



भारतीय प्रौद्योगिकी
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**INDIAN INSTITUTE
OF TECHNOLOGY**
(INDIAN SCHOOL OF MINES)
DHANBAD

GPC510 - Well logging

Semester - Winter 2024; Lecture - 11

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TEACHING OUTLINE

Week 6

[Tutorial 15](#) – Self potential tool and application

AGENDA

- Spontaneous potential log
- Measurement principle
- Application

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 spontaneous potential by Conard Schlumberger and H G Doll

SP LOG

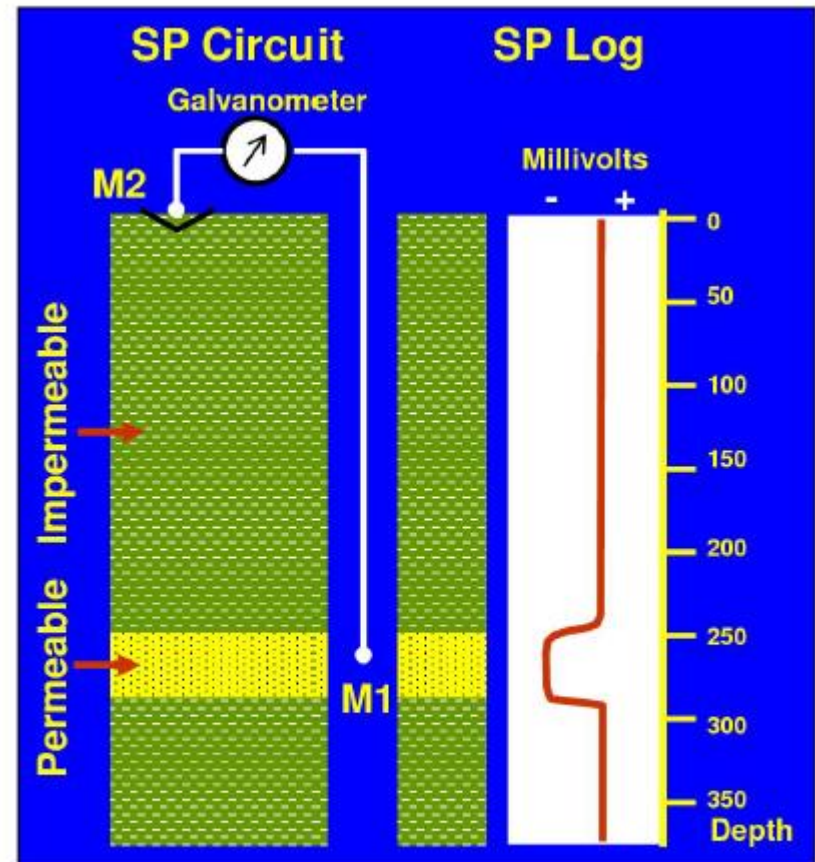
The principal uses of SP logs are:

- 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**

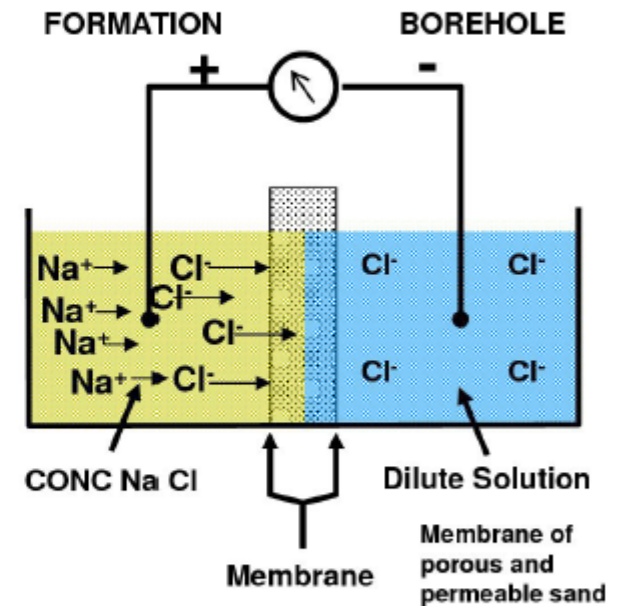
SP LOG

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⁺

Diffusion Potential

(17% of SP)



Schematic illustration of diffusion potential

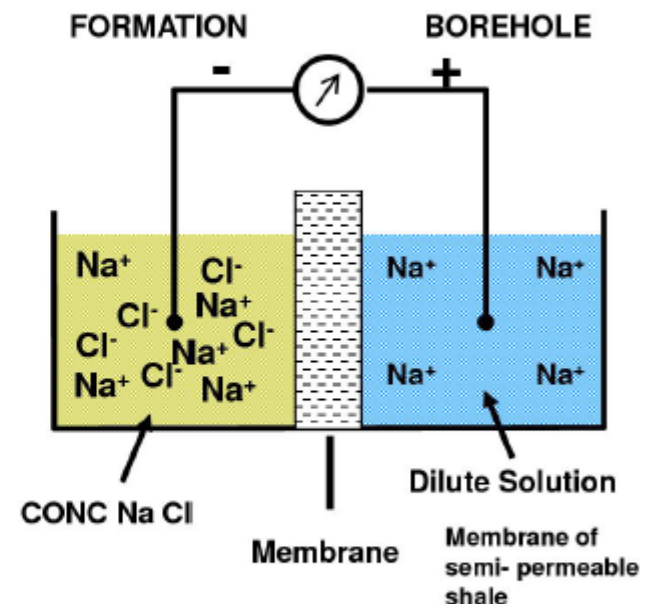
SP LOG

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).

Membrane Potential

(83% of SP)



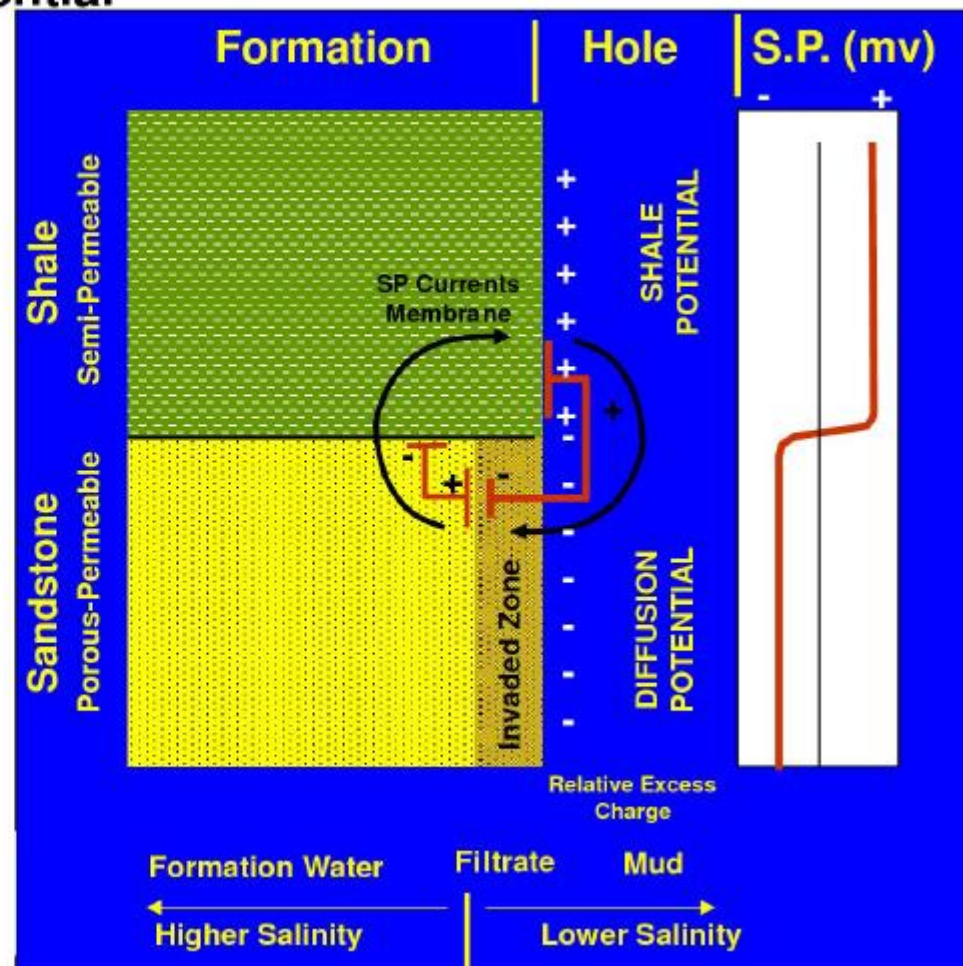
Schematic illustration of membrane potential. (After Rider, 1996)

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

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

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

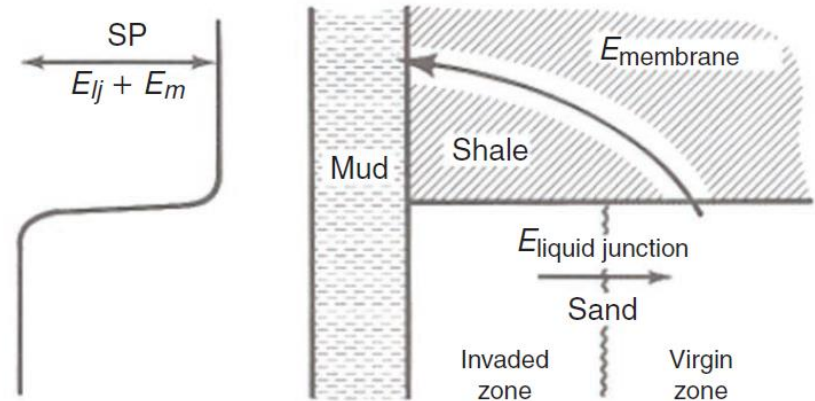
$$E_c = -K \log \frac{a_w}{a_{mf}}$$

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

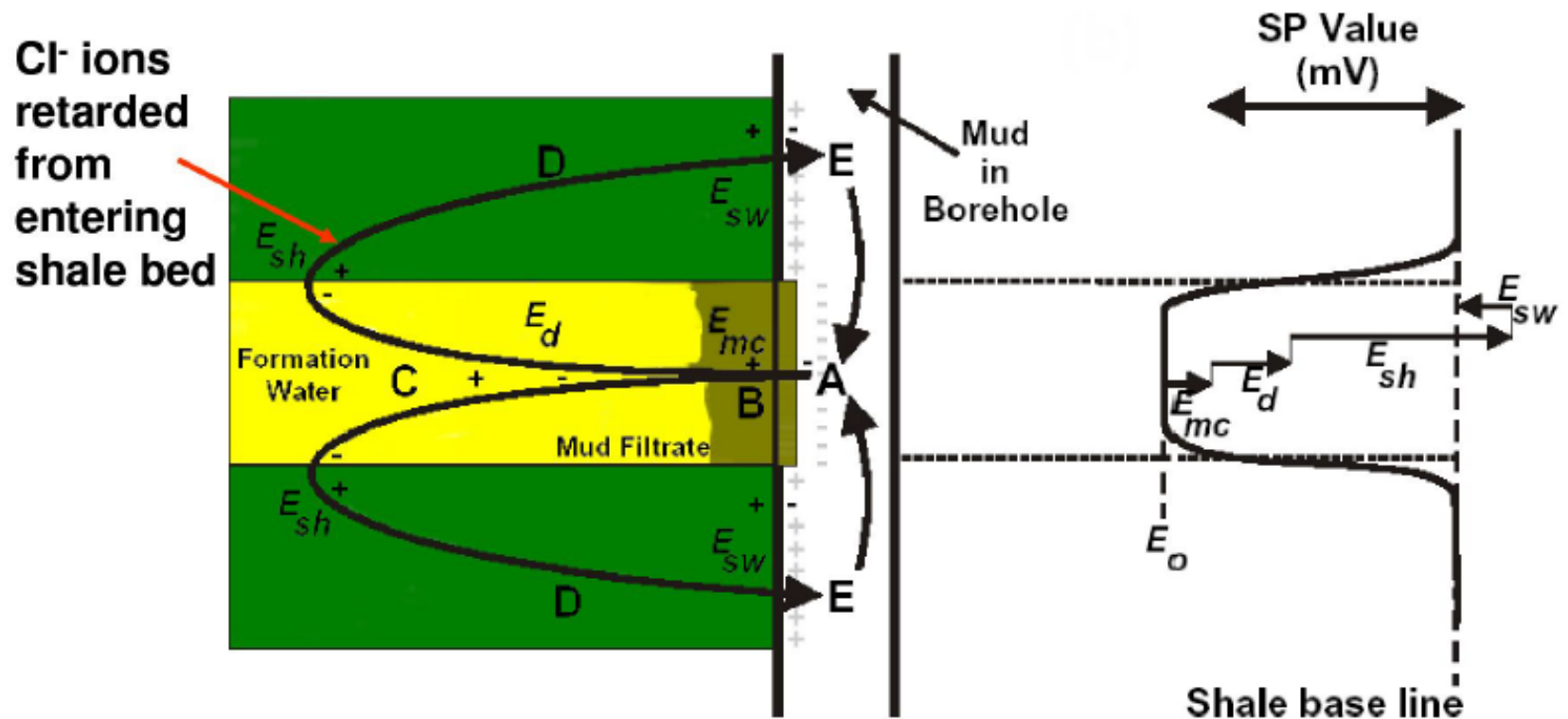
a_w = ionic activity of the formation water

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

T = temperature in $^{\circ}\text{C}$



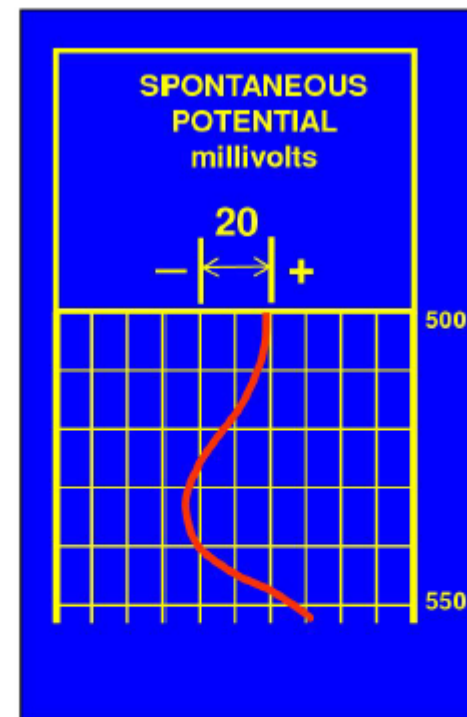
SP LOG



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

SP LOG

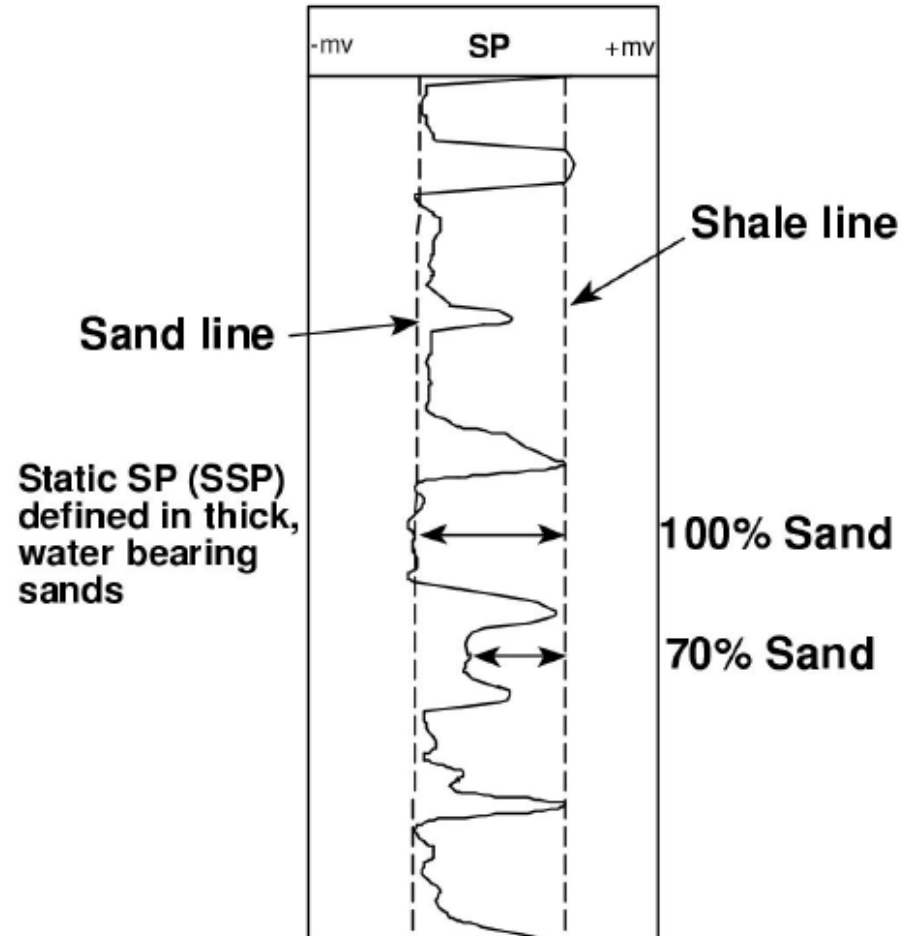
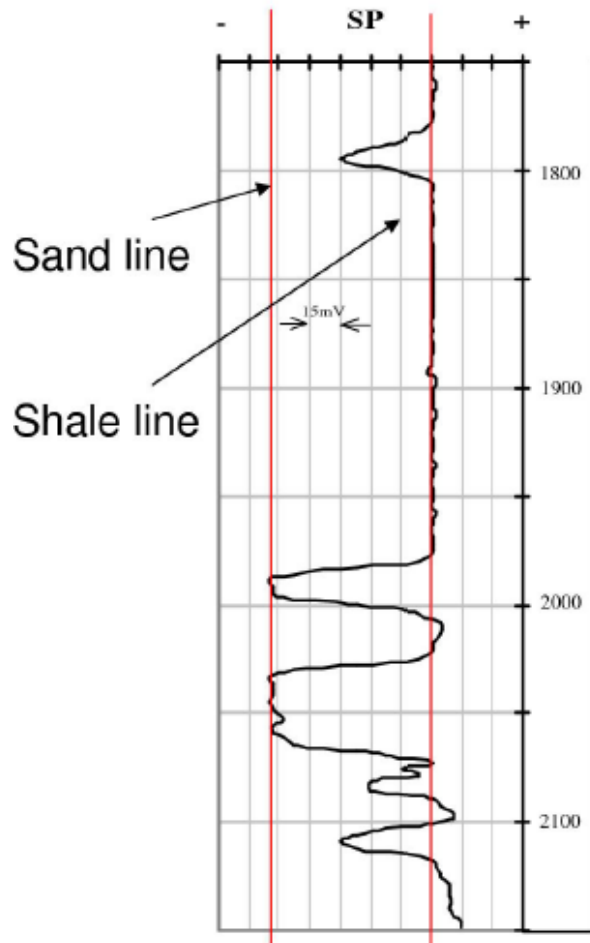
- **Example of an SP log track.**
- **There is no absolute scale, only a relative deflection, which is either positive or negative.**
- **In this case, 1 division equals 10 millivolts.**
- **The deflection is measured from the shale baseline.**



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



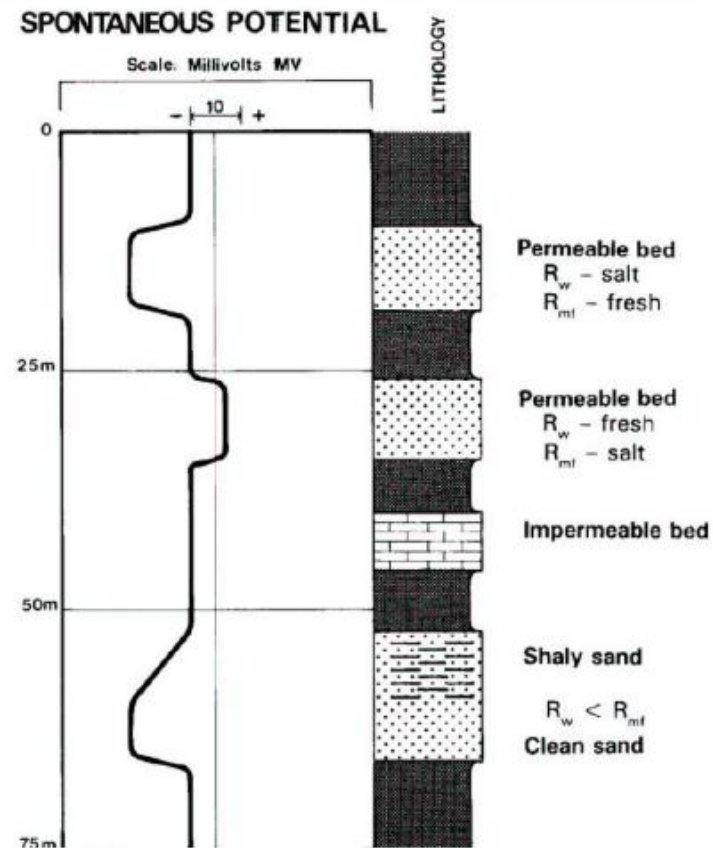
SP LOG

The SP Log

In General:

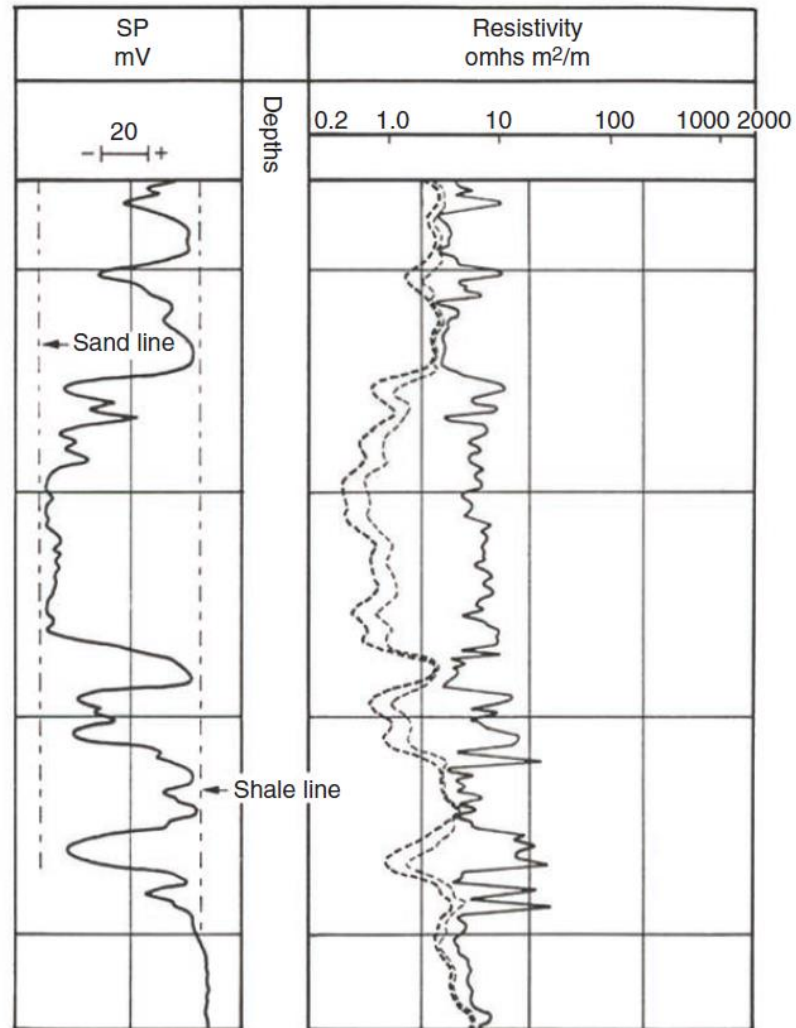
- SP Log used when contrast between formation water and mud salinities.
- Can detect permeable beds and locate their boundaries.
- Can calculate /estimate formation water resistivity
- Estimate shale volume in the formation,
- Facies indicator and for correlation

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



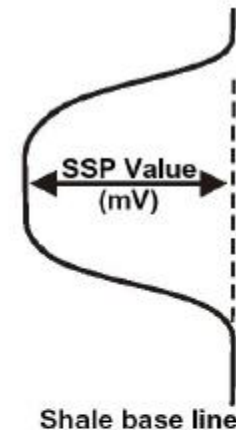
R_w = formation water resistivity
 R_{mf} = mud filtrate resistivity

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 R_{mf} and R_w .
- 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



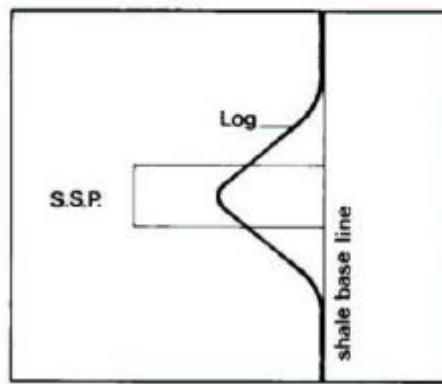
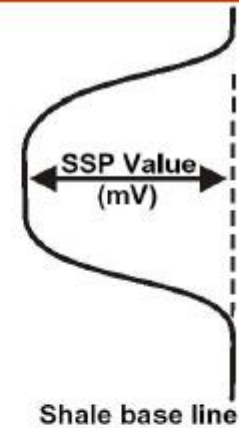
Calculation of SSP from the SP Log

STATIC SP

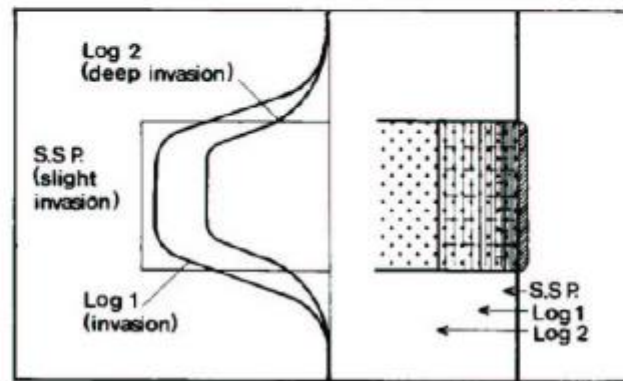
Spontaneous Potential and the SP Log

Static SP (SSP)

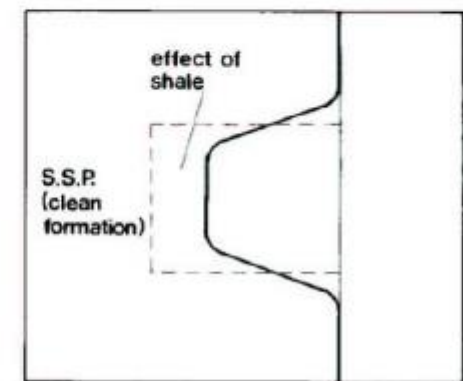
- Beds are too thin
- Invasion is very deep
- Shale in the formation



1. THIN BED



2. INVASION



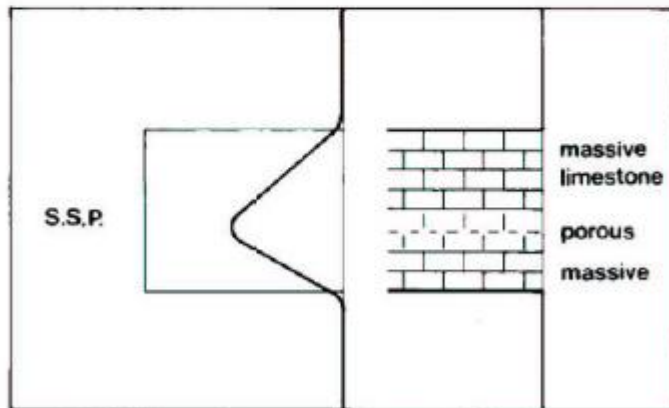
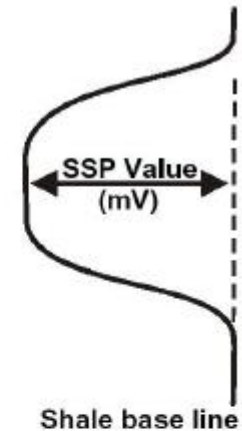
3. SHALY SAND

STATIC SP

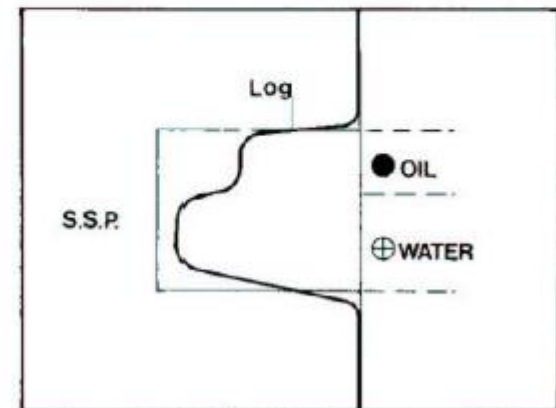
Spontaneous Potential and the SP Log

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 R_w and volume of shale.

Example:

SP= -90 mV in a 10ft bed

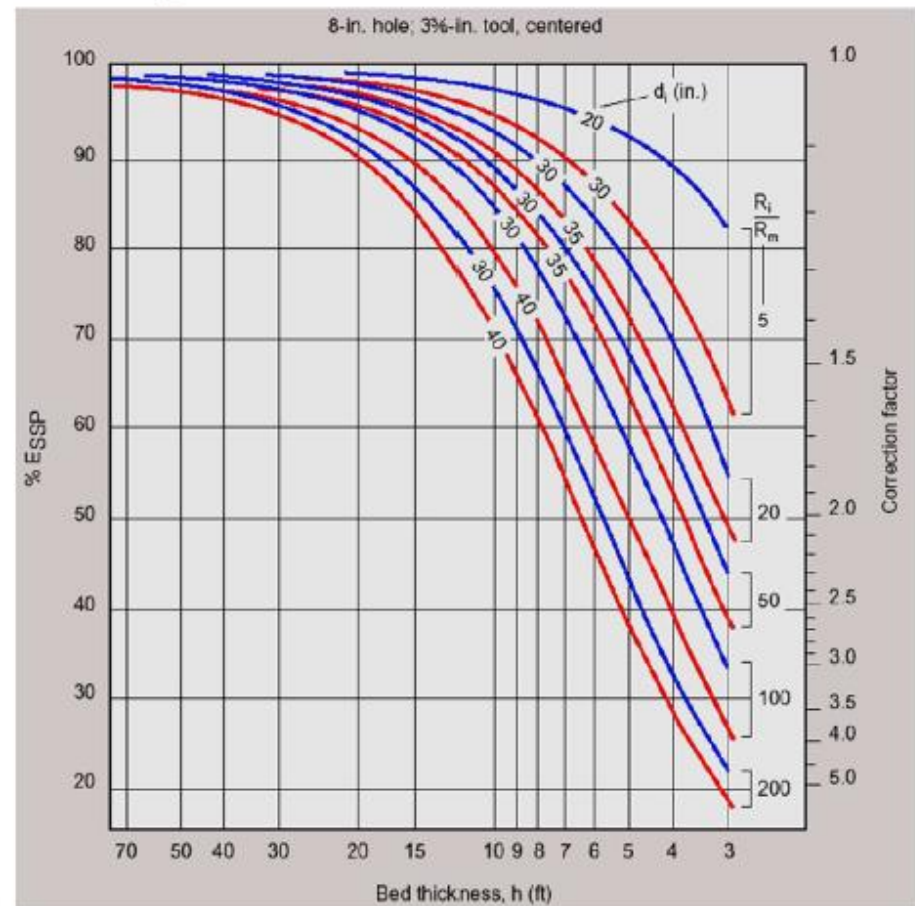
$R_m = 0.5$ ohm-m and

R_i (Rinvaded zone)=10 ohm-m,

both at reservoir temp.

d_i (invasion diameter)= 35 inch

Corrected SP or SSP=?



SUMMARY OF TERMINOLOGY

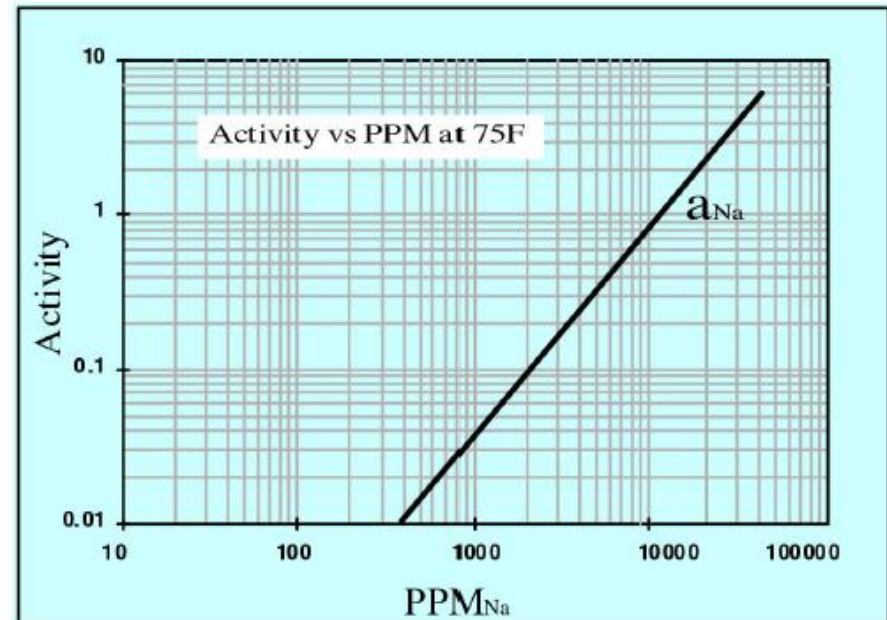
Summary of SP terms

- SSP = Static spontaneous potential
 - *Maximum deflection possible in a thick, shale-free, and water-bearing (wet) sandstone for a given R_{mf}/R_w . 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:

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



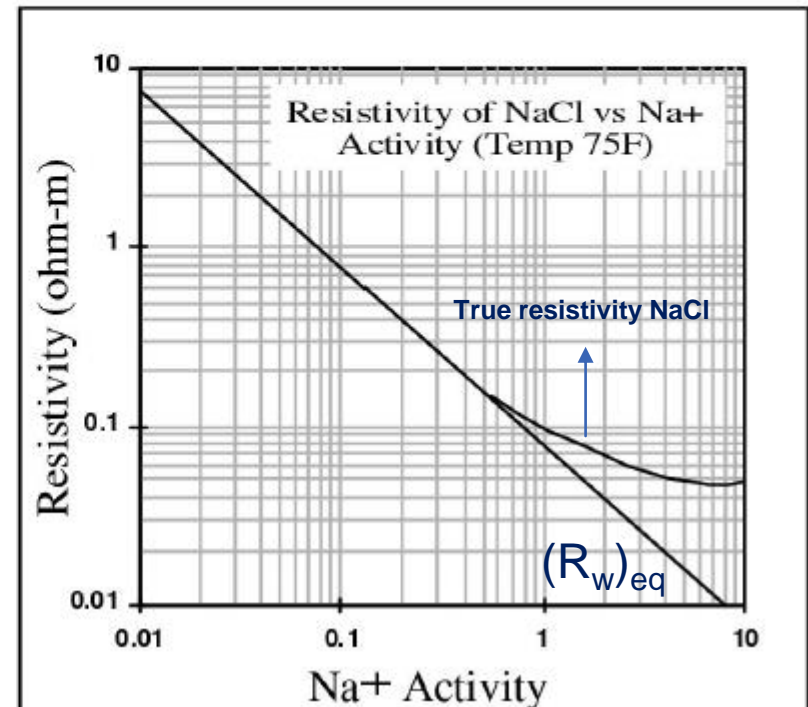
$$SSP = -K * \log_{10} \left(\frac{R_{mf}}{R_w} \right) = -K * \log_{10} \left(\frac{R_{mf_{eq}}}{R_{w_{eq}}} \right)$$

where R_weq and R_mfeq 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)	KHCO ₃ muds

- Since R_{mf} may be measured at the wellsite the SP log enables R_w to be determined.

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

$$TG = (T_{max} - T_{sur}) / (TD)$$

- 3- calculate temperature at reservoir depth

$$T_{res} = T_{max} - ((TD - Depth) * TG)$$

- 4- convert R_{mf} to surface temperature using either Chart Gen-9 or Arps equation:

$$R_2 = R_1 * [(6.77 + T_1) / (6.77 + T_2)]$$

Fahrenheit (ohm-m)

$$R_2 = R_1 * [(21.5 + T_1) / (21.5 + T_2)]$$

Centigrade (ohm-m)

- 5-check whether R_{mf} @ $T_{sur} > 0.1$ ohm-m?

if Yes then:

convert R_{mf} @ T_{sur} to reservoir temperature

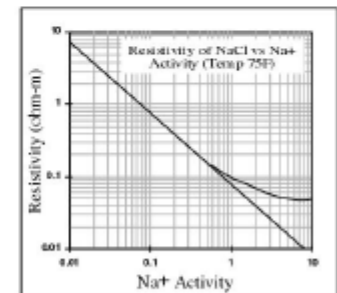
solve for $R_{mf_{eq}} = 0.85 * R_{mf}$ and skip Chart SP-2

if No then:

convert R_{mf} @ T_{sur} to T_{res} using Chart Gen-9 or Arps equ.

solve for $R_{mf_{eq}}$ from [Chart SP-2](#) entering R_{mf} on X-axis;

find intersection vertically with T_{res} ; read $R_{mf_{eq}}$ horizontally from Y-axis.



R_w ESTIMATION

Procedure

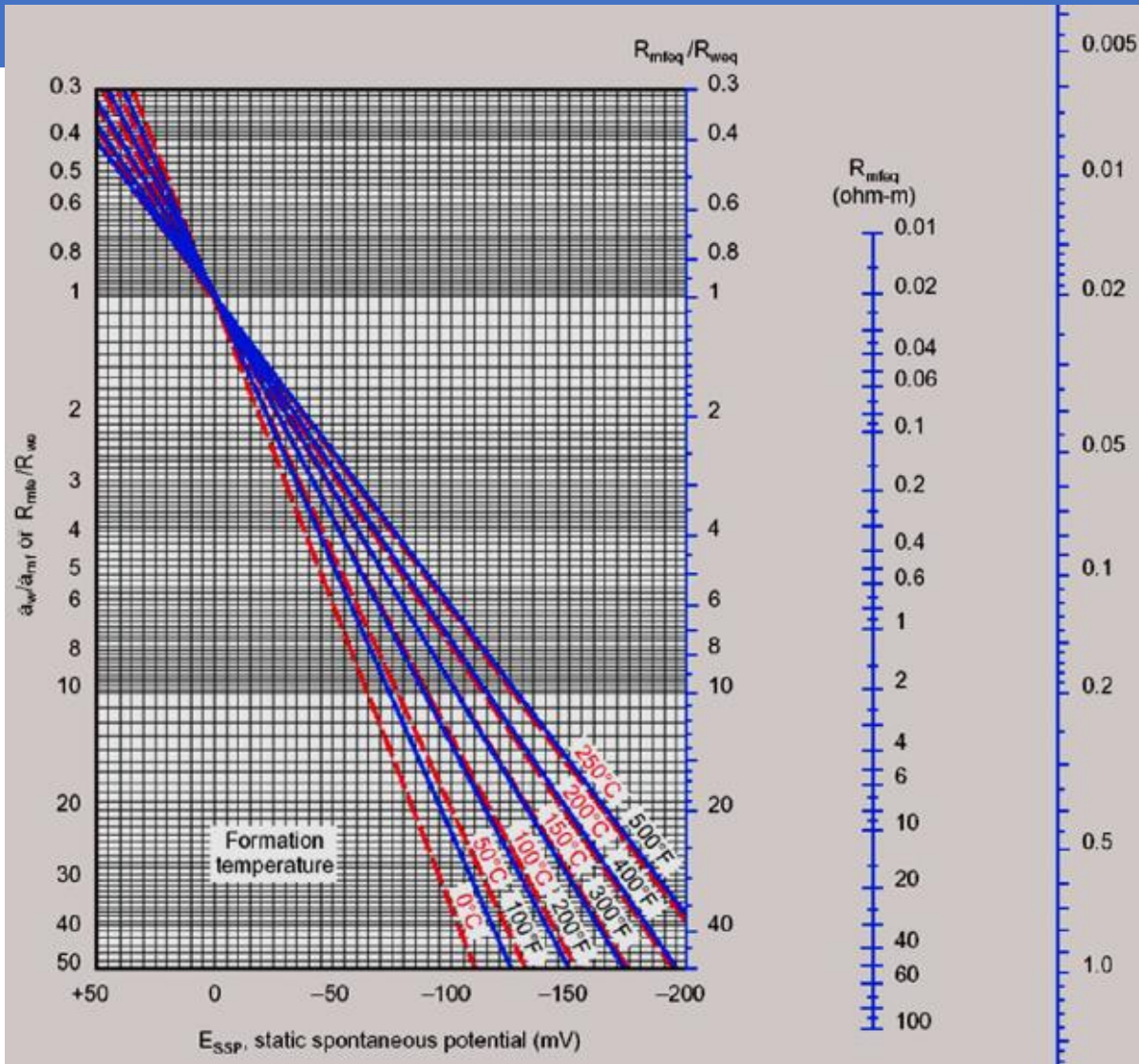
- 6- determining shale baseline on SP log near to the reservoir interval under investigation; use GR log if available for assistance in assessing a thick shale bed
- 7- determine maximum deflection for cleaner permeable reservoir within interval under investigation; use GR log for assistance if available
- 8- calculate $ESSP = \text{clean_baseline} - \text{shale_baseline}$
- 9- solve for R_w using either direct solution from equation:

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

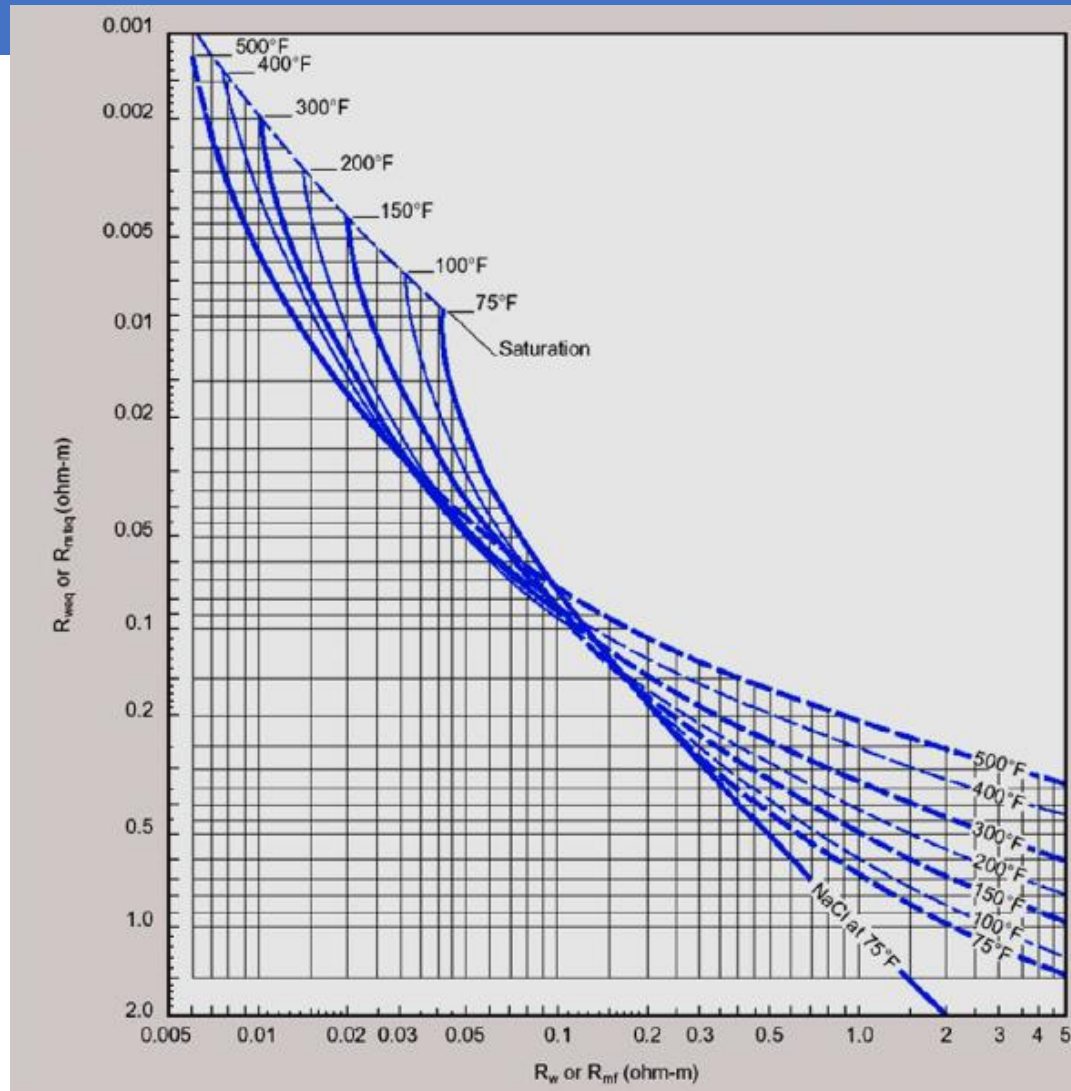
or [Chart SP-1](#)

- solve for ratio R_{mfeq}/R_w using ESSP on SP-1
- solve for R_w using Chart SP-1 by extrapolation from R_{mfeq}/R_w ratio on Y-axis of chart through nomograph of R_{mfeq} value until intersection of R_w nomograph
- solve for R_w by entering Y-axis of Chart SP-2 with value of R_w; move horizontally until intersection with reservoir temperature interpolation; move vertically to X-axis and read R_w.

R_w ESTIMATION – SP1 CHART



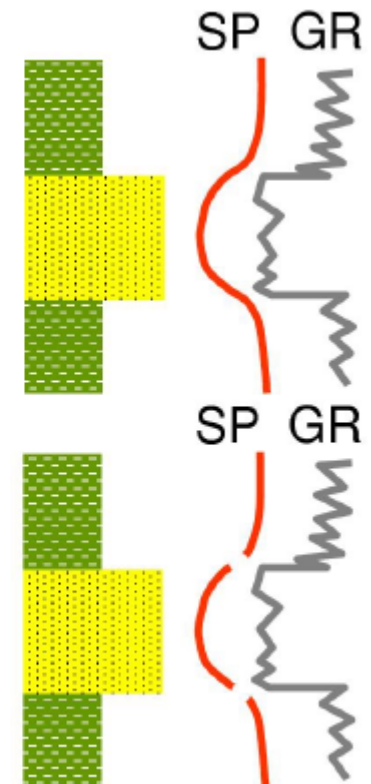
R_w ESTIMATION – SP2 CHART



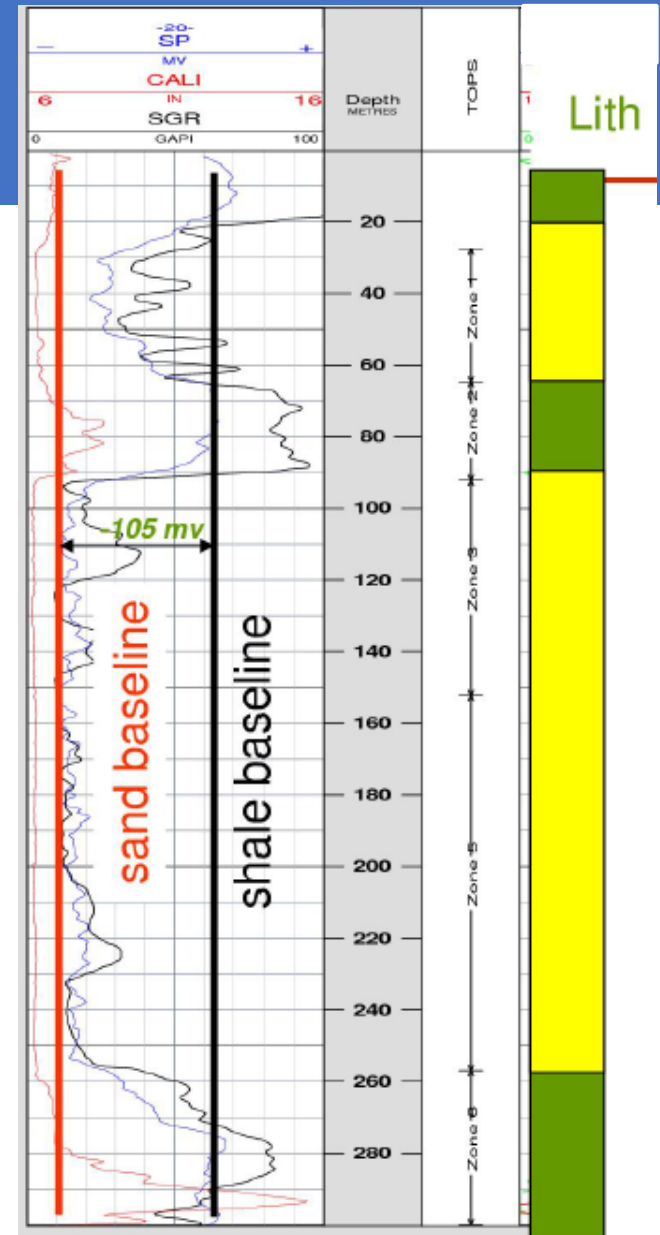
BED BOUNDARIES

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

data collection



H_2 - CH_4 blend
Underground
Storage Reservoir



Geochemistry
analysis



DNA analysis



Subsurface
simulation
experiments

Thank you

Acid formation (H^+ , H_2S)