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Geoscientific Model Development Discussions
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Interactive comment on "Porosity and Permeability Prediction through Forward Stratigraphic Simulations Using GPM™ and Petrel™: Application in Shallow Marine Depositional Settings" *by* Daniel Otoo and David Hodgetts

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Thank you for this detailed comment and suggestions on the manuscript. The response will follow the style (paragraph) as presented in your Comments.

General Comments

Paragraph 1: This is rightly captured in your comment. The idea is to use this forward stratigraphic modeling approach to improve the representation porosity and permeability properties between wells, which in most cases are widely spaced in the early stage of exploration/development.

Paragraph 2: I agree with this comment that GPM software (at least the versions I used; 2017.1 to 2019.1 versions) acts as a “black box”. However, the software tries to replicate a real world sedimentary process. For example, increasing sea level, and subsidence rate in GPM corresponds with an increase in accommodation. Similarly, high land-ward elevation, and erosion increases sediment supply into the basin. This scenarios can be likened to the natural order. In this work, we focused on producing a depositional sequence that is comparable to the seismic section (see Figure 3b).

Paragraph 3: I totally agree with the first part of this comment. This suggestion will be included in the manuscript. For example, the diffusion process is governed by the equation below;

∂z/∂t=kâĹĞ^{2}z, where z is topographic elevation, k the diffusion coefficient, t for time, and âĹĞ^{2}z the Laplacian.

Furthermore, the 20 scenarios are because of the uncertainty associated with the input parameters used to for the simulation. Different inputs were used to obtain a most representative stratigraphic framework. The 50 realizations are generated in the property modeling stage (porosity and permeability) in Petrel software, where synthetic wells data from a simulation (in this instance scenario 4) are used in a geostatistical algorithm (i.e. sequential Gaussian simulation) to generate a range of property representations. This will allow us to compare which outcome(s) match the original Volve field model from Equinor.

Paragraph 4: A desired stratigraphic pattern in this contribution is one that exhibits similarity to the depositional sequence observed in the seismic section shown in Figure 3b. Additional 16 scenarios were generated as an attempt to enhance the results in scenario 4.

Paragraph 5: Thank you for the suggestion. A related work, which compares the forward stratigraphic-based modeling approach to a classical technique (e.g. pixel based modeling) is being worked on. Notwithstanding that, this suggestion will be highlighted in the concluding part of this manuscript.

Specific Comments

Lines 6-8: This statement will be revised to read: “Typically, reservoir modeling requires property-modifying coefficients in the form values to populate properties in inter-well regions to achieve a good match to known subsurface well data in different locations. It will be a reasonable assumption that closely spaced wells will control the effect of property-modifying coefficients in subsurface modeling, but the cost of acquiring subsurface data in deeper and complex geological basins limits the volume of quality datasets that could be obtained; hence reducing our perspective of reservoir property variation and its impact on fluid behaviour”.

Lines 25-27: This statement will be modified to read “but the geostatistical-based method tends to confine reservoir property models to known data and rarely realize geological realism to capture sedimentary that have led to reservoir formation”.

Lines 39: The correction will be made to read “The reservoir interval under study is located within the Hugin formation, which studies by Varadi et al. (1998); Kieft et al. (2011), suggest to be a complex depositional architecture of waves, tides and riverine processes; suggesting that a single depositional model will not be adequate to produce a realisitc lithofacies distributions model.”

Line 69-70: This statement will be revised into “but the total thickness of code F lithofacies is not known (Folkestad & Satur, 2006).”

Line 86-87: The main criteria for evaluating the realistic nature of a stratigraphic model was to compare it to the depositional sequence observed in the seismic section in Figure 3b, and/or interpreted through well correlation.

Lines 99-114: In line with my response in paragraph 3 in the general comments, we will revise the manuscript to include details on the parameterization of the various geological processes involved in the simulation.

Line 128: Yes, TPr is the paleo-topographic surface. The necessary correction will be done in the manuscript.

Line 133-136: The distance should be 4 km and not 4m as stated in the manuscript. This was an error on my part. The necessary changes will be done in the manuscript. Thank you very much.

Line 139-140: The sea level curve used in the simulation followed the Haq global sea level curve generator as well as the Exxon global sea level curve generator formats. The sea level for year 20,000 was assumed to be 45 m, and decreased to 15 m by year zero. The sea level was not kept constant as it is a curve that covered a period of geological period (see figure 1). Averages were used in the manuscript to provide an insight into the mean sea level that was in the simulation scenarios.

Line 148-149: With scenario 1 (Figure 6a) beginning to show some resemblance to the target output (i.e. the depositional pattern observed in seismic section; Figure 3b), we generated input figures that were higher and lesser than those used in generating scenario 1. Example, based on a diffusion coefficient of 8 m2/a that was used in scenario 1, diffusion coefficients +/- 5 of 8 were generated with the aim to improve the development in scenario 1. Since the initial conditions (boundary conditions) at the time of deposition are unknown, an attempt was made to apply reasonable input parameters that will produce a comparable stratigraphic pattern to observation seen in the seismic section (Figure 3b). Aside the initial topography that was kept constant in a simulation run, other input parameters such as diffusion, wave event, steady/unsteady flow, tectonics use curve functions to provide variations within the simulated period.

Line 157: When the sediment source point was shifted to the mid-section (basin-ward, close to the basin slope; see modified image below; labelled Figure 2). It is our view that, the location of the sediment source in the simulation will have a huge impact on the resultant stratigraphic architecture.

Line 176-178: Here, we mean the distal end of the simulation domain at the end of each run in the GPM simulator. The appropriate modification will be done in the manuscript to make the point clearer.

Line 179-180: Wireline-log attributes such as gamma ray, neutron porosity, sonic, and density logs outlined in Table 1 in the supplement.

Line 186: It is actually the multiplication symbol. It will be corrected in the manuscript.

Line 197-218: (i) and (ii) where used to show that the pillar gridding process, horizon, zoning and layering processes are all part of the structural modeling process. The numbering will be modified into a 1 to 4.

Line 223: The sentence will be corrected to read "The original petrophysical model has a grid dimension of 108 m x 100 m x 63 m, and is compressed by 75.27% of cell size" in the manuscript to conform with your correction.

Line 237: This statement will be revised to read; "Ten synthetic wells (SW); ranging between a relatively low of 80 m in length for SW8 and a 120 m for SW4 were positioned in the forward model to capture the distribution of porosity-permeability at different sections of the stratigraphic model. The average distance between these wells as shown in Figure 9c is about 0.9 km apart, with a maximum and minimum of 1.3 km and 0.65 km respectively" to provide more clarity.

Line 243: The synthetic wells derived from the stratigraphic model is to provide an additional well data for use in a traditional modeling workflow as was the case in the building of original Volve model. Using the same structural model was to attain a comparable framework for evaluating the modeling outputs. Upscaling the synthetic well data is a standard procedure to "transform" the data from 1-D into a 3-D framework to build the property model.

Line 249-250: The selection of six realizations was based on visual and statistical comparison of zones in the original Volve field model, and the stratigraphic-based porosity/permeability models. The statistical approach involved the comparison of summary statistics from the original Volve model, and the model realizations generated in the Petrel software. The visual comparison on the other hand looks at how geological realistic the output is, and if it conforms with our conceptual idea of the Volve field model

Line 277-218: No we didn't do that. The explanation is that a property model that has been used for production purposes would have gone through different phases of history matching, hence its adoption as a reasonable base model. The aim is to ascertain the practicability of using the forward stratigraphic modeling technique to predict property variation in a hydrocarbon reservoir.

Line 291: The 20 simulation scenarios generated are related to the depositional models (stratigraphic models). Out of the 20 scenarios, scenario 4 was adopted and populated with porosity and permeability attributes. So out of the 20 stratigraphic modeling scenarios only scenario 4 has a direct relationship to the 50 realizations produced in the property model.

Line 298: This will be revised to read "A porosity-permeability model matching the original petrophysical model was produced using synthetic porosity and permeability logs from the forward stratigraphic model as input datasets in the sequential Gaussian simulation algorithm".

Line 340: More conditioning data (well data) in a model area enhances the chance of attaining realistic distributions in inter-well regions. So with the forward stratigraphic-based property model providing a promising depositional framework in 3-D, we will be in the position to make realistic predictions in area were well logs are widely spaced (e.g. >= 2 km). The data used here refers to wells that have well logs. This clarification will be made in the manuscript.

Line 355-358: In our view, the calculator approach used in estimating the lithofacies proportions in the stratigraphic model were constrained to the extent to which we assume such distributions should go. Meanwhile, with an unsupervised machine learning via neural network, we can attain many outcomes that are not restricted by our cognitive biases. The neural network can be defined with varying components (e.g. weights) to attain different outcomes, from which a best fit vertical profile that is comparable to real well log can be adopted.

Comments on Figures and Tables

Changes will be made to reflect the suggestions with regards to figures and tables.

Figure 2: This will be replaced with the modified figure below (Labelled figure 3 here).

Figure 4 & 5: A landscape format has been used in both cases in the manuscript to make the figures and legends clearer. (labelled figure 4 and 5).

Figure 10: The points in the variogram indicate the experimental data. The lag distance is about 100 m. The figure show the Lags between sample pairs for calculating the variogram in the major direction (NE-SW) of the stratigraphic model. This modification will be included to the figure caption.

Figure 11: The 6 realizations of porosity and permeability as suggested previously in Line 249-250, were to depict the similarity of the forward stratigraphic-based model to the original model in terms of porosity and permeability distribution.

Figure 12: Your suggestion has been taken on board. Caption will be revised read; "Illustrating; a. validation well 1, and b. validation well 2 samples in the synthetic forward-based model and pseudo wells from the original Volve field to compare porosity distribution".

Table 2: For example, if the simulation interval is 1 Ma, but we reach $\frac{3}{4}$ of it, and notice a similarity to the depositional sequence under study is being attained, it can be truncated, without necessarily reaching "0 years". The full extent of the simulations conducted is achieved in the folder on Zenodo.

Table 3: The font size will be increased, and a landscape format used as shown in the supplement.

Table 5: Yes, and in tables i, ii, iii, and iv in the supplement.

Please also note the supplement to this comment:
https://gmd.copernicus.org/preprints/gmd-2020-37/gmd-2020-37-AC1-supplement.pdf

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Stratigraphic curve spreadsheet for 'Trial Sea Level Curve. '

	Geological age	Elevation depth m
0	0.00	15
1	0.10	25
2	0.15	38
3	0.20	45
4	0.25	75
5	0.30	95
6	0.35	92
7	0.40	88
8	0.45	100
9	0.50	120
10	0.55	92
11	0.60	85
12	0.70	100

Figure 1 Sea level curve used for simulation.

Fig. 1.

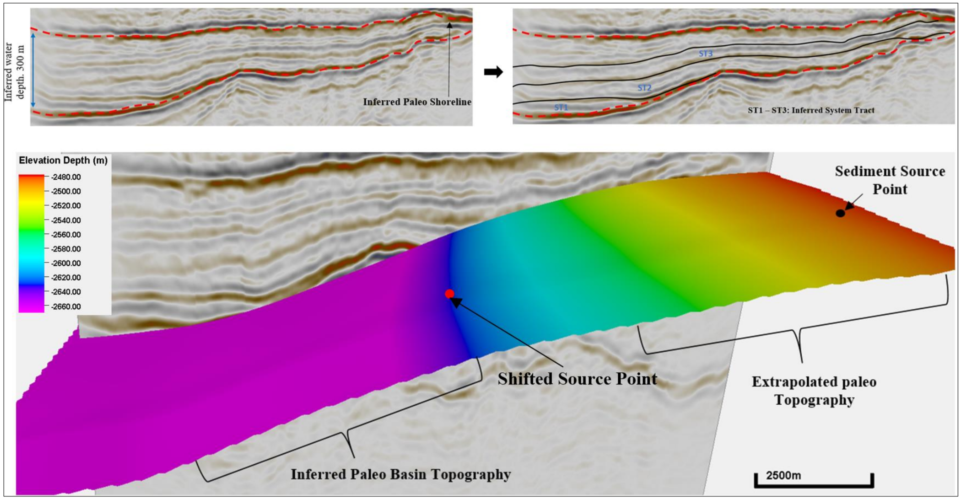

Figure 2 3-D seismic section of the study area, from which the hypothetical topographic surface was derived for the simulation. The sedimentary entry point into the basin is located in the North Eastern section, based on previous study in the model area (e.g. Kieft et al. 2011).

Fig. 2.

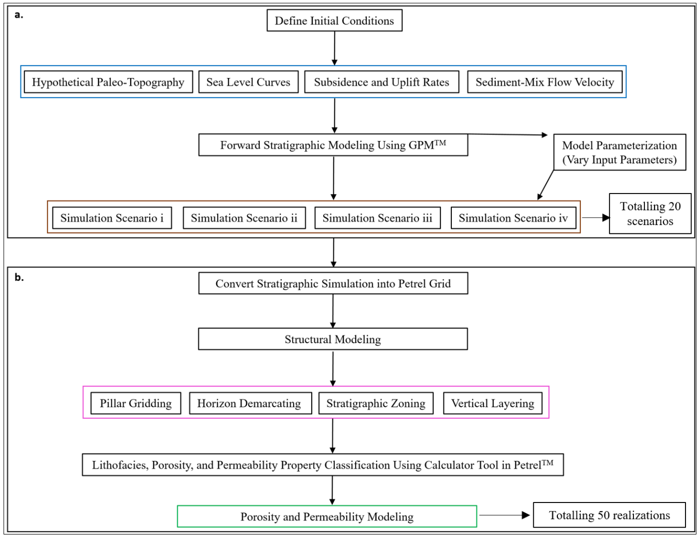

Figure 3 Workflow used in this work

Fig. 3.

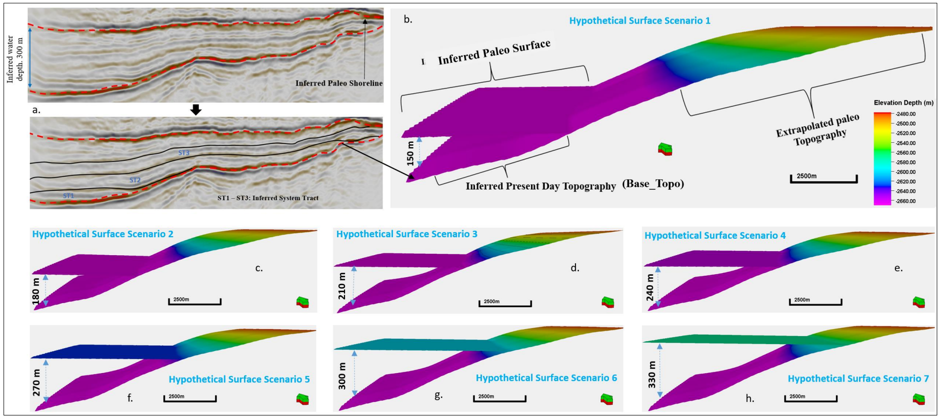

Figure 4 Inferred paleo topographic surface from seismic, also illustrating different topographic surface scenarios used in the simulation.

Fig. 4.

Printer-friendly version

Discussion paper

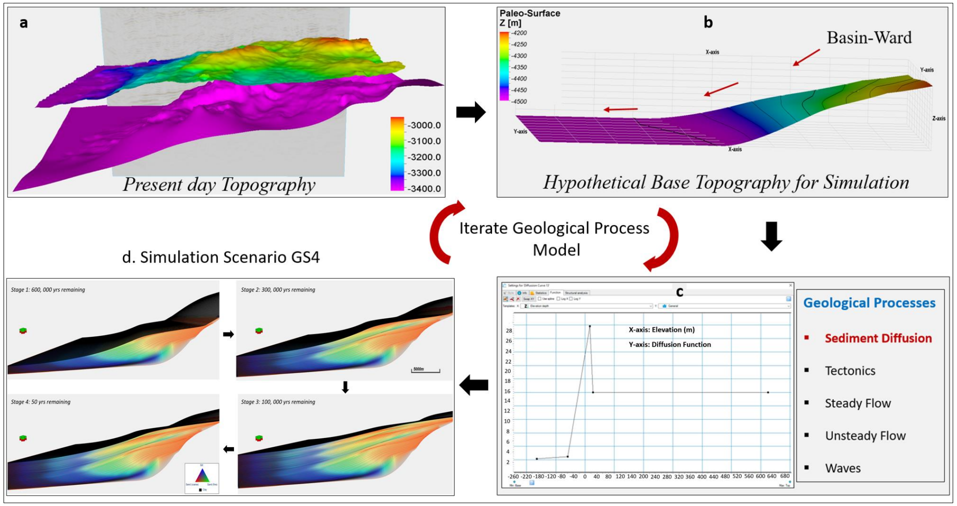

Figure 5 The figure 5c illustrates the diffusion curve used in the simulation of scenario. In addition figure 7 has been modified to make 7b clearer.

Fig. 5.

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Discussion paper

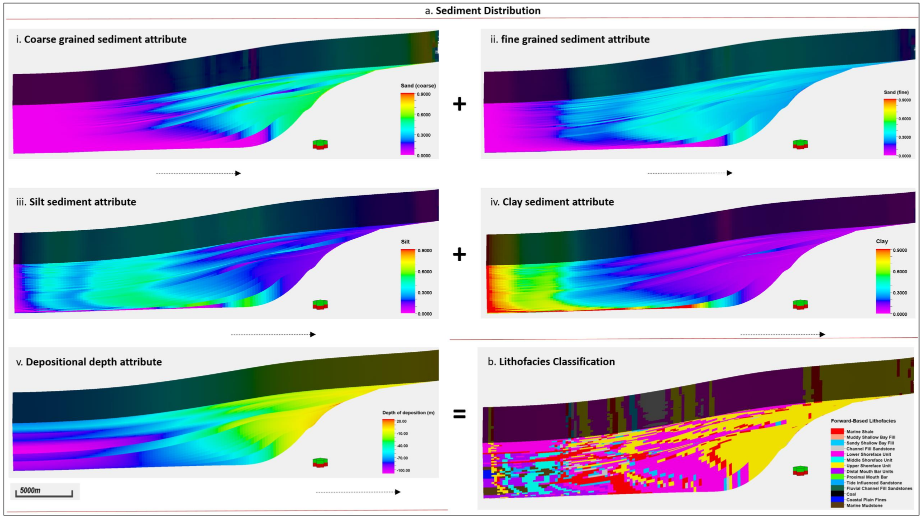

Figure 7 a. Sediment distribution patterns in the geological process modeling software. b. lithofacies classification using the property calculator tool in Petrel™

Fig. 6.

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Discussion paper

The diffusion equation stated may not come out as desired in the online version (preprint), So this pdf is to show the actual equation.

$\partial z/\partial t=k\nabla^2 z$, where z is topographic elevation, k the diffusion coefficient, t for time, and $\nabla^2 z$ the Laplacian.

Fig. 7.