Integration of Core Capillary Pressure Measurements with Petrophysics to Define Saturation/Height Relations and Reservoir Quality Variations

Digital Formation, Inc.

Updated from the Poster Presentation given at the Fall 2009 DWLS workshop, **Beyond the Basics of Capillary Pressure: Advanced Topics and Emerging Applications**

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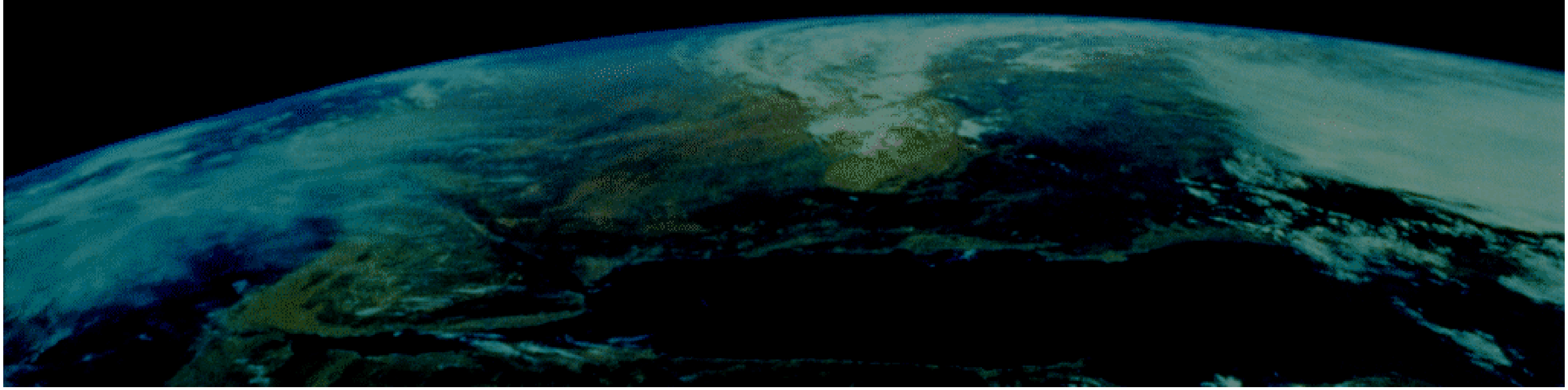
Denver, Colorado

Outline

Reasons for Capillary Pressure/Petrophysical Modeling:

- Combine lab measurements of capillary pressure components with petrophysics, to gain insight into saturation/height functions, porosity/permeability relations as a function of CP-defined rock quality, and profiles of relative and effective permeabilities to the saturating fluids



Outline

Requirements:

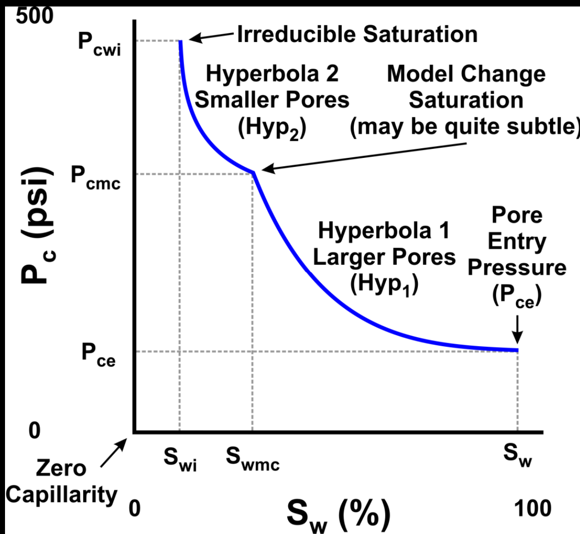
- Representative measurements on a variety of samples, covering the range of rocks present – low to high porosity, low to high permeability. A minimum of about 10 samples is required, and the more available the better.
- A reliable petrophysical log suite, preferably with more than one porosity log.
- If interpretations are to include relative permeability analyses, a set of representative relative permeability curves, or a reasonable "average" relative permeability curves representative of the reservoir.
- Run a standard petrophysical analysis, to define profiles of porosity and water saturation

Outline

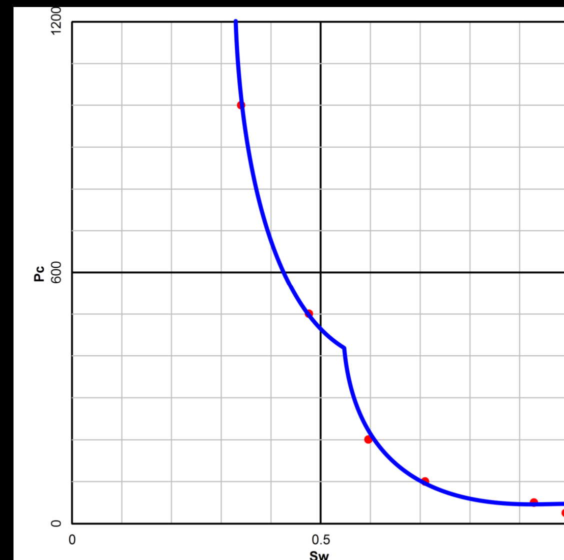
Applications:

- Calculate saturation/height functions on wells within the reservior. Once the model is established, it can be run on wells that have not been cored.
- Identify hydrocarbon/water contacts, even if below the T.D. of the well
- Identify locations of transition zones
- Quantify changing rock quality, as defined by porosity/permeability relations
- Calculate permeability, using specific porosity/permeability transforms identified through definition of rock quality
- Calculate relative and effective permeabilities by comparing actual S_w with theoretical S_{wi}
- Identify reservoir packages in hydraulic continuity

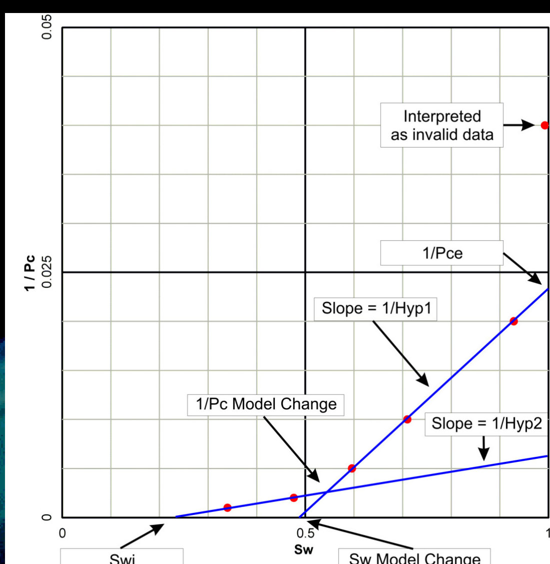
Basic Concepts



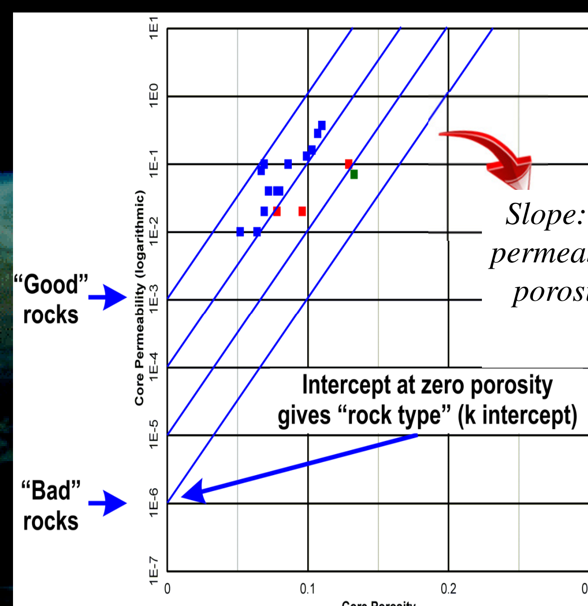
Six elements of CP curve: P_{ce}, Hyp 1, S_{wmc}, P_{cmc}, Hyp 2, S_{wi}



Example capillary pressure curve from MWX-1 plotted in the standard way – capillary pressure vs. water saturation.



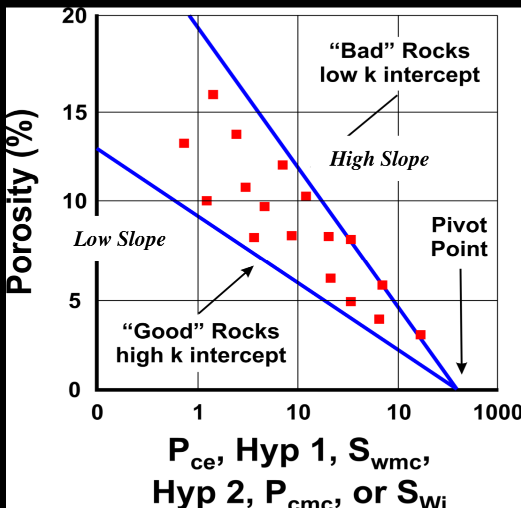
Plot of reciprocal capillary pressure to show how the elements of a capillary pressure curve are chosen.



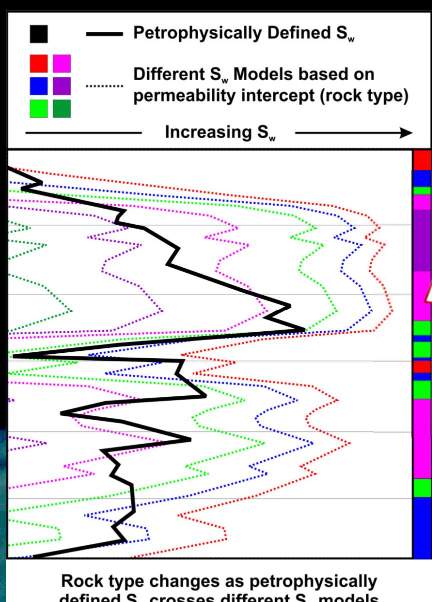
Slope: 3 decades of permeability per 10% porosity empirical choice

Porosity vs. permeability cross-plots for MWX-1 showing distinction of "rock types".

Basic Concepts



Schematic diagram showing comparisons between capillary pressure curve elements and porosity for a series of capillary pressure curves.



Height above zero capillarity

150

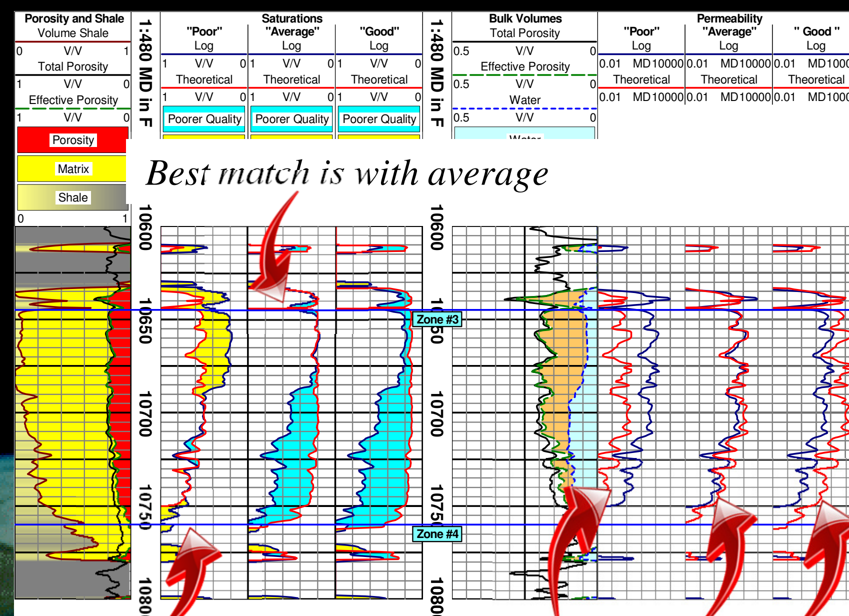
Petrophysical porosity profile

100

500

Zero capillarity

Schematic of the capillary pressure/petrophysical model.



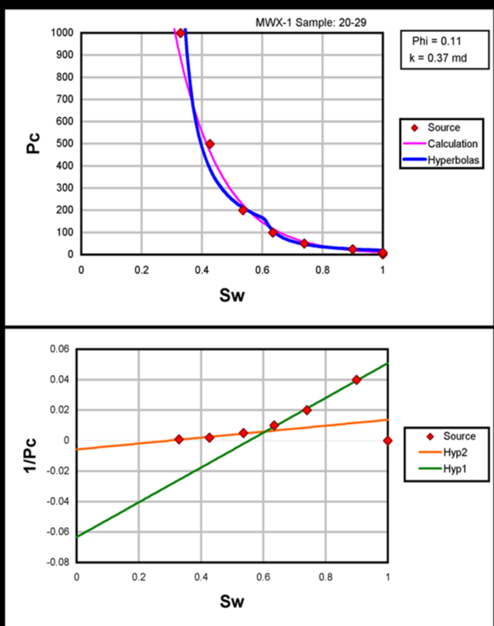
Best match is with average

Best match is with poor

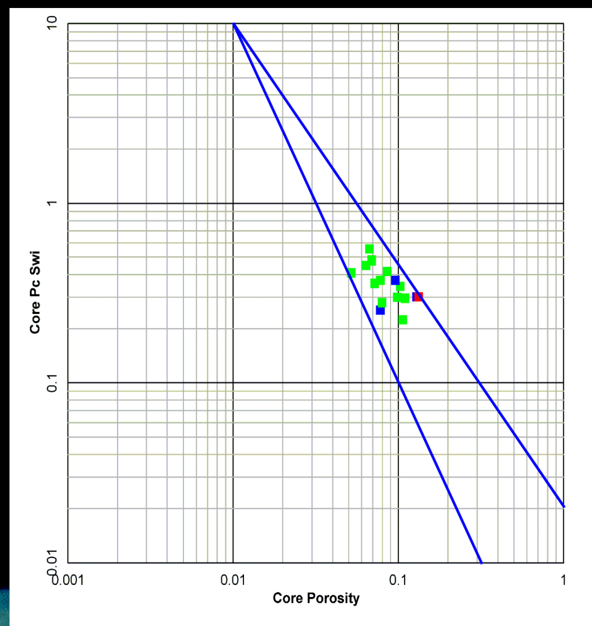
Permeability from CP model (red) compared with a standard Timur permeability (blue)

Simplistic model showing rock categories by S_W comparison

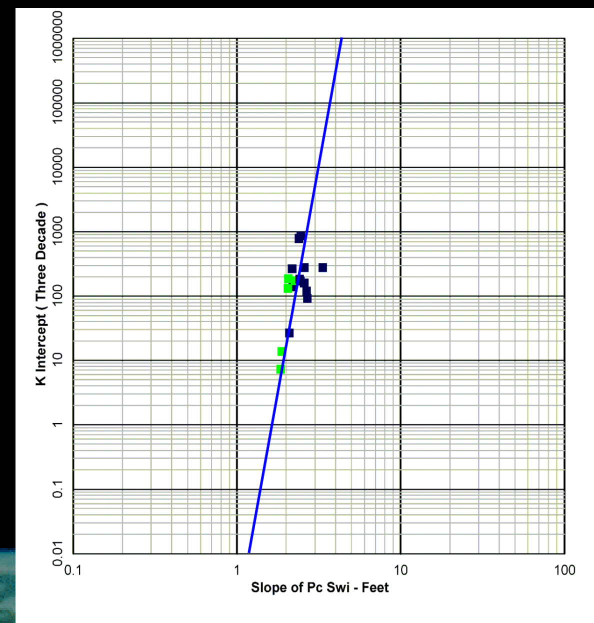
Data Processing for Reservoir CP Modeling



Curve fitting raw Capillary Pressure Data.

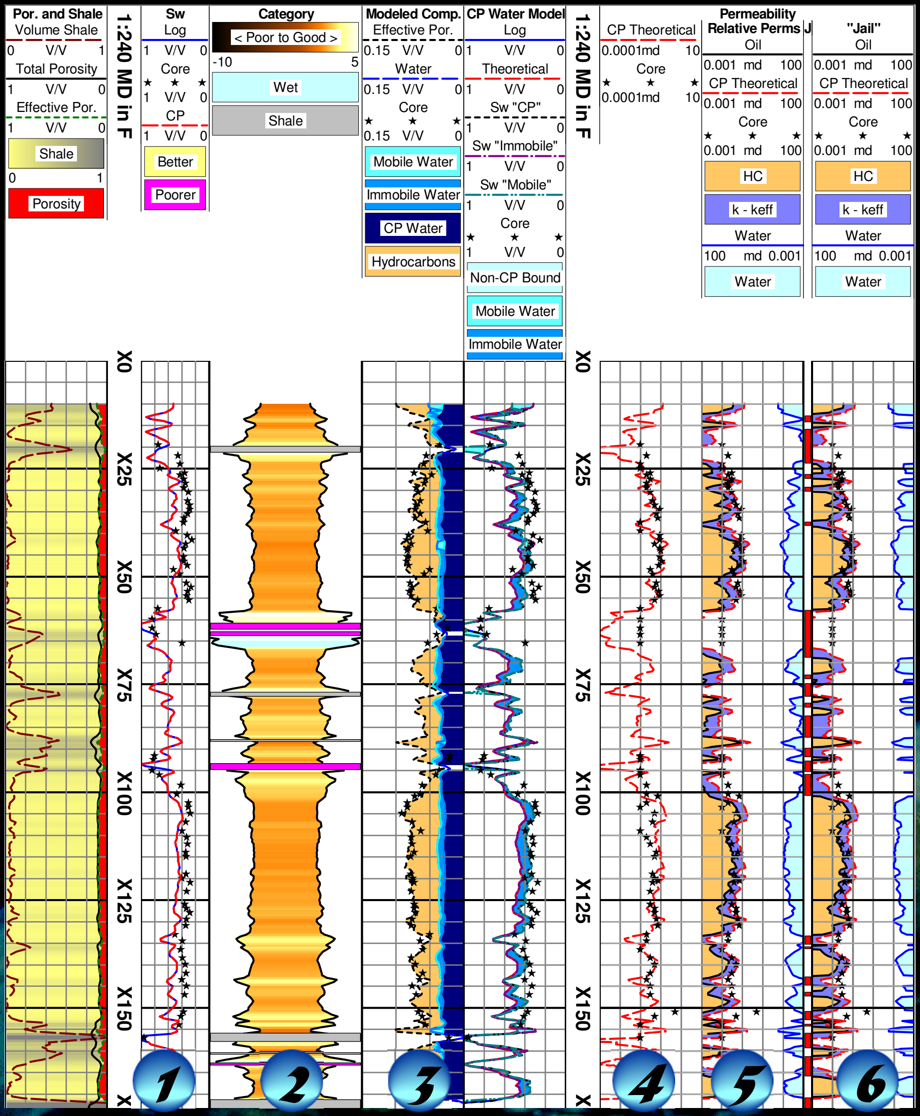


Example comparison



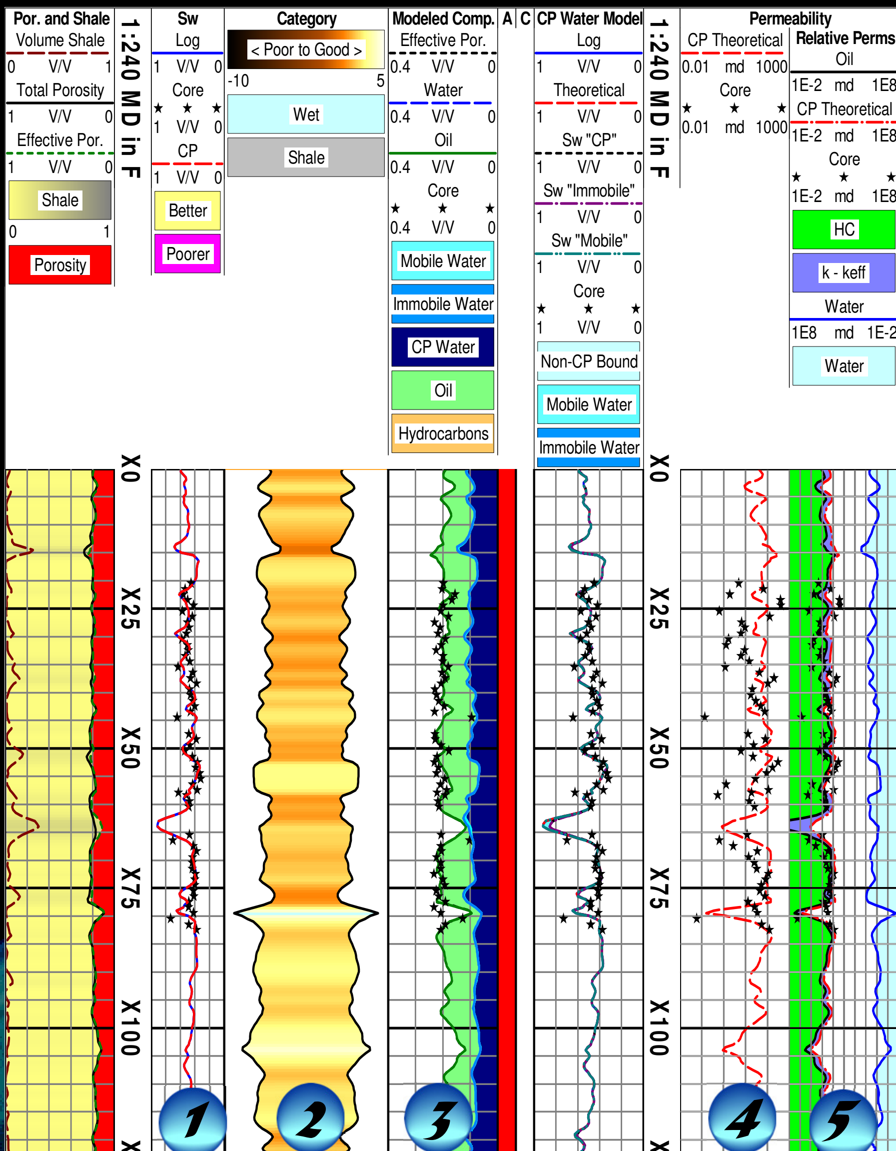
Example correlation between slopes of one of the CP elements vs. porosity, and k intercept. These correlations form the basis of the model.

Data Presentation Examples – Gas Well



1. Comparison of petrophysical S_w with CP model S_w and core S_w
2. Hour glass shows rock quality
   Grey = shale
   Red = outside model limits
3. Fluid categories from CP model
4. Comparison between CP model permeability and core permeability
5. Effective permeability to hydrocarbons and water. Purple indicates where $k > k_{eff}$
6. Permeability outside the "permeability jail" (Shanley, Cluff, and Robinson). Gas wells only. Purple indicates where $k > k_{eff}$

Data Presentation Examples – Oil Well



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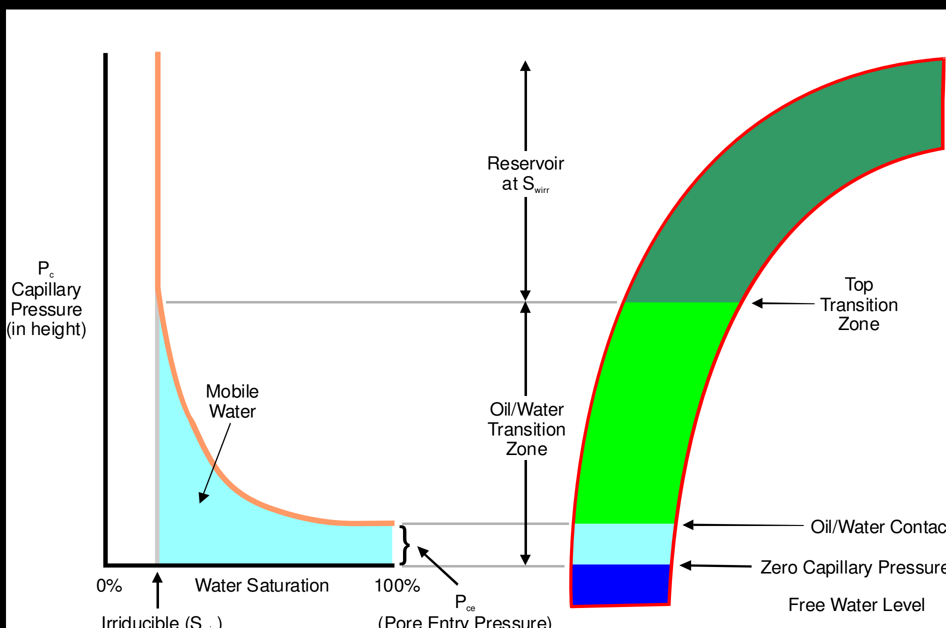
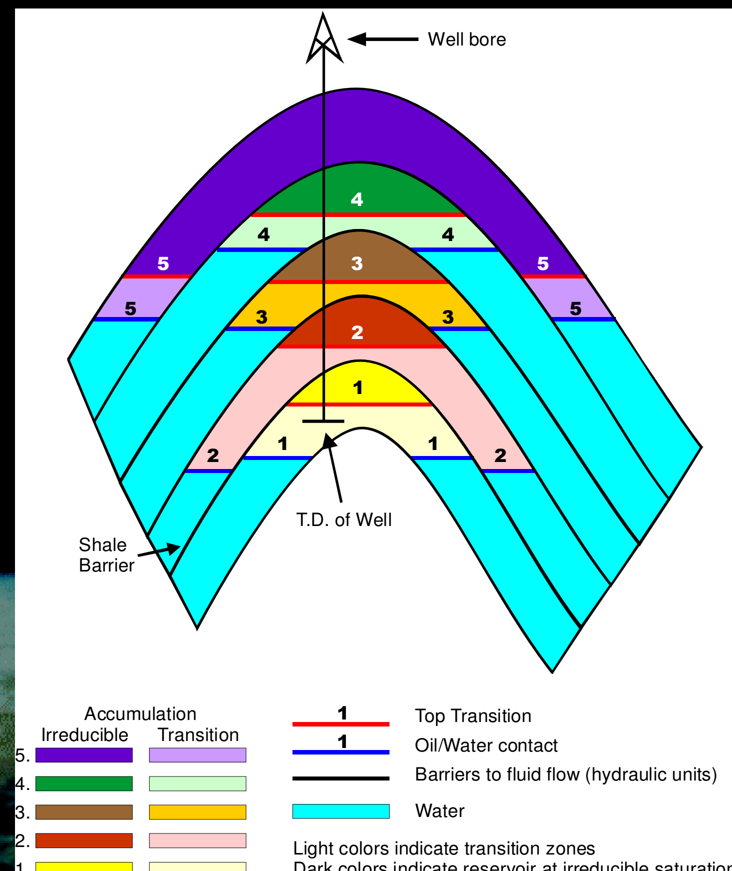
Schematic of Oil Accumulations

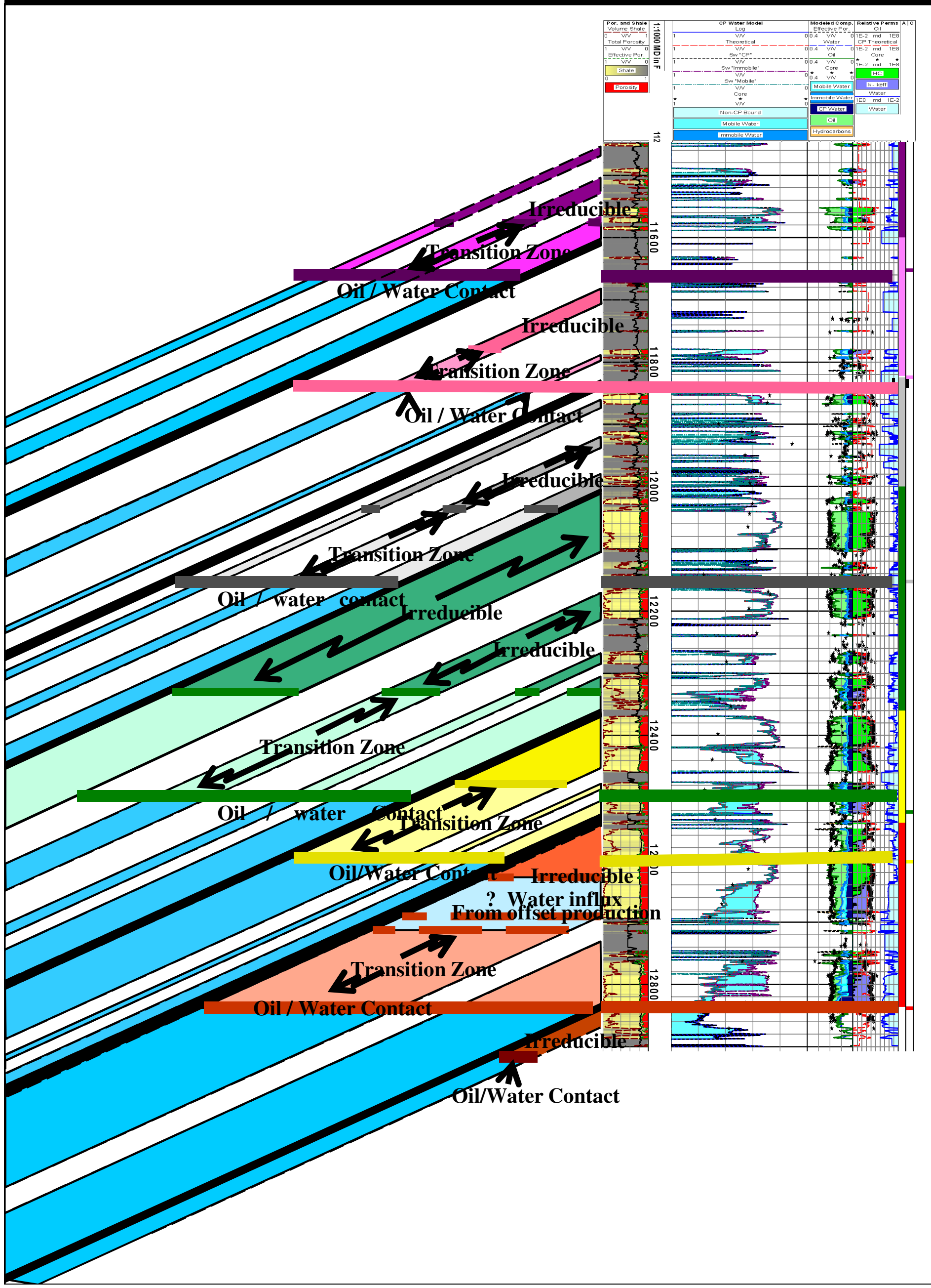


Relations of a single accumulation to capillary type curve.

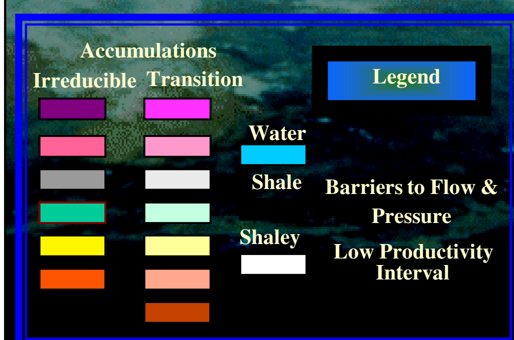


Schematic relations of multiple accumulations.

Stacked Oil Water Accumulations

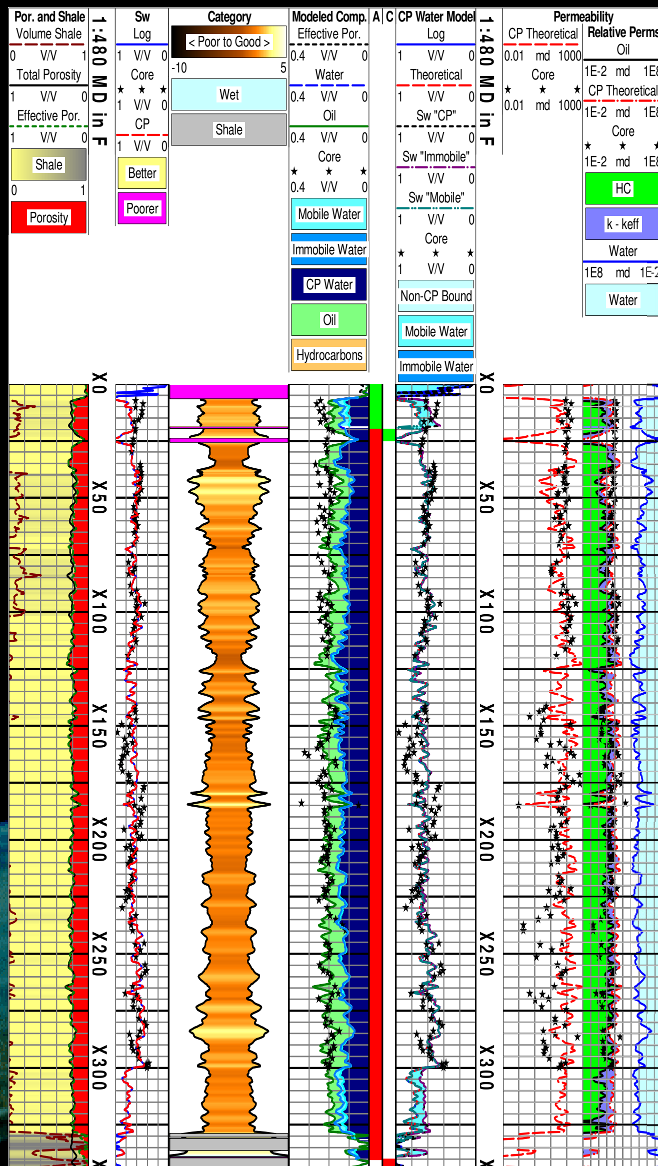


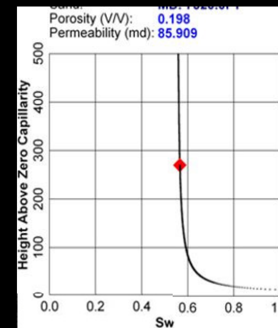
For any one accumulation, the hydrocarbon/water contact is chosen to give the best match of theoretical saturation with petrophysically-defined saturation. This might involve a contact below the T.D. of the well, or below the lower boundary of the accumulation in the wellbore. Once the model is established, transition zones can be distinguished from levels at irreducible water saturation.



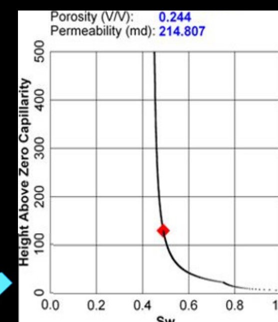
Data Presentation – Different CP Curves from Different Depths

Capillary pressure curves are derived from the model, and are specific to the appropriate depth. S_w location at each depth is shown on the curves.

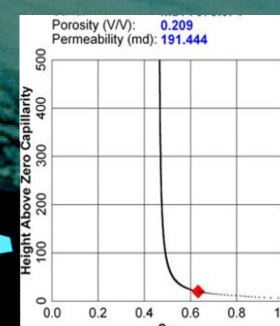




A

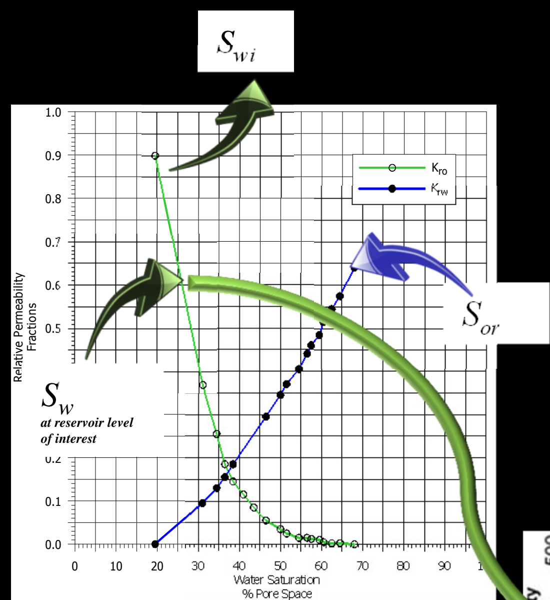


B



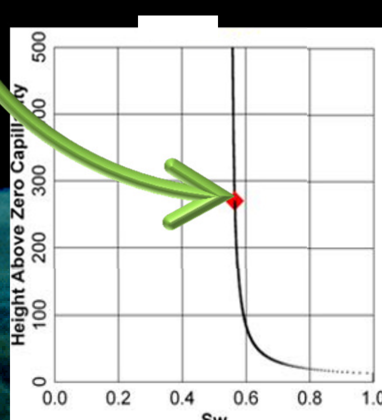
C

Example of Interpretation of an Oil Reservoir CP Model

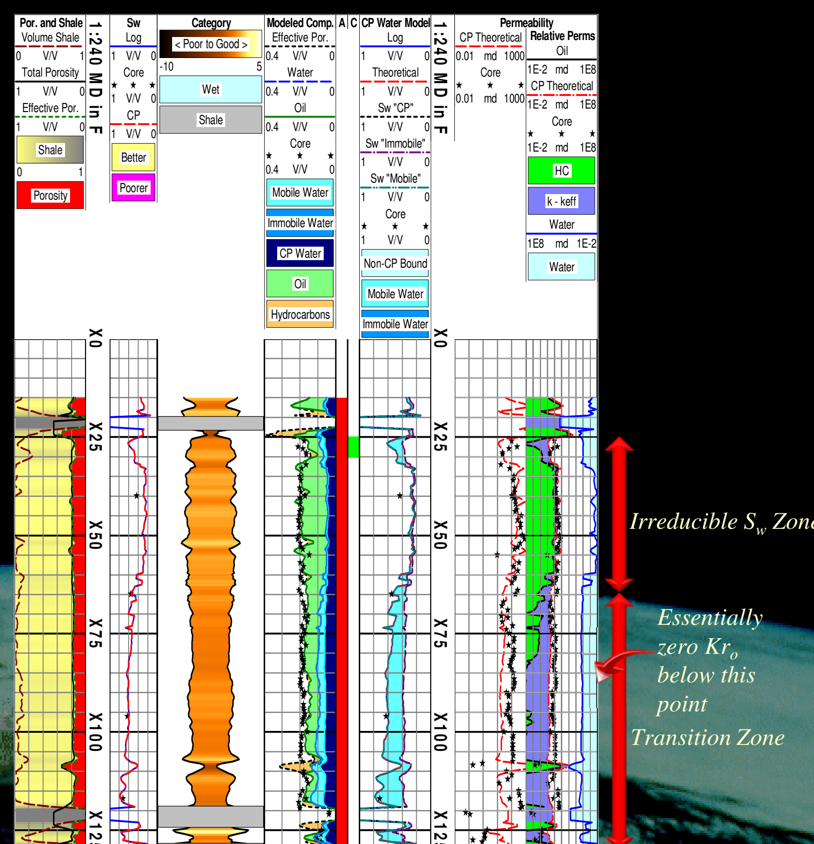


Rocks in the transition zone have very low effective permeability to oil effective permeability to oil, essentially zero at depths below 25 feet from the top of transition zone.

Both S_{wi} and S_w are known, and therefore relative permeability to both wetting and non wetting phase can be calculated. Combined with permeability (from rock quality relations) effective permeabilities can be derived.

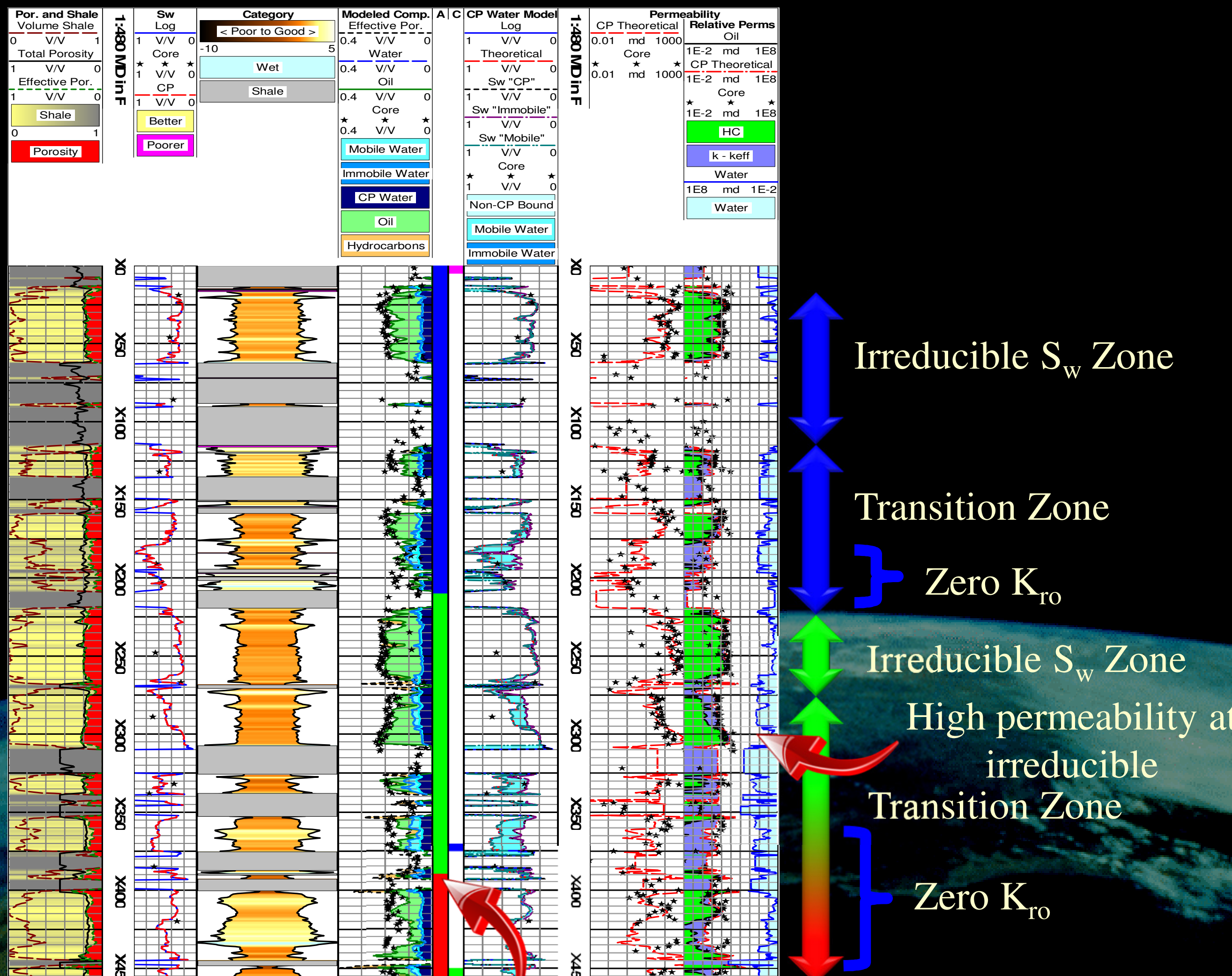


South American Example



Example of Interpretation of an Oil Reservoir CP Model

South American Example



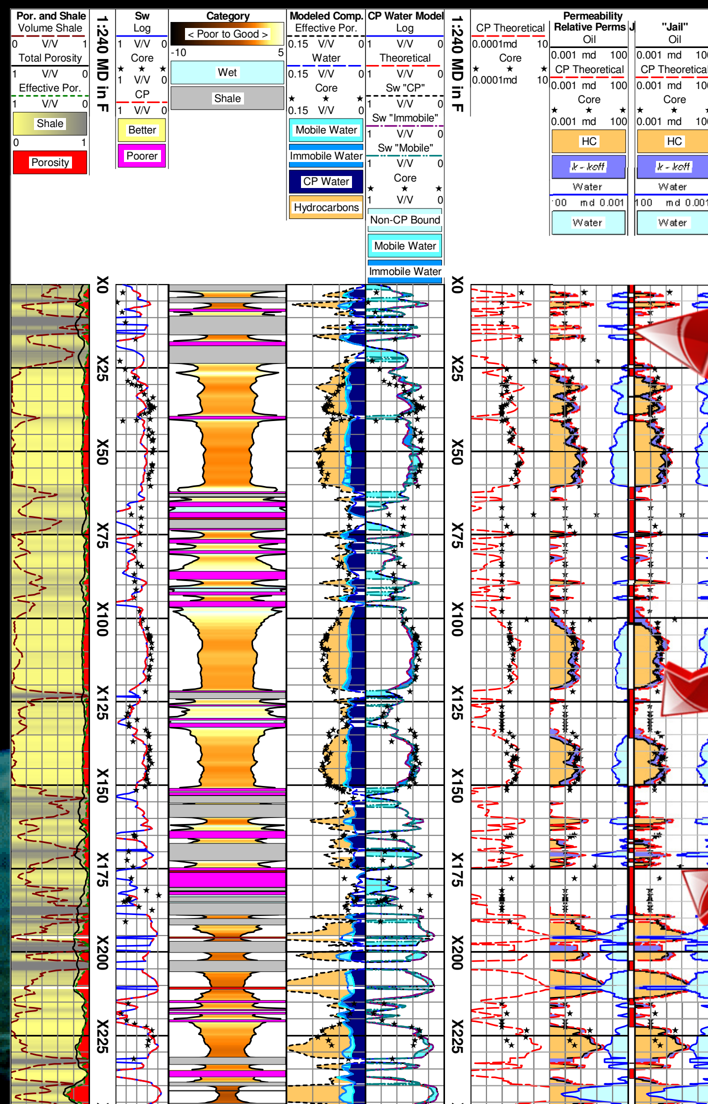
Interpreted accumulations and contacts are illustrated by blue, green, and red vertical bars

Example of Interpretation of a Tight Gas CP Model

Piceance Basin Example

Permeability "jail" (Shanley, Cluff, and Robinson) is defined as rocks with less than 50 microdarcies permeability. Gas will not move from these rocks.

Effective permeability to gas is an indicator of which levels will contribute to recoverable reserves.



Red vertical bars indicate "Permeability Jail"

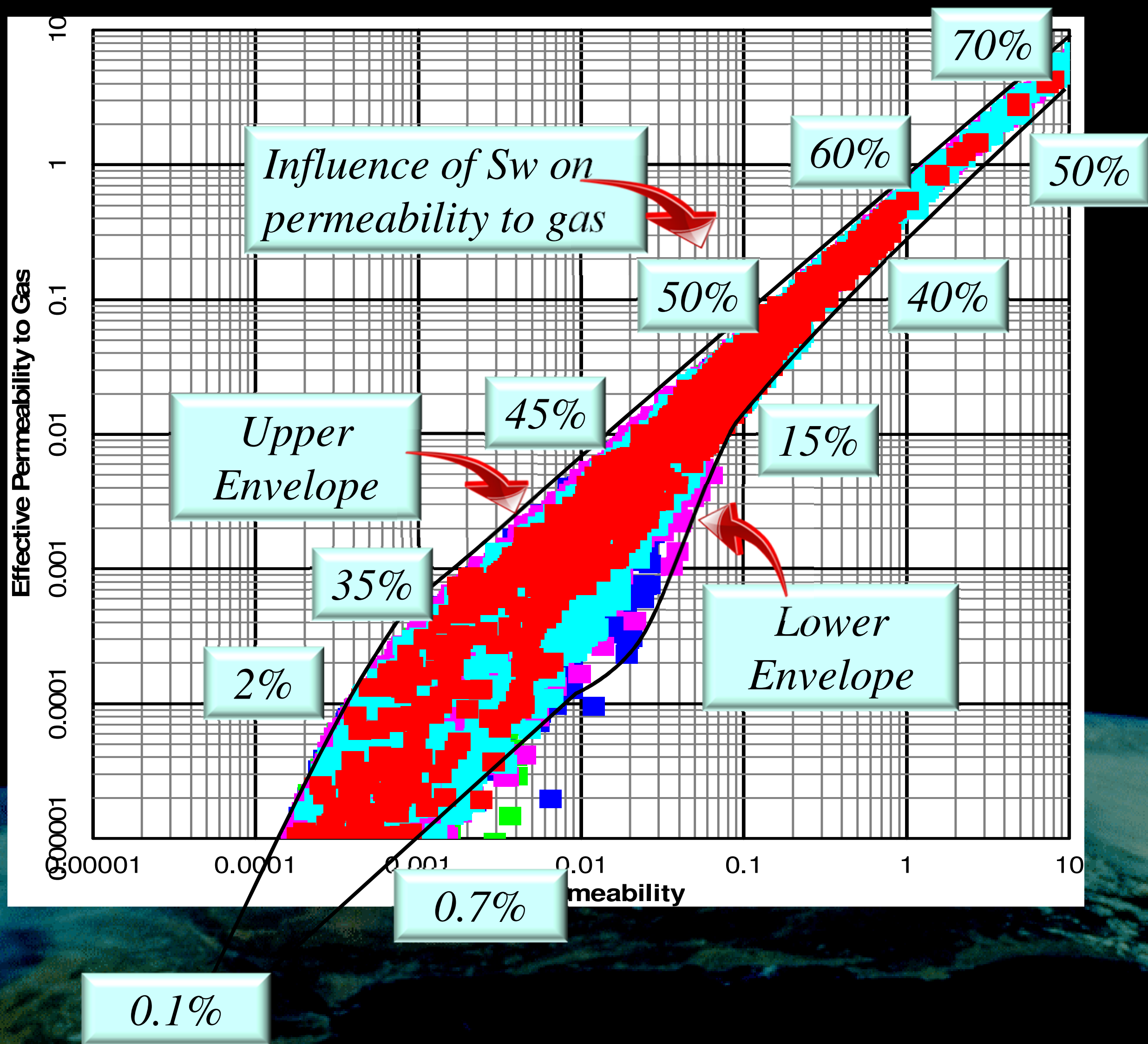
Good match of CP model permeability with core permeability

Very tight sands that do not contribute to flow

Core permeability lower limit of 0.01 mD

Occasional "high" core permeability suggests fractures

Example of Interpretation of a Tight Gas CP Model



Comparison of permeability with effective permeability

Conclusion

- The model logic is entirely deterministic, and incorporates both the transition zone as well as levels at irreducible water saturation
- Each reservoir has a different mix of capillary pressure characteristics, and requires creation of a reservoir-specific model
- Validity of the model can be checked by observing how well the model predicts permeability (by comparing with core permeability)
- Location of hydrocarbon/water contacts can be estimated by iterative changes in the picks, until the best match with petrophysical response is obtained

Conclusions

- Once a reliable match of theoretical saturation curves with petrophysically-defined saturation, a variety of interpretations are possible:

  - Identify transition zones and levels of mobile water

  - Examine the changing profile of rock quality and permeability with depth

  - Determine the profiles of effective permeabilities to both wetting and non wetting phases

  - Distinguish between levels that are potentially productive, and those that are non-productive

References

1. Byrnes, A.P., 2003, Aspects of permeability, capillary pressure, and relative permeability properties and distribution in low-permeability rocks important to evaluation, damage, and simulation: Rocky Mountain Association of Geologists and Rocky Mountain Region of Petroleum Technology Transfer Council – Petroleum Systems and Reservoirs of Southwest Wyoming Symposium.

1. Doveton, J. H., 1994, Geologic log analysis using computer methods, AAPG Computer Applications in Geology, No. 2, p. 1-22.

3. Holmes, M., Holmes, A., Holmes D., 2004. “Petrophysical Analysis of Piceance Basin Tight Gas Sandstones, NW Colorado, to Distinguish Wet Sands from Gas-Bearing Sands, and to Categorize Rock Quality Variation by Incorporating Ca Pressure Interpretations” . RMAG Guidebook.

4. Shanley, K.W., Cluff, R.M., and Robinson, J.W., 2004. “Factors controlling prolific gas production from low-permeability sandstone reservoirs: Implications for resource assessment, prospect development, and risk analysis” AAPG Bull., v 88, n 8, p 1089-1121.