University of Mosul

College of Petroleum & Mining Engineering

Department of Petroleum & Refining Engineering

Well logging

Third Year

Lecture 7

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Resistivity logs

Resistivity logs are electric logs which are used to:

a- Determine hydrocarbon versus water-bearing zones.

b- Indicate permeable zones.

c- Determine resistivity porosity.

The resistivity of a formation is a key parameter in determining hydrocarbon saturation. Because the rock's matrix or grains are non-conductive, the ability of the rock to transmit a current is almost a function of water in the pores. Hydrocarbons, like the rock's matrix, are non-conductive; therefore, as the hydrocarbon saturation of the pores increases, the rock's resistivity also increases.

The resistivity of a formation depends on:

a- Resistivity of the formation water.

b- Amount of water present.

c- Pore structure geometry.

By knowing the formation's water resistivity (R_w), porosity (Ø), and a value for the cementation exponent (m), the formation water saturation (S_w) from the Archie equation:

$$S_w = \left(\frac{F \ x \ R_w}{R_t} \right)^{1/n} \text{ ------------------------ (1)}$$

Where:

S_w: water saturation.

F: formation factor ($a/\emptyset^m$).

a: tortuosity factor.

m: cementation exponent.

R_w: resistivity of formation water.

R_t: true formation resistivity as measured by a deep reading resistivity log.

n: saturation exponent (most commonly 2.0).

Types of resistivity logs:

The two basic types of logs that measure formation resistivity are **induction** and **electrode logs**.

1. **Induction log:**

The most common type of logging device is the induction tool. An induction tool consists of one or more transmitting coils that emit a high-frequency alternating current of constant intensity. The alternating magnetic field which is created induces secondary currents in the formation. These secondary currents flow as ground loop currents perpendicular to the axis of the borehole (Fig. 1), and create magnetic fields that include signals to the receiver coils. The receiver signals are essentially proportional to conductivity which is the reciprocal of resistivity. The multiple coils are used to focus the resistivity measurement to minimize the effect of materials in the borehole, the invaded zone, and other nearby formations. The induction log has a transmitter/receiver spacing of 40 inches and can measure a reliable value for resistivity down to a bed thickness of five feet.

The two types of induction devices are the induction electric log and the dual induction focused log.

Electrode log:

A second type of resistivity measuring device is the electrode log. Electrodes in the borehole are connected to a power source (generator), and the current flows from the electrodes through the borehole fluid into the formation, and then to a remote reference electrode. Examples of electrode resistivity tools include: (1) normal, (2) Lateral, (3) Laterolog, (4) Microlaterolog, (5) Microlog.

Induction logs should be used in non-salt saturated drilling muds (i.e. $R_{mf} > 3R_w$) to obtain a more accurate value of true resistivity (R_t). Boreholes filled with salt-saturated drilling muds ($R_{mf} = R_w$) require electrode logs to determine accurate R_t values.

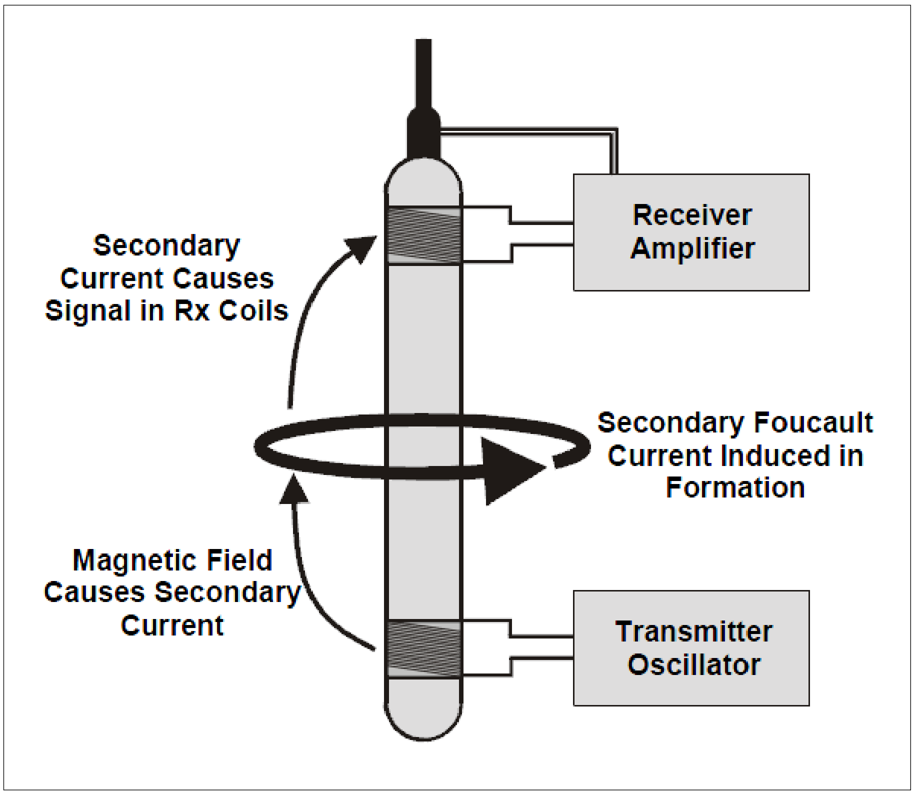

Figure 1: The mode of operation of induction tools.

Induction electric log Curves:

The induction electric log is composed of three curves: short normal, induction, and spontaneous potential or SP, (Fig. 2). These curves are obtained simultaneously during the logging of the well.

The short normal tool measures resistivity at a shallow depth of investigation which is the resistivity of the invaded zone (R_i). When the resistivity of the short normal is compared with the resistivity of the deeper measuring induction tool (Rt), invasion is detected by the separation between the short normal and induction curves (Fig. 2). The presence of invasion is important because it indicates a formation is permeable.

The short normal tool has an electrode spacing of 16 inches and can record a reliable value for resistivity from a bed thickness of four feet. The short normal curve is usually recorded in track #2 (Fig. 2). Because the short normal tool works best in conductive, high resistivity muds (where $R_{mf} > 3R_w$), salt muds (where $R_{mf}=R_w$) are not good environment for its use. In addition to providing a value for resistivity porosity if a correction is made for unflushed oil in the invaded zone. To obtain a more accurate value of R_t from the short normal curve, an amplified short normal curve is sometimes displayed in track #2 along with the short normal curve.

The induction curve on the induction electric log appears in track #2 (Fig. 2). Because the induction device is a conductivity measuring tool, an induction derived conductivity curve is presented in track #3 (Fig. 2). The track #3 conductivity curve is necessary to more accurately determine the R_t value of low resistivity formations, and to eliminate possible errors when calculating true resistivity from conductivity.

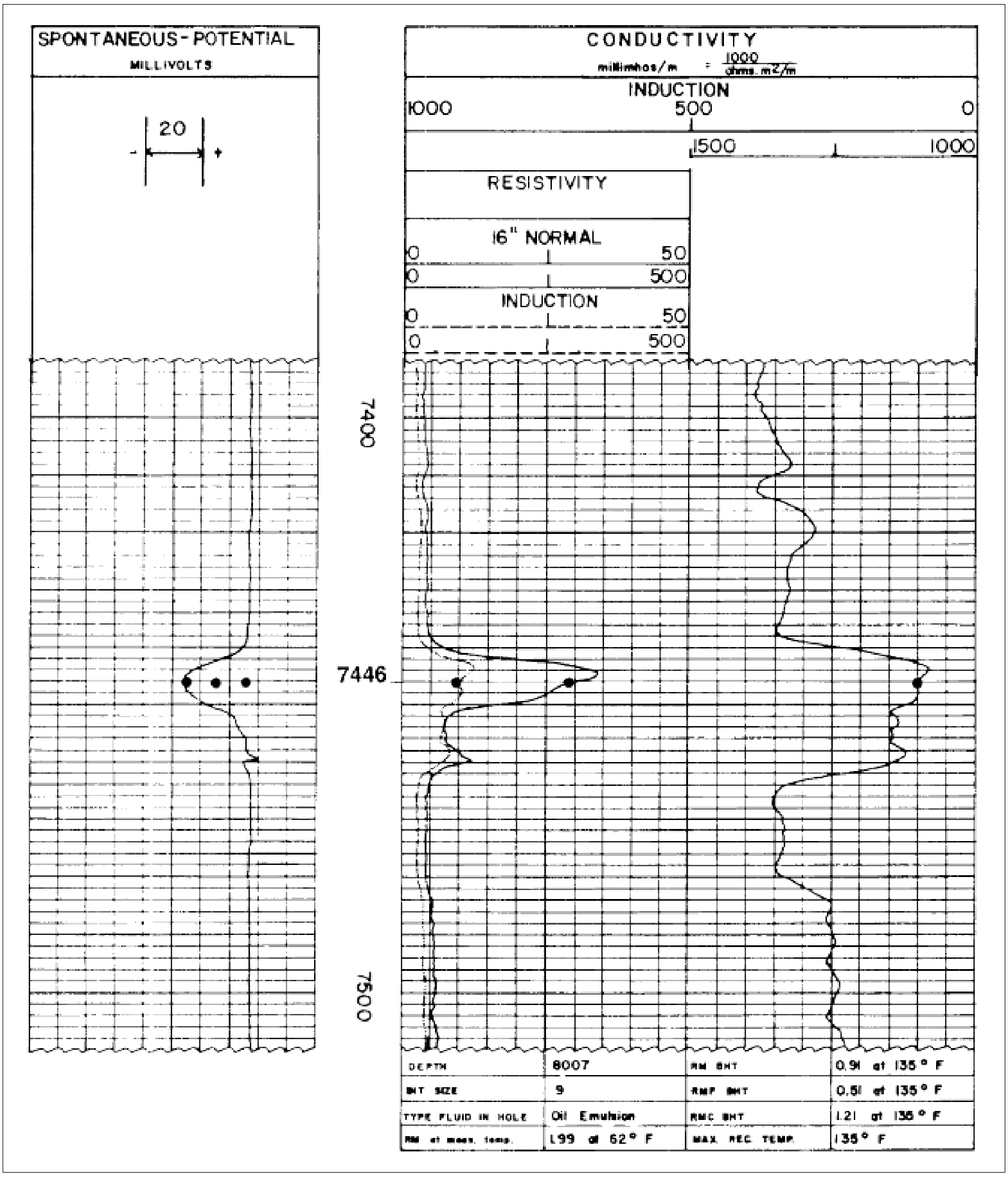

Figure 2: Example of induction electric log.

Typical responses of the resistivity logs:

Figure 3 shows the typical response of the resistivity logs in a sand/shale sequence. Note the lower resistivity in shales, which is due to the presence of bound water in clays that undergo surface conduction. The degree to which the sandstones have higher resistivities depends upon: (i) their porosity, (ii) their pore geometries, (iii) the resistivity of the formation water, (iv) the water, oil and gas saturations (oil and gas are taken to have infinite resistivity).

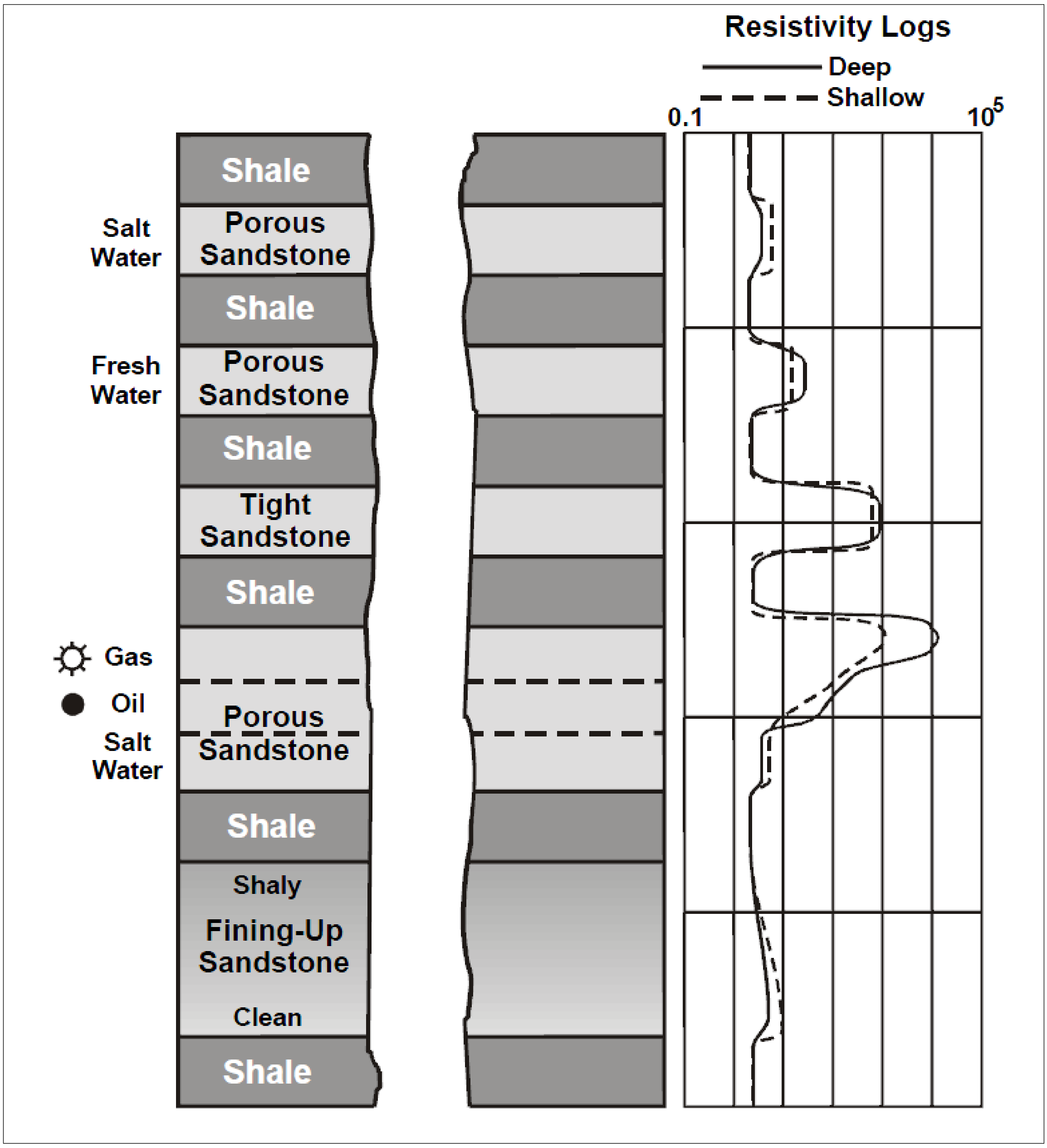

Figure 3: Typical resistivity log responses.