Assigning Volumes for Realistic Assessment of Value in Multiple-Lease Prospects or Discoveries*

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Abstract

Probabilistic assessment of multiple-target exploration prospects should consider three types of geologic relationships between the targets: risk dependency, parameter correlation, and hydrocarbon communication. Definition of these relationships should be a fundamental activity within the geologic evaluation. Failure to evaluate these relationships will result in incorrect assessments of risk and volume.

Targets are also known as zones, reservoirs, segments, or compartments. Targets within an exploration prospect may represent separate stratigraphic intervals, fault blocks, depositional bodies, facies within a depositional body, or traps. Targets are defined by a unique combination of risk and volumetric parameters. They are assessed individually, then aggregated to create the overall prospect assessment. The aggregation must include definition of the geologic relationships between the targets in order to properly assess a prospect's probability of success and success case volume.

Risk dependency defines relationships in the targets' probabilities of success. Targets that share a risk dependency are more likely to succeed together or fail together. Risk dependency impacts both the prospect's overall probability of success and the prospect's success case volume. It is a critical aspect of the geologic evaluation. Evaluations that do not consider risk dependencies will overestimate the prospect's probability of success and underestimate the success case volume.

Parameter correlations define relationships between the targets' volumetric parameters. Targets within the same reservoir interval may have similar net thicknesses and porosities. Targets within the same trap may have similar structural areas and gas-oil-ratios. Parameter correlation impacts the range of the potential success case volumes within the prospect. Failure to consider parameter correlation may contribute to success case P10/P90 ratios for the prospect that are unreasonably narrow.

Hydrocarbon communication refers to spilling or leaking of hydrocarbons between targets in geologic time, as opposed to during production. Communication may result in shared hydrocarbon-water contacts, or migration of hydrocarbons between segments. The assumption that each target will fill individually, and will have a unique hydrocarbon-water contact, usually results in overestimation of prospect volumes.

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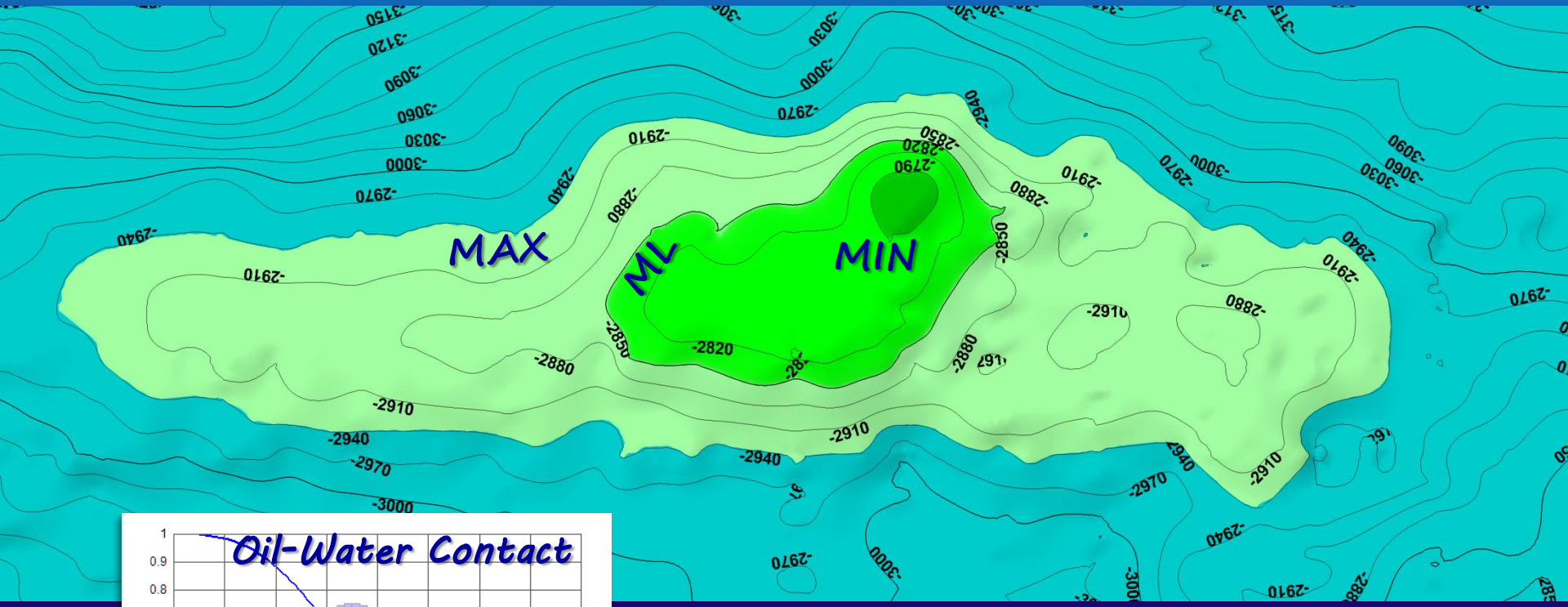
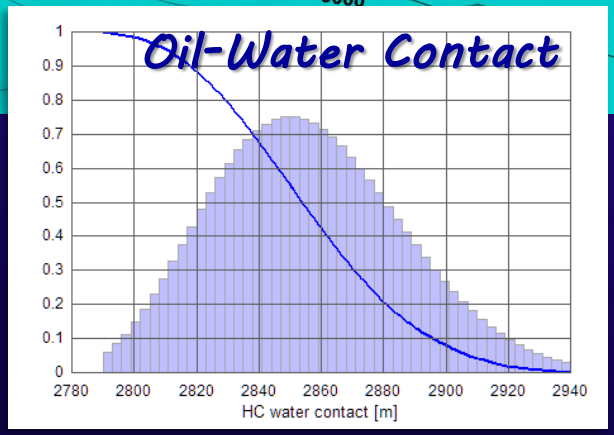
May 2013

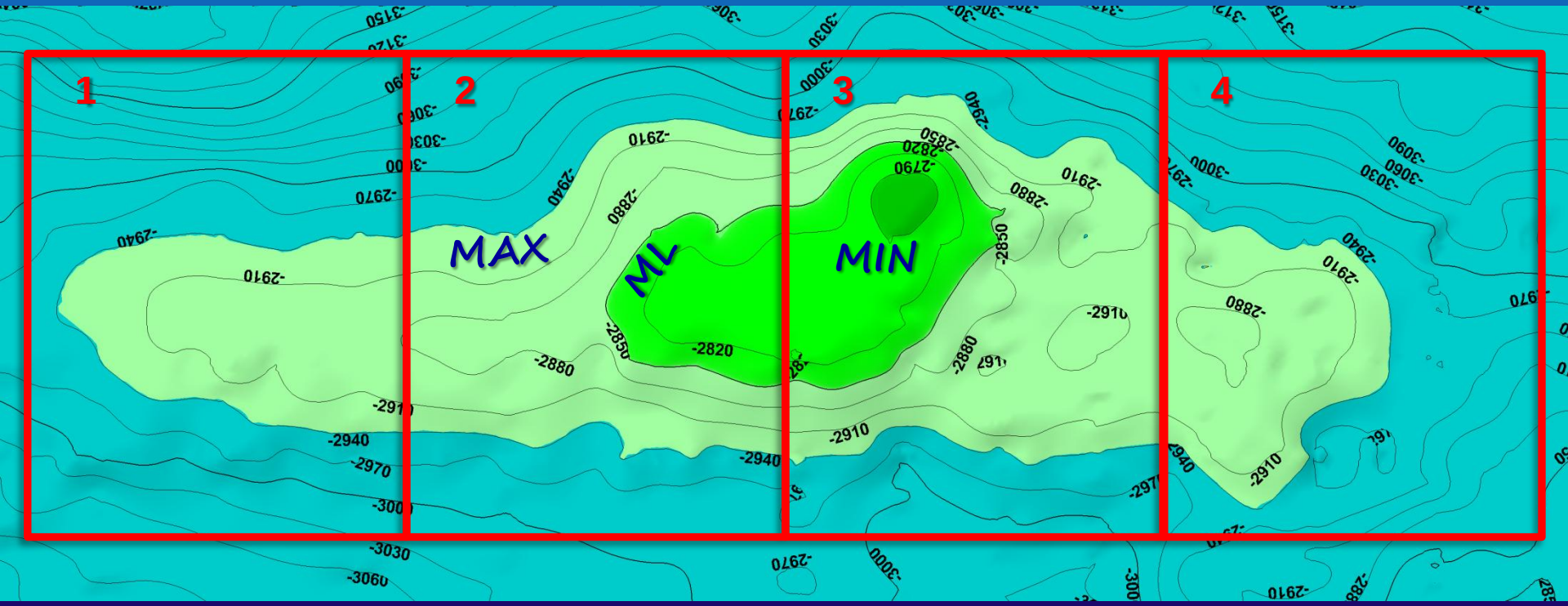
Typical exploration prospect





- Typical conventional exploration prospect
- Undrilled structure with OWC uncertainty

Lease blocks



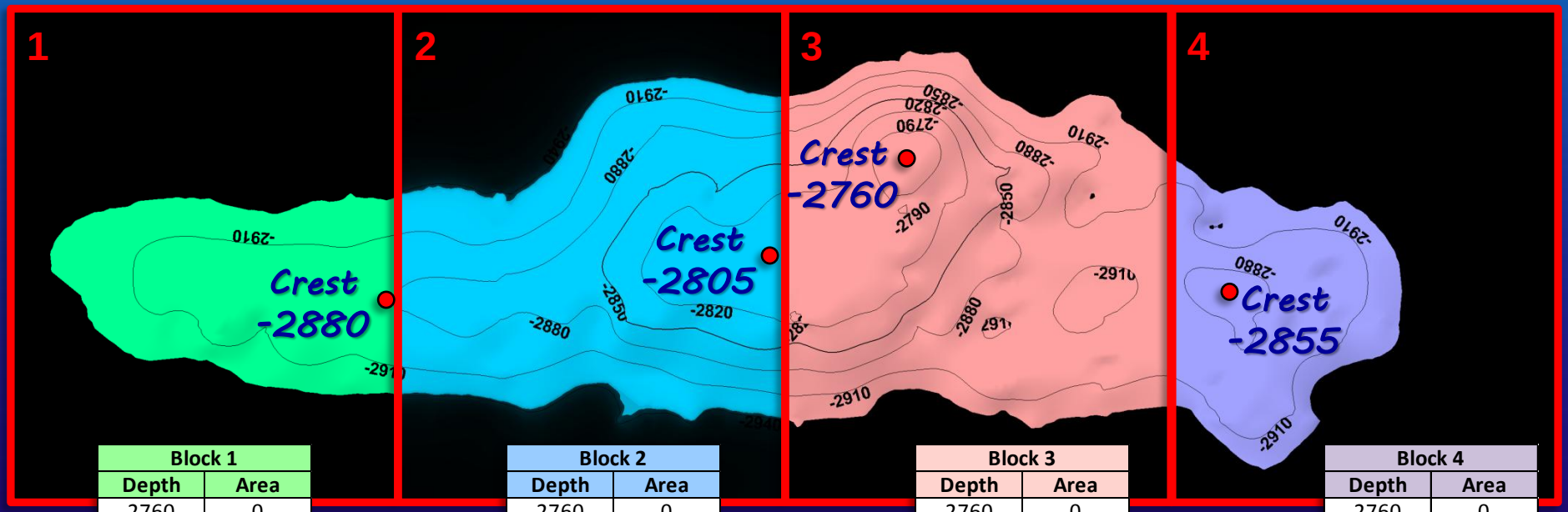
- Prospect extends over four lease blocks
- How should we allocate the resource to each block?
- How do we capture the risk and uncertainty associated with each lease block?

Tools we need

Probabilistic assessment application that allows …

- Segmentation of the prospect
- Depth-dependent volumetrics
- Integration of OWC uncertainty with trap geometry
- Risk dependencies and volume correlations
- Sophisticated analysis of results

Segments and depth-area pairs



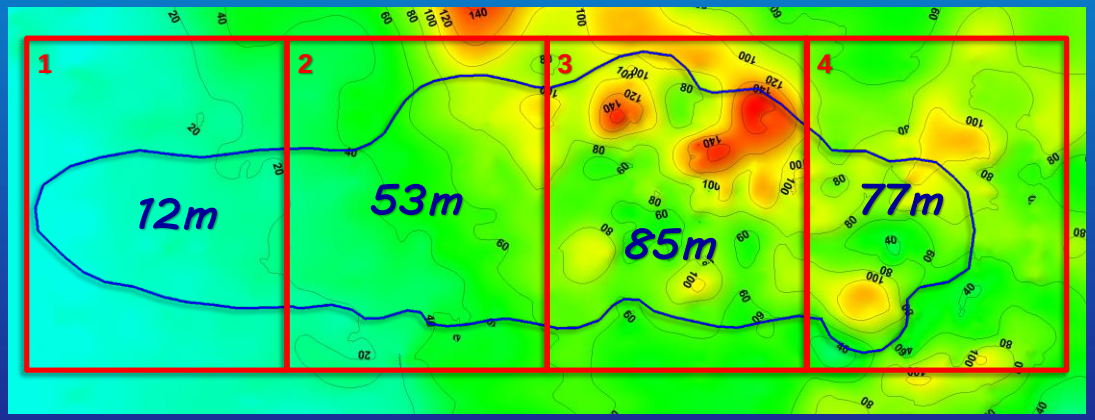
Block 1	
Depth	Area
2760	0
2776	0
2792	0
2808	0
2823	0
2839	0
2855	0
2880	0
2887	0.8
2903	5.09
2918	9.23
2934	13.49
2950	17.83

Block 2	
Depth	Area
2760	0
2776	0
2805	0
2808	1.77
2823	3.81
2839	5.62
2855	7.46
2871	9.71
2887	14.95
2903	18.74
2918	22.09
2934	25.86
2950	29.46

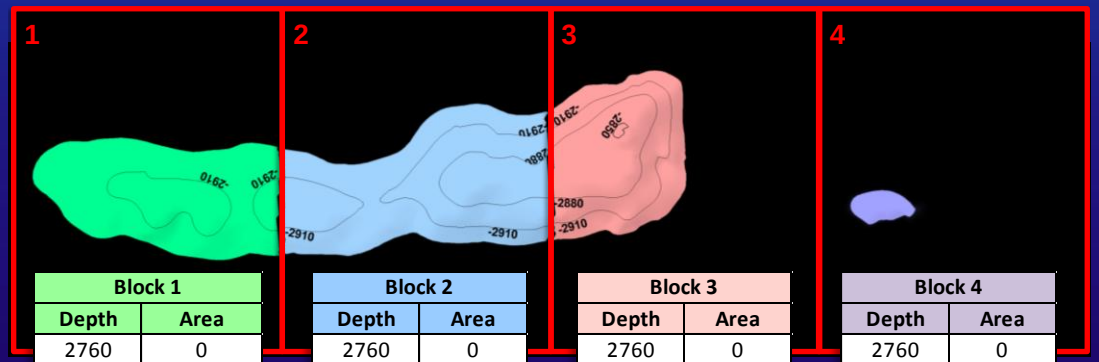
Block 3	
Depth	Area
2760	0
2776	0.3
2792	1.19
2808	4.52
2823	6.61
2839	8.36
2855	10.06
2871	12.05
2887	14.65
2903	21.08
2918	27.98
2934	31.39
2950	34.43

Block 4	
Depth	Area
2760	0
2776	0
2792	0
2808	0
2823	0
2839	0
2855	0
2871	0.25
2887	2.2
2903	5.32
2918	8.11
2934	10.62
2950	12.75

Gross thickness and base structure



- Little or no gross thickness uncertainty
- Main reservoir uncertainty is net sand and porosity within gross interval



Block 1	
Depth	Area
2760	0
2776	0
2792	0
2808	0
2823	0
2839	0
2855	0
2880	0
2887	0
2903	0
2918	5.91
2934	10.77
2950	15.57

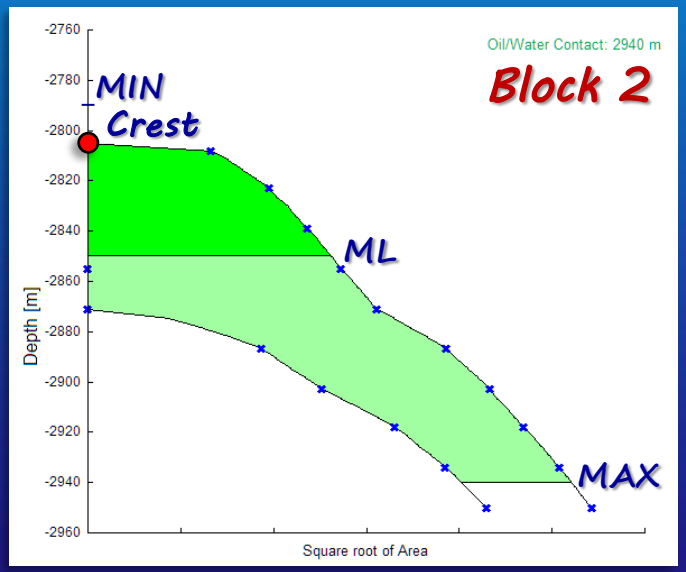
Block 2	
Depth	Area
2760	0
2776	0
2805	0
2808	0
2823	0
2839	0
2855	0
2871	0
2887	3.49
2903	6.35
2918	10.92
2934	14.8
2950	18.47

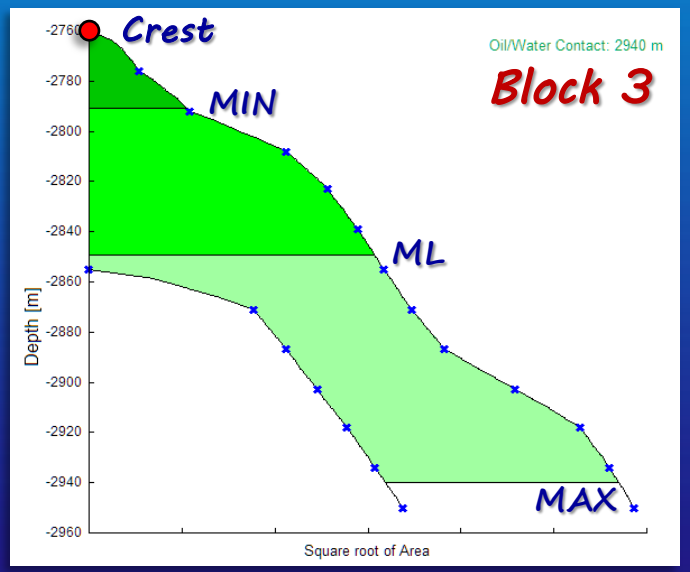
Block 3	
Depth	Area
2760	0
2776	0
2792	0
2808	0
2823	0
2839	0
2855	0
2871	3.17
2887	4.53
2903	6.05
2918	7.7
2934	9.49
2950	11.39

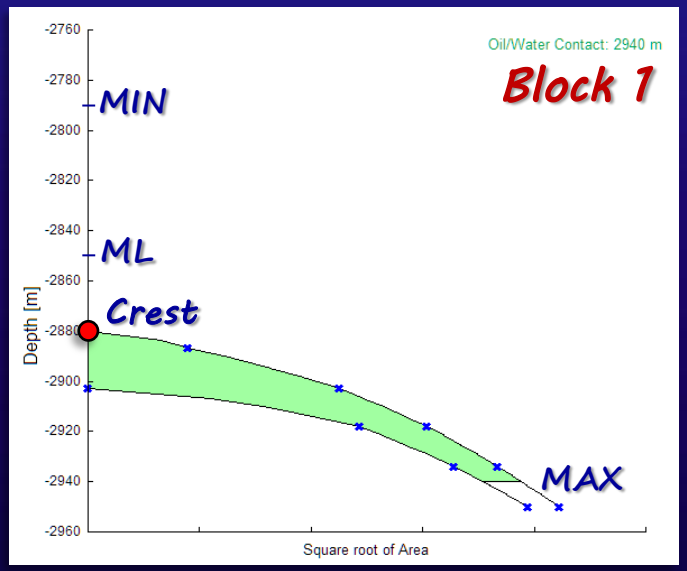
Block 4	
Depth	Area
2760	0
2776	0
2792	0
2808	0
2823	0
2839	0
2855	0
2871	0
2887	0
2903	0
2918	0
2934	0.45
2950	1.86

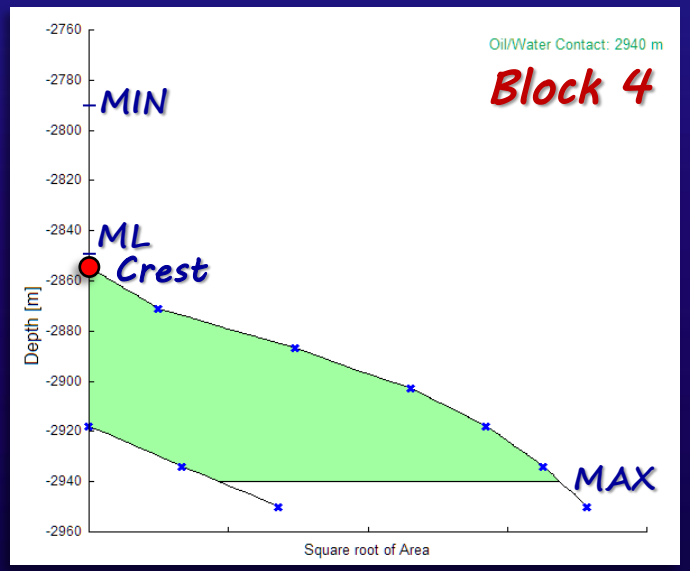
- Depth-area pairs on base surface allow better representation of reservoir geometry
- Thicker sections are in updip areas of blocks

Trap geometry graph

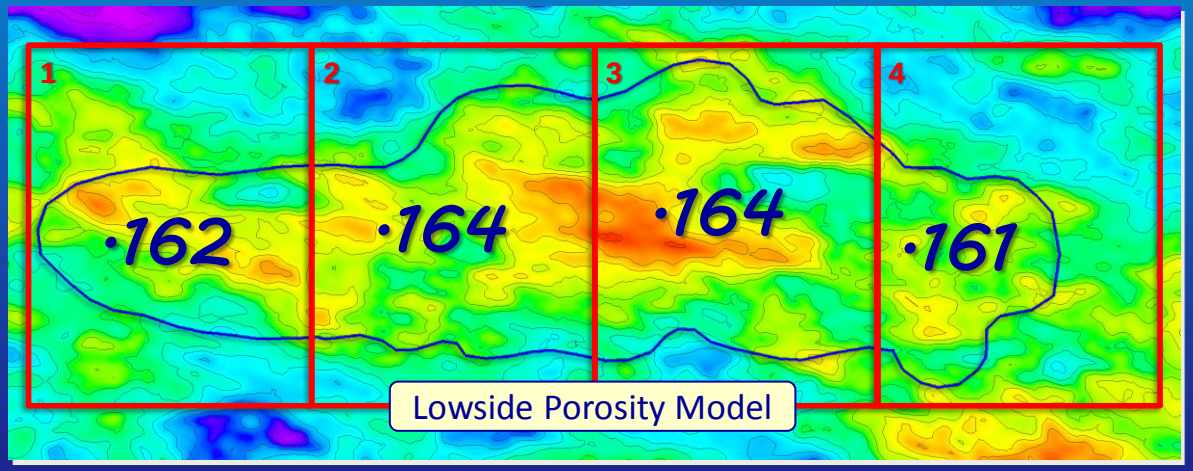


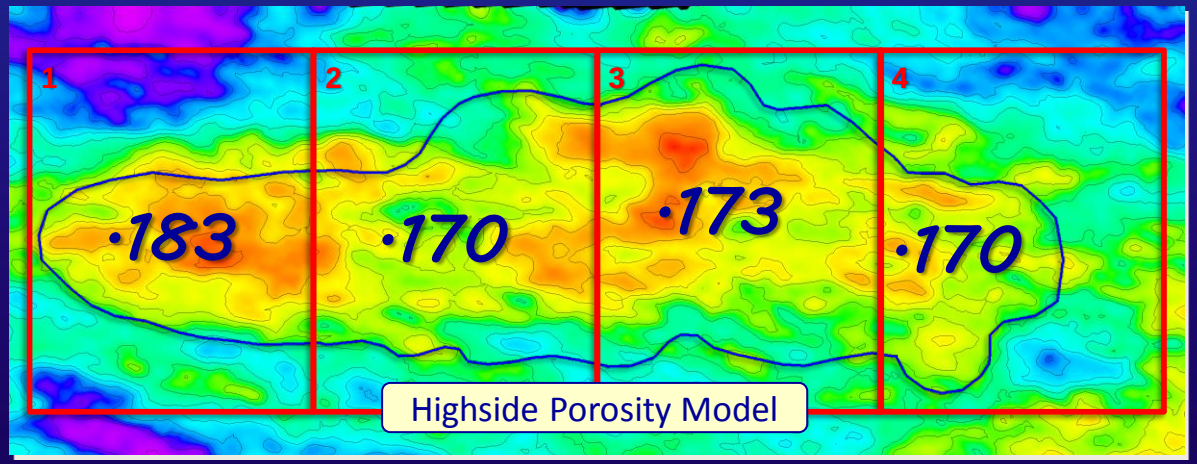


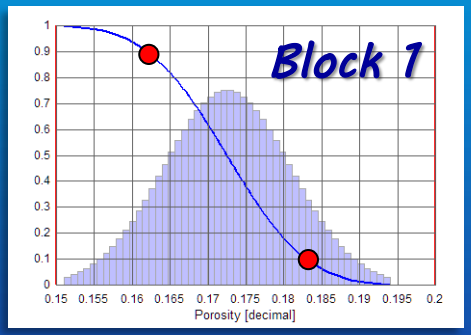


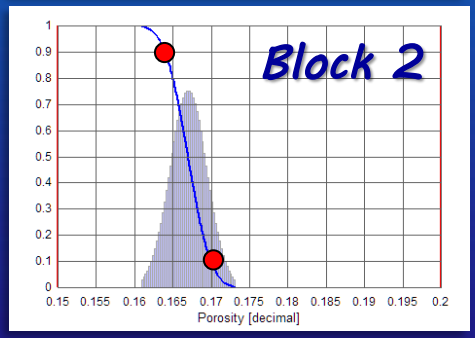


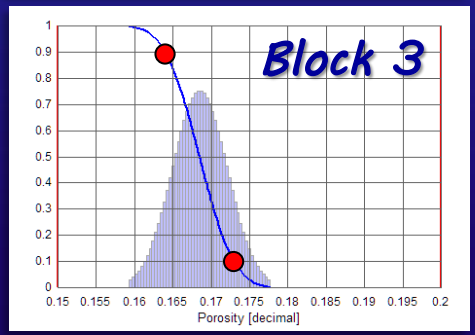
Porosity uncertainty

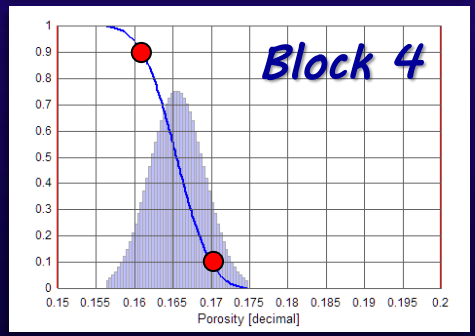






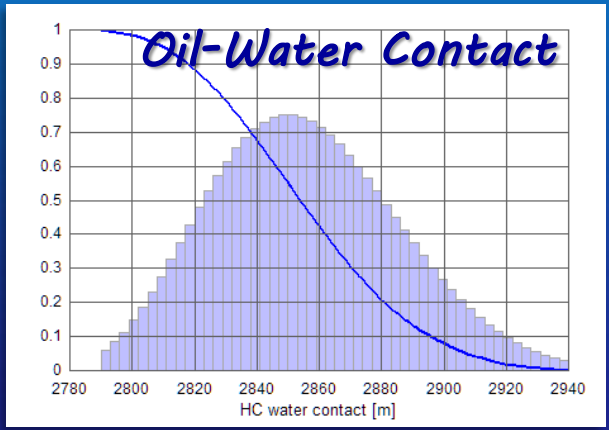


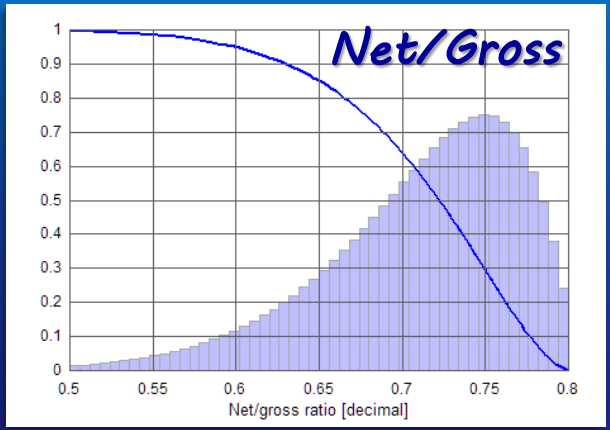


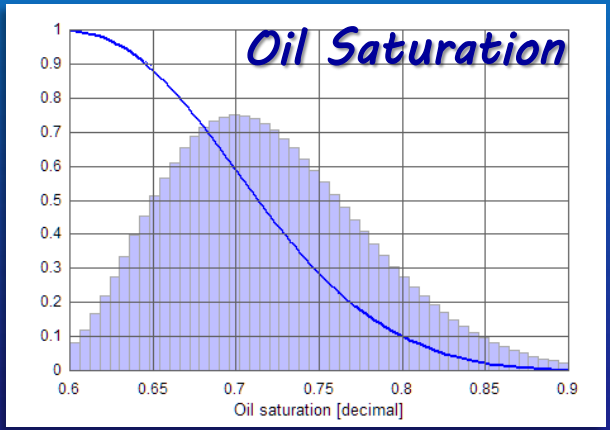


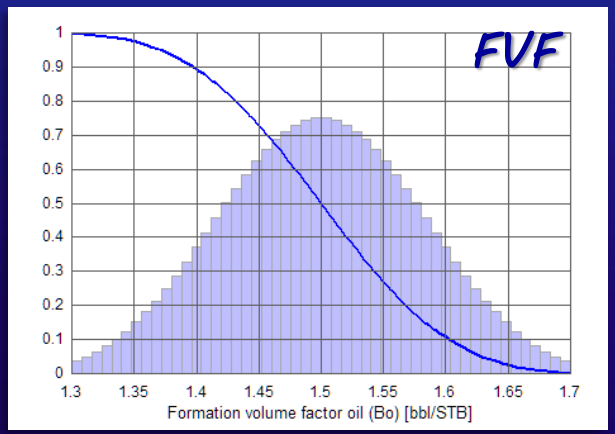
- Uncertainty around average porosity
- Assume lowside = p90, highside = p10

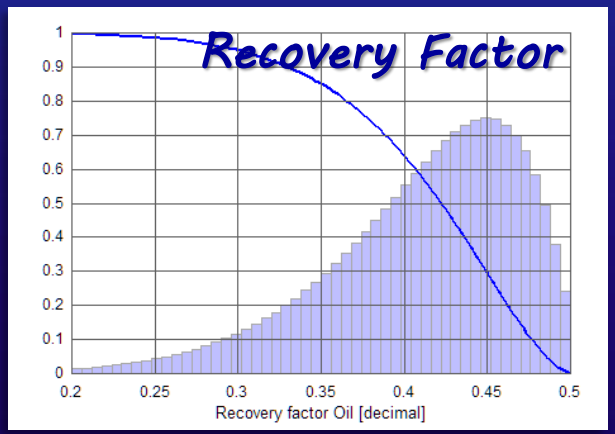
Other parameters





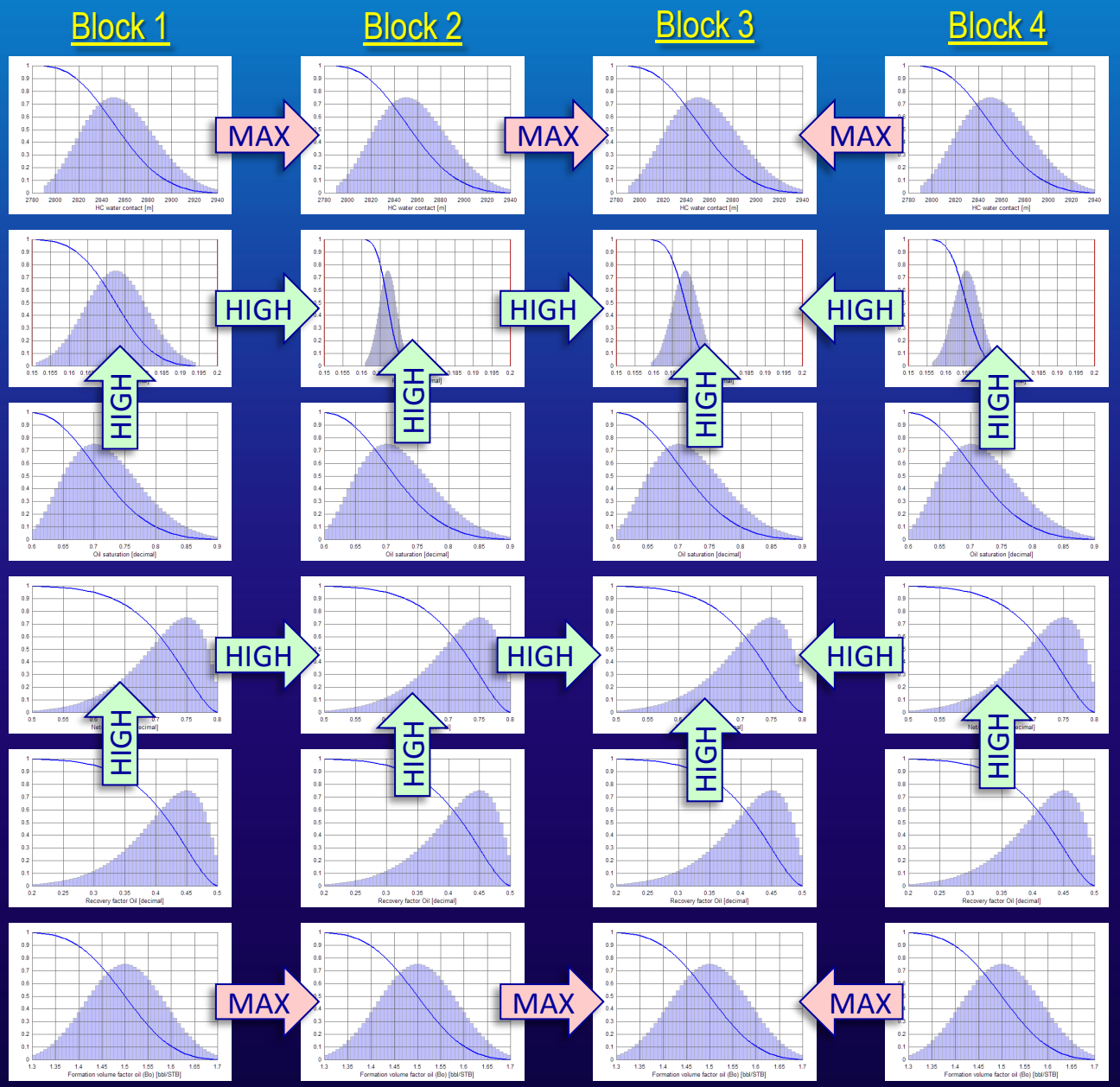




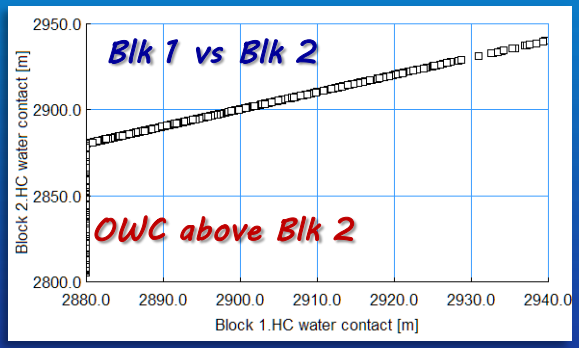


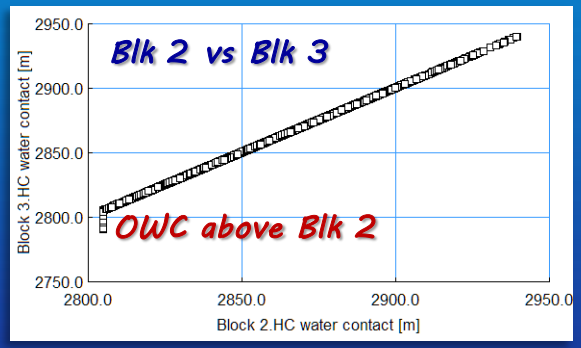
- Same distributions applied to all segments

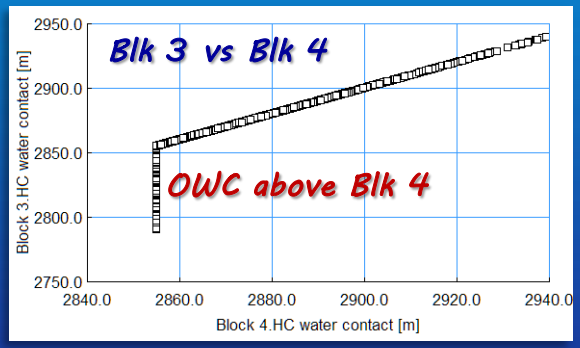
Correlation matrix



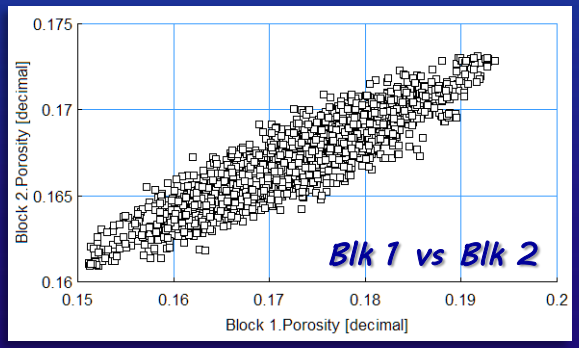
Correlation results

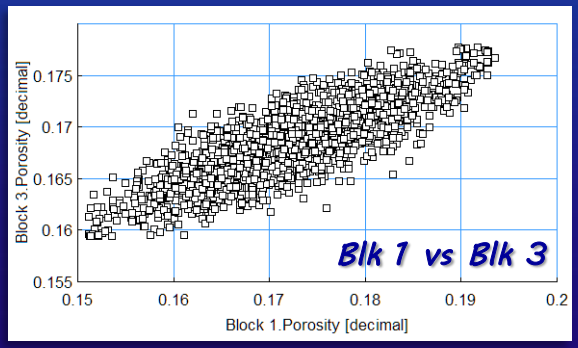


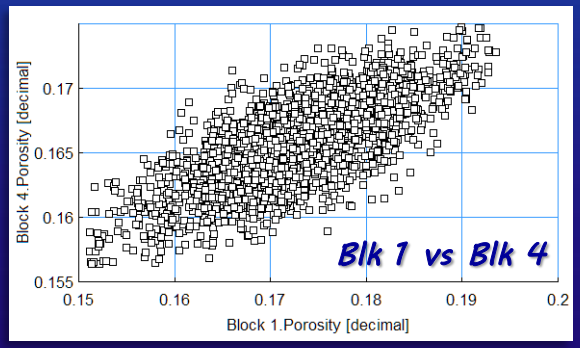




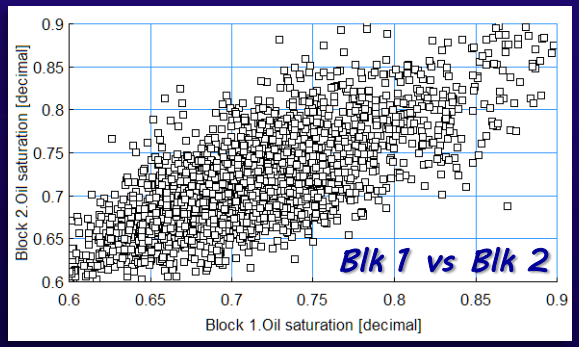
OWC

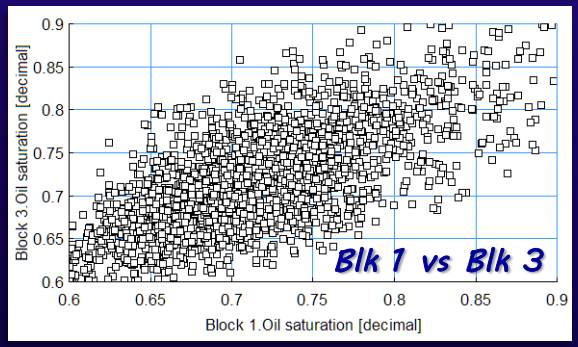


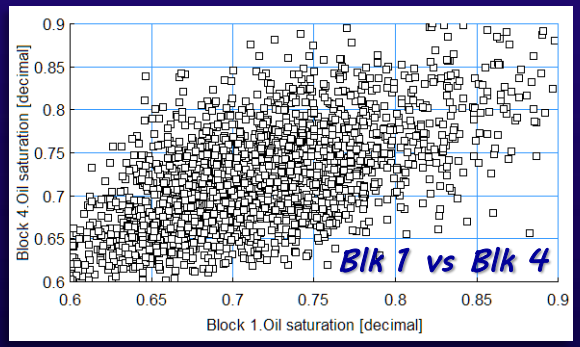




Porosity







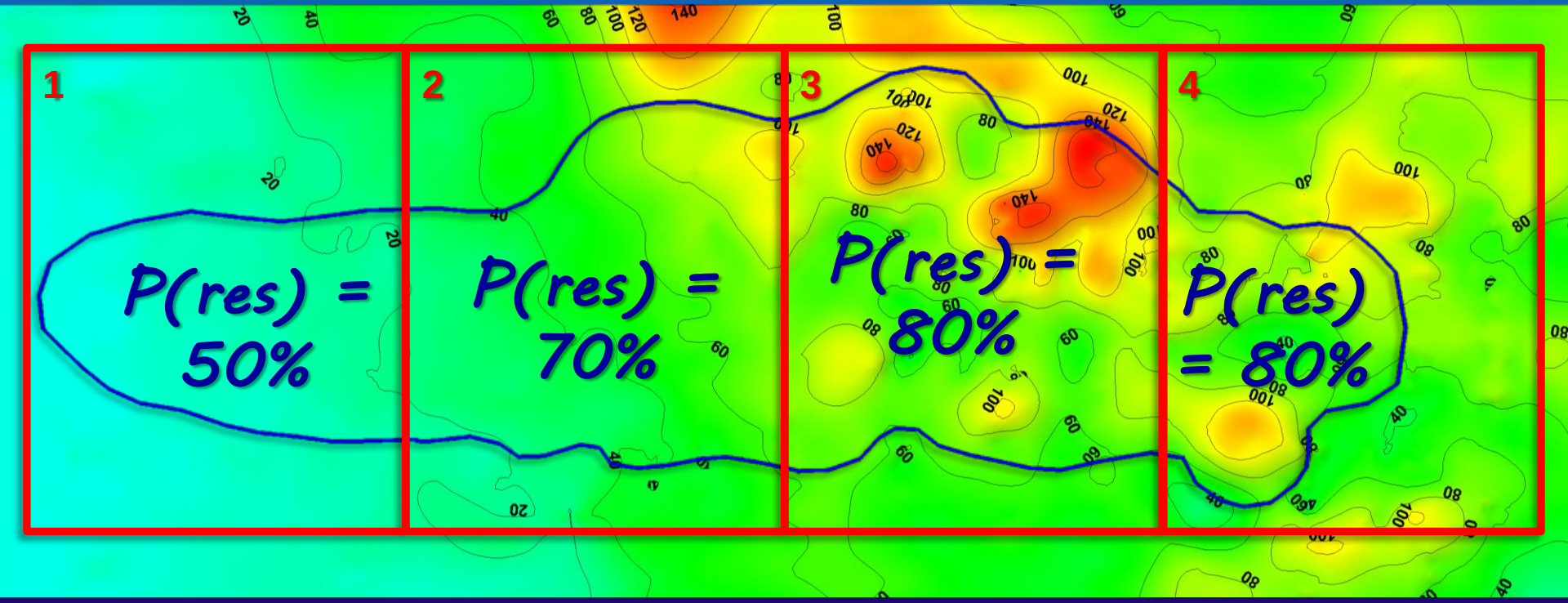
Oil Saturation

Risk summary

Risk Factor	Chance of Adequacy				Risk Dependency
	Block 1	Block 2	Block 3	Block 4	
Trap	1.00	1.00	1.00	1.00	---
Seal	.80	.80	.80	.80	Maximum
Reservoir	.50	.70	.80	.80	Maximum
Source	.80	.80	.80	.80	Maximum
Migration	1.00	1.00	1.00	1.00	---
Pg	**.320**	**.448**	**.512**	**.512**	

- All blocks share the same top seal and source
- Reservoir becomes riskier to the west
- Reservoir risk dependency prevents western blocks from succeeding without eastern blocks

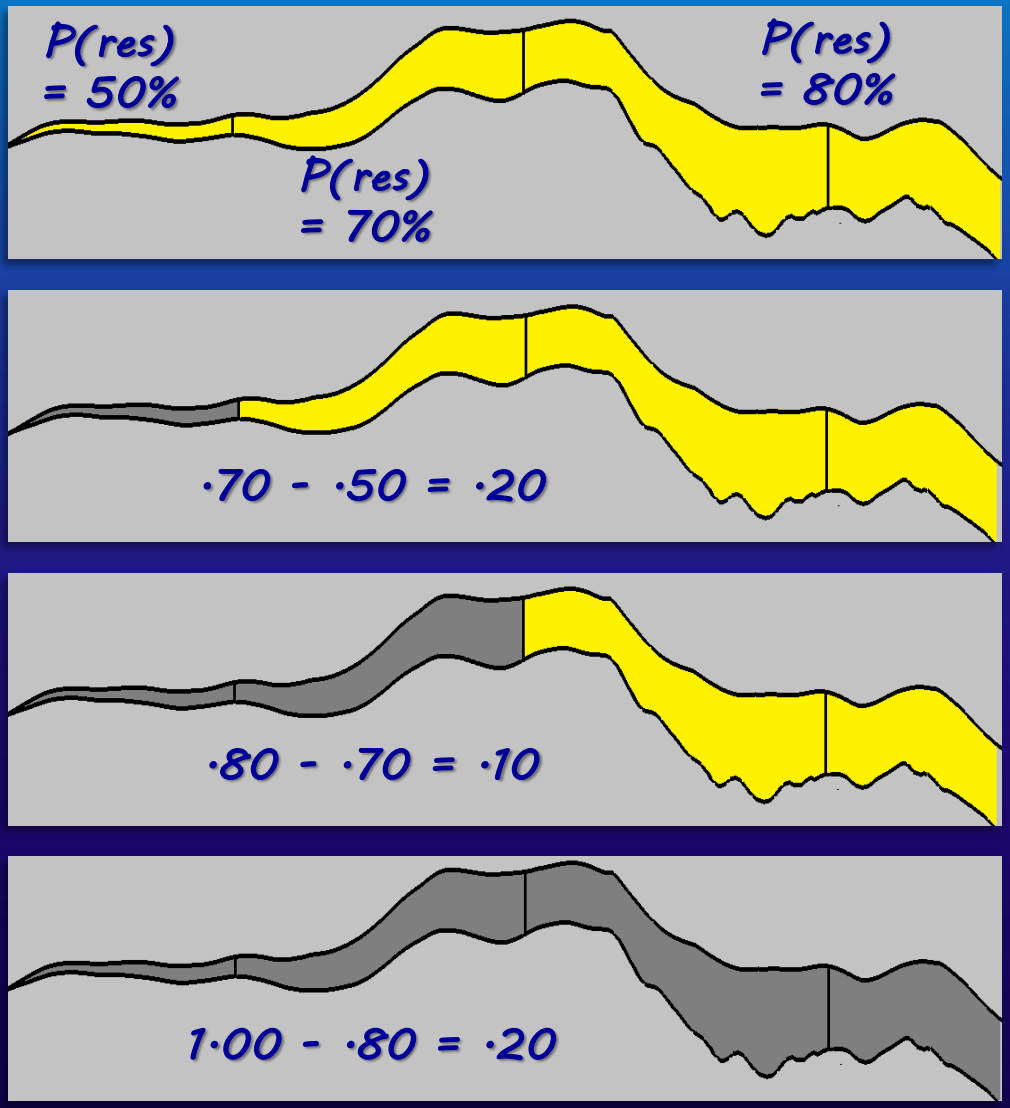
Gross thickness and reservoir chance



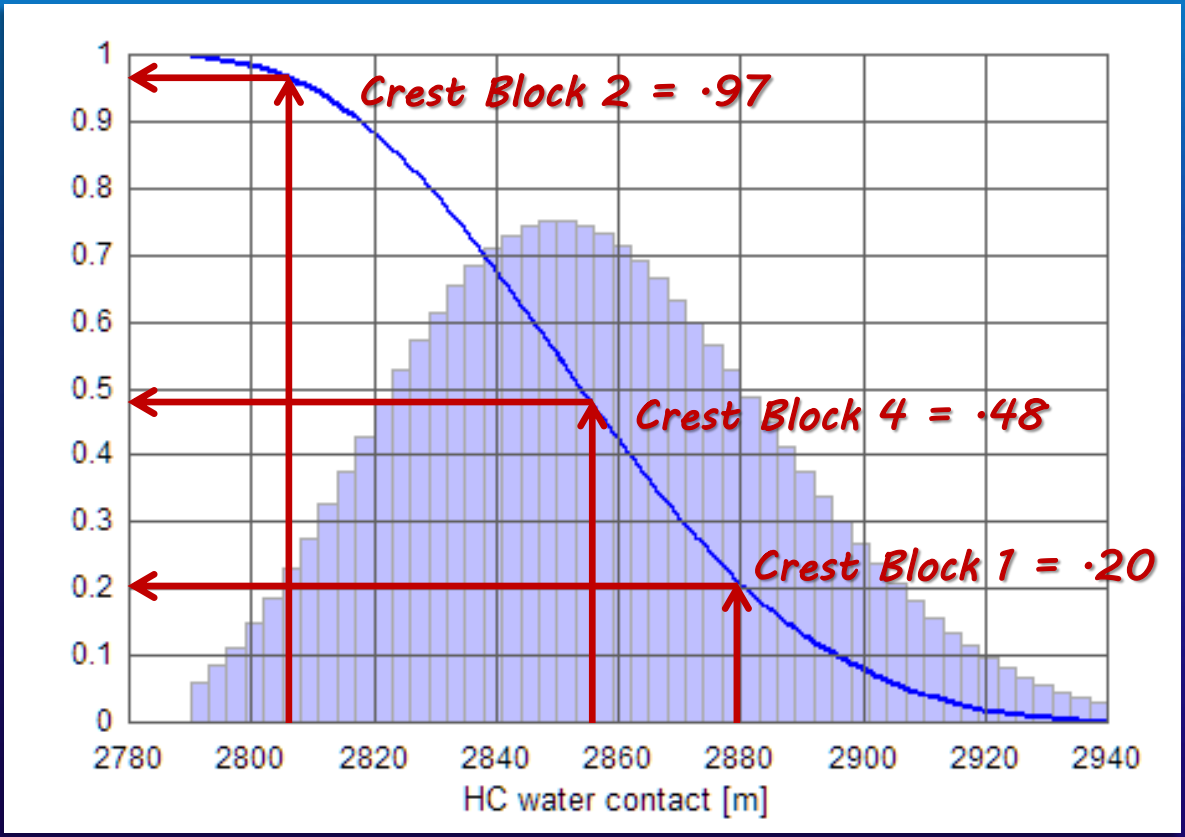
- Gross section thins to the west
- Blocks 1 and 2 are less likely to contain continuous, reservoir quality sand

Reservoir risk dependency

- All blocks = 0.50
- Blocks 2, 3, 4 = 0.20
- Blocks 3, 4 = 0.10
- Reservoir absent = 0.20

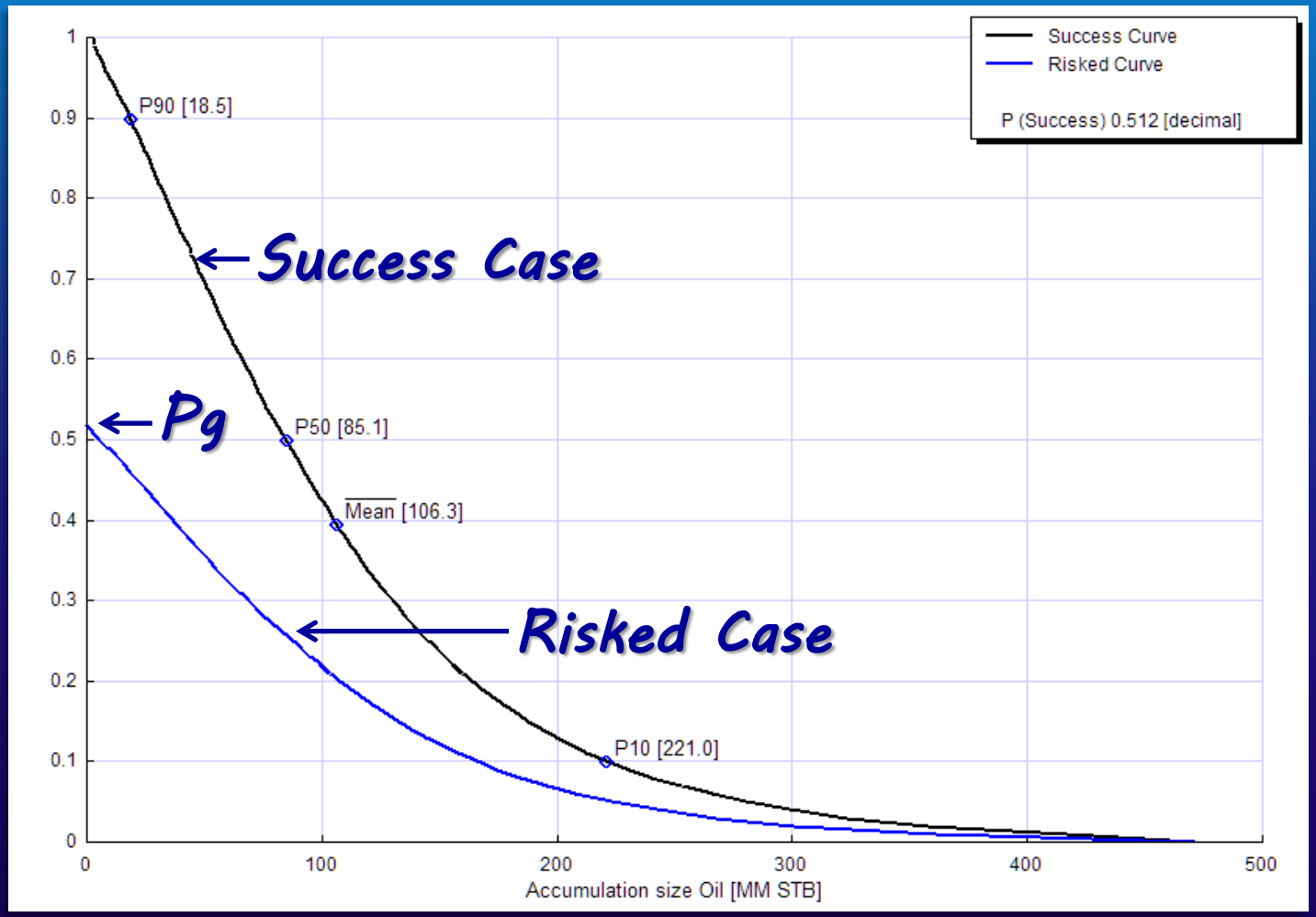


Additional risk



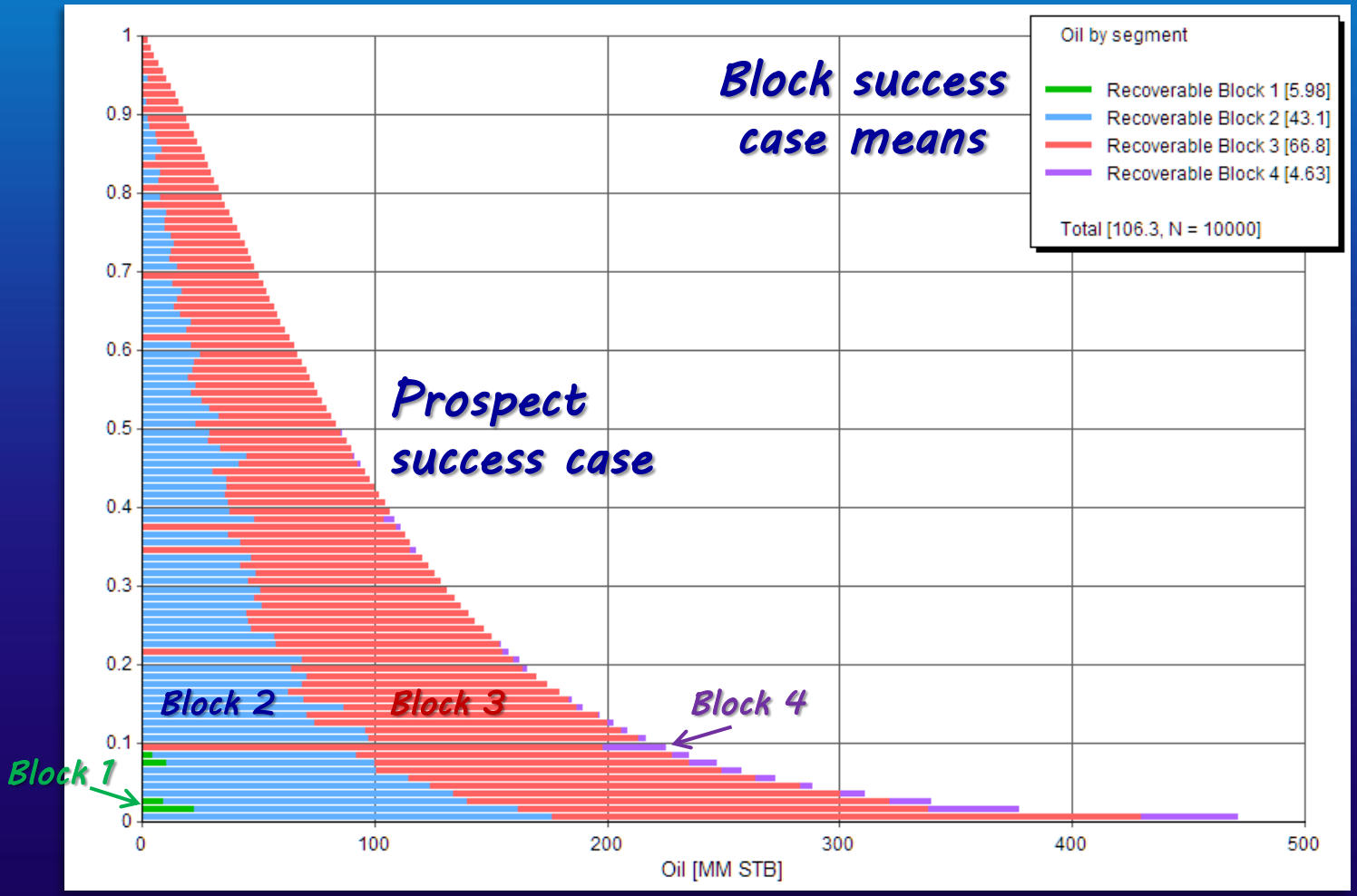
- Segment (block) fails if OWC is above highest point in the block
- Exceedance probability at highest point represents chance the block contains oil, given that all other geologic elements succeed
- Results from integration of OWC uncertainty and depth-area pairs

Prospect results



- Prospect Pg = 51% (chance on highest block)
- Prospect success mean = 106 MMBO (recoverable)

Resource diagram



- Blocks 1 and 4 make an insignificant contribution
- Low chance of success, small success case volume

Block chances of success

Block	Input Pg	P(contact below crest)*	Resulting COS
1	.320	.20	.32 x .20 = .064
2	.448	.97	.448 x .97 = .435
3	.512	1.00	.51 x 1.00 = .512
4	.512	.48	.51 x .48 = .246

Predicted results

* From OWC exceedance probability curve

N	Block 1 [0.0666]	Block 2 [0.4337]	Block 3 [0.5123]	Block 4 [0.2522]	Probability
4176		X	X		0.2139
2990		X	X	X	0.1532
1300	X	X	X	X	0.0666
901			X		0.0462
633			X	X	0.0324
---					0.4877

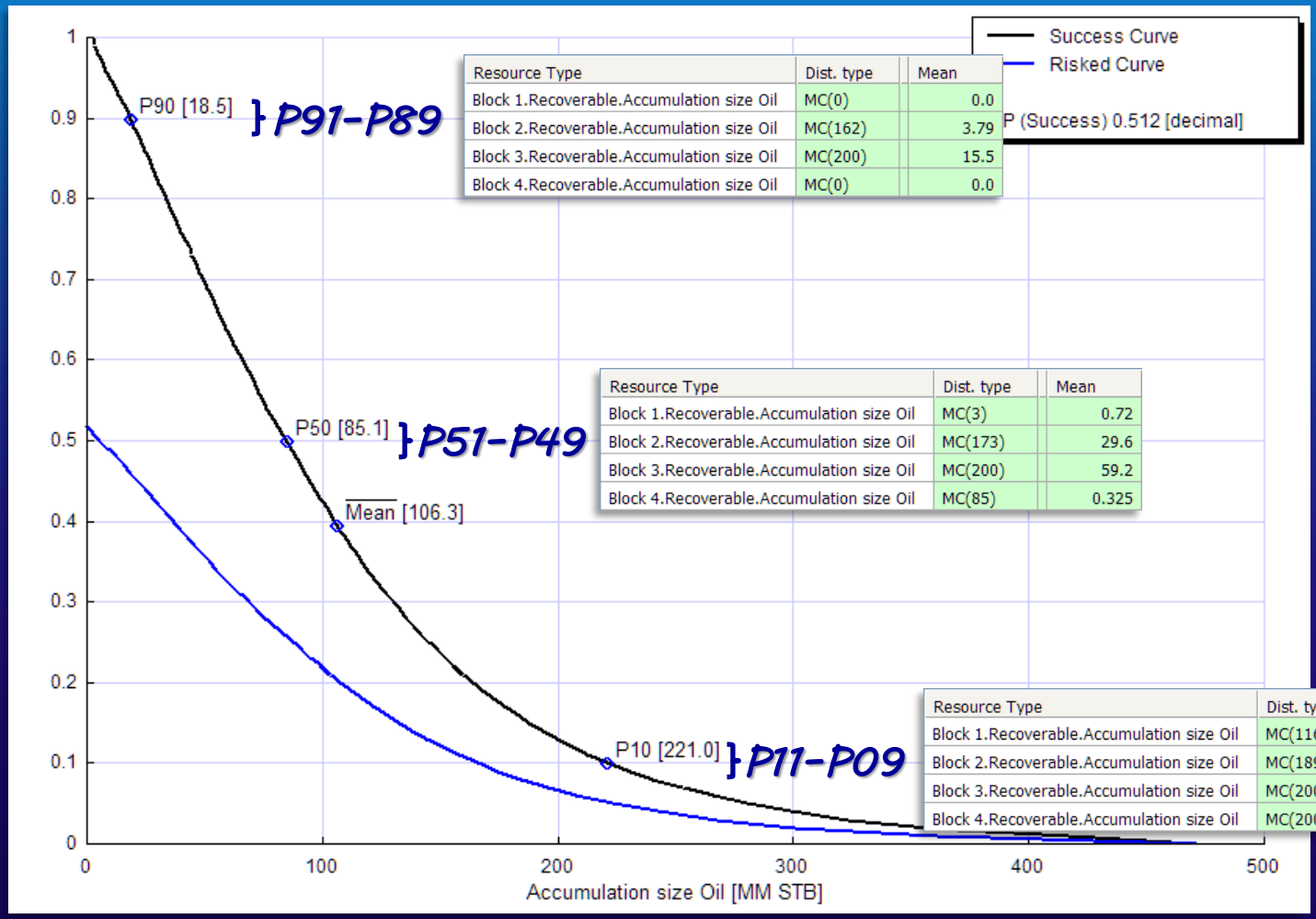
Monte Carlo results

Block relative values

Block	Success Mean (MMBO)	COS	Risked Mean (MMBO)	Relative Value
1	5.98	.067	5.98 x .067 = .40	1%
2	43.1	.434	43.1 x .434 = 18.7	34%
3	66.8	.512	66.8 x .512= 34.2	63%
4	4.63	.252	4.63 x .252 = 1.2	2%
Prospect	**106.3**	**.512**	**54.5**	**100%**

- Relative Value = (block risked mean) / (prospect risked mean)

“Percentile neighborhoods”



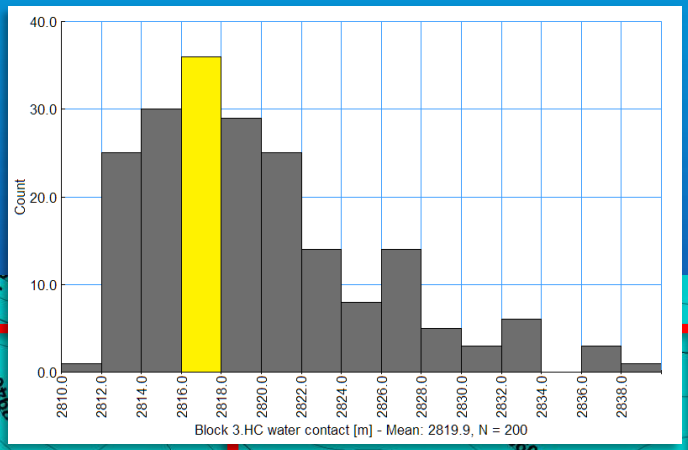
Resource Type	Dist. type	Mean
Block 1.Recoverable.Accumulation size Oil	MC(0)	0.0
Block 2.Recoverable.Accumulation size Oil	MC(162)	3.79
Block 3.Recoverable.Accumulation size Oil	MC(200)	15.5
Block 4.Recoverable.Accumulation size Oil	MC(0)	0.0

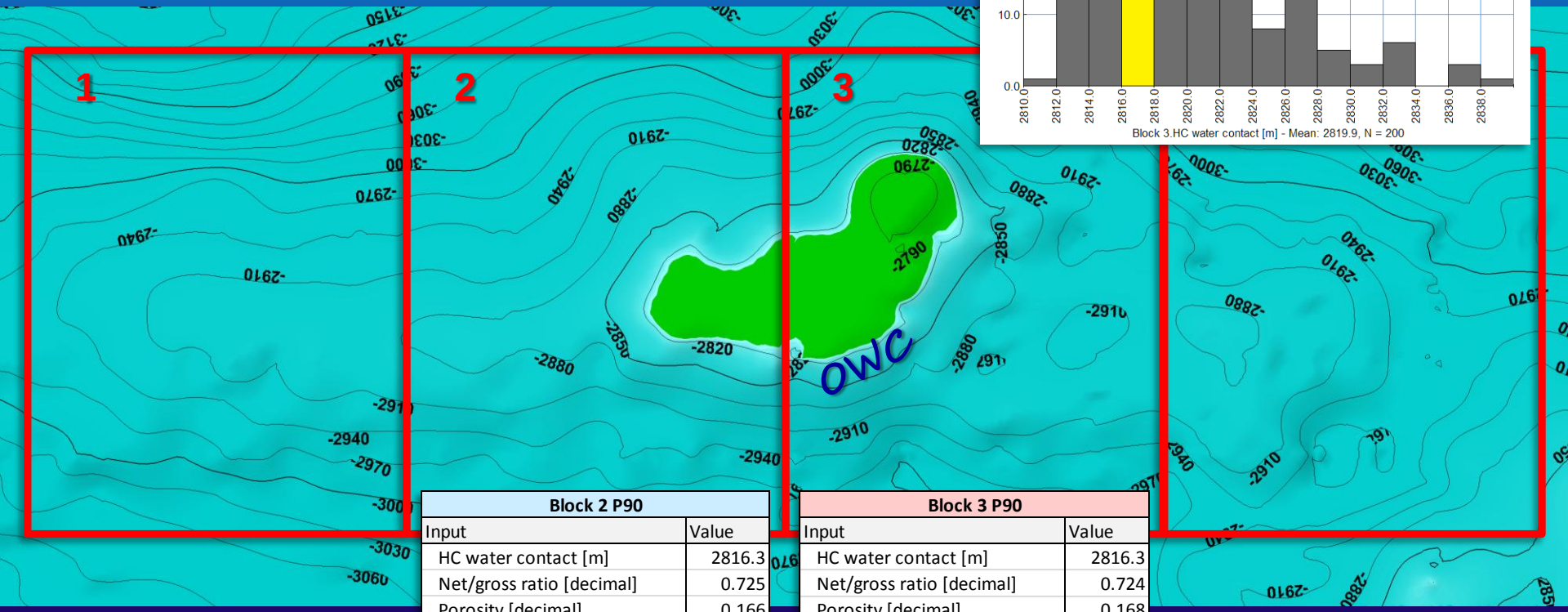
Resource Type	Dist. type	Mean
Block 1.Recoverable.Accumulation size Oil	MC(3)	0.72
Block 2.Recoverable.Accumulation size Oil	MC(173)	29.6
Block 3.Recoverable.Accumulation size Oil	MC(200)	59.2
Block 4.Recoverable.Accumulation size Oil	MC(85)	0.325

Resource Type	Dist. type	Mean
Block 1.Recoverable.Accumulation size Oil	MC(116)	2.64
Block 2.Recoverable.Accumulation size Oil	MC(189)	90.3
Block 3.Recoverable.Accumulation size Oil	MC(200)	127.9
Block 4.Recoverable.Accumulation size Oil	MC(200)	6.39

- Percentile neighborhoods: trials +/- 1 percentile around P90, P50, P10
- Allows analysis of segment contributions and parameters for economics cases

P90 representative trial for economic analysis

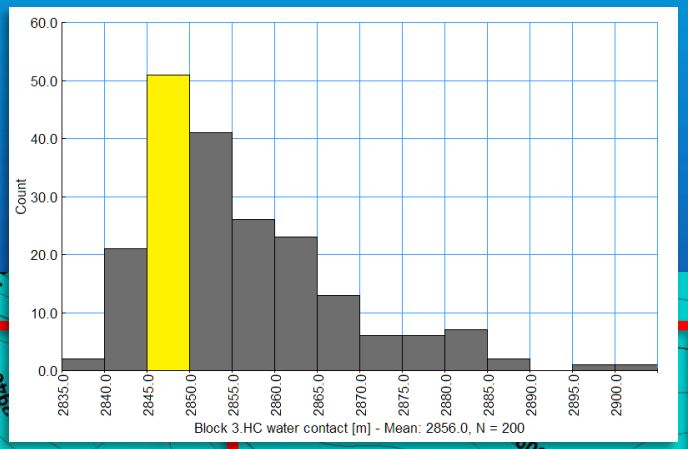


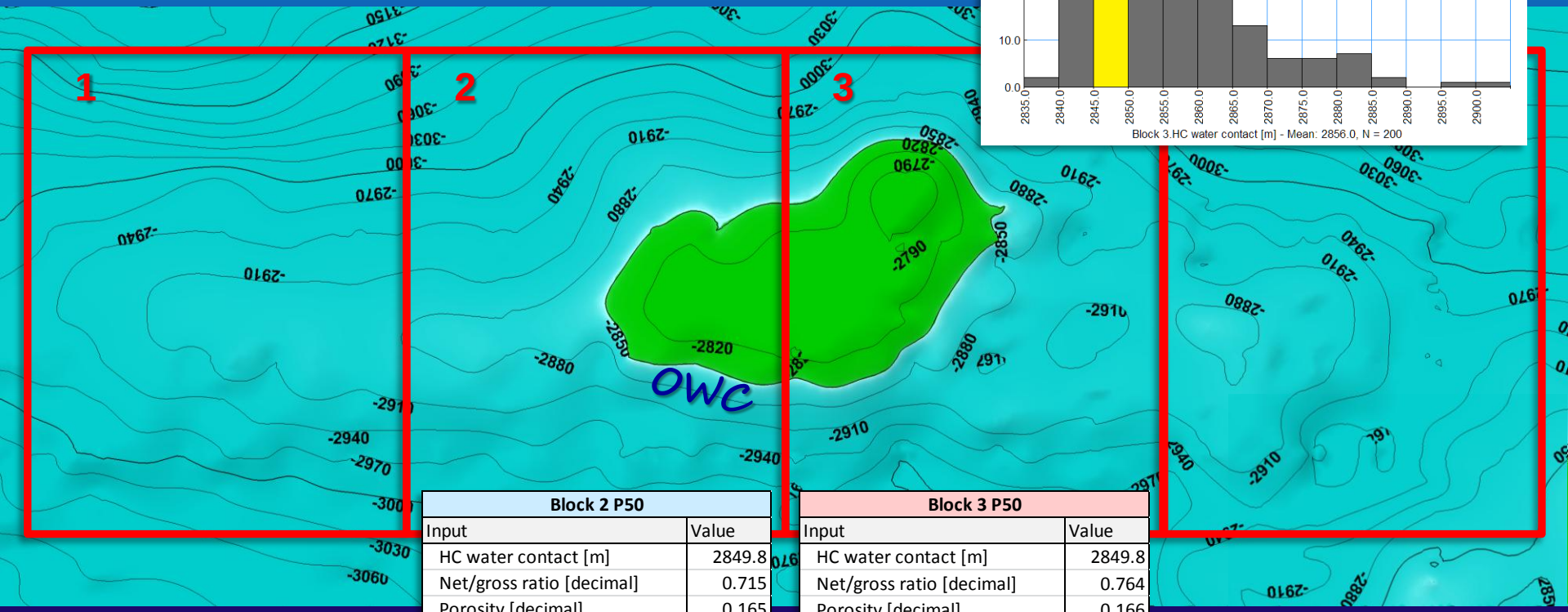


Block 2 P90	
Input	Value
HC water contact [m]	2816.3
Net/gross ratio [decimal]	0.725
Porosity [decimal]	0.166
Oil saturation [decimal]	0.658
FVF (Bo) [bbl/STB]	1.51
Recovery factor Oil [decimal]	0.434
Results	Value
Productive area [km2]	2.87
Average gross pay [m]	7.59
Average net pay [m]	5.5
Inplace Oil [MM STB]	7.2
Recoverable Oil [MM STB]	3.12

Block 3 P90	
Input	Value
HC water contact [m]	2816.3
Net/gross ratio [decimal]	0.724
Porosity [decimal]	0.168
Oil saturation [decimal]	0.731
FVF (Bo) [bbl/STB]	1.51
Recovery factor Oil [decimal]	0.418
Results	Value
Productive area [km2]	5.63
Average gross pay [m]	17.6
Average net pay [m]	12.7
Inplace Oil [MM STB]	36.8
Recoverable Oil [MM STB]	15.4

P50 representative trial for economic analysis

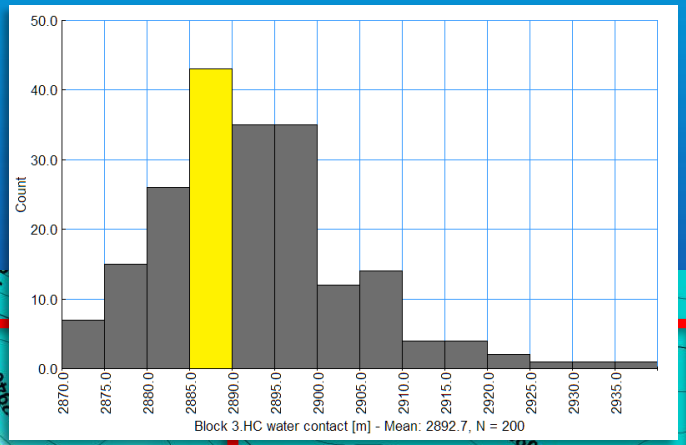


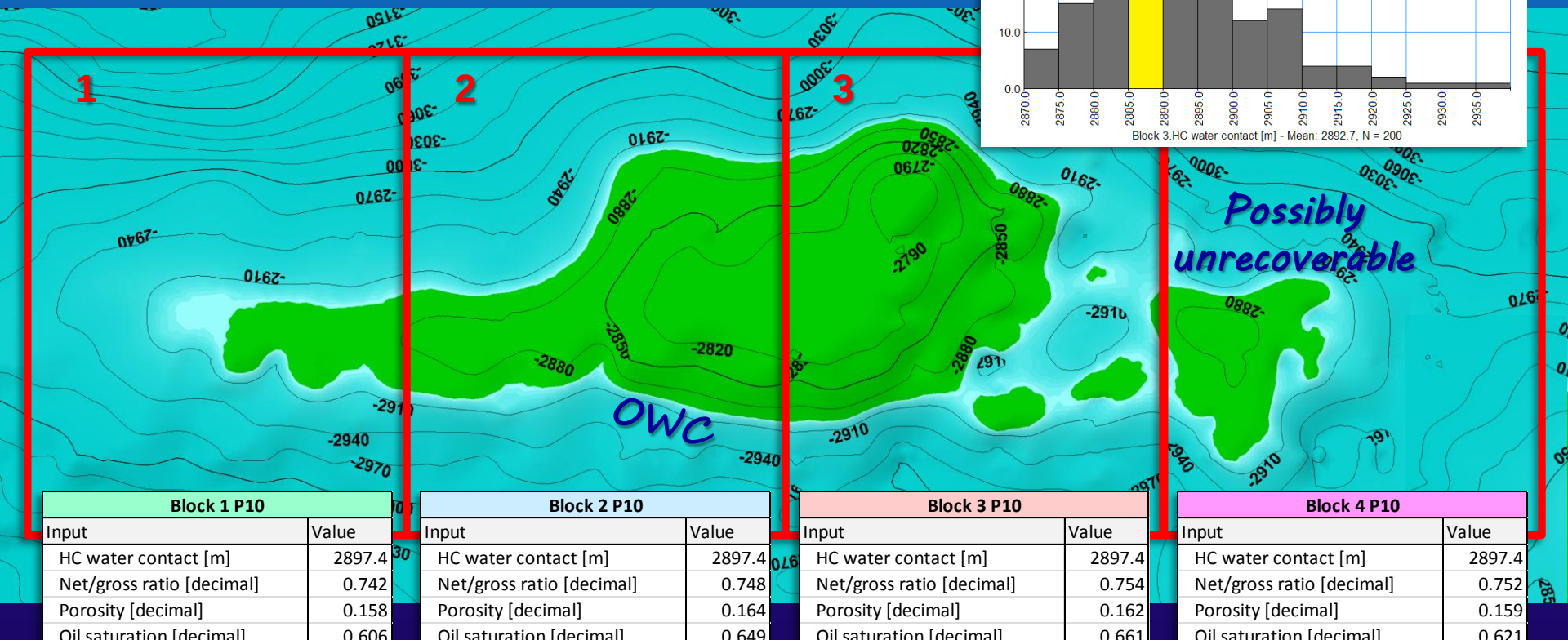


Block 2 P50	
Input	Value
HC water contact [m]	2849.8
Net/gross ratio [decimal]	0.715
Porosity [decimal]	0.165
Oil saturation [decimal]	0.642
FVF (Bo) [bbl/STB]	1.54
Recovery factor Oil [decimal]	0.437
Results	Value
Productive area [km2]	6.84
Average gross pay [m]	27.2
Average net pay [m]	19.5
Inplace Oil [MM STB]	57.8
Recoverable Oil [MM STB]	25.3

Block 3 P50	
Input	Value
HC water contact [m]	2849.8
Net/gross ratio [decimal]	0.764
Porosity [decimal]	0.166
Oil saturation [decimal]	0.682
FVF (Bo) [bbl/STB]	1.54
Recovery factor Oil [decimal]	0.477
Results	Value
Productive area [km2]	9.49
Average gross pay [m]	37.5
Average net pay [m]	28.7
Inplace Oil [MM STB]	125.6
Recoverable Oil [MM STB]	59.9

P10 representative trial for economic analysis





Block 1 P10	
Input	Value
HC water contact [m]	2897.4
Net/gross ratio [decimal]	0.742
Porosity [decimal]	0.158
Oil saturation [decimal]	0.606
FVF (Bo) [bbl/STB]	1.5
Recovery factor Oil [decimal]	0.43
Results	Value
Productive area [km2]	3.4
Average gross pay [m]	7.05
Average net pay [m]	5.23
Inplace Oil [MM STB]	7.16
Recoverable Oil [MM STB]	3.08

Block 2 P10	
Input	Value
HC water contact [m]	2897.4
Net/gross ratio [decimal]	0.748
Porosity [decimal]	0.164
Oil saturation [decimal]	0.649
FVF (Bo) [bbl/STB]	1.5
Recovery factor Oil [decimal]	0.396
Results	Value
Productive area [km2]	17.4
Average gross pay [m]	37.6
Average net pay [m]	28.1
Inplace Oil [MM STB]	217.6
Recoverable Oil [MM STB]	86.2

Block 3 P10	
Input	Value
HC water contact [m]	2897.4
Net/gross ratio [decimal]	0.754
Porosity [decimal]	0.162
Oil saturation [decimal]	0.661
FVF (Bo) [bbl/STB]	1.5
Recovery factor Oil [decimal]	0.461
Results	Value
Productive area [km2]	18.7
Average gross pay [m]	44.7
Average net pay [m]	33.7
Inplace Oil [MM STB]	283.3
Recoverable Oil [MM STB]	130.6

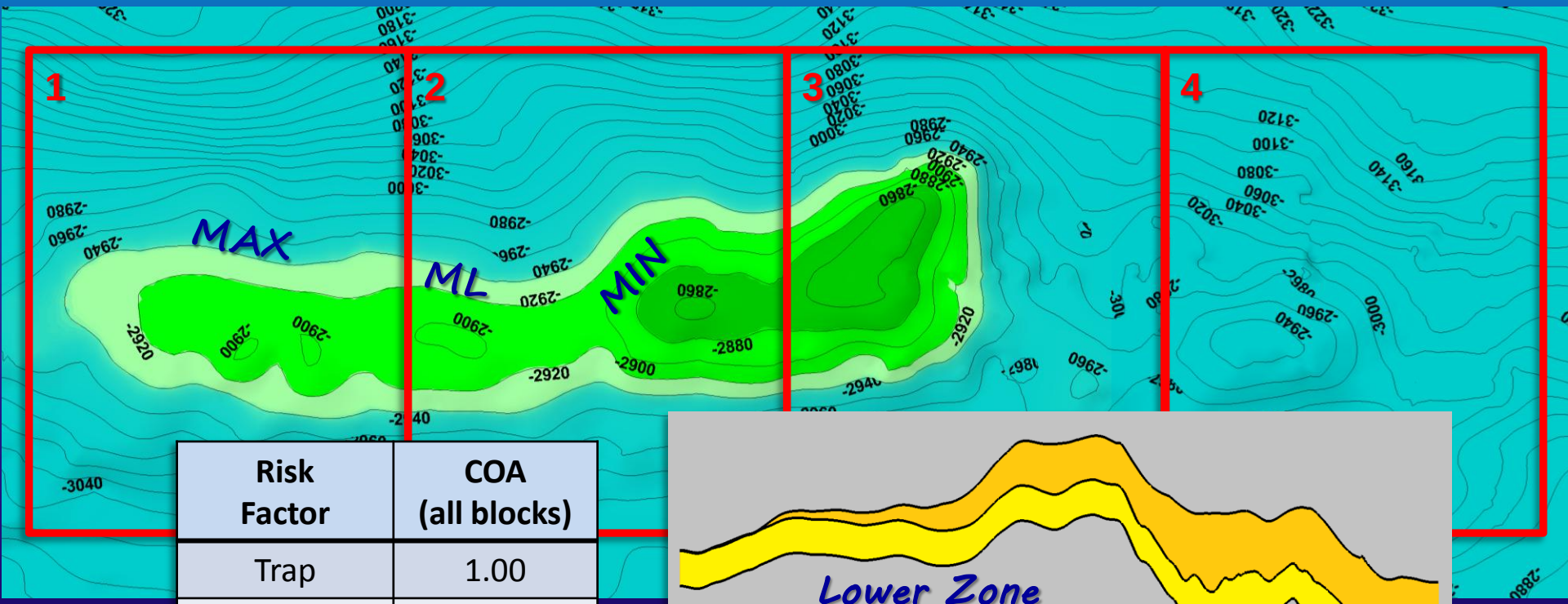
Block 4 P10	
Input	Value
HC water contact [m]	2897.4
Net/gross ratio [decimal]	0.752
Porosity [decimal]	0.159
Oil saturation [decimal]	0.621
FVF (Bo) [bbl/STB]	1.5
Recovery factor Oil [decimal]	0.448
Results	Value
Productive area [km2]	4.07
Average gross pay [m]	12.4
Average net pay [m]	9.31
Inplace Oil [MM STB]	15.7
Recoverable Oil [MM STB]	7.01

Representative trials summary

Block	P90 Group Trial (MMBO)	P50 Group Trial (MMBO)	P10 Group Trial (MMBO)	Discretized Mean .20 - .55 - .25 (MMBO)	Relative Value
1	0	0	3.1	0.8	< 1%
2	3.1	25.3	86.2	36.1	34%
3	15.4	59.9	130.6	68.7	64%
4	0	0	7.0	1.8	2%
Trial Total	**18.5**	**85.2**	**226.9**	**107.3**	**100%**
MC Result	**18.5**	**85.1**	**221.0**	**106.3 (MC mean)**	

- Recoverable oil volumes for representative trials
- Relative Value = (discretized mean) / (sum of discretized means)
- Relative values are similar to those calculated from risked means
- Monte Carlo (MC) results presented for comparison

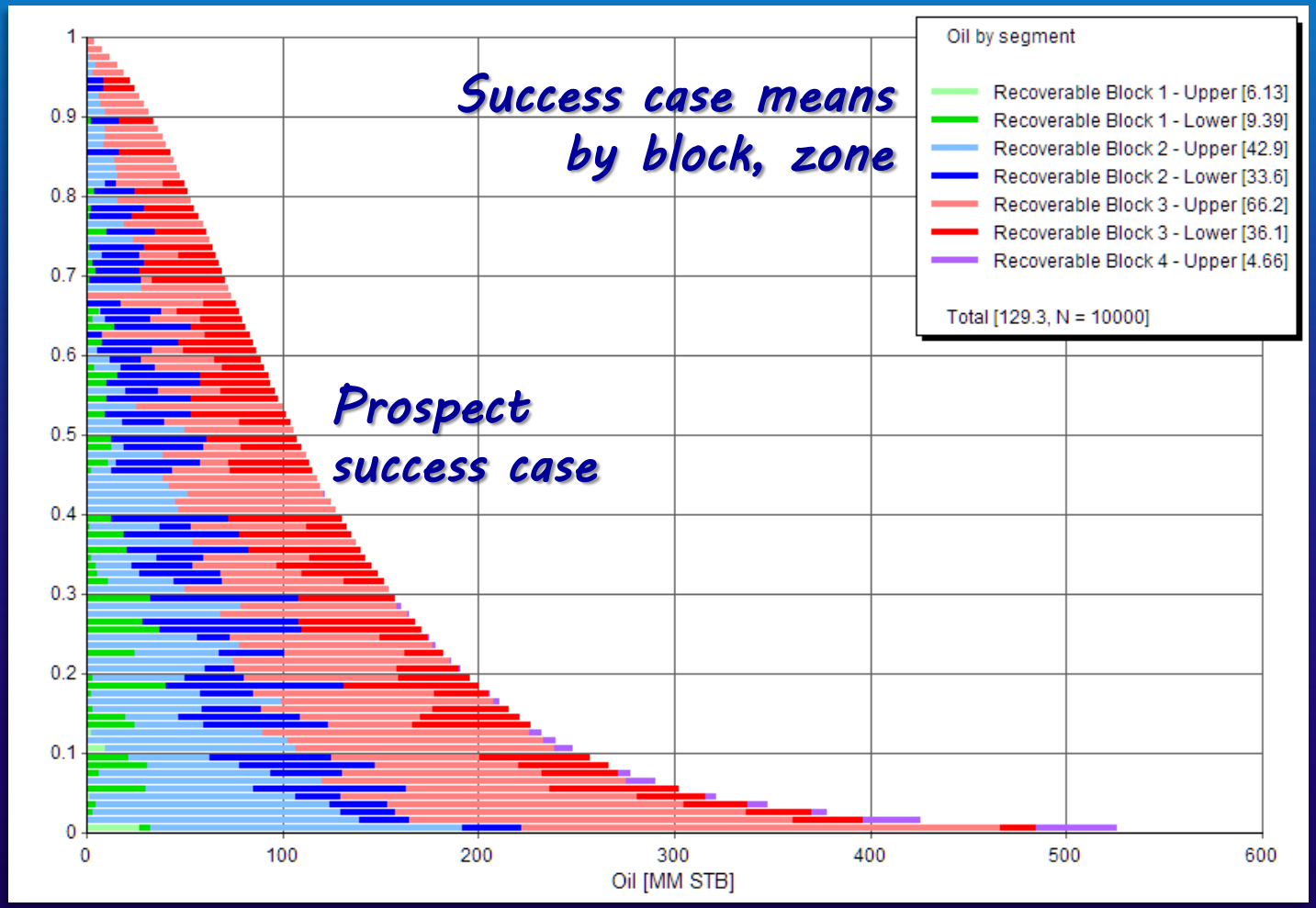
Lower zone



Risk Factor	COA (all blocks)
Trap	1.00
Seal	1.00
Reservoir	.50
Source	.80
Migration	1.00
Pg	**.40**

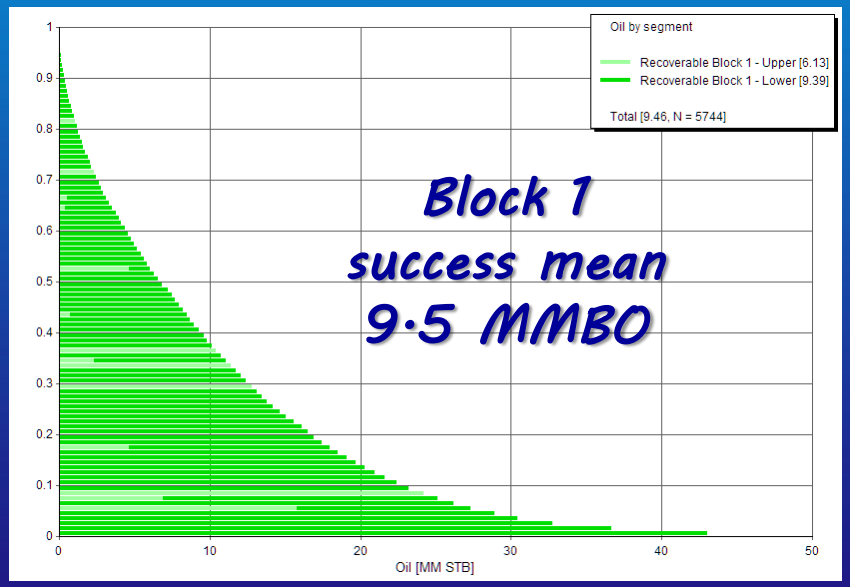
- Lower blocks share reservoir and source risk dependency (maximum)
- Upper and Lower zones share source risk dependency (maximum)

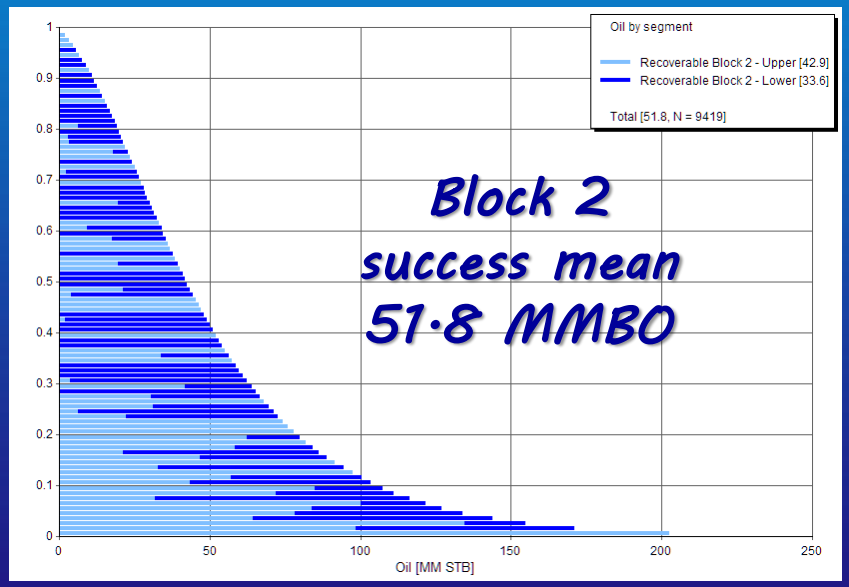
Upper zone + Lower zone

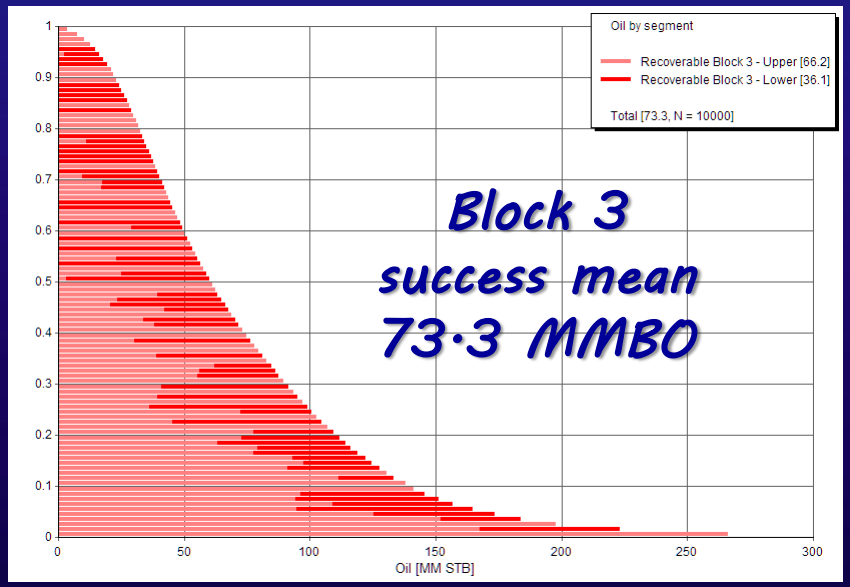


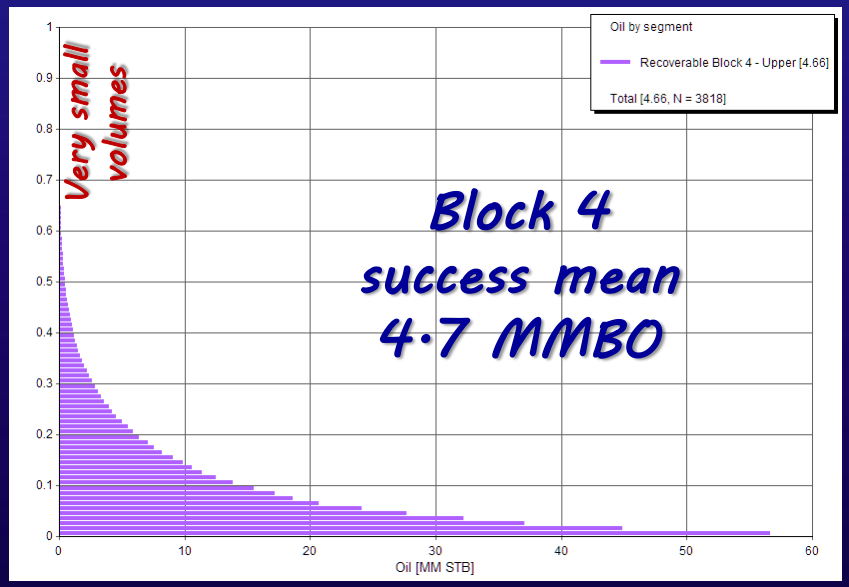
- Each zone is divided into segments by lease block
- Prospect assessment defines vertical and lateral relationships between segments

Resource by block









Summary

- Prospects may be segmented by lease block
  - Uncertainty and risk assessed for individual blocks
  - Integration of OWC uncertainty with trap geometry
  - Risk and volume relationships between segments
- Advantages
  - Improved ability to assign value to lease blocks
  - Improved pre-drill development economics
  - Improved representation of the geologic evaluation