Tishk International University
Engineering Faculty
Petroleum and Mining Department

Well Logging I

Lecture 1: Introduction

3rd Grade - Fall Semester 2021-2022

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Content

- Borehole environment
- Invasion zones
- Drilling fluid
- Classification of logs
- Logging resolutions
- Lithology
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- Saturation

Introduction

The main job of the (well-loggers) is to evaluate the amount of hydrocarbons in place in the reservoir. Hence, the evaluation sequence for a straightforward reservoir (for any given well interval) will be as follows:

- Distinguish between clean zone and non-clean zone(Clean zones characterized by low GR.)
- Distinguish between reservoir and non-reservoir rock (Reservoir rock contains a reasonably high connected porosity.)
- For the reservoir intervals only, distinguish between hydrocarbons and water filling the pores, (Hydrocarbons are electrical insulators, while water conducts.)hence calculate water saturation in reservoir rocks
- For the hydrocarbon fraction, distinguish between oil and gas, hence calculate gas and oil saturations in reservoir rocks (Gas has a much lower density than oil).

Borehole Environment

Invasion process

During the drilling operation the mud in the borehole is usually conditioned so that the hydrostatic pressure of the mud column is greater than the pressure of the formations.

The differential pressure forces mud filtrate into the permeable formation makes several contamination zones around the hole which are: **mud cake, flushed zone**, and **transition zone** before ended by uninvaded zone or zone of true formation (**uninvaded zone**).

Borehole Environment

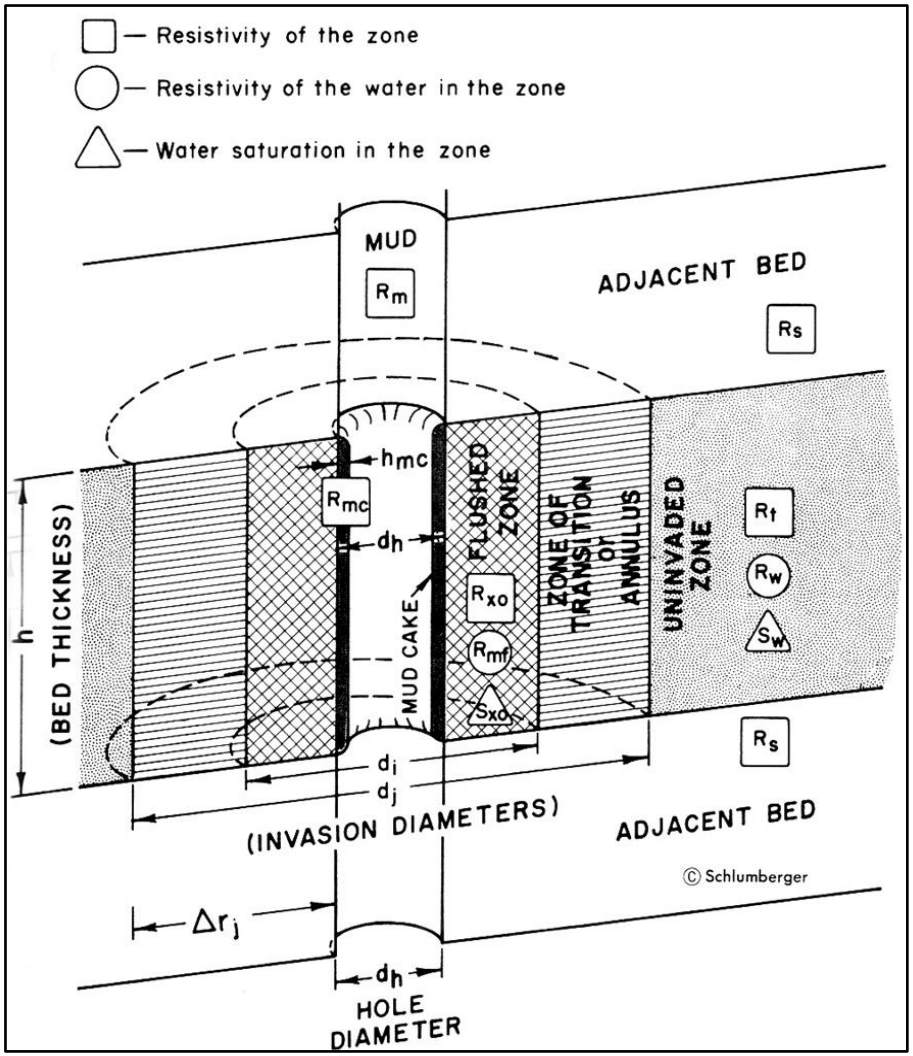
In general the environment around the borehole divided into two main zones:

- Invasion zone
  - Flushed zone
  - Transition zone
  - Annulus zone
- Uninvaded zone

The differential pressure forces mud filtrate into the permeable formation and the solid particles of the mud are deposited on the borehole wall were they form **mud cake,** (Low permeable bed reduce the rate of infiltration).

During the drilling operations a new condition (environment) forms around the bore hole.

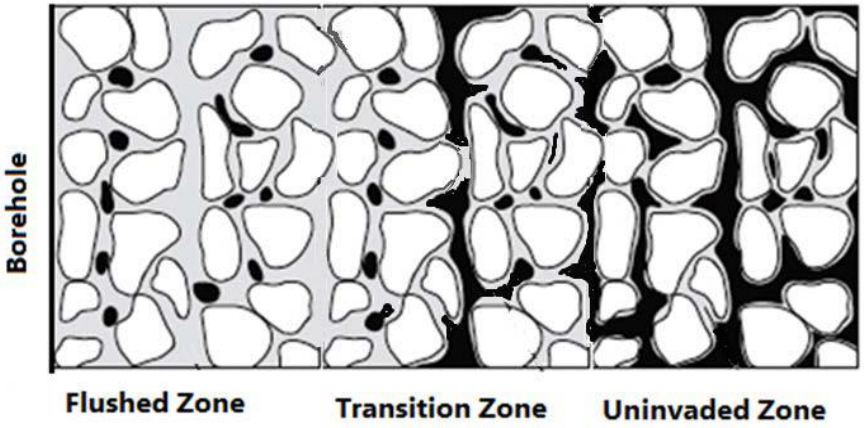
Borehole Environment



Borehole Environment

Section of a reservoir before drilling

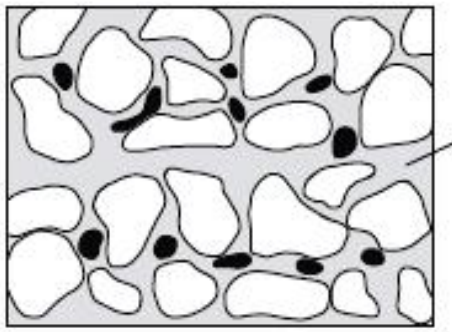
Section of a reservoir after drilling



Borehole Environment

Flushed zone:

- Very close to the hole, all formation fluids (water & oil) flushed away by filtrate and replaced by the liquids come from the drilling mud.
- This zone highly affected by the chemical compound of the drilling mud, especially salinity.

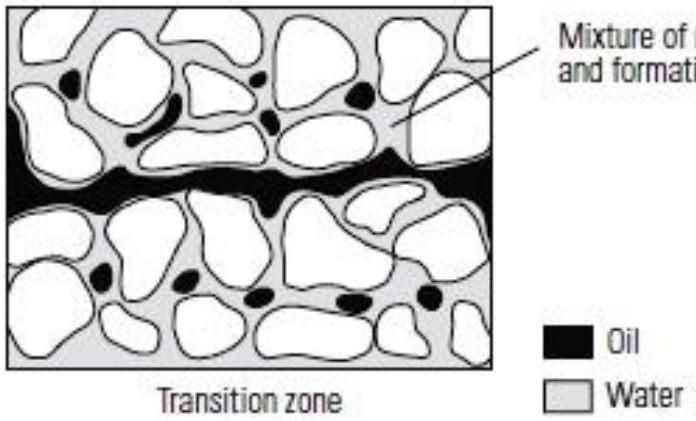


Flushed zone

Borehole Environment

Transition zone:

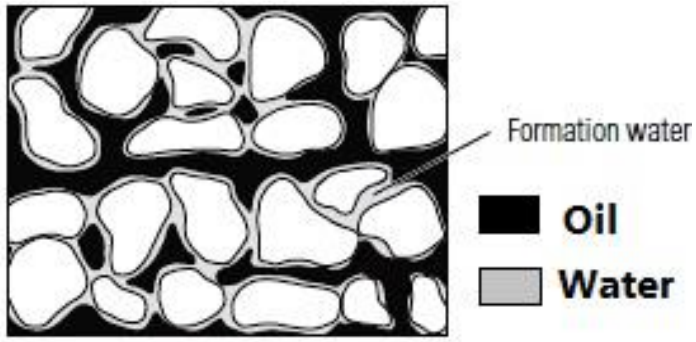
- Farther out from the borehole the displacement of formation fluids is less and less complete, resulting in transition zone with progressive change in resistivity from **Rxo**….**Ri**…**Ran**to **Rt**of the uninvaded zone.



Borehole Environment

Uninvaded zone; non contaminated or original formation (true formation).

- In general, invasion is small in very porous and permeable formations, the mud cake building up rapidly to block dynamic filtration.
- Where mud cake is slow and invasion may be very deep, up to several meters in poorly permeable zones (vuggy carbonate or fractured formations).
- The depth of invasion related to the hole **diameter** and **porosity** of formation, with increasing of hole diameter the depth of invasion increase, and the increasing of porosity reduce invasion depth.



Uninvaded zone

The Circulating System

The drilling fluid, commonly called mud, enters the drill string through the Kelly or top drive unit. There are many ways in which the mud aids the drilling process and, in fact, is a vital component to the successful drilling of a well.

Common drilling fluids

- Air/Gas
- Foam or Aerated Fluids
- Water-Base Muds
- Oil-Emulsion Muds
- Oil-Base Muds

Purposes of the drilling fluid

- Cool and Lubricate the Bit and Drill string
- Bottom Hole Cleaning
- Control Subsurface Pressures
- Line the Hole with Filter Cake (prevent caves-in & damaging)
- Help Support the Weight of the drilling pipes & casing tube
- Cuttings Removal and Release
- Transmit Hydraulic Horsepower to the Bit
- Hole Stability
- Formation Protection and Evaluation

The Circulating System

Functionally, drilling fluid components provide:

1. Density, or weight
2. Viscosity
3. Filtration control
4. Rheology control
5. Alkalinity, or pH-control
6. Lost-circulation control (LCM)
7. Surface activity modification
8. Lubrication
9. Shale stabilization
10. Protection from toxic and/or corrosive agents

Classification of Logs

Below is a list of the main types of logs that may be run, and why they are run during the life of the well.

- Logging While Drilling (LWD) or measurement while drilling (MWD)…. real time data.
- Wireline Open hole Logging immediately after drilling (before casing).
- Wireline Cased Hole Logging (after casing).
- Pipe-Conveyed Logging; tools are typically run-on drill-pipe, the cable pass from the inside of the pipe to the annulus. Where the borehole deviation or dog-leg severity is such that it is not possible to run tools using conventional wireline techniques

Classification of Logs

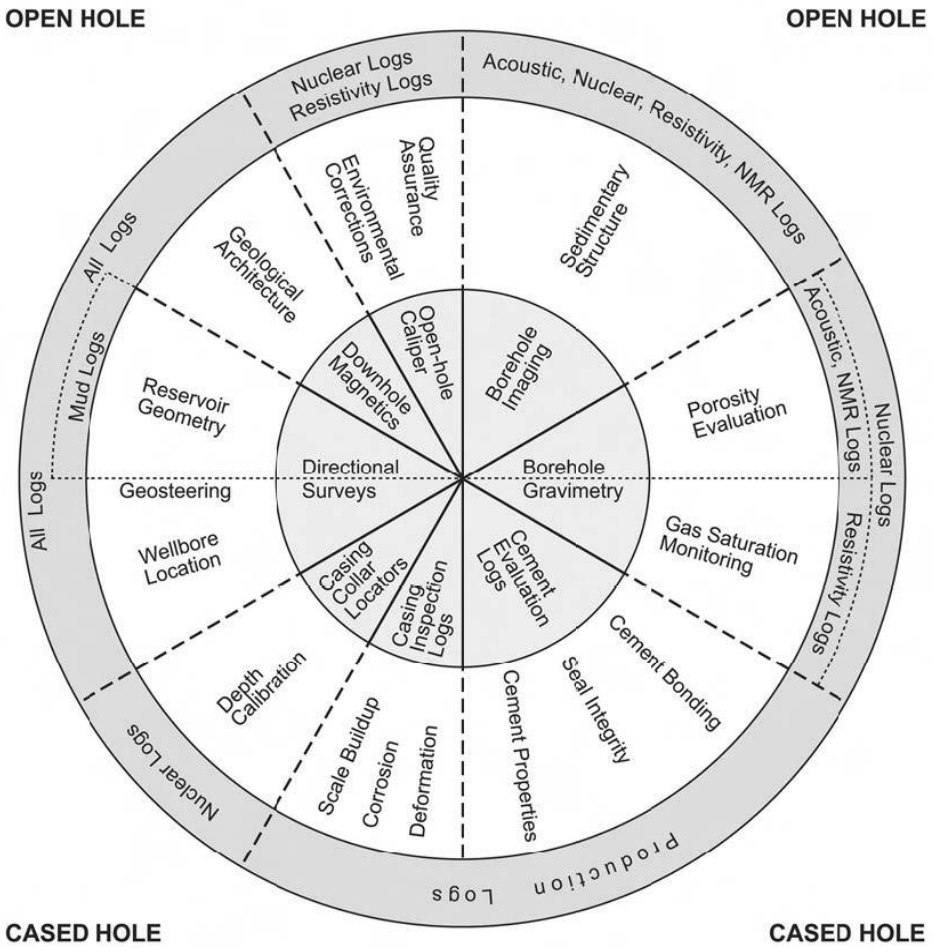
According to their technique the common open hole Wireline log tools classified into the following types:-

Log technique	Log type		Formation parameter measurement
1- Mechanical measurements	Caliper		Hole Diameter
2- Spontaneous measurements	Temperature		Borehole temperature
	Sp		Spontaneous electrical current
	GR		Natural radioactivity
3- Induced measurements	Resistivity Logs	Resistivity	Resistivity to electrical current
		Induction	Conduction to electrical current
	Sonic		Velocity to sound propagation
	Density		Reaction to gamma ray bombardment
	Neutron		Reaction to neutron bombardment
	Nuclear magnetic resonance MNR		Reaction to magnetic field
	Borehole images		Electrical, acoustic& BH video

Classification of Logs

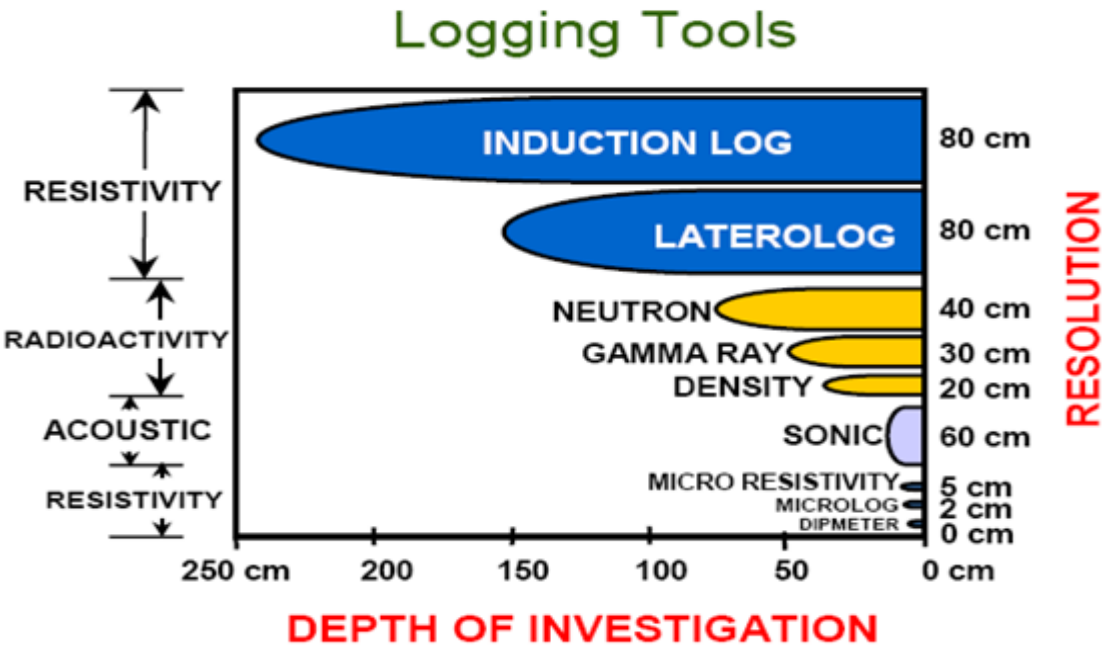
This chart is separated into three concentric areas:

- The middle annular area indicates the subsurface properties to be evaluated,
- The innermost area and the outermost area indicates the logging tools.
- The corresponding innermost and outermost areas show how the different tools complement each other in the investigation of subsurface properties.



Logging Resolution and depth of measurements

The loggings tools are differing from their investigation depth and resolution, the figure bellow show them.



Borehole Depth Measurement MD, TVD, and TVDSS

MD: Measured Depth

Distance measured along the borehole from the surface reference point.

TVD: True Vertical Depth

Vertical depth below surface reference.

TVDSS: Subsea TVD

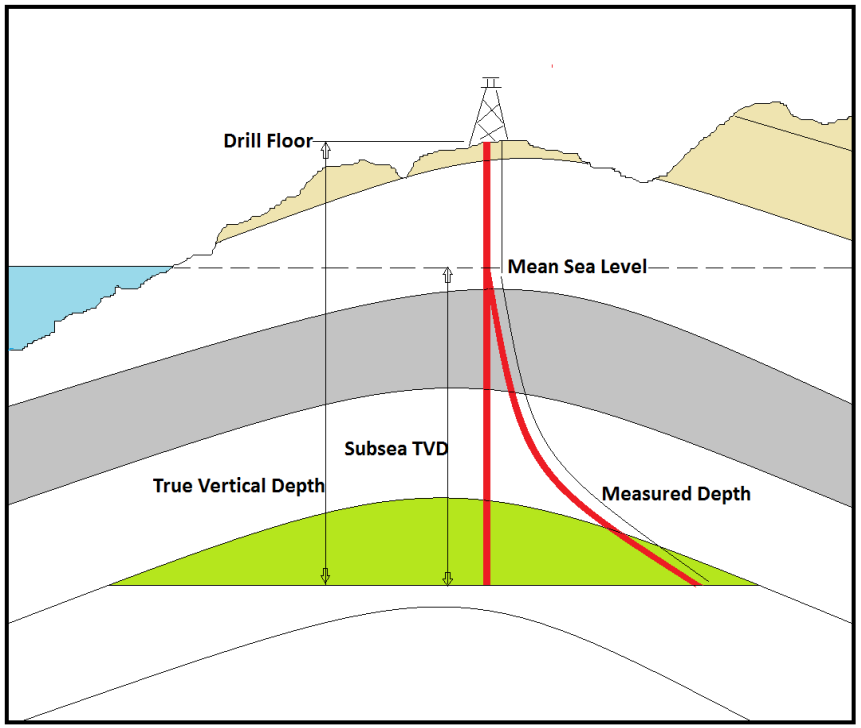
Vertical Depth below mean sea level

TVD

calculation requires inclinomety data (borehole deviation)

TVDSS

calculation requires elevation of surface reference point, in addition to inclinometry data.



Lithology

In general the sedimentary rocks classified into:

- **Clastic Rocks:**(Conglomerate, Sandstone, Siltstone, Claystone, and Shale)

- **Non-Clastic Rocks:**
  - **Carbonate**(Limestone and Dolomite)
  - **Evaporates**(Gypsum, Anhydrite, Salt rocks …)

Porosity (Φ)

Porosity is the percentage of voids to the total volume of rock (Total porosity).

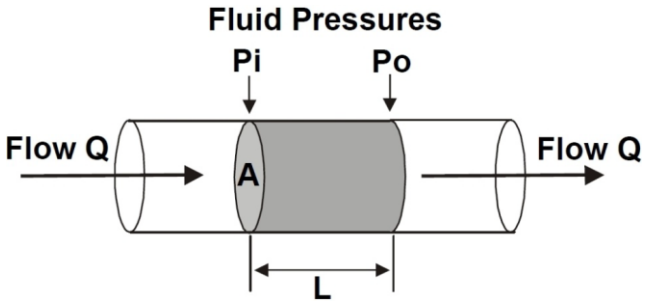
The amount of pores is measures of the amount of fluids (oil, water) a rock will hold.

- Primary & Secondary porosity
- Effective porosity: The amount of interconnected pores that able to transmit fluids.

Permeability (K)

Permeability (K) is the property of a rock has to transmit fluids.

$$K = \frac{Q\mu L}{A\Delta P} \quad \text{or} \quad Q = \frac{KA\Delta P}{\mu L}$$



Q= Flow rate cm3/sec
μ= Viscosity of fluid centipoises
(cp=1/100 poise)… (water μ =1cp, oil μ =4 poise)
L= Length cm. and A = Area cm2
ΔP= (Pi –Po) Atmosphere pressure
1atm= 14.7 psi =10.3m water = 76 cm Hg.
K= Permeability with Darcy.

Permeability Types

Absolute permeability (Ka): the ability of rock to transmit a single fluid when it is 100% saturated with that fluid.

Effective permeability: the ability of the rock to transmit a fluid in the presence of another fluid when two fluids are immiscible

Relative permeability(Kr): is the ratio between effective permeability of fluid at a partial saturation and the permeability of 100% saturation (Ka).

Kro(Oil) =Ko/Ka

Krw(Water) =Kw/Ka.

Reservoir Fluid Saturations

The pore space in a rock is occupied by fluids.

In hydrocarbon reservoirs these fluids are hydrocarbon gasses, oil and an aqueous brine.

We define the pore fraction of each of these as $\mathbf{S_g}$, $\mathbf{S_o}$ and $\mathbf{S_w}$, respectively. Hence, $\mathbf{S_g + S_o + S_w = 1}$.

Water saturation $\mathbf{S_w}$ is the percentage of pore volume in a rock which is occupied by formation water, Hydrocarbon saturation Sh= 1-Sw

Irreducible water saturation $\mathbf{Sw_{irr}}$ & Residual Hydrocarbon $\mathbf{Sh_r}$

The volume of the movable hydrocarbon = $\mathbf{\Phi\ (Sh\text{-}Sh_r).}$