Deriving Pseudo-Capillary Pressure Curves From Standard Core Analysis Data in Heavy Oil Reservoirs and Their Use in Estimation of Original Sw

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The Problem: Original Sw in Old Fields

- Many older oilfields have been in production for 50-100 years, or even more
- It usually becomes necessary to estimate OOIP at some point during the life of the field, property, or project
- But how?
  - In some fields, production started before the introduction of wireline logs
  - Old core data may not be reliable or abundant enough on its own to estimate reservoir properties
  - Available logs represent the reservoir at some point of partial depletion
  - How can we look back with existing data to original saturation conditions?

Capillary Pressure!

Petrophysical Preparation for Capillary Pressure Sw

- Existing field data is usually suitable for a petrophysical field study
  - Wells with porosity logs are analyzed normally
  - A cap-pressure Sw model can be applied to old e-log wells with some special handling
  - A permeability curve is needed and can be derived from several log indicators
  - PKS data from whole core is necessary for the psuedo-Cp from core method

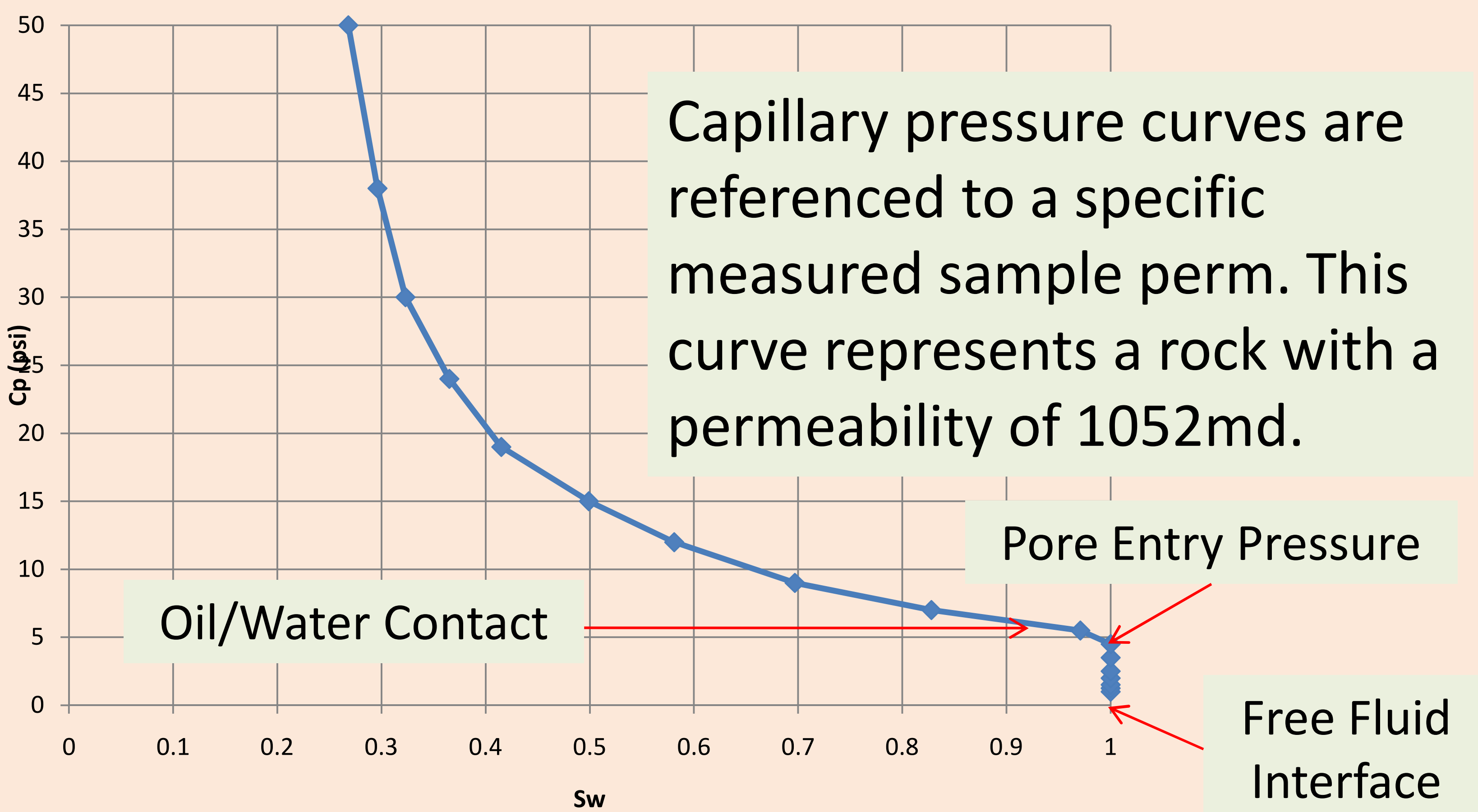
Geological Inputs

- Oil/water contacts are necessary
- These contacts must be assigned by zone and by fault block, if they are different, so reservoir structure and stratigraphy must be known

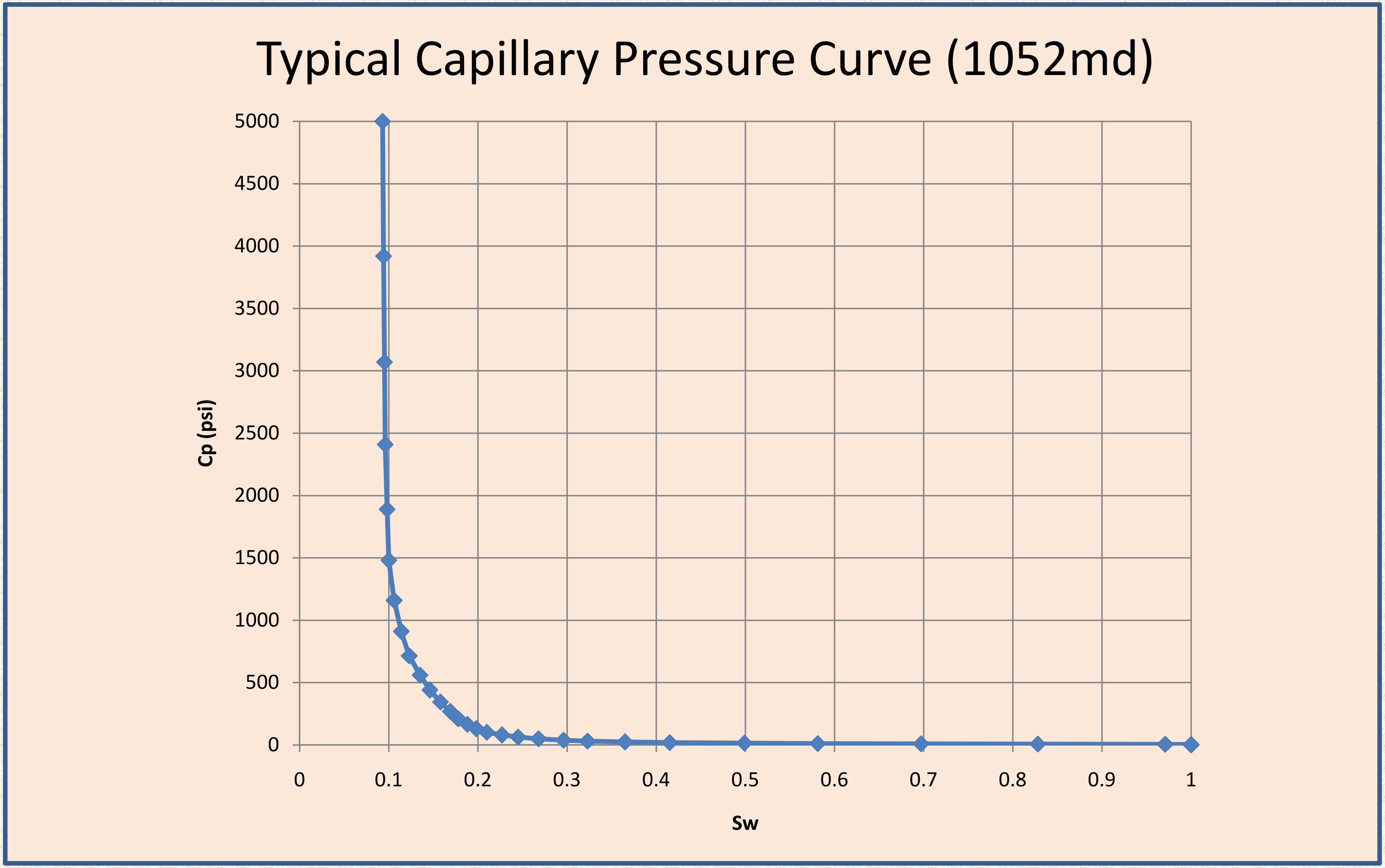
How Does Oil Move Into a Reservoir?

- As oil migrates into the reservoir, it initially enters only the largest pores with the lowest entry pressure
- With continued migration:
  - The height of the oil column increases
  - Capillary pressure of the oil phase also increases with height, allowing oil to enter ever-smaller pores
  - Eventually an oil/water contact is formed, which is always above the Free Fluid Interface because some positive Cp is required to force oil into the pore system
  - In practice, we use the OWC as the FFI most of the time

Low-Pressure Portion of Capillary Pressure Curve



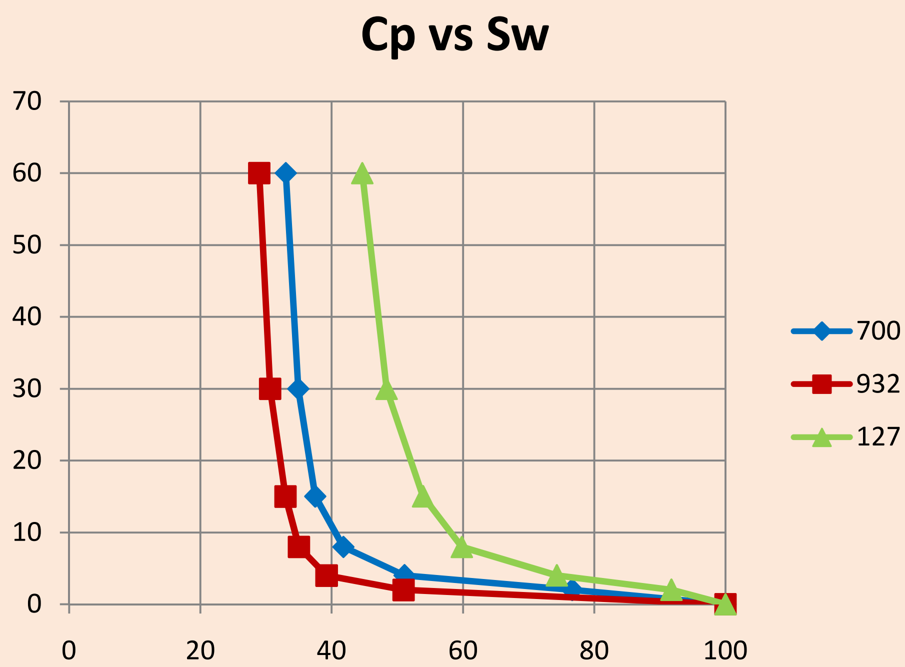
After reaching pore entry pressure, oil enters the system and begins to displace water (Sw decreases). The process is initially rapid, then as pressure continues to increase less and less water is displaced.



Above a certain pressure, very little additional water is displaced and the curve become asymptotic. The minimum Sw reached is equivalent to the irreducible Sw at that permeability.

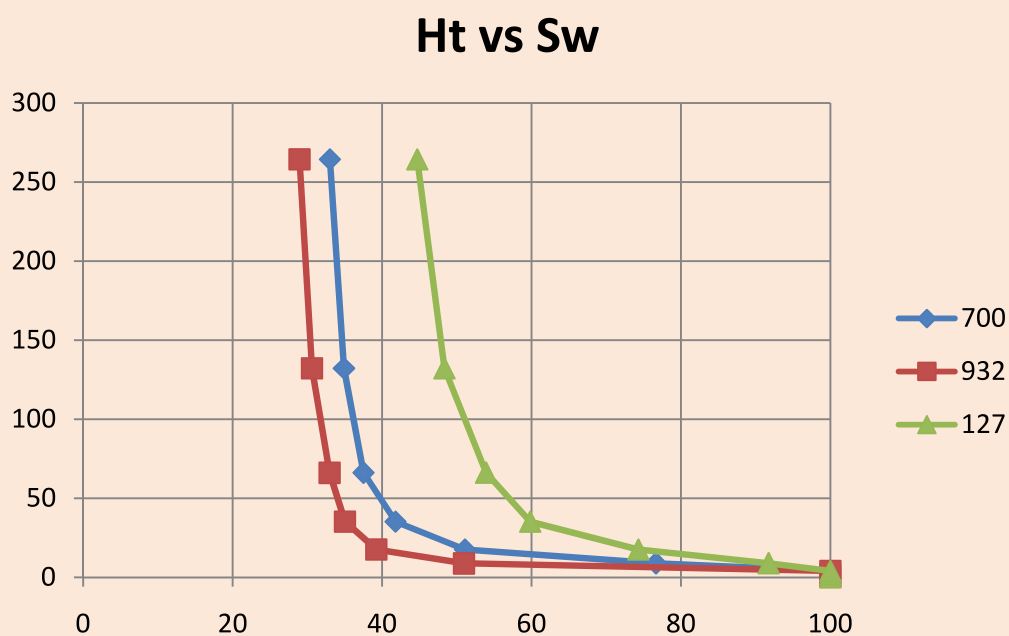
Cp Conversion to Height

- Capillary pressure measurements can be converted to height above the Free Fluid Interface (FFL) based on the properties of the oil
- In practical terms, this means that we have a way of relating the height above the oil/water contact, the rock permeability, and the original Sw
  - We can assign height and permeability to each depth level in a well from reservoir knowledge (elevation of the OWC) and log transforms for permeability
  - Knowing the Sw from capillary pressure for these parameters, we can construct a saturation curve for each well



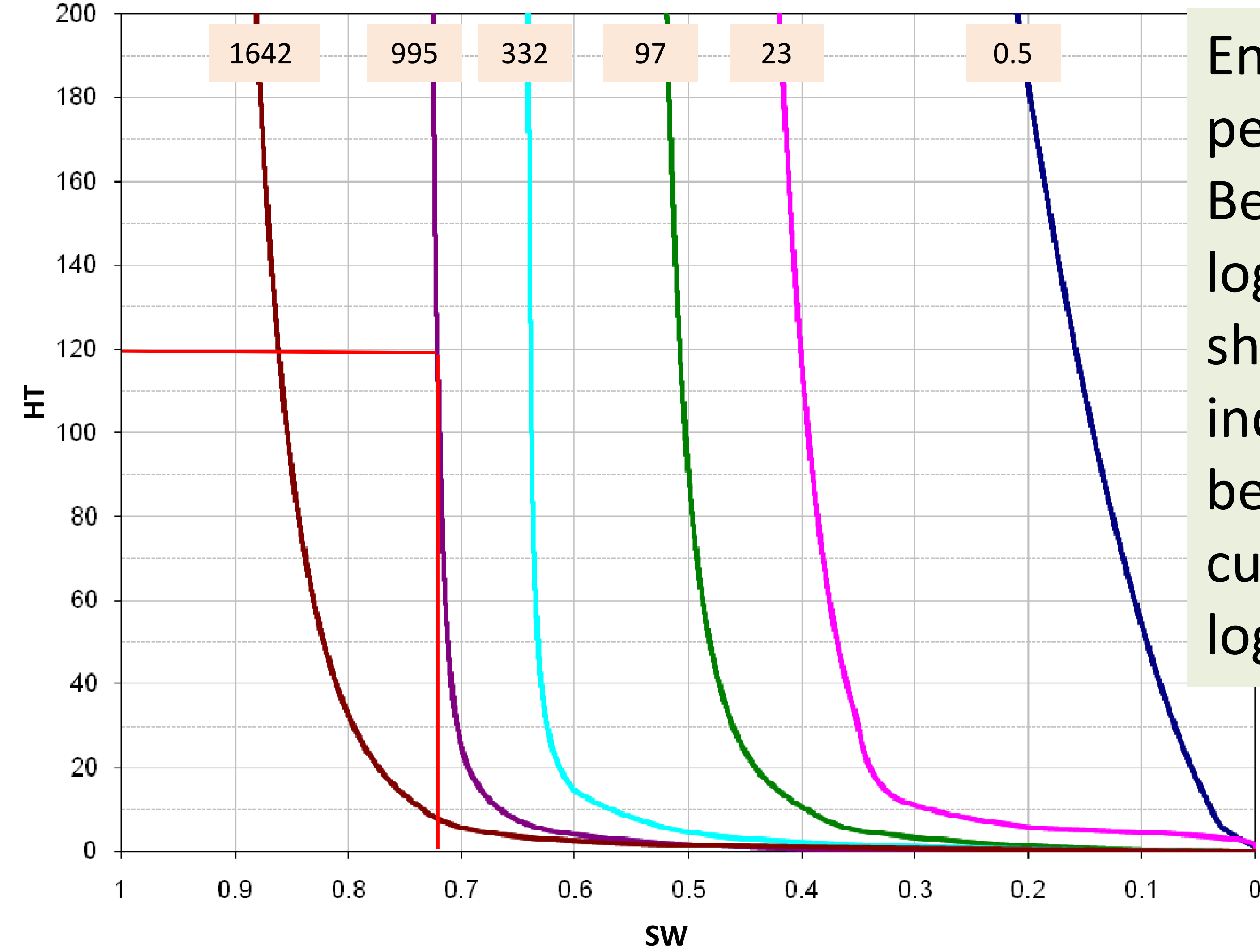
For a sample reservoir, three capillary pressure curves at their reference permeabilities are shown, in terms of Cp vs Sw.

The same curves are shown after a conversion to height using parameters appropriate for the reservoir.



Capillary pressure curves have a characteristic shape as shown above. They also have a characteristic ordering, in which higher permeability samples have a lower Swirr than lower permeability samples. The entry pressure (and therefore entry height) is also higher for low-perm rocks.

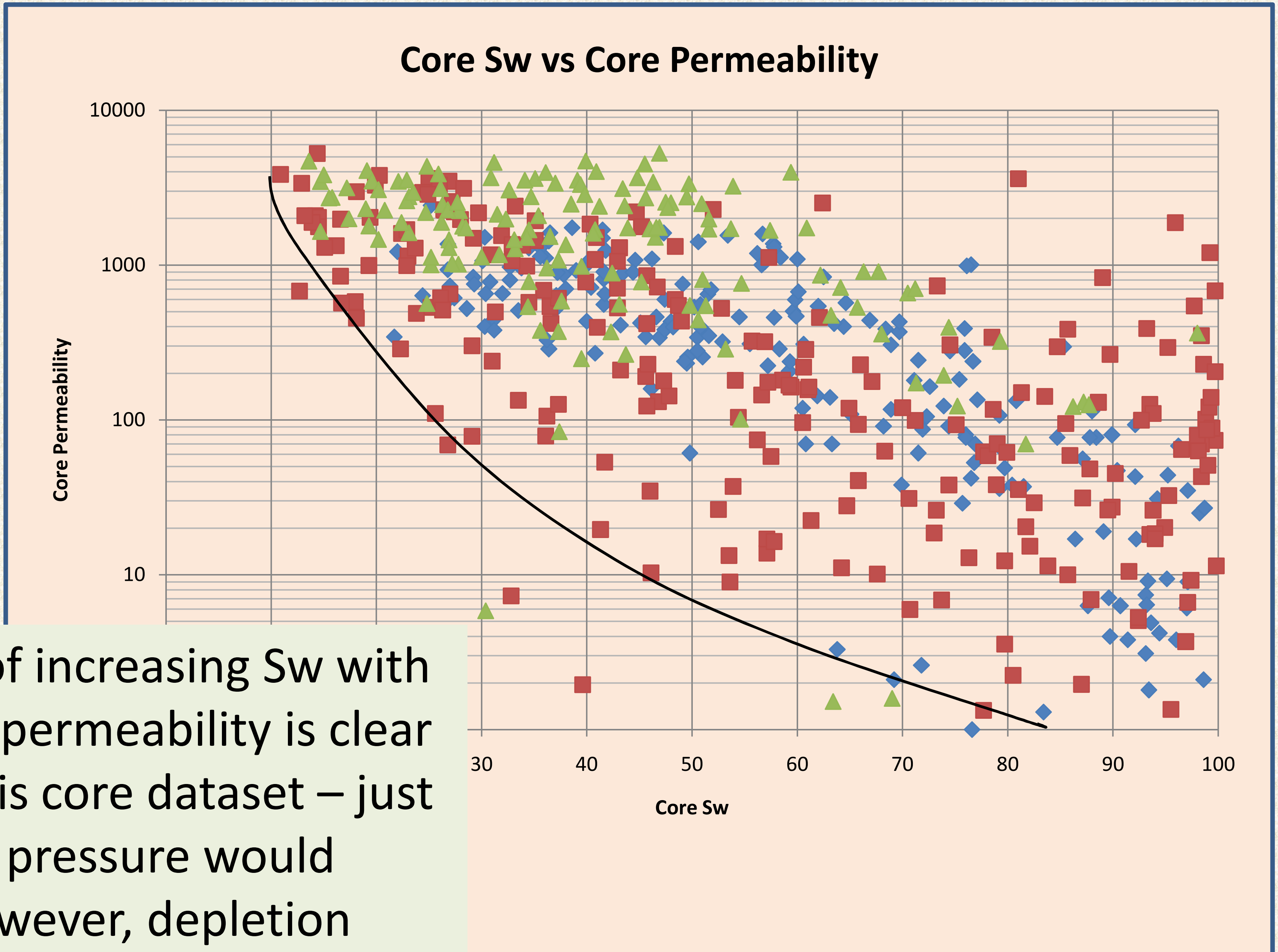
How to Read Sw From Example Set of Capillary Pressure Curves With Permeability References



Enter with Ht 120' at perm 995, Sw = 72%. Because perm has a logarithmic relationship to other indicators, interpolation between permeability curves is not linear but logarithmic.

What If You Don't Have Capillary Pressure Measurements But You Have Heavy Oil?

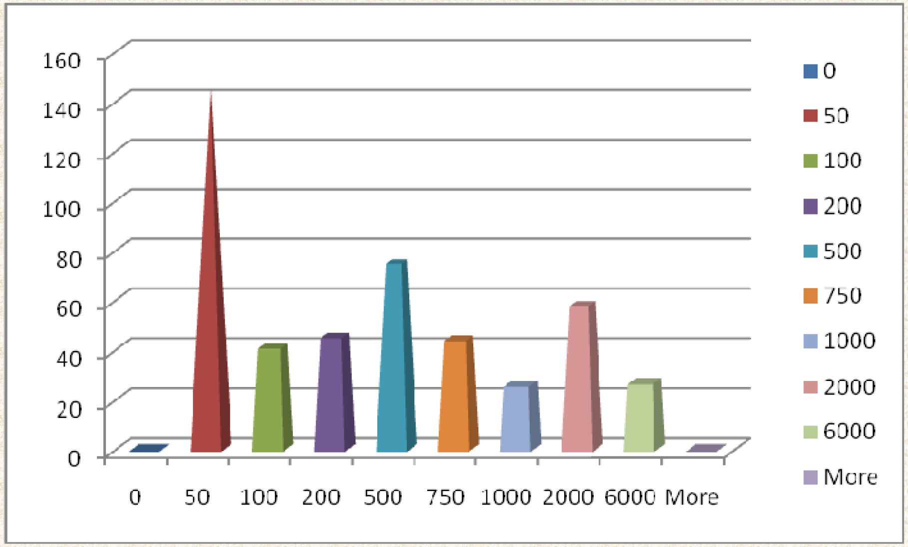
- In many reservoirs, no (or very few) capillary pressure measurements were ever done, and there is no (or insufficient) stored core to make measurements
  - If capillary pressure measurements exist, they do not cover the full range of permeability in the reservoir
  - The existing measurements are not good (for example, the samples broke during testing)
- But you have a lot of PKS data!
  - Heavy oil generally has low mobility and loss of oil from the core is reduced
  - PKS data includes an abundance of permeability/Sw measurements from various heights in the reservoir

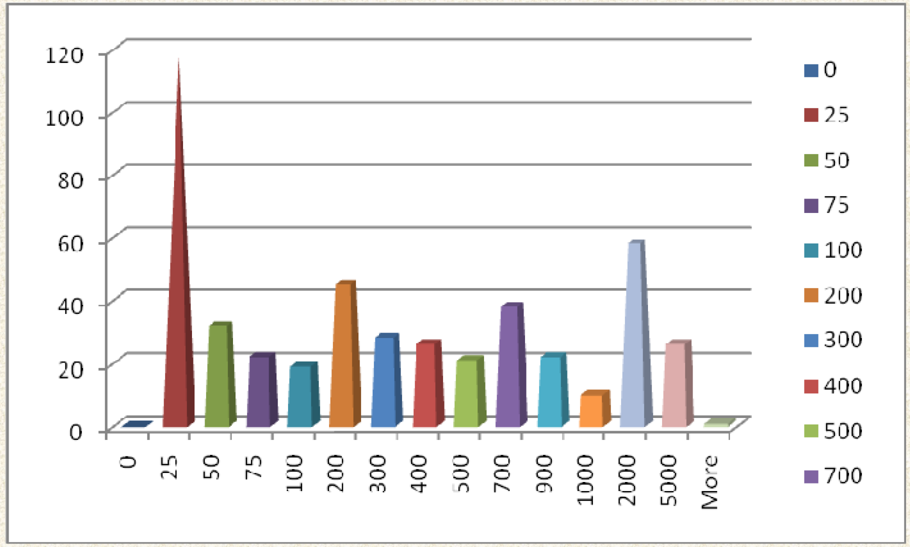


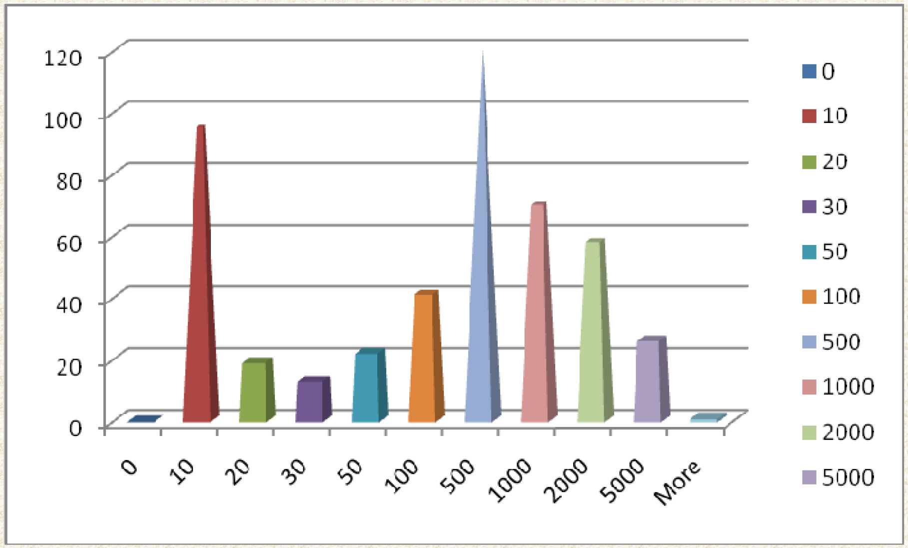
The trend of increasing Sw with decreasing permeability is clear to see in this core dataset – just as capillary pressure would predict. However, depletion trends are also obvious in the data spread from left to right.

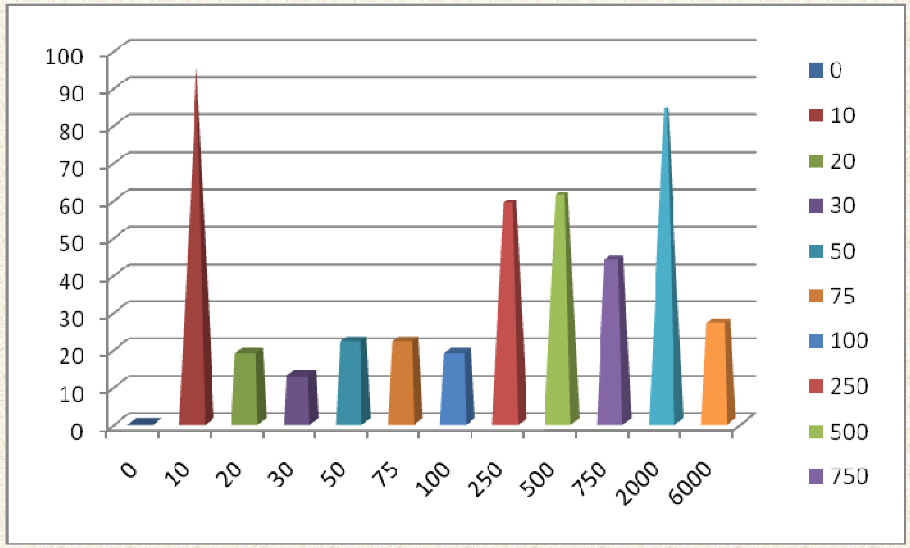
Pseudo-Cp Methodology From Core

- First, assign height (in subsea) above the FFI (OWC) to each core sample. It may be necessary to group them by zone and apply the appropriate OWC for the zone
- Then bin them by permeability group. This is a trial-and-error process; try a number of binning strategies to determine the data range and best grouping for the dataset

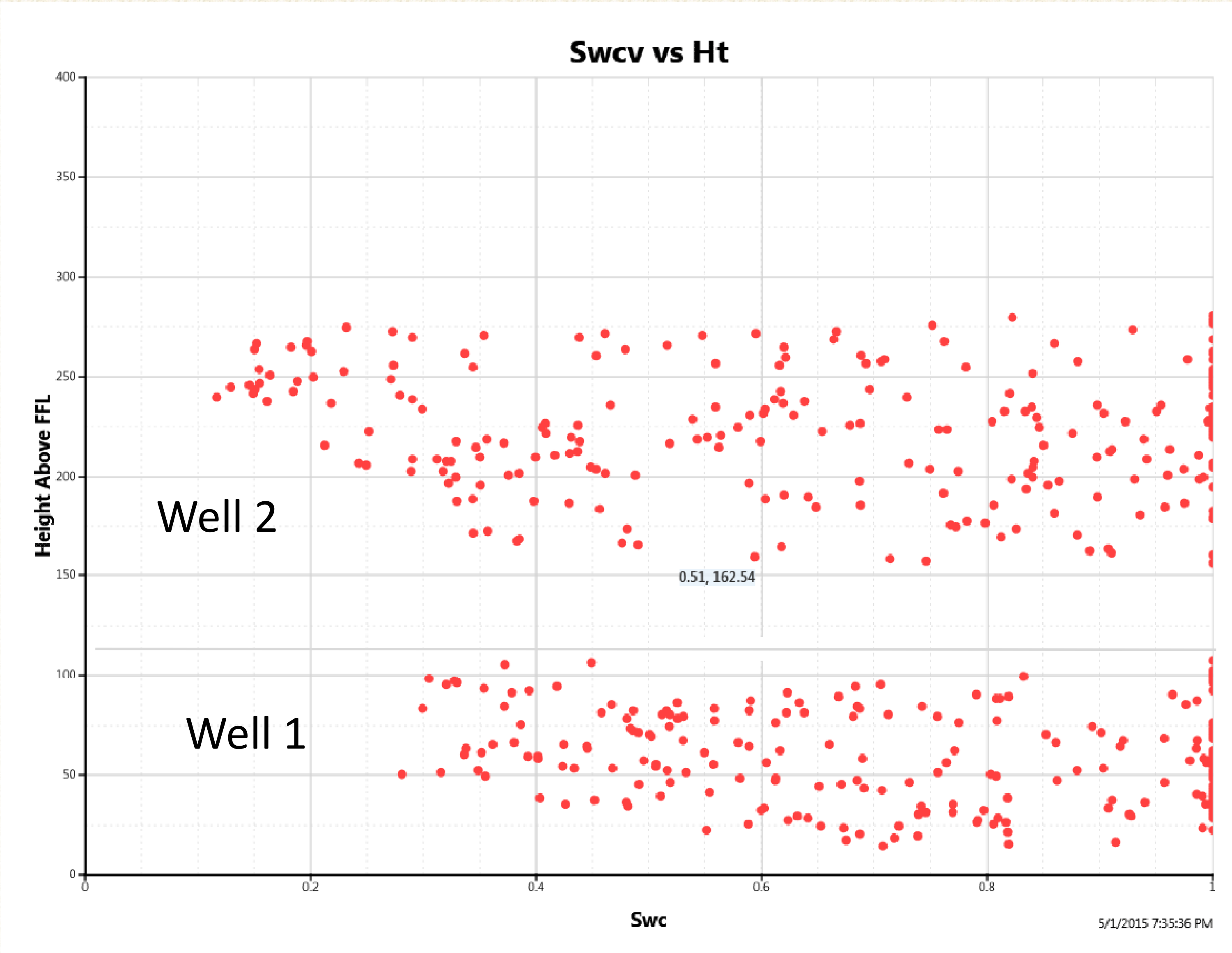








Divide the core data into various permeability bins to see what the distribution is. This dataset is dominated by low and high values, with a moderate distribution in the 250-750 range. These ranges will determine the groupings on which the psuedo-Cp curves are based.

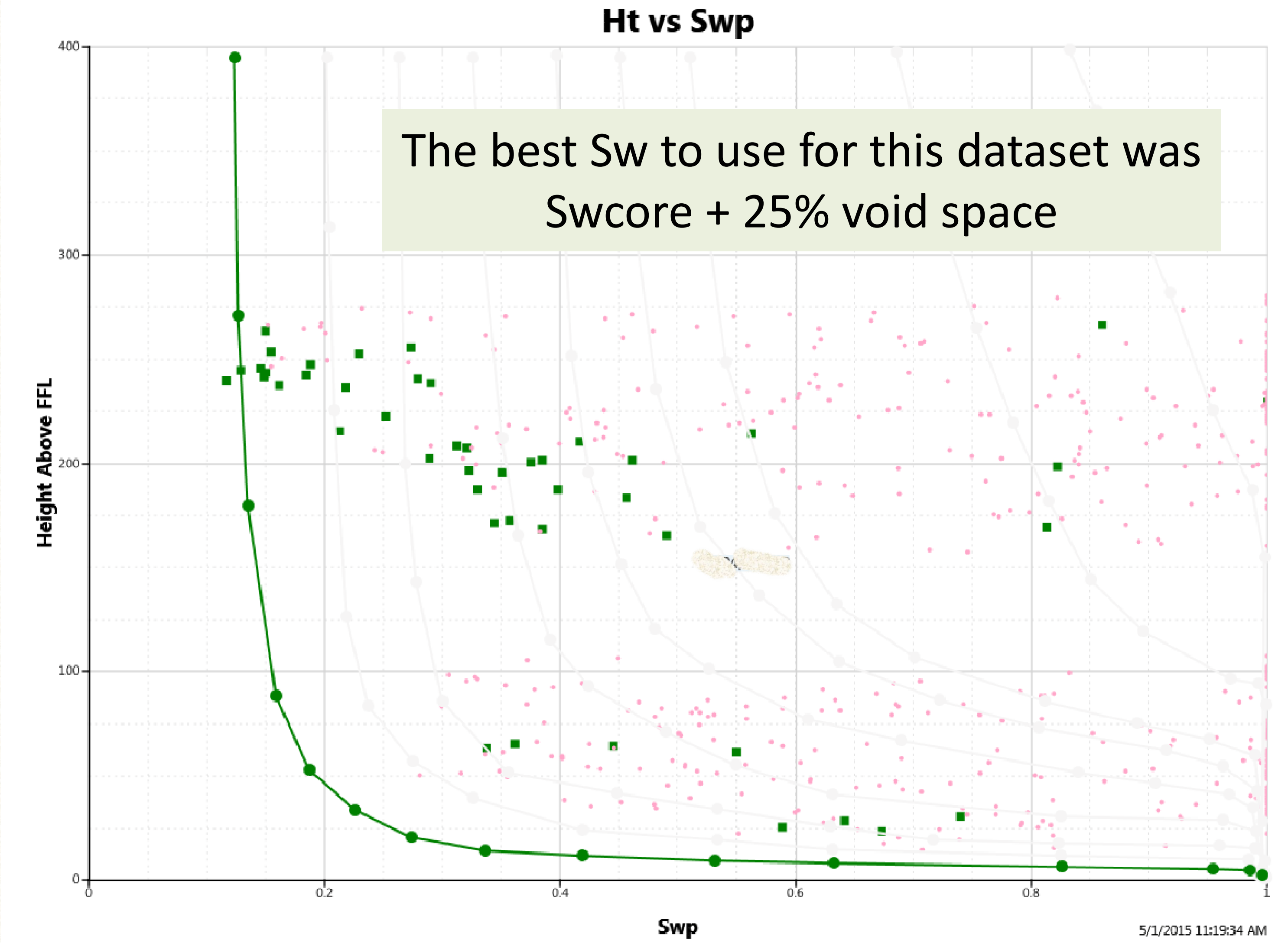


This is a core dataset with two wells at different heights above the oil/water contact. The data suggest that Well 1 is not as high on the capillary pressure curve as Well 2.

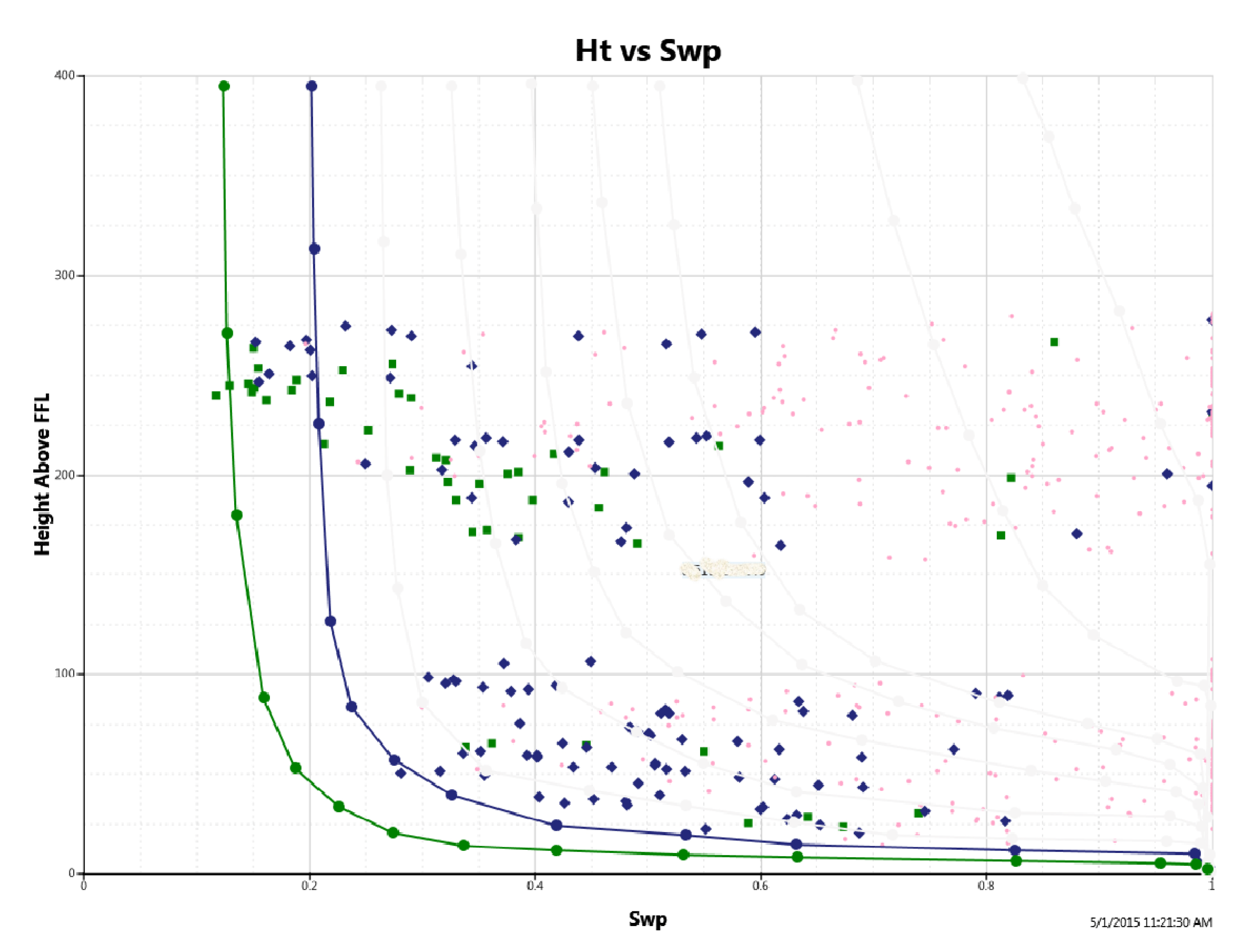
In general, the higher permeability samples have lower Sw and low-permeability samples have higher Sw. The spread of high-permeability data from left to right shows the effects of partial depletion in the reservoir. Some of the very low permeability samples (orange) have anomalously low Sw; they likely represent damaged samples or inaccurate data.

Select the Saturation Values

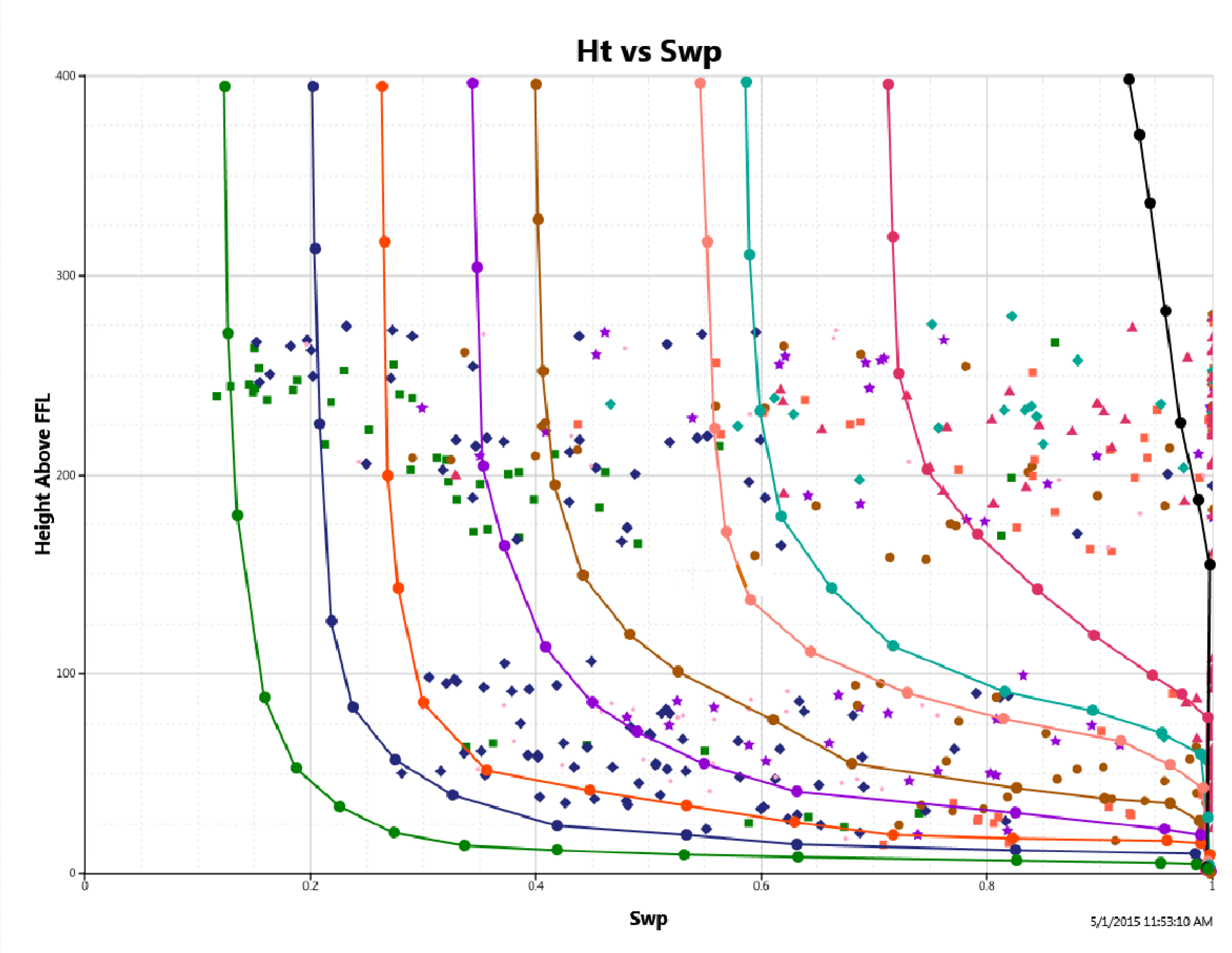
- Core saturation values often total <100%
  - Samples may be measured at pressures lower than net reservoir stress, so are expanded
  - A small amount of gas may have pushed some mobile fluid (often water) out of the core
  - The rock may have failed, disrupting the original texture
- If void space is large and present in most samples, the results of the pseudo-Cp process are often more consistent if a portion of the void space is added back to the Sw
  - It may be necessary to iterate on the %void space combined with the core Sw to achieve the best results



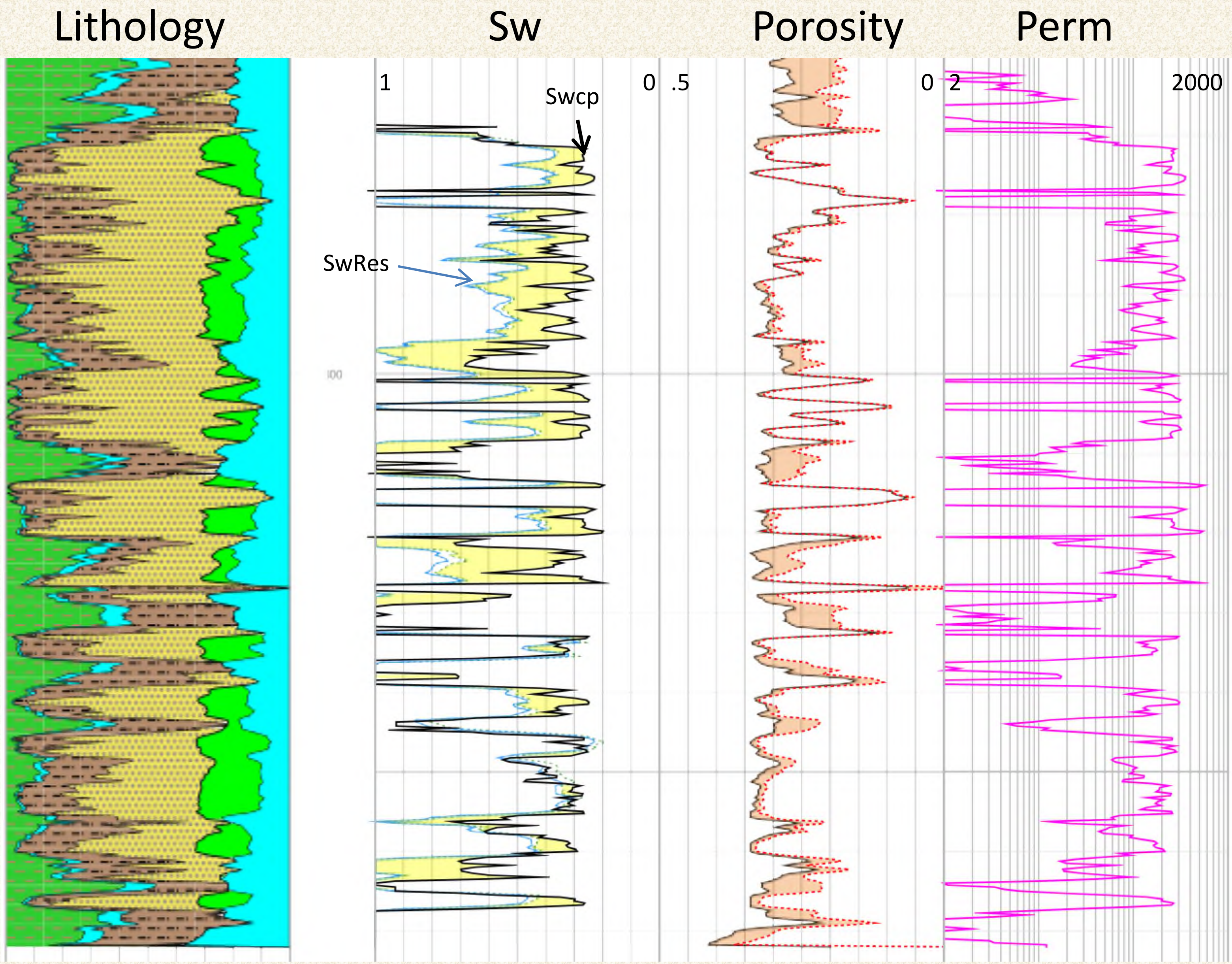
When the correct Sw and the most representative permeability ranges have been chosen from the data, highlight them on the Sw vs Ht plot. Green dots are data with k>1500, and a curve is fitted to the high end of the distribution. The curve represents 5000 md permeability and is intended to bound the model at the high end.



Data between 500-1500 md (blue) area added, with fitted curve = 1500md. A few low-Sw points are ignored. Sample failure and other analytical problems can be common in unconsolidated sands.



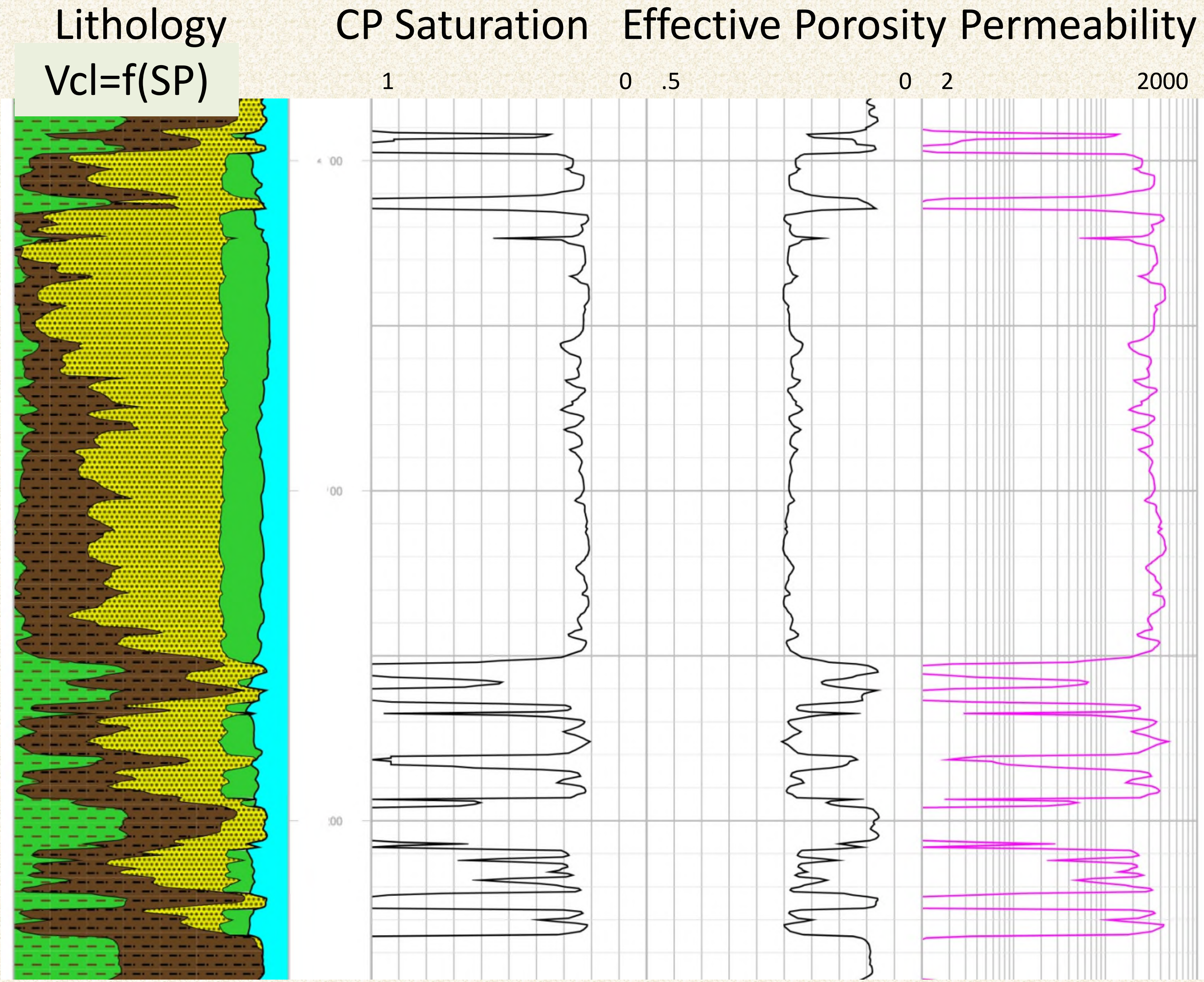
This process is continued until all data are posted and curves are fitted. A final very low-permeability curve (black) is drawn to provide a lower bound for the set of pseudo-capillary pressure curves.



Comparison of Sw from resistivity logs (blue) with Swirr from pseudo-capillary pressure curve set (previous slide). Log-derived permeability curve (pink) was the reference used to enter the Cp model.

Using Old Electric Logs

- The deep-reading measurements on electric logs, the normals and laterals, are asymmetrical in their response to the resistivity of the formation, so they cannot be used directly as RT
- Using empirical transforms and geological knowledge, basic reservoir parameters can be derived from the SP and shallow resistivity curves
- Sw from the psuedo-capillary pressure curves can be derived in the same way as for full-suite logs



Perm=f(SN)

PHITmax = f(depth);

PHIT= f(PHITmax,Vcl);

PHIE= f(PHIT,Vcl)

In this example of a 1950's well with an old e-log, reservoir properties were derived from the SP, SN, and local knowledge. The SwCP was calculated from a set of core-derived pseudo-Cp curves.