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-4

Partha Pratim Mandal
Assistant Professor
Department of Applied Geophysics
E: partham@iitism.ac.in / partha87presi@gmail.com

TEACHING OUTLINE

Week 3

Tutorial 4 – Borehole effects, environmental impacts

Tutorial 5 – Tool geometry, resolution, rock composition, resistivity

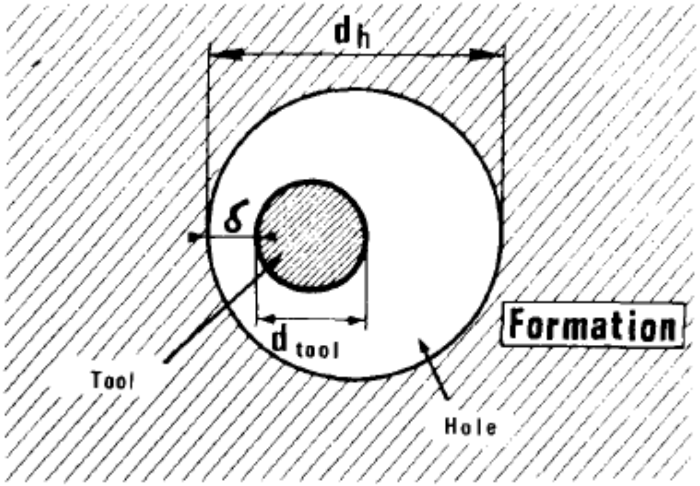
Tutorial 6 – Resistivity, salinity, clay definition

EFFECTS OF TOOL GEOMETRY

Tool geometry		
Tool positioning	Spacing sensors	Vertical resolution

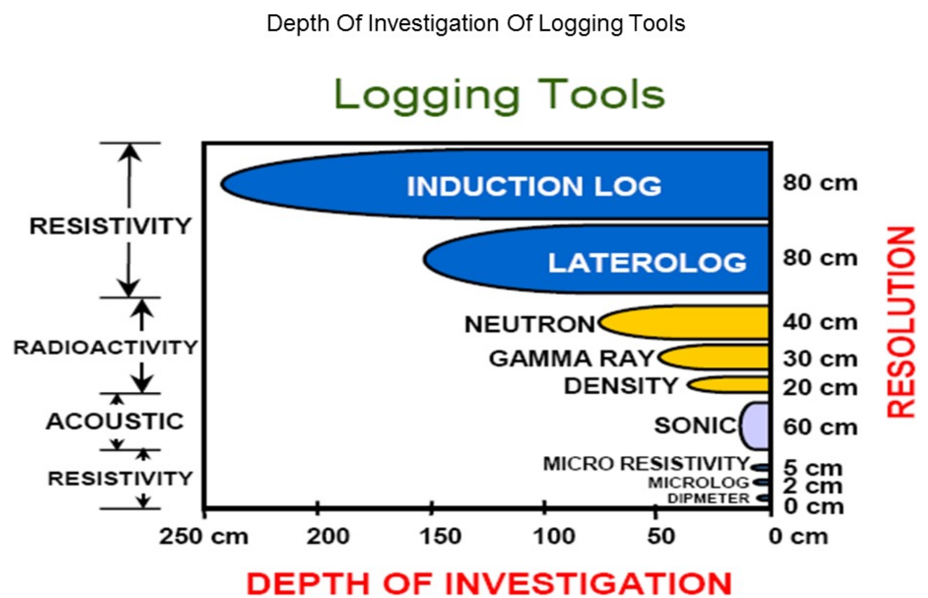
TOOL POSITIONING

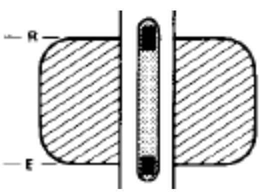
- Borehole diameter need to be higher than logging tool for a safer data acquisition
- Tool can be placed in any of the three positions relative to hole axis (i) centralized (ii) excentralized (δ =0) (iii) stood of from the wall by an amount (δ = constant)
- The coefficient of excentralized is defined as $\epsilon = \frac{2\delta}{(d_h - d_{tool})}$, where ϵ=1 for perfectly centered tool sonde
- Multi-arm centralizers (BHC), one-arm excentralizer (CNL), etc



DEPTH OF INVESTIGATION

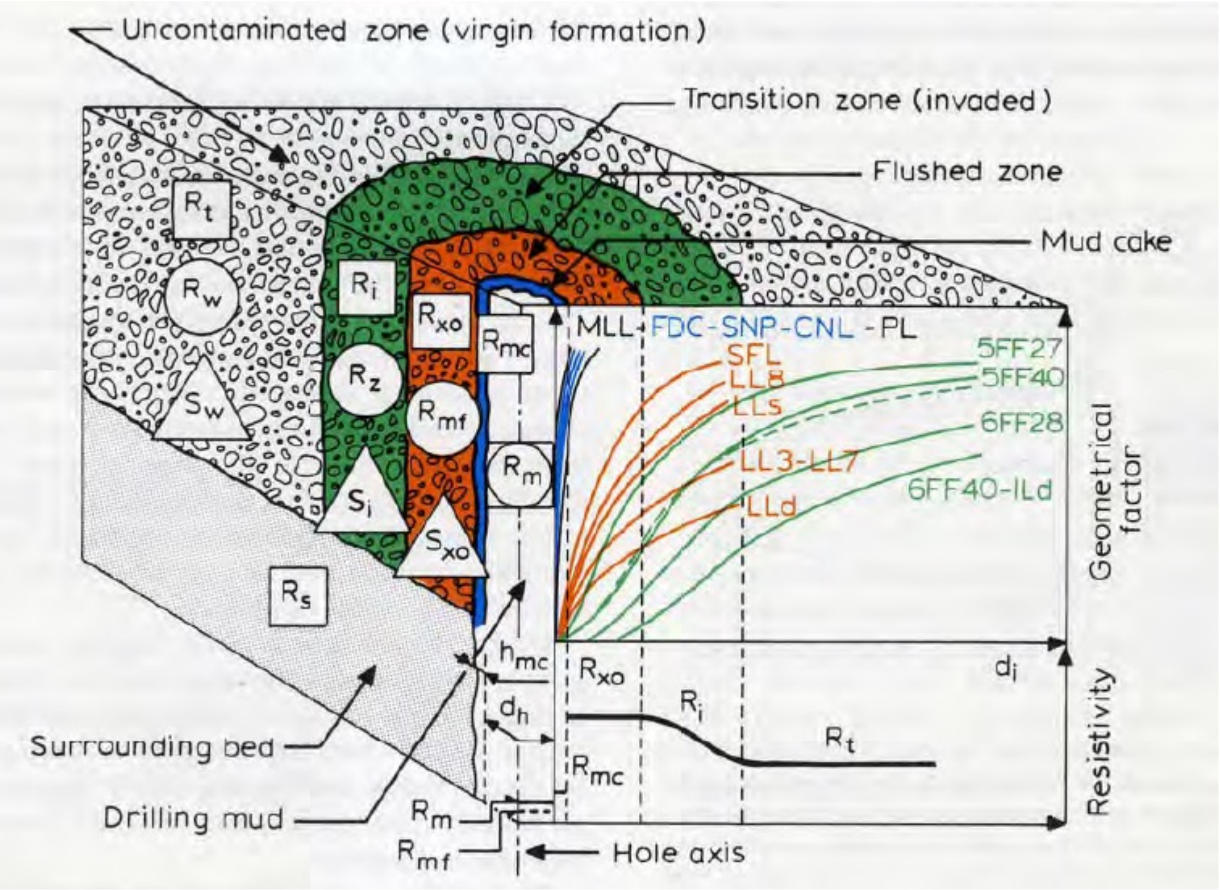
- Logging tools do not take point readings, the received signals come from a finite volume of formation surrounding the sensor
- Single detector devices accumulates data from the spherical volume surrounding the sensor
- For source (S) and receiver (R) devices (electrical, acoustic), the signal is coming from a volume whose height is equal to **S-R** spacing
- For double detector system (compensated sonic), the difference between received signals is a measure of distance of the formation approx. to detector spacing
- Log measurements are average values, integrated over a volume of formation whose dimensions and shape depend on the tool geometry, as well as the nature of the measurement.
- Tools are categorized according to their depth of investigation





Ref: Bond, 2009

DEPTH OF INVESTIGATION



- Resistivity tools can provide different depth of investigation (shallow, medium, deep)

VERTICAL RESOLUTION

- Bed resolution on a log run across a sedimentary rock formations depend upon several factors. Such as:

(i) Bed thickness

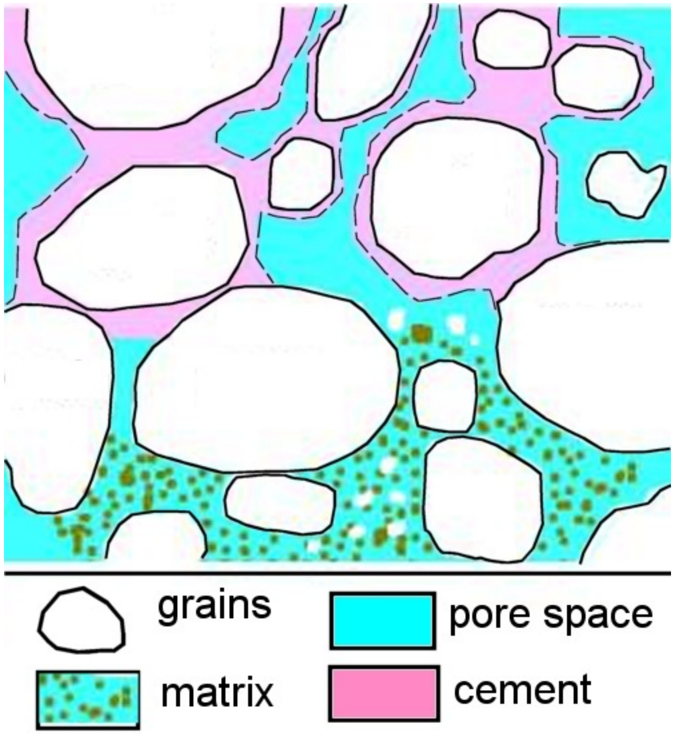
(ii) Tool geometry and type of measurement

(iii) Contrast between readings of the investigated bed and its neighbours

- For radioactive tools, bed resolution can vary according to logging speed and time constants
- Bed boundaries on logs are not perfectly sharp but appear as a gradual transition between a lower and a higher reading
- **Rule of thumb**, depth of investigation increases with sensor spacing while vertical resolution deteriorates.

ROCK COMPOSITION

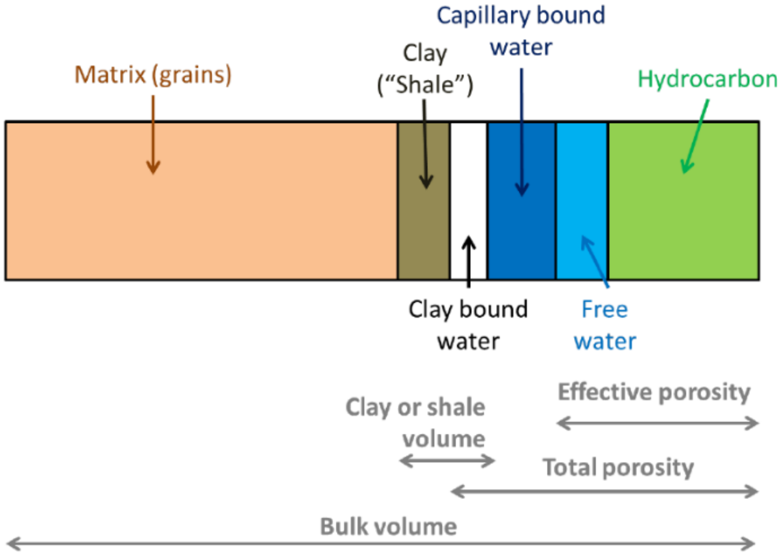
- In well-log analysis, the reservoir rock is divided into three components: (i) **matrix** (all solid components) (ii) **shale** and (iii) **pore space**
- Matrix composed of all solid constituents including grains, matrix and cement



Ref: Virtual-geology

ROCK COMPOSITION

- Shale is a fine-grained, indurated sedimentary rock formed by a combination of clay and/or silt
- It is fissile and laminated
- Silt: fine-grained detrital particles with diameter in the range 1/256 – 1/16 mm
- Clay: extremely fine-grained with particles smaller than 1/256 mm, composed of hydrous silicates (kaolinite, smectite, Illite, etc)
- Clays have high water hydrogen content
- Log response will vary according to the clay fractions and its characteristics



BASIC ROCK PROPERTIES

Four fundament properties of interest for reservoir characterization:

1. Resistivity
2. Porosity
3. Permeability
4. Water saturation

RESISTIVITY & CONDUCTIVITY

- 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

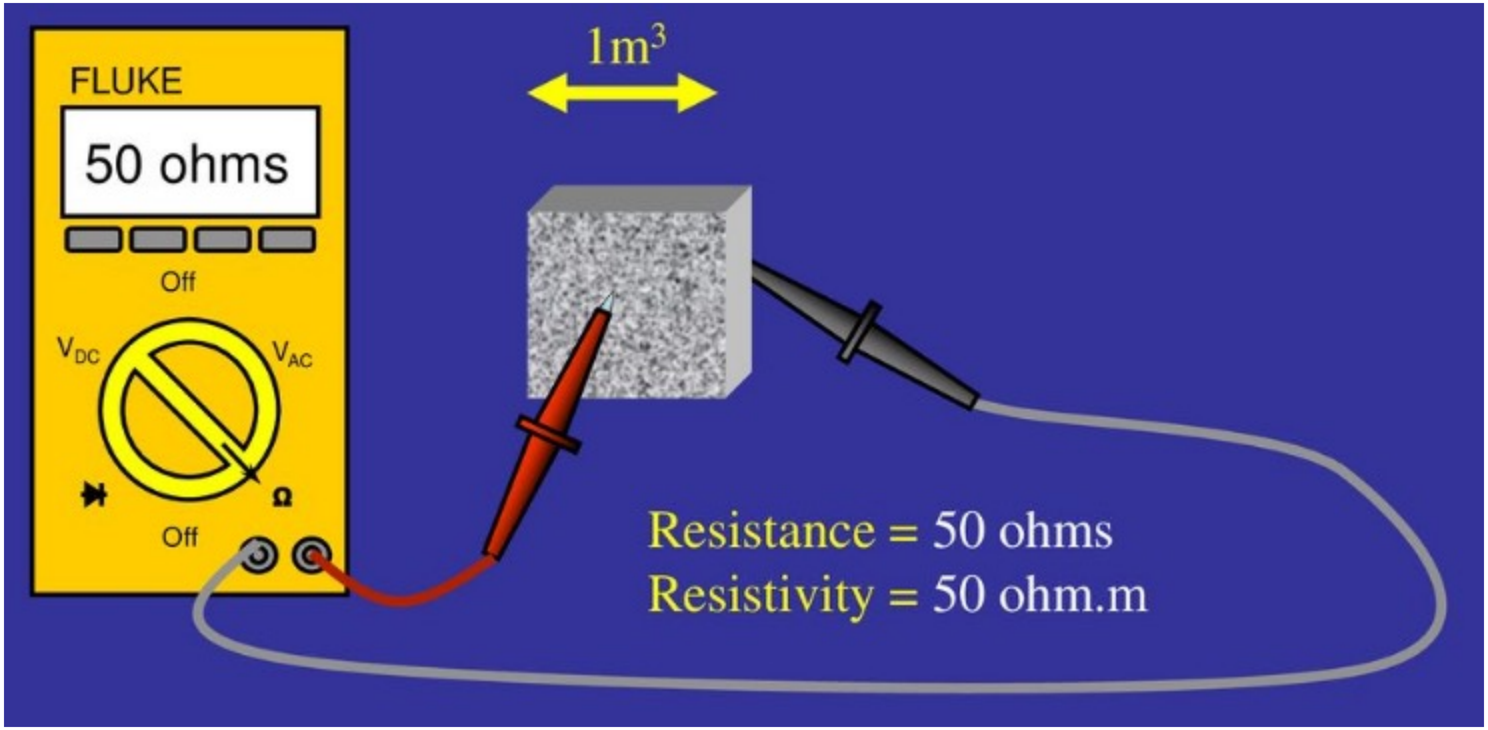
- Resistivity (R) is a measure of the resistance of a given volume of material

$$R = r * A/L$$

Where R= resistivity (ohm-m), r = resistance (ohms), A = cross-sectional area (m^2), L= length (m)

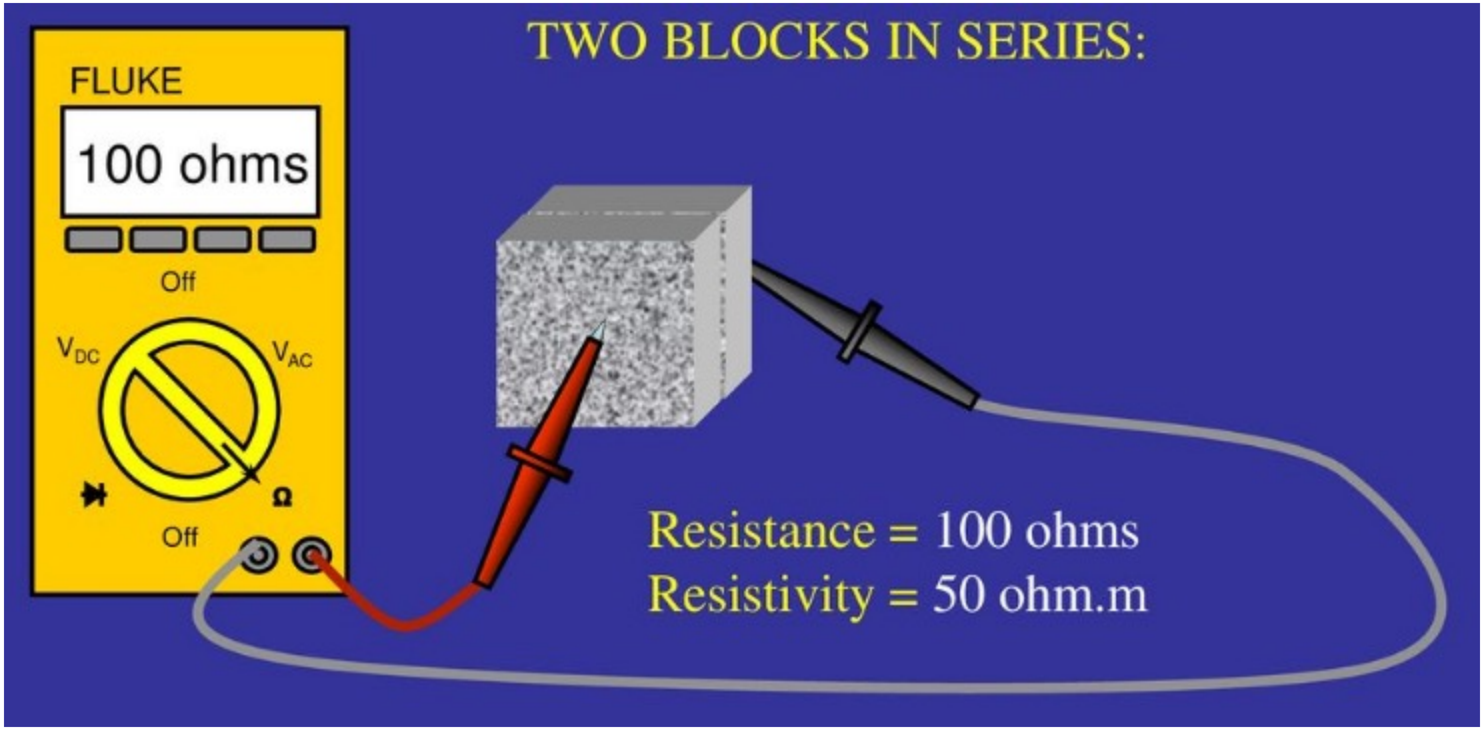
RESISTIVITY

- What is the difference between resistivity and resistance ?



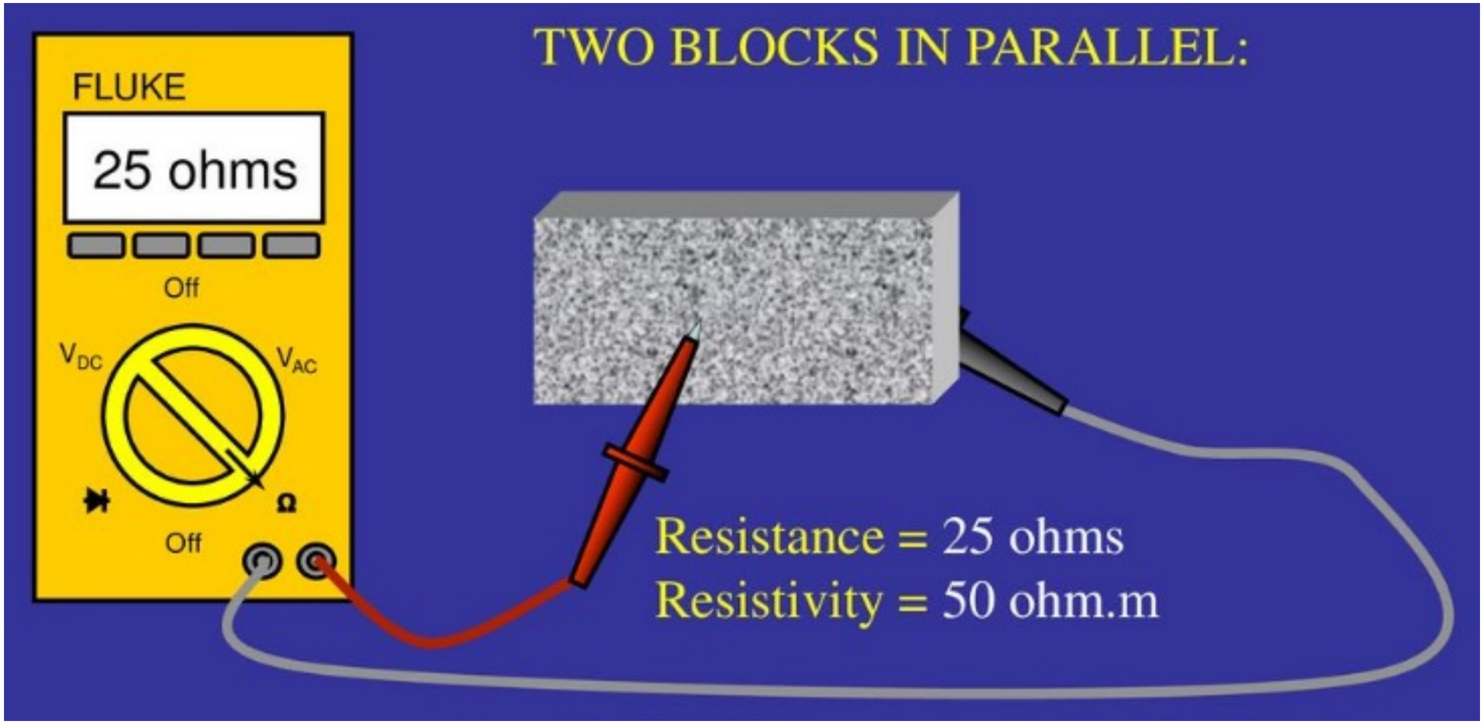
RESISTIVITY

- What is the difference between resistivity and resistance ?



RESISTIVITY

- What is the difference between resistivity and resistance ?



CONDUCTIVITY

- The electrical conductivity is the measure of the material's ability to conduct electricity

$$C = 1/R$$

- Where R = resistivity (ohm-m), C = conductivity millimhos/m, mmho/m , C (mmho/m) = 1000/R (ohm-m)
- Two types of conductivity (i) electronic - property of solids (ii) electrolytic
- Sedimentary rocks have electrolytic conductivity – presence of water in pore space

FACTORS AFFECTING RESISTIVITY IN ROCKS

- Water resistivity (R_w) present within the pores. Will vary with nature and concentration of salt
- Porosity and saturation
- Lithology
- Texture
- Temperature

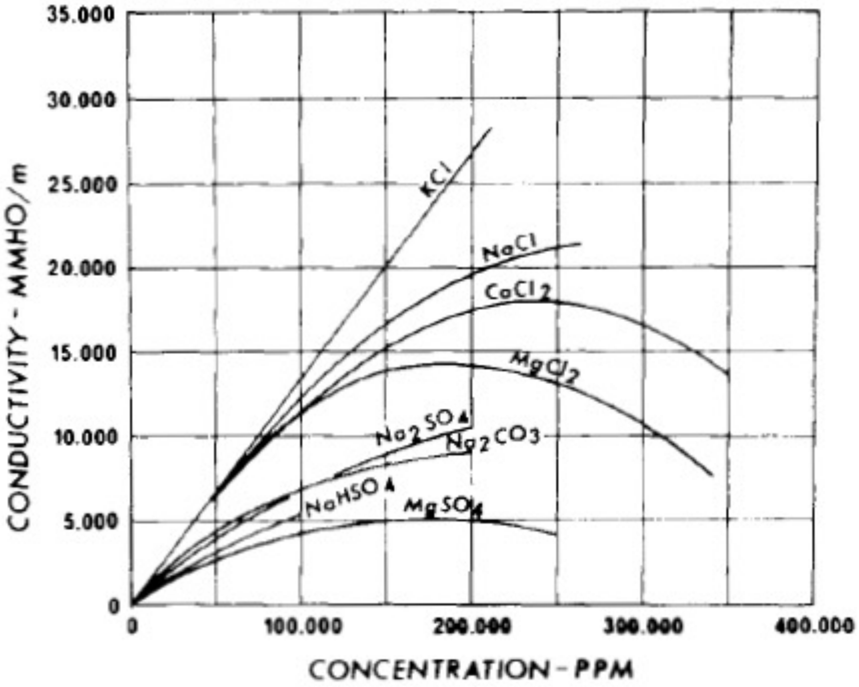
ANISOTROPIC RESISTIVITY

- Horizontal resistivity (R_H) along the bedding plane and vertical resistivity (R_V) is perpendicular to bedding plane
- We define anisotropic coefficient $\lambda = \sqrt{\frac{R_v}{R_H}}$, ranges from 1 to 2.5

- Tool measured horizontal resistivity
- Mean resistivity of an anisotropic formation is $R = \sqrt{R_v R_H}$

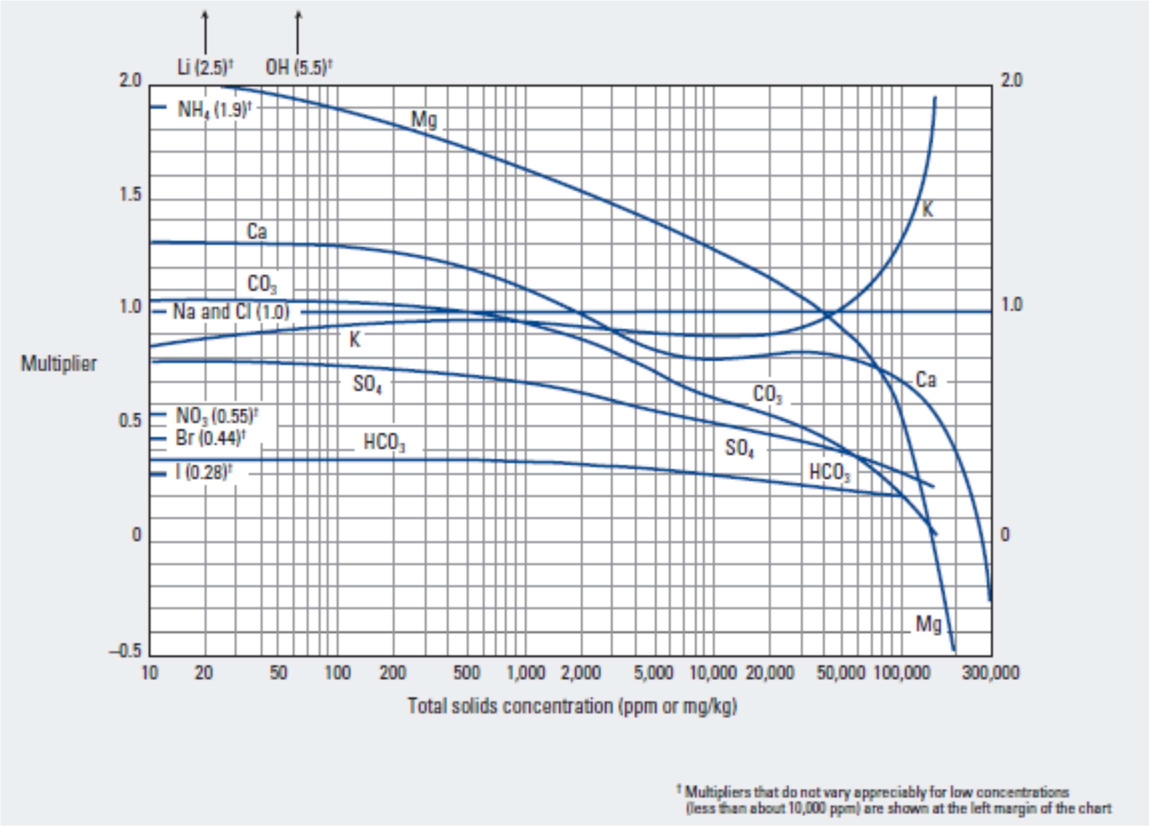
RESISTIVITY AND SALINITY

- Resistivity of an electrolyte depends upon concentration and type of dissolved salts



RESISTIVITY AND SALINITY

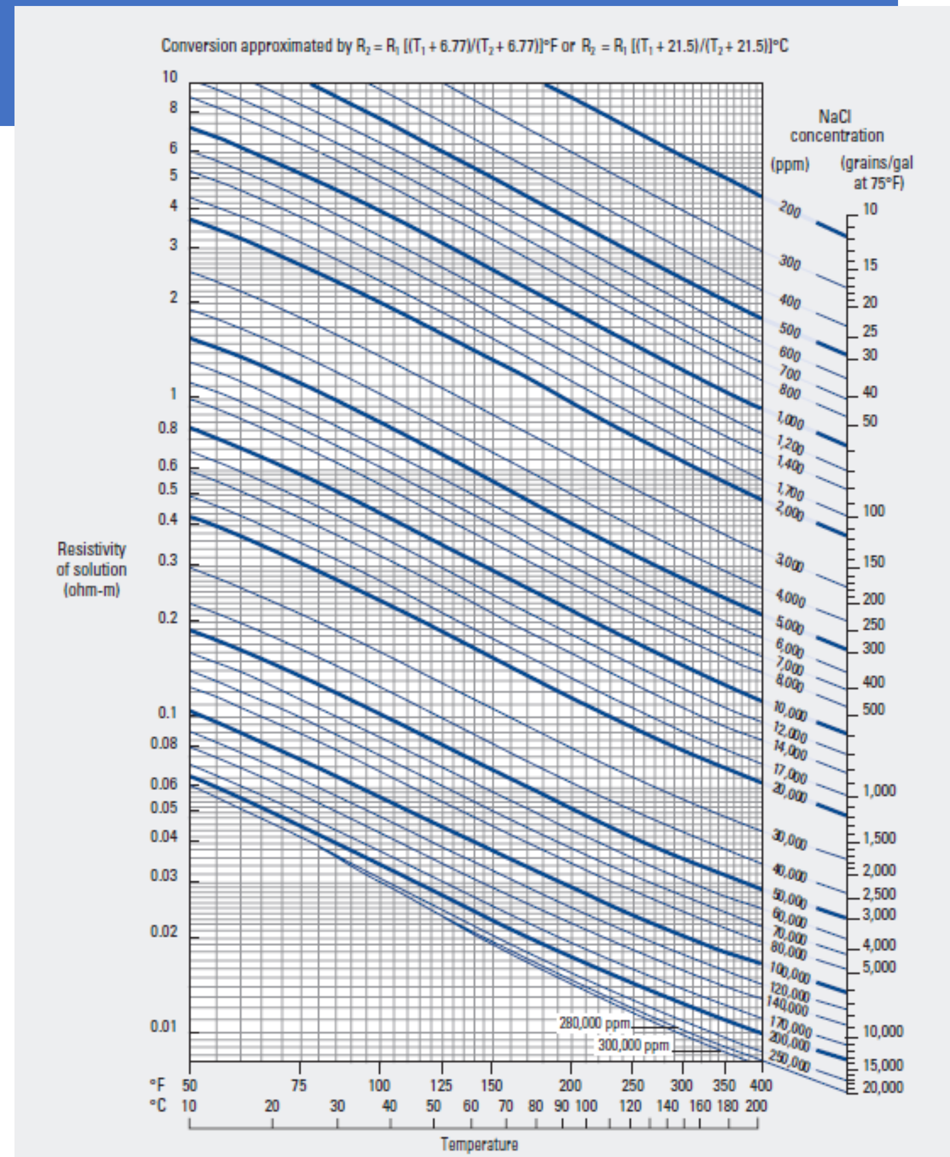
- Charts to convert other dissolved salts in terms of equivalent NaCl



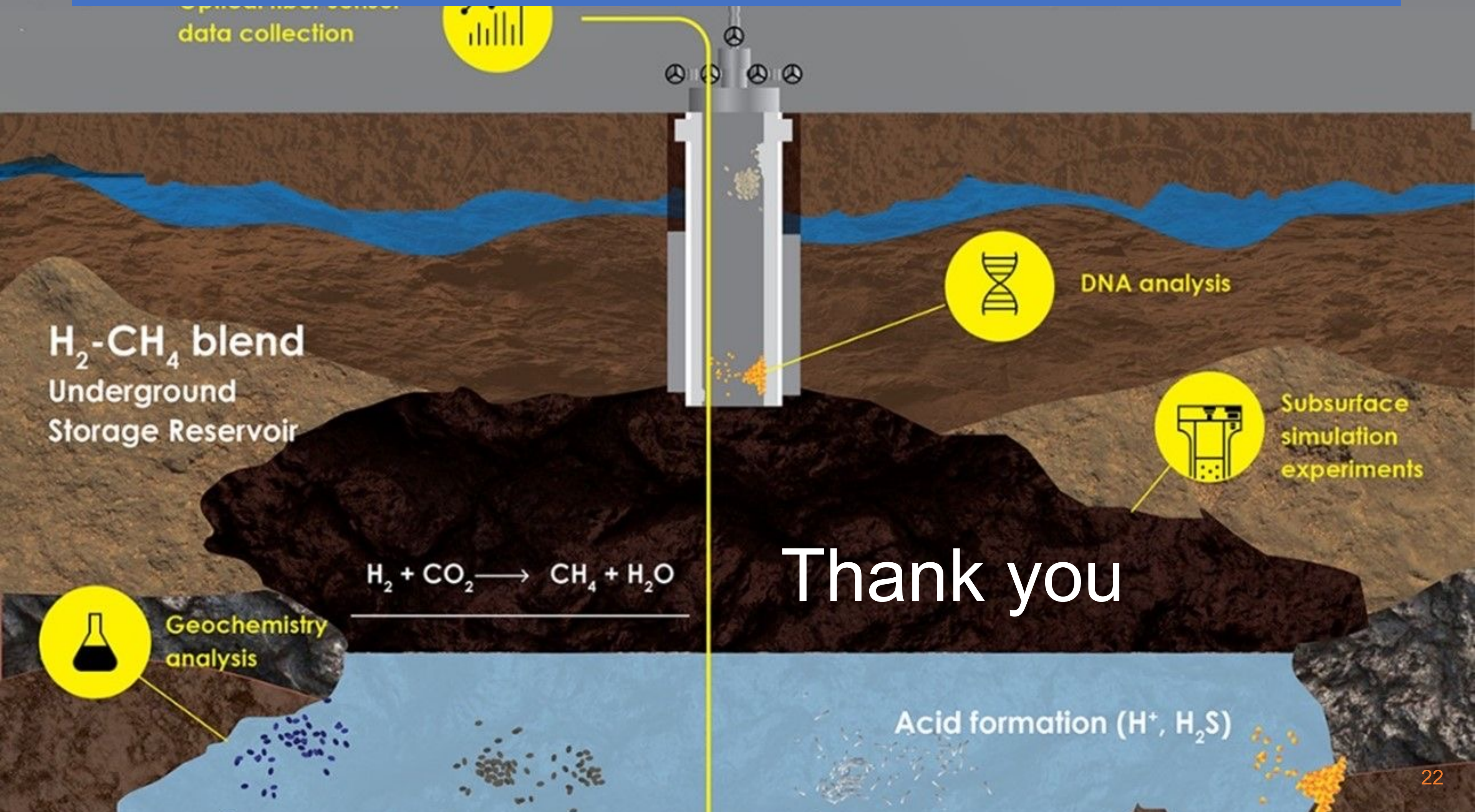
Ref: Schlumberger

RESISTIVITY& TEMPERATURE

- Resistivity of a solution decreases with increasing temperature
- $R_{wT2} = R_{wT1} \left[\frac{T_1+6.77}{T_2+6.77}\right]$ in (^{0}F)
- $R_{wT2} = R_{wT1} \left[\frac{T_1+21.5}{T_2+21.5}\right]$ in (^{0}C)
- Chart presented here can be used to convert resistivity at a given temperature to that at any other temperature



END OF LECTURE



Thank you