Subsurface Parameter Uncertainty: A Structured Approach*

Arnout Everts[1], Laurent Alessio[1], Peter Friedinger[1], and Faeez Rahmat[1]

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[1]LEAP Energy, Kuala Lumpur, Malaysia (arnout.everts@leap-energy.com)

Abstract

Objective of this paper is to illustrate how a structured approach towards quantifying the expectation ranges of key subsurface parameters, differentiating between true uncertainty and mere variability and recognizing the possibility of biases in our subsurface data, can lead to significantly improved asset management, i.e., better reservoir models, improved accuracy of resource estimates, more objective assessment of appraisal value etc.

In the exploration/appraisal stage especially offshore, wells are scarce and therefore well-based property estimates are typically complemented by indirect evidence from seismic. On the other hand, developed fields especially onshore or resource plays may have a much higher well density but with a distribution clustered around interpreted reservoir sweet spots or chosen surface development sites. With this limited ‘ground truthing', our challenge is to make as accurate as possible assessments of the subsurface parameters in our fields, specifically:

- Determine the expectation ranges for the field- or block-wide average of key reservoir properties. For fields in the exploration or appraisal phase especially where wells have been drilled on seismic amplitude anomalies, data representativeness is an issue that may easily lead to over-optimism and underestimation of the uncertainty range. On the other hand, in fields with high well density such as resource plays, it is important to distinguish between reservoir variability, which may be very profound from well to well, and genuine remaining uncertainty on the field property averages.

- Define the distribution model or models to be used for populating reservoir properties in our 3D reservoir models. Geostatistical property mapping typically uses distribution models fit to well data, in combination with transforms to reflect of spatial trends e.g., facies conditioning, depth trends or seismic inversion-based trends. However, where well data is scarce, clustered or sampling anomalous parts of the reservoir, distribution models based on wells alone may not be representative and give rise to inappropriate reservoir property mapping.

This paper will show examples of how to overcome these limitations and potential pitfalls in a structured manner, by relating back to the principles of sampling statistics and by introducing a holistic approach that addresses not only distribution uncertainty but also sampling biases and measurement uncertainty on the parameters themselves.

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Arnout Everts

with contributions by Laurent Alessio, Peter Friedinger and Faeez Rahmat

AAPG ICE – September'12

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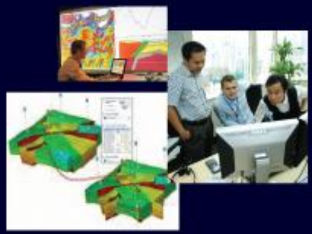

LEAP Energy

Main Office:
G-Tower, level 14
Kuala Lumpur, Malaysia
Tel: +60 3 2161 4710
Web: www.leap-energy.com
Email: info@leap-energy.com

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Paper Objective and Outline

- Discuss and illustrate various ways of quantifying the expectation ranges of key subsurface parameters e.g., Thickness, Net-to-Gross, Porosity, Sw, in a structured and reproducible manner
  - differentiating between true uncertainty and mere variability
  - recognizing the possibility of biases in our subsurface data

- Outline of the paper:
  1. Parameter choices for 1D (Monte Carlo) volumetric
  2. Uncertainty modeling in 2D and/or 3D

Challenge for the geologist

- **The task: anticipating the range of likely subsurface outcomes on the basis of sparse data:**
  - **Predicting the range in field-average reservoir properties to estimate a field's HC resource**
  - **Predicting the variability in reservoir properties that may be encountered when drilling new (development) wells**

- **Some guiding principles:**
  - **The confidence in a field's mean properties and resource *should* increase with more data (uncertainty decreases)**
  - **Drilling more wells increases the chance of sampling outliers (the more wells, the more subsurface variability is seen)**

Sampling statistics principle

To predict a field's mean reservoir property values and a confidence level around it, we can treat the <u>reservoir average</u> computed for each well as a sample in a 'Z-test' approach:

The principle of Z-test

A samples Mean is expected to fall within a specified confidence band around the population MEAN as follows:

- σ (the standard deviation of the population)

First calculate the standard error (SE) of the mean:

$$\mathrm{SE} = \frac{\sigma}{\sqrt{n}}$$

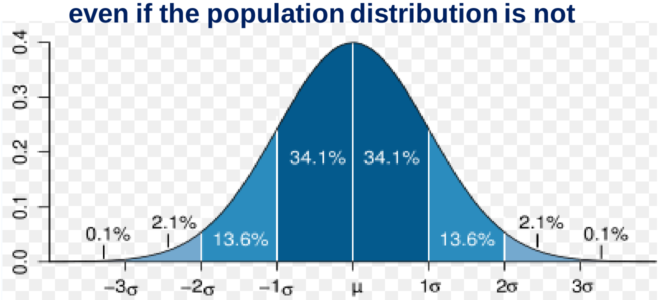
The formula for calculating the z score for the Z-test is as follows:

$$z = \frac{x - \mu}{\mathrm{SE}}$$

where:

- x is a mean score to be standardized
- μ is the mean of the population

If the number of samples is large enough, the distribution of sample means will be normal even if the population distribution is not



Since the population Standard deviation is unknown, assume: σ = SD

As the number of samples (n= number of wells) increases, SD may remain stable or increase but SE = SD/Sqrt(n) should reduce

<u>Common issues and pitfalls:</u>

- **Each well is a sample, not each datapoint in each well is a sample**
  - ***Reason being, we are estimating the reservoir average in the field, not the reservoir average in a well***
- **If the number of wells drilled is very small, the approach becomes less reliable**
  - ***If n=1, SD = 0 hence SE=0; no uncertainty ??***
- **Biased sampling, for example where wells have been drilled on seismic sweet-spots**

Mature field illustration of sampling statistics

Porosity in a mature clastic reservoirs oil field

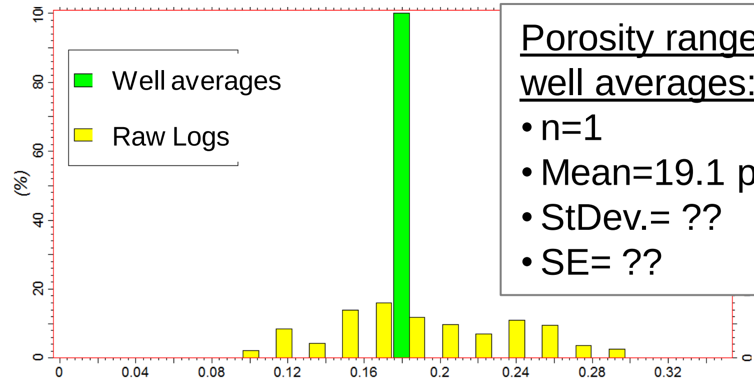
OBSERVATIONS:

- The spread in raw log data values doesn't change much with drilling more wells
  - *A measure of reservoir variability but NOT uncertainty around the field mean*
- The confidence band (calculated using SE) around the field mean narrows with drilling more wells despite finding more outliers

ISSUES:

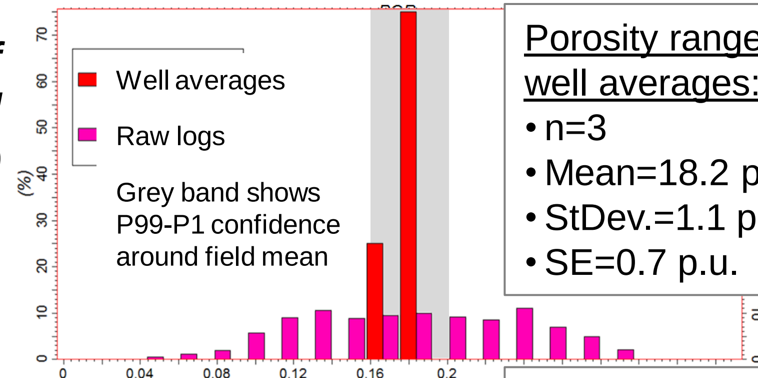
- How do we deal with the one well situation ?
- Is 3 wells (end of appraisal stage) enough to confidently estimate the SE ?

Discovery well



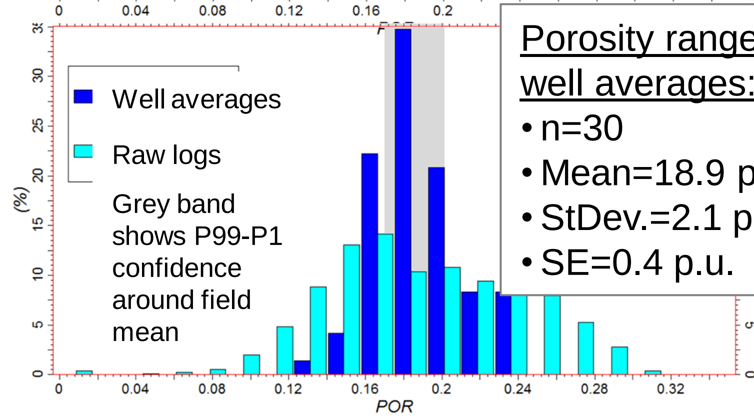
Porosity range from well averages:
- n=1
- Mean=19.1 p.u.
- StDev.= ??
- SE= ??

End of appraisal (3 wells)



Porosity range from well averages:
- n=3
- Mean=18.2 p.u.
- StDev.=1.1 p.u.
- SE=0.7 p.u.

Mature development (30 wells)



Porosity range from well averages:
- n=30
- Mean=18.9 p.u.
- StDev.=2.1 p.u.
- SE=0.4 p.u.

The “single well” challenge

- Now I have only one well drilled on the field What values do I assume for the mean reservoir properties? And how do I estimate the uncertainty ranges around those assumed mean values?

POSSIBLE METHODS:

- Refer to analogues
- Treat zone-averages of stacked reservoir intervals as one population (to get more sample points)
- Break up the reservoir into meaningful subzones and compute the average properties for each of those (again, to get more sample points)

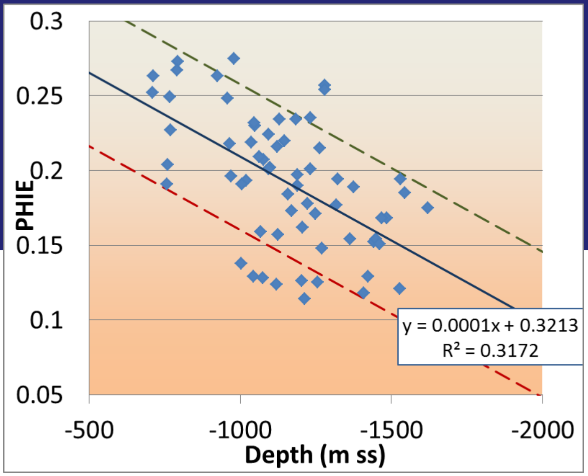
Possible workflow: Treating stacked reservoirs as one population

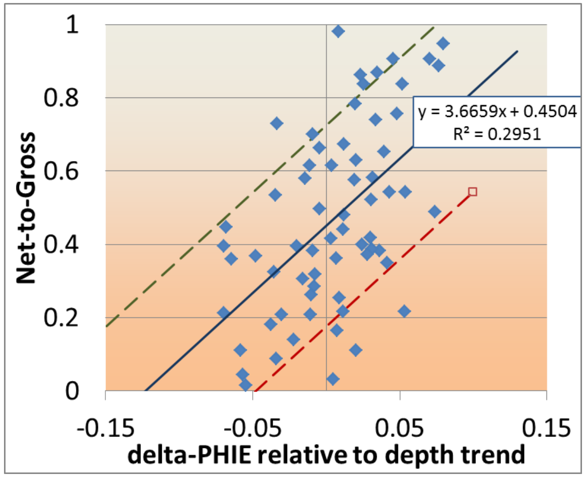
Calculate all reservoir-(sub)zone averages over the interval of interest

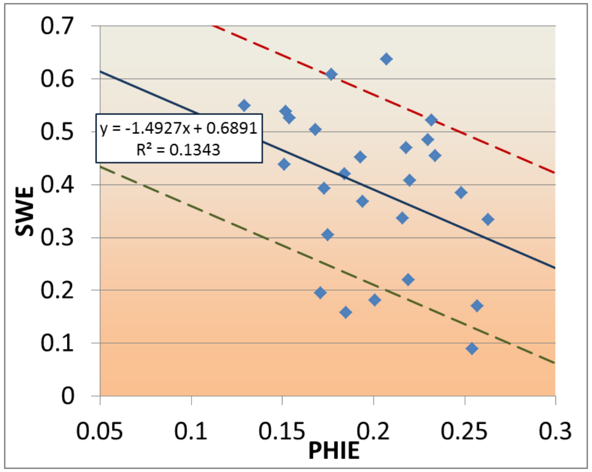
Determine parameter correlations e.g., Porosity vs. depth, Porosity vs. Sw, depth-normalized porosity vs. Net-to-Gross

Determine the uncertainty bands around the parameter correlations
(Standard Error of Y-estimate)

Tabulate parameter ranges per reservoir using the well observed values as the mid and the ranges observed from the cross plots to yield Low/High

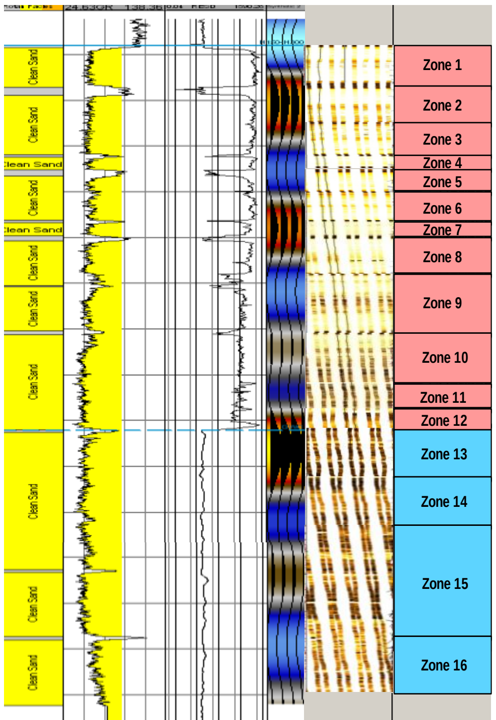




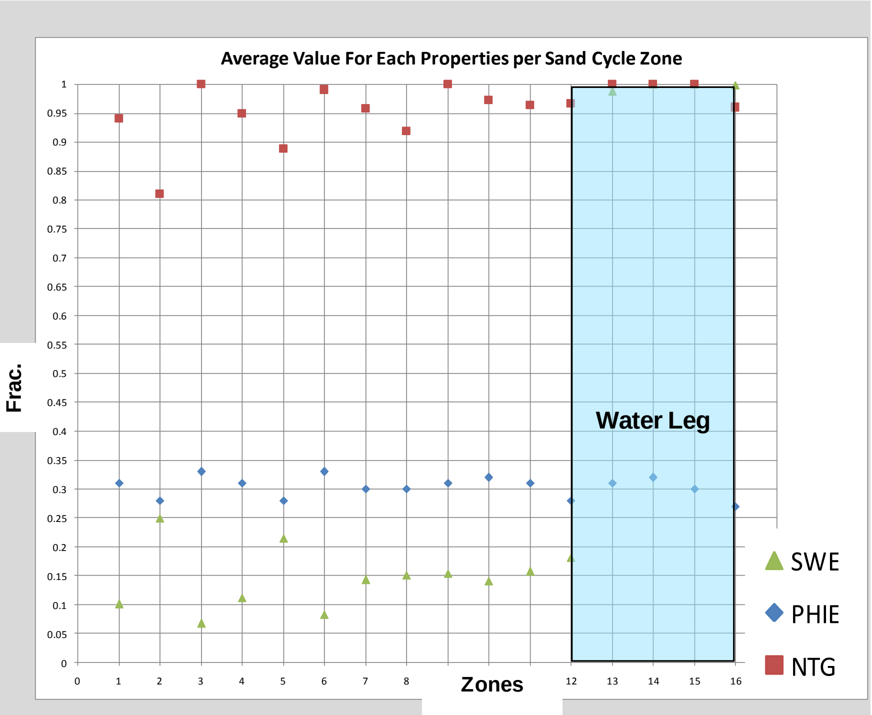


Possible workflow: breaking up a single reservoir into subzones

Example: deepwater turbidite well



Determine reservoir sub zonation based on OBMI interpretation

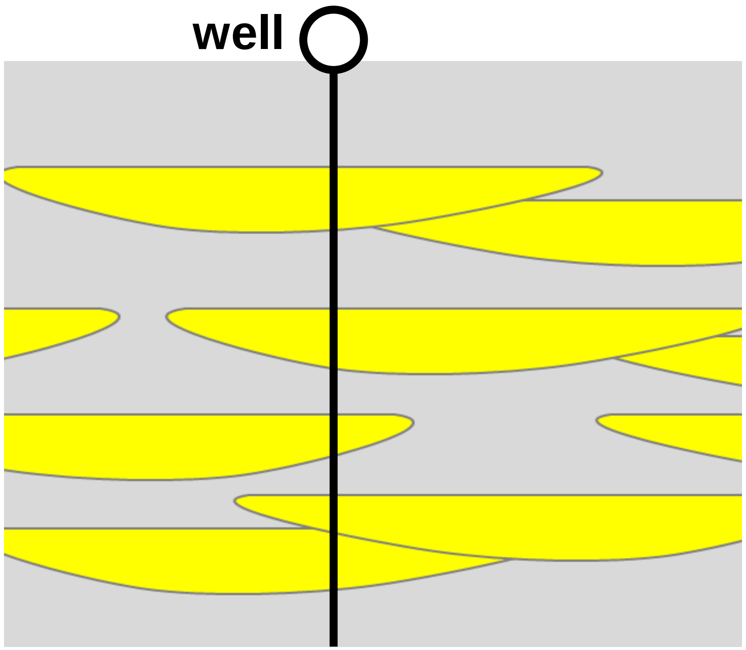


Calculated sums and averages for each subzone, and determine mean and std deviation for entire reservoir and HC zone only

Use the statistic to as a reference to create mid, low and hi case for each property

Note: this method gives an idea of the possible spread in the reservoir averages but still, n = number of wells drilled and NOT the number of subzone samples

Importance of Conceptual Geological Model

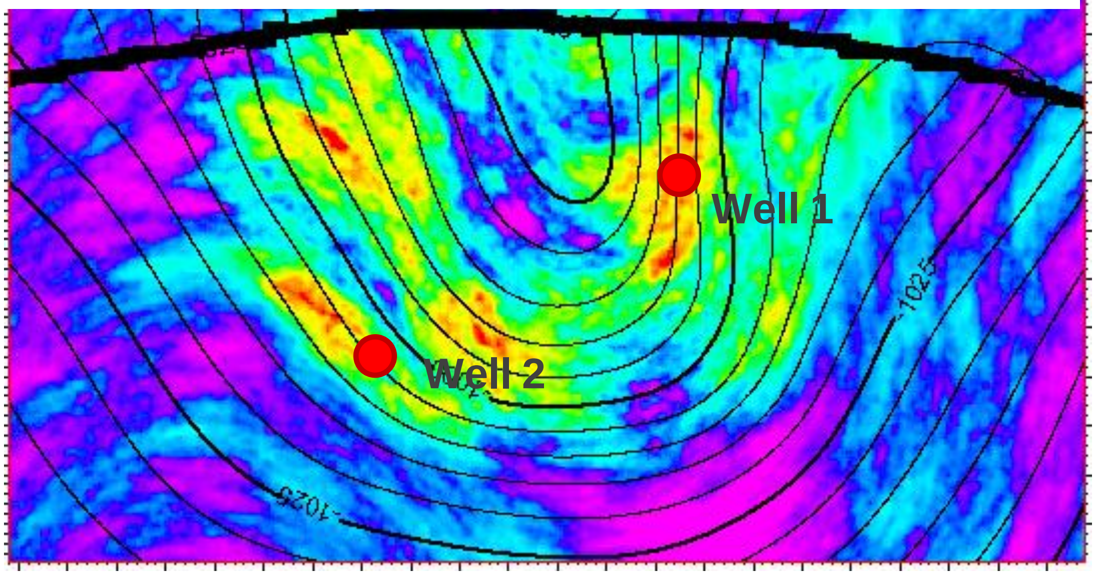


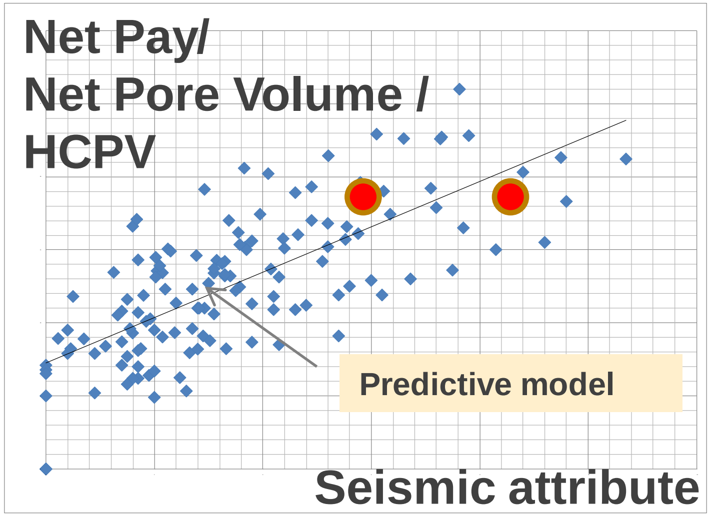
If the geological setting implies reservoirs that are relatively continuous, then our best assumption may be that the MEAN per reservoir is the mean of the well(s) in that reservoir

However, in reservoirs that are highly variable laterally our best estimate of a reservoir zone MEAN may be the mean of the entire reservoirs stack

Bottom line:* *ALWAYS interpret and use reservoir statistics in the context of conceptual geology

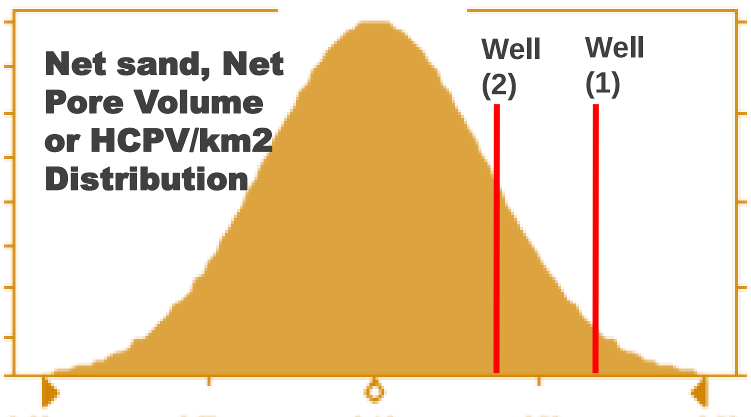
The issue of biased sampling

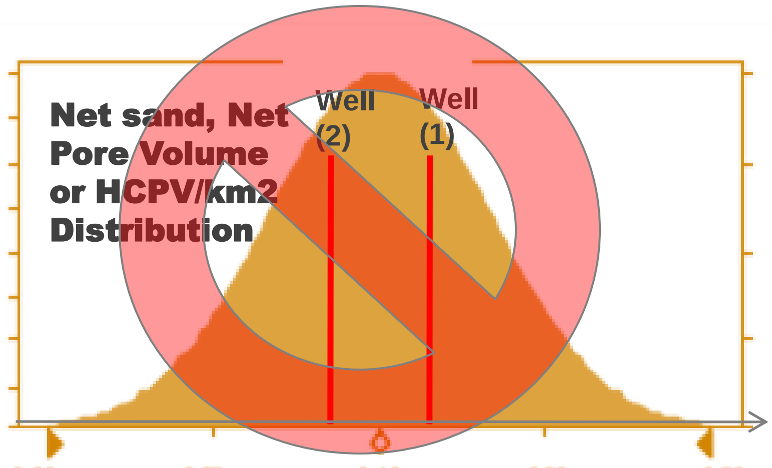




Amplitude / Seismic attribute 'sampled' at wells (RED) are typically not representative

Exploration high-grades prospects and drilling occurs on high amplitude





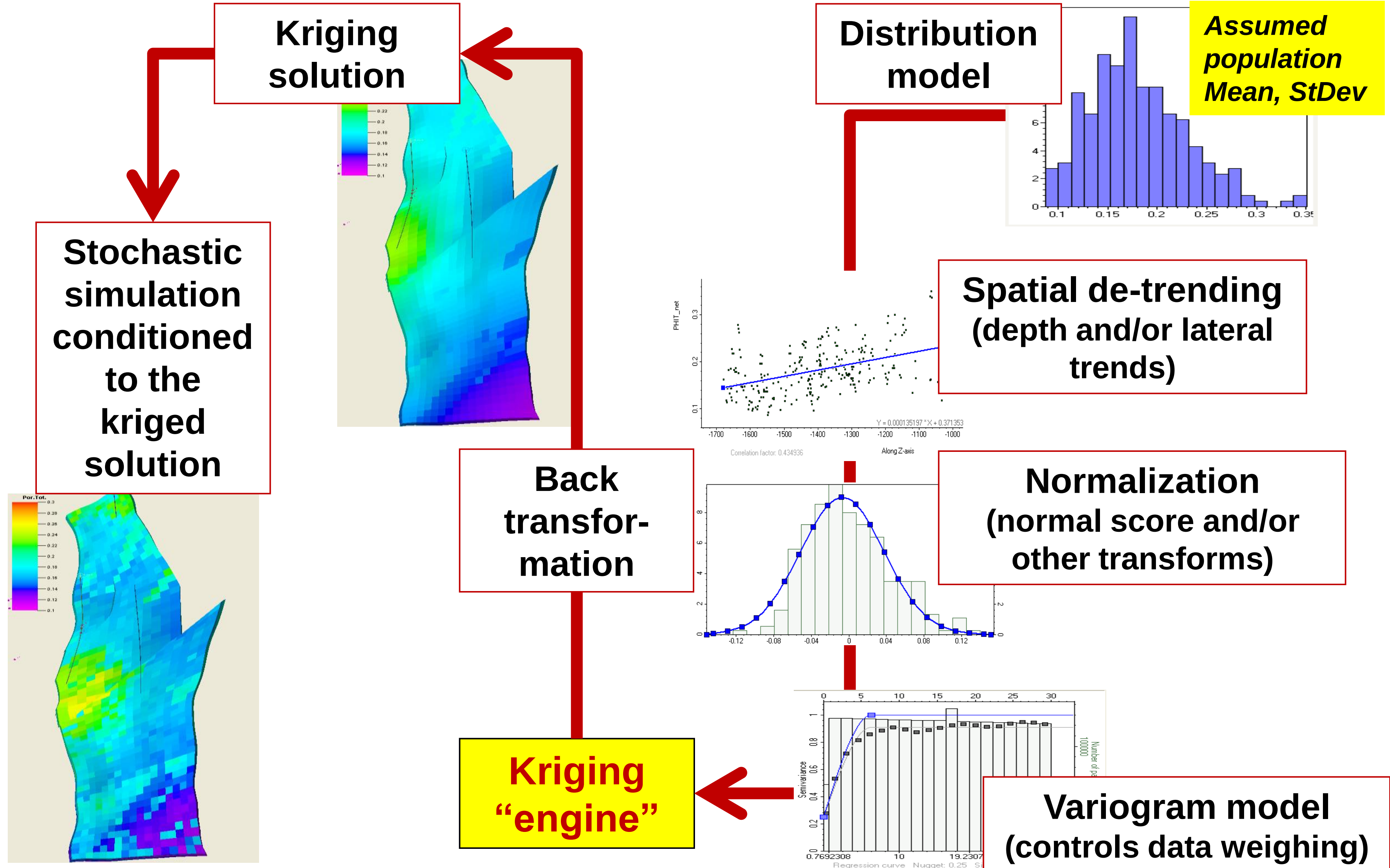
As a result, wells (RED) are biased and a correction should be made before volume calcs

But often, this happens !

Parameter Uncertainty in Mapping and 3D Modeling

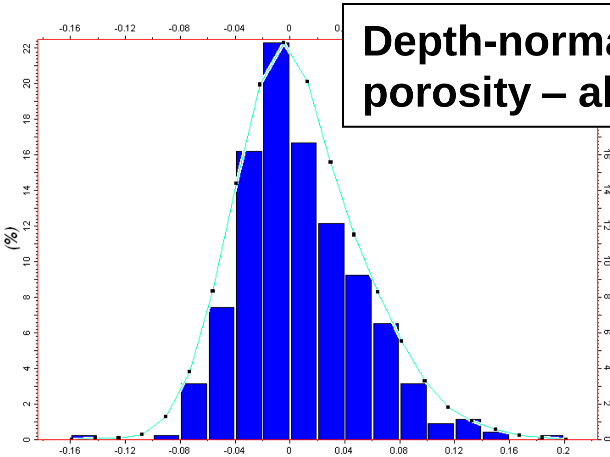
- Principles of Geostatistical Gridding
- Data Representativeness
– well sampled Property versus population (=field) Mean
- Depth and Spatial Trends

Geo-statistical gridding
- kriging and related algorithms

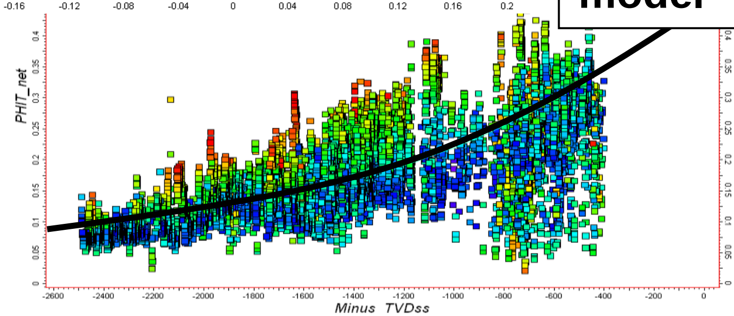


Statigraphic zone / facies bias

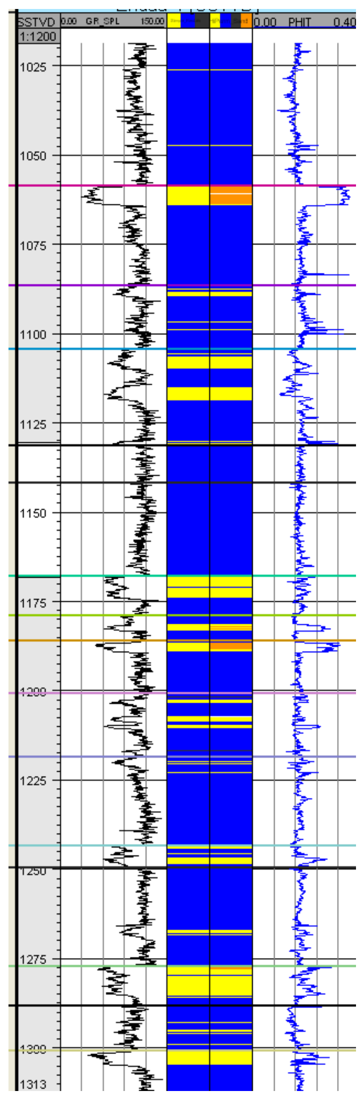
- Property sampling per stratigraphic zone is typically limited
  - How do we know the data is representative?

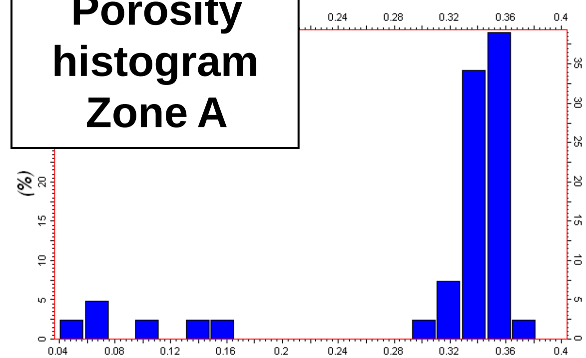


Depth-normalized porosity – all zones

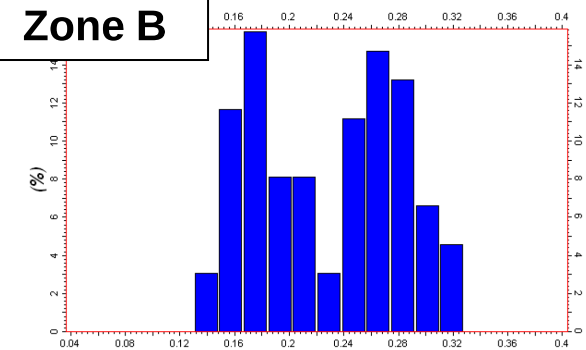


Regional Por-Z model

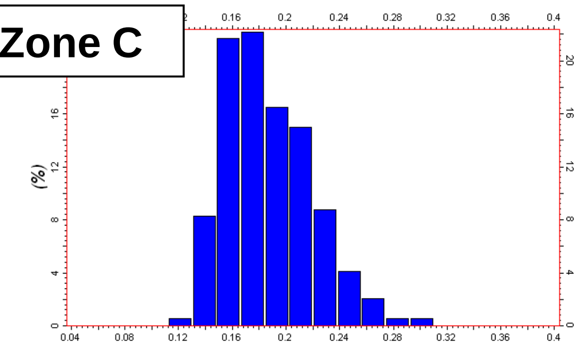




Porosity histogram Zone A



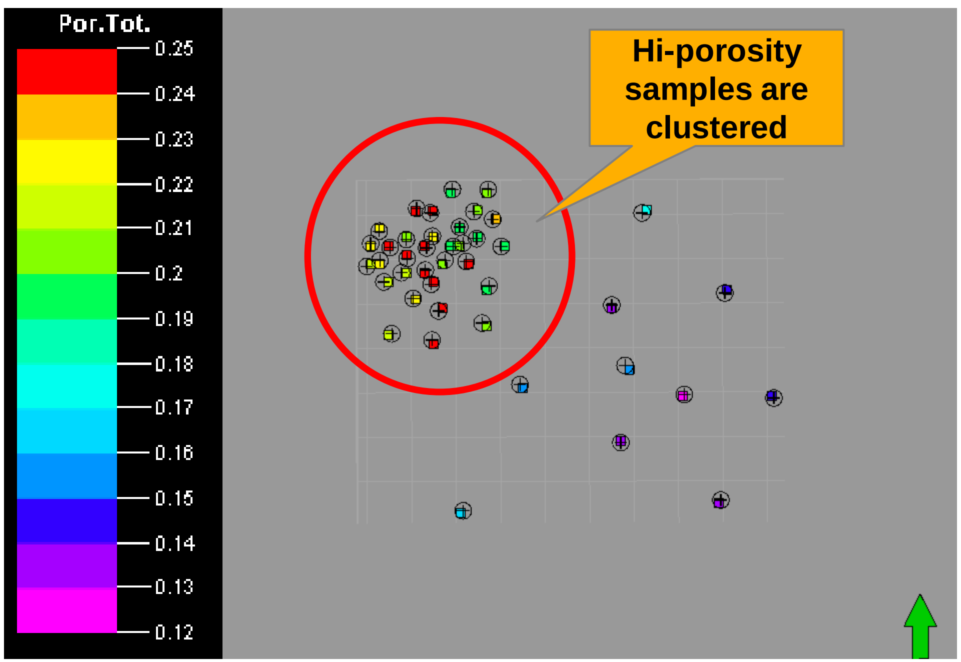
Zone B



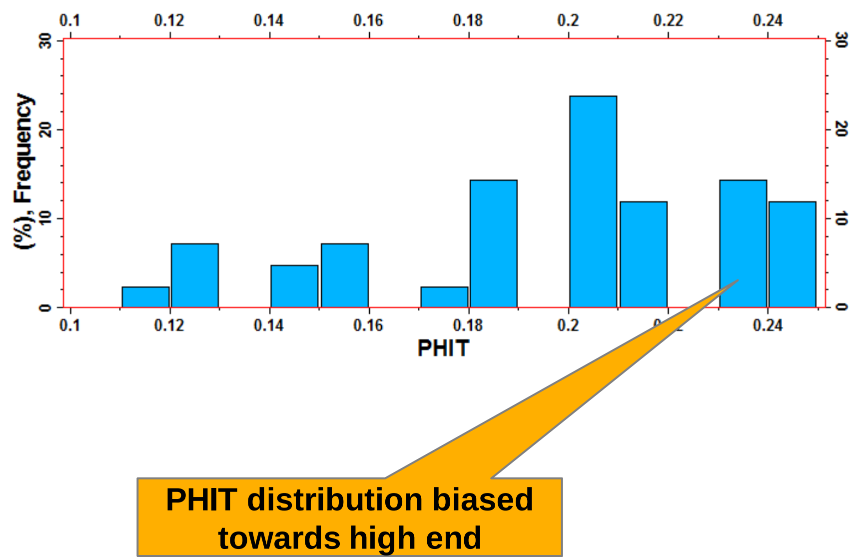
Zone C

Biased and spatially clustered Sampling

- Clustered sampling with a sampling bias occurs when wells are clustered on/near presumed reservoir sweet spots
- Very common in the energy industry because of a desire to drill good reservoir combined with drilling access limitations
- How can we obtain the “real” distribution?

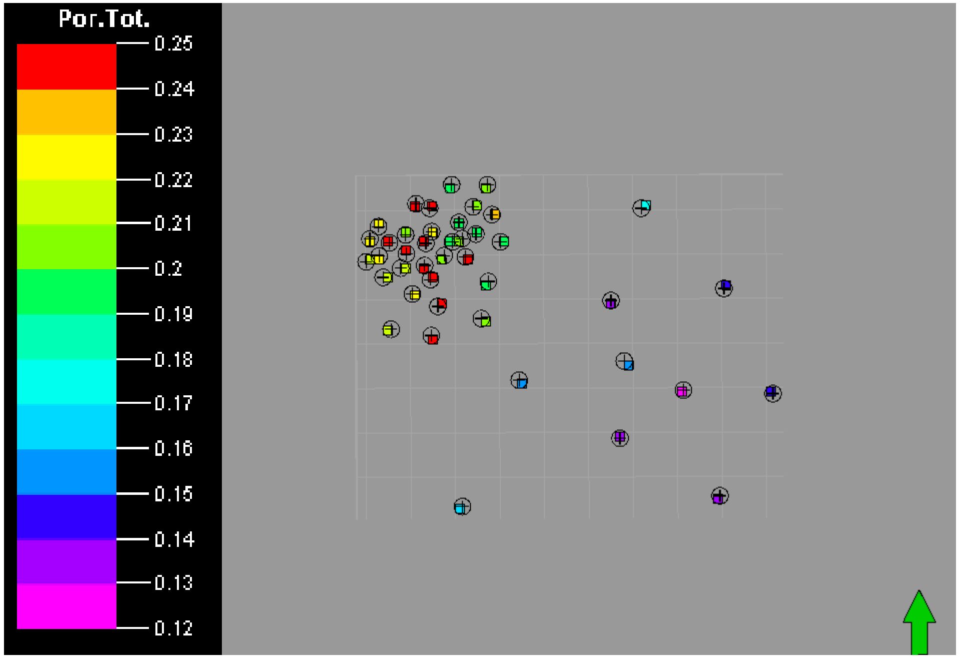


PHIT Distribution



Sample De-clustering

Cell size 2 x 2



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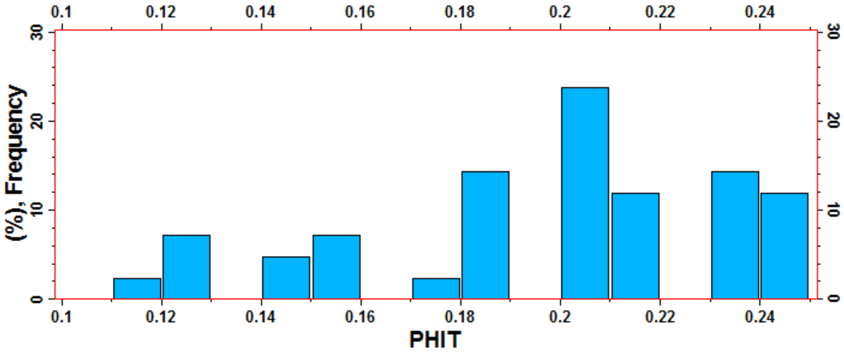
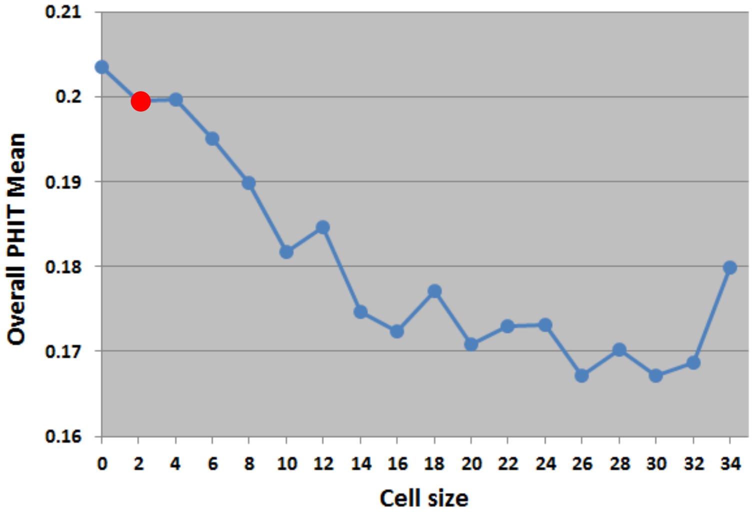
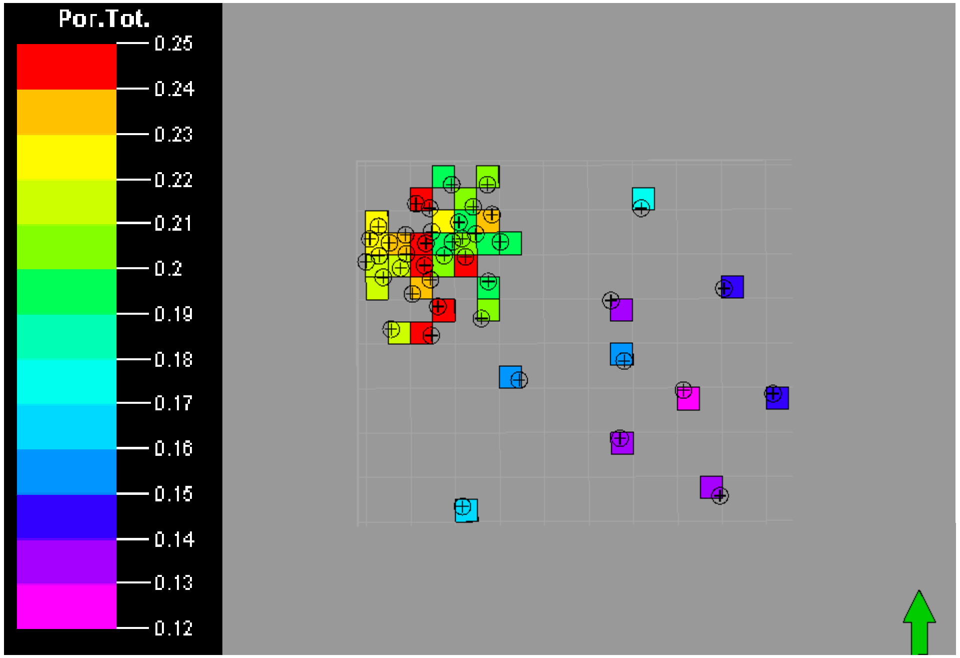


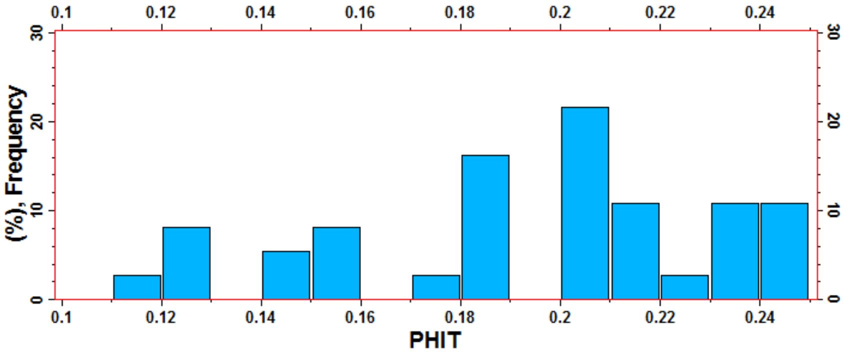


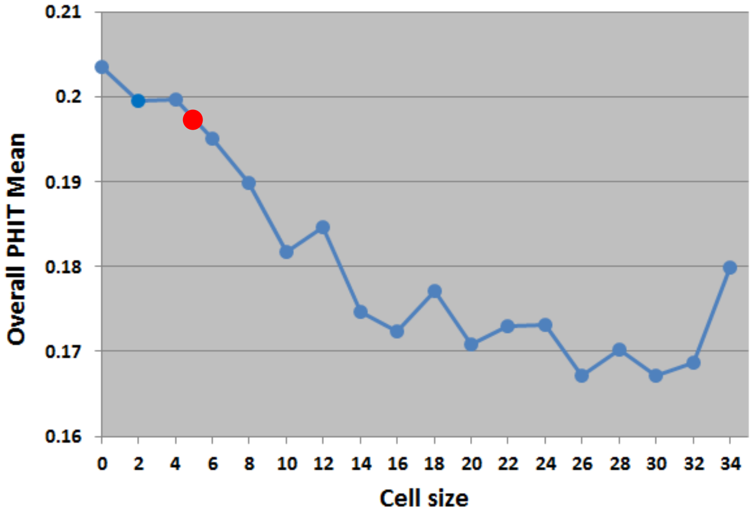
Sample De-clustering

Cell size 5 x 5



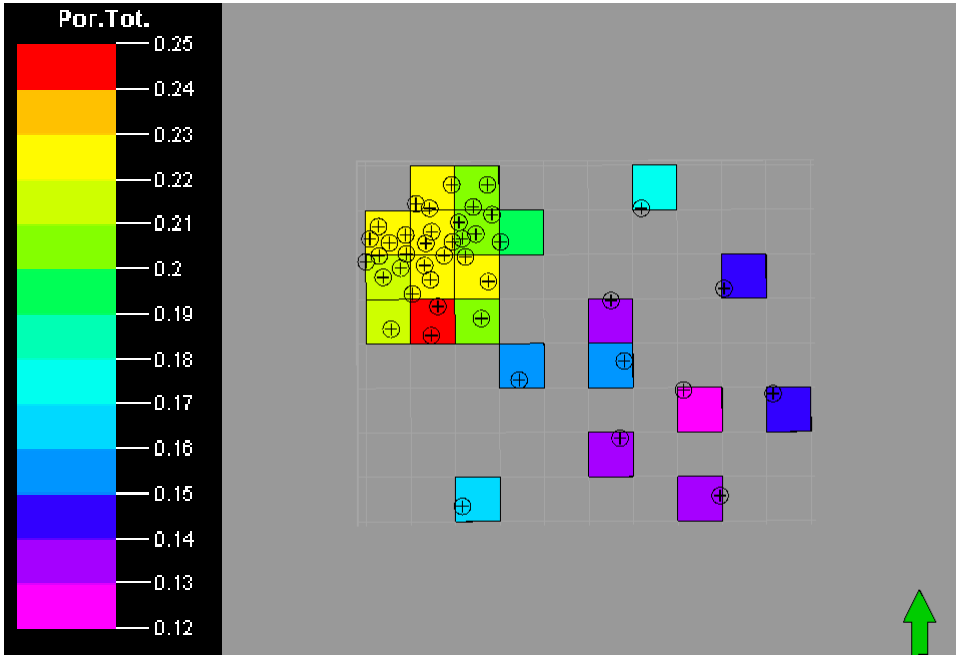
PHIT Distribution





Sample De-clustering

Cell size 10 x 10



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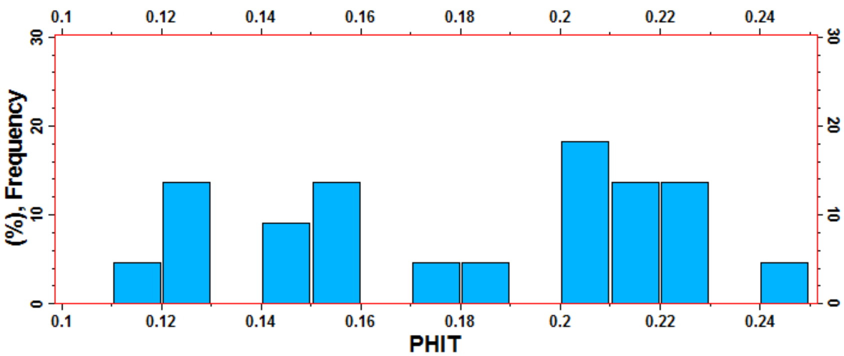
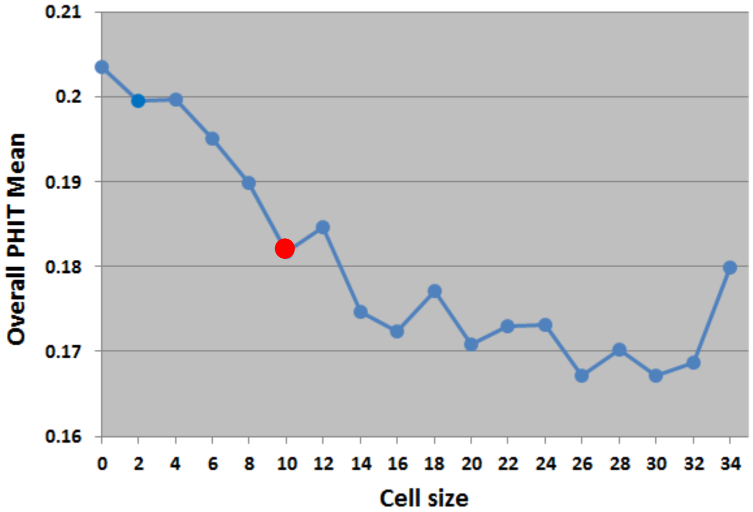
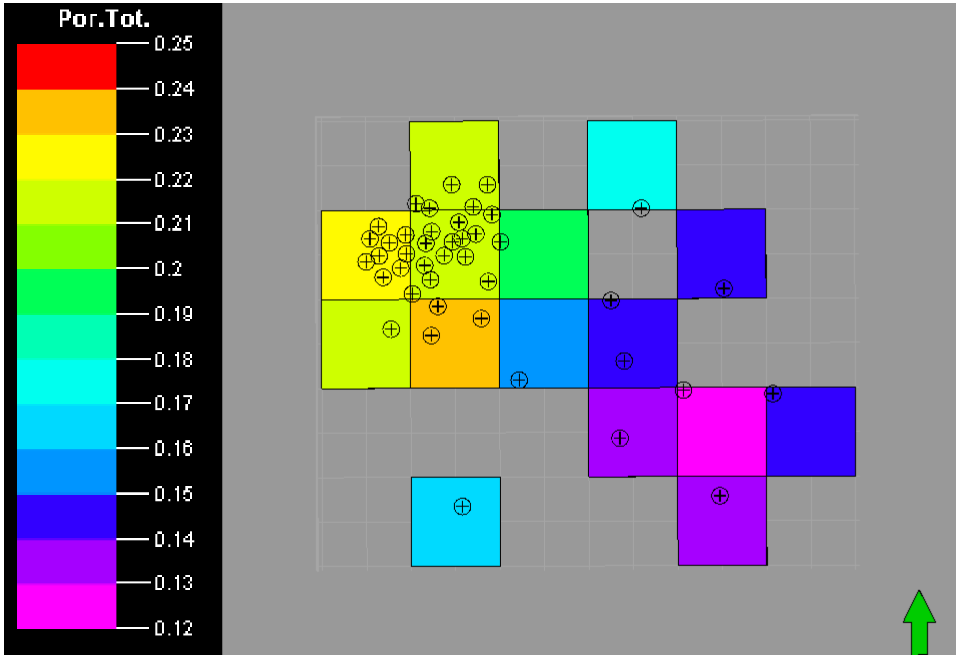




Sample De-clustering

Cell size 20 x 20



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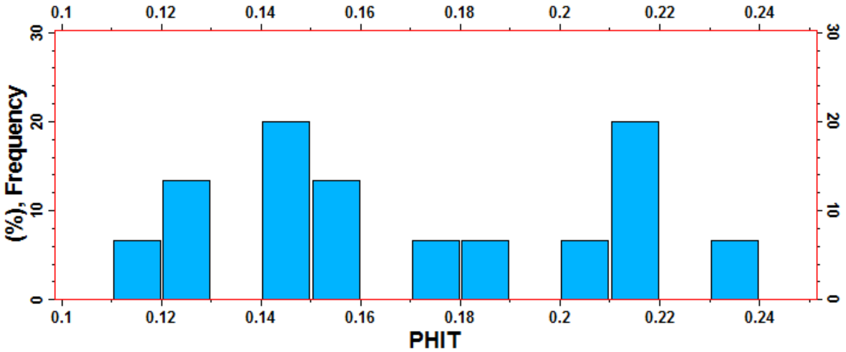
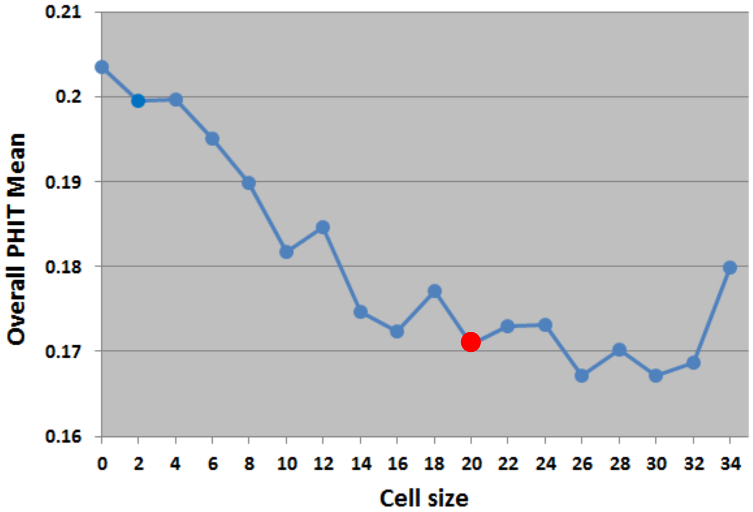
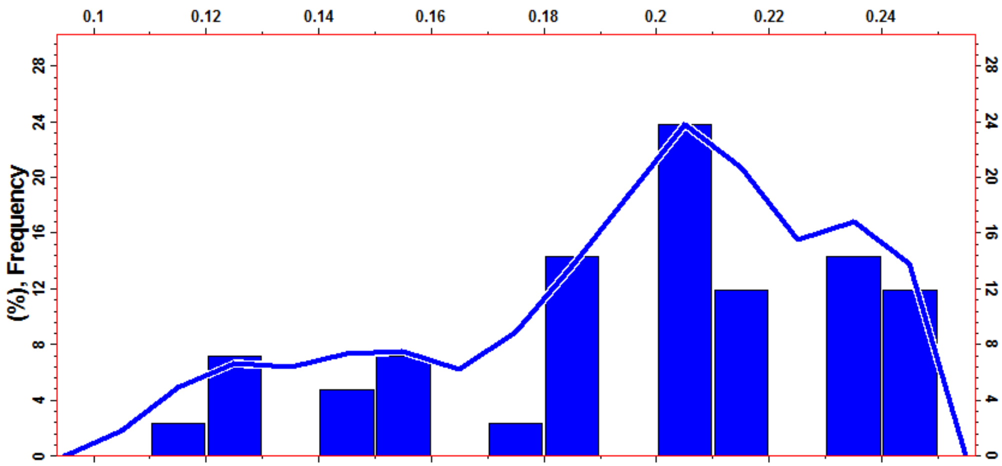
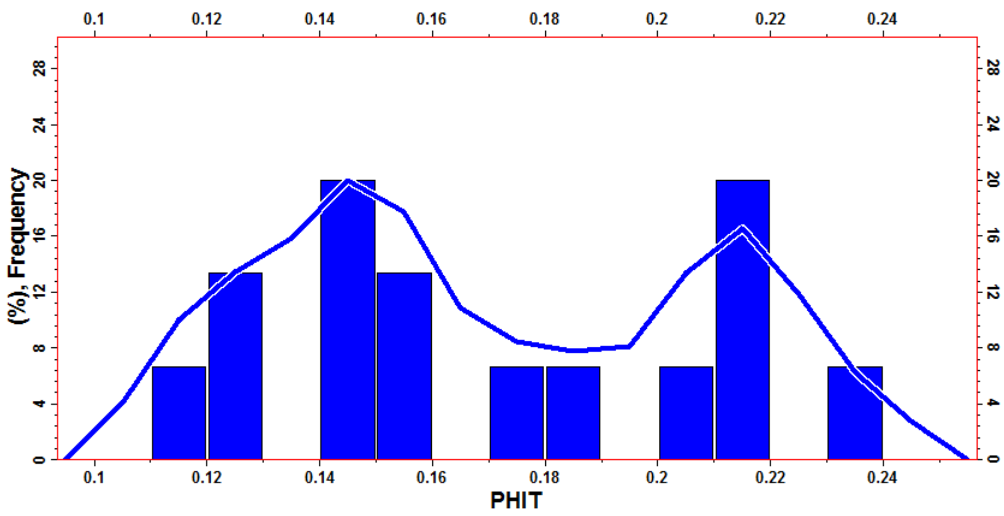




Distribution models: de-clustered versus original



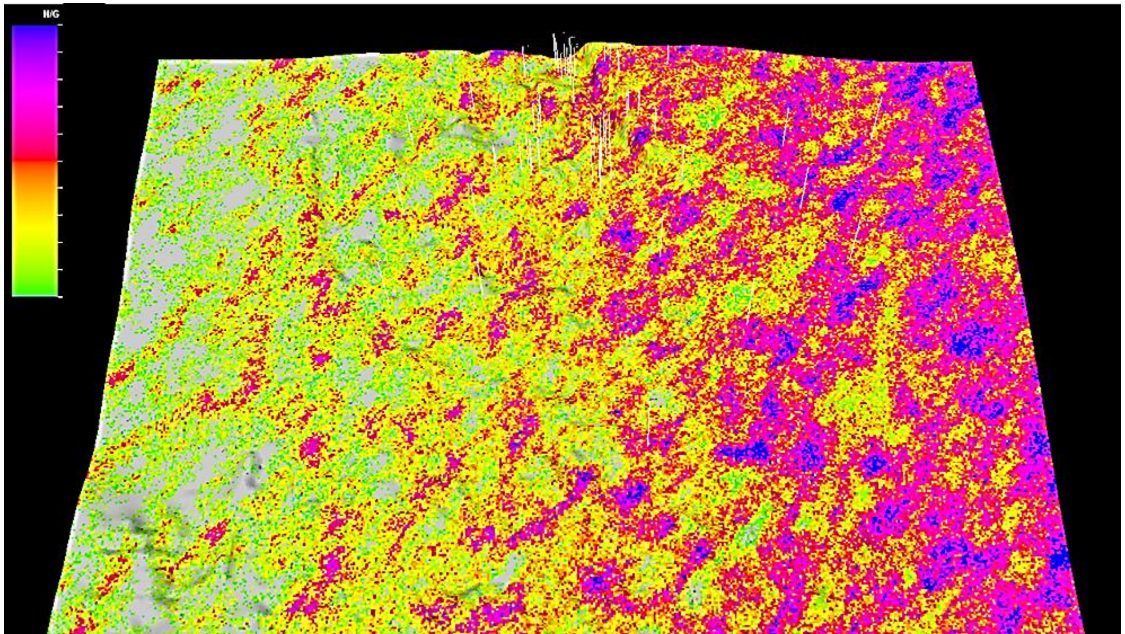
original distribution

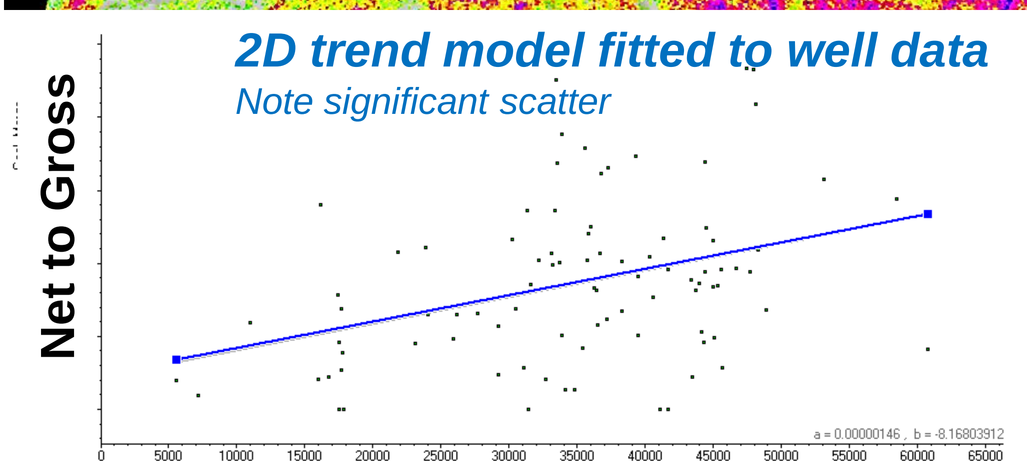


declustered distribution

Reservoir Property Trends in context of Uncertainty

Recognizing and Capturing lateral Trend Uncertainty





- Regional property trends are often present and broadly recognized but the trend uncertainty is not
- Example is from an unconventional play with areas of dense well data and area with sparse wells

Recommended workflow:

1. De-cluster the data
2. Establish the range of trend models that could fit the data
3. Perform uncertainty runs simulating uncertainty in the trend model on top of local variability (seed)

Reservoir Parameter Uncertainty
- Quantifying the impact

Reservoir Parameter Uncertainty – holistic view

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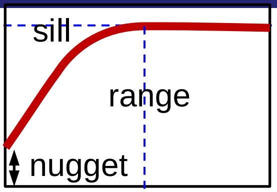
Petrophysical Evaluation Uncertainty

- Localised errors (individual zones/ wells) → Quantify, use as variogram nugget
- Systematic errors (affecting all wells) → Quantify, simulate as a stochastically sampled bulkshift



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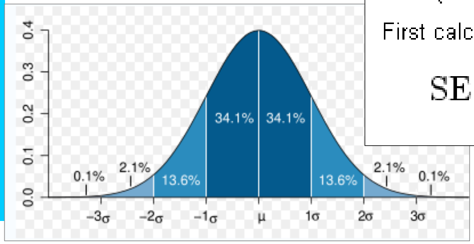
Population Mean Uncertainty (= sampling bias)

- Use Z-test principle to simulate sampling bias



- σ (the standard deviation of the population)

First calculate the standard error (SE) of the mean:

$$SE = \frac{\sigma}{\sqrt{n}}$$

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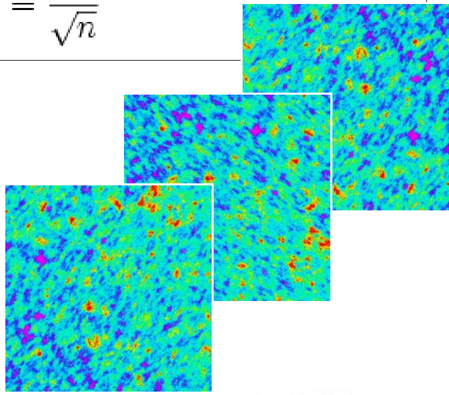
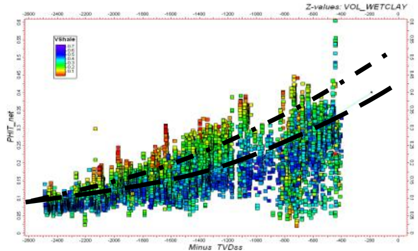
Distribution Uncertainty

- Local distribution pattern → Random seed in stochastic simulation
- Field-wide trends → Consider alternative trend models





Summary of Key Messages

- Use concept of sampling statistics but with care
  - Discriminate between uncertainty and variability
  - Importance of scale vis-à-vis the entity we try to estimate (a well is a sample of a reservoir MEAN, a log datapoint is not)
  - Consider treating multi-stacked reservoirs as one population
  - Recognize and mitigate biases in our dataset
  - ALWAYS refer back to a conceptual geological model

- Understand the strengths and limitations of stochastic simulation
  - Consider de-clustering techniques where wells spacing is clustered
  - Look for subsurface trends but also identify and quantify the uncertainty around those
  - Recognize the limited size of per-reservoir sampling and hence the confidence in sample distributions
  - Recognize what a random seed iteration can and cannot address