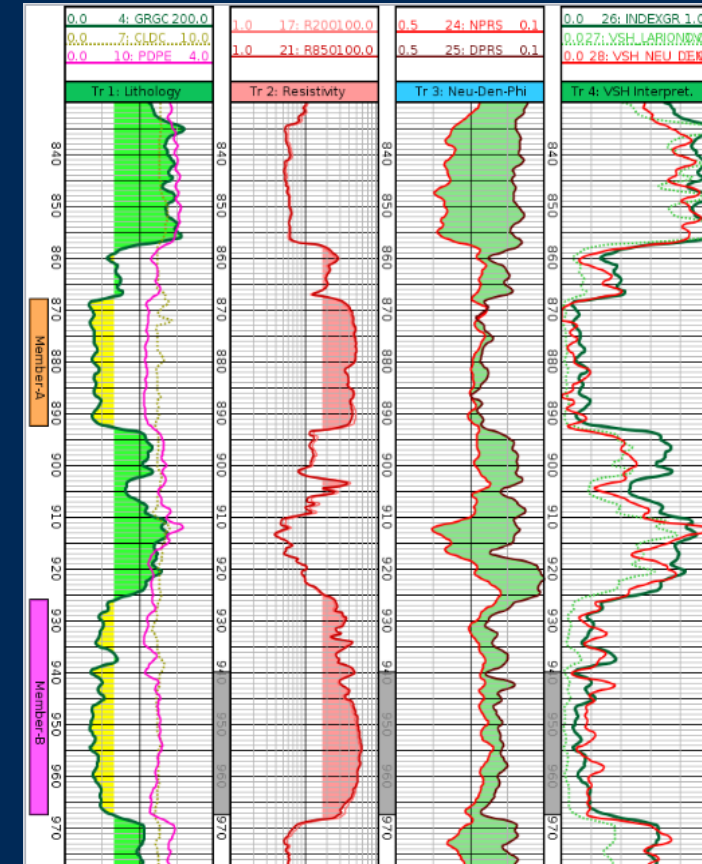
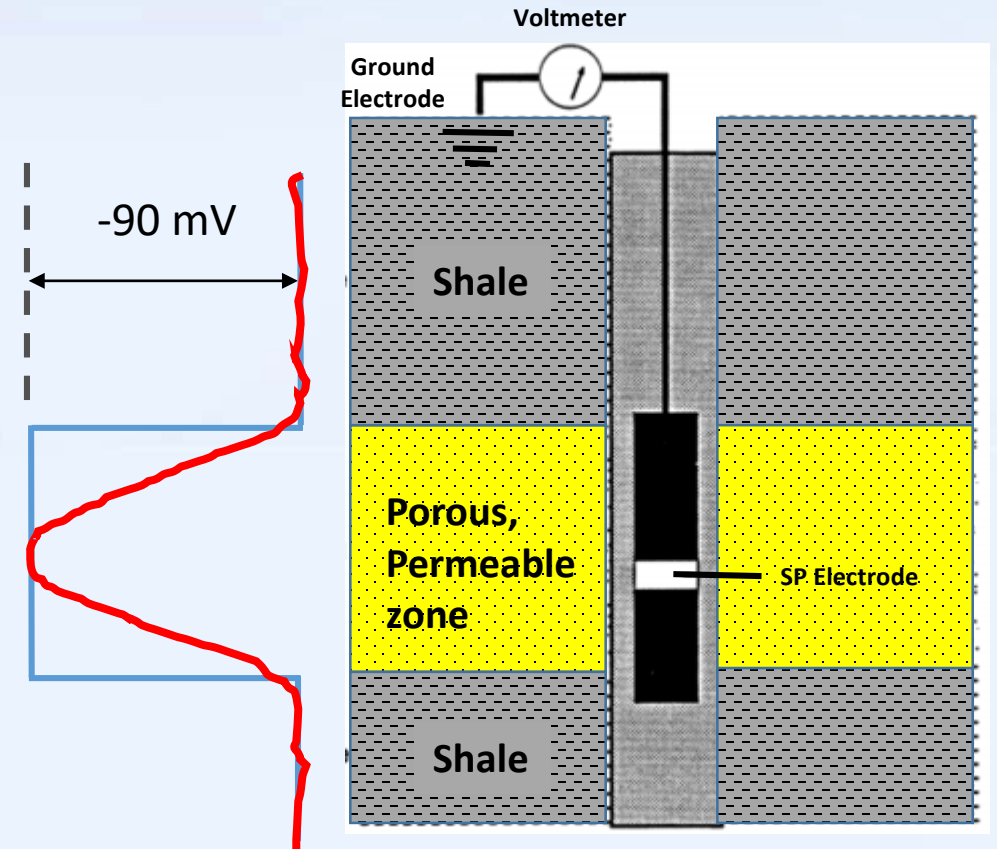


Spontaneous Potential Log SP Log



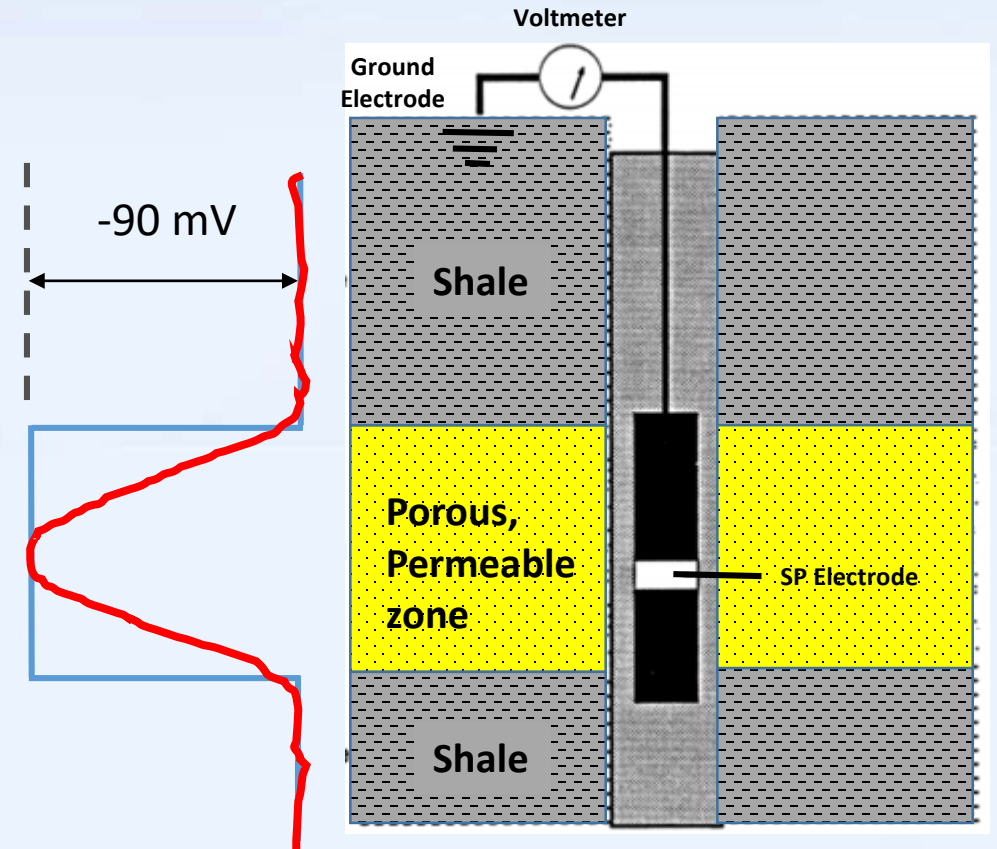
Introduction

- ❑ SP is a passive measurement and no energy is provided by the logging tool.
- ❑ SP log is a record of direct current (DC) voltage differences between the naturally occurring potential of a moveable electrode in the well bore, and the potential of a fixed electrode located at the surface.
- ❑ Electric potentials are created by chemically induced electric current.
- ❑ This electric potential is measured in **millivolts**.



Applications

- ❑ Indicating permeable zones
- ❑ Detecting permeable zone boundary
- ❑ Indicating shaliness (shale volume) of a formation
- ❑ Determining R_w and hence of formation water salinity
- ❑ Indicating depositional environment changes
- ❑ Correlation



SP Sources

1) Electrochemical :

- **Liquid Junction Potential (E_{lj})**

- ✓ Diffusion of ions with higher mobility (Cl^-) from concentrated solution to the dilute solution.
- ✓ Happens from virgin zone to the invaded zone.

- **Membrane Potential (E_m)**

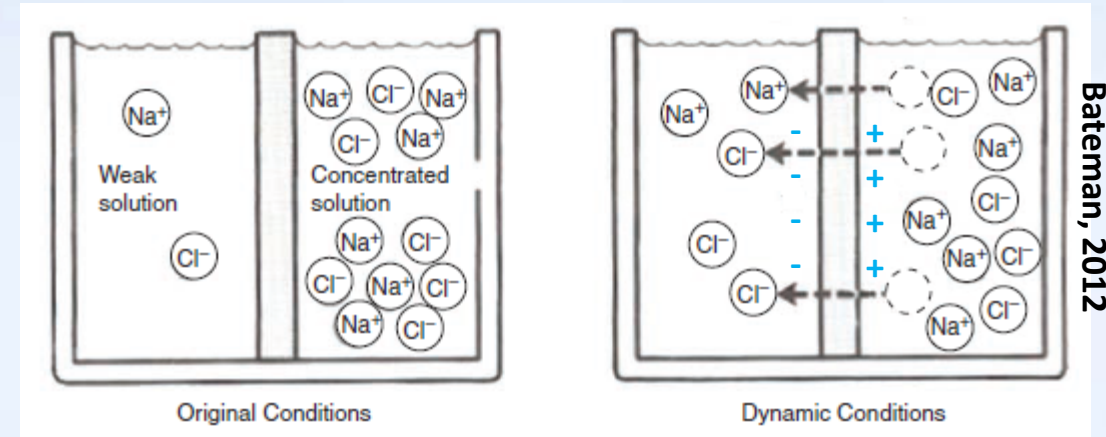
- ✓ Selective diffusion of ions (Na^+) from concentrated solution to the dilute solution.
- ✓ Happens from virgin zone to the borehole.
- ✓ Dominant source of SP

2) Electro-Kinetic :

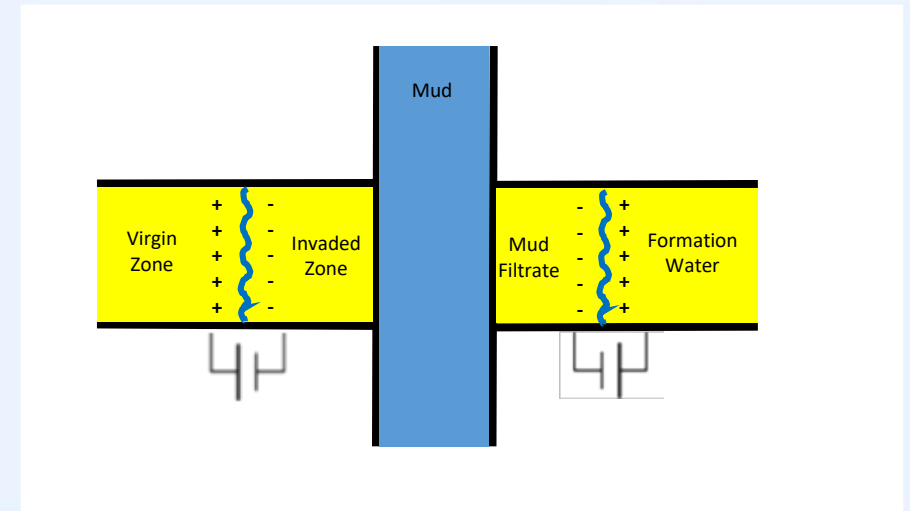
- ✓ Produces by electrolyte passage through porous media (E_k)
- ✓ Small potential and commonly disregarded.

Liquid Junction Potential

- If two sodium chloride solutions of different concentrations are separated by a permeable membrane, then ions from the most concentrated solution will tend to migrate into the less concentrated solution.
- Na^+ and Cl^- ions do not move with the same alacrity. Cl^- ions (anions) move faster than Na^+ ions (cations). The net effect of more anions (negative ions) in the weak solution and more cations (positive ions) in the more concentrated solution creates a potential difference. This is known as a **liquid junction effect**.
- In terms of the solutions present in a formation, mud filtrate can be substituted for the weak solution and formation water for the more concentrated solution. The potential is referred to as the **liquid-junction potential (E_{lj})**.

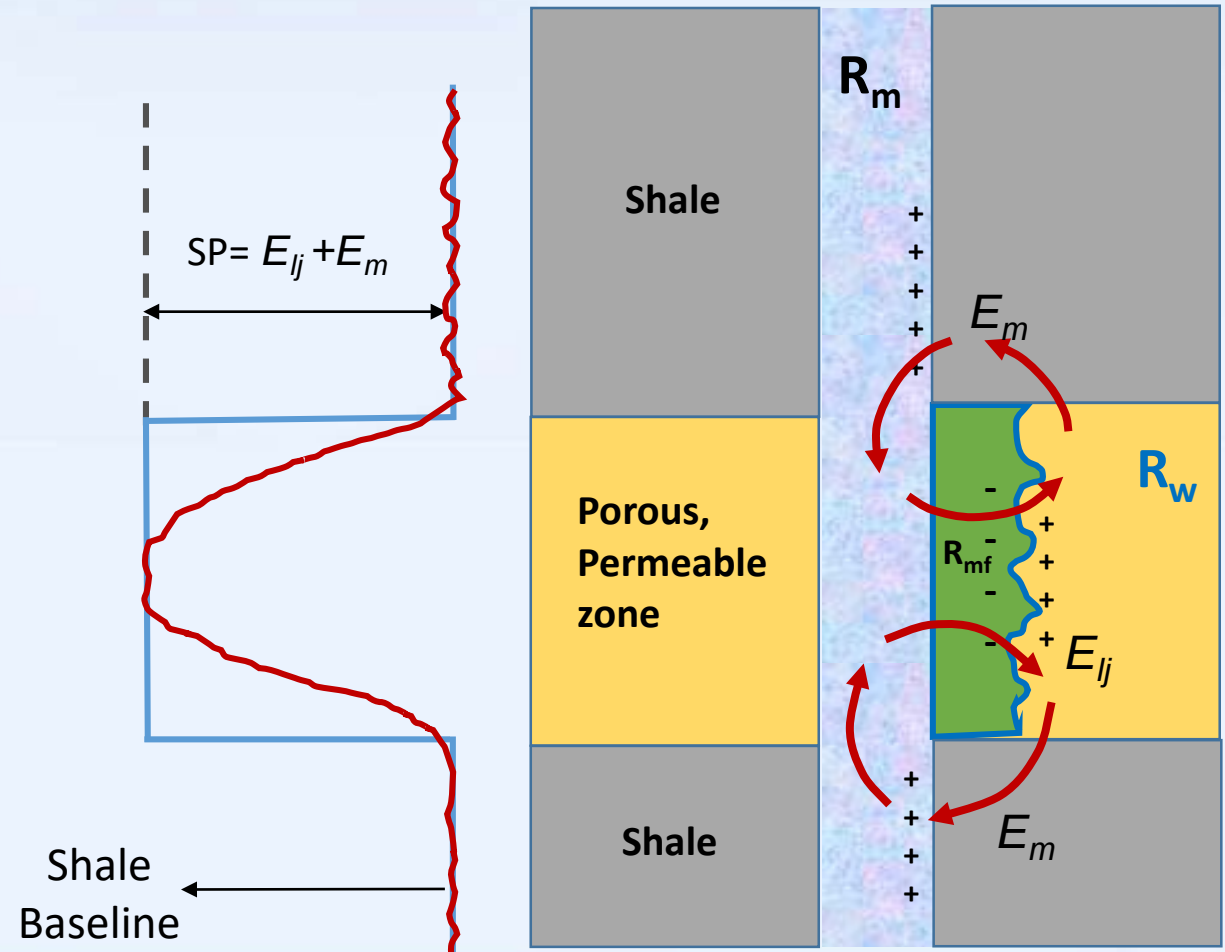


Bateman, 2012



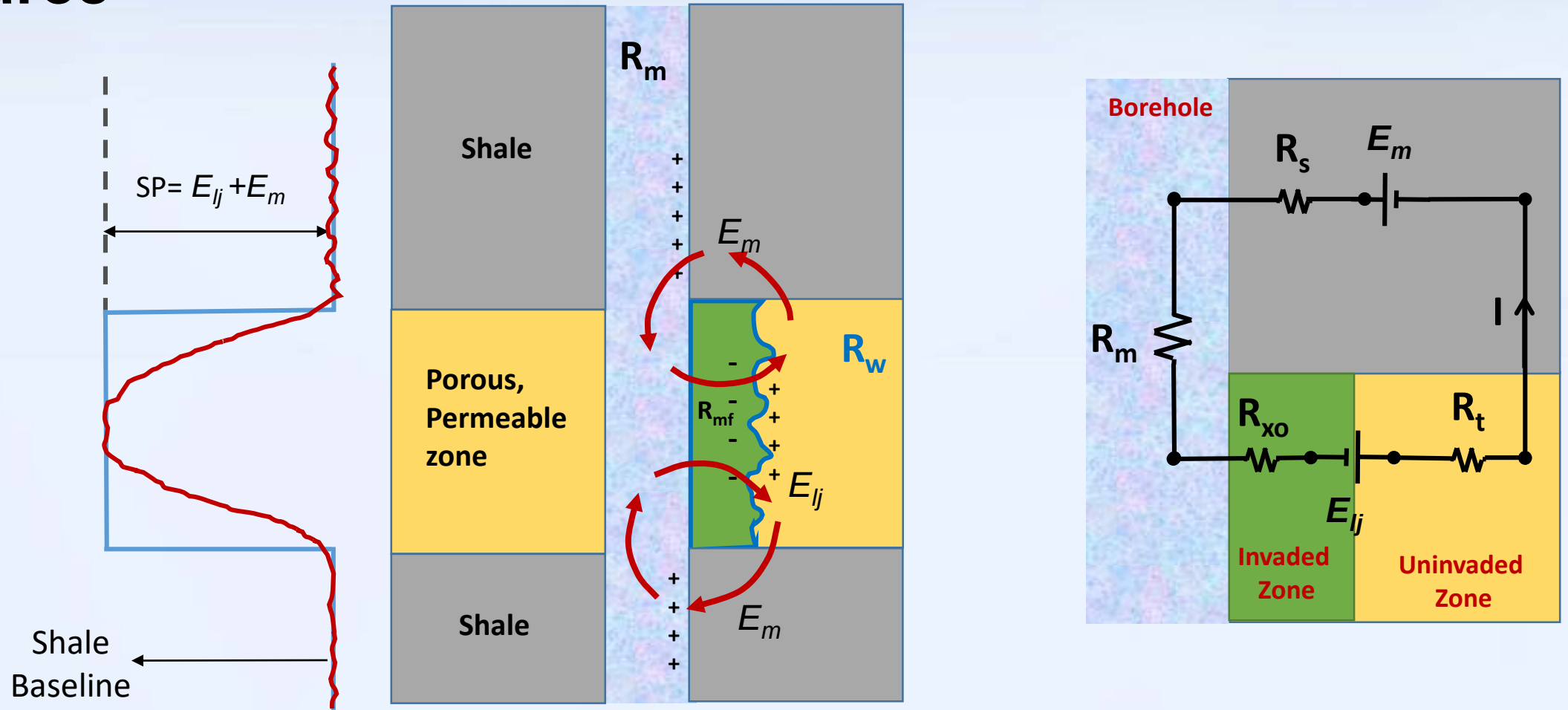
Membrane Potential

- Shales are permeable to Na^+ ions, but not so permeable to Cl^- ions. A shale, therefore, acts as an ionic sieve. This phenomenon occurs because of the crystalline structure of clay minerals, which have exterior surfaces with exchange sites to which cations can temporarily cling.
- Because Na^+ ions effectively manage to penetrate the shale bed from the saline formation water to the less saline mud column, a so-called **membrane potential (E_m)** is created.
- $E_T = E_{lj} + E_m = SP$



SP Log

SP Source

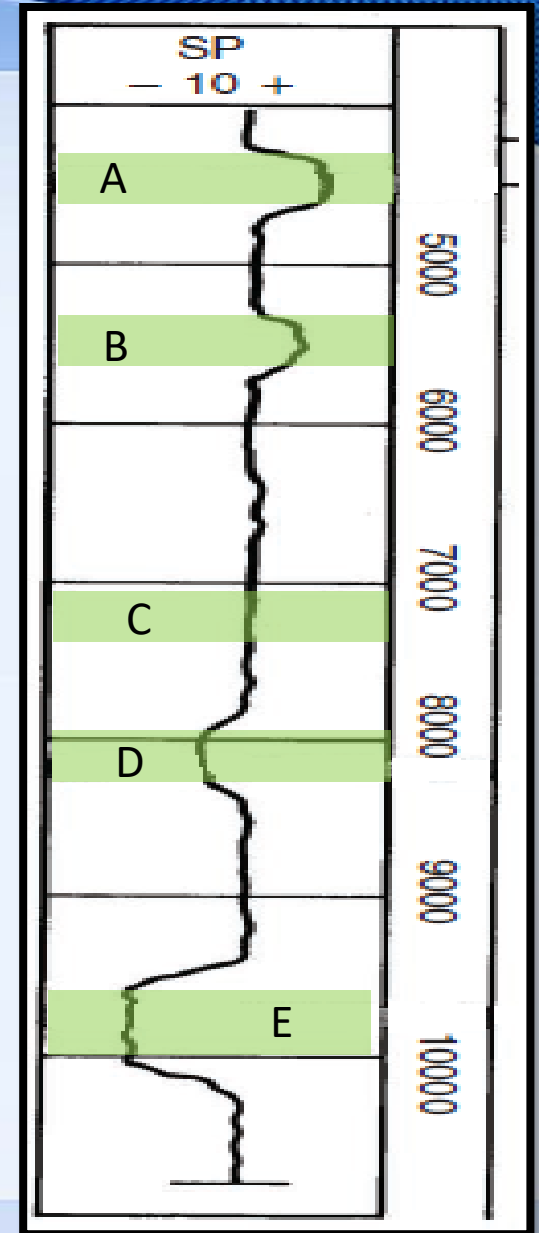


Normal SP vs. Reverse SP

- A. $R_w \gg R_{mf}$ Large positive (right) deflection
- B. $R_w > R_{mf}$ Positive (right deflection)
- C. $R_w = R_{mf}$ No deflection
- D. $R_w < R_{mf}$ Negative (left) deflection
- E. $R_w \ll R_{mf}$ Large negative (left) deflection

Reverse SP
Positive

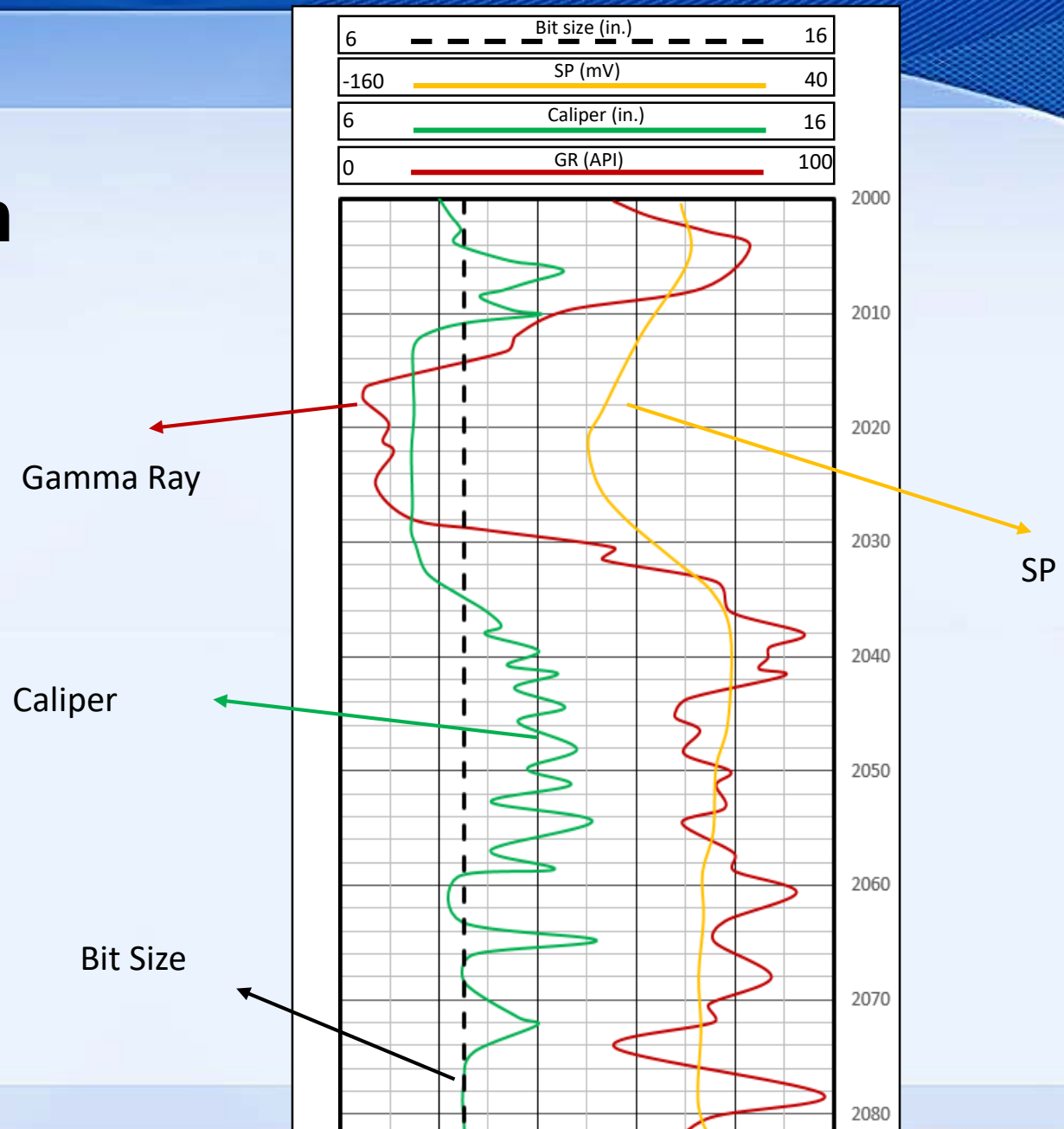
Normal SP
Negative



SP Log

SP Log Presentation

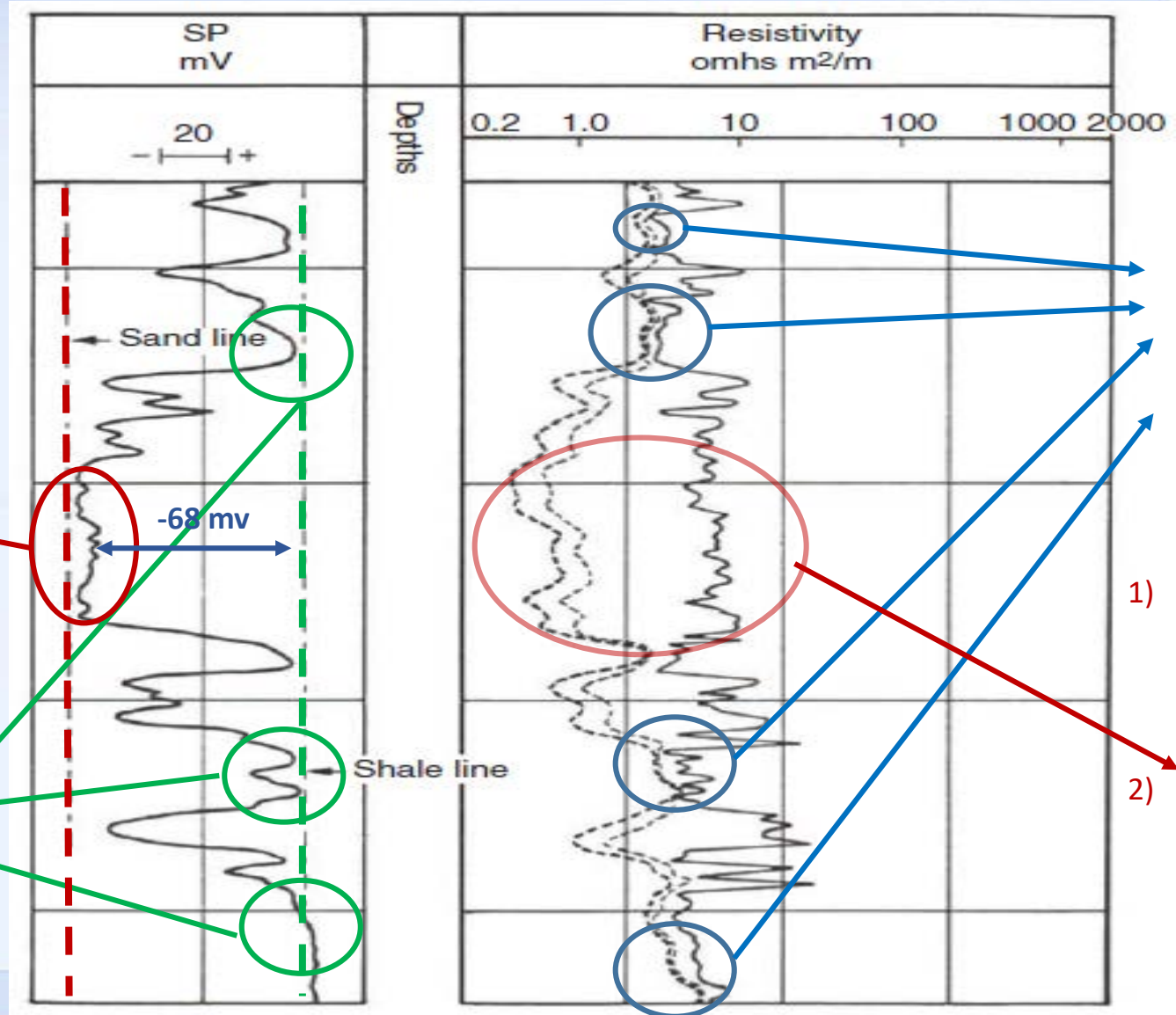
- Usually on Track 1
- Linear
- Increasing left to right



Shale/Sand Lines

High SP deflection combined with GR log (Not available here) would suggest sandy formation

Shale baseline is the SP @ thick shale zone or several shale zones



No separation in resistivity logs along high SP (GR) is indicative of non permeable zone (shale)

- 1) Separation between resistivity logs is indicative of permeable zone
- 2) Low resistivity suggests water bearing zone

SP as Shale Indicator

The presence of shale in an otherwise clean sand will tend to reduce the SP. This fact can be used to estimate the shale content of a formation. If SP_{sand} is the value observed in a clean, water-bearing sand and SP_{shale} is the value observed in shale, then any intermediate value of the SP may be converted into a value for the shale volume (V_{sh}) by use of the following relationship:

$$(V_{sh})_{SP} = \frac{SP - SP_{sand}}{SP_{shale} - SP_{sand}}$$

SP Log

Example

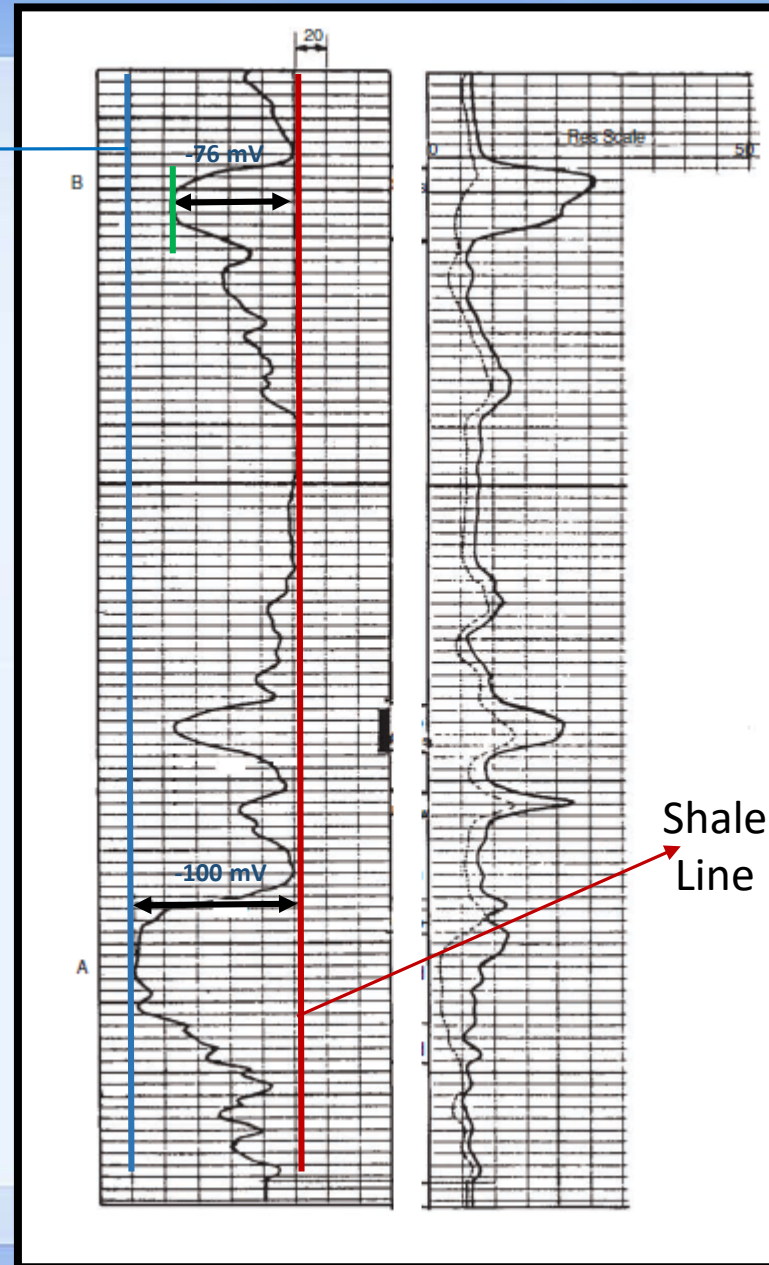
What is the shale volume in zone "B" if Zone "A" is a clean water bearing sand zone?

$$(V_{sh})_{SP} = \frac{SP - SP_{sand}}{SP_{shale} - SP_{sand}} =$$

$$\frac{(SP_{shale} - SP_{sand}) - (SP_{shale} - SP)}{SP_{shale} - SP_{sand}}$$

$$(V_{sh})_{SP} = \frac{-100mV - (-76 mV)}{-100 mV} = 24\%$$

Sand
Baseline



Static SP (SSP)

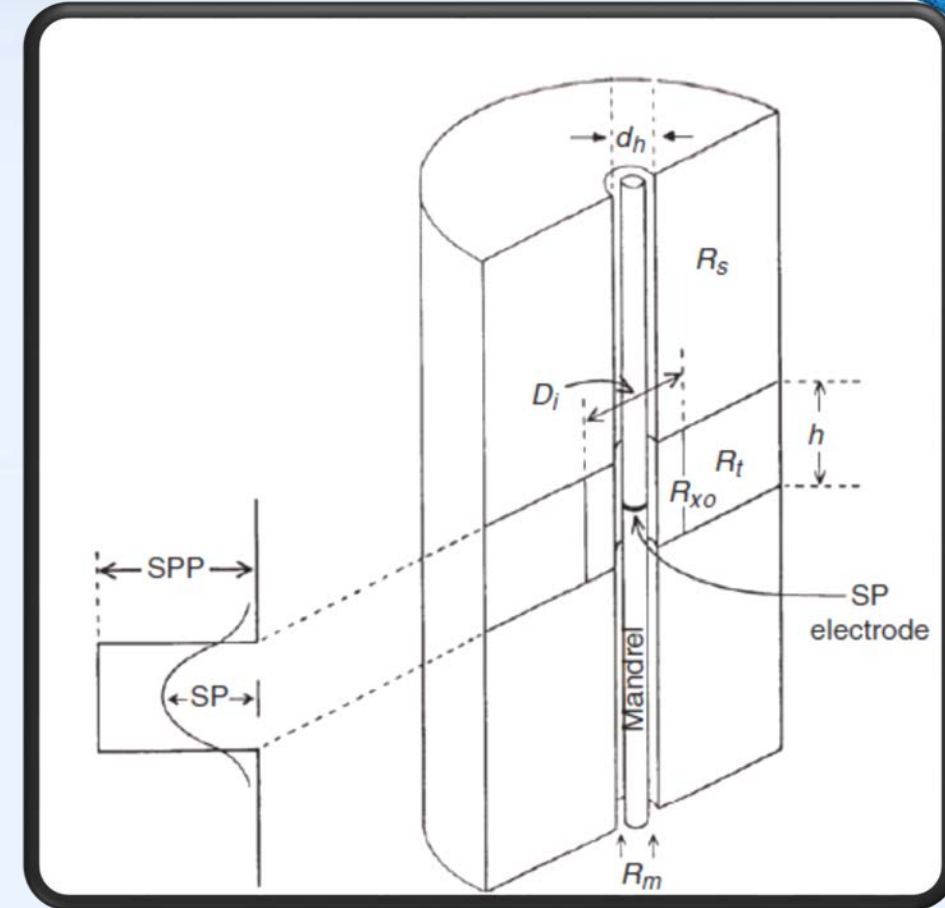
In the terminology used here, SP refers to observed SP deflection on the log and SSP (static SP) to the value it would have had if all disturbing influences were removed. These disturbing influences result in a smaller recorded SP deflection than SSP deflection.

Conditions where SP measurement is equal to SSP:

- ✓ Thick formations
- ✓ Water-bearing zones
- ✓ Clean (no shale) zones
- ✓ High permeable formations

Factors Affecting SP

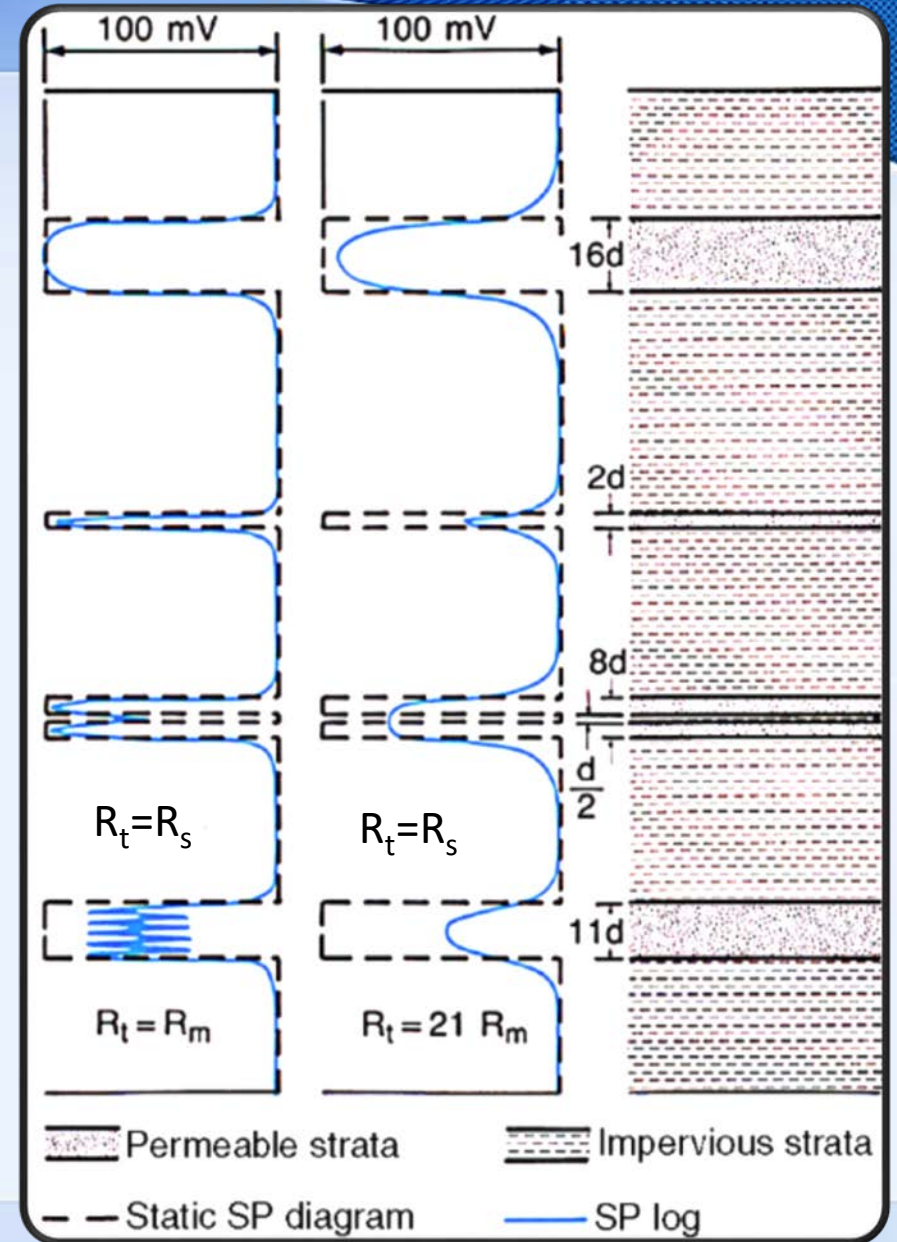
- ✓ No SP in oil-based muds: absence of electrical path in the mud column
- ✓ Shaly formation will reduce the measured SP.
- ✓ Hydrocarbon saturation reduces SP deflection.
- ✓ Thin beds avoid SP to fully develop.
- ✓ SP amplitude deflection is also affected by following parameters:
 - The formation true resistivity, R_t .
 - The invaded zone diameter, D_i .
 - The invaded zone resistivity, R_{xo} .
 - The surrounding formations resistivity, R_s .
 - The mud resistivity, R_m .
 - The diameter of the borehole, d_h .



Bateman, 2012

SP Log

Effect of Bed Thickness, R_m/R_t on SP



From Schlumberger

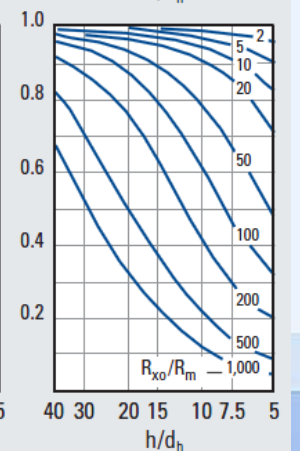
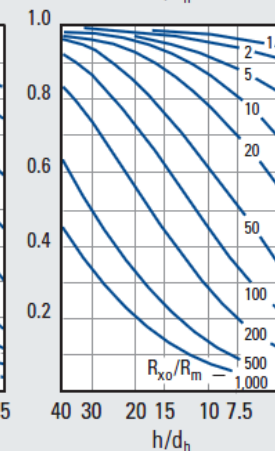
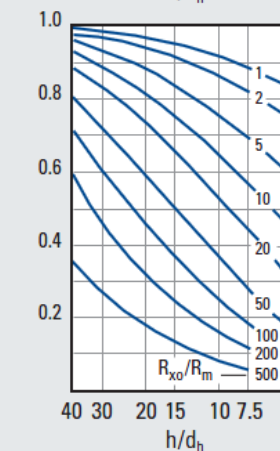
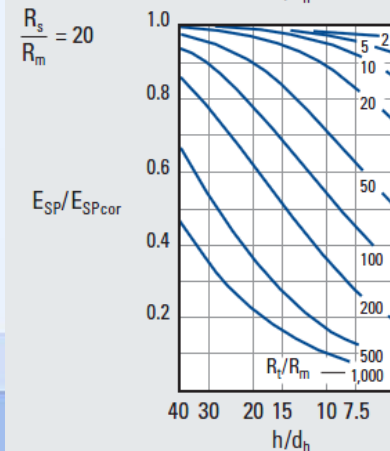
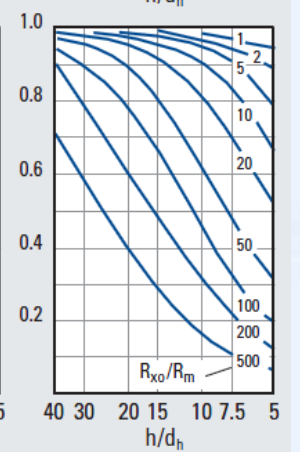
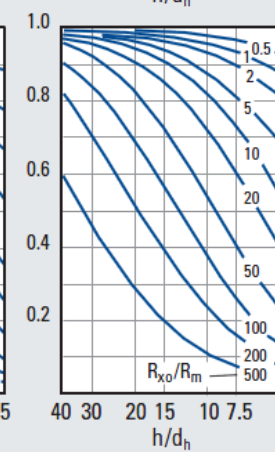
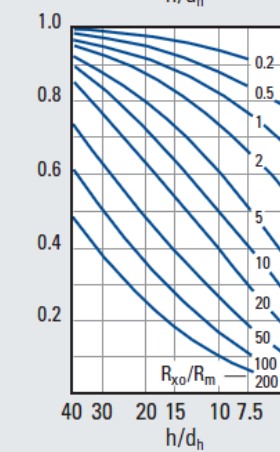
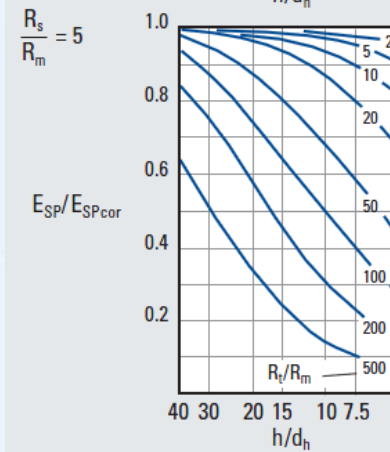
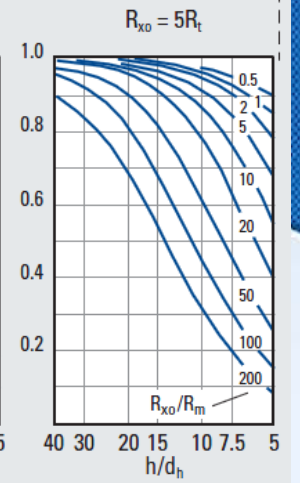
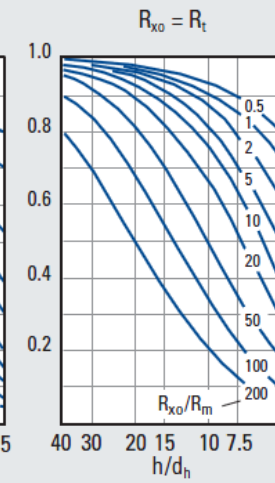
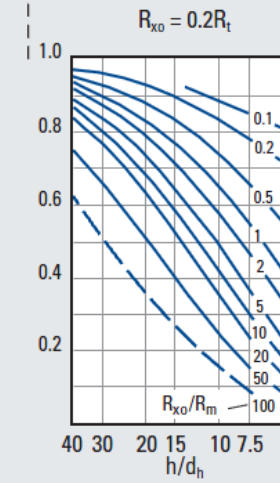
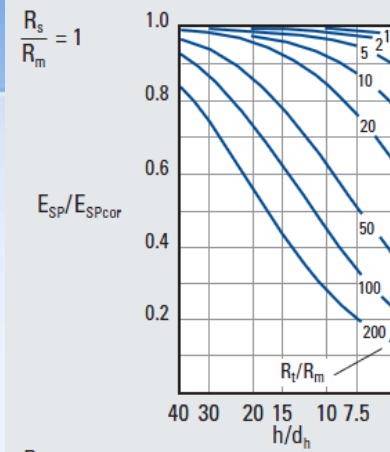
SP Log

SP Thickness Correction

SP-4

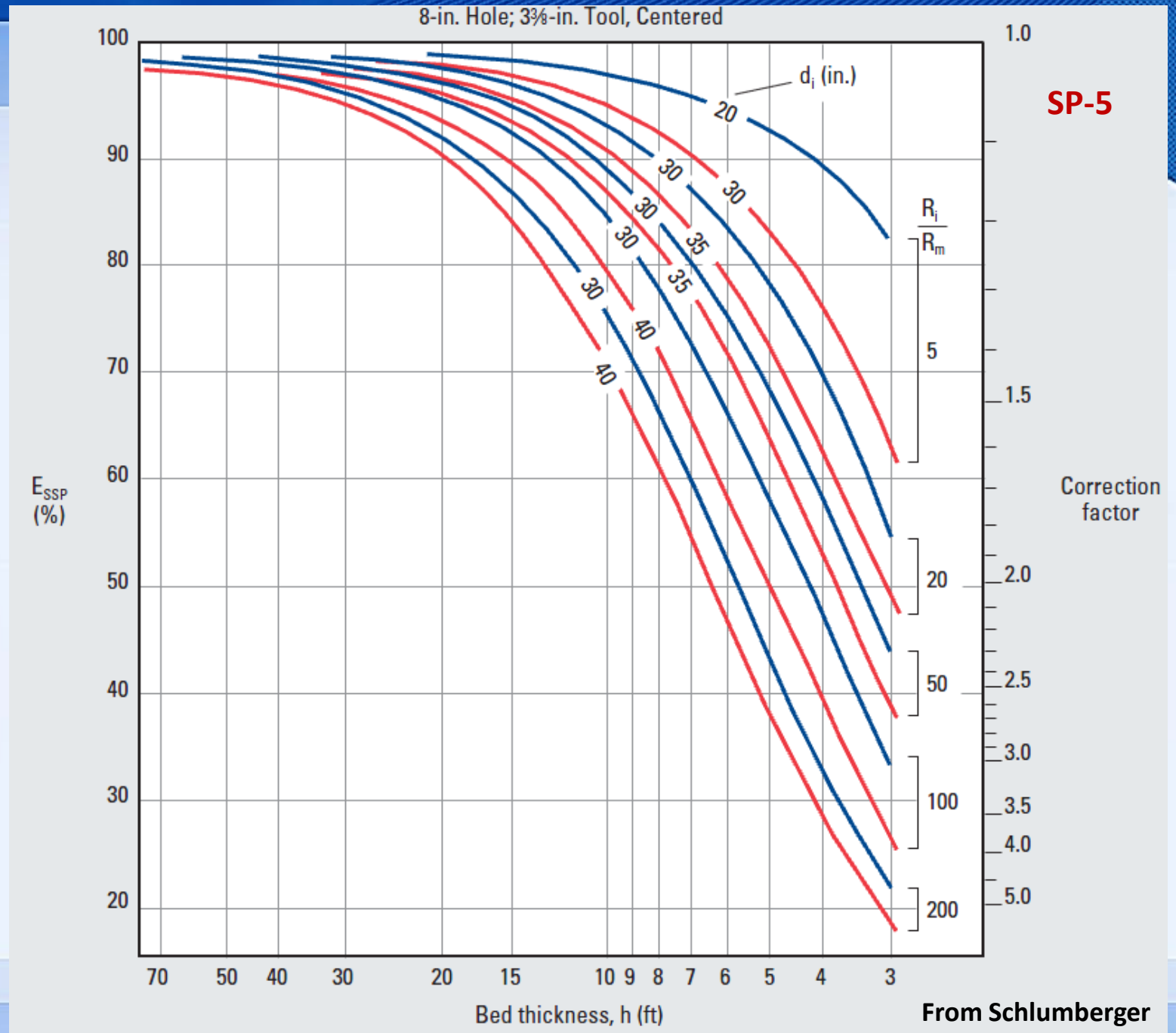
No Invasion

Invasion, $d_i/d_h = 5$



SP Log

SP Thickness Correction (Empirical)



SP Log

Determining R_w from SP Log (Bateman and Konen 1977)

Step by Step Procedure by Using Charts:

1) Reading R_{mf} @ surface temperature, Max depth and Max Temp from Log header

2) Estimating formation temperature from chart **Gen-2**.

3) Calculating R_{mf} @ formation temperature and 75°F using chart **Gen-6**.

4) Converting R_{mf} to R_{mfe} :

if $R_{mf} > 0.1 \Omega.m$ @ 75 °F, $R_{mfe} = 0.85R_{mf}$

if $R_{mf} < 0.1 \Omega.m$ 75 °F, use chart **SP-2**

5) Calculating R_{we} : $SSP = -K \log \frac{R_{mfe}}{R_{we}}$

SP must be corrected for SSP (SP-4 or SP-5)

6) Converting R_{we} to R_w @ formation temperature using chart **SP-2**

SP Log

Determining R_w from SP Log (Bateman and Konen 1977)

Step by Step Procedure by Using Equations:

1) Reading R_{mf} @ surface temperature, Max depth and Max Temp from Log header

2) Estimating formation temperature:

$$T_f = T_{surf} + Depth \times Temp. Gradient$$

3) Calculating R_{mf} @ 75°F :

$$R_2 = R_1 \frac{T_1 + 6.77}{T_2 + 6.77} \text{ } ^\circ\text{F}$$

4) Converting R_{mf} to R_{mfe} :

$$R_{mfe} = \begin{cases} 0.85 \times R_{mf} & \text{if } R_{mf} > 0.1 \text{ at } 75^\circ\text{F} \\ \frac{146R_{mf} - 5}{377R_{mf} + 77} & \text{if } R_{mf} < 0.1 \text{ at } 75^\circ\text{F} \end{cases}$$

5) Calculating R_{we} from:

$$SSP = -K \log \frac{R_{mfe}}{R_{we}} \quad \text{SP must be corrected for SSP (SP-4 or SP-5)}$$

6) Converting R_{we} to R_w @ 75°F :

$$R_w = \begin{cases} -(0.58 - 10^{(0.69 \times R_{we} - 0.24)}) & \text{if } R_{we} > 0.12 \text{ at } 75^\circ\text{F} \\ \frac{77R_{we} + 5}{146 - 377R_{we}} & \text{if } R_{we} < 0.12 \text{ at } 75^\circ\text{F} \end{cases}$$

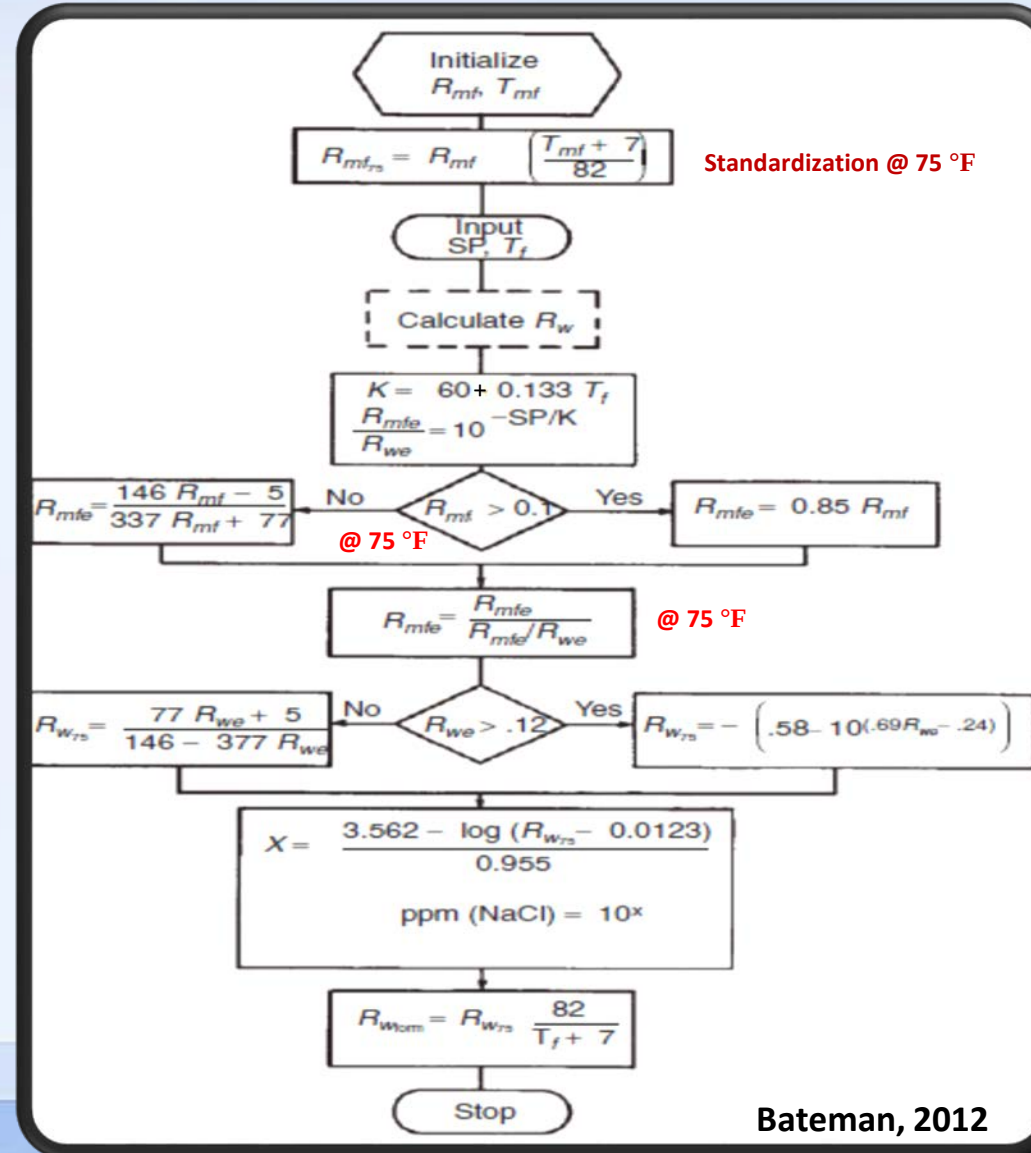
7) Calculating R_w @ formation Temp. :

$$R_2 = R_1 \frac{T_1 + 6.77}{T_2 + 6.77}$$

SP Log

Determining R_w from SP Log (Bateman and Konen 1977)

By Using Equations



Example

The R_{mf} is measured $0.0676 \Omega.m$ @ $90^\circ F$. If SP is measured in a thick, clean water bearing zone to be -120 mV at depth of $11,000 \text{ ft}$, what is the water formation resistivity, R_w ?

The temperature gradient is $1^\circ F/100\text{ft}$ and annual mean surface temperature is $70^\circ F$.

- 1) By using charts
- 2) By using equations (computations)

SP Log

Example

1) Finding Formation Temperature

$$T_f = T_{surf} + Depth \times Temp. Gradient$$

$$T_f = 70 + 11,000 \times 1.0 \frac{^{\circ}F}{100ft} = 180^{\circ}F$$

2) Calculating R_{mf} @ $75^{\circ}F$:

$$R_2 = R_1 \frac{T_1 + 6.77}{T_2 + 6.77} \quad ^{\circ}F$$

$$R_2 = 0.0676 \frac{90 + 6.77}{75 + 6.77} = 0.08 \Omega.m \quad R_{mf} @ 75^{\circ}F$$

3) Converting R_{mf} to R_{mfe} :

$$R_{mfe} = \begin{cases} 0.85 \times R_{mf} & \text{if } R_{mf} > 0.1 \text{ at } 75^{\circ}F \\ \frac{146R_{mf} - 5}{377R_{mf} + 77} & \text{if } R_{mf} < 0.1 \text{ at } 75^{\circ}F \end{cases}$$

$$R_{mfe} = \frac{146R_{mf} - 5}{377R_{mf} + 77} = \frac{146 \times 0.08 - 5}{377 \times 0.08 + 77} = 0.0642 \text{ at } 75^{\circ}F$$

4) Calculate R_{we}

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

$$K = 60 + 0.133 T_f$$

$$K = 60 + 0.133 \times 180 = 83.94$$

$$-120 = -83.94 \log \frac{0.0642}{R_{we}}$$

$$R_{we} = 0.002387 \quad @ 75^{\circ}F$$

5) Converting R_{we} to R_w @ $75^{\circ}F$

$$R_w = \begin{cases} -(0.58 - 10^{(0.69 \times R_{we} - 0.24)}) & \text{if } R_{we} > 0.12 \text{ at } 75^{\circ}F \\ \frac{77R_{we} + 5}{146 - 377R_{we}} & \text{if } R_{we} < 0.12 \text{ at } 75^{\circ}F \end{cases}$$

$$R_w = \frac{77R_{we} + 5}{146 - 377R_{we}} = \frac{77 \times 0.002387 + 5}{146 - 377 \times 0.002387} = 0.0357 \text{ at } 75^{\circ}F$$

6) R_w @ formation Temp.

$$R_2 = R_1 \frac{T_1 + 6.77}{T_2 + 6.77}$$

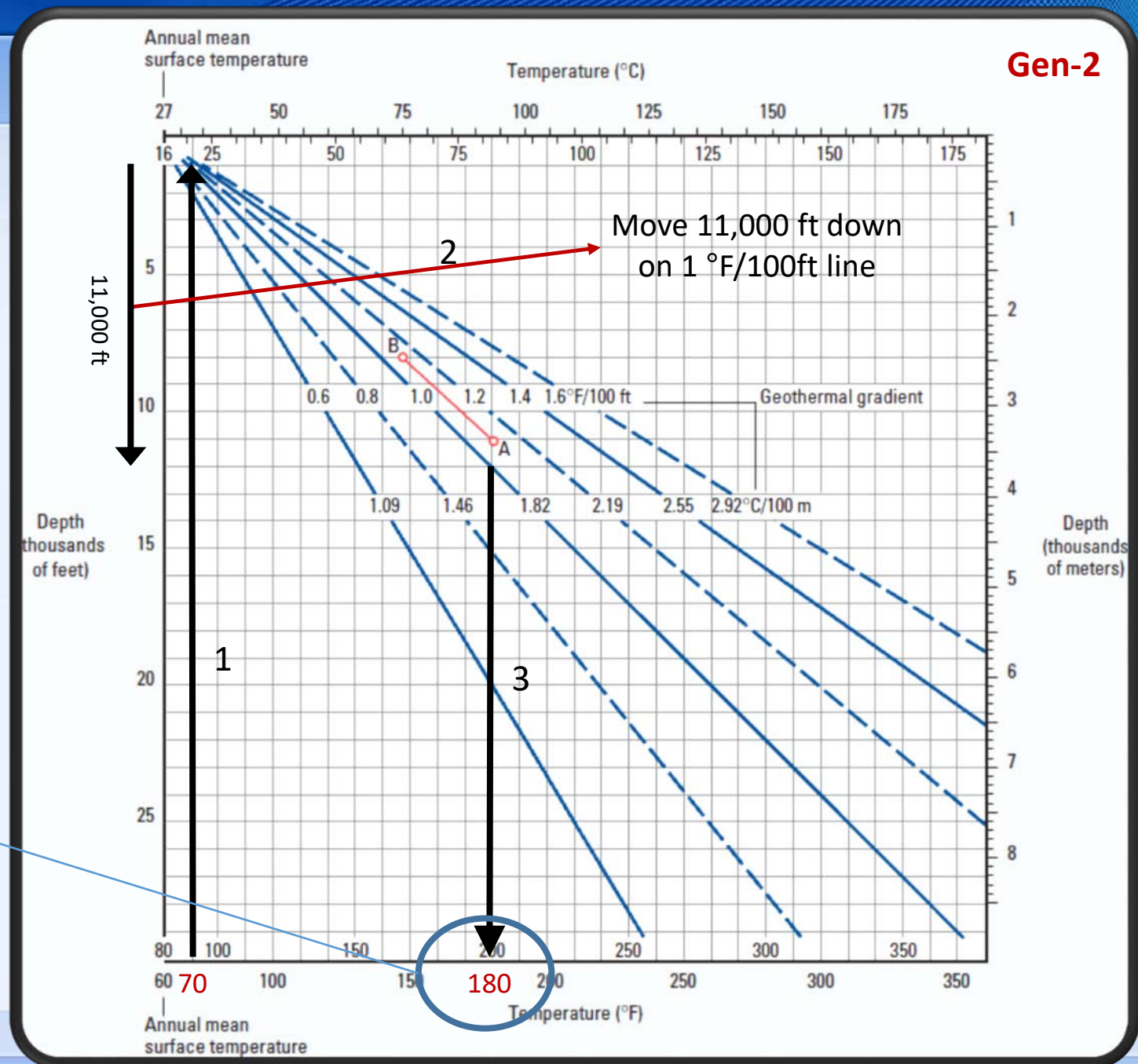
$$R_2 = 0.0357 \frac{75 + 6.77}{180 + 6.77} = 0.01563 \Omega.m \quad R_w @ 180^{\circ}F$$

SP Log

Example (Using Charts)

1) Finding Formation Temperature

$T_f = 180^\circ\text{F}$



SP Log

Example

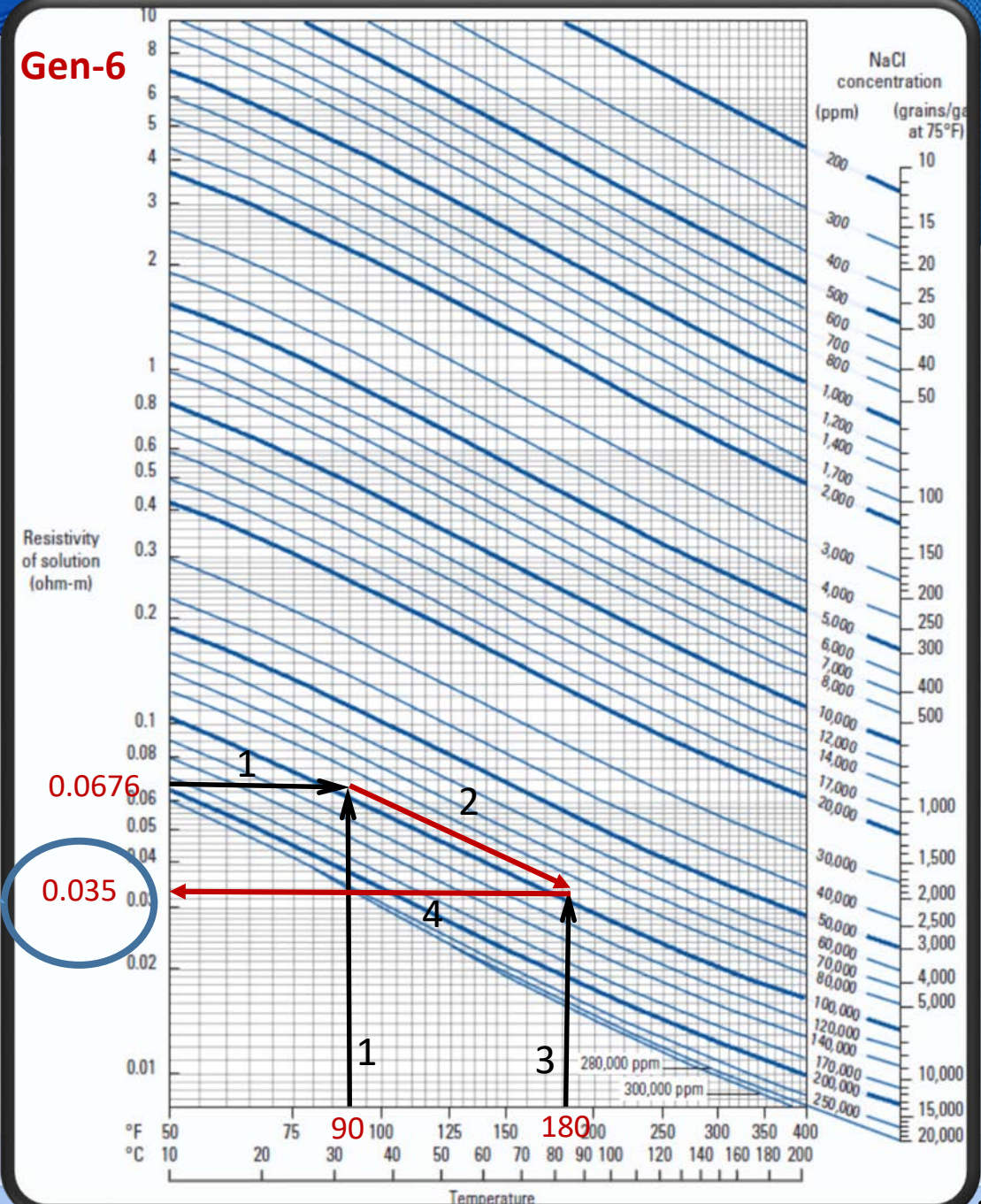
2) Finding R_{mf} @ T_f & 75 °F

$$R_{mf} @ 180\text{ }^{\circ}\text{F} = 0.035\ \Omega \cdot m$$

Similarly:

$$R_{mf} @ 75\text{ }^{\circ}\text{F} = 0.08\ \Omega \cdot m$$

Gen-6



SP Log

Example

3) Converting R_{mf} to R_{mfe} :

$R_{mf} = 0.08 < 0.1 \Omega.m$ 75 °F, use chart **SP-2**

R_{mfe} @ 180 °F = 0.027 $\Omega.m$

4) Calculate R_{we}

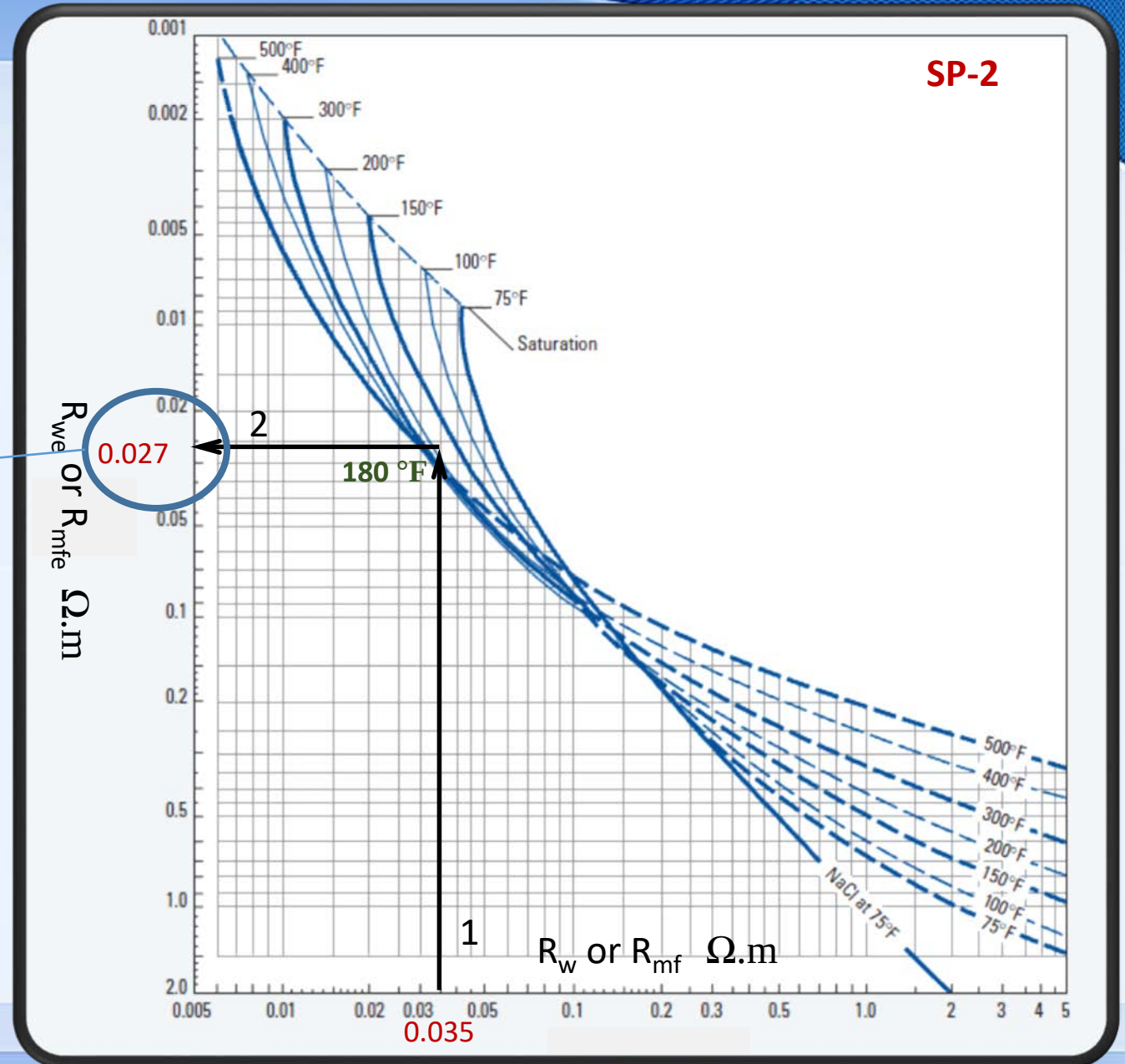
$$SSP = -K \log \frac{R_{mfe}}{R_{we}}$$

$$K = 60 + 0.133 T_f$$

$$K = 60 + 0.133 \times 180 = 83.94$$

$$-120 = -83.94 \log \frac{0.027}{R_{we}}$$

$$R_{we} = 0.001 \text{ @ } 180^\circ\text{F}$$



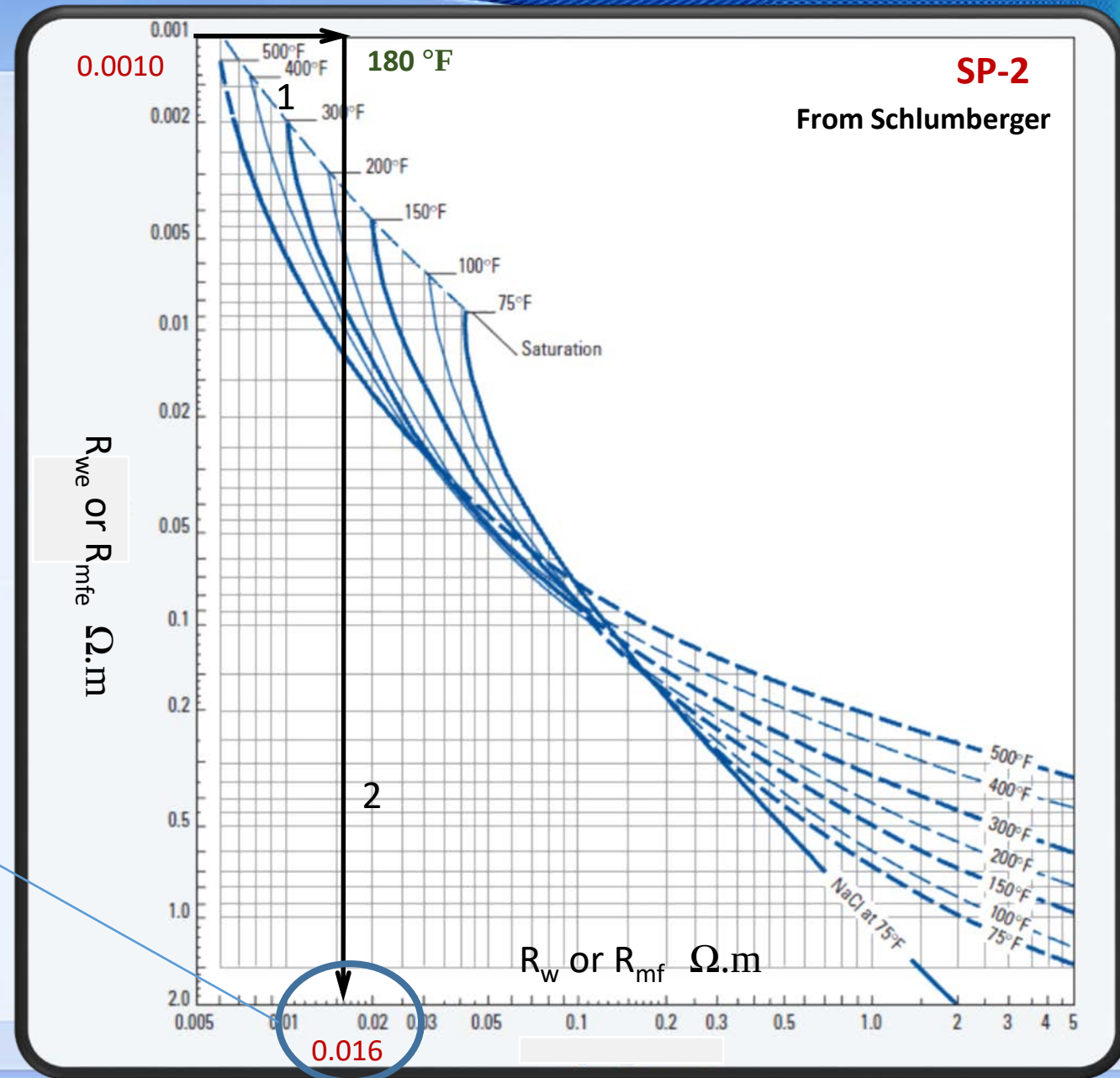
SP Log

Example

5) Convert R_{we} to R_w

0.016 $\Omega \cdot m$

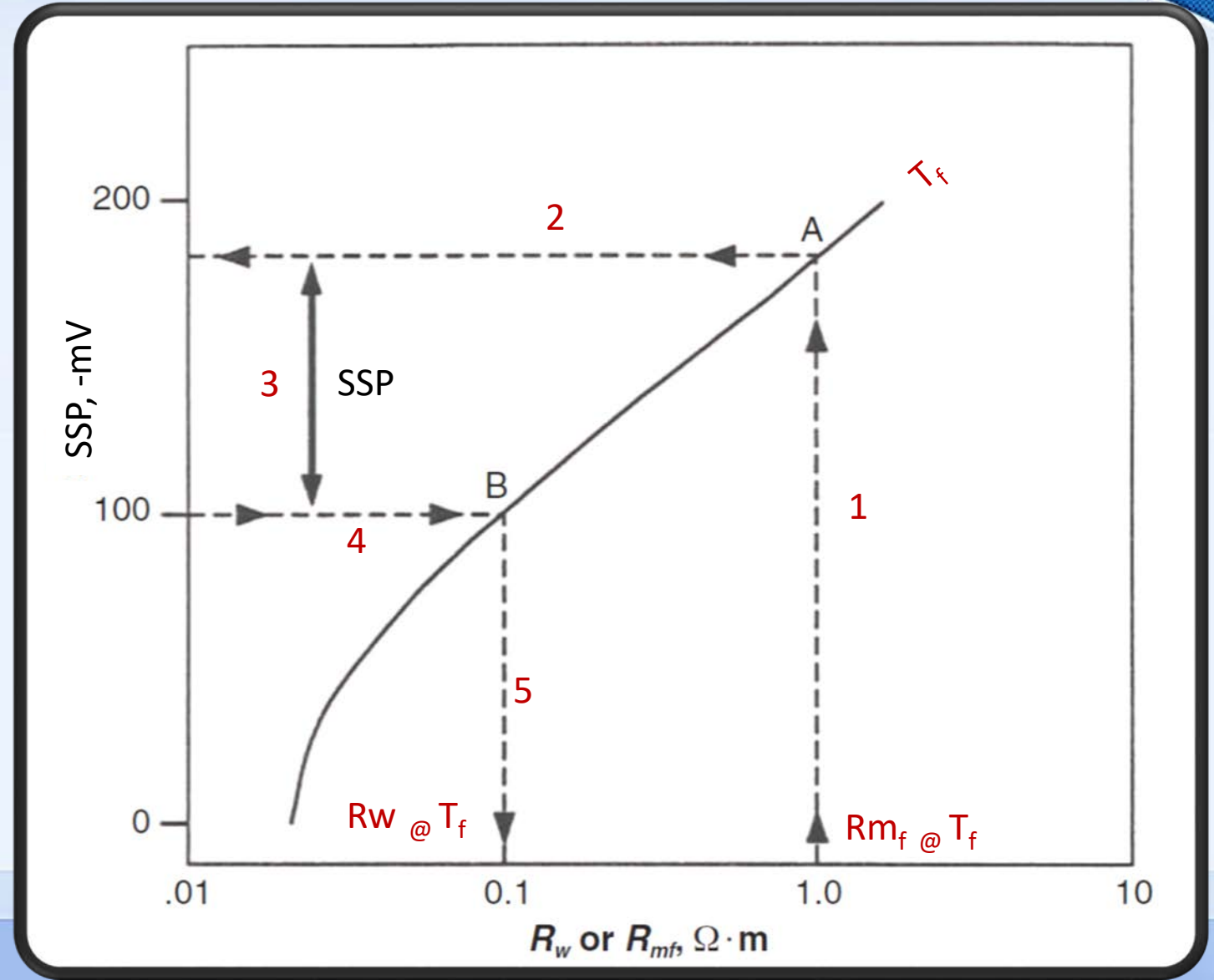
$R_w @ 180^\circ F$



SP Log

Determining R_w from SP Log (Silva and Bassiouni 1981)

By having R_{mf} @ T_f and SP value, R_w can be estimated from a single chart:



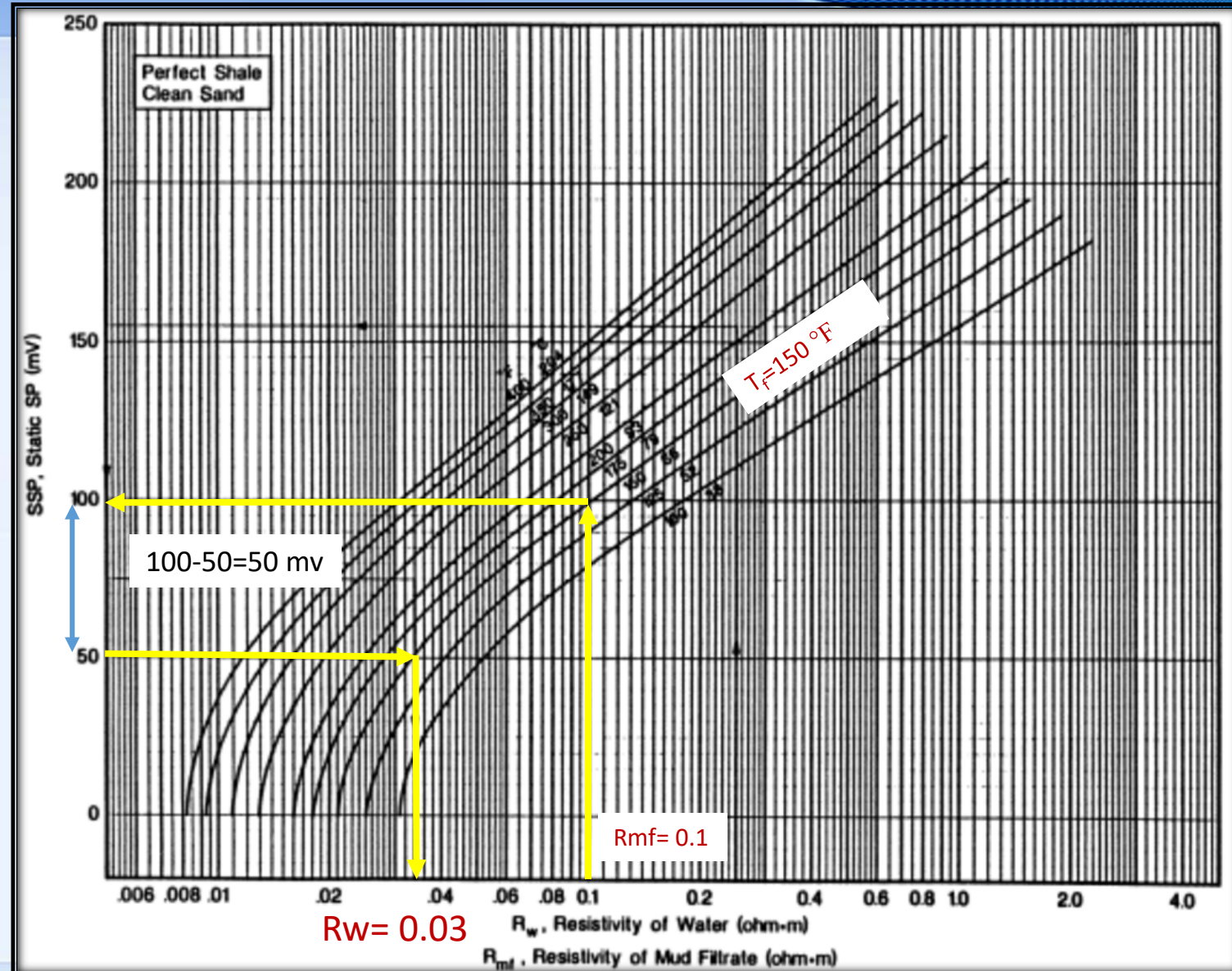
SP Log

Example

R_{mf} is calculated 0.1 $\Omega \cdot m$ at formation temperature of 150°F. If SP is measured in a thick, clean water bearing zone -50 mV, what is R_w ?

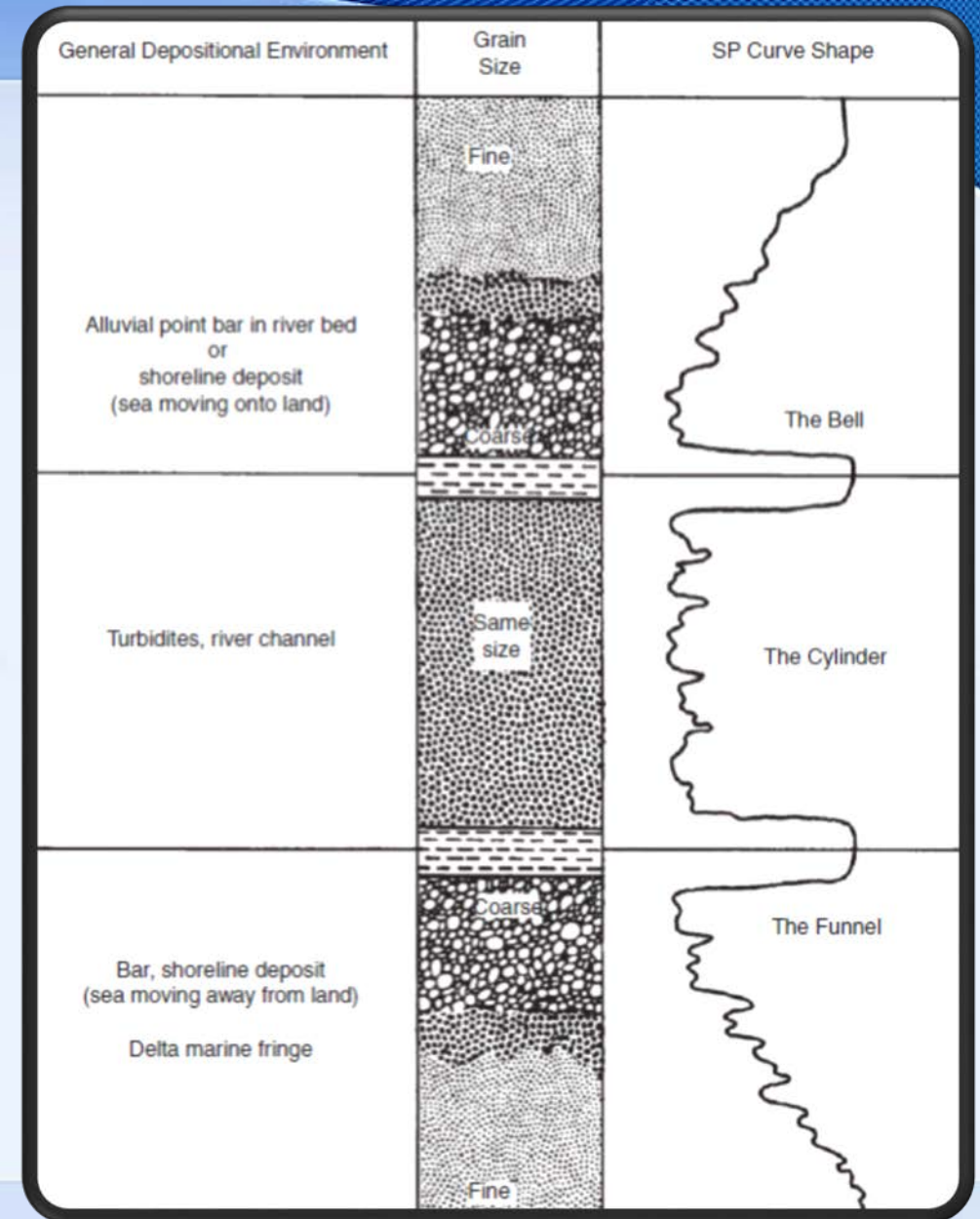
Compare this method with classic (Bateman and Konen) method:

$$R_w = 0.031 \text{ ohm} \cdot m$$



SP Depositional Patterns

SP deflections also respond to depositional changes. In particular, channels, bars, and other depositional sequences where sorting, grain size, or cementation change with depth produce characteristic SP shapes. These are variously described as bells or funnels.



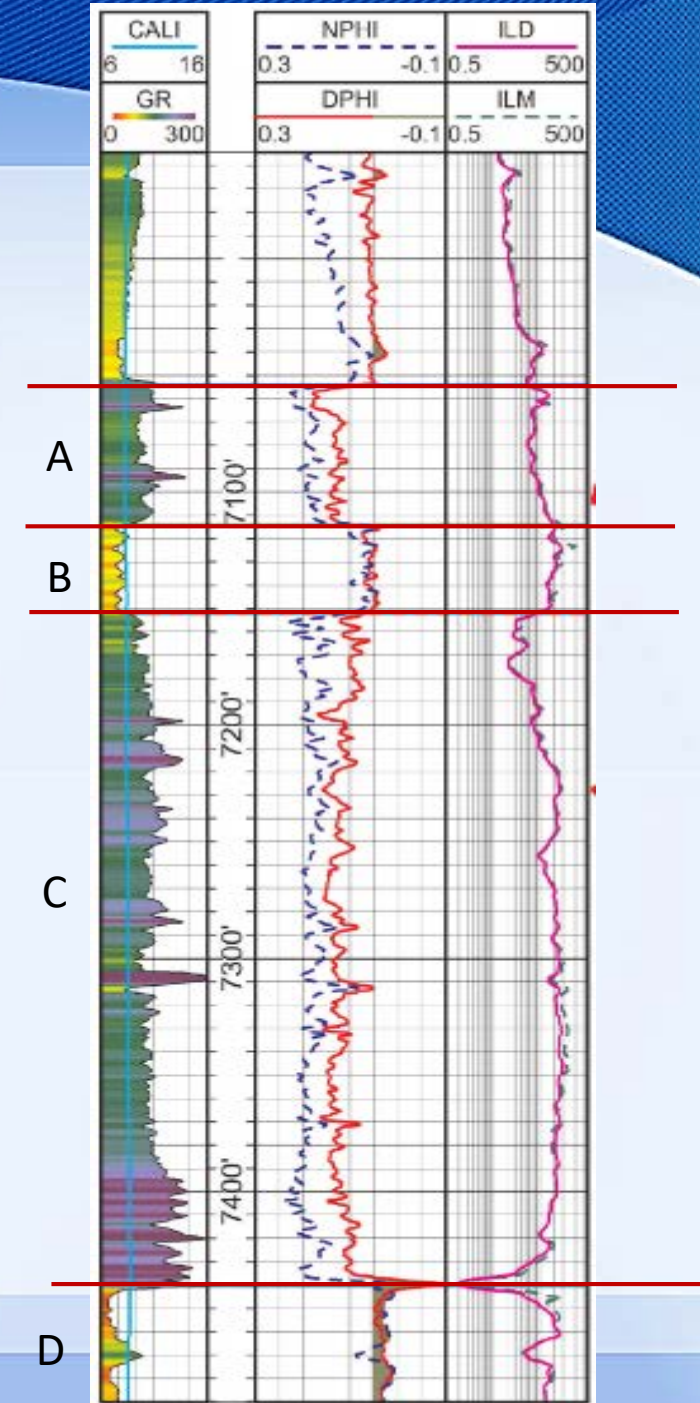
Log Zonation

Zone:

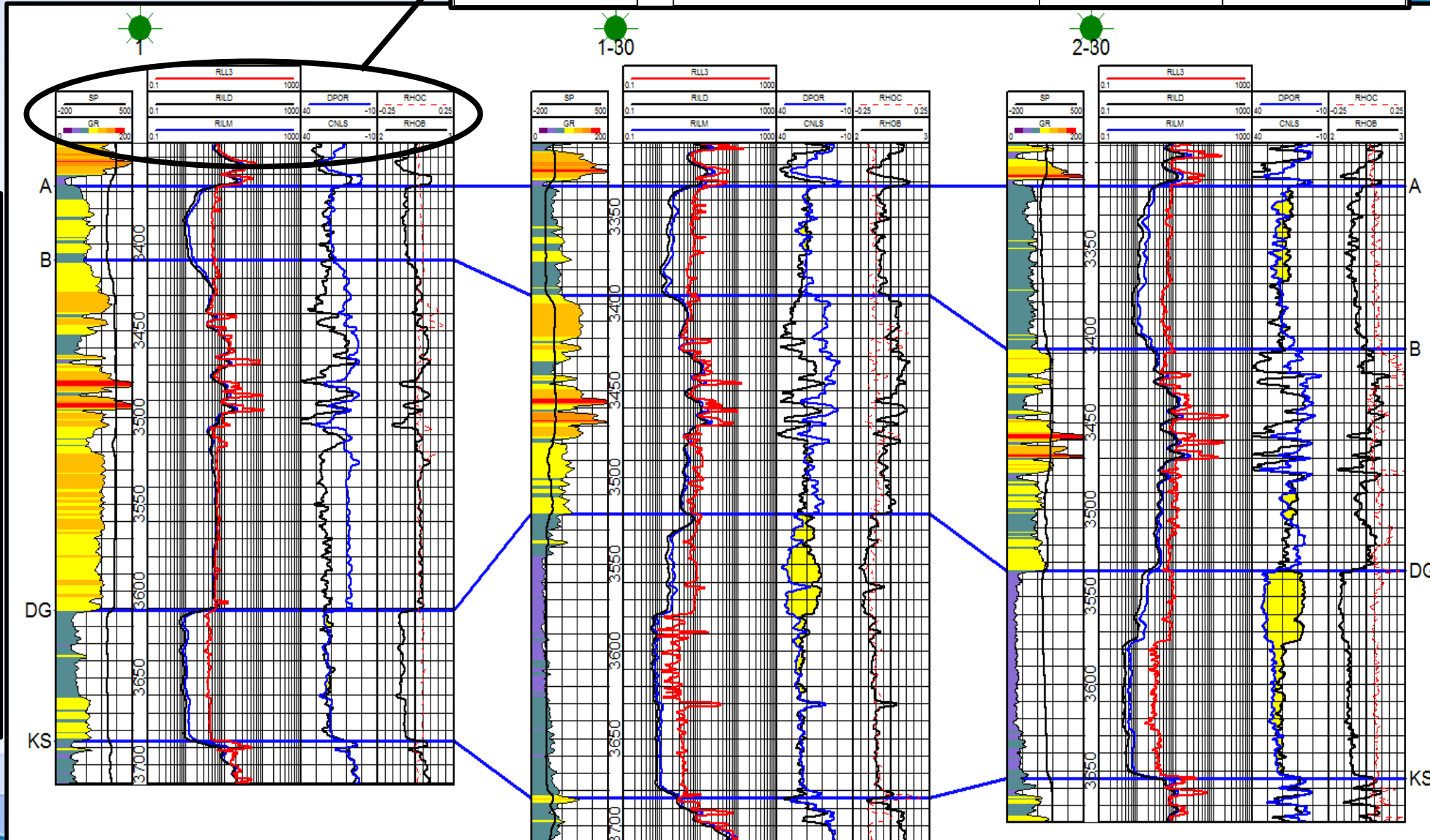
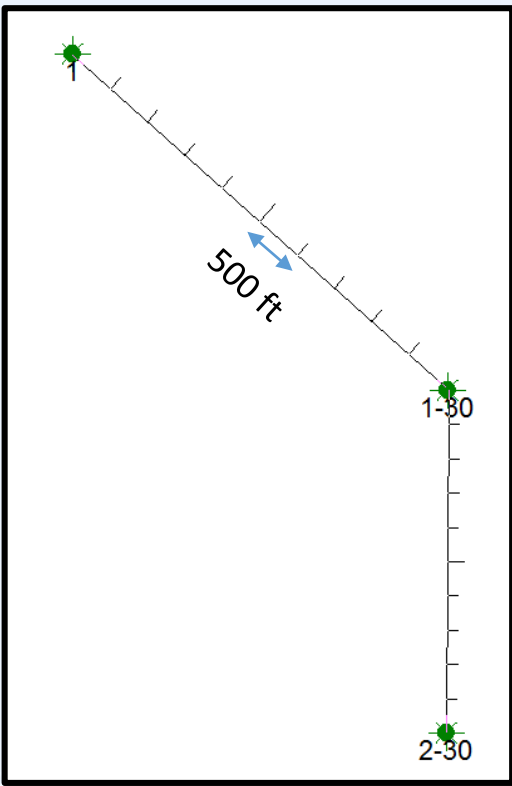
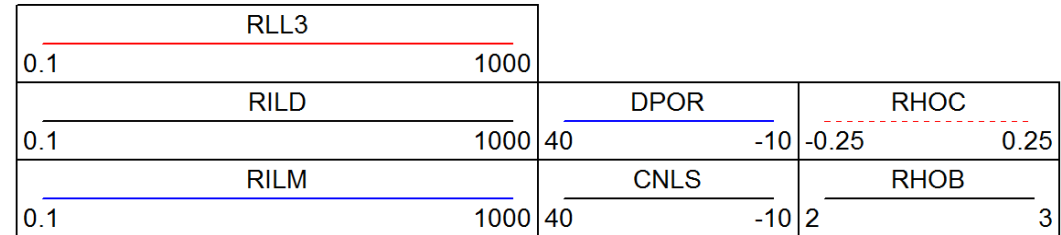
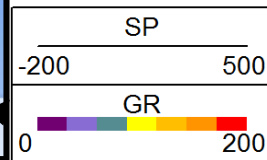
An interval with similar properties for interval evaluation or well to well correlation.

Criteria:

- ✓ Lithology
- ✓ Fluid Type (Oil, Gas, Water)
- ✓ Rock Property (Permeability, Porosity)



Correlation



Summary

- SP log deflection is the result of electric potential exists between the wellbore and formation due to the different salinity/resistivity between mud filtrate and formation water:
 - ✓ Negative deflection (normal SP) when $R_{mf} > R_w$
 - ✓ Positive deflection (Reverse SP) when $R_{mf} < R_w$
 - ✓ No deflection when $R_{mf} = R_w$
- SP log can be used to:
 - ✓ Detect permeable formations
 - ✓ Detect boundary of permeable formation
 - ✓ Calculate Shale volume, V_{sh}
 - ✓ Calculate formation water resistivity, R_w
- SP log is affected by several parameters and requires correction:
 - ✓ Formation thickness
 - ✓ Resistivity (mud, surrounding formation, invaded/uninvaded region)
 - ✓ Shaliness
 - ✓ Presence of HC

Useful Charts from Chart-book (2013 Edition)

	oSP-2
oGen-2	
	oSp-4
oGen-6	
	oSP-5

SP Log

Example

A well has been logged with SP tool to the max. depth of 4,800 ft.

The temperature @ max. depth is recorded 120 °F.

Also the $R_{mf}=1.47 \Omega.m$ @ 74 °F & $R_m=2.07 \Omega.m$ @ 74 °F.

What is R_w for zone “B”?

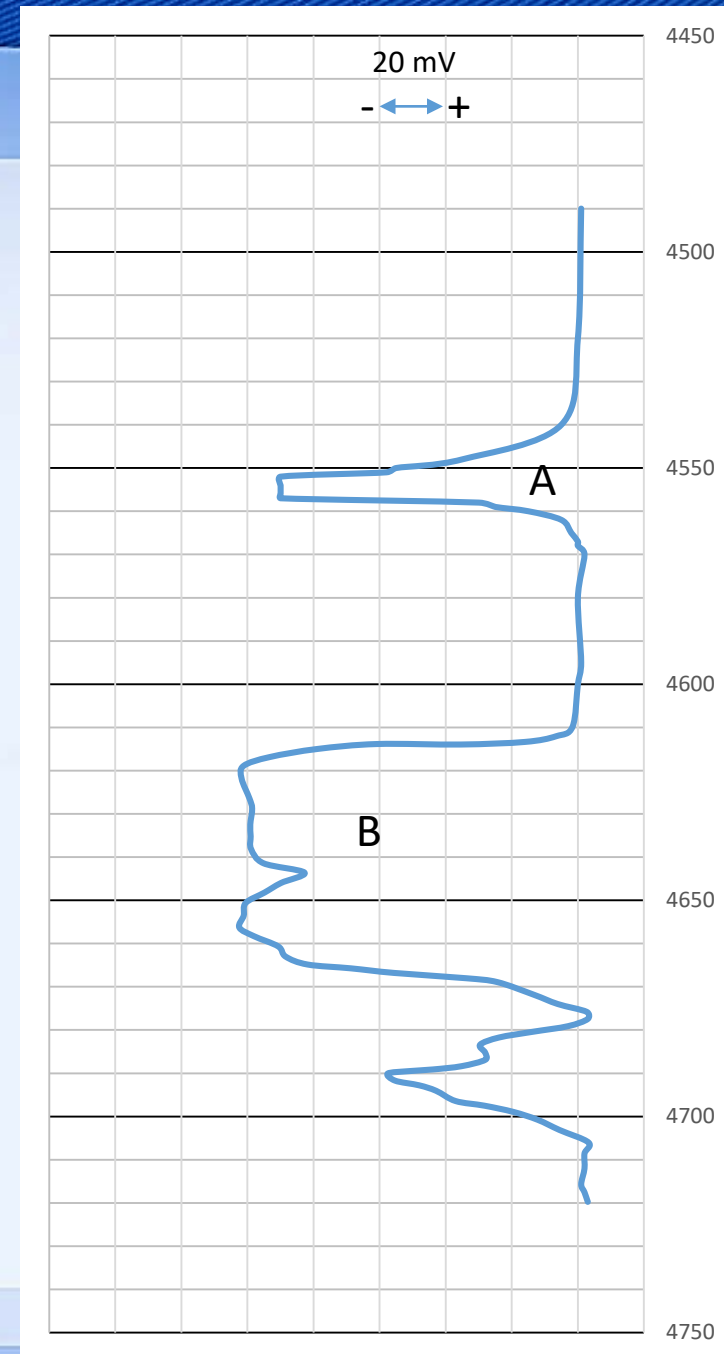
What is R_w for “A”.

Assume both zones are clean water bearing zones and:

for zone A: $d_i=35''$ and $R_i=27 \Omega.m$.

for zone B: $d_i=30''$ and $R_i=22 \Omega.m$.

Average annual surface temperature is 67 °F.



SP Log

Example

Zone A thickness : 10 ft Zone A SP : -90mV

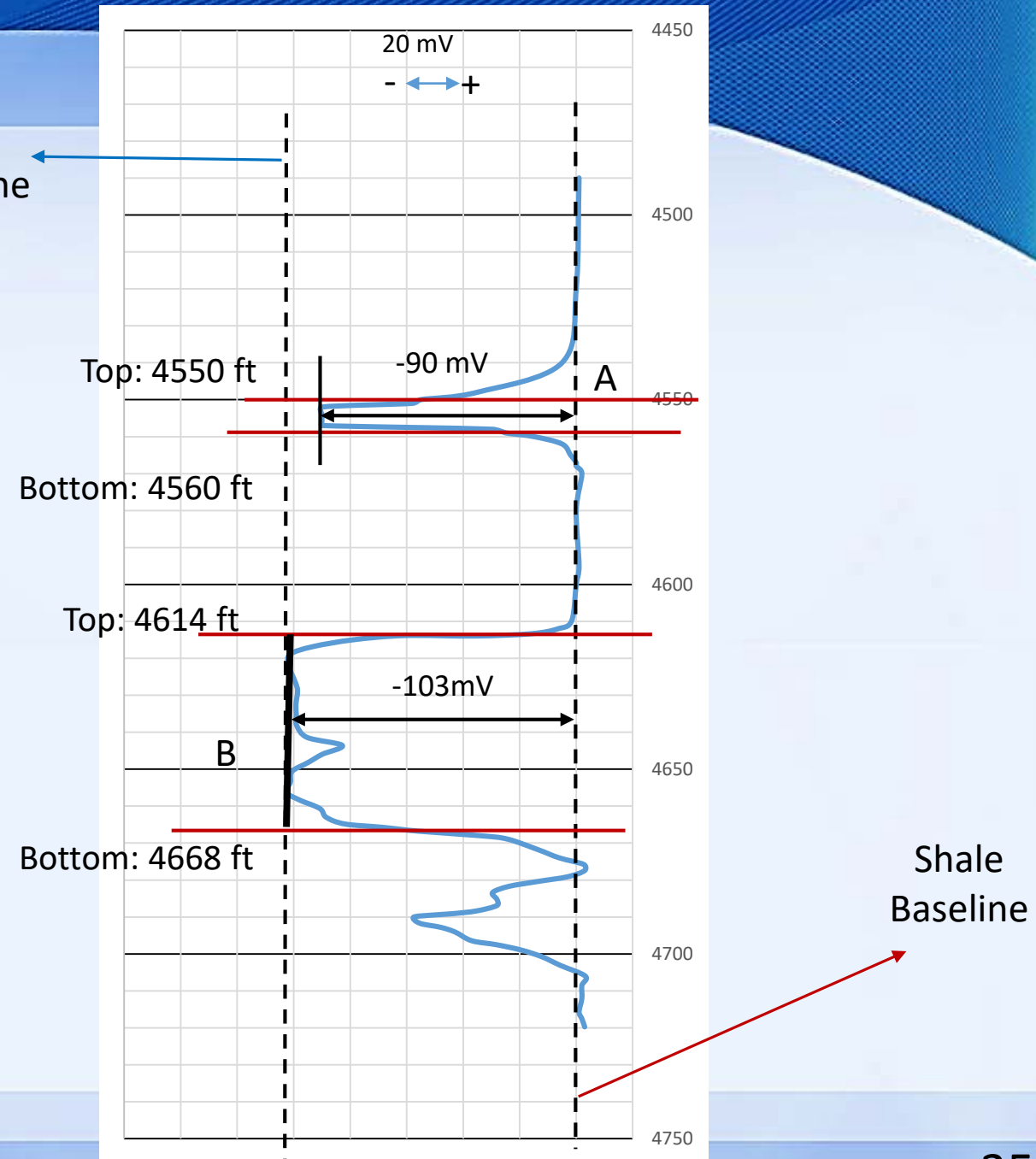
Zone B thickness : 54 ft Zone B SP : -103mV

$$T_f = T_{surf} + Depth \times Temp. Gradient$$

$$120 = 67 + 4800 \times Temp. Gradient$$

$$Temp. Gradient = 1.104 \frac{^{\circ}F}{100ft}$$

Sand
Baseline



Example

Zone A analysis:

Zone A thickness : 10 ft

Zone A SP : -90mV

Mid zone A: (4550+ 4560)/2=4555 ft

$$T_f = T_{surf} + Depth \times Temp. Gradient$$

$$T_f = 67 + 4555 \times 1.104 = 117.29 \text{ }^{\circ}\text{F}$$

$$R_2 = R_1 \frac{T_1 + 6.77}{T_2 + 6.77} \quad ^{\circ}\text{F}$$

$$R_2 = 2.07 \frac{74 + 6.77}{117.29 + 6.77} = 1.348 \text{ } \Omega.m \text{ } R_m @ 117.29 \text{ }^{\circ}\text{F}$$

$$R_2 = 1.47 \frac{74 + 6.77}{117.29 + 6.77} = 0.957 \text{ } \Omega.m \text{ } R_{mf} @ 117.29 \text{ }^{\circ}\text{F}$$

$$R_2 = 1.47 \frac{74 + 6.77}{75 + 6.77} = 1.452 \text{ } \Omega.m \text{ } R_{mf} @ 75 \text{ }^{\circ}\text{F}$$

Zone B analysis:

Zone B thickness : 54 ft

Zone B SP : -103mV

Mid zone B: (4614+ 4668)/2=4642 ft

$$T_f = T_{surf} + Depth \times Temp. Gradient$$

$$T_f = 67 + 4642 \times 1.104 = 118.26 \text{ }^{\circ}\text{F}$$

$$R_2 = R_1 \frac{T_1 + 6.77}{T_2 + 6.77} \quad ^{\circ}\text{F}$$

$$R_2 = 2.07 \frac{74 + 6.77}{118.26 + 6.77} = 1.337 \text{ } \Omega.m \text{ } R_m @ 118.26 \text{ }^{\circ}\text{F}$$

$$R_2 = 1.47 \frac{74 + 6.77}{118.26 + 6.77} = 0.95 \text{ } \Omega.m \text{ } R_{mf} @ 118.16 \text{ }^{\circ}\text{F}$$

SP Log

Example (SP to SSP)

Zone A Analysis:

$$R_2 = 2.07 \frac{74 + 6.77}{117.29 + 6.77} = 1.348 \Omega.m \quad R_m @ 117.26^\circ F$$

Zone A thickness : 10 ft

Zone A SP : -90mV

$d_i = 35"$

$R_i = 27 \Omega.m$

$$\frac{R_i}{R_m} = \frac{27}{1.348} = 20$$

Zone B Analysis:

$$R_2 = 2.07 \frac{74 + 6.77}{118.26 + 6.77} = 1.337 \Omega.m \quad R_m @ 118.26^\circ F$$

Zone B thickness : 54 ft

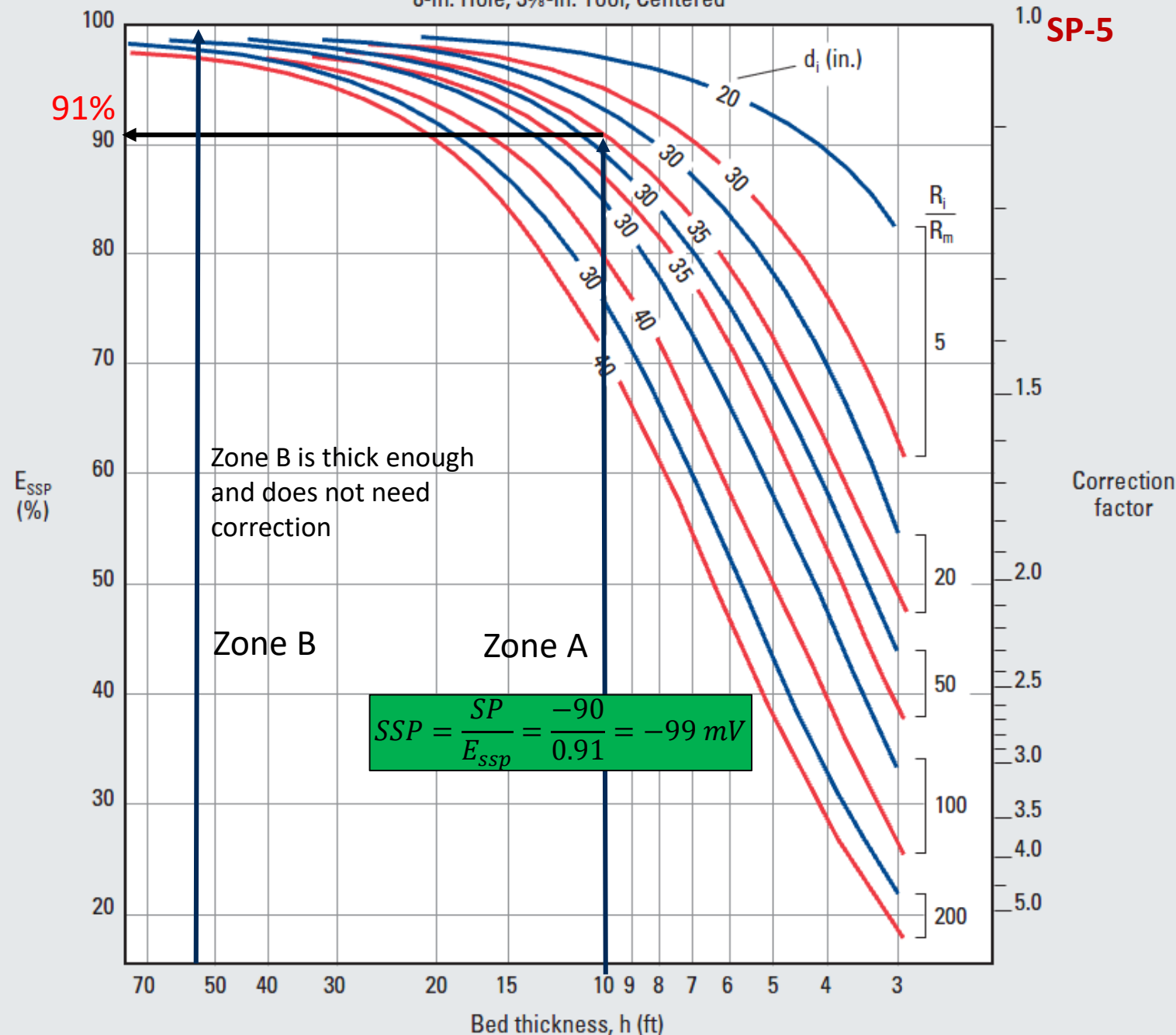
Zone B SP : -103mV

$d_i = 30"$

$R_i = 22 \Omega.m$

$$\frac{R_i}{R_m} = \frac{22}{1.348} = 16.3$$

8-in. Hole; 3 3/4-in. Tool, Centered



Example

Zone "A" R_w :

1) Converting R_{mf} to R_{mfe} :

$$R_{mf} = 1.452 \, \Omega.m \text{ @ } 75^\circ\text{F}$$

$$R_{mfe} = \begin{cases} 0.85 \times R_{mf} & \text{if } R_{mf} > 0.1 \text{ at } 75^\circ\text{F} \\ \frac{146R_{mf} - 5}{377R_{mf} + 77} & \text{if } R_{mf} < 0.1 \text{ at } 75^\circ\text{F} \end{cases}$$

$$R_{mfe} = 0.85 \times R_{mf} = 0.85 \times 1.452 = 1.234 \text{ at } 75^\circ\text{F}$$

2) Calculate R_{we}

$$SSP = -K \log \frac{R_{mfe}}{R_{we}} \quad K = 60 + 0.133 \times 117.29 = 75.60$$

$$K = 60 + 0.133 T_f \quad R_{we} = 0.0608 \text{ @ } 75^\circ\text{F}$$

3) Converting R_{we} to R_w @ 75°F

$$R_w = \begin{cases} -(0.58 - 10^{(0.69 \times R_{we} - 0.24)}) & \text{if } R_{we} > 0.12 \text{ at } 75^\circ\text{F} \\ \frac{77R_{we} + 5}{146 - 377R_{we}} & \text{if } R_{we} < 0.12 \text{ at } 75^\circ\text{F} \end{cases}$$

$$R_w = \frac{77R_{we} + 5}{146 - 377R_{we}} = \frac{77 \times 0.0608 + 5}{146 - 377 \times 0.0608} = 0.0786 \text{ at } 75^\circ\text{F}$$

4) R_w @ Formation Temp.

$$R_2 = R_1 \frac{T_1 + 6.77}{T_2 + 6.77}$$

$$R_2 = 0.0786 \frac{75 + 6.77}{117.26 + 6.77} = 0.052 \, \Omega.m \text{ } R_w \text{ @ } 117.29^\circ\text{F}$$

Example

Zone "B" R_w :

1) Converting R_{mf} to R_{mfe} :

$$R_{mf} = 1.452 \, \Omega.m \text{ @ } 75^\circ\text{F}$$

$$R_{mfe} = \begin{cases} 0.85 \times R_{mf} & \text{if } R_{mf} > 0.1 \text{ at } 75^\circ\text{F} \\ \frac{146R_{mf} - 5}{377R_{mf} + 77} & \text{if } R_{mf} < 0.1 \text{ at } 75^\circ\text{F} \end{cases}$$

$$R_{mfe} = 0.85 \times R_{mf} = 0.85 \times 1.452 = 1.234 \text{ at } 75^\circ\text{F}$$

2) Calculate R_{we}

$$SSP = -K \log \frac{R_{mfe}}{R_{we}} \quad K = 60 + 0.133 \times 118.29 = 75.73$$

$$K = 60 + 0.133 T_f \quad R_{we} = 0.0538 \text{ @ } 75^\circ\text{F}$$

3) Converting R_{we} to R_w @ 75°F

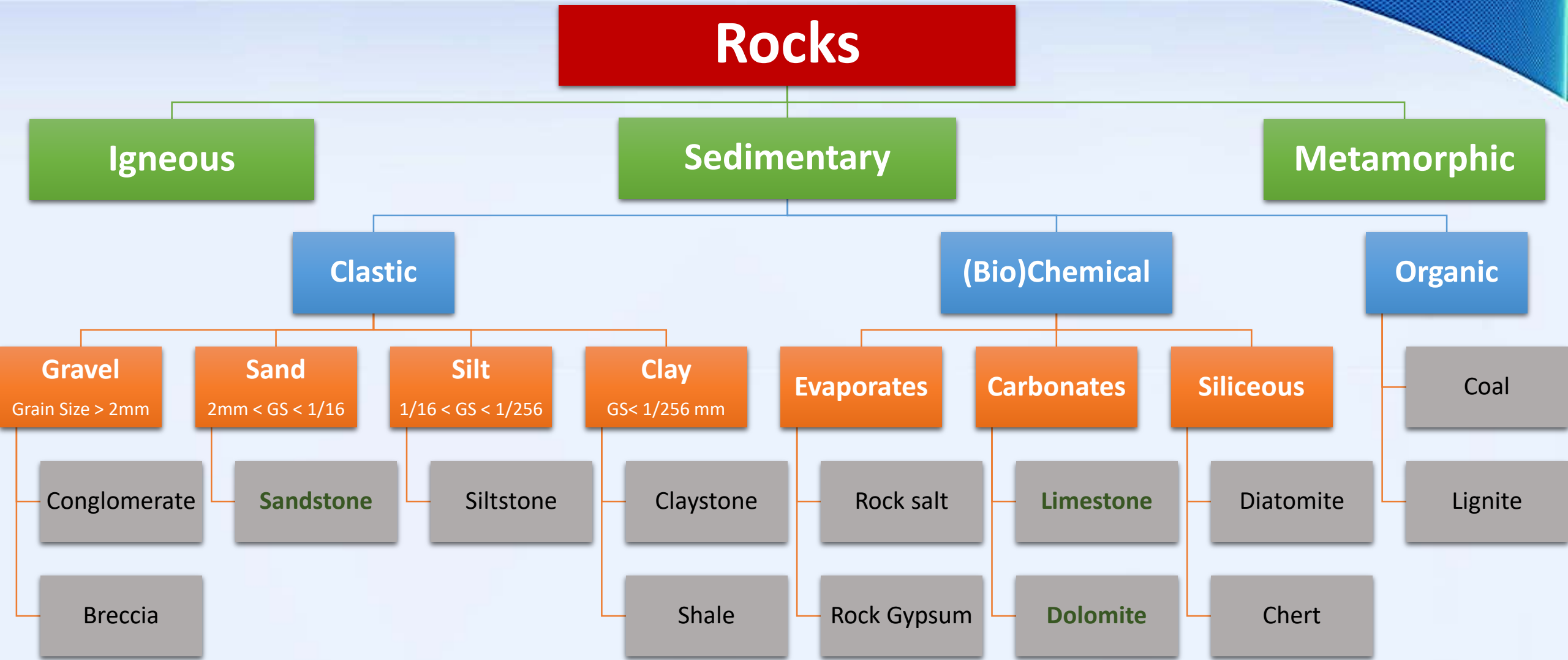
$$R_w = \begin{cases} -(0.58 - 10^{(0.69 \times R_{we} - 0.24)}) & \text{if } R_{we} > 0.12 \text{ at } 75^\circ\text{F} \\ \frac{77R_{we} + 5}{146 - 377R_{we}} & \text{if } R_{we} < 0.12 \text{ at } 75^\circ\text{F} \end{cases}$$

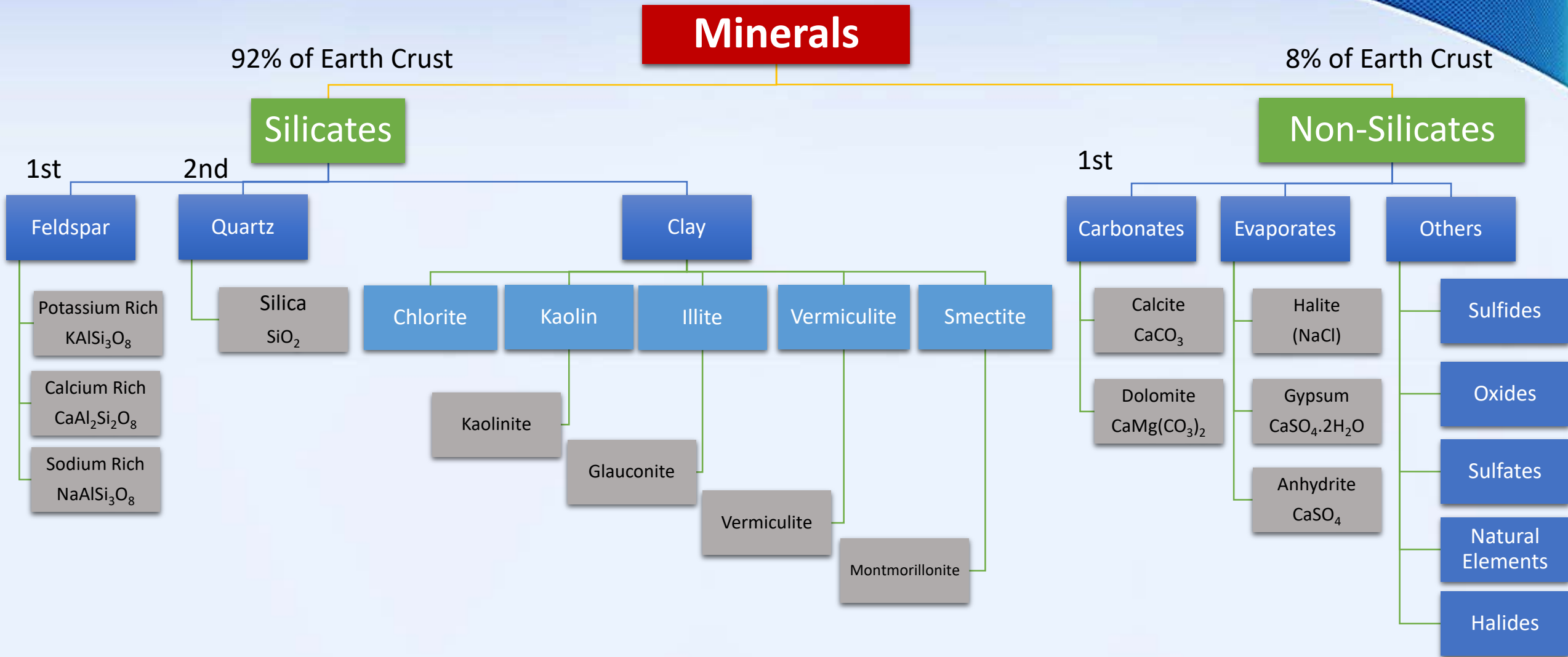
$$R_w = \frac{77R_{we} + 5}{146 - 377R_{we}} = \frac{77 \times 0.0538 + 5}{146 - 377 \times 0.0538} = 0.0727 \text{ at } 75^\circ\text{F}$$

4) R_w @ Formation Temp.

$$R_2 = R_1 \frac{T_1 + 6.77}{T_2 + 6.77}$$

$$R_2 = 0.0727 \frac{75 + 6.77}{118.26 + 6.77} = 0.047 \, \Omega.m \text{ } R_w \text{ @ } 118.29^\circ\text{F}$$





Mineralogy vs. Lithology

- In well logging literature, mineralogy and lithology are used with ambiguity.
- In many cases, the rock name is used as (most dominant) mineral name or vice versa.

Lithology

Sandstone

Limestone

Dolomite (Dolostone)

Shale

Salt

Mineral

Quartz , SiO_2

Calcite, CaCO_3

Dolomite $\text{CaMg}(\text{CO}_3)_2$

Clay minerals (illite, kaolinite, montmorillonite)

Halite, NaCl