A METHOD TO QUANTIFY GAS SATURATION IN GAS/WATER SYSTEMS, USING DENSITY AND NEUTRON LOGS – INTERPRETATION OF RESERVOIR PROPERTIES WHEN COMPARED WITH GAS SATURATIONS FROM RESISTIVITY ANALYSIS

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ABSTRACT

A standard approach to evaluate gas effects on porosity logs is the "density/neutron cross over" response. In the presences of gas, bulk density is reduced, and the neutron log is suppressed.

The degree of cross over can be related quantitatively to gas saturation, so long as accurate knowledge of matrix lithology is available. In the calculations presented in this presentation, porosity calculations (lithology corrected) for the density and neutron logs are compared with the cross plot density/neutron porosity. This latter calculation requires no input of matrix properties and, in gas/water systems, is relatively insensitive to fluid content.

Differences between the individual porosity log calculations and cross plot porosity yield quantified estimates of gas saturation for each log individually. These estimates, when compared with standard resistivity modeling of gas saturation can be used to gain insight into gas reservoir characteristics:

- If gas saturations agree, the conclusion can be drawn that all sources of petrophysical data are consistent, and the model is robust. Agreement also suggests that all sources of data are equally affected by the wellbore environment, i.e. the porosity logs have not been influenced by invasion.
- If, as is common, gas saturations from porosity logs are significantly less than that derived from resistivity analysis, a number of possible explanations exist:
    - Matrix properties are inaccurate.
    - There has been pervasive invasion by mud filtrate, with extensive flushing of gas away from the wellbore.
    - The calculations of shale volume are inaccurate – for example presence of kaolin that a gamma ray measurement might not detect.
    - Presence of fresh water sands, with high values of water resistivity that have been mistaken for gas-bearing sands when analyzed by resistivity modeling.

Examples from tight gas sands of the Rocky Mountains are presented, to show variable reservoir responses as outlined above.

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A Method to Quantify Gas Saturation in Gas/Water Systems, Using Density and Neutron Logs – Interpretation of Reservoir Properties When Compared With Gas Saturations from Resistivity Analysis

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  - Grand Valley Piceance Basin
  - Panhandle of Texas, Brown Dolomite
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Introduction

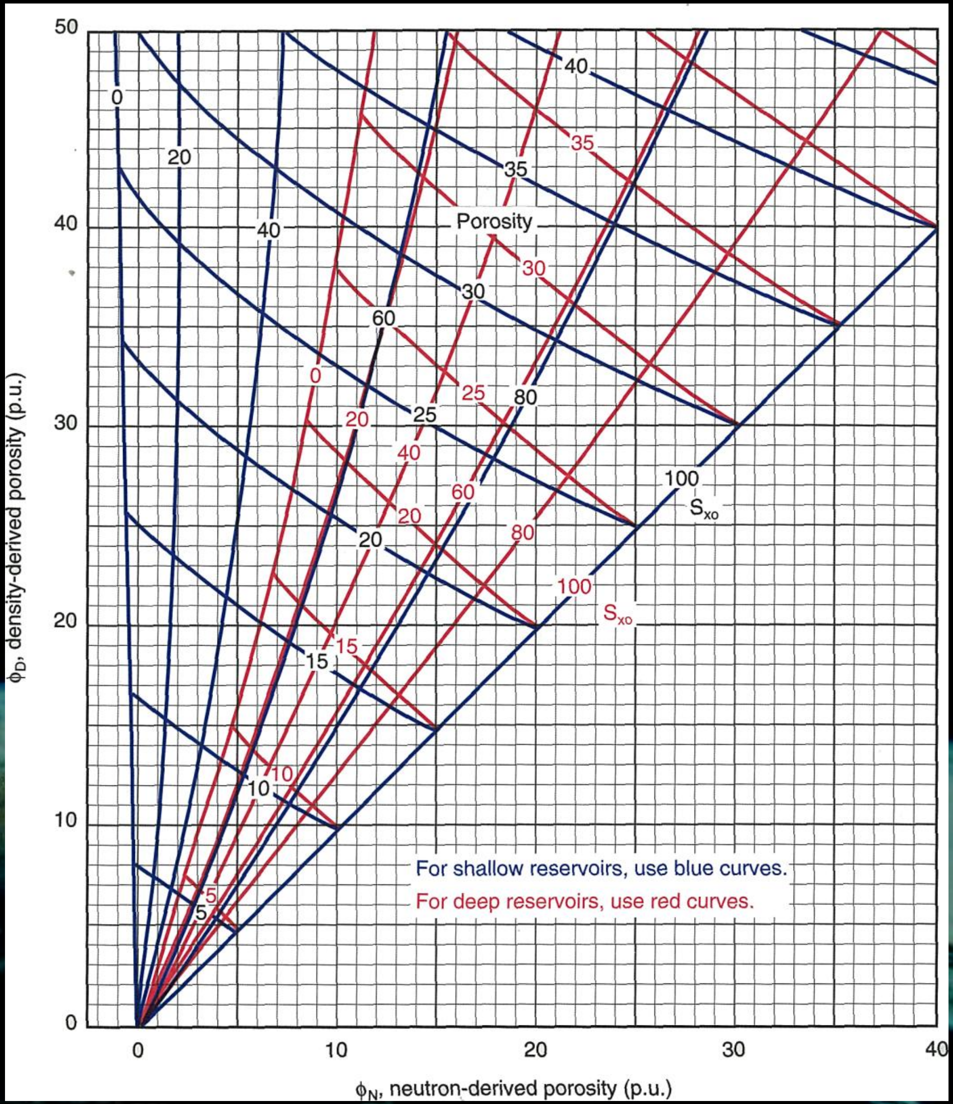
- Problem of distinguishing fresh water sands from gas-bearing sands where the two types of reservoirs are interbedded
- Both types show high resistivities
  - Fresh water sands have high water resistivity, Rw
  - Gas bearing sands have lower Rw, with gas
- Unless Rw is available from independent sources, standard shaley formation saturation analysis will not categorically distinguish between the two

Introduction

- Density and Neutron logs are affected by the presence of gas, independently of the salinity of formation water. The neutron log reads anomalously low porosities in gas saturated rocks due to lower concentrations of hydrogen as compared with wet rocks. The bulk density log reads low due to the presence of gas in the pores. These two properties account for the density/neutron cross-over effect in gas.
- Qualitative distinction between the two reservoir types is a standard approach in petrophysical interpretation
- This presentation outlines a quantitative approach whereby gas saturation from porosity logs is compared with gas saturation from standard resistivity saturation analysis

Effects of Gas on Density and Neutron Logs

- This chart, reproduced from Schlumberger, illustrates gas effects on the density/neutron log combination



Effects of Gas on Density and Neutron Logs

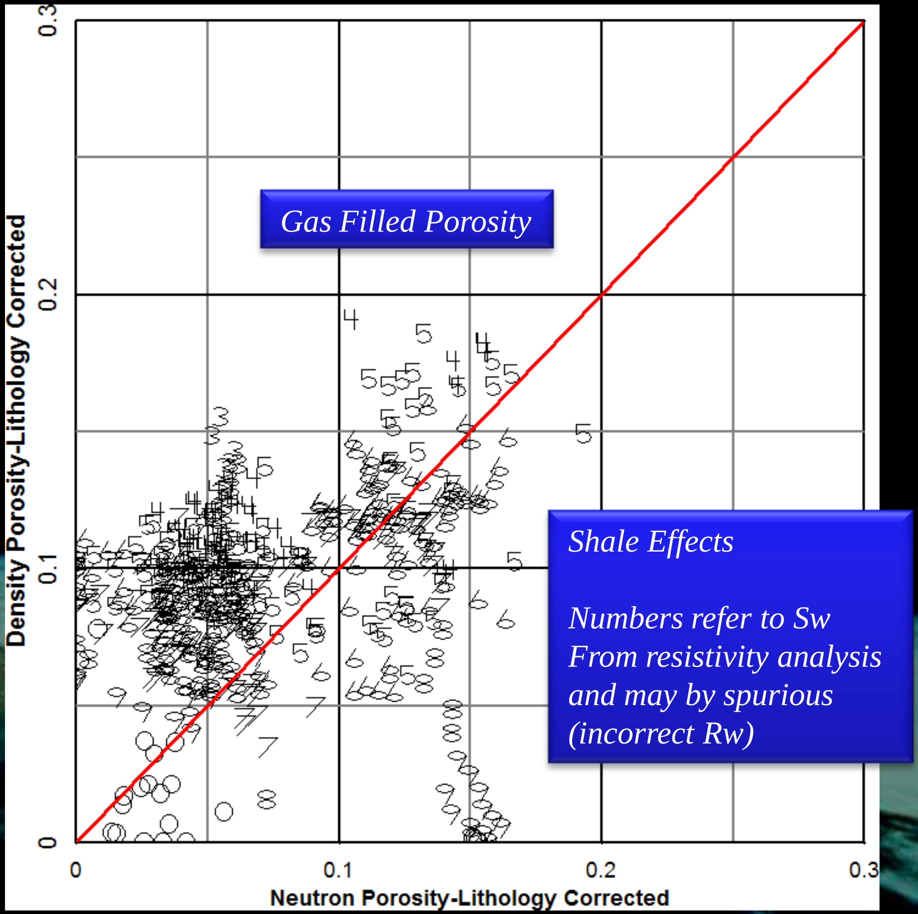
- Lithology must be accounted for before porosity calculations are made
- Gas effects are porosity dependent
- Solve for gas saturation as follows:
  - Liquid-filled porosity from density/neutron porosity cross plot
  - Compare individual porosity log responses with cross plot porosity, and define gas saturation for the density and neutron logs individually

Data Analysis and Presentation

- Perform a standard shaley formation petrophysical analysis using density/neutron cross plot porosity and shale volume
- Determine lithology-corrected porosity profiles for both density and neutron logs individually
- Calculate gas saturation from both density and neutron logs and compare with gas saturation from resistivity logs

Data Analysis and Presentation

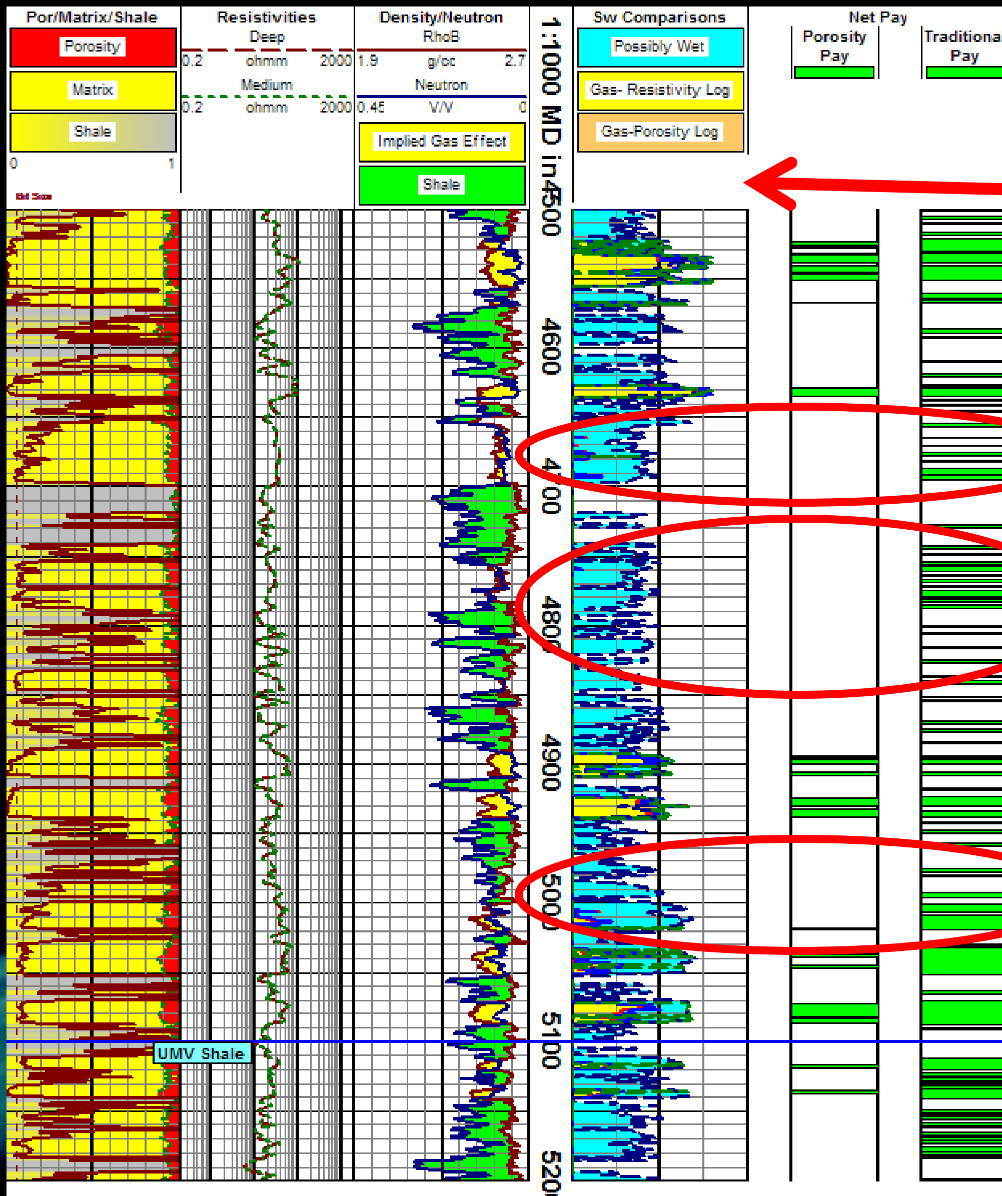
- Data points that fall below the clean liquid filled line are shaley, or could be interpreted in one or more ways:
  - Clay effects not seen by the gamma ray log; e.g., low radioactivity kaolin
  - Incorrect shale volume calculation
  - Incorrect lithology choices giving erroneous porosity calculations
- Gas effects on the porosity logs may be suppressed if invasion by mud filtrate is excessive (applies to both water and oil based muds)



Examples

- MWX – 1 Well Piceance Basin, Williams Fork Formation
- Grand Valley Well Piceance Basin, Williams Fork Formation
- Panhandle Field of Texas, Brown Dolomite

MWX – 1 Well Piceance Basin, Williams Fork Formation

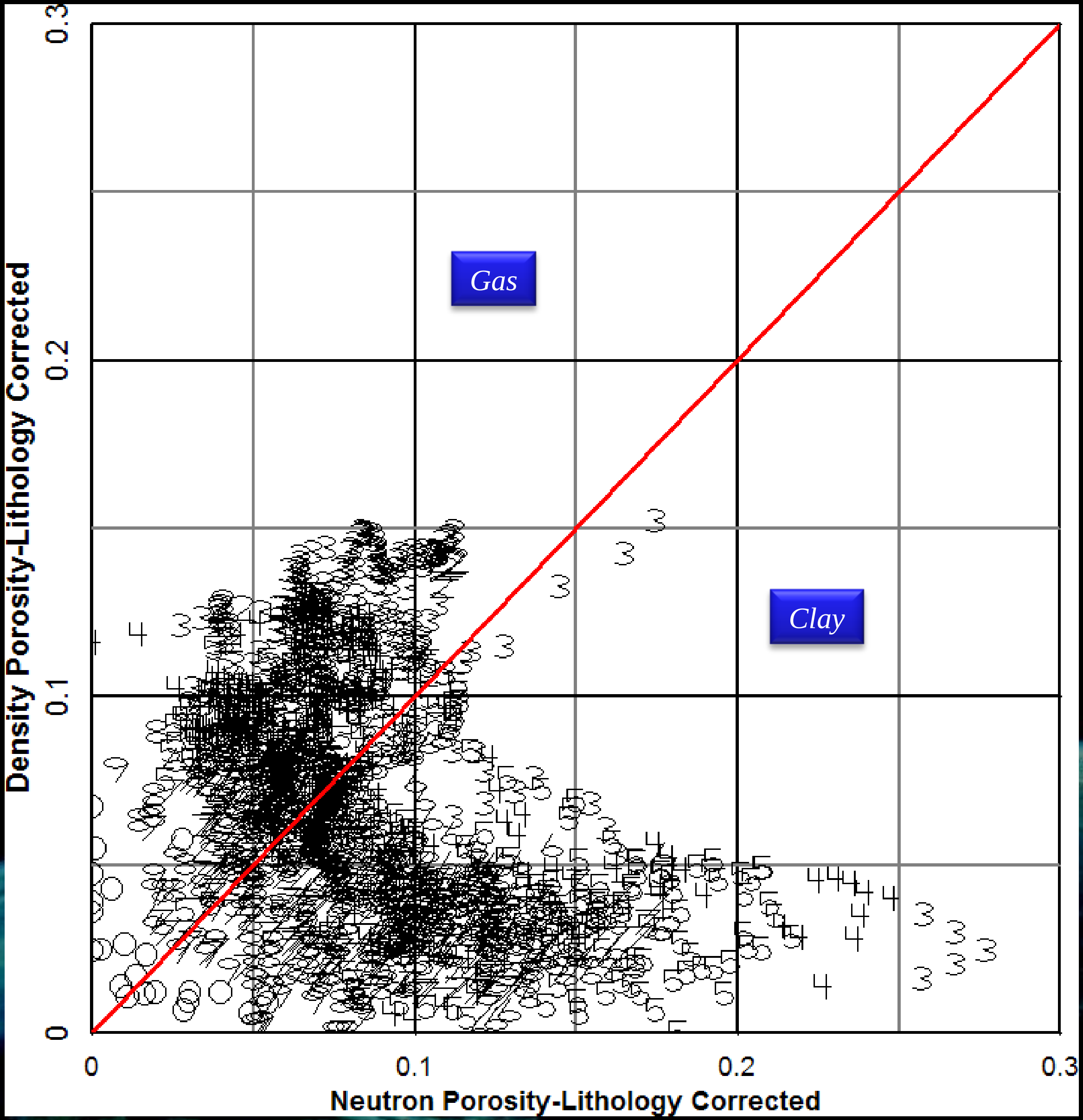


Blue indicates a possible wet interval
Yellow/Brown is gas identified from both resistivity and porosity log analysis

Wet

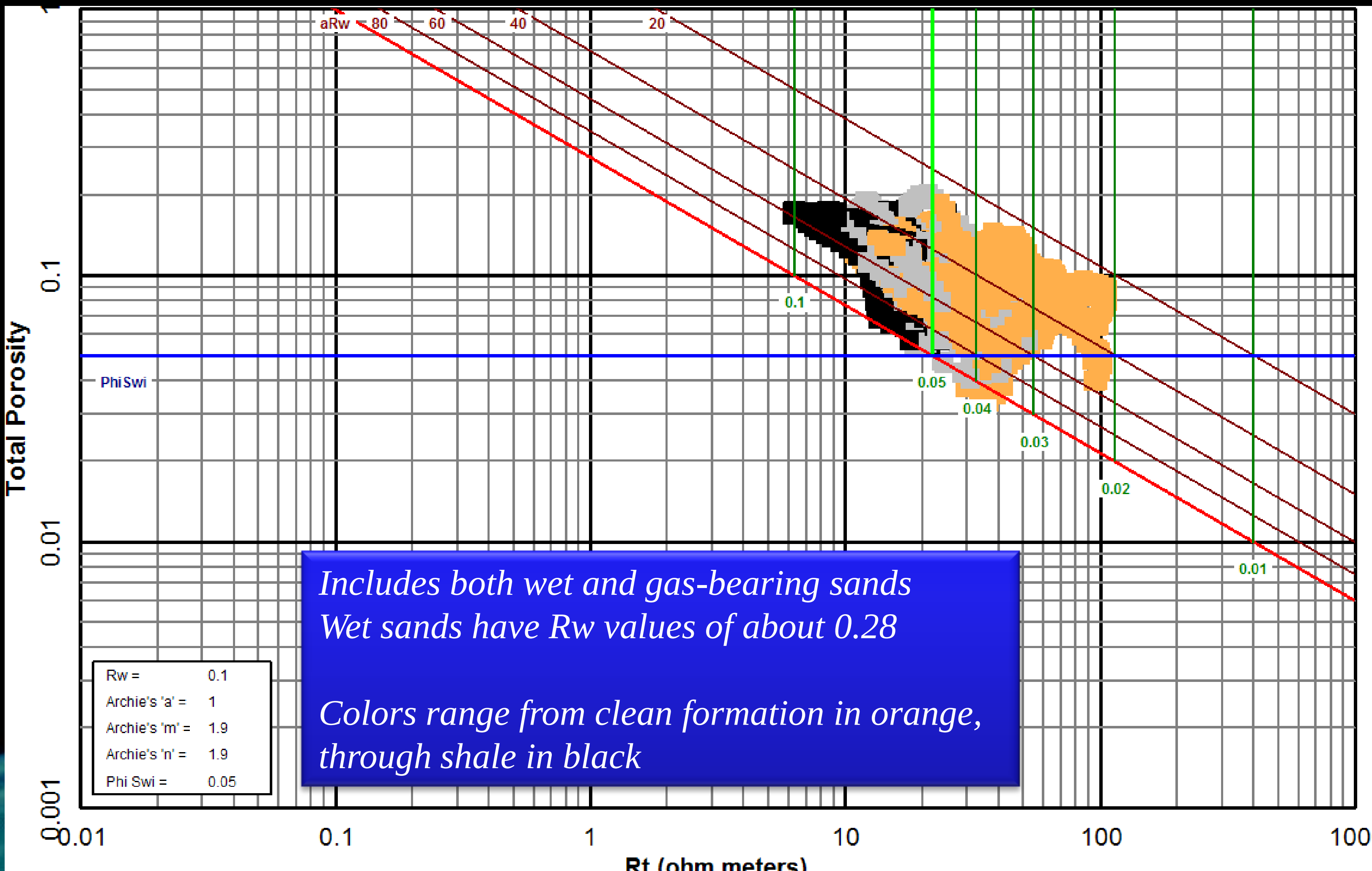
Green bars are net pay
From porosity log analysis on the left
From traditional analysis on the right

MWX – 1 Well Piceance Basin, Williams Fork Formation



Porosity Modeling Suggests the presence of Clay and no gas

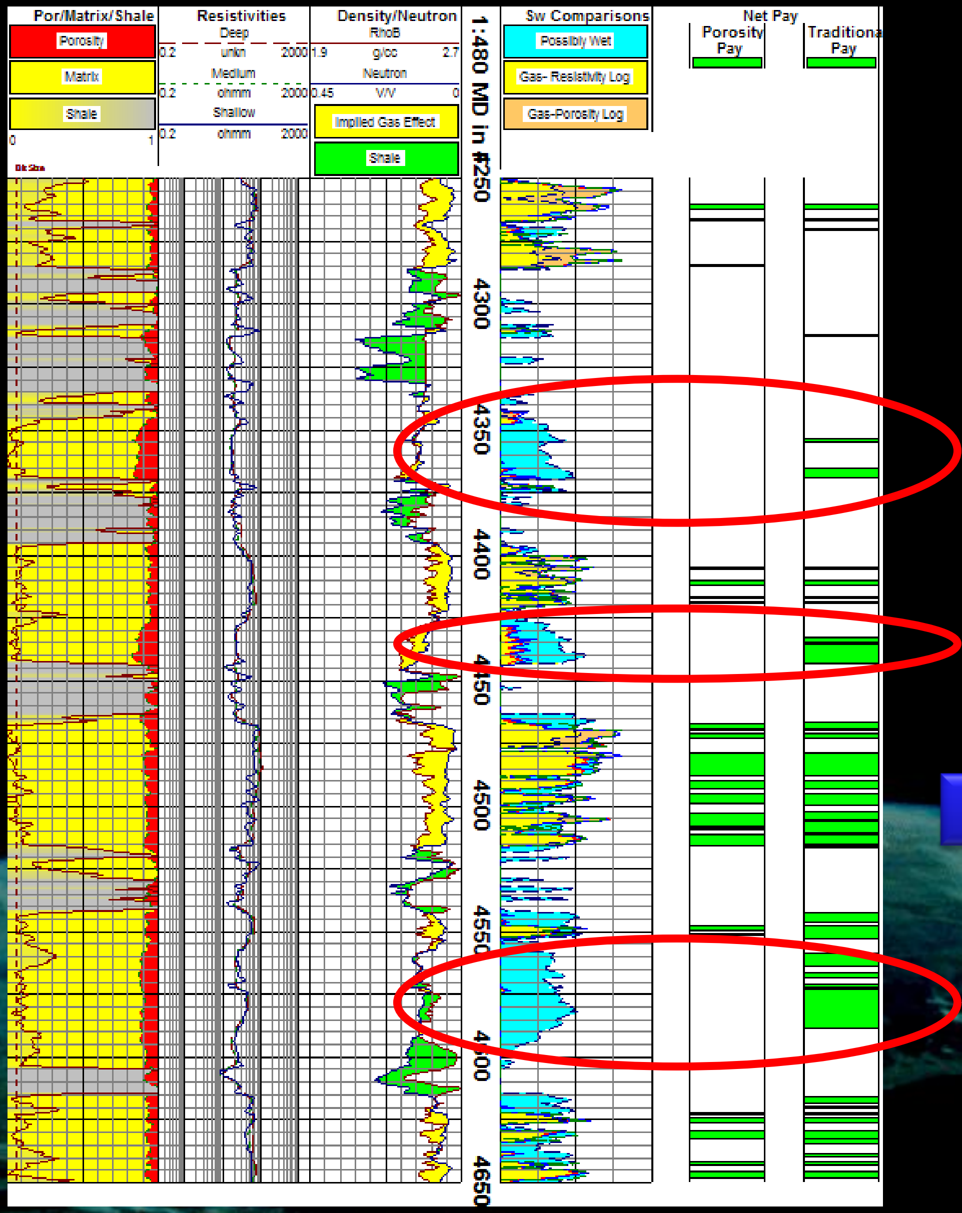
MWX – 1 Well Piceance Basin, Williams Fork Formation



Includes both wet and gas-bearing sands
Wet sands have Rw values of about 0.28

Colors range from clean formation in orange, through shale in black

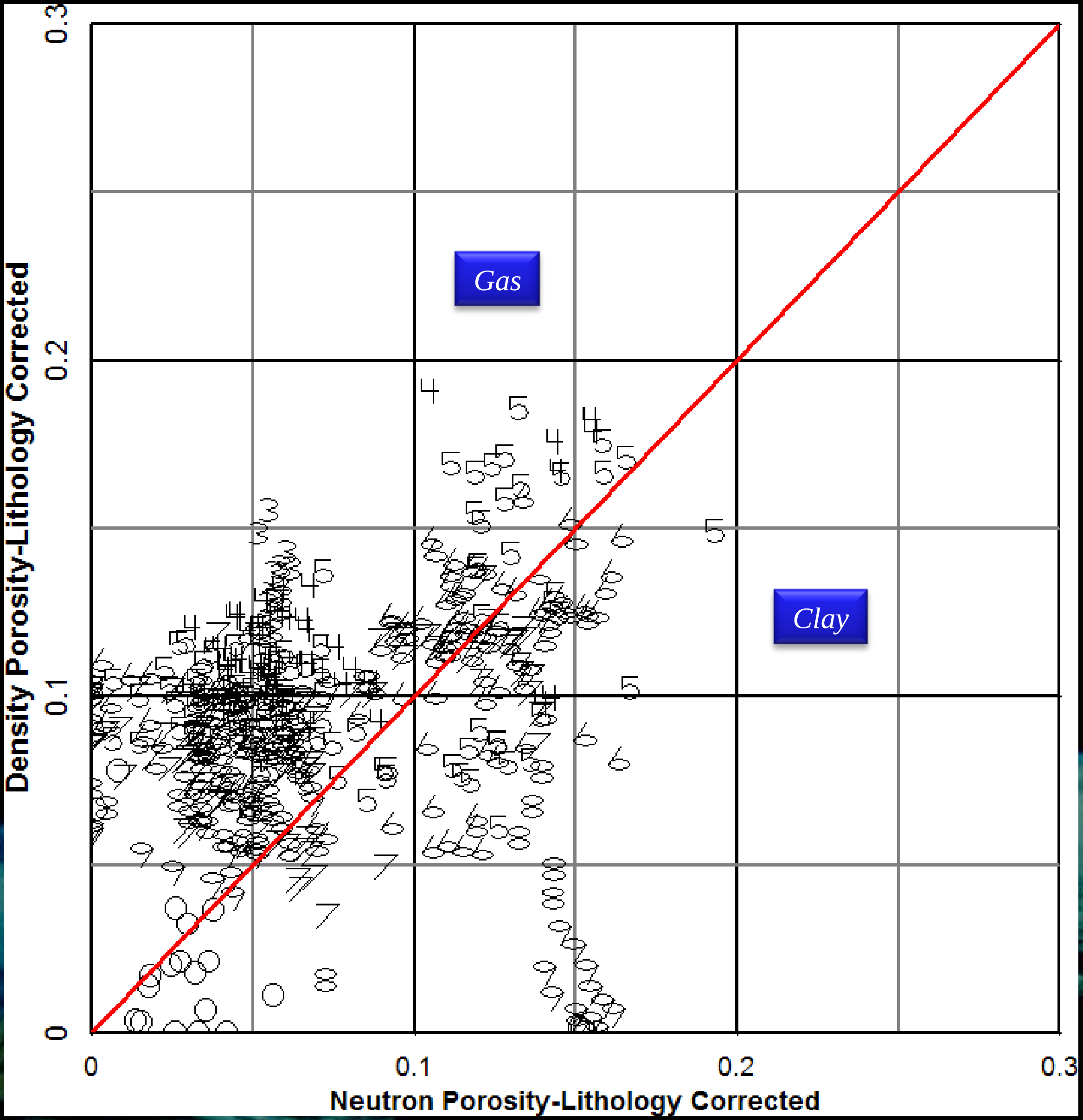
Grand Valley Well Piceance Basin, Williams Fork Formation



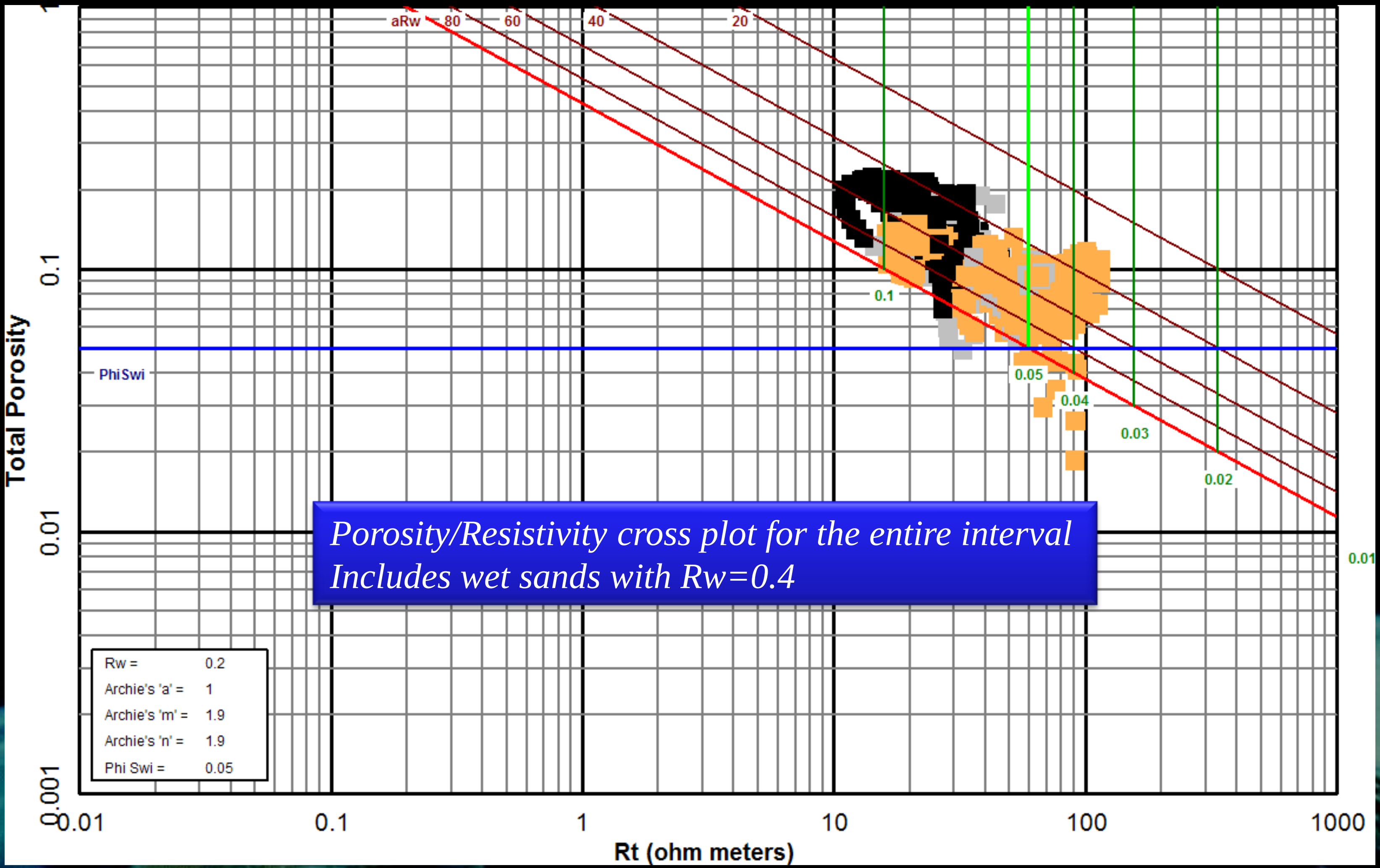
Wet

Sand will be shown expanded on a later slide

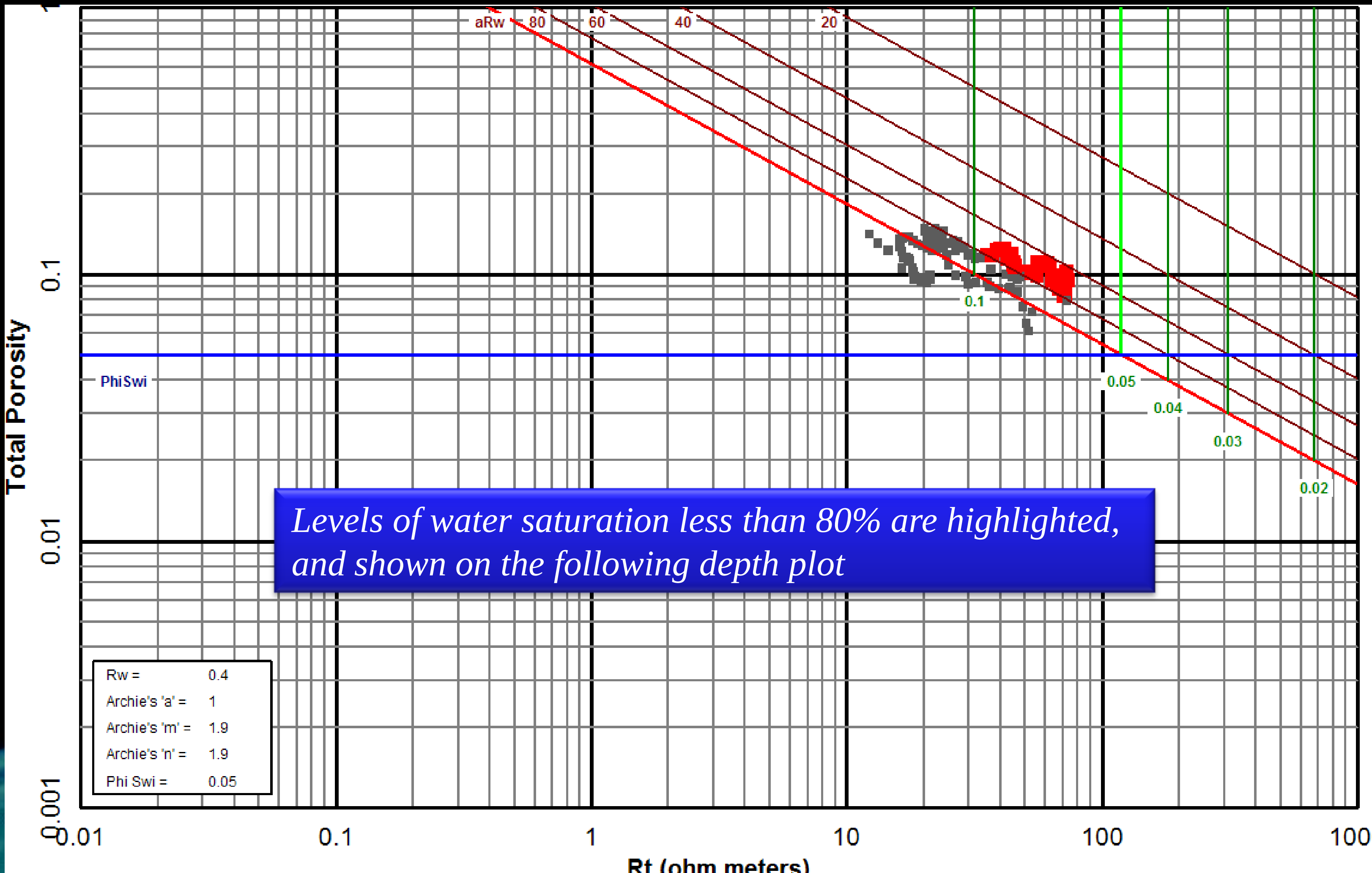
Grand Valley Well Piceance Basin, Williams Fork Formation



Grand Valley Well Piceance Basin, Williams Fork Formation

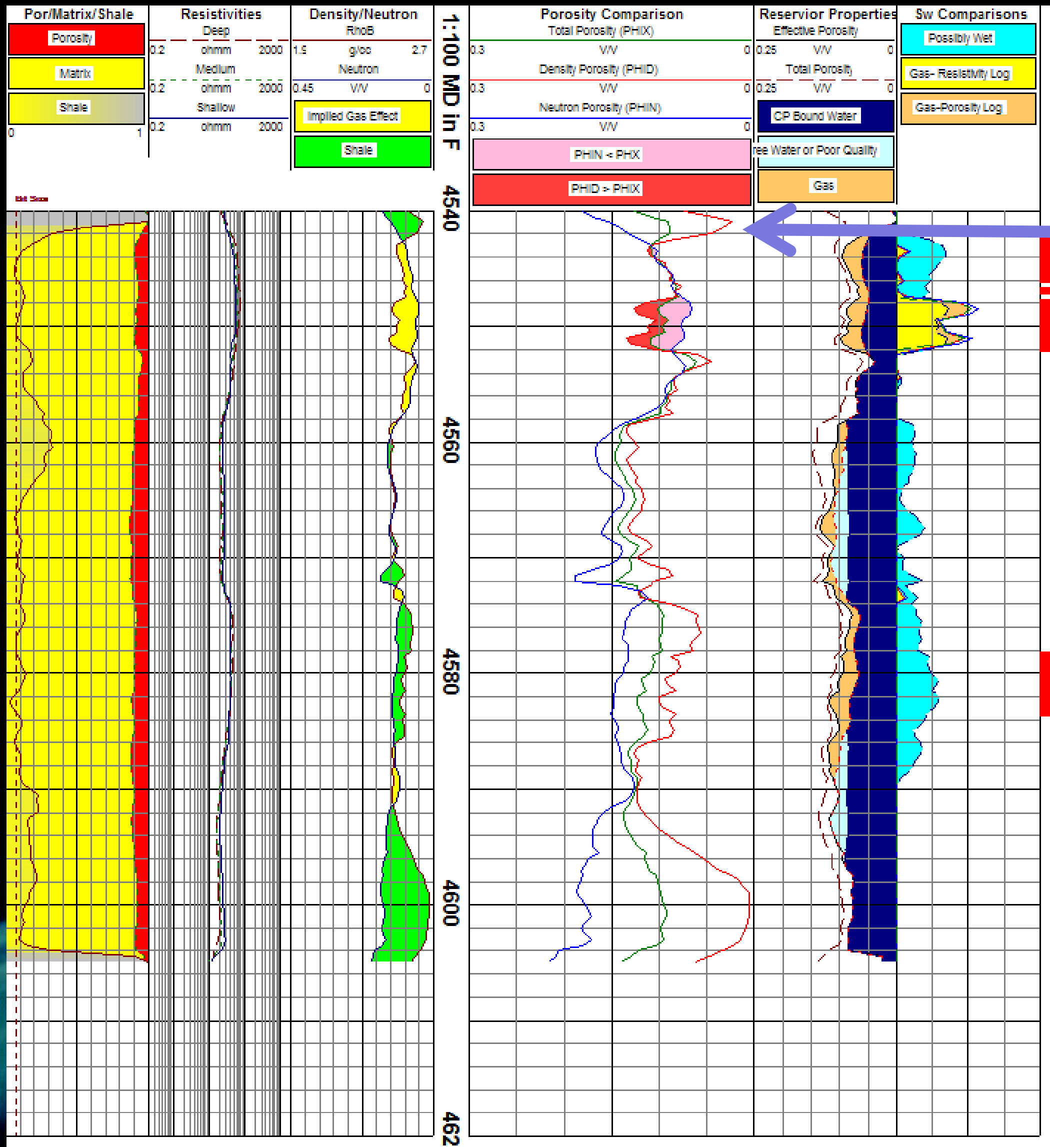


Grand Valley Well Piceance Basin, Williams Fork Formation
Wet Sand



Levels of water saturation less than 80% are highlighted, and shown on the following depth plot

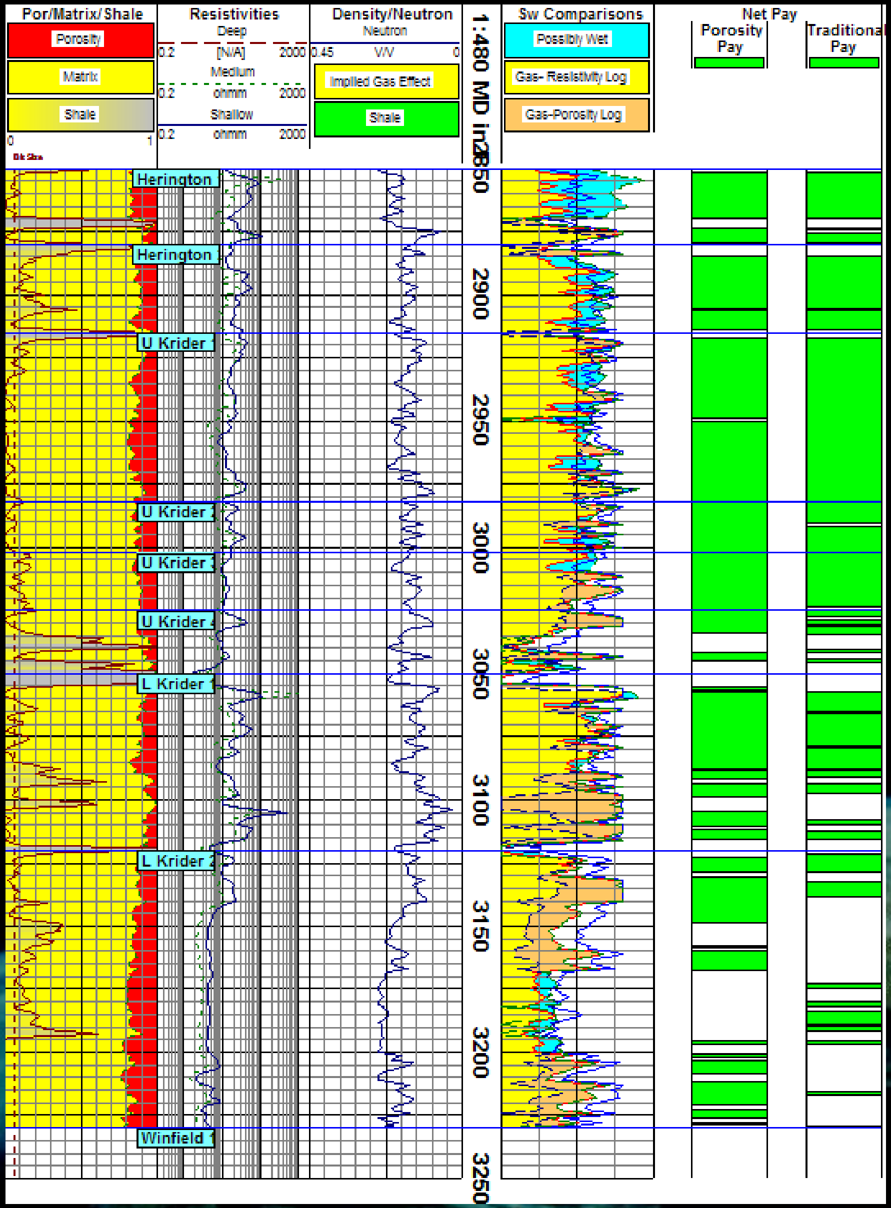
Grand Valley Well Piceance Basin, Williams Fork Formation Wet Sand



Quantification of gas from porosity logs

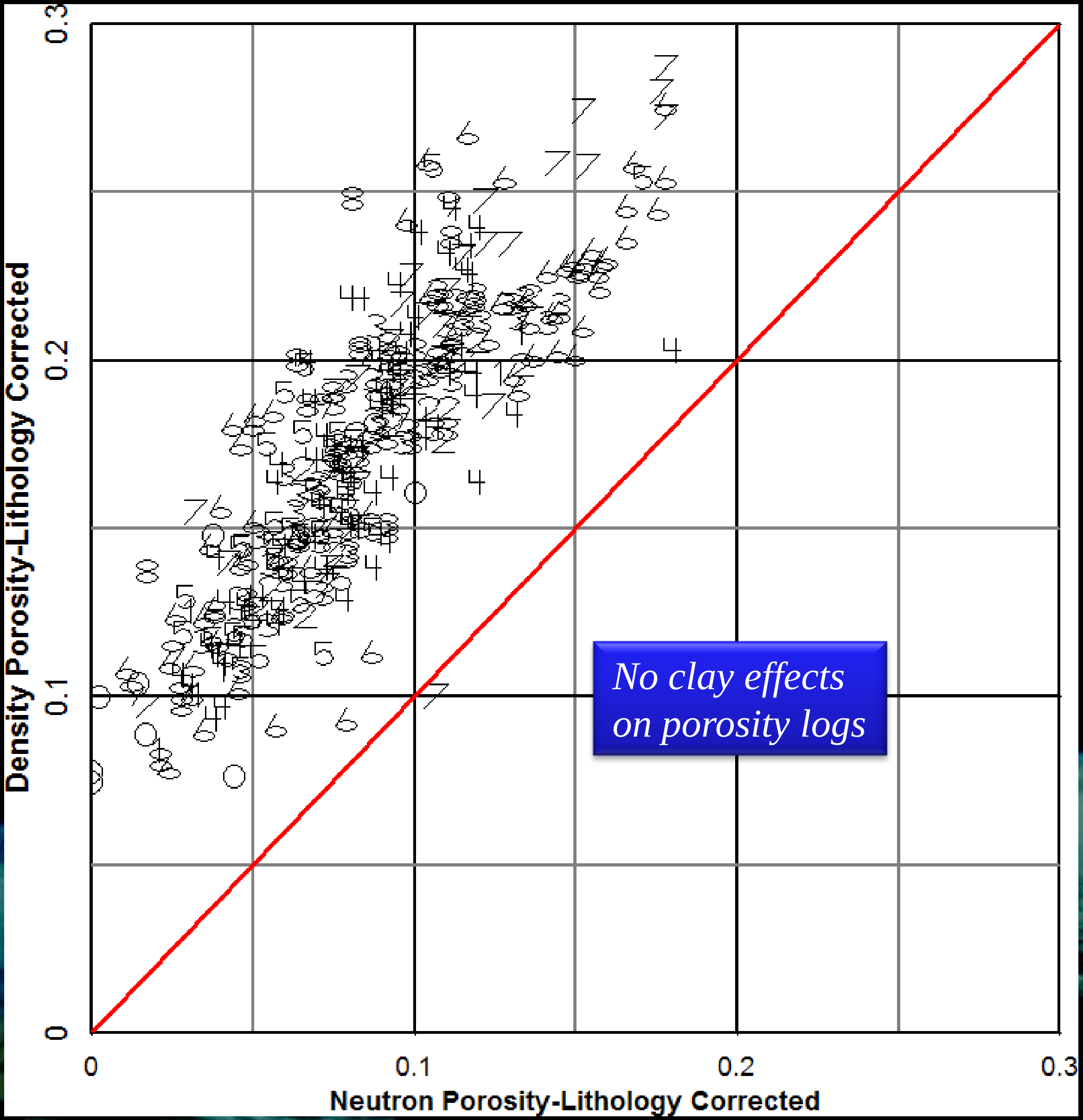
Rw=0.4, Gas-bearing sand at 4548-4556 is accompanied by good density/neutron cross over

Panhandle Field of Texas, Brown Dolomite



Standard log analysis and porosity log analysis for Sw give closely similar results. Interval has constant Rw, and is essentially clay free.

Panhandle Field of Texas, Brown Dolomite



Discussion

- For the tight gas Piceance Basin examples, there is a clear distinction between sands that show gas effects on porosity logs and those that do not. This distinction is not seen on gas saturation calculation from shaley formation resistivity analysis.
- Calculations of net pay are significantly reduced (for the intervals analyzed in this presentation) if porosity log gas indications are used as the basis for analysis
- For the Texas Panhandle carbonate, where issues of varying Rw and shale responses are not present, the evaluations involving resistivity and porosity logs give essentially the same results with respect to gas saturation values

Summary of Findings

- For reservoir intervals of interbedded fresh water and gas bearing sands, detailed analysis of porosity log responses can be used to quantify gas saturation independent of any prior knowledge of water salinity
- When porosity log gas saturation values are compared with standard shaley formation resistivity calculations of gas saturation, distinction between the two types of reservoirs is abundantly clear

Summary of Findings

- By combining the two calculation procedures, determination of net pay can be made eliminating any potential wet sand intervals
- Interpretations are influenced by:
  - Correct identification of rock lithology
  - Shale volume calculations – presence of kaolin may result in the underestimation of shale volume if the gamma ray log is used
  - Degree of mud filtrate invasion (deep invasion will suppress the gas effects on porosity logs for both oil and water based muds)