PS Geologic Modeling and History Matching of Multi-Scale Flow Barriers in Deep-Water Reservoirs: Methodology and Field Application*

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Search and Discovery Article #40491 (2010)
Posted February 26, 2010

*Adapted from poster presentation at AAPG Annual Convention and Exhibition, Denver, Colorado, June 7-10, 2009

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Abstract

This work addresses the situation where multi-scale shale drapes are present along channel, channel belt and/or valley bounding surfaces, but the channel locations are uncertain or unknown. In order to reduce the uncertainty of shale drape location, first a realistic representation of the channel distribution must be obtained and constrained to hard data; then the channel and drape locations must be calibrated to the production data.

We propose a coupled geologic modeling and history matching method where the channelized reservoir architecture is simulated with a pre-defined stacking pattern using surface-based modeling techniques. Then the discontinuous shale drapes along multi-scale bounding surfaces are simulated using multiple-point statistical techniques. Channel geometry, location and the corresponding shale drape locations are gradually perturbed until the corresponding flow responses match the field production data. The perturbation during the history matching honors the individual channel geometry statistics and the interpreted channel stacking patterns, providing a geologically consistent perturbation.

A 3D geologic model based on a real turbidite reservoir in offshore West Africa is used to demonstrate this modeling and history matching approach. The multi-scale shale drapes along the bounding surfaces of channel, channel belt and canyon are simulated and

perturbed while the reservoir geologic concepts are preserved and the static data are honored. The final history-matched geologic models have better prediction capability than randomly selected geologic models.

References

Alapetite, J., B. Leflon, E. Gringarten and J.L. Mallet, 2005, Stochastic modeling of fluvial reservoirs: the YACS approach, SPE Annual Technical Conference and Exhibition, Dallas, Texas, Oct. 9-12, SPE paper 97271.

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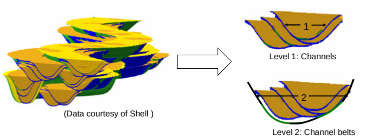
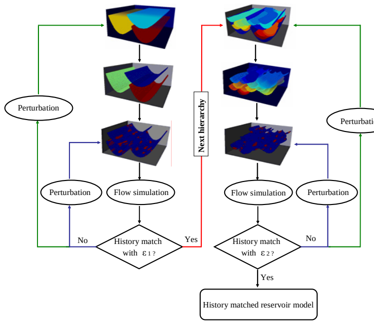
1. Introduction

In deep water turbidite reservoirs, shale drapes may be distributed along the bases of channel belts or along individual channels. These thin (in to ft) shale drapes may serve as flow barriers that compartmentalize the reservoirs. The reservoir connectivity is influenced by the multi-scale hierarchical nature of these shale barriers. An accurate modeling of these multi-scale flow barriers is critical to the successful development and management of reservoirs.



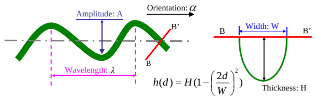
2. Proposed Hierarchical Modeling Workflow



3.1 Proposed workflow: architecture modeling

Desirable elements of a stochastic reservoir channel architecture simulation algorithm:
– Simulated channels are continuous through the reservoir
– Channel boundaries can be identified (for the purpose of attaching shale drapes)
– Easy to match well data
– Reproduce interpreted stacking patterns
– CPU efficient

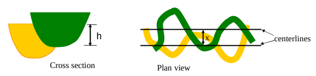
Channel geometry parameters



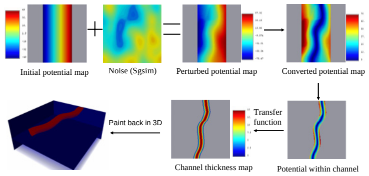
$$h(d) = H(1-(\frac{2d}{W})^2)$$

Channel stacking pattern parameters

Overlap ratio: h/H **Migration ratio**: x/A



Individual channel modeling (YACS approach, SPE97271)



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3.2 Proposed workflow: architecture modeling

Stacking pattern simulation

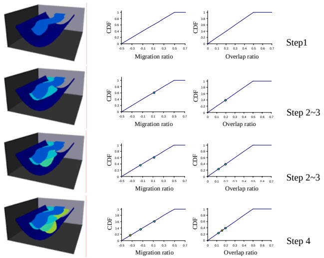
Step 1: In a channel belt, if there are no well data, first simulate a single channel at the channel belt top center; if there are wells passing through this belt, then first generate channels fitting all of the interpreted well channel sections;

Step 2: Draw a value for the migration ratio and overlap ratio from their corresponding distribution functions, and use these ratios to obtain the location relative to the previously simulated channel; simulate a new channel centered at this location

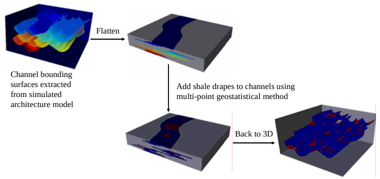
Step 3: If the simulated channel is not fully contained within the channel belt, then it is rejected and step 2 is repeated until a channel is generated that is completely within the channel belt;

Step 4: Repeat step 2-3 to generate a new channel within the channel belt until the given net:gross ratio is approximately reached

Step 5: Repeat step 1-4 for each channel belt in the reservoir



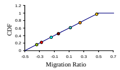
4. Proposed workflow: shale drapes modeling



5. Proposed workflow: architecture perturbation

– History matching channel distribution to production data requires a perturbation method that maintains geological consistency (channel stacking pattern and geometrical characteristics)
– **Key idea**: using gradual deformation perturb channel locations, but maintain interpreted channel stacking pattern and geometry

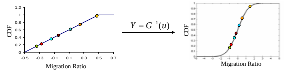
Step 1: Record the Migration ratios and Overlap ratios for each channel (here assuming these parameters are uniform distributed)



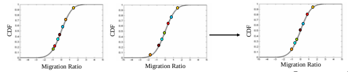
$$U(u_1^M, u_2^M \ldots u_n^M, u_1^O, u_2^O \ldots u_n^O)$$

Where U is a vector and its elements are channels' migration ratio u_i^M and overlap ratio u_i^O

Step 2: Transfer uniform distribution into Gaussian distribution



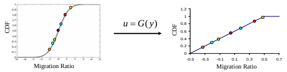
Step 3: Combine the Gaussian realization from Step2 with a new stochastic Gaussian realization



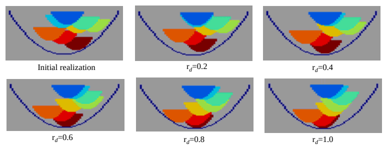
y^0 from step2 y^1 stochastic realization $y = y^0\cos(r_d \times \frac{\pi}{2}) + y^1\sin(r_d \times \frac{\pi}{2})$

Note: r_d is a parameter quantifying the magnitude of the perturbation of channel positions; using a simple 1-D optimization, an optimal value of r_d can be obtained by minimizing an objective function quantifying the discrepancy between the field production data and the equivalent simulated response

Step 4: Transfer y back to uniform distribution



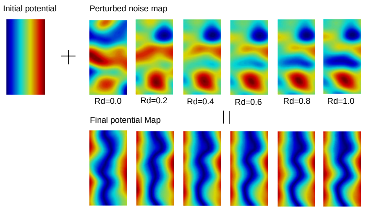
Synthetic Example



Parameter r_d quantifies the magnitude of the perturbation
Note that the stacking pattern and channel geometrical characteristics are maintained

6. Proposed workflow: channel geometry perturbation

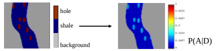
– For the channels passing well locations, the channel geometry can be perturbed
– **Key idea**: using gradual deformation perturb the noise map, but maintain channel position at well location and geometry statistics



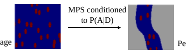
7. Proposed workflow: shale drapes perturbation

– Shale drapes are perturbed in a 2D space, that is after the channel boundaries are flatted. After perturbation, channel boundaries and their associated drapes are convert back to 3D space
– **Key idea**: using probability perturbation method to perturb shale drape locations, but maintain their coverage and distribution pattern

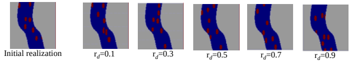
Step1: For an initial channel boundary shale drape model, calculate the probability of scour hole occurrence (A) given production data (D), P(A|D), using equation $P(A \mid D) = (1 - r_d) \times i + r_d \times P(A)$ P(A) is the prior probability of hole occurrence, i is a binary indicator for initial realization



Step2: Run a new multiple-point geostatistic (MPS) simulation conditioned to static data (B) and obtain P(A|B). Combine P(A|B) and P(A|D) to get a perturbed probability model P(A|B,D). Draw realization from this model



Synthetic example



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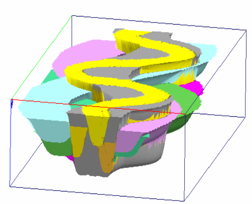
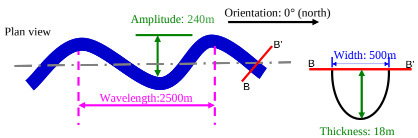
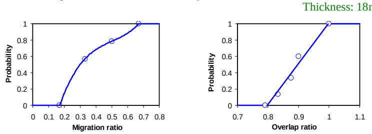
8.1 Application: reference model construction



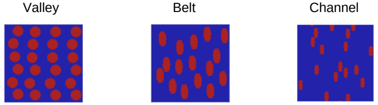
- Realistic reservoir analog built after real offshore West Africa reservoir
- Valley-belt-channel system
- High NTG (0.7-0.8) reservoir
- Channels/belts within valley and outside valley have different amount of shale drapes

Geologic modeling parameters





Scour hole training image

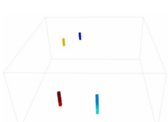


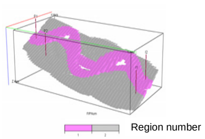
Hole training image for valley proportion: 0.4

Hole training image for belt proportion: 0.25

Hole training image for channel proportion: 0.1

Well facies data and geologic regions

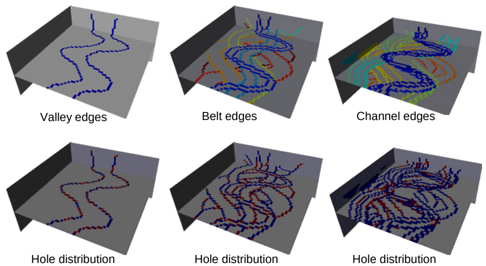




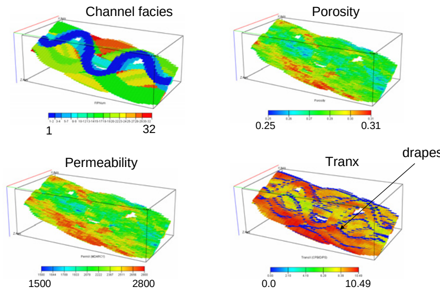
- Region 1 (purple-colored) has shale drape proportion 0.55/0.6/0.65 for valley/belt/channel
- Region 2 (grey colored) has shale drape proportion 0.8/085 for belt/channel

8.2 Application: reference model construction

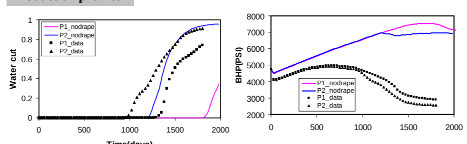
Multi-scale shale drapes

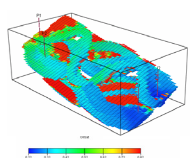


Facies and property models



Production profiles

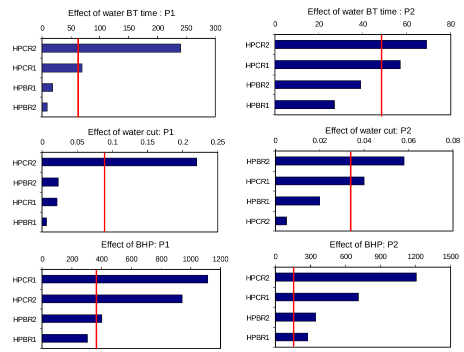




9.Application: region sensitivity study

Factor	Factor level -1	Factor level 1
Hole proportion of belt in Region1 (HPBR1)	0.2	0.4
Hole proportion of channel in Region1 (HPCR1)	0.15	0.35
Hole proprtion of belt in Region2 (HPBR2)	0.2	0.4
Hole proportion of channel in Region2 (HPCR2)	0.15	0.35

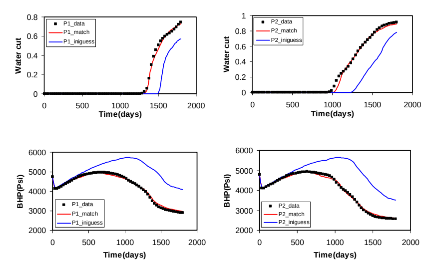
Run	HPBR1	HPCR1	HPBR2	HPCR2
1	-	-	-	-
2	+	-	-	+
3	-	+	-	+
4	+	+	-	-
5	-	-	+	+
6	+	-	+	-
7	-	+	+	-
8	+	+	+	+



- Drape proportion along channels is the most sensitive factor
- WCT and BHP are used to calculate objective function
- BHP can be used to assign producers to regions

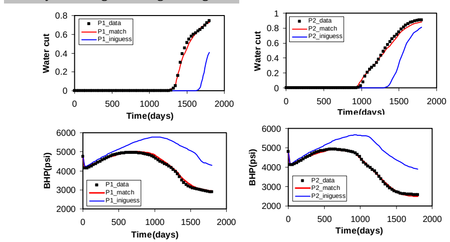
10.1 Application: History matching

History matching assuming two regions

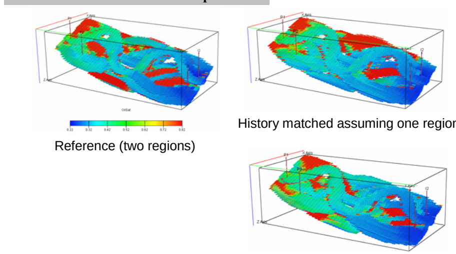


10.2 Application: History matching

History matching assuming one region



Water saturation distribution comparison



Reference (two regions)

History matched assuming one region

History matched assuming two regions

Summary

A methodology for modeling and history matching of multi-scale flow barriers in channelized reservoirs has been presented. With this methodology, reservoir models containing multi-scale facies architecture and associated flow barriers are constructed that match production data and consistent to geologic data such as well-log and conceptual channel stacking patterns.

References

Alapetite, J, B. Leflon, E. Gringarten and J. L. Mallet, 2005, Stochastic modeling of fluvial reservoirs: the YACS approach: SPE Annual Technical Conference and Exhibition , Dallas, Texas, Oct. 9-12, SPE paper 97271

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