Mesaverde

Water Evaluation

Methods for Determining Formation Water Salinity

There are several industries accepted methods for determining formation water salinity from logs. Among them are determining Rw from the SP log, reversal of the SP log, Rw apparent and Pickett plots. None of these methods are quantitative except in clean, thick, water-bearing sands. These conditions are rarely met in the Piceance Basin. However, a range of possible salinity values can be established from a qualitative log analysis. For a thorough discussion of various methods for determining formation water resistivity from logs, please see *Log Interpretation Principles and Applications:*

http://www.slb.com/resources/publications/books.aspx

Spontaneous Potential

The static spontaneous potential (SSP) is the ideal electrochemical potential of the formation in a clean, thick, water-bearing, permeable sand. It can be estimated from an SP curve which has a shale baseline of zero.

$$SSP = -K\log\frac{Rmfe}{Rwe}$$

*Where K = 61 + 0.133*Temperature*

Rmfe = equivalent mud filtrate resistivity (chart corrected)

Rwe = equivalent formation water resistivity (chart corrected)

Rw can therefore be derived from charts provided by the service companies. However, this method is not valid in the Piceance due to the presence of clays, thin beds and hydrocarbons.

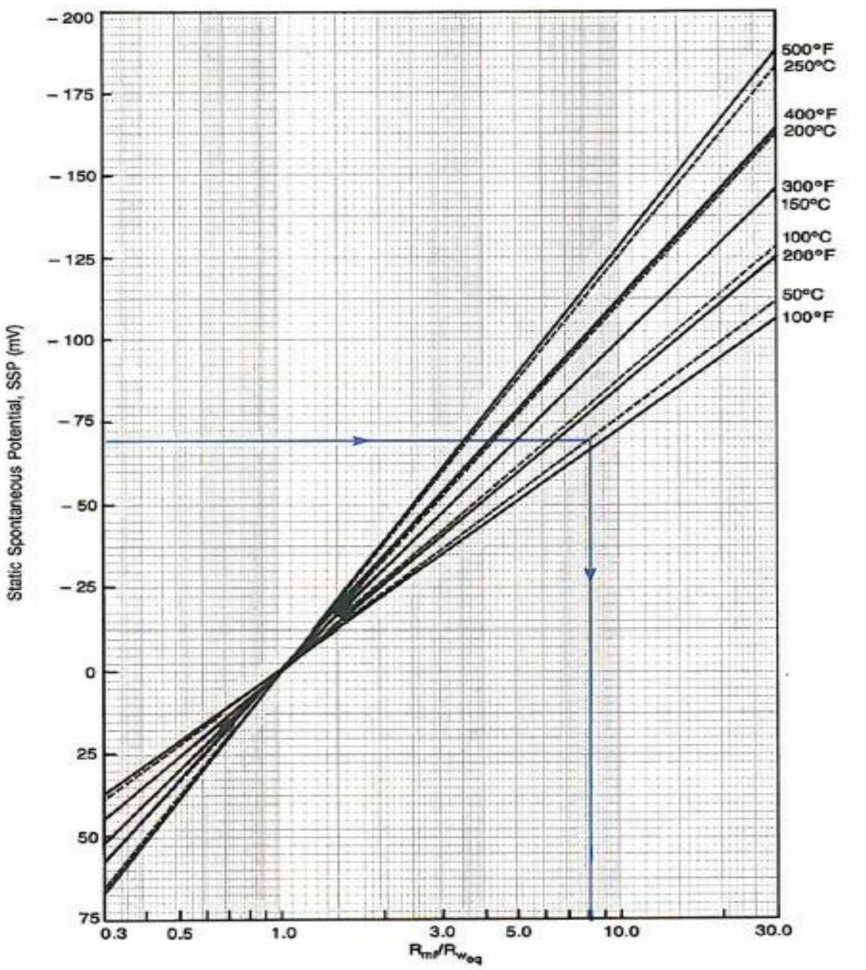


Figure 2.4. Chart used for determining the R_{mf}/R_{we} ratio from *SSP* values. (Western Atlas, 1995, Figure 3-2)

Procedure, using the log data in Figure 2.2 and the values from Figure 2.3:

1. Locate the *SSP* value on the scale on the left edge of the chart.

   $SSP = -59$ mV

2. Follow the value horizontally until it intersects the sloping formation temperature line (130°F; imagine a line between the 100°F and 200°F temperature lines).

3. Move vertically from this intersection and read the ratio value on the scale at the bottom of the chart.

   The R_{mf}/R_{we} ratio value is 5.5

4. Divide the corrected value for R_{mf} by the ratio R_{mf}/R_{we} value.

   $R_{we} = R_{mf}/(R_{mf}/R_{we})$

   $R_{we} = 0.53/5.5$

   $R_{we} = 0.096$ ohm-m

An SP reversal can indicate if the formation water is fresher than the drilling mud. If mud filtrate and formation water resistivities are equal, there will be no deflection in the SP log. If the mud filtrate resistivity is greater than the formation water resistivity (i.e. the formation water is saltier than the mud filtrate) then a normal SP response is observed. If the mud filtrate resistivity is less than the formation water resistivity (i.e. the formation water is fresher than the mud filtrate) then an SP reversal is observed.

334 wells in the Piceance Valley with shallow SP logs were evaluated for this study. No definitive SP reversals were observed.

Rwa Analysis and Pickett Plot

The formation water resistivity apparent is derived from Archie's equation in 100% water saturated sands with no clay:

$$\frac{1}{Rt} = \frac{\phi^m \, Sw^n}{a\,Rw}$$

Where Rt = formation resistivity

a = 1 = tortuosity factor

Rw = formation water resistivity

Φ = porosity

m = cementation exponent

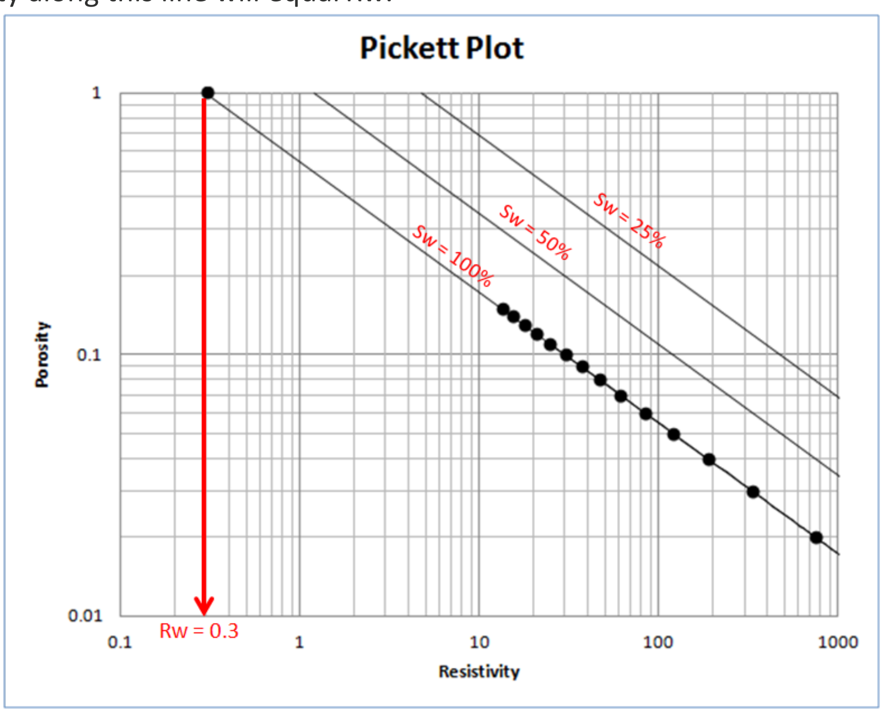
Sw = water saturation

n = saturation exponent

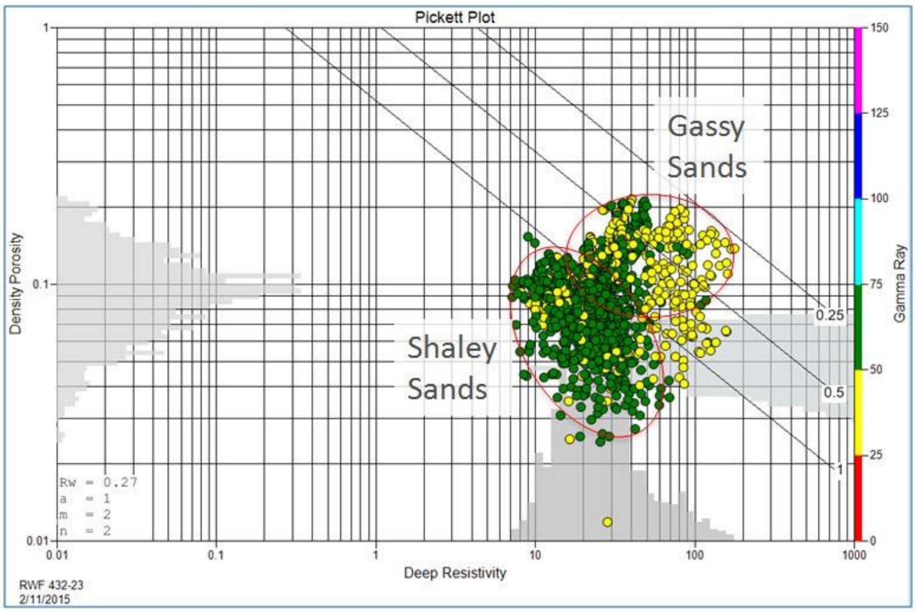
Assuming Sw = 1 then

$$Rwa = \text{formation water resistivity apparent} = Rt * \phi^m$$

The Rwa curve can be displayed in a log plot and should equal Rw in clean, 100% wet sands. Unfortunately, clays and traces of hydrocarbons even at shallow depths make this method unreliable in the Piceance. The Pickett plot is a graphical representation of Archie's equation and quickly shows the problems with the equation in the Wasatch formation. In 100% wet, clean rocks a plot of the porosity and resistivity (both on logarithmic scales) should form a straight line as shown in the following cartoon. Where the porosity equals 1 the value of the resistivity along this line will equal Rw.



In the following example from the Rulison field, a Pickett plot from surface down to the top of the Mesaverde deviates from the theoretical plot due to the presence of clay and trace amounts of hydrocarbons. Clays are indicated by the elevated gamma ray (z-axis colors) and hydrocarbons can be verified on the mud gas curve.



Ground water may contain traces of hydrocarbon even at shallow depths as indicated by mud gas curves. Neutron density cross-over may or may not be a good indicator of gas at shallow depths. Lack of cross-over may be due to the presence of clay in the sands which will cause the curves to separate. Swelling clays, which are common at these depths, will have a greater impact.

Permeability

Permeability in the Williams Fork where TEP typically completes its wells in the Piceance ranges from .0024mD to .0438mD based on routine core analysis. TEP cannot offer advice regarding permeability outside of our cored intervals.