Uncertainty in Petrophysical Evaluation*

Eric Pasternack[1]

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[1]Outsource Petrophysics, Inc., Mendota Heights, Minnesota. (outpetro@aol.com)

Abstract

Petrophysical parameters are key inputs to all estimates of reserves. None of these parameters is measured directly in the reservoir; each is inferred from measurements on cores and/or from various measurements made during wireline logging or logging while drilling. There is uncertainty in every one of these inferred parameters.

Inferred petrophysical parameters include porosity, fluid saturations and net pay, all of which are used for calculations of volumetrics. Permeability is also an inferred petrophysical parameter, used in various ways to infer producibility. There is always some degree of uncertainty in these inferred parameters. Even depth, the most basic measurement of all, has an associated uncertainty that can be extremely important in reserves estimation.

Quantifying the uncertainties in inferred petrophysical parameters requires going back to first principles and understanding the sources of these uncertainties. This presentation addresses these sources of uncertainty and discusses analytic and statistical methods for quantifying their effects on the overall uncertainty of the computed parameters.

Ethical considerations in petrophysics are relatively straightforward. It is the job of the petrophysicist to give the best technical answer with an indication of the uncertainties associated with that answer. All assumptions and calculation methods should be fully documented so that another petrophysicist can duplicate the result.

Uncertainty in Petrophysical Evaluation

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Outsource Petrophysics, Inc.

Sources of Uncertainty

- Uncertainties in measurements
  - Statistical uncertainty in nuclear logs
  - Effects of heterogeneity
  - Thin bed effects
  - Invasion effects
  - Systematic errors requiring “normalization” to correct
  - Tool response issues
  - Depth (LWD vs wireline, for example)
- Uncertainties in interpretation model
  - Shaly sand equations
  - Parameters used for porosity and water saturation determination
  - Lithological or textural assumptions
  - Uncertainties in cutoffs

Propagation of Uncertainties

- Consider any petrophysical interpretation equation
  - For example, porosity from the density log:

    PHI = (RHOma – RHOb)/(RHOma – RHOfl)
- You can estimate uncertainties in the answer based on the uncertainties of the parameters in the equation
  - Analytically
    - Using equations based on the partial derivatives with respect to each quantity
  - Statistically
    - Monte Carlo techniques
      - Beware of correlated variables

Propagation of Uncertainties

- We generally underestimate the uncertainties in petrophysical results due to:
  - Underestimation of uncertainties in the input parameters
    - We think we know more than we do
  - Underestimation of measurement uncertainties
    - Statistics
    - Vertical resolution effects
    - Invasion effects
  - Underestimation of model uncertainties
    - Specific tool response model
    - Interpretation model

Bottom-Line Petrophysical Uncertainties

- Are not necessarily symmetric about a base case
  - Due to physical constraints
    - Sw cannot exceed 1 or be less than 0
    - Porosity cannot go below 0
  - Due to the use of cutoffs in interpretation
    - Net pay cutoffs: clay volume, porosity and water saturation
- Are often correlated
  - For example, uncertainty in porosity results in uncertainty in computed water saturation

What can you do to reduce petrophysical uncertainties?

- Obtain and use appropriate physical data to tie down key parameters
  - Water resistivity measurements
  - Grain density
  - Core porosity and permeability (at net overburden stress)
  - Net pay cutoffs
  - Capillary pressure curves
  - Electrical properties
    - Measurements must be appropriate for, and interpreted consistent with, the interpretation model
      - For example, measurements of Co as a function of Cw instead of simple formation factor determination

What else can you do to reduce petrophysical uncertainties?

- Obtain and use appropriate “reliable” modern logs
  - Gamma ray, density, neutron, photoelectric factor, focused array resistivity, anisotropy, magnetic resonance, wireline formation tester, compressional and shear sonic, capture spectroscopy
- Use appropriate tool response modeling to verify and (in some cases) correct recorded logs. Examples:
  - Environmental corrections
  - Vertical resolution matching
  - Rt from measured resistivity logs

What else can you do to reduce petrophysical uncertainties?

- Incorporate rock information in petrophysical interpretation
  - Physical data
  - Core photos
  - Core descriptions

Conclusion

- Ask your petrophysicist for an estimate of uncertainty in his/her answers
  - Take it with a grain of salt or two aspirins, depending on your petrophysicist and your frame of mind
  - Petrophysical uncertainties are probably larger than you think they are, especially in complex environments