University of Mosul

College of Petroleum & Mining Engineering

Department of Petroleum & Refining Engineering

Well Logging

Third Year

Lecture 1

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Introduction

Well logging is a method used for recording rock and fluid properties to find gas- and oil-containing zones in subterranean formations. The location of petroleum reserves requires an understanding of the nature of the rocks in which these reserves occur, and well logs are one of the primary sources for such data. Well logs are particularly useful in the description and characterization of sedimentary rocks and their pore fluids. Well log is a continuous record of measurement made in bore hole respond to variation in some physical properties of rocks through which the bore hole is drilled.

Objectives of wire line logging:

1-Lithology identification

2-Determination of reservoir characteristics (e.g. porosity, saturation, permeability).

3-Identification the fluid type in the pore space of reservoir rock (gas, oil, water)

4-Identification of productive zones.

5-Determination of the depth and thickness of productive zones.

6-Locating reservoir fluid contacts.

7-Determination formation dip and hole angle and size.

1- Types of well logging:

Typically well logging data are classified into three broad categories depending on well condition logged:

a- Open hole:

Log which done right away after drilling process completed prior to case the well.

- Logging While drilling (LWD)
- Logging After drilling (Wireline)

b- Cased hole:

Log done after well been cased, (analysis behind casing).

c- Production log:

Log done after well been produced or fluid flowing.

1.1 Logging While Drilling (LWD):

Advances in drilling/logging technology have allowed the acquisition of log data via tools placed in the actual drilling assembly. These tools may transmit data to the surface on a real-time basis or store the data in downhole memory from which it may be downloaded when the assembly is brought back to the surface.

LWD tools present a complication for drilling, as well as additional expense. However, their use may be justified when:

- Real-time information is required for operational reasons, such as steering a well (e.g. a horizontal trajectory) in a particular formation or picking of formation tops, coring points, and/or casing setting depths.
- Acquiring data prior to the hole washing out or invasion occurring.
- Safeguarding information in there is a risk of losing the hole.
- The trajectory is such as to make wireline acquisition difficult (e.g. in horizontal wells).

LWD data may be stored downhole in the tools memory and retrieved when the tool is brought to the surface and/or transmitted as pulses in the mud column in real time while drilling. In a typical operation, both modes will be used, with the memory data superseding the pulsed data once the tool is retrieved. However, factors that might limit the ability to fully use both sets of data are:

- Drilling mode: Data may be pulsed only if the drillstring is having mud pumped through it.
- Battery life: Depending on the tools in the string, tools may work in memory mode only between 40 and 90 hours.
- Memory size: Most LWD tools have a memory size limited to a few megabytes. Once the memory is full, the data will start to be overwritten. Depending on how many parameters are being recorded, the memory may become full within 20 – 120 hours.
- Tool failure: It is not uncommon for a fault to develop in the tool such as the pulse data and / or memory data are not transmissible/ recordable.

1.2 Wireline Openhole Logging:

Once a section of hole has been completed, the bit is pulled out of the hole and there is an opportunity to acquire further openhole logs either via wireline or on the drillstring before the hole is either cased or abandoned.

1.3 Wireline Cased Hole Logging:

When a hole has been cased and a completion string run to produce the well, certain additional types of logging tools may be used for monitoring purposes.

1.4 Production logging:

This tool, which operates using a spinner, does not measure any properties of the formation but is capable of determining the flow contributions from various intervals in the formation.

2- The field operation:

Wireline logging is done from a logging truck, sometimes referred to as a “mobile laboratory” (Fig. 1). The truck carries the downhole measurement instruments, the electrical cable and winch needed to lower the instruments into the borehole, the surface instrumentation needed to power the downhole instruments and to receive and process their signals, and the equipment needed to make a permanent recording of the log.

The downhole measurement instruments are usually composed of two components:

- The first component contains the sensors used in making the measurement, called **sonde**. The type of sensor depends upon the nature of the measurement. Resistivity sensors use electrodes or coils; acoustic sensors use transducers; radioactivity sensors use detectors sensitive to radioactive; etc. The sonde housing may be constructed of steel and/or fibreglass.
- The second component of the downhole tool is the **cartridge**. The cartridge contains the electronics that power the sensors, process the resulting measurement signals, and transmit the signals up the cable to the truck. The cartridge may be a separate component screwed to the sonde to form the total tool, or it may be combined with the sensors into a single tool. That depends upon how much space the sensors and electronics require and the sensor requirements. The cartridge housing is usually made of steel. The downhole tool is attached to an electrical cable that is used to lower the tool into and remove from the well.

Signal transmission over the cable may be in analog or digital form. The cable is also used to transmit the electrical power from the surface to the downhole tools. The surface instrumentation provides the electrical power to the downhole tools. More importantly, the surface instrumentation receives the signals from the downhole tools, processes and/or analyzes those signals, and responds accordingly. The desired signals are output to magnetic tape in digital form and to a cathode-ray tube and photographic film in analytical form.

The photographic film is processed on the unit, and paper prints are made from the film. This continuous recording of the downhole measurement signals is referred to as the ***log***.

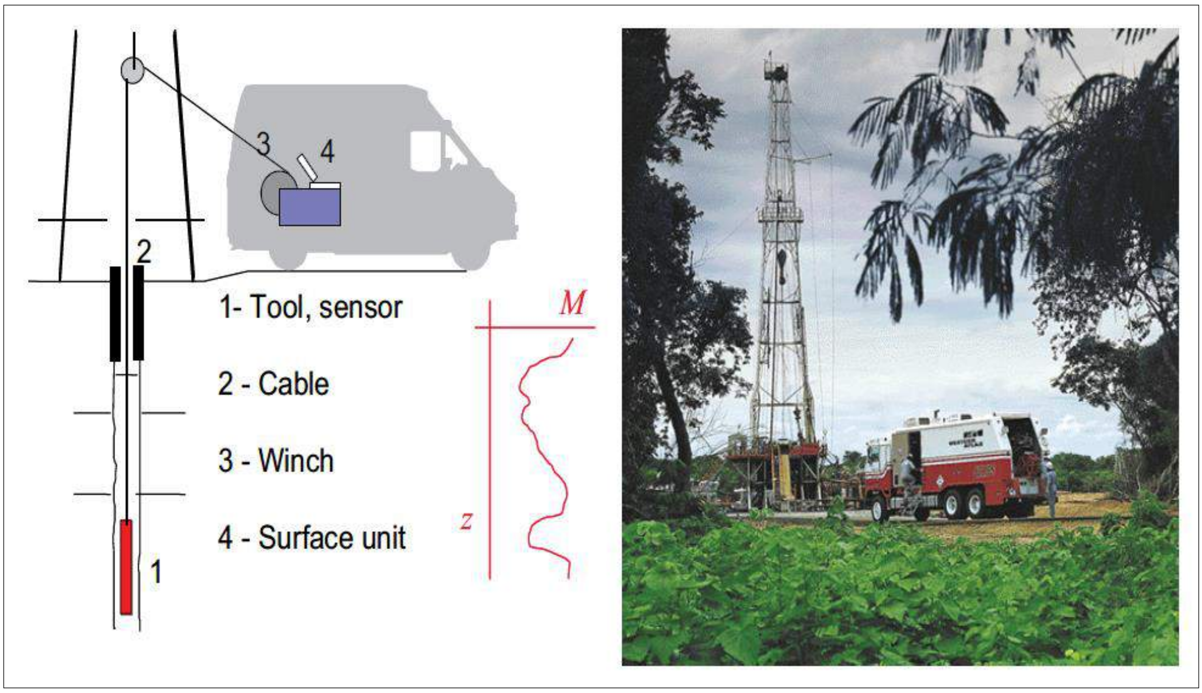

Figure 1: The logging unit.

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Fundamentals of quantitative log interpretation

Almost all oil and gas produced today comes from accumulations in the pore spaces of reservoir rocks, usually sandstones, limestones, or dolomites. The amount of oil or gas contained in a unit volume of the reservoir is the product of its porosity by the hydrocarbon saturation.

In addition to the porosity and the hydrocarbon saturation, the volume of the formation containing hydrocarbons is needed in order to estimate total reserves and to determine if the accumulation is commercial. Knowledge of the thickness and the area of the reservoir is needed for computation of its volume.

To evaluate the producibility of a reservoir, it is necessary to know easily fluid can flow through the pore system. This property of the formation rock, which depends on the manner in which the pores are interconnected, is its permeability.

Then, the main petrophysical parameters needed to evaluate a reservoir are its porosity, hydrocarbon saturation, thickness, area, and permeability. In addition, the reservoir geometry, formation temperature and pressure, and lithology can play important roles in the evaluation, completion, and production of a reservoir.

1- Porosity:

The porosity of a rock is a measure of the storage capacity (pore volume) that is capable of holding fluids. Quantitatively, porosity is defined as the ratio of the pore volume to the total volume of rock (bulk volume). It is measured as a percent and has the symbol (ϕ).

$$\textit{Porosity } (\phi) = \frac{\textit{volume of pores}}{\textit{total volume of rock}} \quad \text{----------------} \; (1)$$

The amount of internal space or voids in a given volume of rock is a measure of the amount of fluids that the rock will hold.

The amount of pore space that is interconnected, and so able to transmit fluids, is called *effective porosity*.

Effective porosity is defined as the ratio of the volume of interconnected pores to the total volume of rock (bulk volume).

$$\textit{Effective porosity} = \frac{\textit{volume of interconnected pores}}{\textit{total volume of rock}} \quad \text{---------------} \; (2)$$

The effective porosity is very important in all reservoir engineering calculations because it represents the interconnected pore space that contains the recoverable hydrocarbon fluids. Porosities of subsurface formations can vary widely. Dense carbonates (limestones and dolomites) and evaporates (salt, anhydrite, gypsum, etc.) may show practically zero porosity. Well-consolidated sandstones may have 10 to 15% porosity. Unconsolidated sands may have 30% or more, porosity. Shales or clays may contain over 40% water-filled porosity, but the individual pores are usually so small the rock is impervious to the flow of fluids.

2- Saturation:

Saturation is defined as the percent or fraction of pore volume occupied by a particular fluid (oil, gas, or water).

$$\textbf{\textit{Fluid saturation}} = \frac{\textit{total volume of the fluid}}{\textit{pore volume}} \quad \text{-------------------- (3)}$$

Water saturation (S_w), then, is the fraction (or percentage) of the pore volume that contains formation water. Oil or gas saturation is the fraction of pore volume that contains oil or gas.

Water saturation represents an important log interpretation concept because we can determine the hydrocarbon saturation of a reservoir by subtracting water saturation from the value 1.0, (where 1.0=100% water saturation).

$$\textbf{\textit{Water saturation}} \ (S_w) = \frac{\textit{volume of water}}{\textit{pore volume}} \quad \text{-------------------- (4)}$$

$$\textbf{\textit{Oil saturation}} \ (S_o) = \frac{\textit{volume of oil}}{\textit{pore volume}} \quad \text{------------------- (5)}$$

$$\textbf{\textit{Gas saturation}} \ (S_g) = \frac{\textit{volume of gas}}{\textit{pore volume}} \quad \text{------------------ (6)}$$

All saturation values are based on pore volume and not on the gross reservoir volume. The saturation of each individual phase ranges between zero to 100%. The sum of the saturations is 100%, therefore:

$$S_o + S_g + S_w = 1.0 \qquad \text{------------------ (7)}$$

The water saturation of a formation can vary from 100% to a quite small value, but it is seldom zero. In the oil or gas reservoir rocks, there is always a small amount of capillary water that cannot be displaced by the oil; this saturation is generally referred as irreducible or connate water saturation.

Similarly, for an oil- or gas-bearing reservoir rock, it is impossible to remove all the hydrocarbons by ordinary fluid drives or recovery techniques. Some remain trapped in parts of pore volume; this hydrocarbon saturation is called the residual oil saturation.

3- Permeability:

Permeability is a property of the porous medium that measures the capacity and ability of the formation to transmit fluids. The rock permeability (k) is a very rock property because it controls the directional movement and the flow rate of the reservoir fluids in the formation. Permeability is controlled by the size of the connecting passages (pore throats or capillaries) between pores. It is measured in darcies or millidarcies, and is represented by the symbol (k). The ability of a rock to transmit a single fluid when it is 100% saturated with that fluid is called ***absolute permeability***.

Effective permeability refers to the presence of two fluids in a rock, and is the ability of the rock to transmit a fluid in the presence of another fluid when the two fluids are immiscible.

Formation water (connate water in the formation) held by capillary pressure in the pores of a rock serves to inhibit the transmission of hydrocarbons. Stated differently, formation water takes up space both in pores and in the connecting passages between pores. Therefore, it may block or otherwise reduce the ability of other fluids to move through the rock.

Relative permeability is the ratio between effective permeability of a fluid at partial saturation, and the permeability at 100% saturation (absolute permeability). When relative permeability of a formation's water is zero, then the formation will produce water-free hydrocarbons (i.e. the relative permeability to hydrocarbons is 100%). With increasing relative permeability to water, the formation will produce increasing amounts of water relative to hydrocarbons.