[PS]Geomorphology of Carbonate Systems and Reservoir Modeling: Carbonate Training Images, FDM Cubes, and MPS Simulations*

By
Marjorie Levy[1], Paul M. (Mitch) Harris[1], Sebastien Strebelle[1], and Eugene C. Rankey[2]

Search and Discovery Article #40289 (2008)
Posted July 15, 2008

*Adapted from poster presentation at AAPG Annual Convention, Long Beach, CA, April 1-4, 2007

[1]Chevron Energy Technology Company, San Ramon, CA (levm@chevron.com; MitchHarris@chevron.com; stsb@chevron.com)
[2]University of Miami CSL, Miami, FL (grankey@rsmas.miami.edu)

Abstract

Modern carbonates serve as important analogs for reservoir studies, especially with a recent change in emphasis to more quantification of facies characteristics. The purpose of this study is to demonstrate the utility of facies attributes from modern analogs in Multiple-Point Statistics (MPS)/Facies Distribution Modeling (FDM) of carbonate reservoirs.

To explore use of data from the Modern, an isolated platform was modeled using training images, FDM cubes, and MPS simulations for varied grainstone and reef reservoir types. Grainstone shoals are linear, sinuous, or crescent-shaped; each can contain barcrest, barflank, and island environments. These examples are based on modern analogs from the Bahamas and show a range of grainstone geometries that might be expected in the subsurface. Our reef examples are based on modern analogs from Belize. Barrier reefs are continuous and discontinuous; continuous barrier reefs can have associated sand aprons. Patch reefs and small aprons can occur in the platform interior.

MPS training images are constructed for individual facies and for combined facies associations drawing upon a dimensional database for input parameter ranges. The training image is a 3D conceptual model of the reservoir, containing information about facies dimensions and relationships among facies geobodies. Facies depocenter maps are generated for the various facies, and the stratigraphy of the reservoir is modeled by digitizing a vertical proportion curve reflecting the variations of facies proportions with depth. The map data and the vertical data are combined to generate facies probability cubes. The facies probability cube allows controlling the spatial distribution of the facies in the MPS model when combined with the training image. These facies-based MPS earth models are being used to test which input parameters have the greatest impact on flow behavior for uncertainty management.

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Marge Levy, Paul (Mitch) Harris, Sebastien Strebelle
Chevron Energy Technology Company, San Ramon, CA

Gene Rankey
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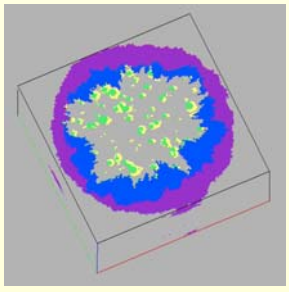

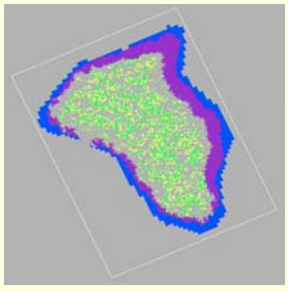

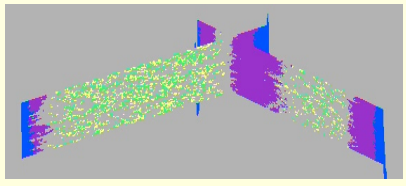

Modern carbonates serve as important analogs for reservoir studies, especially with a recent change in emphasis to more quantification of facies characteristics. The purpose of this study is to demonstrate the utility of facies attributes from modern analogs in Multiple-Point Statistics (MPS)/Facies Distribution Modeling (FDM) of carbonate reservoirs.

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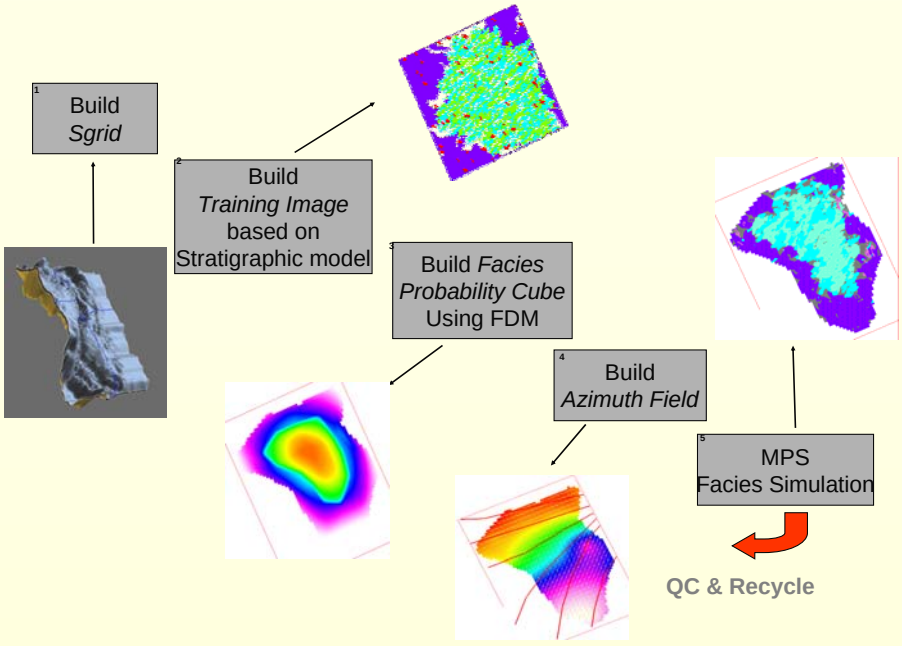
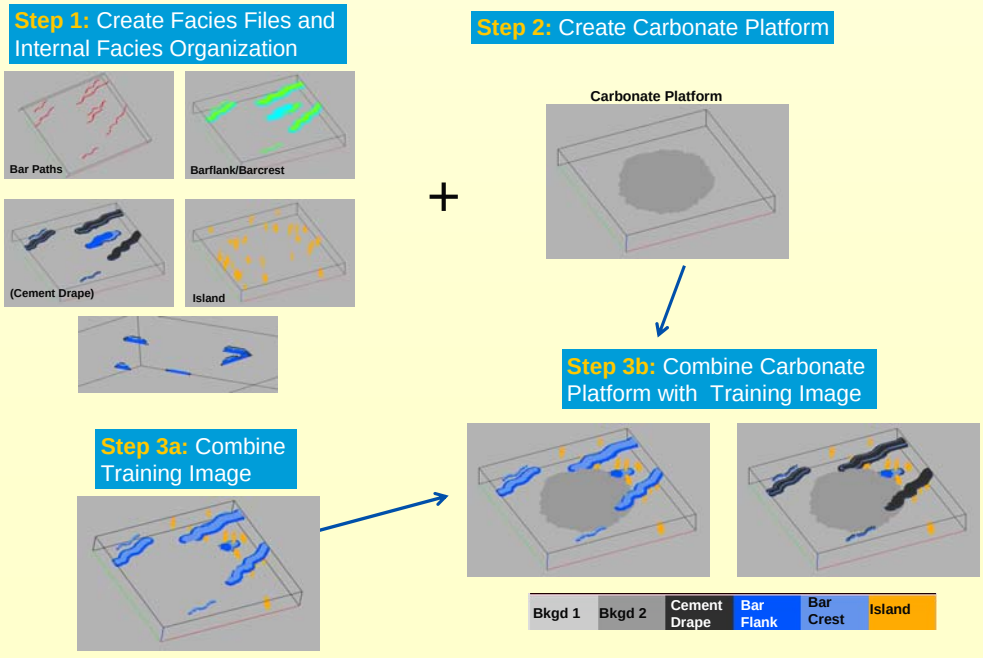
MPS/FDM Workflow



MPS uses 3D conceptual geological models as training images to integrate geological information into reservoir models. Replacing the traditional variogram with a training image allows MPS to capture complex spatial relationships among multiple facies, and to model non-linear shapes such as sinuous bars that conventional variogram-based modeling techniques typically fail to reproduce. External constraints such as a facies probability cube and an azimuth field help constrain the spatial distribution of facies within the reservoir model.

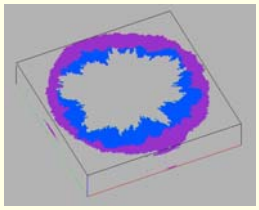
Training Image Workflow



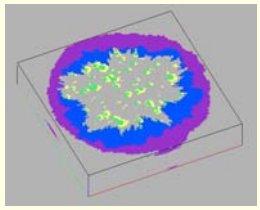
The training image is a 3D conceptual model of the reservoir, containing information about facies dimensions and relationships among facies. It consists of building individual facies files (Step 1) and/or facies belts (Step 2), which are then combined together (Step 3a/3b) to account for facies relationships and to form the final training image

Reef Examples

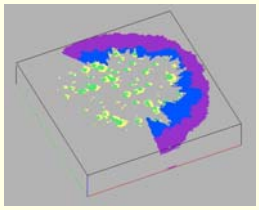
Training Images for Reef Scenarios



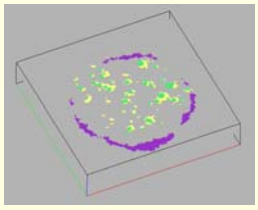
Reef with apron around central platform



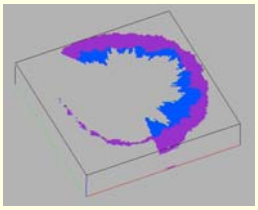
Reef with apron; reef patches with aprons in central platform



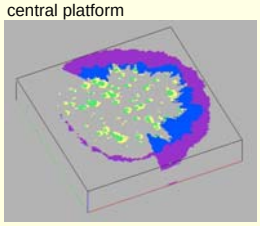
Asymmetric windward reef with apron; patch reefs with aprons in central platform



Discontinuous reef with no apron; patch reefs with aprons in central platform

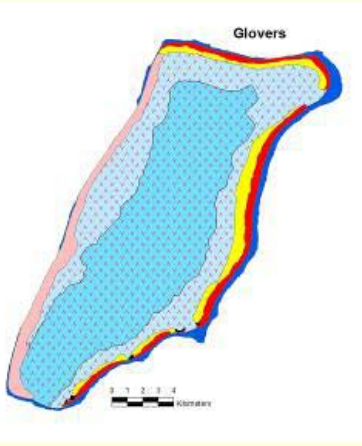


Asymmetric continuous windward reef with apron; discontinuous leeward reef with no apron



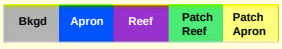
Asymmetric continuous windward reef with apron; discontinuous leeward reef with no apron; patch reefs with aprons in central platform

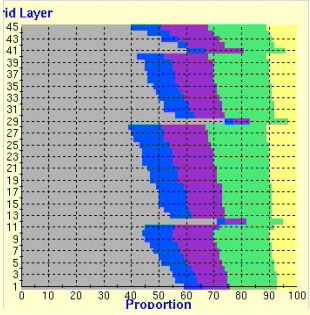
Modern Analog from Belize



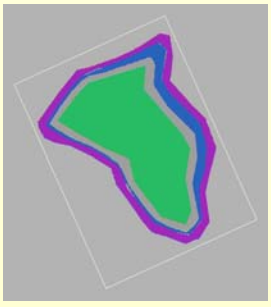
This modern platform contains a reef rim (red) around much of its margin, an apron (yellow) that is best developed (widest) along the windward eastern margin, and numerous patch reefs in the platform interior.

FDM Cube



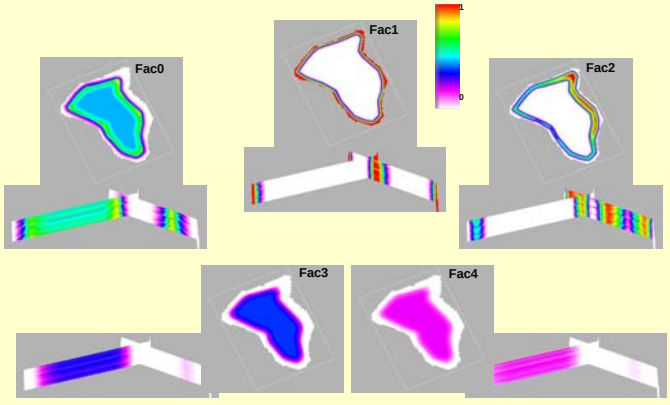


Verical Proportion Curve



Facies Depocenter Map

Stratigraphy is modeled by digitizing a vertical proportion curve reflecting the variations of facies with depth. Facies depocenter maps are generated for each facies. The vertical data and the map data are combined to generate a facies probability cube.



Each map and cross section pair shows an example of the probability of occurrence of that facies.

MPS Simulation

Training Image

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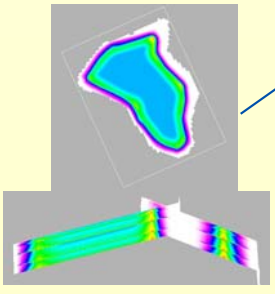
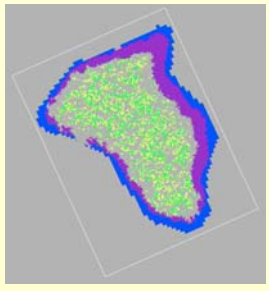
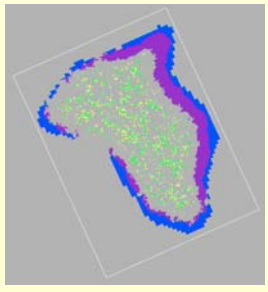
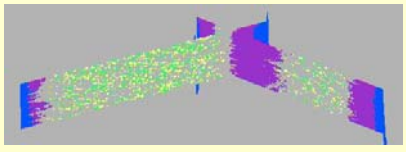


Facies Probability Cube





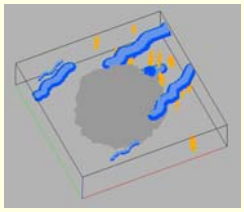
MPS Simulation



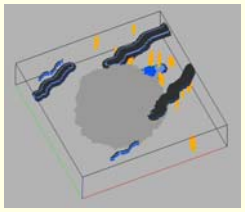
The facies probability cube controls the spatial distribution of the facies in the MPS model when combined with the training image. Based on a training image with reef and apron completely encircling the platform and patch reefs within the interior, the map and cross section views from the MPS simulation show probable distributions of skeletal grainstone and boundstone reservoir facies. What is seen in modern analogs is well captured in the MPS simulation.

Sand Shoal Examples

Training Images for Linear Bars

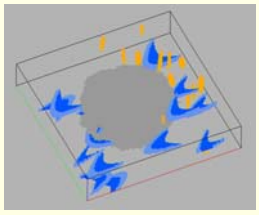


Linear barcrest and barflank with islands

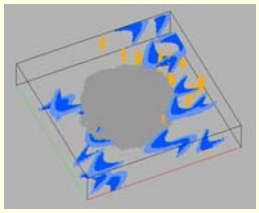


Linear barcrest, barflank, and cement drape with islands

Training Images for Crescent Bars

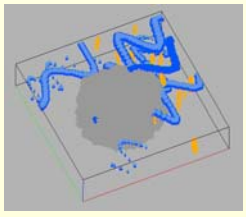


Western flank: bidirectional crescent barcrest and barflank
Eastern flank: unidirection barcrest and barflank with islands

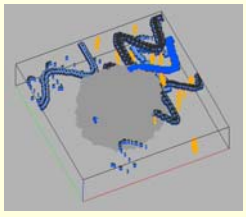


Western flank: bidirectional crescent barcrest and barflank
Eastern flank: bidirectional barcrest and barflank with islands

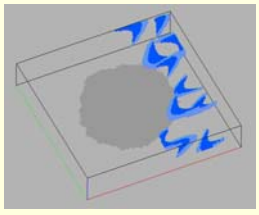
Training Images for Sinuous Bars



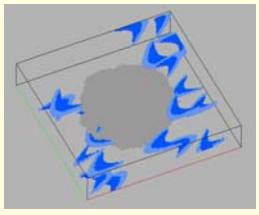
Sinuous barcrest and barflank with islands



Sinuous barcrest, barflank, and cement drape with islands

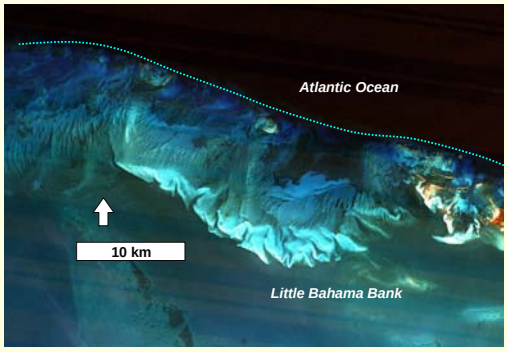


Eastern flank: bidirectional barcrest and barflank



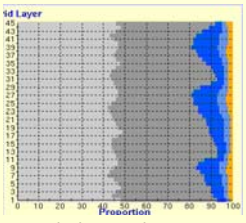
Outer Platform: bidirectional crescent barcrest and barflank around entire platform with no islands

Modern Analog from the Bahamas

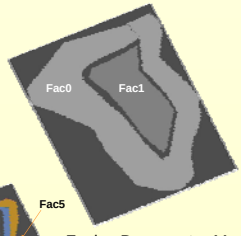


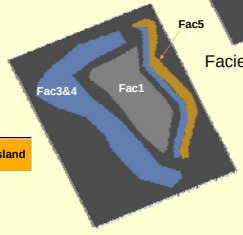
Crescent-shaped bars (parabolas) are well displayed in this sand belt.

FDM Cube for Linear Bar Example

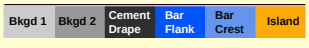


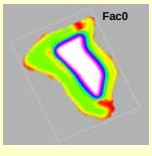
Verical Proportion Curve

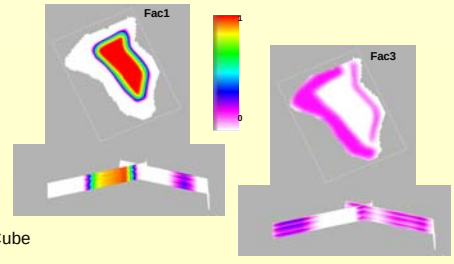




Facies Depocenter Maps

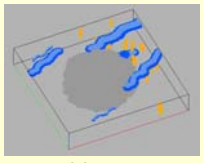






Facies Probability Cube

MPS Simulation for Linear bar Example



Training Image

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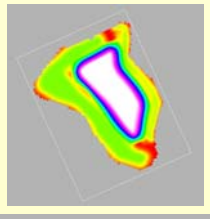
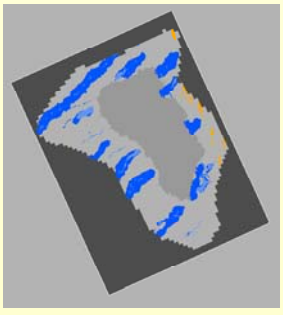
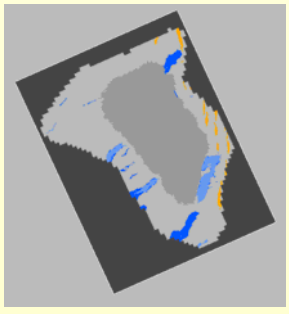
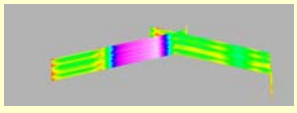


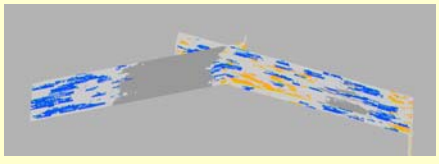




MPS Simulation



Facies Probability Cube



Based on a training image with linear bar crests and bar flanks with islands, the map and cross section views from the MPS simulation show probable distributions of grainstone reservoir facies. As with the reef example, what is seen in modern analogs is well captured in the MPS simulation.

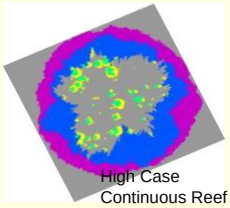
Initial Flow Relevance Studies
(in collaboration with Bill Milliken and Matt Talbert)

Objective: Investigate a reef-rimmed carbonate platform model to determine key parameters that impact flow performance.

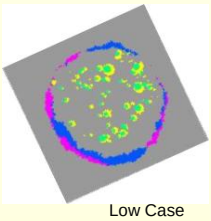
Placket-Burman Experimental Design with 4 independent variables

- Architecture (Continuity of reefs and aprons)
- Cyclicity
- Facies Proportion
- Porosity / Permeability

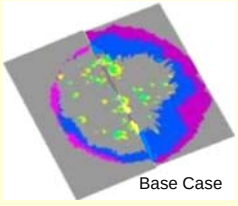
Training Images



High Case
Continuous Reef



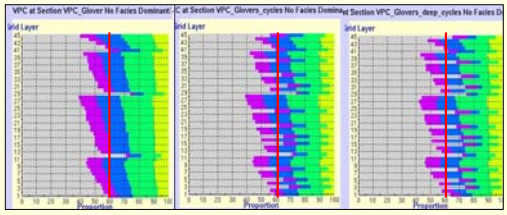
Low Case
Discontinuous Reef



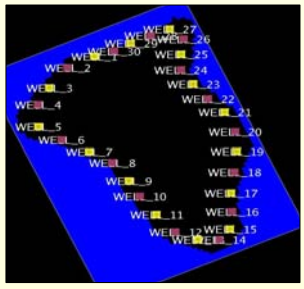
Base Case

Cyclicity

Low Case | Base Case | High Case



Well Distribution – 30 wells

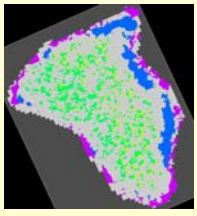


= Injector
= Producer

= Reef
= Apron
= Background
= Patch Reef
= Patch Apron

Earth Models and Streamline Simulations

Low Case

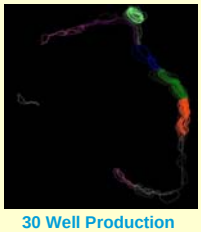


Colors indicate which well fluid is flowing from.

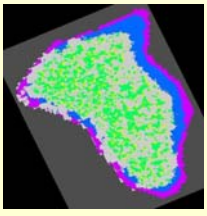
Path can be determined from the location of the producers

10 Well Production Streamlines

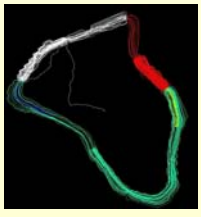
30 Well Production Streamlines



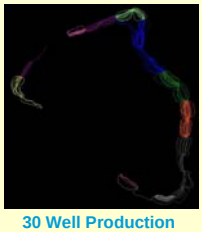
Base Case



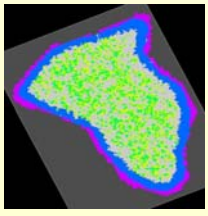
10 Well Production Streamlines



30 Well Production Streamlines

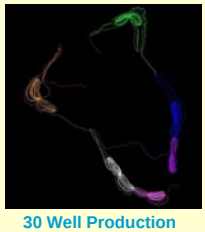


High Case

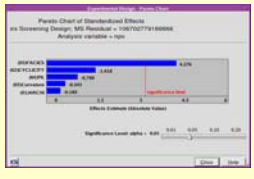


10 Well Production Streamlines

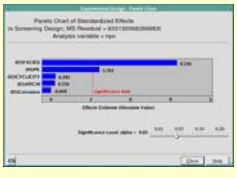
30 Well Production Streamlines



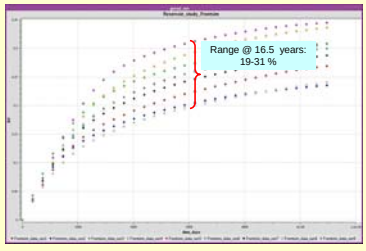
10 Well Pareto Chart – 30 Year



30 Well Pareto Chart – 30 Year



30 Well RF vs. Time



For NET Oil, which in this case is equivalent to the NPV because no water is produced, FACIES % is a significant factor in the 10 well simulation whereas both FACIES % and PK are significant with 30 wells.

These initial studies of flow relevance in a reef-rimmed carbonate platform suggest: (1) continuous reef inhibits platform drainage in the 10 well scenario, whereas discontinuous reef allows platform drainage; and (2) well location, rate, and count alter the Pareto Chart.