ePS Pattern Recognition in a Digital Age: A Gameboard Approach to Determining Petrophysical Parameters*

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Abstract

Archie (1942) provided a path from qualitative log interpretation to quantitative log analysis through an equation that required parameters which were not available from logs, and which, in the time before calculators and computers, required some effort to solve. Aware of the ability of people to recognize patterns, Hingle (1959), then Pickett (1973) developed graphical solutions to Archie's equation which allowed the quick determination of water saturation by observation of the data, and without the need for numerical calculations.

As calculators and computers became available, the primary function of those two methods has turned from the quick prediction of water saturation to the prediction of calculation parameters to be used in faster and more detailed interpretation methodologies. At the same time, the extension of Pickett plots with bulk volume water lines by Greengold (1986), and the suggestion by Gael (1981) and Bassiouni (1994) of using Hingle and Pickett plots in concert, helped to increase the number of parameters predicted, and to do so in a more coherent and cohesive manner.

A Pickett plot and Hingle plots, all with water saturation and bulk volume water lines, and Buckles plots (Buckles, 1965; Morris and Biggs, 1967) in linear and logarithmic scales, constitute a unified pattern recognition display. This "gameboard" presentation in Excel (©Microsoft) presents the data in a variety of graphical displays, and provides interactivity through sliders by which parameter values can be modified. This allows the interpreter to not only quickly recognize possible hydrocarbon-bearing intervals, but more importantly, to simultaneously derive a number of parameters which are required for the computation of water saturation and porosity.

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Abstract

Archie (1942) provided a path from qualitative log interpretation to quantitative log analysis through an equation that required parameters which were not available from logs, and which, in the time before calculators and computers, required some effort to solve. Aware of the ability of people to recognize patterns, Hingle (1959), then Pickett (1973) developed graphical solutions to Archie's equation which allowed the quick determination of water saturation by observation of the data, and without the need for numerical calculations. As calculators and computers became available, the primary function of those two methods has turned from the quick prediction of water saturation to the prediction of calculation parameters to be used in faster and more detailed interpretation methodologies. At the same time, the extension of Pickett plots with bulk volume water lines by Greengold (1986), and the suggestion by Gael (1981) and Bassiouni (1994) of using Hingle and Pickett plots in concert, helped to increase the number of parameters predicted, and to do so in a more coherent and cohesive manner. A Pickett plot and Hingle plots, all with water saturation and bulk volume water lines, and Buckles plots (Buckles, 1965; Morris & Biggs, 1967) in linear and logarithmic scales, constitute a unified pattern recognition display. This "gameboard" presentation in Excel (©Microsoft) presents the data in a variety of graphical displays, and provides interactivity through sliders by which parameter values can be modified. This allows the interpreter to not only quickly recognize possible hydrocarbon-bearing intervals, but more importantly, to simultaneously derive a number of parameters which are required for the computation of water saturation and porosity.

Pattern Recognition in a Digital Age: A Gameboard Approach to Determining Petrophysical Parameters

The Discovery Group, Inc. www.Discovery-Group.com

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The Discovery Group, Denver, CO, USA

AAPG ACE, April 2012, Long Beach CA USA

Well Log Interpretation

Then: Done with pencil, paper, and a slide rule *on the hood of a Chevy, in the middle of the night, in Montana, in December.*

Bulk density or sonic traveltime *plus matrix and fluid values, (slow and laborious to determine.)* → Porosity, Phi

Archie's Equation: $Sw = \left(\frac{a*Rw}{Rt*Phi^m}\right)^{\frac{1}{n}}$

SO: Graphical pattern recognition techniques were developed to minimize the number of calculations needed.

Graphical solutions to Archie's Equation:

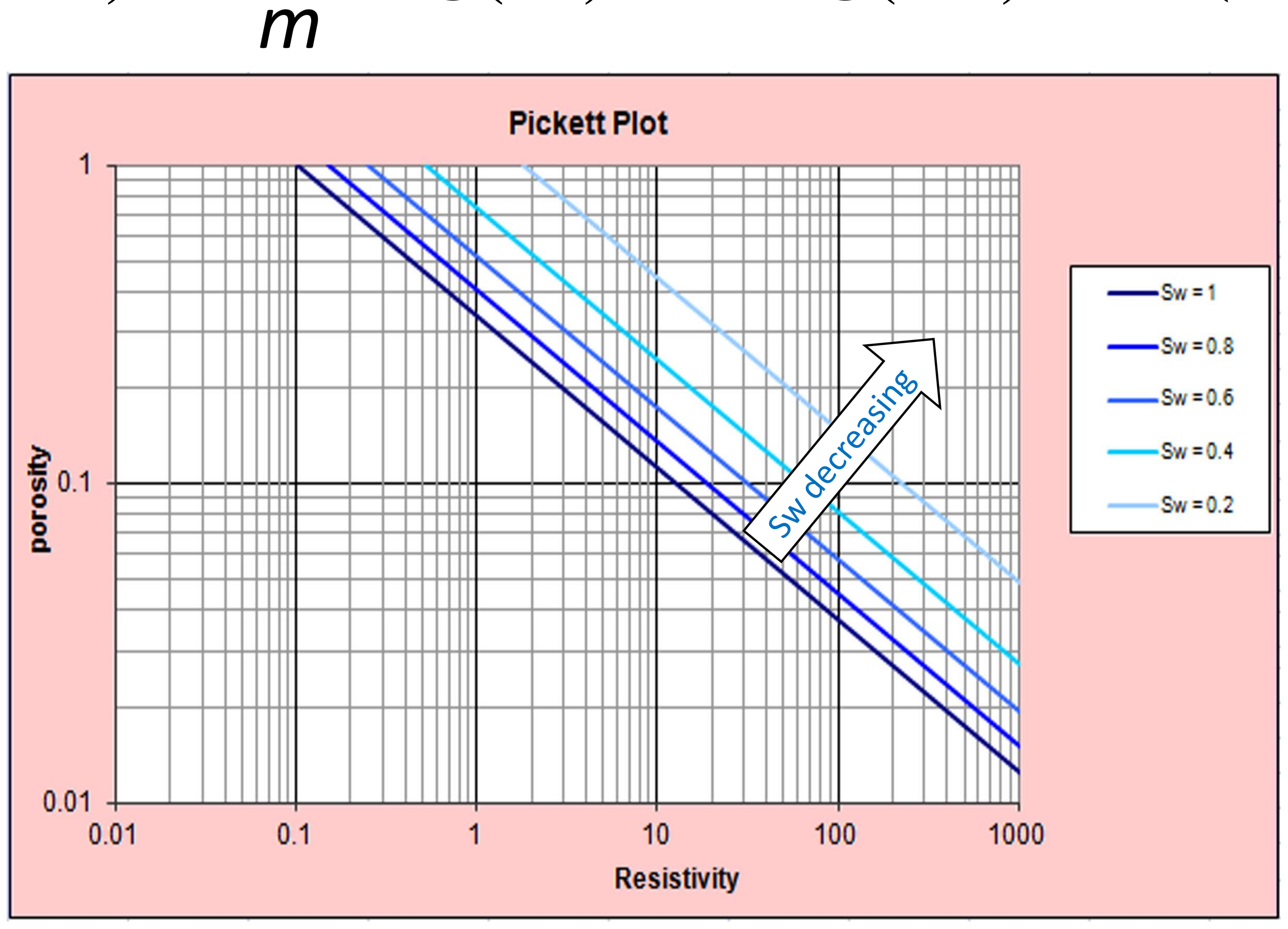
$$Sw = \left(\frac{a*Rw}{Rt*Phi^m}\right)^{\frac{1}{n}}$$

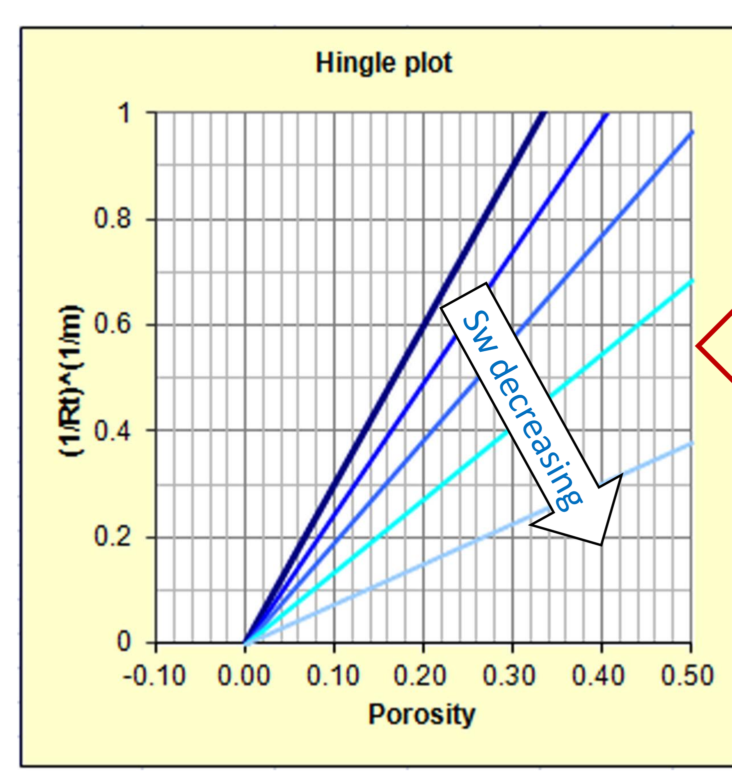
Hingle, 1959

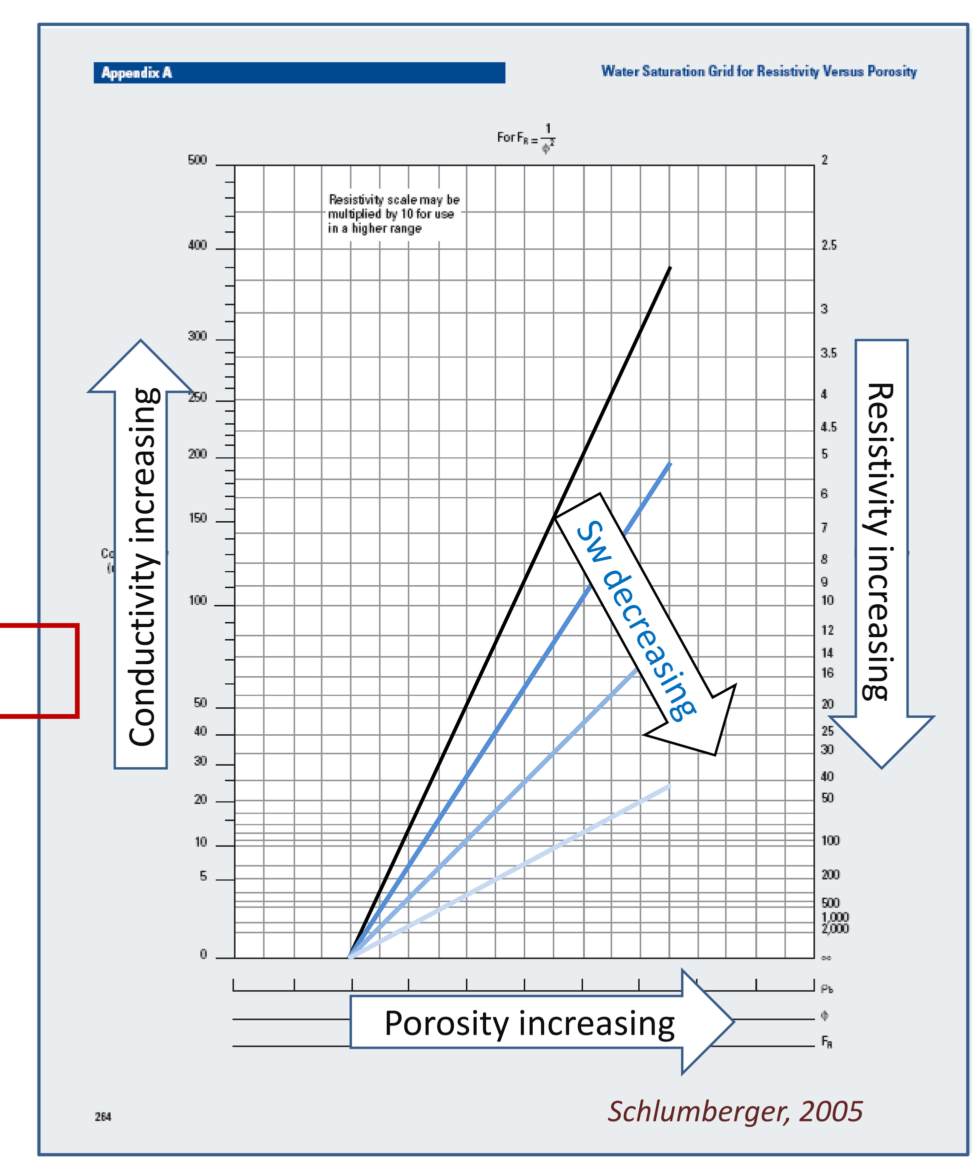
$$\left(\frac{1}{Rt}\right)^{\frac{1}{m}} = \left(\frac{Sw^n}{a*Rw}\right)^{\frac{1}{m}} * Phi$$

Pickett, 1973

$$\log(Phi) = -\frac{1}{m}*\log(Rt) - n*\log(Sw) + \log(a*Rw)$$







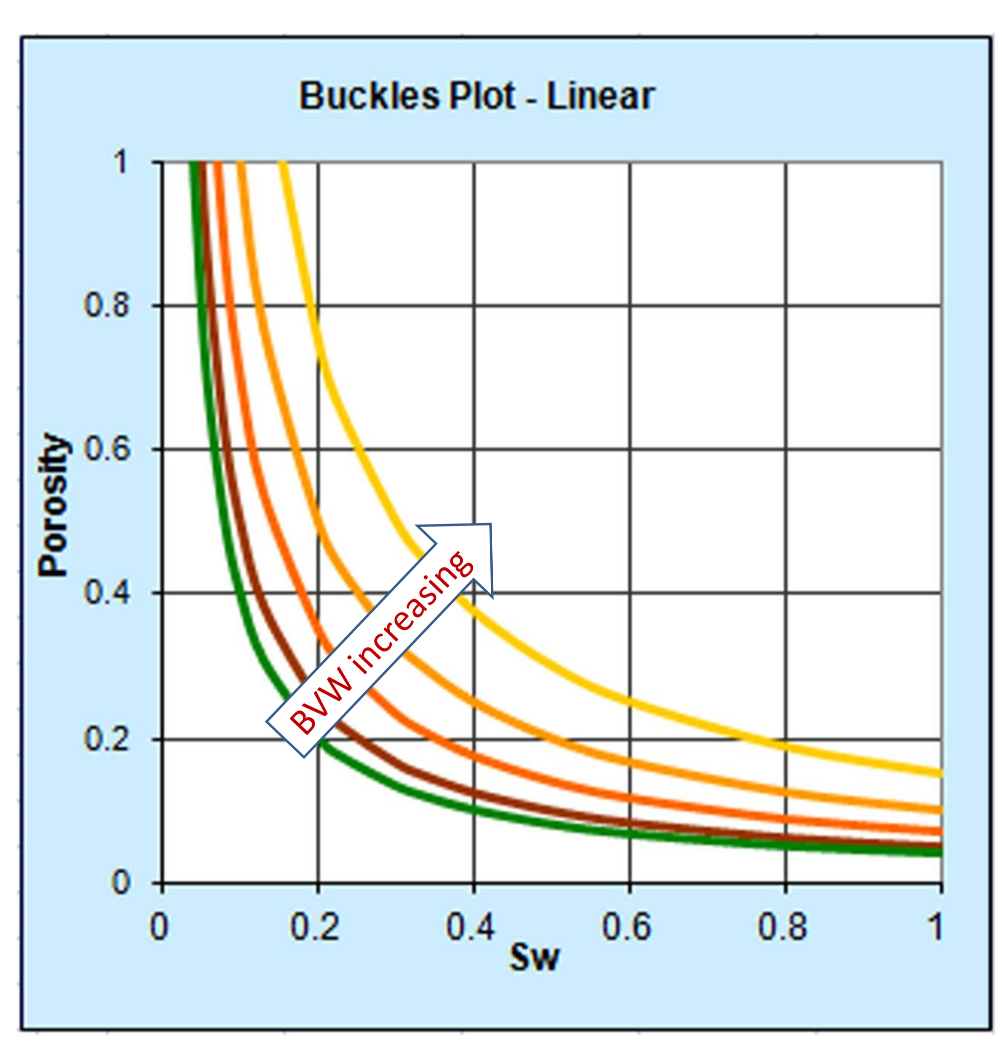
Schlumberger, 2005

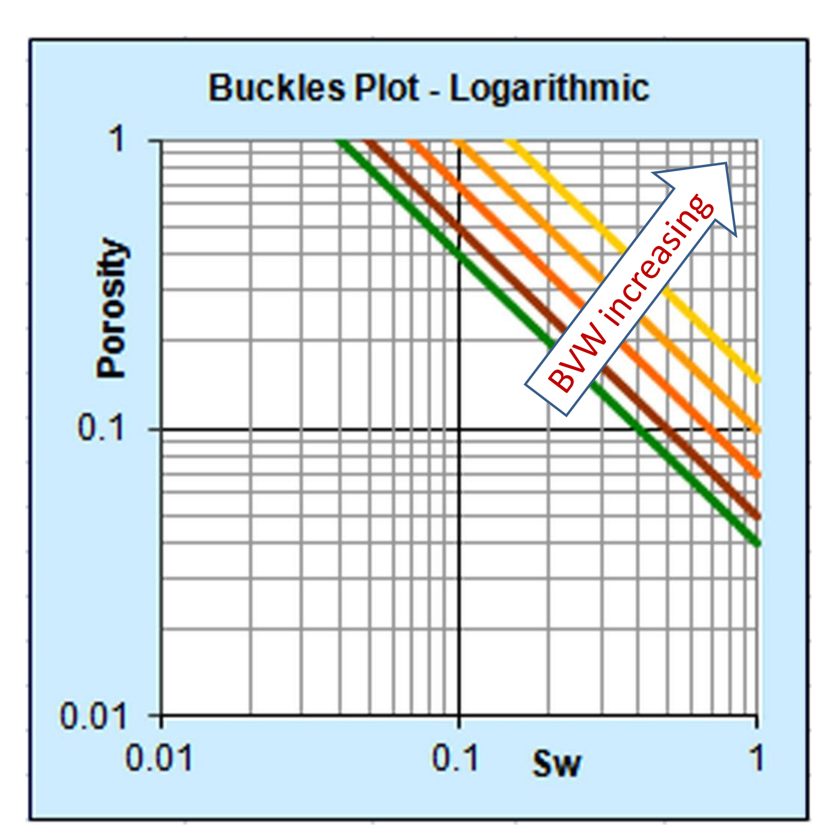
AND: Bulk volume water, BVW = Phi * Sw

BVWminimum implies Sw irreducible, which implies little or no water production.

Plotting Sw vs. Phi (linear or logarithmic scales) displays BVW without having to do the calculation, and identifies the depths at BVWirreducible.

Buckles, 1965; Morris & Biggs, 1967





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Well Log Interpretation

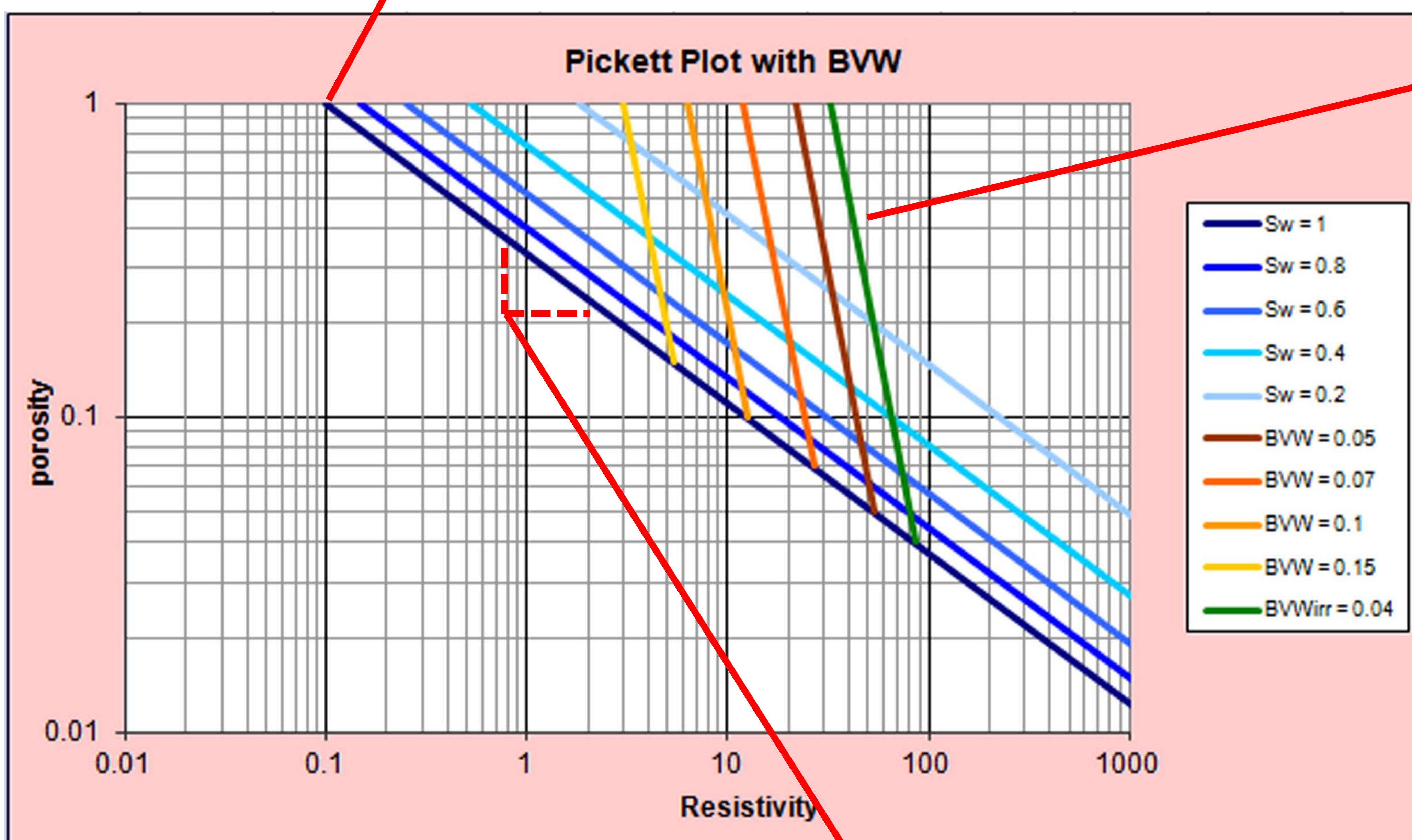
Now: Calculators and computers do the calculations,

and we get paid to interpret the data, not to do arithmetic…

SO: Use graphical pattern recognition techniques to pick the parameters for the calculations, and let the hardware and software do the heavy lifting.

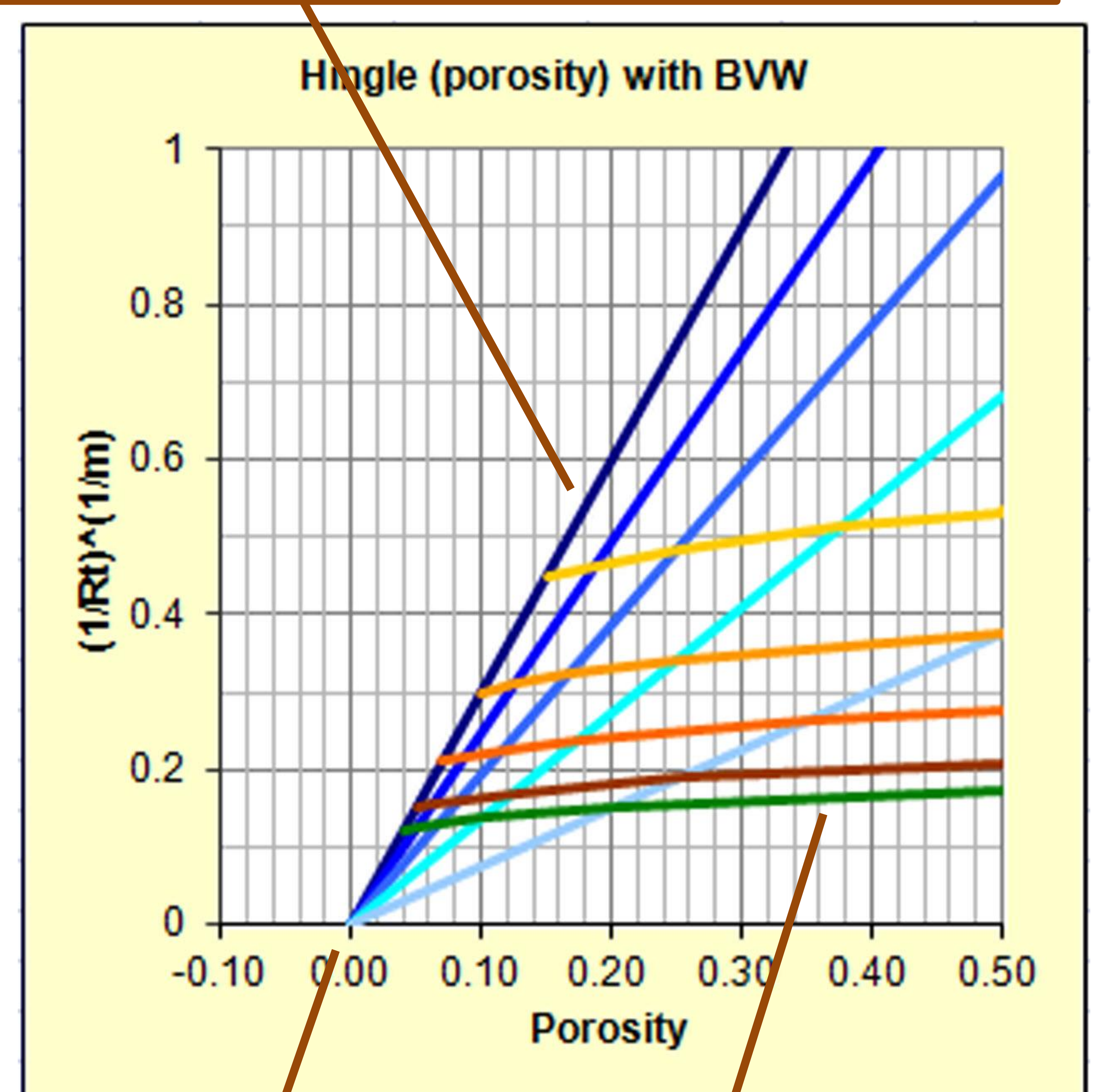
Intercept at Phi = 100% is a* Rw

BVW lines *(Greengold, 1986)*
The slope of the lines determines the saturation exponent, n.
The "eastern" edge of the data determines BVWirreducible.



Slope = -1/m, cementation exponent
The "southwestern" edge of the data determines the location of the water-bearing line.

The "northwestern" edge of the data determines the location of the water-bearing line.



If RHOB or Delta T are plotted, the x-intercept is the matrix value.

BVW lines. The "southern" edge of the data determines BVWirreducible.

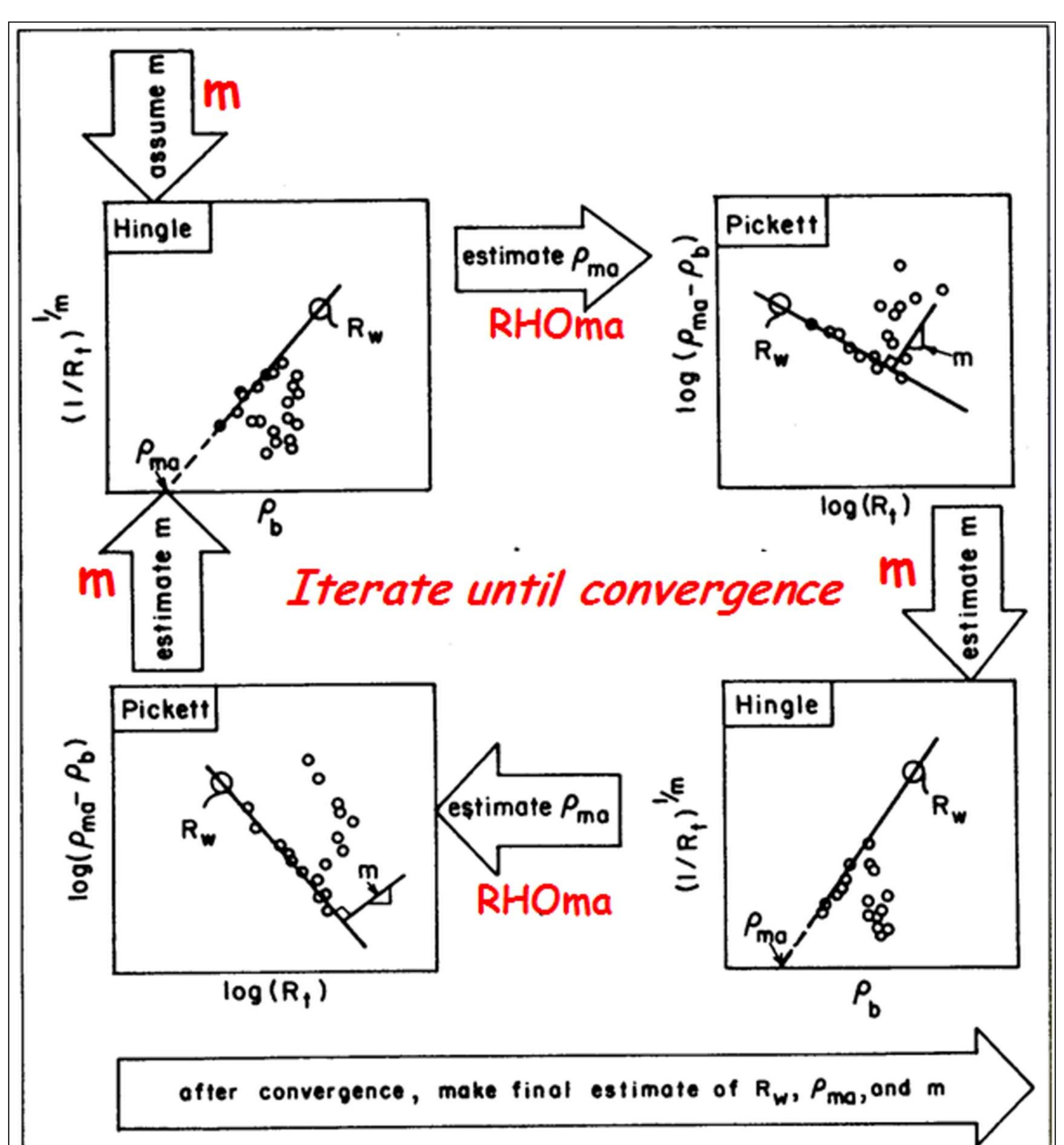
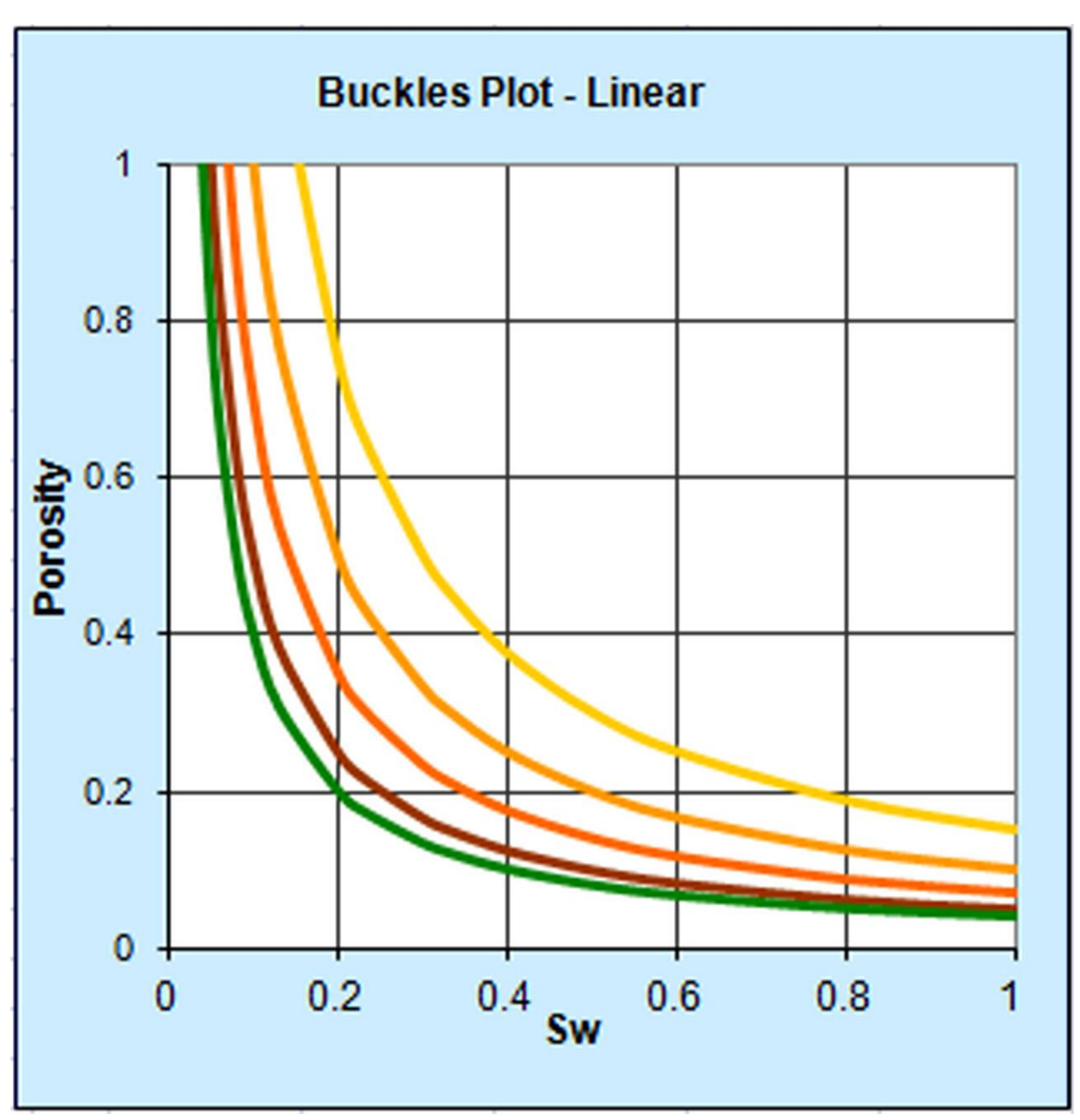
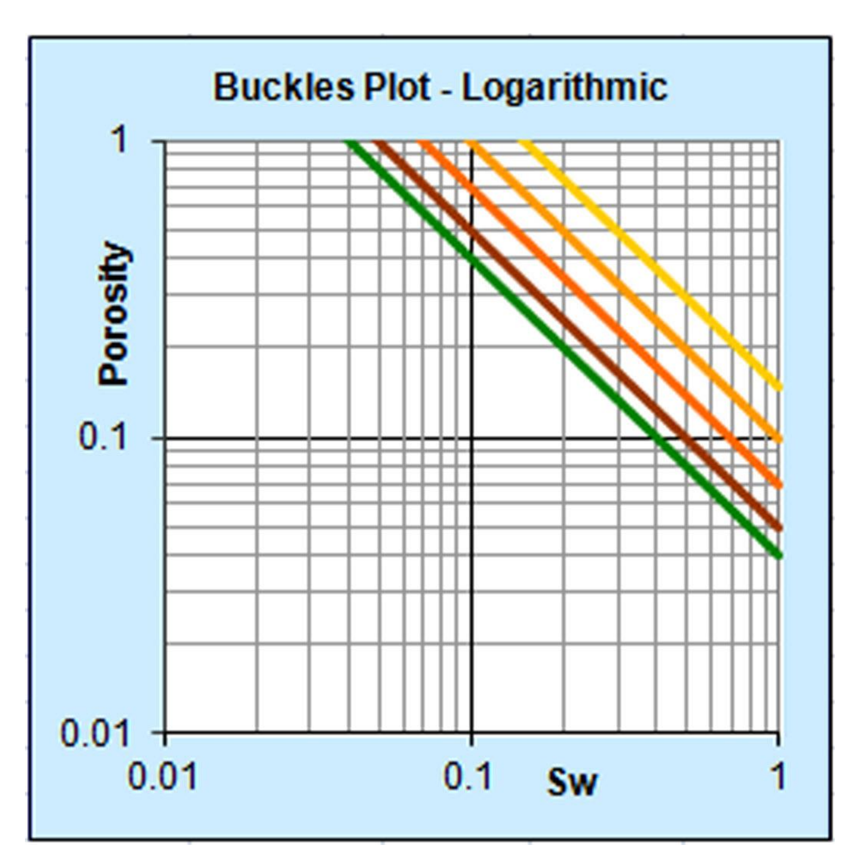


Fig. 13.20—Interplay of Hingle and Pickett crossplots (from Ref. 9).

This iteration technique (Gael, 1981; Bassiouni, 1994) is the basis for the gameboard implemented here.

AND: The final step is to include the Buckles plots (both linear and logarithmic scales) as another approach to determining BVWirreducible.





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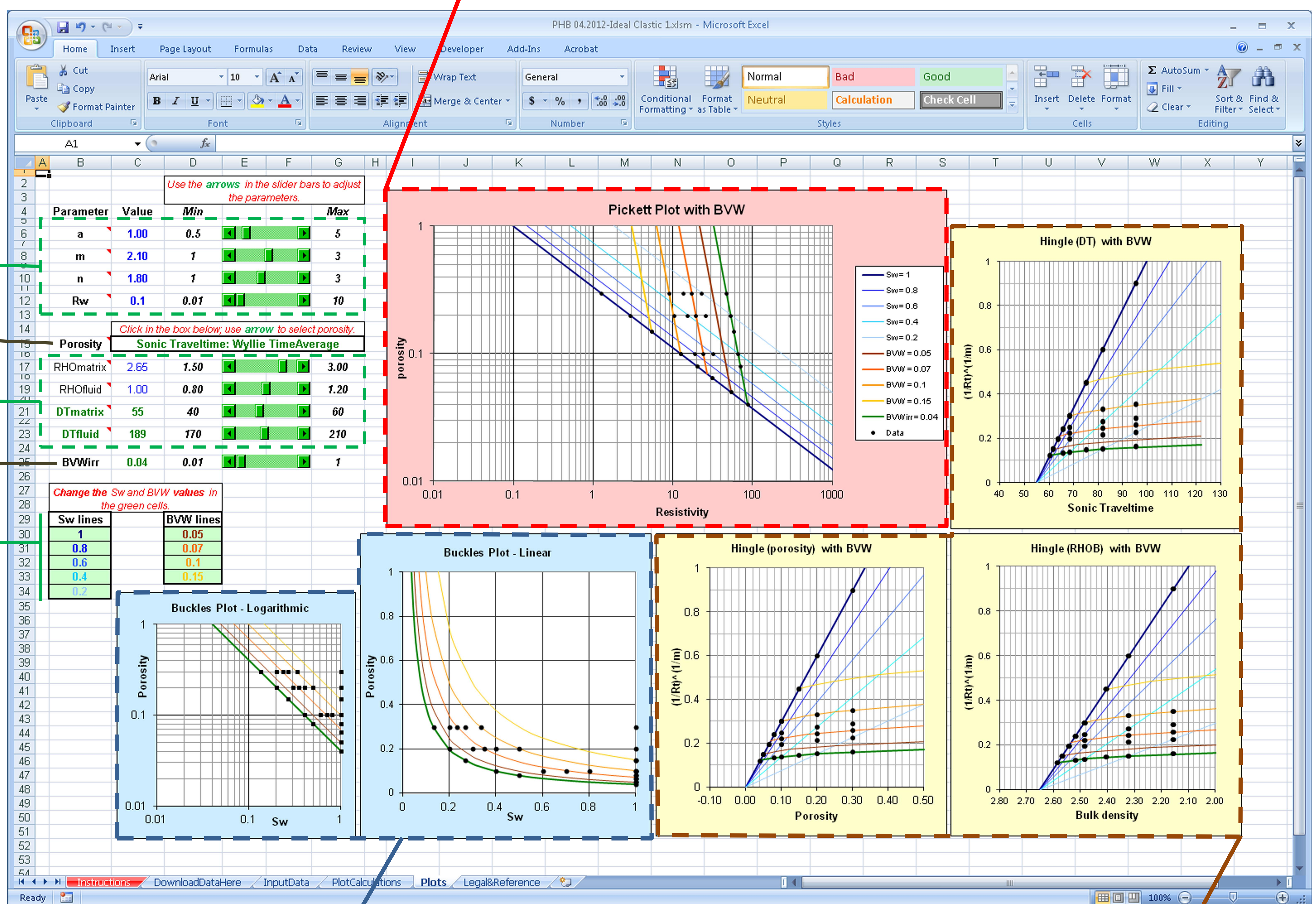
Interpretation parameters are determined on a "gameboard" where the "player" modifies the parameters and immediately sees the results of the changes, and can see the consistency of the selections.

Pickett plot predicting:

- Formation water resistivity, Rw,
- Cementation exponent, m,
- Saturation exponent, n,
- Irreducible Bulk Volume Water, BVWirr.

Selection of:

- Archie parameters
- Porosity source
- Porosity parameters
- BVW irreducible
- Sw and BVW lines

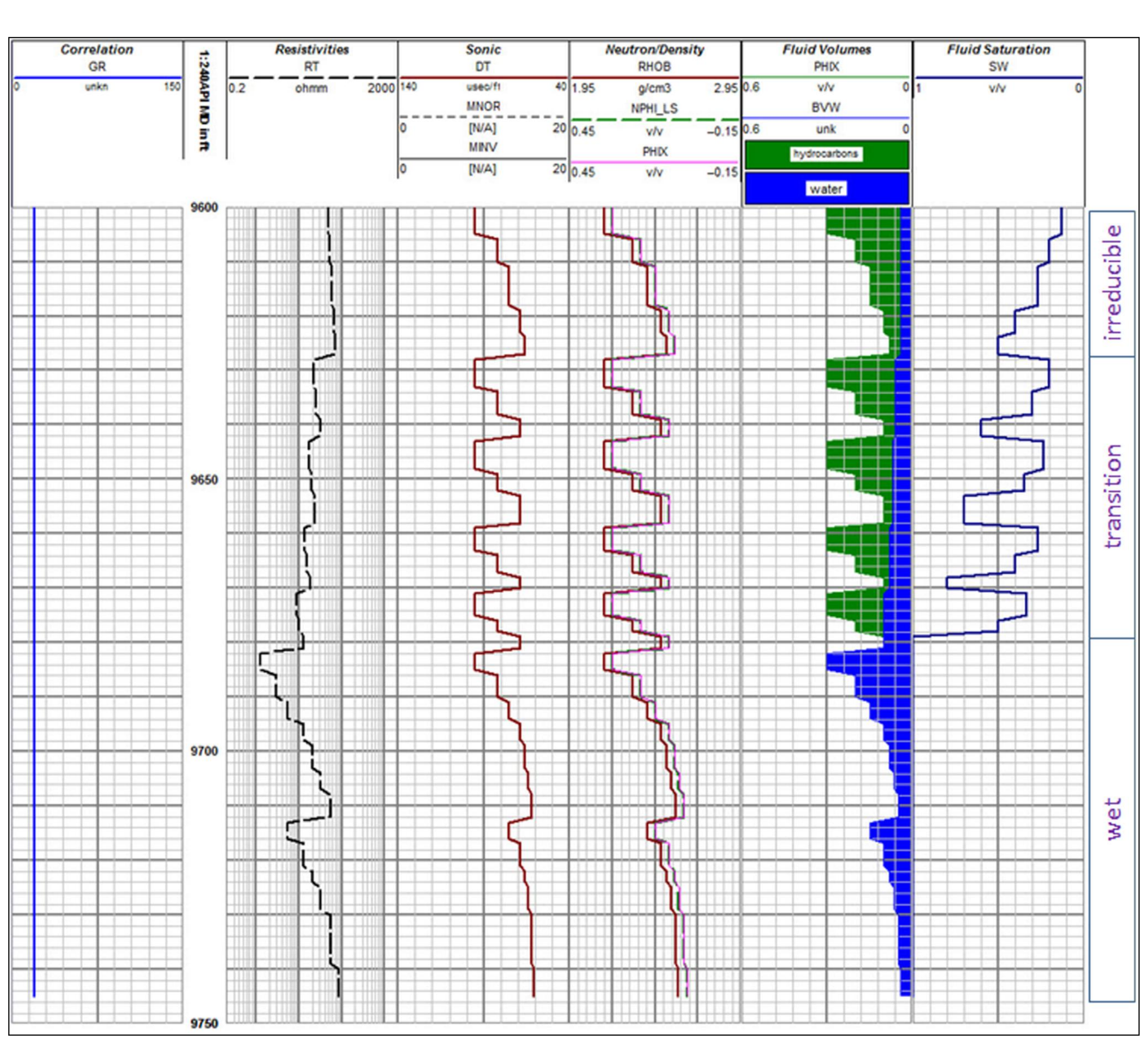


Buckles plots:

- To determine BVWirr, and
- To suggest fluid production.

Hingle plots:

- Showing "raw" porosity measurements to determine matrix values, and
- Showing calculated porosity.



The data shown in the gameboard above is "ideal;" that is, constructed to have zones that are at irreducible water saturation, in a transition zone, and completely water saturated.
The "well" might look something like the log at the left.

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The Gameboard Workflow

- Load the raw data into the spreadsheet:
  - Deep resistivity
  - Sonic traveltime, DeltaT, and/or
  - Bulk density, RHOB, and/or
  - A previously-calculated porosity.
- On the gameboard:
  - Select the porosity source: DeltaT, RHOB, or input porosity.
  - Modify the parameters via the sliders so that the lines in each plot coincide with the data that is displayed.

- *In the Pickett plot:*
  - *The Sw = 1 (100%) line is at the "southwest" edge of the data,*
  - *The BVWirr line is at the "east" edge of the data,*
  - *The values for Rw, m, n, and BVWirr are within acceptable ranges.*
- *In the Hingle plots:*
  - *The Sw = 1 (100%) line is at the "northwest" edge of the data,*
  - *The BVWirr line is at the "south" edge of the data,*
  - *The values for matrix parameter and BVWirr are within acceptable ranges.*
- *In the Buckles plots:*
  - *The BVWirr line is at the "southwest" edge of the data.*

Conclusions

The gameboard provides a method to determine porosity and saturation parameters in concert so that the parameters present a more coherent estimate of those properties than the selection of parameters individually.

While the "proof of concept" of the technique was executed in Microsoft Excel, development inside a petrophysical software system would lead to more flexibility and functionality in the behavior of the software.

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An Example

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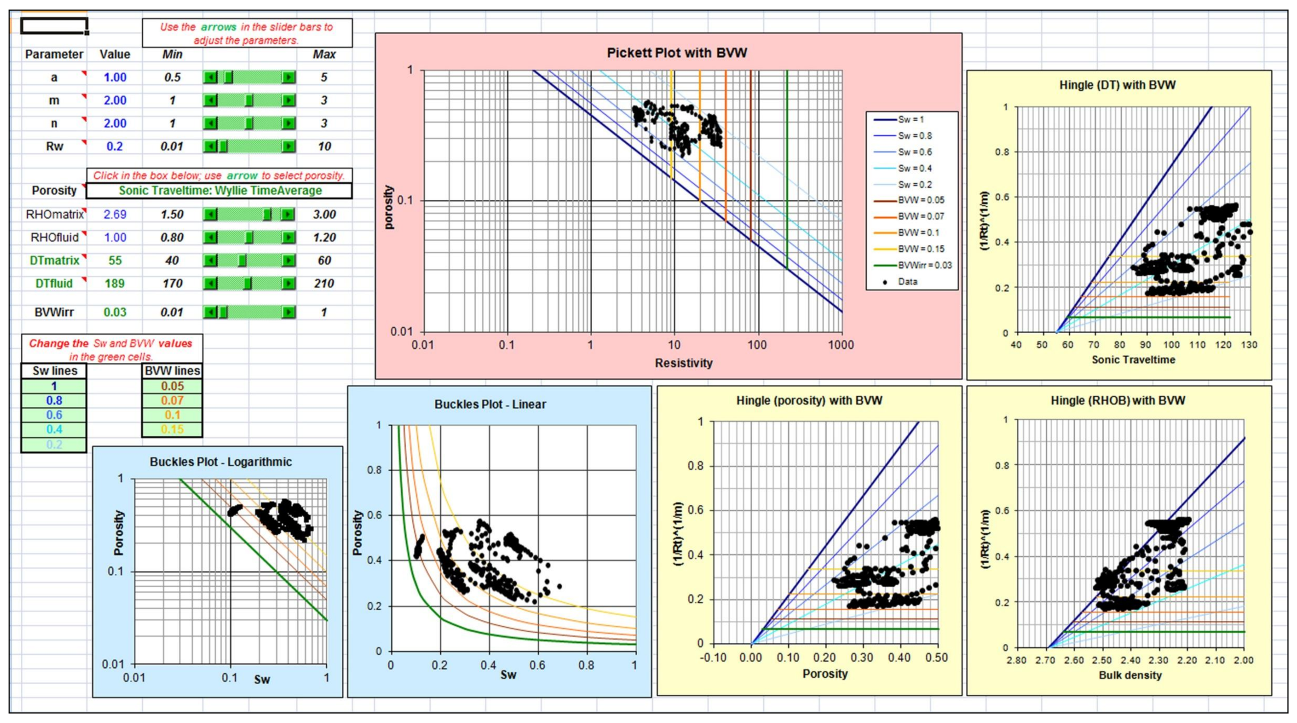
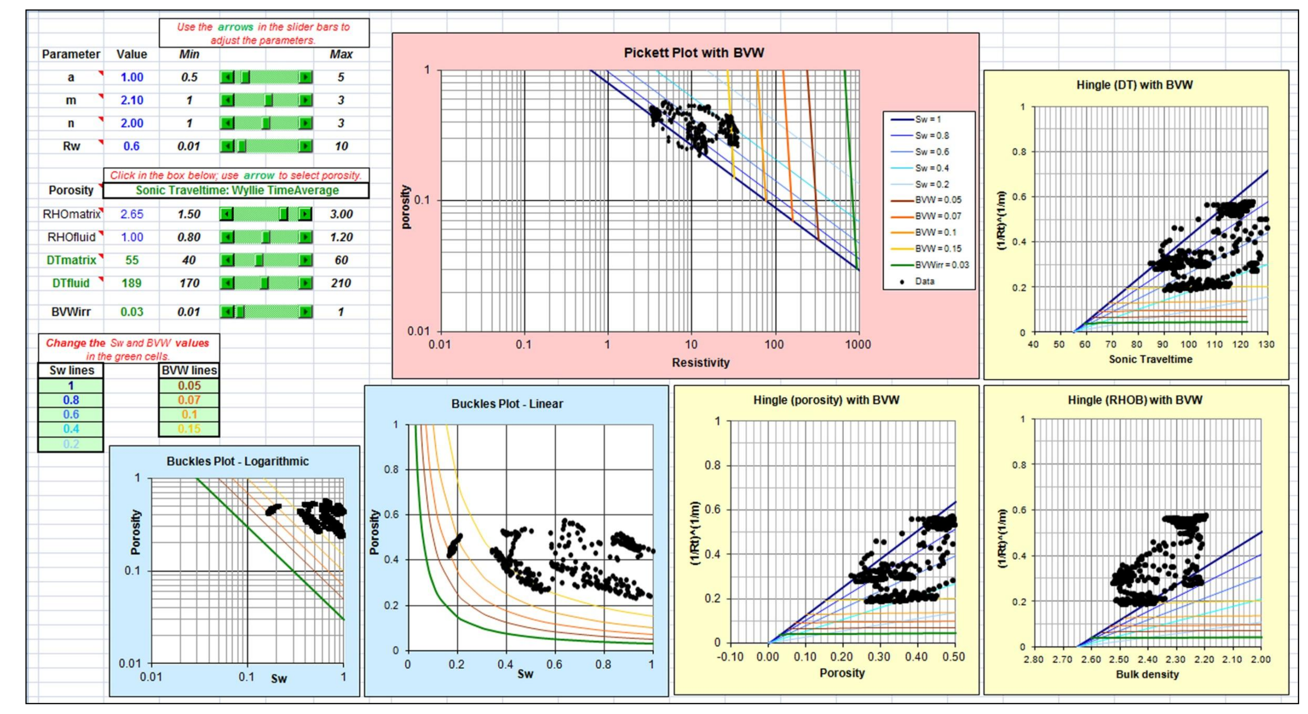
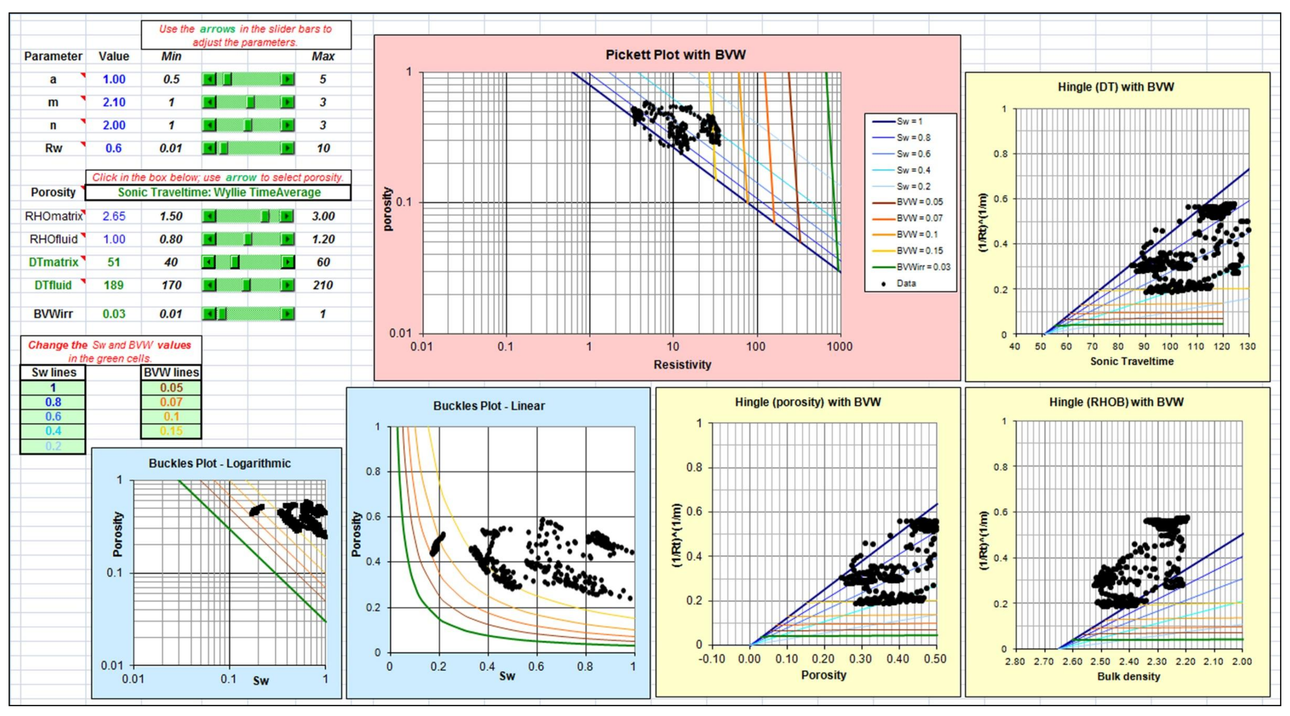


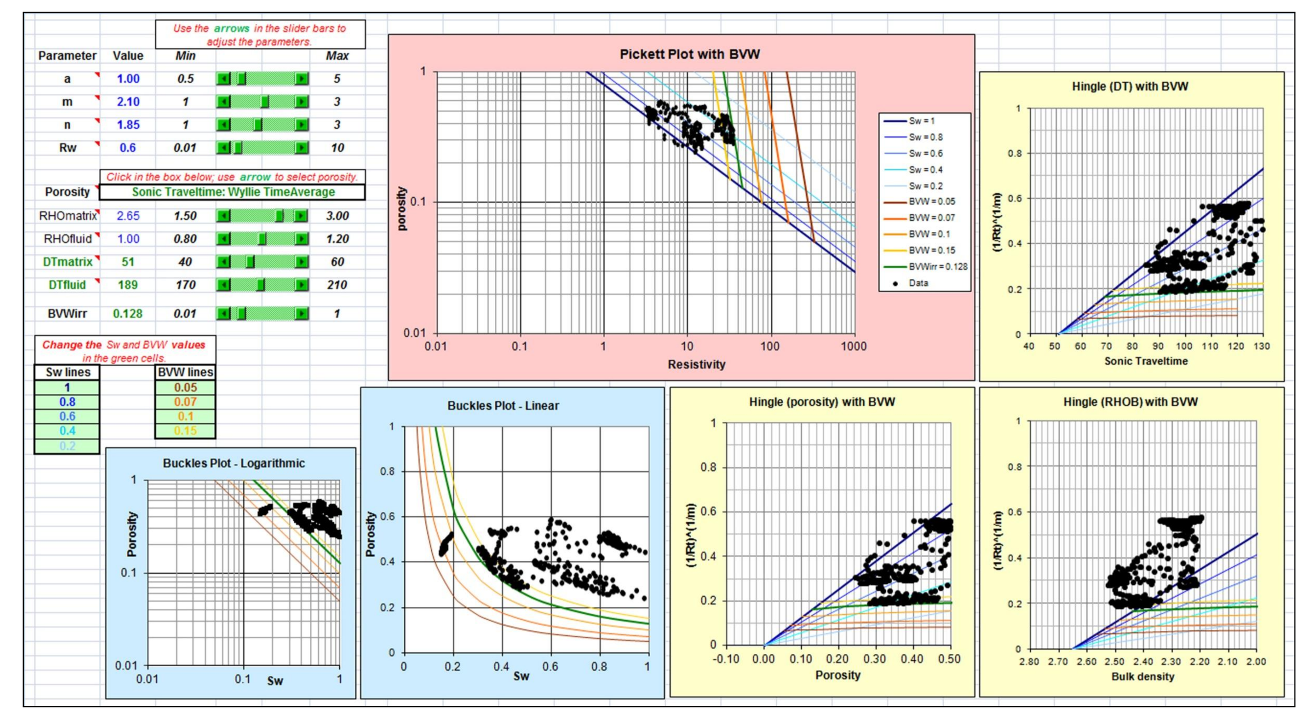
m and Rw changed



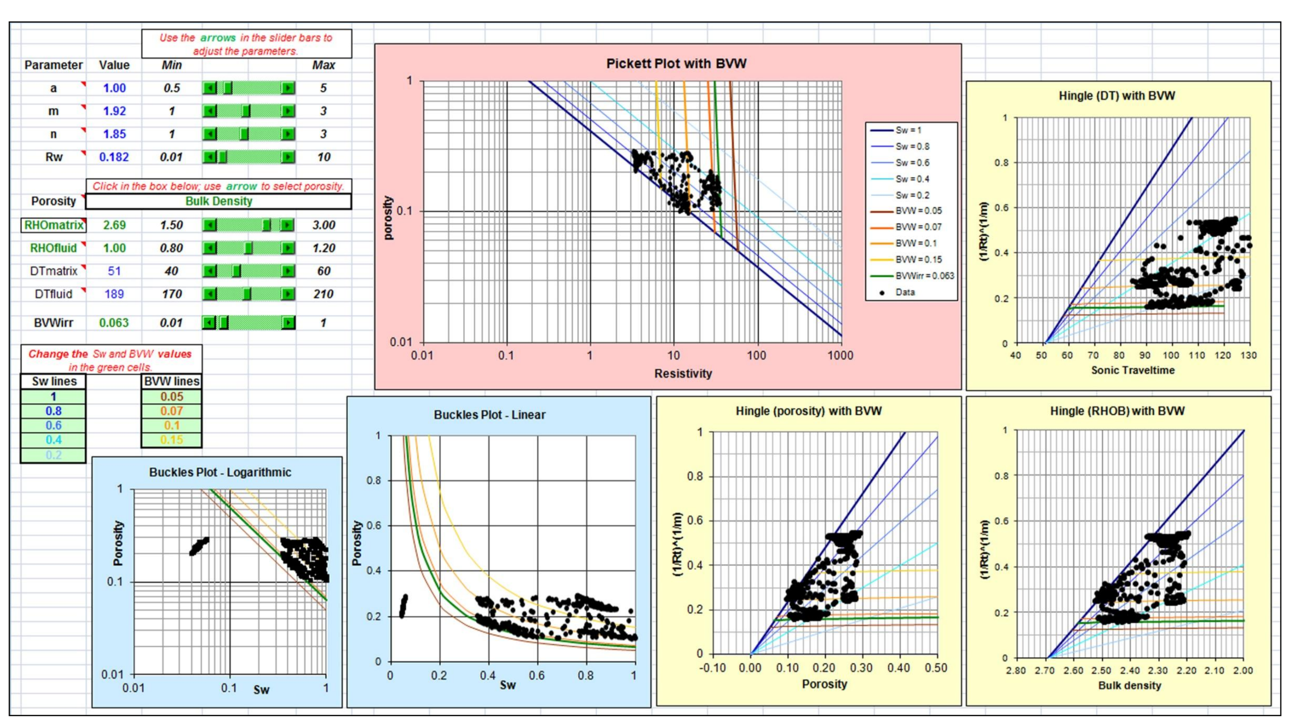
DTmatrix changed



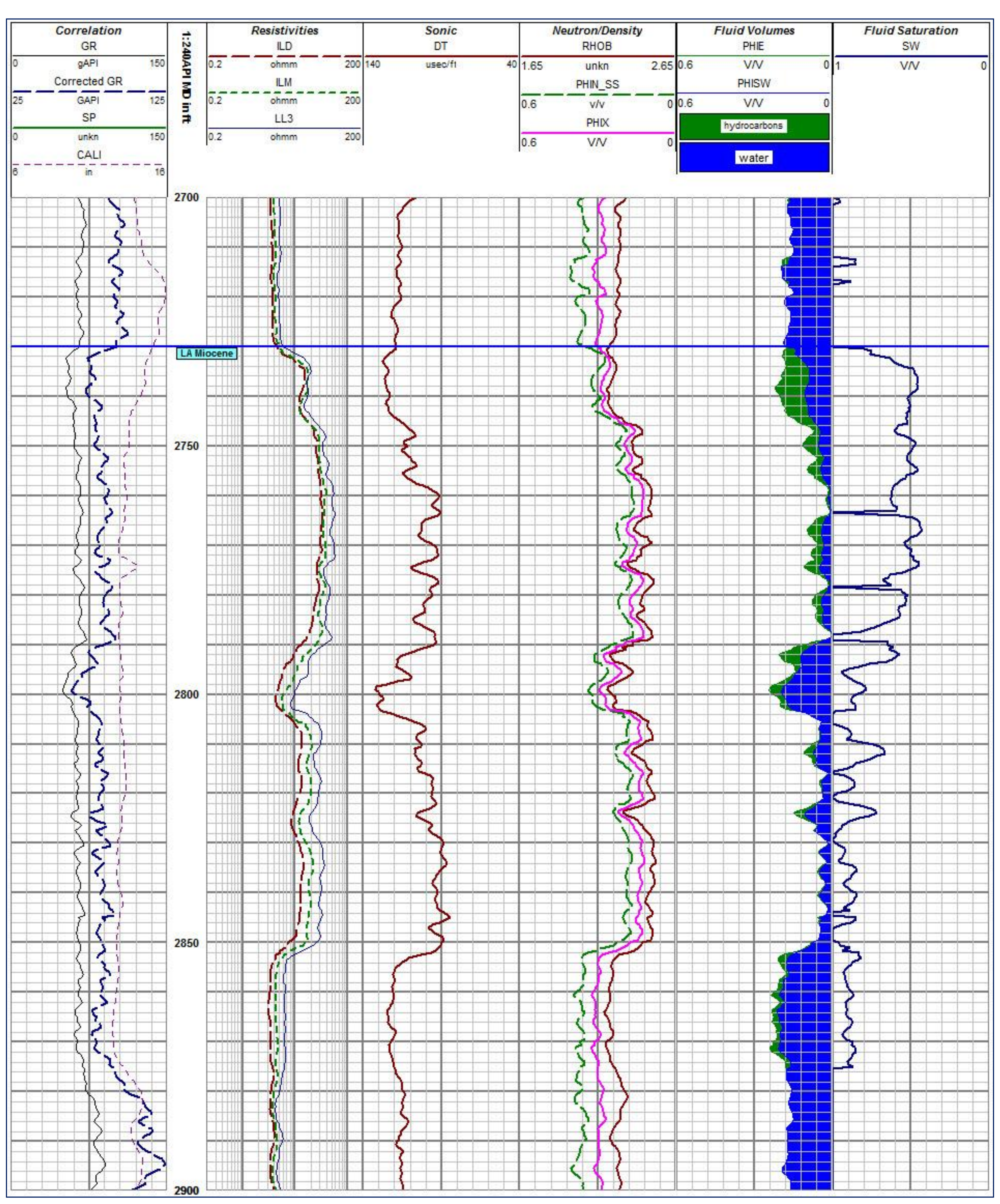
n and BVWirr changed



Using density Instead…



So, why the differences In the parameters?



Sonic

Use the arrows in the slider bars to adjust the parameters.

Parameter	Value	Min	Max
a	1.00	0.5	5
m	2.10	1	3
n	1.85	1	3
Rw	0.6	0.01	10
Porosity	Sonic Traveltime: Wyllie TimeAverage		
RHOmatrix	2.65	1.50	3.00
RHOfluid	1.00	0.80	1.20
DTmatrix	51	40	60
DTfluid	189	170	210
BVWirr	0.128	0.01	1

Click in the box below; use arrow to select porosity.

Density

Use the arrows in the slider bars to adjust the parameters.

Parameter	Value	Min	Max
a	1.00	0.5	5
m	1.92	1	3
n	1.85	1	3
Rw	0.182	0.01	10
Porosity	Bulk Density		
RHOmatrix	2.69	1.50	3.00
RHOfluid	1.00	0.80	1.20
DTmatrix	51	40	60
DTfluid	189	170	210
BVWirr	0.063	0.01	1

Click in the box below; use arrow to select porosity.

An enlarged and rough hole probably affected the density. Is there other information, in this well or one nearby, that can add light to the discrepancy here?

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Presenter's Notes:

Back before calculators and computers were available, or even invented, the interpretation of well log data to get quantities of interest was done by hand, sometimes in the conditions identified here.

The determination of porosity from sonic or density logs required matrix and fluid parameter values which were not determined from logs, but which were inferred from other previously-acquired data, or from a best guess about the values.

Determining water saturation from Archie's equation required not only porosity and resistivity, but also estimates of formation water resistivity, Rw, and the parameters of tortuosity factor, a, cementation exponent, m, and saturation exponent, n.

In order to speed the determination of water saturation, two pattern recognition methods were devised. Both are essentially graphical solutions to Archie's saturation equation, where by plotting resistivity against porosity the water saturation of each point of interest can be determined visually by comparison of the location of the point with lines showing different water saturation values. In both these plots, the location of the lines is determined by the data itself.

The Hingle plot, devised by Tom Hingle, plotted either resistivity or its inverse conductivity on the y-axis, against porosity, or bulk density or acoustic traveltime on the x-axis. Resistivity or conductivity are plotted on a special y-axis. While the axis looks logarithmic, it is not, depending on formation resistivity and the Archie cementation exponent, m. As shown here, the Hingle parameter, one over Rt raised to the one over m power, can also be calculated and plotted on a linear axis, instead of on the specially constructed axis.

The Pickett plot, devised by Dick Pickett, solved Archie's equation differently, and plotted resistivity and porosity, both on logarithmic scales. Like the Hingle plot, water saturation for any point of interest could be read directly from the plot by comparison to water saturation lines, the placement of which was determined by the data itself. In the Pickett plot, the water saturation lines are parallel, while in the Hingle plot, the same lines form a fan from the x-axis intercept.

The final plot shown here is a Buckles plot, described by Buckles, then by Morris and Biggs. This plot of porosity against water saturation, either on linear scales as first published, or on logarithmic scales, is a graphical representation of bulk volume water. The concept here is that a constant value of bulk volume water indicates that a set of zones is at irreducible water saturation, and will produce little, if any, water.

The next page describes well log interpretation as it can be done now.

Back to slide 1 (page 2)

Presenter's Notes:

This page describes log interpretation as it's done now. Because we have computers to do the calculations in a much more detailed fashion, we can concentrate on the interpretation of the data, instead of on the arithmetic.

In our current mode, we can use the same plots, but now we can use the plots primarily to determine the calculation parameters, rather than circumventing the calculations themselves. While the plots still help us quickly visually identify the production potential of zones, their value is in helping us determine the calculation parameters quickly, and in this format, in concert rather than individually. In the Pickett plot shown here, bulk volume water lines have been added to the plot, after Gerry Greengold's work. In this version of the Pickett plot, as with the original plot, the location of all the lines is determined by the data. The slope of the water saturation lines determines the cementation exponent, m. The intercept of the 100 percent water saturation line at a porosity of one (100 percent) is the tortuosity factor, a, times Rw. The slope of the bulk volume water lines indicates the saturation exponent, n, and the right-most BVW line(determined by the data) is BVW irreducible.

In this work, bulk volume water lines have been added to the Hingle plot as well. The lines are slightly curved and almost horizontal. In this plot, BVW irreducible is indicated by the bottom BVW line, again determined by the plotted data. While porosity is plotted in the x-axis here, if bulk density or acoustic traveltime is plotted instead, the x-intercept of the water saturation lines will determine the matrix value, used to calculate porosity.

The Buckles plots are shown here as well, with both linear and logarithmic scales. Both scale types are displayed as people may have a preference for one over the other, in terms of being able to better understand the data in a visual sense.
An iteration technique, described by Gael in a thesis, and referenced in Bassiouni's book is shown here. The iteration between the Pickett and Hingle plots shown in that figure was the basis for the gameboard approach in this document.

[Back to slide 2 (page 3)]

Presenter's Notes:

This page shows the gameboard with a variety of plots, along with some manufactured data which is designed to have a water-bearing zone, a transition zone, and a zone at irreducible water saturation. The gameboard was done in Microsoft Excel as a proof of concept. We use the term "gameboard" because, as when playing a game, when the player makes changes on the board, in this case, through the slider bars at the top left of the display, changes immediately happen to the data displayed on the board, giving feedback to the player, and indicating the next move.

So, some explanation of the gameboard:
At the top left are slider bars for the Archie parameters, a, m, n, and Rw. Below those is a dropdown menu for the porosity source, porosity from acoustic traveltime via the Wyllie Time-Average equation or the Schlumberger Field Observation equation, porosity from bulk density, or a previously-calculated porosity. If bulk density or acoustic traveltime are selected, the slider bars below provide the player the means to select matrix and fluid parameter values.

The lowest slider bar provides the means to select irreducible bulk volume water based on the location of the data in all the plots.
And finally, there are two tables which allow players to set the water saturation and bulk volume water lines to their preferred values.
The Pickett plot, bordered in red, shows water saturation and bulk volume water lines, and the ideal data. The lines are moved by using the slider bars.

There are three Hingle plots, bordered in yellow. They differ in their x-axes, one for acoustic traveltime, one for bulk density, and one for calculated porosity. In each of those plots, the location of the water saturation and bulk volume water lines will depend on the sliders.

And finally, at the lower left, are the two versions of the Buckles plots, bordered in blue, with the bulk volume water lines displayed.
With this ideal dataset, we've used the slider bars to align the lines on the plots with the data. From the slope of the water saturation lines on the Pickett plot, where the water-bearing line is drawn through the points at the southwest edge of the data cloud, the cementation exponent is determined to be 2.1. From the intercept of the 100 percent water saturation line at 100% porosity, and assuming a value of tortuosity factor, a, of 1, Rw is predicted to be 0.1 ohm-meters. From the slope of the BVW lines, the saturation exponent is determined as 1.8. And from the BVW line at the eastern edge of the data cloud, irreducible BVW is 0.04.

In the Hingle plots, the northwestern edge of the data cloud defines the location of the 100 percent water saturation line. In the plot using acoustic traveltime, the matrix traveltime is predicted to be (at the x-intercept) 55 microseconds per foot. In the plot with bulk density as the x-axis, the matrix density is predicted to be 2.65 grams per cubic centimeter. And in the plot with porosity as the x-axis, the water-bearing line intersects the x-axis at zero porosity. In all three plots, the southern edge of the data describes the value of irreducible bulk volume water, analogous to that in the Pickett plot.

Both Buckles plots show the lowest values of bulk volume water at the southwest of the data cloud, consistent with the Pickett and Hingle plots

So, in this one gameboard display, we've determined five to seven parameters simultaneously (depending on the data available), instead of determining them in sequence. This should produce a more coherent set of parameters than when they are determined in a stepwise process.

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Presenter's Notes:

This page shows the workflow for using the spreadsheet on which this gameboard is built.
When the data is loaded to the spreadsheet, the data is immediately displayed on the plots, and any necessary calculations are done on the basis of the parameter values.

The first step on the gameboard is to select the porosity source.
The next step is to modify the parameters until the lines on the plots coincide with the data plotted there. It may be best to start with the matrix values if using acoustic traveltime or bulk density, but the choice of which parameters to modify, and the order in which they are modified, is up to the player.

The bullet points in italics here are a reminder of what the plots should look like when the player has properly manipulated the parameter values.

Our conclusions:
A gameboard approach provides the means to select a group of calculation parameters in concert, with the idea that the parameters selected in this way present a more coherent picture of the subsurface than if they are chosen individually through a stepwise interpretive process.
And, while this process was implemented in Microsoft Excel, development inside an existing petrophysical package will probably lead to more functionality in display; as easily displaying another curve variable as point color or symbol type. So this is intended to be more of a proof of concept, rather than a rigorous application of functionality.

The next page shows an example with actual well data.

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Presenter's Notes:

In this example, the data is loaded to the spreadsheet and is immediately displayed on all the plots. The dataset has acoustic traveltime and bulk density data, but no previously-calculated porosity values.

In the workflow shown here, acoustic traveltime with the Wyllie equation, was selected as the porosity source. Then cementation exponent, m, and formation water resistivity, Rw, were first changed to move the lines closer to the data. Next, the matrix traveltime, DTmatrix, was modified to get the Hingle plot lines aligned with the data there. Finally, saturation exponent, n, and BVW irreducible were modified to better align the lines with the data, especially in the Buckles plots.

Similar steps were followed after the bulk density was chosen as the porosity source.

As shown in the two parameter displays, the parameters in each case are slightly different. While the matrix density and traveltime values seem to indicate a sandstone with perhaps a bit of calcite cement, the Archie parameters and BVW irreducible do not agree. Observation of the log indicates a bit of an enlarged and rough hole that could be affecting the density measurement. As is often the case, more information, either from this well or one nearby, might help decrease the uncertainty in the results.

Please note that the Microsoft Excel spreadsheet that is the basis for this gameboard method is available on the website of The Discovery Group, at www.Discovery-Group.com.

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