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Problems Correlating Porosity Uncertainty to Rock Volume*

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Abstract

Probabilistic models of potential hydrocarbon volumes in exploration prospects typically include an estimate of "average" porosity. The estimate is input as a range defined by a probability density function such as a normal or lognormal distribution. Geologists often mistakenly assume that the distribution represents the range of porosities that may exist within the prospect: the porosity that might be encountered at any single point within a discovered field. The range actually represents the uncertainty around the total porosity within the field. Each porosity value within the distribution must be an appropriate representation of the percentage of the net rock volume above the hydrocarbon-water contact that is within pore spaces. The misconception that the porosity range represents the range of porosities within the field, rather than uncertainty around total porosity, often results in input ranges that are too broad, yielding unrealistic high-side resource estimates. A very broad porosity range is appropriate, however, if the field is very small, with a limited area or column height. If the field is small, there will be less room for vertical or lateral variation in porosity, and therefore a greater chance that the average porosity within the field will be very high or very low. The possibility of a high porosity within a small field should not be overlooked, as fields of this type are often economically attractive. As the productive area or column height increases, the degree of porosity uncertainty, the difference between the minimum and maximum values, should decrease. If the field covers a large area or interval, there is a greater chance that a high porosity in one portion of the field will be offset by a small porosity in another portion of the field, resulting in a narrower range of uncertainty around the average porosity within the field. The correlation of the degree of uncertainty to gross rock volume is difficult to capture using a single-zone Monte Carlo model. The solution lies in the use of multiple-zone, or multiple-segment models. If each segment represents a stratigraphic layer, or a

portion of the potential productive area, and each segment is assigned the same range of porosities, then increasing the number of productive segments will decrease the range of total porosity. The number of segments should reflect the potential heterogeneity within the field.

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Problems Correlating Porosity Uncertainty to Rock Volume

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Probabilistic prospect assessments

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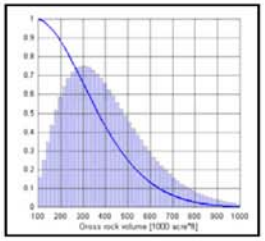
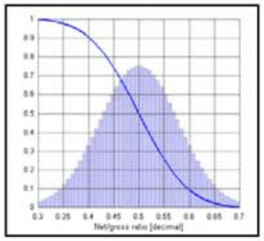
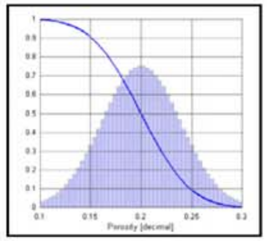


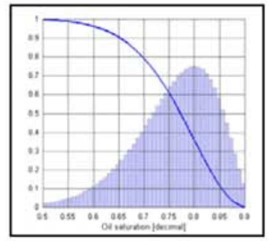
GRV



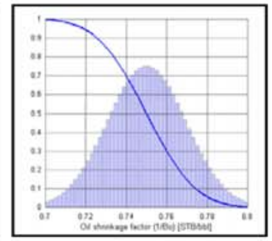
Net-Gross



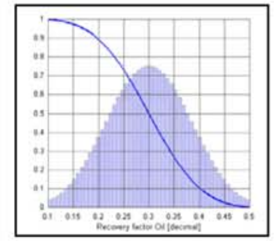
Average Porosity



Saturation



Shrinkage



Recovery

Notes by Presenter: Probabilistic assessments of prospect volumes define the uncertainty around each of several volumetric parameters using probability density functions such as normal or lognormal distributions.

Probabilistic prospect assessments

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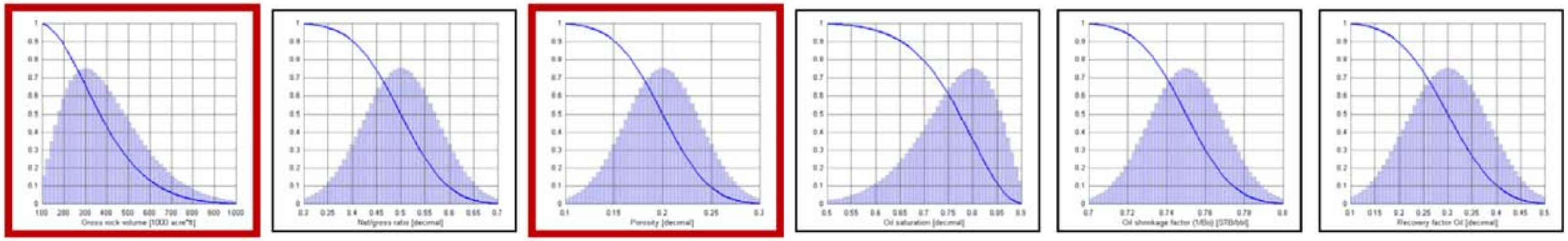
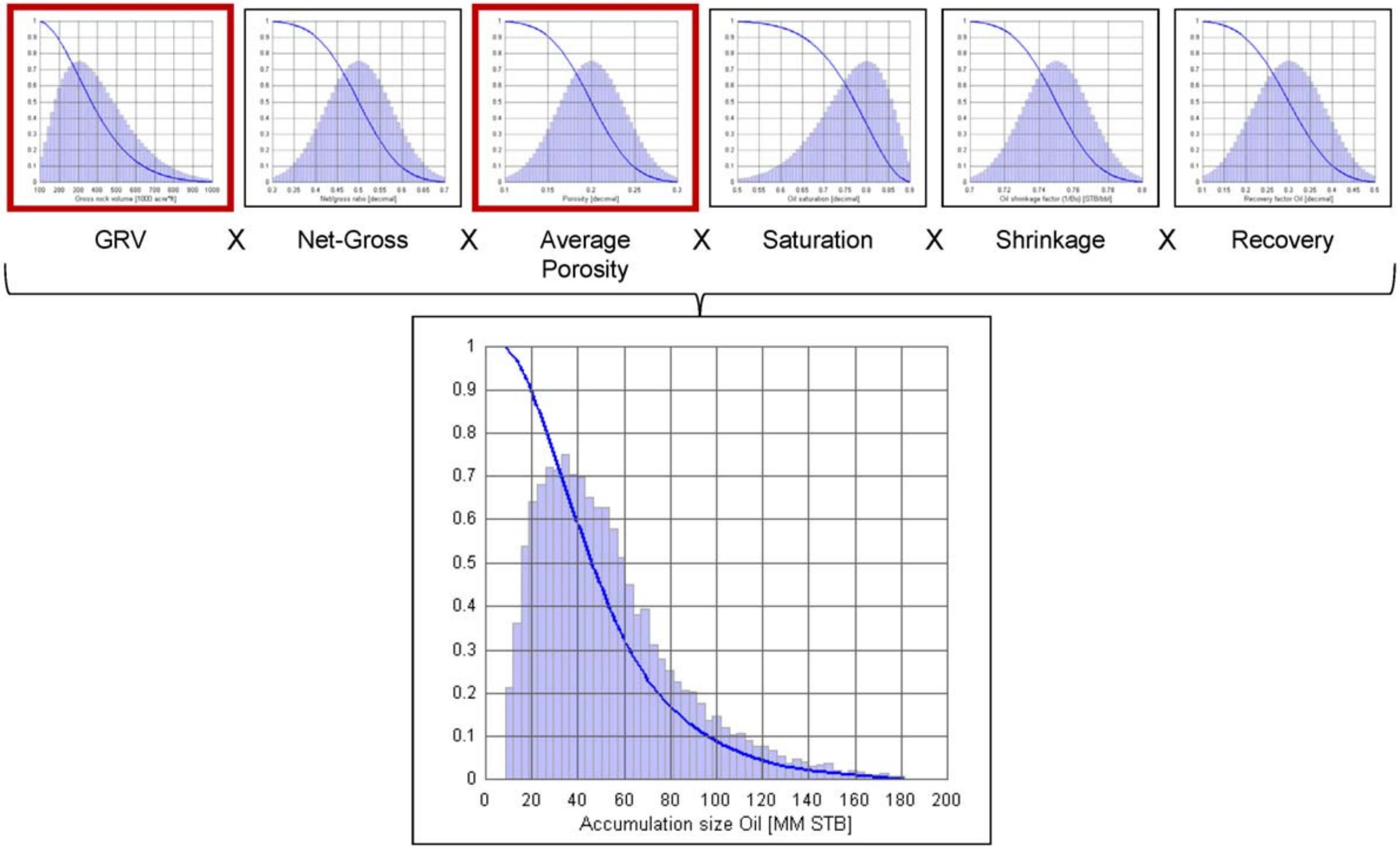


GRV | Net-Gross | Average Porosity | Saturation | Shrinkage | Recovery

Notes by Presenter: The parameters typically include Gross Rock Volume and average porosity. The relationship between these parameters is the subject of this presentation.

Probabilistic prospect assessments



Notes by Presenter: Monte Carlo simulations combine the input distributions by running a series of trials, with each trial representing a unique calculation of resource volume. A value for each parameter is chosen in each trial. The values are then multiplied together to yield a resource volume. The different combinations of parameter values yields a range of resource volumes, and their associated probabilities.

Single-zone assessment

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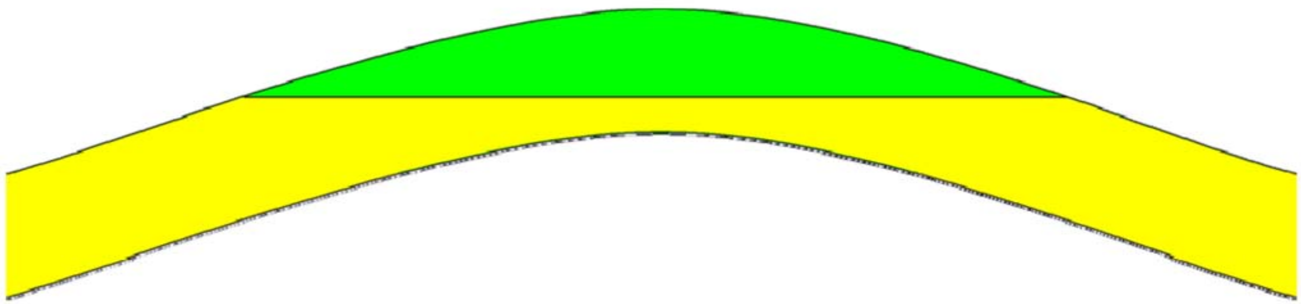
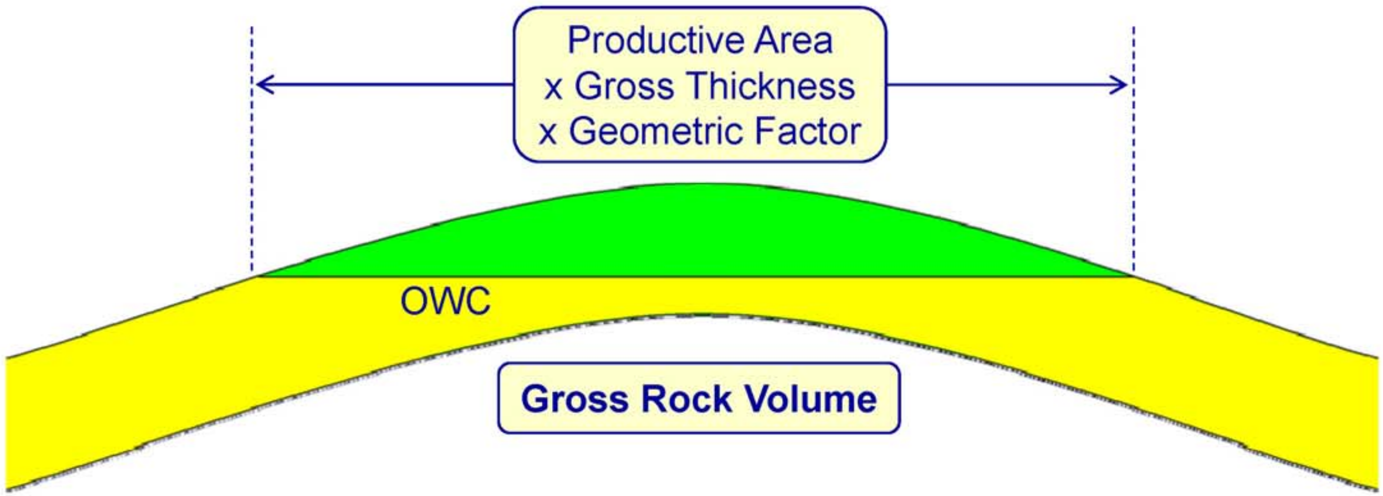


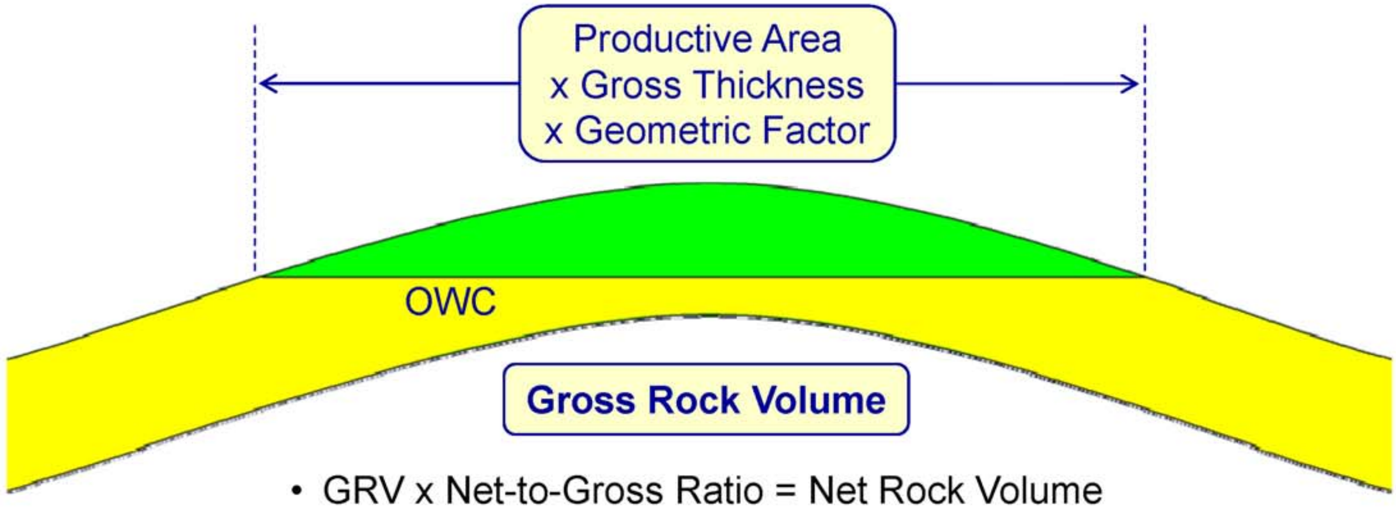
Notes by Presenter: Single-zone probabilistic assessments assume that the entire prospect is one reservoir, regardless of how variable, discontinuous, faulted, or heterogeneous, the rock actually is. Single-zone assessments have, unfortunately, dominated the assessment world for the last 20 years even though multiple-zone assessments are well-understood and easy to do.

Single-zone assessment



Notes by Presenter: The Gross Rock Volume of the zone is the volume of the gross interval above the hydrocarbon-water contact. It is usually calculated indirectly based on inputs of productive area, gross thickness, and an estimation of a geometric factor.

Single-zone assessment



- GRV x Net-to-Gross Ratio = Net Rock Volume

Notes by Presenter: Multiplying the gross rock volume by the net-to-gross ratio yields Net Rock Volume.

Single-zone assessment

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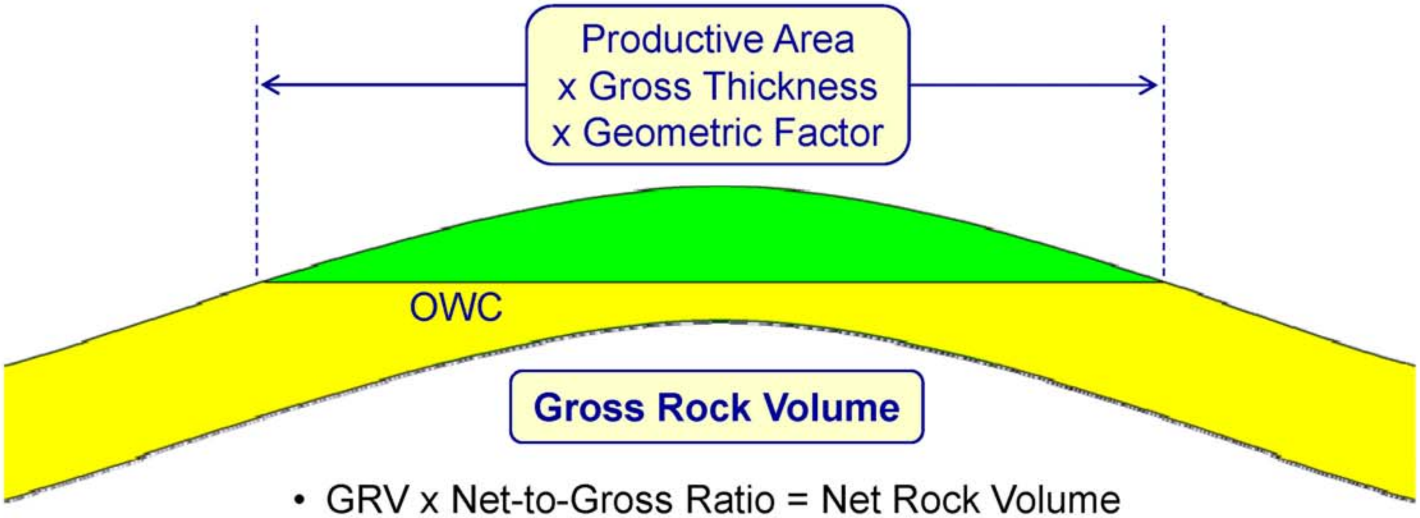

- GRV x Net-to-Gross Ratio = Net Rock Volume
- NRV x Average Porosity = Net Pore Volume

Notes by Presenter: Multiplying the net rock volume by the Average Porosity yields the Net Pore Volume.

Single-zone assessment

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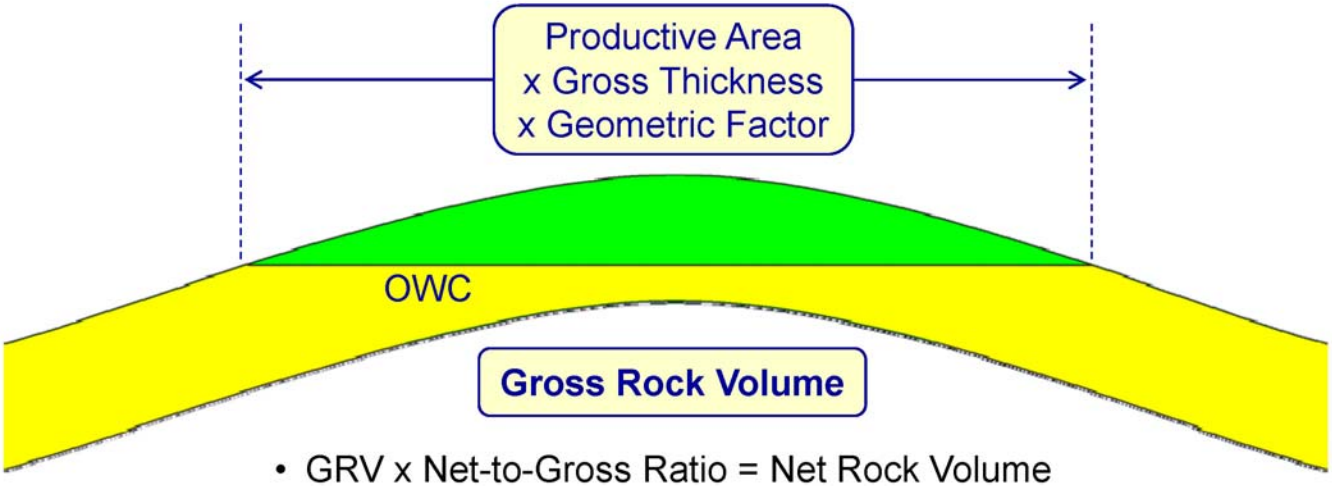

- GRV x Net-to-Gross Ratio = Net Rock Volume
- NRV x Average Porosity = Net Pore Volume
- Average Porosity = Fraction of the NRV that is within pore space

Notes by Presenter: The average porosity is the fraction of the net rock volume that is pore space. The term "Average Porosity" is somewhat misleading since we aren't necessarily averaging anything. It is simply the porosity within this large piece of rock, just as the porosity of a core plug is the porosity within that small piece of rock.

Average porosity

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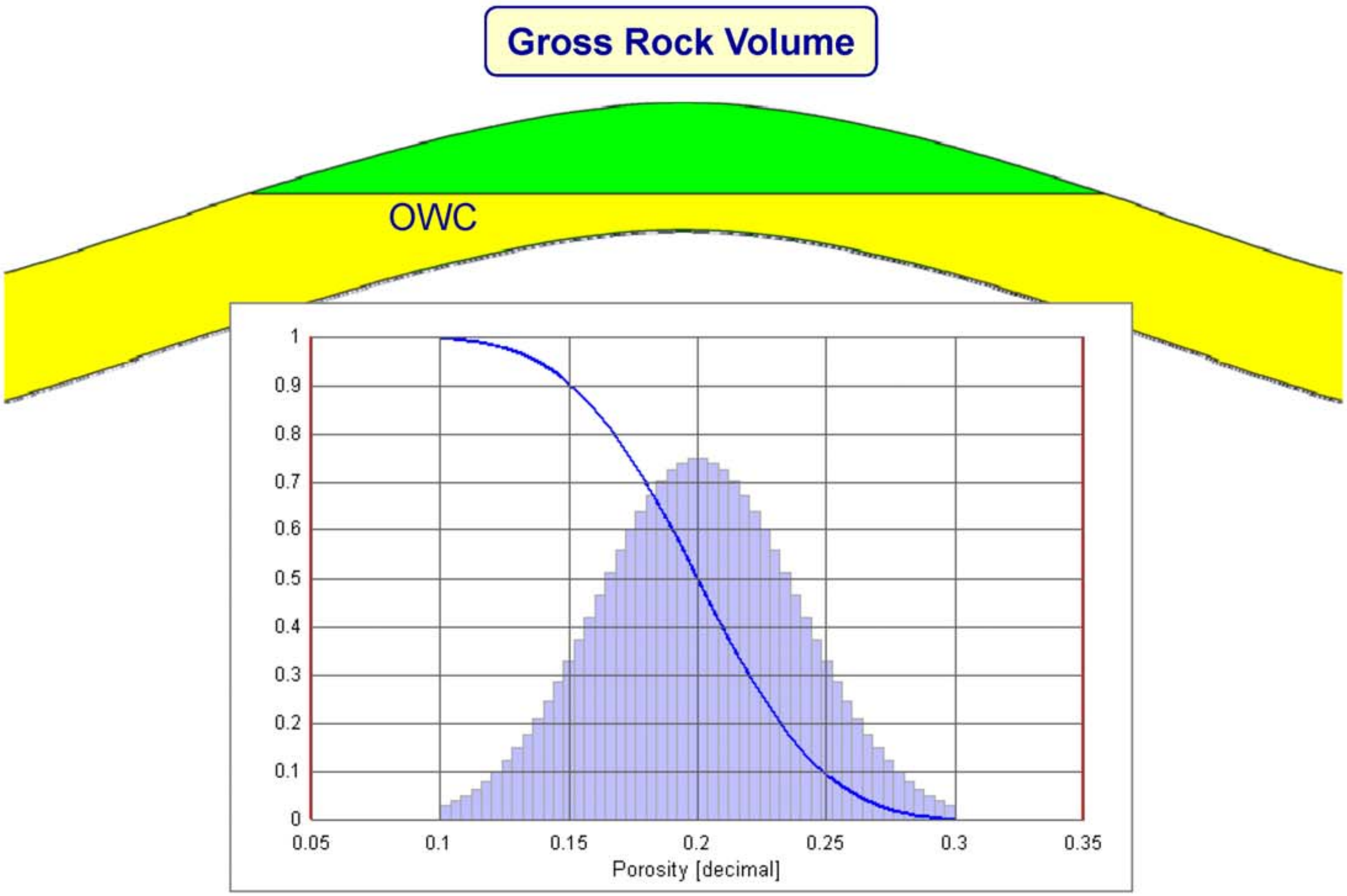

Notes by Presenter: The uncertainty in the average porosity is expressed as a probability density function.

Average porosity

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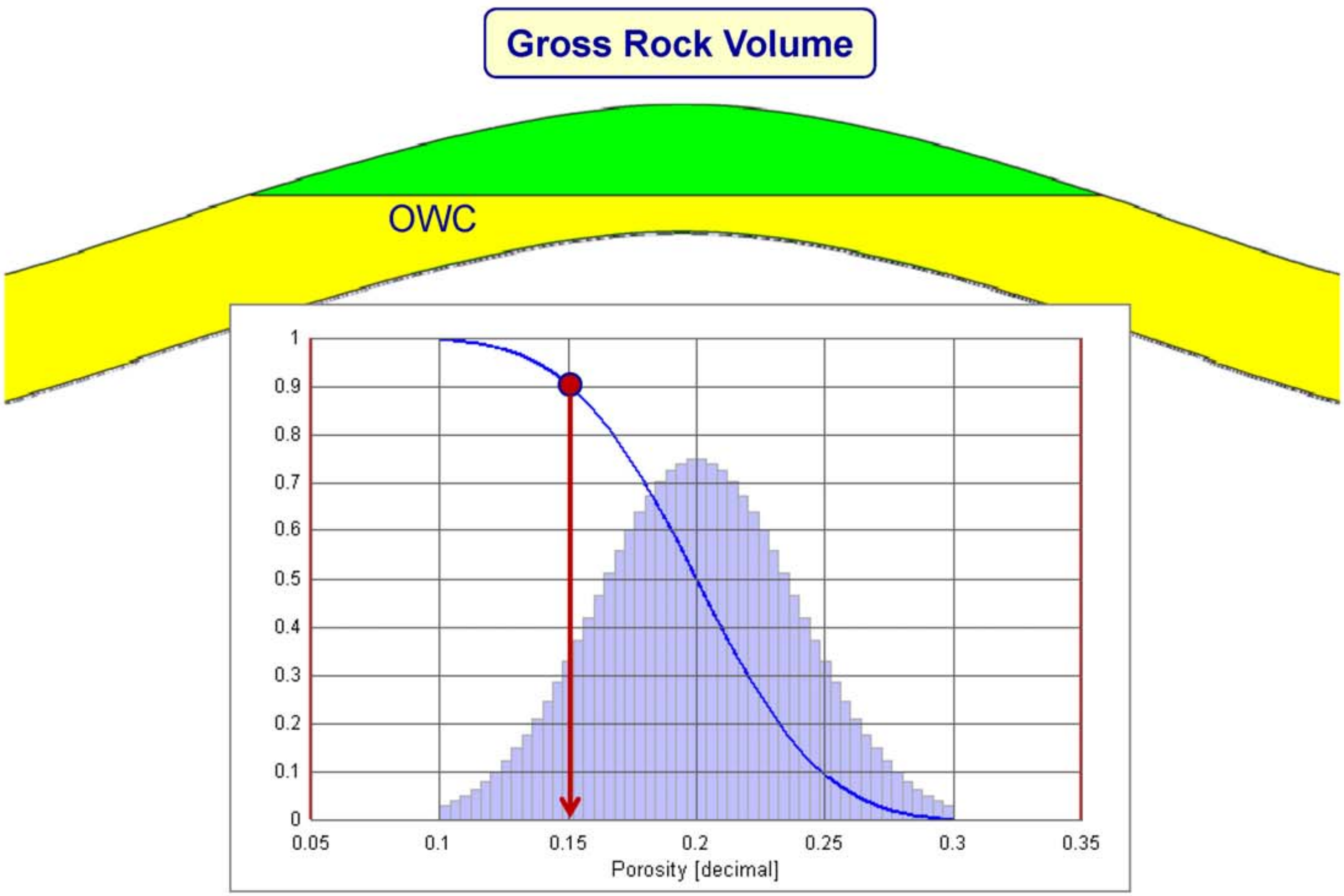
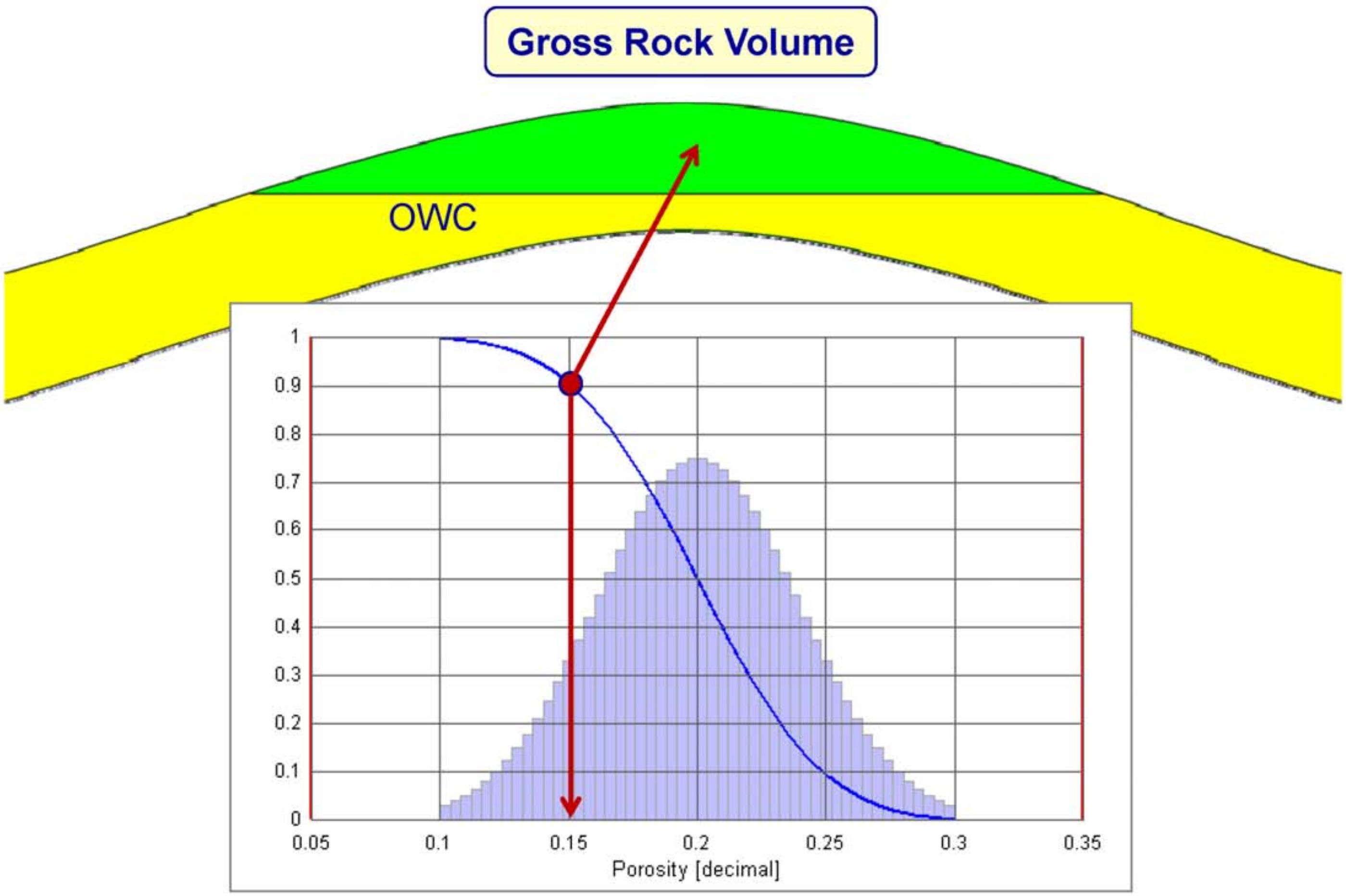


Notes by Presenter: In each Monte Carlo trial, a single value is selected from the porosity distribution.

Average porosity



Notes by Presenter: This value is applied to the entire net rock volume to yield the Net Pore Volume.

Average porosity

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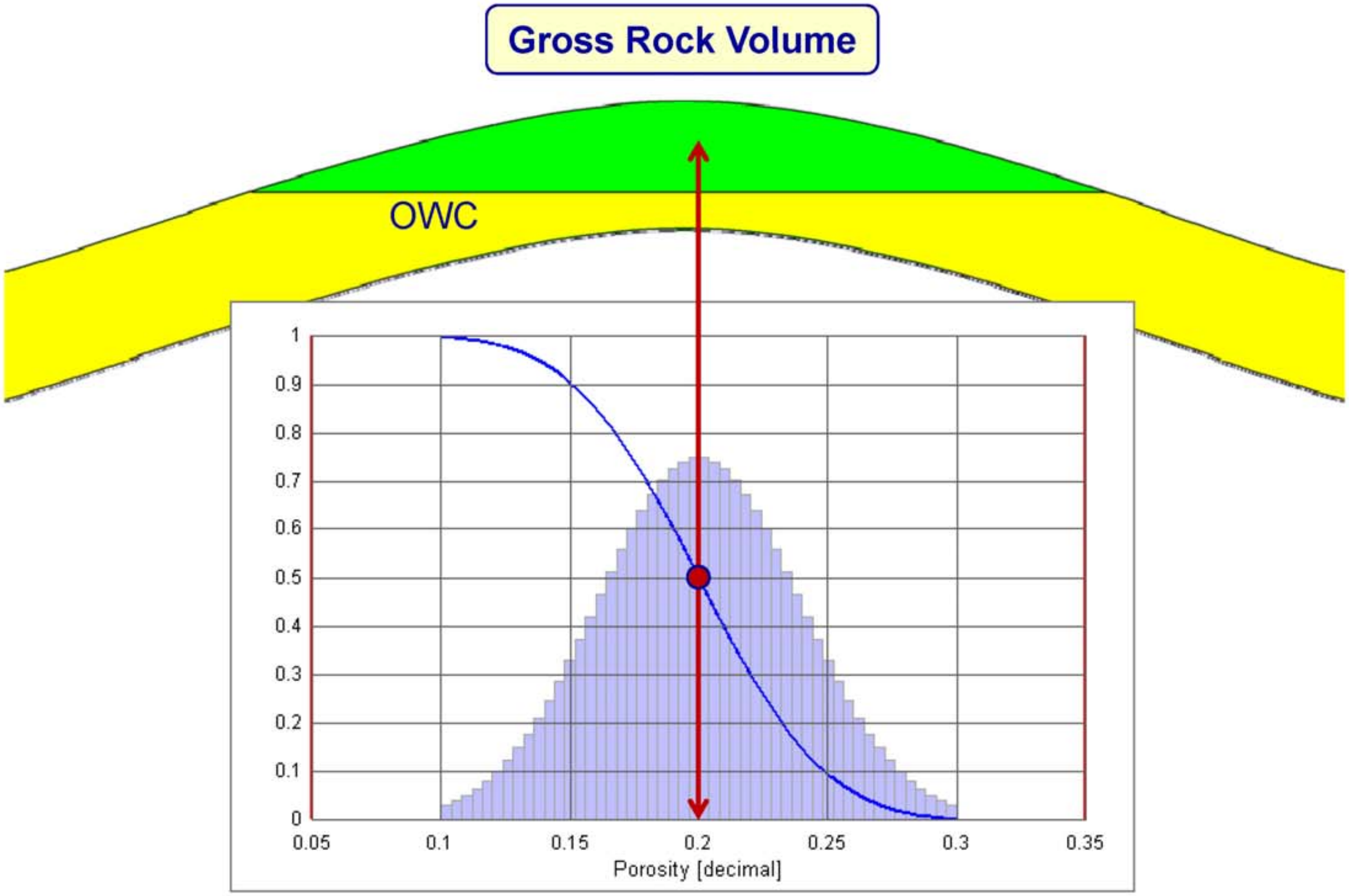
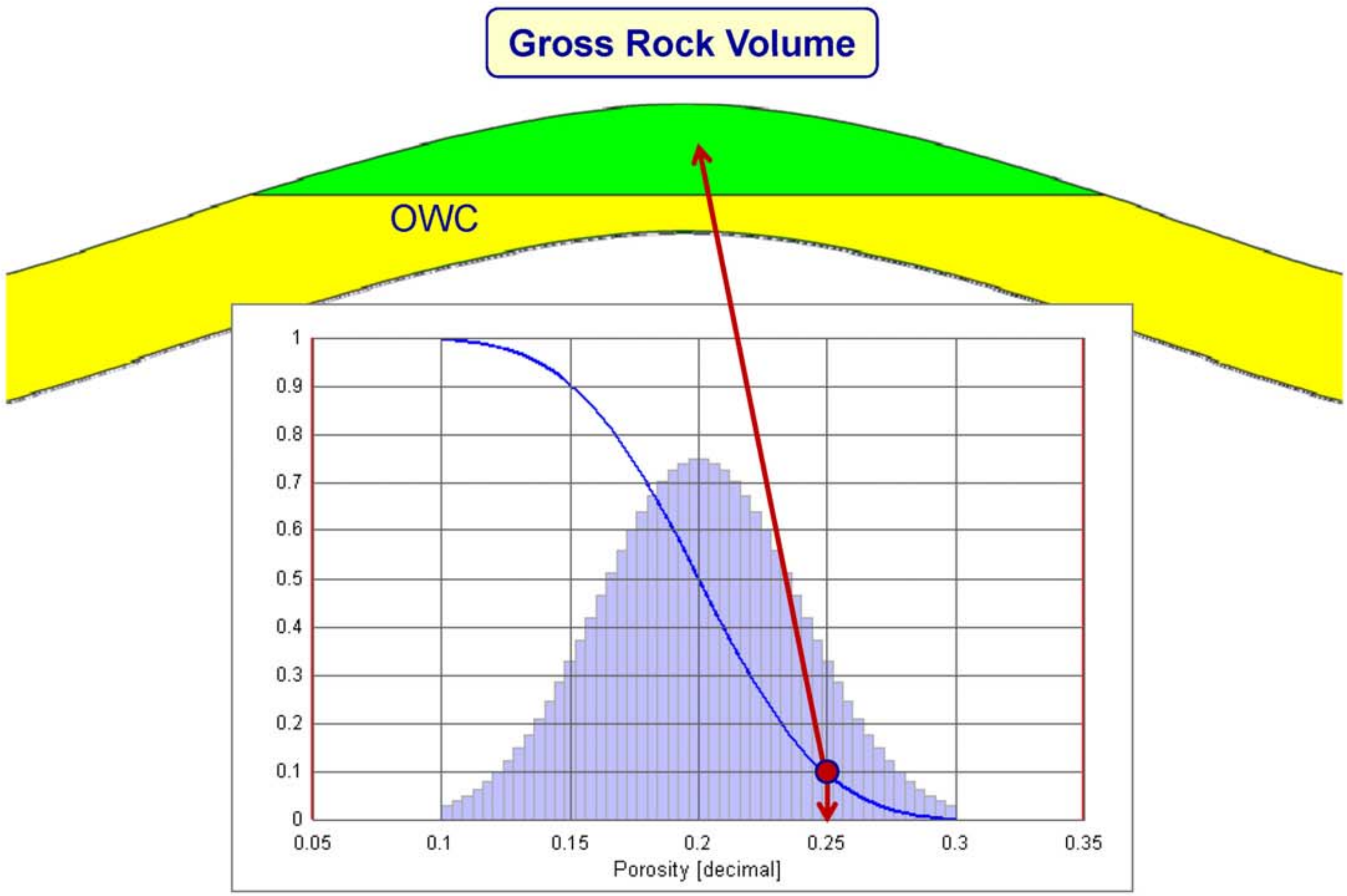


Notes by Presenter: The probability distribution of average porosity defines uncertainty.

Average porosity



Notes by Presenter: It is not the same as the histograms of porosity that are often created by petrophysicists and that are used as inputs to cell-based geologic models.

Average porosity

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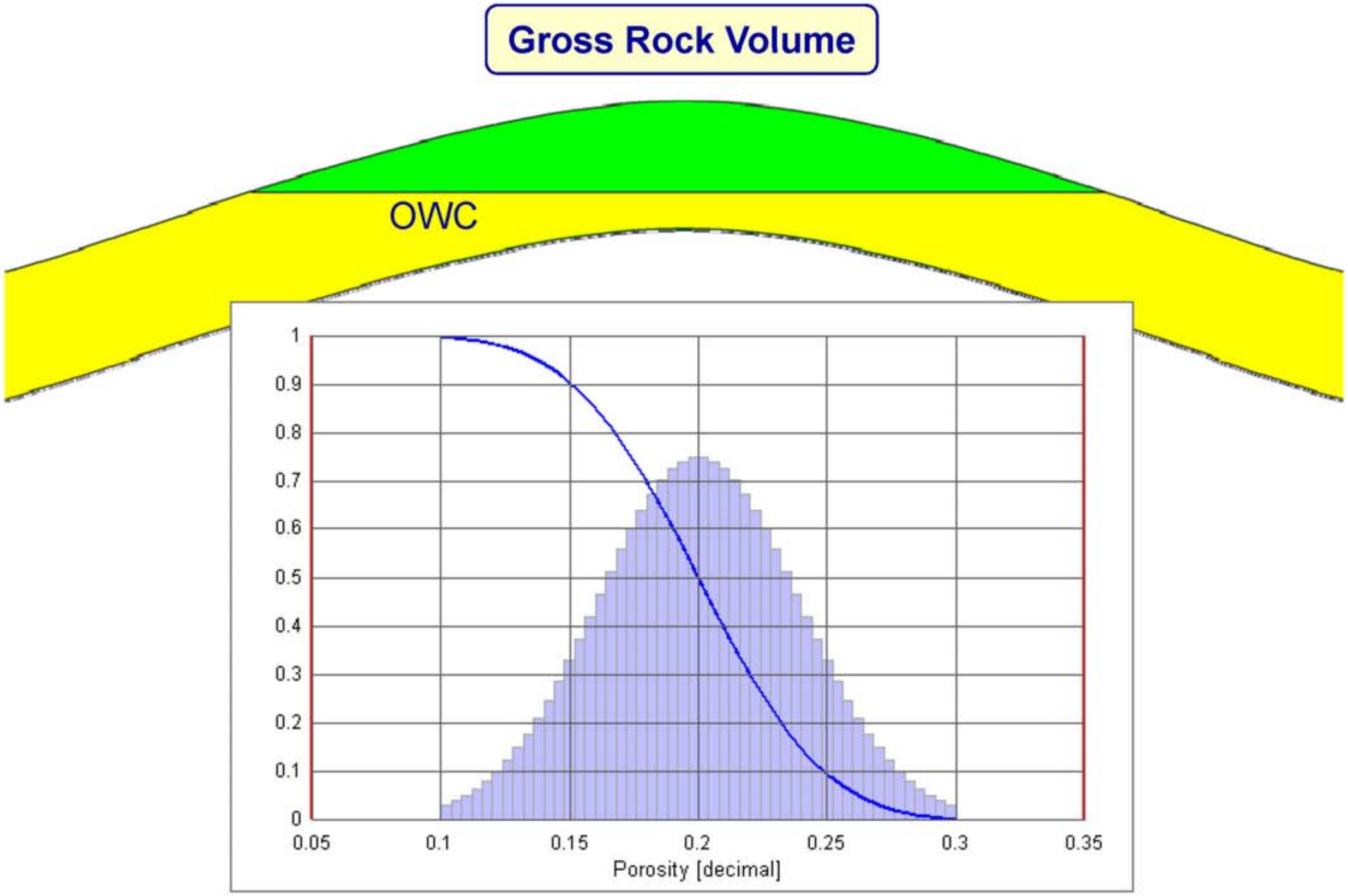

Notes by Presenter: In a heterogeneous reservoir, the range or variance of the uncertainty distribution should be correlated to the size of the gross rock volume.

Average porosity

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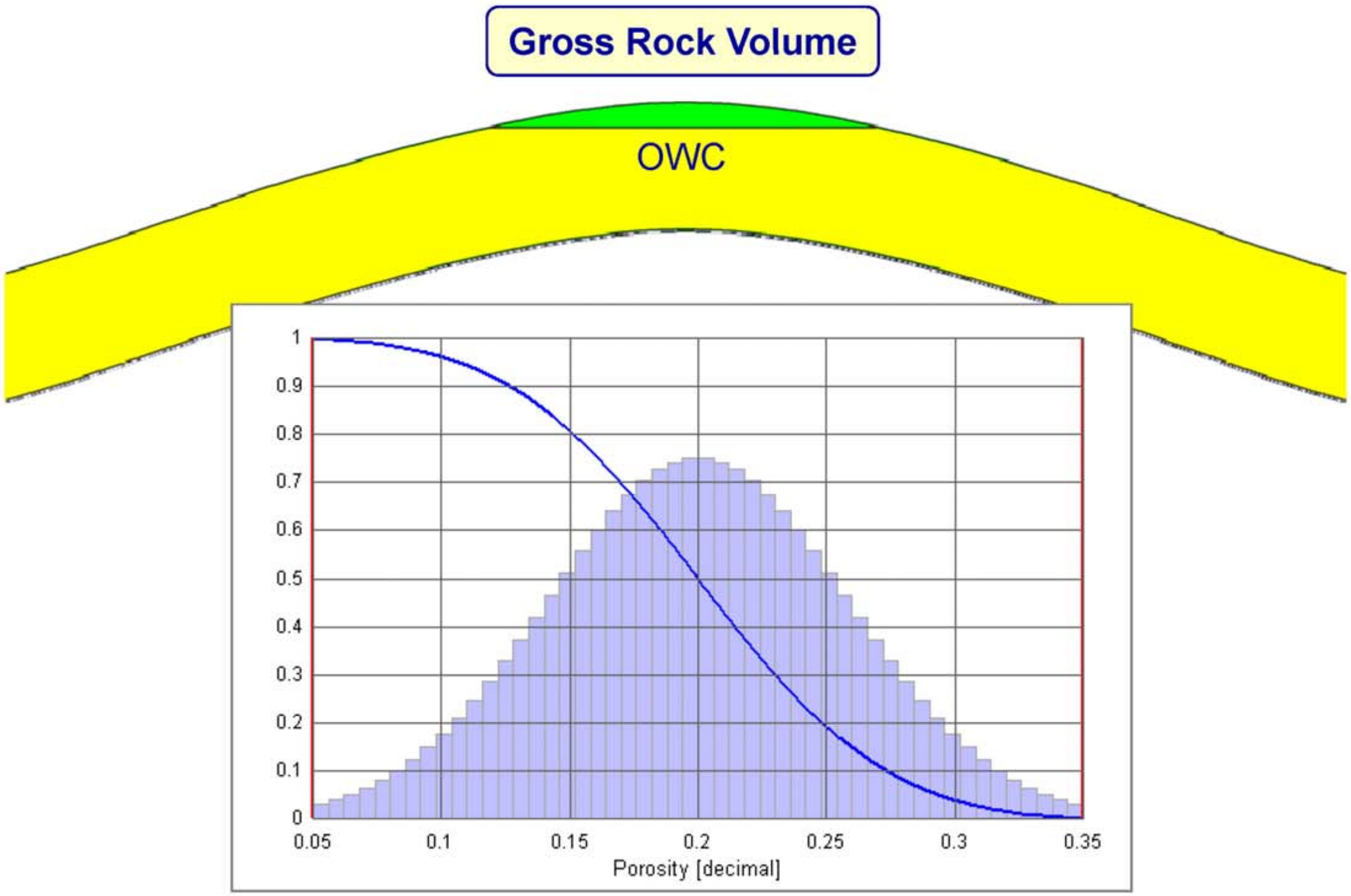

Notes by Presenter: If the accumulation is small, the porosity range should be wide.

Average porosity

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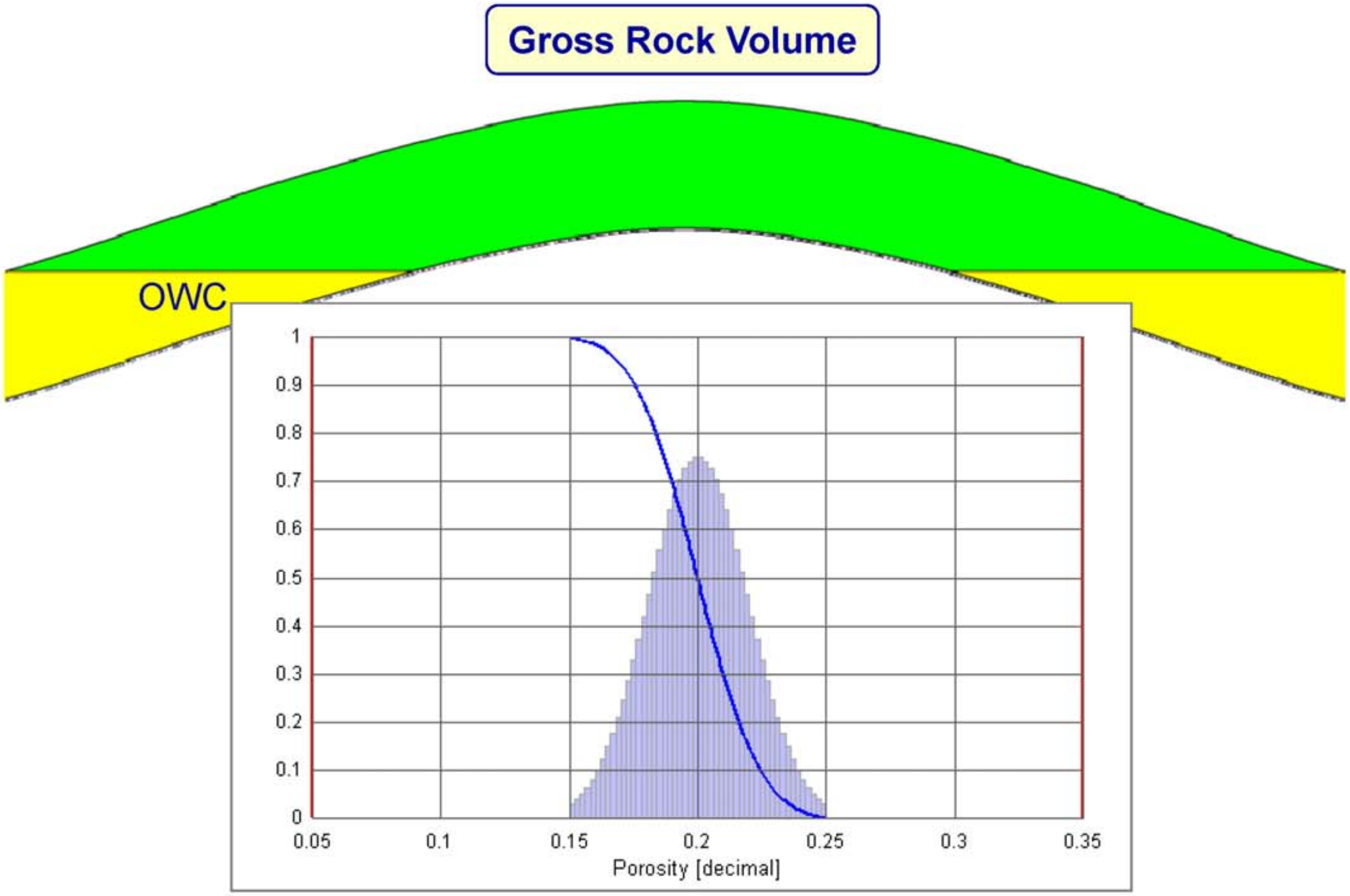

Notes by Presenter: If the accumulation is small, the porosity range should be narrow. This correlation of uncertainty range to GRV value is impossible to create using a single-zone assessment model. Let us see why it occurs.

Reservoir with vertical heterogeneity

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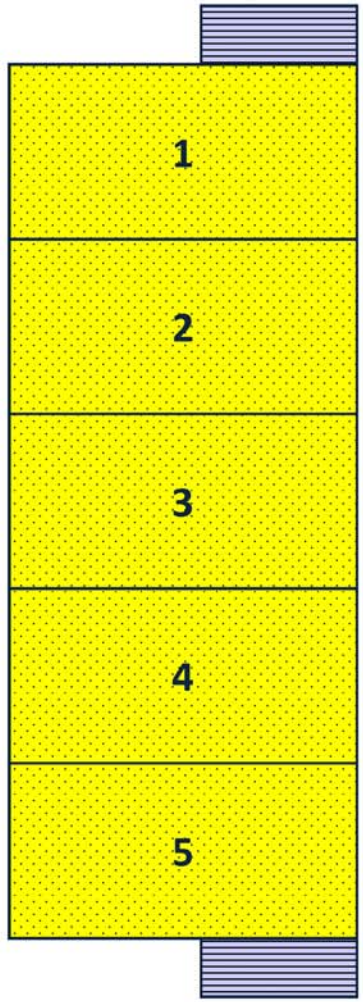

Notes by Presenter: Assume a stratigraphic interval with 5 zones or layers.

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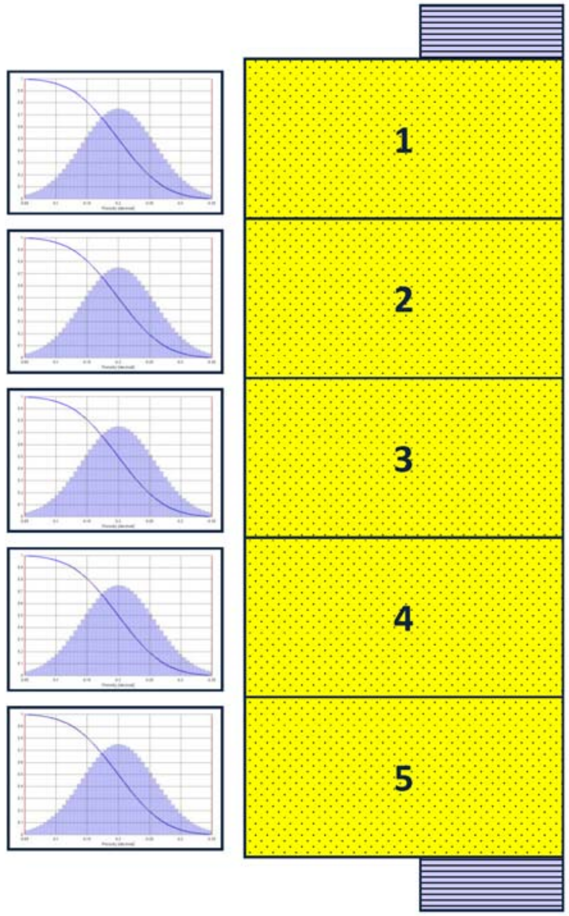
Reservoir with vertical heterogeneity

<u>Normal distribution</u>

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056



Notes by Presenter: For each individual layer, the uncertainty of average porosity may be described by a normal distribution with a minimum of 5% porosity, and a maximum of 35% porosity. The uncertainty between the zones is not correlated: In each Monte Carlo trial, one zone may have high porosity, while the next zone has low porosity. How will the uncertainty of average porosity within a productive interval be impacted by uncertainty of the OWC?

Reservoir with vertical heterogeneity

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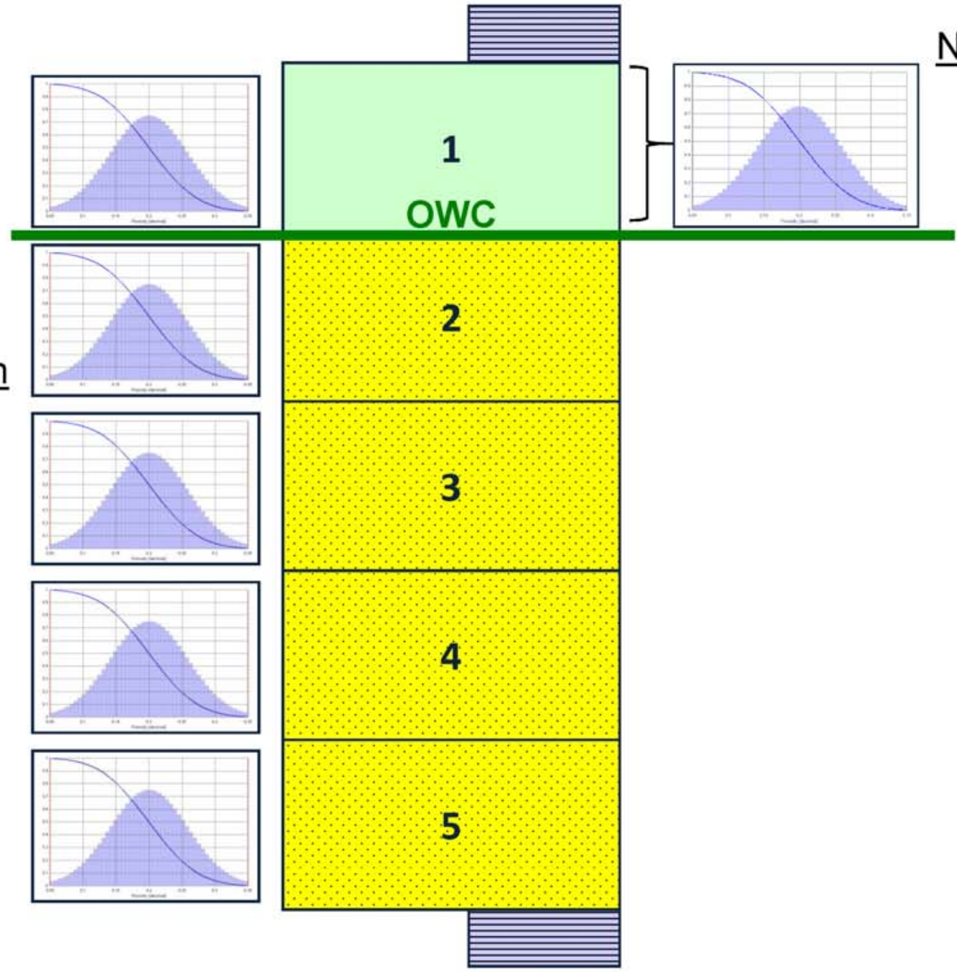

Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056

Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056

Notes by Presenter: If the oil-water contact is at the base of Zone 1, then the porosity uncertainty is identical to the uncertainty for an individual layer.

Reservoir with vertical heterogeneity

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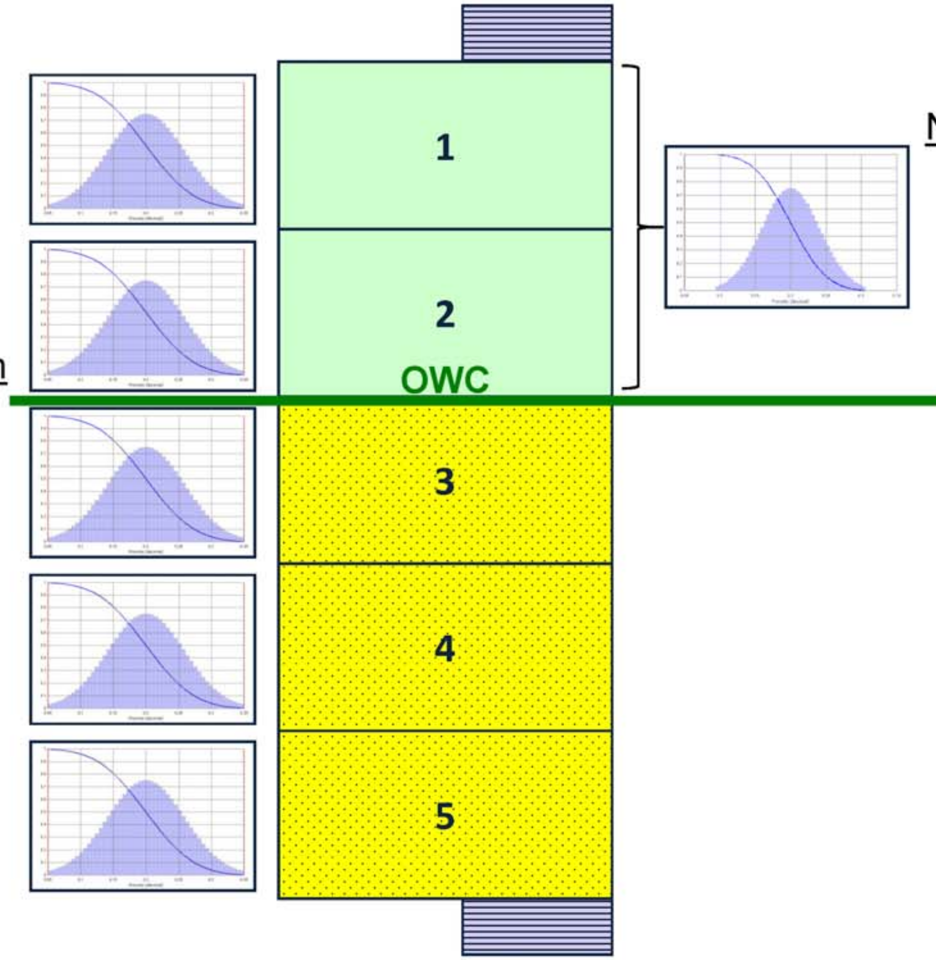
Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056



Normal distribution

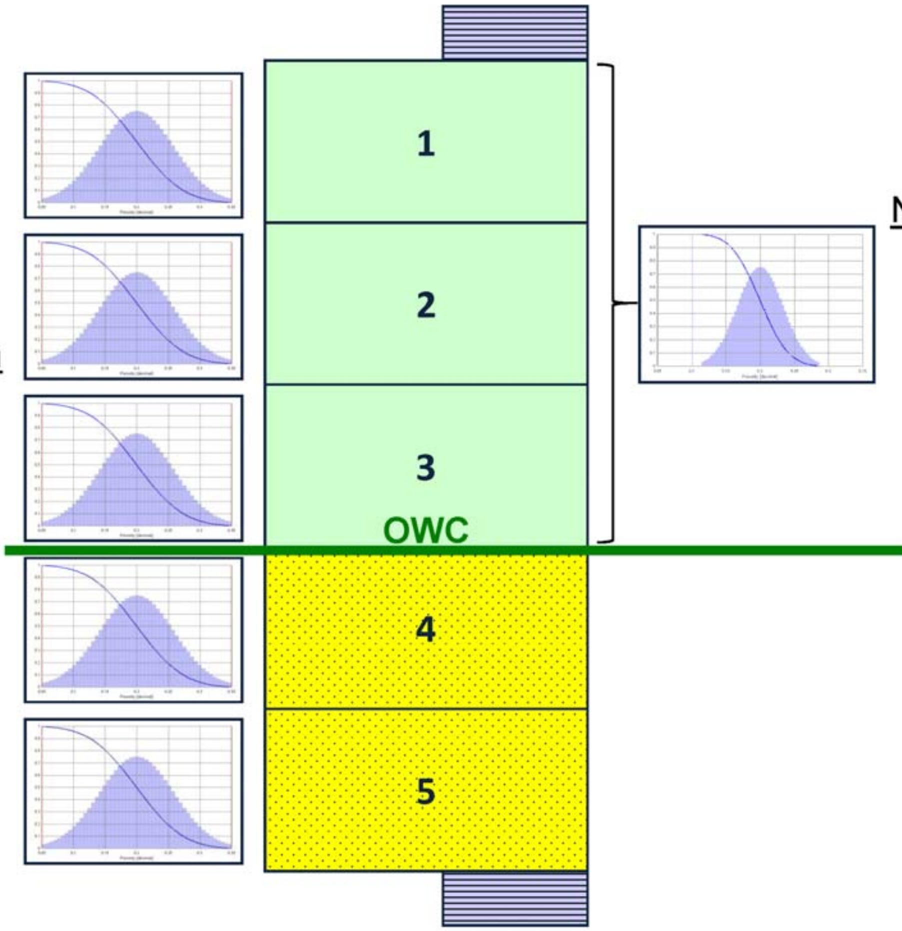
- Min = .09
- Max = .31
- Mean = .20
- St Dev = .039

Notes by Presenter: If the oil-water contact is at the base of Zone 2, the porosities within the two productive zones are averaged together in each Monte Carlo trial to get the average porosity for the entire productive Gross Rock Volume. A high porosity in one zone is likely to be cancelled out by a low porosity in the other zone. As a result, the range of average porosity uncertainty decreases, though the mean remains constant.

Reservoir with vertical heterogeneity

Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056



Normal distribution

- Min = .11
- Max = .29
- Mean = .20
- St Dev = .032

Notes by Presenter: As GRV increases due to a deepening oil-water contact, the range of porosity uncertainty must decrease. This assumes, of course, that the porosity distributions for the individual zones are uncorrelated. This is often the case in heterogeneous reservoirs. I believe that assessors are often too quick to assume that distributions should be correlated. Nature is often more variable than we realize.

Reservoir with vertical heterogeneity

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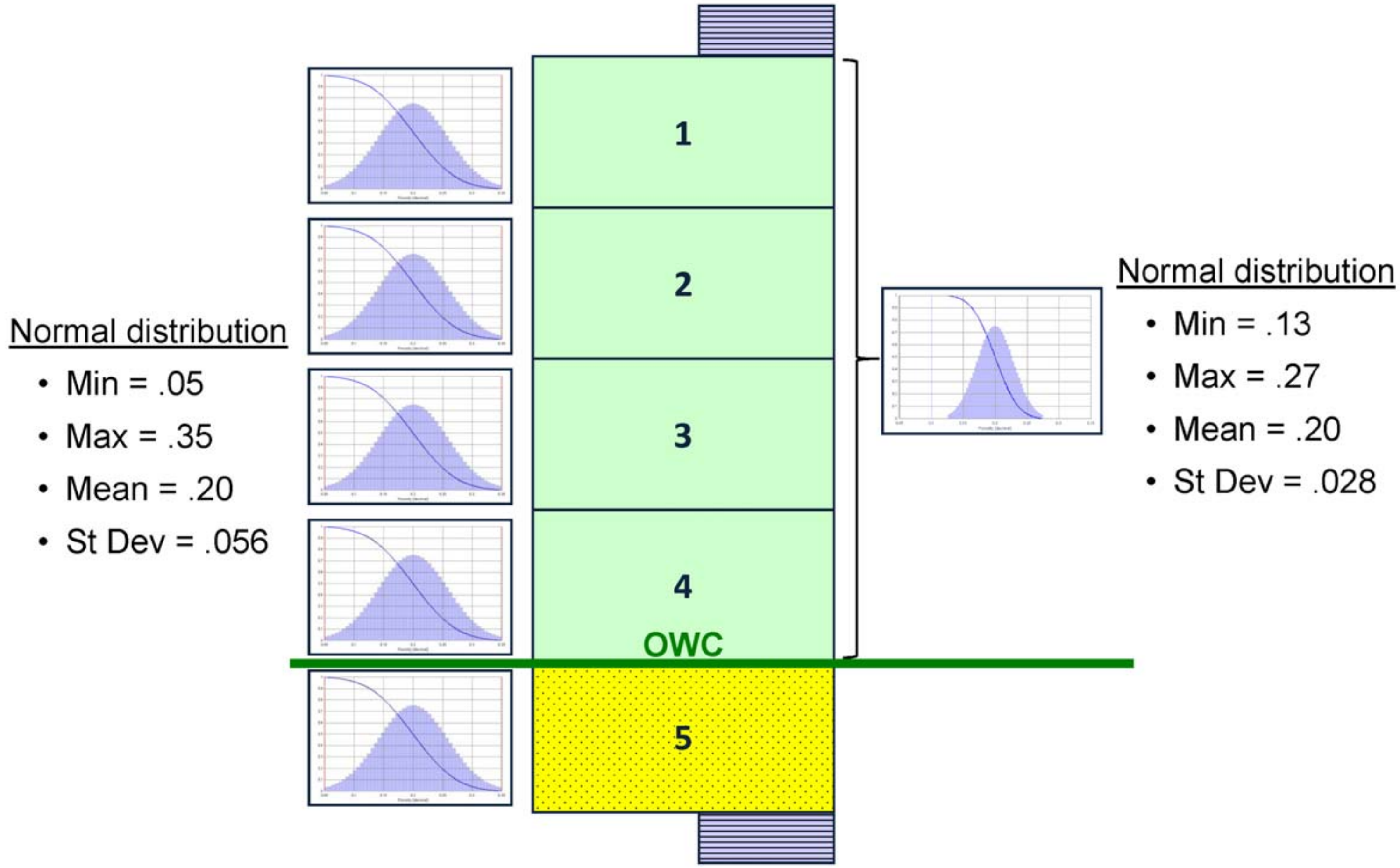

Notes by Presenter: As additional productive zones are averaged in, the range of porosity uncertainty continues to decrease. Although this example is based on varying the oil-water contact, the same phenomenon will occur if we vary the depositional thickness of the interval. A single thin zone will have great porosity uncertainty. An interval that comprises many thin zones will have a narrower range of uncertainty.

Reservoir with vertical heterogeneity

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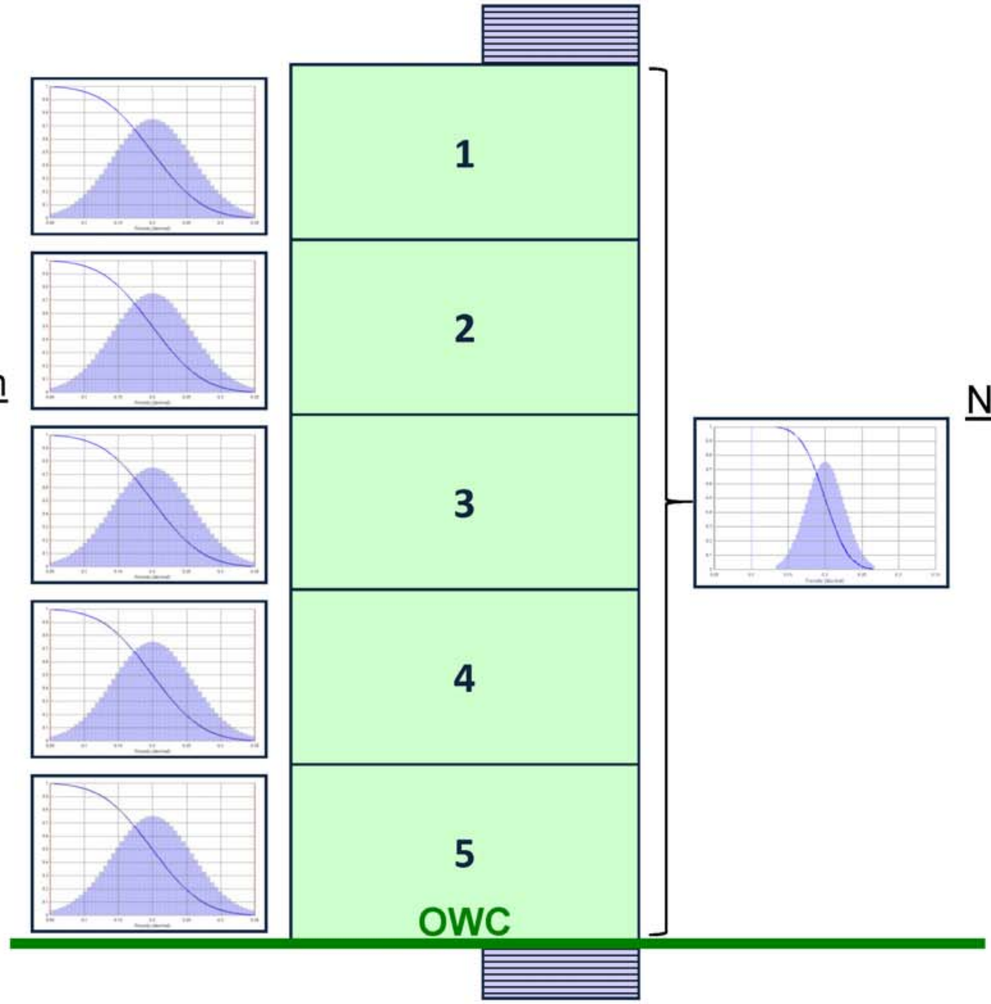
Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056



Normal distribution

- Min = .14
- Max = .26
- Mean = .20
- St Dev = .025

Notes by Presenter: The effect continues as more zones are added. But the rate of change in the range decreases with each additional zone.

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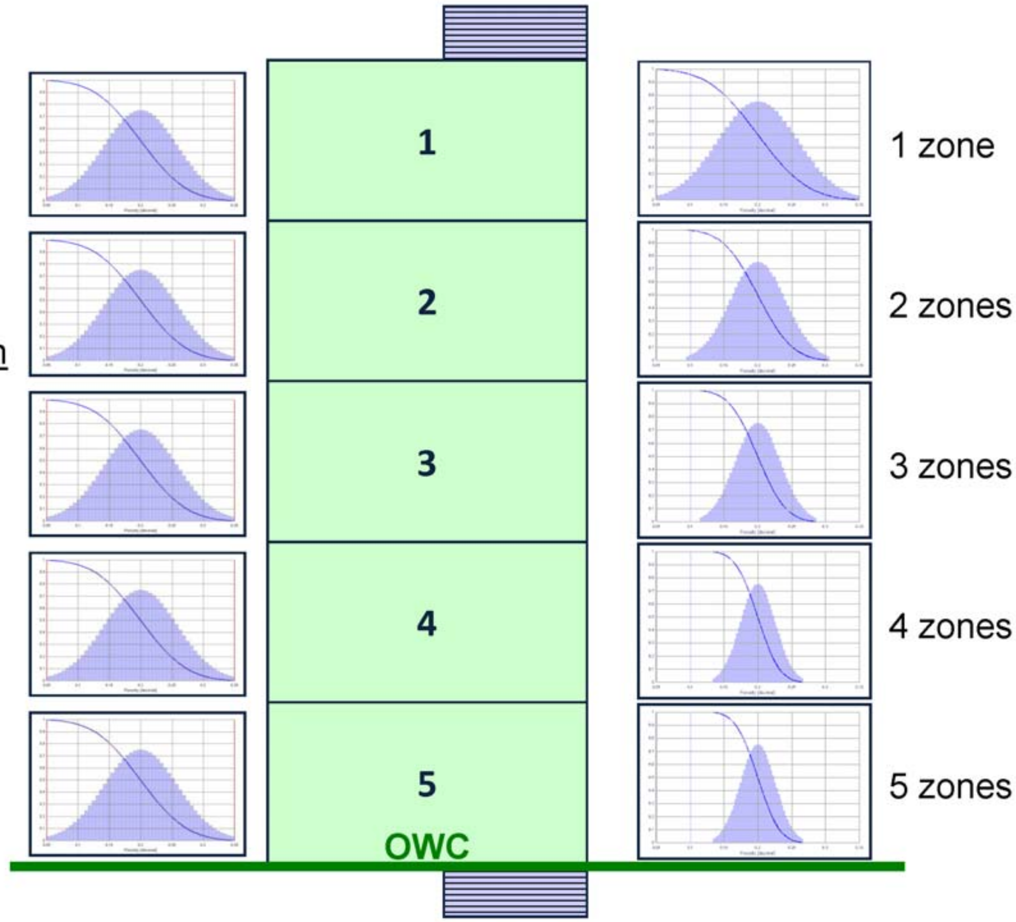
Reservoir with vertical heterogeneity

Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056



Notes by Presenter: We see that the uncertainty distribution for 5 zones is almost identical to the distribution for 4 zones, though it is slightly narrower. The difference will be a function of the distributions used for the individual zones. It will also be impacted by the productive area. This example considers only the thickness. When area is considered, the lower zones will have a greater impact, since they will extend over a greater area and will make up a greater percentage of the gross rock volume.

Reservoir with lateral heterogeneity

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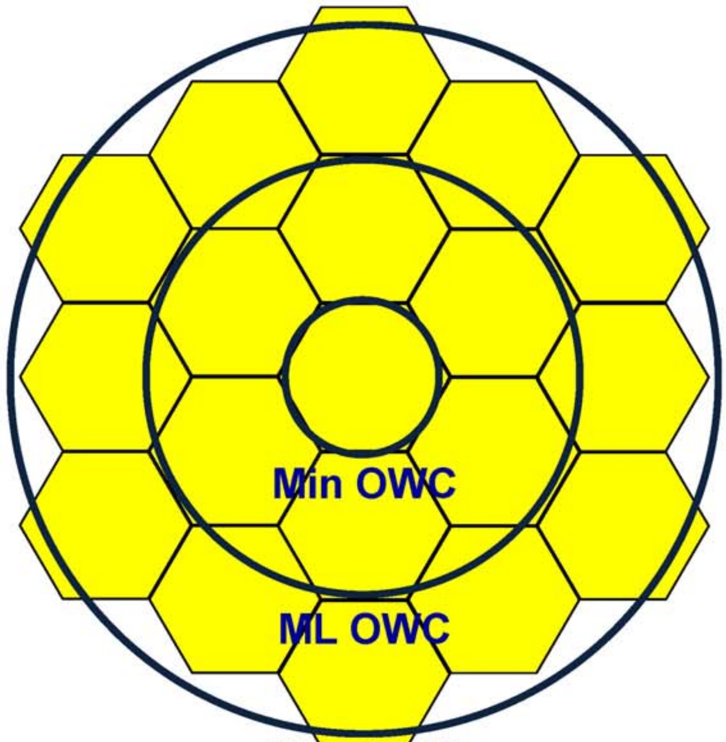

Notes by Presenter: Now let's look at a reservoir with lateral heterogeneity, and consider the impact of varying productive area. Assume a structure with a large number of potential drainage areas, represented as hexagons, and uncertainty of oil-water contact.

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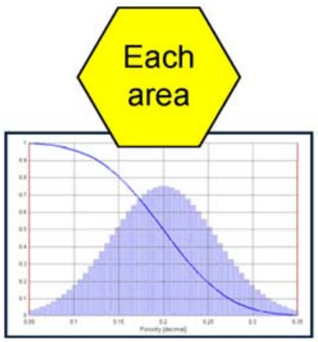
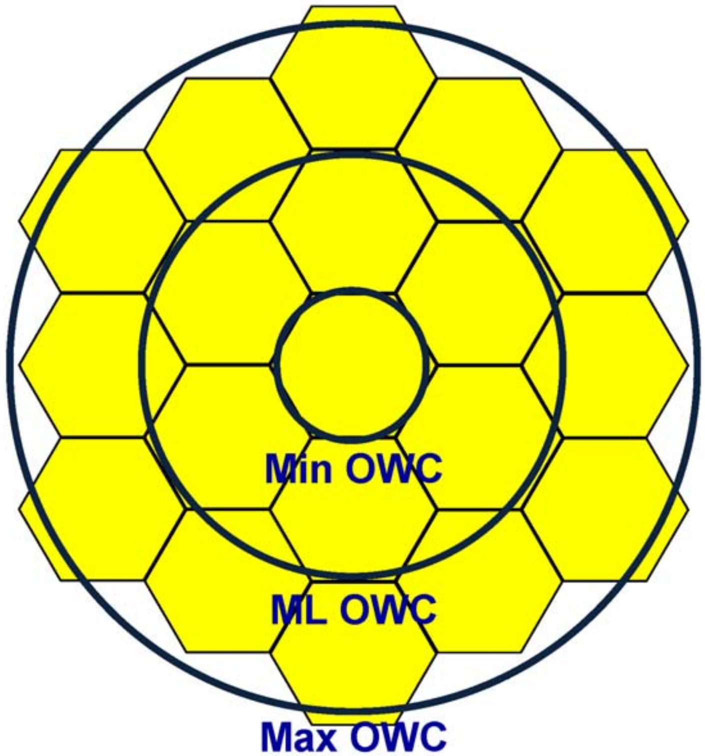
Reservoir with lateral heterogeneity



Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056



Notes by Presenter: For each drainage area, the uncertainty of average porosity may be described by a normal distribution with a minimum of 5% porosity, and a maximum of 35% porosity. As in the previous example, the uncertainty between the zones is not correlated. This is probably not entirely realistic, since there may be depositional trends across. But these trends may not be known when the prospect is assessed.

Reservoir with lateral heterogeneity

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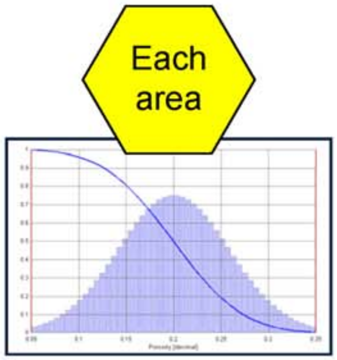
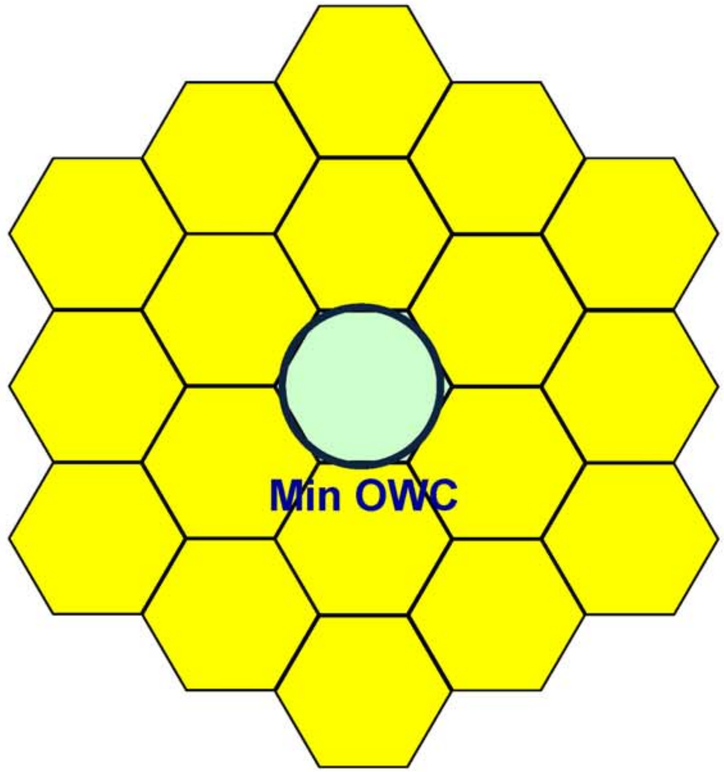
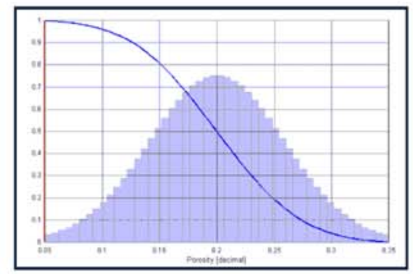


Normal distribution
- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056



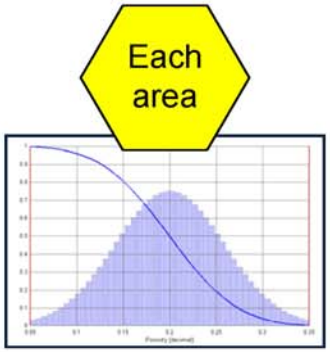
Within Min. OWC
1 drainage area



Normal distribution
- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056

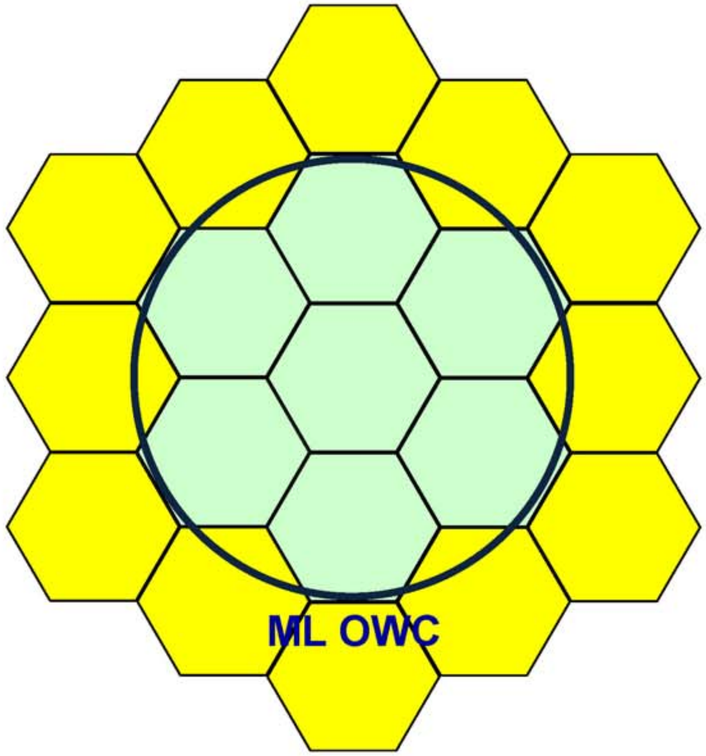
Notes by Presenter: When only one drainage area is productive, the porosity uncertainty range is very wide.

Reservoir with lateral heterogeneity

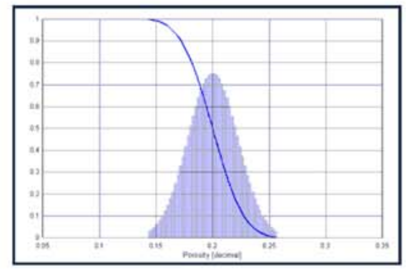


Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056



Within ML OWC
7 drainage areas



Normal distribution

- Min = .14
- Max = .26
- Mean = .20
- St Dev = .021

Notes by Presenter: As the contact moves downdip, the number of drainage areas within the contact increases rapidly, causing a significant decrease in the porosity uncertainty range.

Reservoir with lateral heterogeneity

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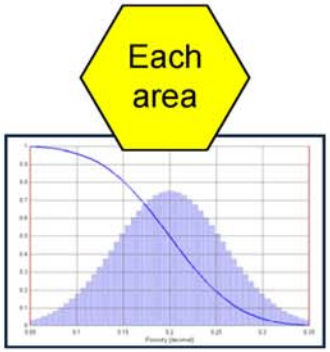
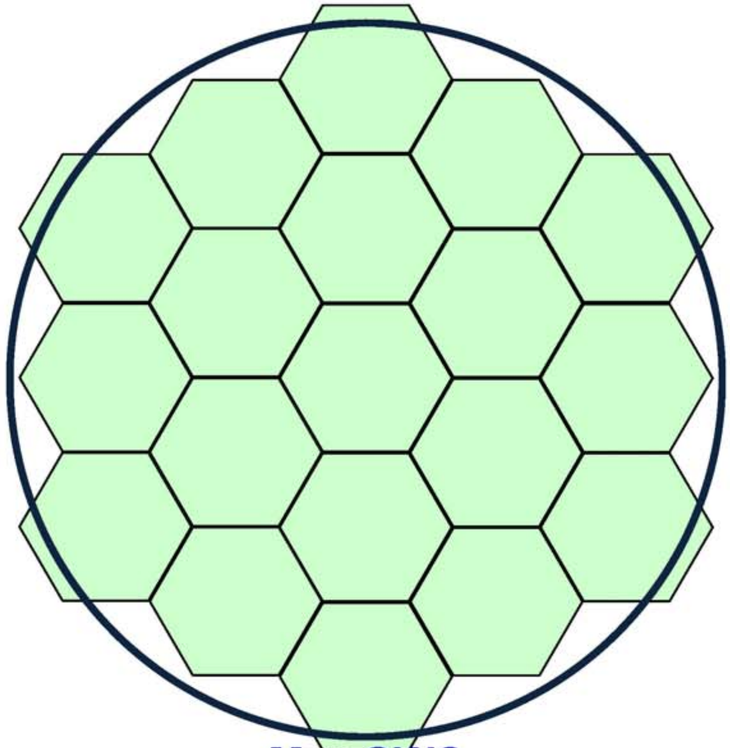


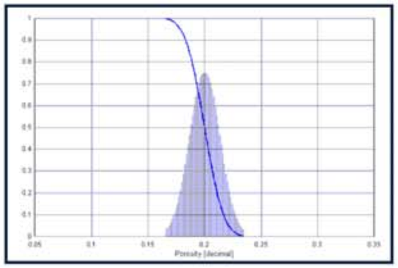
Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056



Max OWC

Within ML OWC
19 drainage areas



Normal distribution

- Min = .17
- Max = .23
- Mean = .20
- St Dev = .013

Notes by Presenter: In our example the maximum area comprises 19 drainage areas. The range of average porosity uncertainty is very narrow, with a minimum of 17% and a maximum of 23%.

Reservoir with lateral heterogeneity

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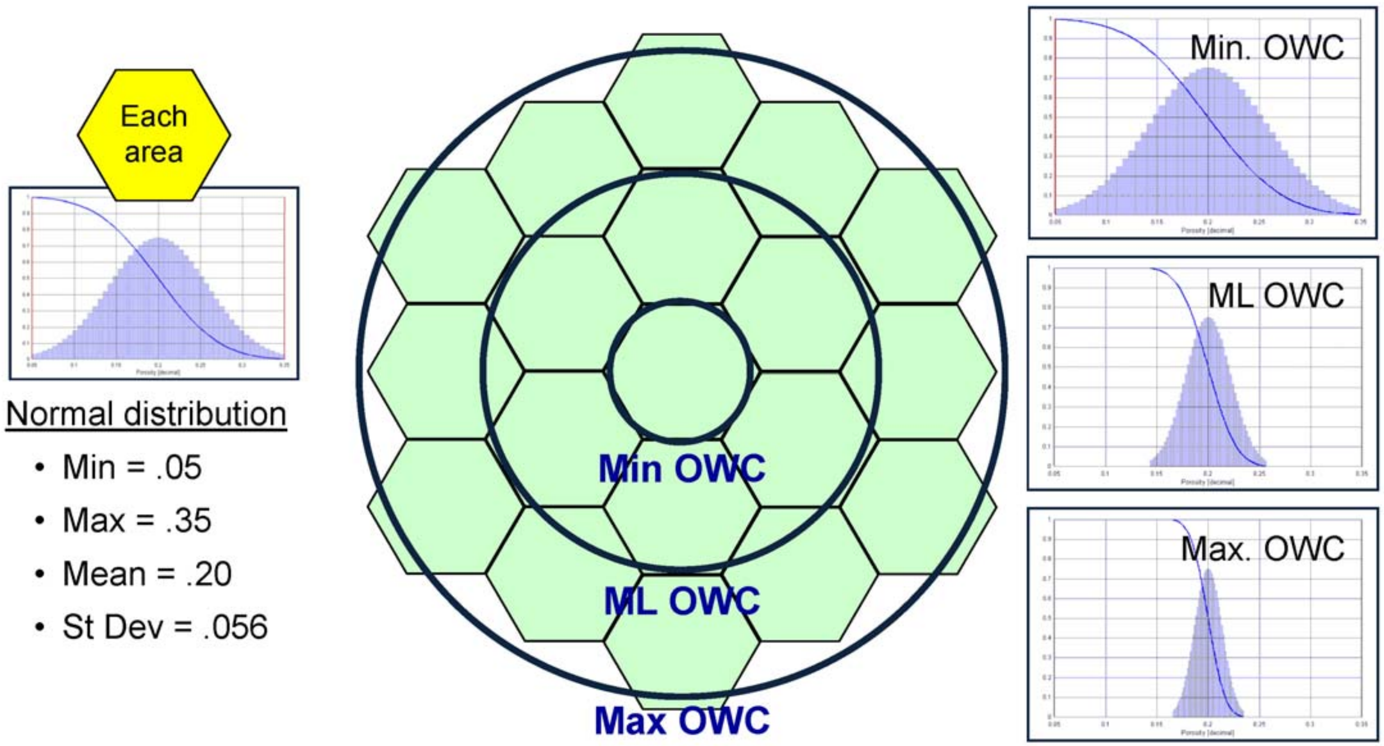

Normal distribution

- Min = .05
- Max = .35
- Mean = .20
- St Dev = .056

Limited highside

Notes by Presenter: In reality the impact would be even greater. This example considers only the area. If the sand thickness exceeds the column height, then lowering the oil-water contact will increase both the area and the gross thickness. And again, this example assumes that the uncertainty distributions for the individual areas are uncorrelated. This correlation of uncertainty range to GRV value cannot be assessed using a single-zone assessment model. Notice that, in the Max OWC case, the porosity distribution has a limited highside. It is not possible to find BOTH the large productive area AND the large average porosity. Single-zones assessments that allow both in the same trial may be overly optimistic.

Coarsening upward interval

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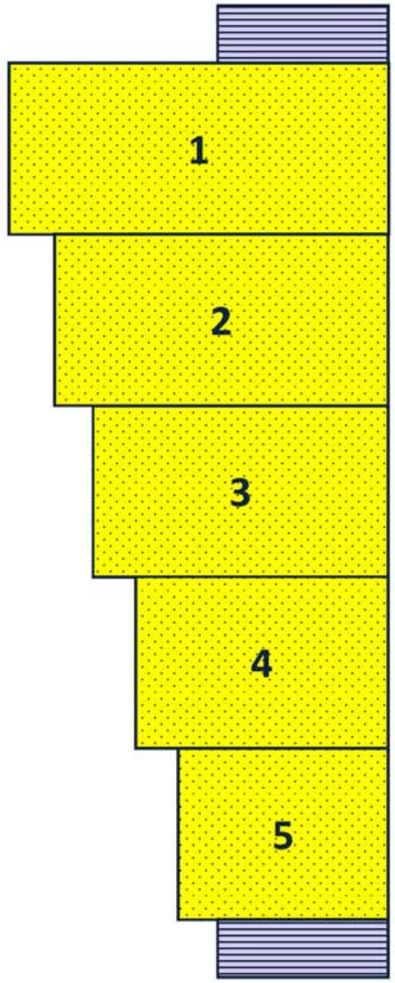


Notes by Presenter: In this example we are looking at a coarsening upward sequence.

Coarsening upward interval

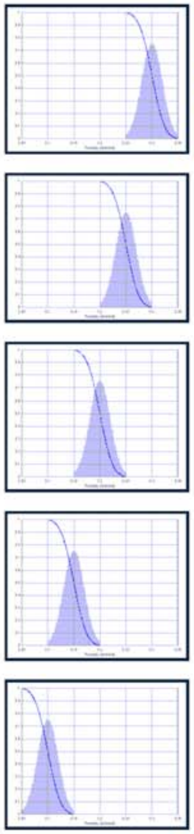
Min = .25, Max = .35

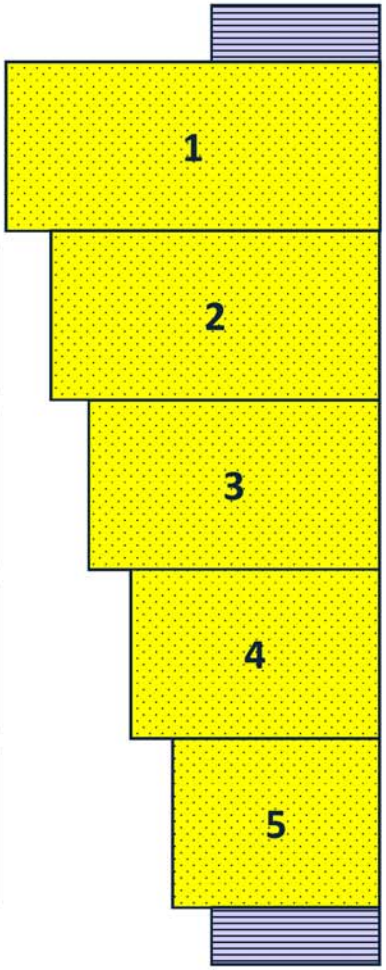
Min = .20, Max = .30

Min = .15, Max = .25

Min = .10, Max = .20

Min = .05, Max = .15

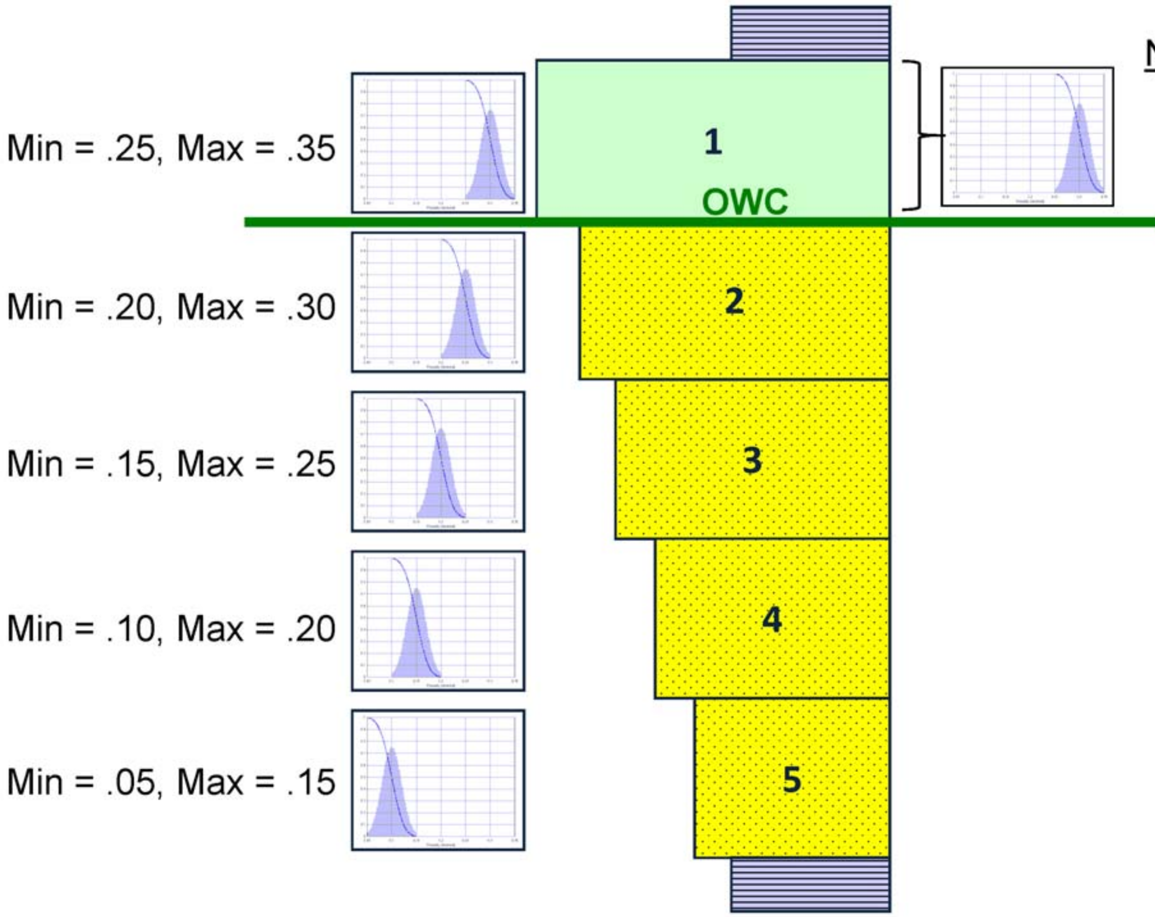




Notes by Presenter: The porosities are very good at the top of the interval, and get steadily worse as we go deeper into the section.

GeoKnowledge
Making knowledge work

Coarsening upward interval



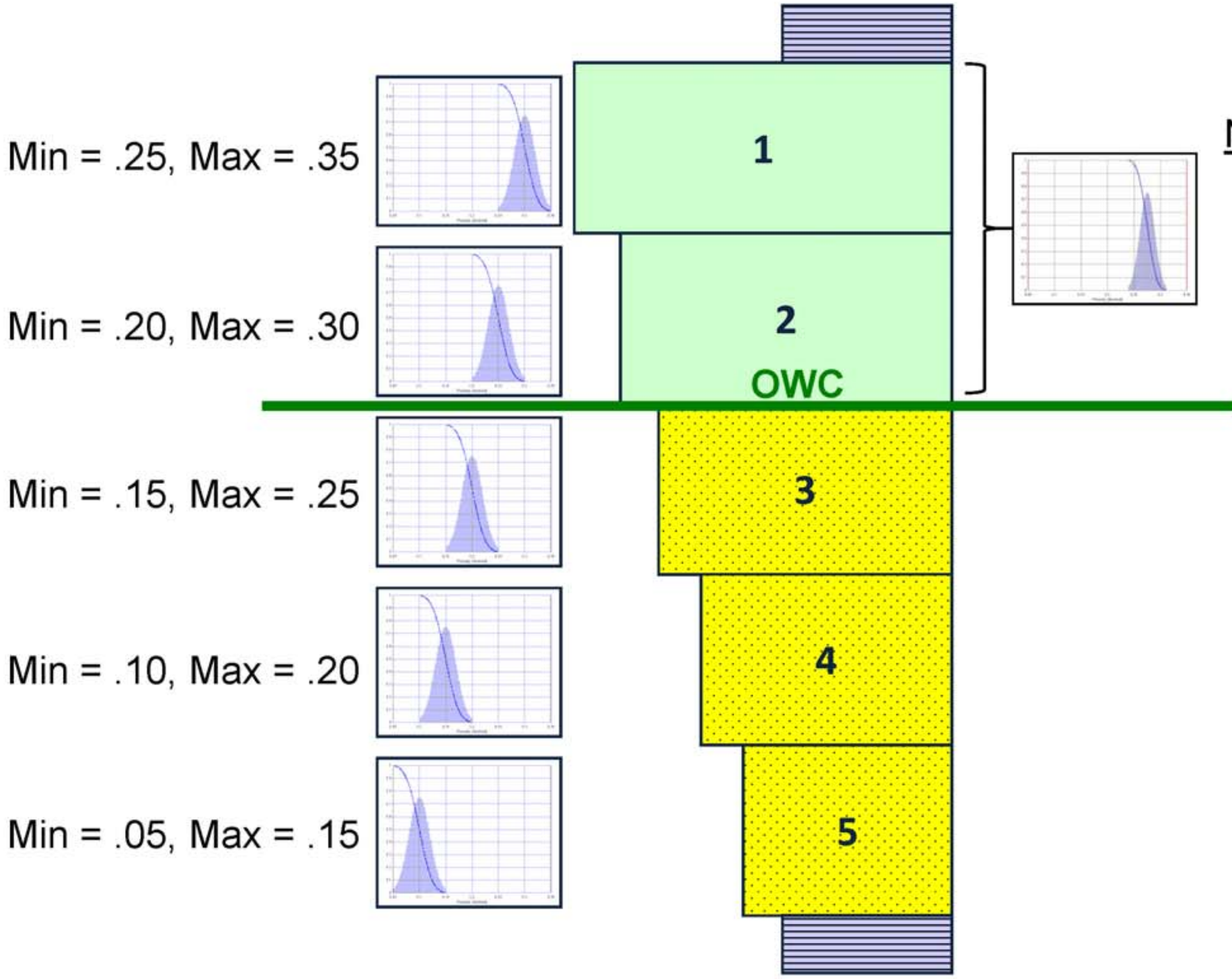
Normal distribution

- Min = .25
- Max = .35
- Mean = .30
- St Dev = .019

Notes by Presenter: As with the first example, when only the first layer is productive, the porosity uncertainty is widest and, in this case, within the highest porosities.

Coarsening upward interval

GeoKnowledge
Making knowledge work



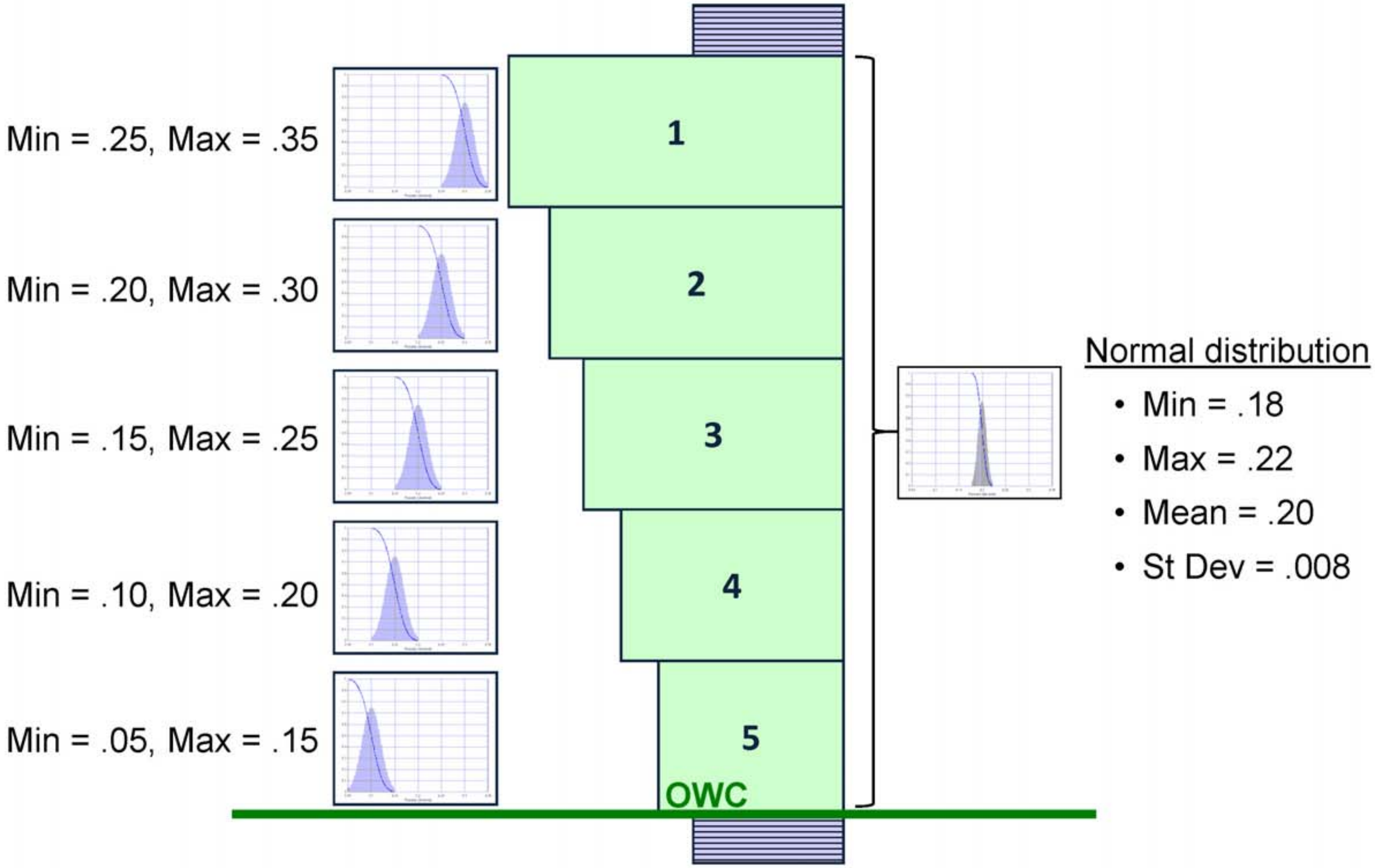
Normal distribution

- Min = .24
- Max = .31
- Mean = .275
- St Dev = .013

Notes by Presenter: As we add productive layers, we see two effects: the range narrows AND the mean porosity decreases.

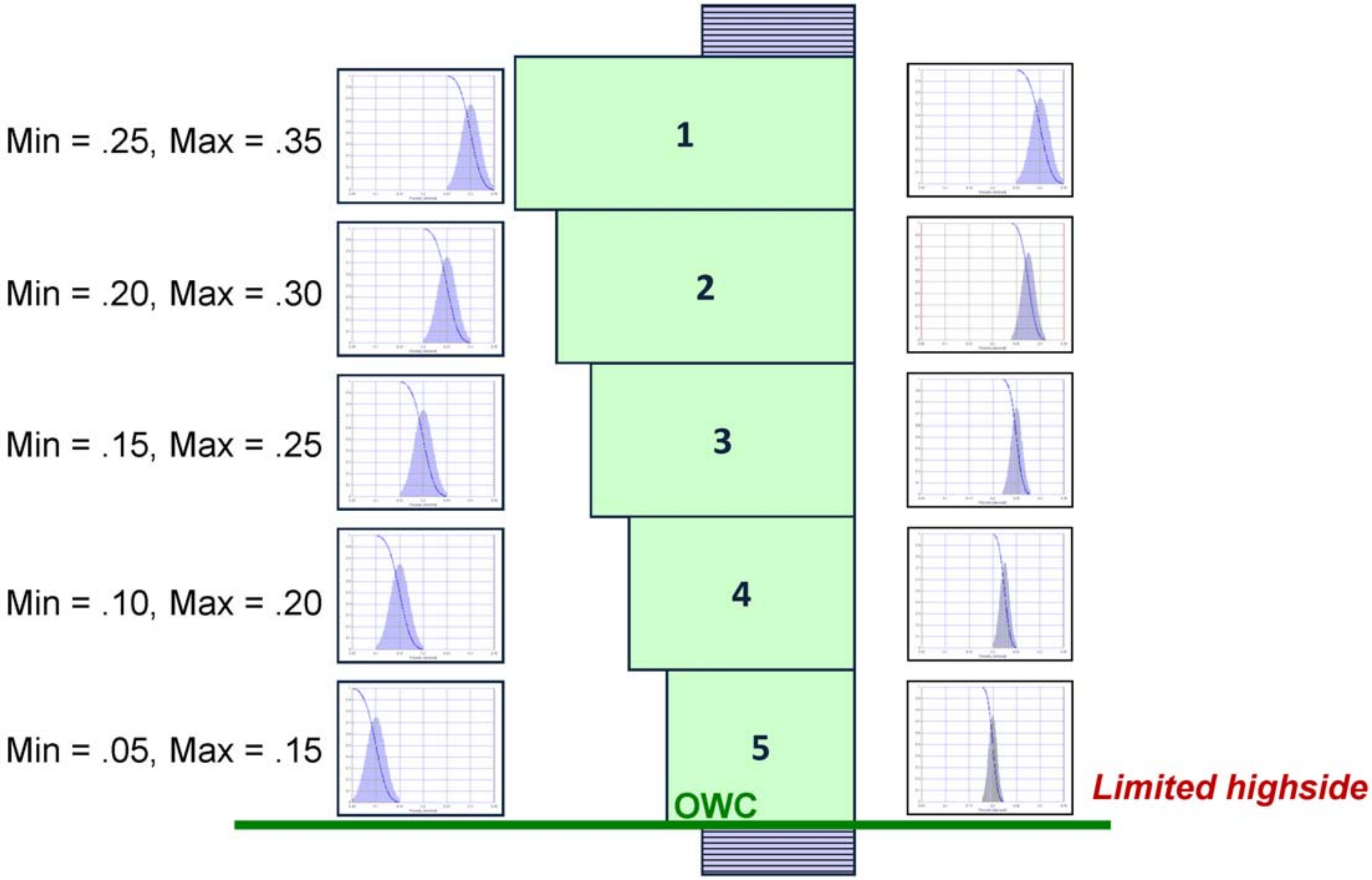
Coarsening upward interval

GeoKnowledge
Making knowledge work



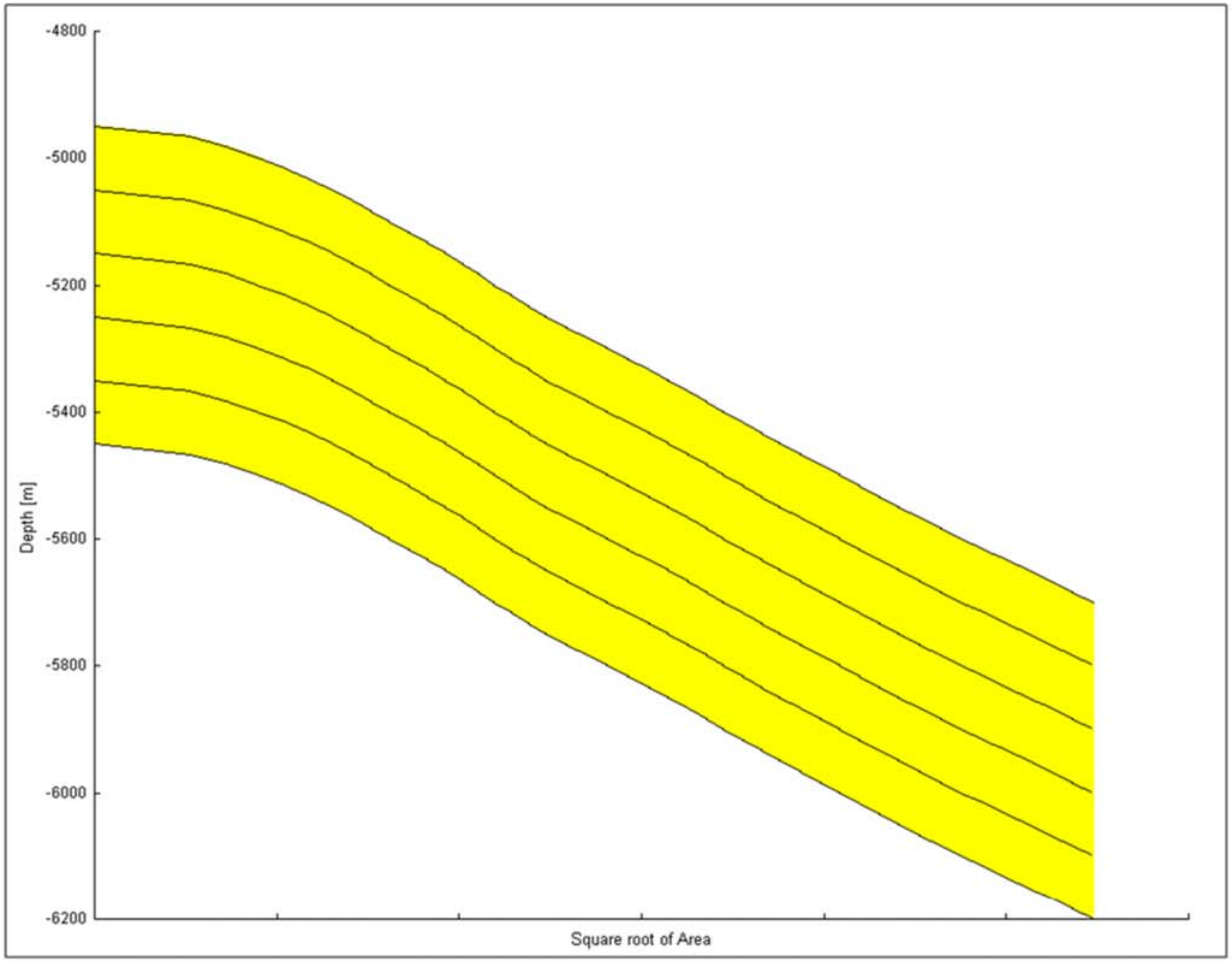
Notes by Presenter: When all 5 layers are productive, the mean porosity is equal to the mean of the middle layer AND the uncertainty range is very narrow, narrower than the uncertainty range for any individual layer.

Coarsening upward interval



Notes by Presenter: The summary slide shows the progressive decline in the mean porosity and the narrowing of the uncertainty range as Gross Rock Volume is added. It is impossible to accomplish this using a single-zone assessment model. Notice that, when all five zones are present, the average porosity distribution has a very limited highside. Single-zone models that allow both high GRV and high average porosity in the same trial may be overly optimistic.

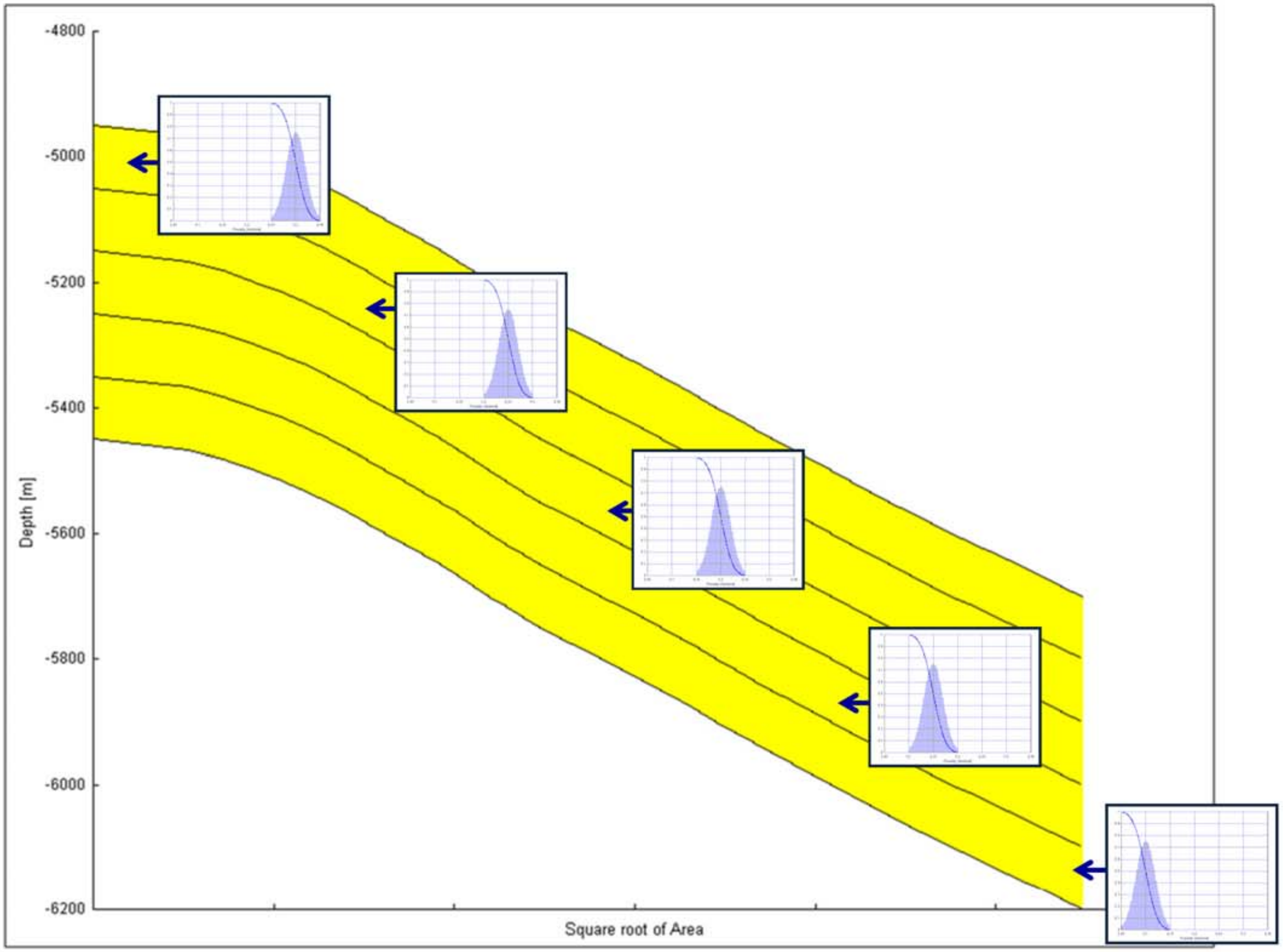
Multiple segment solution



Notes by Presenter: The solution is to discard the single-zone assessment. Instead, assess the prospect as an aggregation of five separate zones.

Multiple segment solution

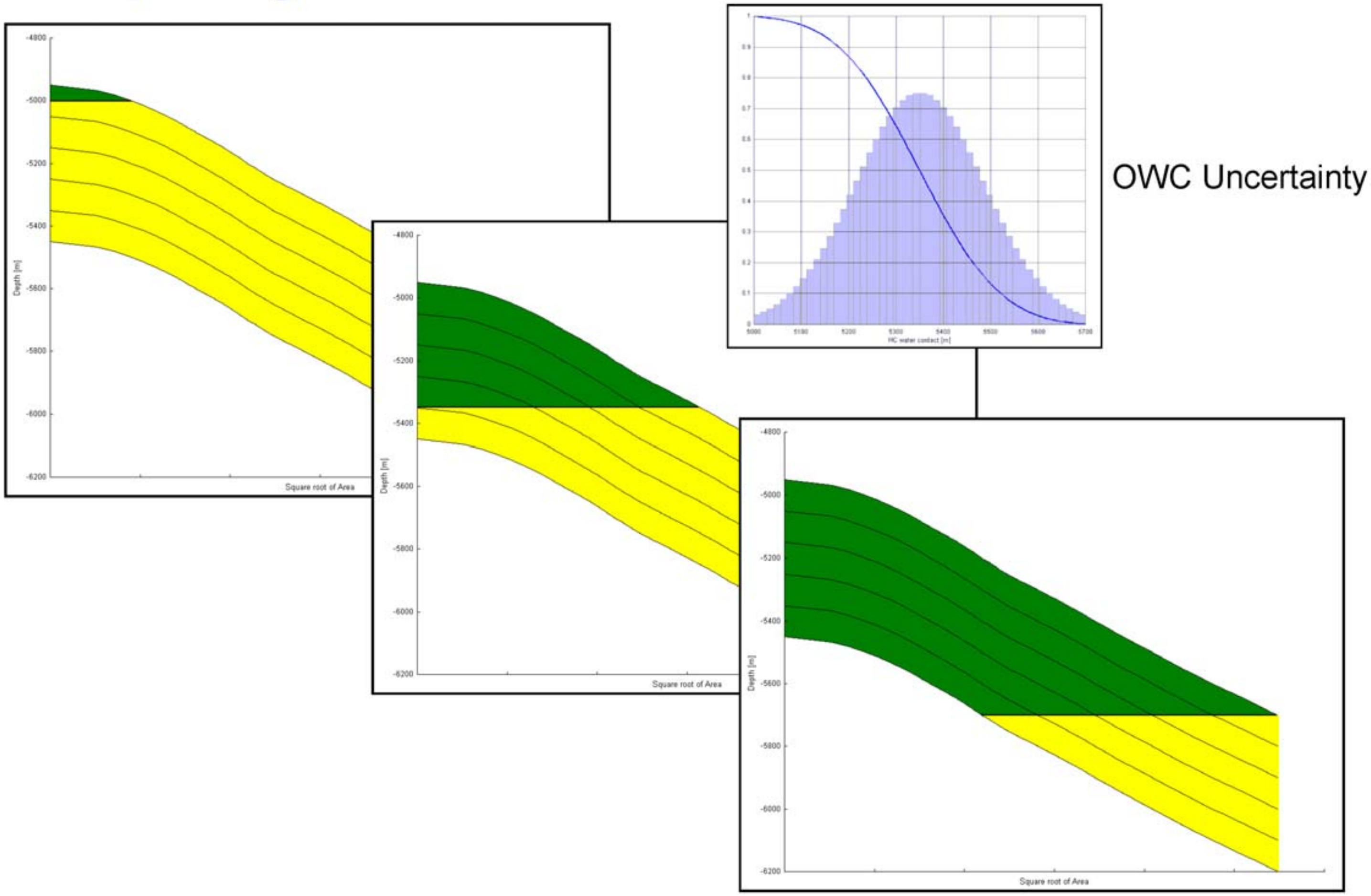
GeoKnowledge
Making knowledge work



Notes by Presenter: Each zone may be assigned a unique porosity distribution. Each zone may also be assigned a unique risk for reservoir presence or quality. This is not possible with a single-zone model.

GeoKnowledge
Making knowledge work

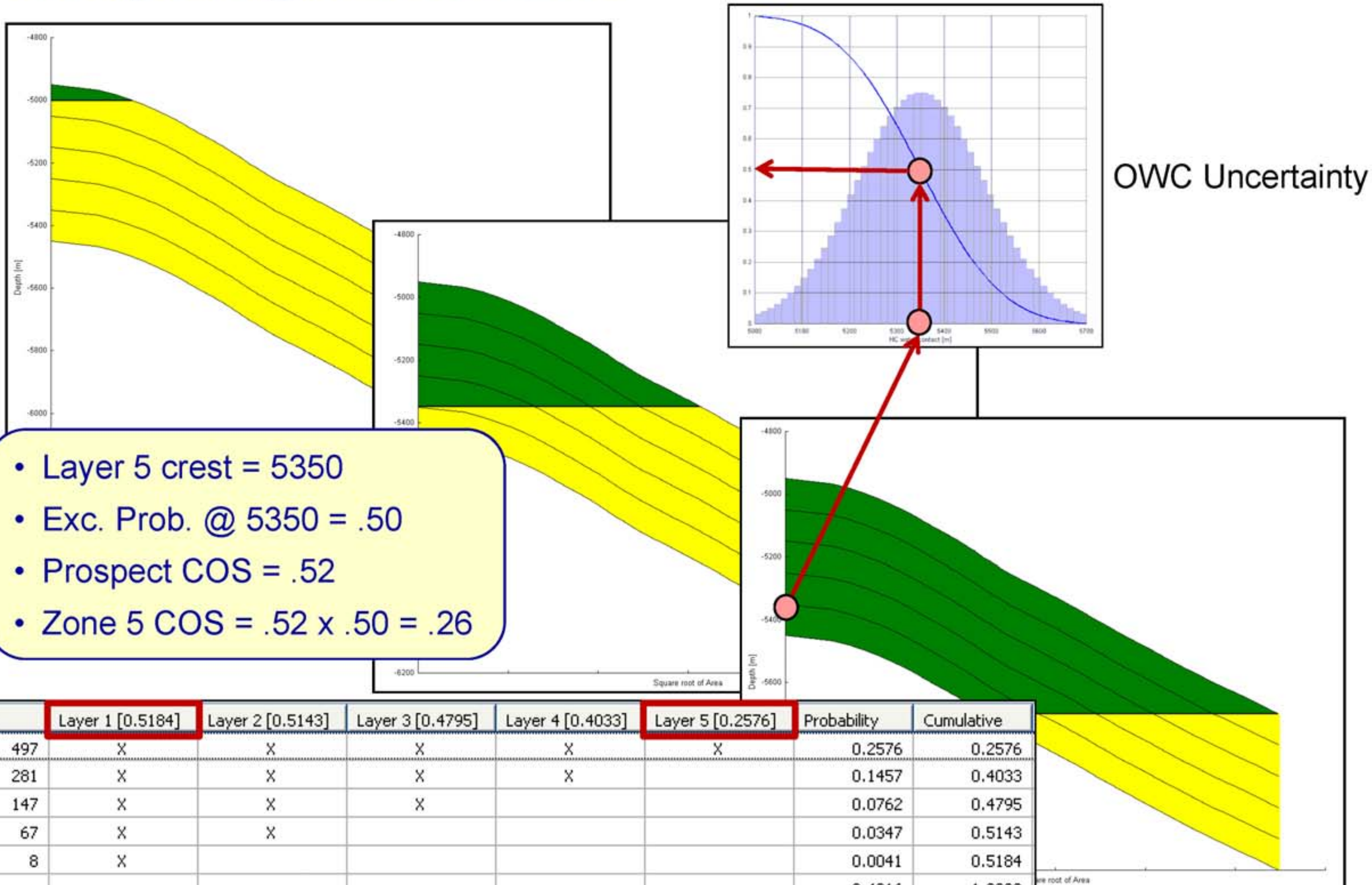
Multiple segment solution



Notes by Presenter: If the zones are in communication, a single Oil-Water Contact distribution may be applied to the entire interval. The GRV within each zone will be function of the thickness of the zone, the column height, and the structural interpretation. In any given trial, zones at the top of the section will have a greater GRV than those at the base of the section. By integrating the structure, thickness uncertainty, and contact uncertainty, along with the unique average porosity distribution for each zone, we insure that the average porosity of the prospect is correct, and is properly correlated to the prospect gross rock volume.

Multiple segment solution

GeoKnowledge
Making knowledge work



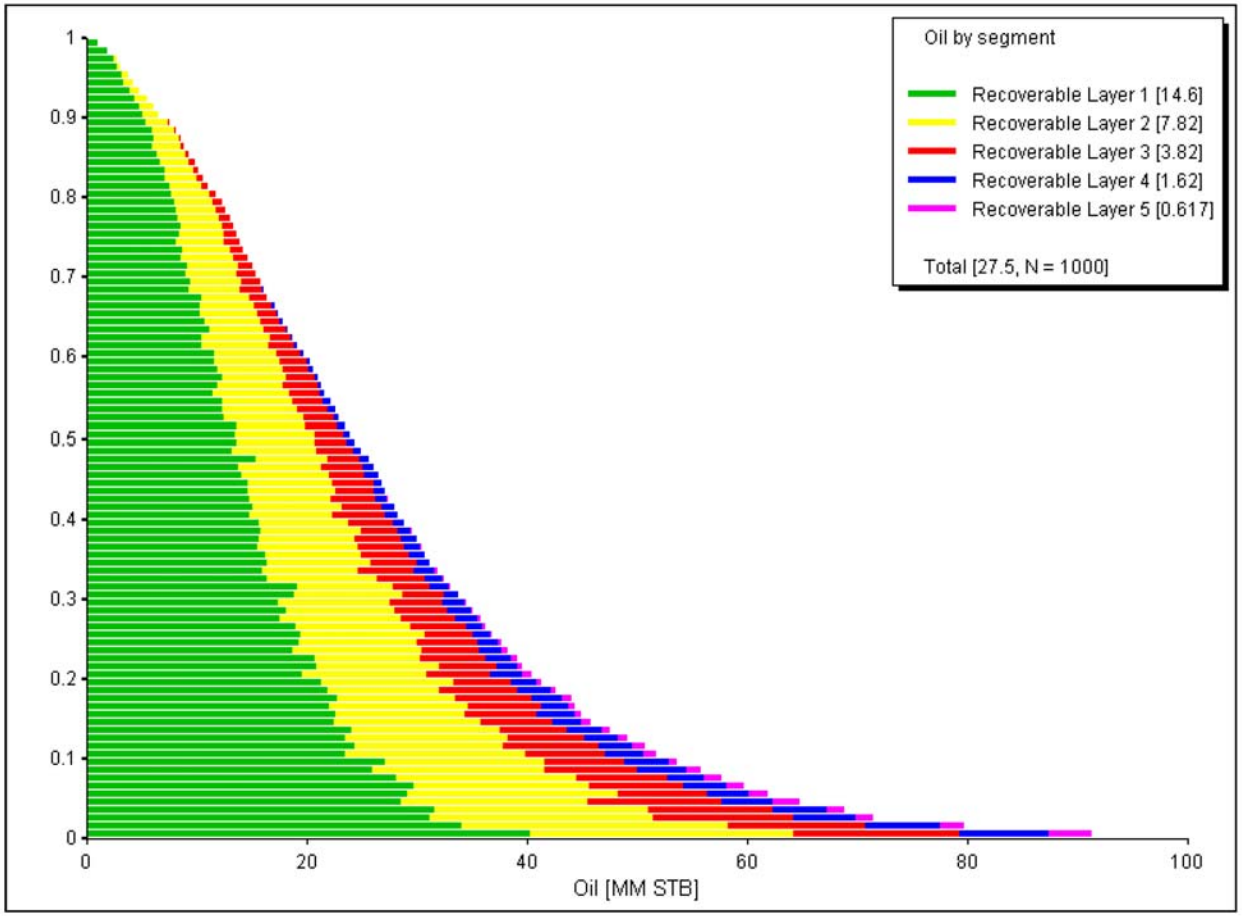
- Layer 5 crest = 5350
- Exc. Prob. @ 5350 = .50
- Prospect COS = .52
- Zone 5 COS = .52 x .50 = .26

N	Layer 1 [0.5184]	Layer 2 [0.5143]	Layer 3 [0.4795]	Layer 4 [0.4033]	Layer 5 [0.2576]	Probability	Cumulative
497	X	X	X	X	X	0.2576	0.2576
281	X	X	X	X		0.1457	0.4033
147	X	X	X			0.0762	0.4795
67	X	X				0.0347	0.5143
8	X					0.0041	0.5184
---						0.4816	1.0000

Notes by Presenter: The joint segment probability table shows the chance of each combination of zones, and demonstrates that the zones' chance of success decreases with depth, reflecting the lower exceedance probability for deeper contact depths. Here we demonstrate that the overall prospect chance of success is 52%, while the COS for Layer 5 is only 26%.

Multiple segment solution

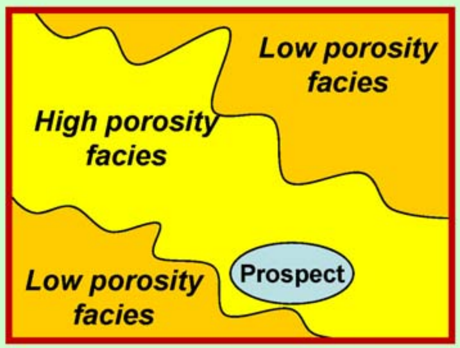
GeoKnowledge
Making knowledge work



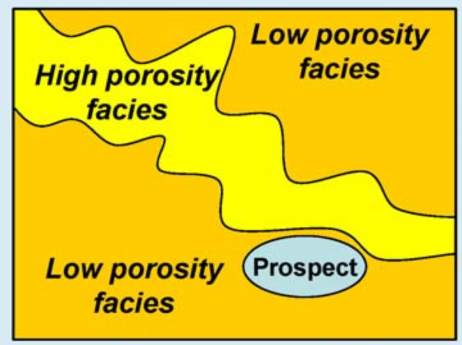
Notes by Presenter: The resource diagram is the exceedance probability curve for the prospect success case, defined as all trials in which at least one succeeds. We see that the chance of success for each zone decreases with depth. Only Layer 1 is present in all success case trials. The volume contributed by each zone decreases with depth, reflecting the decrease in both GRV and, in our example, porosity with depth.

Challenges

- The average porosity range (uncertainty) that results from aggregating several zones or areas is smaller than expected
- How do we increase the uncertainty of average porosity?
  - Increase the ranges on the individual zones? ×
  - Increase the level of correlation between zones? ×
  - Use alternative models? ✓



Base Case
The prospect is probably within a high porosity facies.
NG between 15% and 35%



Alternative Model
The prospect may be within a low porosity facies
NG between 5% and 15%.

Notes by Presenter: When the gross rock volume of a reservoir is large, and the depositional model is known, the range of average porosity should be narrow. But, instinctively, we perceive the range as TOO narrow. How can we increase the range? There are three ways to increase the range: increase the range within the individual zones or drainage areas, increase the correlation between the zones, or use alternative depositional models. There is limited potential for increasing the range. The example used a very large range and we saw that the range of average porosities narrowed significantly as soon as multiple zones were introduced. Adding correlations between the zones is not appropriate in a reservoir that is by definition heterogeneous. The answer lies in alternative depositional models. IF the environment of deposition is known, the range SHOULD be narrow. It is the possibility that the EOD is NOT known that adds to the uncertainty.