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John has more than 10 years of experience integrating seismic interpretation, geologic and geophysical data, and resource assessment to evaluate and develop profitable oil and gas prospects in conventional and unconventional plays. As a Senior Geologist, his specialties include integrated structural geology, stratigraphy, geophysics, and play and prospect assessment.

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GEOLOGY OF UNCONVENTIONALS

By: John S. Allen

GEOSCIENCE IN SLU RATINGS

- SLU process opens the market to Generalist Investors not currently equipped to assess Oil & Gas Assets.
- Ryder Scott (RSC), with SLE, has implemented a standardized Quality & Commerciality Rating System to evaluate Undeveloped assets.
- How does subsurface geology fall in the scope of the Rating System for Undeveloped acreage in Unconventional Plays?
- This talk outlines the geologic workflow used for evaluating resources for Undeveloped Assets in Unconventional Plays.

INTRODUCTION – UNCONVENTIONAL RESOURCES

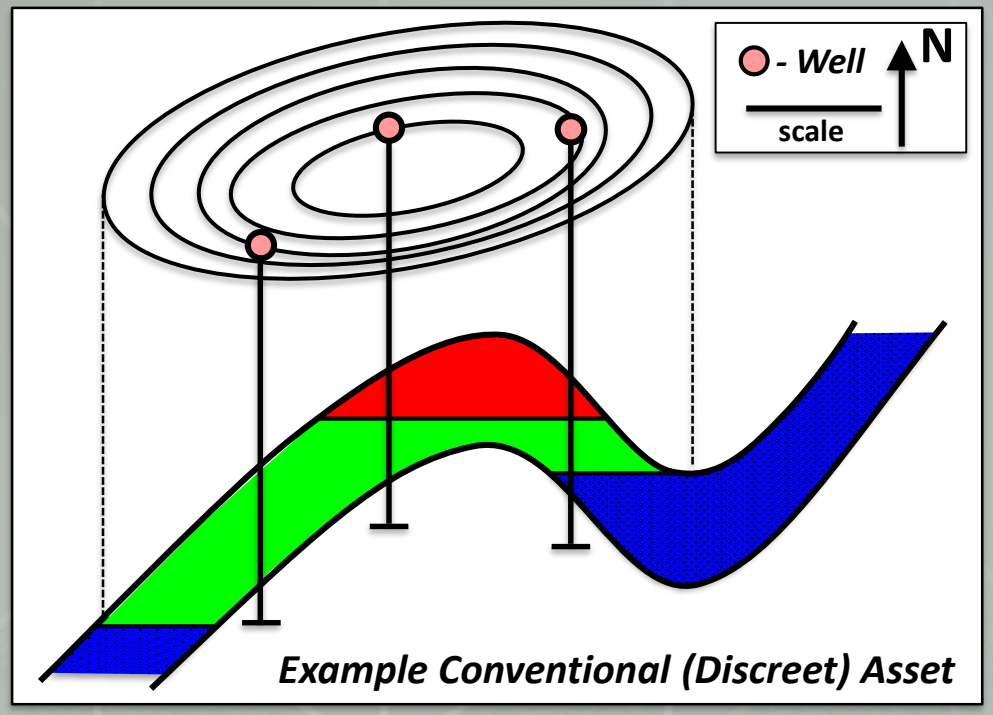
- **What are "*Unconventionals*"?**

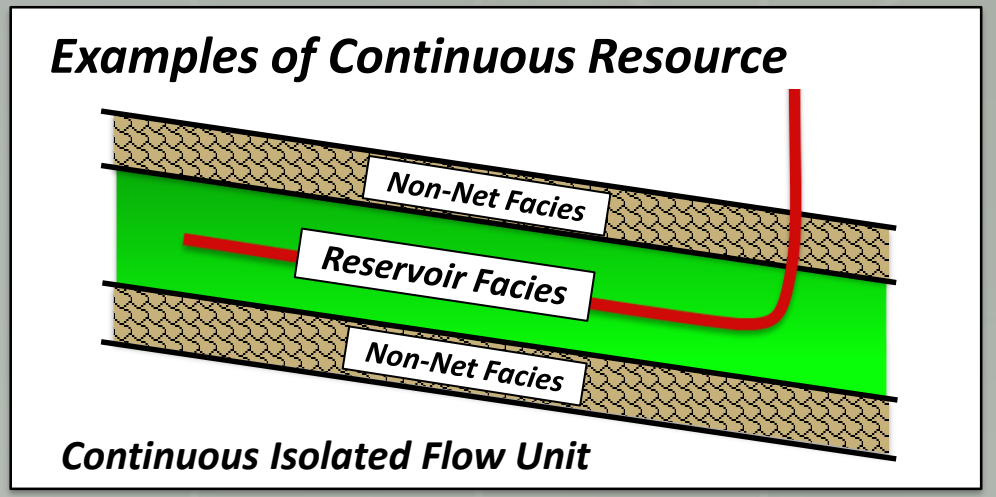
Currently understood to be a resource play that:

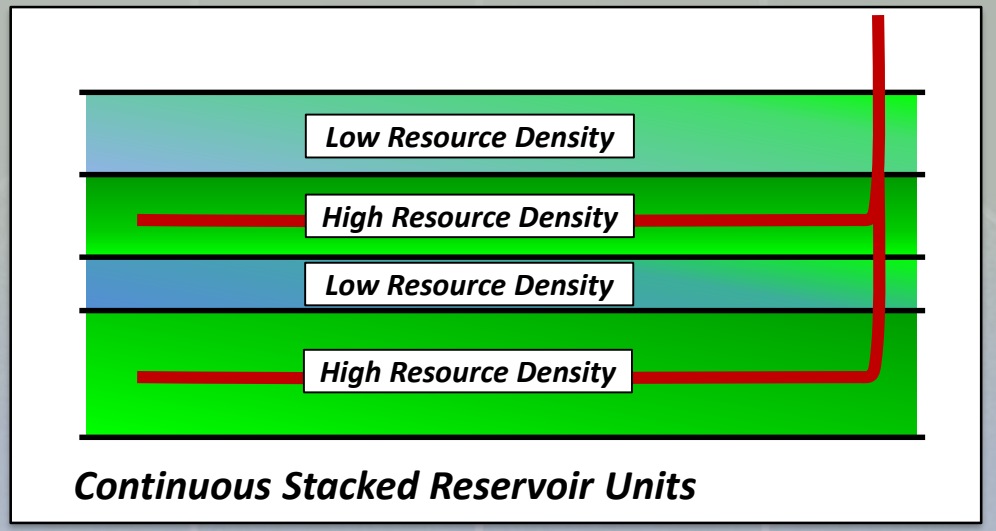
1. Occurs in predominantly fine-grained rocks
2. Have low average porosity (ϕ < 10%)
3. Have ultra-low permeability (K < 1 mD)
4. Are typically self sourced
5. Pay is vertically continuous and laterally extensive (no traps required).

- **Types of Unconventional Resources**
  - Coalbed Methane
  - Gas Hydrates
  - Basin Centered Gas
  - Natural Bitumen
  - ***Shale Gas***
  - ***Shale Oil***

DISCREET VS CONTINUOUS RESOURCE



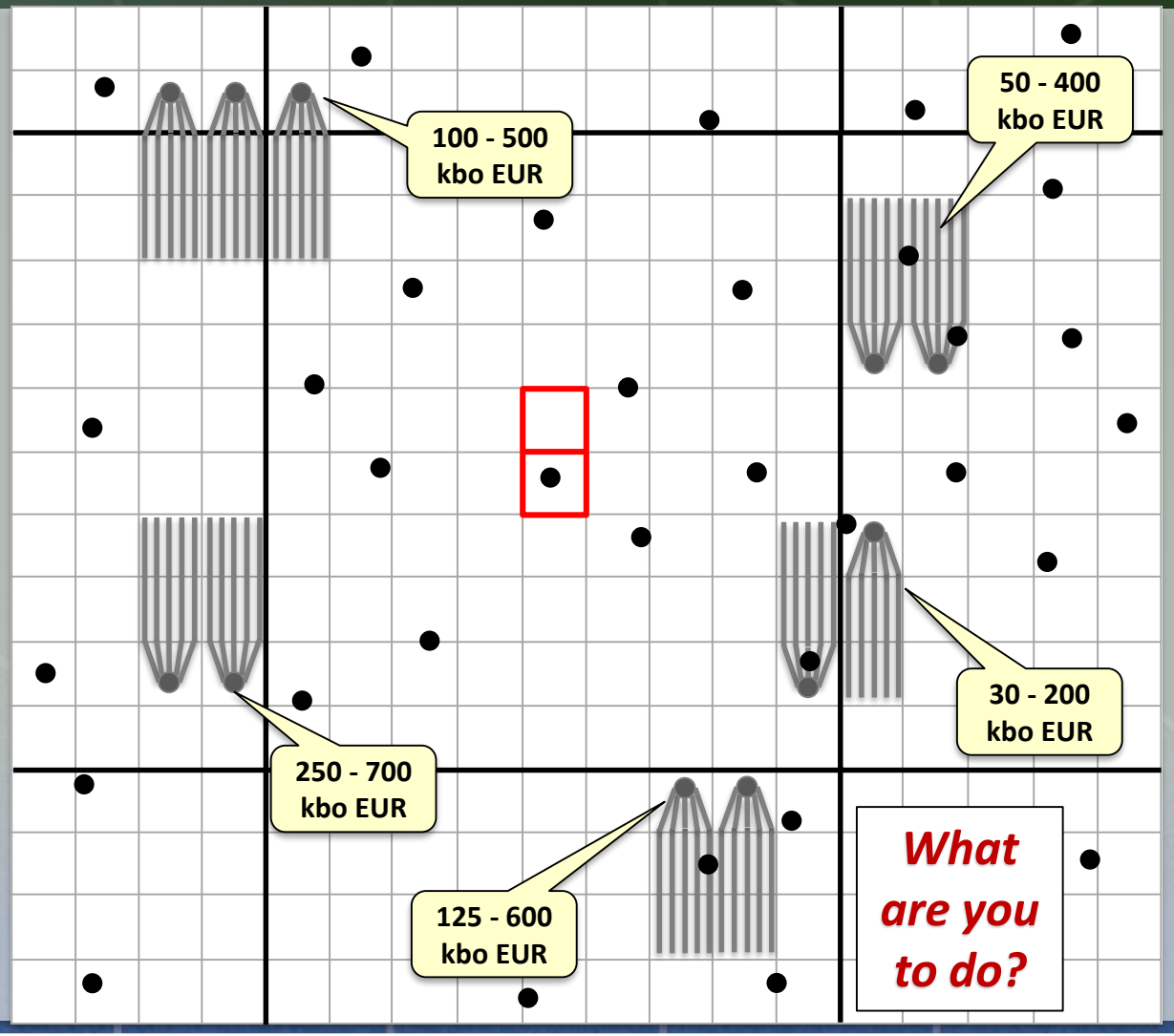




- Conventional Resources are contained in discreetly mappable & connected accumulations of distinct phases (Gas + Oil + Water).
- Continuous (Unconventional) Resources do not typically conform to trap configurations nor are distinct/connected phase boundaries apparent.

INTRODUCTION – THE HOOK

- You have an Unconventional Asset that is Undeveloped
- The nearest analogous horizontal producers are miles away
- Wide Range of Forecasted EURs from your analog producers
- You have access to vertical wells with Open Hole logs that penetrate your preferred targets
- Some of these vertical wells are near or even within your Undeveloped acreage



INTRODUCTION – OIL IN THE ROCK

- How can Geology contribute to resource evaluation for undeveloped Unconventional assets?
- Reservoir Delineation and Characterization from Well Logs
- Mapping Important Reservoir / Flow-Unit Tops
- Structural Analysis & Fault Framework Mapping
- Stratigraphic Frameworks / EOD Facies Maps
- Quantitative Reservoir Characterization from Petrophysical Analysis
- Resource Density (i.e., OOIP, OGIP, etc…)
- Deliverability (i.e., Geomechanics, Fracability)
- It all starts with solving for the Volumetric Equation!!!

VOLUMETRIC EQUATION

But does it work for Unconventionals?!?

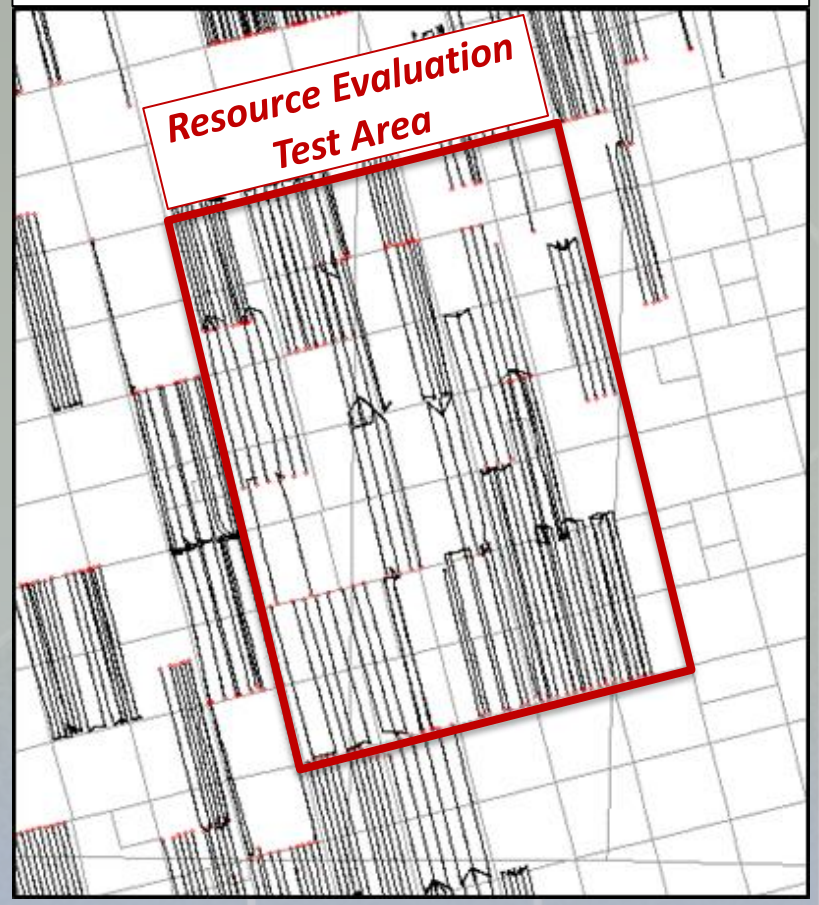
$$GRV \times N/G \times \Phi \times S_{hc} \times 1/FVF \times RF \times CF = EUR$$

The Volumetric Equation describes how the "estimated ultimate recoverable" (EUR) hydrocarbons in a subsurface opportunity is calculated. A numerical module is calculated from variables that characterize the geologic system.

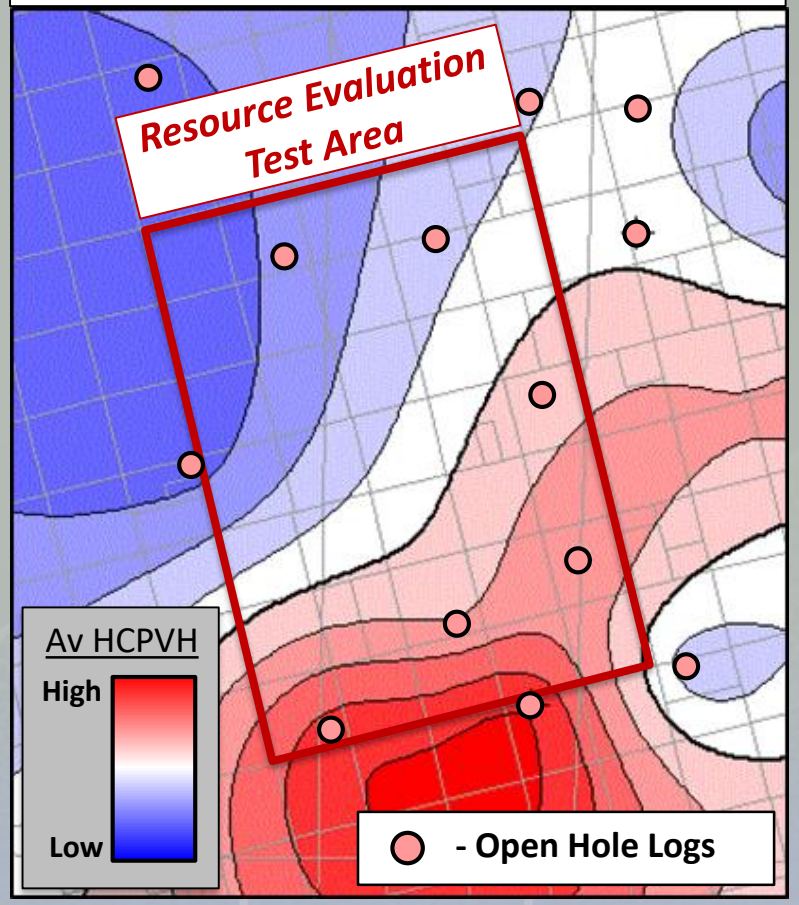
GRV	*Gross Rock Volume* → the volume of reservoir-bearing rock in the prospect.
N/G	*Net-to-Gross* ratio → the fraction of the GRV that is actual reservoir lithology.
Φ	*Porosity* (phi) → the fraction of reservoir lithology that is pore space.
S_{hc}	*Hydrocarbon Saturation* → the fraction of the pore spaces filled with hydrocarbons.
FVF	Inverse of *Formation Volume Factor* → relative volume of hydrocarbons at surface conditions versus reservoir conditions.
RF	*Recovery Factor* → fraction of reservoir hydrocarbons that can be produced to the surface.
CF	*Conversion Factor* → converts GRV units to hydrocarbon volume units.

PROOF OF CONCEPT

Horizontal Prod. Wells in Test Area



Map of HCPVH & Vertical Data Wells

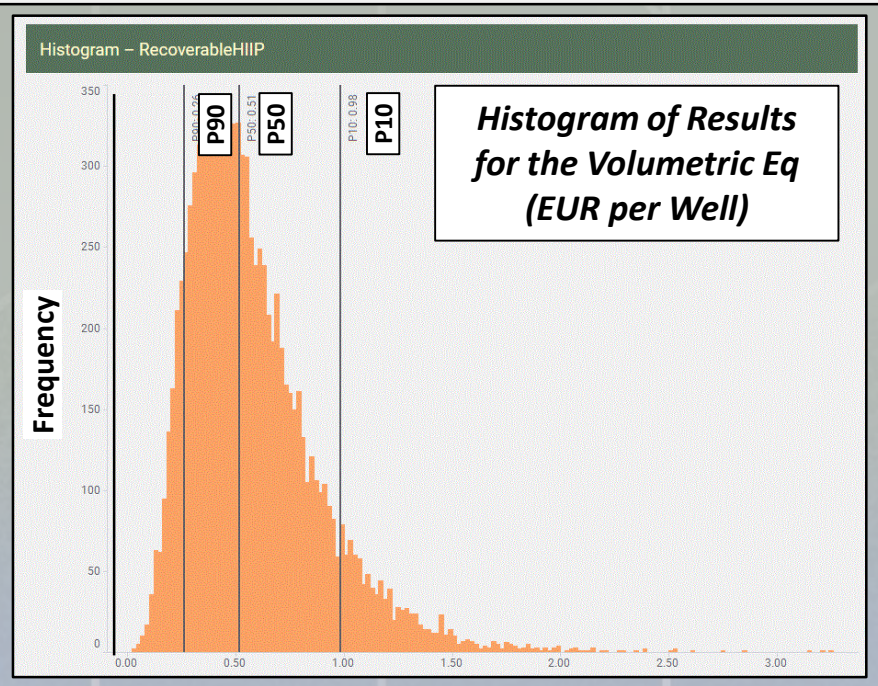


- To determine if the volumetric equation can be used for forecasting OIP & EUR in tight reservoirs, a study area was chosen with sufficient data to generate inputs to solve the equation for EUR, ***and*** with adequate production history as a blind test for modeled EURs.
  - 45+ production horizontals with 0 - >10 years of production data
  - 42 wells with open hole logs in the sub-region
  - 13 wells in or near the study area

PROOF OF CONCEPT: STOVOL ANALYSIS

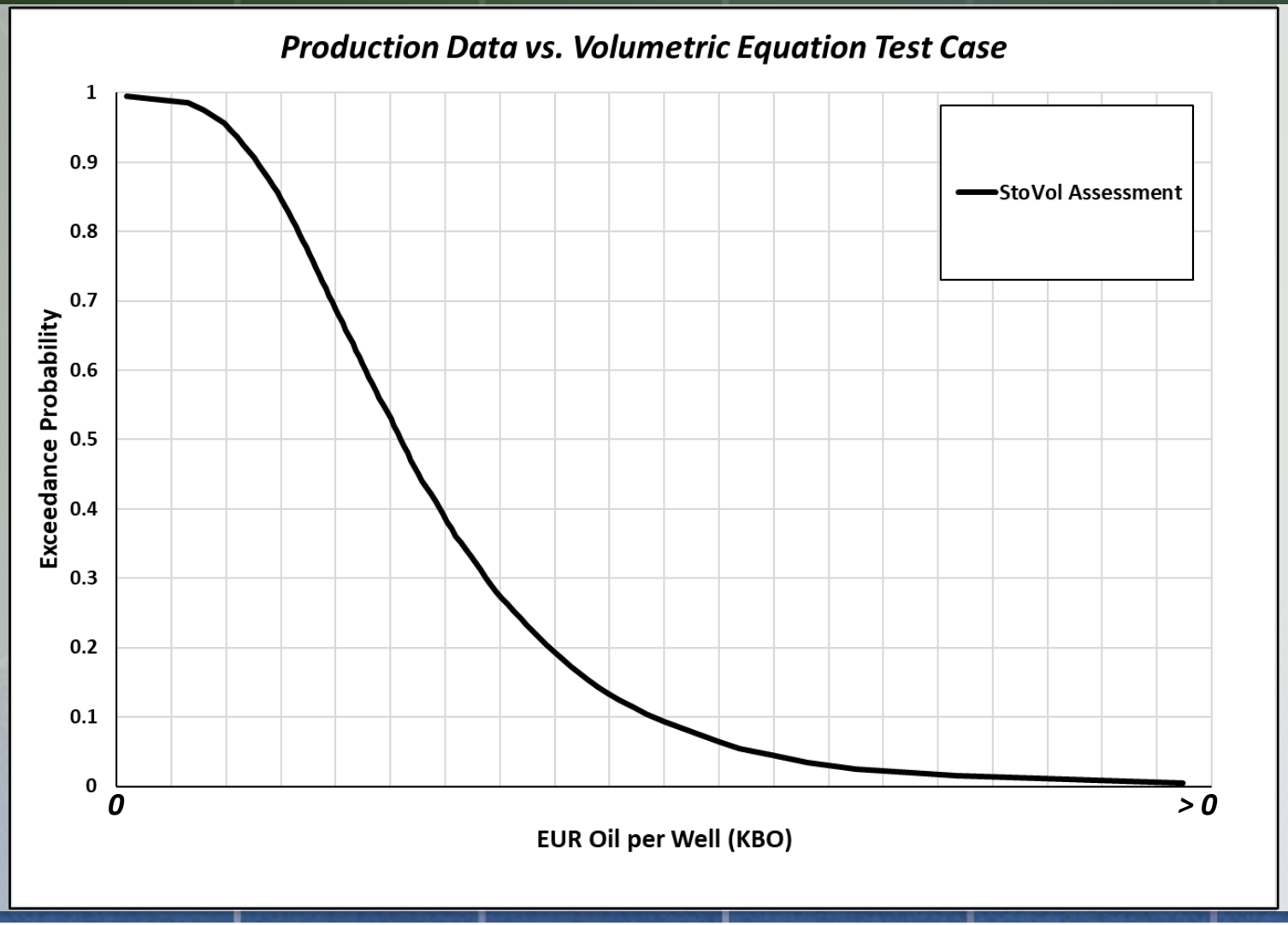
Volumetrics Calculation Input Table

variable	distribution	perc1	value1	pe...	value2	high truncation	low truncation	depend...
Area	LogNormal	P90	90.0000	P10	150.0000	299.6390	0.0000	NONE
Gross Thickness	Normal	P90	200.0000	P10	400.0000	670.9117	0.0000	Area
Net to Gross	Uniform	P90	90.0000	P10	100.0000	-9999.9900	0.0000	NONE
Porosity	Normal	P90	3.5000	P10	6.0000	9.3864	0.0000	NONE
HCsat	Normal	P90	60.0000	P10	90.0000	100.0000	0.0000	Porosity
Formation Volume Fac...	Normal	P90	1.0500	P10	1.3000	1.6386	0.0000	NONE
RecoveryFactor	LogNormal	P90	5.0000	P10	10.0000	25.5719	0.0000	NONE



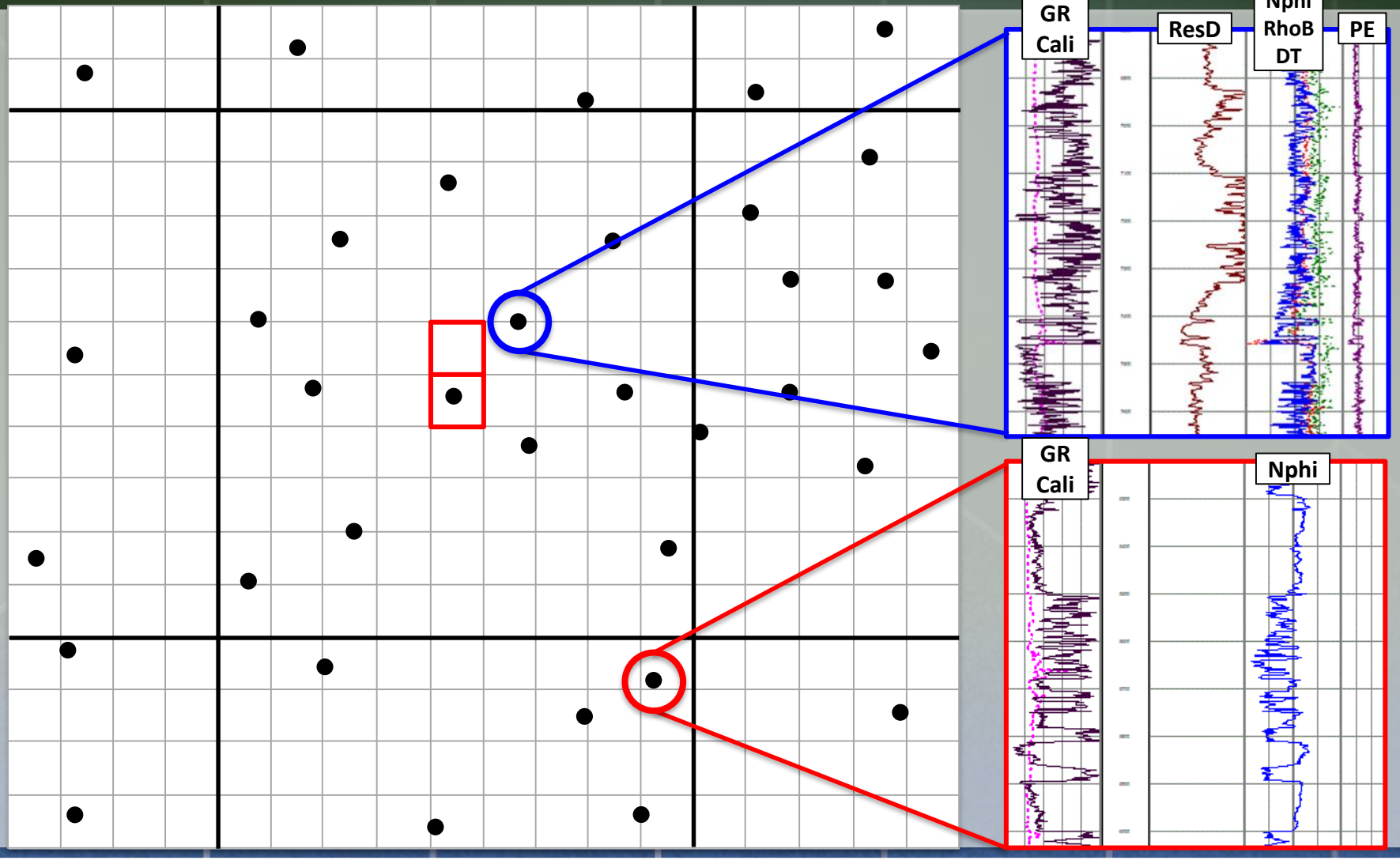
- Ranges for inputs to the Volumetric Equation were determined based on available data (i.e., open hole logs).
- Probabilistic model (EUR / Well) was created using Ryder Scott's in-house stochastic volumes simulator (STOVOL).
- The Probabilistic Model to be compared against actual EUR Production forecasts from Horizontal Producers.

PROOF OF CONCEPT: RESULTS



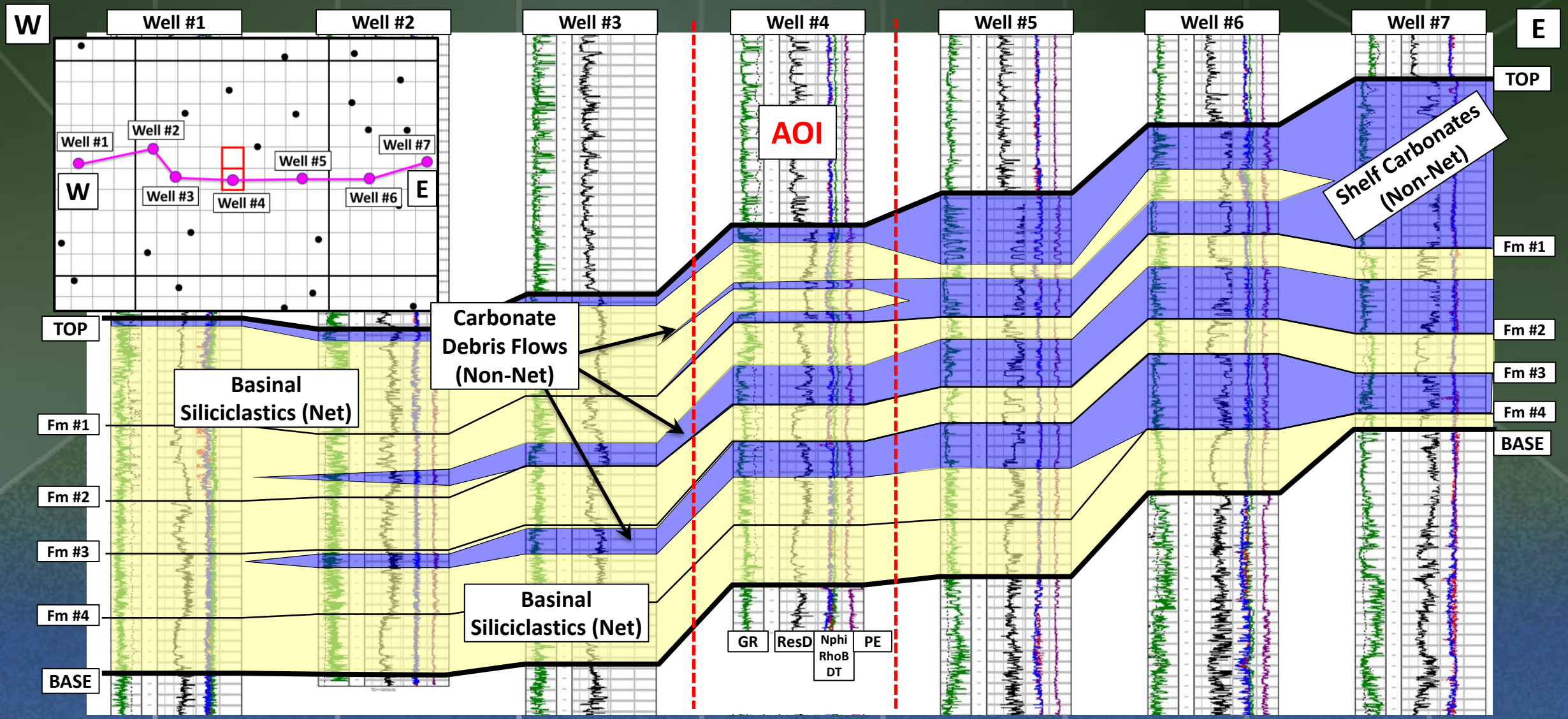
- Solid black line is the model curve of EUR per Well predicted for the Test Area using the Volumetric Equation in STOVOL.
- Red dots are Forecasted EUR Oil for horizontal producers.
- Solid Red line is best fit curve to the Forecasted Production EURs.
- Study indicates the Volumetric Equation can be used to evaluate subsurface hydrocarbons in Unconventional Plays.

HOW DO WE DO THIS: WELL DATA



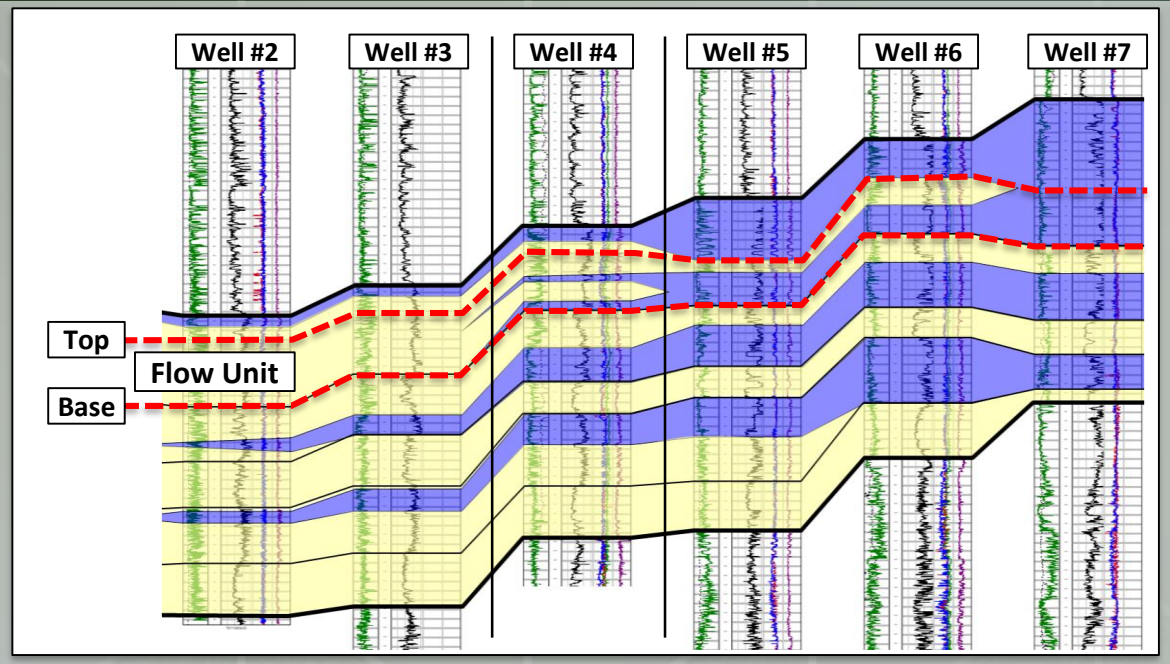
- What can well data get me?
- It depends on the quality, availability, and density of the wells logs.
- Quad Combo + PEF is ideal.
- Conventional Core is nice, too!

GEOLOGIC CROSS-SECTION

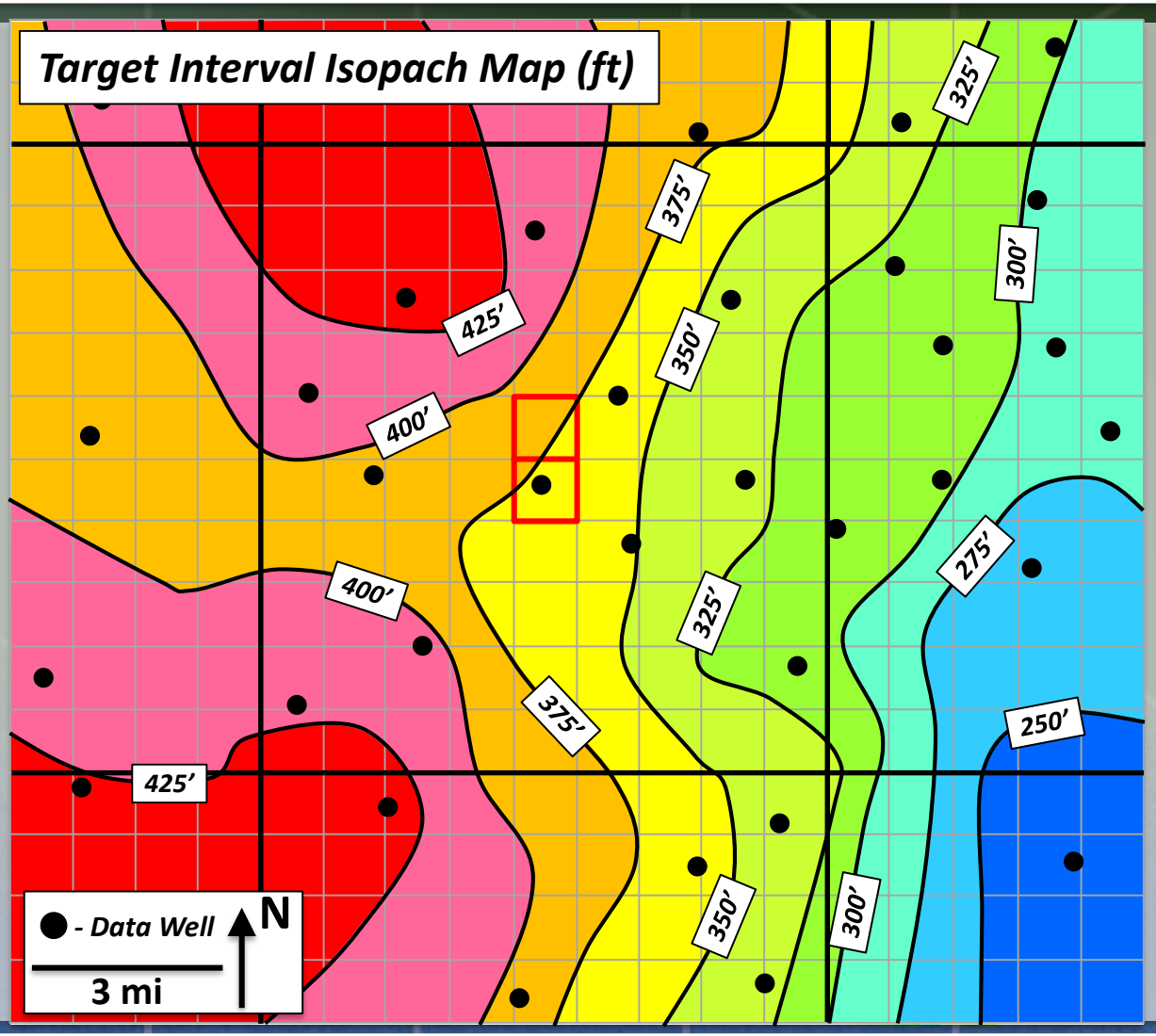


UNIT THICKNESS

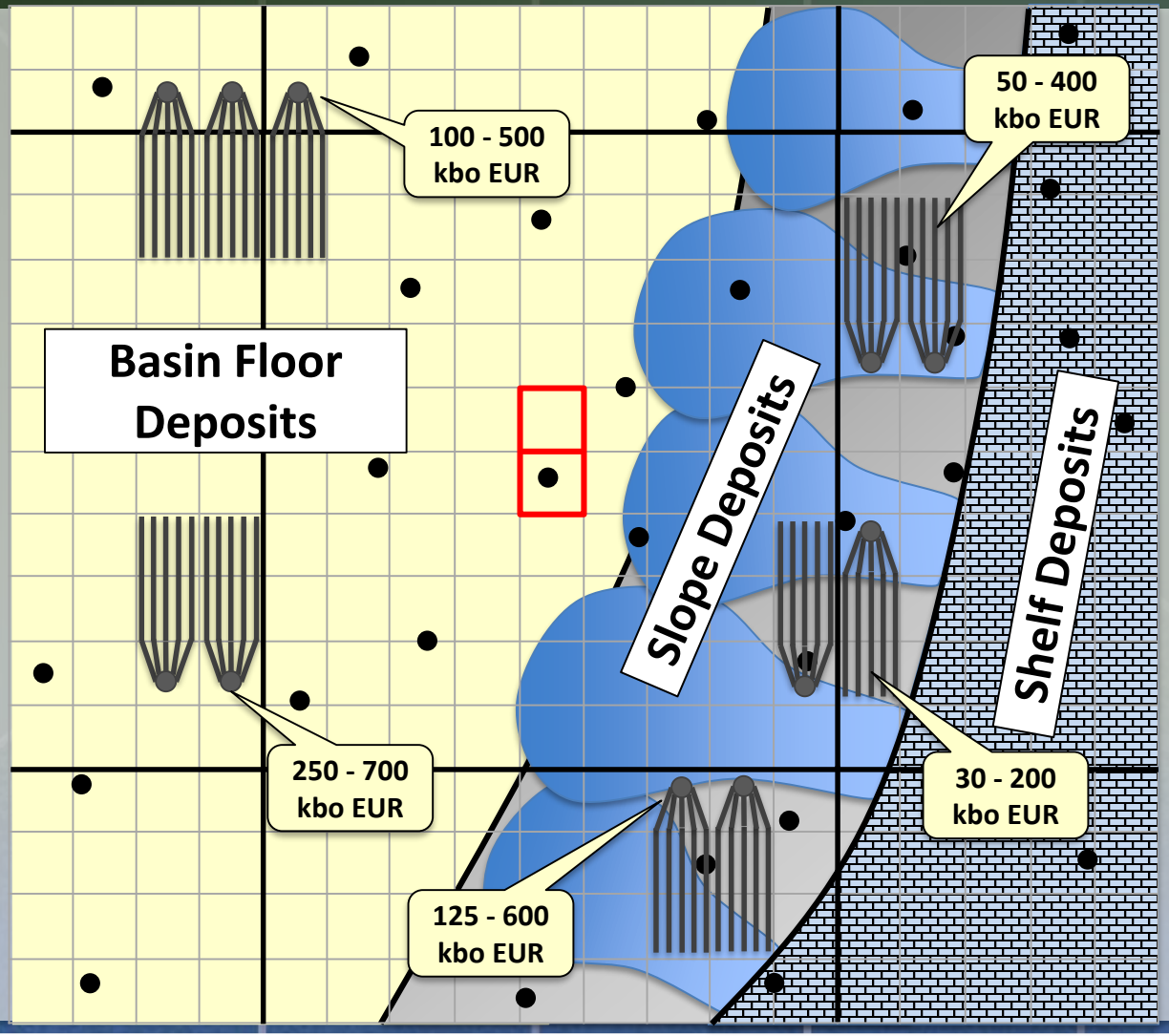
$$GRV \times N/G \times \Phi \times S_{hc} = HCPVH$$



- Depth structure and Isopach maps can be generated once target intervals have been delineated.
- These can be used to define important stratigraphic and structural boundaries.

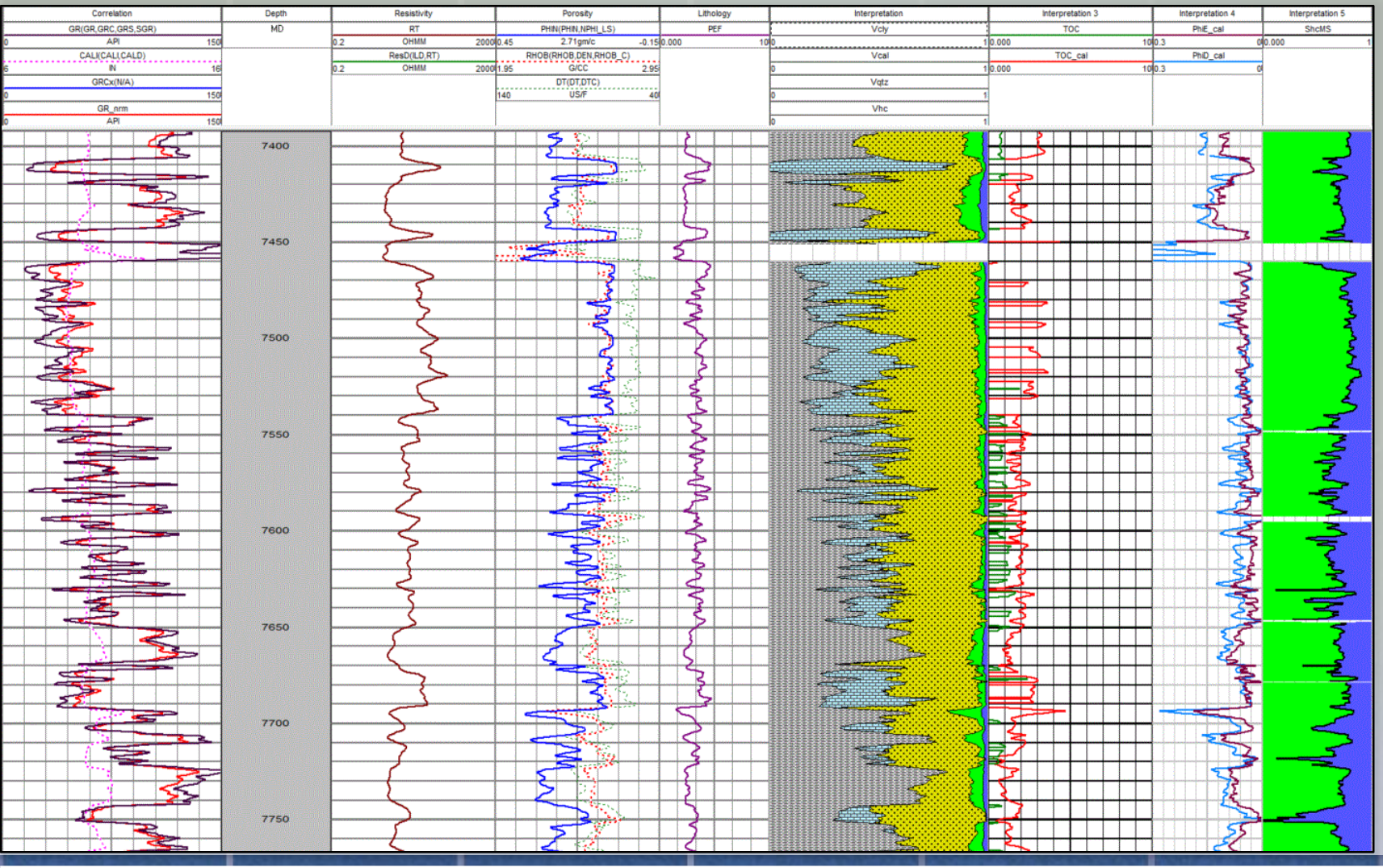


CONCEPTUAL MODEL: EOD MAP



- Base level geologic interpretation of available vertical well data should result in basic entry level products:
  - Depth Structure Maps
  - Thickness/Isopach Maps
  - Fault Frameworks
- Stratigraphic correlation of log facies can also lead to rudimentary predictive models (i.e., EOD maps)
- In all cases, models should be QC'ed against independent datasets to check validity.

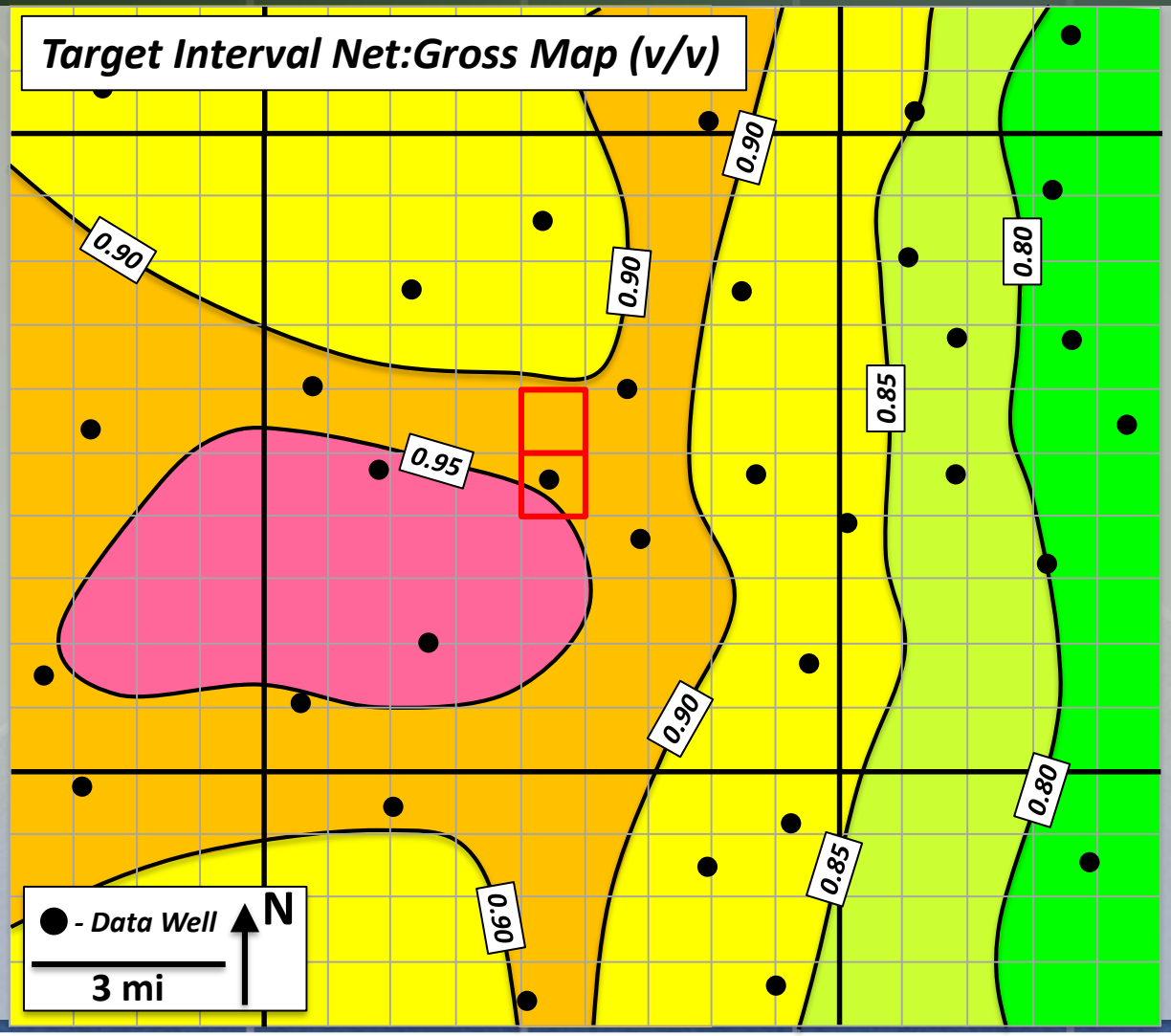
PETROPHYSICAL ANALYSIS



- Subsurface petrophysical workflow incorporates current methodologies to establish key reservoir characteristics for resource evaluation:
  - TOC Calculation
  - Lithology modeling
  - Density Porosity, Effective Porosity
  - Water Saturation
- Petrophysical workflow allows for flexibility with focus on fit-for-purpose results.

NET-TO-GROSS

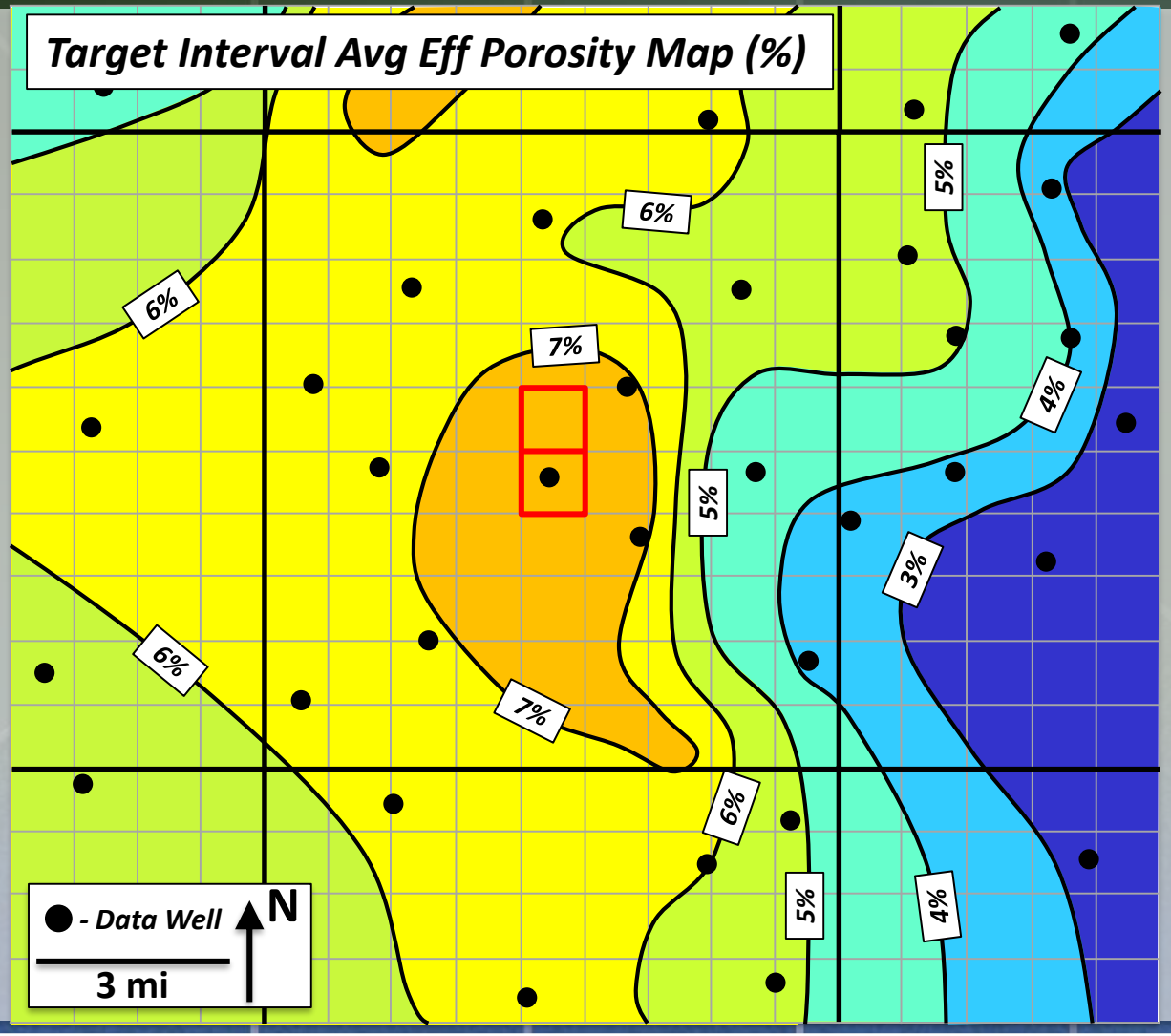
$$GRV \times N/G \times \Phi \times S_{hc} = HCPVH$$

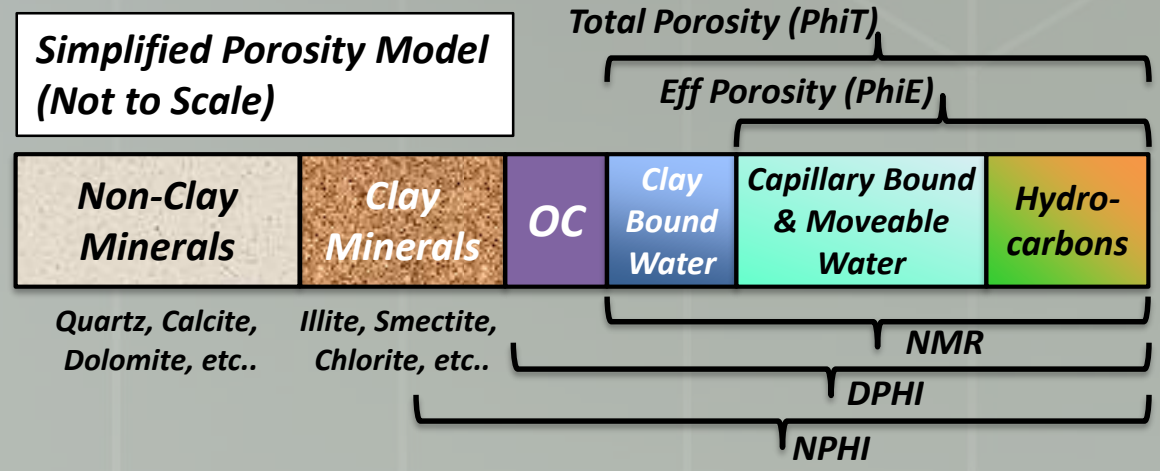


- Net-To-Gross is a legacy term from traditional “Conventional” Prospects and Plays.
  - In Unconventionals, N:G is a fairly trivial calculation as most of the target bench or flow unit is Net.
- Typically based on V-Shale and/or Porosity Cut-offs.
- Cut-Offs need to be correlated to meaningful data sets (i.e., Core Permeability, TOC, etc…).

POROSITY

$$GRV \times N/G \times \Phi \times S_{hc} = HCPVH$$

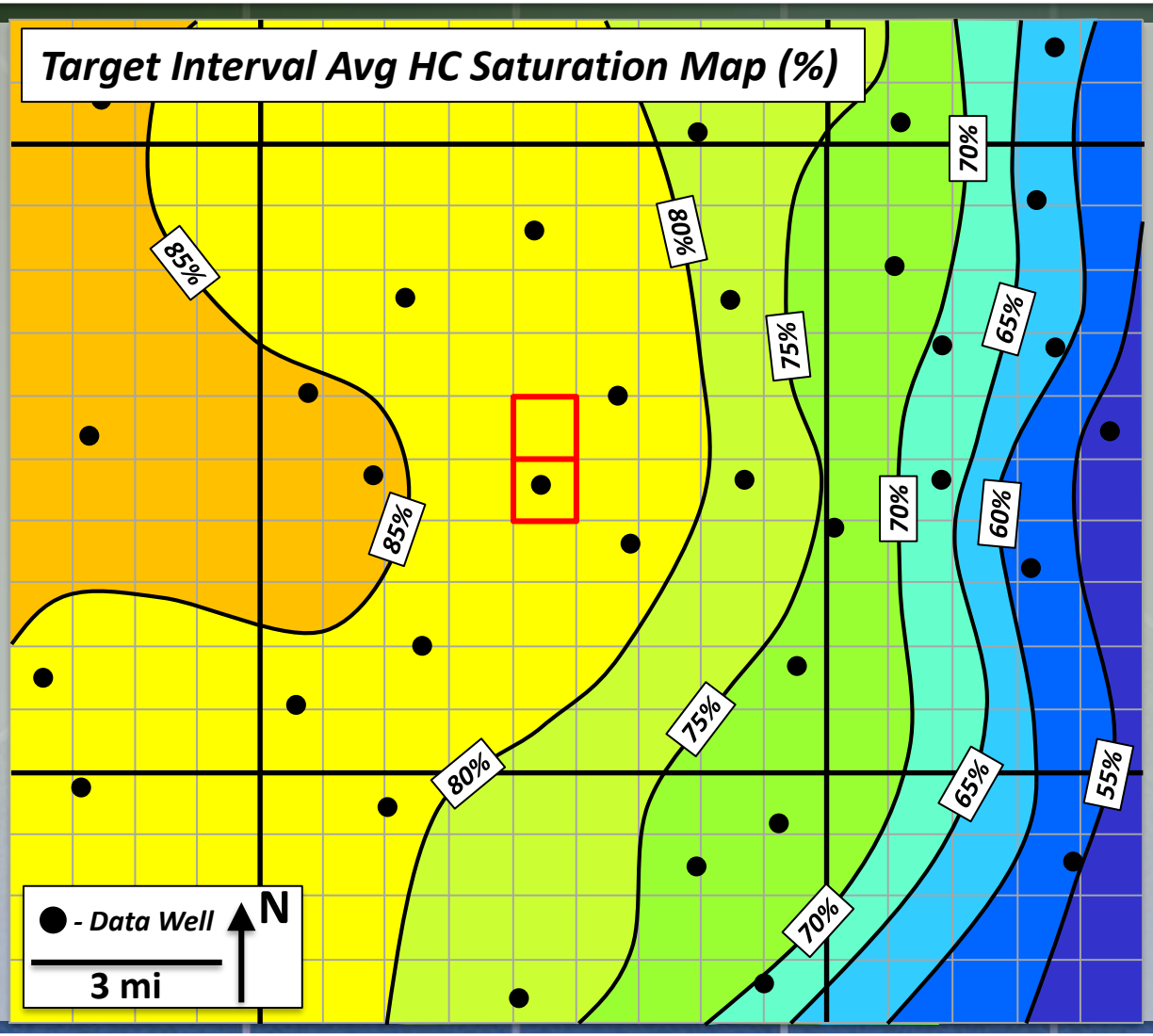




- Porosity is the single most important property of a reservoir to calculate.
  - Represents the Storage Capacity for a given target bench or Flow Unit
  - Many other calculations depend on Porosity
- Consistent use of Measured/Calculated Porosity in a geologic workflow is vital.

HC SATURATION

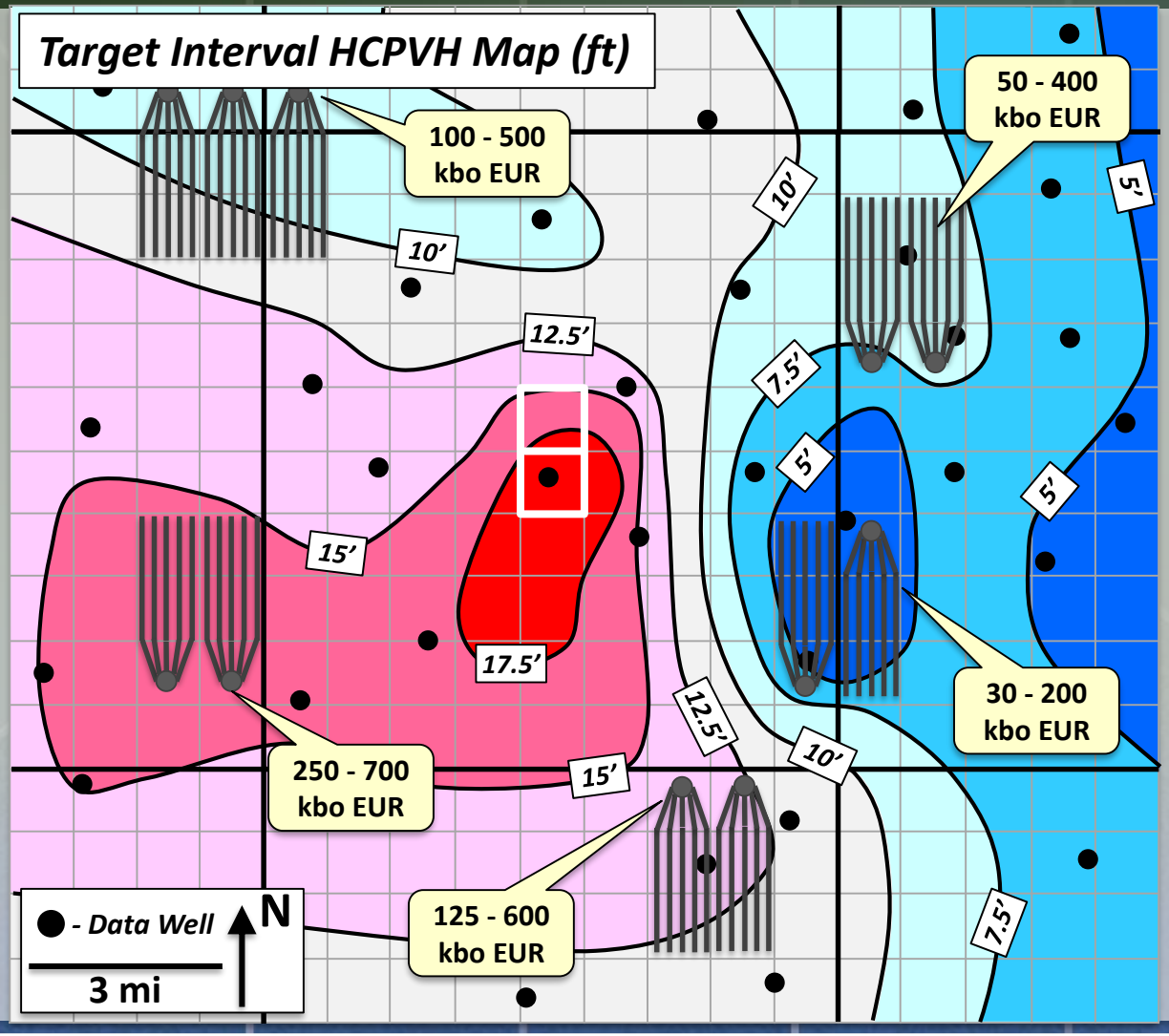
$$GRV \times N/G \times \Phi \times S_{hc} = HCPVH$$



- Once Porosity has been established via Electric Logs or Core, Water Saturation (S_w) can be calculated.
- Several options are available to the Geologist to accomplish this:
  - Modified Simandoux Model
  - Dual Water Model
  - Archie's Equation
- S_{hc} then equals $(1 - S_w)$.
- Calibration to core is recommended.
- Methodology accounts for Free Gas saturation, Absorbed Gas handled by Core Analysis or TOC correlation.

RESOURCE DENSITY

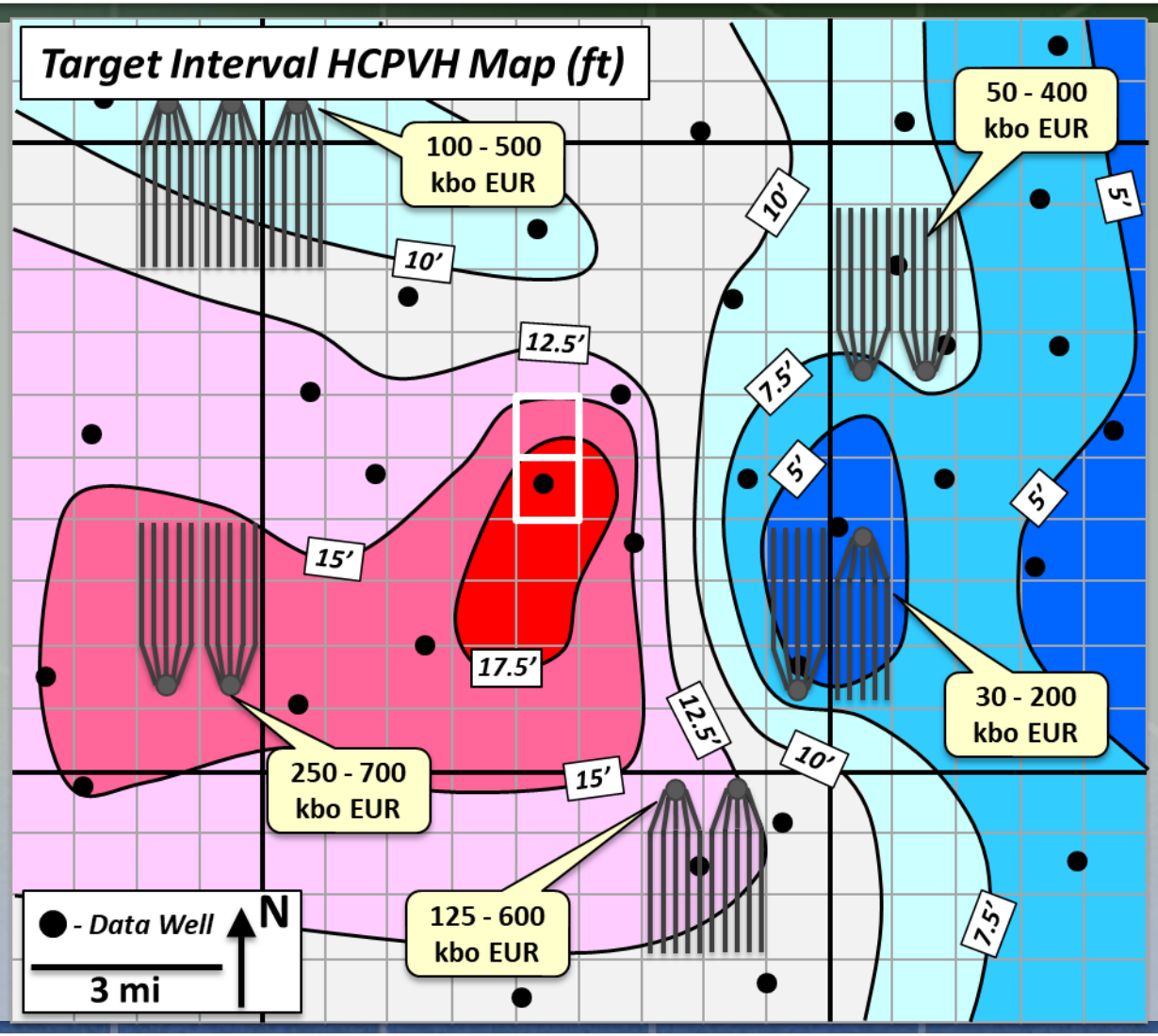
$$GRV \times N/G \times \Phi \times S_{hc} = HCPVH$$



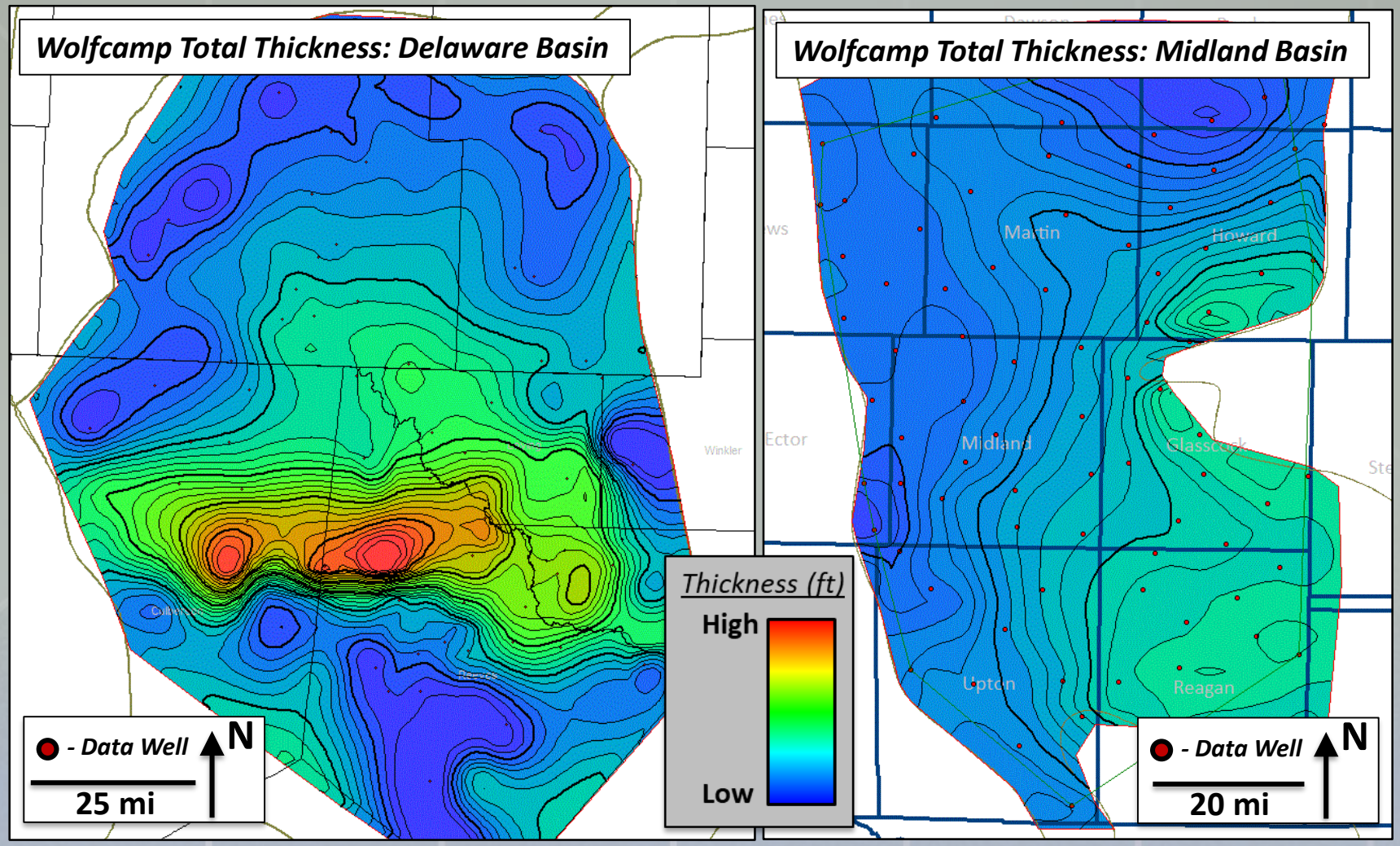
- Hydrocarbon Pore Volume Height (HCPVH) can be calculated from thickness, porosity, and saturation.
- HCPVH is a proxy for In-Place Resource Density (OOIP & OGIP can be calculated if a FVF is known).
- Maps of HCPVH can be used in various ways:
  - Establish *reasonable certainty* of a target resource's lateral continuity in the subsurface
  - Provide subsurface geologic confidence in the projection of Discovered Developed resources to Undeveloped Assets some distance away.
  - Selection of analog production areas when generating type-curves for Undeveloped assets.
- How does this HCPVH Map account for the variability of Production around the Undeveloped acreage?
- How would you classify the Undeveloped acreage in light of this new geologic information?

SUMMARY & CONCLUSIONS

- Geoscientific analysis is an import tool for the delineation and appraisal of subsurface hydrocarbons in Unconventional plays/assets.
- Classical methods for volumetric estimation (i.e., Volumetric Equation) apply to Unconventional Reservoirs.
- Quantitative Petrophysical modeling can lead to maps of Porosity, Saturation, and Resource Density over a section or field.



RSC PERMIAN BASIN PROJECT



- RSC Geoscience team has created a subsurface geologic framework for Midland and Delaware Basins in support of the SLU Rating System.
- This effort covers 18+ counties in west TX & southeast NM, and incorporates tops from ~3000 data wells.
- Products from the geologic framework will feed directly into the SLU Resource Evaluation workflow.

QUESTIONS