Rose & Associates

Do I need an Engineer on my Risk Consistency Team?

Session Theme
Aiming for Improvements of Prospect Evaluation Methods

Risk Coordinators Workshop
21 – 22 November 2016

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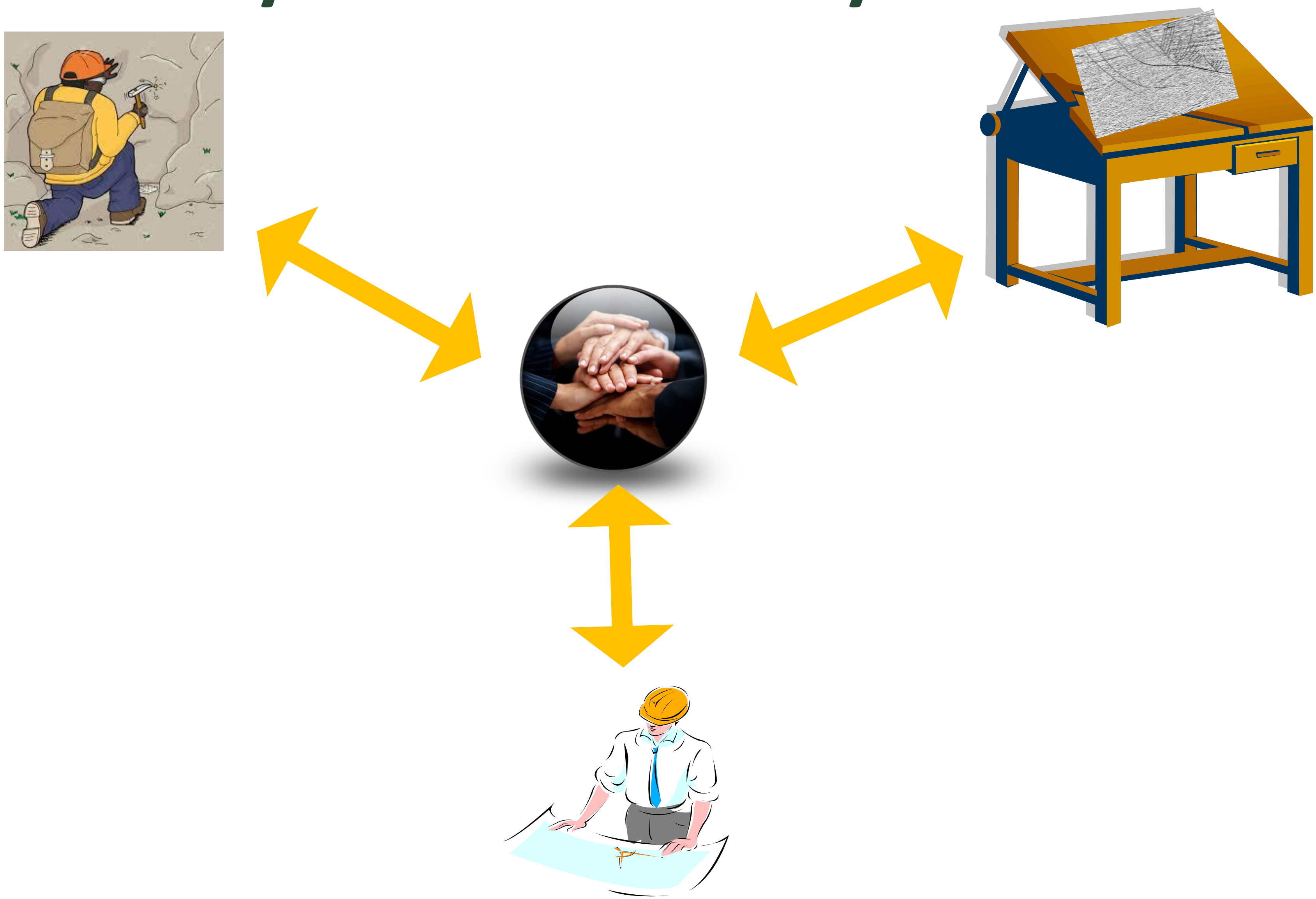
Rose & Associates

Do I need an Engineer on my Risk Consistency Team?



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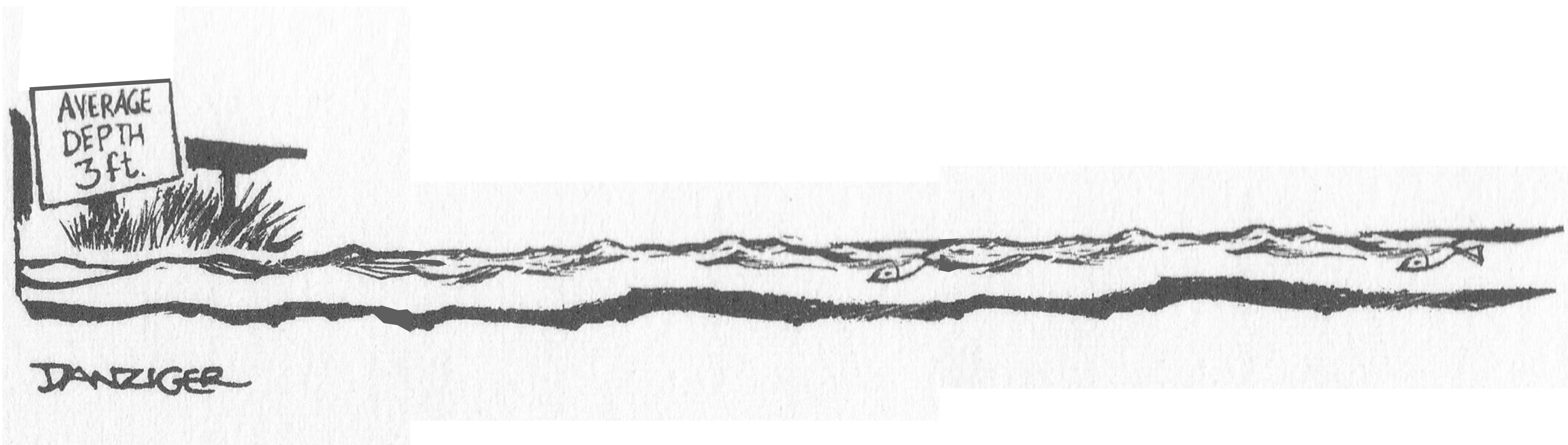
Before we get started….

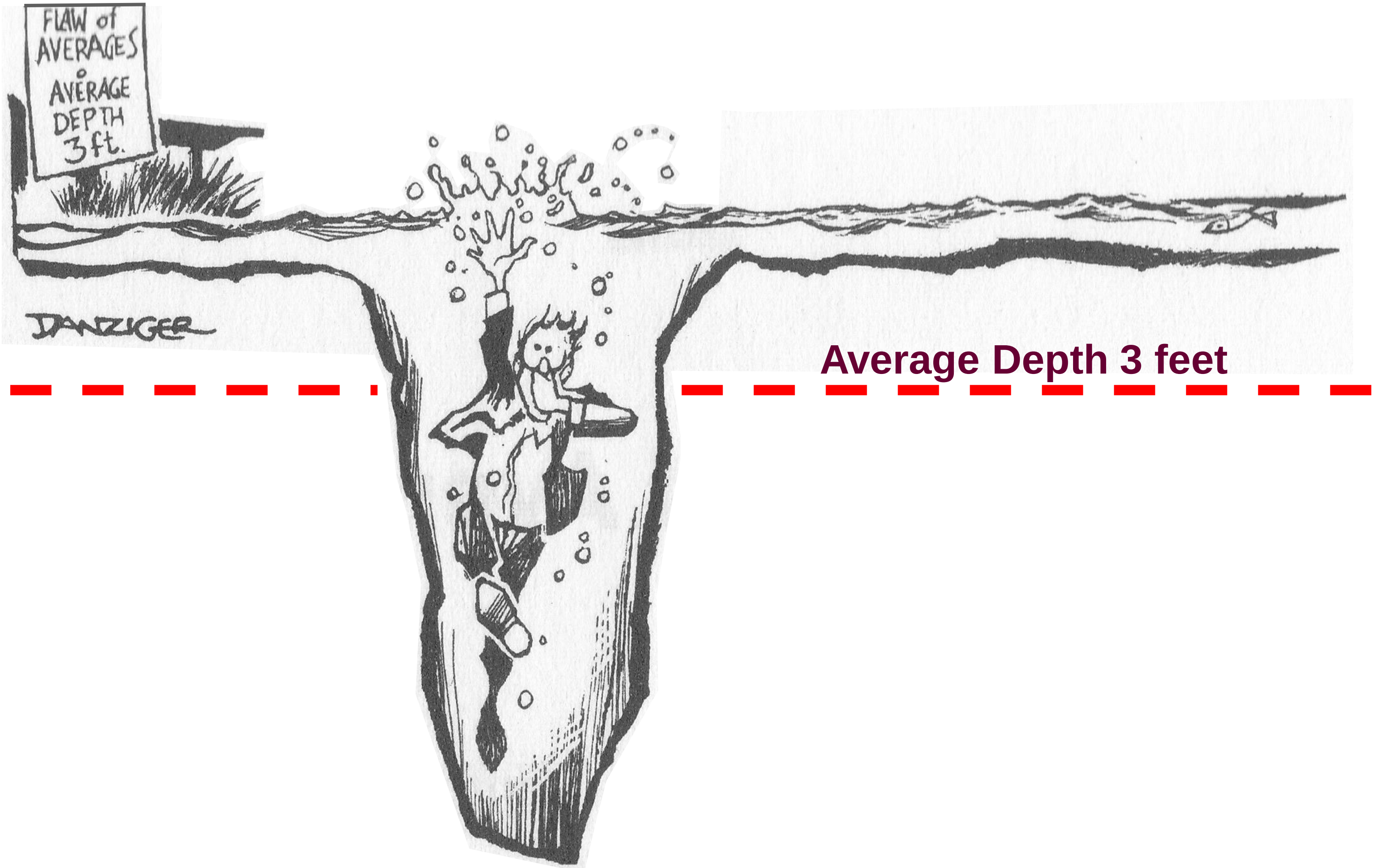
Reminder of why we characterize uncertainty with distributions

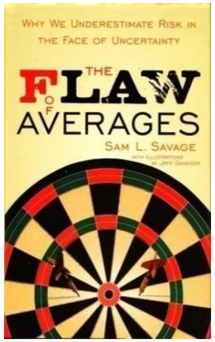
Case 1: Shallow & Safe enough for a child to cross?



Case 1: Flaw of Averages

Without Ranges, cannot assess the real danger





Case 2: Where to go for a Warm Summer Vacation?

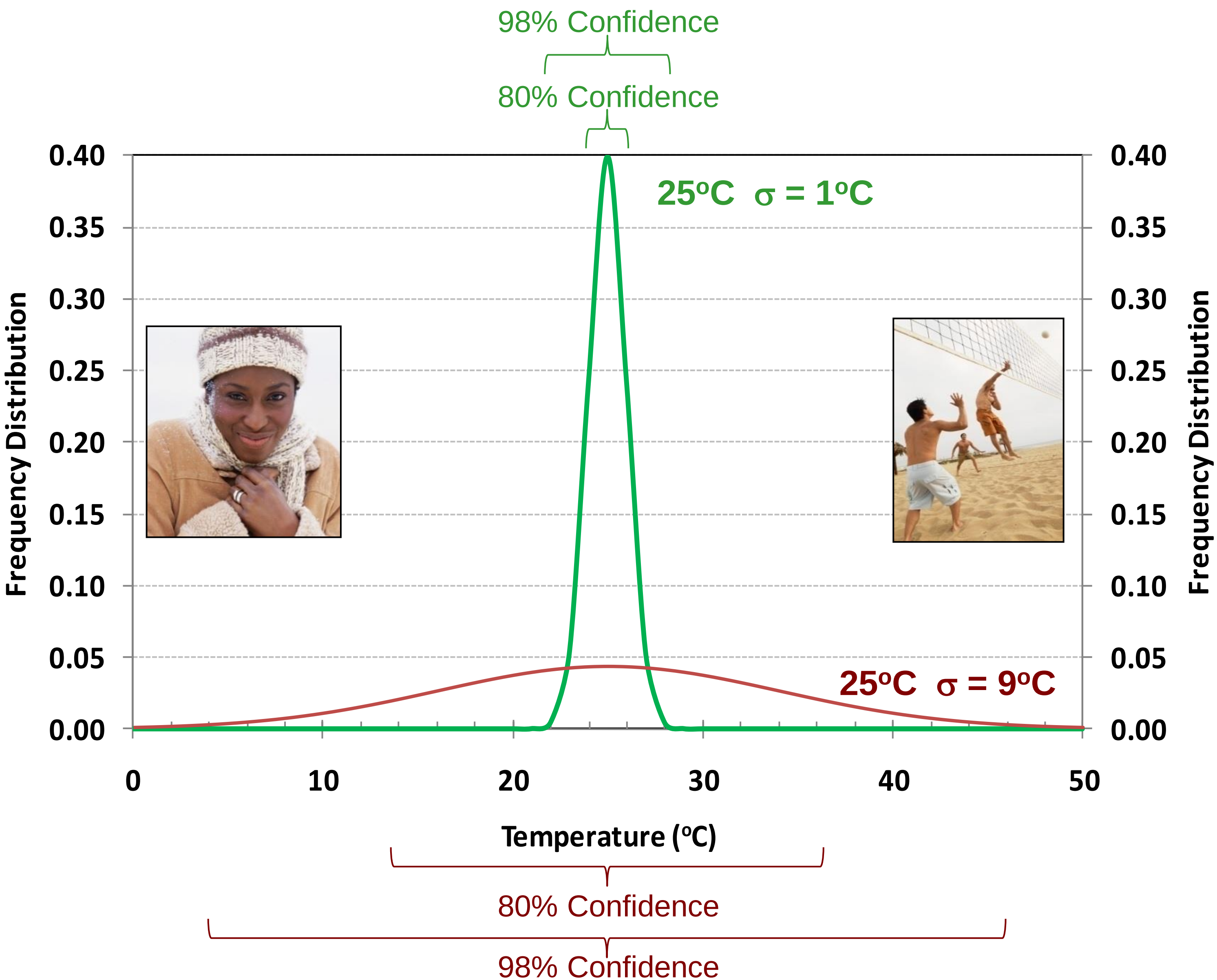
Average Temperature

Option 1	**Option 2**
25^{o}C	**25^{o}C**
(77^{o}F)	**(77^{o}F)**

Standard Deviation

Option 1	**Option 2**
1.0^{o}C	**9.0^{o}C**
(1.8^{o}F)	**(16.2^{o}F)**

Case 2: Flaw of Averages
Without Ranges, not prepared for all situations



Is there room on my Risk Team for an Engineer?

- Most Risk Teams don't have an engineer
  - *Why should it be considered?*
- Barriers to Overcome to have an engineer
  - *Management Barriers*
  - *Technical Staff Barriers*
- Examples of Engineering Experience improving the process
- Benefits Achieved with Engineer on the Team
  - *Enough to Justify an Engineer on every Risk Team?*

Why consider an Engineer for the Risk Team?

- **Reality Check Hydrocarbon Recovery Yield**
  - *Smallest Impact on Resource Size not same as Not Important*
- **Group Wisdom**
- **Multiple Working Hypothesis**
- **Providing a New Perspective**
- **Diverse & Complimentary Skill Sets**

But do these reasons add value to the process?

Risk Team has Corporate Responsibility

- **Systematic, unbiased resource estimates**
- **Consistent assessment of chance of success**
  - *Leads to better portfolio decision making*
  - *Leads to more predictable portfolio results*

Objective is Not to Make Geologic Discoveries, but rather to Have Profitable Developments

- *Prospect Evaluation is not simply OOIP and P_g*
- *Development Plan, Recovery Efficiency & MCFS Impact*
- *Engineering & Economics are Important Inputs to the process of building an optimized exploration portfolio*

Risk Teams benefit from Diverse & Complimentary Skill Sets

Geosciences

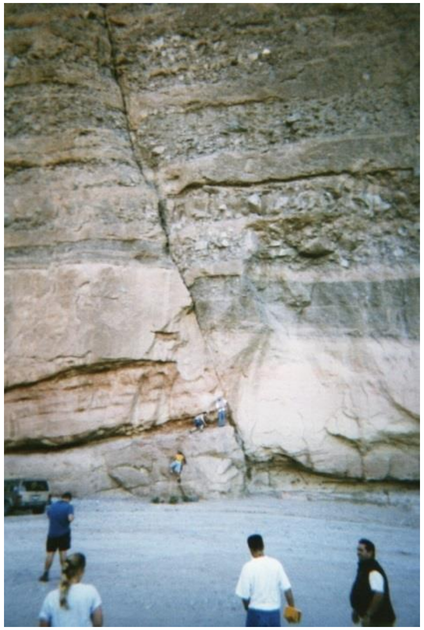
hydrocarbon generation, migration pathways,
seal capacities, seismic attributes, DHI analysis,
trap interpretation, fault analysis, etc.

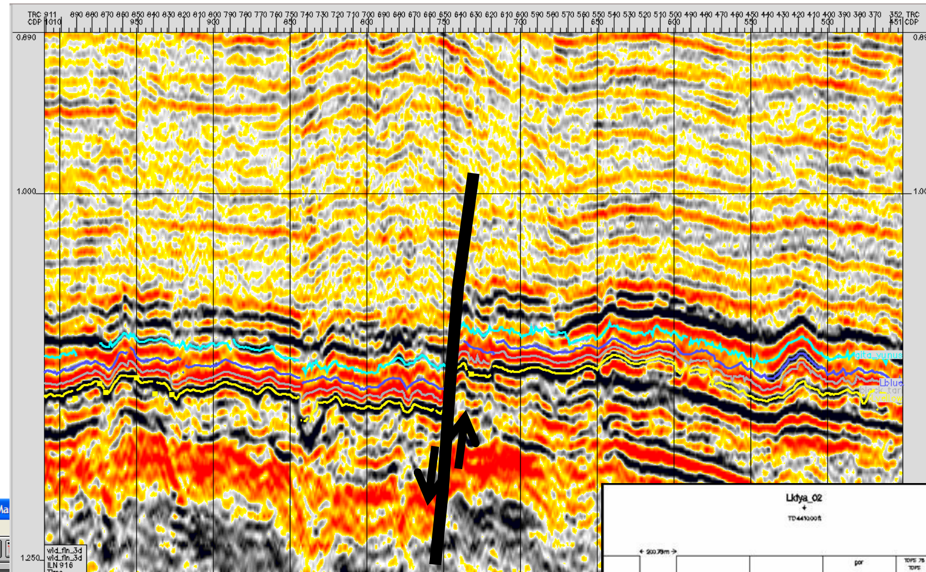
Engineering

recovery efficiencies of primary & secondary products
oil & gas FVF, porosities, saturations, permeability
impact of MCFS on exploration decision making
development scenarios impacting economics, etc.

This is how a Fault looks in an Outcrop
How do we see a Fault that is buried?

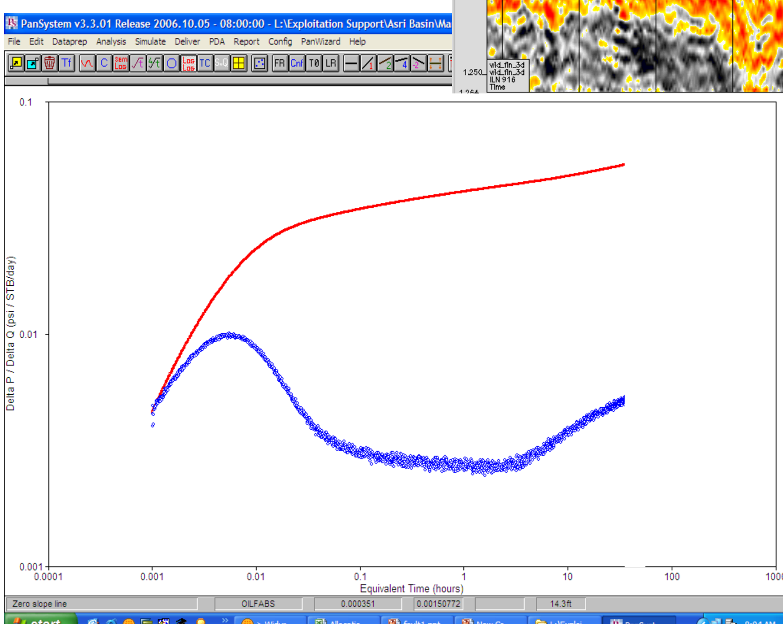
Depends on your perspective !!

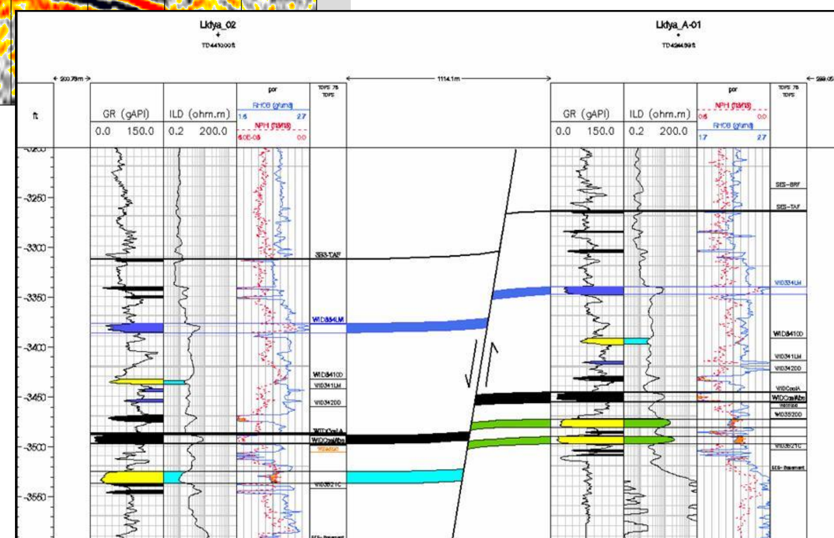




Geophysicist with seismic line

Geologist with cross-sections





Reservoir Engineer with Pressure Transient Analysis

Risk Teams Geoscience Members ensure Consistency But also Provide Another Level of Quality Control

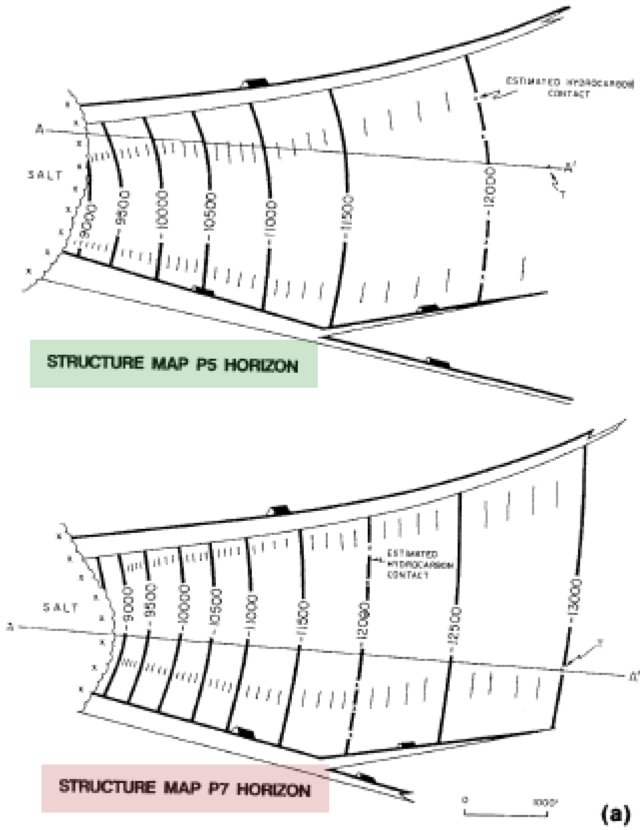


Figure 3-13a Structural interpretation of Horizons P5 and P7 based on available seismic data. A-A′ is an illustration aid cross section across the structure. (Daniel J. Tearpock/Richard E. Bischke, APPLIED SUBSURFACE GEOLOGICAL MAPPING, 1991, p. 151. Reprinted by permission of Prentice-Hall, Englewood Cliffs, New Jersey.)

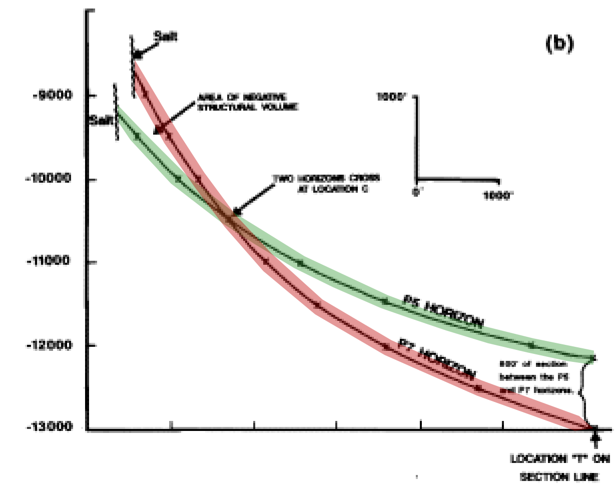
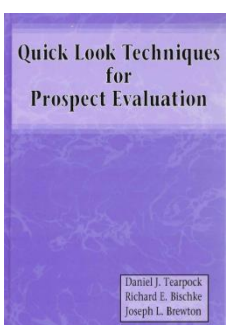


Figure 3-13b This cross section shows that the lower P7 Horizon crosses the upper P5 Horizon at Location C and is mapped shallower than P5 from this position updip to the salt. This is an impossible interpretation. (Tearpock/Bischke, APPLIED SUBSURFACE GEOLOGICAL MAPPING, 1991, P. 151. Reprinted by permission of Prentice-Hall, Inc.)



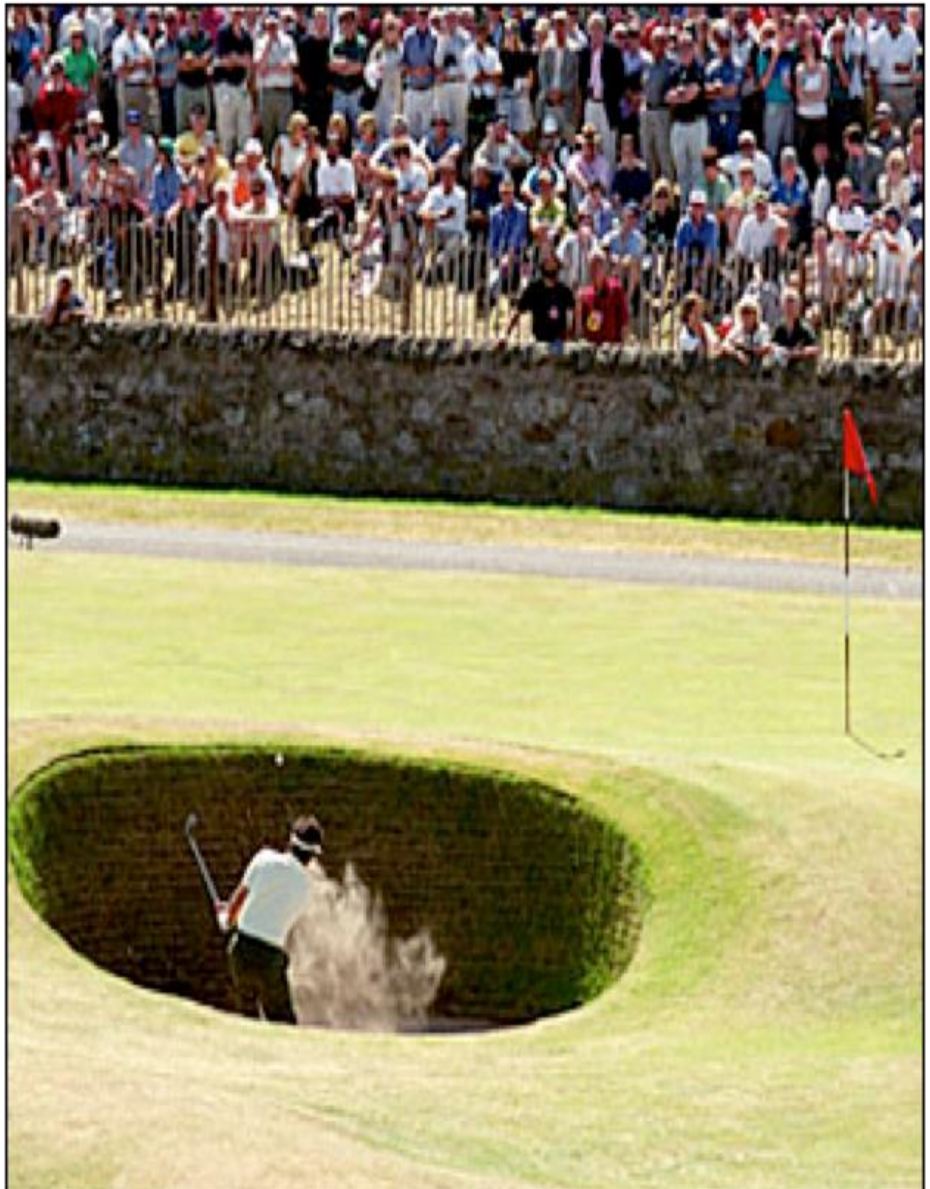
Numerically Insightful Individuals, often Engineers, can provide Quality Control on all sorts of information

Reported Fluid Rates for 20 Wells with Average

Well	Oil (BOPD)	Gas (MCFD)	Water (BWPD)
1	841	1,032	1,615
2	701	1,250	1,160
3	925	843	1,053
4	684	1,346	1,379
5	731	1,391	1,244
6	607	1,064	1,139
7	946	1,072	1,365
8	820	1,271	1,177
9	888	1,692	1,193
10	819	1,486	1,663
11	632	1,364	1,623
12	952	1,019	1,347
13	874	1,020	1,161
14	958	1,520	1,057
15	892	1,152	1,520
16	772	1,263	1,458
17	892	1,236	1,337
18	602	1,427	1,396
19	921	1,268	1,253
20	743	1,241	995
Average	1,002	1,248	1,307

Is the Average Oil Rate:
About Right?
Too High?
Too Low?
How should I know?

Too High
Computer Age has led many people to turning off their brain



Barriers to Overcome

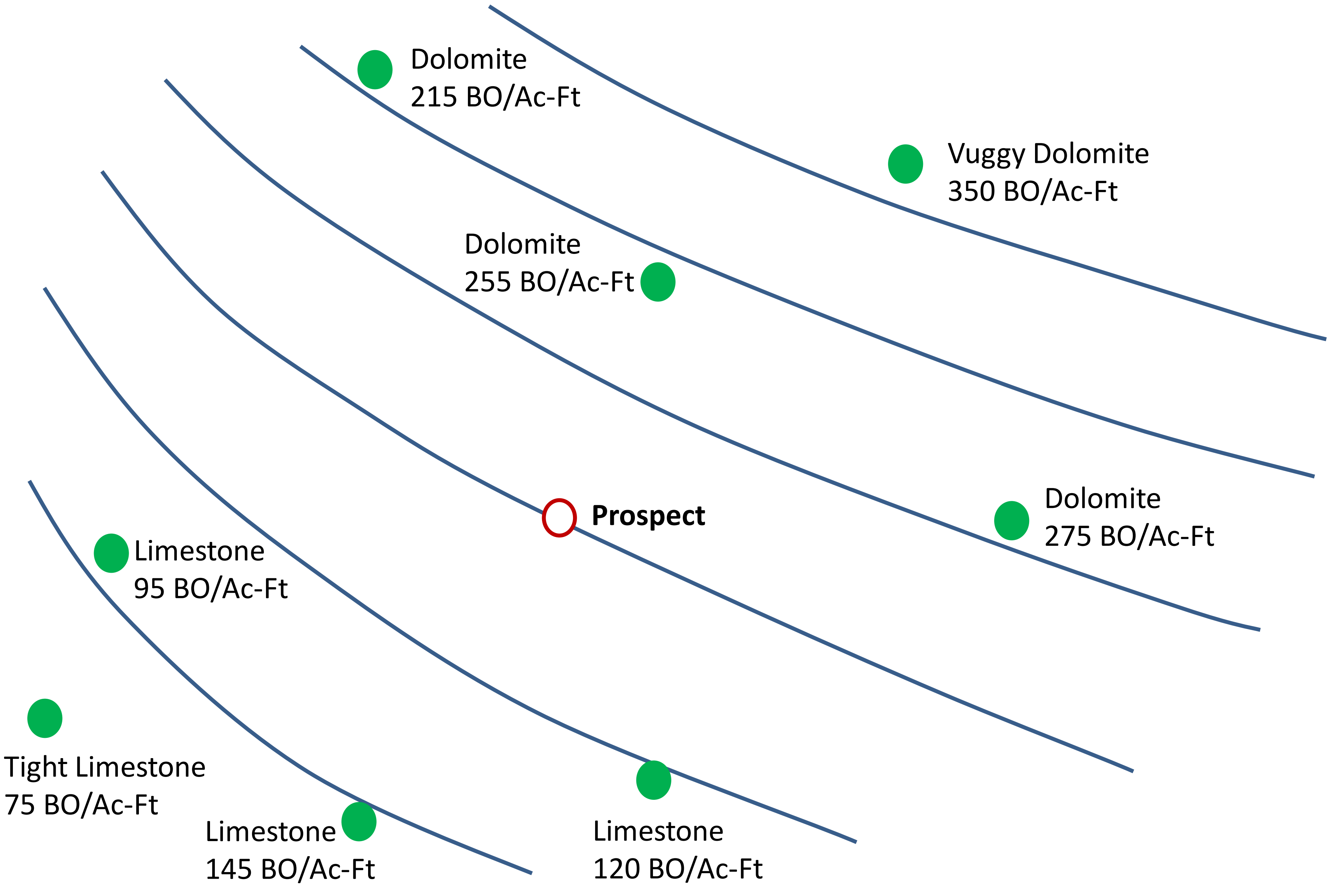
Barriers to Overcome to add an Engineer on Risk Team

- Exploration Management
  - "I don't want an engineer on the team because they are too pessimistic and I won't get all my prospects drilled"
- Development Management
  - "I'm short-handed and I need my engineers working on producing assets, not wells that are going to be dry holes"
- Risk Team Members & Exploration Staff
  - Want to Focus on Most Important Aspects of NRV and Pg
- Engineers don't feel like it is good career move
- Keep Team Smaller to Reduce Expenses

But do any of these reasons provide valid justification to keep an engineer off the Risk Team?

Examples of Engineering Experience improving Prospect Evaluations

Engineers also need to think spatially about recovery efficiency
Impact of lithology on Hydrocarbon Recovery Yield (BO/AcFt)



Log Probability Chart

Toolbox v4-3-110 (Office 2007-2010) May 2012

ANALOG DATA SAMPLES (not curve fit statistics)

	Count	Smallest	Average	Largest
Group 1		Analog Data Values		
		All		
	n = 8	70.00	190.63	350.00
Group 2		-		
		-		
	-	-	-	-
Group 3		-		
		-		
	-	-	-	-
Group 4		-		
		-		
	-	-	-	-
Group 5		-		
		-		
	-	-	-	-

CURVE FITS DISPLAYED

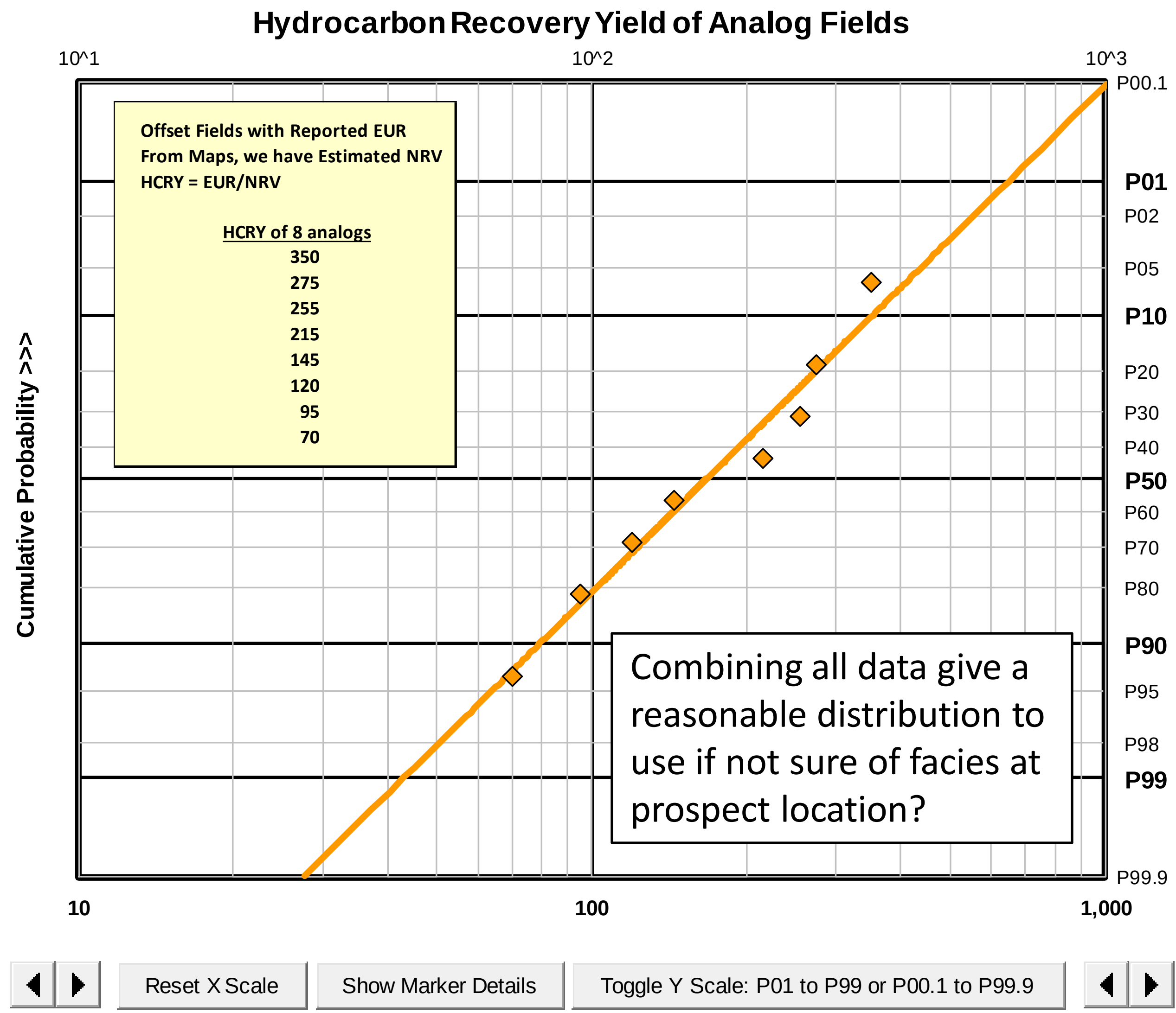
Unconstrained Lognormal	ACTIVE
Lognormal but Matches Data Mean	OFF
Lognormal Bounded	OFF
Lognormal w/1 Specified Point	OFF
Lognormal User-Defined	OFF
Beta Curve Fit	OFF
Normal Curve	OFF
Polynomial	OFF
Piecewise Linear	OFF
Discrete, Unweighted	OFF

NUMERICAL LIMITS & BETA SCALING

Minimum	OFF
Maximum	OFF

OTHER

Plotting Position Calculation Method: MIDPOINT



Log Probability Chart

Toolbox v4-3-110 (Office 2007-2010) May 2012

ANALOG DATA SAMPLES (not curve fit statistics)

	Count	Smallest	Average	Largest
Group 1			-	
			-	
	-	-	-	-
Group 2			Analog Data Values	
			Limestone	
	n = 4	70.00	107.50	145.00
Group 3			Analog Data Values	
			Dolomite	
	n = 4	215.00	273.75	350.00
Group 4			-	
			-	
	-	-	-	-
Group 5			-	
			-	
	-	-	-	-

CURVE FITS DISPLAYED

Unconstrained Lognormal	ACTIVE
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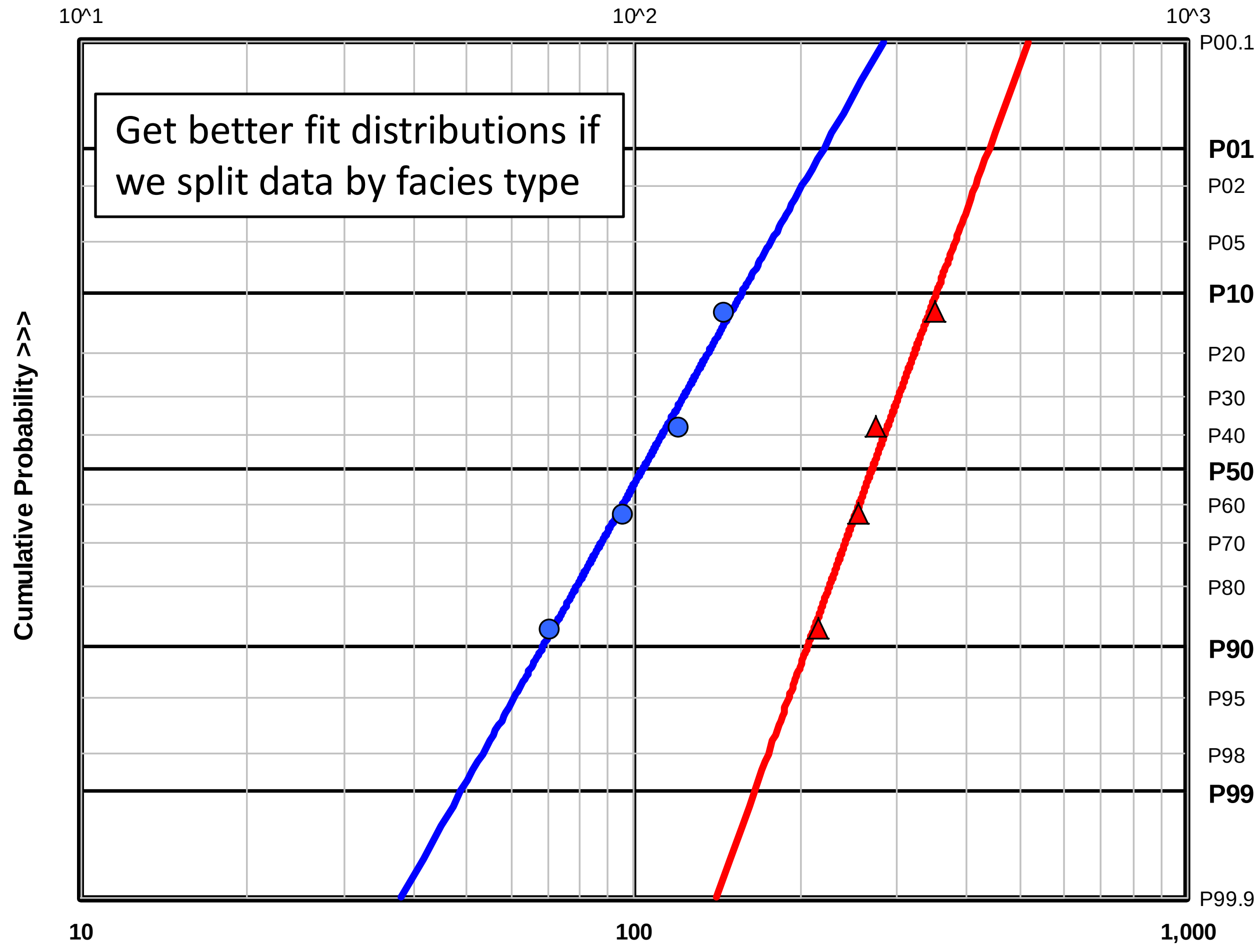
NUMERICAL LIMITS & BETA SCALING

Minimum	OFF
Maximum	OFF

OTHER

Plotting Position Calculation Method: MIDPOINT

Hydrocarbon Recovery Yield of Analog Fields



Reset X Scale | Show Marker Details | Toggle Y Scale: P01 to P99 or P00.1 to P99.9

Log Probability Chart

Toolbox v4-3-110 (Office 2007-2010) May 2012

ANALOG DATA SAMPLES (not curve fit statistics)

Count	Smallest	Average	Largest
Group 1	Analog Data Values		
	All		
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n = 4	215.00	273.75	350.00
Group 4	-		
	-		
-	-	-	-
Group 5	-		
	-		
-	-	-	-

CURVE FITS DISPLAYED

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Lognormal but Matches Data Mean	OFF
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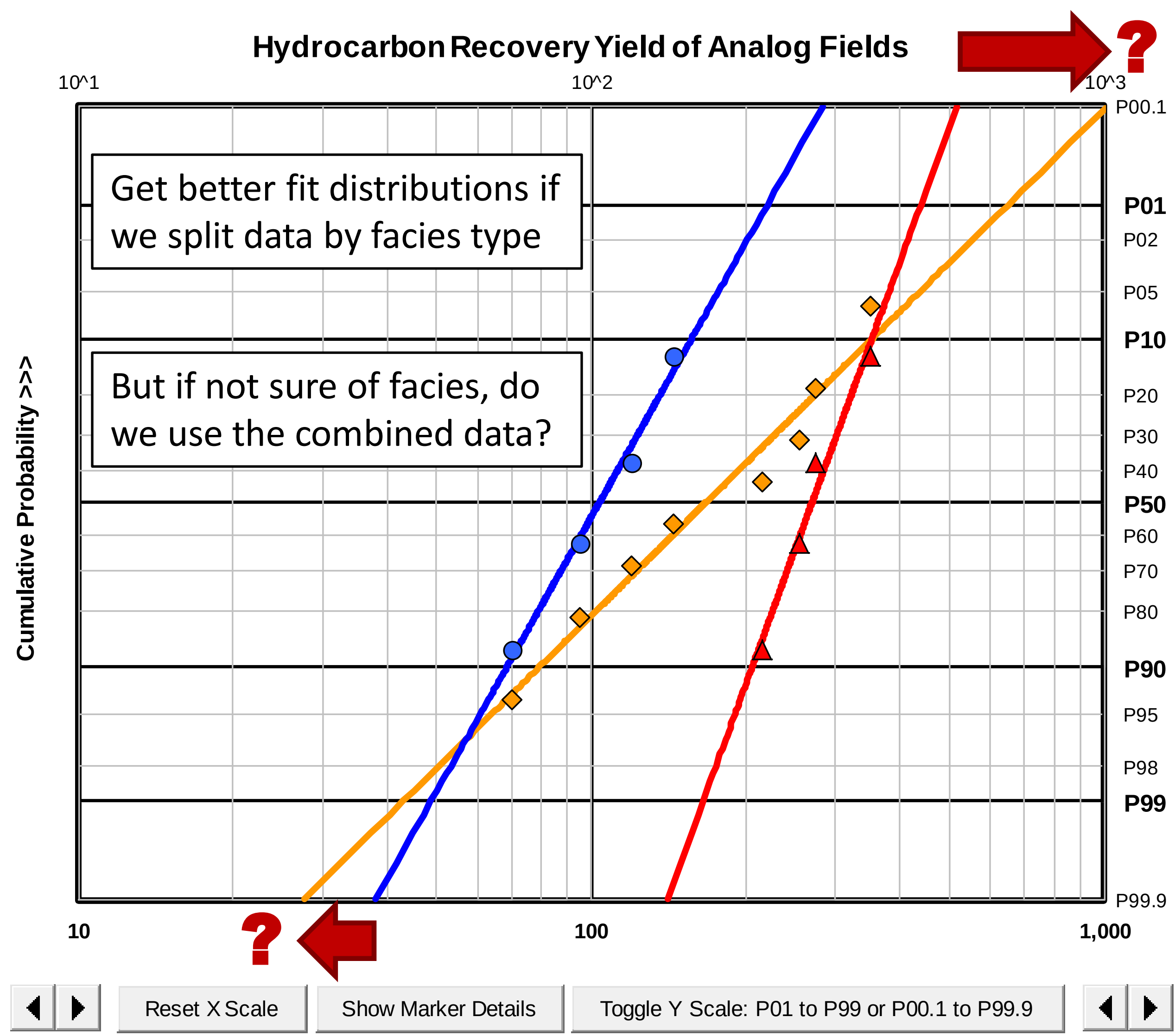
NUMERICAL LIMITS & BETA SCALING

Minimum	OFF
Maximum	OFF

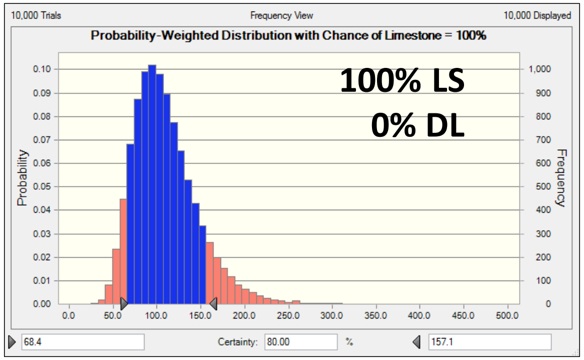
OTHER

Plotting Position Calculation Method: MIDPOINT

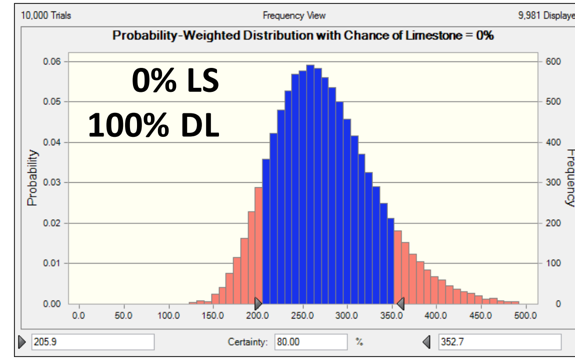


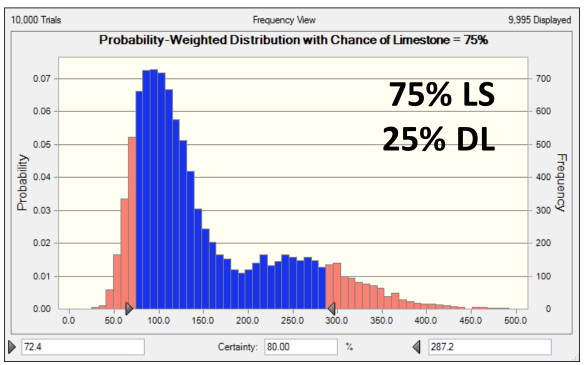
Maybe not, note the P1 of combined distribution is larger when the tight limestone is included in distribution. Is it reasonable to increase the P1 Dolomite value by adding poor limestone values to distribution? No.

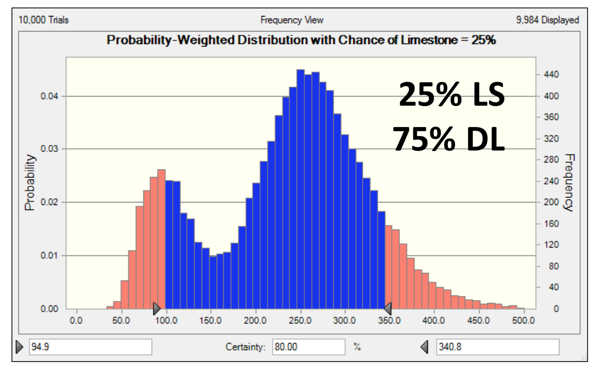
Combining Limestone & Dolomite Distributions

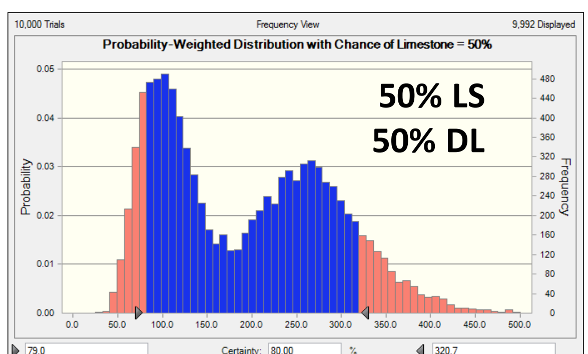


<u>Scenario Approach:</u>
Sample each distribution probability weighted by expectation of facies type









Estimating Exploration EUR

$$EUR = \frac{A \times \text{Avg } NP \times 7758 \times \text{Avg } \Phi \times (1-\text{Avg } S_w) \times \text{Rec. Eff.}}{FVF}$$

EUR sensitivity:

AREA

NP

RY

RY sensitivity:

Rec. Eff.

Avg Φ

(1-Avg S_w)

FVF

Recovery Efficiency often the largest uncertainty of the Hydrocarbon Recovery Yield variables

Oil Recovery Efficiency

Drive Mechanism	Primary Recovery (P90 – P10)*	Secondary Recovery (P90 – P10)*
Depletion (solution gas drive)	15% - 30%	15% - 40%
Gas Cap	15% - 40%	15% - 45%
Water Drive	20% - 45%	20% - 50%
HPHT reservoirs – Oil expansion above P_b	1% - 5%	5% - 12+% with partial natural aquifer support

*Assumptions - light gravity oil
Mid (15° – 25°) Subtract 5% - 10%
Heavy (< 15°) Subtract 10% - 15% (in 8° to 12° API oil, we have seen foamy oils with recoveries of 6% to 12%)
Questionable reservoir continuity Subtract 5% - 10%

After Cronquist, 2001

Gas Recovery Efficiency

Drive Mechanism	Conventional Reservoirs (P90 – P10)	Unconventional Reservoirs (P90 – P10)
Depletion (gas expansion drive)	60% - 80% *	5% - 60%
Water Drive (Medium)	50% - 70% *	
Water Drive (Strong)	40% - 60% *	
Unconventional Gas		Dependent on spacing and stimulated rock volume

*Assumes good reservoir quality (continuity)

For questionable reservoir continuity subtract 10% - 30%+ for conventional reservoir – much higher for unconventional reservoirs

After Cronquist, 2001

Guidelines are just a reference;
Not to be used for specific prospects

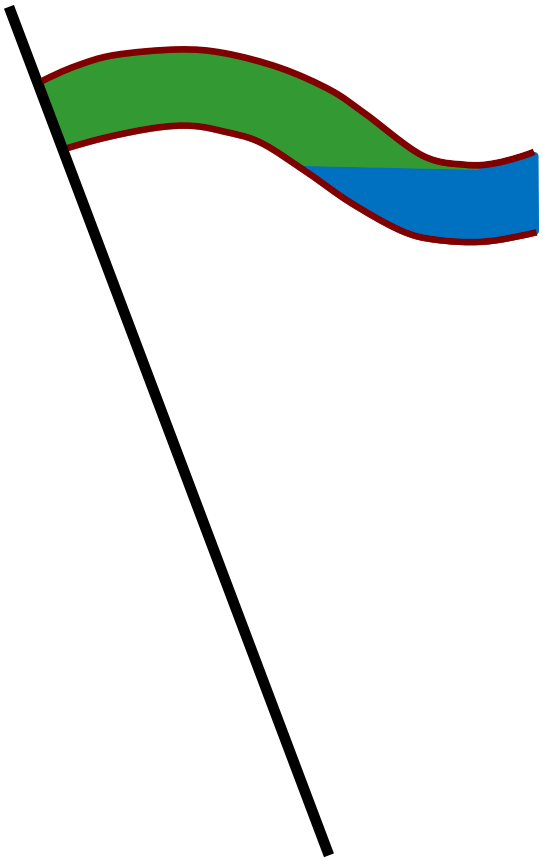
Oil RE can vary by factor of 2 to 3
Gas RE can vary by factor up to 2

Recovery Efficiency is function of:

- Reservoir Quality
- Reservoir Continuity
- Reservoir Compartmentalization
- Aquifer Size & Quality
- Fluid Properties
- Development Plan
- Product Prices (impact on Eco Limit)

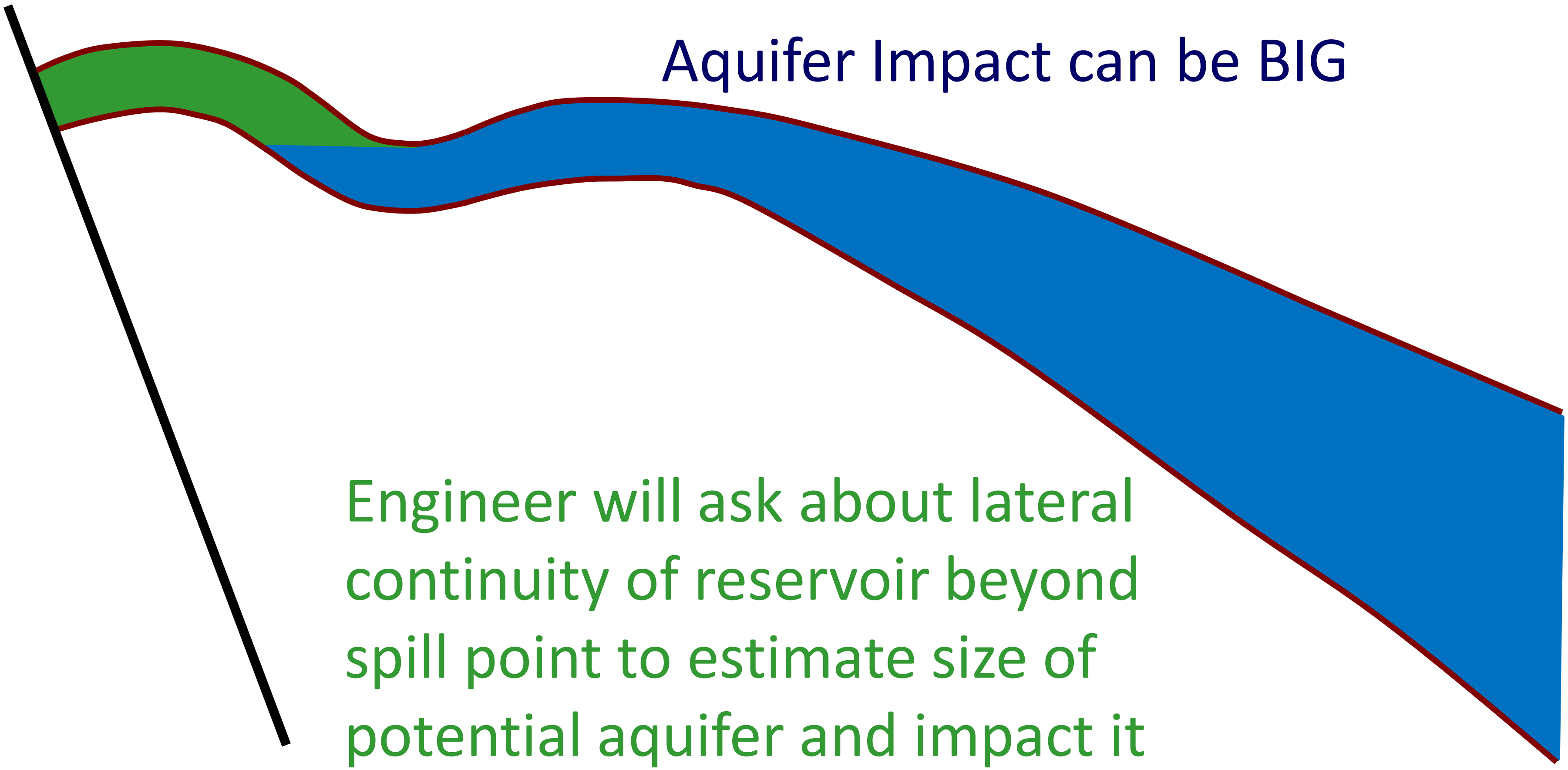
Recovery Efficiency – Impact of Aquifer Size

Geoscientist will focus on the NRV above the Spill Point for a structural prospect



Recovery Efficiency – Impact of Aquifer Size

Geoscientist will focus on the NRV above the Spill Point for a structural prospect

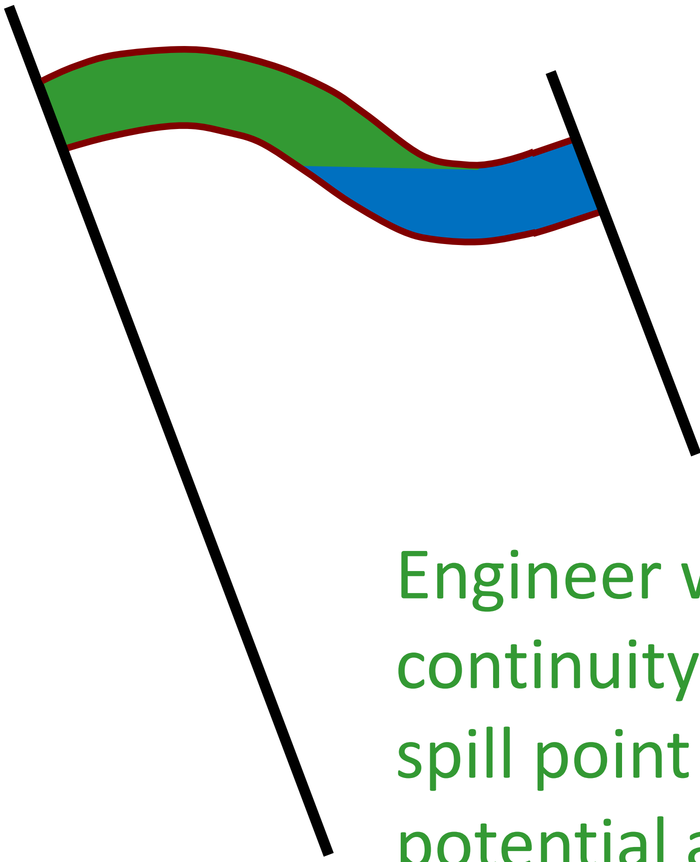


Aquifer Impact can be BIG

Engineer will ask about lateral continuity of reservoir beyond spill point to estimate size of potential aquifer and impact it will have on recovery efficiency

Recovery Efficiency – Impact of Aquifer Size

Geoscientist will focus on the NRV above the Spill Point for a structural prospect



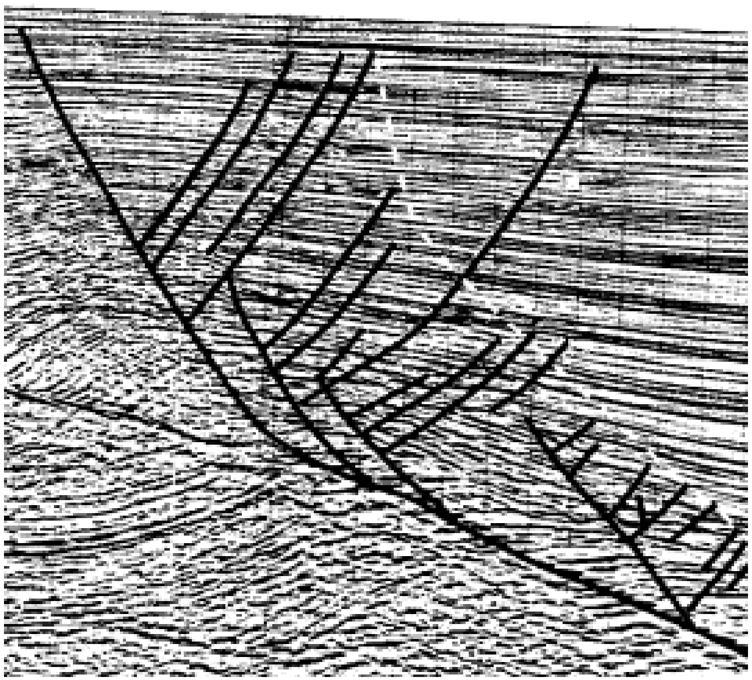
Aquifer Impact can be SMALL

Engineer will ask about lateral continuity of reservoir beyond spill point to estimate size of potential aquifer and impact it will have on recovery efficiency

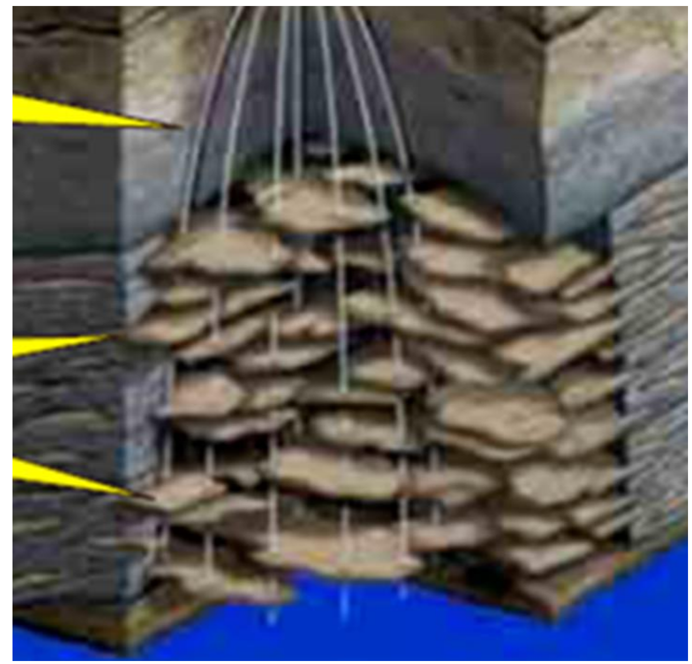
Reservoir Volume Dynamically Connected by Wells

Its not going to produce if you don't have a well in it

Fault Compartmentalization

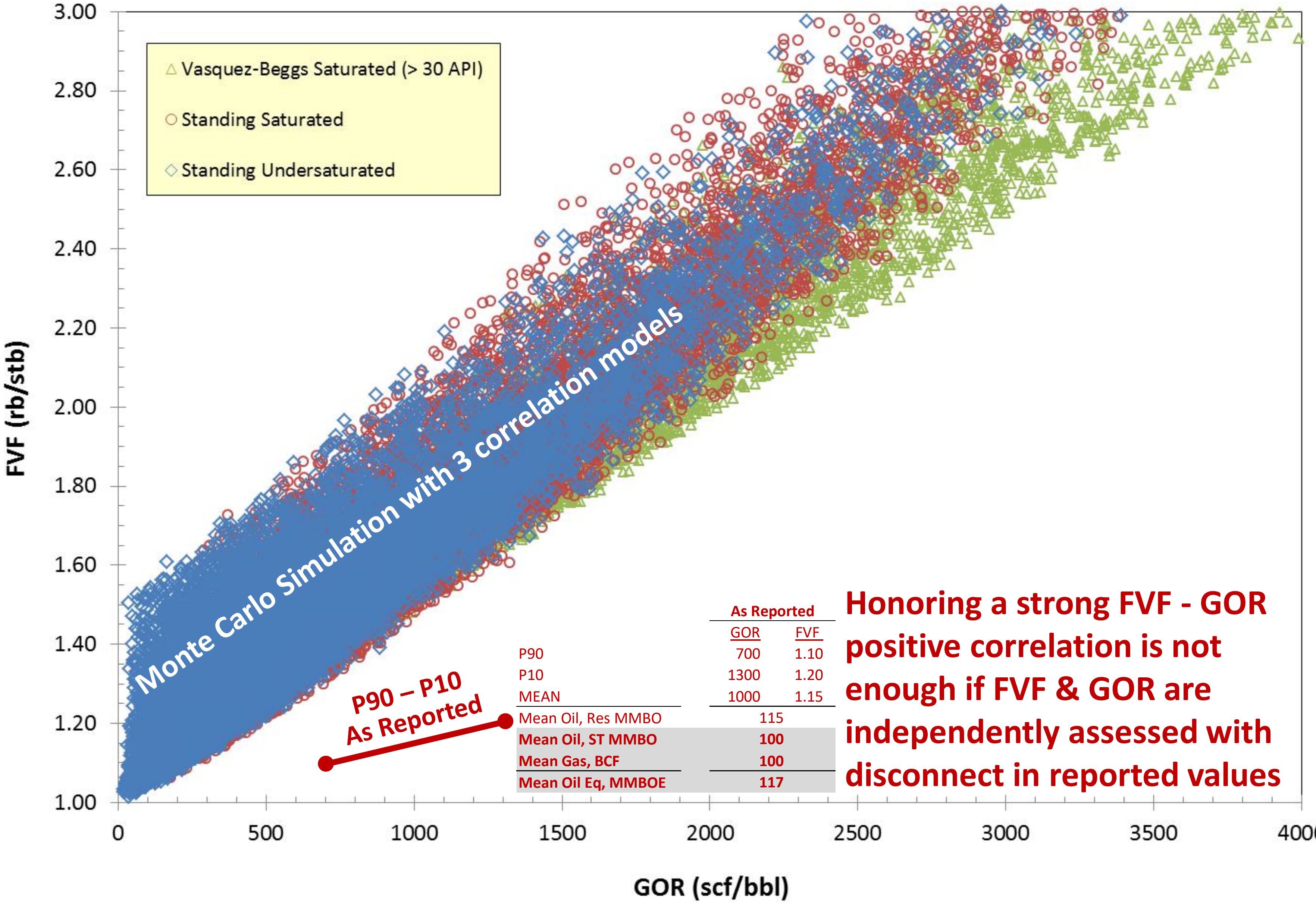


Lateral Discontinuous



Reservoir geometry will have significant impact on recovery efficiency and development strategy required to maximize value

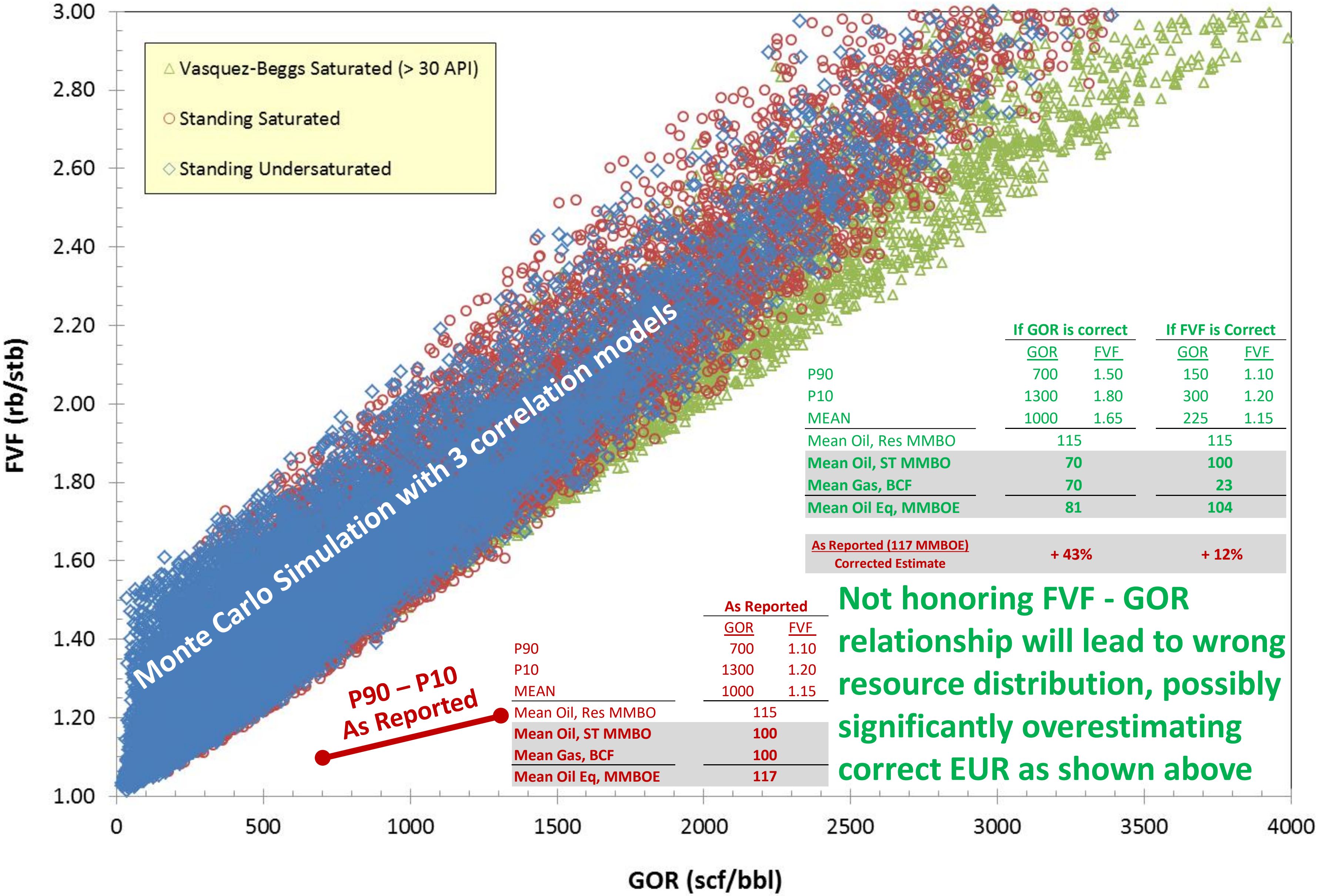
Stay On Guard for Oil FVF-GOR Disconnects



	As Reported GOR	As Reported FVF
P90	700	1.10
P10	1300	1.20
MEAN	1000	1.15
Mean Oil, Res MMBO	115	
Mean Oil, ST MMBO	**100**	
Mean Gas, BCF	**100**	
Mean Oil Eq, MMBOE	**117**	

Honoring a strong FVF - GOR positive correlation is not enough if FVF & GOR are independently assessed with disconnect in reported values

Stay On Guard for Oil FVF-GOR Disconnects

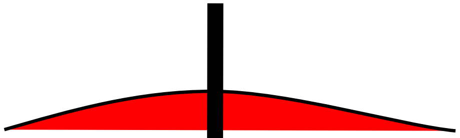


	If GOR is correct		If FVF is Correct	
	GOR	FVF	GOR	FVF
P90	700	1.50	150	1.10
P10	1300	1.80	300	1.20
MEAN	1000	1.65	225	1.15
Mean Oil, Res MMBO	115		115	
Mean Oil, ST MMBO	**70**		**100**	
Mean Gas, BCF	**70**		**23**	
Mean Oil Eq, MMBOE	**81**		**104**	
As Reported (117 MMBOE) / Corrected Estimate	**+ 43%**		**+ 12%**	

	As Reported	
	GOR	FVF
P90	700	1.10
P10	1300	1.20
MEAN	1000	1.15
Mean Oil, Res MMBO	115	
Mean Oil, ST MMBO	**100**	
Mean Gas, BCF	**100**	
Mean Oil Eq, MMBOE	**117**	

Not honoring FVF - GOR relationship will lead to wrong resource distribution, possibly significantly overestimating correct EUR as shown above

Remembering what controls GEF (= 1/FVF_{gas})



Reservoir	Gas (Reservoir BCF)	GEF (SCF/RCF)	Gas (Standard BCF)
Shallow	0.250	320	80
with Correct GEF		80	20

With Wrong GEF, EUR overestimated by Factor of 4

Gas Expansion Factor (GEF = Eg = 1/Bg)

Field/Prospect: Deep Gas Prospect with Shallow Secondary Zone **Reservoir:**

Toolbox v4-3-110 (Office 2007-2010) May 2012

◉ Imperial Units ○ SI / Metric Units

INPUT

		Deep Zone	Shallow Zone
	Water Depth (ft) (if Offshore)		
	Reservoir Depth (ft) (BML, if Offshore)	12,000	2,200
Bottom Hole Temperature (°F)	Direct Input		
	BHT (Calculated) °F	270	74
	Surface/Mud Line Temperature (°F)	30	30
	Temp Gradient (°F/100ft)	2.00	2.00
Initial Bottom Hole Pressure (psia)	Direct Input		
	BHPi (Calculated) psia	8,415	1,005
	Surface Pressure (psia)	14.70	14.70
	Water Pressure Gradient (psi/ft) if Offshore	0.45	0.45
	Overburden Pressure Gradient (psi/ft)	0.70	0.45
Gas & Fluid Properties	Separator Gas Specific Gravity	0.710	0.630
	Condensate Yield (bc/mmcf)	30	2
	GOR (scf/stb)	33,333	500,000
	Cond Gravity (°API)	50	60
	Cond Gravity (decimal)	0.780	0.739
	Wellstream Gas Specific Gravity	0.800	0.636
Non-Hydrocarbon Gas Components	CO2 (%)	5.0%	
	N2 (%)	2.0%	
	H2S (%)	0.0%	

RESULTS

	Deep Zone	Shallow Zone
Zi	1.279	0.839
Bgi (rcf/scf)	0.00313	0.01256
GEF = 1/ Bgi (scf/rcf) [MMRA input]	320	80

Required Input	Calculated Value
Optional Input	Units Selection
Optional Input Overridden	
Recommended MMRA Input Values	

This tool calculates Bg (scf / rcf or stm^3/ rm^3) for hydrocarbon gases based on estimated reservoir conditions and gas composition.

GEF = Eg = 1/Bg = [Tsc * P] / [z * T * Psc]

Standard Conditions

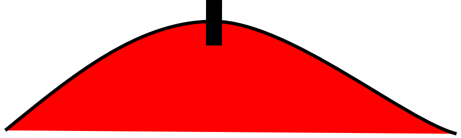
Standard Pressure (psia)	14.65
Standard Temperature (°F)	60

Comments

GEF estimated for BOTH ZONES

What controls GEF?

Pressure is King !!

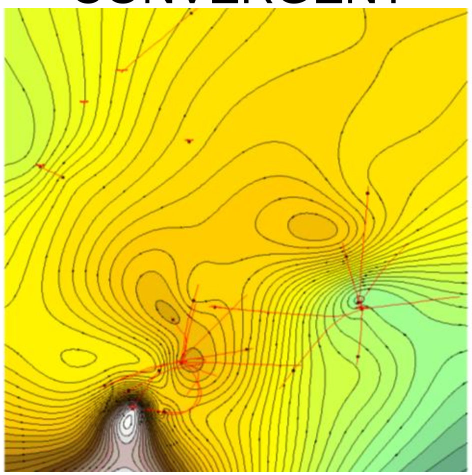


Reservoir	Gas (Reservoir BCF)	GEF (SCF/RCF)	Gas (Standard BCF)
Deep	1.000	320	320

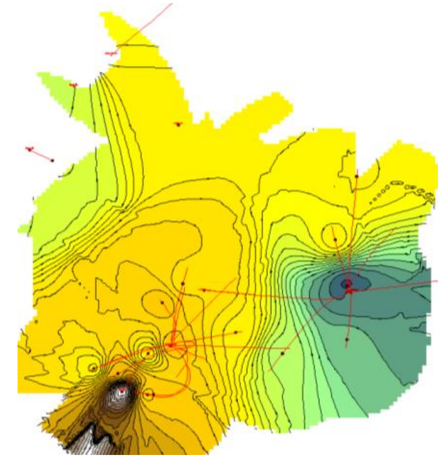
What do you do when all your Markers off the line?

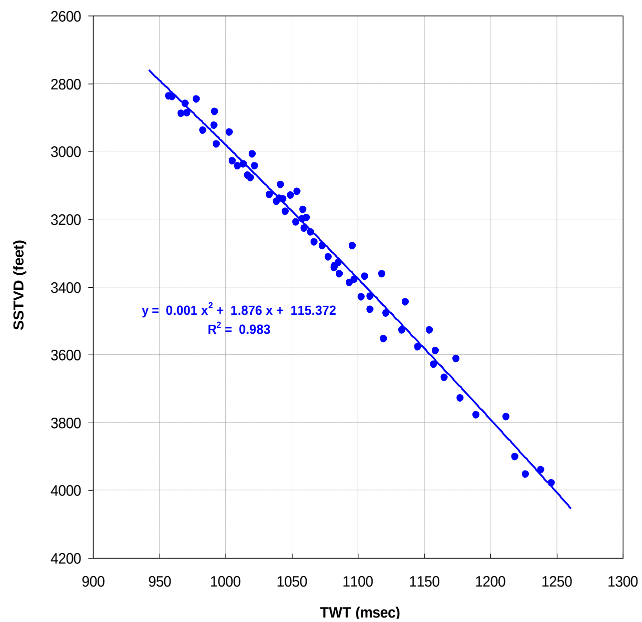
Final Map is based on a Residual Map Correcting All the Errors

CONVERGENT

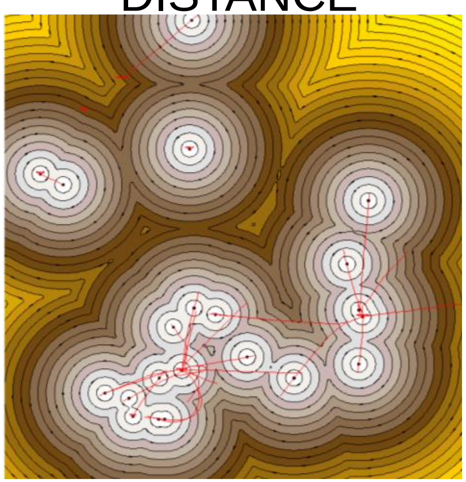


MOVING

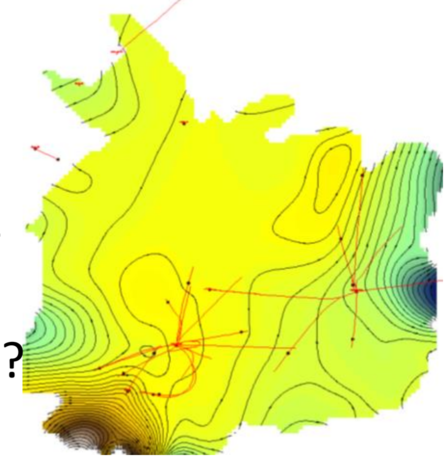




DISTANCE



LEAST SQUARE



4 Algorithms to Generate Residual Map

There are lots more algorithms available

Are you going to get a different final map?

Lookout for Tricks unfairly improving Prospect Ranking

Real Examples of an Uneven Playing Field

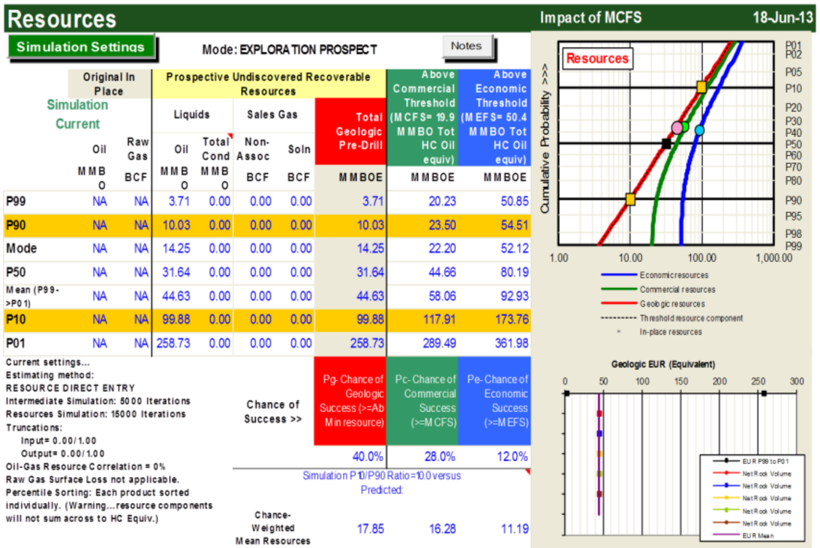
- Preferential Selection of MCFS to rely on nonexistent infrastructure

- Arbitrary Selection of Area & Net Pay to reduce costs and increase production

Impact of MCFS & Development Planning on Exploration Prospect Evaluations can be significant and affect budget funding

Impact of Commercial Threshold on Prospect Ranking

Normalizing MCFS Methodology is important for consistent decision making

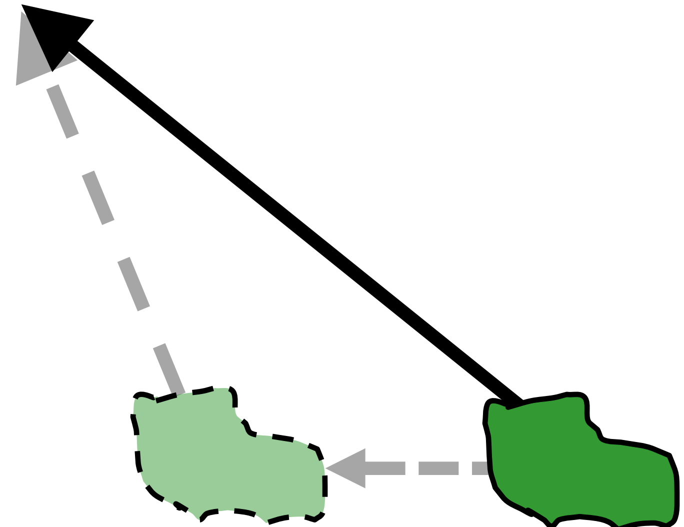


	Original In Place: Oil (MMBO)	Original In Place: Raw Gas (BCF)	Liquids: Oil (MMBO)	Liquids: Total Cond (MMBO)	Sales Gas: Non-Assoc (BCF)	Sales Gas: Soln (BCF)	Total Geologic Pre-Drill (MMBOE)	Above Commercial Threshold (MCFS= 19.9 MMBO Tot HC Oil equiv) (MMBOE)	Above Economic Threshold (MEFS= 50.4 MMBO Tot HC Oil equiv) (MMBOE)
P99	NA	NA	3.71	0.00	0.00	0.00	3.71	20.23	50.85
P90	NA	NA	10.03	0.00	0.00	0.00	10.03	23.50	54.51
Mode	NA	NA	14.25	0.00	0.00	0.00	14.25	22.20	52.12
P50	NA	NA	31.64	0.00	0.00	0.00	31.64	44.66	80.19
Mean (P99->P01)	NA	NA	44.63	0.00	0.00	0.00	44.63	58.06	92.93
P10	NA	NA	99.88	0.00	0.00	0.00	99.88	117.91	173.76
P01	NA	NA	258.73	0.00	0.00	0.00	258.73	289.49	361.98

Current settings...
Estimating method:
RESOURCE DIRECT ENTRY
Intermediate Simulation: 5000 Iterations
Resources Simulation: 15000 Iterations
Truncations:
Input= 0.00/1.00
Output= 0.00/1.00
Oil-Gas Resource Correlation = 0%
Raw Gas Surface Loss not applicable.
Percentile Sorting: Each product sorted individually. (Warning...resource components will not sum across to HC Equiv.)

	Pg- Chance of Geologic Success (>=Ab Min resource)	Pc- Chance of Commercial Success (>=MCFS)	Pe- Chance of Economic Success (>=MEFS)
Chance of Success >>	40.0%	28.0%	12.0%
Chance-Weighted Mean Resources	17.85	16.28	11.19

Simulation P10/P90 Ratio=10.0 versus Predicted:



Tie-in to Undrilled Prospect

Stand-Alone

	Geologic	Tie-in	Stand-Alone
Chance of Development	40%	28%	12%
EV Mean Resources (MMBO)	18	16	11
MCFS (MMBO)	0	20	50
Commercial Mean (MMBO)	45	58	93

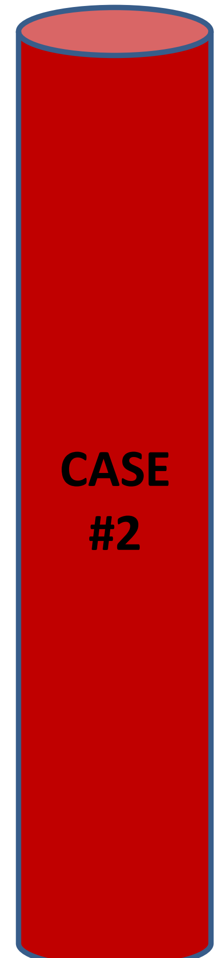
Consistent Development Planning

Is the hard work over once the resource distribution is finalized and discrete cases are chosen for economic evaluation?

Consider the following two cases to develop a Prospect's NRV:

Parameter	Units	Case #1	Case #2
NRV	ac-ft	20,000	20,000
Area	acres	2,000	400
Net Pay	feet	10	50
Drainage Area	acres/well	100	100
Well IP	BOPD/ft	30	30
Number of Wells	count	20	4
Well IP	BOPD	300	1,500

Is economic value the same for both?



Benefits of Engineers on Risk Team

Benefits with an Engineer on Risk Team

- **Hydrocarbon Recovery Yield Reality Checks**
  - **Recovery Efficiency, Porosity, Saturation and FVF**
  - **Consistently applied across all prospects**
- Recovery Efficiencies appropriate for the Geological Model, Lateral Continuity, Fluid Properties, Development Plan, MCFS
- FVF for Oil & Gas, including GOR & CGR of secondary phases, reality checked for possibility of simultaneous occurrence
- Reality checking MCFS and Development Plan concept ensuring decision making based on consistent methodology
- Different Perspective adds values to overall evaluation

Further Discussion?