

**Schlumberger**  
**Log**  
**Interpretation**  
**Principles/Applications**

**1989**

---

**Schlumberger**  
Log Interpretation  
Principles/Applications

---

Seventh printing. March 1998  
© Schlumberger 1991

Schlumberger Wireline & Testing  
225 Schlumberger Drive  
Sugar Land, Texas 77478

All rights reserved. No part of this book may be reproduced, stored in a retrieval system, or transcribed in any form or by any means, electronic or mechanical, including photocopying and recording, without prior written permission of the publisher.

SMP-7017

---

An asterisk (\*) is used throughout this document to denote a mark of Schlumberger.

---

# **Schlumberger**

## **Log Interpretation Principles/Applications**

---

---

# Contents

---

1	Introduction.....	1-1
	History .....	1-1
	The Field Operation .....	1-3
	Log Data Acquisition .....	1-5
	Data Processing .....	1-5
	Data Transmission .....	1-6
	References .....	1-7
2	Fundamentals of Quantitative Log Interpretation .....	2-1
	Porosity.....	2-1
	Saturation .....	2-1
	Permeability .....	2-2
	Reservoir Geometry.....	2-2
	Temperature and Pressure.....	2-3
	Log Interpretation .....	2-3
	The Invasion Process.....	2-4
	Resistivity .....	2-5
	Formation Factor and Porosity.....	2-5
	Water Saturation .....	2-6
	Resistivity Logging.....	2-7
	Water Resistivities .....	2-7
	Porosity .....	2-7
	Shaly Formations .....	2-8
	References .....	2-9
3	Spontaneous Potential and Natural Gamma Ray Logs .....	3-1
	The SP Curve .....	3-1
	Origin of SP .....	3-1
	Electrochemical Component of the SP .....	3-2
	Electrokinetic Component of the SP .....	3-3
	SP Versus Permeability and Porosity .....	3-3
	Static SP .....	3-3
	Determination of SSP .....	3-4
	Shape of the SP Curve.....	3-4
	Highly Resistive Formations .....	3-5
	Shale Baseline Shifts .....	3-5

---

## Contents

---

SP Anomalies Related to Invasion Conditions .....	3-6
SP Anomalies—Noise .....	3-7
The GR Log .....	3-7
Properties of Gamma Rays .....	3-7
Equipment .....	3-8
Calibration .....	3-8
Borehole Correction Curves .....	3-8
Applications .....	3-8
The NGS Log .....	3-8
Physical Principle .....	3-8
Measurement Principle .....	3-9
Log Presentation .....	3-10
Borehole Correction Curves .....	3-10
Interpretation .....	3-10
Applications .....	3-11
References .....	3-11
4 Formation Water Resistivity Determination .....	4-1
$R_w$ From Water Catalog .....	4-1
$R_w$ From Chemical Analysis .....	4-1
$R_w$ From the SP .....	4-1
Determination of $R_{mfe}$ .....	4-2
Determination of $R_w$ .....	4-2
Environmental Corrections and Precautions .....	4-2
Salts Other Than NaCl .....	4-2
SP Anomalies .....	4-3
$R_w$ From Resistivity-Porosity Logs .....	4-3
$R_{wa}$ Log .....	4-3
$R_{wa}$ -SP Plots .....	4-4
Resistivity-Porosity Plots .....	4-4
$R_w$ From $R_{xo}$ and $R_t$ .....	4-4
References .....	4-4
5 Porosity Logs .....	5-1
Sonic Logs .....	5-1
Principle .....	5-1

---

## Contents

---

Equipment .....	5-2
Log Presentation .....	5-6
Sonic Velocities in Formations .....	5-6
Porosity Determination (Wyllie Time-Average Equation).....	5-6
Consolidated and Compacted Sandstones .....	5-6
Carbonates .....	5-6
Uncompacted Sands.....	5-6
Empirical Equation Based on Field Observations.....	5-8
Correlations With $\delta$ Curve .....	5-8
Abnormal Formation Pressures .....	5-8
Shear-Wave Interpretation .....	5-8.
Density Logs .....	5-9
Principle .....	5-9
Equipment .....	5-10
Logging Empty Holes .....	5-10
Log Presentation .....	5-10
Calibration .....	5-11
Borehole Effect .....	5-11
Electron Density and Bulk Density.....	5-11
Porosity From Density Log .....	5-12
Effect of Hydrocarbons.....	5-13
Effect of Shale .....	5-13
Effect of Pressure .....	5-13
Litho-Density* Log .....	5-14
Equipment .....	5-14
Photoelectric Absorption .....	5-15
Tool Response .....	5-17
Neutron Logs .....	5-17
Principle .....	5-17
Equipment .....	5-17
Log Presentation .....	5-18
Calibration .....	5-19
Investigation Characteristics .....	5-20
Tool Response.....	5-20
Hydrogen Index of Salt Water .....	5-20
Response to Hydrocarbons .....	5-20

---

# Contents

---

Shales, Bound Water .....	5-22
Effect of Lithology .....	5-22
Determining Porosity from Neutron Logs .....	5-22
SNP Corrections .....	5-22
Thermal Neutron Measurement .....	5-22
Applications .....	5-23
Logging While Drilling Formation Density and Porosity .....	5-23
References .....	5-24
<b>6      Lithology and Porosity Determination .....</b>	<b>6-1</b>
Neutron-Density Crossplots .....	6-1
Sonic-Density Crossplot .....	6-2
Sonic-Neutron Crossplots .....	6-3
Density-Photoelectric Cross Section Crossplots .....	6-3
NGS Crossplots .....	6-4
Effect of Shaliness on Crossplots .....	6-4
Effect of Secondary Porosity on Crossplots .....	6-5
The Secondary Porosity Index Log .....	6-5
Effect of Hydrocarbons on Crossplots .....	6-5
M-N Plot .....	6-6
MID Plot .....	6-7
$\rho_{maa}$ vs. $U_{maa}$ MID Plot .....	6-8
Complex Lithology Mixtures .....	6-9
Litho-Analysis Program .....	6-10
Presence of Evaporites .....	6-12
Fluid Identification .....	6-13
References .....	6-13
<b>7      Resistivity Logs .....</b>	<b>7-1</b>
Conventional Electrical Logs .....	7-1
Principle .....	7-1
Resistivity Devices .....	7-2
Normal and Lateral Curves .....	7-2
$R_t$ From the ES Log .....	7-4
Focusing Electrode Logs .....	7-5
Laterolog 7 .....	7-5
Laterolog 3 .....	7-5

---

## Contents

---

Laterolog 8 .....	7-8
Dual Laterolog- $R_{xo}$ System .....	7-8
Delaware Effect .....	7-9
Groningen Effect .....	7-9
Scales .....	7-10
Spherically Focused Log .....	7-10
Influence of Wellbore Variables and Log Corrections .....	7-11
Borehole Effect .....	7-11
Adjacent Bed Effect .....	7-11
Pseudogeometrical Factors .....	7-11
Invasion Correction .....	7-12
Induction Logging .....	7-12
Principle .....	7-12
Geometrical Factor .....	7-13
Focusing .....	7-13
Deconvolution .....	7-13
Skin Effect .....	7-14
Equipment .....	7-14
Log Presentation and Scales .....	7-15
Environmental Corrections Prior to Phasor Induction .....	7-15
Borehole Correction .....	7-16
Surrounding Bed Correction .....	7-16
Invasion Correction .....	7-16
High-Resistivity Formations .....	7-16
Effect of Dipping Beds .....	7-16
Annulus .....	7-17
Salt Muds .....	7-18
Phasor Induction SFL Tool .....	7-18
Phasor Tool Description and Features .....	7-18
Environmental Corrections .....	7-19
Shoulder Effect and Vertical Resolution .....	7-20
Skin Effect .....	7-21
Borehole and Cave Effect .....	7-21
Large Boreholes .....	7-22
Invasion Corrections .....	7-23

---

## Contents

---

	Interpretation in the Presence of Transition Zones .....	7-25
	Oil-Based Mud .....	7-25
	Phasor Case Studies .....	7-26
	Induction Versus Laterolog Measurements .....	7-32
	Microresistivity Devices .....	7-33
	Microlaterolog .....	7-34
	Principle .....	7-34
	Interpretation .....	7-34
	Microlaterolog .....	7-34
	Principle .....	7-34
	Response .....	7-34
	Proximity Log .....	7-35
	Principle .....	7-35
	Response .....	7-35
	Vertical Resolution .....	7-35
	MicroSFL .....	7-35
	Environmental Corrections .....	7-36
	Resistivity Interpretation .....	7-36
	Determination of $R_{xo}$ .....	7-36
	Resistivity Invasion Corrections .....	7-36
	Compensated Dual Resistivity .....	7-37
	References .....	7-39
8	Determination of Saturation .....	8-1
	Introduction .....	8-1
	Clean Formations .....	8-1
	Resistivity - Vs. - Porosity Crossplots .....	8-1
	Microresistivity-Vs.-Porosity Crossplots .....	8-3
	$R_{wa}$ Comparison .....	8-4
	Logarithmic Overlays .....	8-5
	Log F-Log $R_{deep}$ Overlay .....	8-5
	$R_0$ Overlay and F Overlay .....	8-5
	Resistivity Ratio Methods .....	8-6
	Flushed Zone Method .....	8-7
	Invaded Zone Method .....	8-7
	Porosity Balance .....	8-7
	Other Ratio Charts .....	8-9

---

## Contents

---

Invasion-Corrected Ratio Methods .....	8-9
$R_{xo}/R_t$ Overlay .....	8-9
$R_{xo}/R_t$ Quicklook .....	8-10
F-MOP Movable Oil Plot .....	8-12
Porosity and Gas Saturation in Empty Holes .....	8-12
Shaly Formations .....	8-13
Laminated Sand-Shale Simplified Model .....	8-14
Dispersed Shale Simplified Model .....	8-15
Total Shale Relationship .....	8-15
Saraband* and Coriband* Models .....	8-16
Saraband Model .....	8-16
Coriband Model .....	8-18
Dual Water Models .....	8-20
VOLAN* Model .....	8-22
Cyberlook* Program .....	8-24
GLOBAL* Method .....	8-26
References .....	8-30
 9     Electromagnetic Propagation Logs .....	9-1
Introduction .....	9-1
EPT Log .....	9-2
ADEPT: The Adaptable EPT Tool .....	9-3
Interpretation Methods .....	9-4
CRIM Method .....	9-5
CTA Model .....	9-5
$t_{po}$ Method .....	9-6
Endfire Array .....	9-7
Broadside Array .....	9-8
Deep Propagation Tool (DPT) .....	9-8
Environmental Effects .....	9-10
Interpretation Methods .....	9-11
$t_{po}$ Modified Method .....	9-11
Dual Water $t_{po}$ Modified Method .....	9-12
The $p_a$ Versus $R_{fa}$ Plot .....	9-12
Dual Saturation Method .....	9-13

---

## Contents

---

	Tool Specifications and Limitations .....	9-15
	References .....	9-16
10	Permeability and Productivity .....	10-1
	Permeability .....	10-1
	Irreducible Saturations .....	10-2
	The Transition Zone - Capillary Pressure Effects .....	10-2
	Permeability From Resistivity Gradients .....	10-2
	Permeability Estimates From $\phi$ and $S_{wi}$ .....	10-3
	Permeability and the Nuclear Magnetism Log.....	10-5
	Principle .....	10-5
	Applications/Interpretation .....	10-6
	Effective and Relative Permeabilities .....	10-7
	Water-Cut Prediction .....	10-7
	Permeability From Geochemically Derived Mineral Abundances .....	10-7
	Permeability From the Formation Tester Tools.....	10-8
	Drawdown Analysis .....	10-9
	Pressure Buildup Analysis .....	10-10
	Productivity .....	10-12
	The Producibility Log .....	10-13
	References .....	10-14
11	Wellbore Seismic .....	11-1
	Well Seismic Equipment .....	11-1
	Digital Check-Shot Survey .....	11-3
	Time-to-Depth Conversion and Velocity Profile .....	11-3
	Geogram Processing .....	11-4
	Vertical Seismic Profile .....	11-5
	VSP Processing.....	11-8
	Offset Vertical Seismic Profile .....	11-8
	Walkaway Surveys .....	11-8
	DSA Tool for VSP Acquisition .....	11-13
	Primary Uses of the VSP Summary .....	11-14
	Proximity Survey Interpretation .....	11-14
	References .....	11-14

---

## Contents

---

12	Geologic Services .....	12-1
	Introduction .....	12-1
	Correlation .....	12-1
	Stratigraphic Information From the Dipmeter .....	12-6
	HDT Dipmeter Tool .....	12-8
	Dual Dipmeter Tool .....	12-9
	Wellsite Processing .....	12-13
	Dipmeter Advisor* Program .....	12-13
	Formation MicroScanner* Service .....	12-14
	Electrofacies Identification .....	12-14
	Faciolog Computation .....	12-15
	Geocolumn Display .....	12-16
	Reservoir Description Services .....	12-19
	Missing Data .....	12-19
	Estimation of Permeability .....	12-20
	Lumping .....	12-21
	Gridding and Mapping .....	12-22
	References .....	12-23
13	Mechanical Properties of Rocks .....	13-1
	Natural Fractures .....	13-1
	Fracture Detection .....	13-1
	Sonic Measurements .....	13-1
	Caliper Measurements .....	13-3
	Density Measurements .....	13-4
	Resistivity Measurements .....	13-5
	Photoelectric Absorption Measurements .....	13-5
	Dipmeter Measurements .....	13-5
	Borehole TelevIEWER Tool .....	13-6
	Formation MicroScanner* Tool .....	13-6
	Other Measurements .....	13-6
	Conclusion .....	13-7
	Elastic Constants .....	13-7
	Inherent Strength Computations and Their Relationship to Formation Collapse .....	13-8
	Stresses Around a Producing Cavity .....	13-8
	Solution to the "Collapse" Problem .....	13-9

---

## Contents

---

Griffith Failure Criterion .....	13-9
Mohr-Coulomb Failure Criterion .....	13-10
Stress Analysis in Relation to Hydraulic Fracturing .....	13-11
Calibration with Mini-Frac Data .....	13-12
Fracture Pressure Computations .....	13-13
Hydraulic Fracture Geometry Analysis .....	13-13
Fracture Height .....	13-14
The FracHite* Program .....	13-15
Fracture Propagation Azimuth .....	13-15
References .....	13-19

Note: A companion book "Cased Hole Log Interpretation Principles/Applications-1989," provides similar information for cased hole services. Throughout this document references are made to charts, nomograms, and tables necessary for quantitative interpretation of data from our various logging tools. Refer to the *Schlumberger Log Interpretation Charts—1989* book for the most up-to-date version of these charts.