भारतीय प्रौद्योगिकी संस्थान (भारतीय खनि विद्यापीठ) धनबाद

IIT ISM

INDIAN INSTITUTE OF TECHNOLOGY (INDIAN SCHOOL OF MINES) DHANBAD

GPC510 - Well logging

Semester - Winter 2024; Lecture - 12

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TEACHING OUTLINE

Week 8

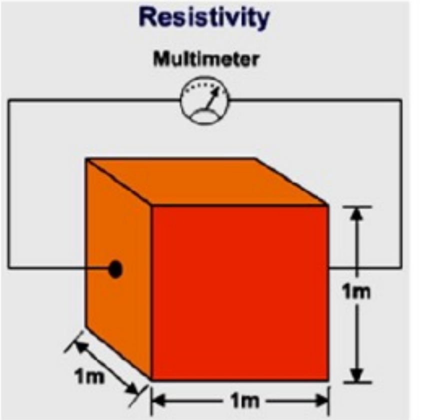
Tutorial 16 – Resistivity logging tools, correction and limitation

AGENDA

- Resistivity theory
- Basic tool principle
- Invasion profile
- Normal and lateral tool
- Laterolog

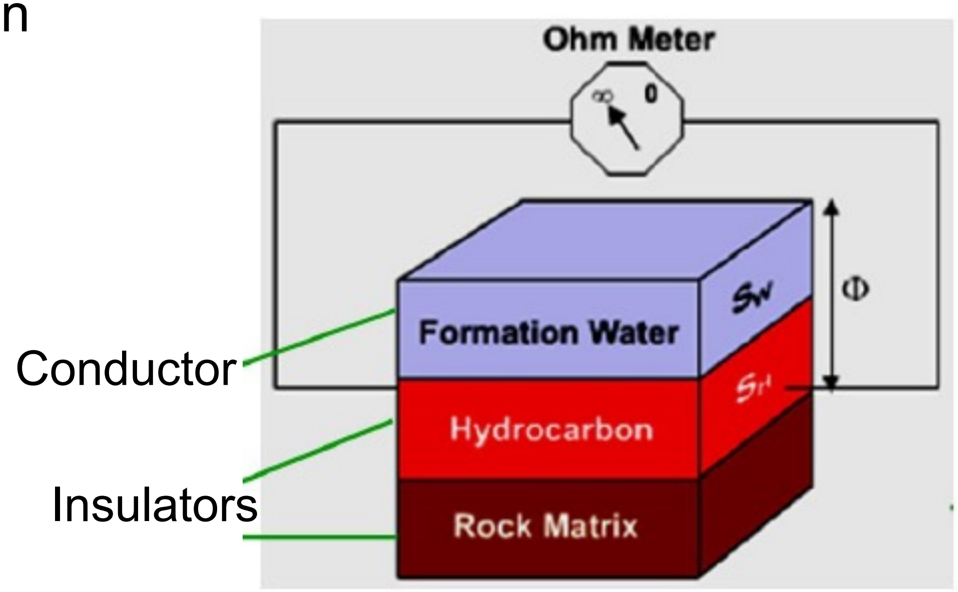
RESISTIVITY THEORY

- Electrical resistance is defined as the ability of the material to obstruct the flow of current
- Ohm's law: $E = i * r$ where E= electromotive force (volts), i = current (amperes) and r = resistance (ohms)
- Resistivity (R) is the measure of the resistance to the passage of an electrical current in a given volume of material
- The electrical conductivity (C) is the measure of the material's ability to conduct electricity
- Electricity resistivity is a measure how the materials resists the flow of electrical current, SI unit ohm-m
- Two types of conductivity (i) **electronic** - property of solids (ii) **electrolytic** - brine



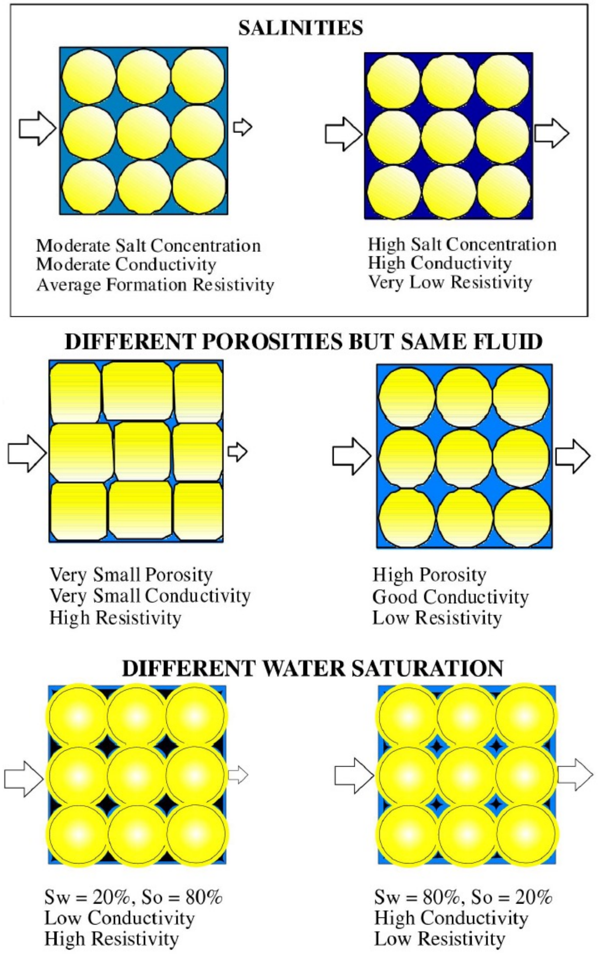
RESISTIVITY THEORY

- Rock materials i.e., rock matrix are mostly insulators
- Subsurface rocks contain fluids in pore spaces, fractures
- Fluids are good conductors except hydrocarbons (infinite resistive)
- High values of resistivity log response may indicate hydrocarbon bearing formation

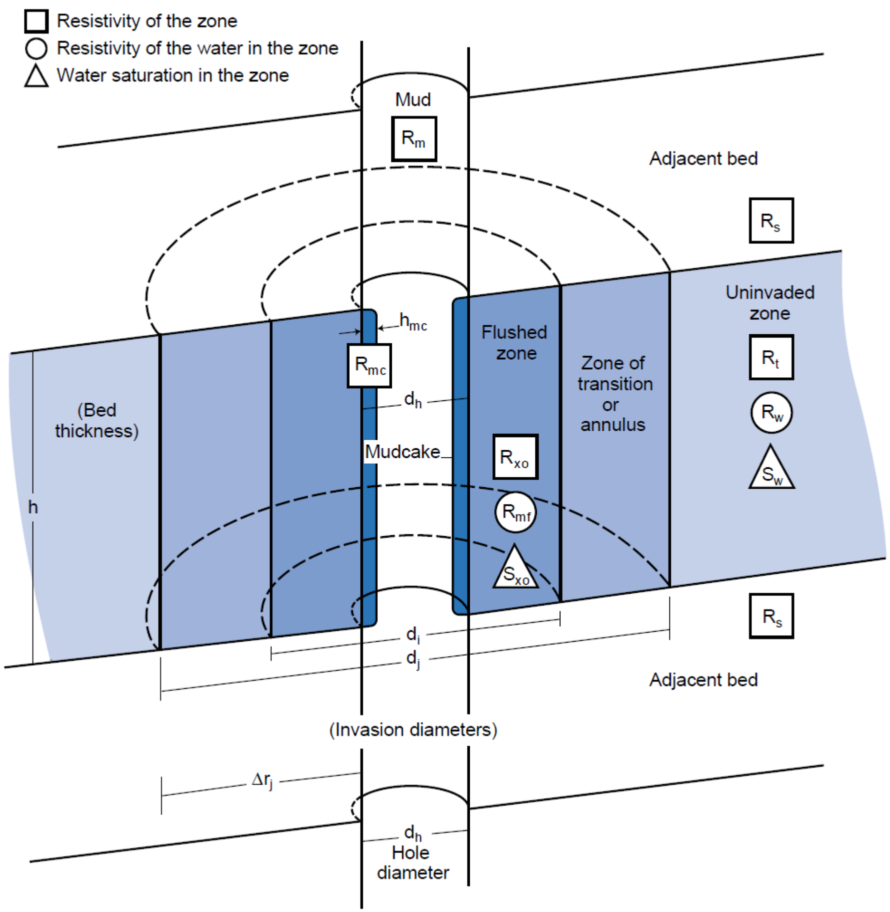


RESISTIVITY OF POROUS ROCKS - DEPENDENCY

- Salinity of water
- Rock properties (Porosity, lithology, texture)
- Water saturation



INVASION



R_t – resistivity of uninvaded zone (True resistivity)

R_w – resistivity of formation water

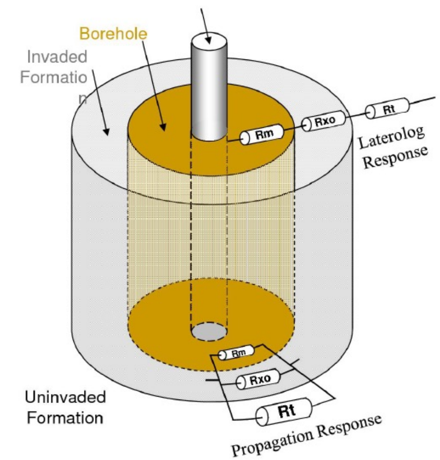
S_w – water saturation of uninvaded zone

R_{xo} – resistivity of flushed zone

R_{mf} - resistivity of mud filtrate

S_{xo} – water saturation of flushed zone

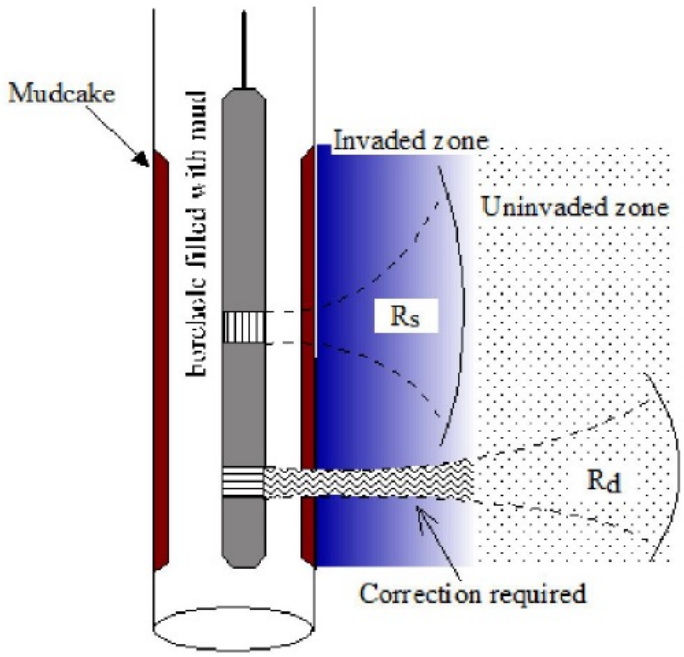
R_{mc} – resistivity of mud cake



Serra, 1985; Schlumberger, 2013

RESISTIVITY MEASUREMENT

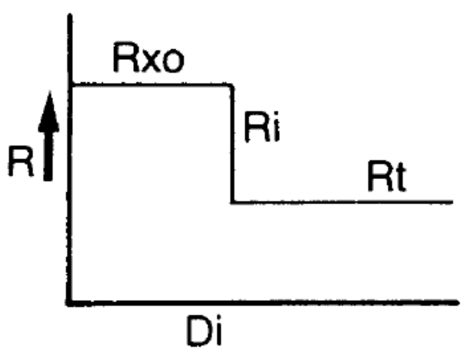
- Resistivity measurement is a complex process due to invasion
- A combination of tools allows to evaluate apparent resistivity (R_a), R_{xo} and d_i
- From this combination a correction may be calculated for the invasion by mud filtrate and a reasonable estimate of R_t can be achieved



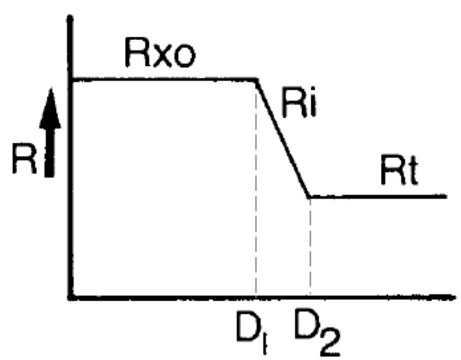
INVASION PROFILE

- Transition can be in any format depending upon invasion profile
- Flushed Zone: Adjacent to the borehole the invasion process flushes out the original water and some of the hydrocarbons (if any were present). The resistivity of this zone is termed R_{xo}; the water saturation is called S_{xo} where:

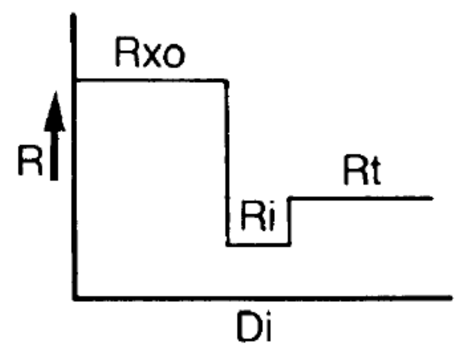
$S_{xo}^2 = \frac{FR_{mf}}{R_{xo}}$ for a clean formation.



Case 1
Step Profile



Case 2
Transition
Profile



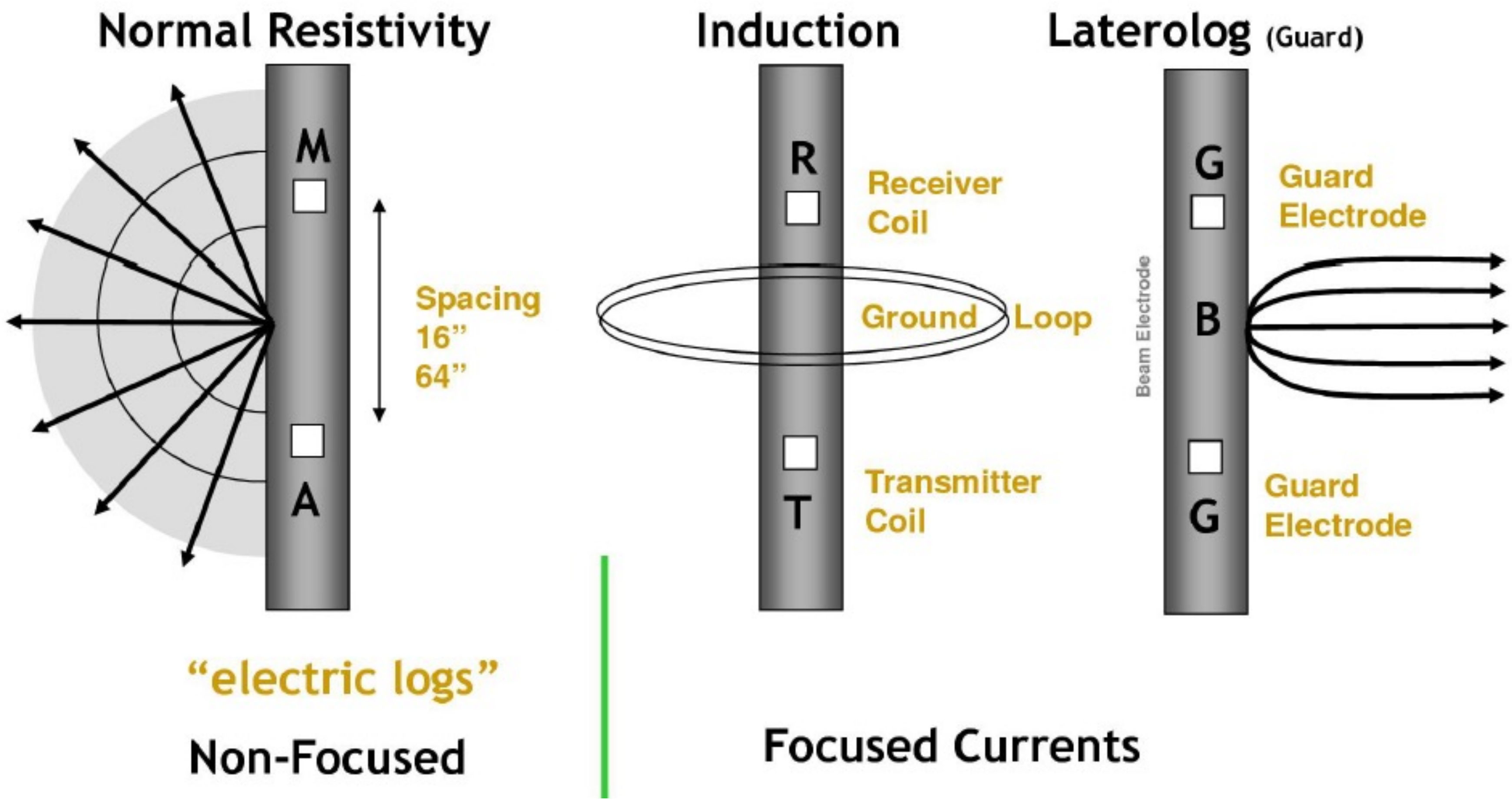
Case 3
Annulus
Profile

RESISTIVITY TOOLS

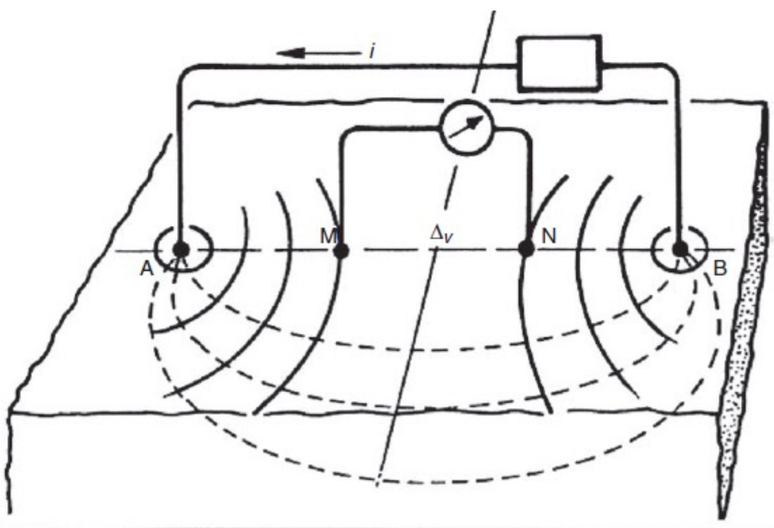
- Different tools exist depending upon their design, configuration and depth of investigation
- Deeper tools are hole centred while shallow tools are pressed against borehole wall mounted on a pad

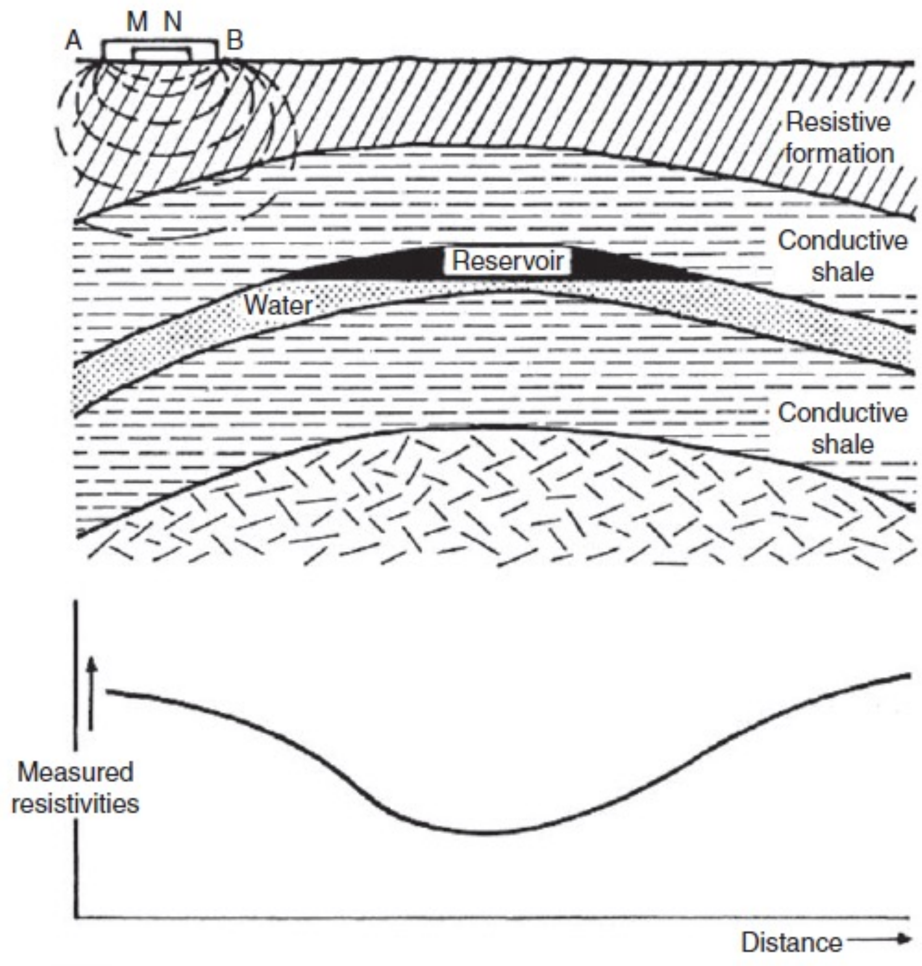
	flushed zone	shallow	medium	deep
Current-flow devices • Short Normal • Focused (Laterolog)		16" Normal	64" Normal	
	Microlog	LL8		
	MLL	LLS		LLD
	MSFL	SFL		
Induction devices • Induction tools • Array			ILM	ILD
			PHASOR Processing	
		RPhase	RAttenuation	
Depth of Investigation	1 - 6 inches	0.5 - 1.5 ft	1.5 - 3 ft	>3 ft

RESISTIVITY TOOLS



BACKGROUND





Bateman, 2012

PRINCIPLE

- In an infinite, isotropic and homogeneous media where a spherical electrode emitting current **I** radially in spherical distribution pattern, the voltage drop between two consecutive spherical shells with radii k and k + dk is defined as

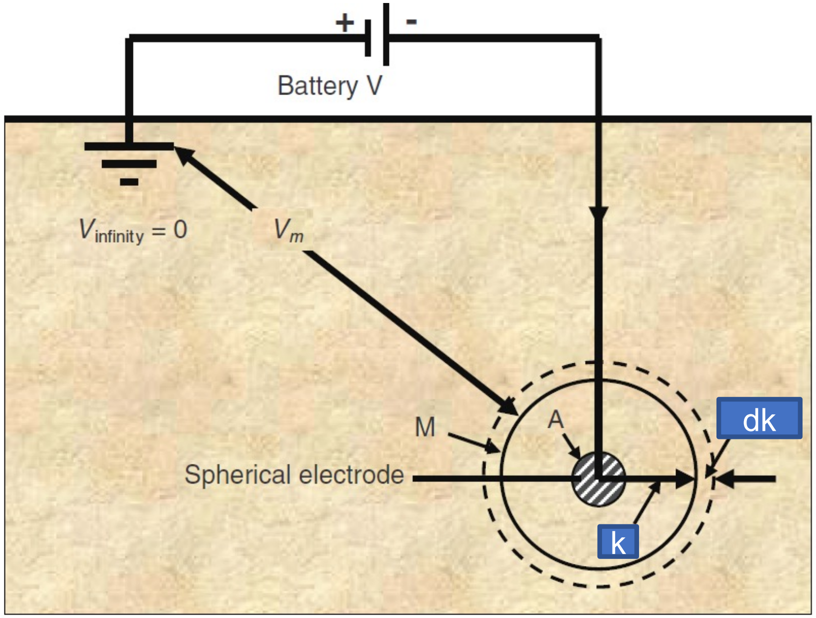
dV = I x dr [dV = voltage drop, I= current, dr = resistance between two shells].

If we consider **R** is the resistivity of the medium:

$dr = R * \frac{dk}{4\pi k^2}$ (2) and $dV = I * R * \frac{dk}{4\pi k^2}$ (3)

- To measure voltage V_m between an infinite ground and some point M in the formation, integrate equation 3 from k = A to k= M, the equation becomes

$$V_m = -I * \frac{R}{4\pi} * \int_A^M \frac{dk}{k^2}$$

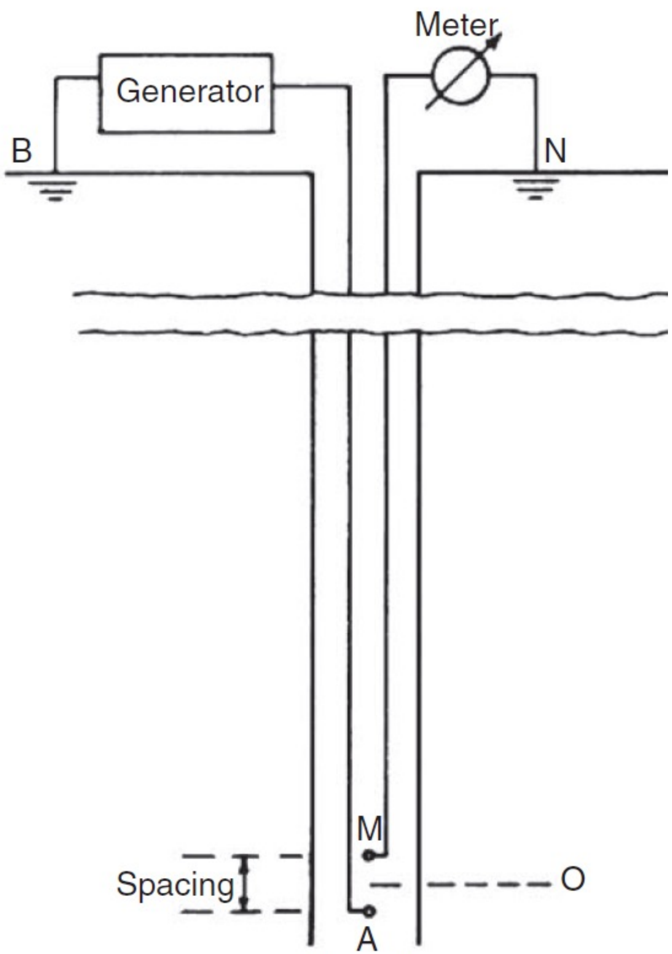


Therefore, after integration
The distance AM is called the spacing.

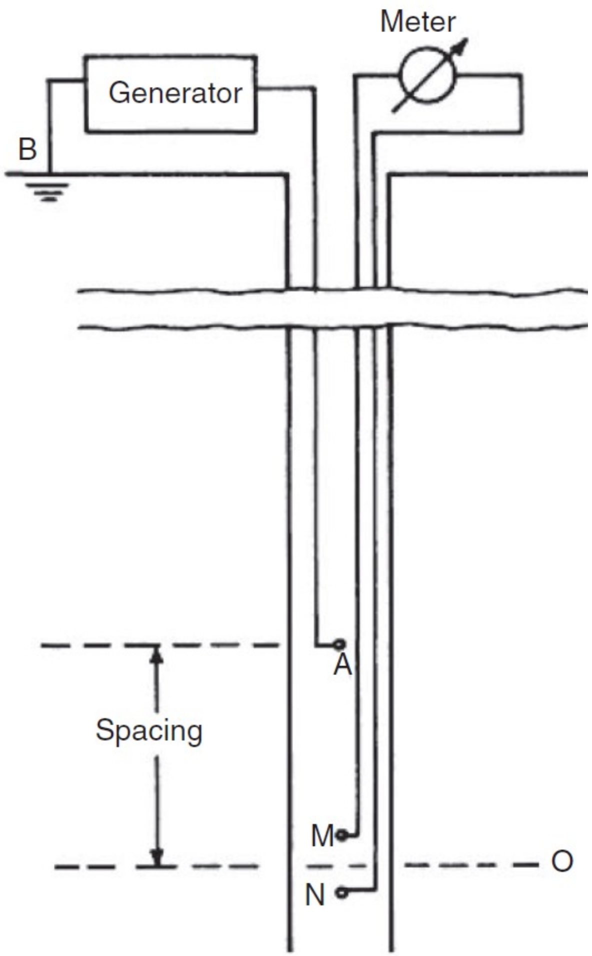
$$V_m = \frac{RI}{4\pi AM}$$

AM = 16'' (short normal)
AM = 64'' (long normal)

NORMAL & LATERAL



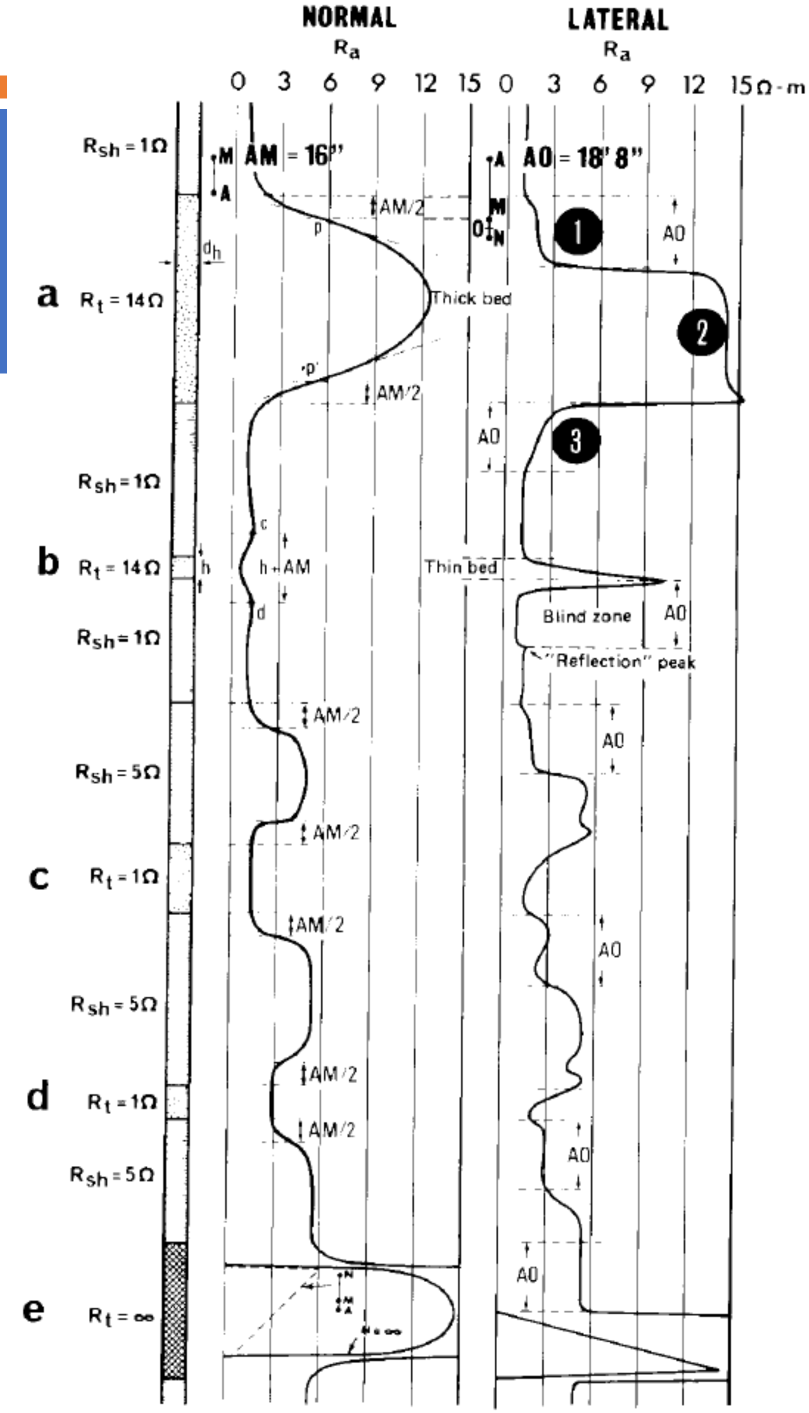
Normal



Lateral (Basic Arrangement)

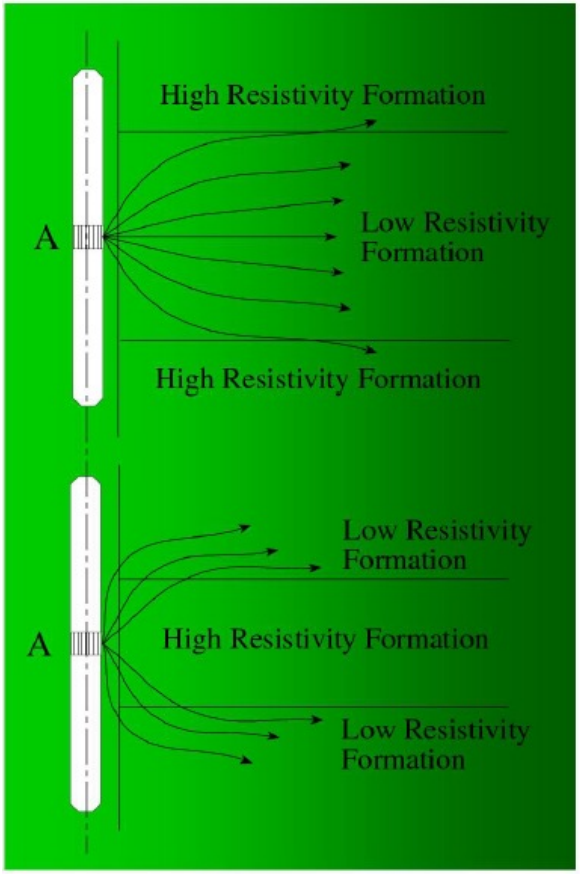
BED THICKNESS

- Thick resistive beds (h > AM)
- Thin resistive beds (h < AM)
- Conductive beds (C, D)



CHALLENGES OF NORMAL & LATERAL CONFIGURATION

- Thin beds (h ~ spacing), the apparent resistivity is a poor estimate of the true value
- The current may be short-circuited by the presence mud column when it highly conductive
- Depth of investigation affected by higher formation resistivity i.e., presence of hydrocarbons



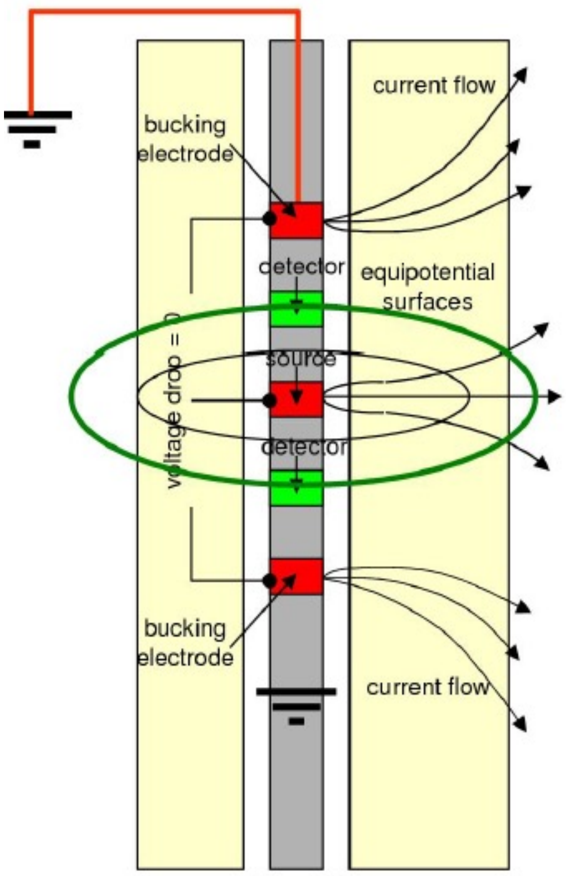
LATEROLOG

- The laterolog configuration uses a current electrode A_0 with remote return. Two symmetrical guard electrode emit focusing currents which constrain the A_0 current beam I_0 perpendicular into the formation. (LL3)
- Bucking electrodes

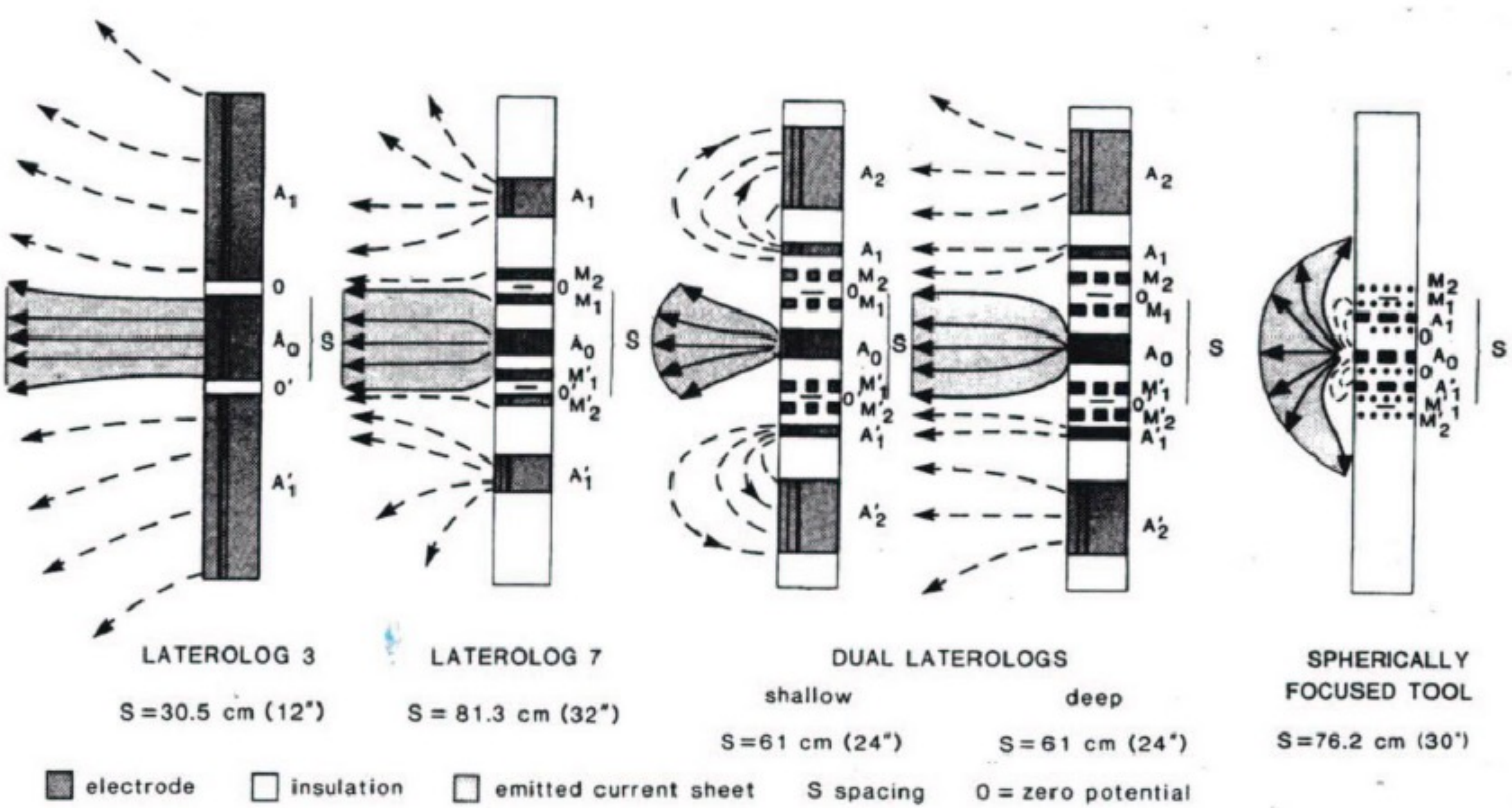
(i) maintain zero voltage with source

(ii) No up and downward current flow, only lateral

- Guard Log (LL3) – 3 electrodes
- Laterolog (LL7) – 7 electrodes
- Dual laterolog shallow/deep (LLS/LLD) – 9 electrodes
- Micro Spherically Focused Log (MSFL) – 5 rectangular electrodes

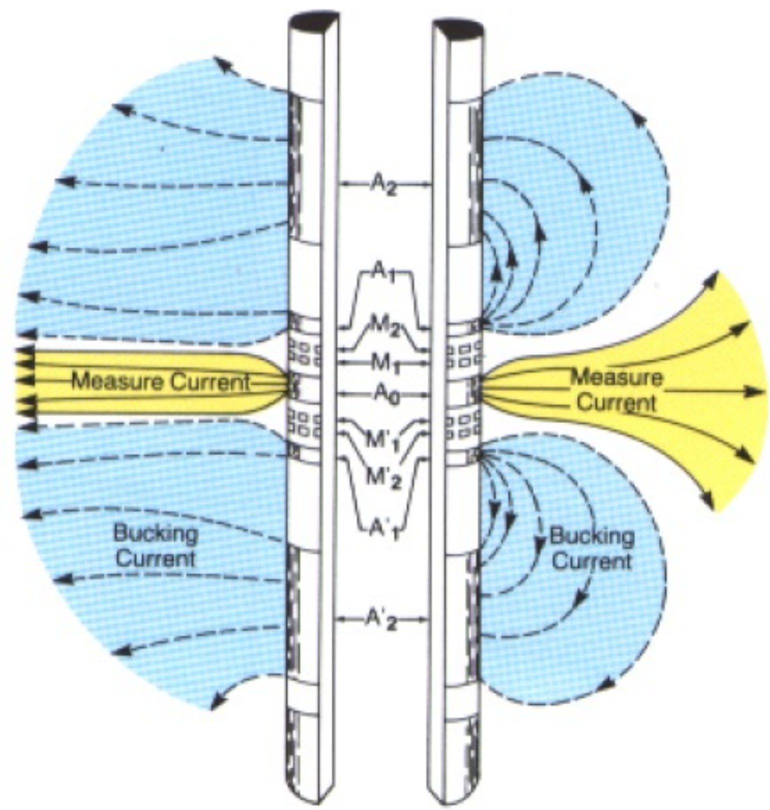


RESISTIVITY TOOLS



DUAL LATEROLOG

- DLL makes simultaneous deep and shallow readings
- LLD system uses remote return for the main and bucking currents
- LLs uses A2-A2’ electrode-pair as the return for the bucking current from A1-A1’, which reduces the effectiveness of focusing of I_0



LLD

A_0	Measure Current Electrode
M_1, M_2	Monitoring Electrode
A_1	Bucking Current Electrode
A_2	Bucking Current Electrode

LLS

A_0	Measure Current Electrode
M_1, M_2	Monitoring Electrode
A_1	Bucking Current Emitting Electrode
A_2	Bucking Current Return Electrode

TOOL CHARACTERISTICS

1. The Dual Laterolog performs most effectively in saline mud (high R_t/R_m ratios) or where $R_{mf}/R_w < 2.5$.

2. The tool has an excellent resistivity range; by utilizing a unique design, resistivity resolution from 0.2 to 40,000 ohm-m is possible.

3. Vertical resolution is excellent, R_t can be obtained in beds as thin as 60 cm (2 feet).

4. The LLd has very little borehole effect in large holes.

5. When combined with an R_{xo} measurement, the LLd, LLs curves may be used to study invasion profiles and compute a more accurate R_t.

6. Assuming borehole conditions are suitable, the separation of the LLS, LLD curves may be used to give **quick look** indications of hydrocarbons; particularly in salt mud. In salt muds R_{xo}/R_t will be less than one so the better the zone, the greater the separation between LLs and LLd.

LIMITATIONS

1. The tools should not be used in freshmuds (R_{mf}/R_w > 2.5.)

2. The tools requires good centralization to minimize borehole influence on the LLs.

3. If invasion is deep, a good value of R_{xo} (e.g., from a Micro-Spherically Focused Log) is required to correct LLd for invasion influence to obtain an accurate value of R_t.

ENVIRONMENTAL CORRECTION

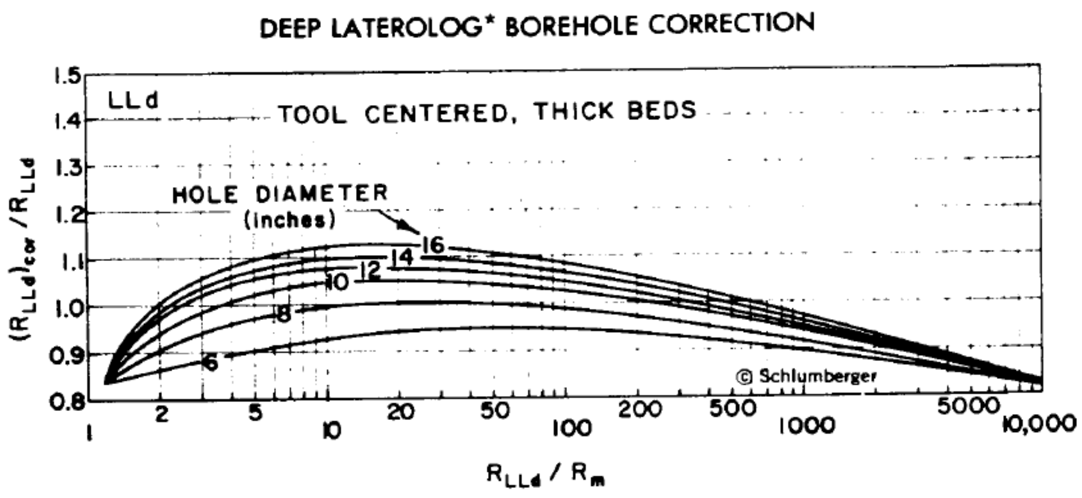
The measured apparent resistivity R_a is a function of several parameters

$R_a = f(R_m, d_h, R_{xo}, d_i, R_s, h, R_t)$

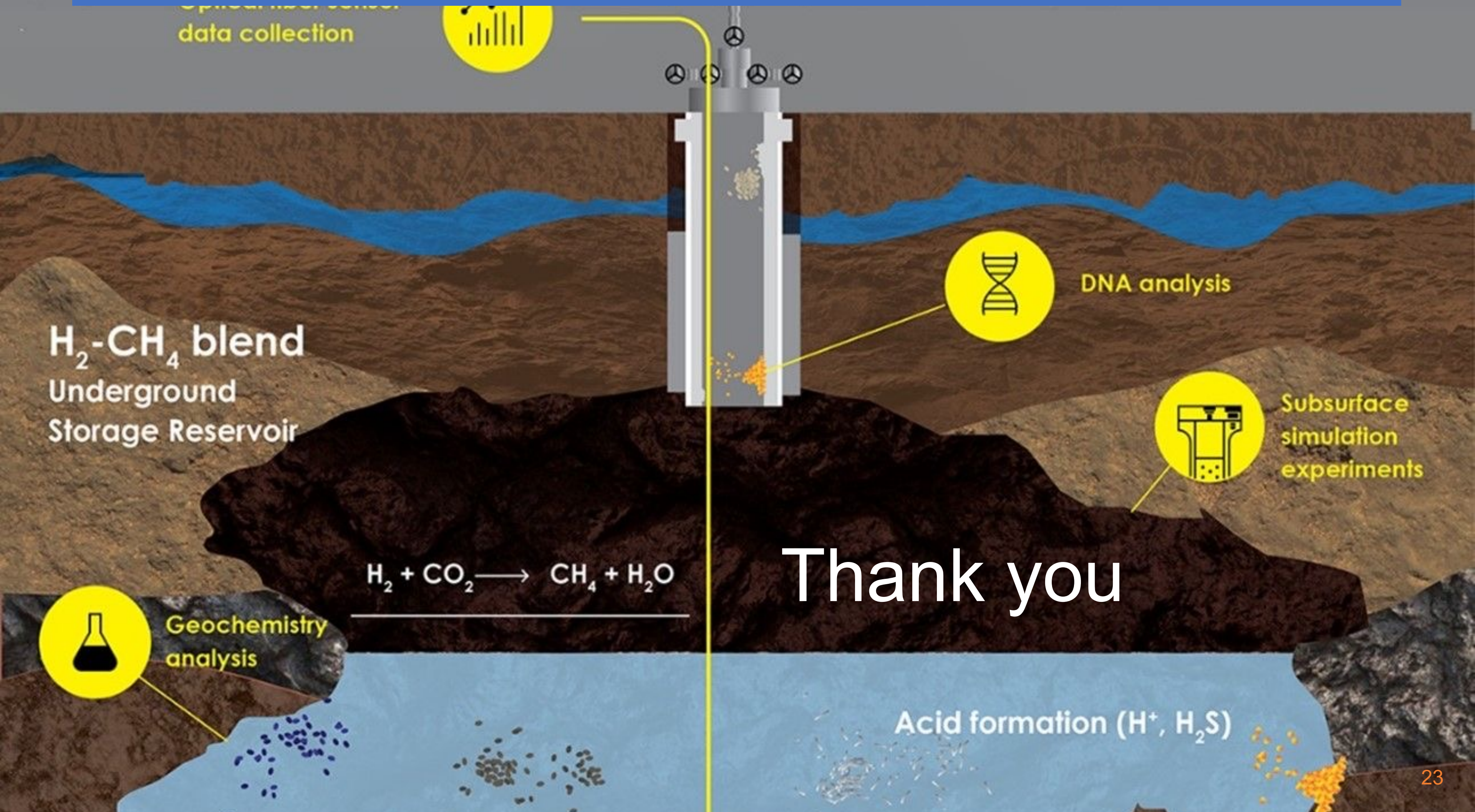
Corrected resistivity is obtained by considering borehole and adjacent beds correction.

$$R_{(a)c} = R_{xo}J_{xo} + R_tJ_t$$

where $J_{xo} + J_t = 1$



END OF LECTURE



Thank you