Well Logging and Formation Evaluation

PAB2084 & PCB 2044

Spontaneous Potential (SP) Log

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Learning Outcome

At the end of the lecture, students should be able to

1. Understand the physical principles behind the operation of spontaneous potential (SP) logging,
2. Learn how to interpret SP logs in terms of lithology and petrophysical properties, and
3. Understand what corrections need to be applied to SP logs before using them for interpretation.

Contents

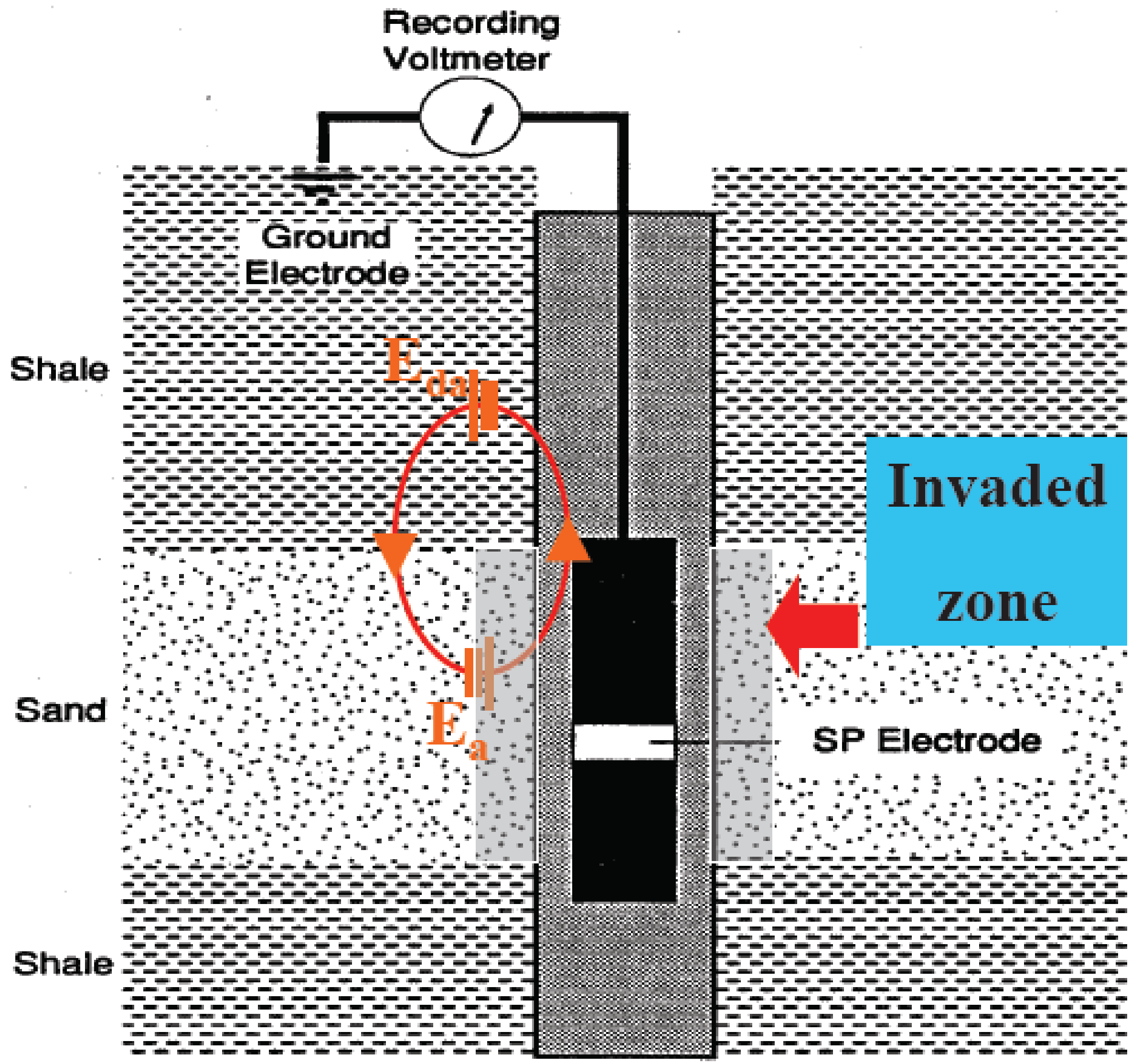
1. Introduction
2. SP measurement principle
3. Relationship between SP and R_{mf} or R_w
4. Environmental effect on SP
5. Applications of SP Log.
6. Conclusion

Introduction

- A self-induced, natural electrical potential (voltages) that occurring in the wellbore spontaneously between reservoir rocks and a fluid-filled borehole.
- *The SP log is the oldest type of log and is still common.*
- It measures the D.C. voltage difference between surface and borehole electrodes

SP measurement principle

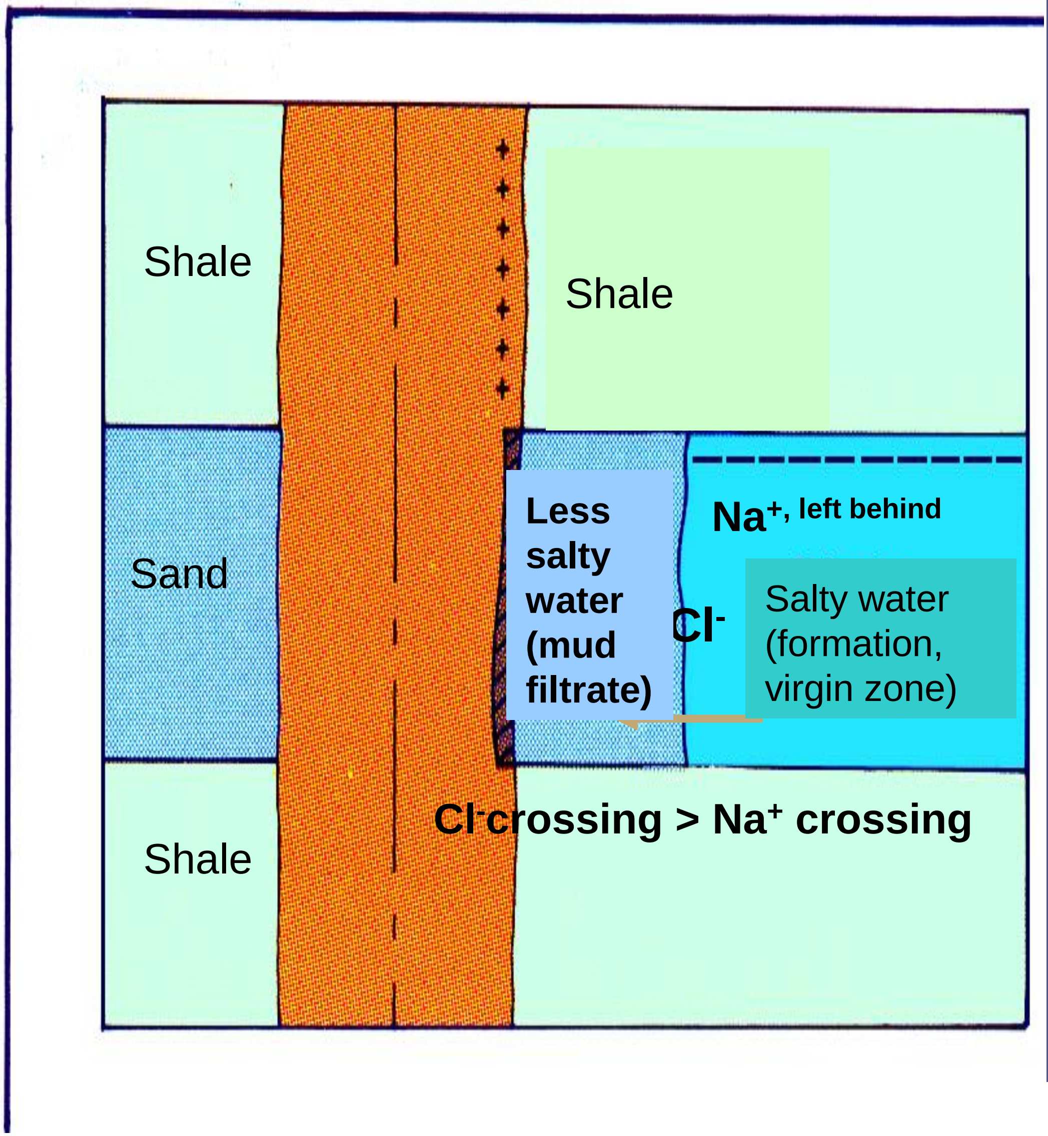
- SP is a natural occurring potential measured in the borehole mud . This potential is created by chemically induced electric current flow.



Liquid Junction Potential (Ej) Generation Mechanism

- Occurs at the boundary between the flushed zone and the virgin zone.
- Because of the high salinity of the formation water, both cations (Na^+) and anions (Cl^-) will migrate towards the mud filtrate.
- The anions (Cl^-) move faster than the cations (Na^+),and the net effect is a current flowing.

Liquid Junction Potential (E_j)

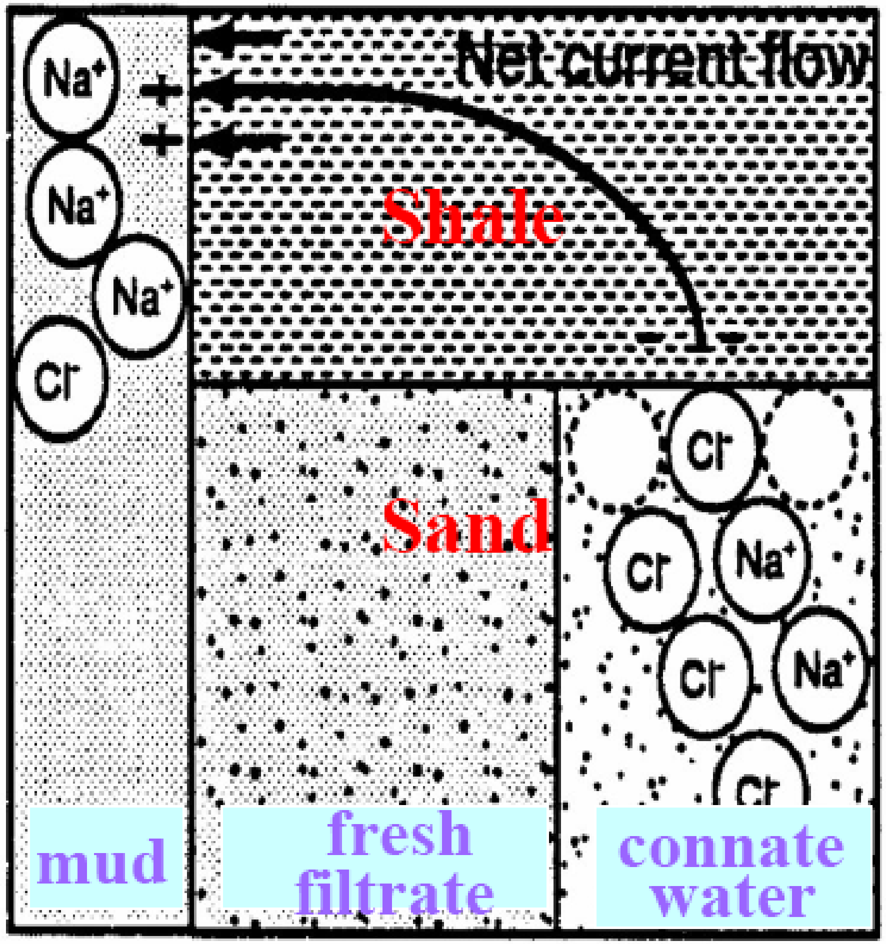


The Na+ ion is comparatively large and drags 4.5 molecules of water, while the Cl^- ion is smaller and drags only 2.5 molecules of water. Hence, the anion Cl^- will migrate more easily than the Na+ ions.

More positive charges left behind in the formation water. These positive charges restrict further Cl- migration towards the flushed zone.

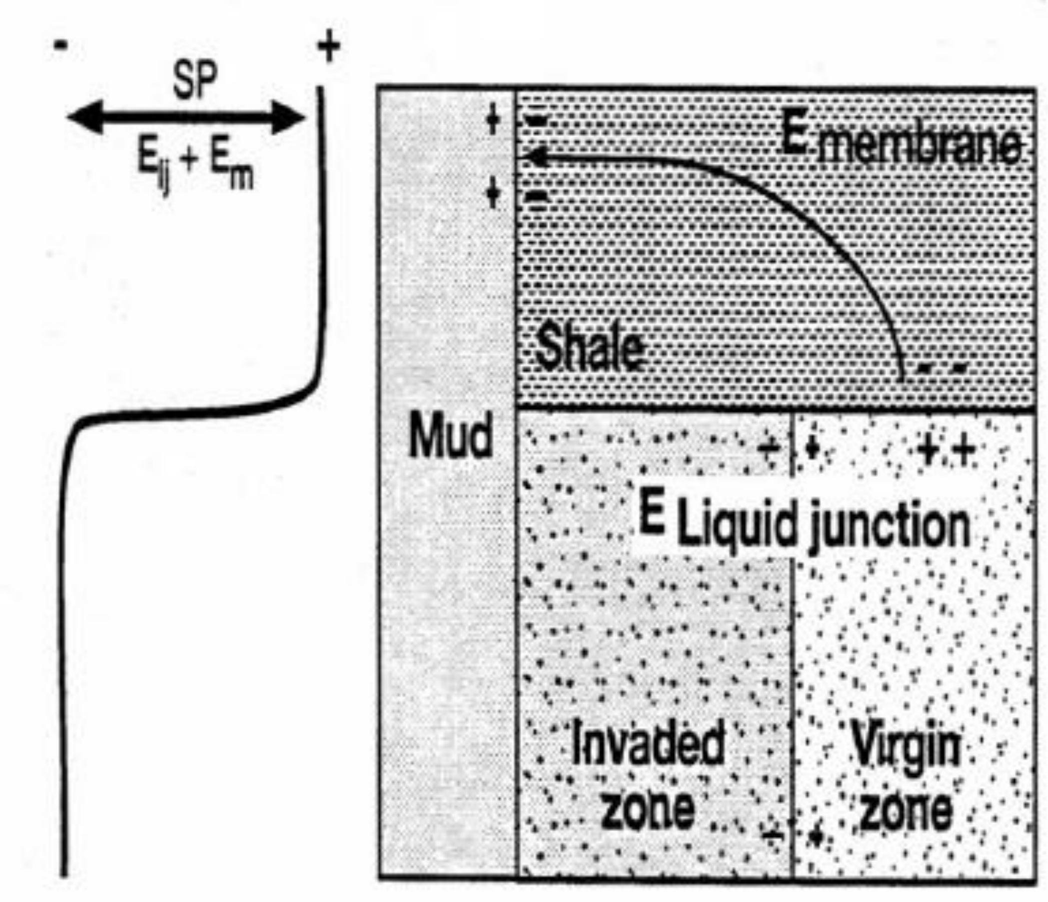
Membrane Potential (E_m) Generation Mechanism

- Because of its molecular structure, shale are more permeable to Na^+ cations than the Cl^- anions; a shale acts as an ionic sieve. Since Na^+ ions effectively manage to penetrate the shale bed through from the saline formation water to the less saline mud column, a potential is created known as the membrane potential (E_m).

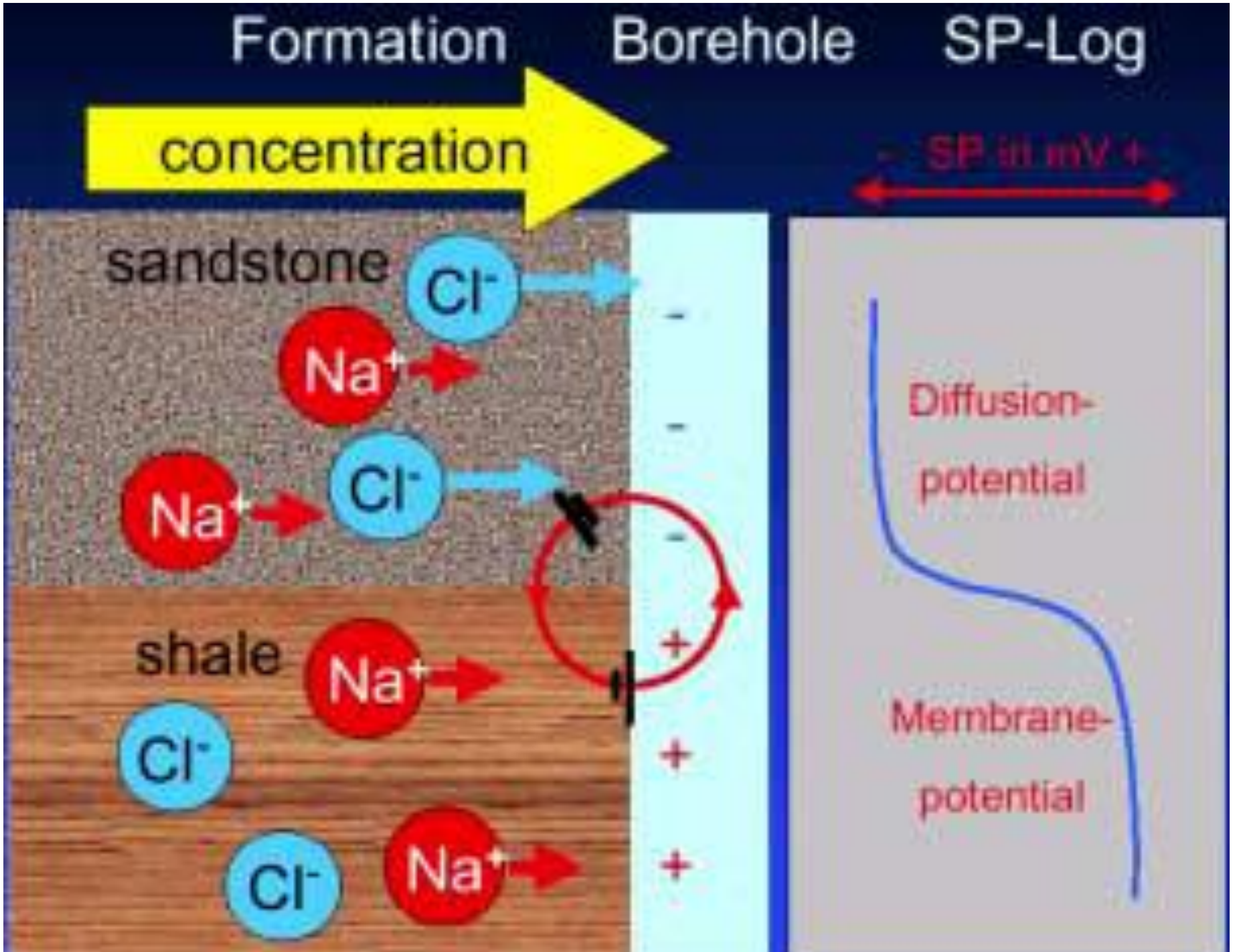


Generation Mechanism

- The total SP potential is the sum of two components:
- $E_{total} = E_j + E_m$
- This total potential is measured in the borehole as the SP.
- The total potential is also called the electrochemical component of the SP.

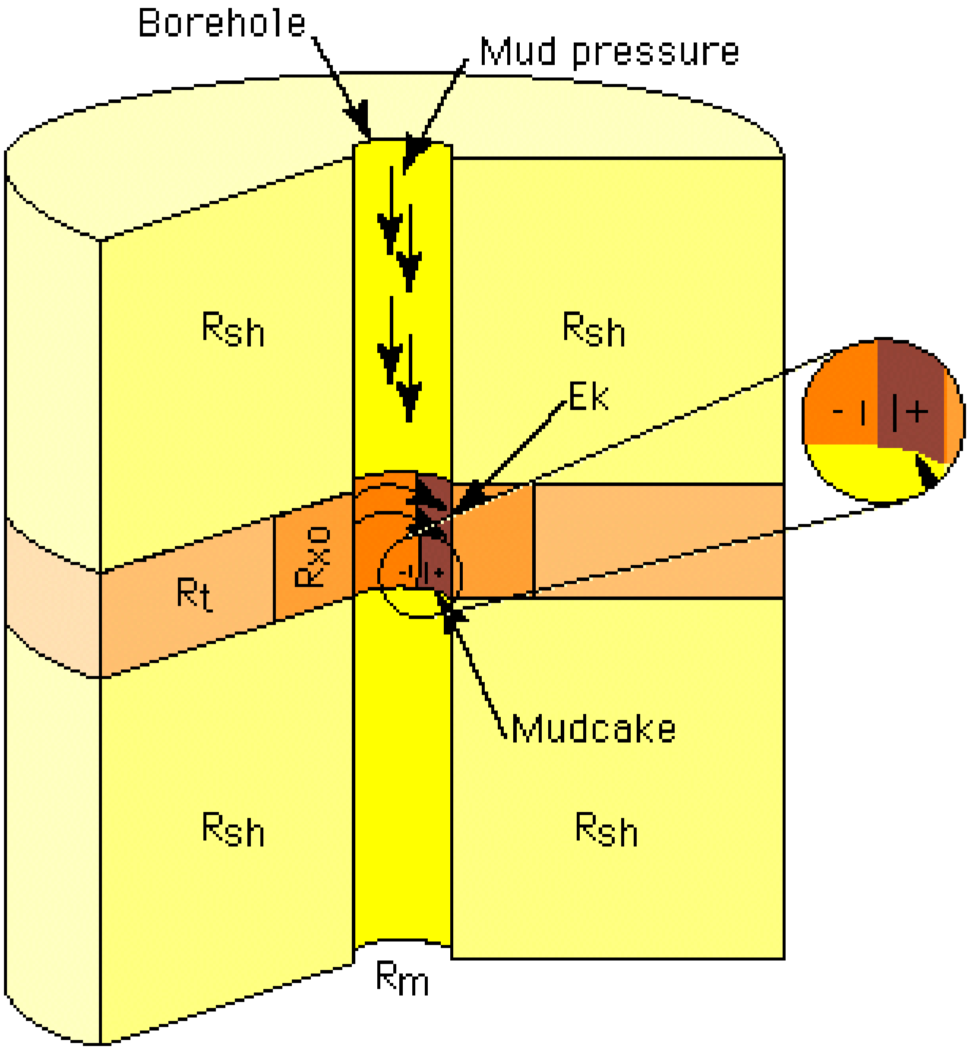


Borehole Phenomenon



Electrokinetic (Streaming, E_k) Potential

- E_k exists due to the flow of an electrolyte through a nonconductive medium- mudcake.
- This flow exists because of the differential pressure between the mud column and the formation.
- It is normally very small and will stop as soon as the mudcake becomes impermeable.



Static SP (SSP)

- By definition the SSP is the sum of the membrane (E_m) and junction potential (E_j)

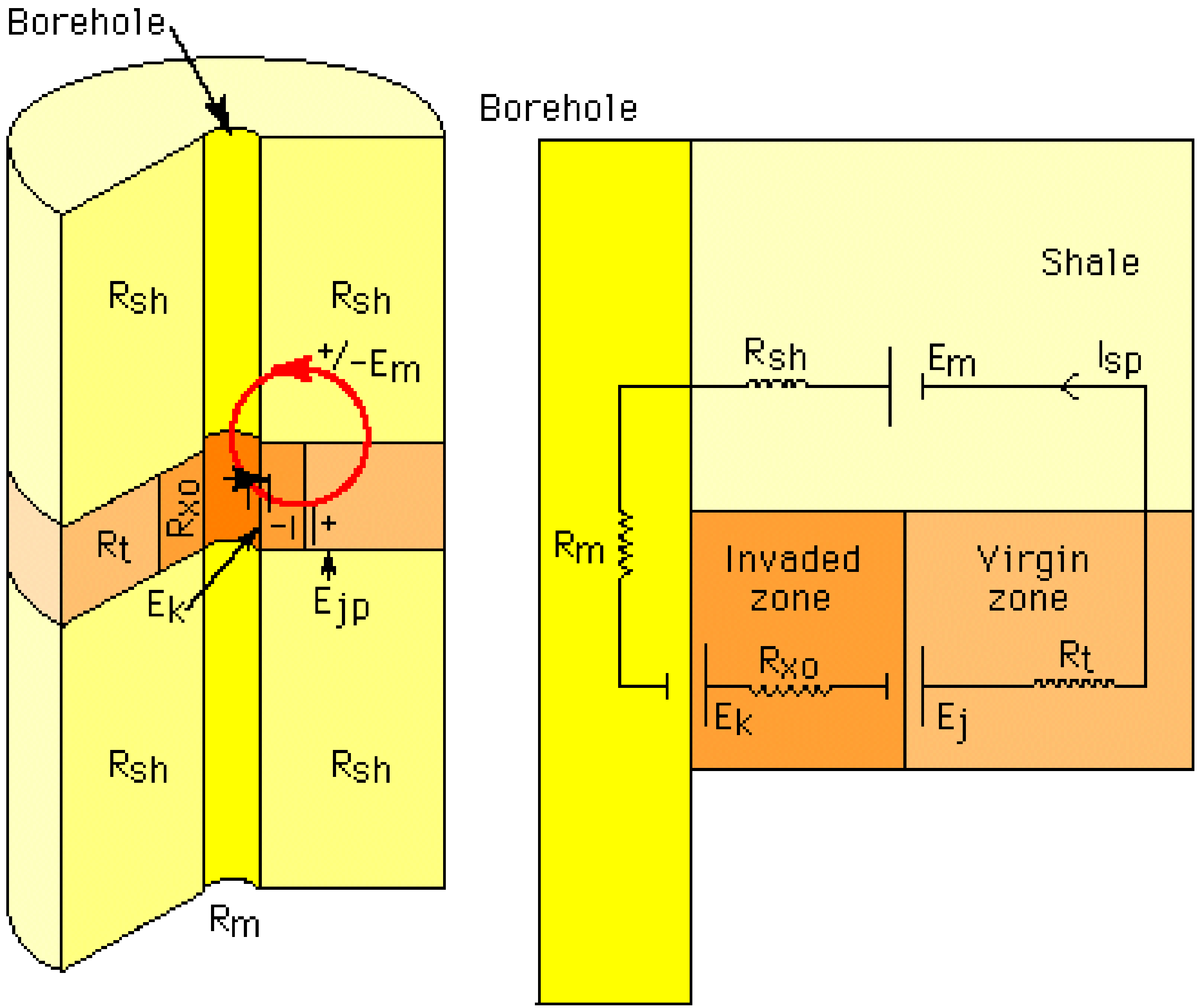
$$\mathrm{SSP}=\mathrm{E_m}+\mathrm{E_j}=(R_{xo}+R_t+R_{sh}+R_m)*I_{SP}$$

Where I_{SP} is the SP current.

- The SP we measure is the change in potential from one point in the well bore to another. It is developed across the resistance of the mud column (R_m) from one point to another due to the SP current (I_{SP})

$$\mathrm{SP}=R_m*I_{SP}$$

Static SP (SSP)



Static SP (SSP)

$$E_D = \frac{RT}{F} \cdot \frac{v-u}{v+u} \cdot \ln\left(\frac{C_w}{C_{mf}}\right) = \frac{RT}{F} \cdot \frac{v-u}{v+u} \cdot \ln\left(\frac{R_{mf}}{R_w}\right)$$

$$E_D = K_D . Log\left(\frac{C_w}{C_{mf}}\right) = 11.6 \; Log\left(\frac{C_w}{C_{mf}}\right)$$

Where R ≡ ideal gas constant, T ≡ absolute Temperature
F ≡ Faraday constant, C_w ≡ formation water concentration
C_{mf} ≡ mud filtrate concentration,
R_w ≡ formation water resistivity, R_{mf} ≡ mud filtrate resistivity
u ≡ mobility of Cl, v ≡ mobility of Na

Static SP (SSP)

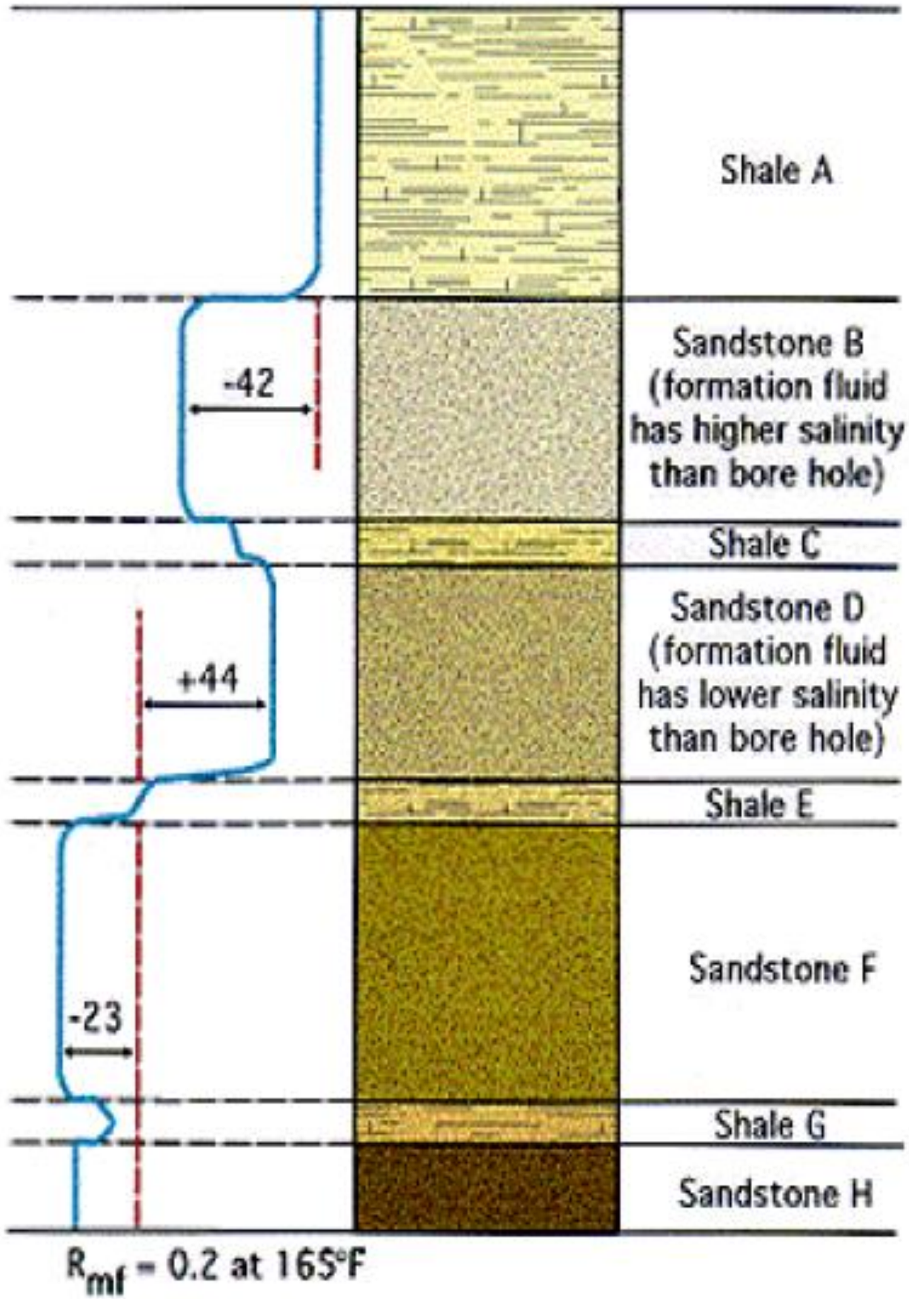
$$\mathrm{E_m} = \frac{RT}{F}.\ln\left(\frac{C_w}{C_{mf}}\right) = \frac{RT}{F}\ln\left(\frac{R_{mf}}{R_w}\right)$$

$$E_m = K_m.Log\left(\frac{C_w}{C_{mf}}\right) = 59.1\,Log\left(\frac{C_w}{C_{mf}}\right)$$

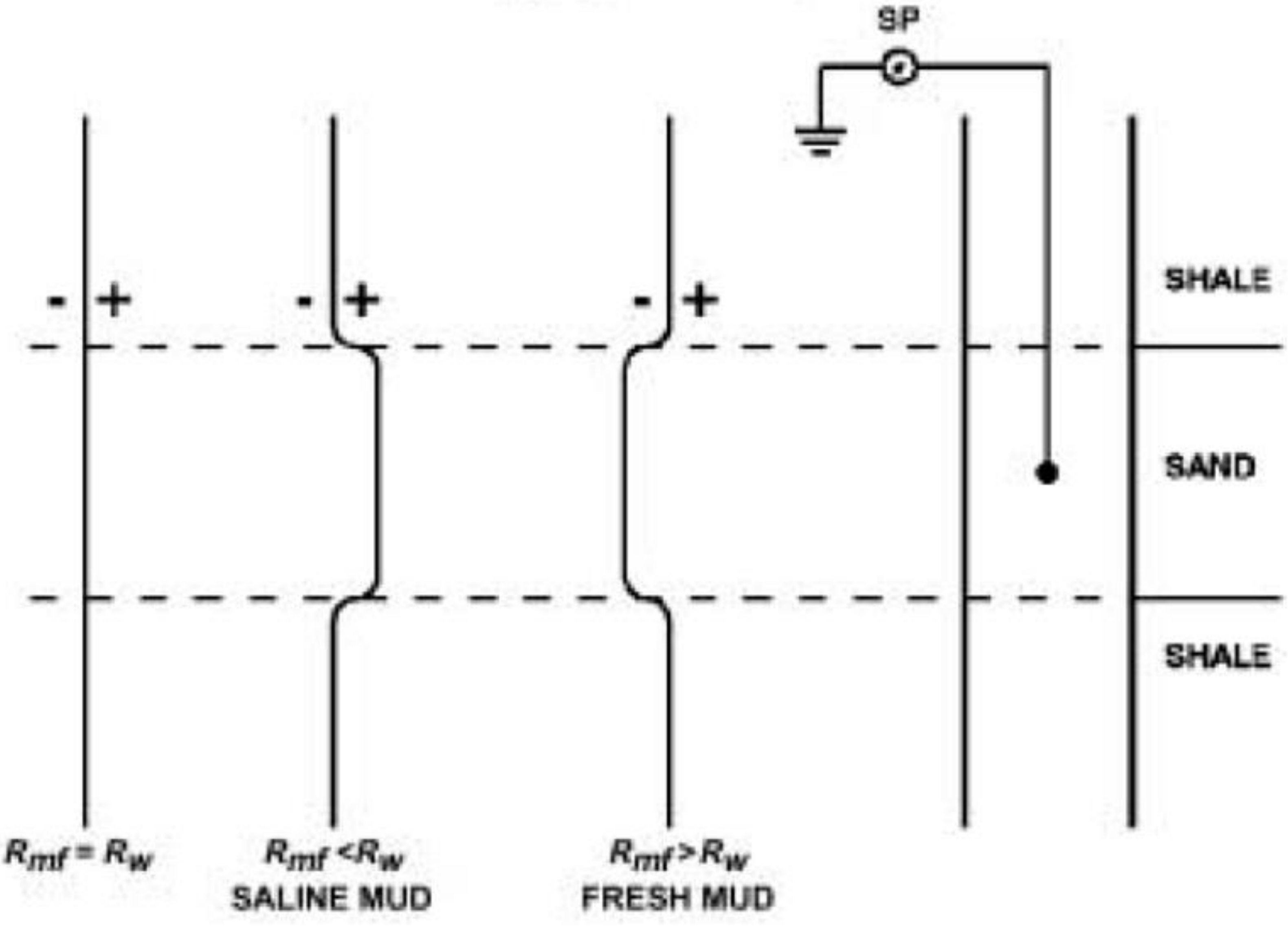
$$\mathrm{SSP{=}E_D + E_m = K_{SP}\,log}\left(\frac{C_w}{C_{mf}}\right) = 71.\,Log\left(\frac{C_w}{C_{mf}}\right)$$

SP Log Salinity Effect

- If formation fluid has higher salinity than that of borehole fluid the deflection is to the left of shale baseline (Red dashed line) and vice versa if formation fluid has lower salinity.
- Baseline shift may be due to unconformity.

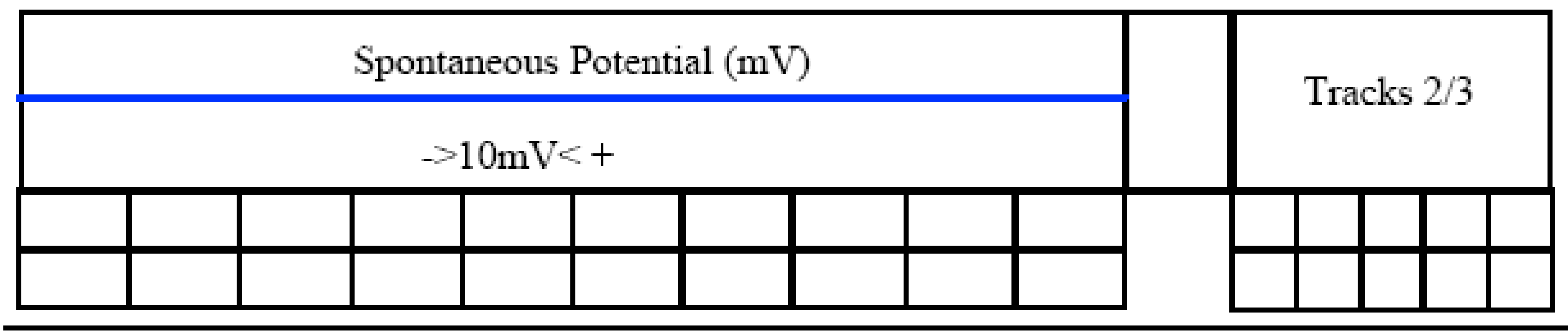


Relationship between SP and R_{mf} or R_w



SP Scales

- The SP is measured in millivolts, mV.
- The scale on the log shows a number of mV per division for example 20mV/division. This gives a total for the track of 200mV.
- The scale across the track is variable and depends on the conditions in the well.



Environmental effect on SP

(1) Oil Base Muds & Air-Filled Boreholes

- Due to a complete lack of an electrical path in the borehole, no SP will be generated in wells where the hole is filled with oil-based muds or air.

(2) Shaly Formations

- Shale will reduce the measured SP. This effect permits the shaliness to be estimated if a clean sand of the same water salinity is available for comparison.

Environmental effect on SP

(3) Hydrocarbons

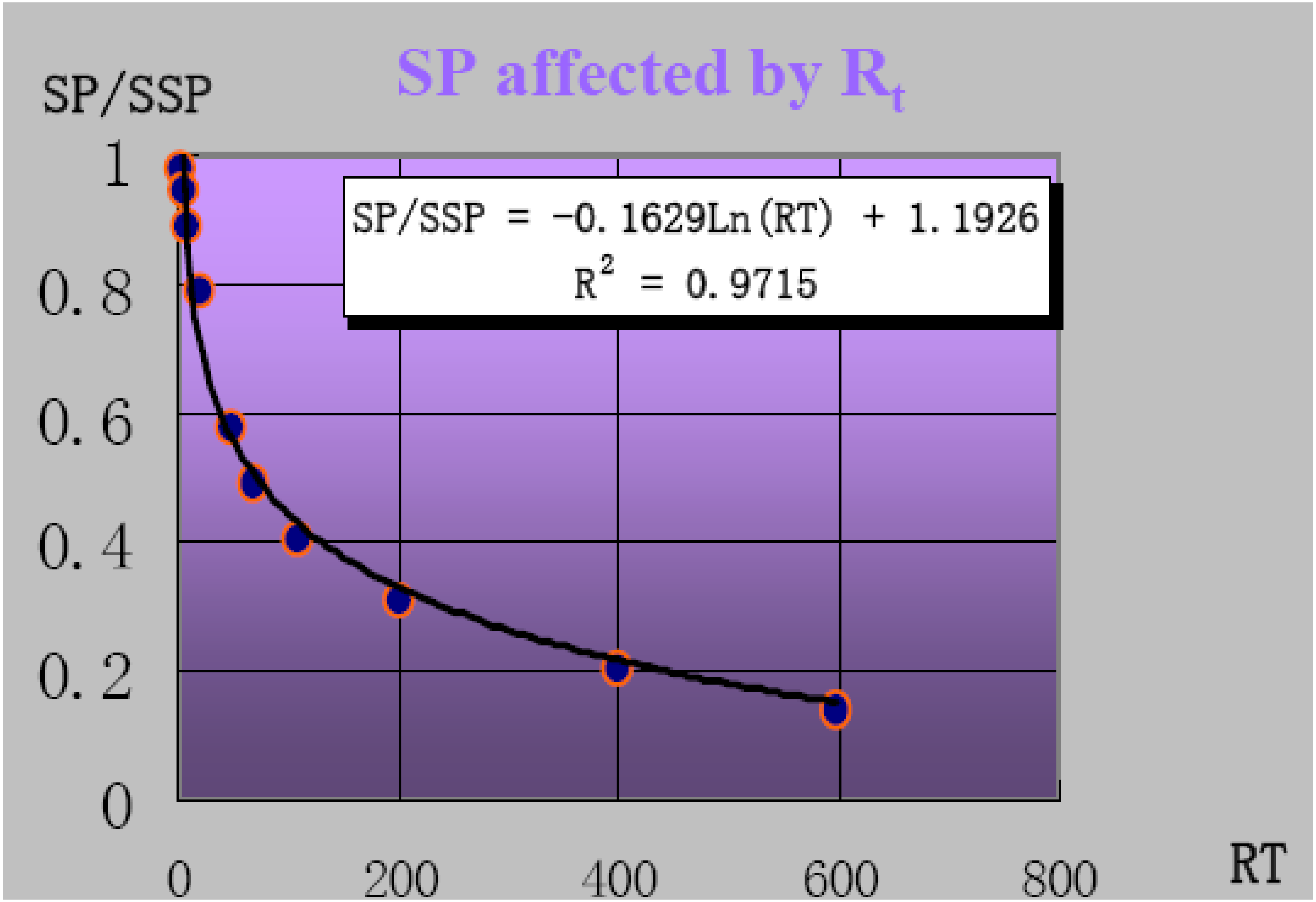
- Hydrocarbon saturation may reduce SP measurements, so only water-bearing sands should be used for determining Rw from the SP.
- *So a hydrocarbon bearing zone suppress the SP curve.*
- **(4) Unbalanced Muds**
- Unbalanced mud columns, with differential pressure into the formation, can cause "streaming" potentials that increase the SP deflection, especially in depleted reservoirs. There is no way to handle it quantitatively. This effect is called the electrokinetic SP.

Environmental effect on SP

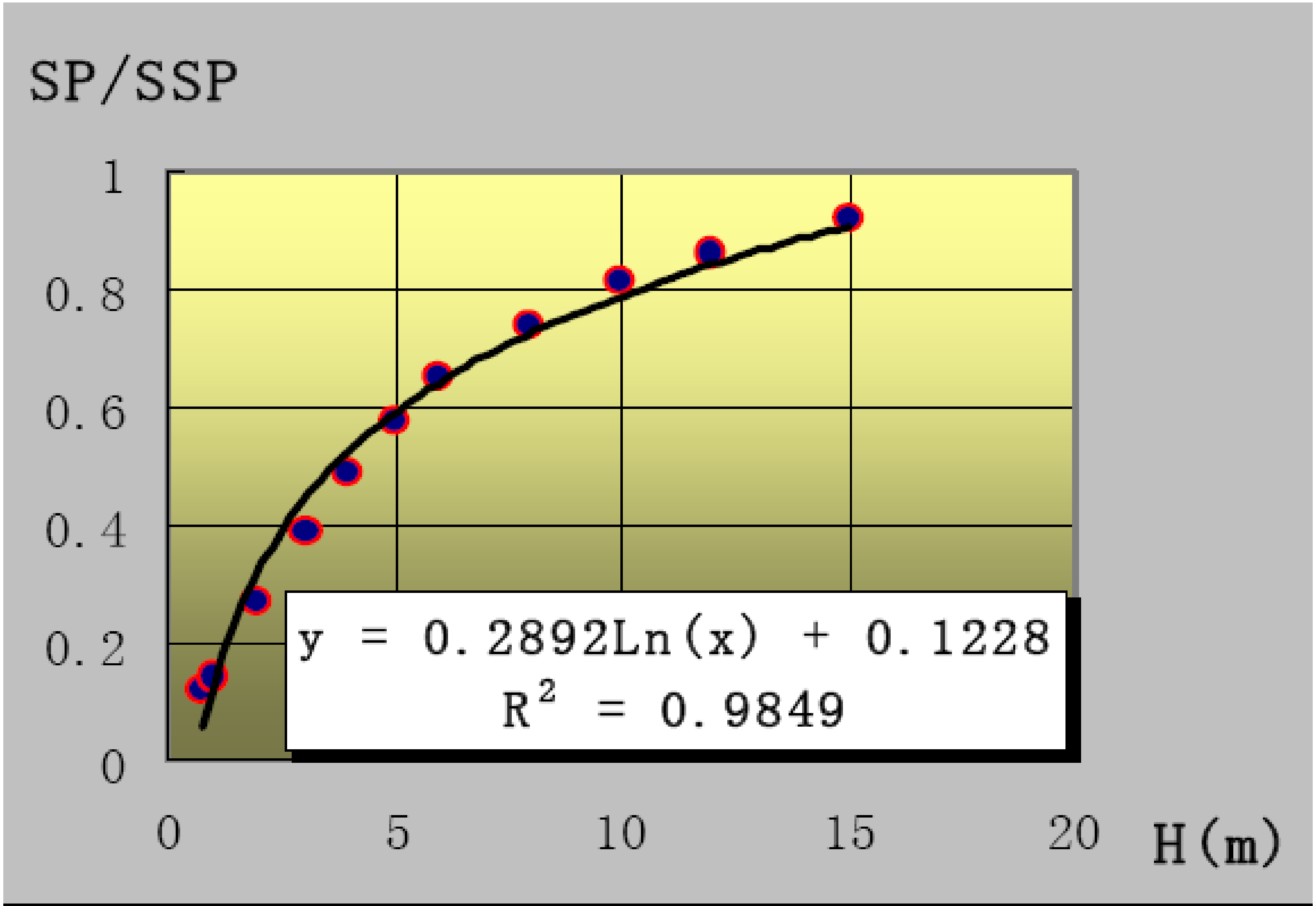
(5) KCL Muds

- The use of potassium chloride muds affects the derivation of R_w from SP. A quick correction for KCL mud effects is simply to take the observed SP deflection, subtract 25 mV, then treat it as a NaCl mud SP. The R_{mf} to R_{mfe}, relationship is slightly different for KCL filtrates than for NaCl filtrates.
- A quick rule-of-thumb is to add 30% to the measured R_{mf} and convert to R_{mfe} as a NaCl filtrate.

Environmental effect on SP



SP affected by layer thickness



Applications of SP Log

SP Log is usually used to:

(1) identify permeable zones (Porosity and permeability indications);

(2) define bed boundaries ;

(3) compute shale content (Lithology indication);

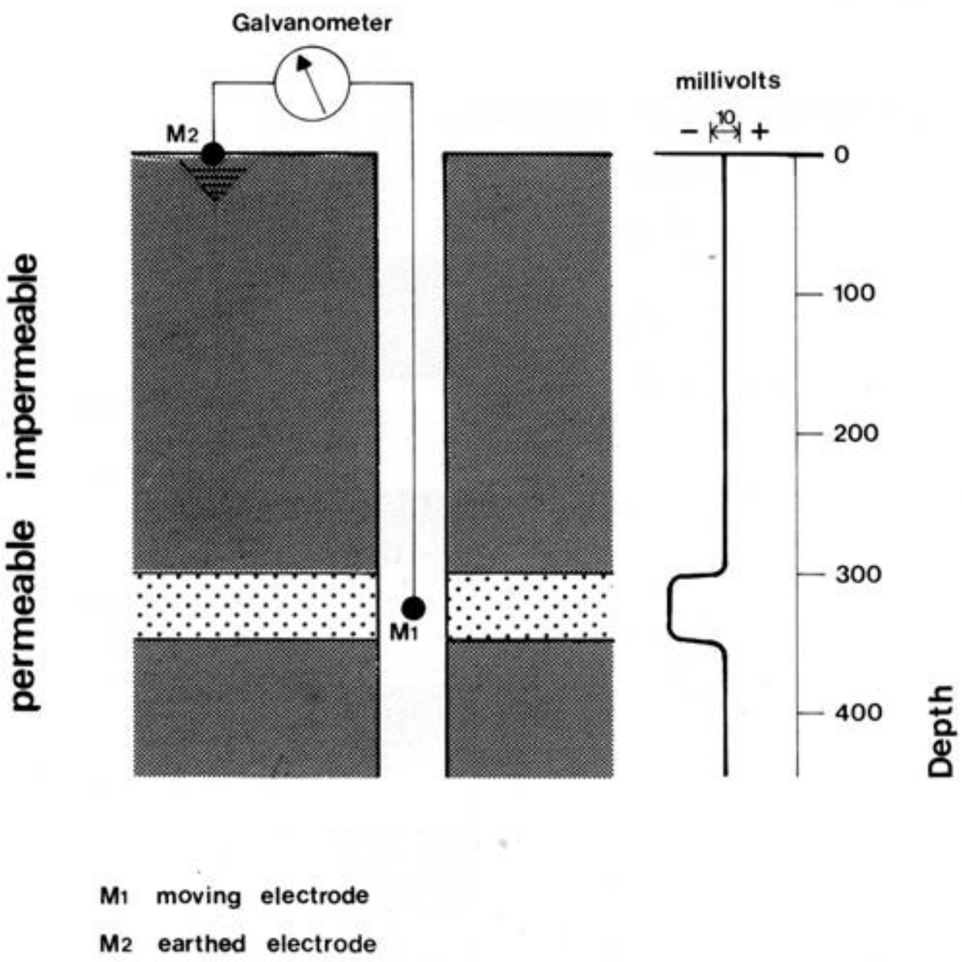
(4) Depositional Environment from the SP (Correlation)

(5) determine values of formation water resistivity Rw;.

SP Uses

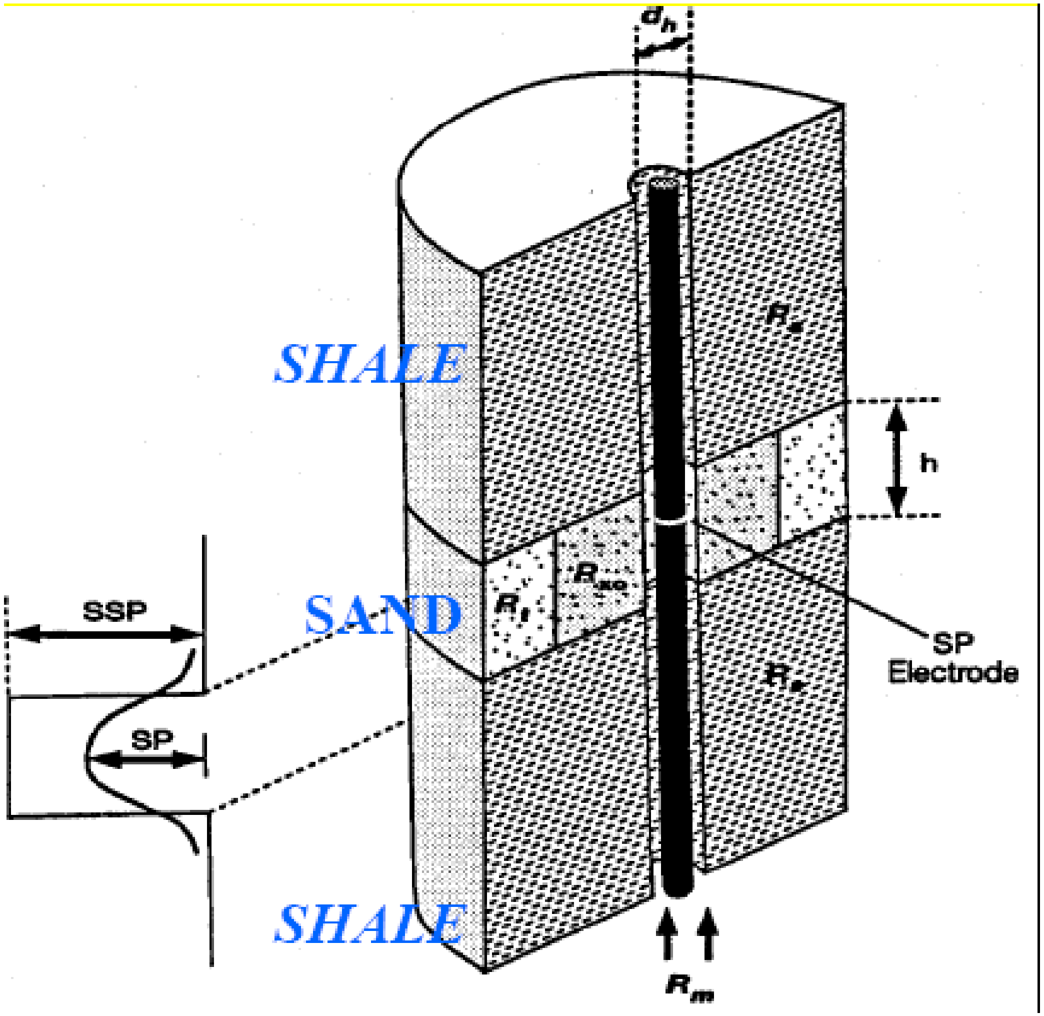
(1) Identify permeable zones

- The negative abnormal on SP curve usually indicates the permeable zone ; the higher abnormal range , the more permeable of the formation .
- Since invasion can only occur in permeable formations, deflections of SP can be used to identify permeable formations.



SP Uses (2) Define bed boundaries

- Half of abnormal amplitude point will be boundaries of shale and sand.
- The bed thickness is the interval between two boundaries .
- The vertical resolution of SP is poor, and often the permeable bed must be 30 ft or more to achieve a static (flat baseline) SP



SP Uses (3) Compute shale content

- The presence of shale in a “clean”sand will tend to reduce the SP . This effect can be used to estimate the shale content of a formation (maximum deflection is clean sand; minimum is shale).

$$(\mathrm{V_{sh}})_{\mathrm{SP}} = \frac{SP - SP_{clean}}{SP_{Shale} - SP_{clean}}$$

Where

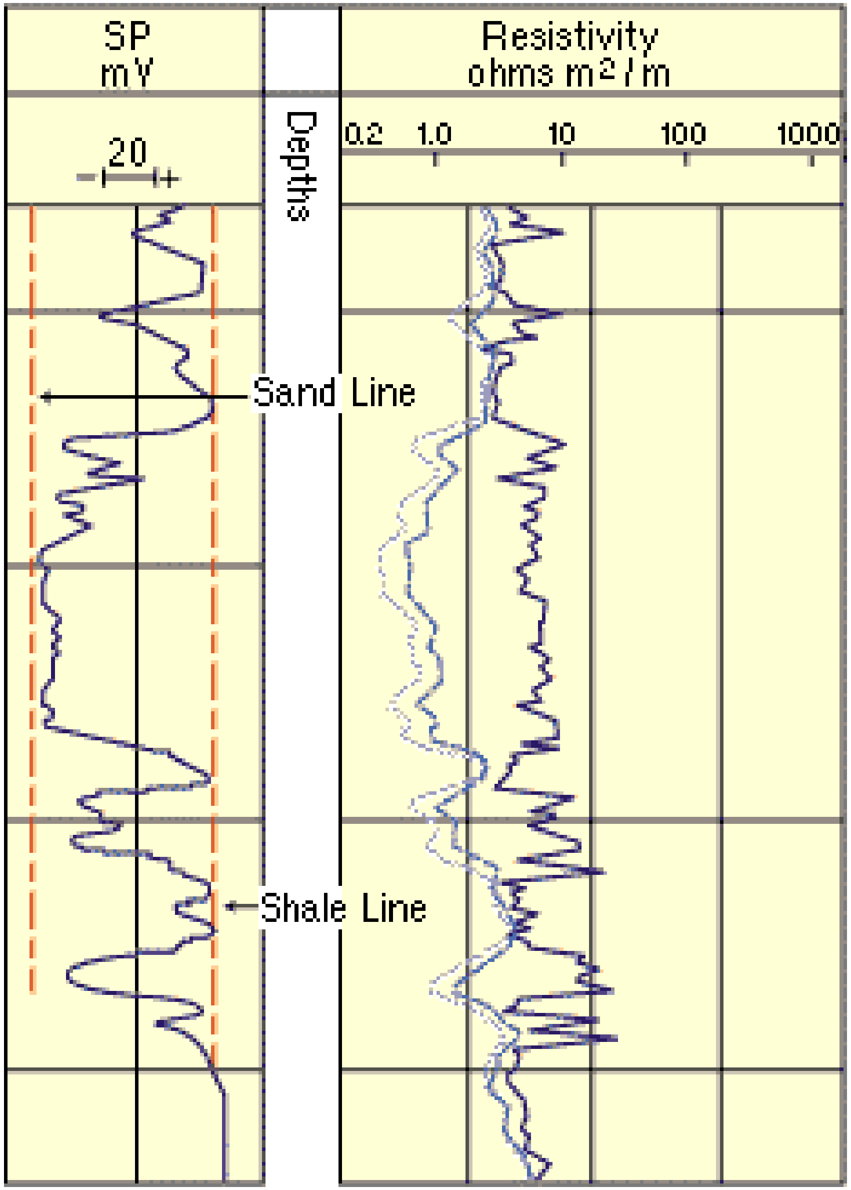
SP_{shale} is the value observed in a shale ;

SP_{clean} is the value observed in a clean, water-bearing sand;

We also call SP_{shale} the base line of shale .

SP Uses (3) Compute shale content

- Shale and sand baselines



When to Consider SP for V_{sh} Estimates

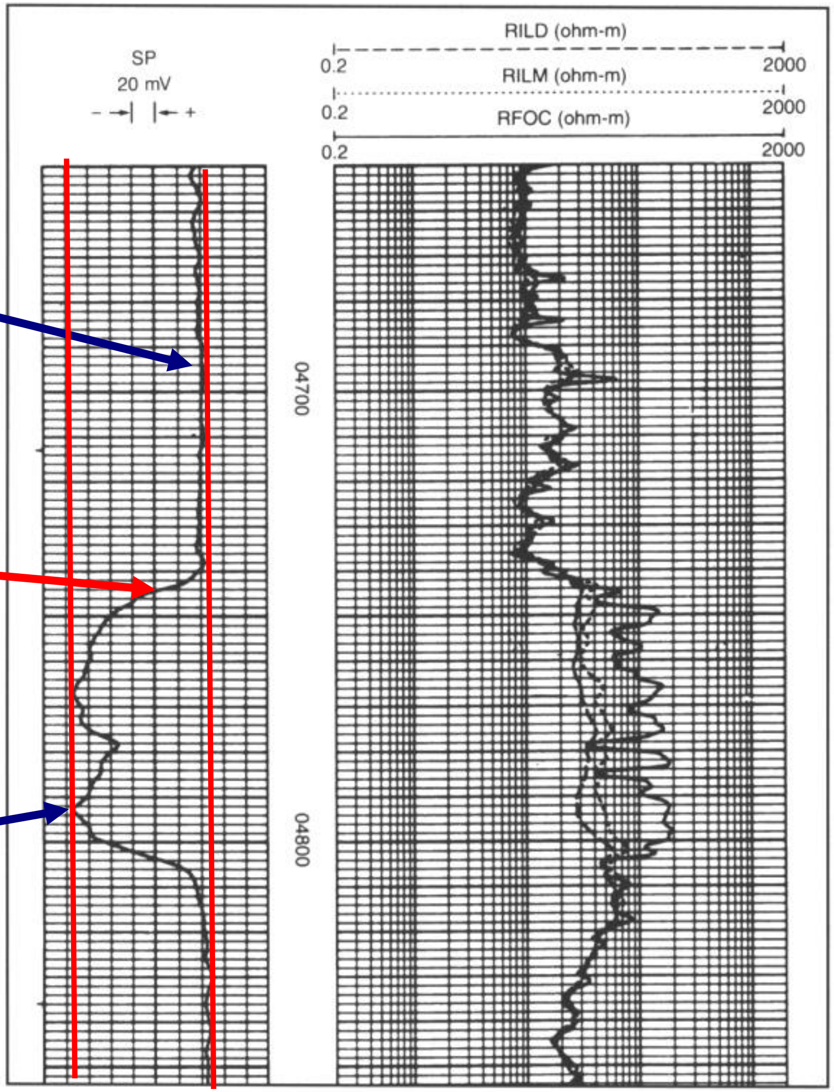
- Beds should be > 5 ft (1.5 m) thick
- R_{mf} / R_w contrast should be > 4.0
- Some permeability must exist

SP-Shale Volume

Shale have SP lying on the right side of the log (higher voltage).
Set as shale base line = 0 mv

Point A
2 divisions x 20 mv=40 mv

Clean, permeable rocks lie on the left side (lower voltage)
Set as sand base line =6 divisions x 20mv = 120 mv



SP-Shale Volume

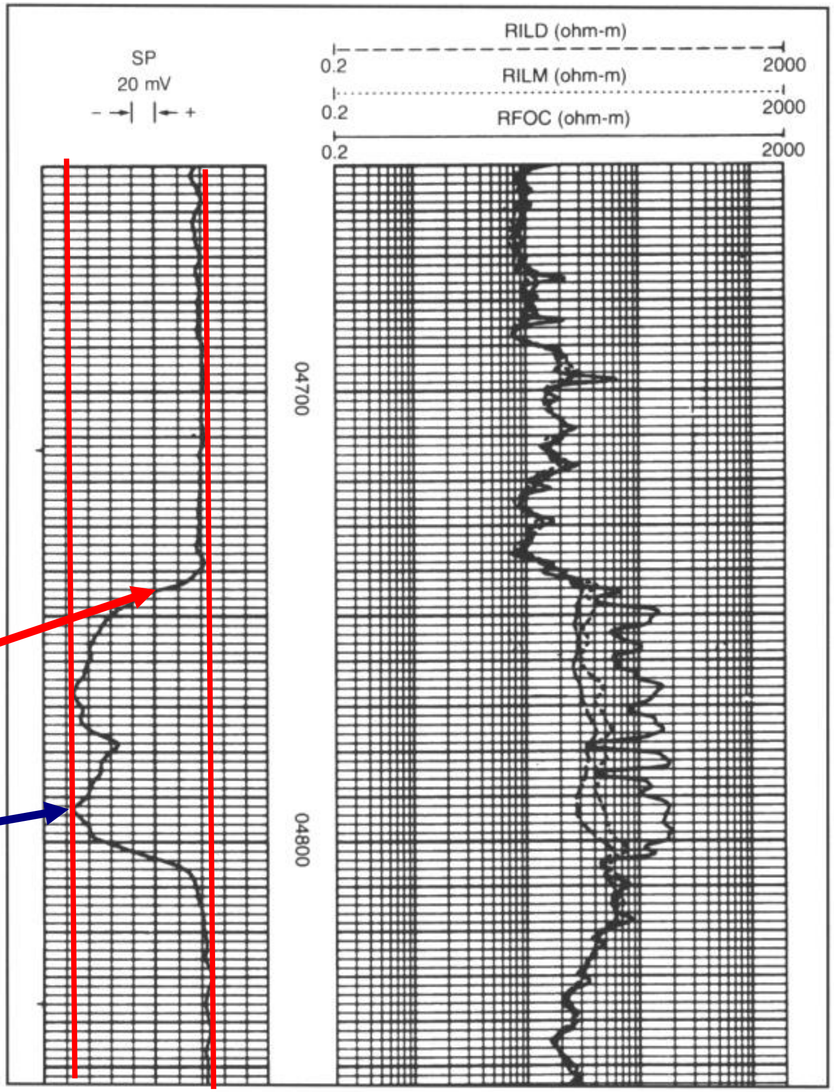
Estimate shale volume at Point A

$$V_{sh} = \frac{SP_{log} - SP_{clean}}{SP_{sh} - SP_{clean}}$$

$$V_{sh} = \frac{40 - 120}{0 - 120} = 0.67$$

Point A
2 divisions x 20 mv=40 mv

Clean, permeable rocks lie
on the left side (lower voltage)
Set as sand base line =6 divisions x 20mv
= 120 mv



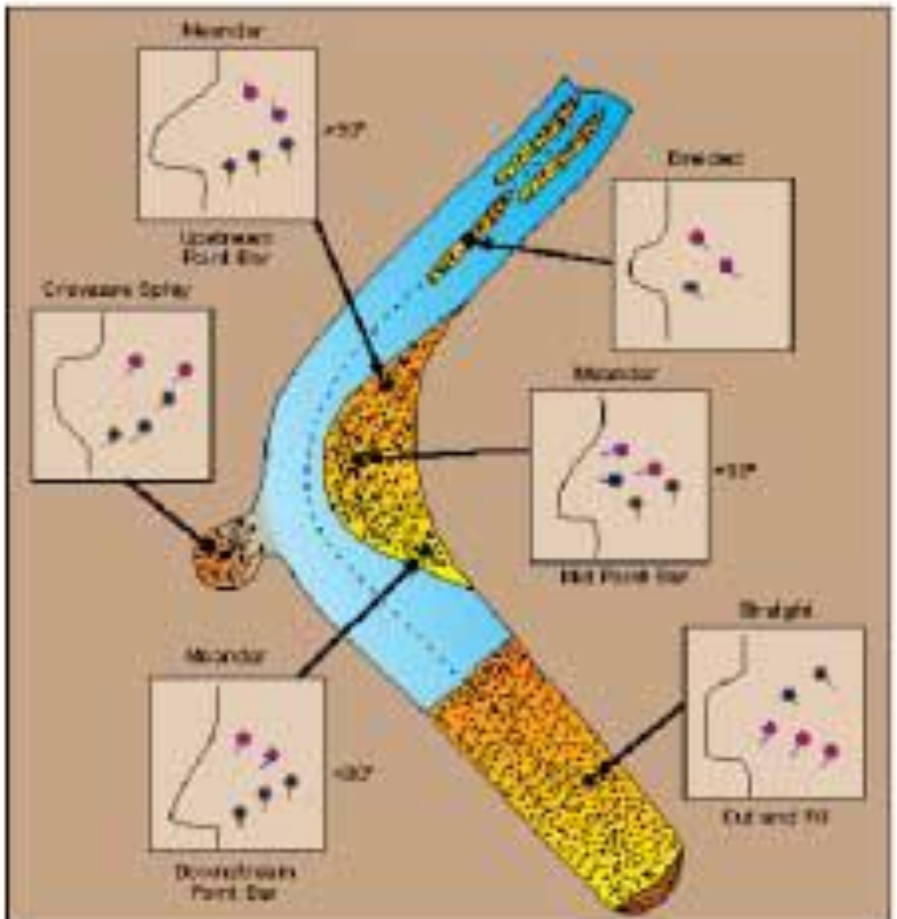
SP Uses

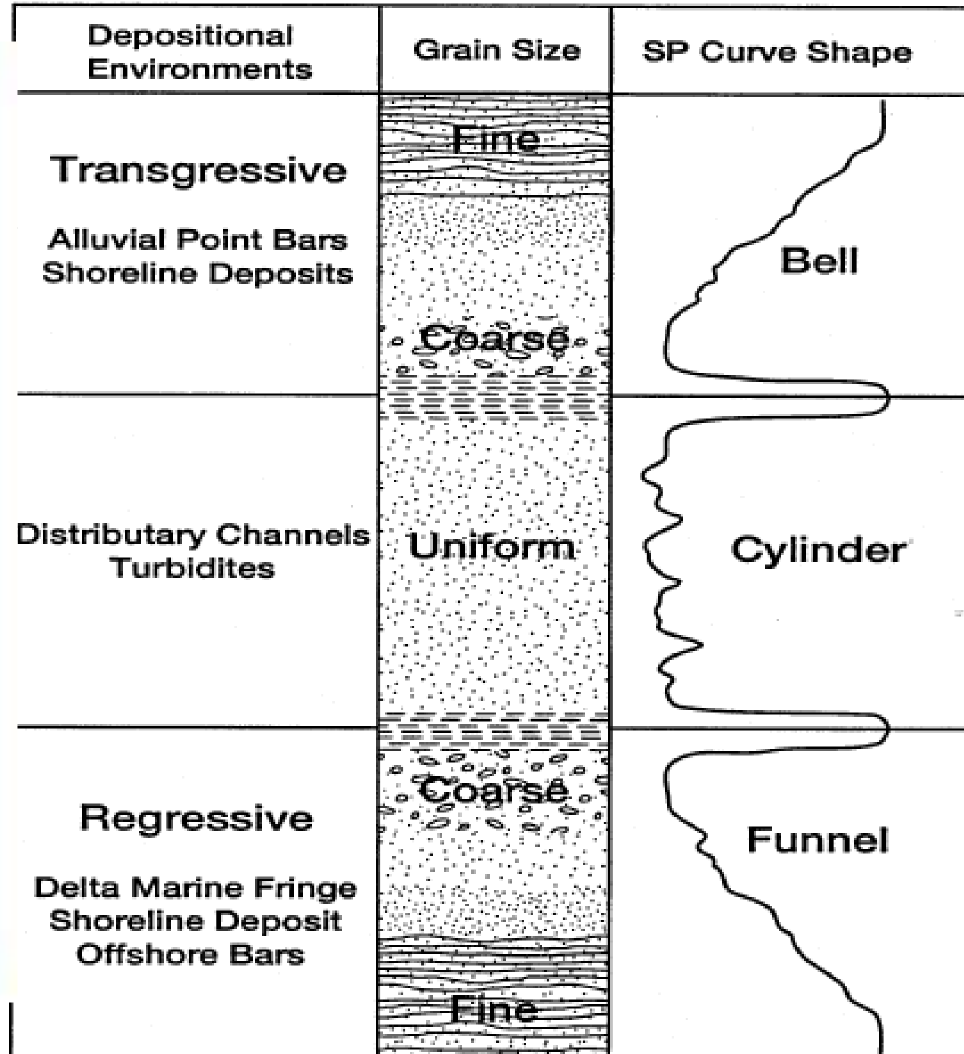
(4) Depositional Environment from the SP

- Since shales and clays are generally finer-grained than sands, a change in SP suggests a change in grain size. Thus, SP deflections can be indicate depositional sequences, where either sorting, grain size or cementation change with depth and produce characteristic SP shapes. These shapes are referred to as bells, funnels, or cylinders (Following Figure).

SP Uses

(4) Depositional Environment from the SP





SP Uses

(5) Determine values of formation water resistivity

SP's are useful for water resistivity (Rw) determination under the following favorable conditions:

- Available clean water bearing zone with a constant R_{mf} value for calibration
- Drilling mud : Moderate resistivity, conductive
- Formation water : NaCl waters with high salinity.
- Appreciable formation permeability
- Adequate bed thickness (at least 30 feet.)
- Hole size less than 10"
- **These conditions are rare, and large errors in the Rw estimate may occur. Use this technique with care!**

R_w used in Archie Eq. to calculate Water Saturation (S_w)

$$S_w^n = \frac{FR_w}{R_t},$$

SP Uses

(5) Determine values of formation water resistivity

- R_w is often known from client information or local knowledge.
- The SP can be used to check the value or to compute it when it is unavailable.

- SP curve can be used for estimation of R_w. The equation is :

$$SP = -K \log \frac{R_{mfe}}{R_{we}}$$

where R_{mfe}, R_{we} are "equivalent "R_{mf} or R_w which suppose no shoulder bed effect on them .

- K is a constant - depending on the temperature.
- $Kc = 61 + 0.133\ T^{o}F$
- $Kc = 65 + 0.24\ T^{o}C$

R_w from SP

(1) R_w from the SP- background

$$SP = -K \lg \frac{R_{mf}}{R_w}$$

- Where SP is measured in millivolts and K is a constant which depends on temperature.
- The SP deflection can be read in a shale-free water-bearing sand that is thick enough to allow for full development of the potential.
- A reasonable approximation for K is:
- $K = (T_f + 505)/8$ where T_f is formation temperature in °F, and
- $K = (T_f + 336)/5$ where T_f is formation temperature in °C.

R_w from SP

(2) R_w from the SP-Classical Method

1) Determine formation temperature T_f.

2) Find R_{mf} at formation temperature.

3) Convert R_{mf} at formation temperature to an R_{mfe} value.

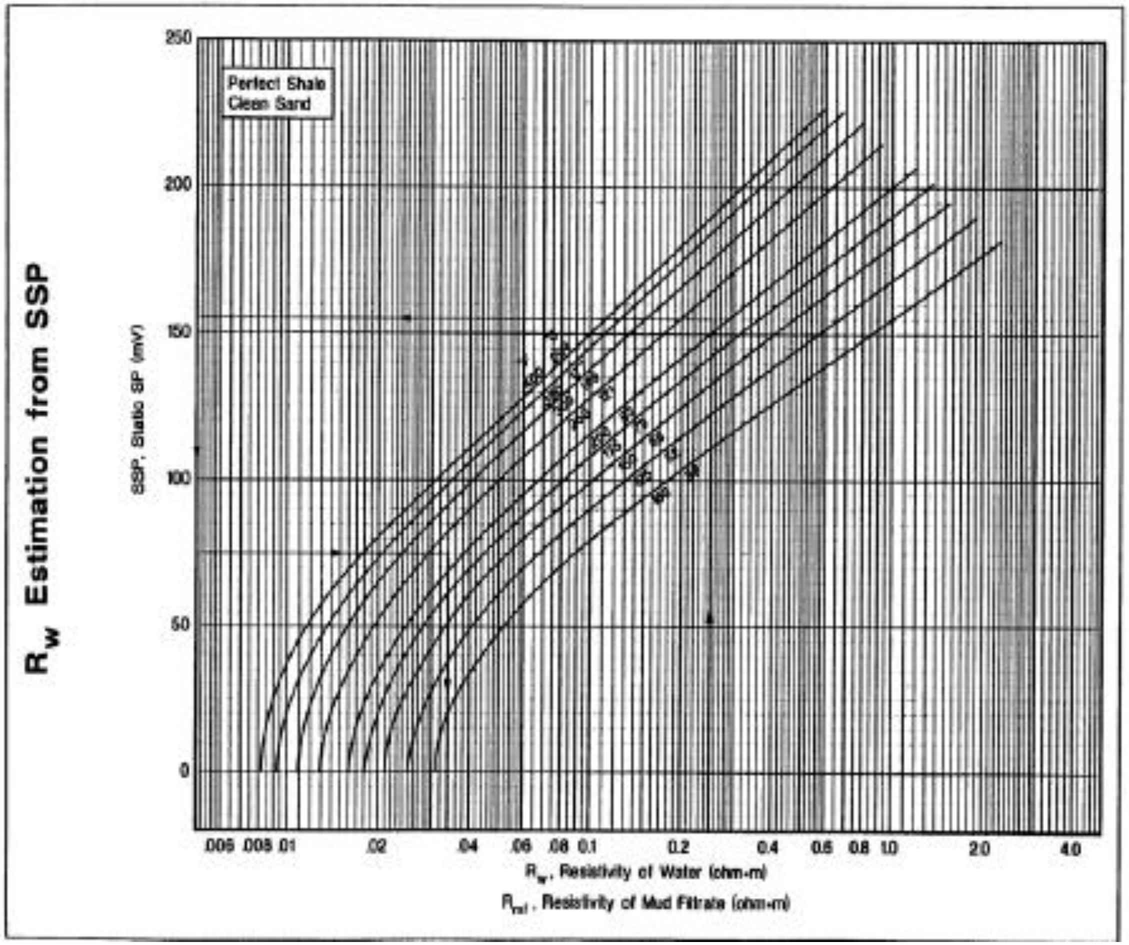
4) Compute the R_{mfe}/R_{we} ratio from the SP.

5) Compute R_{we}

6) Convert R_{we} at formation temperature to an R_w value.

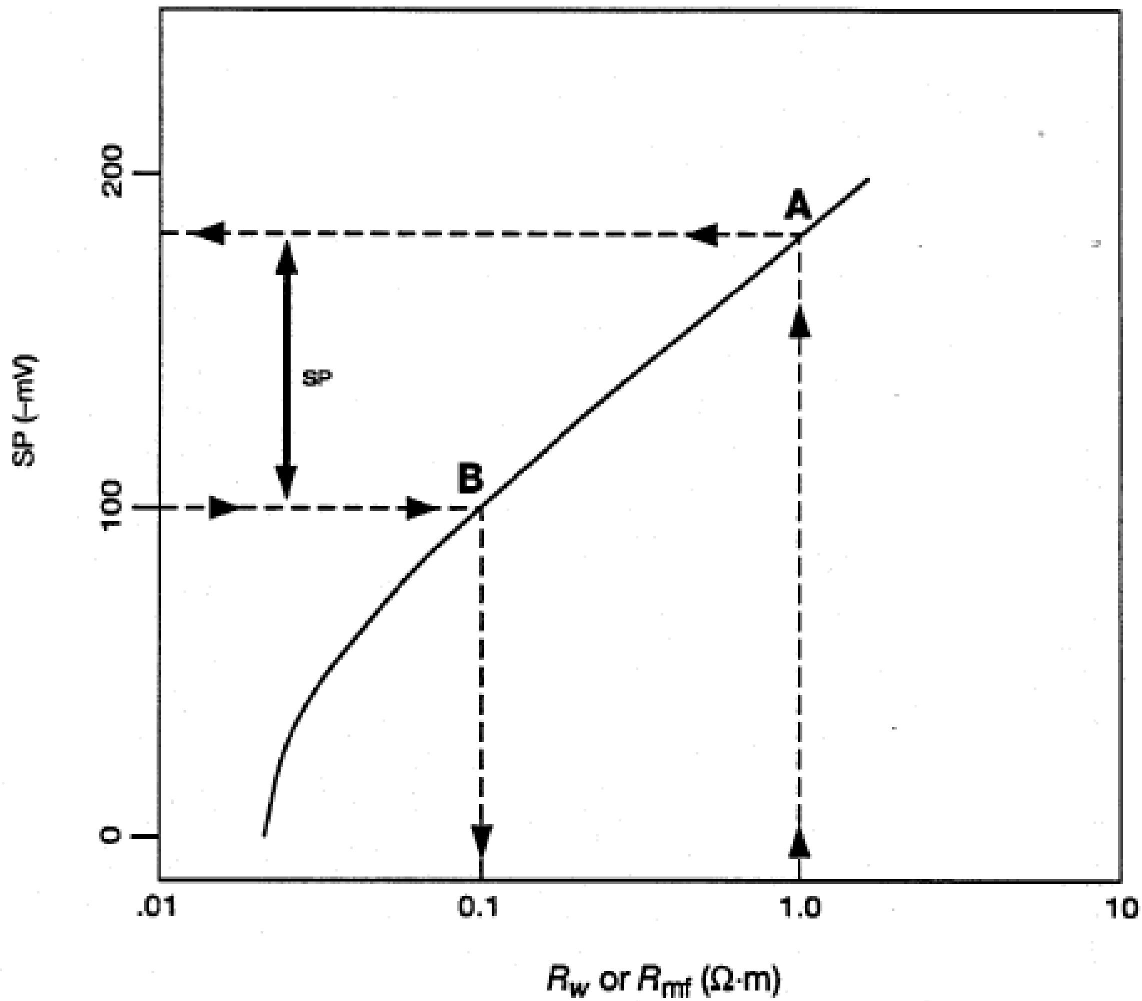
(3) Rw from the SP-Silva-Bassiouni Method

- A recent study has found that a simple method is available and theoretically justified.
- The entire process is reduced to a single chart, shown in the right Figure.



(3) Rw from the SP-Silva-Bassiouni Method

- The use of the chart is illustrated in the right Figure.



Limitations

- The SP cannot be recorded in air or oil-base muds, since there is no conductive fluid in the borehole.
- Conductive mud is essential for generation of a spontaneous potential.
- In salt-mud, SP tends to be straight line (less salinity contrast).
- If bed is too thin, the full SP will not develop. Chart exist to correct for this effect, but only significant for bed thickness < 20ft.
- Hydrocarbon and shale in the formation reduce SP development.

Conclusions

- The Spontaneous Potential (SP) is due to a combination of two phenomena :

Electrochemical potential : Created by the contact of two solutions of different salinity. Composed of a membrane potential and a liquid junction potential.

Electrokinetic potential: Created when a solution is forced, by differential pressure, to flow through a membrane. Usually negligible.

Conclusions

- SP Log is usually used to identify permeable zones, bed boundaries and depositional environment ; and to compute shale content and formation water resistivity Rw.
- Reasonable salinity difference between formation water and mud column, bed thickness and borehole diameter are the most important requirements for SP usage.

Thank You