MicroModelling in a Complex Shaly Sand Reservoir: A Case Study in Greater Burgan Field, Kuwait*

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Search and Discovery Article #51246 (2016)**
Posted April 18, 2016

*Adapted from oral presentation given at AAPG/SEG International Conference & Exhibition, Melbourne, Australia, September 13-16, 2015

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Abstract

Heterogeneity within the Cretaceous Upper Burgan sands was observed at multiple scales. MicroModelling for two different depositional environments i.e. Bay and Tidal Flat containing heteroliths were attempted. Objective of the work was to characterize this reservoir heterogeneity and analyze its impact on permeability tensor in the reservoir. The Bay MicroModel was constructed at the grid scale whereas the Tidal flat model was developed at whole core scale. The Bay MicroModel had its dimension limited to 100m x 100m x 3.5ft with a cell increment of 1m. The Tidal Flat MicroModel was developed using a slabbed core image 4 × 8 inches in size which was interpreted for bed forms and facies classification. The facies classified from high resolution core interpretation as well as borehole image were incorporated into the modeling software. For the Tidal Flat MicroModel, additional high resolution core mini-permeameter data were also integrated. Streamline simulation was used to compute the equivalent permeability in the longitudinal, traverse, and vertical directions. A pressure gradient was imposed in each direction at a time by keeping closed boundaries in the other two. From the total flow, the equivalent permeability was back calculated and permeability anisotropy ratios were computed. The MicroModelling simulation results were compared with analog reservoir information, core plug Kv/Kh data and statistical estimators from high resolution mini-permeameter grid. The permeability anisotropy ratios derived from the MicroModelling exercise were input into larger simulation models of areas of the Greater Burgan Field.

References Cited

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AAPG SEG International Conference & Exhibition 2015
13-16 September • Melbourne, Australia
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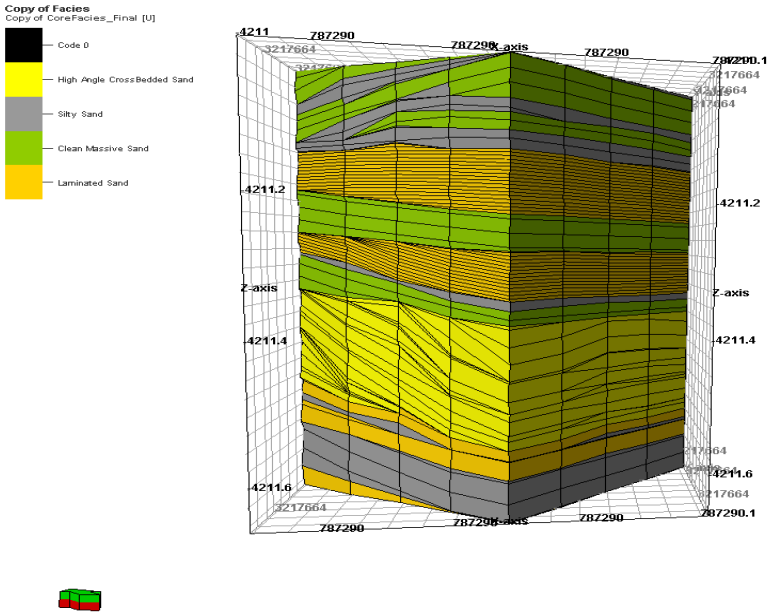
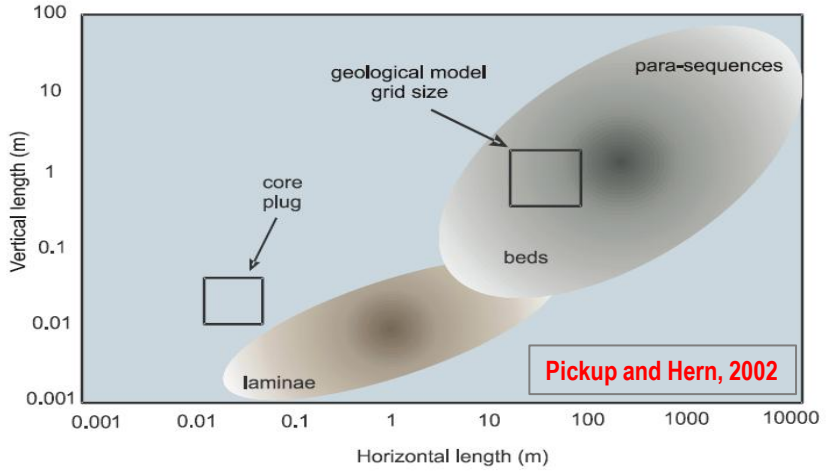
Schlumberger

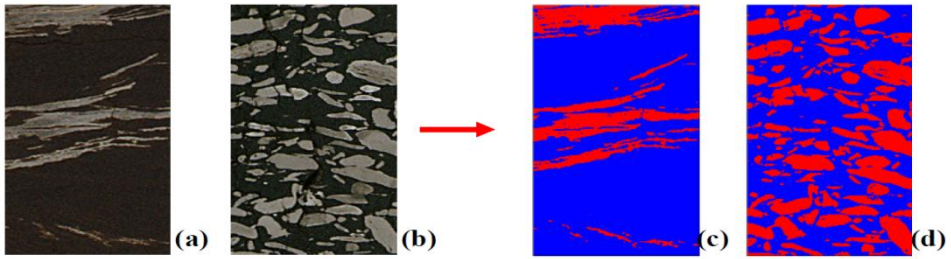
Outline

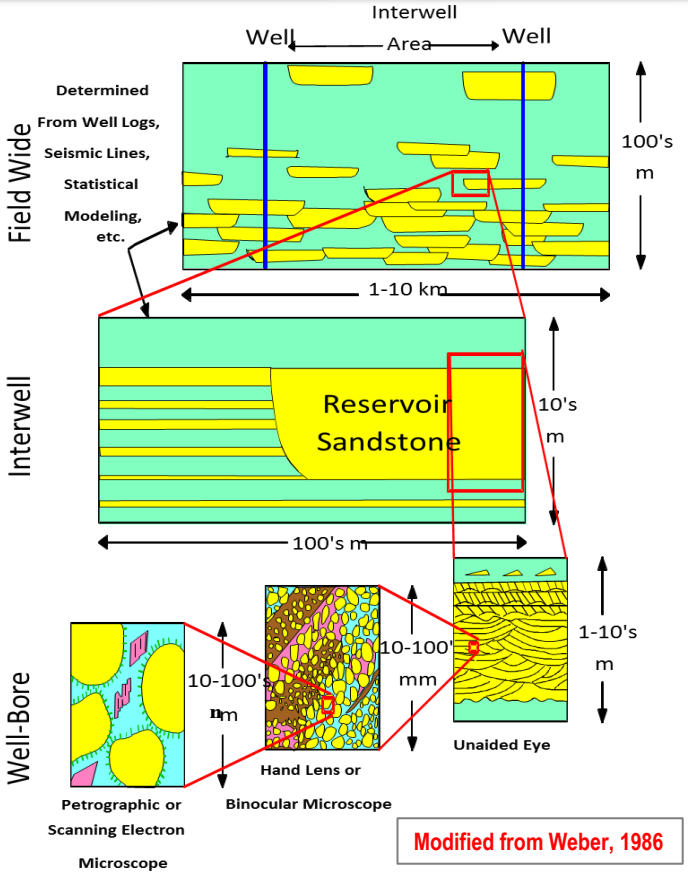
- Introduction
- Burgan Sequence Stratigraphy
- Micro-Modeling and Simulations
  - Tidal Flat depositional facies
  - Bay Shales depositional facies
- Core plugs & Kv/Kh summary
- Implementation in pilot sector
- Conclusions



Scales of Geological Reservoir Heterogeneity

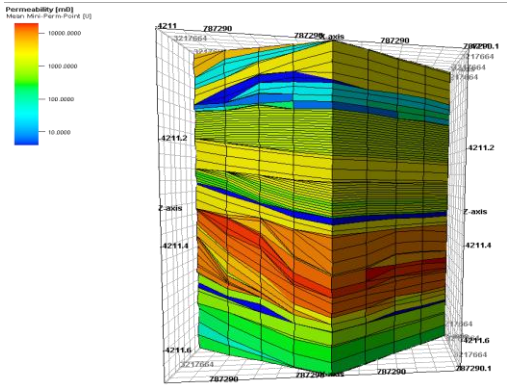


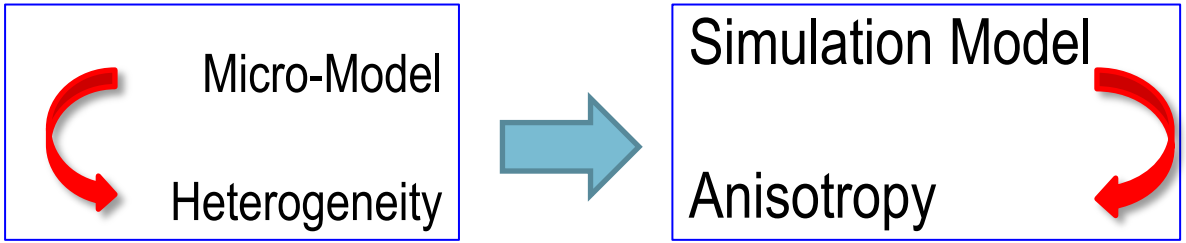




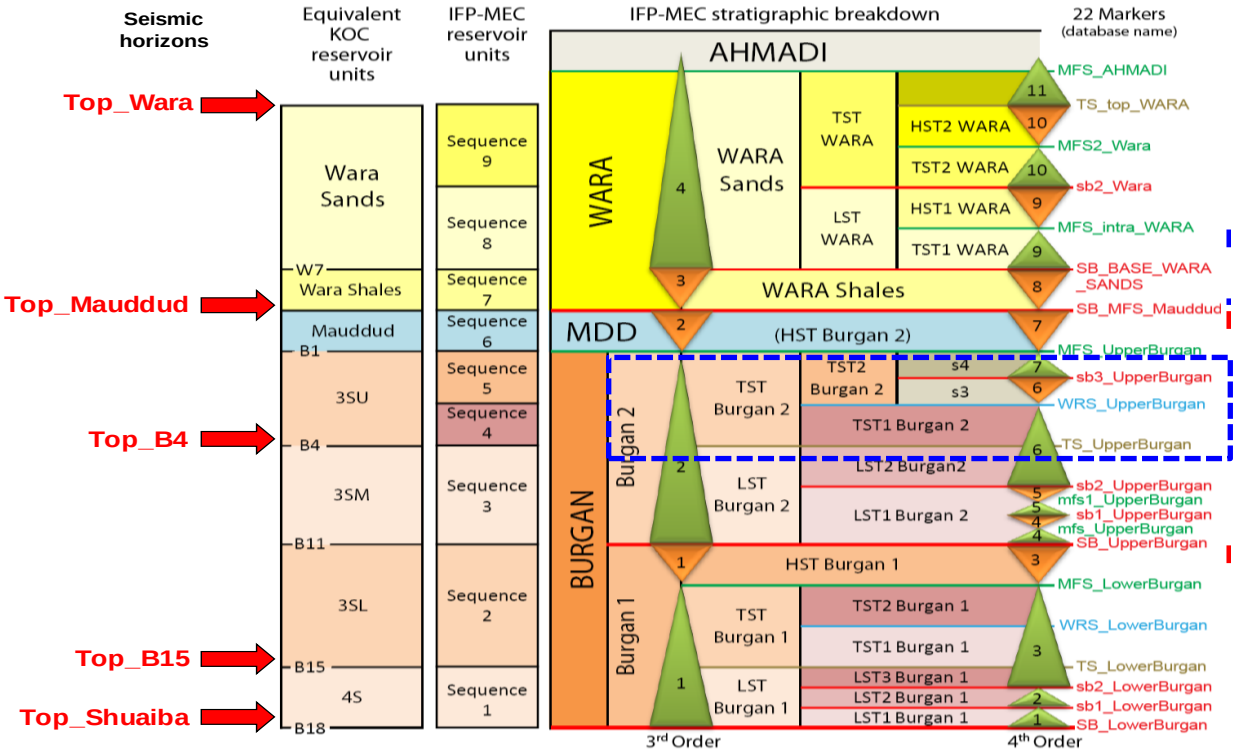
Micro-Models

1. High resolution facies characterization
   - Core photos, description, depositional environment
   - Borehole images, Inferred depositional environment
2. Lithofacies, structural facies and dip data
3. Surfaces, horizon and zones mapping
4. Property modeling
5. Flow based up-scaling

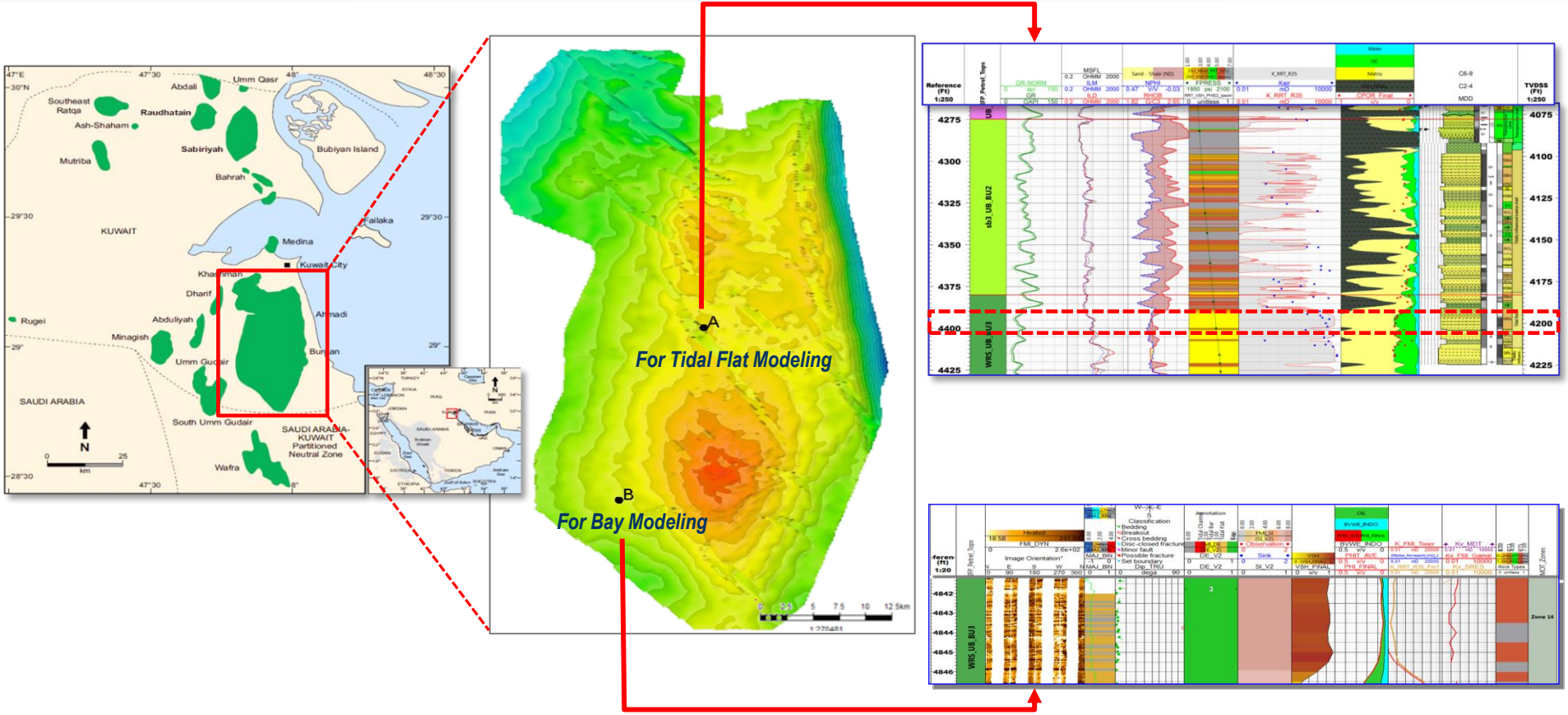




Burgan Field Sequence Stratigraphy



MicroModeling Well locations



Well-A (Tidal Flat) Core and Borehole Image

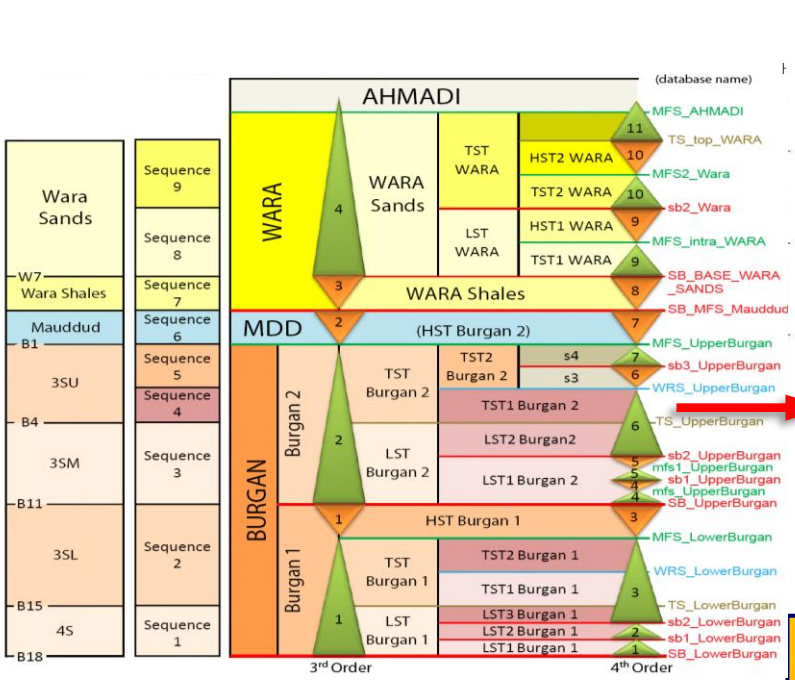
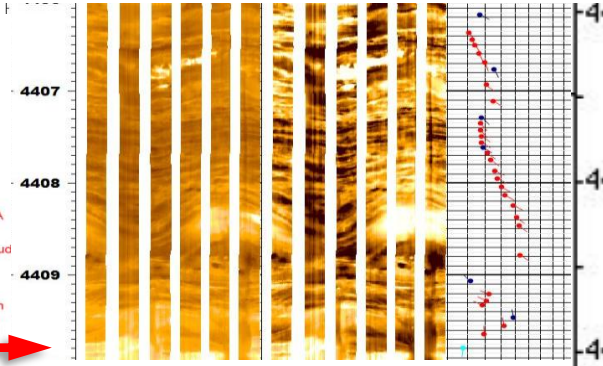
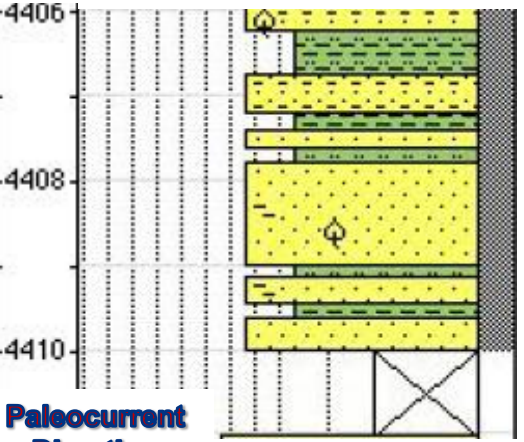


Image Log



Core Log



Paleocurrent Direction

Bedding Azimuth: 110-135°
Bedding dip: 10-45°

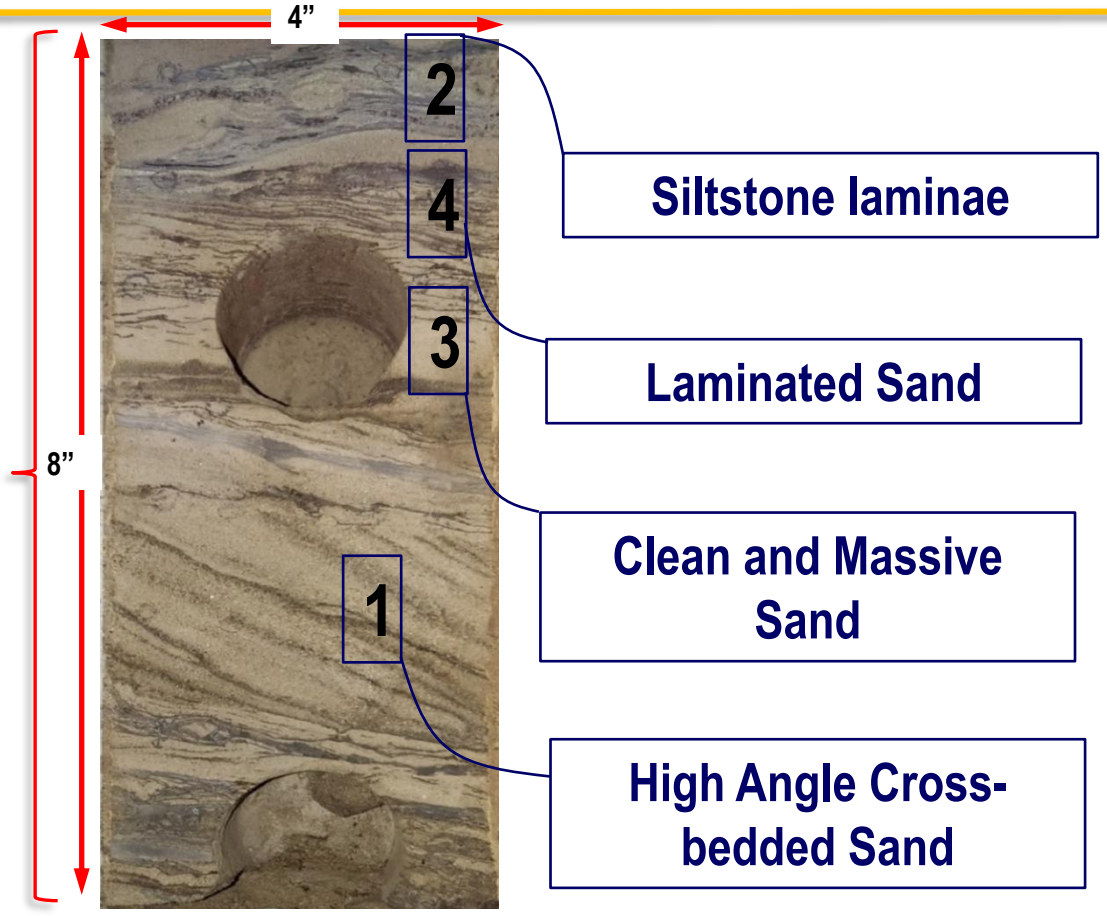
Static and Dynamic borehole Image (enhanced color) and interpreted dip set for bedforms. The cross-beds indicate Palaeocurrent direction

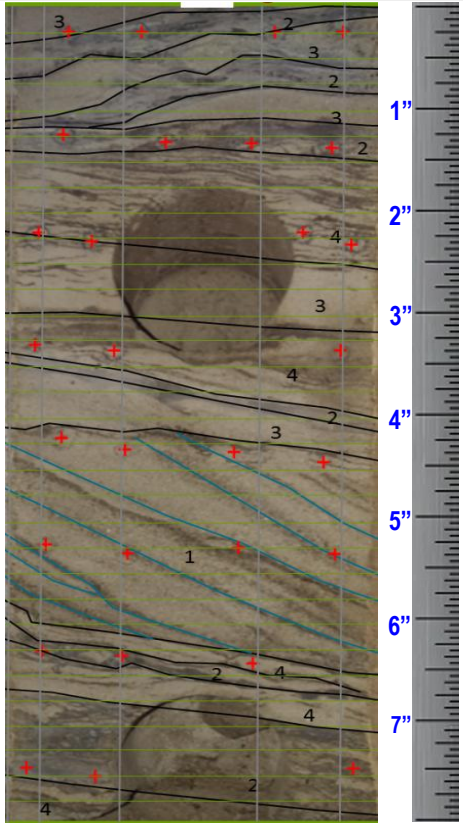
Thinner individual Sand packages with clay/carbonaceous rich intervals as planar laminated top sets

Tidal Flat Core…

Bedding Association:

- \+ indicate mini-permeameter points
- 16 Horizons in total
- 6 sub-horizons within foresets for Facies-1
- Min Bed Thickness: 0.001’ (0.012”)
- Max Bed Thickness: 0.089’ (1.068”)

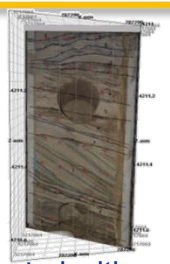


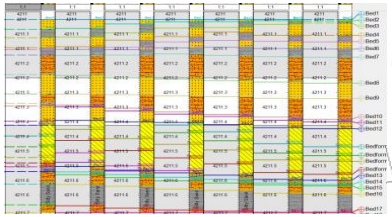


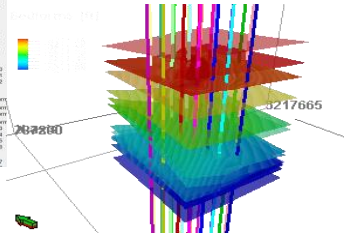
MicroModeling using Core (Summary)

Geological Attributes from Core Image

- Appropriate Cored interval selection
- Manual Interpretation of Bed-forms, Facies



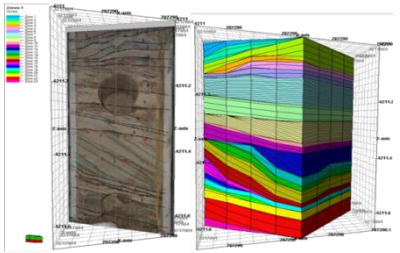




Micro-Wells, Well Tops, facies and log data preparation

- Well tops for all horizons loaded with other pertinent log data
- Current model include mini-perm points, facies logs

2D 3D

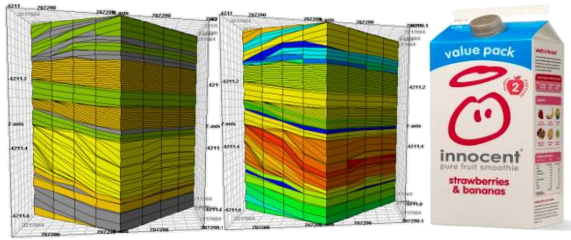


Grid Construction, Horizon Mapping, Zonation and Layering

- Grid resolution based on input data 4” x 4” x 8”
- Cells: 1904, Xinc, Yinc: 1” Zinc: 0.1”
- Horizon mapping applying geological knowledge

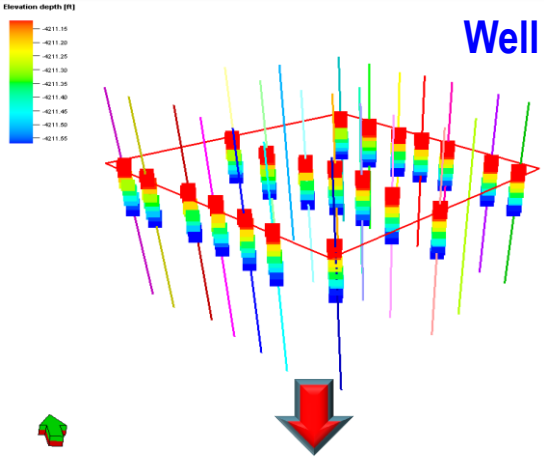
Property Population with available data

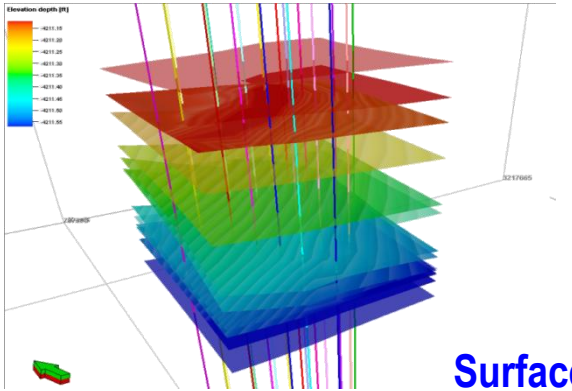
- Scale-up well logs
- Facies and Petrophysical Modeling



Well Tops and Facies logs

Well Section through Pseudo Wells





Horizon Mapping

Index	Horizon name	Color	Calculate	Horizon type	Conform to another horizon		Status	Smooth iterations	Use horizon-fault lines	Well tops	Input #1
1	Bed1		Yes	Erosional	No	1	Done	0	Yes	Bed1 (Tidal	Bed1
2	Bed2		Yes	Conformable	Yes	1	Done	0	Yes	Bed2 (Tidal	Bed2
3	Bed3		Yes	Conformable	Yes	1	Done	0	Yes	Bed3 (Tidal	Bed3
4	Bed4		Yes	Conformable	Yes	1	Done	0	Yes	Bed4 (Tidal	Bed4
5	Bed5		Yes	Discontinuous	No	1	Done	0	Yes	Bed5 (Tidal	Bed5
6	Bed6		Yes	Conformable	Yes	1	Done	0	Yes	Bed6 (Tidal	Bed6
7	Bed7		Yes	Conformable	Yes	1	Done	0	Yes	Bed7 (Tidal	Bed7
8	Bed8		Yes	Conformable	Yes	1	Done	0	Yes	Bed8 (Tidal	Bed8
9	Bed9		Yes	Erosional	No	1	Done	0	Yes	Bed9 (Tidal	Bed9
10	Bed10		Yes	Conformable	Yes	1	Done	0	Yes	Bed10 (Tid	Bed10
11	Bed11		Yes	Conformable	Yes	1	Done	0	Yes	Bed11 (Tid	Bed11
12	Bed12		Yes	Erosional	No	1	Done	0	Yes	Bed12 (Tid	Bed12
13	Bedform1		Yes	Conformable	No	1	Done	0	Yes	Bedform1 (	Bedform1
14	Bedform2		Yes	Conformable	No	1	Done	0	Yes	Bedform2 (	Bedform2
15	Bedform3		Yes	Conformable	No	1	Done	0	Yes	Bedform3 (	Bedform3
16	Bedform4		Yes	Conformable	No	1	Done	0	Yes	Bedform4 (	Bedform4
17	Bedform5		Yes	Conformable	No	1	Done	0	Yes	Bedform5 (	Bedform5
18	Bedform6		Yes	Conformable	No	1	Done	0	Yes	Bedform6 (	Bedform6
19	Bed13		Yes	Base	No	1	Done	0	Yes	Bed13 (Tid	Bed13
20	Bed14		Yes	Conformable	Yes	1	Done	0	Yes	Bed14 (Tid	Bed14
21	Bed15		Yes	Conformable	Yes	1	Done	0	Yes	Bed15 (Tid	Bed15
22	Bed16		Yes	Conformable	Yes	1	Done	0	Yes	Bed16 (Tid	Bed16
23	Bed17		Yes	Conformable	Yes	1	Done	0	Yes	Bed17 (Tid	Bed17
24	Bed18		Yes	Base	No	1	Done	0	Yes	Bed18 (Tid	Bed18

Consistent with observed Geology

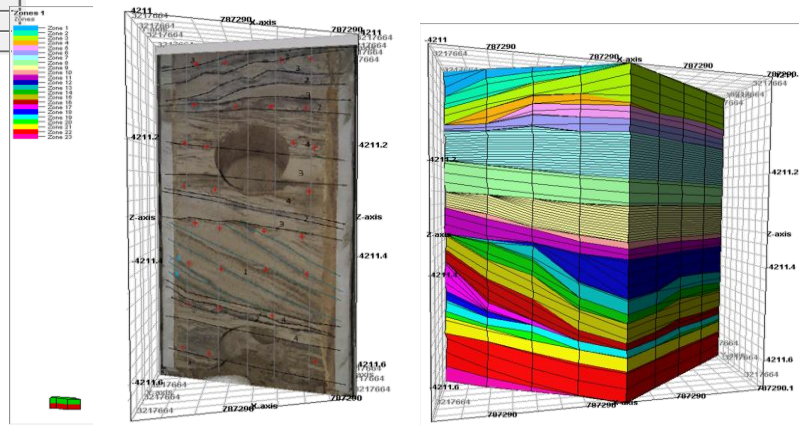
Zonation and Layering…

	Name	Color	Calculate	Zone division			Reference surface	Restore eroded	Restore base	Status
	Zone 1		Yes	Follow base	Cell thickness:	0.02	Bed1	Yes	Yes	Done
	Zone 2		Yes	Follow surface	Cell thickness:	0.02	Bed2	Yes	Yes	Done
	Zone 3		Yes	Follow surface	Cell thickness:	0.02	Bed3	Yes	Yes	Done
	Zone 4		Yes	Follow surface	Cell thickness:	0.02	Bed4	Yes	Yes	Done
	Zone 5		Yes	Follow base	Cell thickness:	0.02	Bed5	Yes	Yes	Done
	Zone 6		Yes	Follow surface	Cell thickness:	0.02	Bed6	Yes	Yes	Done
	Zone 7		Yes	Follow surface	Cell thickness:	0.01	Bed7	Yes	Yes	Done
	Zone 8		Yes	Follow surface	Cell thickness:	0.02	Bed8	Yes	Yes	Done
	Zone 9		Yes	Follow base	Cell thickness:	0.01	Bed9	Yes	Yes	Done
	Zone 10		Yes	Follow surface	Cell thickness:	0.02	Bed10	Yes	Yes	Done
	Zone 11		Yes	Follow surface	Cell thickness:	0.02	Bed11	Yes	Yes	Done
	Zone 12		Yes	Follow base	Cell thickness:	0.03	Bedform	Yes	Yes	Done
	Zone 13		Yes	Follow surface	Cell thickness:	0.03	Bedform	Yes	Yes	Done
	Zone 14		Yes	Follow surface	Cell thickness:	0.02	Bedform	Yes	Yes	Done
	Zone 15		Yes	Follow surface	Cell thickness:	0.02	Bedform	Yes	Yes	Done
	Zone 16		Yes	Follow surface	Cell thickness:	0.02	Bedform	Yes	Yes	Done
	Zone 17		Yes	Follow base	Cell thickness:	0.02	Bedform	Yes	Yes	Done
	Zone 18		Yes	Follow surface	Cell thickness:	0.03	Bedform	Yes	Yes	Done
	Zone 19		Yes	Follow surface	Cell thickness:	0.03	Bed14	Yes	Yes	Done
	Zone 20		Yes	Follow surface	Cell thickness:	0.03	Bed15	Yes	Yes	Done
	Zone 21		Yes	Follow surface	Cell thickness:	0.03	Bed16	Yes	Yes	Done
	Zone 22		Yes	Follow base	Cell thickness:	0.03	Bed17	Yes	Yes	Done
	Zone 23		Yes	Proportional	Number of layers:	1		Yes	Yes	New

Strong Correlation with “assumption” of planar uniformity

2D

3D

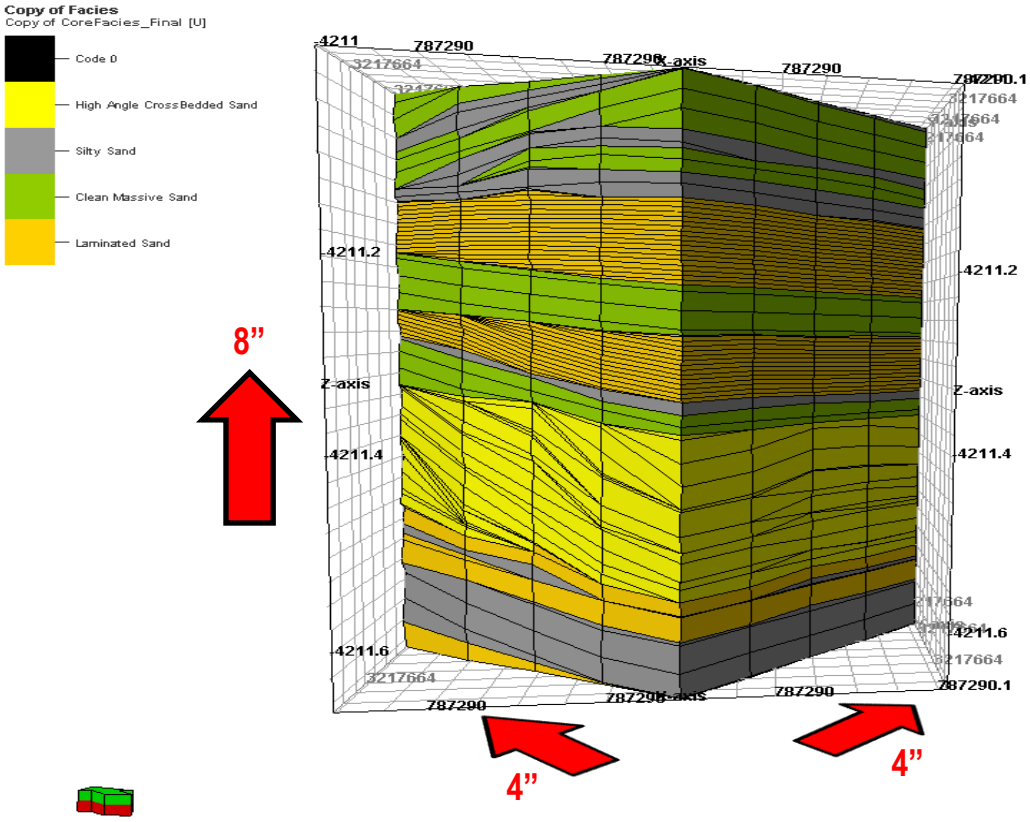


Facies Modeling

Sequential Indicator Simulation

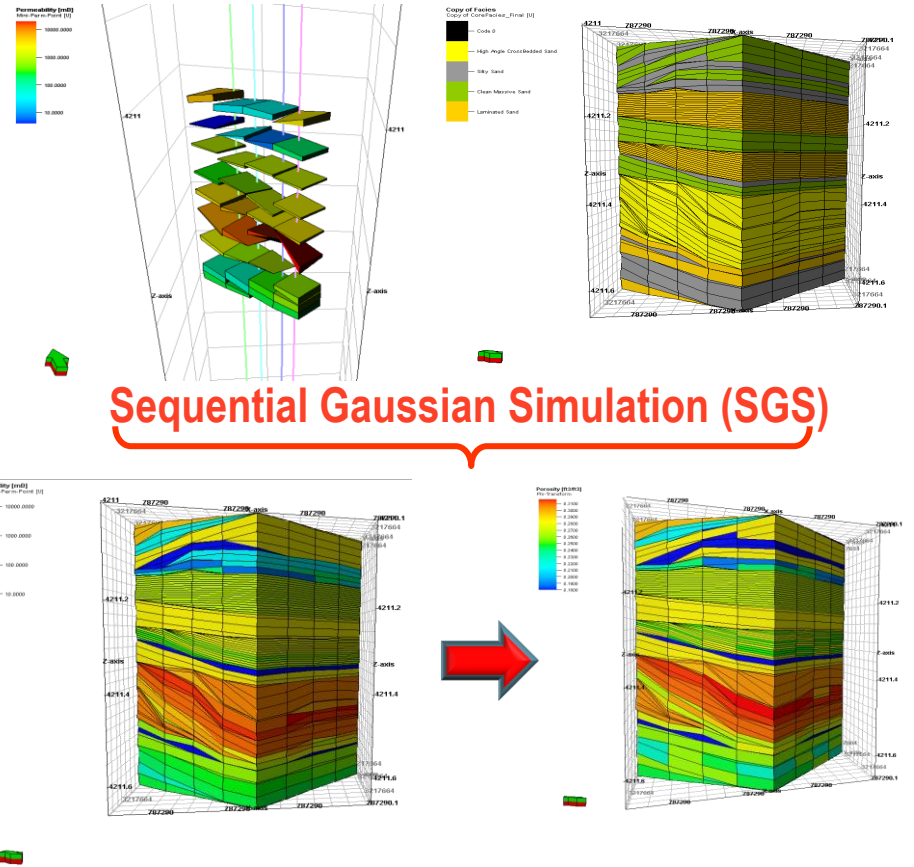
Variogram parameters as:

- Anisotropy Range Major: 0.0254, Minor: 0.0127, Vertical: 0.04
- Major direction orientation from BH Image, Azimuth: 100-135Deg, Dip: 10-45 Deg (per facies)

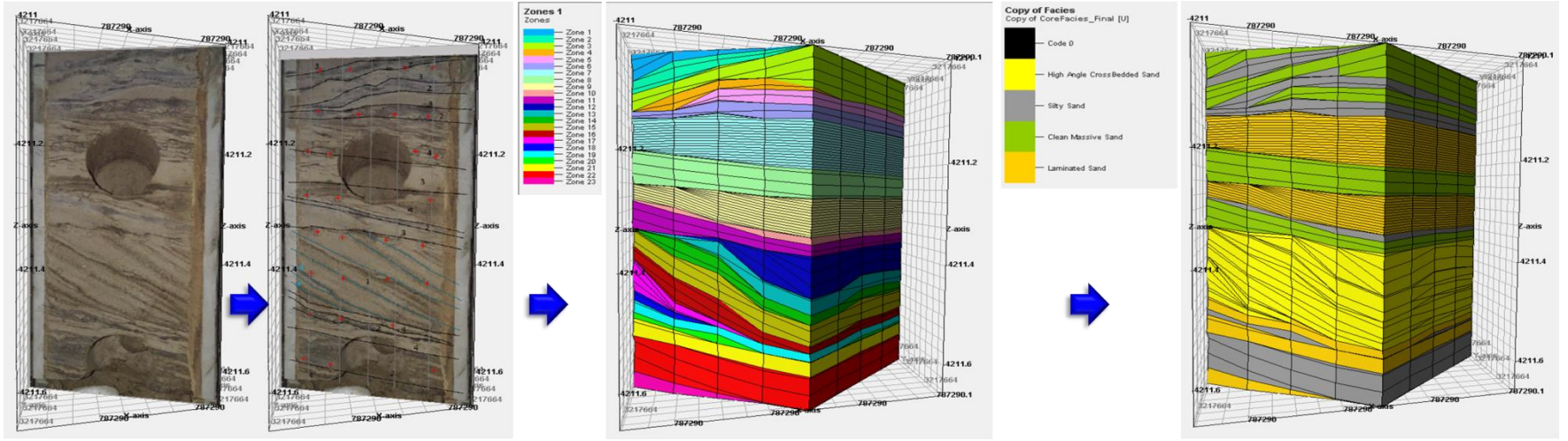


Property Modeling

- Mini-perm values upscaled to grid
- Sequential Gaussian Simulation conditioned to facies
- Constant values for zones having no data points (non-upscaled cells)
- Similar variogram parameters as in facies modeling
- Porosity modeled using core based linear transformation



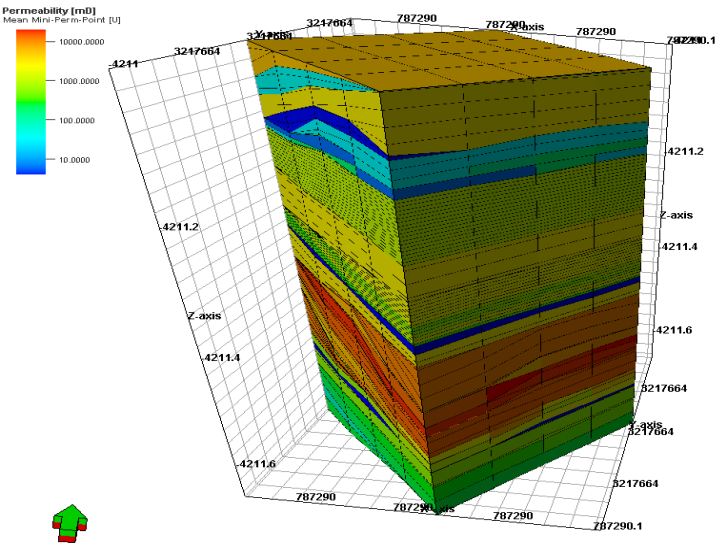
Summary of Tidal Flat MicroModeling

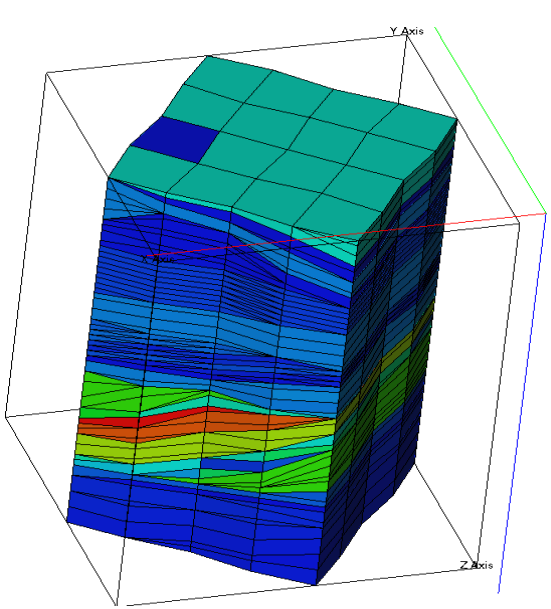


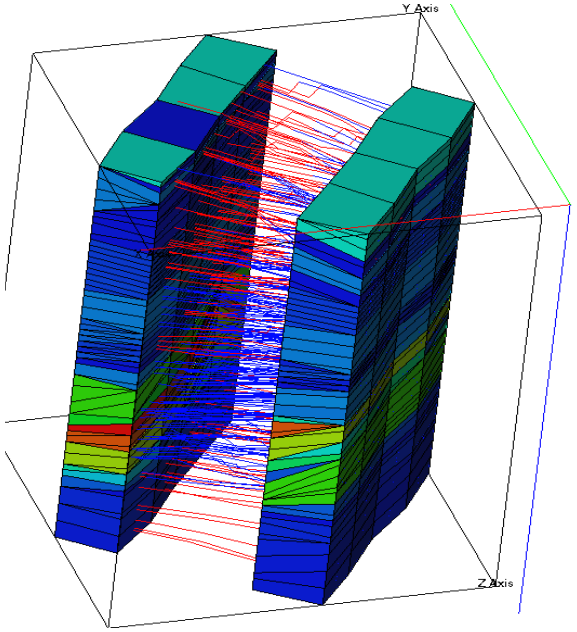
Flow based Simulations

Tidal Flat Micro-Modeling Simulation

T3_NW_SE Simulation

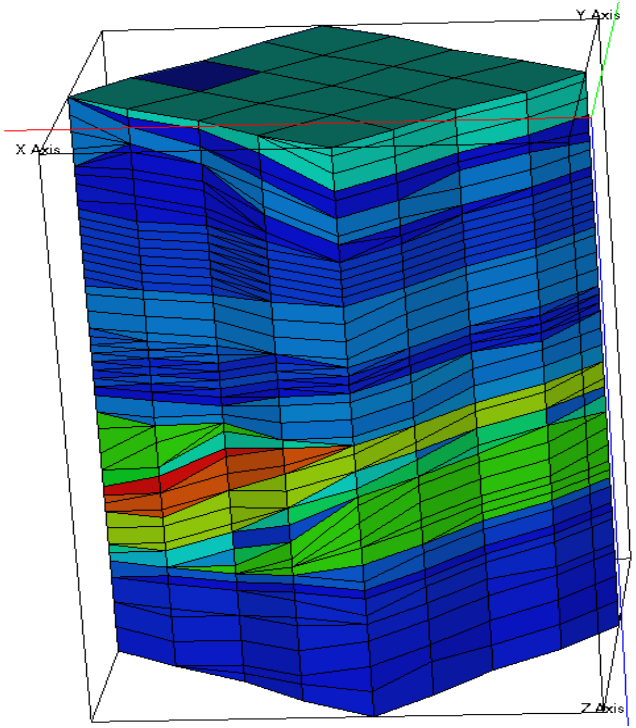


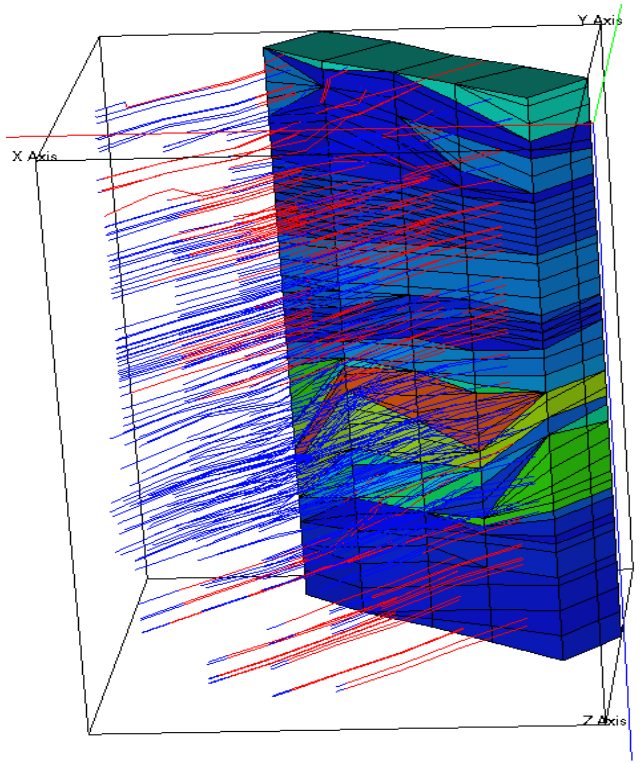




PERM_NW_SE = 2837.3 [mD]

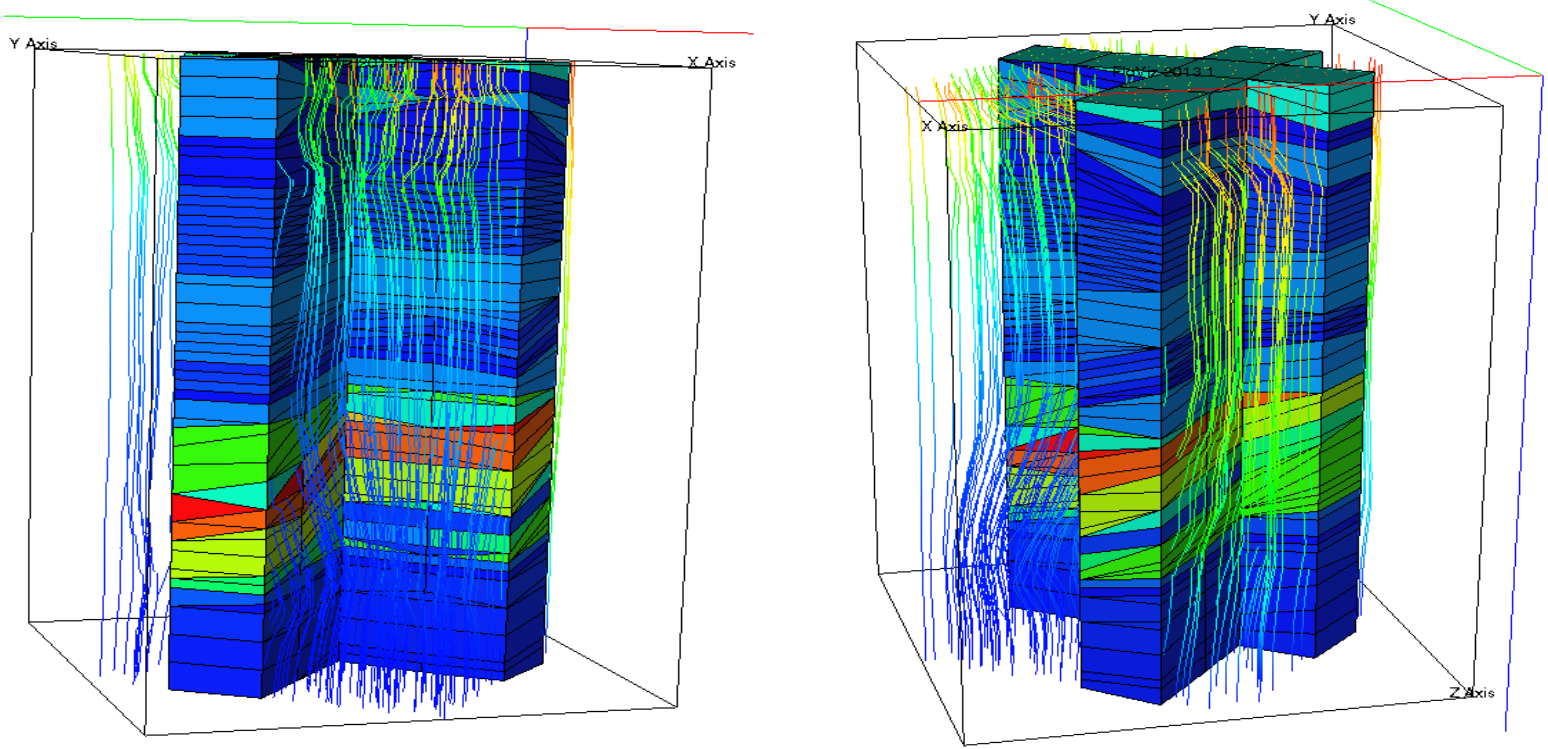
T4_NE_SW Simulation





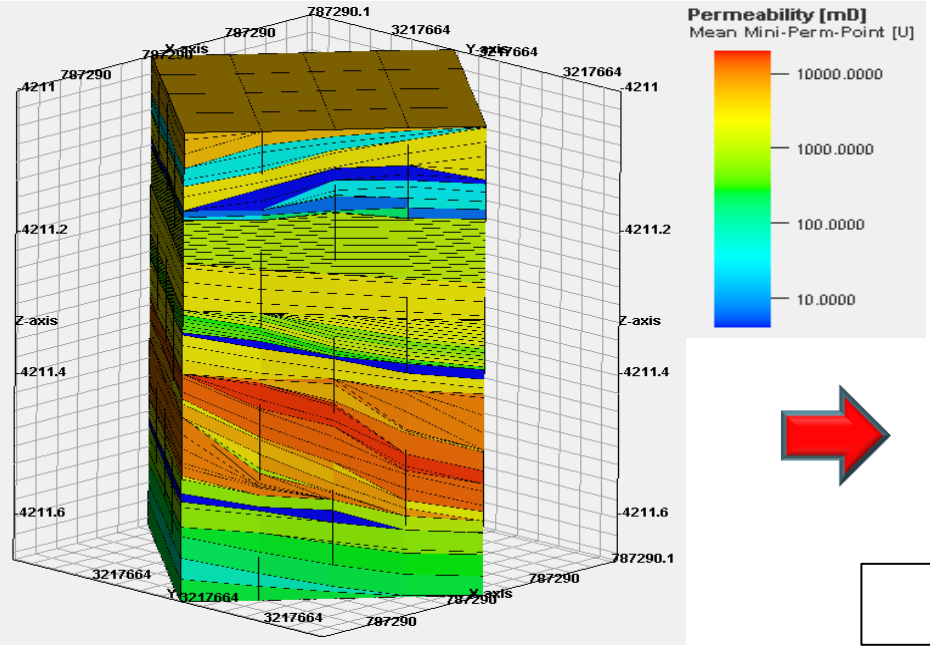
PERM_NE_SW = 3602.8 [mD]

T5_TOP_BOT Simulation



PERM_TOP_BOT = 59.90 [mD]

Tidal Flat MicroModel Simulation Summary

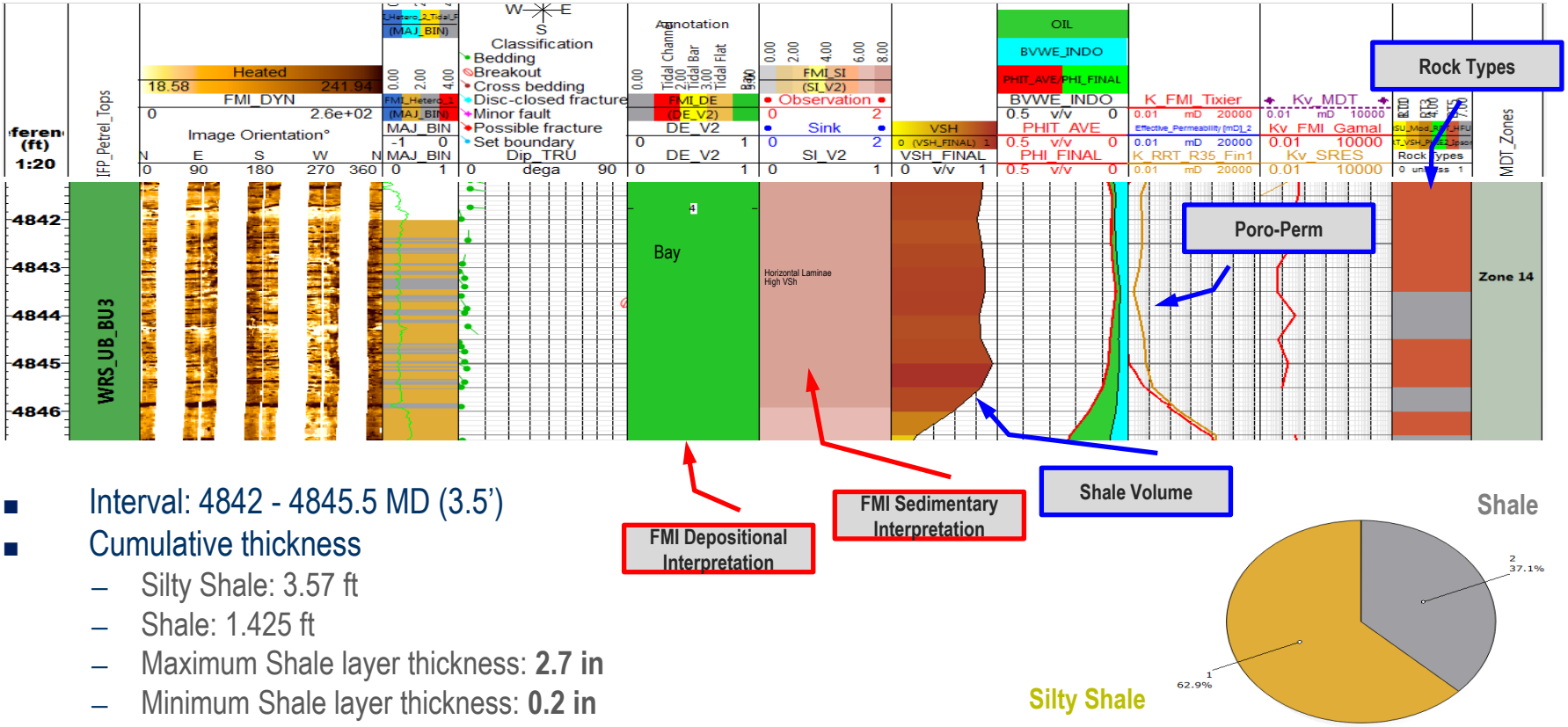


	Direction	Perm [mD]
Simulations	NW_SE	2837.3
	NE_SW	3602.8
	TOP_BOT	59.9

Permeability Anisotropy Ratio: 0.016

Bay Micro-Model

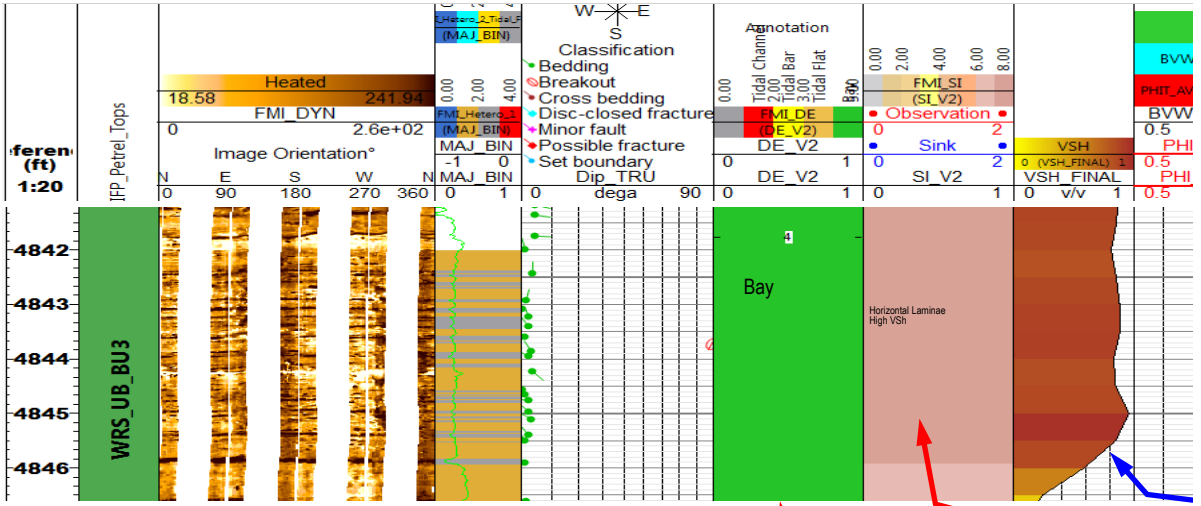
Micro-Model 2 (Bay Shales-Heterolithic) Well-B



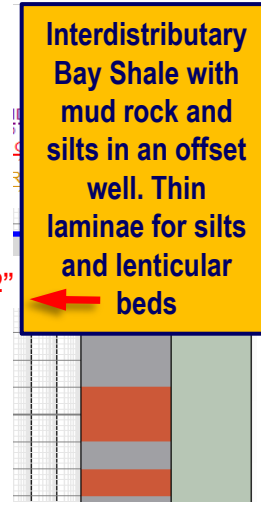
- Interval: 4842 - 4845.5 MD (3.5')
- Cumulative thickness
  - Silty Shale: 3.57 ft
  - Shale: 1.425 ft
  - Maximum Shale layer thickness: **2.7 in**
  - Minimum Shale layer thickness: **0.2 in**

Micro-Model 2 (Bay Shales-Heterolithic) Well-B

Offset well



12”



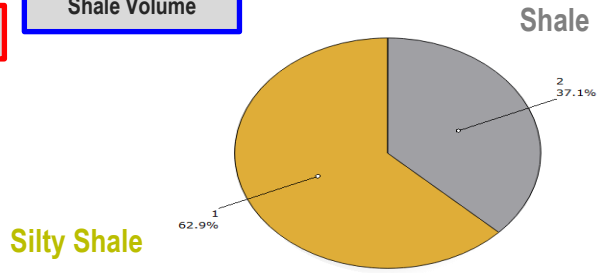
Interdistributary Bay Shale with mud rock and silts in an offset well. Thin laminae for silts and lenticular beds

- Interval: 4842 - 4845.5 MD (3.5’)
- Cumulative thickness
  - Silty Shale: 3.57 ft
  - Shale: 1.425 ft
  - Maximum Shale layer thickness: **2.7 in**
  - Minimum Shale layer thickness: **0.2 in**

FMI Depositional Interpretation

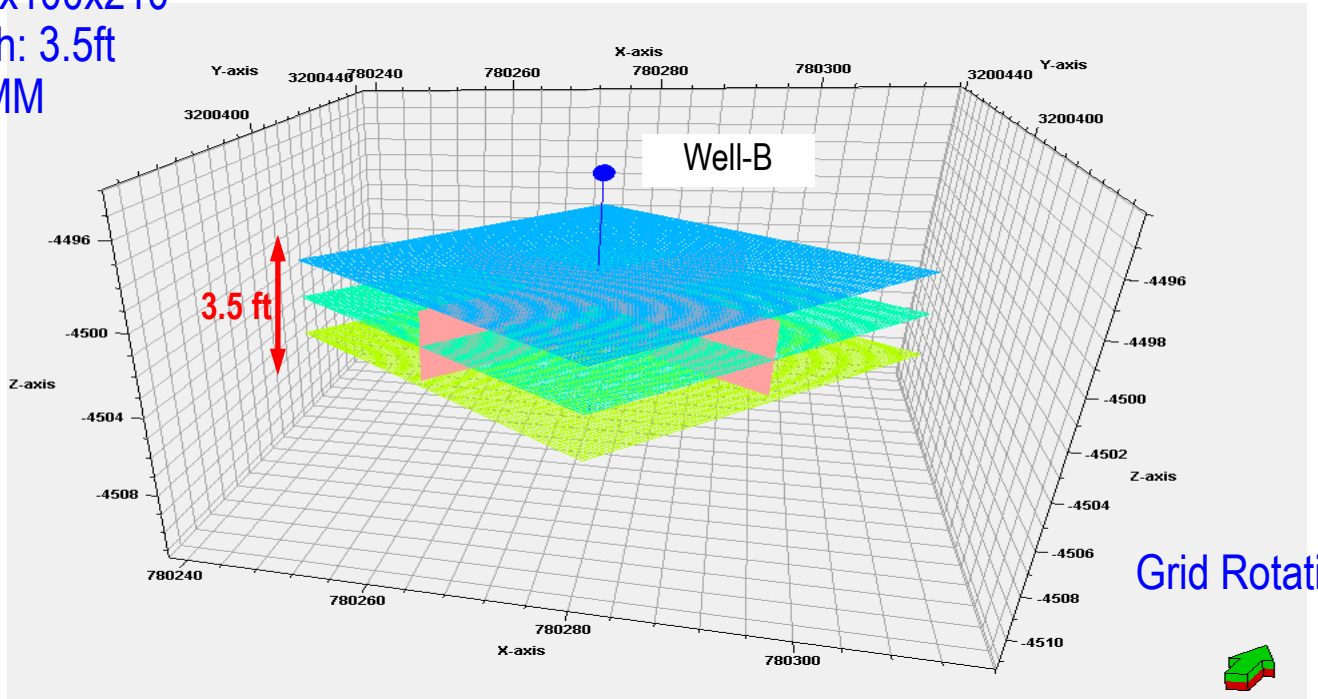
FMI Sedimentary Interpretation

Shale Volume



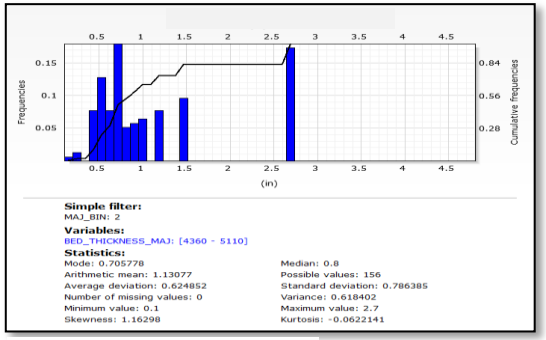
MicroModel-2 (Bay)

Grid Cells: 100x100x210
Elevation Depth: 3.5ft
# of Cells: 2.1MM

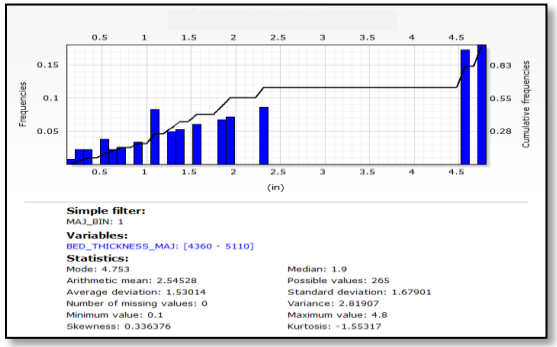


Grid Rotation: 40Deg

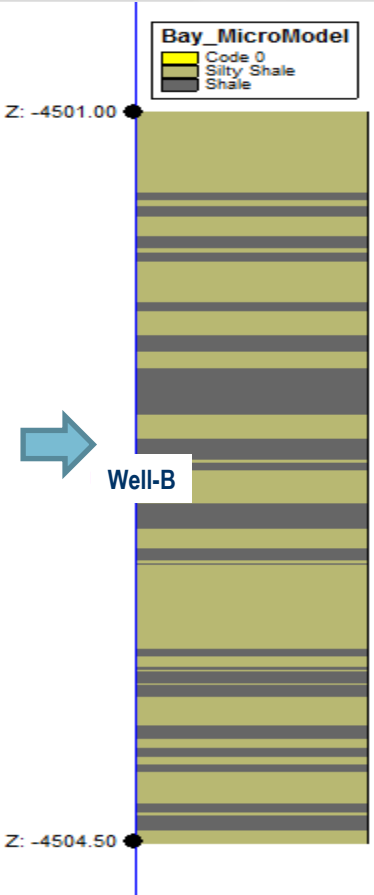
Object Based Modeling (2 Facies, Shale + SiltyShale)

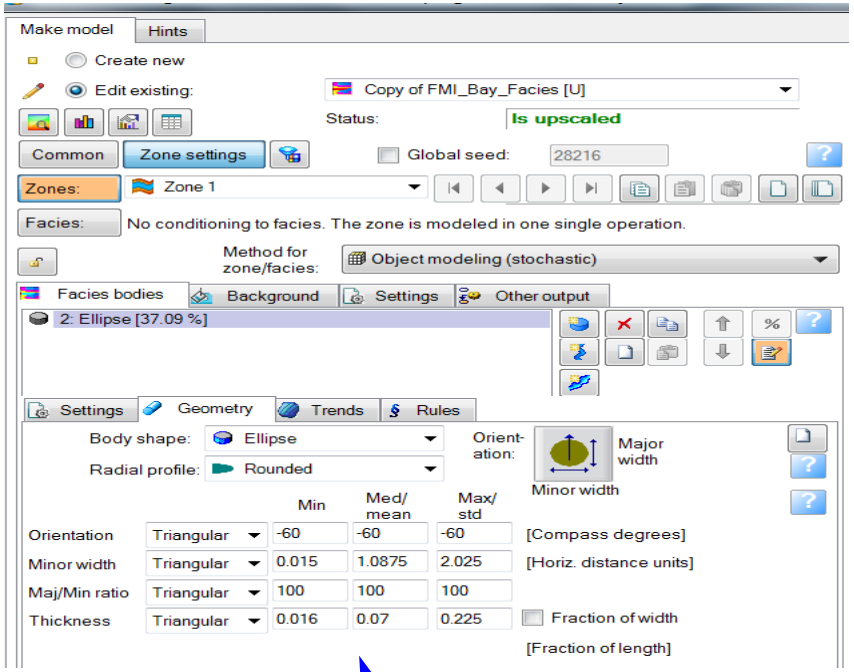


Shale



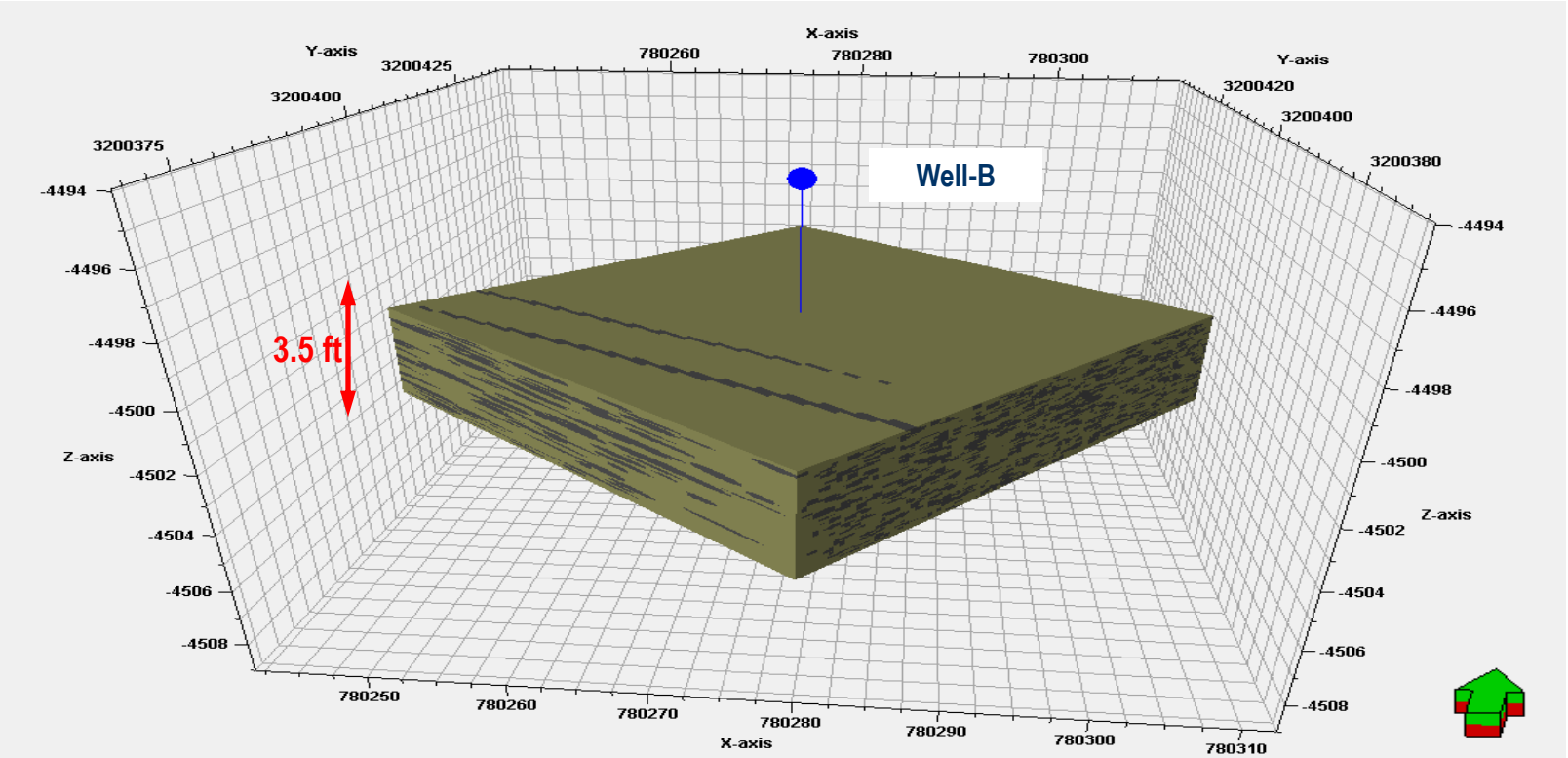
Silty Shale





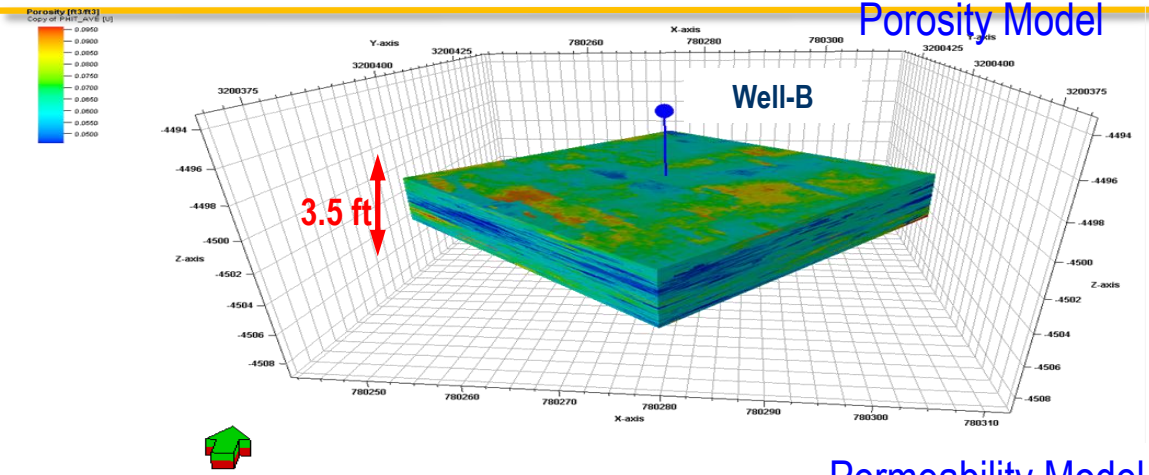
Geometry From Begg et al., 1989

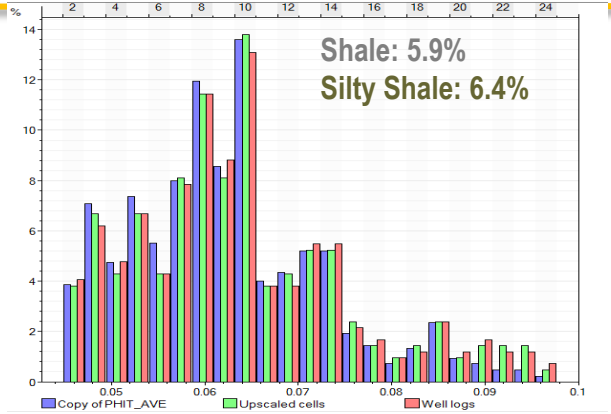
Bay Facies Model



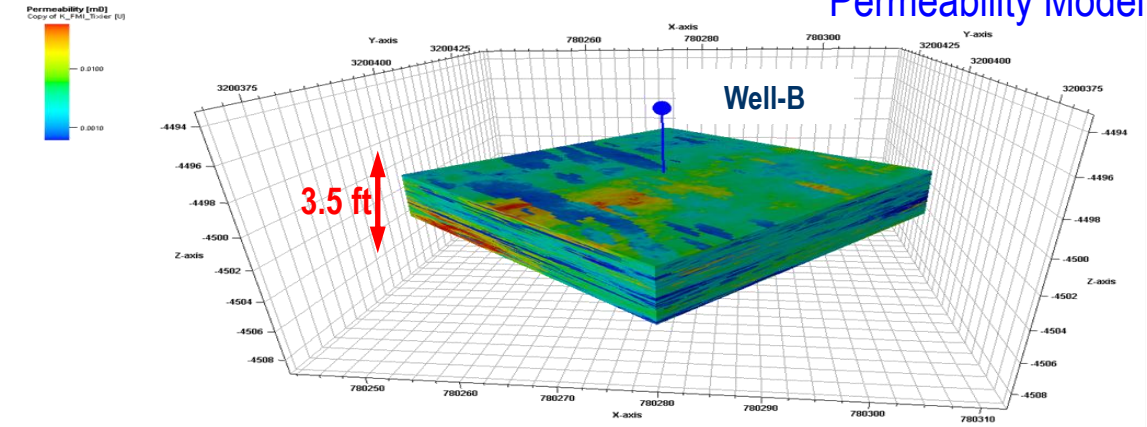
Bay Porosity-Permeability Models

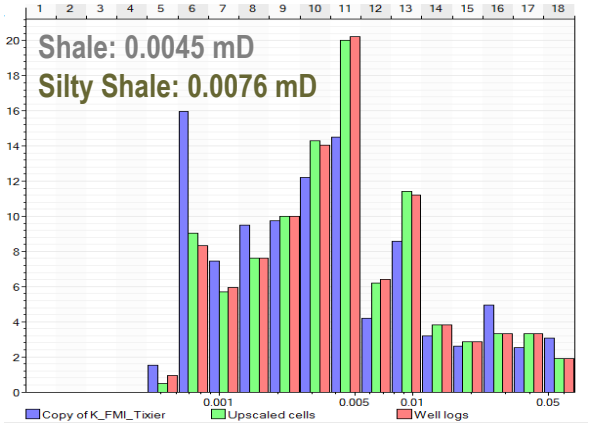
Porosity Model





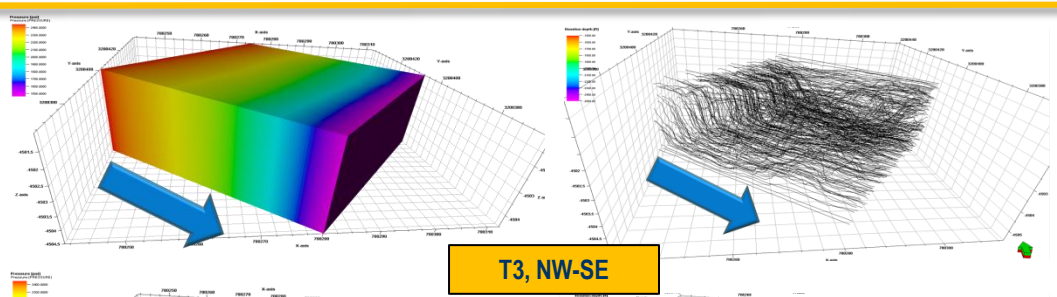
Permeability Model



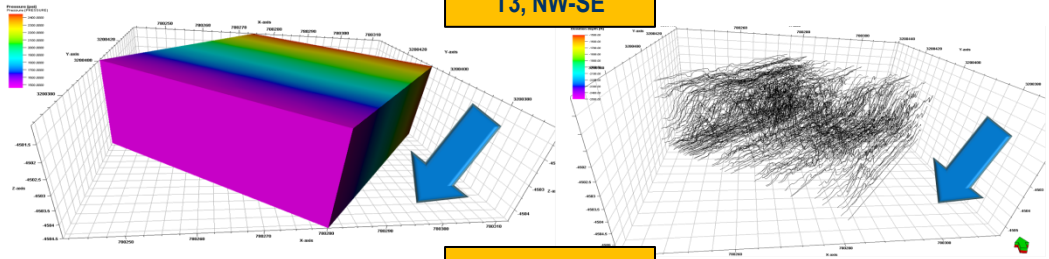


Bay Micro-Modeling Simulation

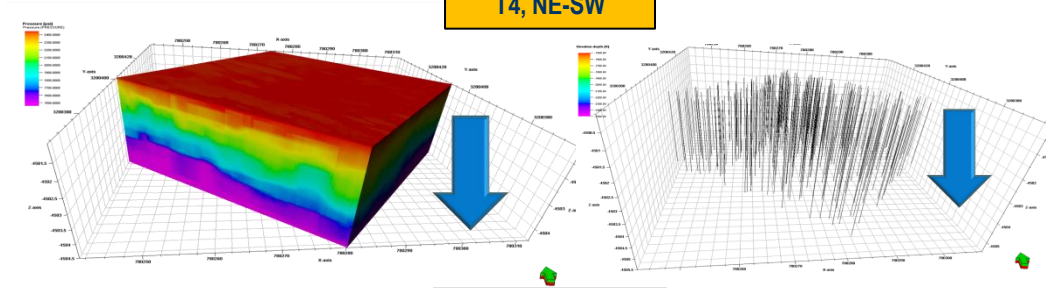
Bay MicroModel Simulation Summary



T3, NW-SE



T4, NE-SW

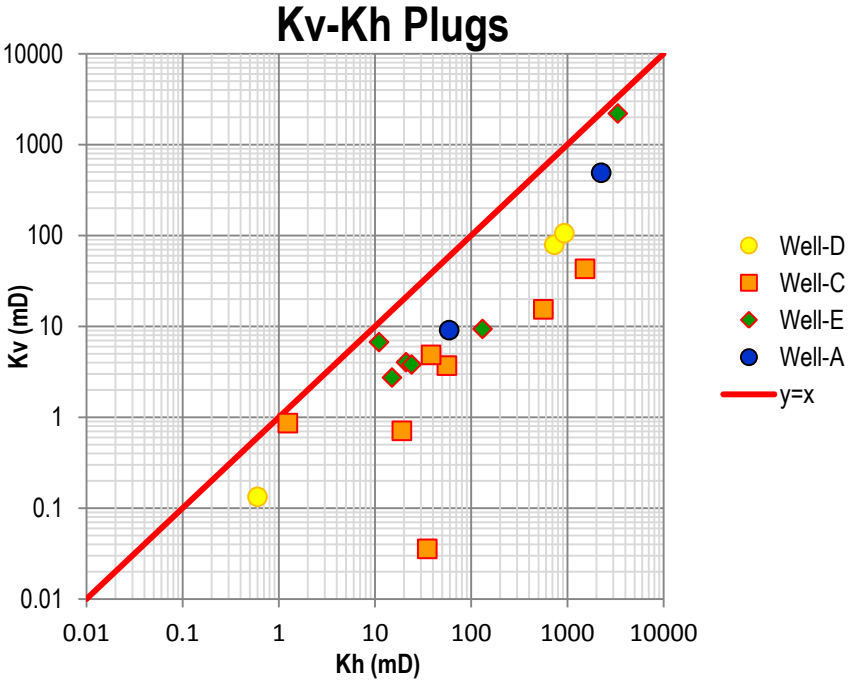


T5, TOP-BOTTOM

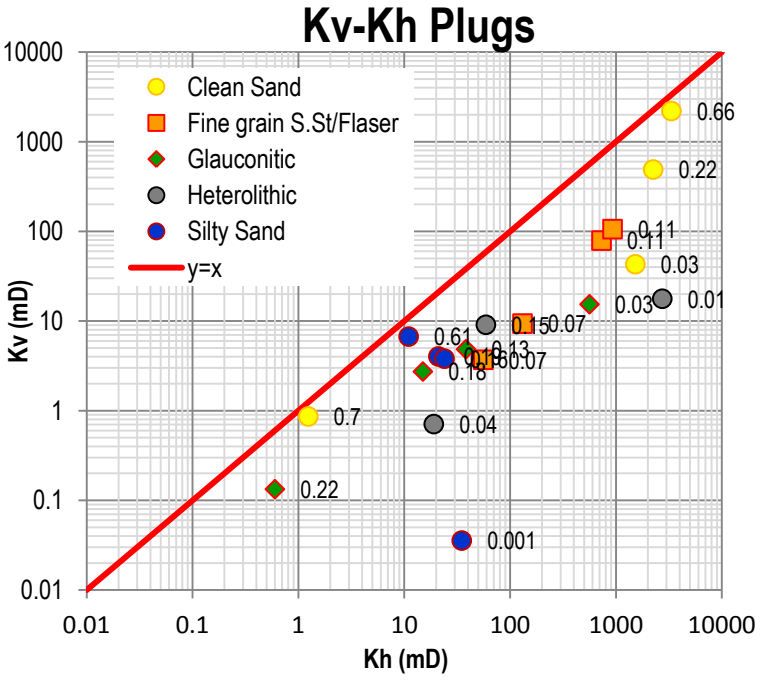
	PERM [mD]	Anisotropy_Ratio (X as basis)
T4_NE_SW (X)	0.006838	
T3_NW_SE (Y)	0.005729	0.8378
T5_TOP_BOT (Z)	0.0000335	0.004899

New Vertical Plugs across 3SU reservoir

Kv/Kh from Plugs



Well wise



Facies wise

Summary of Kv/Kh per facies in 3SU

BU1-2

Facies	Facies Code	From Core plugs	From Mini-Perm Avg	MicroModel Simulations
Shale	0	0.037		-
Shaly Sand	1	0.11-0.159 (0.13*)	0.02-0.07	-
Sand	2	0.22-0.3		-
Carbonate	3	(0.13?)		-
Glauconitic Sand	4	0.155	0.01	-

BU3

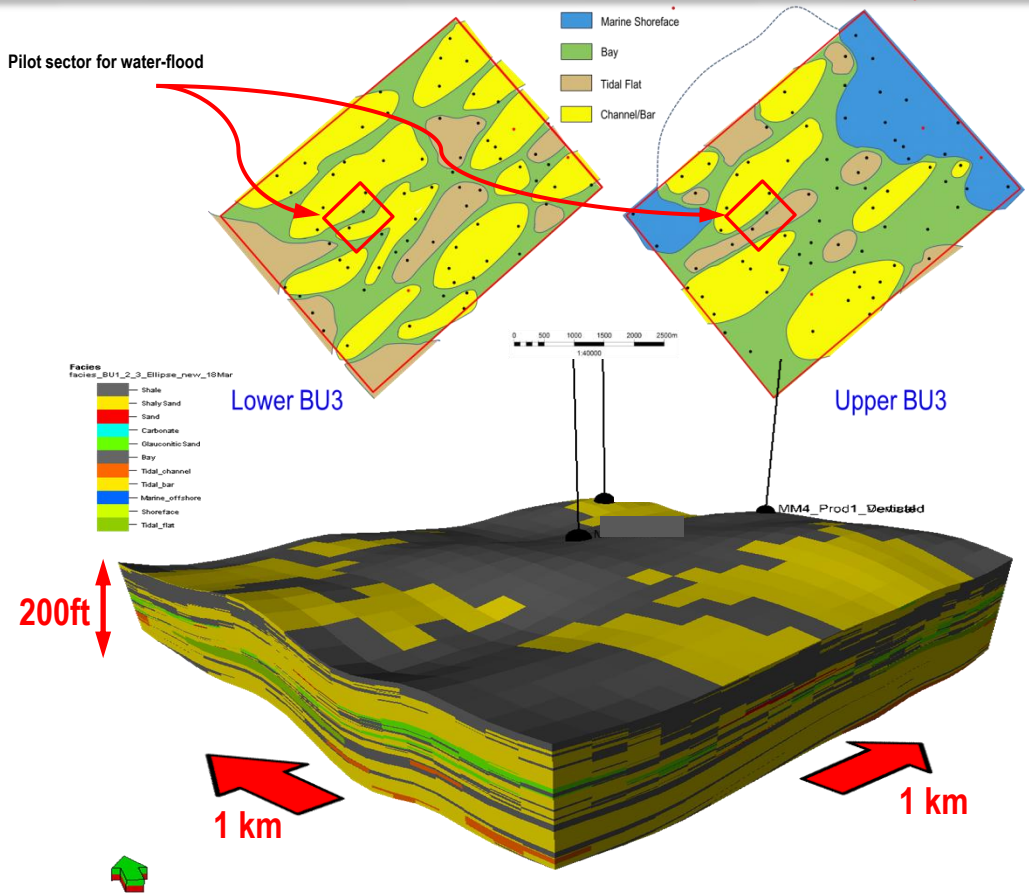
Facies	Facies Code	From Core plugs	From Mini-Perm Avg	MicroModel Simulations
Bay	5	0.037	0.02-0.07	**0.005**
Tidal Channel	6	0.439		(0.3 from VIT)
Tidal Bar	7	0.439		(0.3 from VIT)
Tidal Flat	10	0.11-0.159 (0.13*)	0.22-0.3	**0.016 (0.05-0.07^)**
Marine Offshore	8	0.11-0.159 (0.13*)		
Shoreface	9	0.155		

*denotes median value

^denotes 2 halves simulated

Kv/Kh in Simulation Sector Models

3SU Facies Model and Kv/Kh



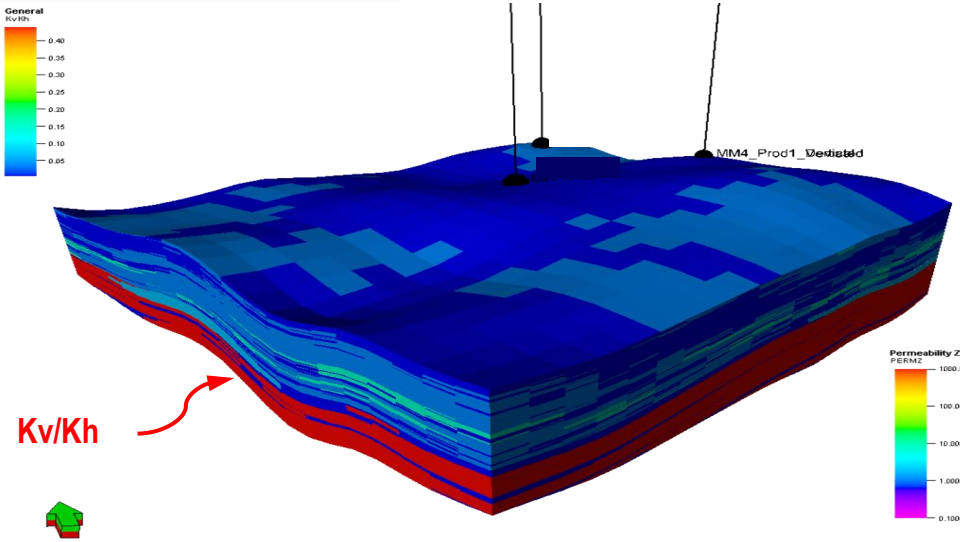
Code	Name
0	Shale
1	ShalySand
2	Sand
4	GlauconiticSand
5	Bay
6	Tidal_channel
7	Tidal_bar
10	Tidal_flat

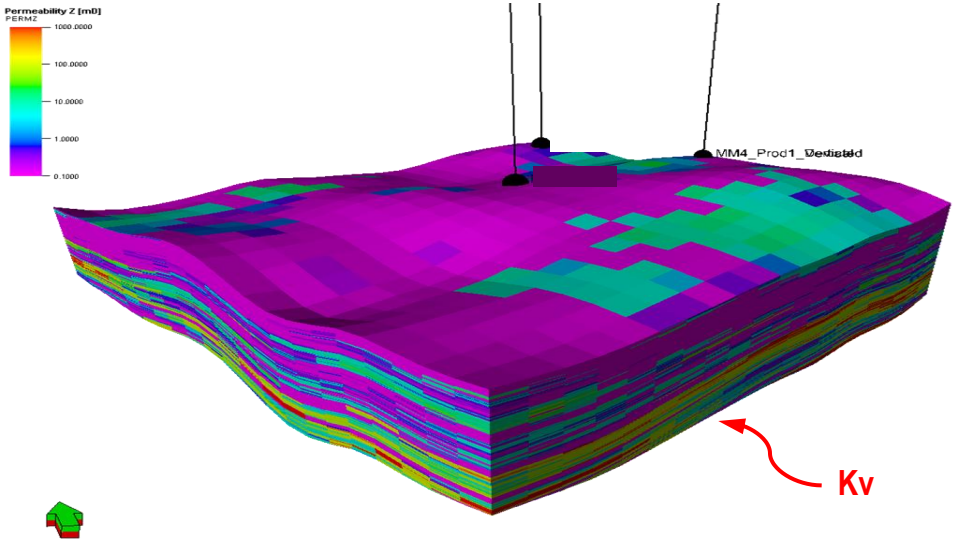
Note no codes for facies 3 (carbonates) and 8,9 (Marine Offshore, Shoreface) respectively as they do not exist in this sector model

Code	Kv/Kh
0	0.005
1	0.037
2	0.155
4	0.155
5	0.005
6	0.44
7	0.44
10	0.07

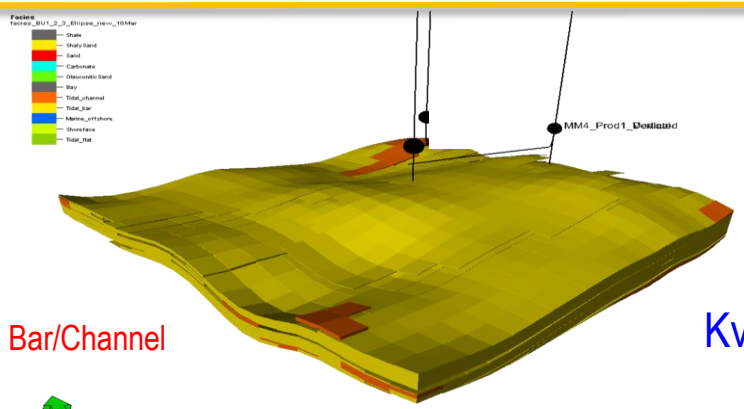
Kv/Kh Summarized from Core Analysis & MicroModeling Simulations

Kv/Kh + PERMZ in Pilot Sector Model



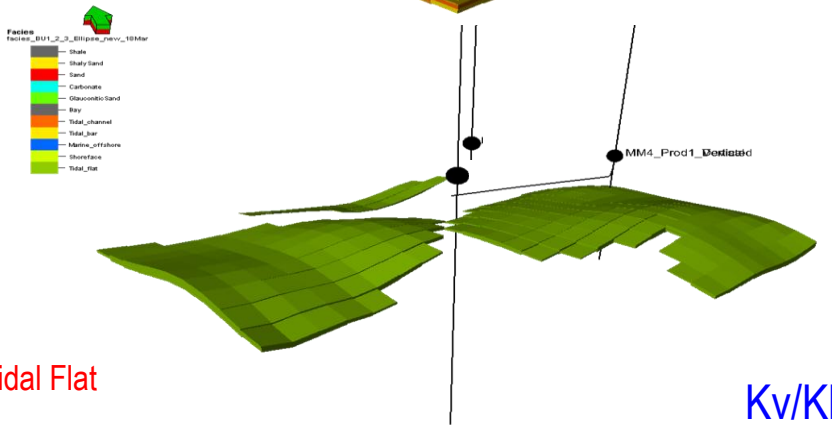


Tidal Bar/Tidal Channel + Tidal Flat (BU3)



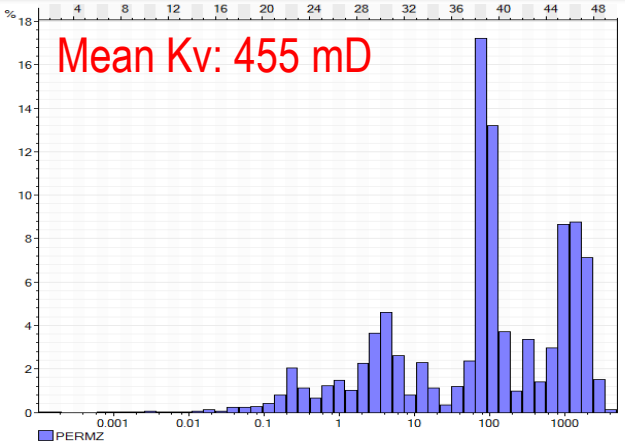
Tidal Bar/Channel

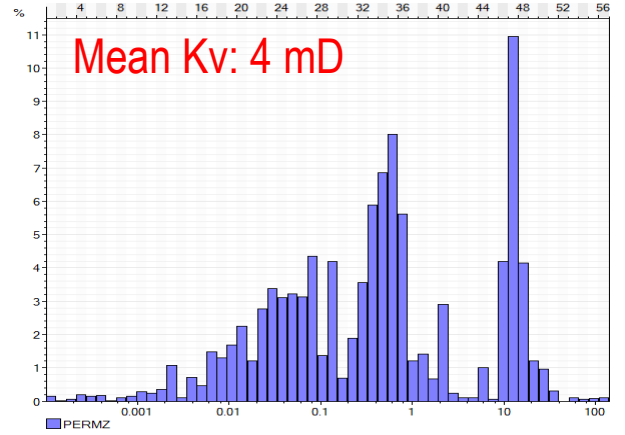
Kv/Kh: 0.44



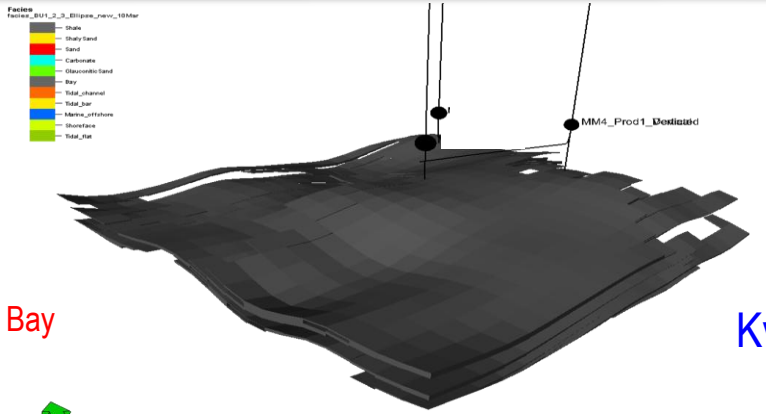
Tidal Flat

Kv/Kh: 0.07



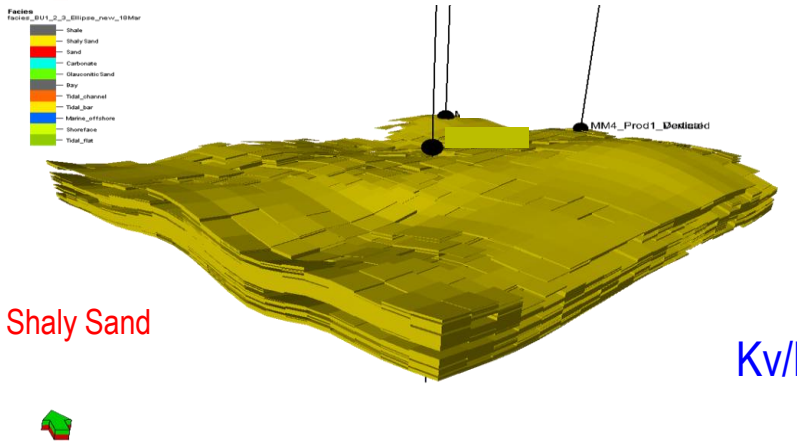


Bay (BU3) + Shaly Sand (BU1_2)



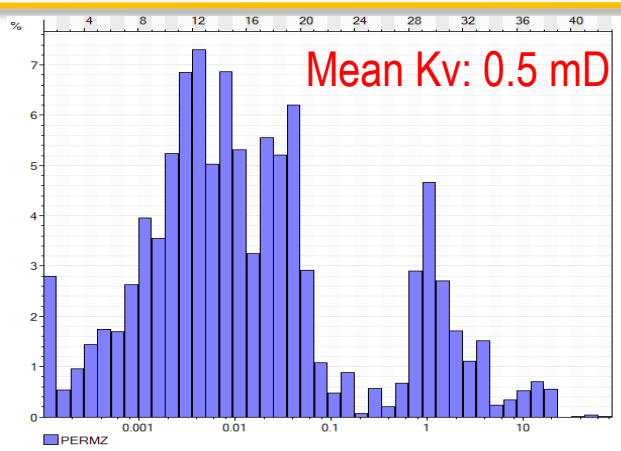
Bay

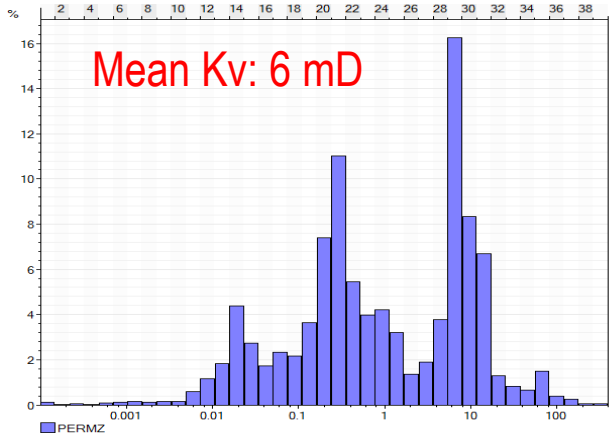
Kv/Kh: 0.005



Shaly Sand

Kv/Kh: 0.037





Conclusions

- Bridging the gap between scale variations in Geological heterogeneity through MicroModeling
- Detailed heterogeneity and permeability anisotropy predictions made
- Integrated analysis using analog reservoir, core plugs, mini-permeameter, Micromodelling and VIT
- Kv/Kh per facies populated into the simulation sector models
- Reservoir simulations on sector models carried out with permeability anisotropies

Acknowledgements

We gratefully acknowledge the collaboration and contribution to this work of the Kuwait Oil Company Greater Burgan Studies team

The authors would like to thank the Management of both Kuwait Oil Company and Schlumberger to allow to publish this work

Thank You