THE SPONTANEOUS POTENTIAL LOG

- The spontaneous potential (SP) log was one of the earliest electric log and has a significant role in well log interpretation.
- The SP log used to:

I. Detect permeable beds.
II. Determine formation water resistivity R_w.
III. Determine the volume of the shale in permeable beds.
IV. Correlate between the wells.

2 Electrodes

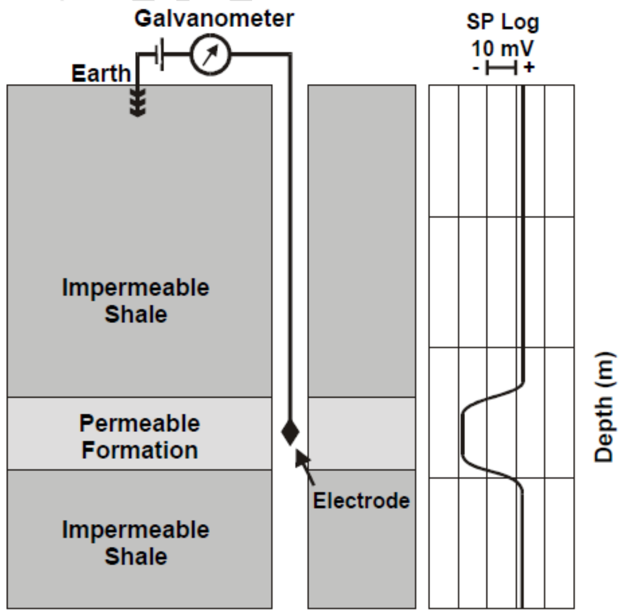
✓ Electrode A moveable

Move Up or Down in the borehole filled with conductive mud.

✓ Electrode B Fixed

Placed in the mud pit at the surface.

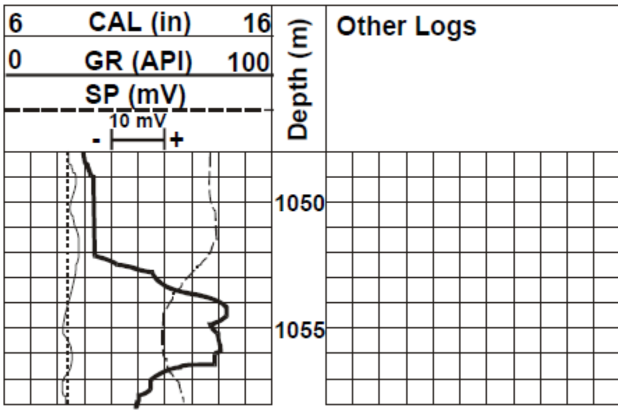
✓ Galvanometer



- The SP log response created by direct electric current (DC) voltage differences between the potential of a moveable electrode in the well bore and the potential of a fixed electrode at the surface.
- Differences between the potentials of electrode A and electrode B arising mainly from ***electrochemical factors*** within the borehole.

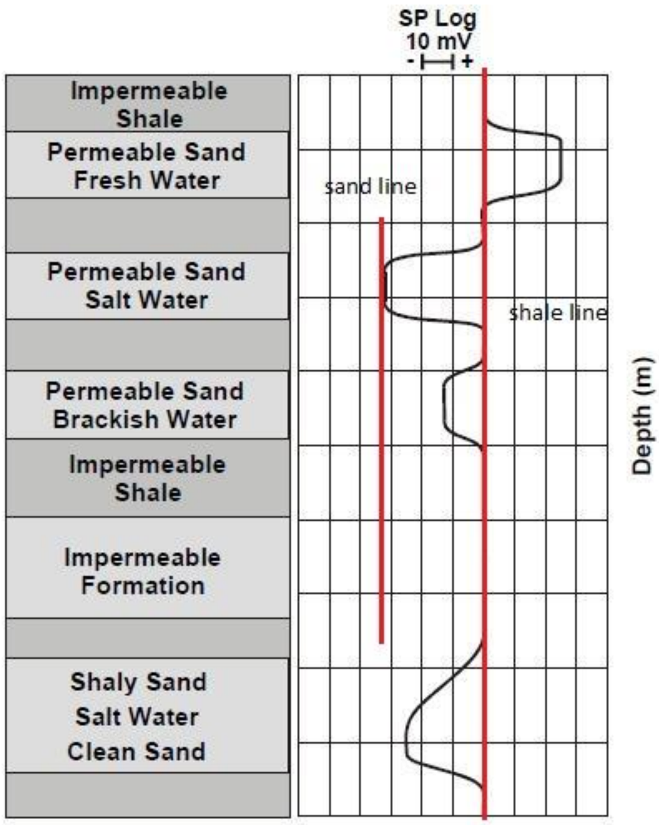
- These ***electrochemical factors*** are brought by differences in salinities between mud filtrate resistivity (R_{mf}) and formation waters resistivity (R_w) in permeable beds.
- There are three requirements for the existence of an SP current:

✓ A conductive borehole fluid (i.e., a water based mud).
✓ A porous and permeable bed·
✓ A difference in salinity between the borehole mud and the formation water.

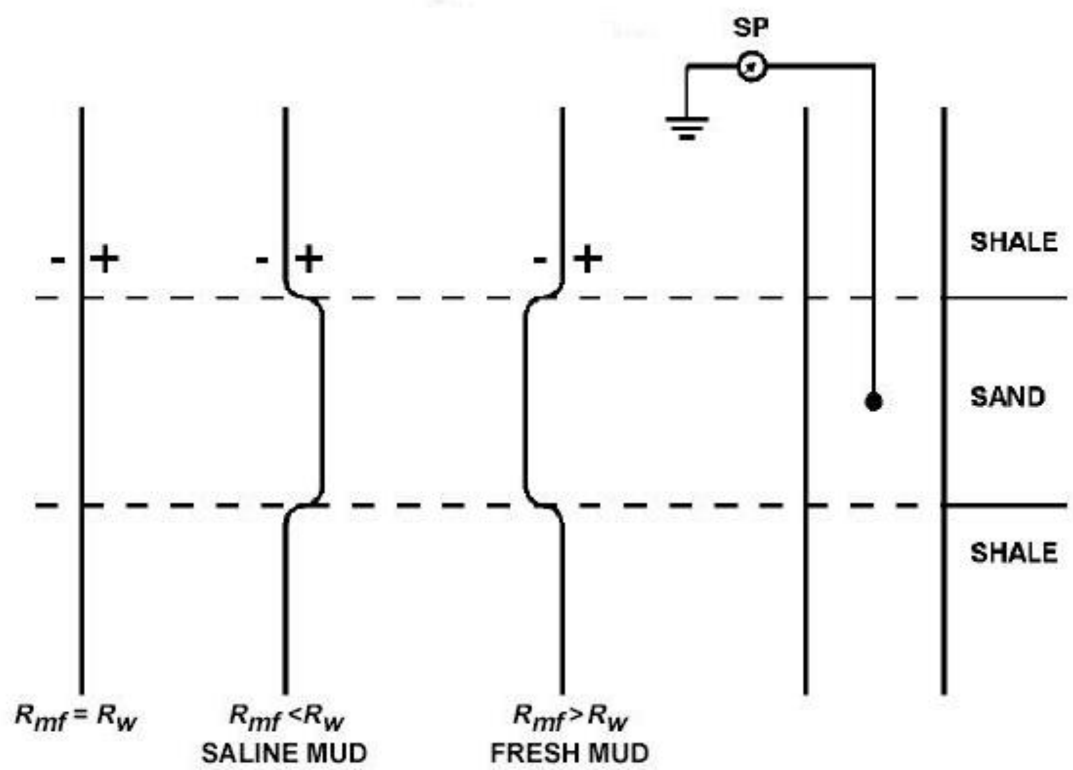


- **SP Log Curve Response Analysis**

- SP log in millivolts recorded in the track #1 in millivolts with Gamma ray log in API, and Caliper log in inch.
- In shale formation the SP curve is relatively constant and follows a straight line called a **shale baseline**. SP curve deflections are measured from this shale baseline.
- The position of the shale baseline on the log has no useful meaning, only used for interpretation purposes.
- In permeable sandstone formations, the curve shows deflections from the shale baseline to reach constant deflection defining a **sand line**.

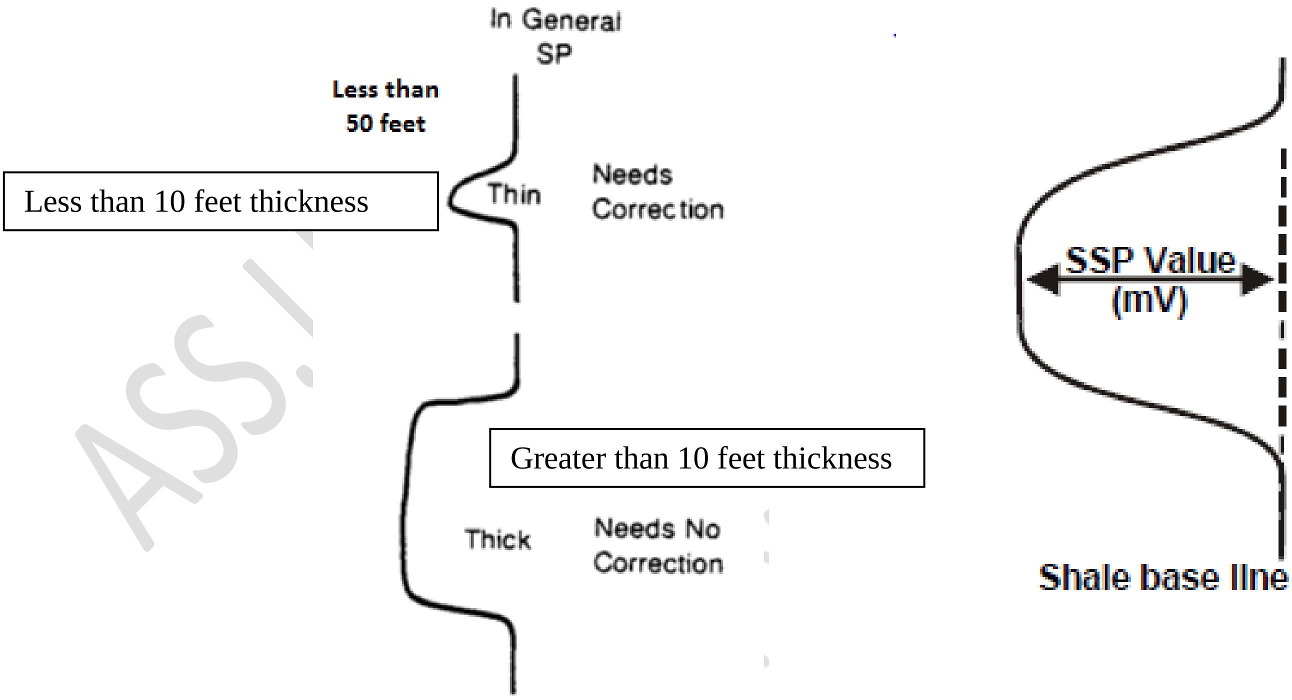


- The deflection may be either to the left shale line (*negative*) or to the right shale line (*positive*), depending mainly on the relative salinities of the formation water and the mud filtrate.
- If the formation water salinity is greater than the mud filtrate salinity,(or $R_w < R_{mf}$) the deflection is to the *left*. (Fresh Mud Using).
- If the formation water salinity is less than the mud filtrate salinity,(or $R_w > R_{mf}$) the deflection is to the *right*. (Saline Mud Using).
- If the salinities of the mud filtrate and formation water are about similar or **equal** (i.e. $R_w=R_{mf}$), there is no SP deflection opposite a permeable bed. (Note that ; $Salinity \propto \frac{1}{resistivity}$)



○ Static SP (SSP)

- The **static SP**, or **SSP**, is the maximum SP deflection opposite a thick, clean, porous, permeable formation. { **thick formation ≥ 10 feet thick** }
- The SSP is the difference between the SP log at the shale base line and that in the center of the thick clean formation.
- SP (spontaneous potential) is the SP response due to the presence of thin beds and/or the presence of gas and/or the presence of the shale.
- The SSP is important concept because it is a necessary element for determining accurate values of R_w and volume of shale.
- *As* a formation is shaly or thins (i.e. < 10 feet thick) the SP measured in the borehole will record an SP value less than SSP , in this case the SP must be corrected to find a value of SSP.



- The SP curve can be corrected by chart for the effects of bed thickness.

(use **chart SP-5** for **thickness** in feet, or **chart SP-6** for **thickness** in meter)

- *As a general rule whenever the SP curve is narrow and pointed in shape, the SP should be corrected for bed thickness*.

  - **pseudo-static SP**

- ***Pseudo-Static Spontaneous Potential*** **(PSP) is** the SP deflection obtained for homogeneous shaly formations and/or thin shaly beds after correction for bed thickness, i.e. is the SP response if shale is present.

❖ **Factors Influencing The SP Log Responses**

1. **R_{mf}/R_w Ratio**.

   $R_{mf}/R_w > 1$ deflection to the left shale line (*negative*)

   $R_{mf}/R_w = 1$ no deflection

   $R_{mf}/R_w < 1$ deflection to the right shale line (*positive*)

2. Bed thickness

   Thin beds (<3m or 10 ft) reduce the deflection of the SP curve

3. formation resistivity (Rt).

   Higher Rt both reduce the deflection of the SP curve

4. Invasion

   Usually very small and can, in general, be ignored

5. Shale content

   increased shale content reduces SP deflection

6. Borehole diameters.

   Usually very small and can, in general, be ignored

7. Hydrocarbon Content

   In hydrocarbon-bearing zones, the SP curves deflection is reduced

Example// SP Log Deflection From The Shale Baseline.

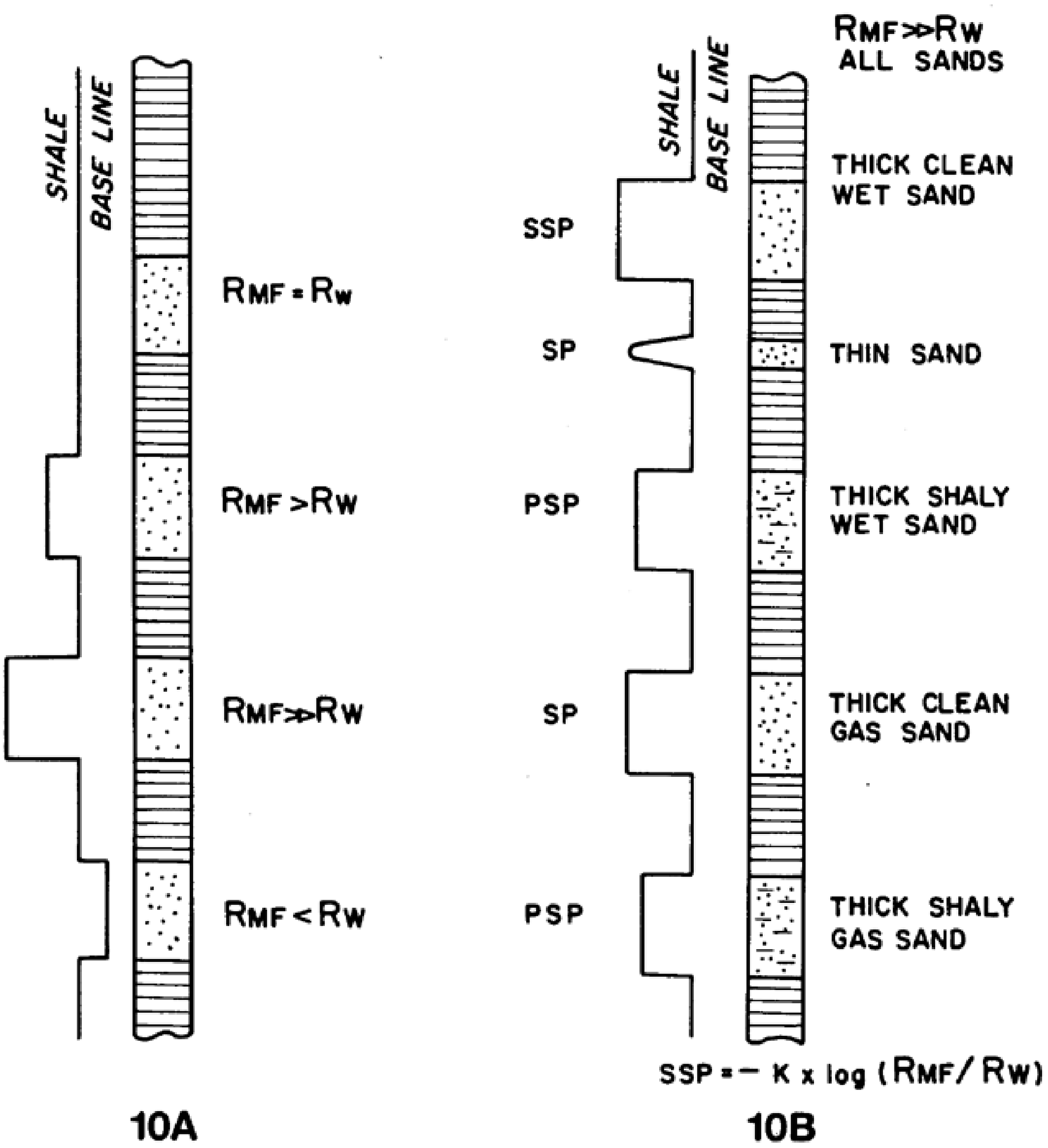
Figure A / SP log deflection with different resistivity of mud filtrate (R_{mf}) and formation water (R_w).

- ✓ When $R_{mf} = R_w$ there is no deflection.
- ✓ When $R_{mf} > R_w$ SP log deflects to the left of shale line (negative deflection).
- ✓ When $R_{mf} >> R_w$ the deflection is proportionately greater.
- ✓ When $R_{mf} < R_w$ SP log deflects to the right of shale line (positive deflection).

Remember, the spontaneous potential log (SP) is used only with conductive (salt water based) drilling muds.

Figure B / SP deflection with resistivity of the mud filtrate (R_{mf}) much greater than formation water (R_w).

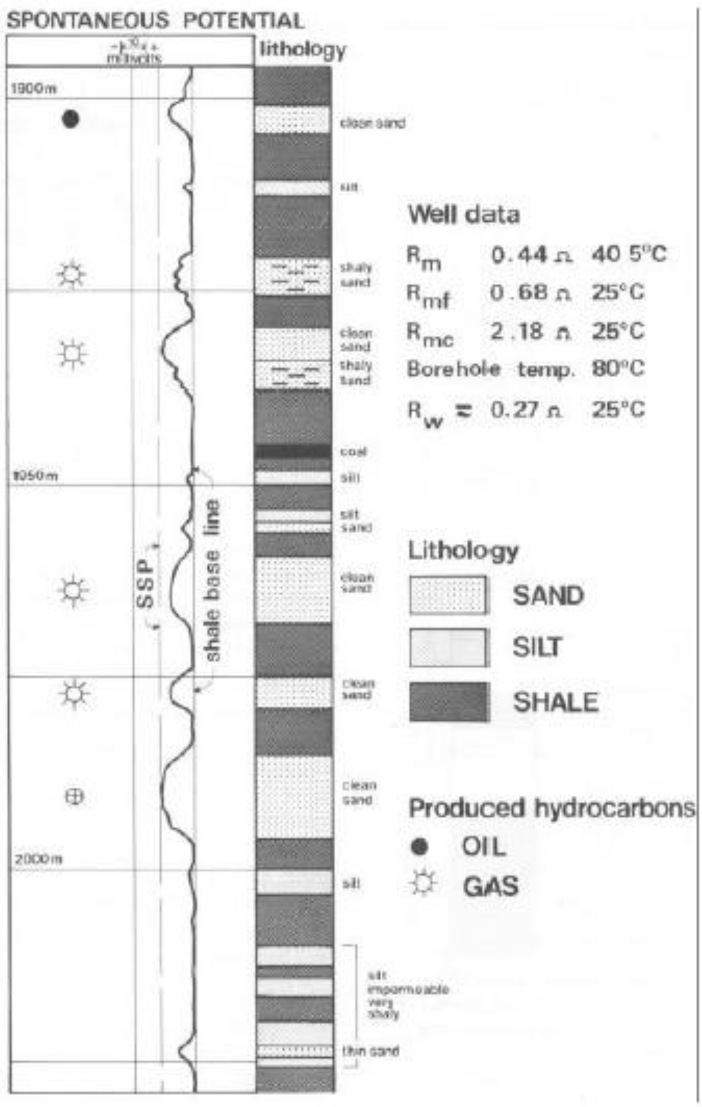
- ✓ SSP (static spontaneous potential) at the top of the diagram, is the maximum deflection possible in a thick, shale free, and water bearing ("wet ") sandstone for a given ratio of R_{mf}/R_w. All other SP log deflections are less, and are relative in magnitude.


SHALE
BASE LINE
RMF = Rw
RMF > Rw
RMF >> Rw
RMF < Rw
10A
RMF >> Rw
ALL SANDS
SHALE
BASE LINE
SSP
THICK CLEAN
WET SAND
SP
THIN SAND
PSP
THICK SHALY
WET SAND
SP
THICK CLEAN
GAS SAND
PSP
THICK SHALY
GAS SAND
SSP = − K x log (RMF / Rw)
10B

SP Log Applications

1) The detection of permeable beds.

- Permeable zones are indicated if there is a small deflection in the SP log from the shale baseline.
- Permeable bed boundaries are detected by the point of the inflection from the shale baseline.
- It should be noted that some permeable beds might give no deflection, such as those where there is no difference in salinity between the formation fluids and the mud filtrate.



2) Calculation of Water Resistivity (Rw) from SP Log

1. Identify the *shale baseline* and *clean sand lines* on the SP log. The difference is SP.
2. Correct the SP reading to SSP for bed thickness.

(use **chart SP-5** for **thickness** in feet, or **chart SP-6** for **thickness** in meter).

$$SSP = correction\ factor\ \ x\ Sp \qquad (1)$$

3. Calculate the formation temperature.
   - **By using equation;**

$$T_f = \left(\frac{BHT - T_o}{D_T}\right)(D_f) + T_o \qquad (2)$$

T_f = formation temperature at any depth.
BHT = Bottom hole temperature.
T_o= annuls mean surface temperature = 80° F
D_f = formation depth and D_T = total well depth

   - **Or by using chart Gen-2**

4. Convert R_{mf} at measured temperature to $\mathbf{R_{mf}}$ at formation temperature.

$$R_2 = R_1\left(\frac{T_1 + 7}{T_2 + 7}\right) \ldots\ldots\ldots\ldots(3)$$

Note; R_{mf} and R_m obtained from log heading (i.e. given),,,, if R_{mf} not given in log heading, we can calculate it from;

$$R_{mf} = 0.75\ R_m \ldots\ldots\ldots..(4)$$

$$R_{mc} = 1.5\ R_m \ldots\ldots\ldots\ldots\ldots(5)$$

5. If formation water salinity is **low** (less than 80000 ppm NaCl)

$$ssp = -k\log\frac{R_{mf}}{R_w} \qquad (6)$$

$$R_w = \frac{R_{mf}}{10^{-(SSP/K)}} \ldots\ldots\ldots.(7)$$

Where, K = constant

$$k = 0.133\,T_f + 61 \qquad (8)$$

6. If formation water salinity is **high** (greater than 80000 ppm NaCl) we must calculate R_{mf} equivalent, or R_{mfe}.

$$A.\ If \quad R_{mf}\ @\ 75^o\ F\ (24^oC)\ < 0.1\ \Omega.m$$

- **Use Chart SP-2(T in F^o) , or chart SP-3(T in C^o)**

This chart using to convert $R_{mf} \longrightarrow R_{mfe}$

$R_{we} \longrightarrow R_w$

Do not use the dashed lines, they are for gypsum based muds.

- **Or use the following eq**.

$$R_{mfeq} = \frac{(146 \text{ x } R_{mf}) - 5}{(337 \text{ x } R_{mf}) + 77} \ldots\ldots\ldots\ldots(9)$$

$$B.\ If \quad R_{mf}\ @\ 75^o\ F(24^oC) = 0.1\ \Omega.m \ \ to \ \ 0.25\ \Omega.m$$

$$R_{mfe} = 0.85\ R_{mf\ @TF} \qquad (10)$$

$$C.\ If \quad R_{mf}\ @\ 75^o\ F(24^oC)\ >\ 0.25\ \Omega.m$$

$$R_{mf} = R_{mfe}$$

7. Calculate the equivalent formation water resistivity, Rwe

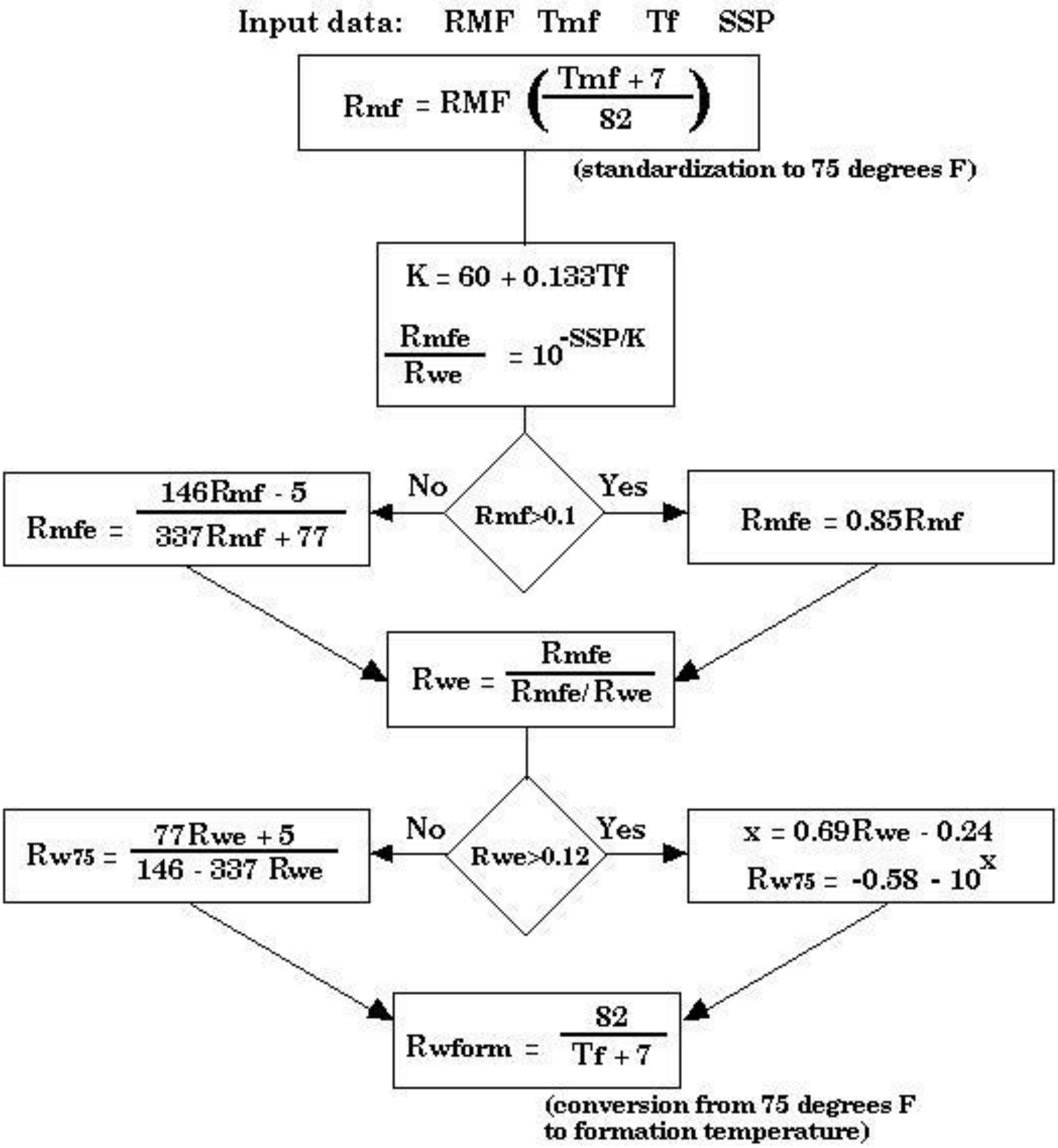
$$ssp = -k \log \frac{R_{mfe}}{R_{we}} \qquad (11)$$

$$R_{we} = \frac{R_{mfe}}{10^{-(SSP/K)}} \ldots\ldots\ldots\ldots(12)$$

Or find R_{we} using **chart SP-1**

8. Calculate the formation water resistivity, R_w

Use Chart SP-2 (T in F^o) , or chart SP-3 (T in C^o)


Input data: RMF Tmf Tf SSP
Rmf = RMF ((Tmf + 7)/82)
(standardization to 75 degrees F)
K = 60 + 0.133Tf
Rmfe/Rwe = 10^-SSP/K
Rmf>0.1
No
Yes
Rmfe = (146Rmf - 5)/(337Rmf + 77)
Rmfe = 0.85Rmf
Rwe = Rmfe/(Rmfe/Rwe)
Rwe>0.12
No
Yes
Rw75 = (77Rwe + 5)/(146 - 337 Rwe)
x = 0.69Rwe - 0.24
Rw75 = -0.58 - 10^x
Rwform = 82/(Tf + 7)
(conversion from 75 degrees F
to formation temperature)

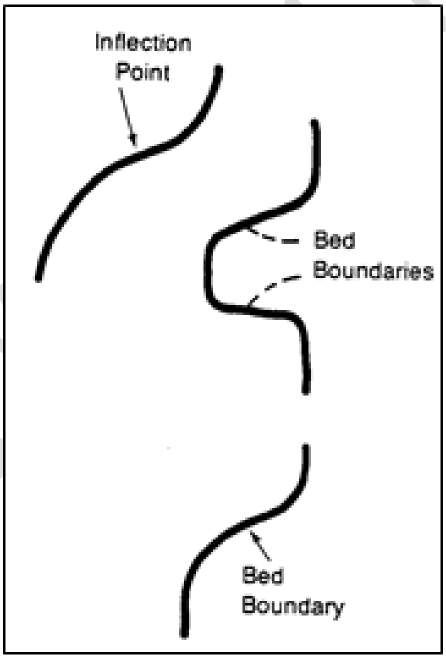
3) Calculation The Volume Of Shale In Permeable Beds.

The shale volume is sometimes calculated from the SP log using the relationship:

$$V_{sh} = 1 - \frac{PSP}{SSP} \qquad (13)$$

PSP = SP log read in a thick homogeneous shaly sand zone.

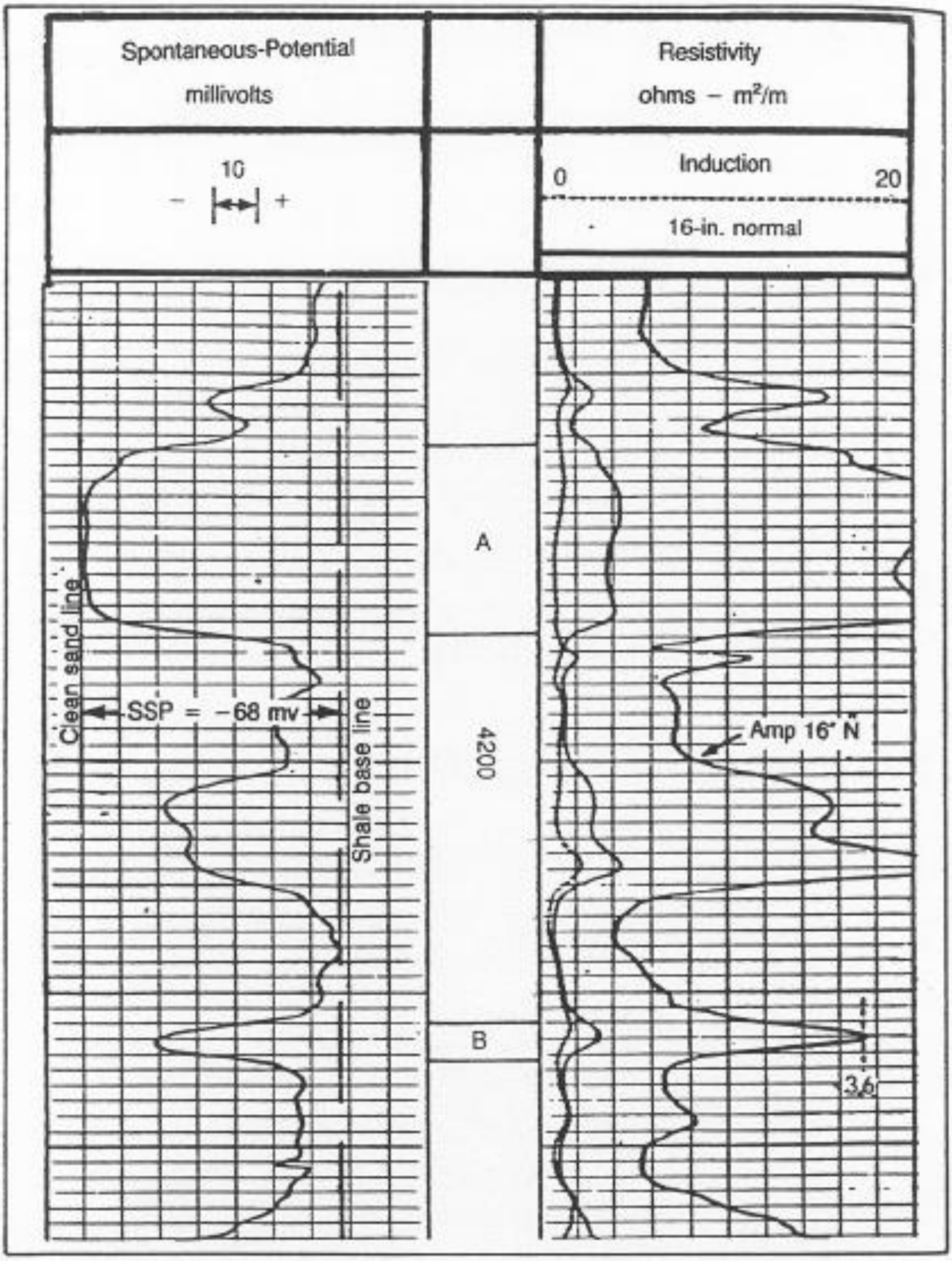
SSP = SP log read in the thick clean sand zone.



Example; Given;

T_{TD}= 196 deg F @ TD = 9,400 ft.
Gulf Coast well
R_{mf} = 0.71 @ T_m =68 deg. F
R_m = 1.00 @ T_m =68 deg. F

Calculate R_w for zones A and B.



Solution;

Step 1: *The shale baseline and clean sand line are drawn on the figure.*
SP = -68 mV is the potential difference.

Step 2: *The formation temperature can be computed by:*

$$T_f = (196 - 75)\frac{4170}{9400} + 75 = 129\,°F$$

Step 3: *The R_{mf} at formation temperature is:*

$$(R_{mf})_f = 0.71\left(\frac{68 + 6.77}{129 + 6.77}\right) = 0.39\,\Omega\text{-}m$$

Similarly, R_m = 0.55 ohm-m @ T_f

Step 4: *Bed thickness = 24ft.; R_i, = 4 ohm-m from the 16" short normal; thus R_i/R_m = 7.2 ≈7.5. From the figure the correction factor = 1.00.*

Step 5: *Since R_{mf} > 0. 25 then R_{mfe} = 0.39 ohm-m.*

Step 6: *Calculate the equivalent formation water resistivity.*

$$R_{we} = 0.39 * 10^{\left(\frac{-68}{61+0.133(129)}\right)} = 0.052\,\Omega\text{-}m$$

Step 7: *Since R_{we} < 0. 1, R_w = 0. 060 ohm-m*

<u>**Note ;**</u> we can obtain the Rw value from the following equations depending on Rwe;

1. If $R_{we} < 0.12$

$$R_{w75} = \frac{(77 \text{ x } R_{we}) + 5}{146 - (377 \text{ x } R_{we})}$$

2. $R_{we} > 0.12$

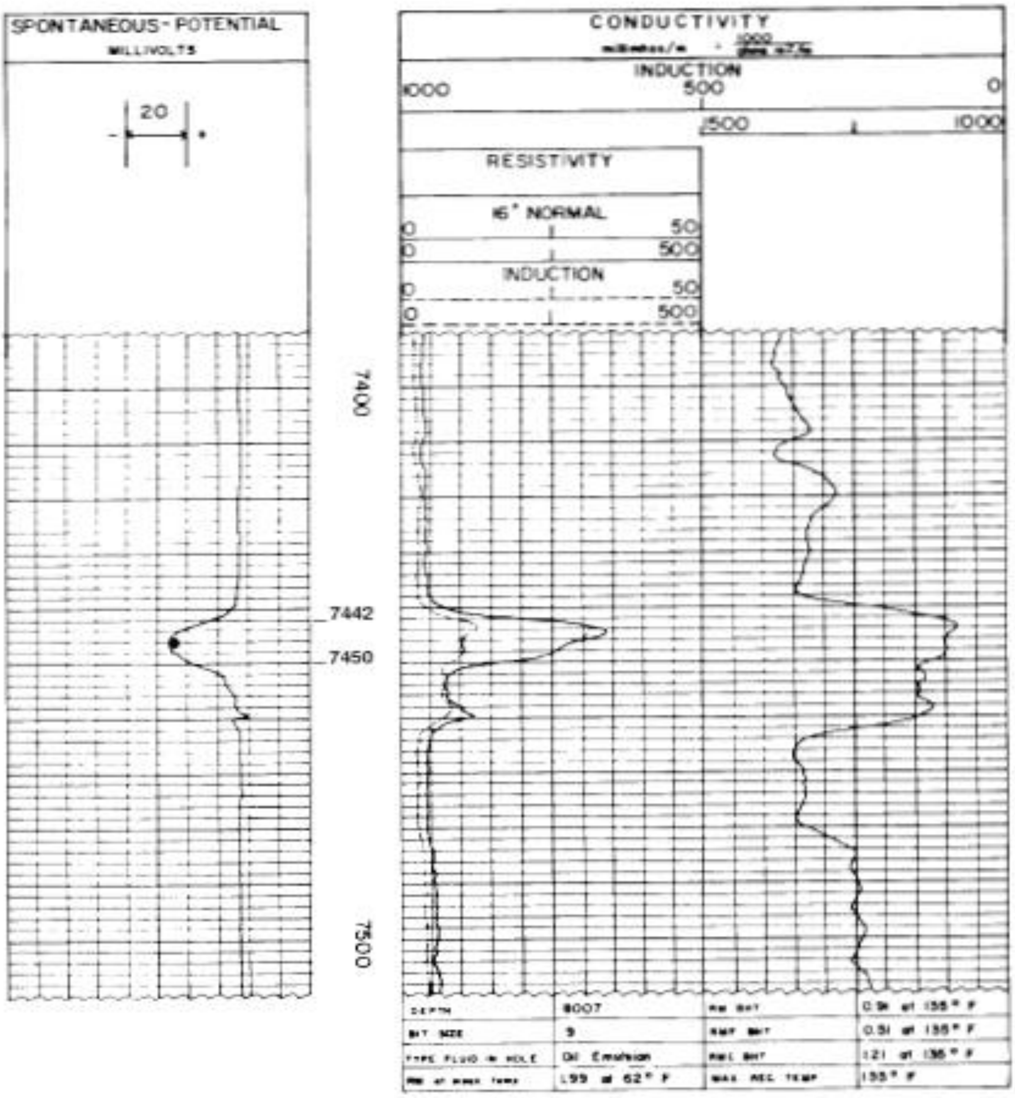
$$R_{w75} = -0.58 + 10^{(0.69 R_{we} - 0.24)}$$

3. Correct Rw @ 75° F to Rw @ T_f

Problem 1: Given: R_w = **0.22** ohm-m at **250°F** and resistivity of the mud filtrate (R_{mf}) = **0.7** ohm-m at **100°F**, converted to **0.33** at **250°F**.
Find:

1) SP or ESSP .
2) Salinity.

Problem 2: Determination of formation water resistivity (R_w) from SP log shown in figure below.
Given:
R_{mf} = **0.51@ 135° F**
R_m = **0.91@ 135° F**
Surface temperature (T_{sc})= **60° F**
Total depth = **8007 ft**
Bottom hole temperature (BHT) = **135° F**
R_i = **28 Ω – m.**
Bed thickness = **8 ft**.



Problem-3: Figure below show conventional resistivity logs with SP log for limestone formation below **7000** ft.

Given data:

R_m **= 0.4 Ω-m @183 °F**.

Bit size **= 8 5/8"**.

R_o **= 0.9 Ω-m**.

T_f **= 185 °F**.

Calculate:

1- R_t
2- S_w
3- R_w
4- Φ
5- Salinity.