— University of Mosul —
College of Petroleum & Mining Engineering

Well Logging Engineering

Lecture Four

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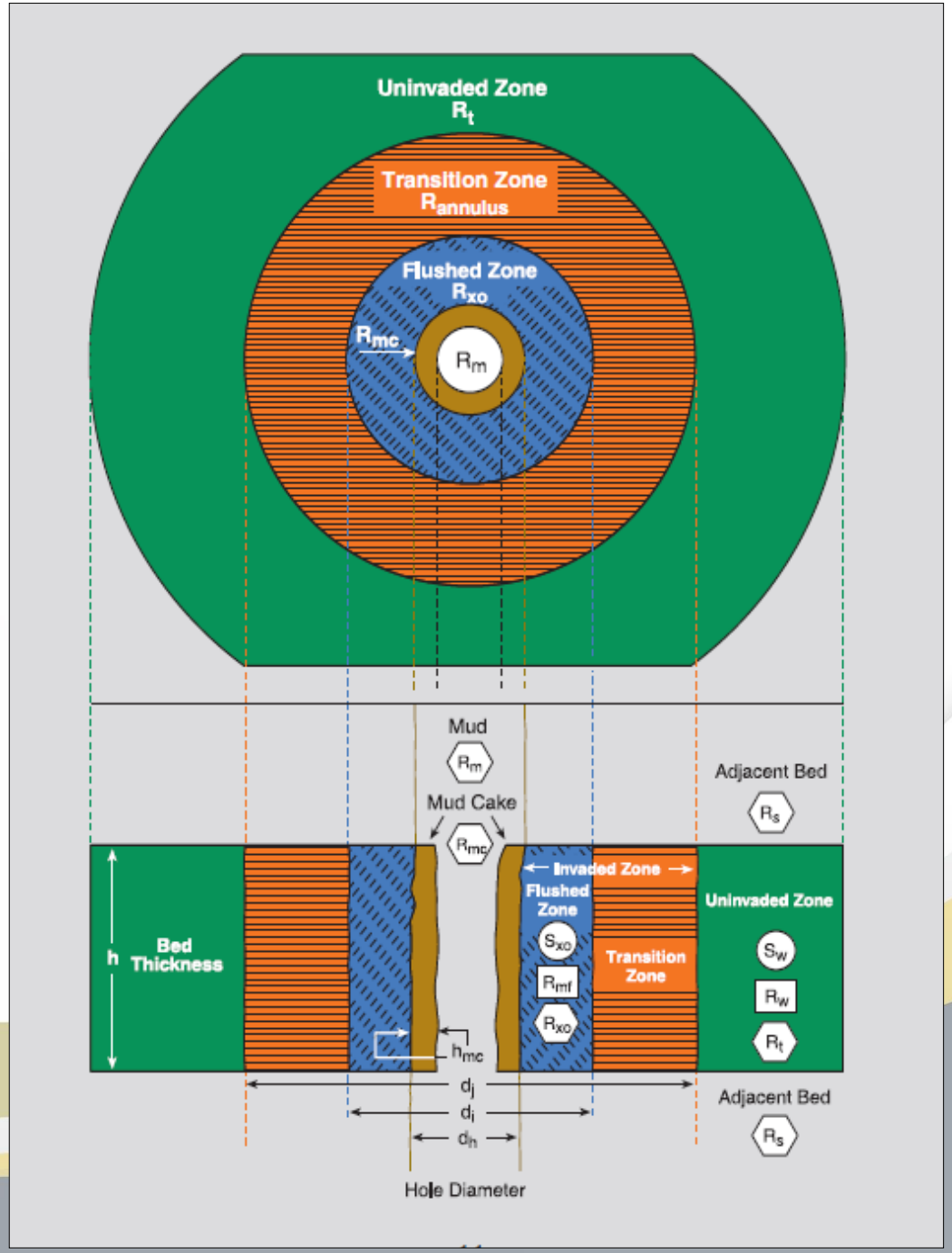
- Borehole Environment
- Hole Diameter
- Drilling Mud
- Invaded Zone
- Uninvaded Zone

- **Borehole environment**
- Where a hole is drilled into a formation, the rock plus the fluids in it (rock-fluid system) are altered in the location of the borehole.
- The borehole and the rock surrounding it are contaminated by the drilling mud, which affects logging measurements.
- Figure 1 is a schematic illustration of a porous and permeable formation that is penetrated by a borehole filled with drilling mud.

- **Borehole environment**



• Borehole environment

The definitions of each of the symbols used in Figure 1 are listed as follows:

dh: Hole diameter.

di: Diameter of invaded zone (inner boundary; flushed zone).

dj: Diameter of invaded zone (outer boundary; invaded zone).

hmc: Thickness of mudcake.

Rm: Resistivity of the drilling mud.

Rmc: Resistivity of the mudcake.

Rmf: Resistivity of mud filtrate.

Rs: Resistivity of shale.

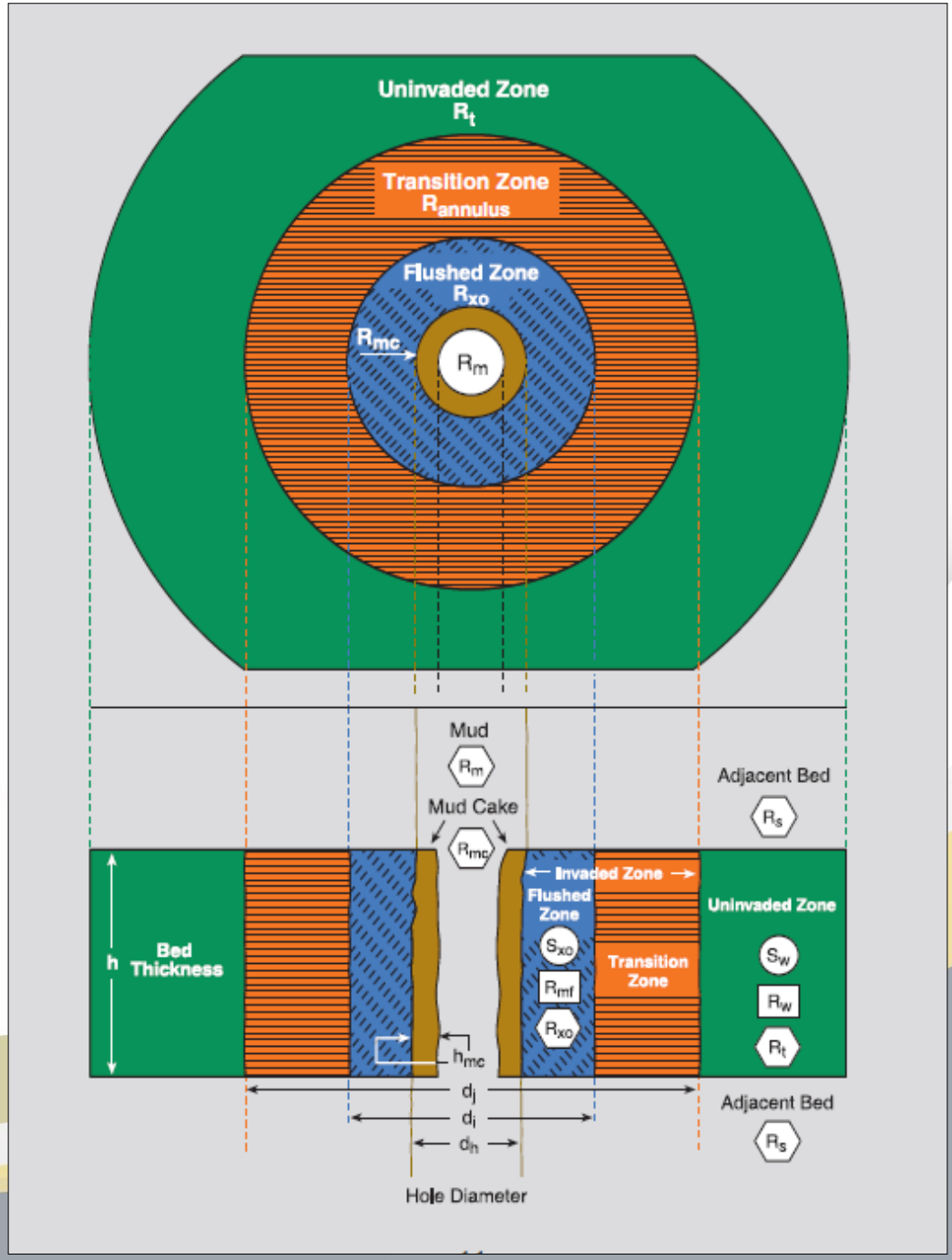
Rt: Resistivity of uninvaded zone (true resistivity).

Rw: Resistivity of formation water.

Rxo: Resistivity of flushed zone.

Sw: Water saturation of uninvaded zone.

Swo: Water saturated flushed zone.



- **1- Hole diameter (dh):**
- The borehole size is described by the outside diameter of the drill bit. But, the diameter of the borehole may be larger or smaller than the bit diameter because of:
- a-Wash out and/or collapse of shale and poorly cemented porous rocks.
- b- Build-up of mudcake on porous and permeable formations (Fig. 1).
- The borehole size normally varies from 7 to 12 inches, and modern logging tools are designed to operate within these size ranges. The size of the borehole is measured by a caplier log.

- **2- Drilling mud (Rm):**
- Most wells are drilled with rotary bits and use special mud as a circulating fluid. The mud helps remove cuttings from the well bore, lubricate and cool the drill bit, and maintain an excess of borehole pressure over formation pressure.
- The excess of borehole pressure over formation pressure prevents blow-outs.
- The density of the mud column is always greater than the formation pressure.
- This pressure difference forces some of the drilling fluid to invade porous and permeable formations.
- As invasion occurs, many of the solid particles (i.e. clay minerals from the drilling mud) are trapped on the side of the borehole and form mudcake (Fig. 1).
- Fluid that filters into the formation during invasion is called mud filtrate (Fig. 1).
- The resistivity values for drilling mud, mudcake, and mud filtrate are recorded on a log’s header.

- **3- Invaded zone:**
- The zone, which is invaded by mud filtrate, is called the invaded zone. It consists of a flushed zone (Rxo) and a transition or annulus (Ri) zone.
- The flushed zone (Rxo) occurs close to the borehole (Fig. 1), where the mud filtrate has almost completely flushed out a formation's hydrocarbons and/or water (Rw).
- The transition or annulus (Ri) zone, where a formation's fluids and mud filtrate are mixed, occurs between the flushed (Rxo) zone and the uninvaded (Rt) zone.
- The uninvaded zone is defined as the area beyond the invaded zone where a formation's fluids are uncontaminated by mud filtrate.

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- **3- Invaded zone:**
- In front of the porous and permeable rocks (potential reservoirs), due to the differential pressure between the pressure exerted by the mud column and the formation pressure in order to avoid blow out, the mud filtrate can penetrate in the near pore space, in other terms invades the formation. This invasion depends on several factors:
- - The differential pressure.
- - The mud type and its ability to build an efficient mud-cake avoiding a deep invasion.
- - The permeability of the formation, presence of micro-fissures, vugs.
- - The porosity, as a same volume of mud filtrate will occupy a larger volume if the formation has a lower porosity for an equivalent permeability.
- - The depth of investigation of the tool.
- The depth of mud filtrate invasion into the invaded zone is referred to as the diameter of invasion (di & dj; Fig. 1). The diameter of invasion is measured in inches or expressed as a ratio: dj/dh (where dh represents the borehole diameter).

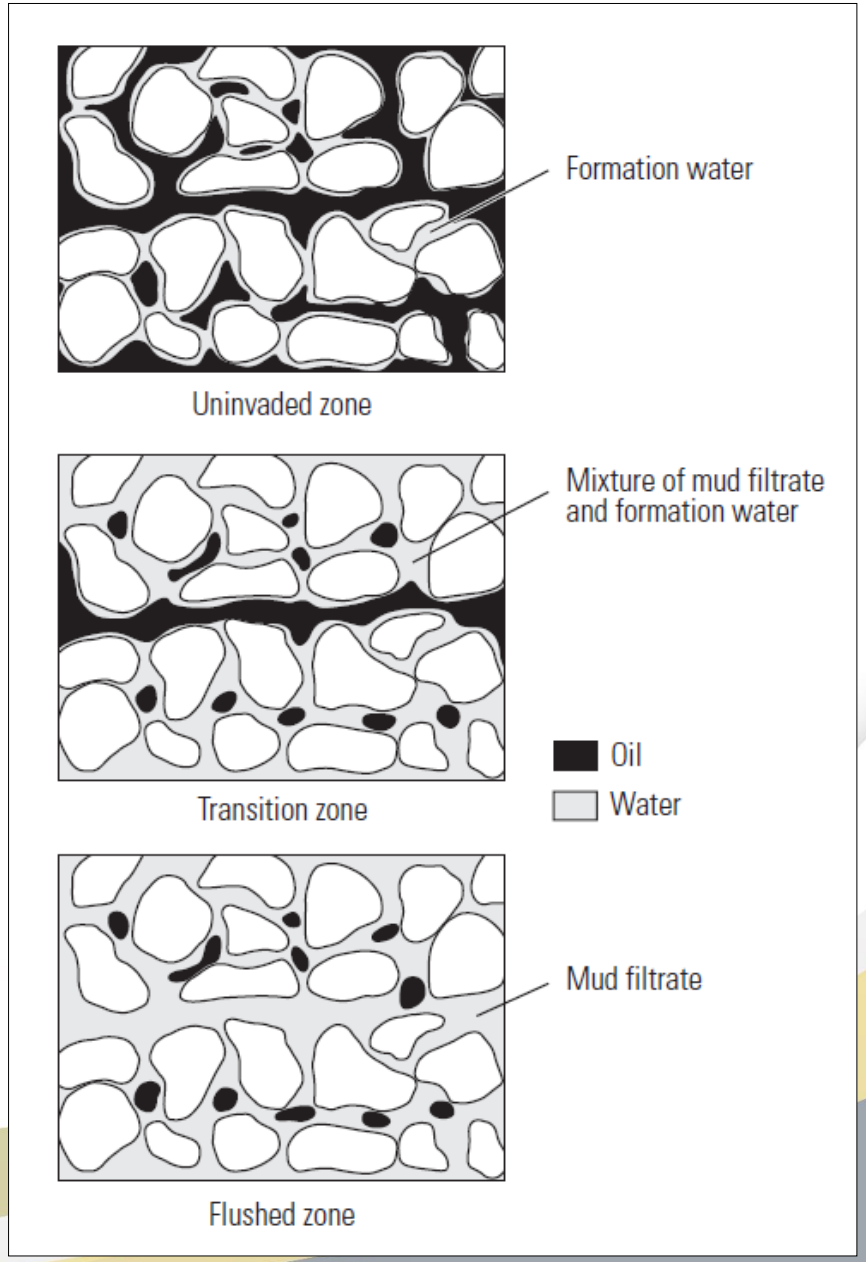
- **4- Flushed zone (Rxo):**
- The flushed zone extends only a few inches from the wellbore and is part of the invaded zone.
- If invasion is deep or moderate, most often the flushed zone is completely cleared of its formation water (Rw) by mud filtrate (Rmf).
- When oil is present in the flushed zone, you can determine the degree of flushing by mud filtrate from the difference between water saturation in the flushed zone (Sxo) and the uninvaded zone (Sw).

- **5- Uninvaded zone (Ri):**
- The uninvaded zone is located beyond the invaded zone (Fig. 1). Pores in the uninvaded zone are uncontaminated by mud filtrate.
- Instead, they are saturated with formation water (Rw), oil or gas (Figure 2). Even in hydrocarbon-bearing reservoirs, there is always a layer of formation water on grain surfaces.
- Water saturation of the uninvaded zone is an important factor in reservoir evaluation because, by using water saturation data, we can determine the reservoir hydrocarbon saturation. The formula for calculating hydrocarbon saturation is:

- $$Sh = 1 - Sw \qquad \text{---------- (1)}$$

- Sh: Hydrocarbon saturation (the fraction of pore volume filled with hydrocarbons).
- Sw: Water saturation uninvaded zone (the fraction of pore volume filled with water).
- The ratio between the uninvaded zone's water saturation (Sw) and the flushed zone's water saturation (Sxo) is an index of hydrocarbon moveability.

- Figure 2: Distribution of pore fluids in zones around a well that initially contained hydrocarbons.



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