A Comprehensive Water Saturation Model for Low-Porosity Sandstones*

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Abstract

Technical advances on many aspects of producing hydrocarbons from low-porosity sandstone have led to increased exploration in basins around the world. It is critical for commercial success to understand the porosity and hydrocarbon saturation relationships associated with these systems. In many basins where tight sandstones are being evaluated for the potential of commercial hydrocarbon accumulations, prospective intervals range in thickness from a few feet to several thousand feet and may cross stratigraphic horizons with various depositional environments.

Determining formation water resistivity (RW) is a critical component in determining if sandstones may be at or close to irreducible water saturation (SWirr). Often during exploration efforts there is very little information available for RW estimates. Calculating RW from SP curves can be misleading due to low porosity/permeability, sand body thickness and the potential for the presence of variable anions associated with formation water. Pickett plots have been used for RW determination for many years, but the technique requires prior knowledge or assumption for the value of the Archie saturation exponent “m” and representative sandstones that are water-saturated.

A cornerstone to improved petrophysical understanding of low-porosity sandstone was recently published by the DOE/KGS project, “Regional petrophysical properties of the Mesaverde low-permeability sandstones (Byrnes et al., 2007) and “Evidence for a variable Archie porosity exponent “m” an impact on saturation calculations for Mesaverde tight gas sandstone: Piceance, Uinta, Green River, Wind River and Powder River basins” (Cluff et al., 2008). Results of the Byrnes et al. project document several physical aspects of low-porosity sandstones in the Rocky Mountain region including a core-derived relationship indicating that a decrease in porosity and/or water salinity results in a decrease in the Archie saturation exponent “m”.

Pickett plots from productive wells from several basins in Colorado, Utah, and Wyoming are presented to demonstrate the application of the variable “m” as described by Byrnes et al. Results indicate the variability of the formation water salinity not only areally between wells within a particular field but between sand bodies within a single well bore over the potential interval of interest. Pickett plots are also demonstrated to be a good tool for determining the bulk volume of irreducible water and consequently a porosity cutoff for hydrocarbon storage.

A Comprehensive Water Saturation Model for Low-Porosity Sandstones

AAPG – June 10, 2009

by

Darrell Hoyer

Hoyer Petrophysics Inc.

Low Porosity Sands - Issues

- Drilled but not often tested
  - **The sands may have gas shows**
  - **Are the sands porous/permeable reservoirs?**
  - **Is the gas/oil saturation high enough to flow?**

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- Several 1000's of feet of potential reservoir
  - **Span several geologic horizons**
  - **Lack of evident water-bearing intervals**
  - **Variable formation water resistivity (RW)**
  - **Questionable SP development**
  - **Low/unstable water recovery from tests**

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- Hydraulic fracture stimulation completions

Cost - $$$

Petrophysical Water Saturation Model

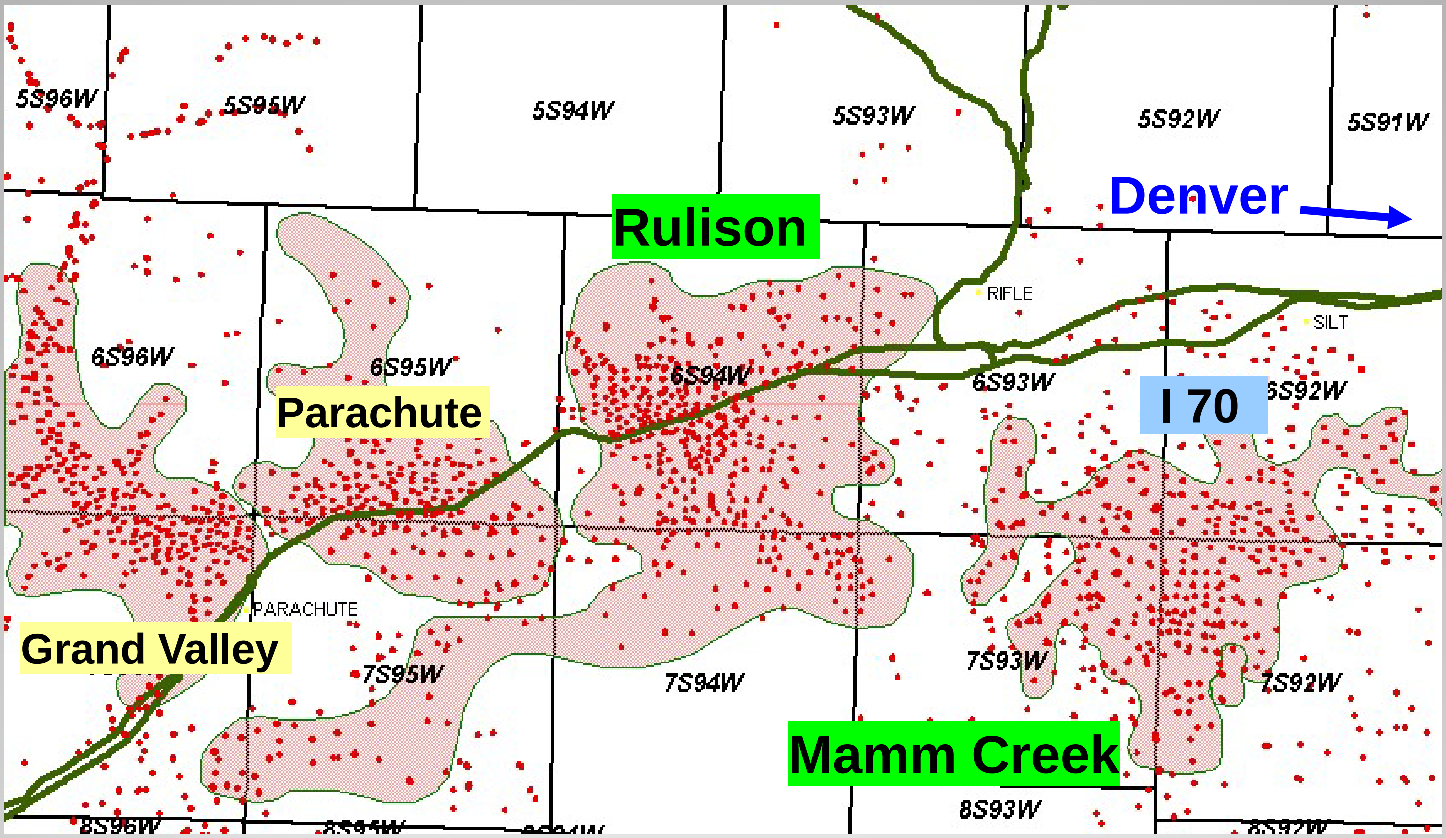
- Archie water saturation equation is empirical
  - Laboratory experiments and observation
- Several “shaly sand” equations have been developed
  - All regress to the basic Archie equation at 0% clay volume
- Is the water saturation model consistent at in situ conditions ??

$$SW = (RW / RT * a / PHIE^{m})^{1/n}$$

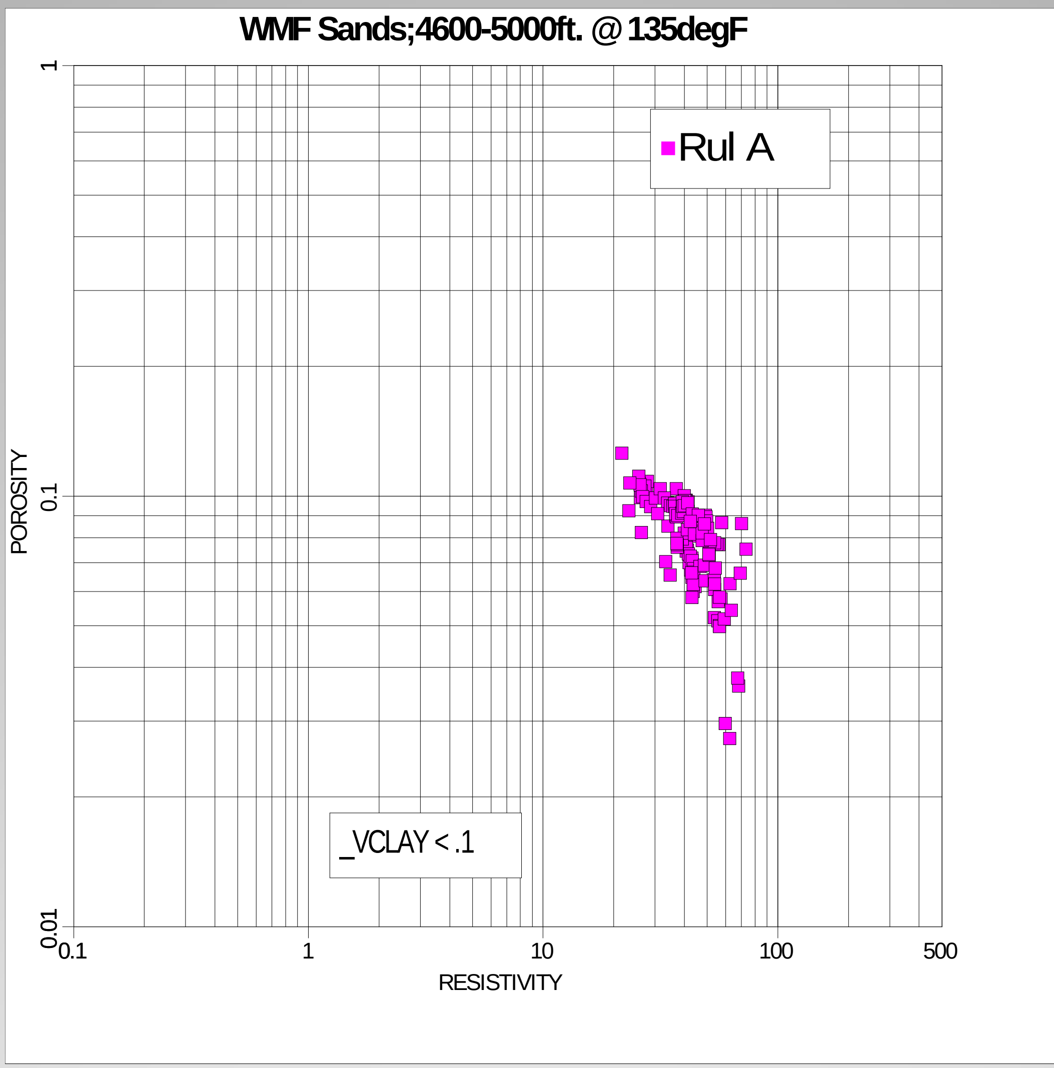
- Bulk Volume Water

$$BVW = Porosity * SW$$

Piceance Basin – I 70 Corridor



Pickett Plot - Piceance Basin @ Rulison
Upper Williams Fork Water Saturated Sands



Archie Water Saturation Equation

$$SW = (RW/RT * a/PHIE^{m})^{1/n}$$

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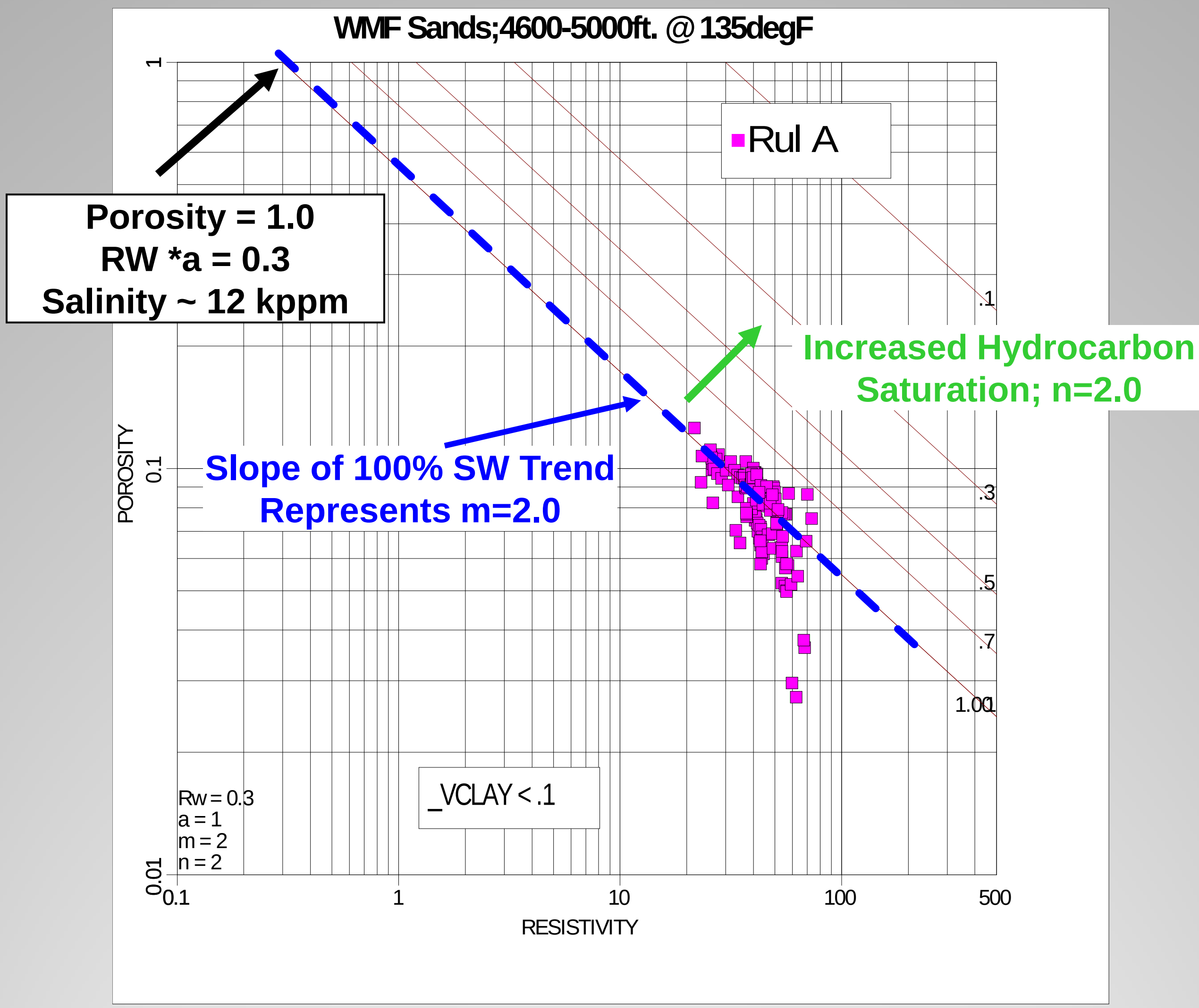
Pickett Plot – U WMF Water Sands
Often Assumed Archie Exponents
a=1, m=2 and n=2



Archie Water Saturation Equation

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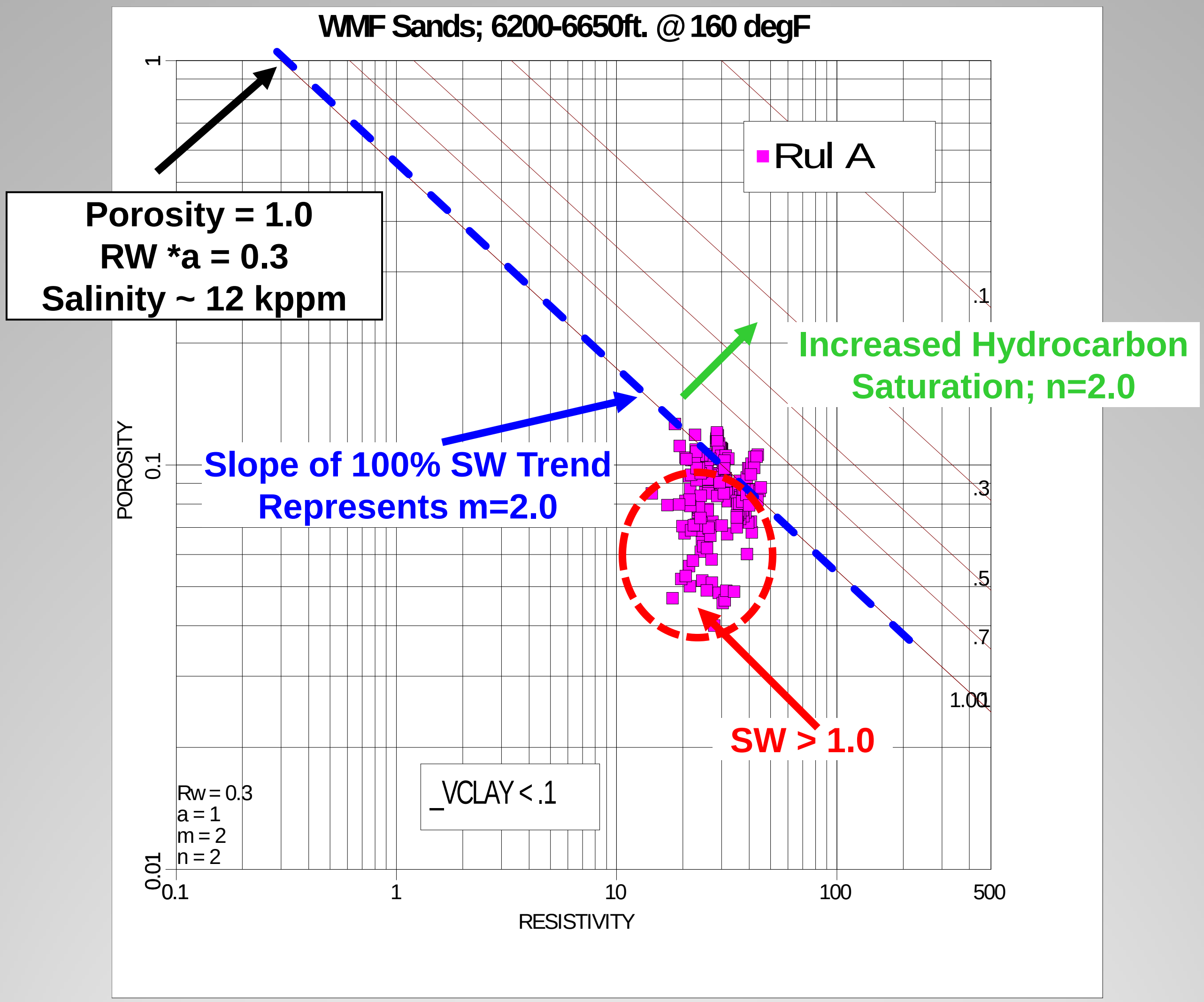
Pickett Plot – WMF Gas Cell
Assumed Archie Constants
a=1, m=2 and n=2



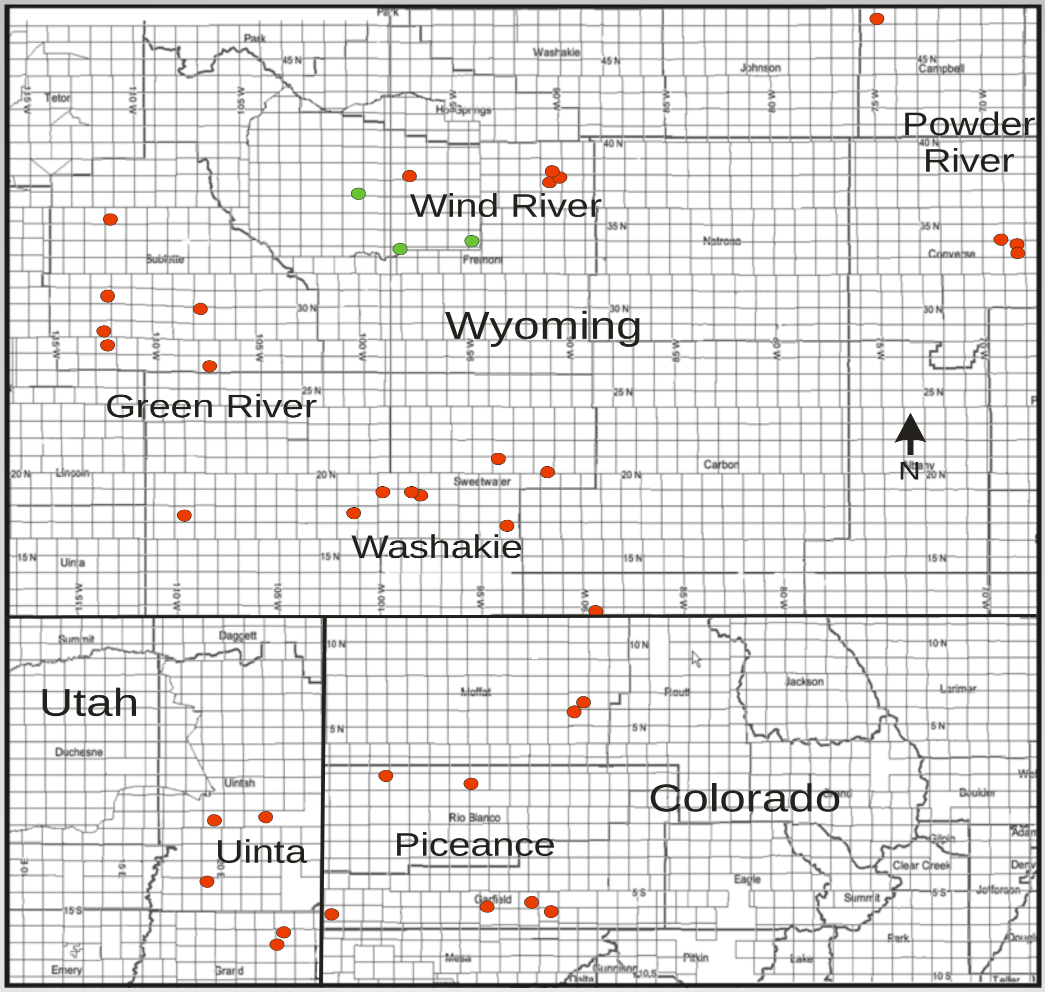
EUR ~ 1.6 BCF

Recent published data (July, 2008) from the DOE/KGS project;

Regional Petrophysical Properties of Mesaverde Low-Permeability Sandstones

Byrnes, Cluff & Webb

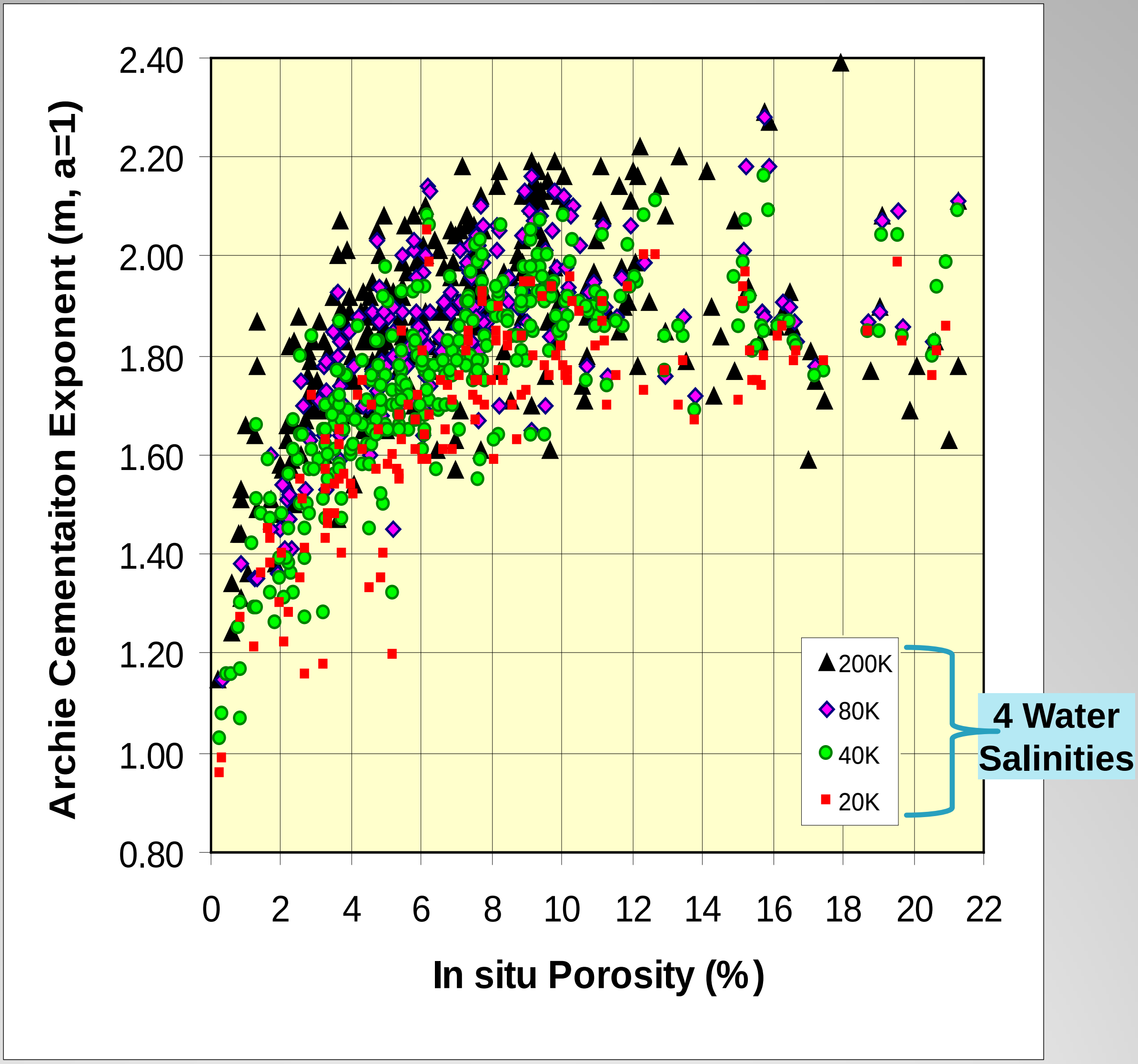
- **Systematic Characterization of Kmv lithofacies over Rocky Mtn. region**
- **44 wells / 6 Basins**
- **Described ~7000 ft. of core (digital)**
- **2200 core samples**
- **120- 400 advanced properties samples**



DOE / KGS Project Results;

335 Kmv Samples @ 4 Water Salinities

Archie Cementation Exponent "m" decreases with Porosity and Water Salinity.

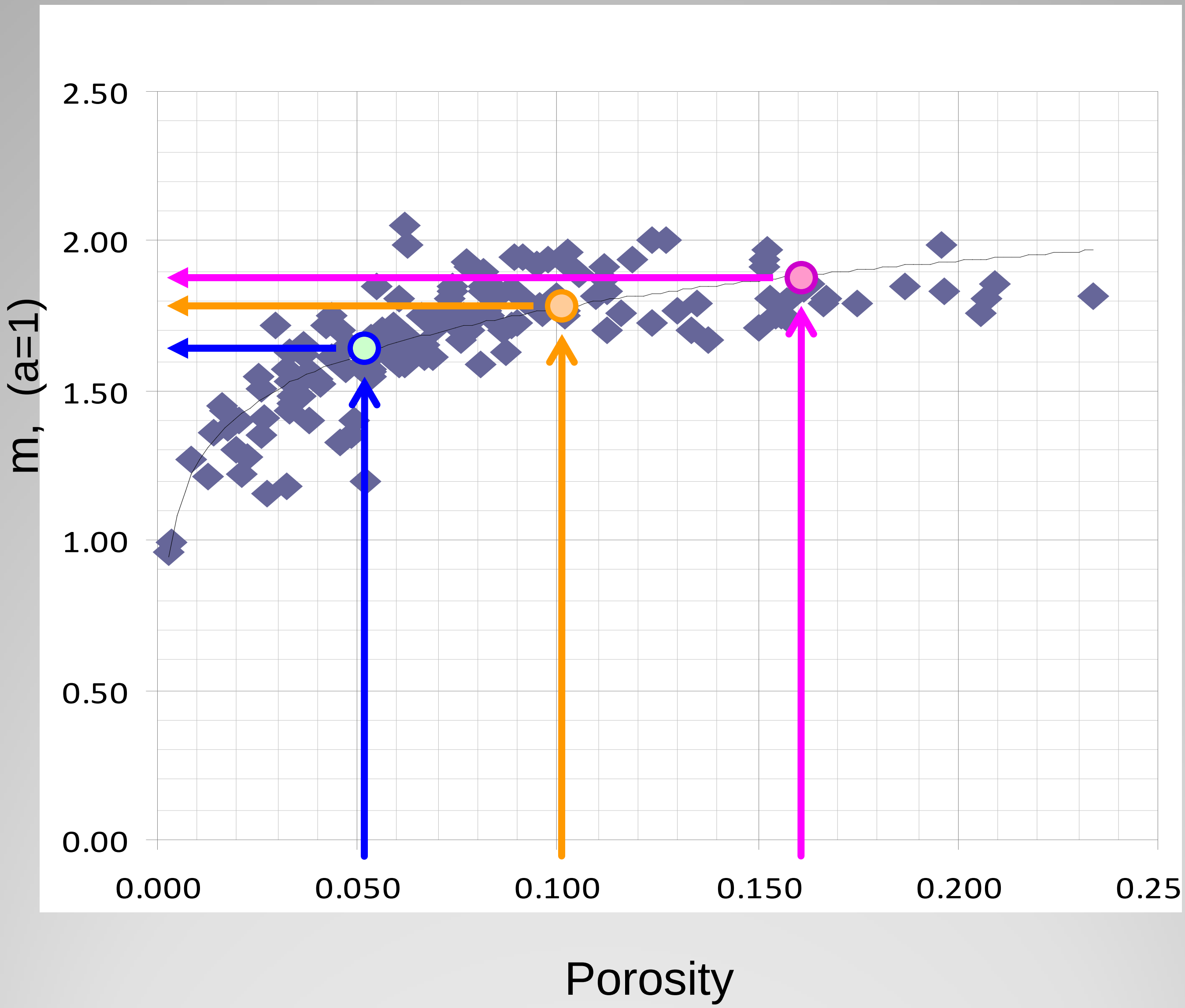


"Behavior is consistent with increasing electrical efficiency with decreasing porosity, whatever the pore scale architecture."

DOE / KGS Results;

335 Kmv Samples @ 20,000 ppm NaCl-

Archie Cementation Exponent "m" decreases with Porosity.



m ~ 1.65 @ 5% Porosity

m ~ 1.80 @ 10% Porosity

m ~ 1.90 @ 16% Porosity

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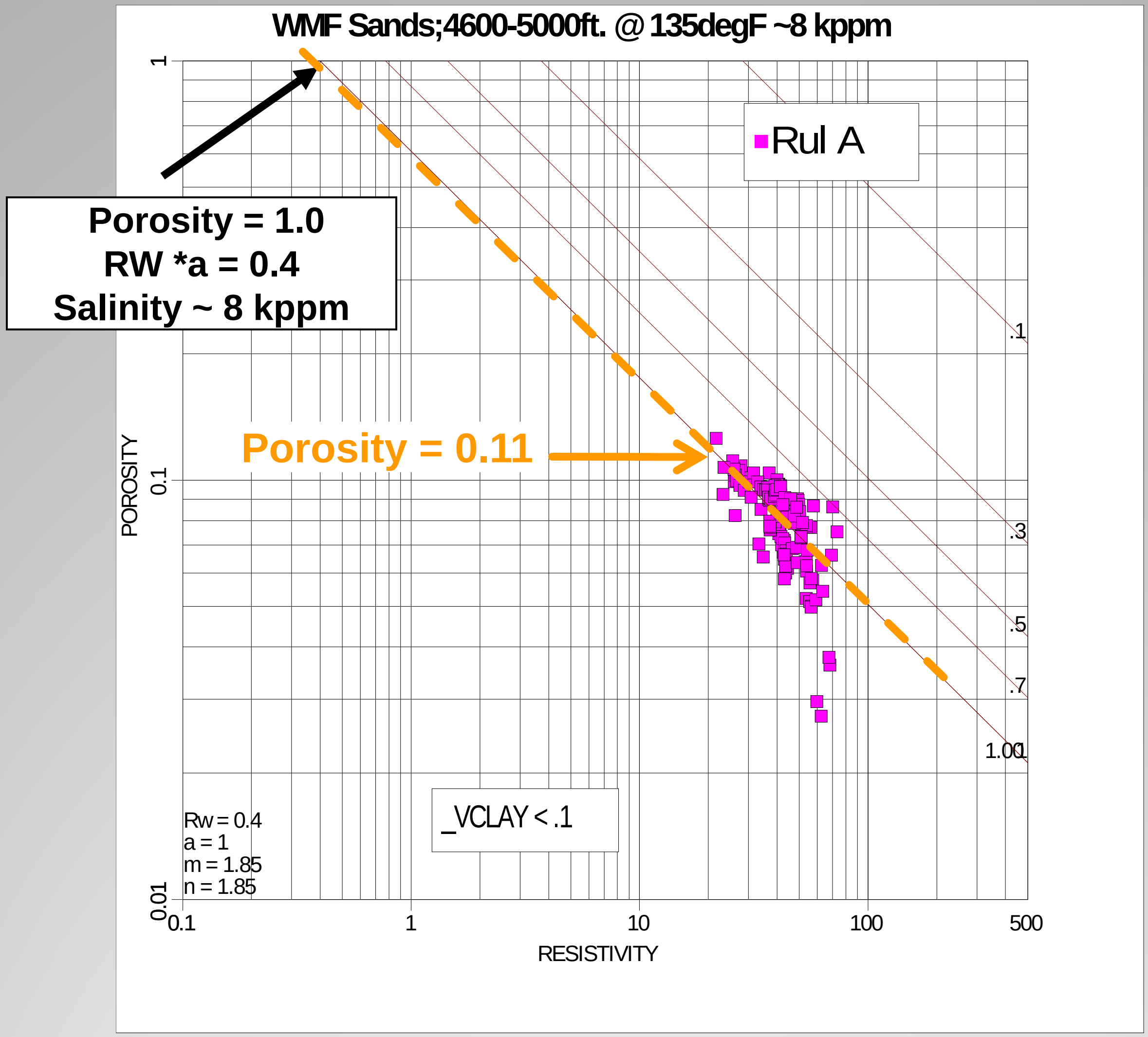
Piceance Basin @ Rulison
U WMF – Water-Saturated Sands
m=1.85 @ 11 % Porosity



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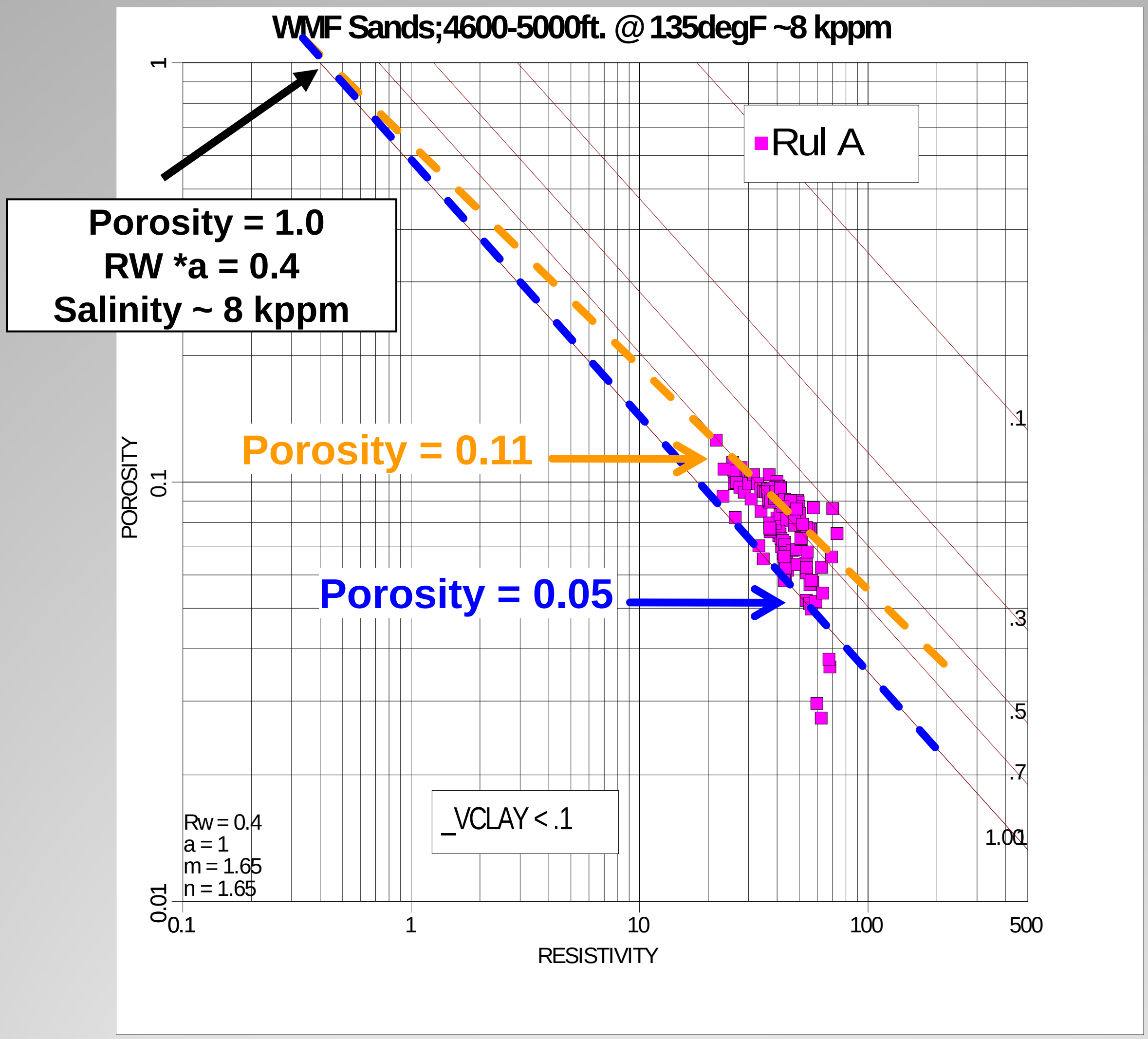
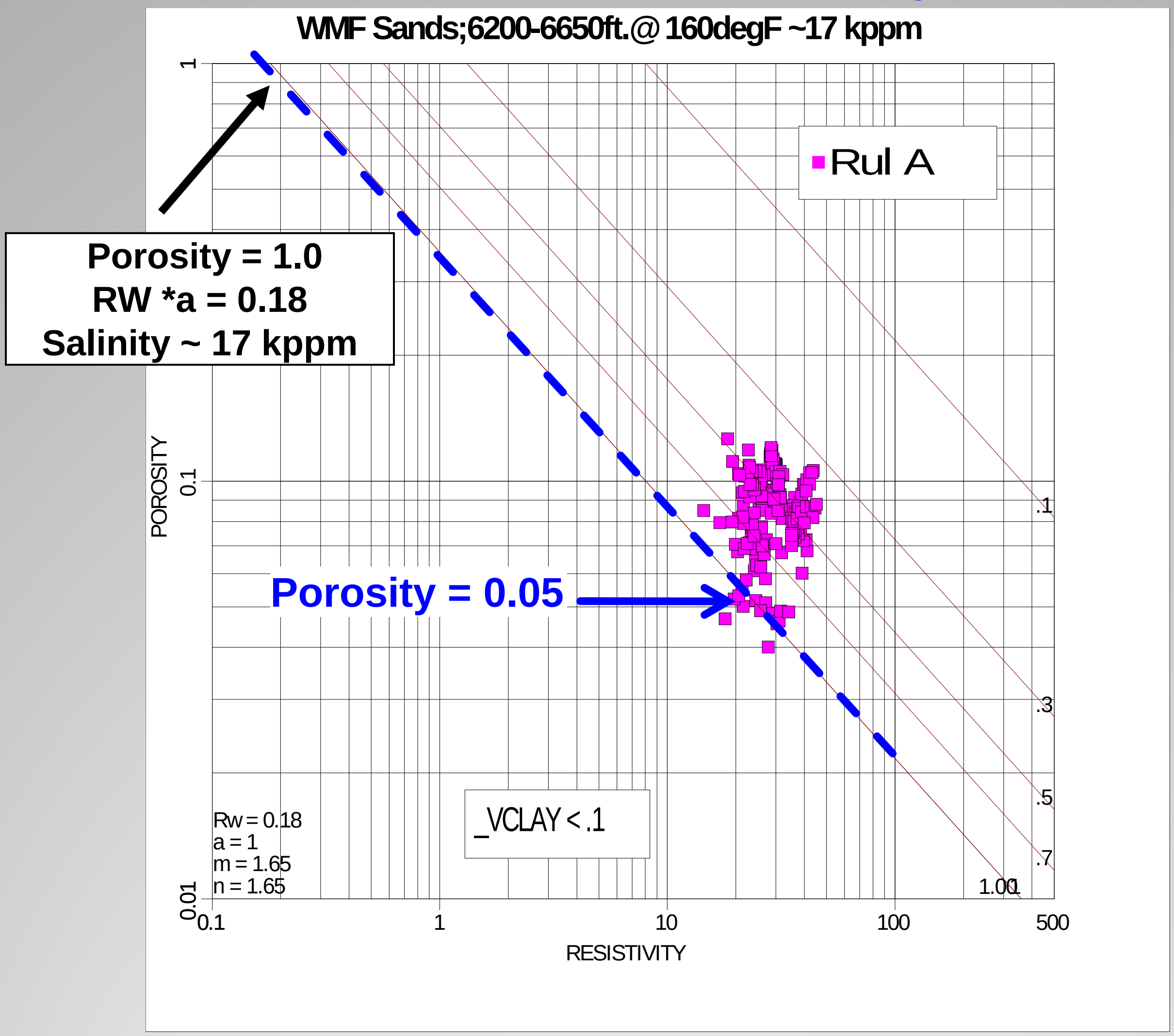


Piceance Basin @ Rulison
WMF – Gas Cell

m=1.85 @ 11 % Porosity

m=1.65 @ 5 % Porosity



EUR ~ 1.6 BCF

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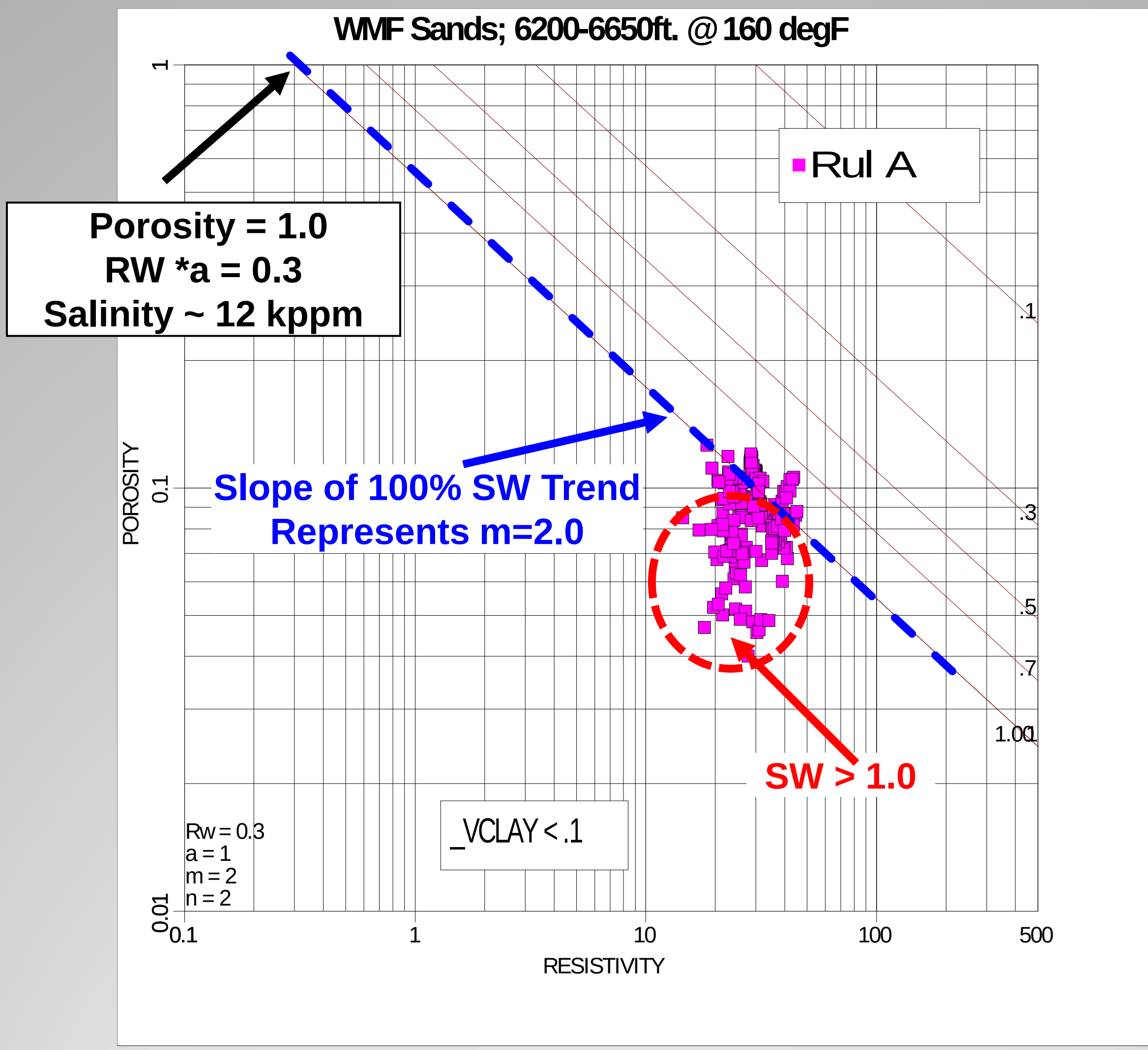

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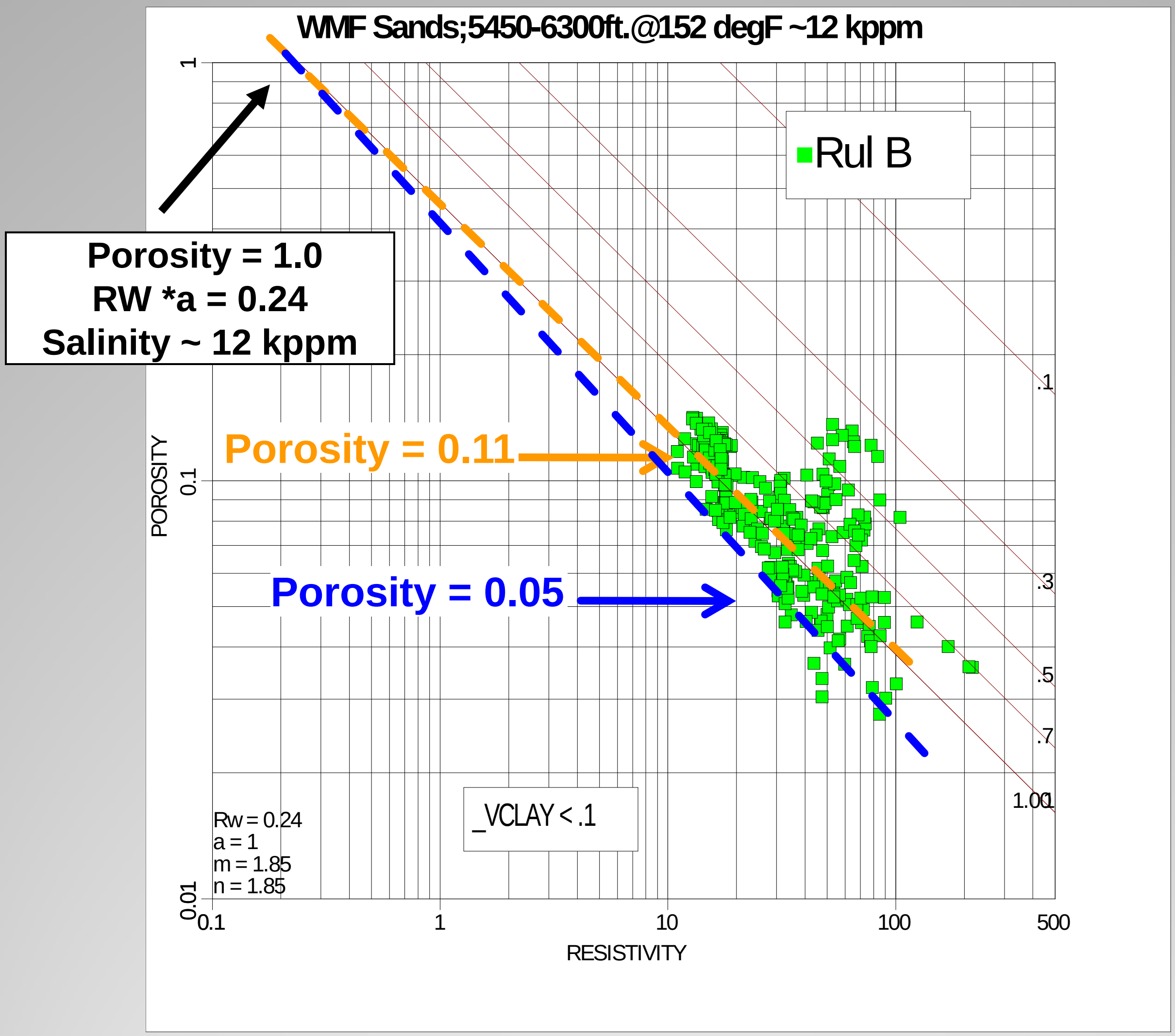

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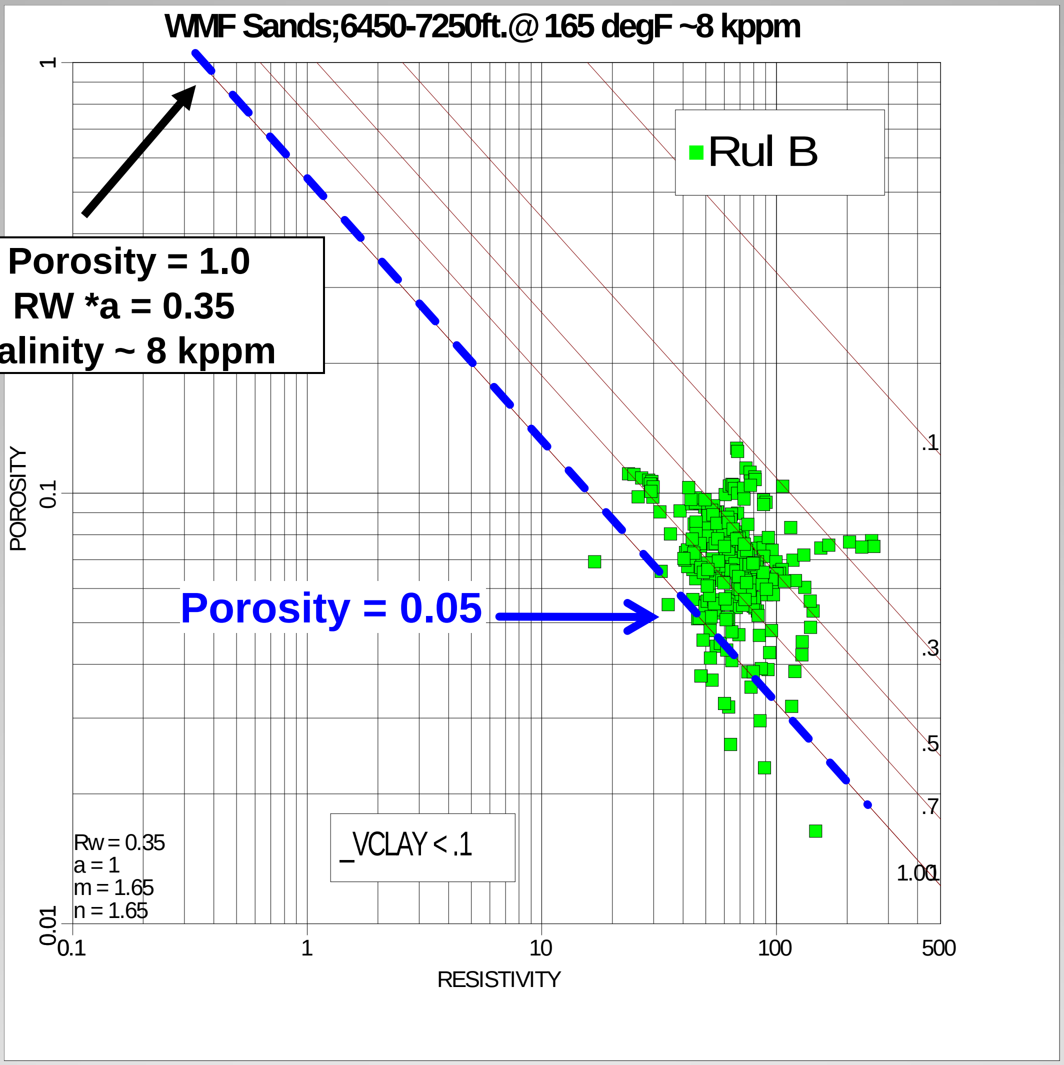
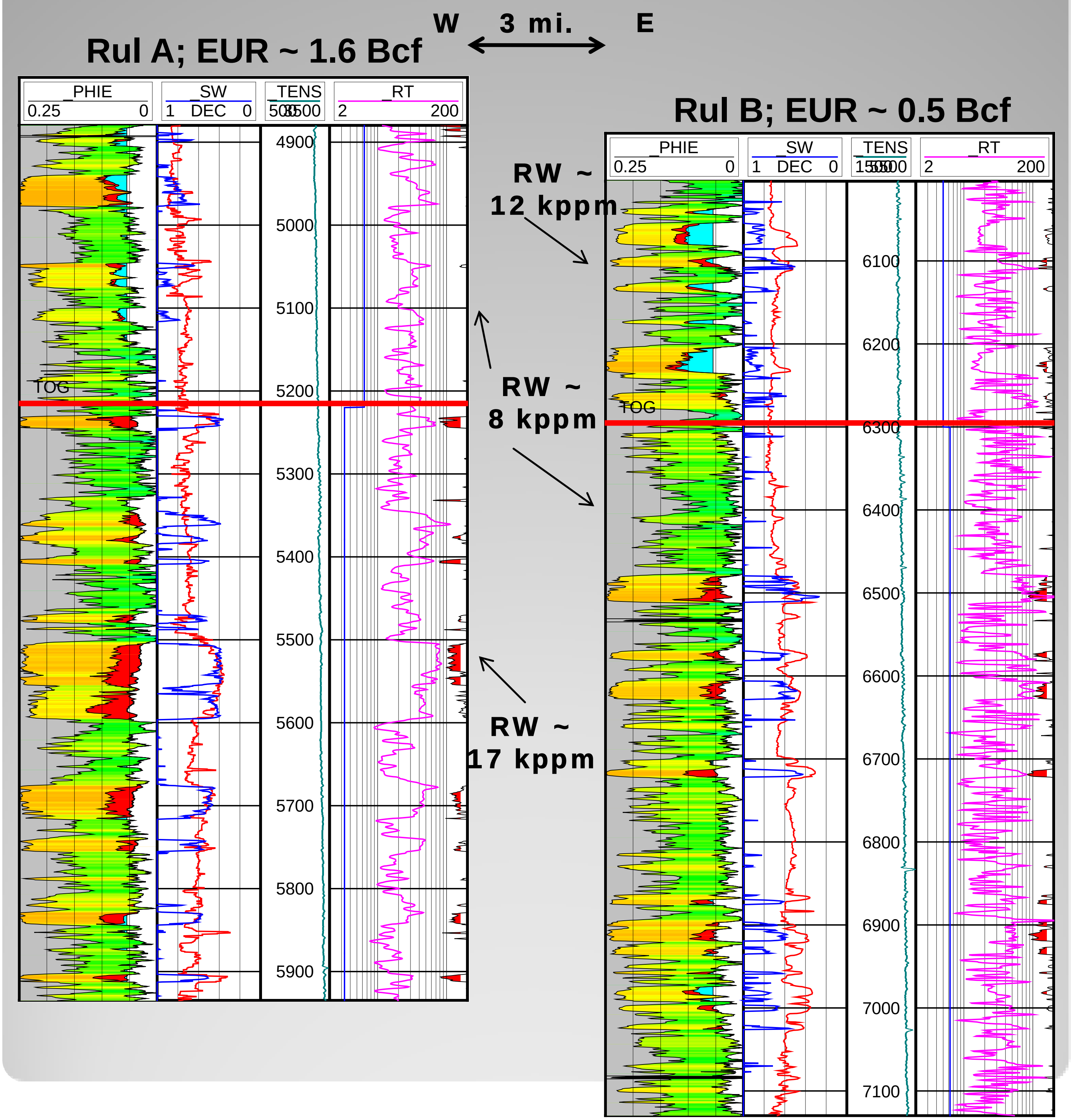


EUR ~ 0.5 BCF

Piceance Basin @ Rulison

Formation Water Salinity Change @ Gas-Water Contact



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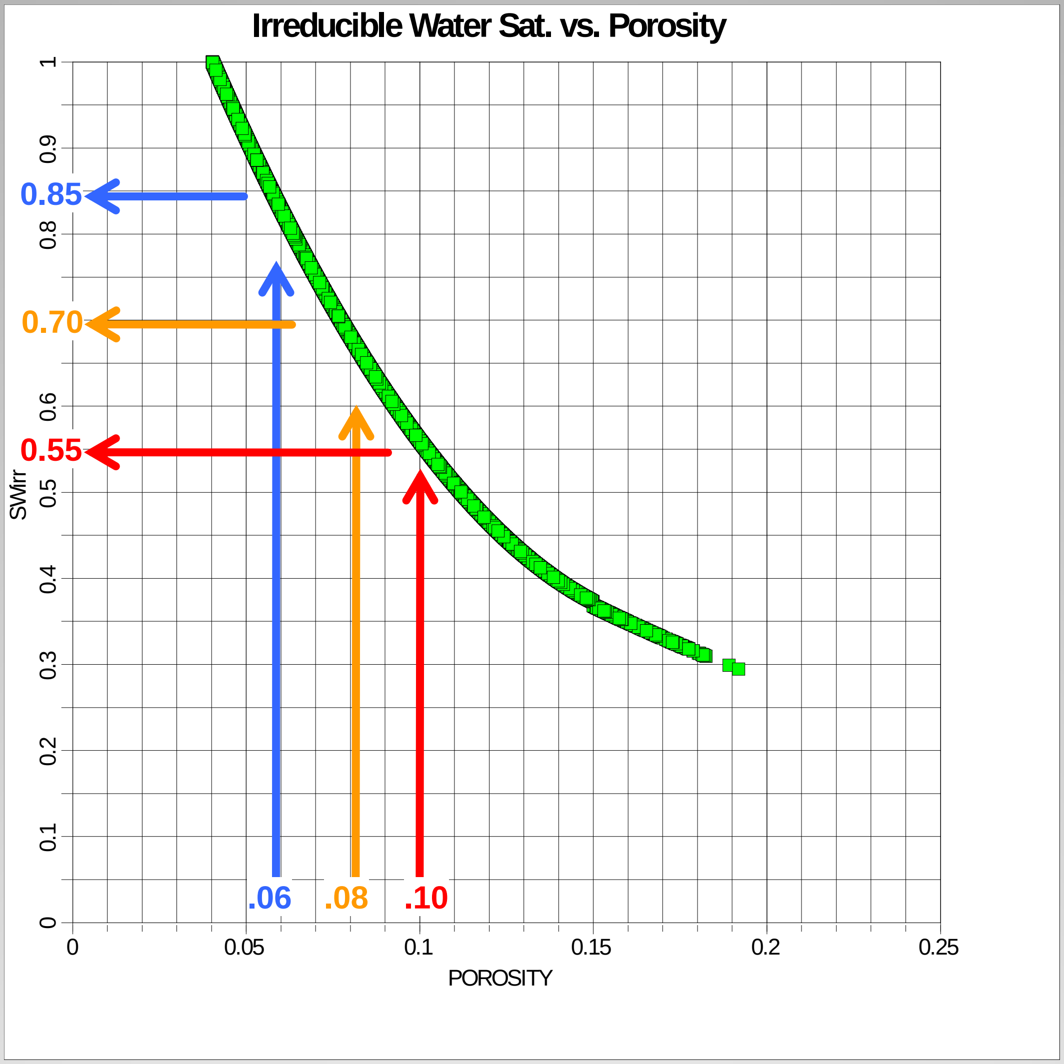
SW Cutoff - Varies with Porosity
BVW Cutoff = 0.055



BVW = Porosity * SW

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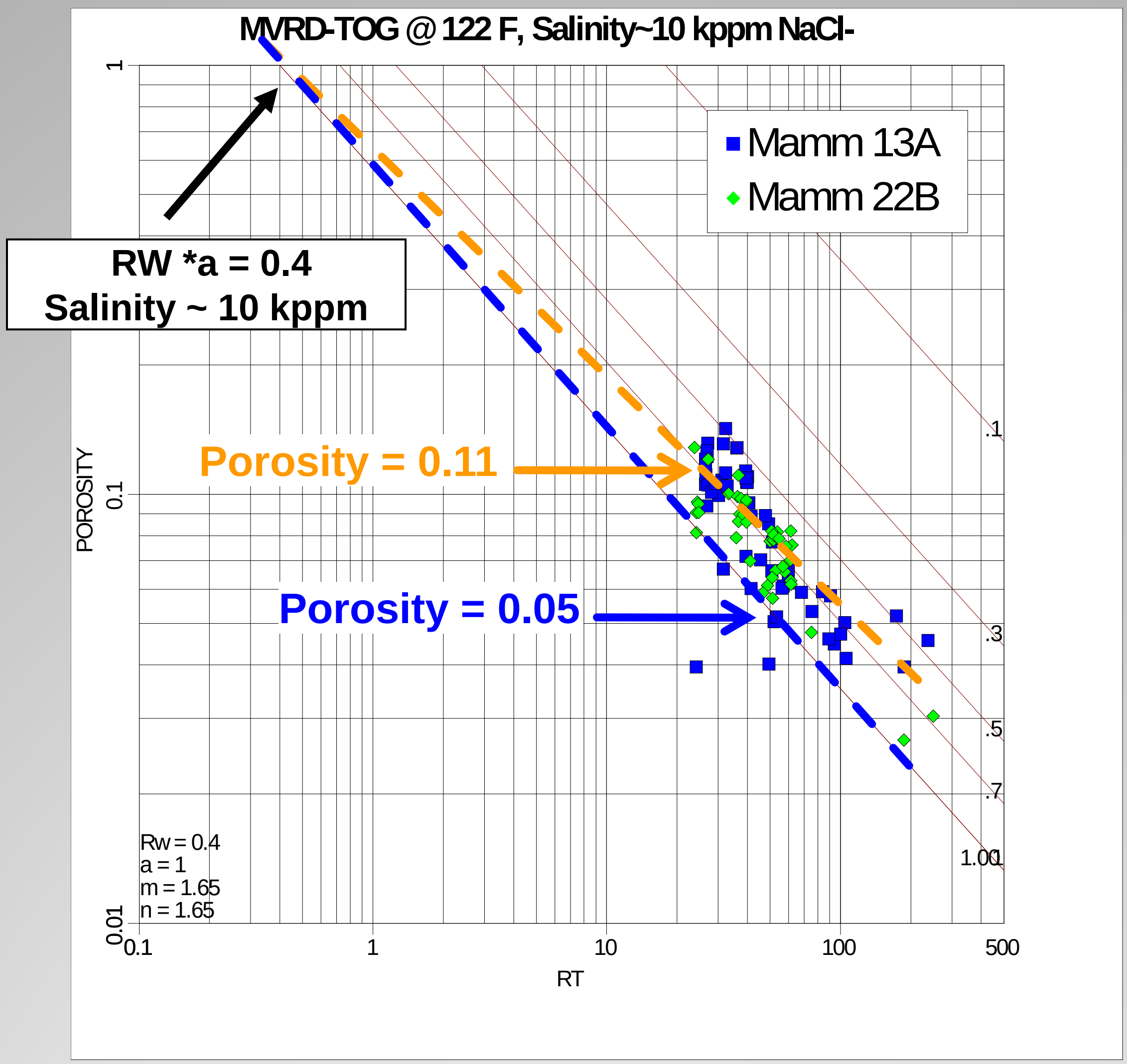
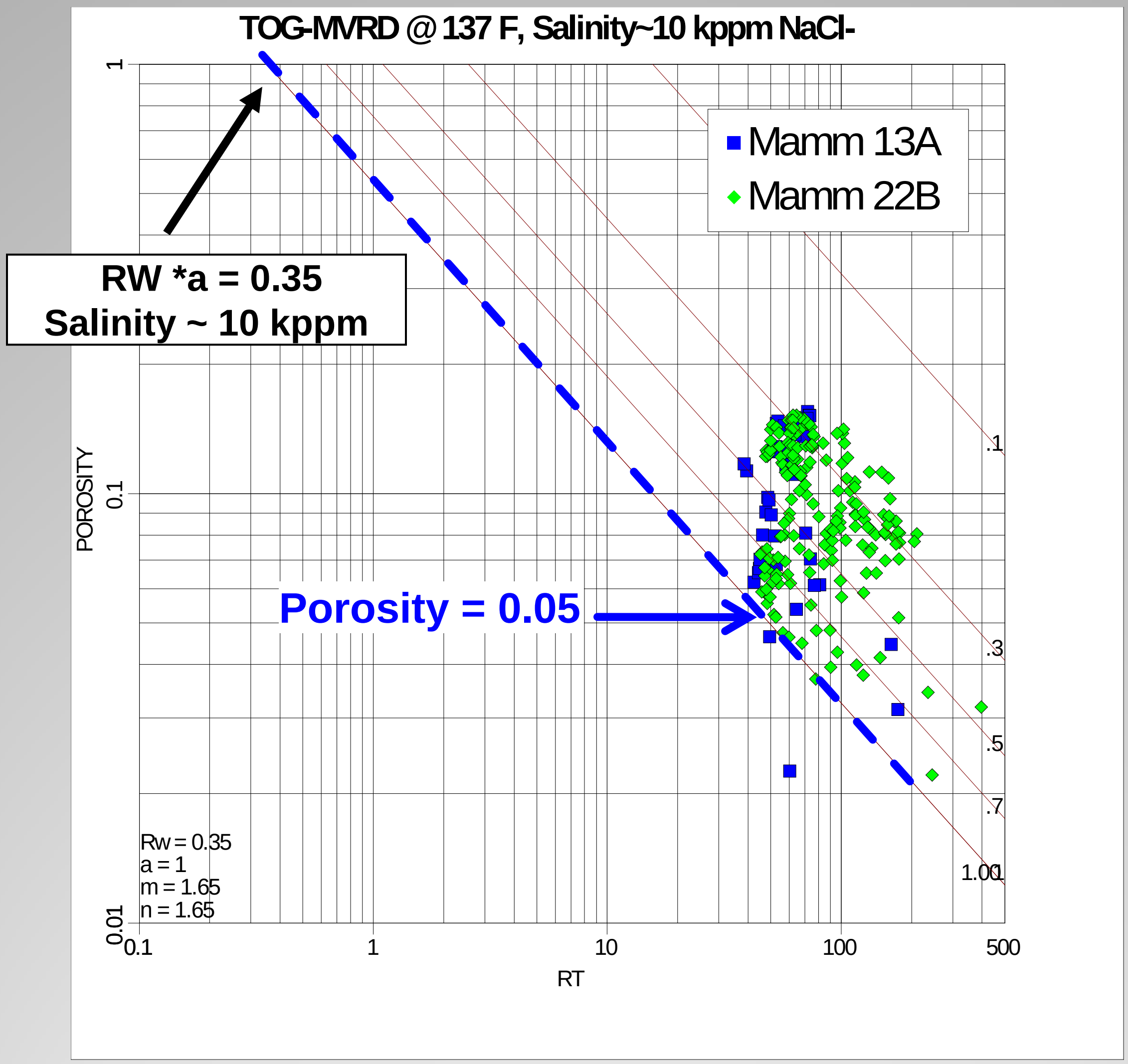
Piceance Basin @ Mamm Creek
U WMF – Water-Saturated Sands

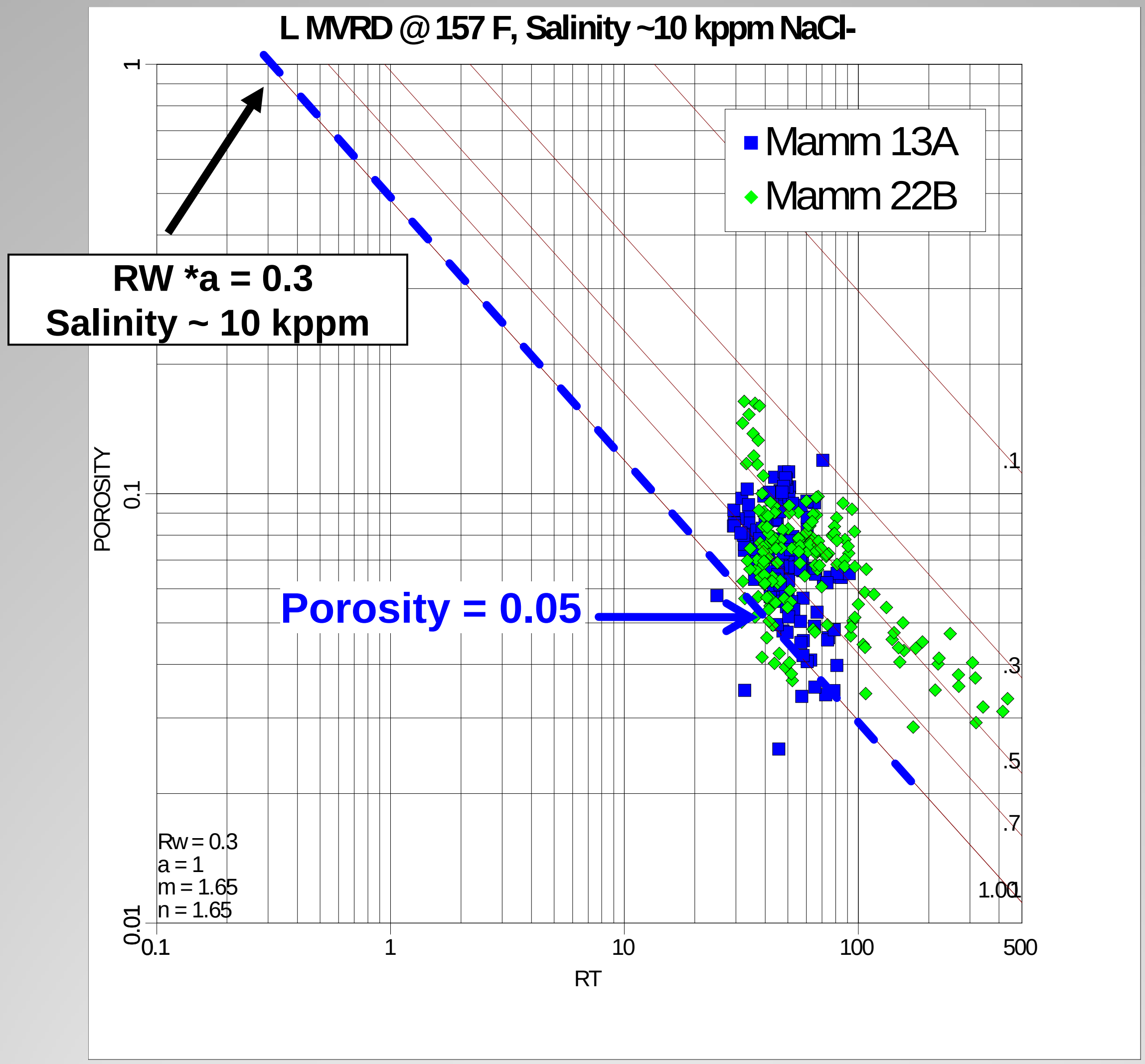


Piceance Basin @ Mamm Creek
U WMF – Gas Cell



Gas Storage - Porosity > 6%

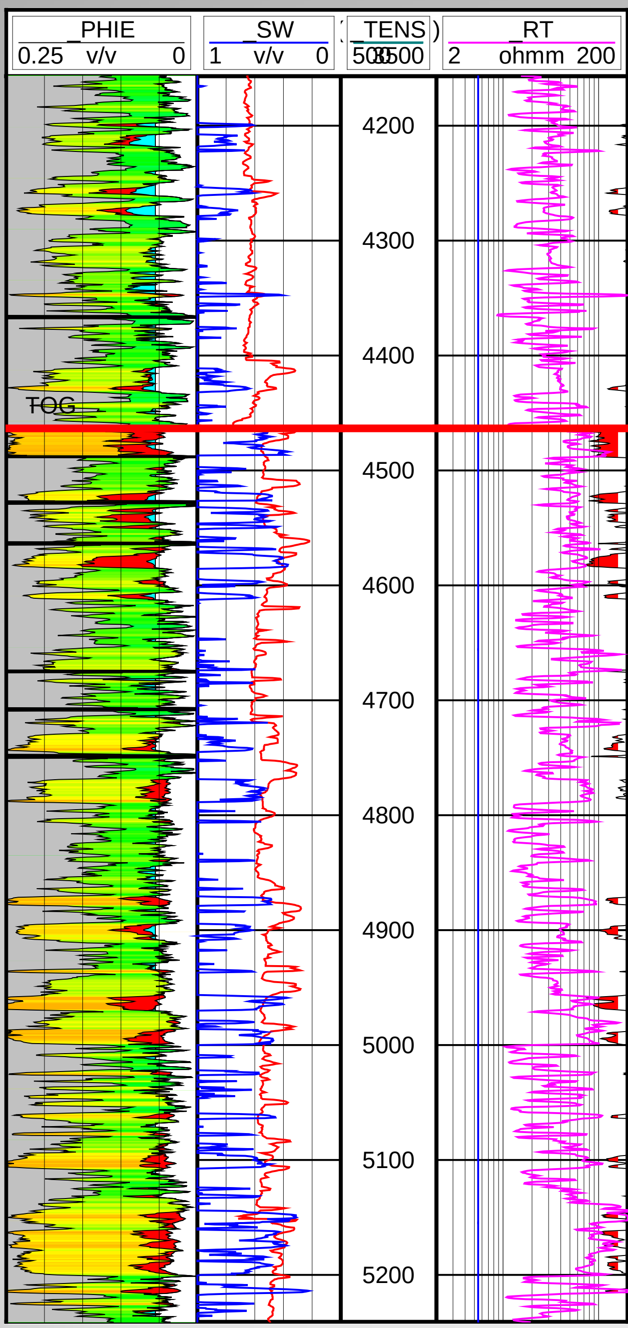
Piceance Basin @ Mamm Creek
L WMF – Gas Cell



Gas Storage - Porosity > 6%

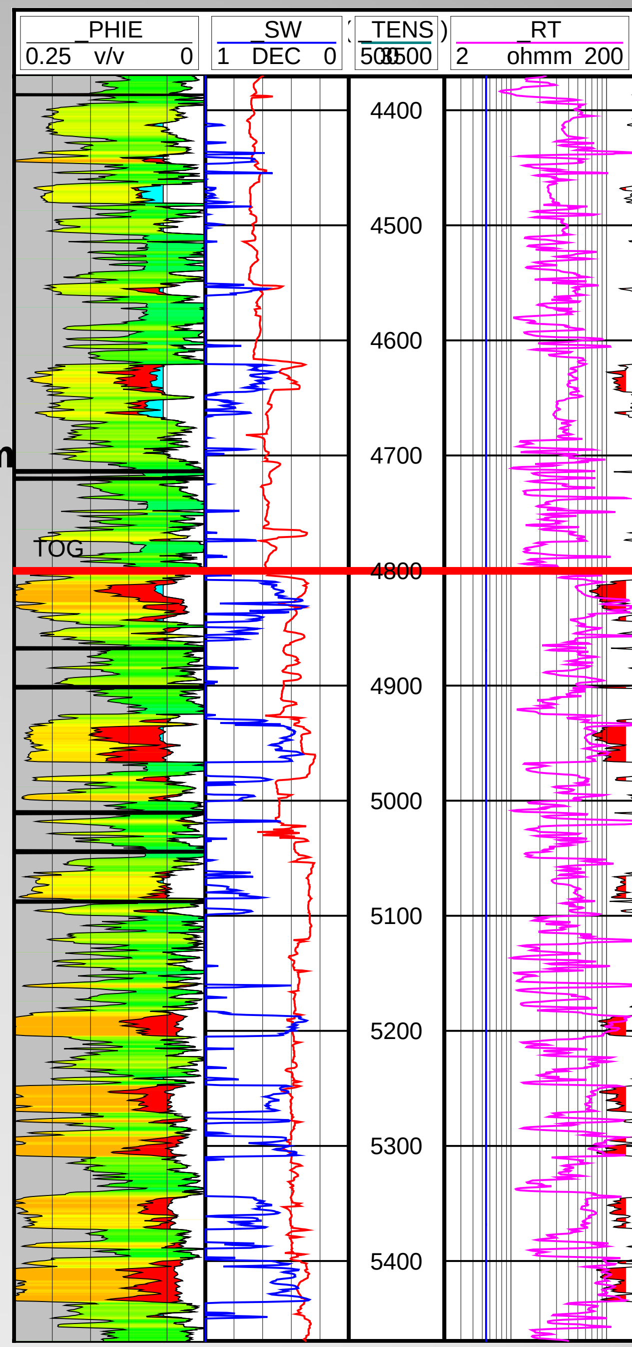
Piceance Basin @ Mamm Creek
Gas-Water Contact

Mamm13A; EUR ~ 1.3 Bcf



RW ~ 10 kppm

Mamm13A; EUR ~ 1.8 Bcf



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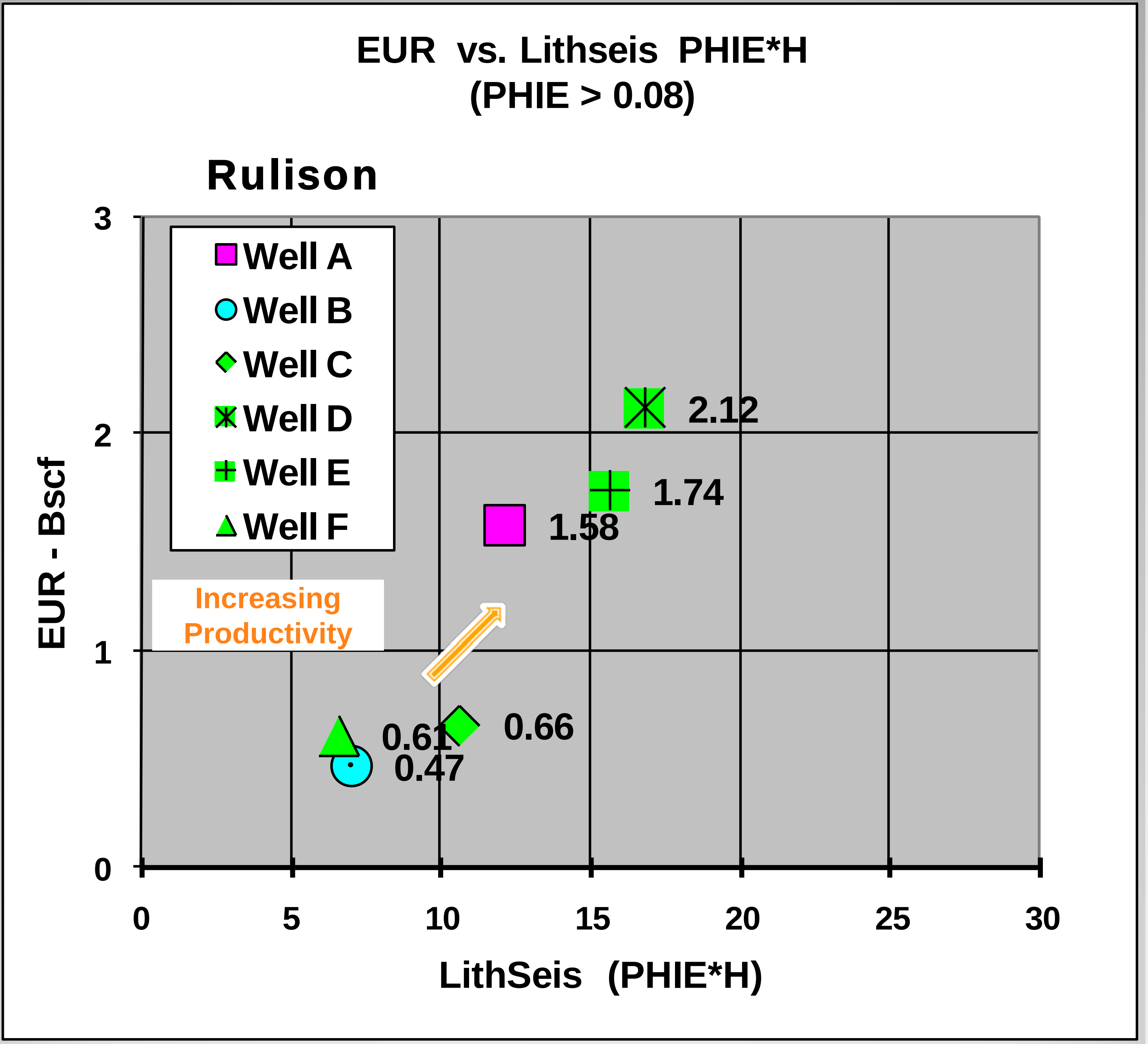
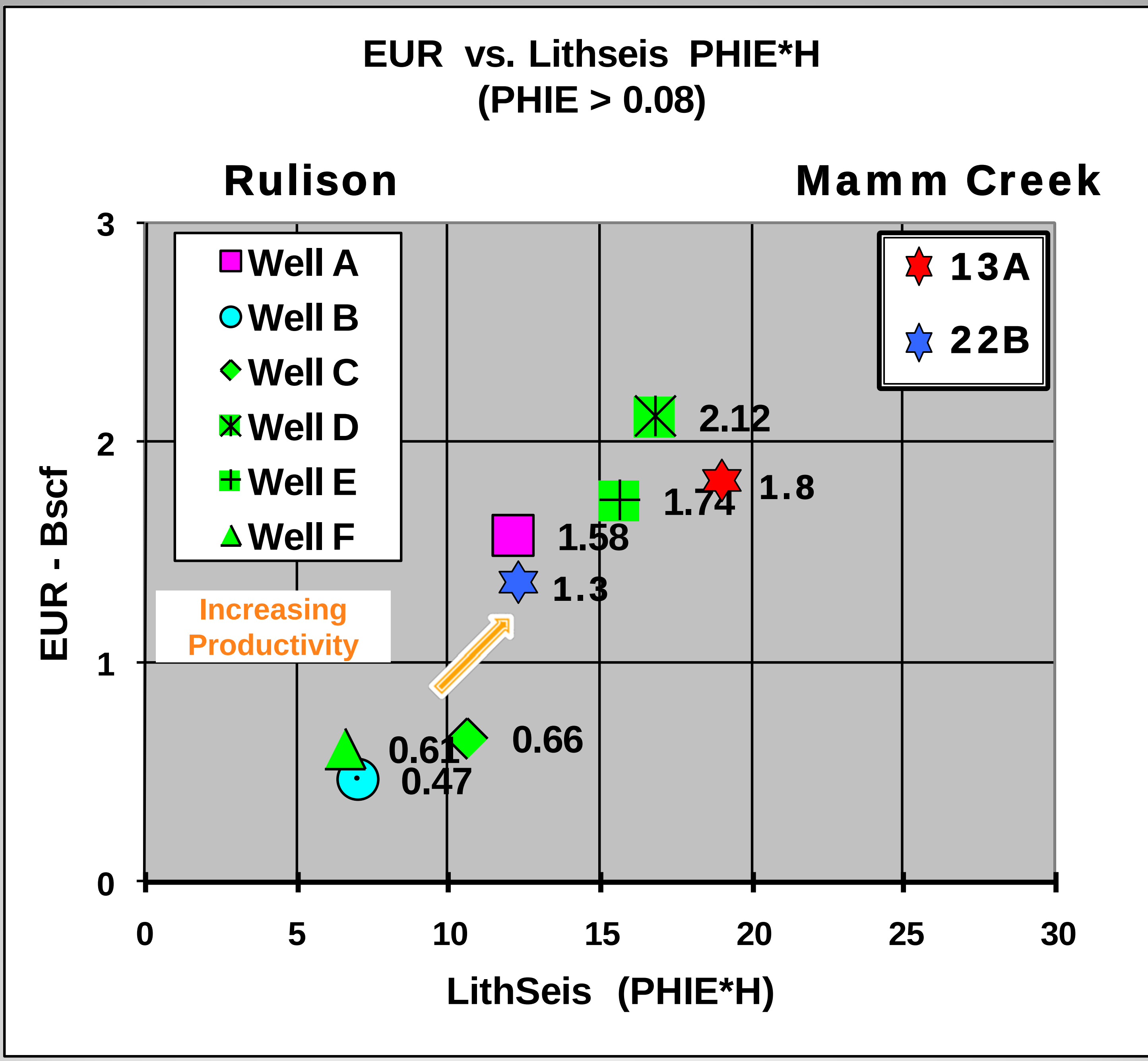
Piceance Basin @ Rulison
Seismic PHIE *H vs. EUR



After; Hoyer & Young
RMS AAPG - 2008

Piceance Basin
Rulison vs. Mamm Creek



After; Hoyer & Young
RMS AAPG - 2008

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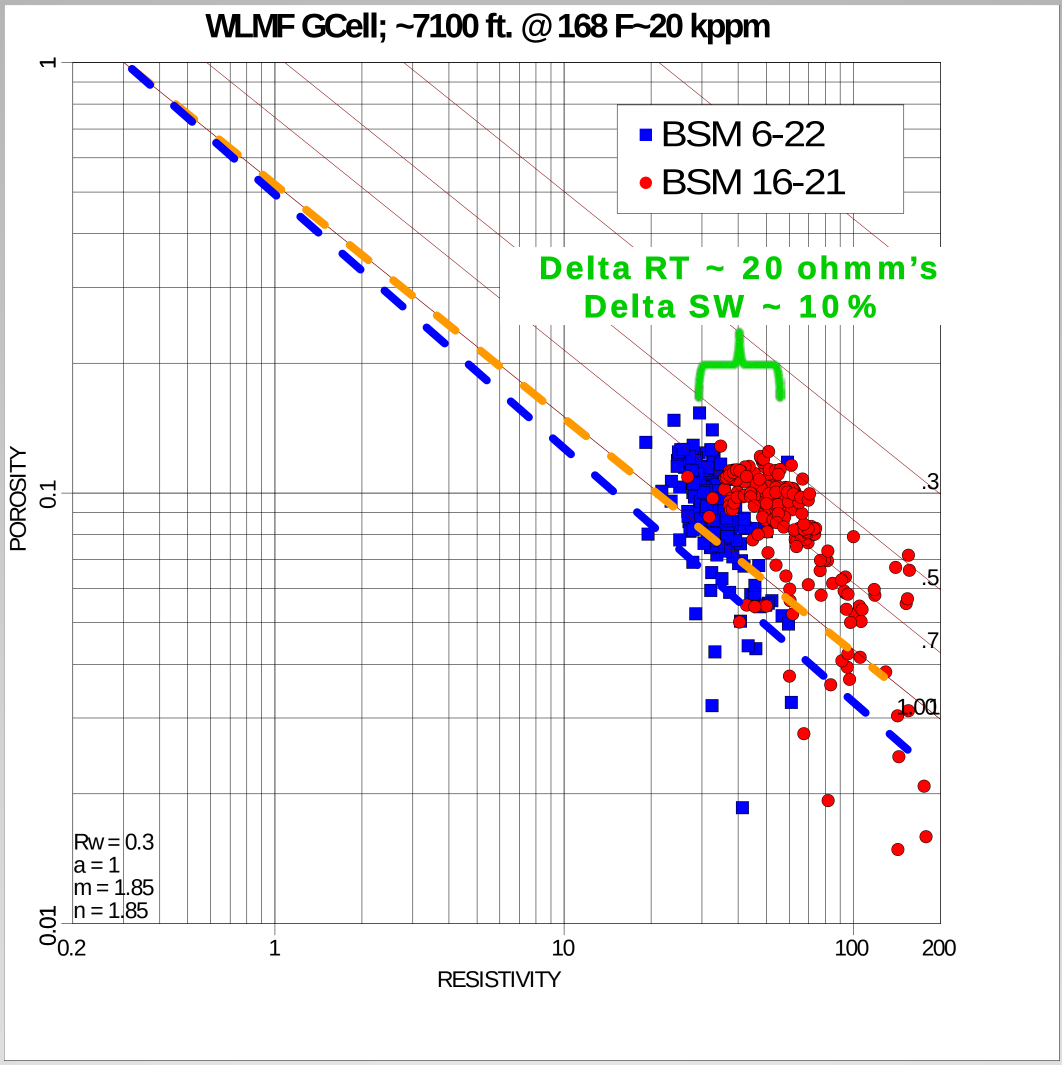
North East - Piceance Basin
Example; Critical Gas Saturation



BSM 6-22 ~ Tested mostly water & Slight Gas

BSM 16-21 ~ Tested 0.315 mmscfd

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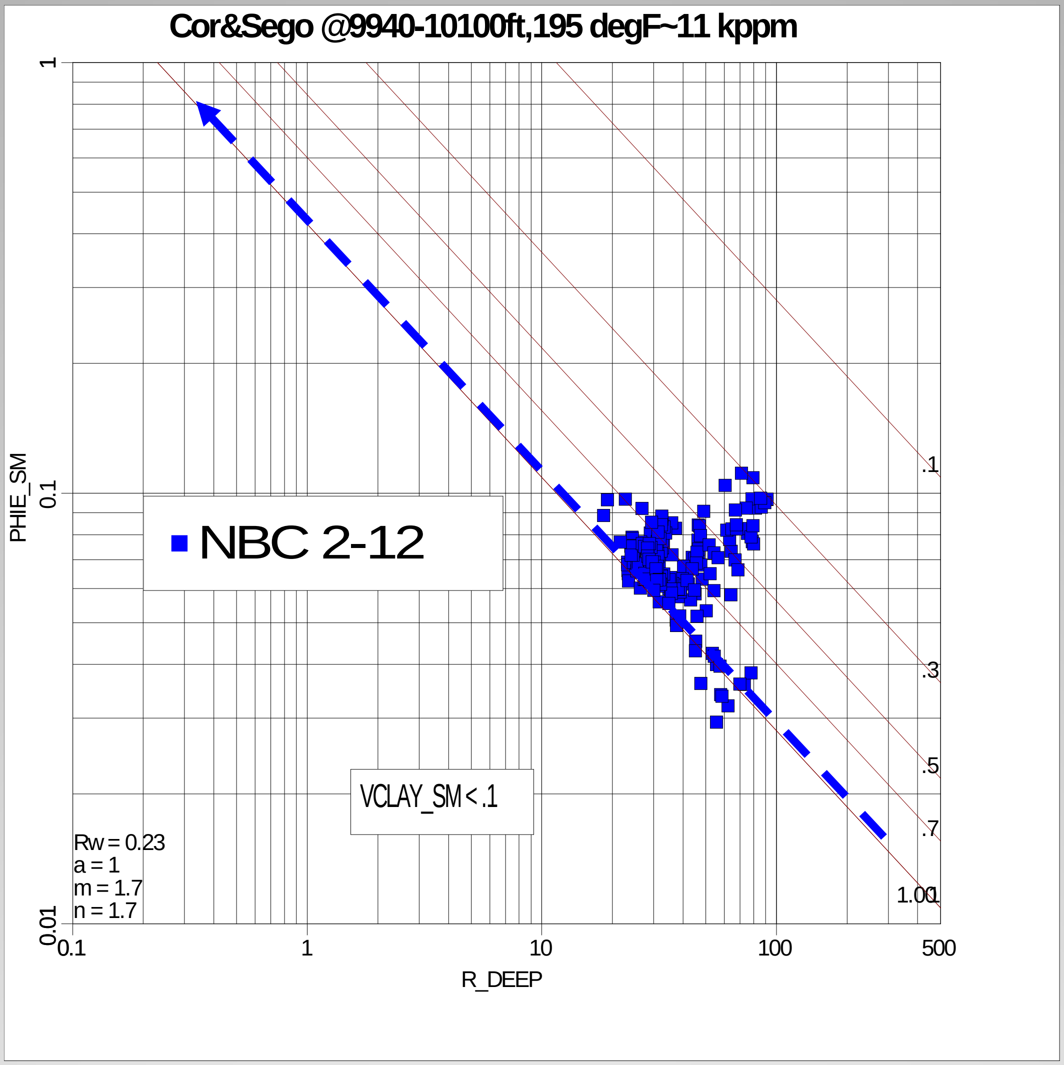
North West - Piceance Basin
Corcoran & Sego Sands
Gas & Water Production



Production Log Results;
0.5 mmscf/d & 320 bbls Water

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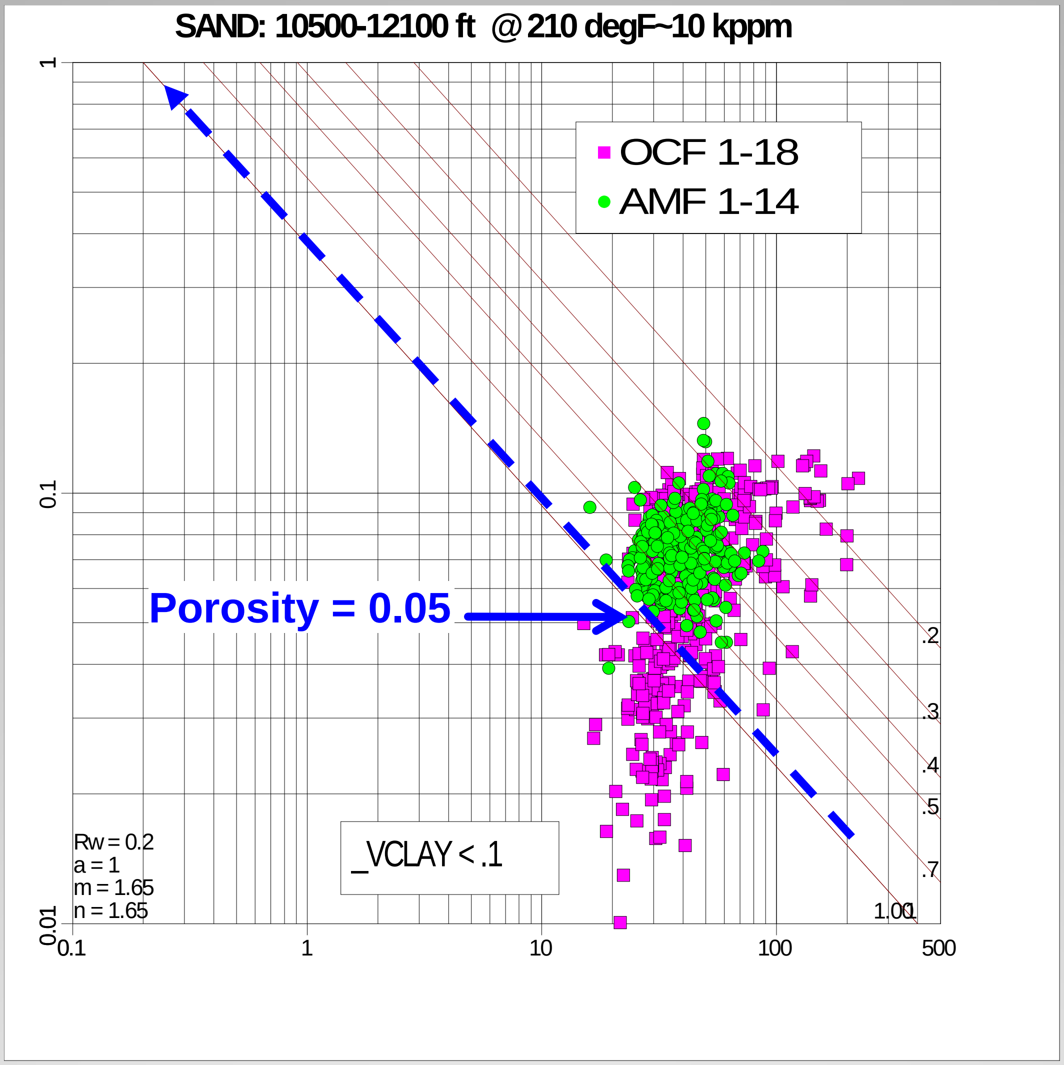
Wyoming; - L. Fort Union & Lance
Gas Saturated Sands



WR OCF 1-18
IP @ 3.8 mmcf/d,
70 bbls/d Oil & 132 bbls/d Water

Conclusions

- Rigorous petrophysical evaluation of low-porosity sands require error minimization
  - Log QC & Normalization
  - Core data – DOE/KGS study
  - Formation water chemistry/distribution
- Pickett Plots are valuable visual tools for development & QC of the SW model
  - Log inputs RT and PHIE
  - Archie exponents a, m & n
  - RW determination
  - Saturation profile
  - Gas/Oil Storage

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- A Coherent petrophysical model optimizes exploration & development efforts

Saves - $$$

References

Byrnes, Alan P., Robert M. Cluff, and John C. Webb, 2007, Regional petrophysical properties of Mesaverde low-permeability sandstones (abstract): Rocky Mountain Section AAPG Meeting, Snowbird, Utah, October 7-9, 2007; Search and Discovery Article #90071 (2007) (http://searchanddiscovery.net/abstracts/html/2007/rocky_mountain/abstracts/byrnes.htm).

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Hoyer, Darrell, and Roger Young, 2008, Seismic petrophysics in tight gas sands - a Piceance Basin, Mesa Verde example (abs.): Rocky Mountain Section, AAPG Meeting, Denver, Colorado, July 9-11, 2008. Web accessed 20 August 2009. http://www.rms-aapg.org/2008_meeting/RMS-AAPG2008abstracts.pdf