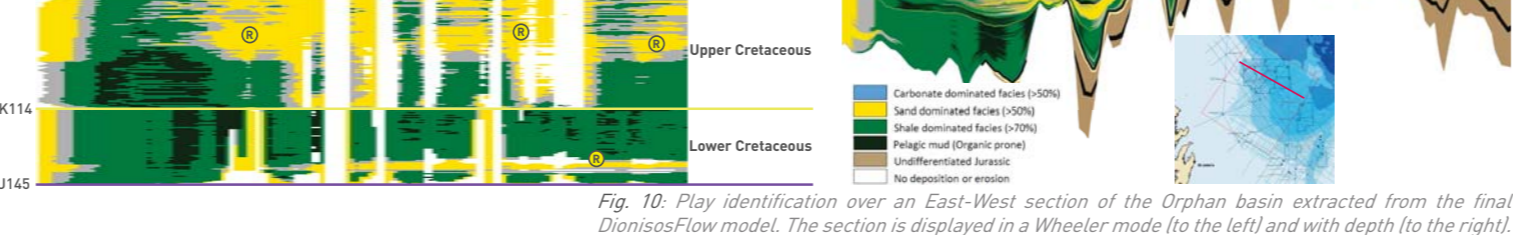


Fig. 10: Play identification over an East-West section of the Orphan basin extracted from the final DionisoFlow model. The section is displayed in a Wheeler mode (to the left) and with depth (to the right).

EVOLUTIVE & DETAILED 3D FACIES MODEL: The depositional environments and corresponding deposited facies are modeled through time, allowing characterizing the extension and thickness of the different elements of the petroleum system.



Fig. 11: Resulting facies model at 4 different time steps corresponding to the main plays.

FOCUS ON THE EOCENE PLAY: The Cape Free turbiditic prospect, visible on seismic, can be modeled and derisked with FSM.

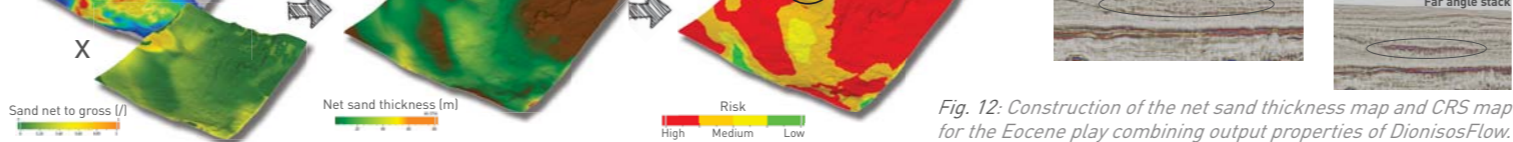


Fig. 12: Construction of the net sand thickness map and CRS map for the Eocene play combining output properties of DionisoFlow.

6. UNCERTAINTY ANALYSIS RESULTS

UNCERTAIN PARAMETERS DEFINITION: The main input parameters impacting the sediment deposition in the Cape Free area were identified and a range of variation was defined for each of them, making sure the calibration of the model would not be impacted.

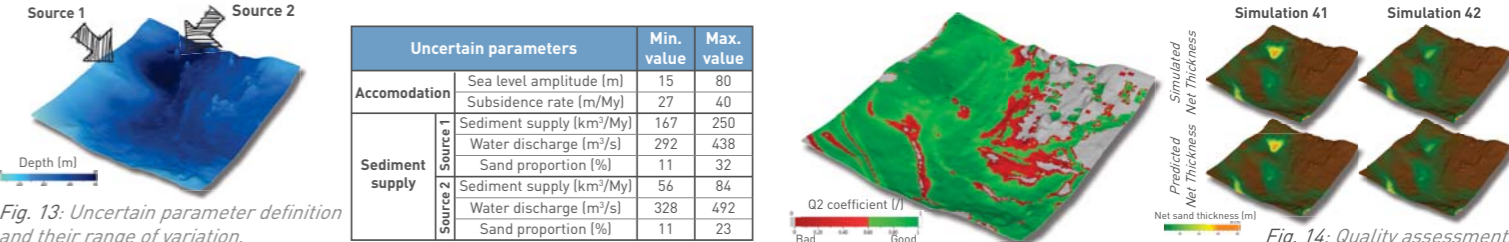


Fig. 13: Uncertain parameter definition and their range of variation.

SENSITIVITY ANALYSIS: This analysis allows quantifying the influence of each uncertain parameter on the output property, the net sand thickness here. This can help to better understand the processes at stake in the different parts of the basin, and to discard the less influential parameters in a calibration process.



Fig. 15: Maps showing the spatial effect of each uncertain parameter on the net sand thickness.

RISK ANALYSIS: Thanks to a Monte-Carlo sampling of 10.000 samples on the proxies, a quantified average map and its associated standard deviation alongside with percentile maps, can be obtained in just a few minutes. This analysis allows estimating the range of potential values for the output property, the net sand thickness here.

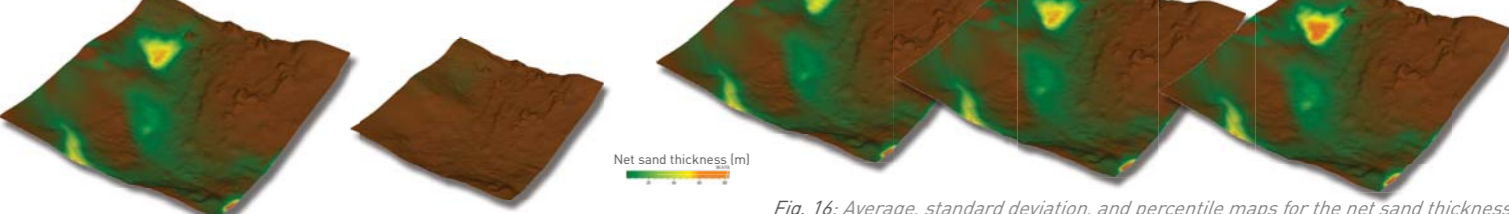


Fig. 16: Average, standard deviation, and percentile maps for the net sand thickness.

PROBABILITY MAPS AND QUANTIFIED CRS MAPS: From the risk analysis results, it is possible to estimate probability maps to estimate the chances of having a good reservoir or not. A quantified CRS map can then be deduced from these probabilities representing 10.000 potential scenarios. An equivalent work was done on the net shale thickness of the Eocene seal sequence to obtain a seal CRS map and a final quantified CCRS map representing the total potential of the play.

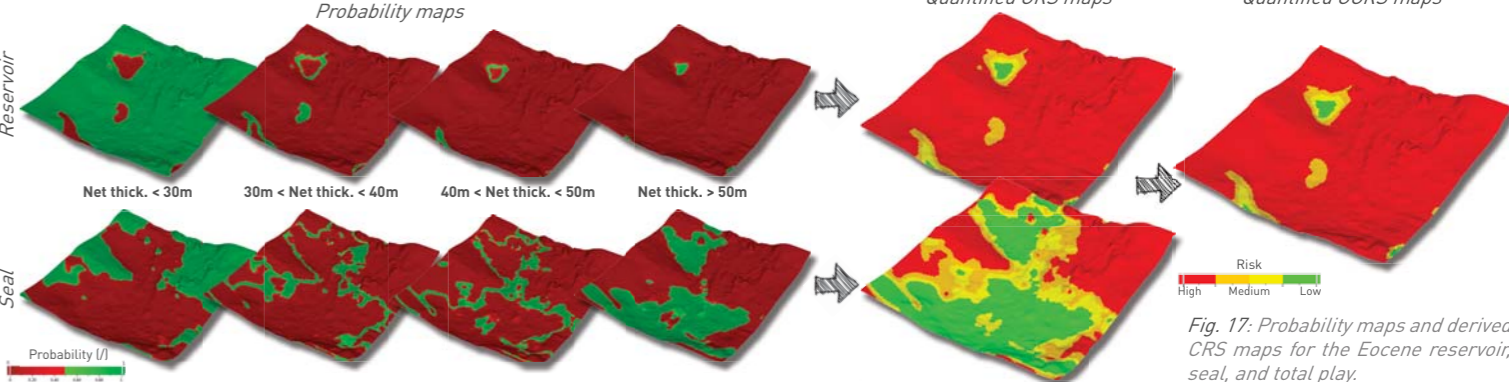


Fig. 17: Probability maps and derived CRS maps for the Eocene reservoir, seal, and total play.

7. CONCLUSION

PROPOSED APPROACH: This workflow combining forward stratigraphic modeling and spatial uncertainty analysis based on proxies from surrogate models seems like a good trade-off between required time and relevance and consistency of the results. It makes it possible to perform quantitative sensitivity analyses at the scale of the basin and to estimate probability maps for the elements of the petroleum system as well as the resulting CRS maps. For the Cape Free prospect, a minimum net sand thickness of 40m and a maximum one of 80m was estimated. This play was also derisked as a chance of presence of 100% was obtained for the reservoir and seal presence out of 10.000 simulations performed. The same approach could be applied to other disciplines, like basin modelling for instance.

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- Gervais V. et al., 2018, Probability maps of reservoir presence and sensitivity analysis in stratigraphic forward modeling. AAPG Bulletin, 102(4), 613-628
- Hawie N. et al., 2017, Uncertainty Analysis in Forward Stratigraphic Modeling: New Approaches to De-risk Geological Models, EAGE Annual Conference, Paris, June 2017