

Deepwater Reservoir Characterization: From Core Description to 3-D Facies Propagation and Reservoir Modeling*

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Abstract

Deepwater depositional processes result in complicated patterns of facies distribution. The physical properties of the sediments retained in each facies have significant impact on reservoir quality, connectivity, and flow deliverability. Therefore, properly describing the stratigraphic complexity, especially the architecture of various facies, is one of the key issues facing the geoscience community when tackling the tasks in reservoir characterization and modeling. This article presents a new methodology in which a number of processes are built into an integrated workflow for facies analysis and reservoir modeling. These processes include:

- outcrop analog and development of conceptual depositional models,
- whole core description and detailed facies recognition,
- Multi-Resolution Graph based Clustering (GRGC) analysis to group the detailed facies types into fewer number of facies associations,
- prediction of facies associations in uncored intervals,
- propagation of facies associations in 3D space, and
- distribution of facies-linked reservoir properties (net-to-gross, porosity, etc.) in the geological model.

The article also shows a case study in the Gulf of Mexico to delineate the workflow, and discusses some necessary details in topics related to facies analysis, grouping, and reservoir property distribution.

References

Booth, J.R., A.E. Du Vernay III, D.S. Pfeiffer, and M.J. Styzen, 2000, Sequence stratigraphic framework, depositional models, and stacking patterns of ponded and slope fan systems in the Auger Basin: Central Gulf of Mexico slope, *in* P. Weimer, R.M. Slatt, J. Coleman, N.C. Rosen, H. Nelson, A.H. Bouma, M.J. Styzen, and D.T. Lawrence, (eds.), Deep-water reservoirs of the world: Gulf Coast Section, SEPM 20th Annual Research Foundation Conference, 3-6 December 2000, Houston, Texas (CD-ROM), p. 82–103.

Bouma, A.H., 1962. Sedimentology of some Flysch Deposits: A Graphic Approach to Facies Interpretation: Elsevier, Amsterdam, 168 pp.

Groenenberg, R.M., D.M. Hodgson, A. Prelat, S.M. Luthi, and S.S. Flint, 2010, Flow-deposit interaction in submarine lobes; insights from outcrop observations and realizations of a process-based numerical model: JSR, v. 80/3, p. 252-267.

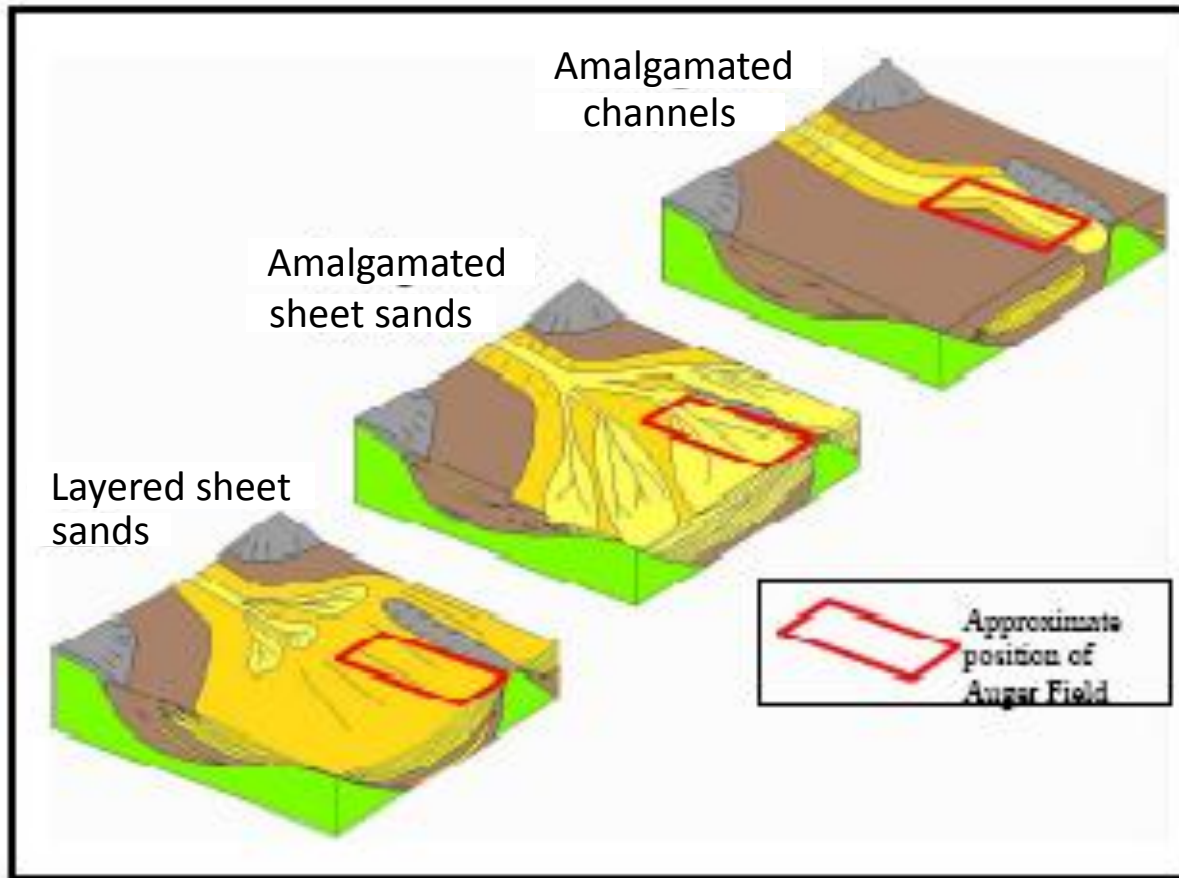
Deepwater Reservoir Characterization: From Core Description to 3D Facies Propagation and Reservoir Modeling

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Introduction

- Deepwater depositional processes result in complicated patterns of facies distribution.
 - Channel, levee, lobe, transitional, slumps. pelagic mud, etc
- The facies types, their configuration, and physical properties of the sediments retained in each facies have significant impact on reservoir quality, connectivity and flow deliverability.
- Therefore, properly describing the stratigraphic complexity, especially the architecture of various facies, is one of the key issues facing the geoscience community.
- This paper presents a new methodology in which a number of processes are built into an integrated workflow for facies analysis and reservoir modeling.

Why depositional facies are important



Modified from Booth et al, GCSSEPM, 2006

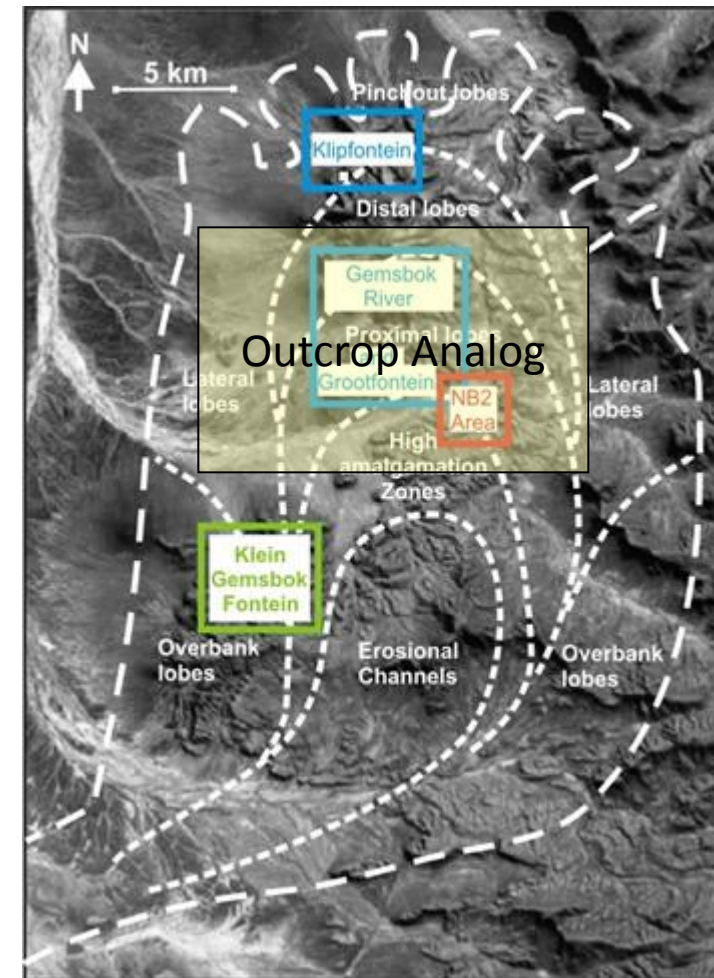
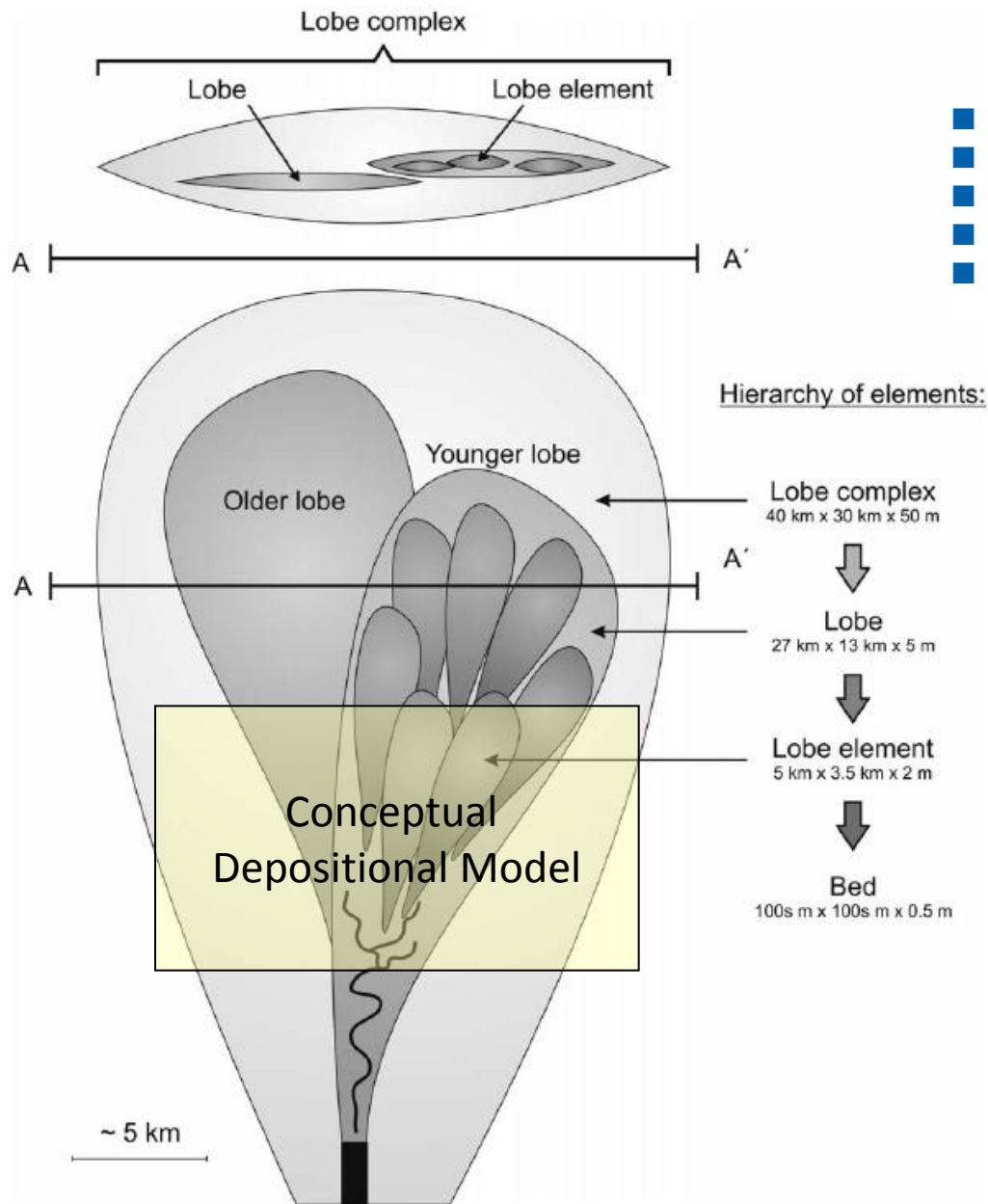
- Conceptual geological scenarios
- Design and development of reservoir model workflow
- Implication of reservoir connectivity and pore volume
- Bottom line: project economics and long-term planning

Workflow

- Outcrop analog and development of conceptual depositional models
- Whole core description and detailed facies recognition
 - Rock types
 - Facies and facies associations
- Multi-Resolution Graph-based Clustering (GRGC) analysis to group the detailed facies types into fewer numbers of facies associations (facies groups)
- Prediction of facies associations in uncored intervals using standardized logs
- Propagation of facies associations in 3D model space
 - Data and logic driven
 - QC: comparison of facies proportions in different scales
- Distribution of facies-linked reservoir properties (net-to-gross, porosity, SW and so on) in the geological model
 - Further QC: volumetric evaluation on different scenarios

Importance of Analog

- Object modeling
- Scale comparison
- Aspect ratio: width, length, and thickness
- Progradational versus retrogradational successions
- Reservoir property distribution



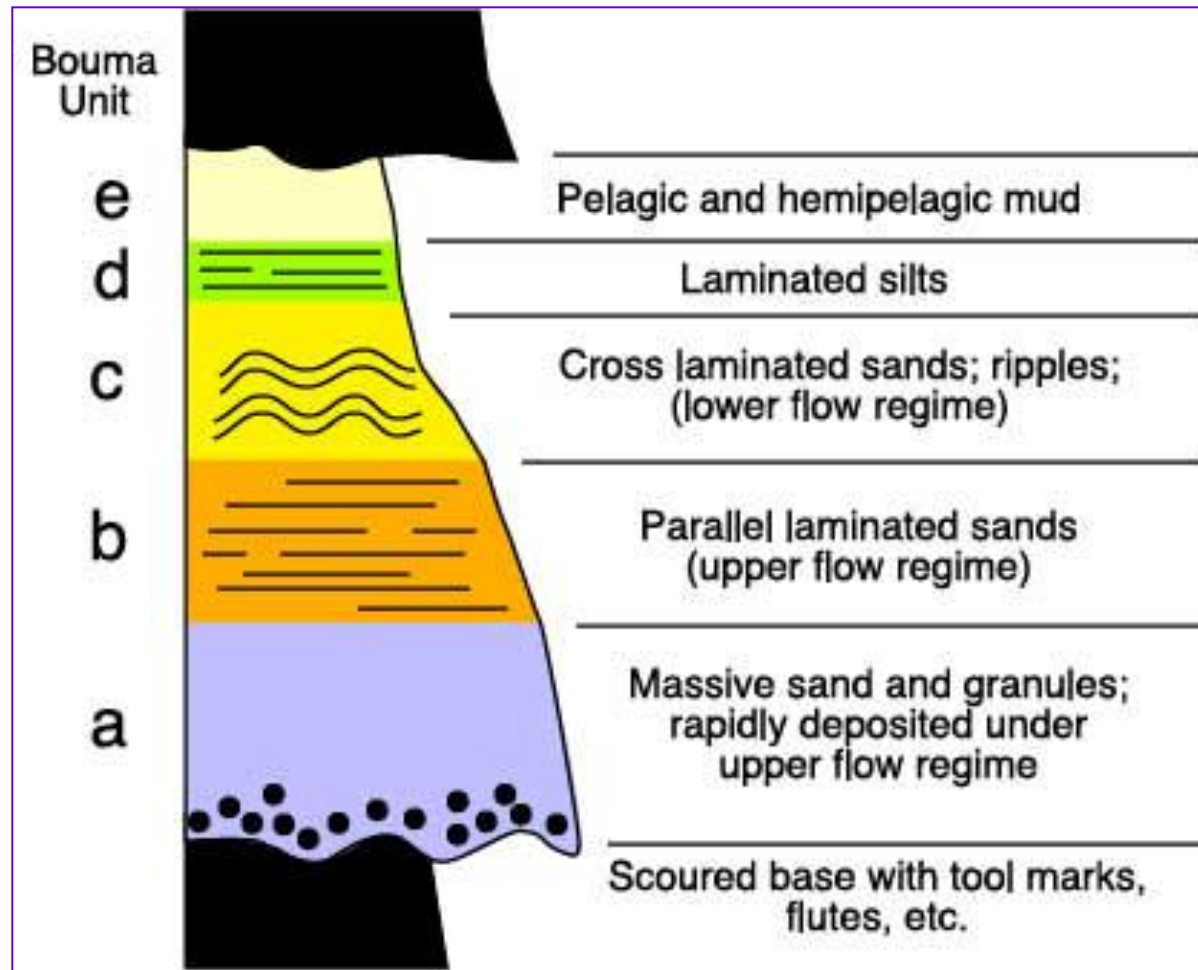
Architectural element distribution within a single aggradational zone in Fan 3.

(Modified from Groenenberg et al., 2010, J. Sedimentary Research)

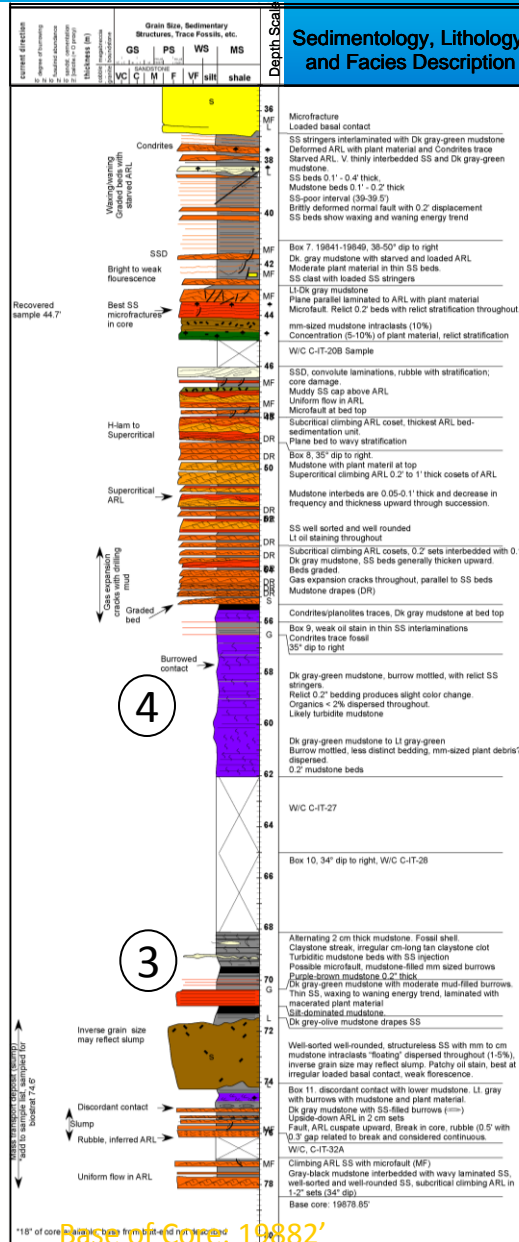
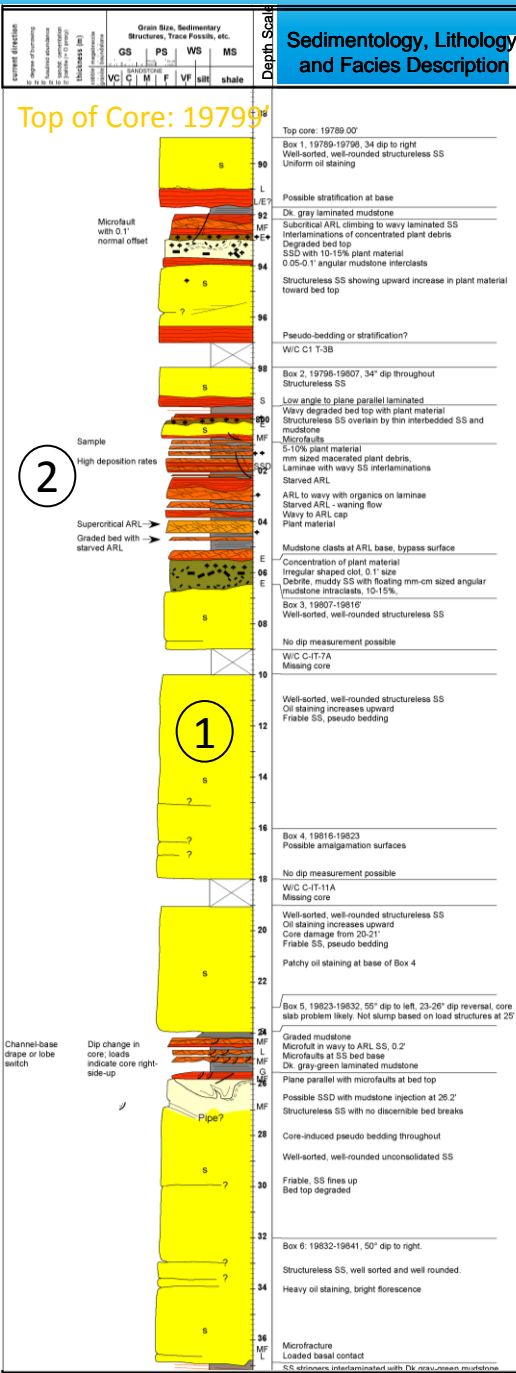
Classical Turbidite: Bouma Sequence (1962)

Recognizing Deepwater Sediment Facies Variation

- On one hand: Not all the units present in all outcrops or inferred subsurface facies profiles.
- On the other hand: One facies unit may contain multiple facies types, at least at core scale.



















Whole Core Description



- Whole core 19799-19881.62' (md) from a GOM Deepwater Well
- At least 11 rock facies can be identified.
- Four major facies categories:
 1. structureless - slightly altered sandstone, lobe center facies;
 2. laminated sandstone, lobe margin and transitional;
 3. bedded/graded mudstone, turbidite tail flows; and
 4. pelagic mudstone, *in situ* deep water shale.
- **The vertical facies successions cause vertical compartmentalization to occur. Therefore, facies recognition provides detailed information on the vertical separation of reservoir compartments.**

Explanation of Facies

- | | | | | | | | | |
|---|---|--|----|---|-----------------------------------|----|---|-----------------------------------|
| 1 |  | Clast-rich SS (>5%) | 6 |  | Sandy debris with floating clasts | 11 |  | Bioturbated sandstone |
| 2 |  | Space-stratified SS | 7 |  | Muddy debris | 12 |  | Slumped mudstone |
| 3 |  | Structureless SS | 8 |  | Plane-parallel laminated SS | 13 |  | Bioturbated mudstone |
| 4 |  | Soft-sediment deformed SS | 9 |  | Supercritical ripple-laminated SS | 14 |  | Bedded/graded mudstone |
| 5 |  | Structureless SS with floating clasts at bed tops (predominantly plant material) | 10 |  | Subcritical ripple-laminated SS | 15 |  | Lt. gray-green mudstone/claystone |
| | | | | | | 16 |  | Missing Core |

Four major facies groups for reservoir modeling purpose

Core-Log Integration

Well Log

Plane Light

UV Light

Background

Margin

Channel/Lobe Axis

Off-axis

Bouma Sequence

Bouma Unit

e

d

c

b

a

Pelagic and hemipelagic mud

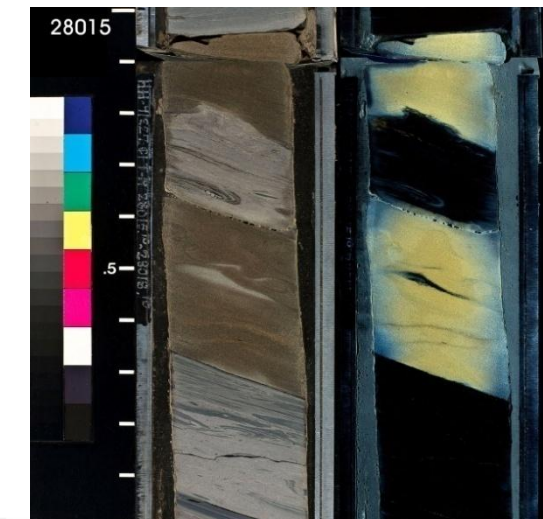
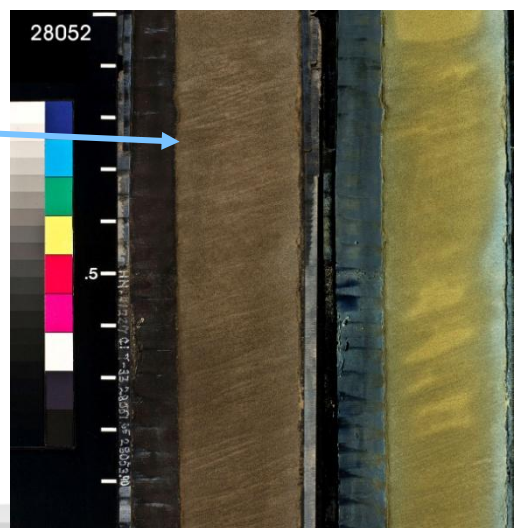
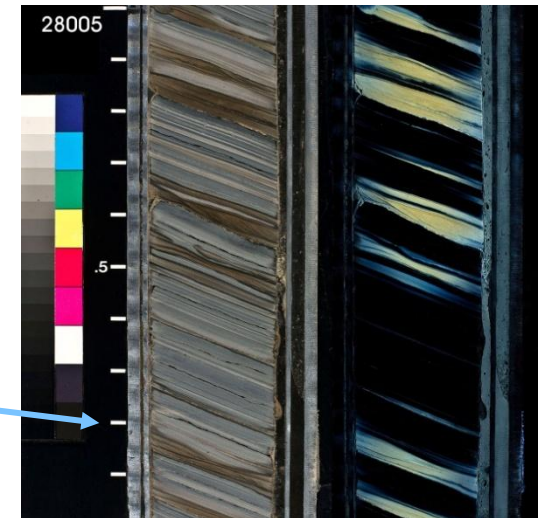
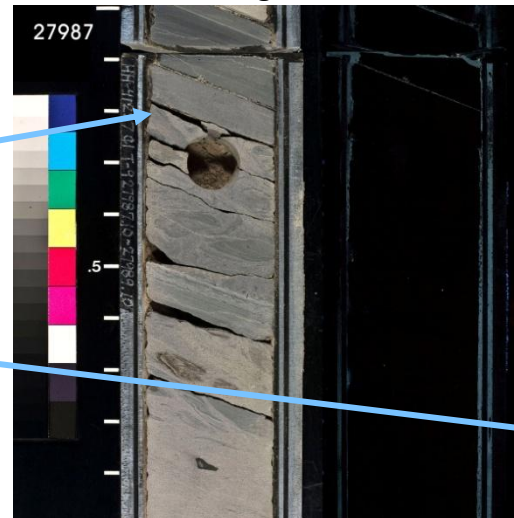
Laminated silts

Cross laminated sands; ripples;
(lower flow regime)

Parallel laminated sands
(upper flow regime)

Massive sand and granules;
rapidly deposited under
upper flow regime

Scoured base with tool marks,
flutes, etc.



Facies Analysis and Grouping Methods

■ Cluster

- Multi-Resolution Graph-Based Clustering (MRGC)
- Self Organizing Map
- Dynamic Clustering (DYN)

■ Similarity

- Similarity Threshold Method (STM)

■ Neural Network (ANN)

Benefits of MRGC method

- Required no prior knowledge of data structure
- No operation bias
- Faster against large datasets

MRGC: Selection of Model Logs and Associated Logs

(Objective: Facies types from core analysis)

MODEL LOGS
ASSOCIATED LOGS
TRAINING DATA
PROPAGATION

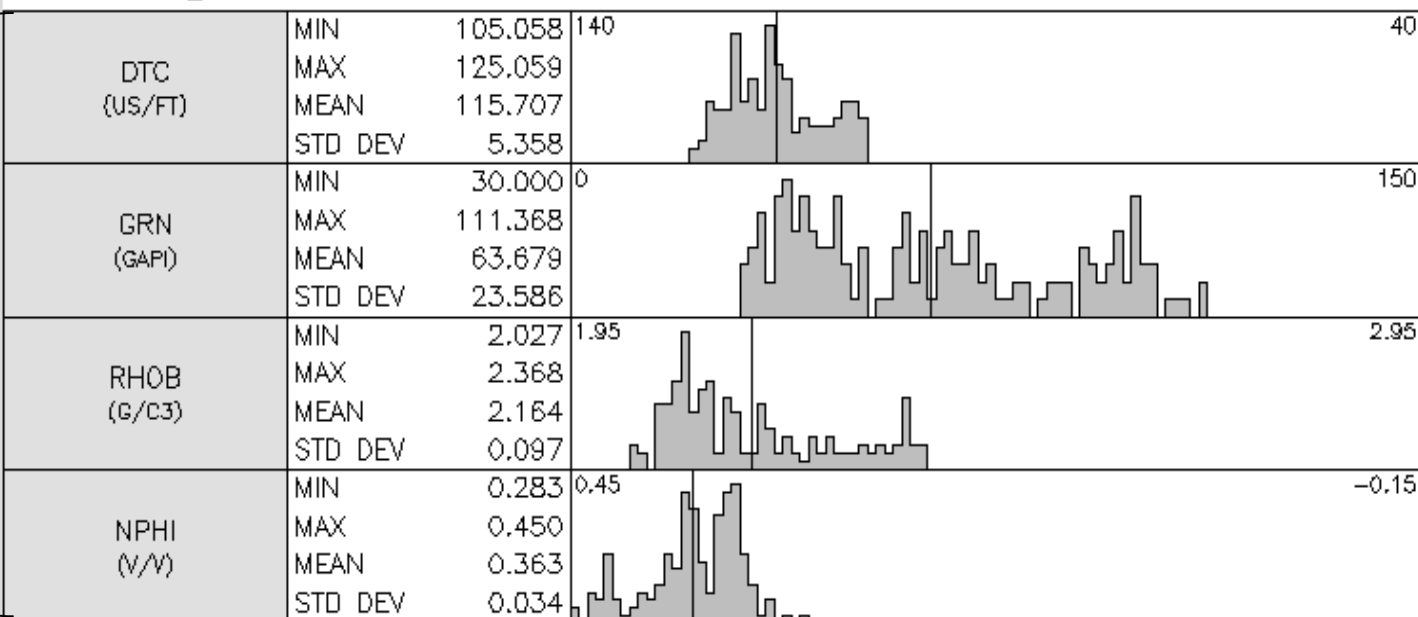
Histograms

Crossplots

165 Samples – 41 Samples outside plot limits

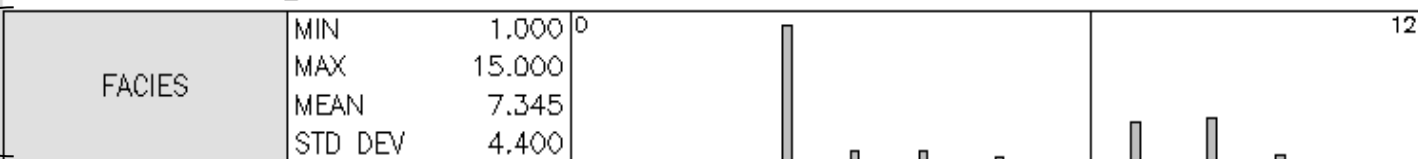
Model Logs

Logs to be
used for
prediction

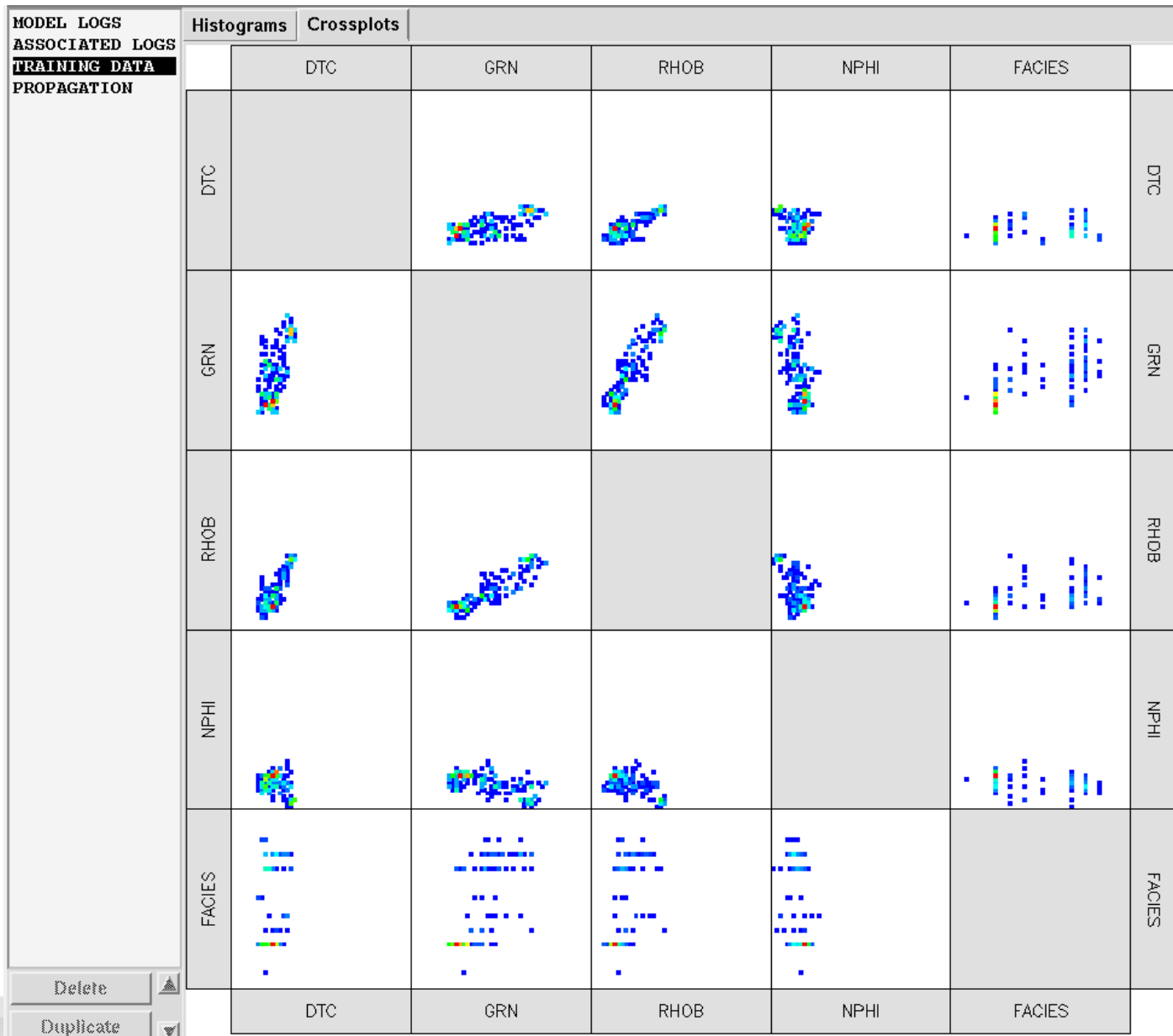


Associated Logs

Logs to be
predicted



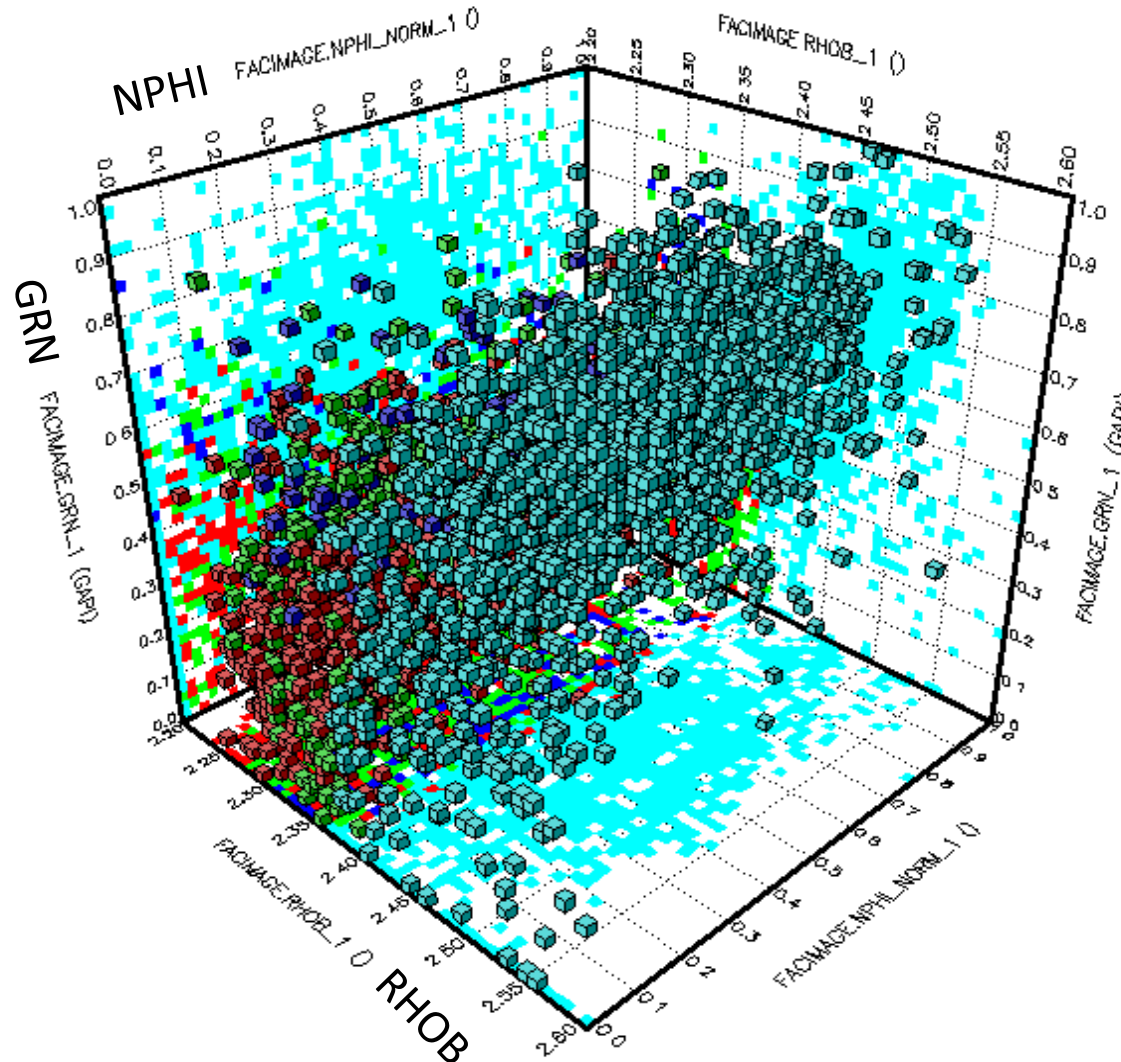
MRGC: Crossplots showing the relationships between various model logs



MRGC Method: Concepts and Models

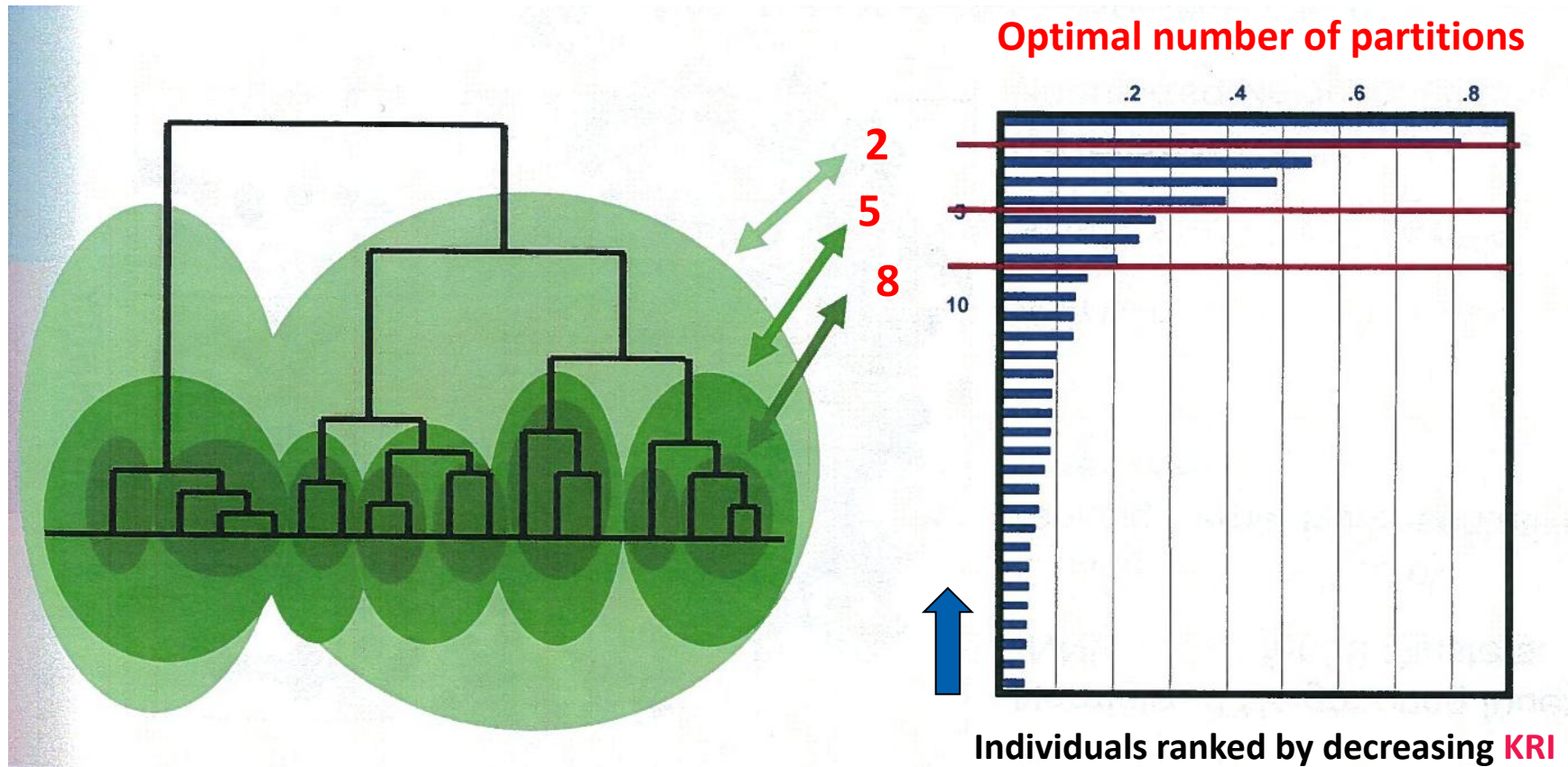
3D Cluster Distribution Based on MRGC

3451
3470



- Kernels: “Seeds”
- Attraction set: Smallest, “sub-cluster” built around a Kernel.
- KRI: Kernel Representative Index
- Clusters determined by ranking Kernel Representative Index

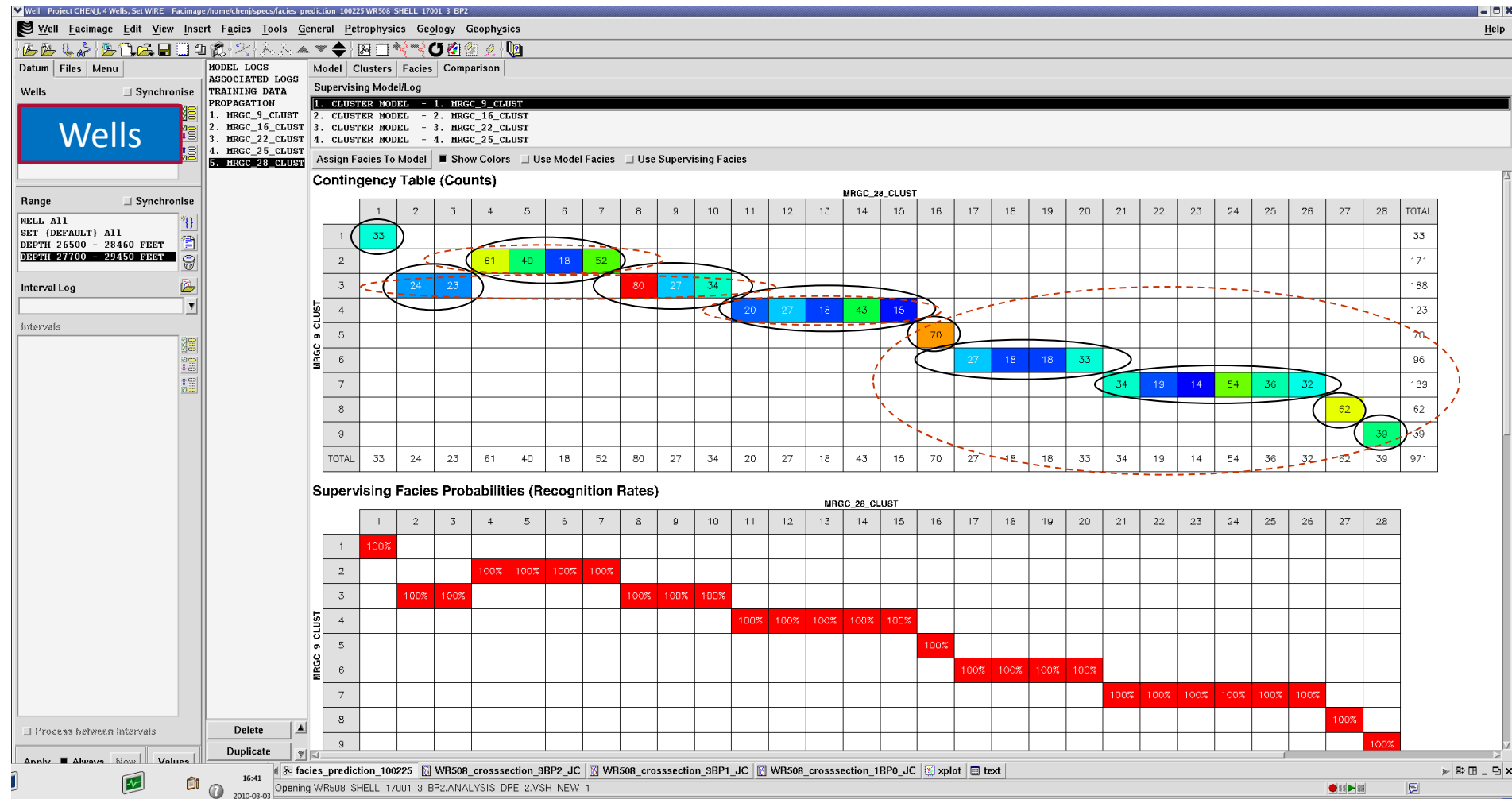
MRGC Method: Concepts and Models



Breaks at decreasing ordered KRI curve define the optimal number of partitions

(Courtesy of Paradigm)

Case Study: Facies Comparison in a 28 Clusters Model



Facies Grouping:

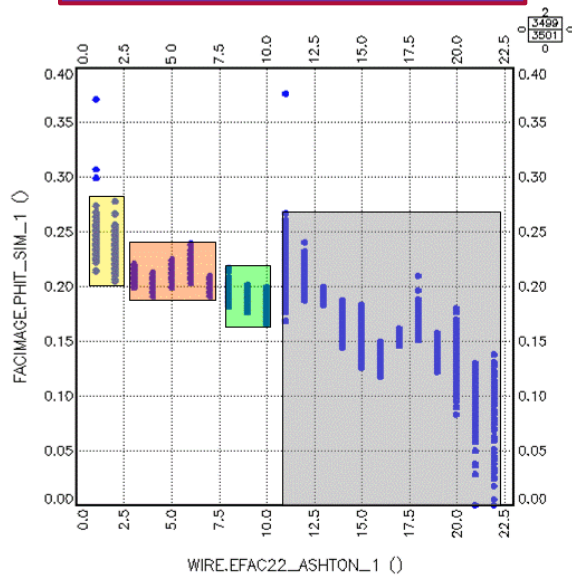
Maximum of 10 groups

Minimum of 4 groups

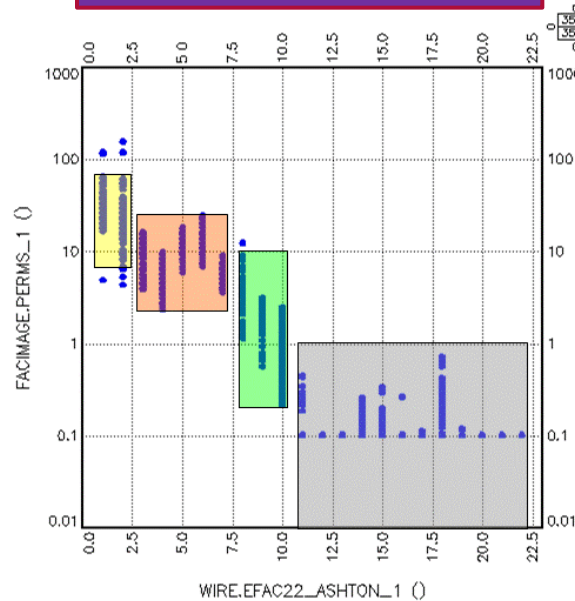
Facies Prediction and Grouping Based on Core Description

(From 22 facies to 4 facies groups)

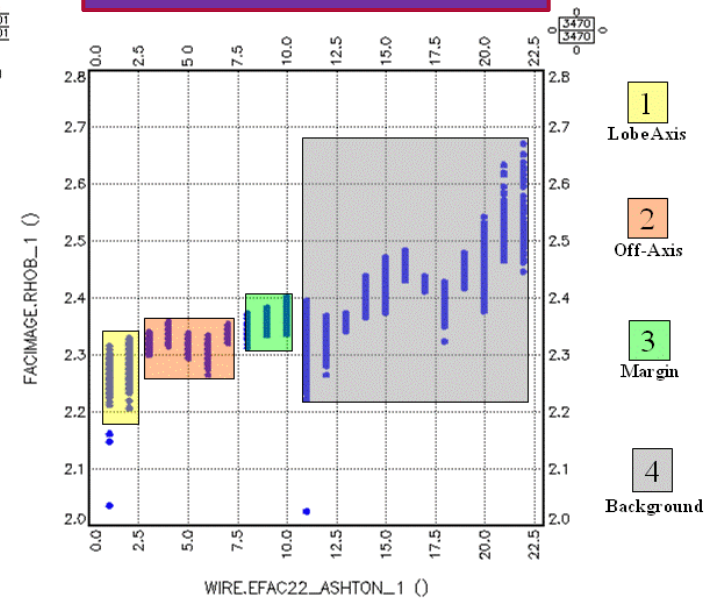
Porosity



Permeability



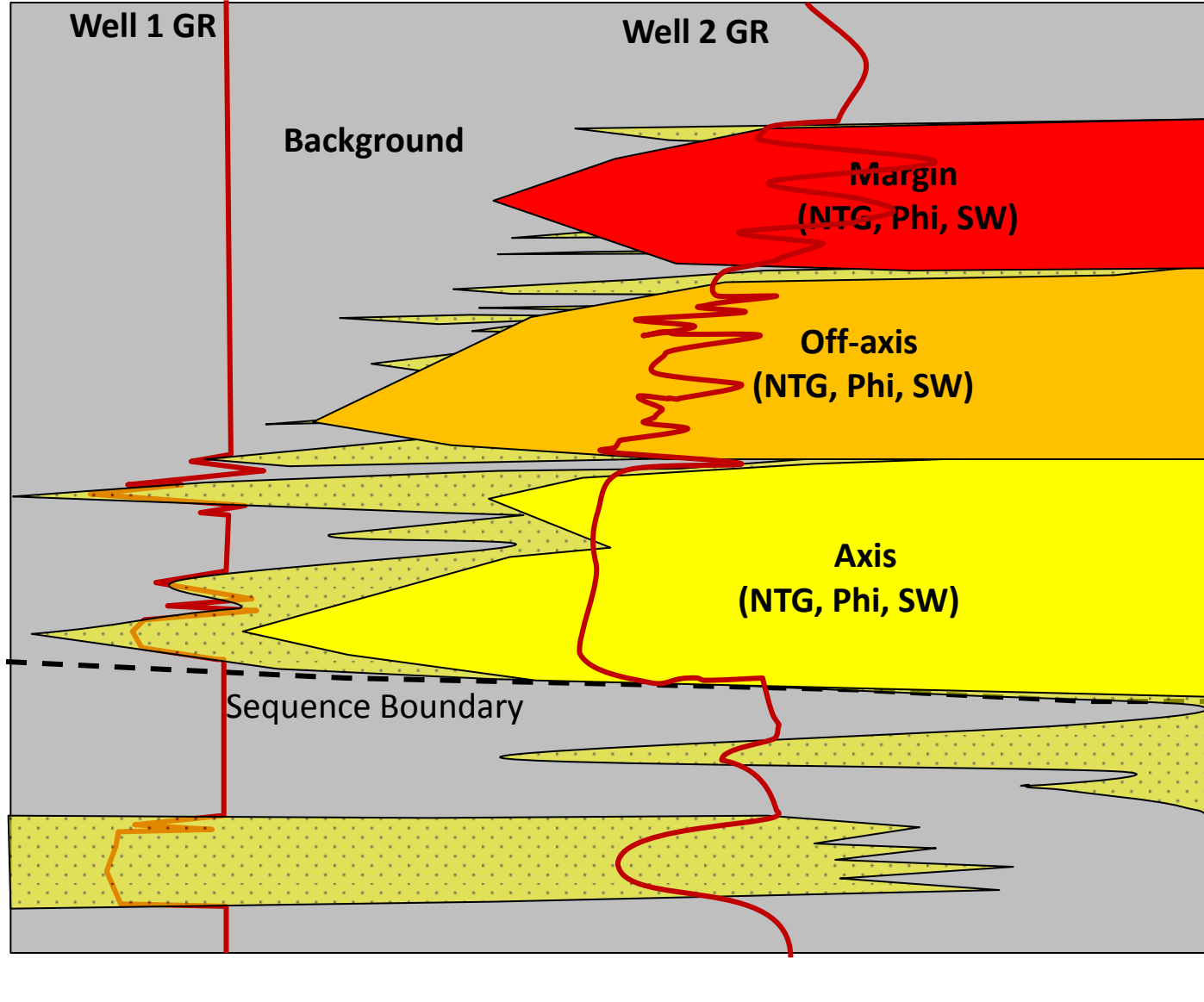
Density



Facies analysis using Facimage (Geolog plug-in)

- Conduct detailed facies analysis from core description (sedimentology / stratigraphy/ depositional environment).
- Define **training data set** and **associated logs** which are to be predicted
- Predict facies and then group the facies into meaningful facies sets.

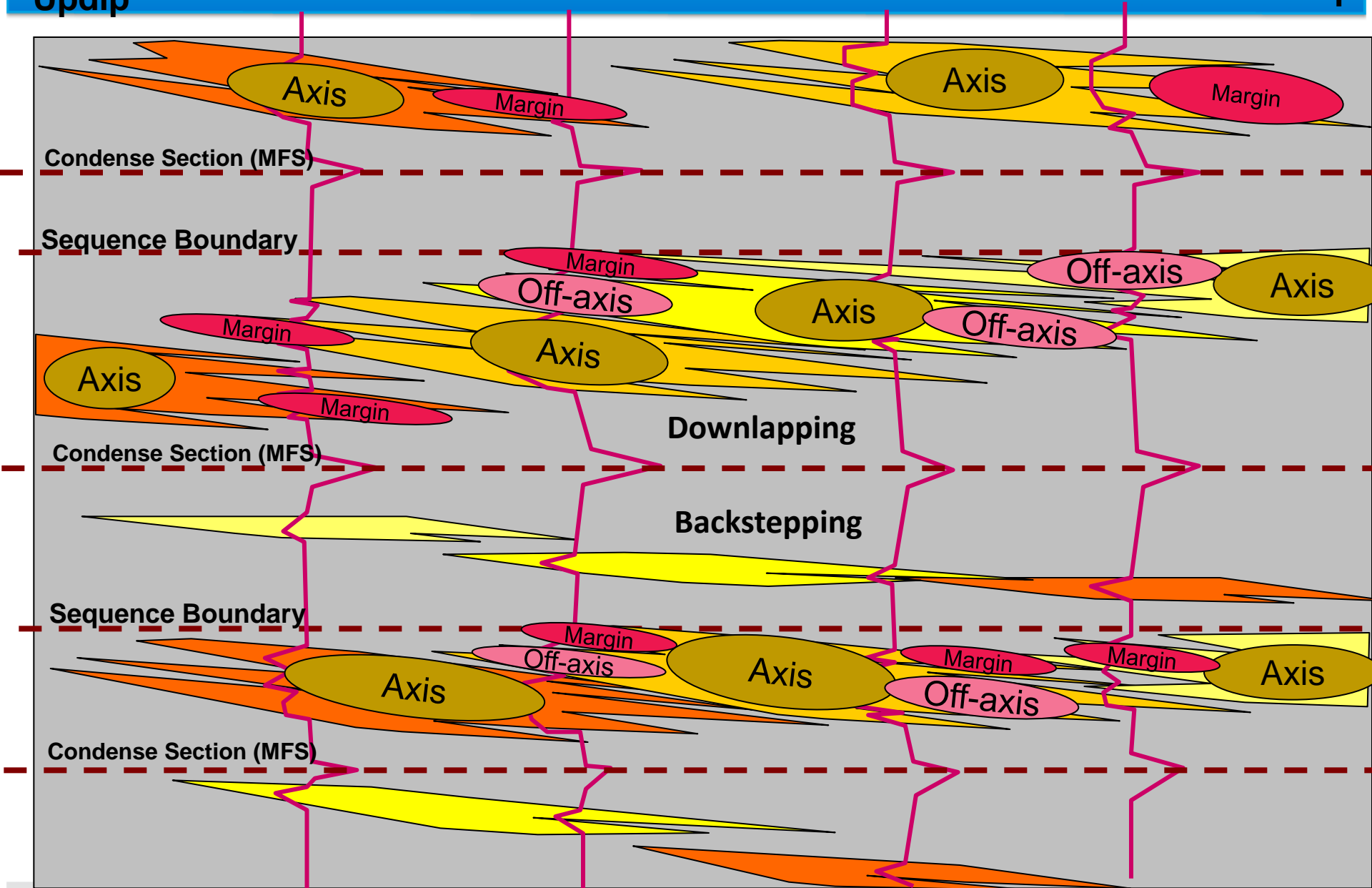
Facies = Depositional Environment + Rock Type + Properties



- The concept of facies
- Environmental setting
- The materials with the context
- The properties of the materials
- Reflection of facies in well logs, outcrop and subsurface

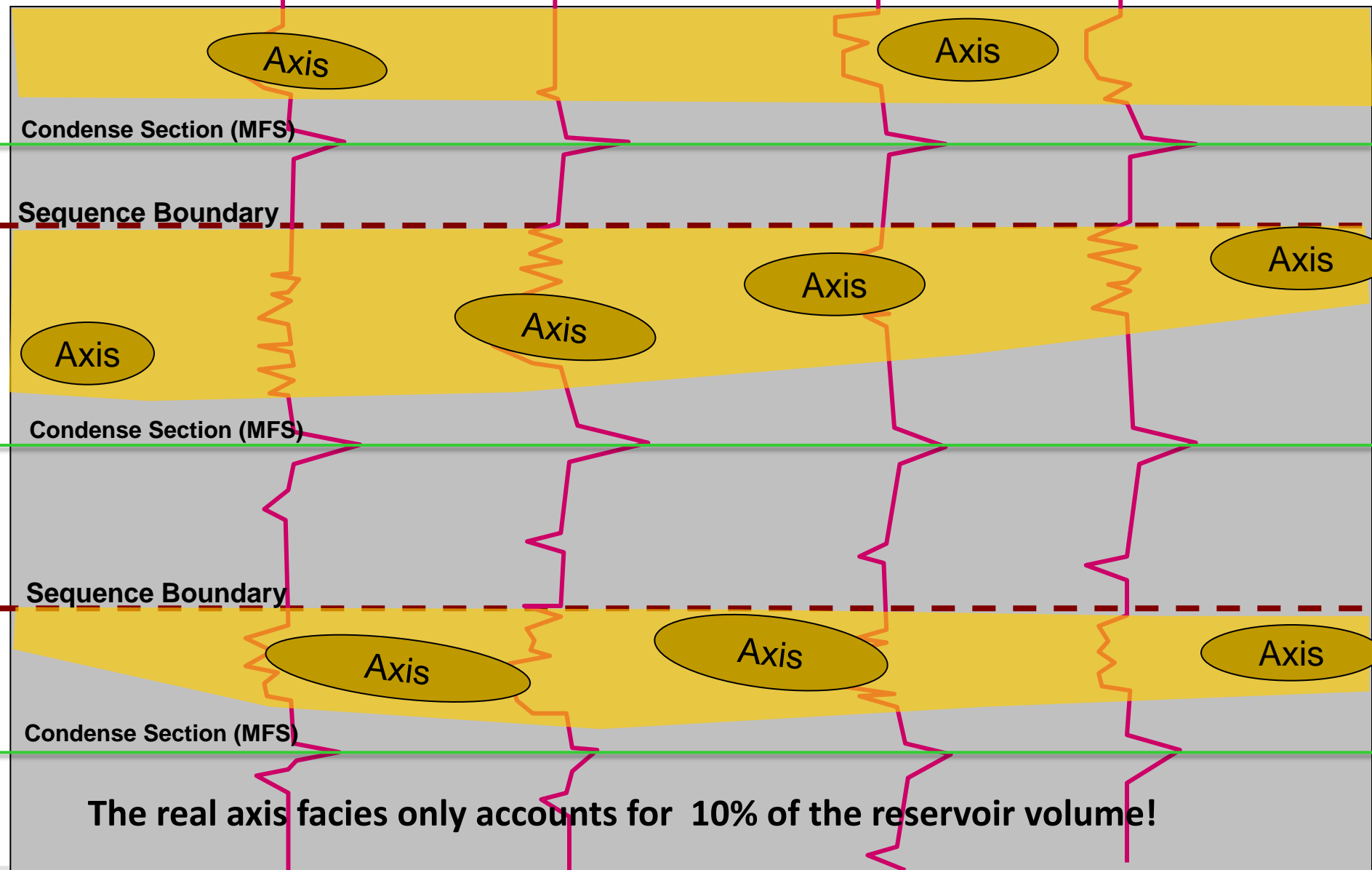
Sand Body Distribution in A Conceptual Deep Water Setting

Updip GR W1 GR W2 GR W3 GR W4 Downdip



Sand Body Distribution in A Conceptual Deep Water Setting

Updip GR W1 GR W2 GR W3 GR W4 Downdip



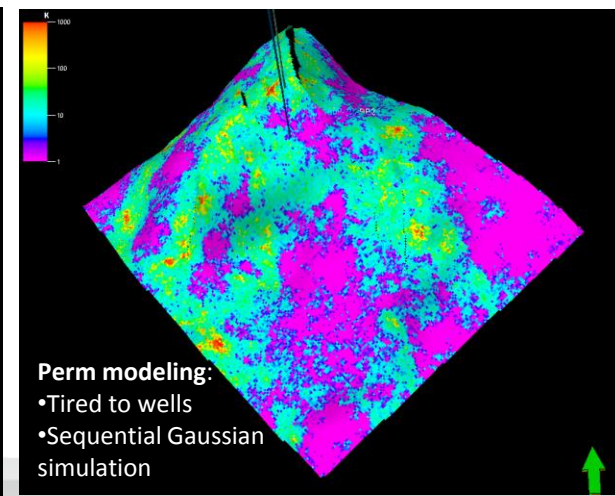
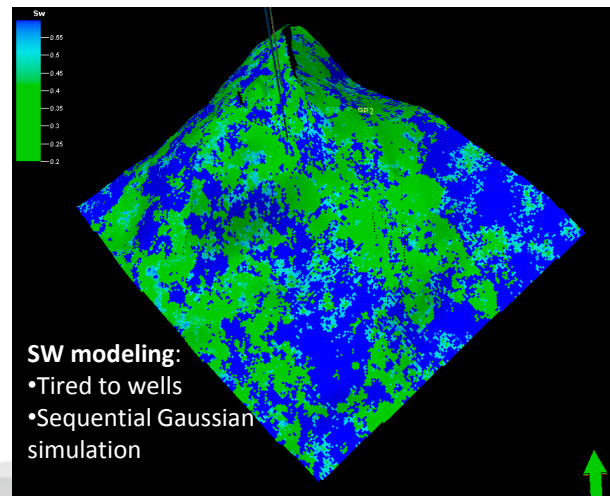
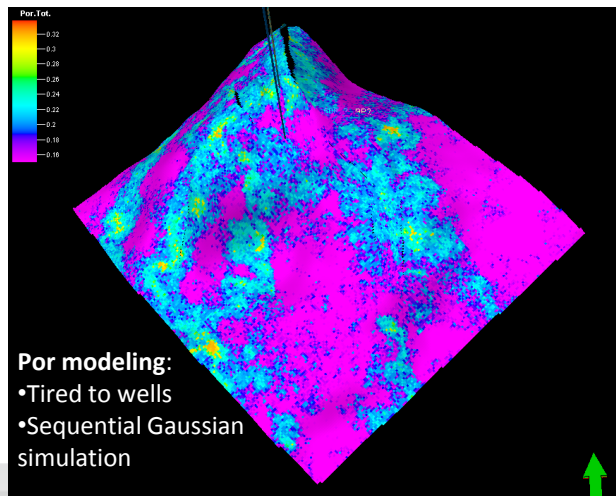
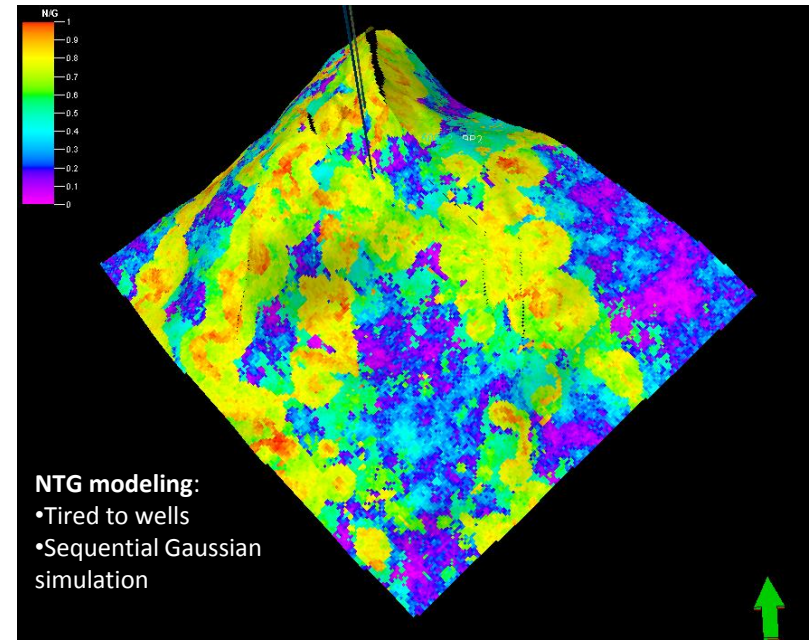
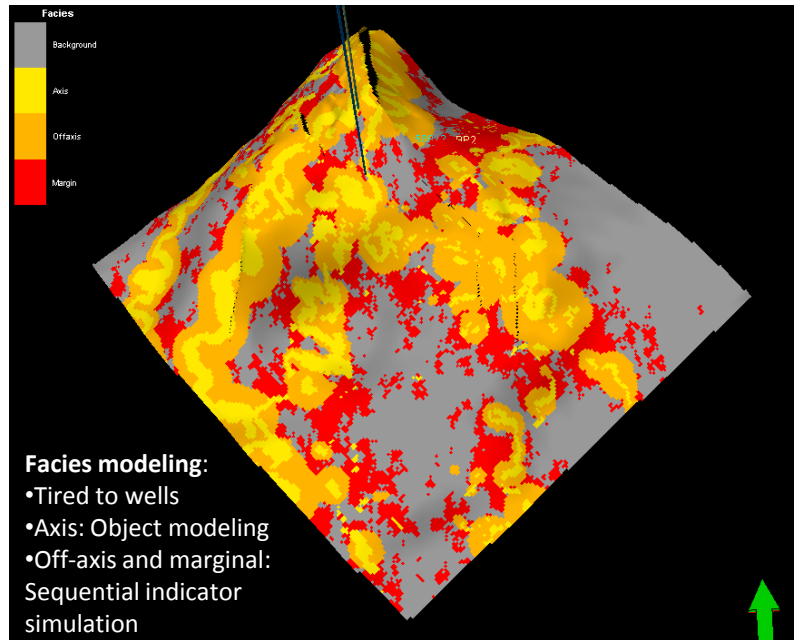
Robust Facies Modeling Results in More Accurate Definition of Reservoir Architecture

- Failure to recognize facies assemblages results in oversimplification of reservoir architecture
- Reservoir model built unrealistically increases total volume of sand
- Additional impact if NTG is not applied
- Sands that are not connected are considered connected
- Cause unexpected write-down later during field operation

Log Preparation

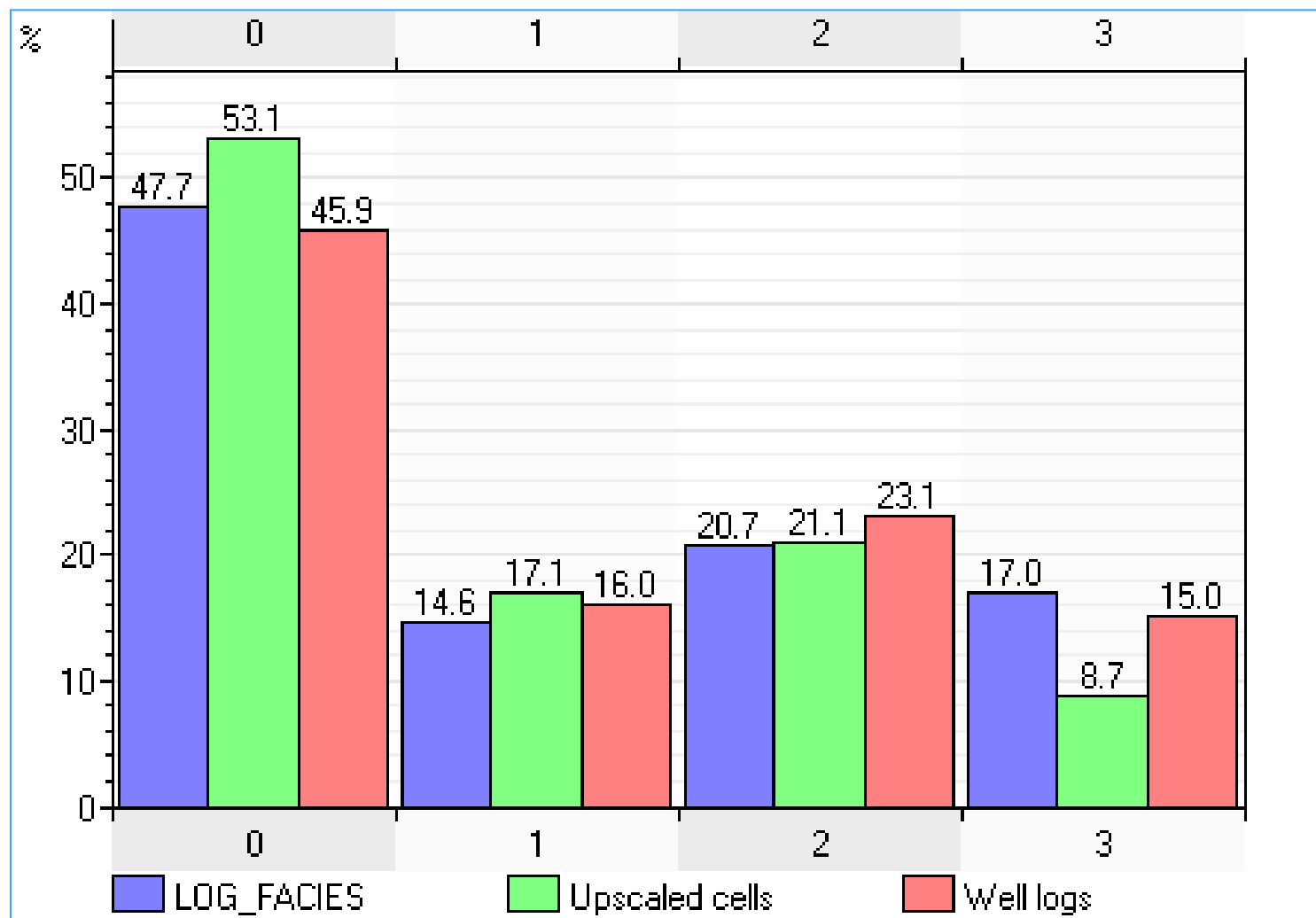
- Model Logs: the logs Facimage will use to perform the facies prediction
- Associated Logs: Example logs which are to be predicted
- Training Data: All or some of the model logs and associated logs. Should be a good representation of the data in order to obtain credible predictions
- Wells must contain the same logs – model logs and associated logs must have the same name.
- Logs must be put into the same set.
- Well and depth intervals for prediction must be specified.

Propagating Facies in 3D Model and Distributing Facies-linked Reservoir Properties



QC: Results of Facies Modeling

Comparison of Model and Well Facies Distribution



Conclusion: Business Case for Facies Prediction

- Both in-place volume and connectivity are facies driven
- Have a geological framework model that needs to be propagated with facies distribution
 - No seismic: object modeling for reasonable stochastic analysis (trend and body ratio based on knowledge)
 - With seismic: object modeling driven by seismic trend (AI, PI, etc.)
- Have whole core intervals that have been studied depositional facies in detail
- Have decent log suite that can be used to compare with core studies

Needed for building a Reservoir Model
Needed for reserve distribution

Conclusion: Predicting Deep-Water Depositional Facies

- Stochastic evaluation of total resource size for any reservoirs requires propagation of depositional facies throughout the static reservoir model.
- Object facies modeling technique can be reasonably applied using industrial software packages like Petrel.
- The key issue is to predict depositional facies using well log data and based on detailed whole core description.
- The detailed facies types from core description can be simplified into a few facies associations that satisfy the need for reservoir modeling.
- Facies prediction combining cores and log data makes the distribution of depositional facies in area beyond the cored intervals possible, with or without seismic control.