Importance of Facies-Based Earth Models for Understanding Flow Behavior in Carbonate Reservoirs*

By
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Abstract

Reservoir models attempt to mimic the distribution of reservoir properties in subsurface systems, and in carbonate reservoirs should capture geologically meaningful and realistic heterogeneity. Comparing SGS-generated models with facies-based Multiple-Point Statistics (MPS)/Facies Distribution Models (FDM) highlights the importance of incorporating facies into models. These facies-based models provide a template to test which carbonate characteristics have the greatest impact on subsurface flow.

To explore different types of carbonate platforms, reef- and grainstone-dominated systems were simulated using training images, FDM cubes, and MPS simulations. On the basis of modern analogs from the Bahamas, grainstone shoals are modeled as linear, sinuous, or crescent-shaped, and include bar crest, bar flank, and island facies. Modeled reef-dominated platforms utilize analogs from Belize, and include barrier reef, discontinuous reef, and apron facies. All simulations use quantitative data and a conceptual model from a modern system as input.

Two types of flow experiments are run:
(1) the impact of depositional facies is tested keeping all other parameters the same; and (2) an experimental design guided set of experiments varying:

- a) proportions of reservoir facies vs non-reservoir facies,
- b) proportions of bar flank/bar crest reservoir facies,
- c) dimensions of facies,

d) diagenetic zones, e) stratigraphic cyclicity,
f) spatial distribution of reservoir facies (distributed across platform vs. localized),
g) shape of reservoir facies (bars vs. crescents),
h) porosity histogram, and
h) permeability transform.

Each model was tested using reservoir simulation and considered different development scenarios and recovery processes. Models were compared on the basis of static measures of OOIP, reservoir connectivity and permeability heterogeneity; and on the basis of dynamic measures of recovery factor vs. time, recovery factor vs. pore volumes injected, net present oil, cumulative oil produced, and water breakthrough time.

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Introduction

Using experimental design, we examine the uncertainty in input parameters on flow performance using Multiple Point Statistics for a synthetic carbonate platform.

- **The objectives of this study are to:**
  - Assess the value of facies-based models
  - Explore stratigraphic and textural uncertainty in grainstone-dominated carbonate systems

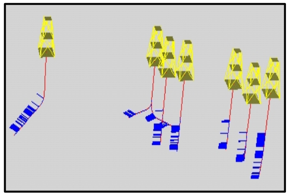
- **Methodology includes using:**
  - Modern analogs from the Bahamas for training images
  - Subsurface data for reservoir properties
  - A workflow combining Multiple Point Statistics (MPS) simulation and Facies Distribution Modeling (FDM), and streamline simulation

Multiple Point Statistics (MPS)

MPS is an innovative reservoir facies modeling technique that uses conceptual geological models as 3D training images to generate geologically realistic reservoir models:

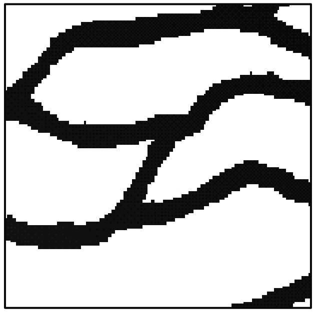
- **Ability to reproduce "shapes" of object-based algorithms**
- **Speed, flexibility and easy data conditioning of variogram-based algorithms**

Well data



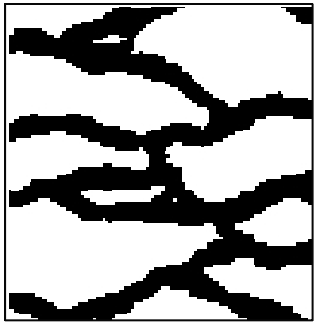
Geological interpretation (well logs and analogs)

3D Training image = Conceptual geological model



Pattern reproduction conditional to available data

MPS model

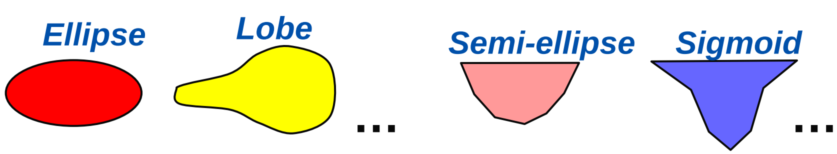


What is a Training Image

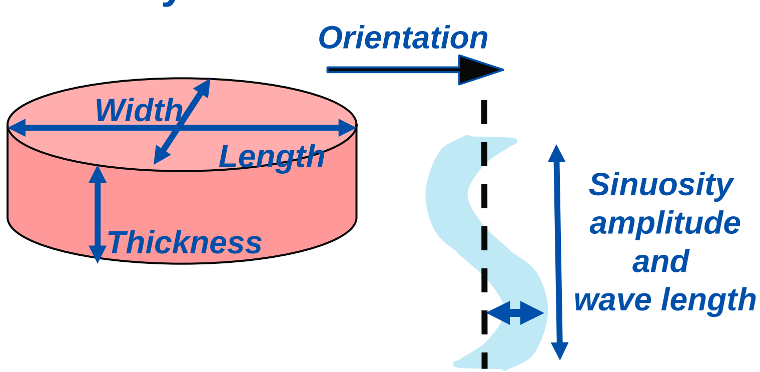
The 3D training image is a rendering of the geological model that defines relative facies body dimensions and shapes, as well as associations between facies

First describe geometry of each facies:

- Define map view and cross-section shapes:

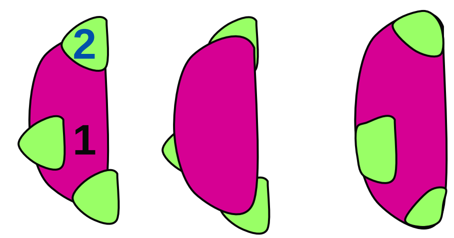


- Define dimensions, orientation, sinuosity:

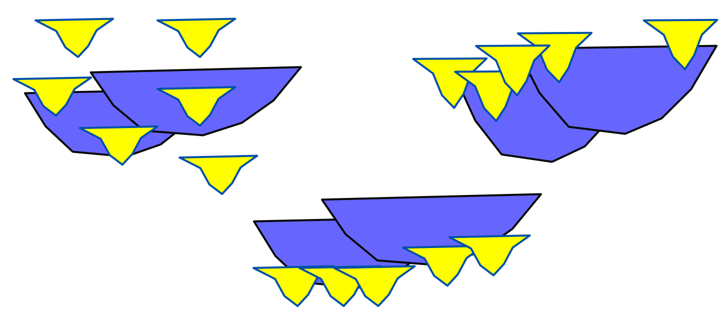


Then specify relationships between facies:

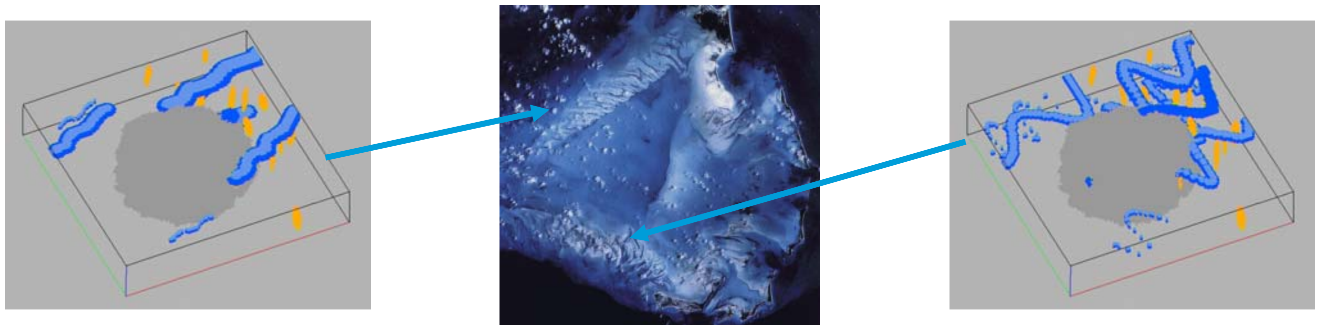
- Define Facies erosion rules:



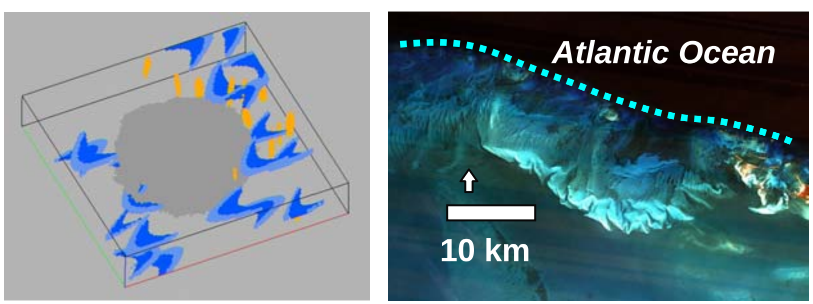
- Define vertical and/or horizontal constraints:



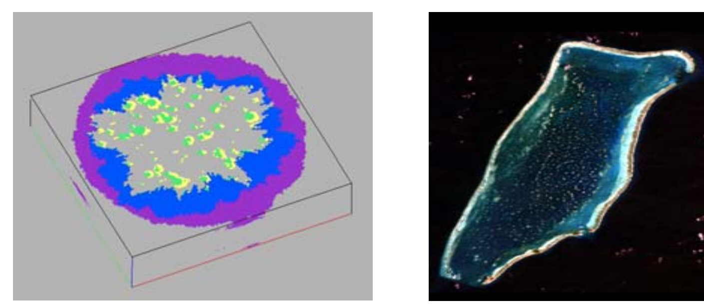
Examples of Carbonate Training Images



Modern Analog: Berry Islands, Great Bahama Bank, Bahamas

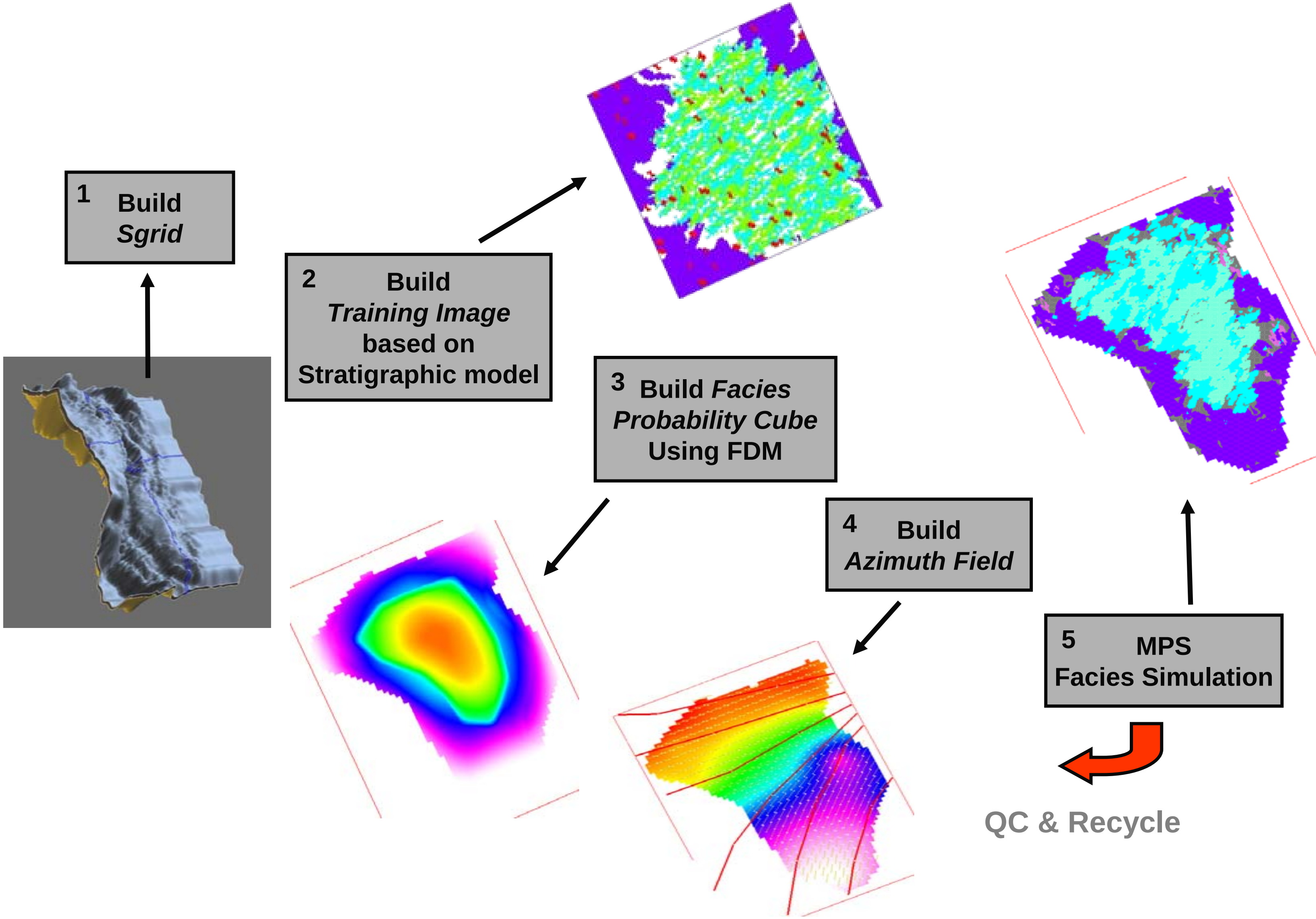


Modern Analog: Lily Bank, Little Bahama Bank, Bahamas



Modern Analog: Glovers Reef, Belize

MPS / FDM Reservoir Modeling Workflow



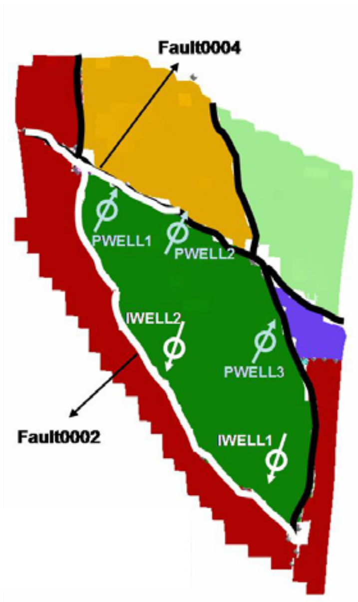
Carbonate Reservoir Modeling Study

Givens for study:

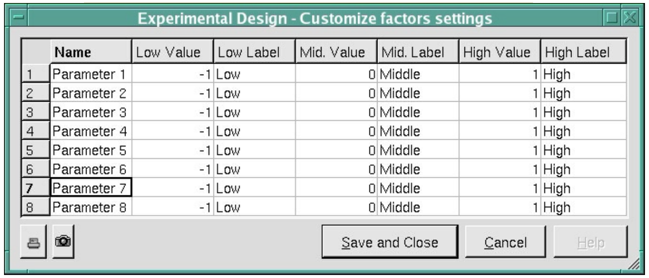
- **Models are facies-based**
- **Geologic setting is grainstone-dominated platform consisting of barcrest, barflank, and island reservoir facies and a background facies.**
- **There are 5 delineation wells. Facies and porosity data are generated in the wells, and all models are conditioned to that data.**
- **All models are simulated assuming a waterflood recovery mechanism.**
  - **Different well counts and different well patterns are considered.**
  - **Results of the simulation have been analyzed with respect to a range of measures (RF vs time, RF vs PVI, NPV, CumOil, etc).**

Experimental Design Workflow

Experimental designs are protocols that provide maximum information about a problem with the minimum number of experiments. Plackett-Burman is a *Screening Design.*



Reservoir Description

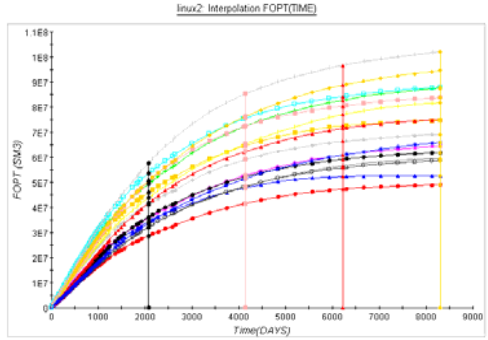


Experimental Design - Customize factors settings

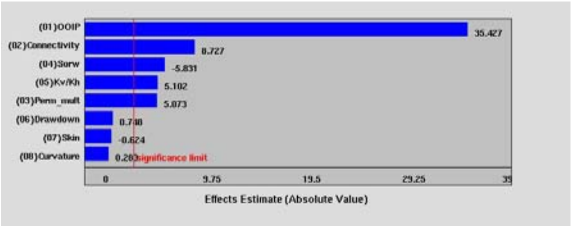
	Name	Low Value	Low Label	Mid. Value	Mid. Label	High Value	High Label
1	Parameter 1	-1	Low	0	Middle	1	High
2	Parameter 2	-1	Low	0	Middle	1	High
3	Parameter 3	-1	Low	0	Middle	1	High
4	Parameter 4	-1	Low	0	Middle	1	High
5	Parameter 5	-1	Low	0	Middle	1	High
6	Parameter 6	-1	Low	0	Middle	1	High
7	Parameter 7	-1	Low	0	Middle	1	High
8	Parameter 8	-1	Low	0	Middle	1	High

Save and Close | Cancel | Help

Design of Experiments

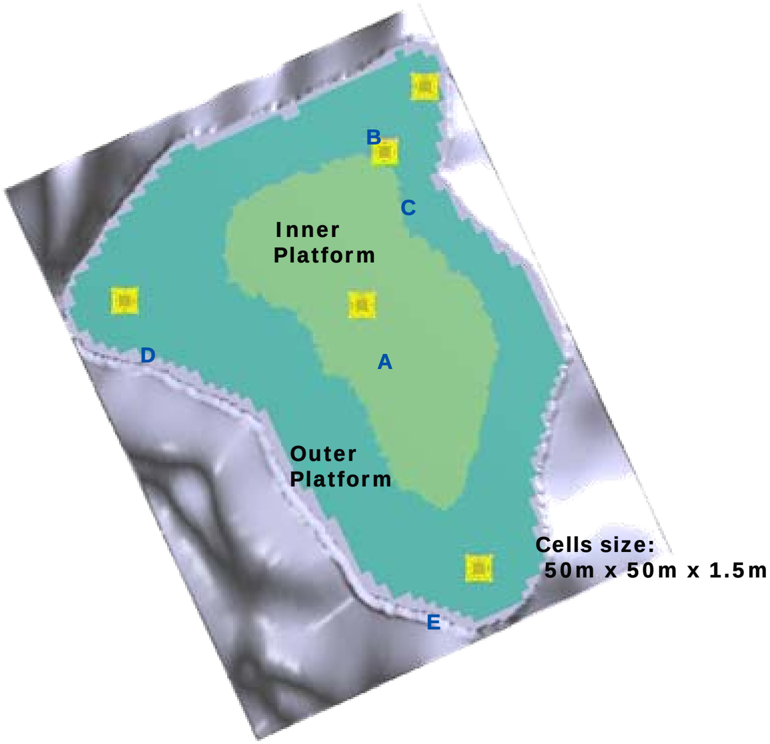


Recovery Profiles

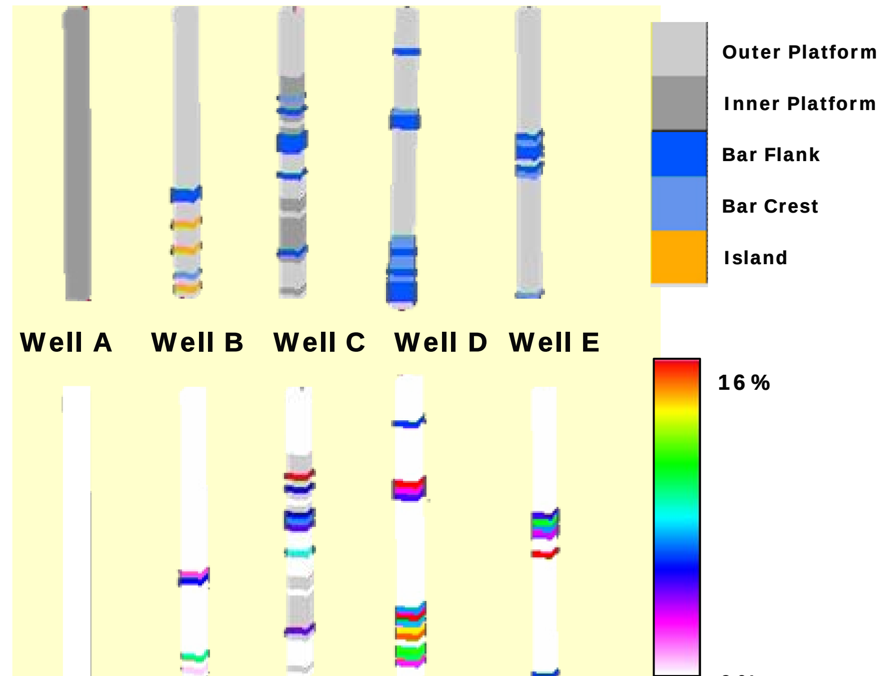


Ranking of Parameters

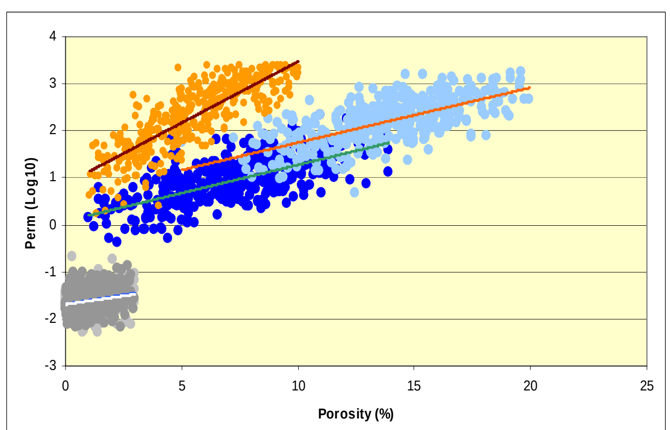
Sgrid and Conditioning Data



Facies Data



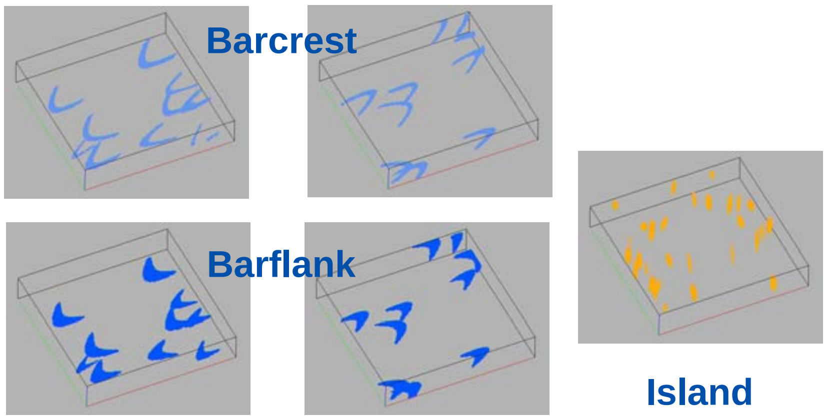
Porosity Data



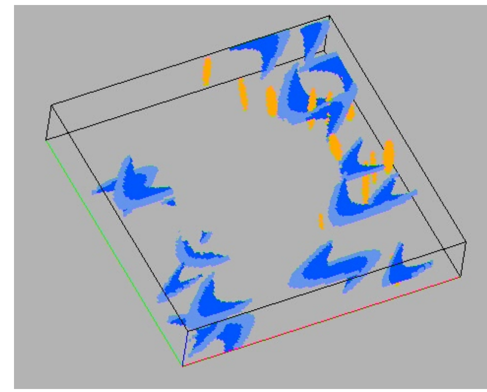
Input Permeability Cloud

Training Image Generation Workflow: Grainstone Shoal-Crescent Bars

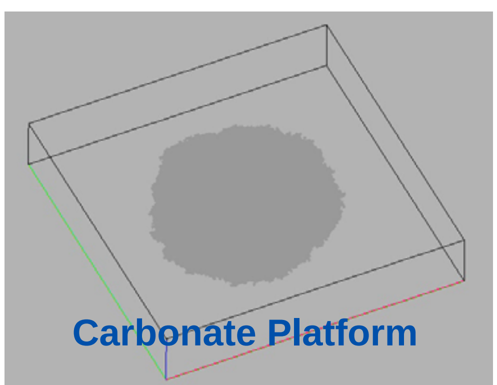
Step 1: Create Facies Files and Internal Facies Organization



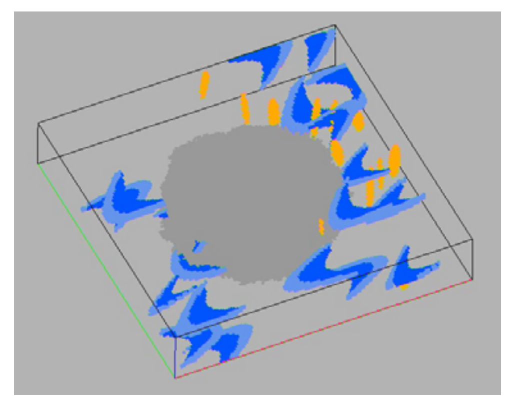
Step 2: Combine Facies Files in Outer Platform Region



Step 3: Create Carbonate Platform and Regions

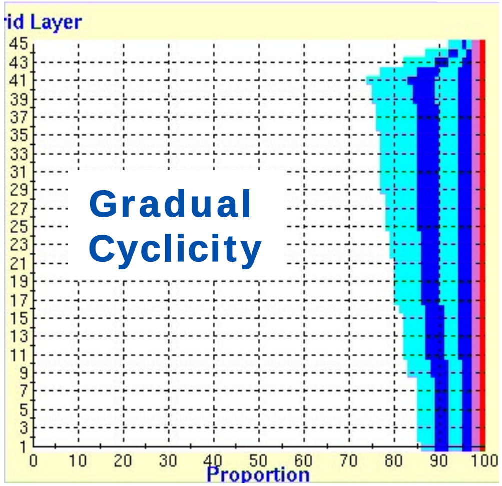


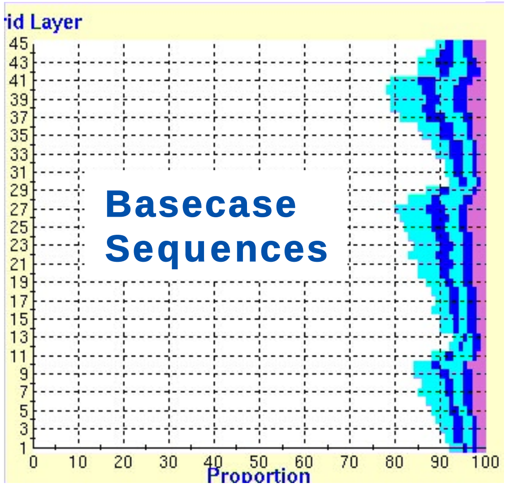
Step 4: Combine Training Images and Platform Regions

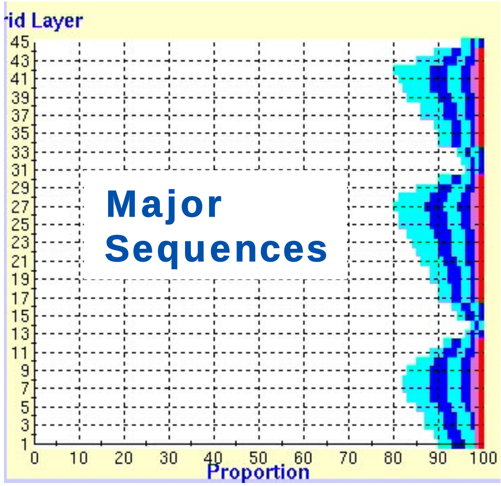


FDM Cube: Grainstone Shoals – Crescent Bars
Modern Analog: Lily Bank, Bahamas

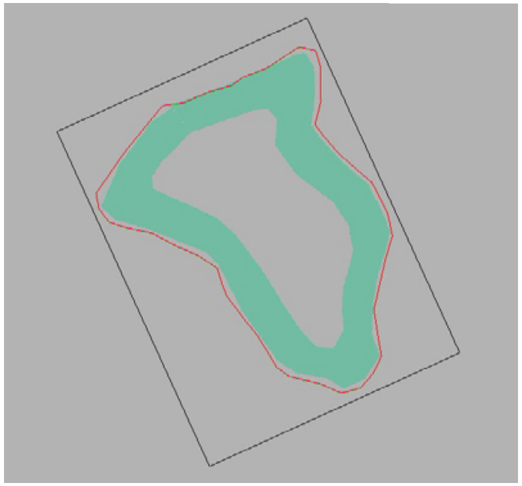
Vertical Proportion Curves







Map Depocenters

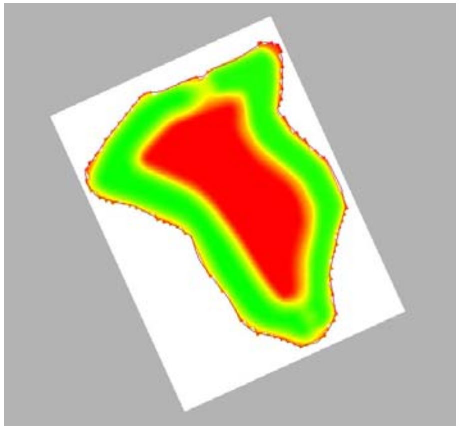


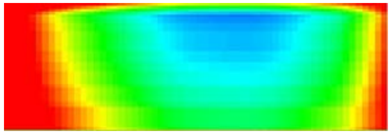
Barflank / Barcrest Facies

Island Facies

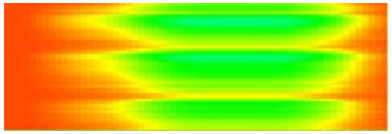
FDM Cube: Grainstone Shoals – Crescent Bars
Modern Analog: Lily Bank, Bahamas

Background Facies

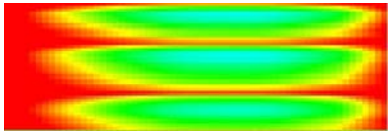




Gradual Cyclicity

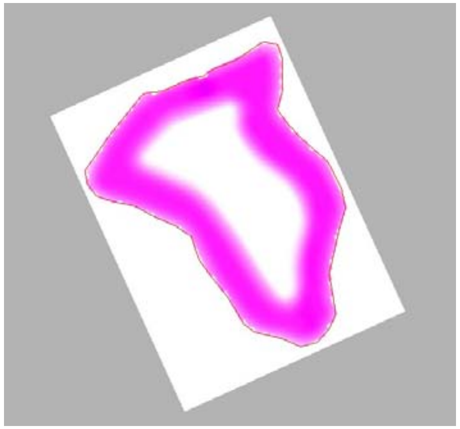


Basecase Sequences

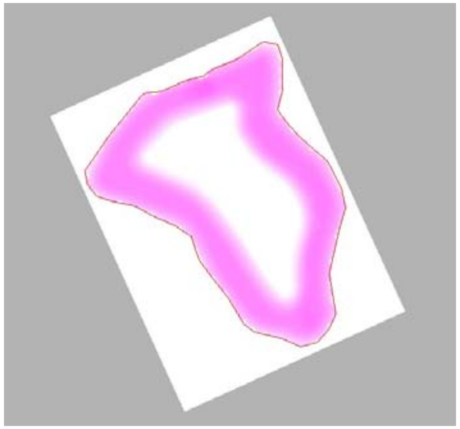


Major Sequences

Barflank Facies

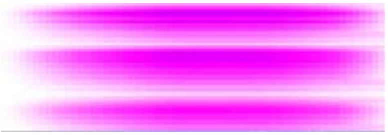


Barcrest Facies



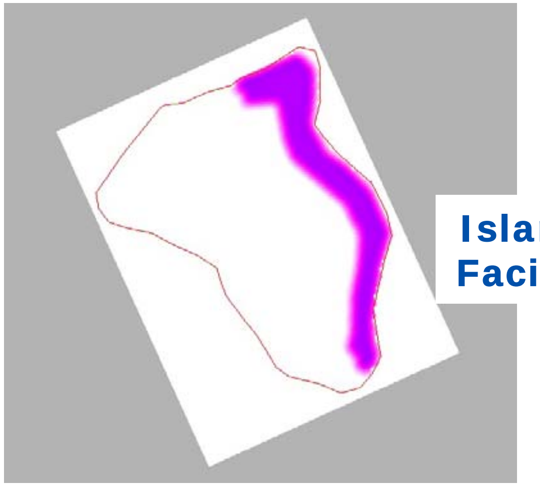
Gradual Cyclicity

Base Case Sequences



Major Sequences

Probability of Facies Occurrence



Island Facies

Experimental Design Run Table

RunTable <2>

	RUN	$crescent_size$	$crescent_ratio$	$distribution$	$cyclicity$	$poro$	$diagenesis$	$ktransform$	$res_quality_facies$
1	run1	large_crescent	narrow_crest	windward	major_seq	LCS	-1	HKtrans	high
2	run2	large_crescent	wide_crest	everywhere	gradual	LCS	-1	LKtrans	high
3	run3	small_crescent	wide_crest	windward	major_seq	HCS	-1	LKtrans	low
4	run4	large_crescent	narrow_crest	windward	gradual	LCS	1	LKtrans	low
5	run5	large_crescent	wide_crest	everywhere	gradual	HCS	-1	HKtrans	low
6	run6	large_crescent	wide_crest	windward	major_seq	HCS	1	LKtrans	high
7	run7	small_crescent	wide_crest	windward	gradual	LCS	1	HKtrans	low
8	run8	small_crescent	narrow_crest	windward	gradual	HCS	-1	HKtrans	high
9	run9	small_crescent	narrow_crest	everywhere	gradual	HCS	1	LKtrans	high
10	run10	large_crescent	narrow_crest	everywhere	major_seq	HCS	1	HKtrans	low
11	run11	small_crescent	wide_crest	everywhere	major_seq	LCS	1	HKtrans	high
12	run12	small_crescent	narrow_crest	everywhere	major_seq	LCS	-1	LKtrans	low
13	run13	mid	mid	mid	mid	MCS	0	mid	mid

Total number of runs = 13

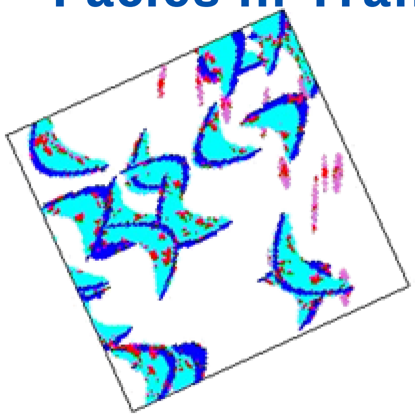
Close

Variables

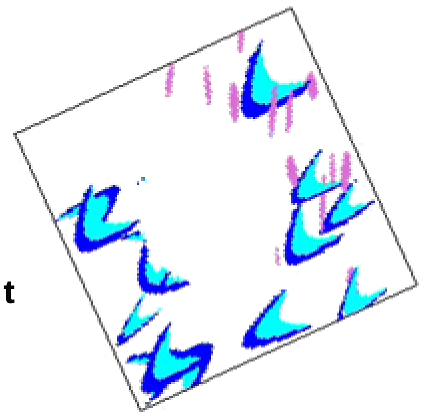
- Crescent Size
- Barflank / Barcrest Ratio
- Areal Distribution
- Cyclicity
- Porosity Histogram Overlap
- Diagenesis
- Permeability Transform
- Percent of Reservoir Facies

Plackett-Burman Experimental Design Variables

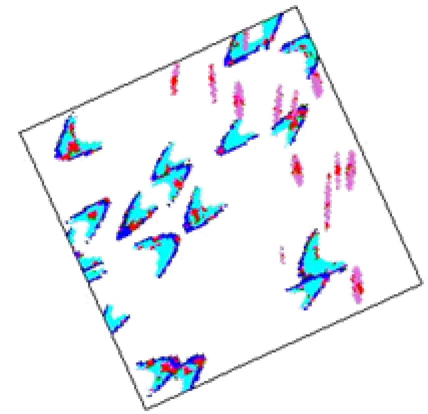
- **Size and Ratio of Barcrest and Barflank Reservoir Facies in Training Image**



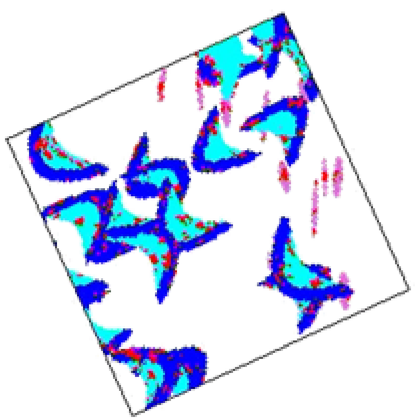
Large crescents with narrow crest



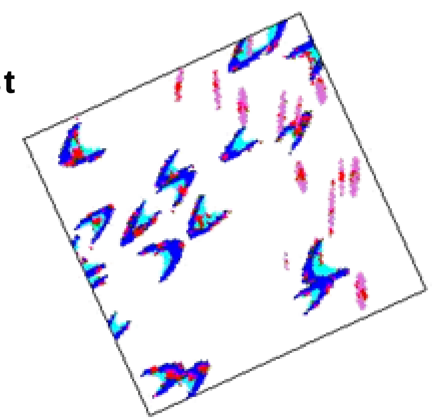
Mid-size crescents with mid-size crest



Small crescents with narrow crest



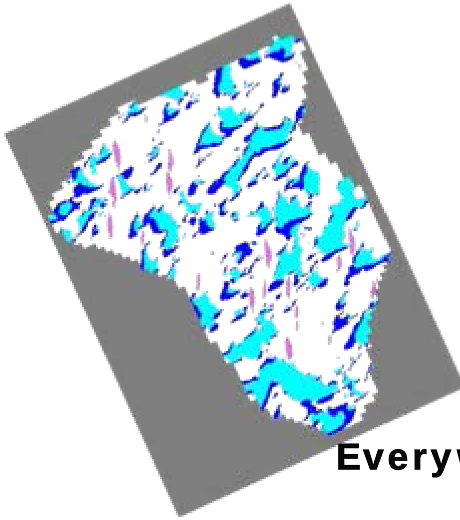
Large crescents with wide crest



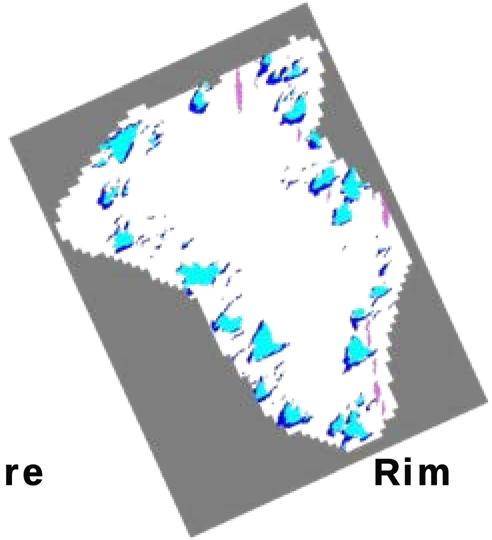
Small crescents with wide crest

Plackett-Burman Experimental Design Variables

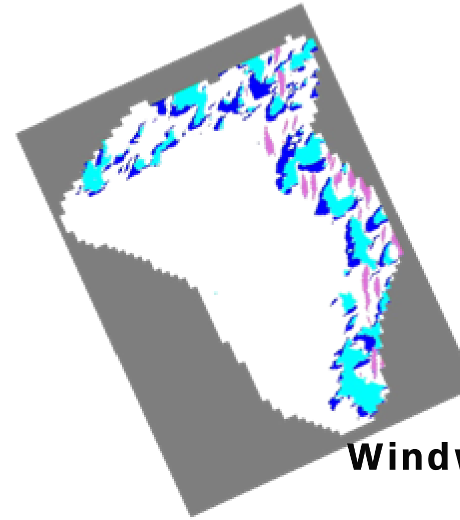
- **Distribution of reservoir facies**



Everywhere

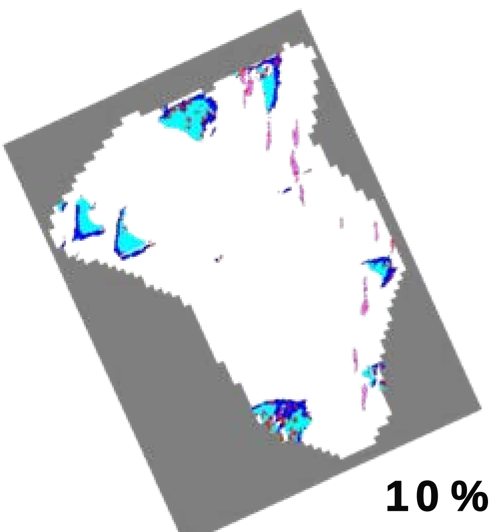


Rim

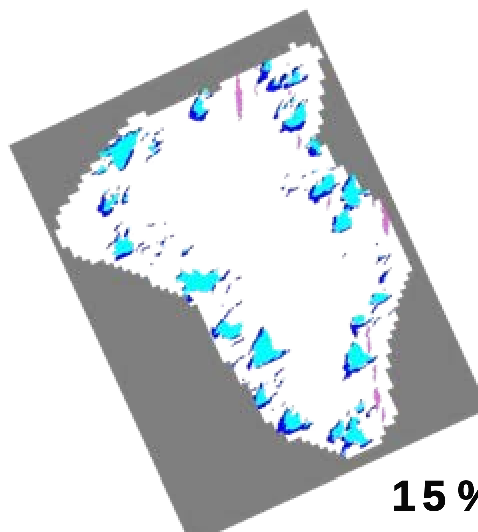


Windward

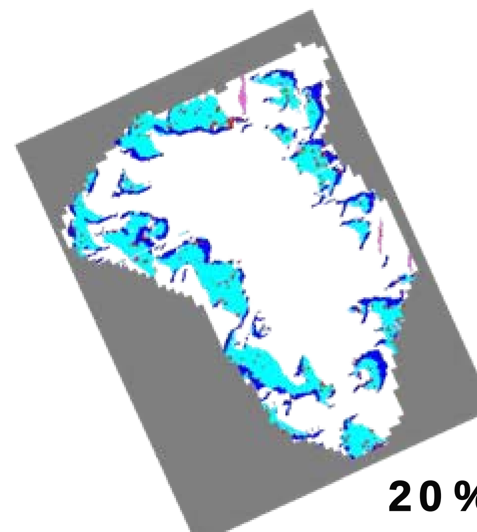
- **Percentage of total reservoir facies**



10%



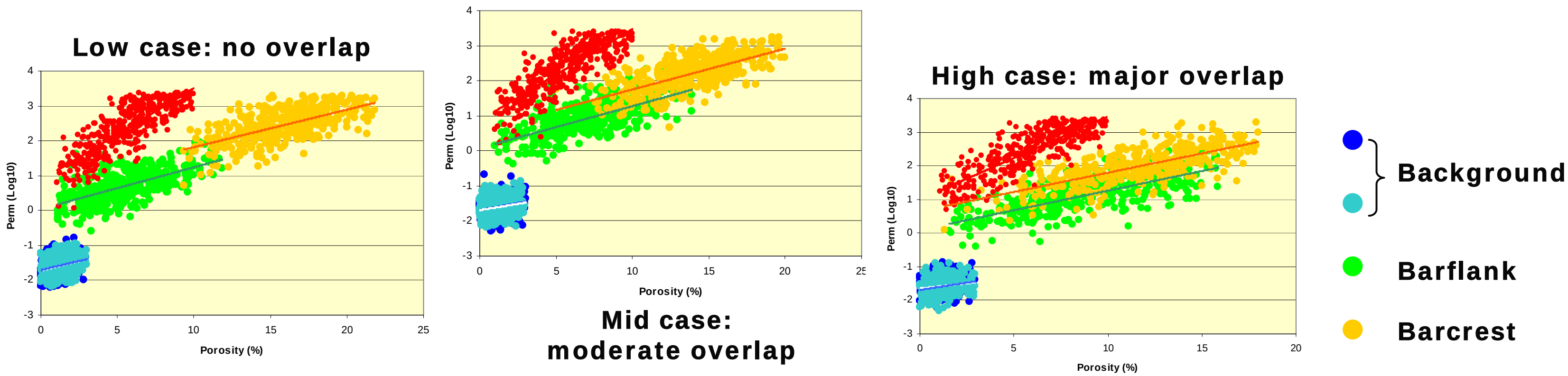
15%



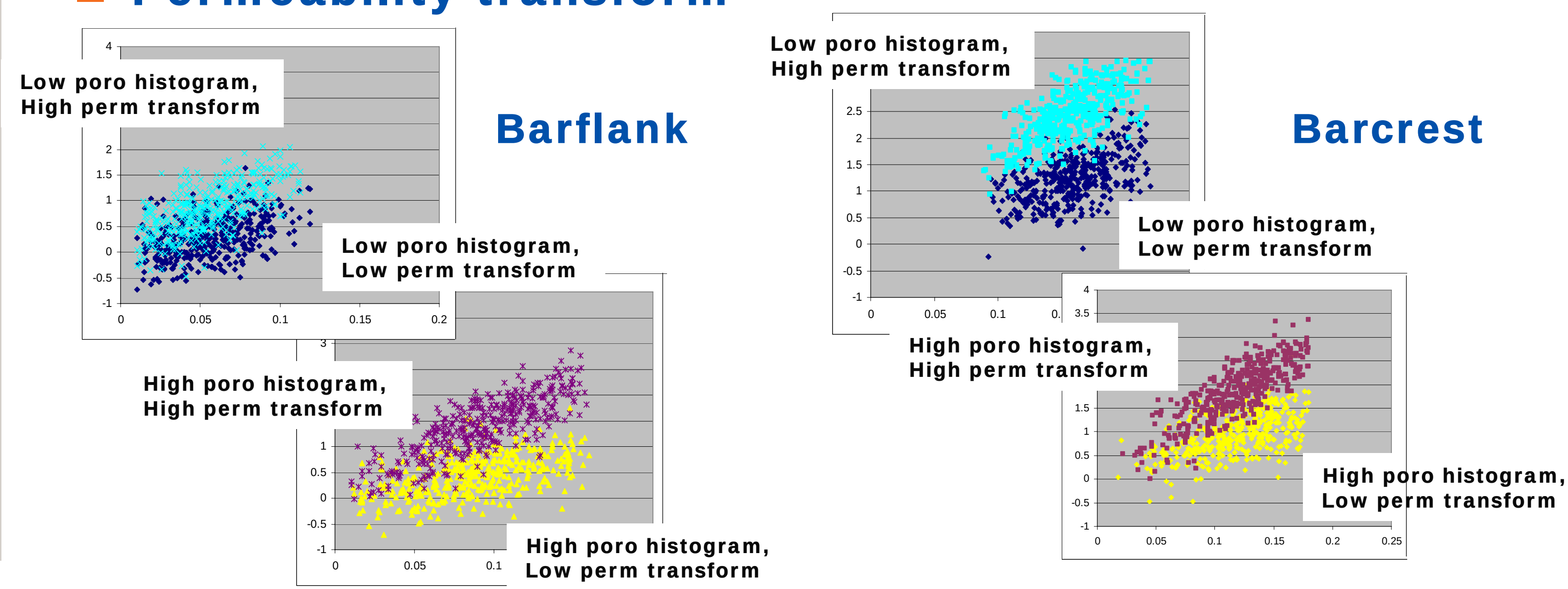
20%

Plackett-Burman Experimental Design Variables

Barflank/Barcrest Porosity histogram overlap



Permeability transform



Plackett-Burman Experimental Design Variables

- **Cyclicity**

Low case: Major breaks between reservoir facies

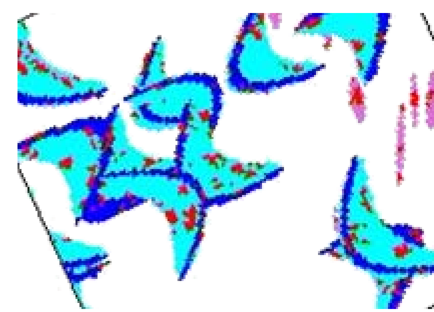
Mid case: Minor breaks between reservoir facies

High case: No breaks between reservoir facies

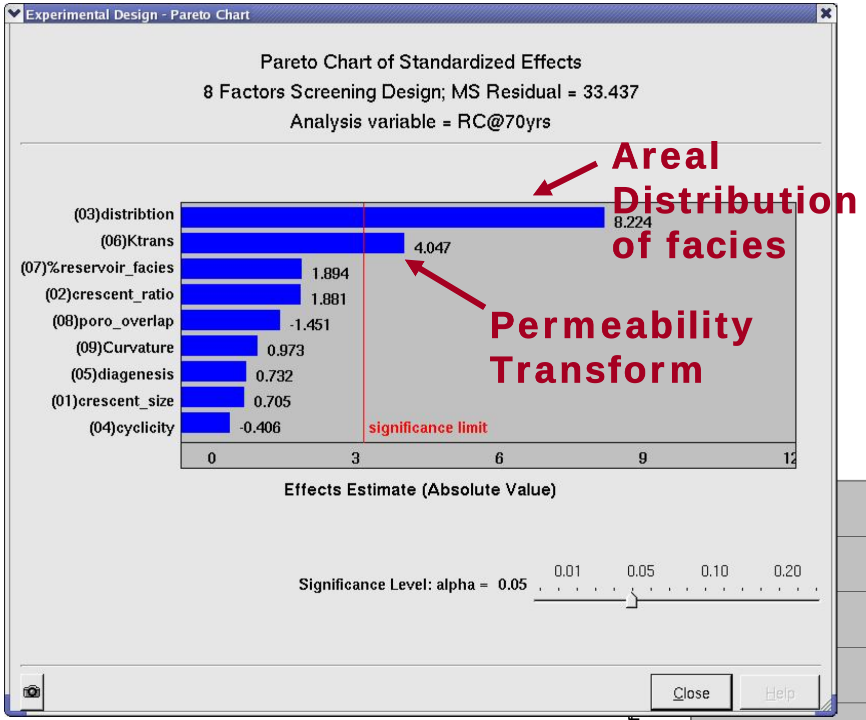
- **Diagenesis**

  Diagenetic facies stochastically distributed within reservoir facies

  - **High case:**
    - Assumed significant ***dissolution***
    - Populated with high porosity and high permeability distribution
  - **Mid case:**
    - No diagenetic overprint
  - **Low case:**
    - Assumed significant ***cementation***
    - Populated with no porosity or permeability

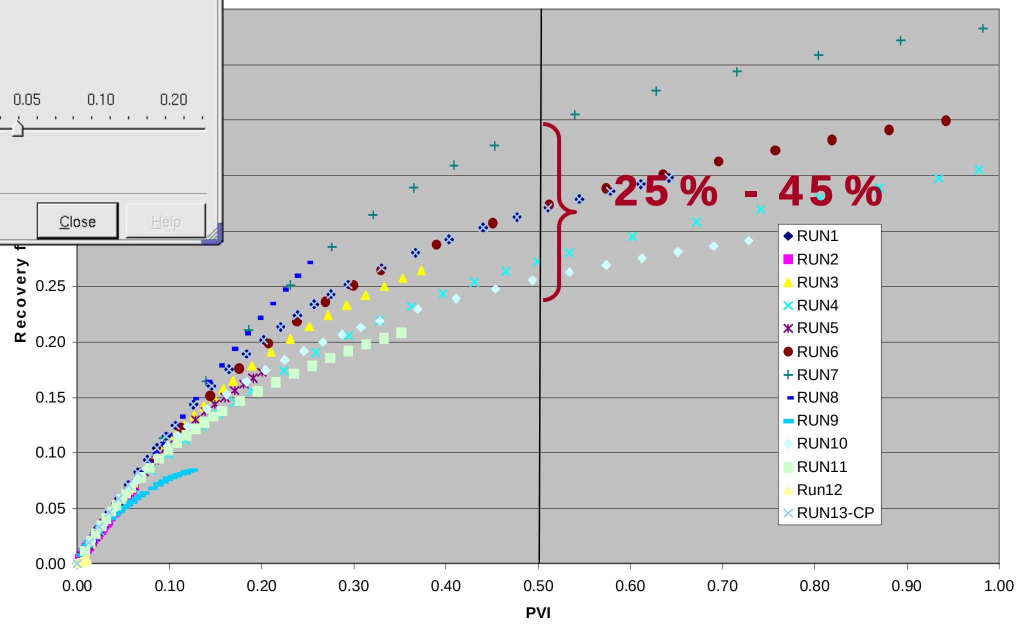


Flow Simulations Results:
Using Variable Distribution Parameter



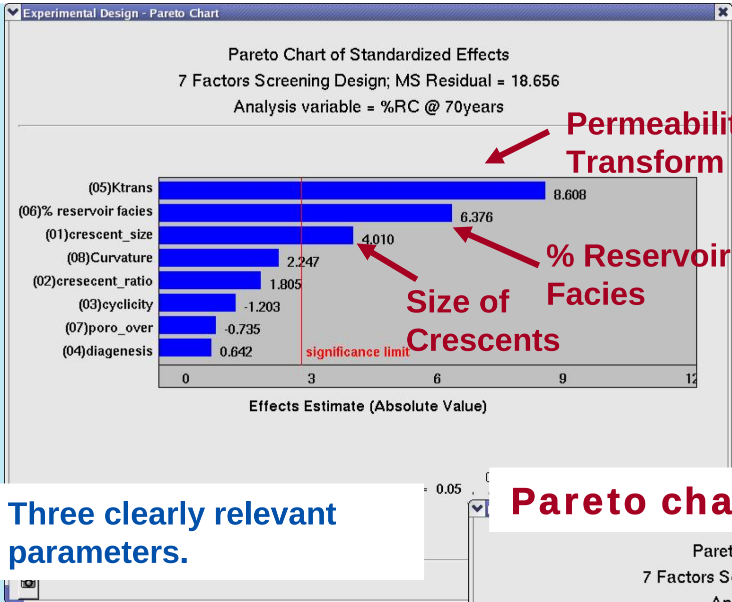
Pareto Chart of R_f@ 70yrs

Sweep Efficiency at 0.5 PVI



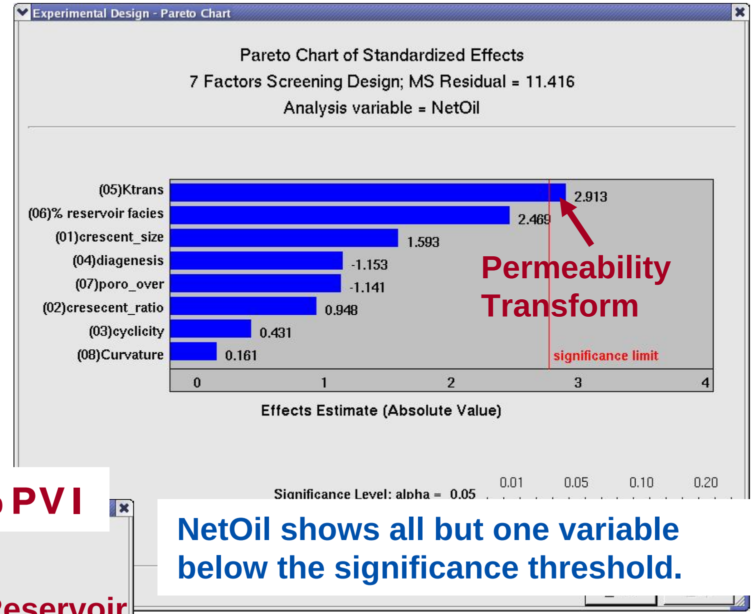
Flow Simulation Results: Rim Distribution

Pareto chart for RC @ 70 years



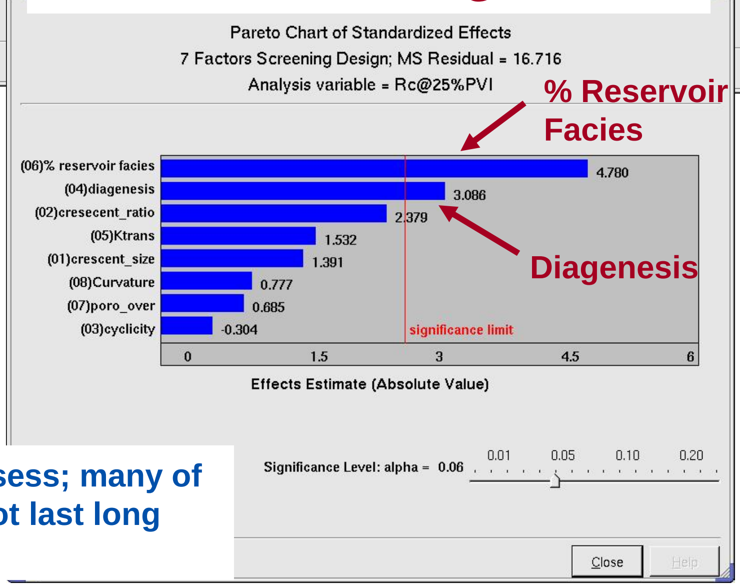
Three clearly relevant parameters.

Pareto chart for Net Oil



NetOil shows all but one variable below the significance threshold.

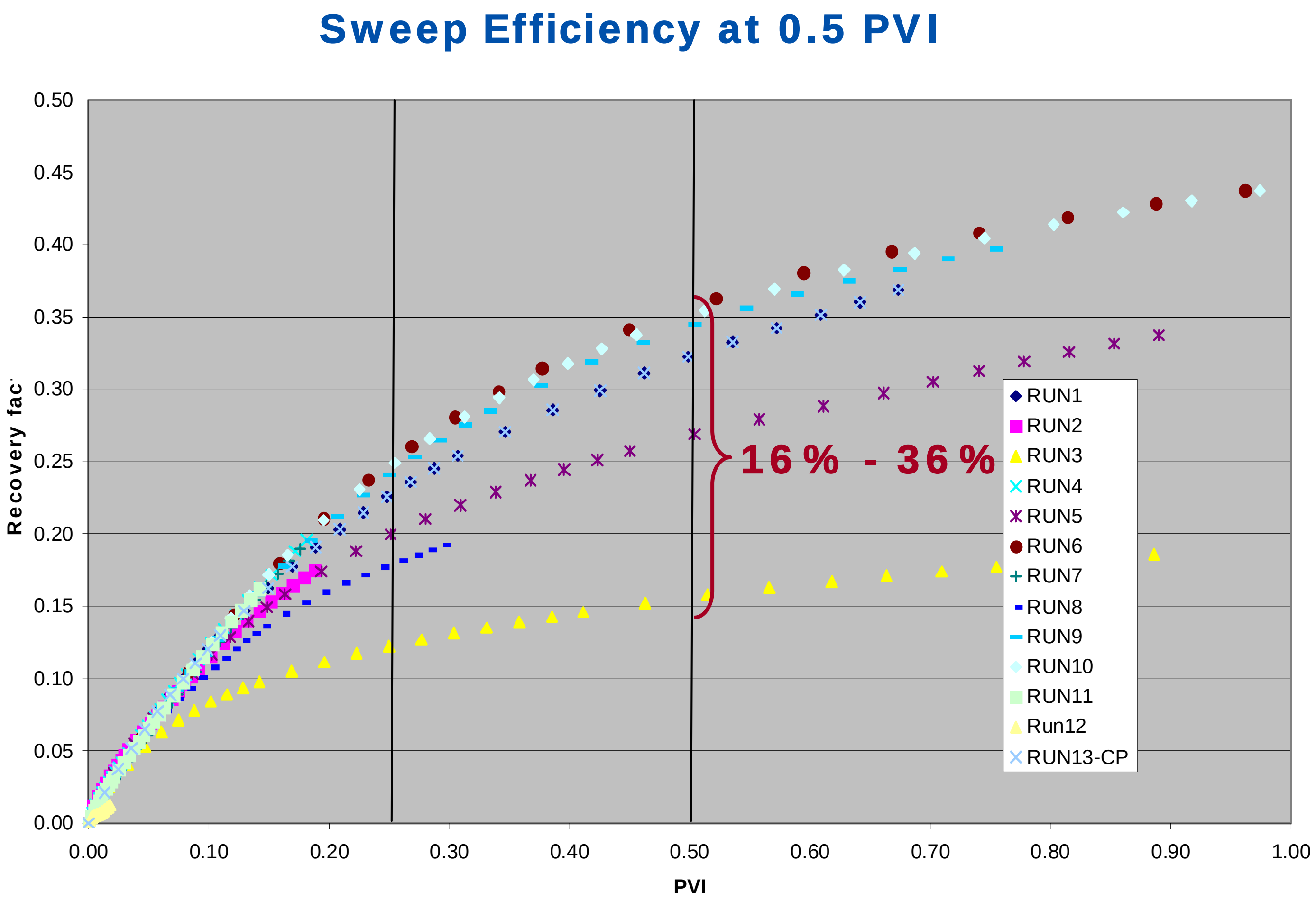
Pareto chart for RC @ 25%PVI



Difficult to assess; many of the runs do not last long enough

The permeability transform and the percent of reservoir facies consistently are the big hitters.

Flow Simulation Results: Rim Distribution



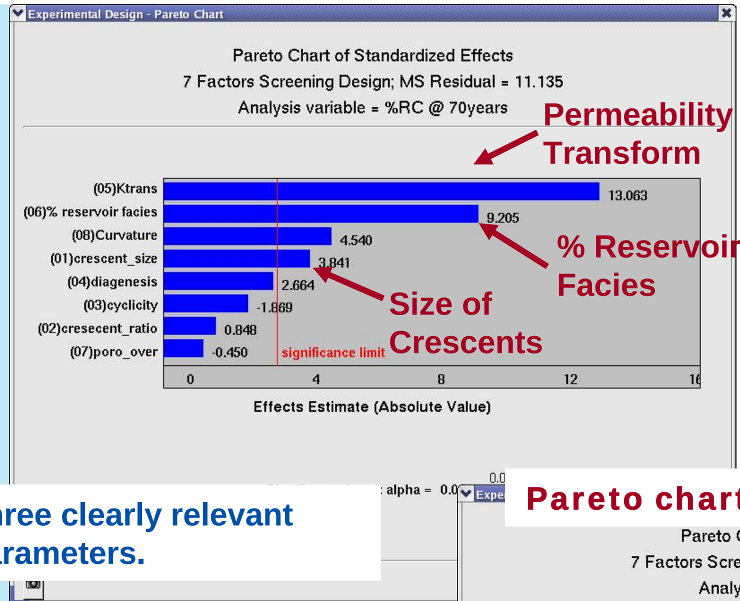
- **Huge variation in the sweep efficiency curves and this is a conservative estimate of the variation. The performance of some models is so small that the curves could not be simulated to 0.5 PVI. The actual variation is over 30% in recovery.**

Summary of Experimental Design Study

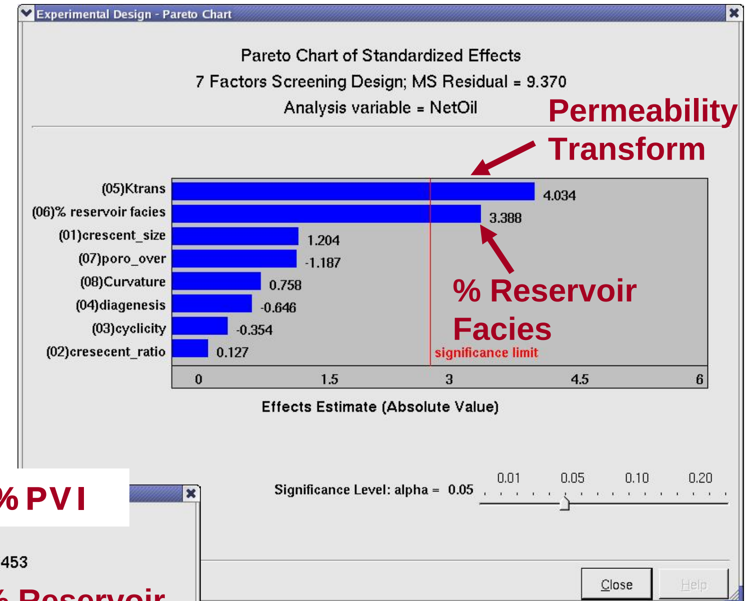
- Analyzed the effect of architectural and textural parameters on fluid flow in a synthetic grainstone-dominated carbonate platform
- Workflow used MPS/FDM to generate facies geobodies
- Areal distribution of reservoir facies shows a first-order impact on flow performance with respect to different measures of flow
- With areal distribution held constant, the most significant parameters were:
  - Absolute permeability values
  - Percent of reservoir facies
  - Size of reservoir facies geobodies
  - Ratio of barcrest to barflank facies

Flow Simulation Results: Windward Distribution

Pareto chart for RC @ 70 years

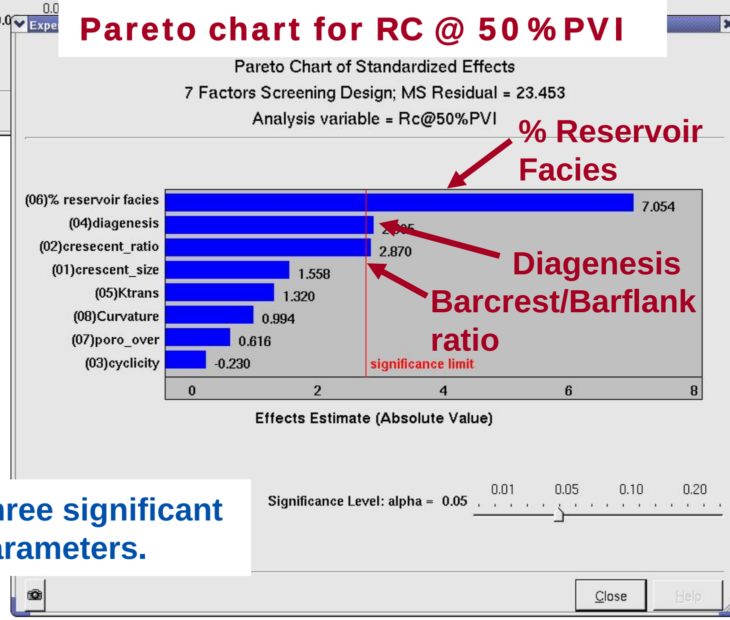


Pareto chart for Net Oil



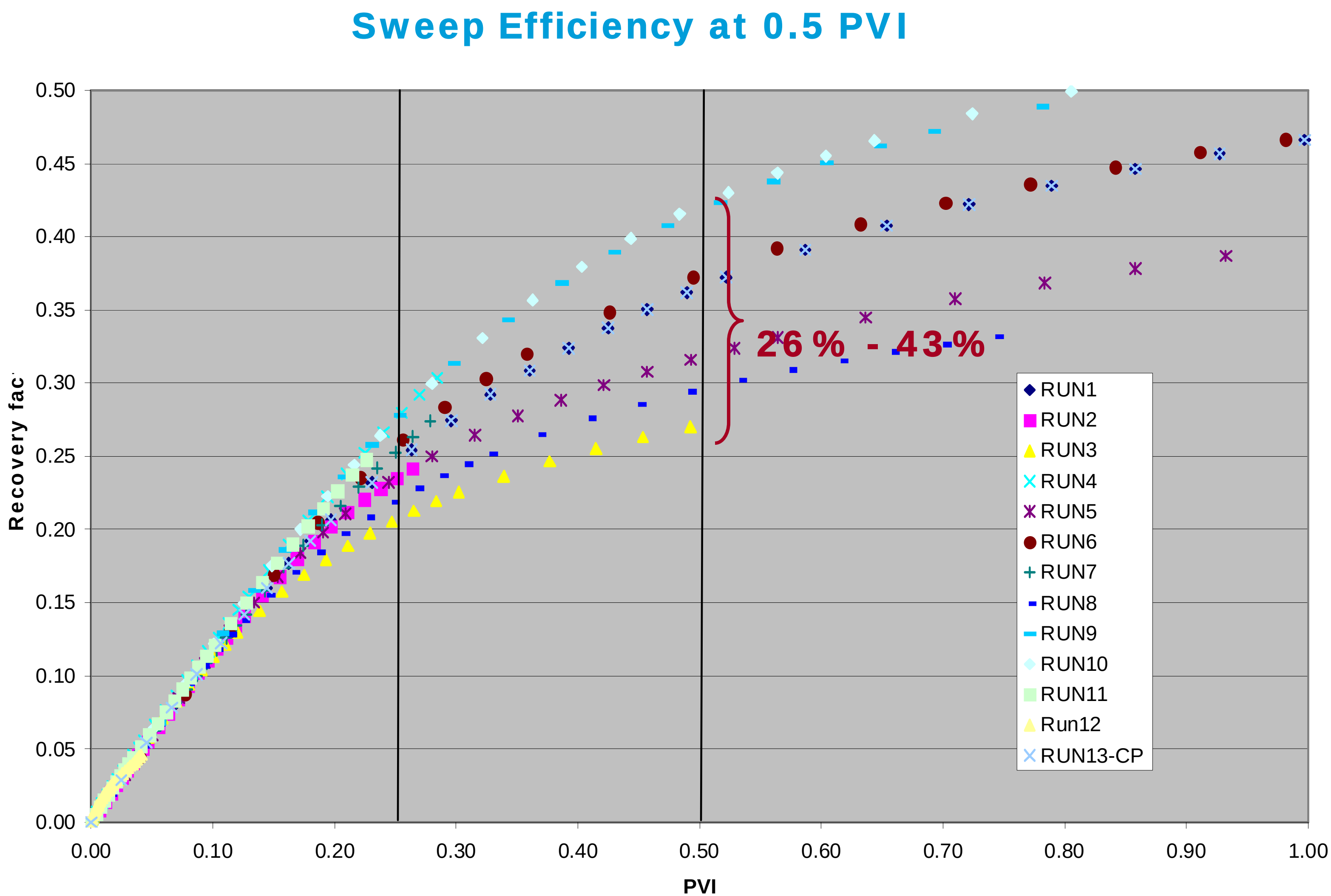
Three clearly relevant parameters.

Pareto chart for RC @ 50%PVI



Three significant parameters.

Flow Simulation Results: Windward Distribution



Again, large variation in sweep efficiency at 0.5 PVI