Recapitulation of physical rock properties & applications

1. General introduction

9.1 GENERAL INTRODUCTION

In this chapter the physical properties and applications of the chapters 4 to 7 are resumed. The most important logging tools, with their lateral resolution and vertical resolution, are related to equations for rock/pore/fluid-interpretations and rock/pore/fluid-interactions. Although, the chapters 1,2 and 3 are as much important as the others, they are not resumed because of their diversity in subjects.

9.2 RESISTIVITY LOGS

Applications:
Resistivity measurements of:

- un-invaded zone (R_t),
- flushed zone (R_{xo}),
- mudcake (R_{mc})
- mud (R_m)

Combination of the first two gives an “apparent” diameter of invasion: d_i

Advantages (+); Limitation (-)

ELECTRICAL SONDE	(-) Normal tools do not read far into the formation (-) Strongly affected by adjacent beds		
Tool	Short Normal	Long Normal	Lateral
Spacing	16 inch	64 inch	18ft-8inch

INDUCTION LOGS	(+) Measure deep into the formation (-) Vertical resolution deep induction tools only 5 ft (+) Operate reliable in resistive muds (-) Conventional tools not accurate at high resistivities			
Tool	IES	IES	ISF	DIL
Spacing	40 inch	28 inch	40 inch	40 inch
Combination	6FF40	6FF28	6FF40	6FF40
	SN	SN	SFL	Ilm
	SP	SP	SP	SP
			Sonic	LL8

LATEROLOGS	(+) Measure deep into the formation (+/-) Vertical resolution limited to 3 ft (+) Operate reliable in salt saturated muds (+) DLL can be combined with micro-resistivity tool (-) Does not operate reliable in resistive muds			
Tool	LL3	LL7	LL9	DLL
Spacing	1 ft	3 ft	2 ft	2 ft

MICRO RESISTIVITY TOOLS	(+) Reading confined to first few inches (+) Very good vertical definition ~ 6” ML The best tool for thin/permeable bed definition MLL MSFL MCFL excellent vertical definition 2” (combined with new high resolution density tool from Schlumberger)

9.3 SP (SPONTANEOUS POTENTIAL)

APPLICATIONS

- Correlation between logs run in different wells, and between logging runs in the same well with different tool combinations, which both contain an SP module
- Shale volume content
- Bed boundaries
- Reservoir versus non reservoir (shale)
- Formation water resistivity
- Environment of deposition

OPERATING PRINCIPLE

The spontaneous potential in the reservoir is measured using only one electrode at the tool and a reference electrode at the surface. The chemical and kinetic potentials create a current across the bed boundary between reservoir and clay causing a potential drop in the mud at the boundary.

INTERPRETATION PRINCIPLE

- The PSP (Pseudo Static Potential) of the reservoir is a relative measure towards the shale base line.
- The PSP is corrected with the appropriate charts and converted into the SSP (Static Spontaneous Potential).
- The kinetic potential of mudcake (E_{kmc}) and shale (E_{ksh}) can be estimated and subtracted from the SSP.
- The resulting effective chemical potential can be used to obtain the formation water resistivity in waterbearing zones.
- The chemical potential consists of the membrane (E_m) and liquid junction (E_j) potentials.

$$E_{total} = E_m + E_j + E_{kmc} + E_{ksh}$$

$$V_{sh} = \frac{PSP - SSP}{SSP}$$

LIMITATIONS

- Poor SP response in salt water based mud.
- A salinity contrast between mudfiltrate and formation water is needed.
- In non-conducting muds the SP can not be recorded.
- In Hydrocarbon bearing zones the SP is suppressed.

The vertical and horizontal resolution depend on the formation and borehole characteristics.

- Vertical resolution : 3 ft
- Depth of investigation : variable from 3 - 10 ft depending on invasion profile

9.4 GR (GAMMA RAY)

APPLICATIONS

- Correlation of logs carried out with different logging tools and in different wells
- Shale volume content
- Evaporites (Potassium salts)
- Uranium prospecting
- Cased hole correlation - depth control
- Bed boundaries
- Environment of deposition

OPERATING PRINCIPLE

The natural radiation intensity is measured by a scintillation crystal coupled to a photo-multiplier in the logging tool. The tool also records through the casing. If the gamma rays are sorted by energy the contributions of Uranium, Potassium and Thorium can be separated and recorded as volume fractions.

INTERPRETATION PRINCIPLE

With the GR the shale volume can be calculated as follows:

$$V_{sh} = \frac{GR - GR_{min}}{GR_{sh} - GR_{min}}$$

where: GR = log reading corrected for environmental influences

GR_{min} = GR reading in clean (non-shale) intervals

GR_{sh} = GR reading opposite a shale interval

This linear equation gives the highest shale volume. Other non-linear equations can be used resulting in lower shale volumes depending on the age of the rock.

LIMITATIONS

- Logging speed (ft/sec) x time constant (sec) = 1
- Radioactive minerals in reservoir rock influences interpretation e.g. arkosic sands, micaceous sands.

Depending on speed and time constant the resolution is:

- Vertical resolution : 2 ft
- Depth of investigation: 1-2 ft depending on the density of the formation and presence of casing

9.5 BHC (BOREHOLE COMPENSATED SONIC LOG)

APPLICATIONS

Porosity
Velocity (seismic)
Lithology (in combination with other porosity tools)
Mechanical Properties in combination with the density tool
Correlation
Compaction

OPERATING PRINCIPLE

Acoustic pulses with a frequency of 5-20 kHz depending on tool-type are emitted by an upper and lower transmitter subsequently. These wavetrains travel through the mud and formation and reach 2 receivers spaced 2 ft apart. The wavetrains are recorded as a function of time. The difference in first arrival times of the receivers is used to calculate the velocity. By taking the difference the formation velocity is compensated for borehole effects and tool tilt.

INTERPRETATION PRINCIPLE

$$j = \frac{DT - DT_{fl}}{DT_{ma} - DT_{fl}}$$

where f = porosity, fraction bulk volume.

ΔT = transit time of the log [or slowness in ms/m {10^6 /velocity(m/s){]

ΔT_{ma} = transit time of the matrix

ΔT_{fl} = transit time of the fluid

For unconsolidated sands the above equation usually produces too high porosities, which have too be corrected for compaction.

LIMITATIONS

- Cycle skipping (gas, fractures, borehole) causes too long travel times.
- Noise spikes generally causes too short travel times
- Stretch generally causes too long travel times.
- Shale effect causes generally too long travel times.
- Unconsolidated sands need a compaction factor correction
- In gaszones travel times are commonly unreliable
- Sonic can not be run in boreholes without liquid

ACCURACY

- Vertical resolution : 2 ft
- Depth of investigation : few inches

9.6 DENSITY TOOLS

APPLICATIONS

- Porosity
- Density
- Impedance together with the sonic velocity for seismic sesimic applications
- Lithology (in combination with other porosity tools)
- Gas detection (in combination with the neutron tool)

OPERATING PRINCIPLE

A radio-active source (Caesium 137) emits medium energy gamma rays into the formation. The GR are counted within the energy band where Compton scattering is dominant. The Compton scattering is a function of the formation density. An automatic mudcake correction is obtained by using both the long and short spacing detectors. The correction is already incorporated in the log reading. Measured property: electron density.

INTERPRETATION PRINCIPLE

$$j = \frac{r_{ma} - r_b}{r_{ma} - r_{fl}}$$

H.C.bearing zones:

$$r_{fl} = S_{xo} . r_{mf} + (1 - S_{xo}). r_{hc}$$

where,

ρ_b	=	bulk density, g/cc
f	=	porosity, fr.b.v.(fraction of bulk volume)
ρ_{ma}	=	matrix density, g/cc
ρ_{fl}	=	fluid density, g/cc
ρ_{hc}	=	hydrocarbon density, g/cc
ρ_{mf}	=	mudfiltrate density, g/cc
S_{xo}	=	mudfiltrate saturation, fr.p.v.(fraction of pore volume)

LIMITATIONS

- gas correction needed in gasbearing zones
- borehole correction needed above 9’’

- caliper cuts into the mudcake

- Vertical resolution : 2 ft
- Depth of investigation : 0.5 ft

9.7 PHOTO - ELECTRIC EFFECT

APPLICATIONS
- Lithology (hardly effected by fluid, porosity)
- Fracture detection when using barite mud.

OPERATING PRINCIPLE
A radio-active source (caesium 137) emits medium energy gamma rays into the formation. The GR are counted within the energy band where Compton scattering and the photoelectric effect is dominant. The long-spacing detector detects both and the short-spacing detects only the Compton scattering. The ratio of long/short spacing measurement results in the photoelectric absorption cross section. Since the latter is strongly dependent on the atomic number a good indication of the lithology is obtained.
Standard configuration: GR, CNL and LDT.

Measured property: effective photoelectric absorption cross section

INTERPRETATION PRINCIPLE

$U = P_e . r_e$

where,

P_e units	=	barns/electron
ρ_e units	=	electrons/volume
U	=	the effective photoelectric absorption cross section index per unit volume barns per unit volume.

The parameter U allows adding up the cross sections of the various components of a formation. The formation can then be described by the relative volumes of the components:

$$U = j .U_{fl} + (1 - j).U_{ma}$$

LIMITATIONS
Barite mud influences the P_e curve heavily. P_e of Ba is about a factor 30 higher than of the other minerals. The experience is that above 12 1b/gal mud in combination with rugose holes the presence of barite is detrimental to the P_e measurement. The novel back-scatter density tool from Schlumberger is less affected by these restrictions.

ACCURACY
- Vertical resolution : 1 ft
- Depth of investigation : 0.5 ft

9.8 NEUTRON TOOLS

APPLICATIONS
- Porosity
- Lithology (in combination with other porosity tools)
- Gas detection (in combination with the density tool)

OPERATING PRINCIPLE

A Pu-Be source emits at steady state about $4x10^7$ neutrons/sec. into the formation. The neutrons are slowed down to a thermal level as a function of the hydrogen content. In water or oil bearing zones this results in the porosity being measured. A long-spacing and short spacing detector measure the neutrons at thermal energy level. The combination of both detectors results in a borehole correction and cement correction in cased holes. Standard configuration: GR, CNL and LDT. Measured property: Hydrogen content.

INTERPRETATION PRINCIPLE

- Hydrogen Index of fluid is obtained by normalising the Hydrogen content of the fluid by that of water.
- Water (HI_{water} = 1) contained in a pure limestone results in a direct porosity reading of the neutron log.

- Lithology correction

$$j_n = j \,.HI_{water}$$

- Hydrogen Index correction

$$j_n = j \,.(HI_{mf} .S_{xo} + HI_{hc} .(1 - S_{xo}))$$

- HI_{hc} can be expressed in HI_{gas} or HI_{oil}:

methane	$HI_{gas} = 2.25 \times \rho gas$	e.g.	ρ_{gas} = 0.1 g/cc; HI_{gas} = 0.225
oil	$HI_{oil} = 1.29 \times \rho oil$	e.g.	ρ_{oil} = .78 g/cc; HI_{oil} = 1

where

f_n- tool porosity (LST units)	f - true porosity
HI_w - Hydrogen index water	HI_{gas} - Hydrogen index gas
HI_{oil} - Hydrogen index oil	HI_{mf} - Hydrogen index mudfiltrate
S_{xo} - flushed zone sat., fr.p.v.	ρ_{oil} - oil density, g/cc

LIMITATIONS

- Strong lithology effect
- Strong gas effect results in too low neutron porosity
- Clay gives too high neutron porosity because the Hydrogen Index of clay is high

ACCURACY

- Vertical resolution : 2 ft
- Depth of investigation : 1 ft