

Benchmark Petrophysics Training

Integrated Petrophysics for Reservoir Characterisation - Course Contents

Daily: Recap - Theory - Practical - Lunch - Theory - Practical

DAY1

INTRODUCTION

Course Overview

Objective of Formation Evaluation

Difficult Conditions for Formation Evaluation

Data Sources

Non-Numerical Information

Limitations of Data Sources - General

Scales of Measurement and Heterogeneity

Increased Heterogeneity Requires Increased Sampling

Micropractical

Fine Scale Data Requires Log Correlation

Inequalities Between Laboratory and Reservoir

Non-Unique Transforms between Measured Parameter and Reservoir Parameter

Lack of Rigid Calibration Grid

Deterministic vs. Probabilistic Petrophysics

QUICK LOOK LOG ANALYSIS

Operations Petrophysics: Chronological Tasks and Responsibilities

Environmentally Correct Logs

Compute Vsh

Compute \emptyset

Micropractical

Compute Sw

Compute k

Compute Netpay

DATA PREPARATION

Log Data Preparation

Missing Data

Log to Log Depth Matching

Environmental Corrections

Merge LWD and Wireline

Log Normalisation

Seismic Petrophysics Log Editing Process dt, rhob

Core Data Preparation

Core to Log Depth Matching

Vetting Special Core Data

Preliminary Zonation

LITHOLOGY and CLAY CONTENT: Vcl , Vsh

Objective

Distinction Between Clay and Shale

Uses of Vclay , Vshale

Importance

Common Problems

Non-Radioactive Fines and Radioactive Non-fines

Gas and other Non-Shale Influences Vshale Logs

Is Vclay / Vshale Relevant to Reservoir Beds?

Lack of Core Calibration and a Certain Vshale = Zero Reference

Scales of Heterogeneity in Core Calibration

Lithology, Vcl, Vsh Input Data

Bulk Volume Irreducible from Magnetic Resonance Logs, mbvi, bvf

Movie

Vshale, Vclay & Capillarity from Laser Particle Analysis Grain Size Distribution

Clay Volume from Core Plugs or Trims, Vclcore

Clay Volume from Thin Sections, Vcltx

Thin Section Limitations

Core Photographs and Descriptions

X-Ray Diffraction and Scanning Electron Microscope
Mudlogs and Lithlogs
Practical Session
Log Integration
Method
Shale Volume from Gamma Ray: V_{shgr}
Non-linear V_{sh}
Shale Volume from Density-neutron: V_{shdn}
Shale Volume from Density-sonic: V_{shds}
Shale Volume from Resistivity: V_{shres}
 V_{shgr} , V_{shdn} , V_{shds} or V_{shres} ?
Thomas-Steiber clay distribution

POROSITY: \emptyset
Objective
Importance
Common Problems
Badhole Conditions
Minimising Badhole Conditions
Effective Porosity
Shale
Gas
Unknown Grain Density
Lack of Density Tool

DAY2

Morning Daily Recap, Questions, Debate
Non Shale Corrected Density-neutron Total Porosity
Porosity Input Data
Conventional Coring Criteria
Core Porosity and Grain Density, \emptyset_{core} , ρ_{hg}
Recommended Routine Core Analysis procedure
Core Porosity Method
Core Overburden Porosities
Log Integration
Total and Effective Porosity: \emptyset_t , \emptyset_e
Carbonates: Intergranular and Vuggy Porosity, \emptyset_v
Fracture Porosity, \emptyset_f
Density Total Porosity, \emptyset_d
Mean Grain Density Determination
Grain Density in Complex Lithologies
Correct ρ_{hg} , neutron & sonic matrix in shales
Fluid Density, ρ_{hf}
Magnetic Resonance Total Porosity, \emptyset_{mrt}
Magnetic Resonance Effective Porosity, \emptyset_{mre}
Shale Corrected Neutron Total Porosity, \emptyset_n
Neutron Porosity Method
Shale Corrected Density-Neutron Total Porosity, \emptyset_{dn}
Gas Zones
Micropractical
Shale Corrected Sonic Total Porosity, \emptyset_s
Sonic Porosity Method
Limitations of Multiple Linear Regression Porosity, \emptyset_{mlr}
Probabilistic Porosities
Badhole Conditions
Shale Volume Derived Porosity, \emptyset_{vsh}
Water Saturated Resistivity Porosity, \emptyset_{ro}
Two Stage Minimum Porosity: \emptyset_s , \emptyset_{vsh}
Effective Porosity Equations, \emptyset_e
What is Effective Porosity?
Mainstream Petrophysics Effective Porosity
Traditional log analysis Effective Porosity
Magnetic Resonance Porosities, \emptyset_e , \emptyset_t
Vary ρ_{hg} with shale
Recap - Summary of Typical Porosity Evaluation

FORMATION WATER RESISTIVITY: R_w

Rw Input Data
Recovered Formation Water
Well Tests
Reservoir Temperature, Tres
Wireline Formation Tester Water Samples
Archie Apparent Water Resistivity, Rwa
Certain water zones, Sw100
Micropractical
Archie Apparent Flushed Zone Water Resistivity, Rmfa
Resistivity Ratio Apparent Water Resistivity, Rwrr
SP Logs
Origin of SP
Determining Rwsp
Rwsp Recipe
Rw Catalogues
Wireline Formation Tester Water Gradients
Integration of Rw Values
Practical Session

WATER SATURATED RESISTIVITY: Ro
Summary of Common Problems
Special Core Analysis 'm' Not Equal To In-situ 'm'
Invalid \emptyset , a, or m or Rw and Sw100 zones
 $\emptyset_{sca} \neq \emptyset_{rca} \neq \emptyset_{log}$
Ro Equation Inputs
Total Porosity, \emptyset_t
Formation Water Resistivity, Rw
Cementation Exponent 'm'
'm' Objective
Pickett Plot
'm' Importance
'm' Input Data
Electrical Special Core Analysis Laboratory 'a' and 'm'
Problems with Laboratory 'm' values
Log Analysis Water Zone 'm'
Carbonates: \emptyset_v and Water Zone 'm'
Problems with Log Analysis 'm' values
'm' Log Integration

DAY3

Morning Daily Recap, Questions, Debate
RESISTIVITY SATURATION: Swrt
Summary of Common Problems
Absence of Conventional Core Calibration
Core Analysis 'n' Not Equal To In-situ 'n'
Freshwater Shaly Sands
Formation Heterogeneity Un-Resolved by Rt
Sw Equation Inputs
Formation True Resistivity, Rt
Which Logging Tool?
Rt Problems
Inadequate or Inappropriate Rock Volume Resolution
Deep Invasion
Shoulder Beds
Horizontal and Vertically Resistivity in Laminated Beds (3DEX)
Groningen and Delaware Effects
Cased Hole Resistivity Tool (CHFR) xx
Saturation Exponent, 'n'
'n' Objective
'n' Importance
Laboratory 'n' Problems
Wettability - Containing the Problem
Laboratory 'n' Input Data
Electrical Special Core Analysis Laboratory 'n'
Guidelines for Improved Laboratory 'n'
Micropractical

SHALY SAND Swrt

Waxman Smits Equation Inputs
Cation Exchange Capacity (CEC) and Q_v
 Q_v from Magnetic Resonance Logs, Q_{vmr}
 Q_v from Archie apparent water zone 'm'
Equivalent Conductivity of Exchange Cations, B
Waxman & Smits Cementation Exponent, m_{ws} (m^*)
Waxman & Smits Saturation Exponent, n_{ws} (n^*)
ImageLog Facies as Classes of Clay Distribution and B
Shaly Sand Swrt Log Integration
Is a Shaly Sand Equation Required ?
Log Data
Laboratory Electrical Data
Selecting a Suitably Structured Resistivity Swrt Equation
Core Sw Equation Inputs Do Not Guarantee Sw Output

CORE SATURATIONS

Oil Base Mud Core Sw and 'n' Calibration (Swobm)
Low Invasion Water Base Mud Core Sw and 'n' Calibration
Conventional Core Porosity and Permeability Sw and 'n' Calibration
Minimum Fluids Exchange
Conventional Core Fluid Saturations as Sw Constraints
1 Limitations of Conventional Core Fluid Saturations
Restored State Core
Well Tests as Sw Constraints
Reservoir Saturation Tool, RST

CAPILLARY PRESSURE SATURATION, Swpc

Capillary Pressure Derived Sw and 'n' Calibration
What Is Capillary Pressure?
Capillary Pressure Data Acquisition
Identifying Bad Capillary Pressure Data
Capillary Pressure Data Interpretation
The Reservoir Master Equation, [Sw- ϕ -k-Height]
The J Function Method
The Regression Method
Individual Plug Curve Fit Methods, Skelt etc
Log Integration of Swpc
Problems with Capillary Pressure Derived Sw and 'n'

DAY4

Morning Daily Recap, Questions, Debate
MAGNETIC RESONANCE SATURATION, Swmr
Magnetic Resonance Tool's Swi

RECONCILIATION OF Swrt via n

'n' Log Integration
Implied Sw Constraint from Electrical versus Capillary Pressure 'n' values ?
Field Example of Data Integration Constraining 'n'
Earth Tide Downhole Pressure Variations and Netgas Porosity xx
Sw Logical Constraints
Resistivity Ratio, Swrr
Log(R_t/R_{xo}) v SP Movable Hydrocarbon Indicator

BASE CASE SATURATION - THE Sw DECISION TREE

SATURATION DERIVATIVES

Movable Oil Saturation, Som
Residual Oil Saturation, Sor
Log / Core Minimum R_t for Maximum Water Cut - Netpay
Micropractical

CONTACTS, FLUID ZONES AND CAPILLARY PRESSURE

Objective
Hydrocarbon Types
Reservoir Capillary Pressure: P_c
Importance
Summary of Common Problems

Badhole Unknown Formation Pressure Gradients
Logs respond to Bulk Volumes Not Mobility
Marginal Reservoir
Lack of Density-neutron
Fluid Zone Input Data
Wireline Formation Pressure Gradients and Samples
WFT Problems
Supercharging
WFT Operation and Operational Recommendations
WFT Further Details
GeoTap MWD Formation Tester
Recovered Fluids: Tests, Wireline, Kicks
Kicks
Early Formation Pressure System, EFPS
While Drilling Formation Pressure Tester
 $\rho_{\text{HOB}} - \text{npsc}$, $\text{dt} - \text{nphi}$, and $\rho_{\text{HOB}} - \text{dt}$ will Detect Gas!
Calculated Sw
Bulk Volume Water, BVW
Bulk Density - Rt Trend
Rt/Rxo vs SP
Residual Hydrocarbons seen by Rmfa
Shale Corrected Density-neutron Separation
Non shale corrected Neutron-Sonic Separation for Gas Carbonates
Magnetic Resonance Log Hydrocarbon Typing
Core UV Visible Spectroscopy
Reservoir Master Equation's prediction of Height
Chromatograph, Lithlog / Mudlog: Cut, Fluorescence, Stain
Quantitative Fluorescence Tool
IPL and Neutron Tools
Sonic Tool vp/vs
Maps and Cross Sections
Log Integration
Gas Zone
Oil Zone
Transition Zones
Residual Oil Zones
Coals and False Bulk Volume Hydrocarbon
Water Zone, Sw100 zones

PERMEABILITY: k
Objective
Importance
Relevance of Permeability to Special Log Processing
Common Problems
Dynamic Property Inferred from Static Properties
Inadequate Data for Analytic or Predictive Pore Typing
Core \emptyset - k Regression Applied with Log Effective \emptyset
Unidentified but Influential High Permeability Streaks
Invalid Low End Core kair
Shale and Extreme Low End Prediction
Unrecognised Sw > Swi Zones
Lack of k overburden data
k Input Data
Core Permeability
Conventional Air Permeabilities, kair
Klinkenberg Correction
Equivalent Overburden kbrine
Altered Core Permeabilities
Core Effective Permeability
Magnetic Resonance, kmr
Bulk volume hydrocarbon, bvH
Normalised Resistivity Ratio, RRn
Sidewall Core Laser Particle Analysis
WFT Permeability, kwft
Well Tests Permeability, kh
Well Test Problems
Permeability Averaging
Zonation
Pore Type Zonation: [\emptyset -Sw-k-Pc]
Core Capillary Pressure Data

Core \emptyset - k plots
Log Pore Typing Parameters
Is Facies Based Zonation Useful?
Borehole Image-log Facies Zonation
Other Log Permeability Predictors
Sonic Responses
Specific Surface Area
Log Integration
Timur-Coates Permeability Equation
Components of Bound Fluid Volume and their Log Prediction
Fitting Timur-Coates constants a, b and c
Summary of Conventional Log Permeability Evaluation
Effective Porosity, k_{por}
Saturation, k_{sw}
Reservoir Master Equation Enables k from S_w as well as S_{wi}
Clay / Shale Volume, kv_{sh}
Multiple k Inputs: Accuracy versus Stability
Estimated Production Rates

DAY5

Morning Daily Recap, Questions, Debate
NETPAY and NETROCK: N:G
Objective
Importance
Common Problems
Relevant Hard Data Usually Not Available
Different Understanding of Meaning and Function
Violating the integrity of the petrophysical results table
Impact of Marginal Bed's Thickness and Location
Use Core-log Data not stand-alone Core data
Reservoir Geometry May Isolate Rock Volumes
N:G Input Data
N:G Non-Log-Inputs
Water Encroachment
Depletion
Permeability at Zero Movable Oil from Relative Permeability Data
Core Fluorescence
Capillary Threshold Height and Closure
Borehole Image Logs
Conventional Core Porosity Permeability Data
Well Tests and Production Data
Micropractical
WFTs
Hydrocarbon Pore Volume from Material Balance
N:G Log Inputs
Magnetic Resonance Logs
Invasion Profiles
0.5 Micron Mean Pore Throat Radius
Mudcake Build-up - Microlog
Mudcake Build-up - Caliper
Borehole Image-logs in heterolithic beds
Evaluated Saturation, Porosity and Clay / Shale Volume
Micro Spherically Focused and Microlateral Logs
Log Integration
Criteria: Why Permeability?
Determine Netpay first then Netrock
Determine the Cut-off from Direct Reservoir Observations If Possible
Netpay and Fluid Zones

SENSITIVITIES & UNCERTAINTY

Importance
Cutoff Sensitivities
XLS or Batch Recalculation Sensitivity Studies
P10 P50 P90 Geo.Model Uncertainties
Reducing Sensitivities & Uncertainties Cost-Effectively

SEISMIC - PETROPHYSICAL INTEGRATION

Depth-Time Conversion

**Synthetic Seismograms
Fluid Substitution
Seismic Attributes**

REPORTING RESULTS

**Objective
Importance
Common Problems
Input Data
Data Extraction
Field Petrophysical Reference - The Results Table**

GEOLOGICAL MODELING

**In-Out Petrophysical checks
Permeability upscaling - key points**

WHY INTEGRATE ?

**Problems Resulting from Isolated Analyses
Formats for Integration
Field Database
Electronically Mobile Data
Core Data Sheets
Comprehensive Log Evaluations / Displays
Field Petrophysical Reference - The Answer Table
Enemies of Integration
Principles of Integration
Criteria for Data Hierarchy
Directness of Measurement to Reservoir Parameter
Accuracy of Measurement
Spatial Definition of Measurement
Reservoir Data Hierarchy
Non-Log-Data
Over-determined Systems**

FORMATION EVALUATION RECOMMENDATIONS

**Data Acquisition
Mud
Core
Core Description
Core Analysis
Logs
Saturation
Evaluation**

CASE HISTORY: LOW POROSITY RESISTIVITY

**Review of Core - Log - Well Test and Petrographic Data Integration
Problem
Data
Method
Key Findings
Conclusion: To be Announced**

EQUATIONS

**Lithology
M and N lithology parameters
Shale Volume from Gamma Ray
Shale Volume from SP
Shale Volume from Density-neutron
Porosity
Conversion of Laboratory to Reservoir Core Overburden Porosity
Density Porosity
Density-neutron Porosity
Density-neutron Gas Zone Porosity
Sonic Porosity
Porosity from R_o (water zones) assuming R_w and 'm'
Effective Porosity
Formation Water Resistivity, R_w
Porosity, m Apparent Water Resistivity, R_{wa}
Resistivity Ratio Apparent Water Resistivity, R_{wrr} and equivalent NaCl (chart
Saturation**

Formation Factor
Cementation Exponent
Waxman Smits prediction of water saturated resistivity, R_o
Resistivity Index
Saturation Exponent
Archie Saturation
Logarithmic Form of Archie Equation (where $a = 1$)
Archie Cementation Exponent from Water Zones
 S_{xo} from R_{mfa}
Dual Water Model Saturation
Waxman & Smits Model Saturation
Equivalent Conductivity of Exchange Cations
Effective Concentration of Exchange Cations per Unit Volume of Pore Fluid
Actual BQ_v Required to Satisfy W-S Equation in water zones ($S_{wt} = 1.00$)
 Q_v from Archie apparent water zone 'm'
Waxman Smits m_{ws} from Archie m
Popoun & Leveaux 'Indonesia' Shaly Sand Saturation
J Function Correlation of Pore Types
Conversion to Height above Free Water Level
Mercury capillary pressure clay bound water correction
Saturation Exponent from log independent S_w (S_{wx})
Layer S_w for Mapping Wedge Zones
 R_t for Economic Production (max. water cut)
Permeability
Darcy Permeability
Well Test Permeability Thickness
Empirical Klinkenberg Correction
Kbrine from Kair and CEC (Q_v)
Example k_{log} for Above Transition Zone
 k_{log} for Above Transition Zone - Log Data Only
Normalised resistivity ratio, RR_n
Fractional Flow Equation

FIGURE CAPTIONS

REFERENCES

Petrophysical Related Websites

ABBREVIATIONS

ESSENTIAL SCHLUMBERGER CHARTS

Maximum understanding, minimum time: 420 message driven slides

This course for benchmark, mainstream petrophysics training

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