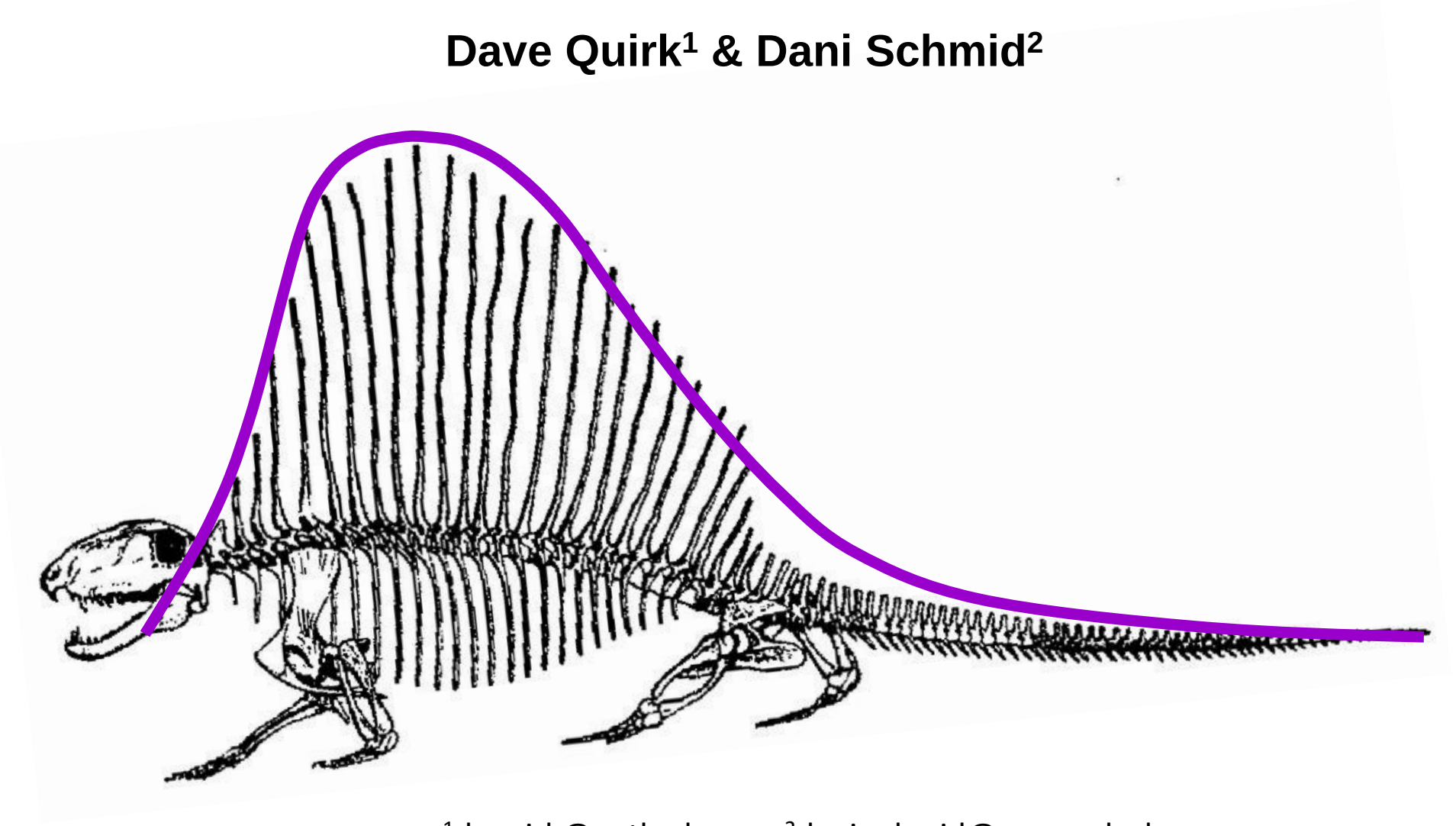
Can we estimate realistic volumes for exploration prospects?

Dave Quirk[1] & Dani Schmid[2]



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Paper can be referenced:

Quirk, D.G. & Schmid, D.W., 2019. Can we estimate realistic volumes for exploration prospects? AAPG Risk and Uncertainty Forum, 18-19 June 2019, Aberdeen. Paper downloadable at: www.manxgeology.com/Bibliography/

The problem…

- Volume predictions in exploration are 2-4 times > delivery

- No obvious improvement with better seismic, advanced software & peer reviews

The problem... but it took for ever to work out where we go wrong

- Volume predictions in exploration are 2-4 times > delivery
- No obvious improvement with better seismic, advanced software & peer reviews
- ...20 years ago thought it was optimism
- ...15 years ago thought it was seismic resolution
- ...10 years ago thought it was the distributions
- ...5 years ago thought it was the software
- ...Now realize the main problem is the calculation method itself

2018 EAGE workshop on Risk & Uncertainty*

- No solutions but...
- 88% agreed we are overoptimistic in exploration volumetrics
- We held a debate as to whether modern software is to blame
- Stochastic modelling is great *provided* probabilities & distributions are known...

- The main issue may not be software, human bias, overconfidence or salesmanship

- Exploration volumetrics need to be:
  - Objective
  - Time efficient
  - Consistent & predictive

**reported in Quirk, Archer, Keith, Herrington, Ramirez & Bjørheim, First Break, Oct 2018*

Estimating under uncertainty

- A team used to weighing things is asked to guess the number of jelly beans in a jar.



Estimating under uncertainty

- A team used to weighing things is asked to guess the number of jelly beans in a jar. Does it make sense to estimate the number of jelly beans as follows:
  - Make a P90 & P10 assessment of the weight of the jar with & without beans (jar-ophysicist)
  - Make a P90 & P10 assessment of the average weight of a bean (bean-ologist)
  - Assume lognormal, normal or stretched beta distributions for the probabilities
  - Produce a range in the number of beans from 10,000 stochastic calculations of (weight of jar with beans – jar without beans) x inverse of avg. weight of a bean



Estimating under uncertainty

- Compare this to:
  - Make P90 & P10 assessments of GRV, column height & net/gross
  - Assume lognormal, normal or stretched beta distributions for these probabilities
  - Produce a range in the volume of pay from 10,000 stochastic calculations where net HC-filled rock volume = GRV of chosen column height x net/gross

Estimating under uncertainty

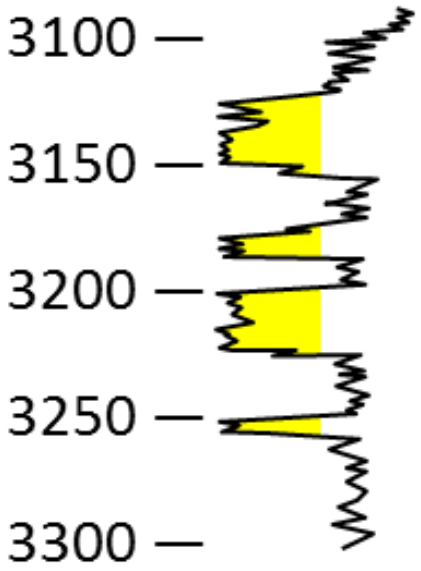
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Estimating under uncertainty

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  - Assume lognormal, normal or stretched beta distributions for these probabilities
  - Produce a range in the volume of pay from 10,000 stochastic calculations where net HC-filled rock volume = GRV of chosen column height x net/gross
- Mathematics appear correct but the inputs do not fit with what we actually know
- Seismic is imprecise, in time & is not geology...

  ...and nor is it tied to seal, reservoir or fluid contacts prior to drilling a well
- Historical statistics do not constrain HC-filled GRV's or 3D net/gross
- Yet we spend days manipulating inputs & reviewing probabilistic models
- Peer reviews are not solving the problem
  – with more work, confidence in charge, reservoir-seal & trap models often grows

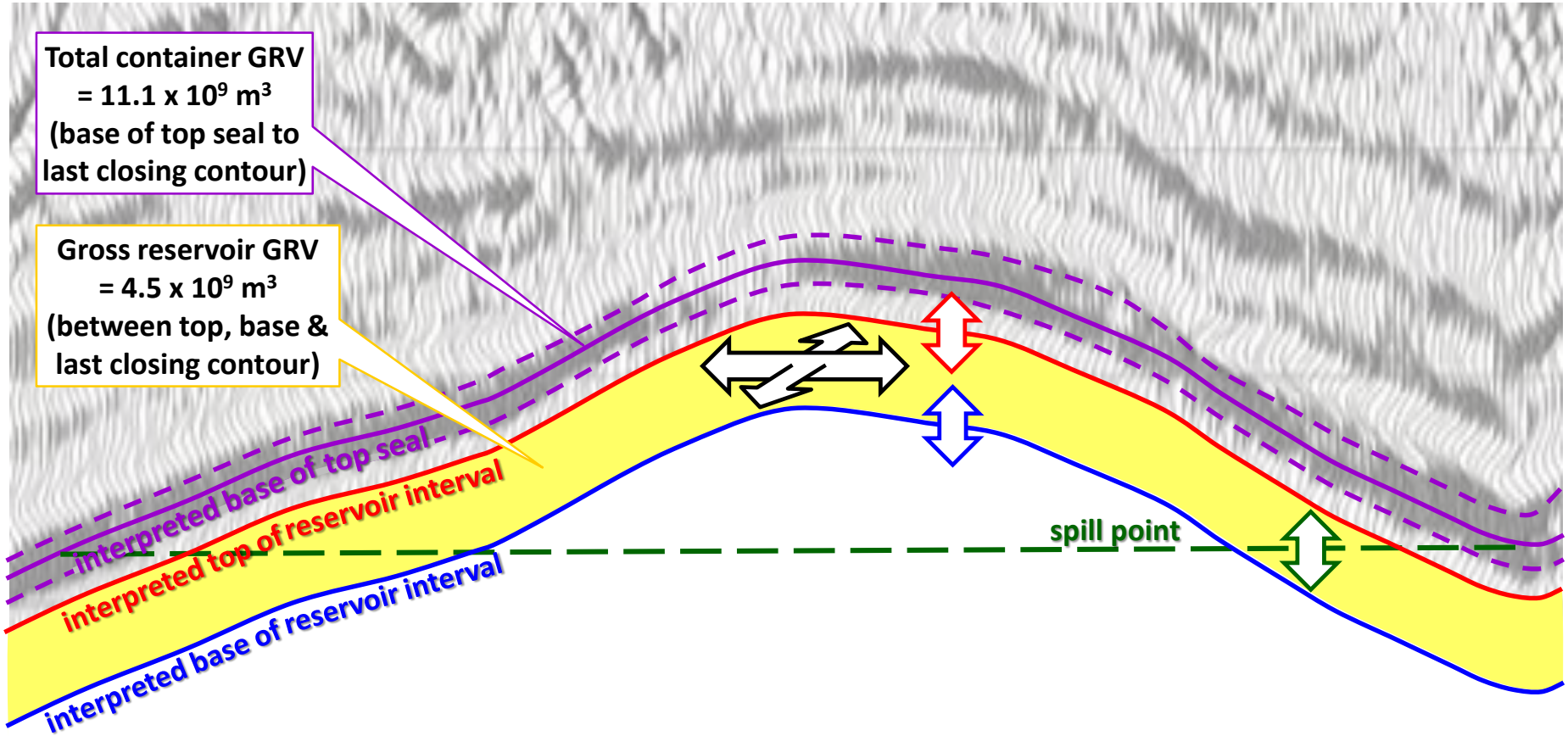
This we understand



But can we quantify this?

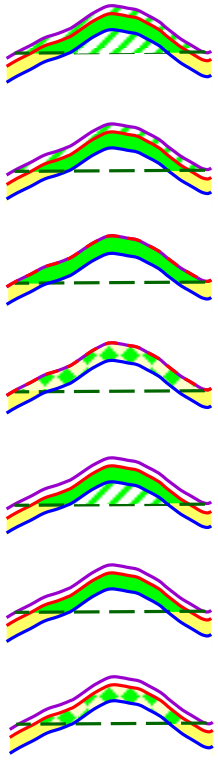
Does this GRV make sense?

What is a reasonable net/gross range?



Which GRV?

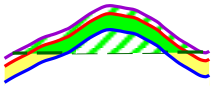
waste zone thickness	50	m, between top of reservoir and base of top seal	
average gross reservoir thickness	100	m	
reservoir net/gross in representative well	50%	assuming it is an exact analogy to prospect	
average net reservoir thickness	50	m	



			% of entire container
volume of entire container enclosed by 3650m contour (spill point)	11064	10^6 m^3 (3650m GRV)	100%
volume of waste zone + reservoir (150m) encl'd by 3650m contour	9676	10^6 m^3 (3650m GRV - 3500m GRV)	87%
volume of gross reservoir (100m) above 3650m assuming no waste zone	8031	10^6 m^3 (3650m GRV - 3550m GRV)	73%
volume of net reservoir above 3650m assuming no waste zone	4016	10^6 m^3 (assuming homogeneous distribution of 50% N/G)	36%
volume of top reservoir beneath 50m waste zone to spillpoint	5917	10^6 m^3 (3600m GRV)	53%
volume of gross reservoir (100m) to spill point	4529	10^6 m^3 (3600m GRV-3500m GRV)	41%
volume of net reservoir (50m) to spill point	2265	10^6 m^3 (assuming homogeneous distribution of 50% N/G)	20%

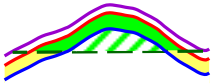
Which GRV?

waste zone thickness	50	m, between top of reservoir and base of top seal
average gross reservoir thickness	100	m
reservoir net/gross in representative well	50%	assuming it is an exact analogy to prospect
average net reservoir thickness	50	m

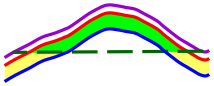


			% of entire container
volume of entire container enclosed by 3650m contour (spill point)	11064	10^6 m^3 (3650m GRV)	100%

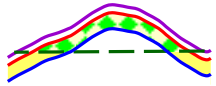
Lognormal & normal distributions are not broad enough to properly capture both upside & downside GRV size and their probabilities are subjective



volume of top reservoir beneath 50m waste zone to spillpoint	5917	10^6 m^3 (3600m GRV)	53%



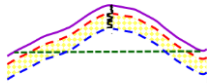
volume of gross reservoir (100m) to spill point	4529	10^6 m^3 (3600m GRV-3500m GRV)	41%



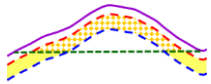
volume of net reservoir (50m) to spill point	2265	10^6 m^3 (assuming homogeneous distribution of 50% N/G)	20%

Net/gross of what?

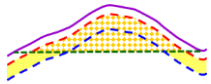
waste zone thickness	50	m, between top of reservoir and base of top seal
average gross reservoir thickness	100	m
reservoir net/gross in representative well	50%	assuming it is an exact analogy to prospect
average net reservoir thickness	50	m



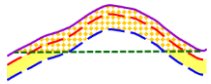
1D net/gross from base of top seal to base of reservoir	33%	including waste zone



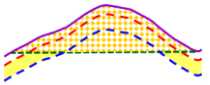
3D net/gross from top of reservoir to base of reservoir above spill point	50%	excluding waste zone & assuming extensive reservoir



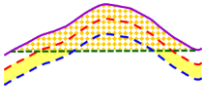
3D net/gross from top of reservoir to spill point	38%	excluding waste zone & assuming extensive reservoir



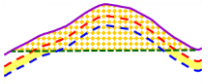
3D net/gross from base of top seal to base of reservoir above spill point	23%	incl. 50m waste zone & assuming extensive reservoir



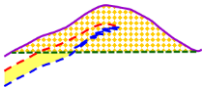
3D net/gross for entire container above spill point	20%	incl. 50m waste zone & assuming extensive reservoir



3D net/gross for entire container above spill point if waste zone is 100m thick	11%	incl. 100m waste zone & assuming extensive reservoir



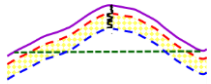
3D net/gross for entire container above spill point if gross reservoir is avg 50m thick	7%	incl. 100m waste zone & assuming extensive reservoir



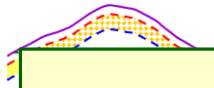
3D net/gross for entire container above spill point if gross reservoir is 100m-0m thick	4%	incl. 100m waste zone & assuming no reservoir in 50% of container

Net/gross of what?

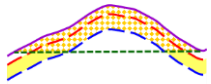
waste zone thickness	50	m, between top of reservoir and base of top seal
average gross reservoir thickness	100	m
reservoir net/gross in representative well	50%	assuming it is an exact analogy to prospect
average net reservoir thickness	50	m



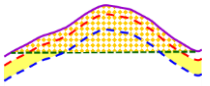
1D net/gross from base of top seal to base of reservoir	33%	including waste zone



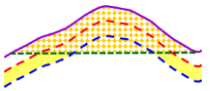
Distribution and probabilities are guesses – totally dependent on interpretation



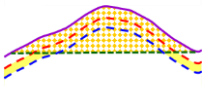
3D net/gross from base of top seal to base of reservoir above spill point	23%	incl. 50m waste zone & assuming extensive reservoir



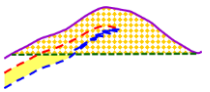
3D net/gross for entire container above spill point	20%	incl. 50m waste zone & assuming extensive reservoir



3D net/gross for entire container above spill point if waste zone is 100m thick	11%	incl. 100m waste zone & assuming extensive reservoir



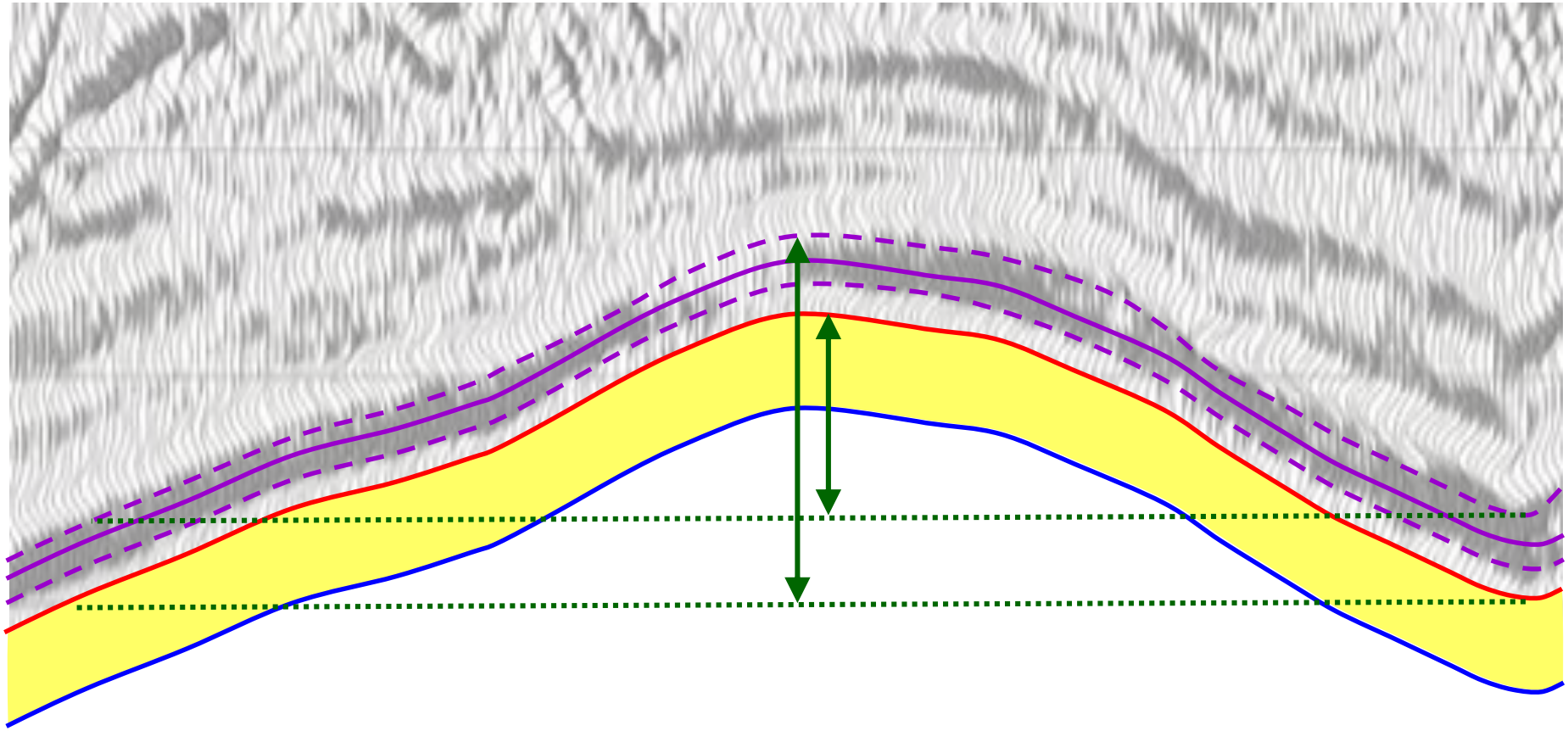
3D net/gross for entire container above spill point if gross reservoir is avg 50m thick	7%	incl. 100m waste zone & assuming extensive reservoir



3D net/gross for entire container above spill point if gross reservoir is 100m-0m thick	4%	incl. 100m waste zone & assuming no reservoir in 50% of container

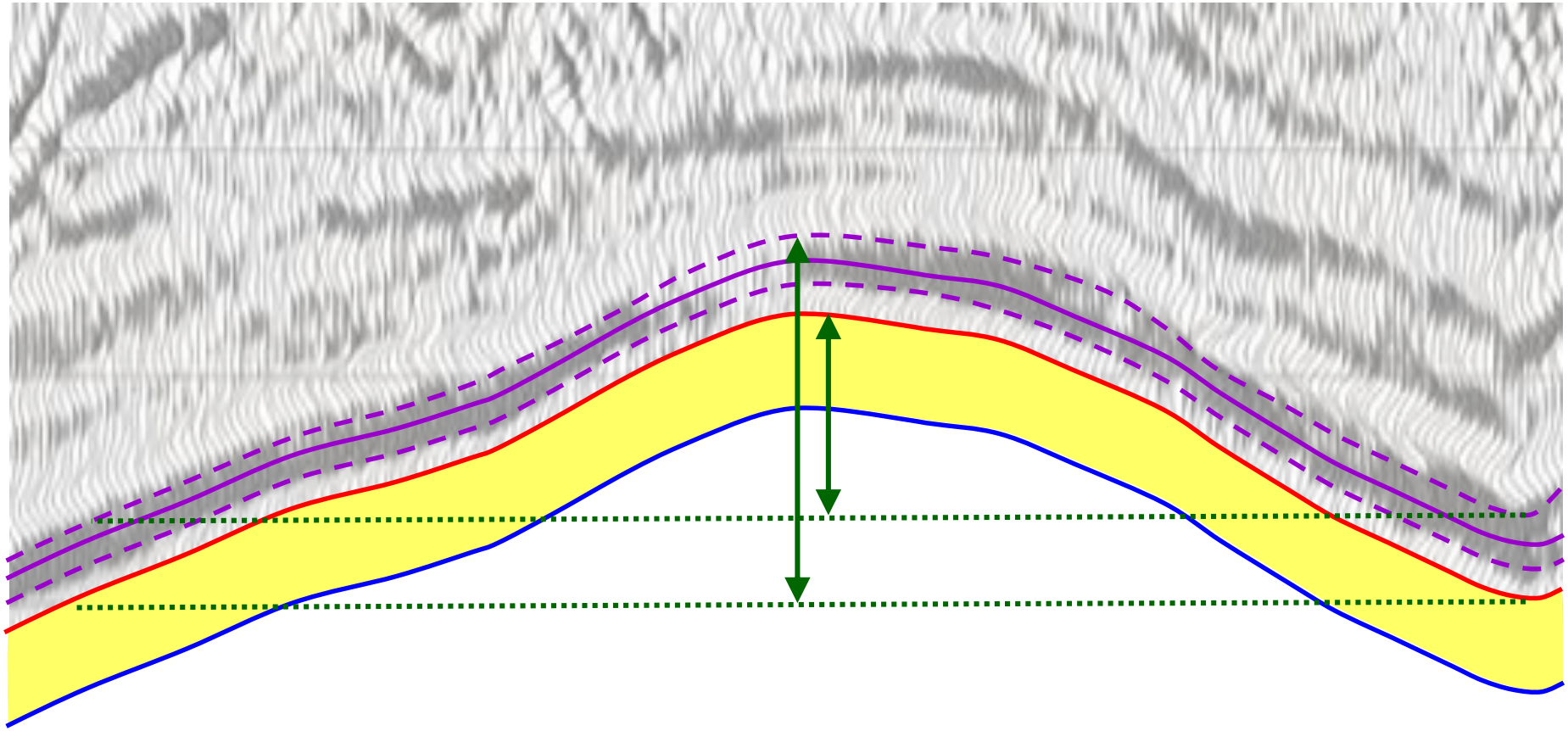
And column height is meant to deal with seismic uncertainty...

...not seal capacity



And column height is meant to deal with seismic uncertainty...

but how do you decide on the range, probabilities & distribution?



Which distribution to use?

Assumed Trap Size Distribution	Cumulative Probabilities of Size of Hydrocarbon-Bearing Trap as Assigned to Specific Depth Contours				Change to Reservoir Distribution from that Assumed in Base Case						Recoverable Resource (million bbl)						Change in Mean from Base (%)	Change in P10/P90 from (%) Base
	Shallow	P50 (m)	Deep	Comment	Parameter	Distribution	P90	P50	P10	Comment**	Mean	P99	P90	P50	P10	P1	Case	
Lognormal hcbGRV	P90 – 4375 m	4429	P5 – 4575 m	base hcbGRV	none (no change to base case; normal distributions from well info)						46.4	0.3	2.6	19.0	110.7	426.6	no change (base case)	
Lognormal hcbGRV	base case	4416	P1 – 4575 m	upside reduced	none	unchanged	unchanged	unchanged	unchanged	base case res parms	29.2	0.3	2.4	14.7	68.6	223.9	– 37	– 33
Lognormal hcbGRV	base case	4438	P10 – 4575 m	upside expanded	none	unchanged	unchanged	unchanged	unchanged	base case res parms	67.2	0.4	2.7	23.0	158.5	698.2	45	38
Normal hcbGRV	base case	4496	base case	symmetric distrib.	none	unchanged	unchanged	unchanged	unchanged	base case res parms	84.8	0.7	8.5	55.3	193.9	433.2	83	– 46
Stretched β hcbGRV	base case	4489	base case	mode at 4475 m	none	unchanged	unchanged	unchanged	unchanged	base case res parms	80.2	0.6	7.9	51.2	185.1	421.2	73	– 45
Uniform hcbGRV	P100 – 4275 m	4502	base case	even distribution	none	unchanged	unchanged	unchanged	unchanged	base case res parms	87.3	0.5	6.8	55.0	207.6	448.6	88	– 28
Triangular hcbGRV	P100 – 4275 m	4498	base case	mode at 4475 m	none	unchanged	unchanged	unchanged	unchanged	base case res parms	88.5	1.2	11.3	59.9	198.2	434.5	91	– 59
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	net/gross	unchanged	unchanged	0.45	0.70	P10 down from 0.80	42.1	0.3	2.5	17.4	99.8	383.5	– 9	– 6
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	net/gross	unchanged	unchanged	0.54	0.90	P10 up from 0.80	49.6	0.3	2.8	20.2	118.6	455.6	7	– 1
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	net/gross	lognormal	unchanged	0.39	unchanged	P50 down from 0.50	39.6	0.4	2.4	16.3	93.6	358.0	– 15	– 8
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	net/gross	stretched β	unchanged	0.44	unchanged	mode of 0.35	43.5	0.4	2.6	17.9	103.7	394.5	– 6	– 6
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	porosity	lognormal	unchanged	0.14	unchanged	P50 down from 0.17	44.1	0.4	2.6	17.9	105.3	399.4	– 5	– 5
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	recovery	base case	0.10	0.30	0.50	P90 and P10 down 0.05	40.9	0.2	2.1	16.2	98.4	385.7	– 12	10
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	recovery	base case	0.20	0.40	0.60	P90 and P10 up 0.05	51.9	0.5	3.1	21.7	122.8	459.4	12	– 7
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	recovery	lognormal	base case	0.28	base case	P50 down from 0.35	40.4	0.4	2.5	16.7	96.5	155.9	– 13	– 9

Which distribution to use?

Assumed Trap Size Distribution	Cumulative Probabilities of Size of Hydrocarbon-Bearing Trap as Assigned to Specific Depth Contours				Change to Reservoir Distribution from that Assumed in Base Case						Recoverable Resource (million bbl)						Change in Mean from Base (%)	Change in P10/P90 from (%) Base
	Shallow	P50 (m)	Deep	Comment	Parameter	Distribution	P90	P50	P10	Comment**	Mean	P99	P90	P50	P10	P1	Case	
Lognormal hcbGRV	P90 – 4375 m	4429	P5 – 4575 m	base hcbGRV	none (no change to base case; normal distributions from well info)						46.4	0.3	2.6	19.0	110.7	426.6	no change (base case)	
Lognormal hcbGRV	base case	4416	P1 – 4575 m	upside reduced	none	unchanged	unchanged	unchanged	unchanged	base case res parms	29.2	0.3	2.4	14.7	68.6	223.9	– 37	– 33
Lognormal hcbGRV	base case	4438	P10 – 4575 m	upside expanded	none	unchanged	unchanged	unchanged	unchanged	base case res parms	67.2	0.4	2.7	23.0	158.5	698.2	45	38
Normal hcbGRV	base case	4496	base case	symmetric distrib.	none	unchanged	unchanged	unchanged	unchanged	base case	84.8	0.7	8.5	55.3	193.9	433.2	83	– 46

Quirk & Ruthrauff (2008) show that with the same probabilities of GRV & net/gross, the choice of distribution can half or double the stochastic mean volume of a prospect

Lognormal hcbGRV	base case	4429	base case	base hcbGRV	net/gross	unchanged	unchanged	0.54	0.90	P10 up from 0.80	49.6	0.3	2.8	20.2	118.6	455.6	7	– 1
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	net/gross	lognormal	unchanged	0.39	unchanged	P50 down from 0.50	39.6	0.4	2.4	16.3	93.6	358.0	– 15	– 8
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	net/gross	stretched β	unchanged	0.44	unchanged	mode of 0.35	43.5	0.4	2.6	17.9	103.7	394.5	– 6	– 6
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	porosity	lognormal	unchanged	0.14	unchanged	P50 down from 0.17	44.1	0.4	2.6	17.9	105.3	399.4	– 5	– 5
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	recovery	base case	0.10	0.30	0.50	P90 and P10 down 0.05	40.9	0.2	2.1	16.2	98.4	385.7	– 12	10
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	recovery	base case	0.20	0.40	0.60	P90 and P10 up 0.05	51.9	0.5	3.1	21.7	122.8	459.4	12	– 7
Lognormal hcbGRV	base case	4429	base case	base hcbGRV	recovery	lognormal	base case	0.28	base case	P50 down from 0.35	40.4	0.4	2.5	16.7	96.5	155.9	– 13	– 9

Main problem lies with the GRV-net/gross-column height method

- In an undrilled prospect we do not know
  - Position of seal or leak points
  - Position of hydrocarbon water contact
  - Position of top & base of gross reservoir
  - 3D net/gross of chosen GRV model & HCW contact
  - Probabilistic distributions for GRV, HCW contact & 3D net/gross

- Nor are there historical statistics to constrain model of GRV & 3D net/gross

- Yet we spend days manipulating inputs & reviewing probabilistic models

- Seismic is imprecise, in time & is not geology...

  ...and nor is it tied to seal, reservoir or fluid contacts prior to drilling a well

Our model of container, reservoir & leakpoint is always incorrect (57% of all discoveries worldwide are not commercial, excl. USA)

- We cannot judge whether a GRV outcome makes sense
- We do not know the appropriate range of net/gross in 3D
- The depth of top seal culmination and spillpoint are interpretations
- The probabilities & distributions are entirely subjective

- Therefore, GRV-net/gross-column height method is bound to fail

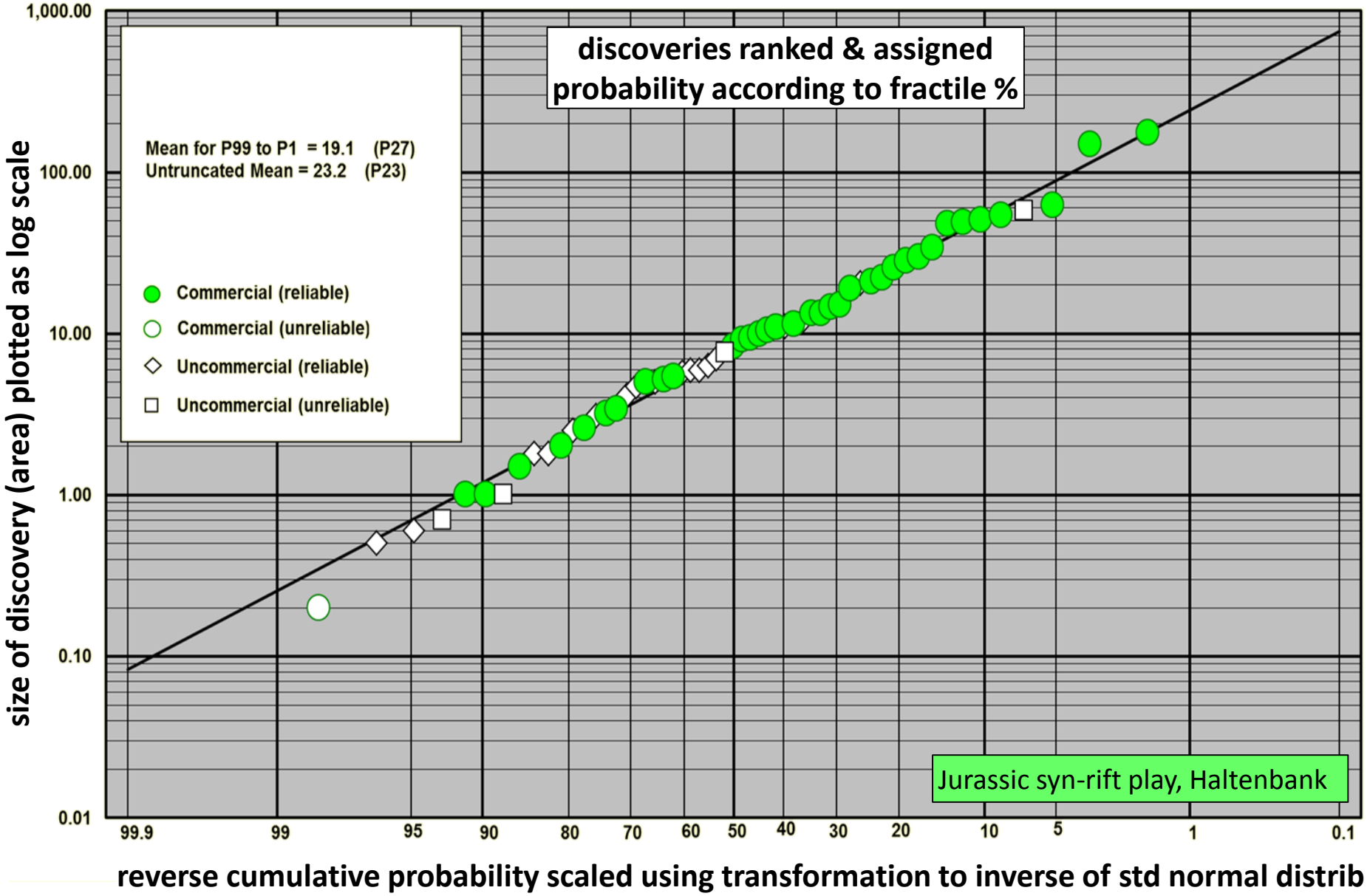
Our model of container, reservoir & leakpoint is always incorrect (57% of all discoveries worldwide are not commercial, excl. USA)

- We cannot judge whether a GRV outcome makes sense
- We do not know the appropriate range of net/gross in 3D
- The depth of top seal culmination and spillpoint are interpretations
- The probabilities & distributions are entirely subjective
- Therefore, GRV-net/gross-column height method is bound to fail
- Weather forecasts have got better because meteorologists learn from the past...

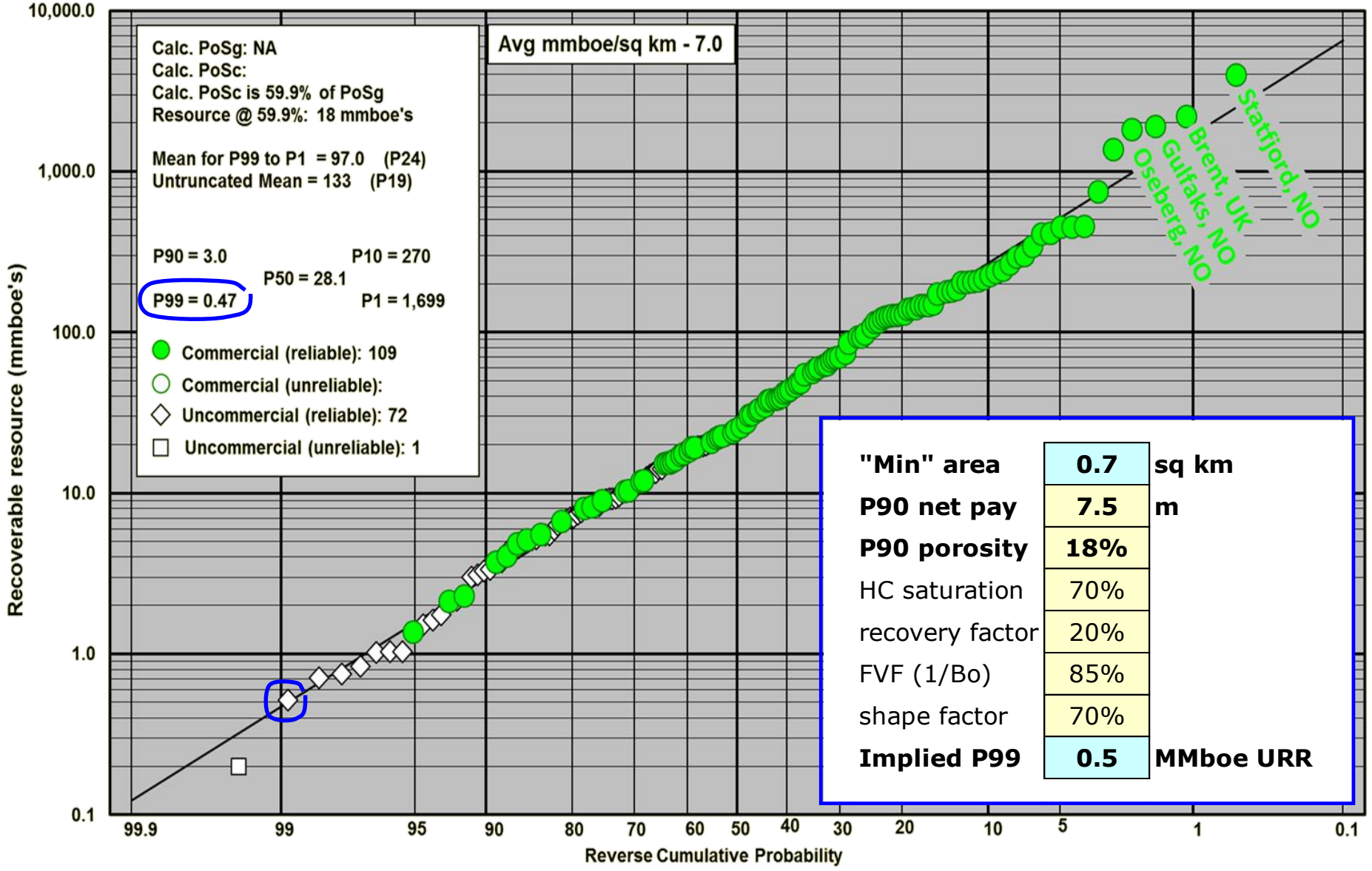
Why use unconstrained GRV, fluid contacts & 3D net/gross when:

- Historical statistics & well data provide the following constraints:
  - Reservoir thickness (top to base)
  - Discovery area (footprint)
  - MMboe/km^2 (discovery resource size/footprint area)
  - Other reservoir properties (also wrapped up in MMboe/km^2)

Discovery size (URR & area) in a play is lognormal



Implied P99 – JM paralic ssts (Brent & Fladen Gps) – disc distrib

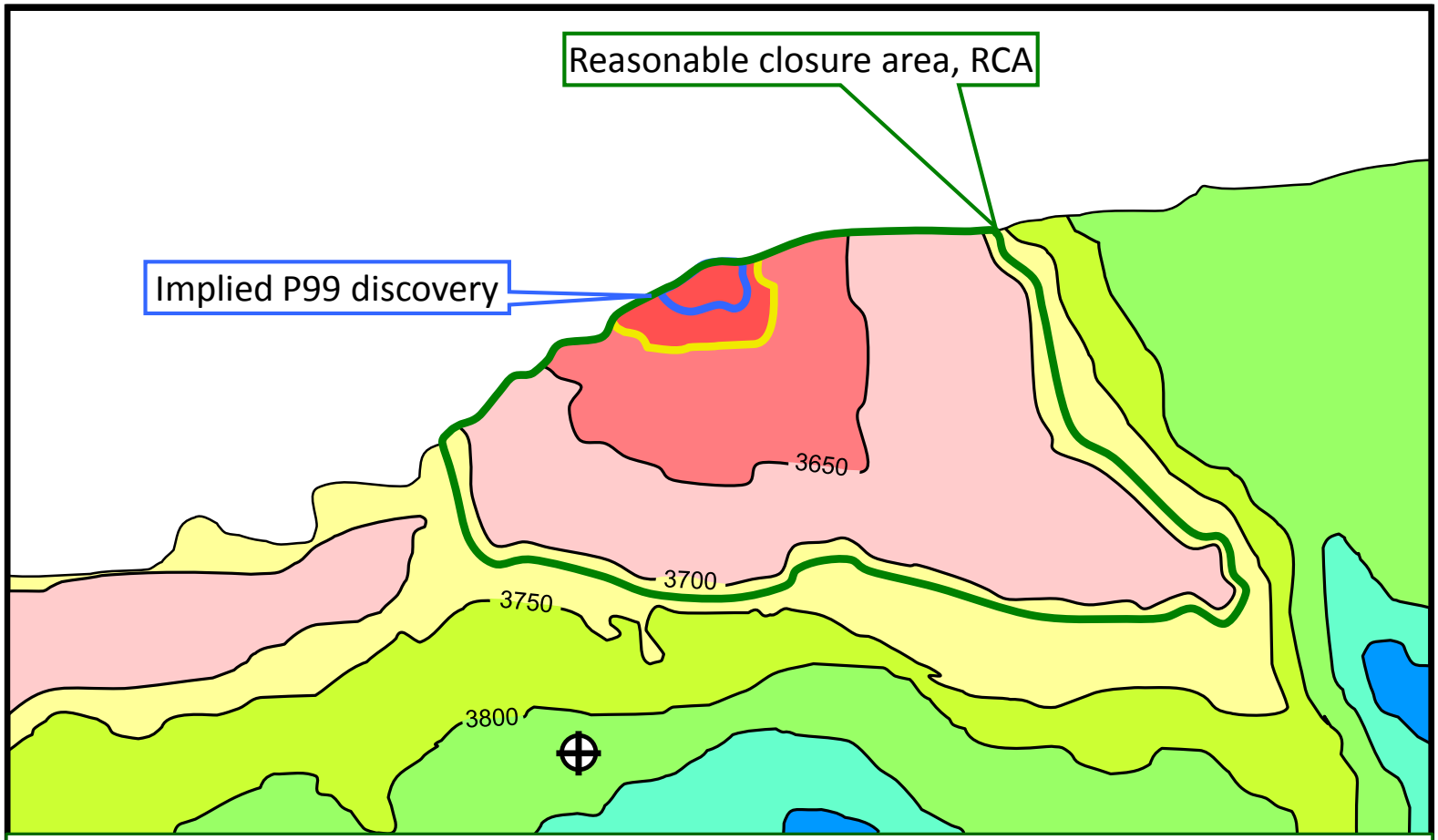


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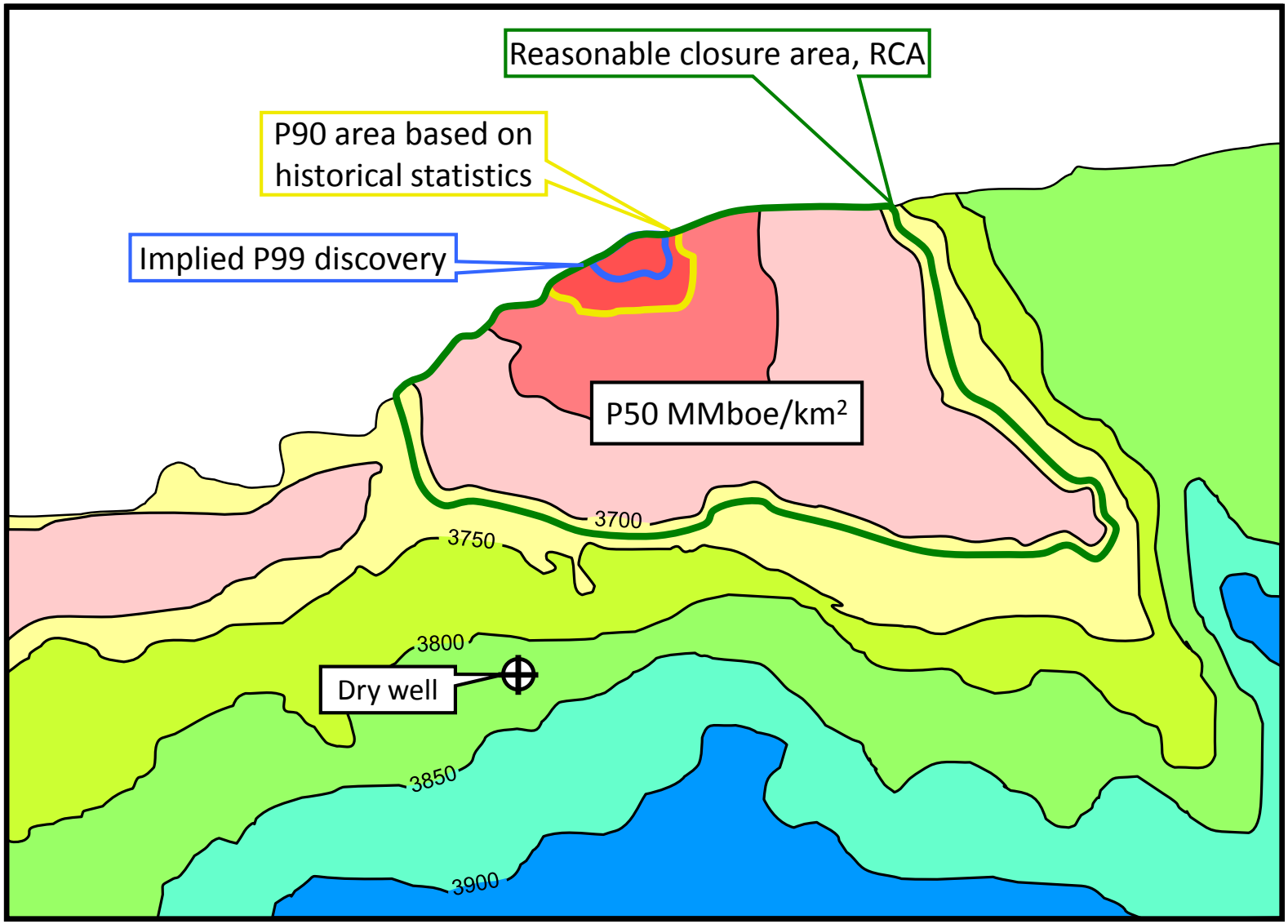
- Interpreters & peers can both evaluate & agree on a reasonable closure area from:
  - Depth map of preferred interpretation of prospect + alternatives
  - Reference to dry wells, seal capacities, possible geophysical anomalies, etc.
  - Shape factor (based on interpreted GRV vs depth)

What we do know & can agree on

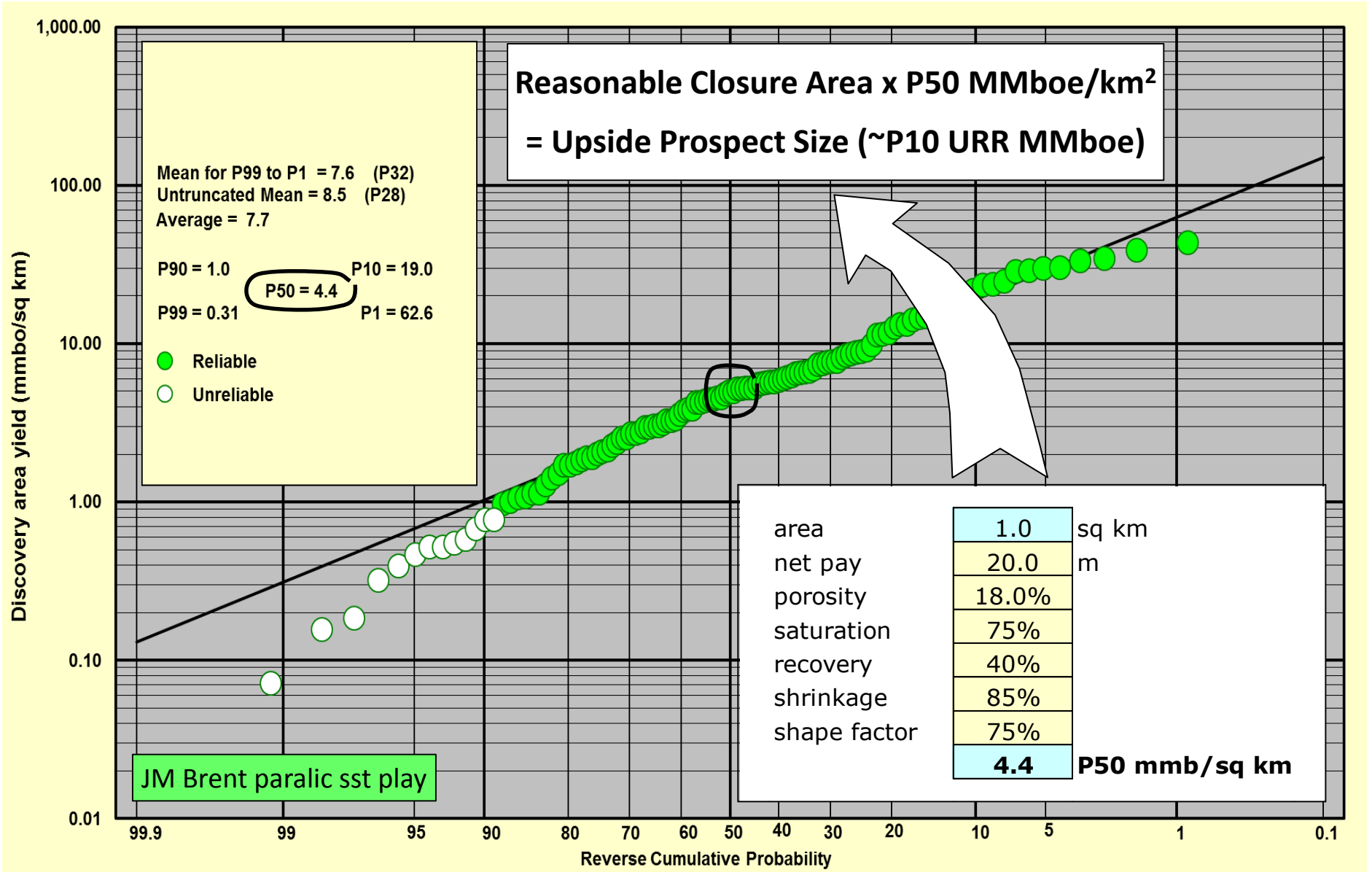


From lookbacks, a company can decide if Reasonable Closure Area represents P10, Pmean (c.P20) or something in between

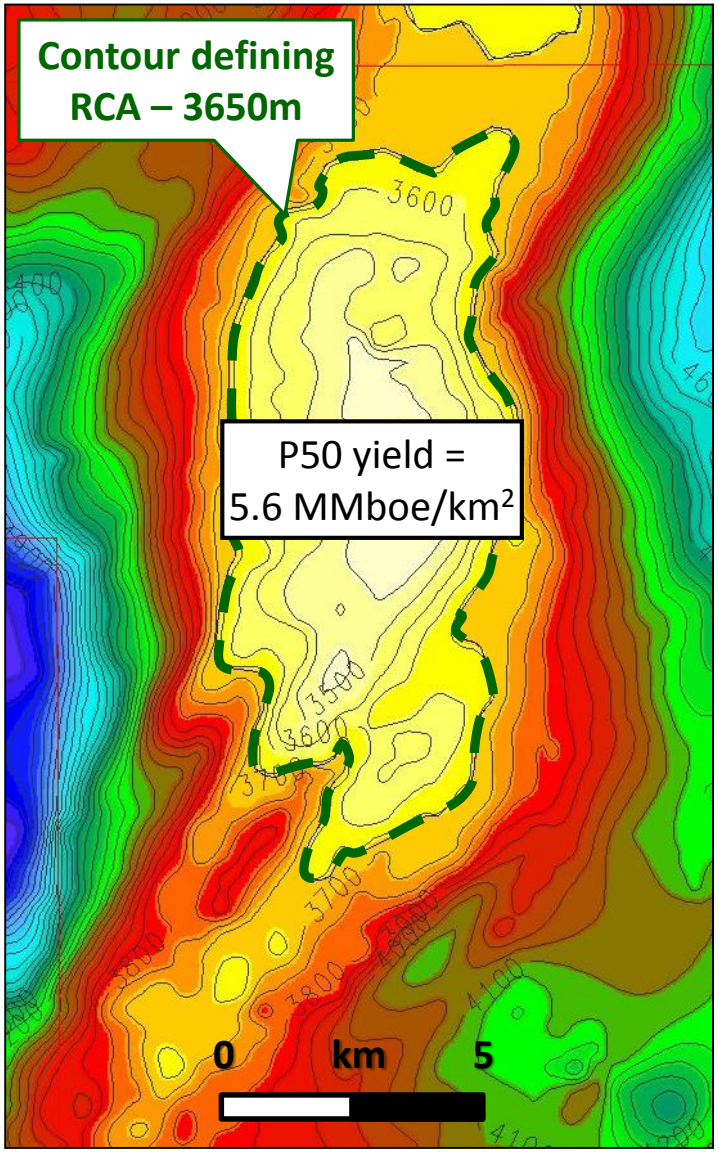
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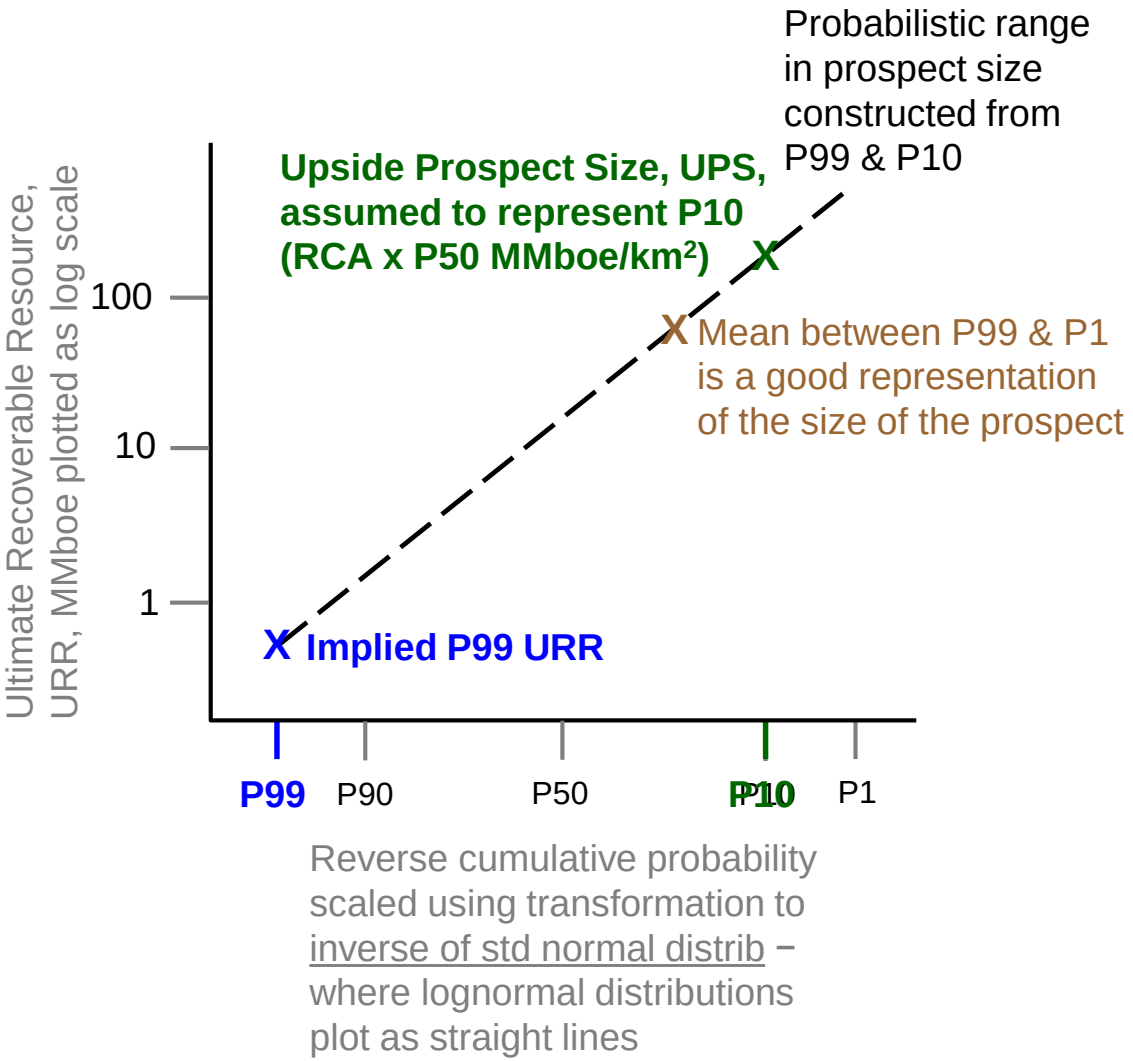


URR MMboe ÷ footprint area km² for each discovery in the play



Propect Area Yield (PAY) method





Example PAY calculation

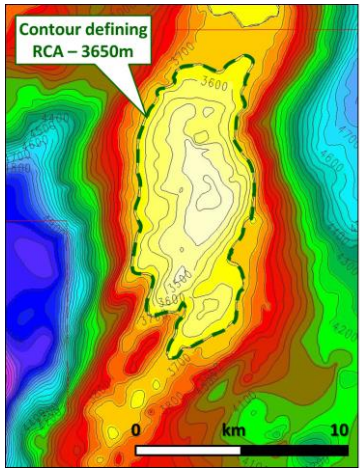
Prospect Name: Sidecar

Inputs for Upside Prospect Size (UPS)

Reasonable Closure Area (RCA): 43.0 km^2 Contour defining RCA: 3650

X

Mid Case Unit Area Yield (P50 MMb/km^2): 5.6 MMboe/km^2 recoverable resource



Result - Upside Prospect Size (UPS)

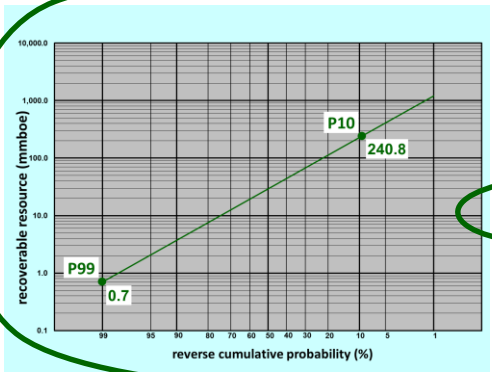
Product of RCA & P50 MMb/km^2: 240.8 MMboe recoverable resource

Assumed probability of UPS: P10

Input for Downside Prospect Size

P99 prospect size: 0.7 MMboe recoverable resource

Prospect size range from UPS & P99



MMboe, URR	
0.7	P99
3.8	P90
30.1	P50
93.4	Mean^{P99-P1}
240.8	P10
1312.0	P1

P24 Probability of Mean^{P99-P1}

MMboe URR 60.0 has probability P33 (minimum economic field size, MEFS)

MMboe URR 24.5 is equivalent to P55 (historical chance that discovery is commercial)

Example PAY calculation

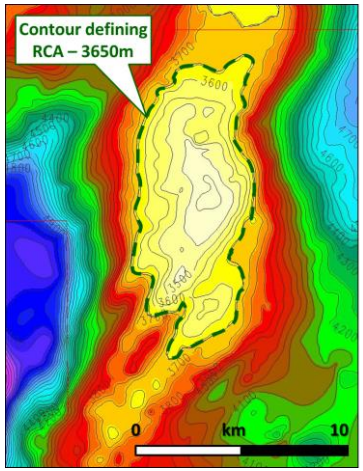
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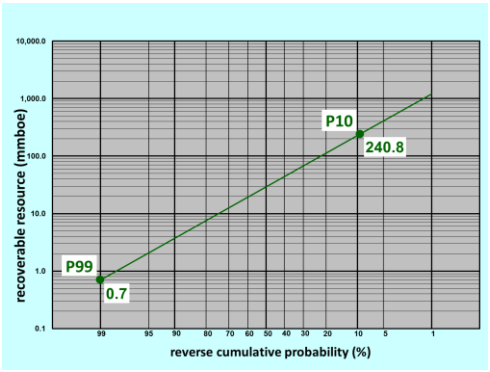
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P24 Probability of Mean^{P99-P1}

RCA x P10 MMboe/km^2 = 1377 MMboe

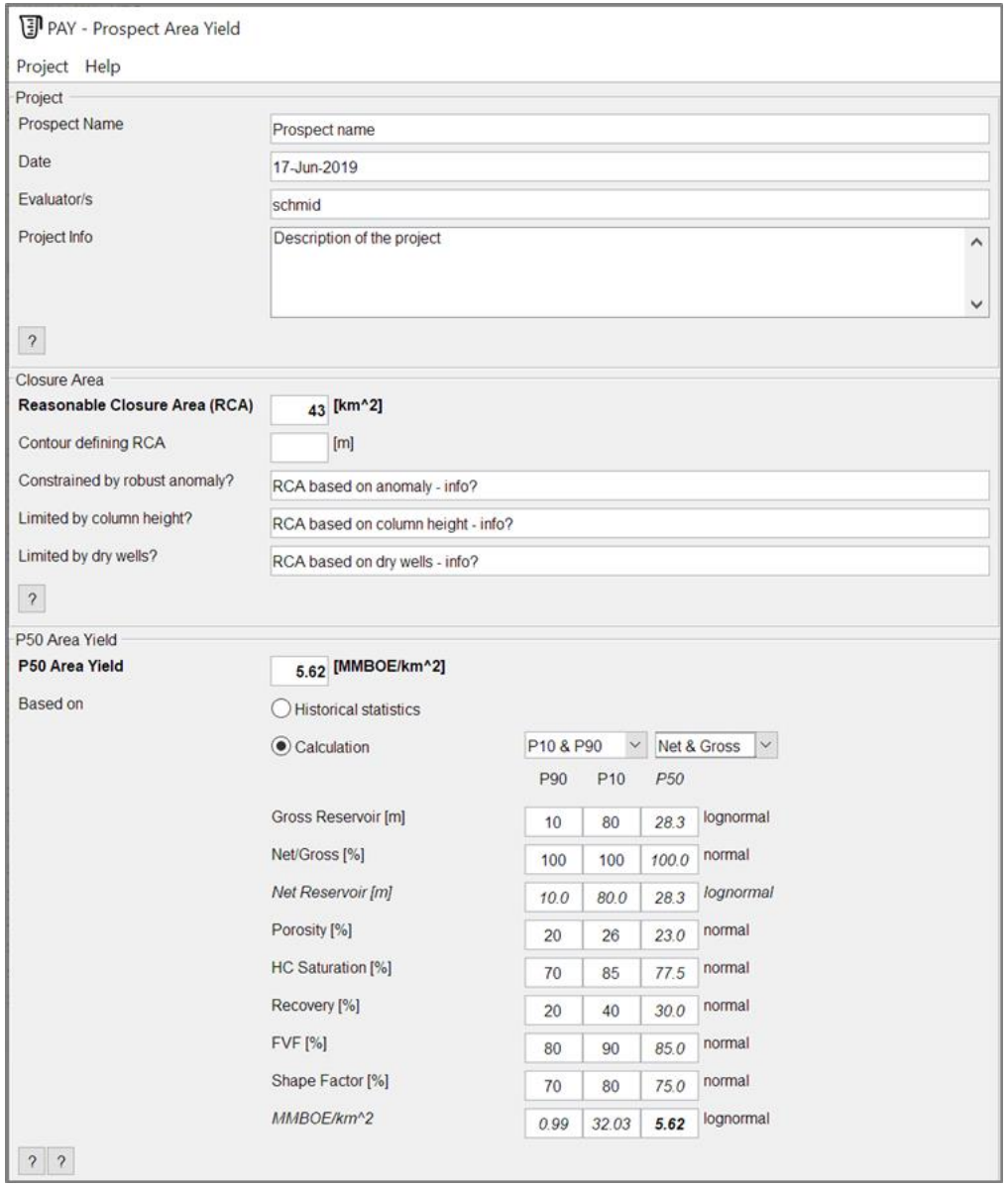
MMboe URR 60.0 has probability P33 (minimum economic field size, MEFS)

MMboe URR 24.5 is equivalent to P55

We would like to test whether UPS is better represented by P10 or Pmean

dgquirk@outlook.com

dani.schmid@geomodsol.com



Choose minimum of 3 inputs, maximum of 27

PAY tool - free to everyone!

Send request to:

dgquirk@outlook.com

dani.schmid@geomodsol.com

We would like to test whether UPS Reasonable Closure Area x P50 MMb/km^2 is better represented by P10 or Pmean

Conclusions

- GRV x net/gross x column height method is destined to fail
  - unconstrained & subjective choices of probabilities & distributions

- Better that we use what we know:
  - Reasonable Closure Area of prospect (QC'd with play statistics or analogues)
  - Implied P99 (calculated & from play statistics or analogues)
  - P50 MMboe/km^2 (from play statistics or analogues &/or calculated)

  Which means we actually don't need complex probabilistic models

- Yes we can estimate realistic volumes...

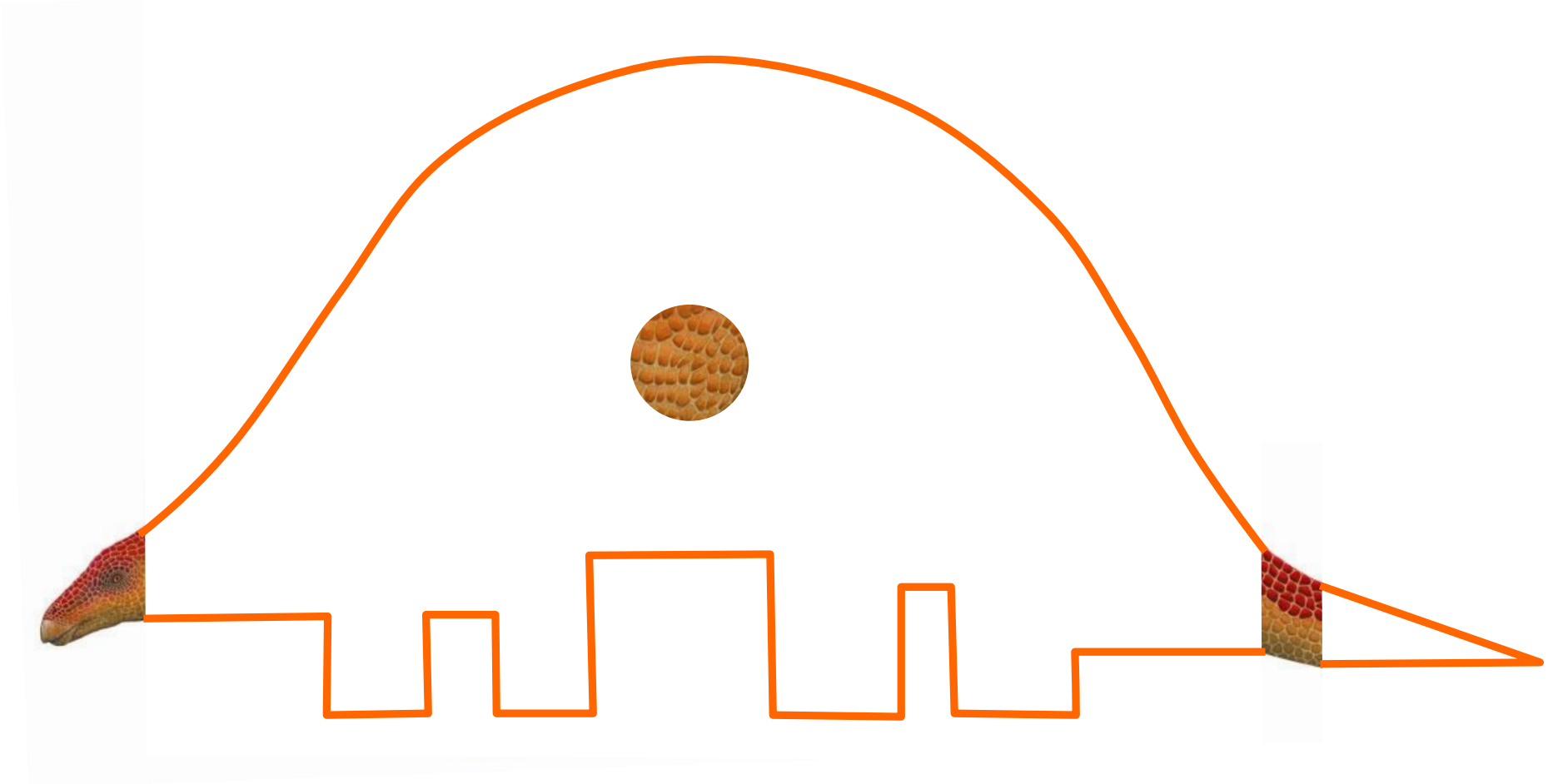
  ...but it might be bad news for some prospects in established plays

feedback or requests to dgquirk@outlook.com or dani.schmid@geomodsol.com

Where the picture is very uncertain, unhelpful complexity is introduced by focussing on unconstrained details & constructing subjective relationships



Hard data on the head & tail provide a good estimate on the size, especially if history guides you on the shape



model by Amalie aged 7

Uncertainty may hide monsters – but keep the picture simple

