[AV]Relationship between Porosity and Water Saturation: Methodology to Distinguish Mobile from Capillary Bound Water*

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Abstract

In 1965, Buckles proposed that porosity and irreducible water saturation are hyperbolically related:

$$\text{Porosity} \times \text{Irreducible Water Saturation} = \text{Constant}$$

The magnitude of the constant was shown to be related to rock type, and indirectly to permeability. The lower the value of the constant, the better the quality of the rock - higher porosity for any given value of porosity.

Extensive analysis of both core data and petrophysical estimates of porosity and irreducible water saturation, from all types of reservoirs worldwide, suggests that Buckles relationship is a unique solution to a more general equation:

$$\text{Porosity}^{Q} \times \text{Irreducible Water Saturation} = \text{Constant}$$

The value of the power function, Q, ranges from about 0.8 to about 1.3, with many reservoirs close to 1.0.

Values of Q and the constant are easily derived by plotting the log of porosity vs. log irreducible water saturation, resulting in a straight line of negative slope = Q. Projection of the straight line to a porosity of 1.0 gives the value of the constant.

The cross plot can be used to distinguish rock groupings with different values of Q and the constant. They also can be used to infer the presence of mobile water. Points that fall above the line suggest that the level is not at irreducible water saturation, or is of poorer rock quality.

By comparing, with depth, theoretical irreducible water saturation with petrophysical calculated water saturation, it is possible to categorize changing rock quality and /or presence of mobile water. This can be very useful in deciding which intervals to complete, and to rationalize water production. Examples from a number of reservoirs are presented, both core data and petrophysical calculations of porosity and water saturation.

References

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Relationship between Porosity and Water Saturation: Methodology to Distinguish Mobile from Capillary Bound Water

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Presented at the AAPG Annual Convention and Exhibition

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- Core data examples showing variable rock quality:
  - Southern Wyoming Tight Gas Sand
  - Piceance Basin, Colorado

Contents

- Log data examples showing variable rock quality and mobile water:
  - Two examples from Piceance Basin, Colorado
  - East Texas Tight Gas
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Introduction

- Buckles (1965) proposed:

$$\text{Porosity} \times \text{Irreducible Water Saturation} = \text{Constant}$$

  - Constant:
    - Sandstone – 0.02 to 0.10
    - Intergranular Carbonates – 0.01 to 0.06
    - Vuggy Carbonates – 0.005 to 0.06

Introduction

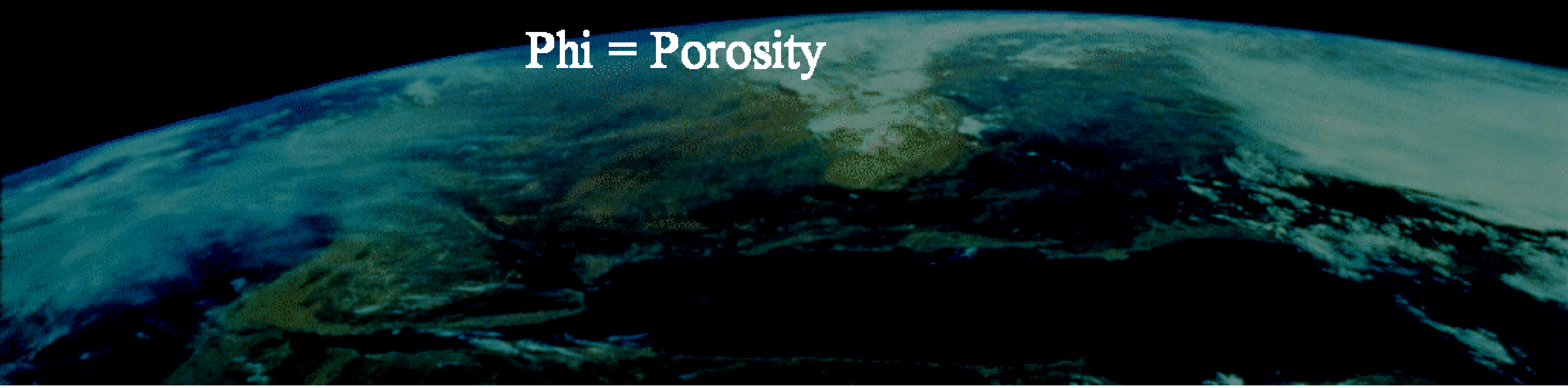
- **Linear version of Buckles:**

$$\log Swi = \log C - \log Phi$$

Swi = Irreducible Water Saturation

C = Constant

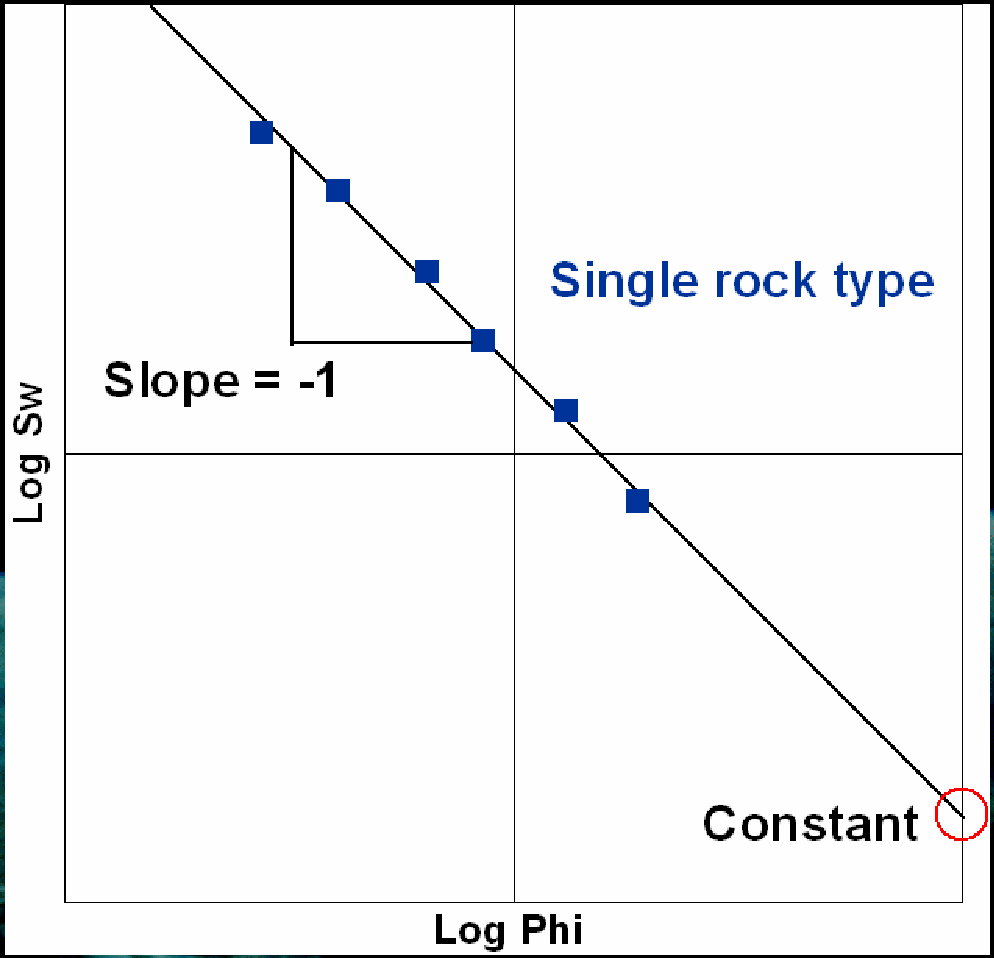
Phi = Porosity



Introduction

- Graphical presentation of Buckles:

$$\text{Porosity} \times \text{Irreducible Water Saturation} = \text{Constant}$$



Introduction

- Holmes-Buckles Equation:
  - Data will be presented suggesting a closer relationship between Phi and Swi
  - Exponent Q is the slope on the log Sw vs. log Phi cross plot:

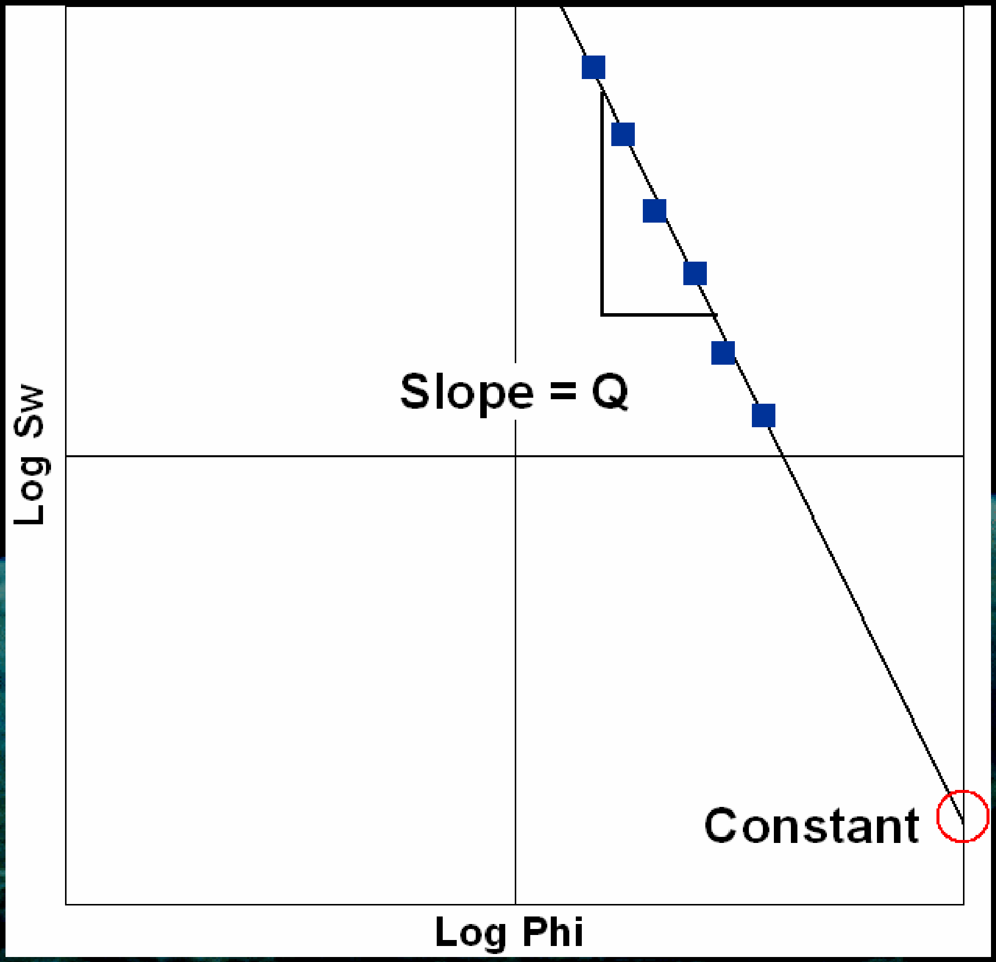
$$\text{Phi}^{Q} \times \text{Swi} = \text{Constant}$$

Phi = Porosity
Swi = Irreducible Water Saturation

Introduction

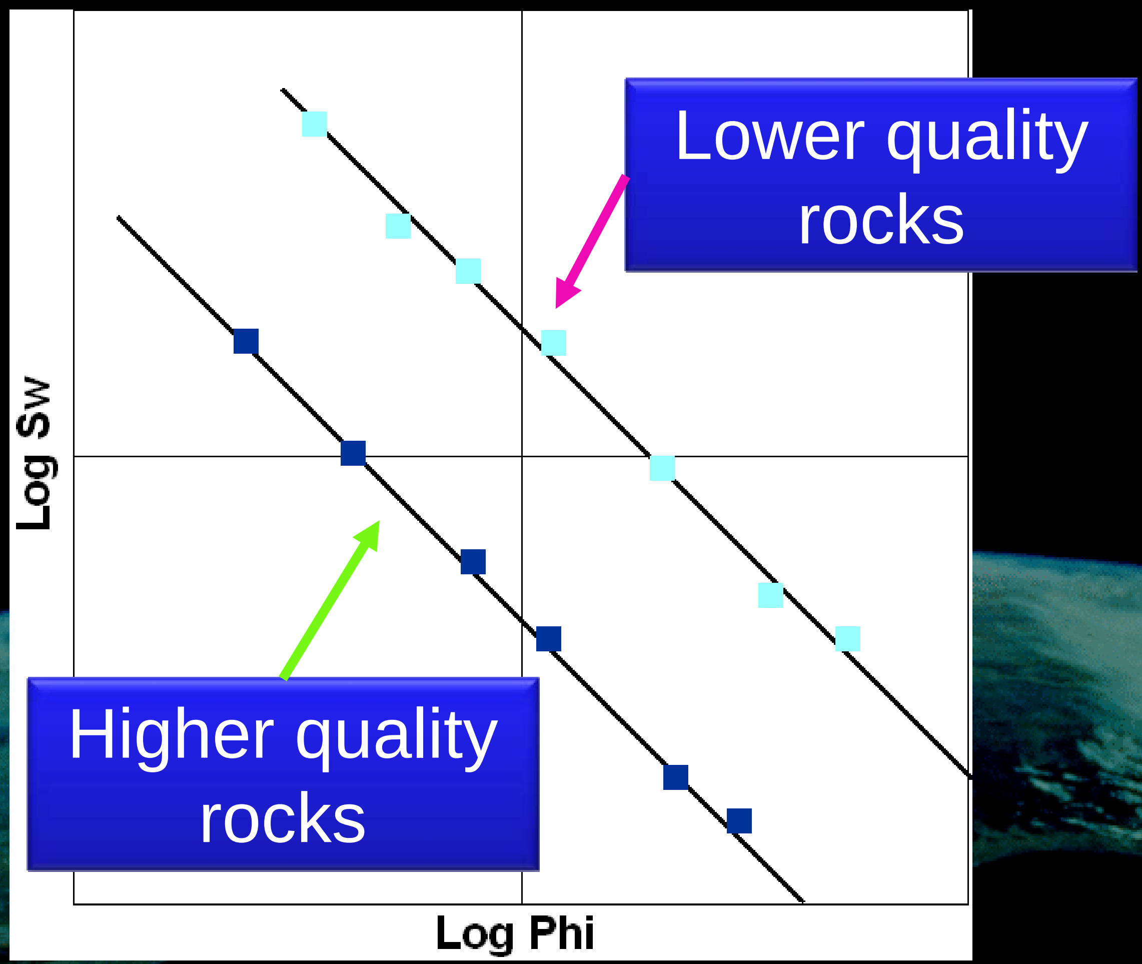
- Graphical presentation of Holmes-Buckles:

$$Phi^{Q} \times Swi = Constant$$

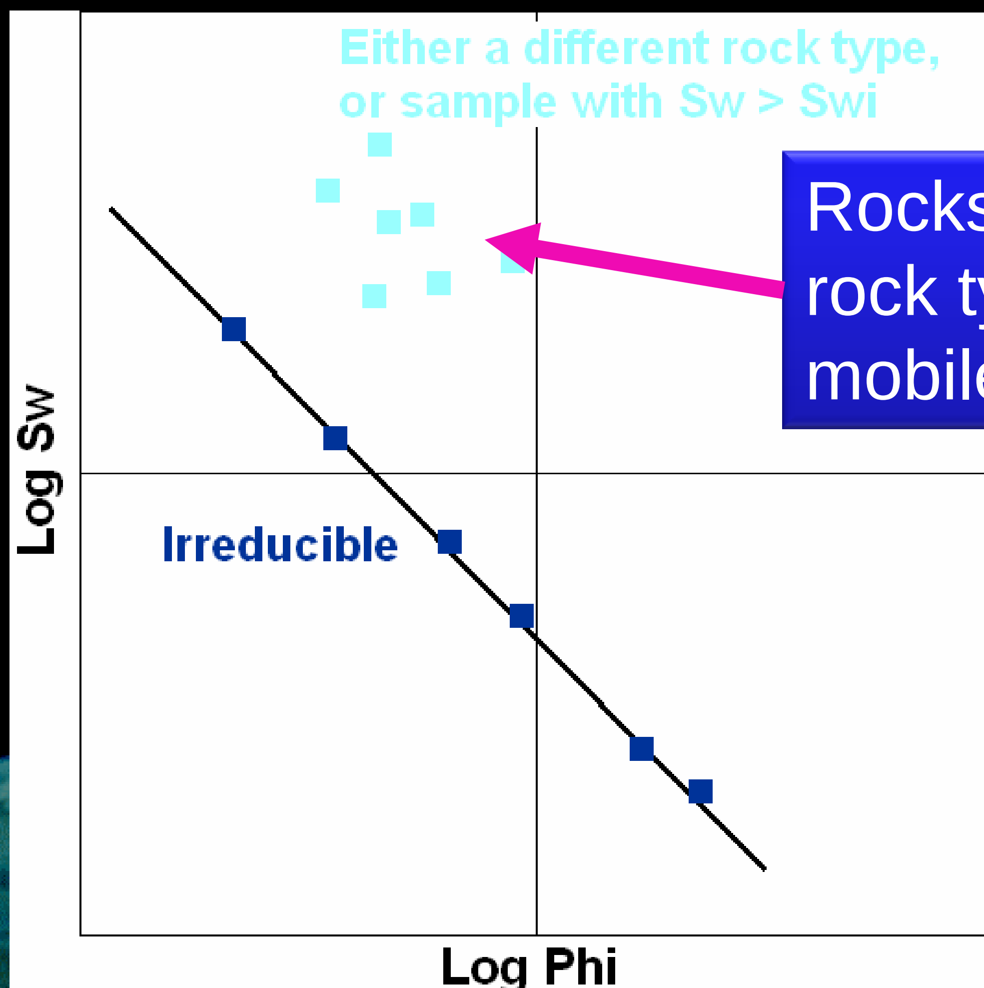


Introduction

- Two different rock types:



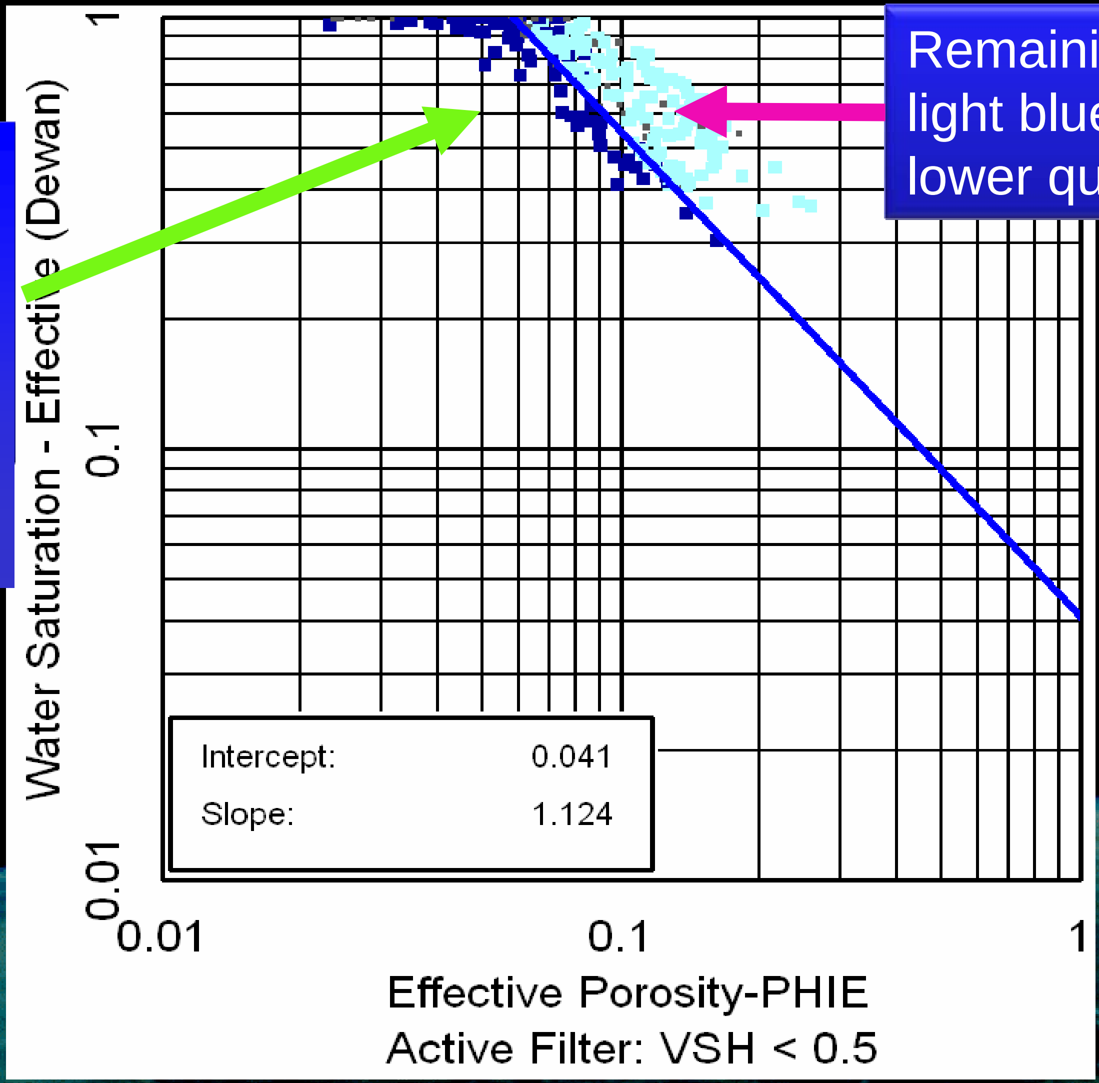
Introduction



Rocks with different rock types, or with mobile water

Core Data Example

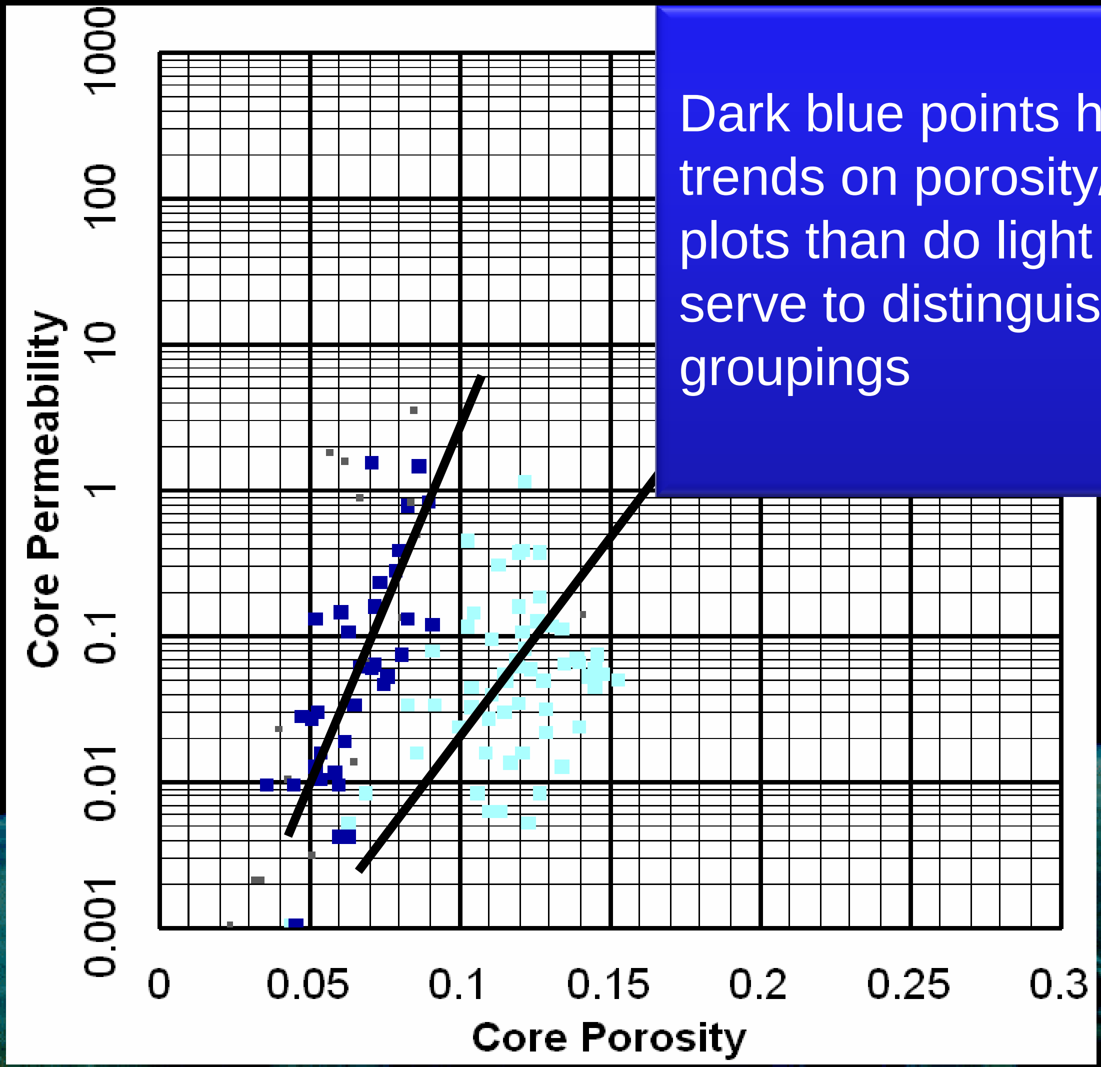
Data on or to the lower left of the Phi-Swi correlation line is coded in dark blue and represents higher quality rocks



Remaining data is coded in light blue and represents lower quality rocks

Southern Wyoming Tight Gas Sand

Core Data Examples



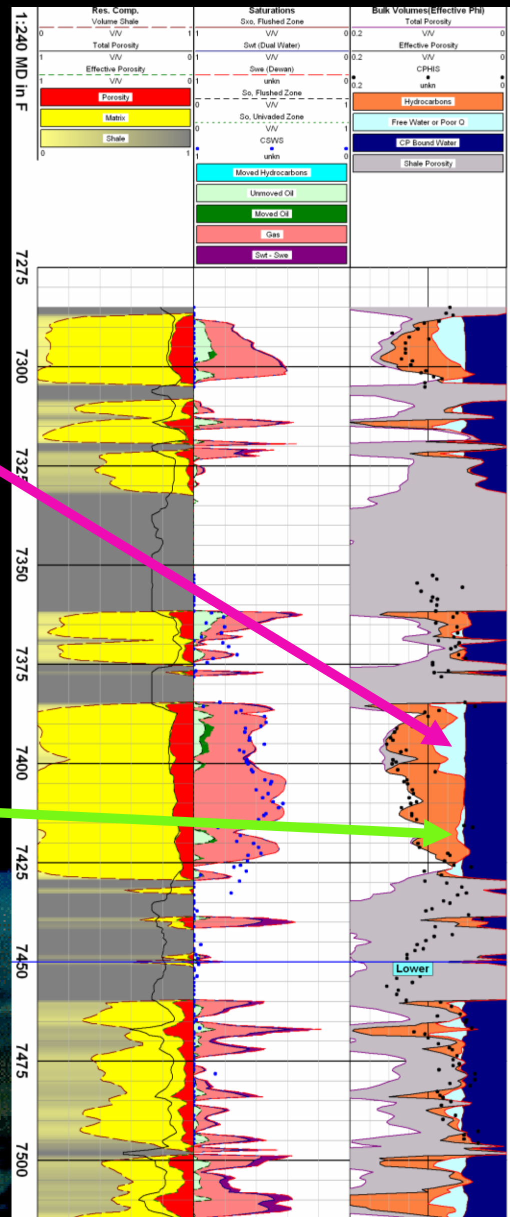
Dark blue points have different trends on porosity/permeability plots than do light blue points, and serve to distinguish different rock groupings

Southern Wyoming Tight Gas Sand

Core Data Examples

Lower quality rocks

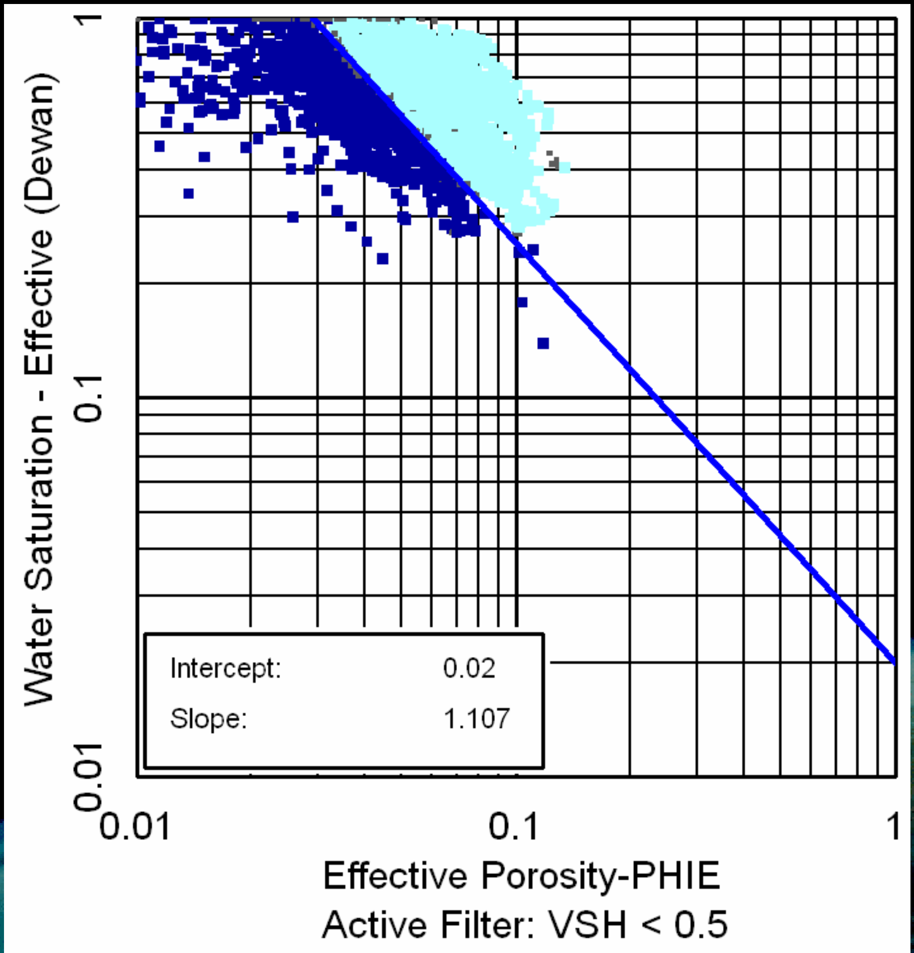
Higher quality rocks

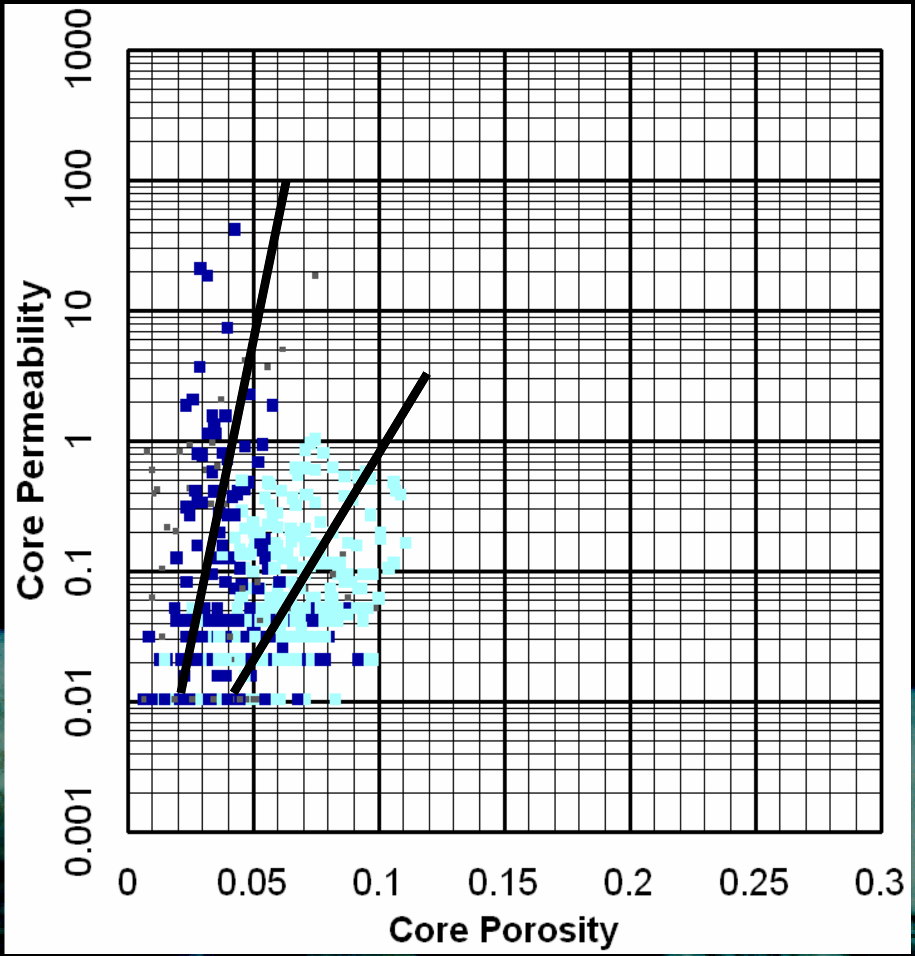


The different groupings are also recognized on the depth plots, and indicate that the rock groupings can be identified when no core data are available

Southern Wyoming Tight Gas Sand

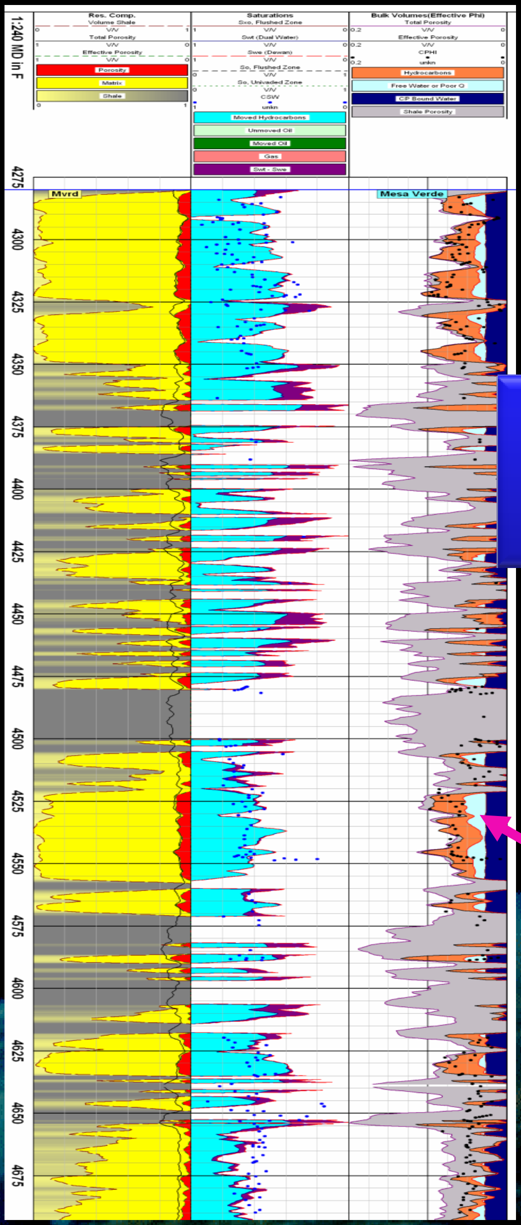
Core Data Examples

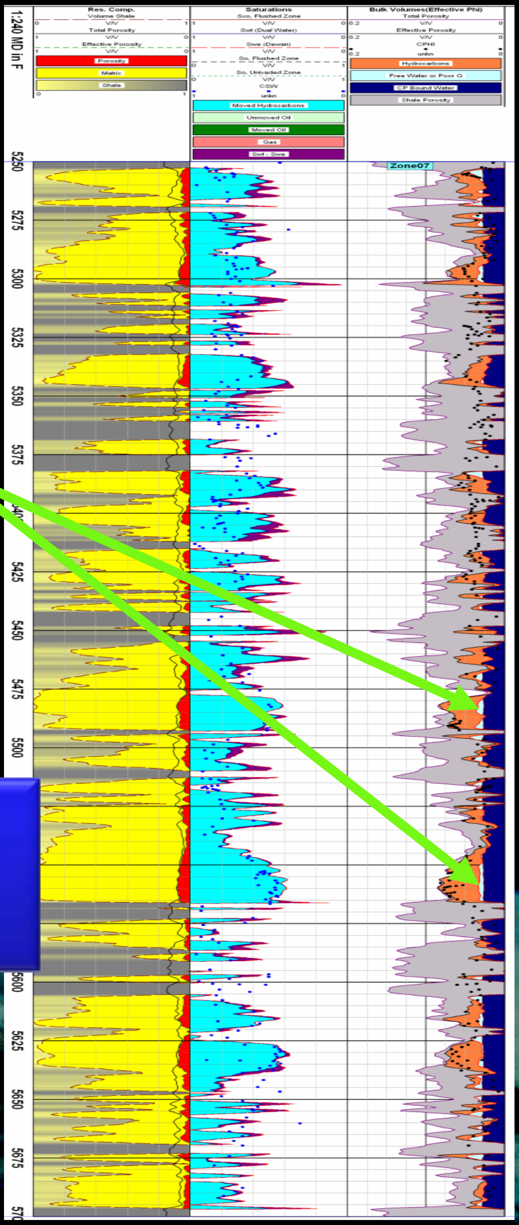




Piceance Basin, MWX-1

Core Data Examples



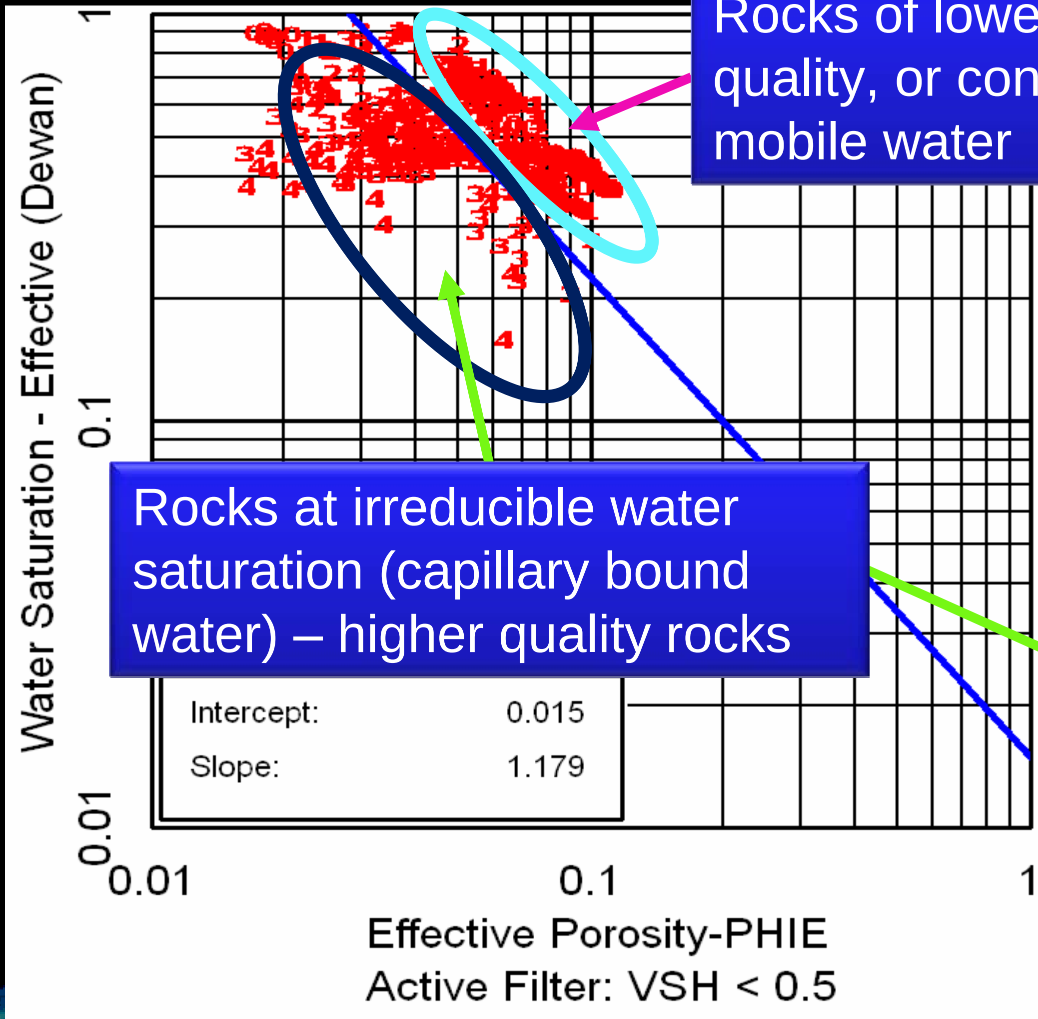


Higher quality rocks

Lower quality rocks

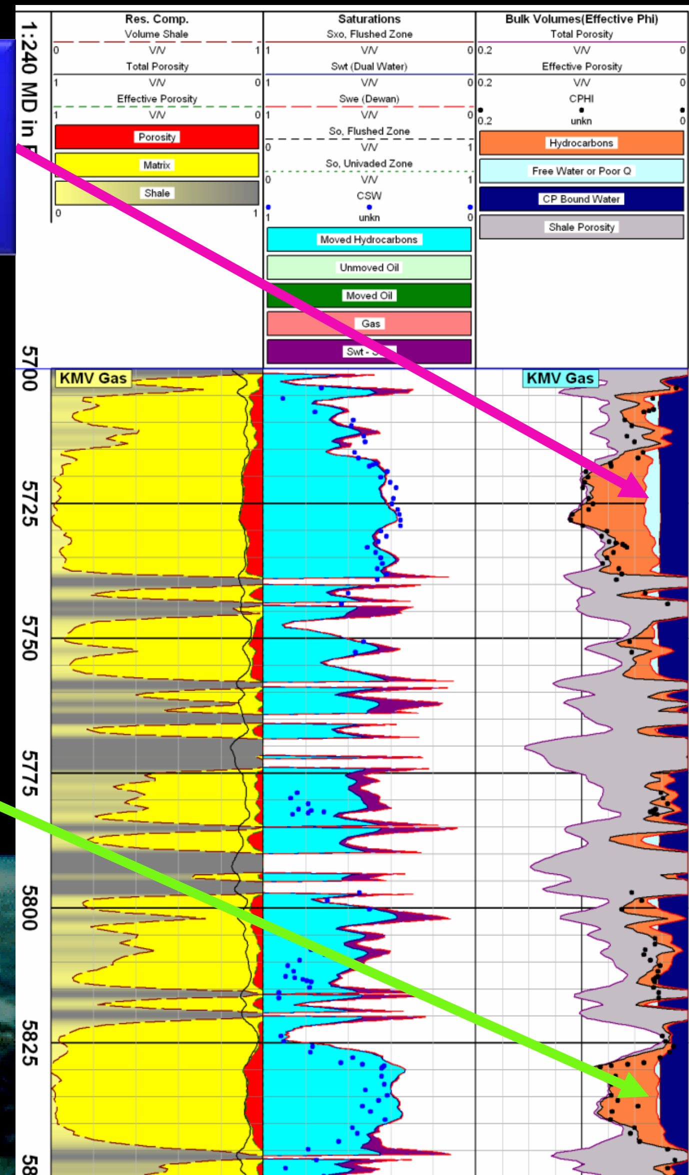
Piceance Basin, MWX-1

Log Data Examples



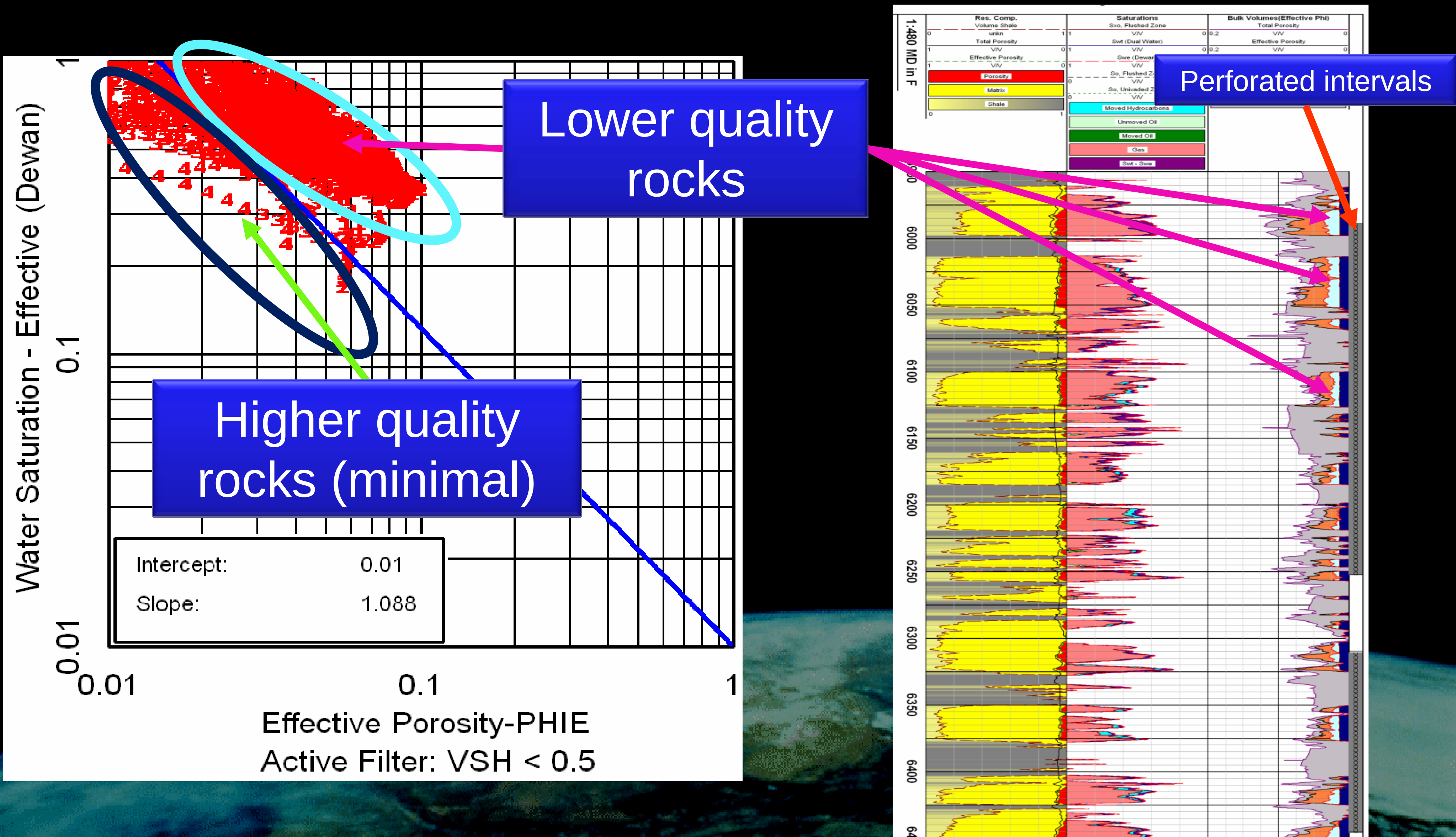
Rocks of lower quality, or containing mobile water

Rocks at irreducible water saturation (capillary bound water) – higher quality rocks



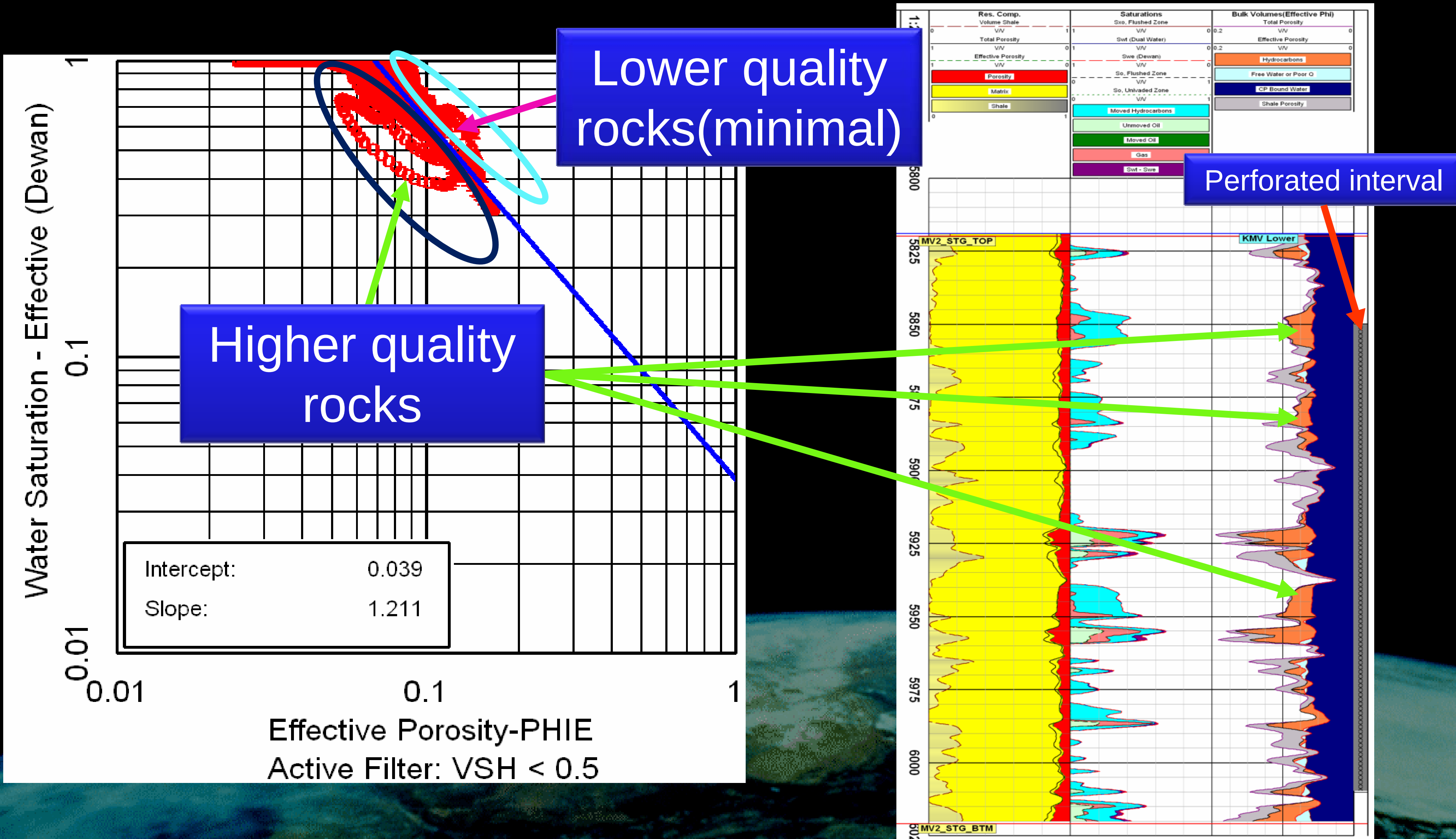
MWX-1 Well, Piceance Basin

Log Data Examples



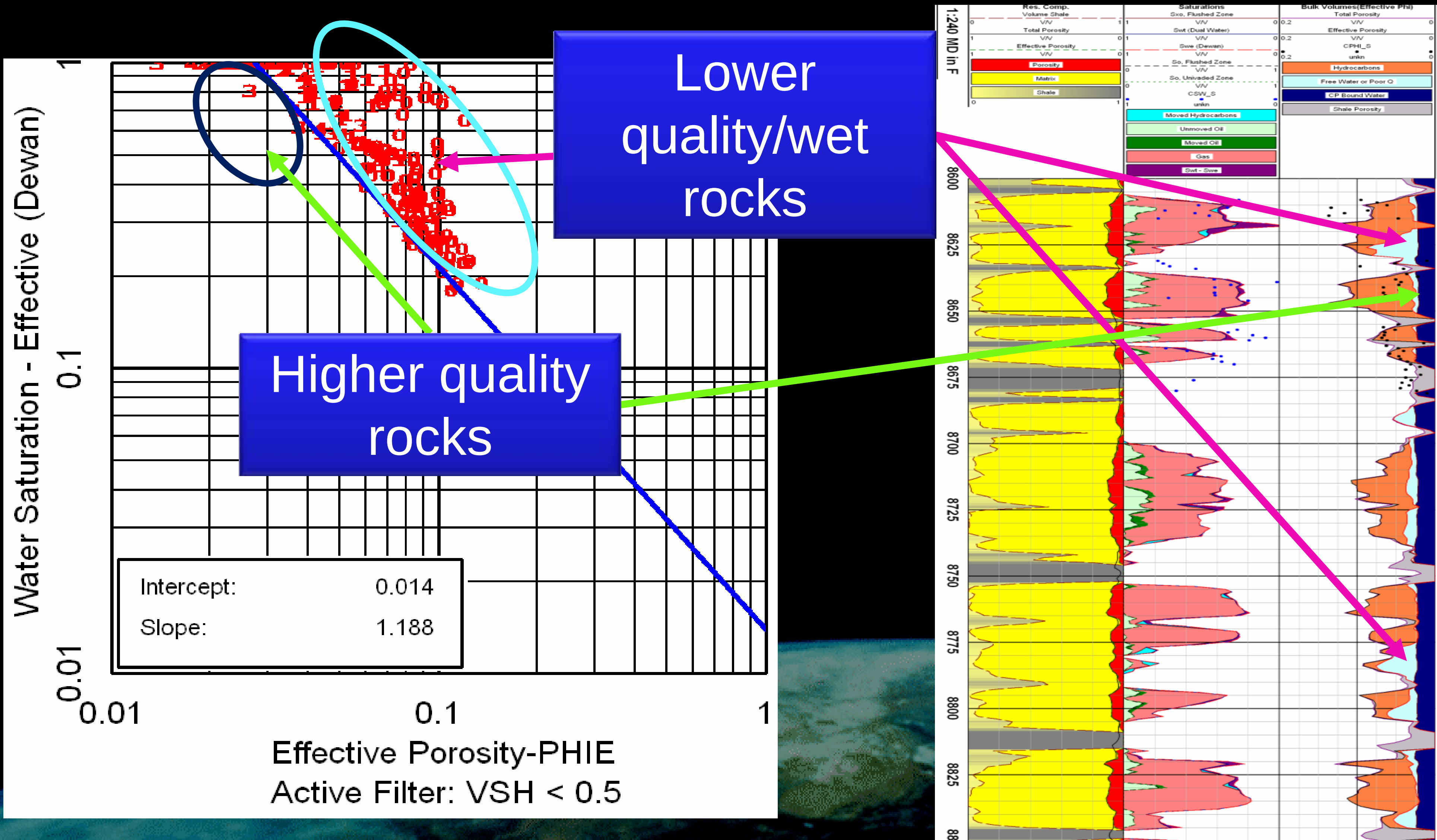
Piceance Basin well with mobile water – 60-80 barrels water per MMCFG

Log Data Example



Piceance Basin well with little or no mobile water – 10 barrels water per MMCFG

Log Data Examples

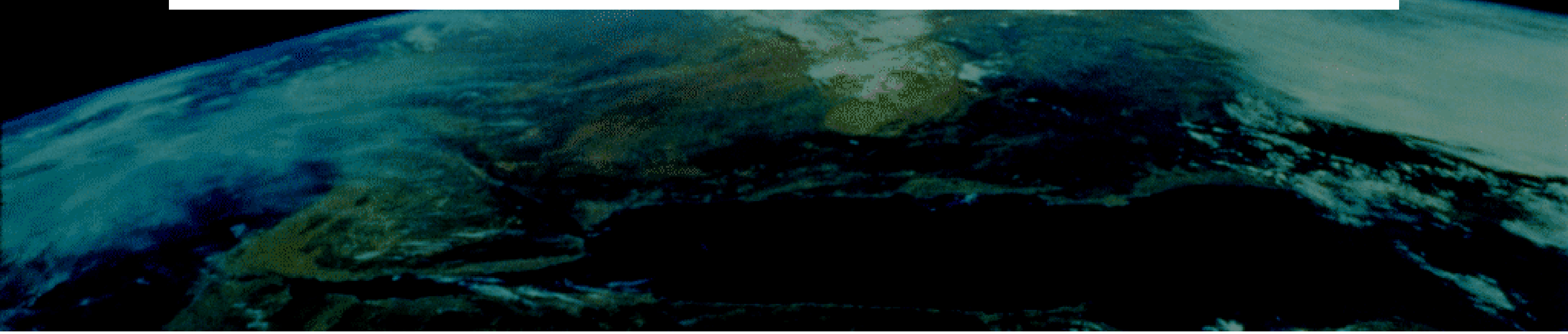


East Texas Tight Gas Sand – sands at irreducible water saturation interbedded with wet sands

Summary

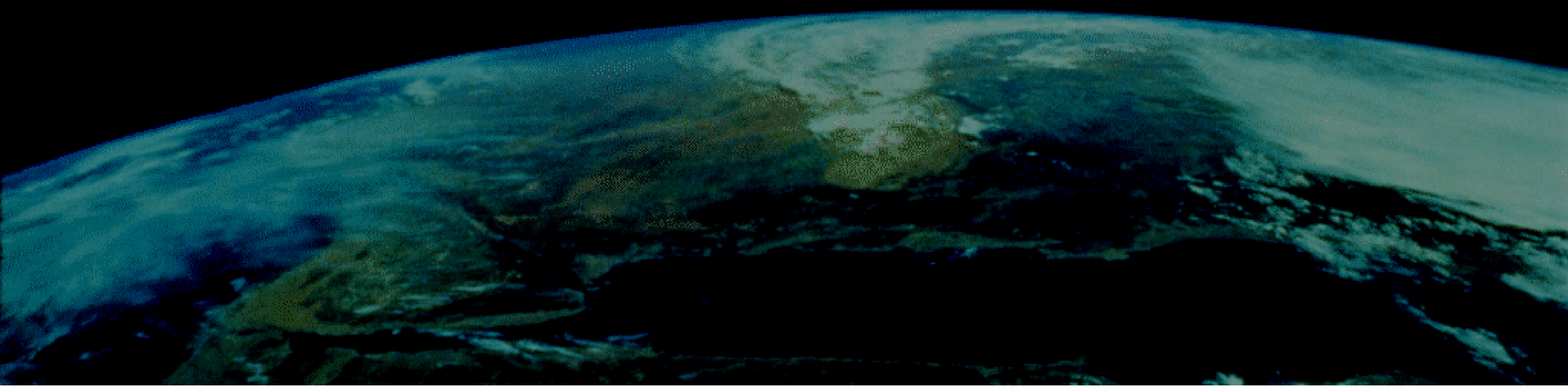
- Examination of many reservoirs, both sands and carbonates, suggest a relationship between porosity and irreducible water saturation of this form:

$$\text{Porosity}^{Q} \times \text{Irreducible Water Saturation} = \text{Constant}$$



Summary

- In prior studies, it assumed that Q is one. Data presented here suggests the exponent is often greater than one, in the range of 1.1 to 1.3.

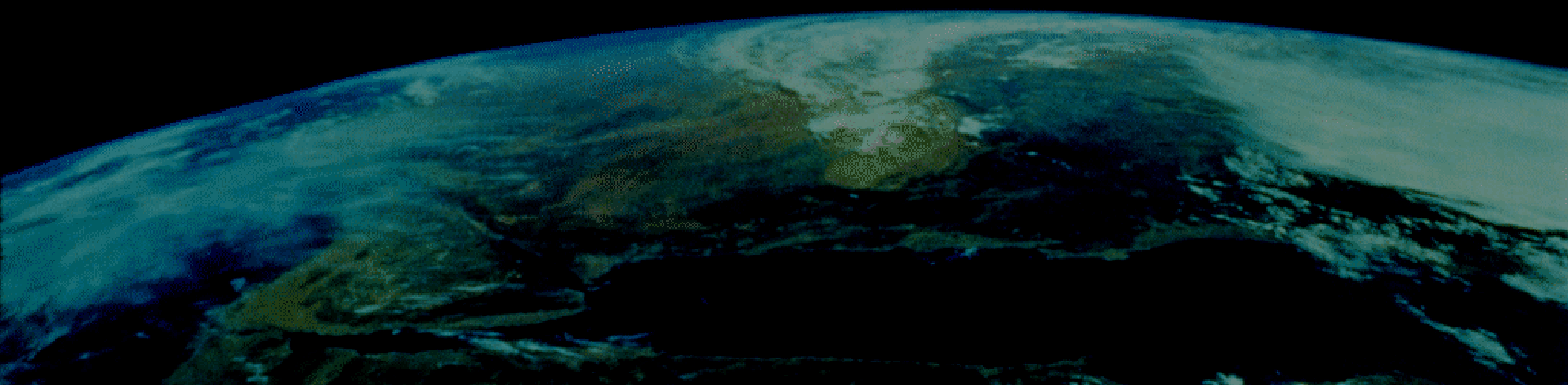


Summary

- By presenting data on a log/log plot, it is possible to distinguish between different rock types and/or identify rocks above irreducible water saturation (i.e. containing mobile water)
- The plots can be used to distinguish different groupings of porosity/permeability correlations

Summary

- Once basic porosity / water saturation / permeability relations have been established using core data, similar groupings can be identified in wells from the same reservoir with no core data available



Acknowledgements

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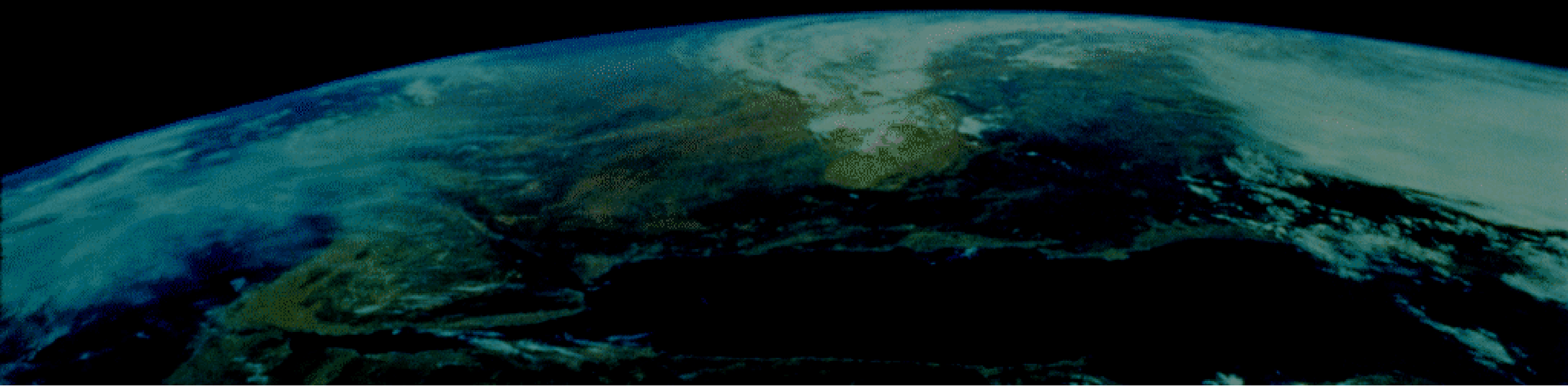

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