भारतीय प्रौद्योगिकी संस्थान
(भारतीय खनि विद्यापीठ)
धनबाद

IIT ISM

INDIAN INSTITUTE OF TECHNOLOGY
(INDIAN SCHOOL OF MINES)
DHANBAD

GPC510 - Well logging

Semester - Winter 2025; Lecture - 8

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TEACHING OUTLINE

Week 4

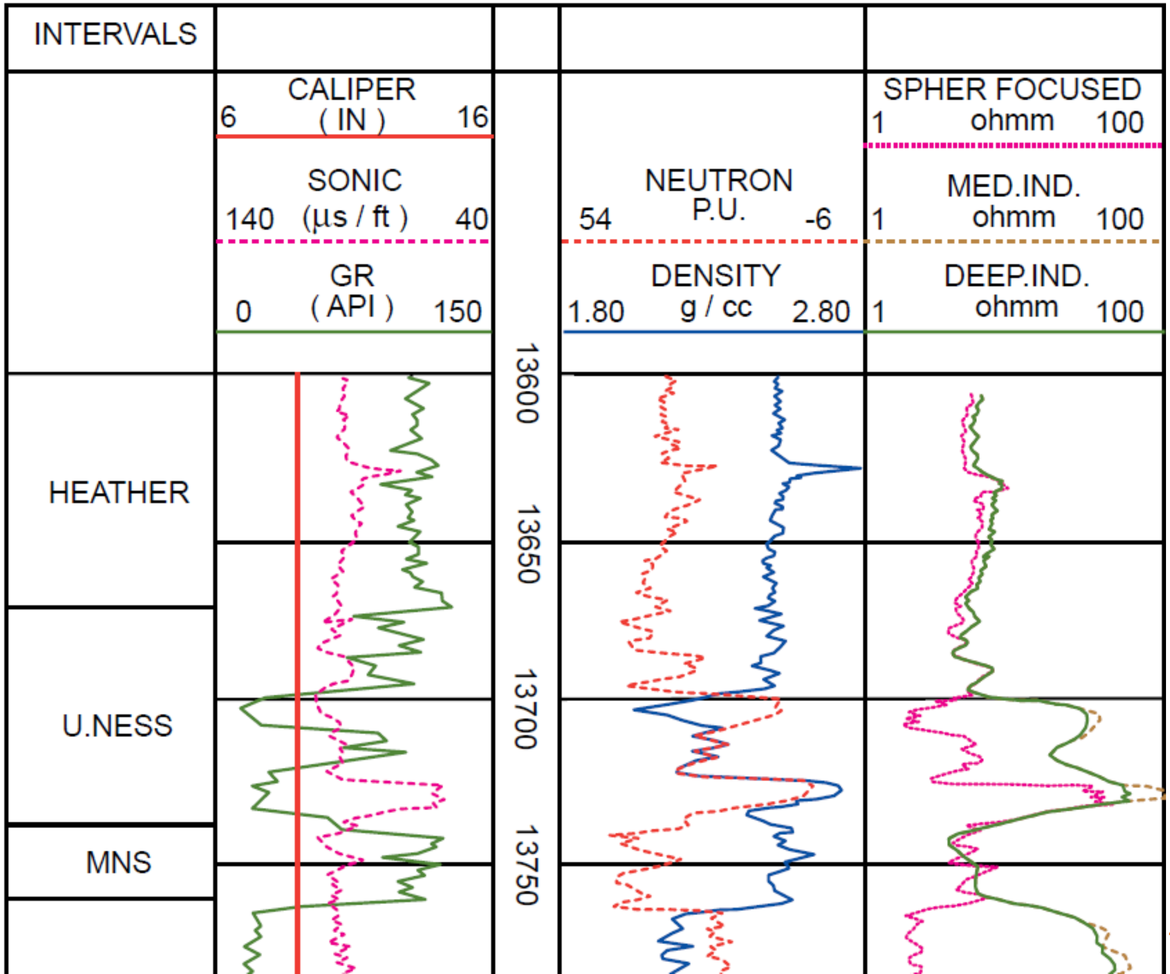
Tutorial 12 – Logging tools, Self potential log and application

AGENDA

- Key logging tool
- Spontaneous potential log
- Measurement principle
- Application

KEY MEASUREMENT TOOLS

- Caliper – borehole diameter
- Gamma ray – radioactive response
- Density – rock density
- Neutron – evaluation of porosity
- Sonic – acoustic wave travel time
- Resistivity – resistivity of rock



INTRODUCTION

- The SP (Spontaneous Potential) log is one the earliest electrical logs used in the hydrocarbon industry
- Discovered in the early 1932, SP log was a major breakthrough- distinguishing between permeable and non-permeable beds
- It has been widely used over the last 80 years
- The SP tool measures a natural self-generated electrical current in the borehole which were termed <u>spontaneous potential</u> by Conard Schlumberger and H G Doll

SP LOG

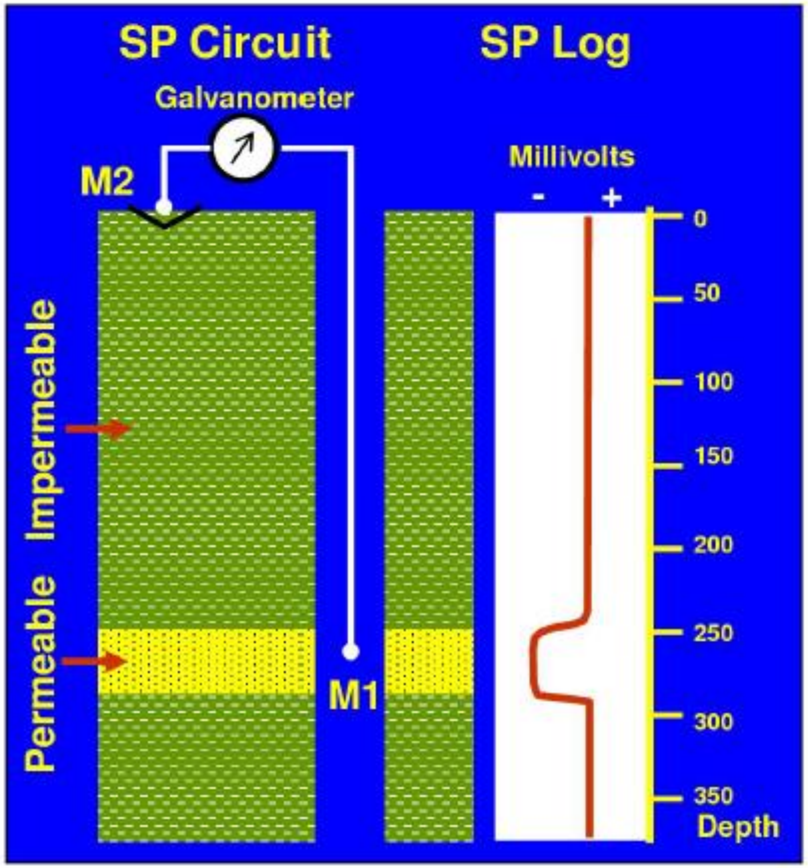
The principal uses of SP logs are:

- Correlation
- Identification of permeable beds
- Estimation of formation water resistivity R_w

SP LOG

SP Log

- SP tool records naturally occurring potentials generated by electrochemical differences between formation water and drilling fluids.
- SP tool measures the current in millivolts between an electrode in the borehole and a reference electrode at the surface
- The SP log tool operates much like a simple circuit; it basically consists of an electrode (lead) mounted on an electrically isolated bridle on the downhole tool.



SP currents in the borehole. (After Rider, 1996)

SP LOG

Principles of measurement

- Three factors are necessary to provoke an SP current:
  - A conductive fluid in the borehole (e.g., water based mud)
  - A porous and permeable bed surrounded by a shale formation
  - A difference in salinity between the borehole fluid and the formation fluid.
- For SP to work, a contrast in salinities (or ionic concentration) should exist between the mud filtrate and the formation water.
- It should be noted that the SP log has problems with oil based muds, which are non-conductive.

SP LOG

Principles of measurement

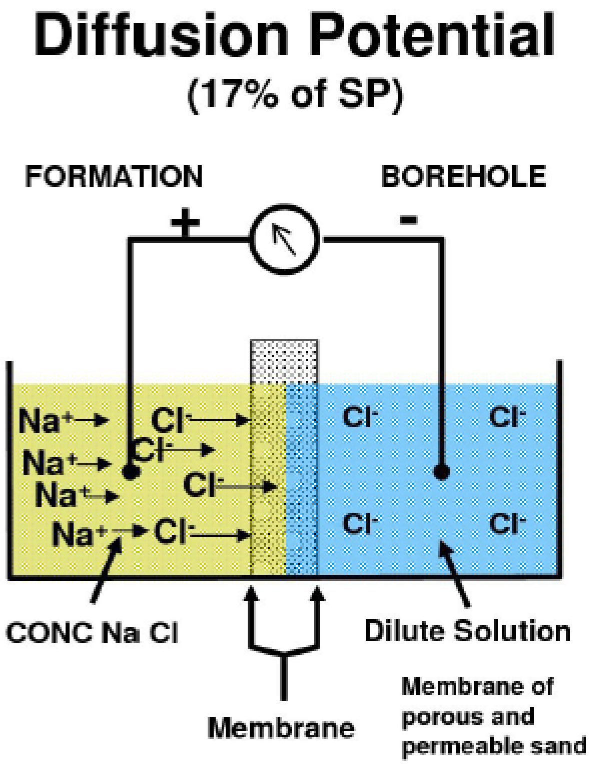
- The most common cause of salinity in oilfields is NaCl.
- SP currents are generated when two different fluids of different salinity are in contact.
- SP relies on two fundamental electrochemical principles called:
  - **diffusion potential** (or liquid junction potential) and
  - **membrane or shale potential**

SP LOG

Diffusion potential

- Diffusion potential occurs when these two solutions mix by the process of ionic diffusion in a porous medium (e.g. porous and permeable sand).

- **Cl^- ion** is more mobile than the **Na^+** ion
- These ions mix (diffuse) at unequal rates.
- Cl^- mixes quickly with more dilute solution (freshwater mud)
- Generates potential between negatively charged dilute solution with excess Cl^- and positively charged, concentrated solution (saline formation water) with excess Na^+



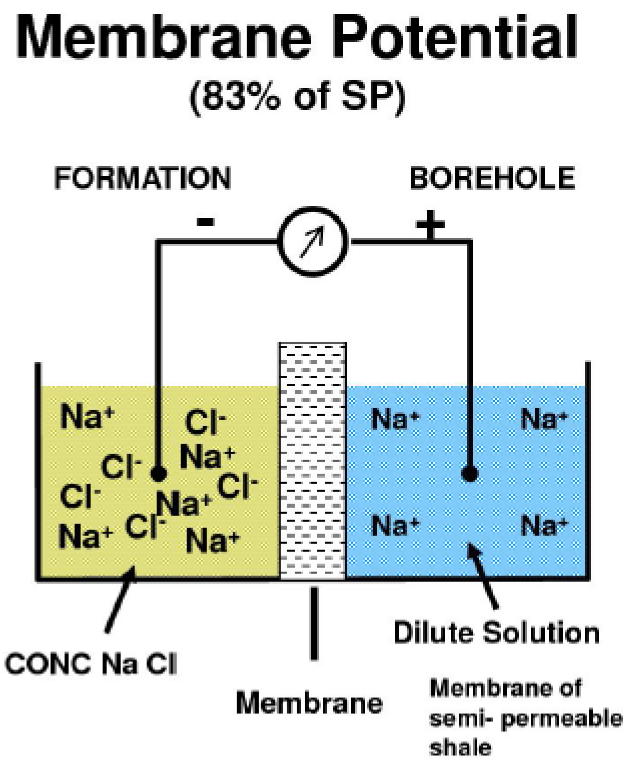
Schematic illustration of diffusion potential

SP LOG

Membrane potential

- Membrane potential is the larger of the two effects, and occurs when the same two solutions are in contact across a semi-permeable membrane, which in the case of a borehole would be shale.

- Shale contains clay minerals with a large negative surface charge.
- Shale is a selective barrier, retarding negative chloride ions (Positive ions are not retarded)
- Overbalance of **Na^+ ions** is created in the dilute solution (borehole), generating a positive charge.
- A corresponding negative charge is produced in the concentrated solution (formation).

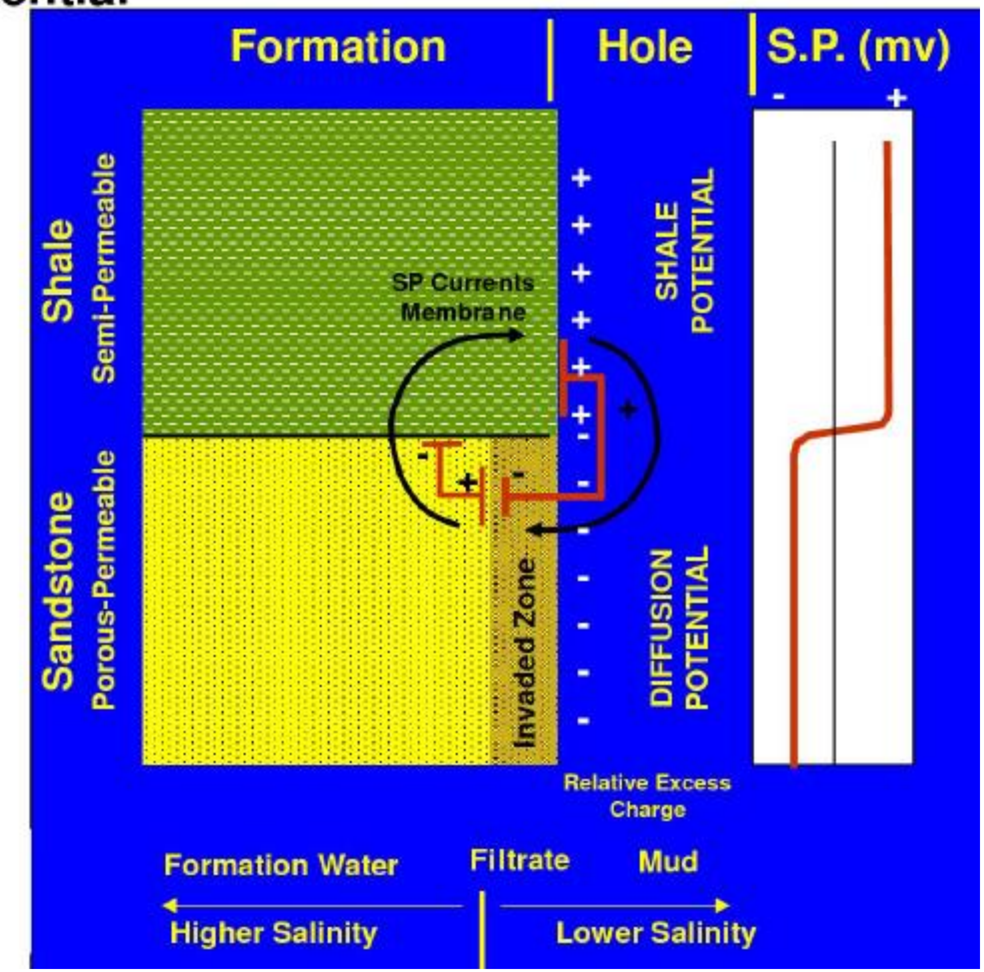


Schematic illustration of membrane potential. (After Rider, 1996)

SP LOG

Diffusion and membrane potential

- Current focused at bed junctions (change in potential).
- Changes only occur at bed boundaries
- SP's are not absolute values, but rather changes in values
- Impermeable beds have no potential change
- But very small permeability is enough to permit current flow and recording of the SP log



SP currents in the borehole. (After Rider, 1996)

SP LOG

Electrochemical potential $E_c = E_m + E_{ij}$

Membrane potential E_m and liquid junction potential E_{ij} are defined as

$$E_m = -K_3 \log \frac{a_w}{a_{mf}}$$

$$E_{ij} = -K_4 \log \frac{a_w}{a_{mf}}$$

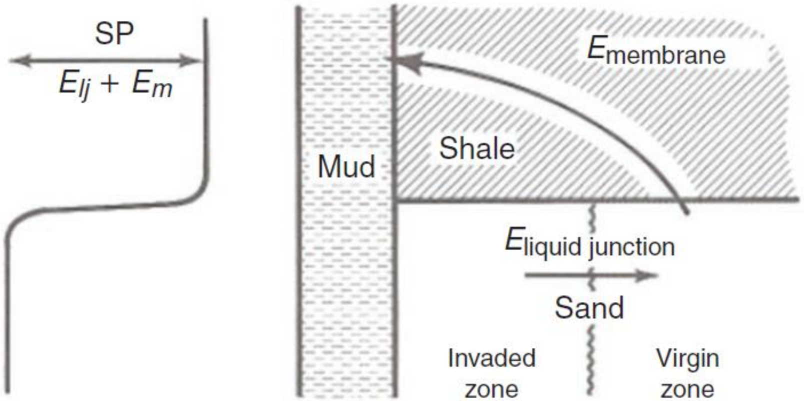
$$E_c = -K \log \frac{a_w}{a_{mf}}$$

where $K = K_3 + K_4 = 60 + 0.133\ T$

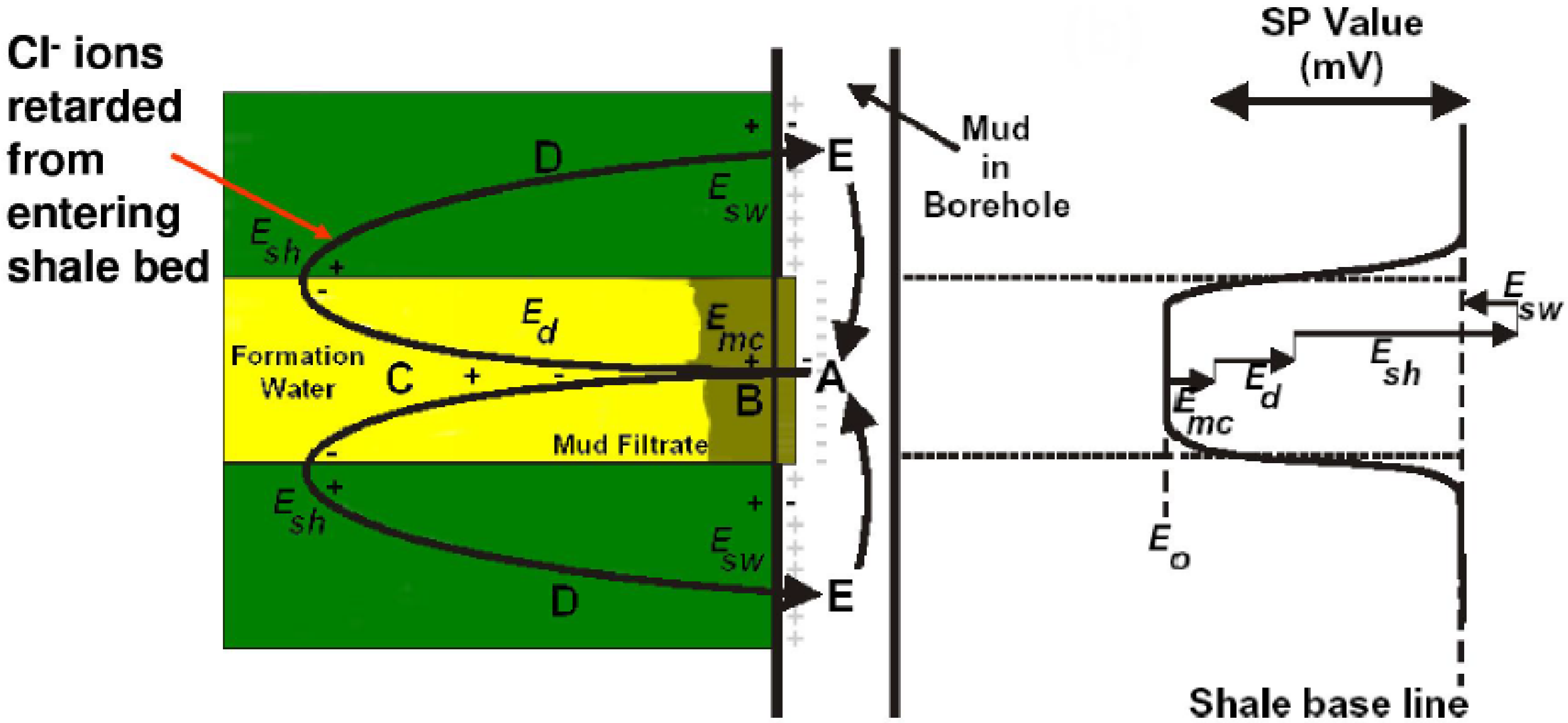
a_w = ionic activity of the formation water

a_{mf} = ionic activity of the mud-filtrate

T = temperature in ^{0}c



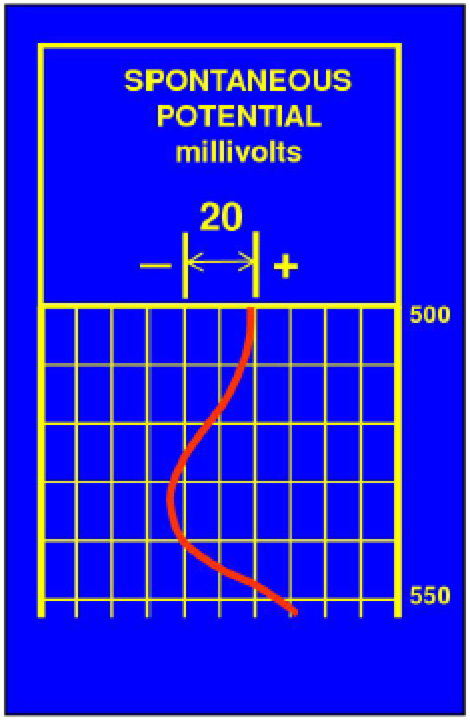
SP LOG



Combination of the electromotive components of the spontaneous potential for the formation water more saline than the mud filtrate.

SP LOG

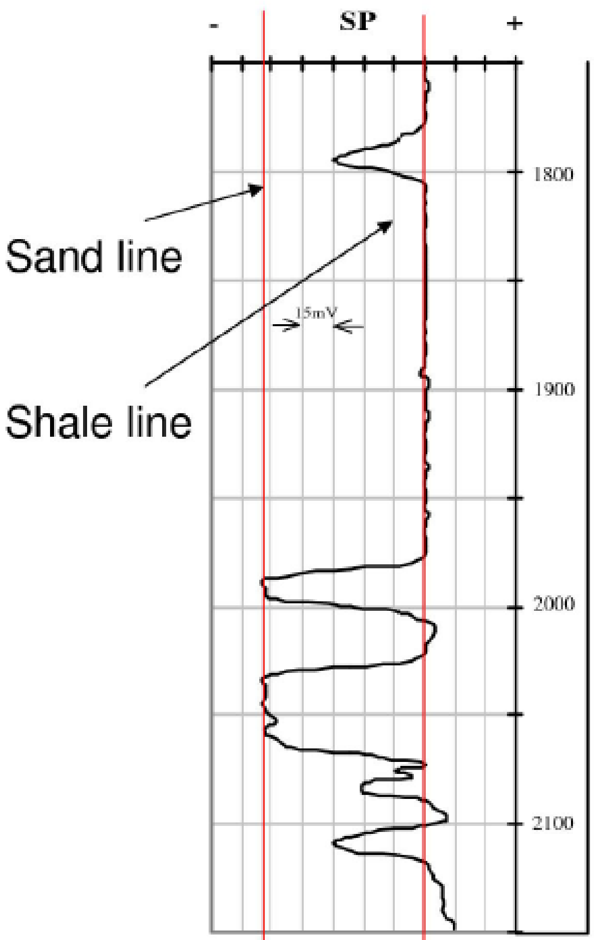
- Example of an SP log track.
- There is no absolute scale, only a relative deflection, which is either positive or negative.
- In this case, 1 division equals 10 millivolts.
- The deflection is measured from the shale baseline.

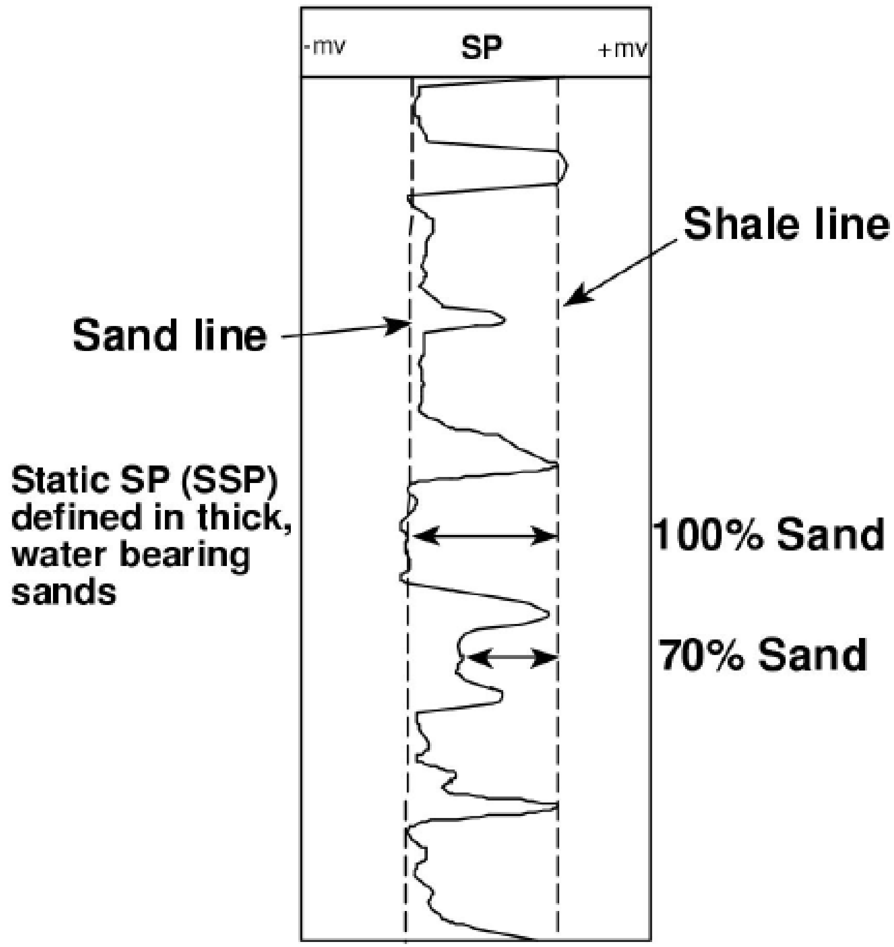


Example of an SP log track. There is no absolute scale, only a relative deflection, which is either positive or negative

SP LOG

Shale and sand baseline on a Spontaneous Potential Log





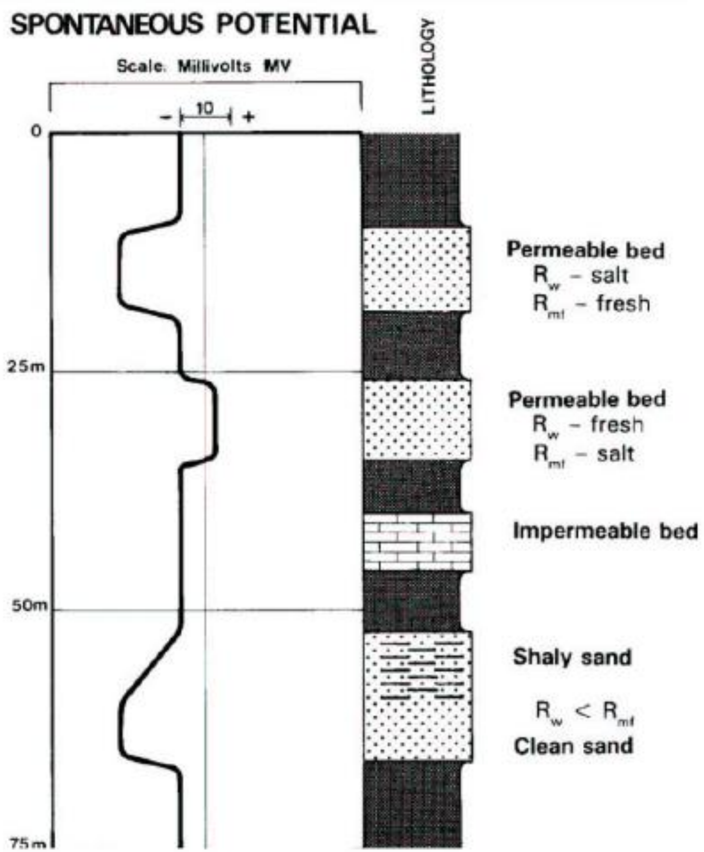
SP LOG

The SP Log

In General:

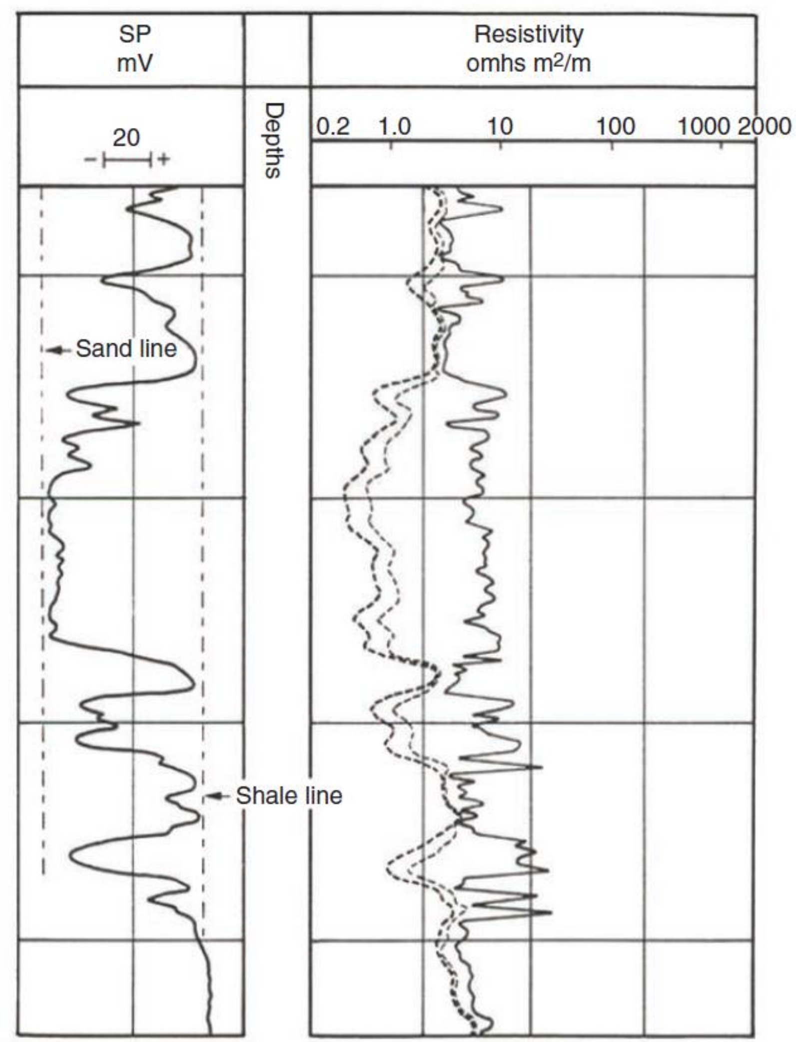
- SP Log used when contrast between formation water and mud salinities.
- Can detect permeable beds and locate their boundaries.
- Can calculate /estimate formation water resistivity
- Estimate shale volume in the formation,
- Facies indicator and for correlation

Typical responses for the SP log (After Rider, 1996)



Rw = formation water resistivity
Rmf = mud filtrate resistivity

TYPICAL SP LOG RESPONSE

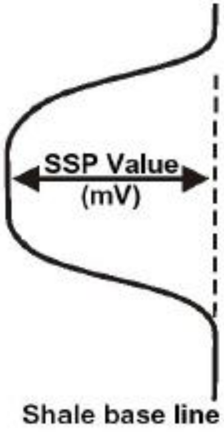


STATIC SP

- The SSP represents the maximum SP that a thick, shale-free, porous and permeable formation can have for a given ratio between Rmf and Rw.

- It should be noted that the SP curve often does not show its full deflection, and this is for many reasons, including:

- Beds are too thin
- Invasion is very deep
- Shale in the formation
- Lithological complications (high resistivity junction beds)
- Hydrocarbons are present



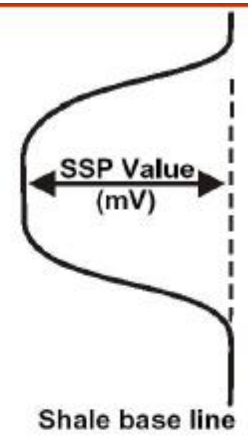
Calculation of SSP from the SP Log

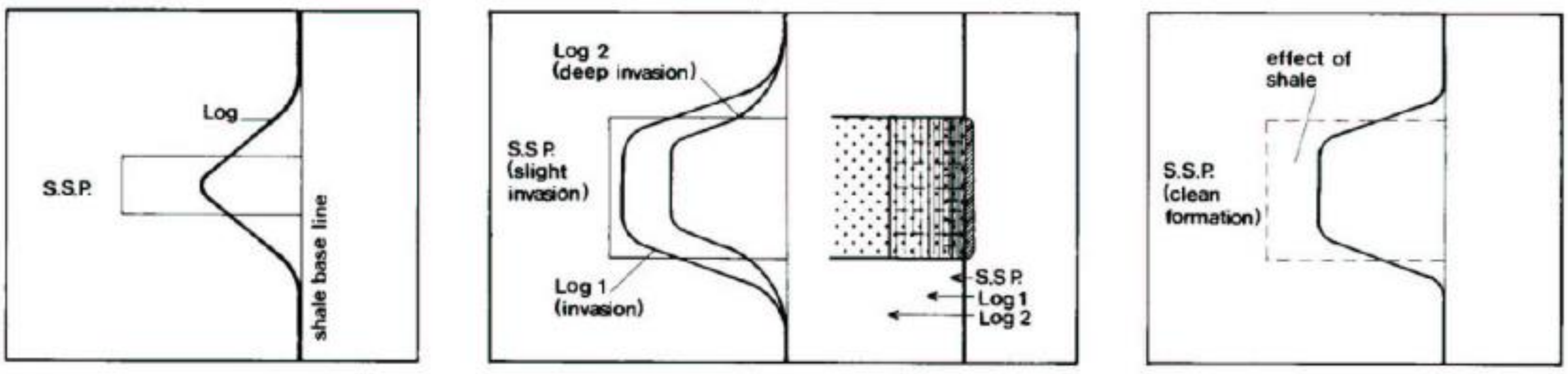
STATIC SP

Spontaneous Potential and the SP Log

Static SP (SSP)

- Beds are too thin
- Invasion is very deep
- Shale in the formation





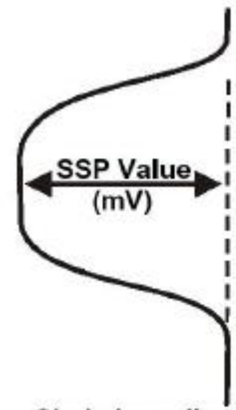
1. THIN BED 2. INVASION 3. SHALY SAND

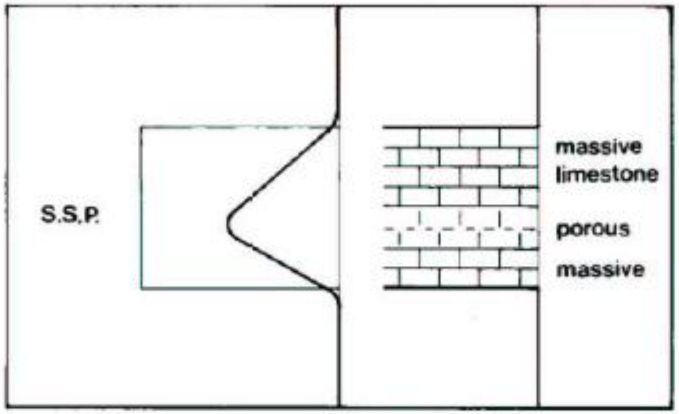
STATIC SP

Spontaneous Potential and the SP Log

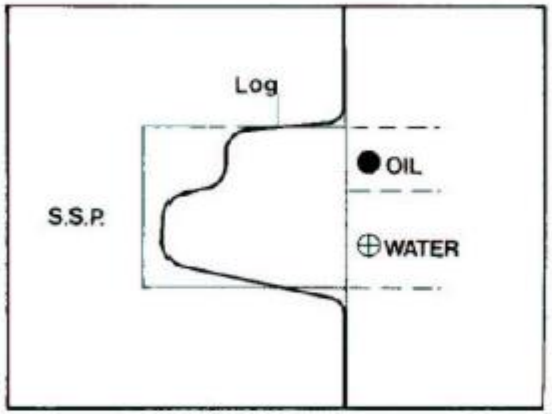
Static SP (SSP)

- Lithological complications
- Hydrocarbons are present





4. LITHOLOGY



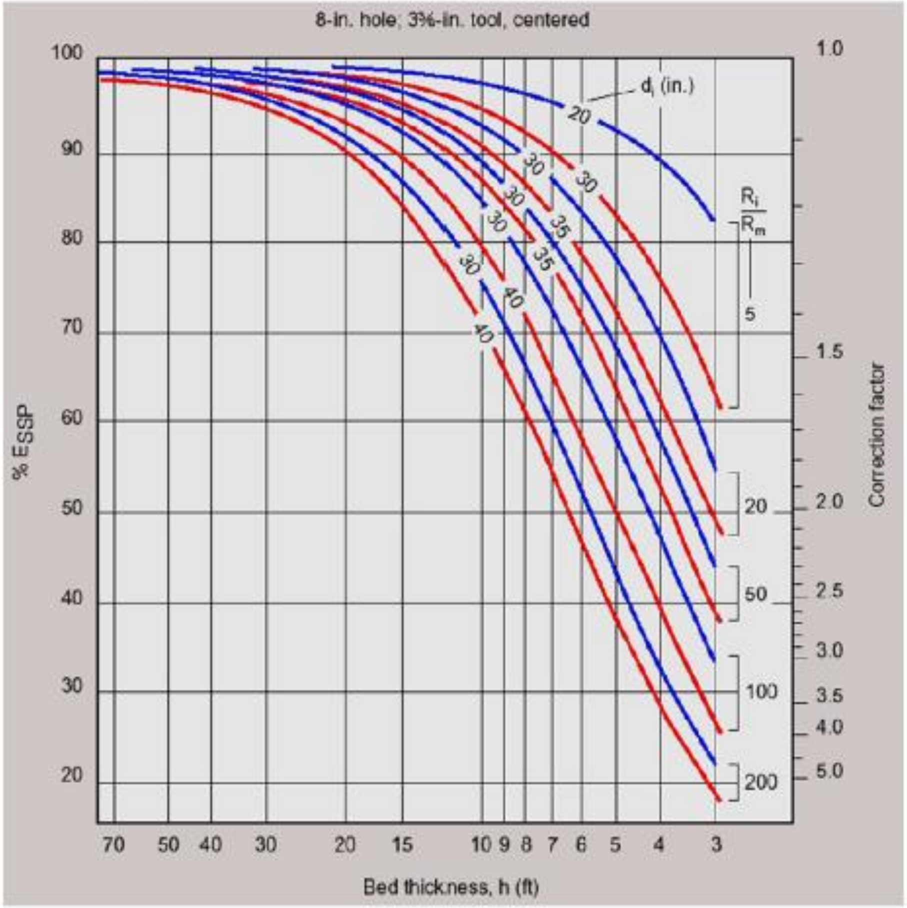
5. HYDROCARBONS

STATIC SP

Static SP (SSP)

Calculation of SSP from the SP Log

- SSP is determined by a formula or chart and is necessary for calculating accurate values of Rw and volume of shale.



Example:
SP= -90 mV in a 10ft bed
Rm= 0.5 ohm-m and
Ri (Rinvaded zone)=10 ohm-m,
both at reservoir temp.
di (invaison diameter)= 35 inch

Corrected SP or SSP=?

SUMMARY OF TERMINOLOGY

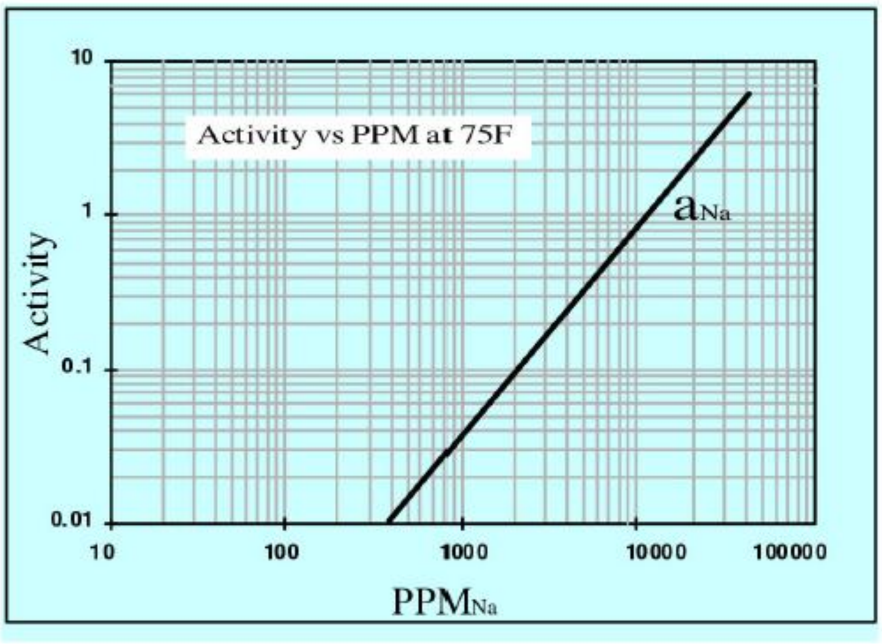
Summary of SP terms

- SSP = Static spontaneous potential
  - *Maximum deflection possible in a thick, shale-free, and water-bearing (wet) sandstone for a given Rmf/Rw. All other deflections are less*
- SP = Spontaneous Potential
  - *SP response due to the presence of thin beds and/or gas*
- PSP = pseudo-static spontaneous potential
  - *SP response if shale is present*

SP LOG

- Ionic activity depends upon valency of the cations i.e. concentration
- In chemistry, activity is a measure of how different molecules in a solution interacts with each other
- Formation water that are predominantly solutions of sodium,

$a_f = (a_{Na})_f$



R_W ESTIMATION

- The resistivity of a solution is inversely proportional to the activity below 80 kppm so:

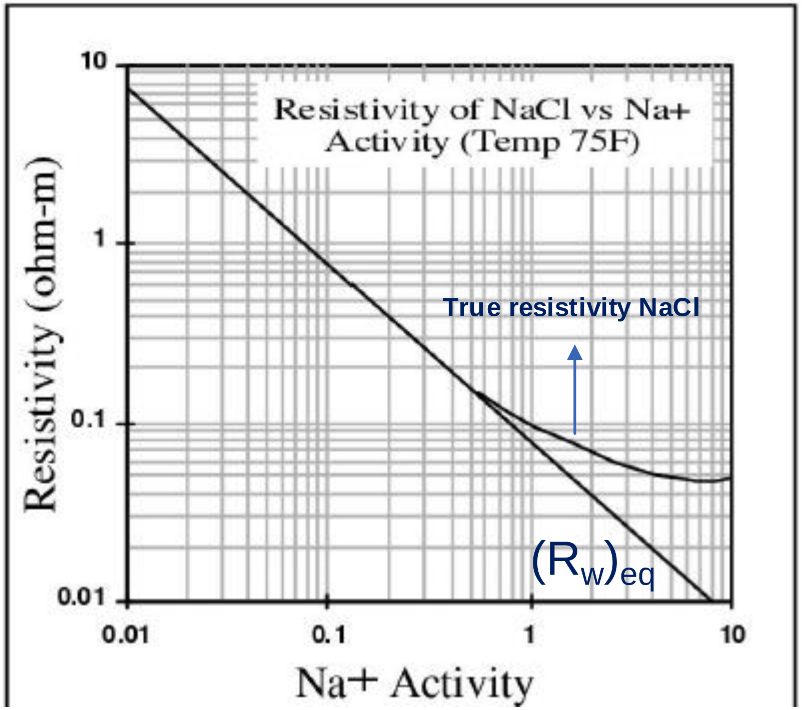
$$E_c = -K \log 10 \frac{a_w}{a_{mf}}$$

$$SSP = -K * \log_{10}\left(\frac{R_{mf}}{R_w}\right) = -K * \log_{10}\left(\frac{R_{mf_{eq}}}{R_{w_{eq}}}\right)$$

where Rweq and Rmfeq are corrected resistivities obtainable from charts.

K = 61 + (0.133 T°F)	NaCl muds
K = 65 + (0.240 T°C)	NaCl muds
K = 22 - (56 + 0.12T°F)	KCl muds
K = 25 - (49 + 0.11T°F)	KHCO3 muds

- <u>Since Rmf may be measured at the wellsite the SP log enables Rw to be determined.</u>



Relationship between ionic activity and resistivity.

R_W ESTIMATION

Procedure

1- read maximum temperature and total depth from the header

2- solve temperature gradient using surface temperature

$$TG = (Tmax - Tsur)/(TD)$$

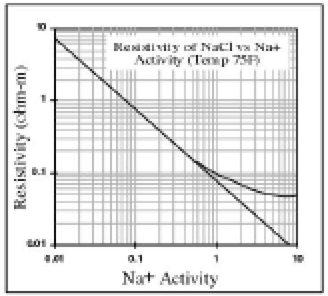
3- calculate temperature at reservoir depth

$$Tres = Tmax - ((TD - Depth)*TG)$$

4- convert Rmf to surface temperature using either Chart Gen-9 or Arps equation:

$$R2 = R1 * [(6.77 + T1)/(6.77 + T2)] \quad \textit{Fahrenheit (ohm-m)}$$

$$R2 = R1 * [(21.5 + T1)/(21.5 + T2)] \quad \textit{Centigrade (ohm-m)}$$



5-check whether *Rmf* @ *Tsur* >0.1 ohm-m?

if Yes then:

convert *Rmf* @ *Tsur* to reservoir temperature

solve for *Rmfeq* = 0.85 * *Rmf* and skip Chart SP-2

if No then:

convert *Rmf* @ *Tsur* to *Tres* using Chart Gen-9 or Arps equ.

solve for *Rmfeq* from Chart SP-2 entering *Rmf* on X-axis;

find intersection vertically with *Tres;* read *Rmfeq* horizontally from Y-axis.

R_W ESTIMATION

Procedure

6- determining shale baseline on SP log near to the reservoir interval under investigation; use GR log if available for assistance in assessing a thick shale bed

7- determine maximum deflection for cleaner permeable reservoir within interval under investigation; use GR log for assistance if available

8- calculate ESSP = clean_baseline - shale_baseline

9- solve for Rweq using either direct solution from equation:

$$R_{w_{eq}} = R_{mf_{eq}} \times 10^{E_{SSP}/K}$$

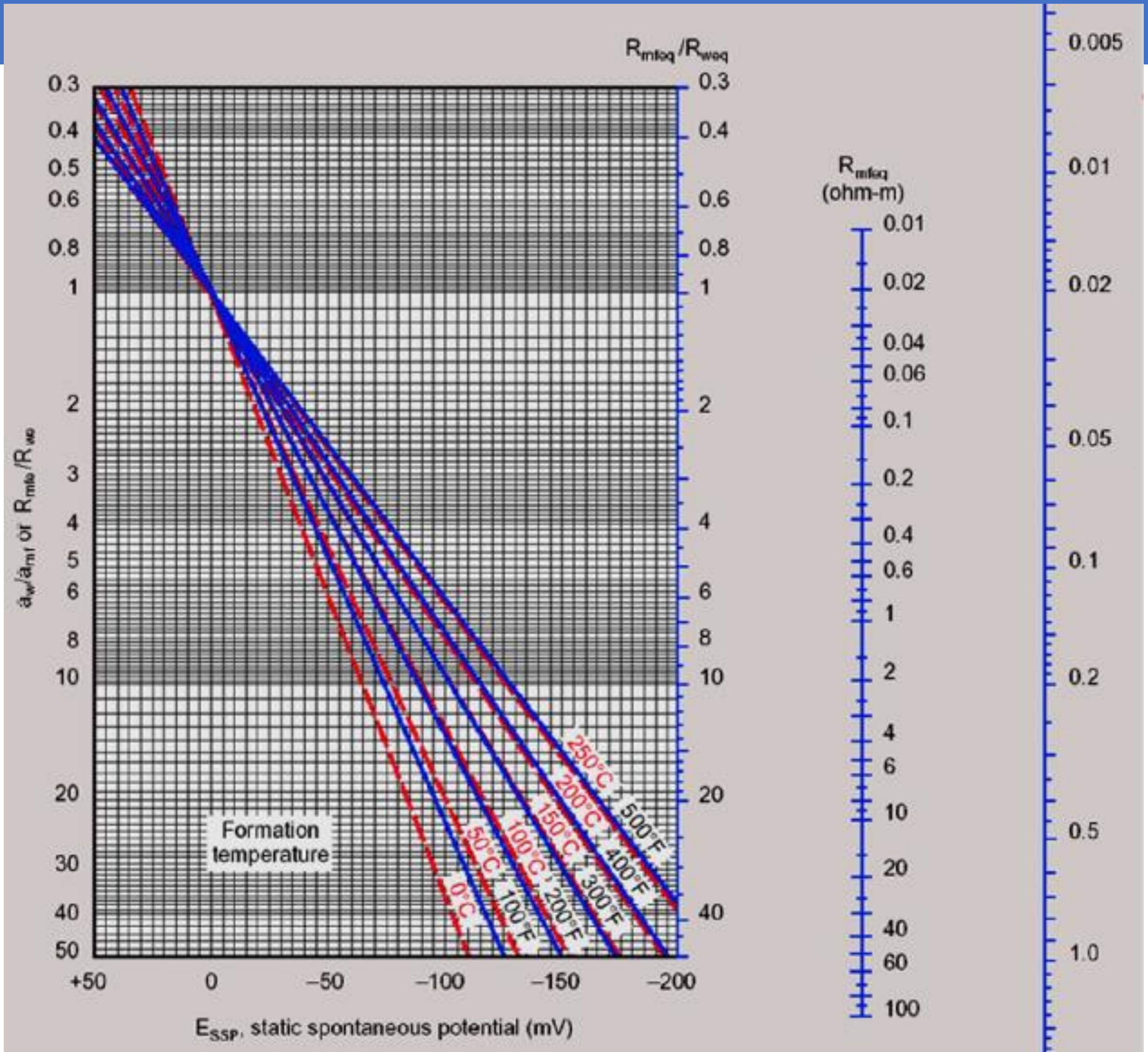
or Chart SP-1

solve for ratio Rmfeq/Rweq using ESSP on SP-1

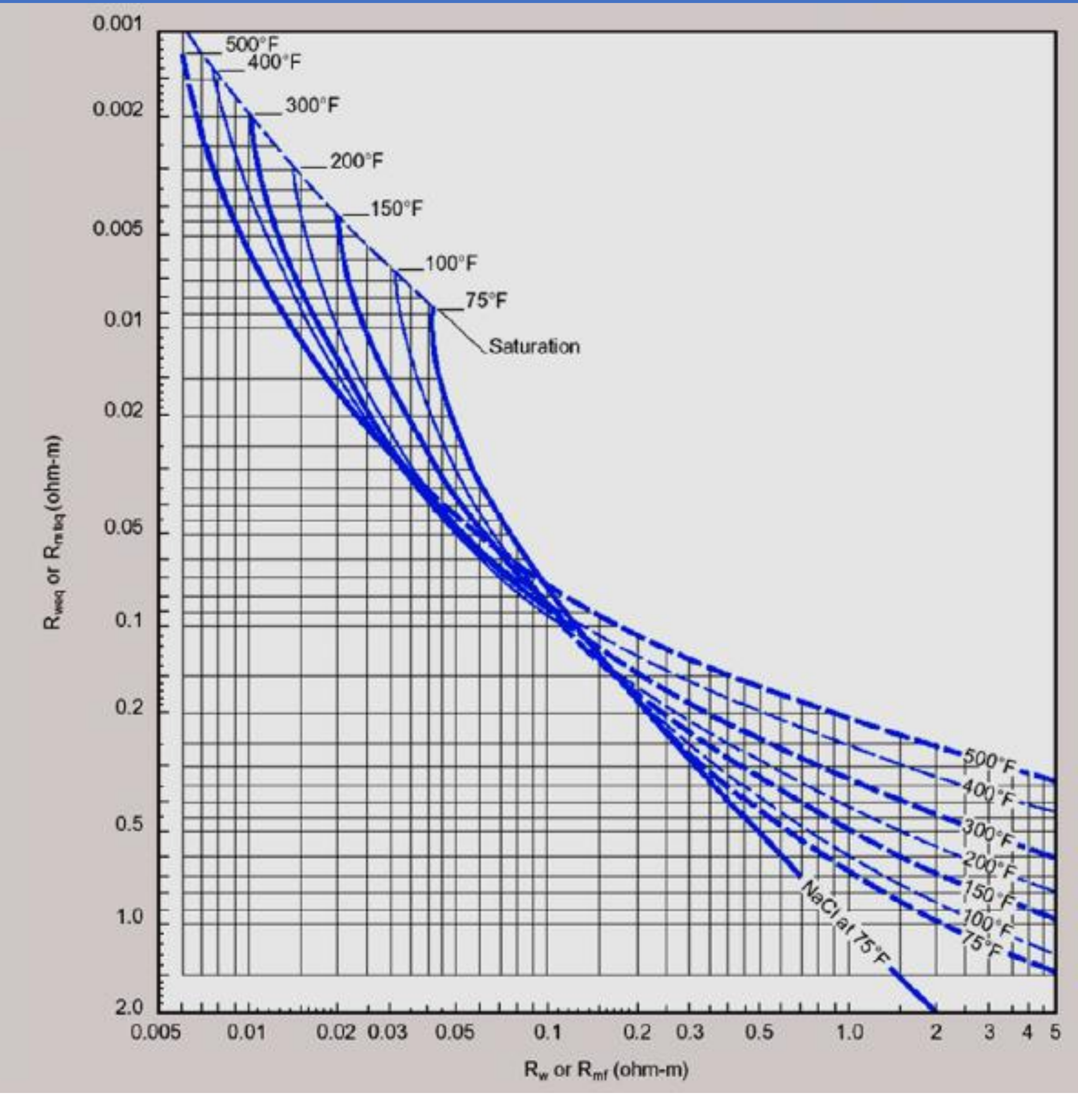
solve for Rweq using Chart SP-1 by extrapolation from Rmfeq/Rweq ratio on Y-axis of chart through nomograph of Rmfeq value until intersection of Rweq nomograph

solve for Rw by entering Y-axis of Chart SP-2 with value of Rweq; move horizontally until intersection with reservoir temperature interpolation; move vertically to X-axis and read Rw.

R_W ESTIMATION – SP1 CHART



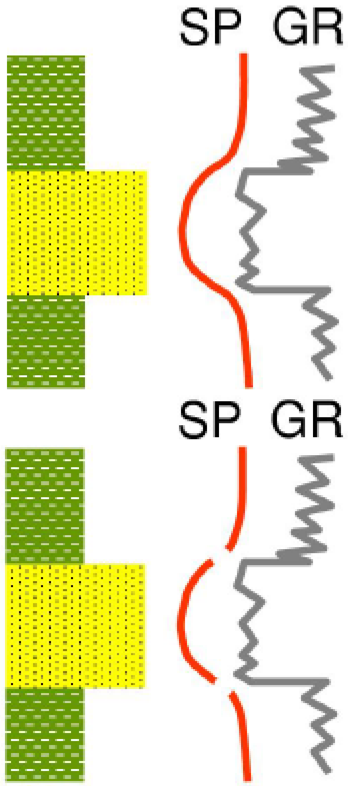
R_W ESTIMATION – SP2 CHART



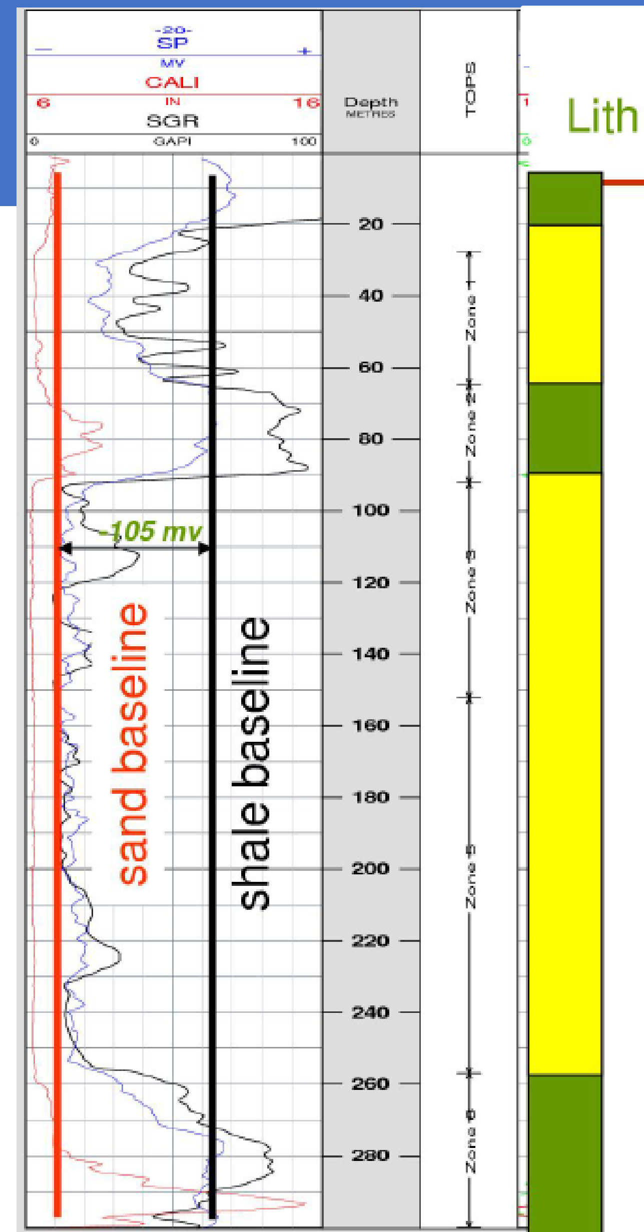
BED BOUNDARIES

Bed boundaries and bed thickness

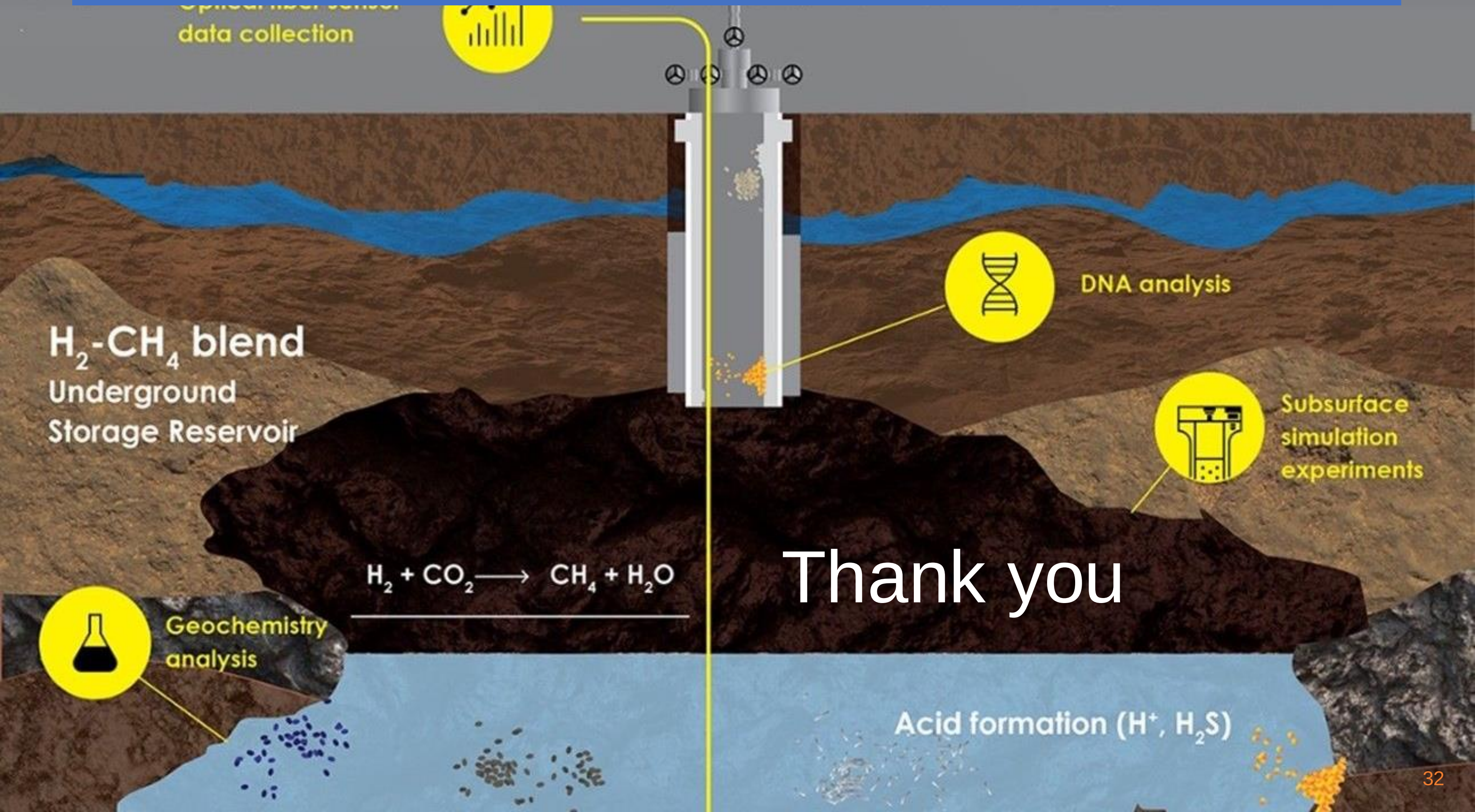
- The SP log is not known for resolving bed boundaries well, because the sharpness of the bed boundary is often poor
- A better log for resolving bed boundaries would be the gamma ray
- However, bed boundaries can be estimated from the SP, if the boundary is drawn from the point of maximum curve slope (rate of maximum change).
- Bed thickness correction charts can also be used



SP LOG - INTERPRETATION



END OF LECTURE



Thank you