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Calculating Formation Water Resistivity from The Spontaneous Potential – Obtaining the Right Result

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Summary

Many papers have been written describing the origin of the Spontaneous Potential (SP) and its utility to provide formation water resistivity, Rw. However, the application has not been successful in most cases in providing a continuous value for Rw.

There are two problems, defining the correct magnitude of the SP deflection and cross-checking the result. The SP curve as recorded has no absolute zero so the deflection must be measured from a defined zero line. Therefore, defining the zero line correctly is critical in calculating a continuous Rw from SP. A second critical step that is usually ignored is a cross-check that the wet resistivity, Ro, is less than or equal to the true resistivity, Rt. Ro must be a clay corrected value, usually obtained with a method of using spectroscopy to define the clay minerals' cation exchange capacity.

Using a conventional method, one draws a shale baseline at the right edge of the SP and the SP deflection is measured from this shale baseline to calculate Rw. However, this method works only in clean wet sands and does not define the Rw in shale sections. Therefore, it is not continuous. Furthermore, since Rw is not continuous, there is no cross-check that Ro<=Rt, so the conventional method usually fails to provide the correct Rw.

A method that works under any conditions including shales is described and an example is given. Obtaining a correct continuous Rw is essential to a valid log interpretation

Introduction

Many attempts have been made in the past to use the Rw from the SP. The common conclusion is it really doesn't work very well. However, when one is dealing with many changes in Rw throughout the well or even throughout a zone like the bitumen-filled sands, one must find a method that works. In 2010, working in a rift basin, we saw Rw changes from very fresh to very salty over the span of 100 metres. The answer by the local operator was to test everything that had free fluid (CMR's CMFF). This expense necessitated the method when we interpreted their wells. Since then, we noted that very few analysts use an Rw from the SP to obtain a valid Rw. Consequently, we wrote this paper to try to help everyone to use a method that works. We assume an activity to resistivity relationship is valid as well as the SP has a significant membrane potential and a low electrokinetic potential component. Furthermore, we compensate for hydrocarbon reduction of resistivity as well as bed thickness effects, hole diameter, invasion, Static SP and resistivity contrasts by calibrating to a known Rw. The key to the method is we cross-check to ensure that clay-corrected, wet resistivity, Ro, is less than or equal to true resistivity, Rt. Without this final step, large errors can occur.

Theory and/or Method

The method involves:

1. Find a zero for the SP. The baseline of the shales does not work.
2. Find the difference between the zero and the deflection of the SP. Call this SP_SHIFT.
3. Find the baseline, which initially is identical to SP_SHIFT.
4. Calculate a Rw from the SP_BASELINED, using the conventional formula.
5. Compare this Rw to a known Rw. If one is not known, assume the known Rw is 0.05 @ 308F. This value will usually get one in the ballpark.
6. Calibrate the Rw to the known Rw by adding a value to the SP_SHIFT. Recalculate SP_Baselined and Rw_SP until a fit is obtained, by iteration.
7. Calculate a wet resistivity, clay corrected, by using elemental capture spectroscopy to find the CEC of the clays, used to correct the Ro for clay.
8. Ensure the Ro is less than or equal to Rt; if not, recalculate Rw and iterate.
9. In this process, one may have to correct for SP drift.
10. When checking that Ro<=Rt, one may use a shale zone, since the Ro is corrected for clay.
11. The important point is to provide a continuous Rw from a continuous SP.
12. When an oil based mud is used and no SP is generated, predict an SP from an offset water-based mud, using the density, neutron, GR and logarithm of resistivity to produce the prediction from either multivariate statistical analysis or a good clustering routine.

Examples

In the following description, we provide detailed equations since users generally fail by not applying this step by step procedure.

A method that works on any environment is to first define a zero Line (SP_ZERO) using the following formula and later do a cross-check that Ro<=Rt, even in shales.

SP_ZERO = [(Log (RMF/RW_ESTIMATED)) * (-1)*(61+0.133*TEMP_DEGF)]+X

Use RW-ESTIMATED = 0.05 AT 308F adjusted for temperature or your best guess at Rw from a catalog. RMF must also be adjusted for temperature.

Start with X = 0 and average the Min-Max values. Add or subtract a value (X) to make SP_ZERO = zero. This gives a straight line that moves with temperature.

Then calculate SP_SHIFT = SP + Z

Add or subtract a number (Z) to SP_SHIFT to give you a SP_BASELINED value that will produce an RW_SP equal or close to the Formation Rw from DST or water catalog, adjusted for Temperature.

SP_BASELINED = SP_SHIFT - SP_ZERO

RW_SP = RMF /[Antilog (SP_BASELINED/(-1*(61+0.133*TEMP_DEGF))]

Plot the SP_SHIFT, SP_BASELINED and RW_SP.

If you have a Rw measurement from DST Water Samples or Water Catalog, generate an Rw_Known curve using Rw@TempF, adjusted for Temperature using the following formula (in this case Temperature is in Fahrenheit):

Rw_known = (Rw*(TempF+6.77)/(TEMP_DEGF+6.77))

e.g. Rw of 0.05@77F, is

Rw_05 = (0.05*(77+6.77)/(TEMP_DEGF+6.77)), where TEMP_DEGF is Temperature in degrees Fahrenheit

The RW_SP is expected to agree with all the RW_samples at their respective depths. When it does not agree, even with a flared curve representing expected error in measurement, examine the samples critically for validity.

EXAMPLE

The example illustrates the work flow on a conventional well (named for confidentiality reasons, Test2) that has four Rw water DST's (5 – 8), with increasing Rw upward. We pick the bottom DST #5 as an Rw_known and see if the resulting Rw_SP matches the other values as expected that it should.

5 = 0.0282 @78.98 F

6 = 0.0395 @ 72.8 F

7 = 0.0508 @ 84.4 F

8 = 0.0788@ 85.1 F

From Log Header, RMF = 0.059 @ 190 F (Fluid Sample 3, not at BHT)

Generate temperature gradient, TEMP_DEGF = 0.0199*Depth in feet; BHT = 204F

Generate RMF curve using: RMF = (0.059*(190+6.77)/(TEMP_DEGF+6.77))

Rw curve for #5 (Brown) ; RW_KNOWN5 = (0.0282*(78.98+6.77)/(TEMP_DEGF+6.77))

Rw curve for #6 (Blue) ; RW_KNOWN6 = (0.0282*(78.98+6.77)/(TEMP_DEGF+6.77))

Rw curve for #7 (Orange) ; RW_KNOWN7= (0.0282*(78.98+6.77)/(TEMP_DEGF+6.77))

Rw curve for #8 (Green) ; RW_KNOWN8= (0.0282*(78.98+6.77)/(TEMP_DEGF+6.77))

SP_SHIFT = SP + Z (Z=0 to start)

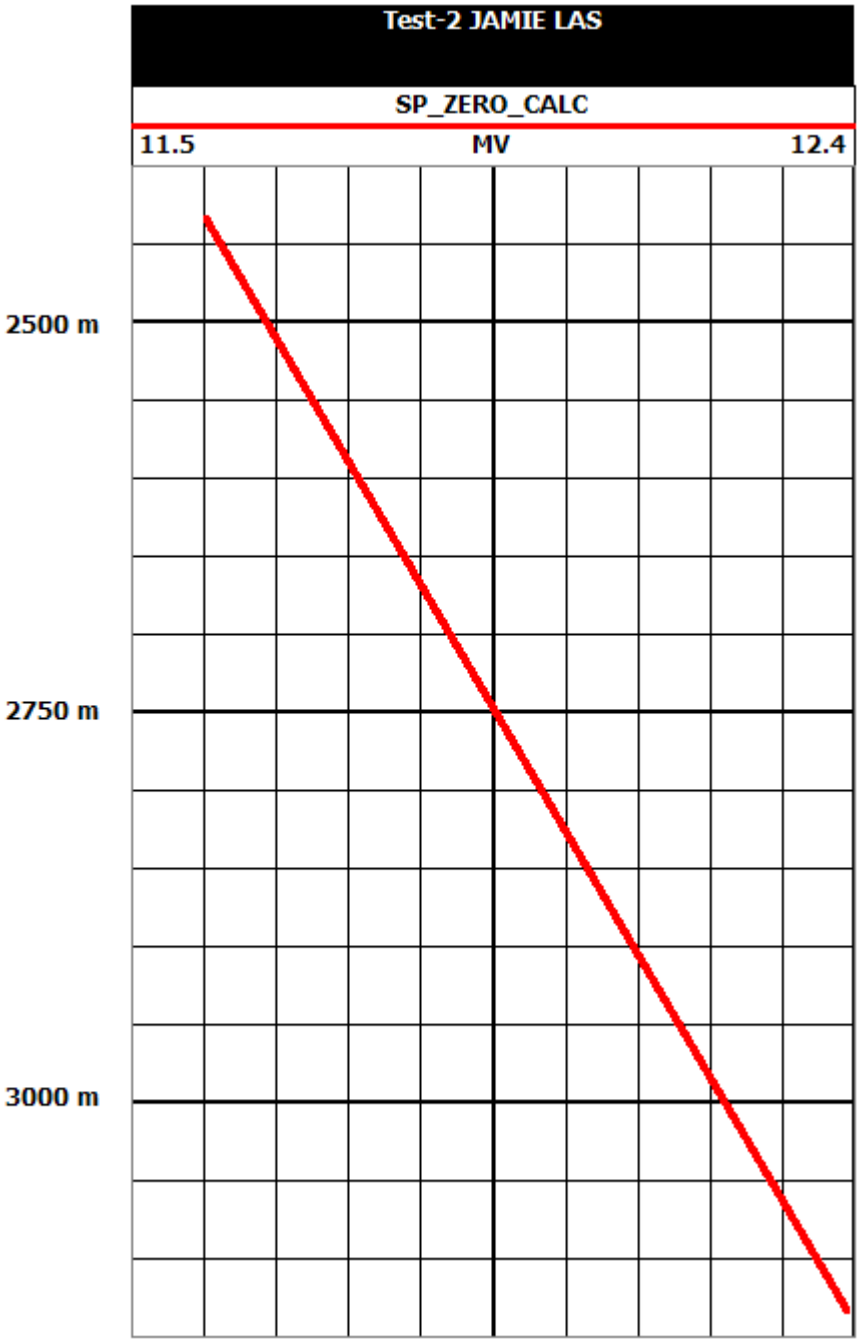
SP_BASELINED = SP_SHIFT - SP_ZERO (SP_ZERO unknown to start)

RW_SP = RMF / [Antilog (SP_BASELINED/(-1*(61+0.133*TEMP_DEGF))]

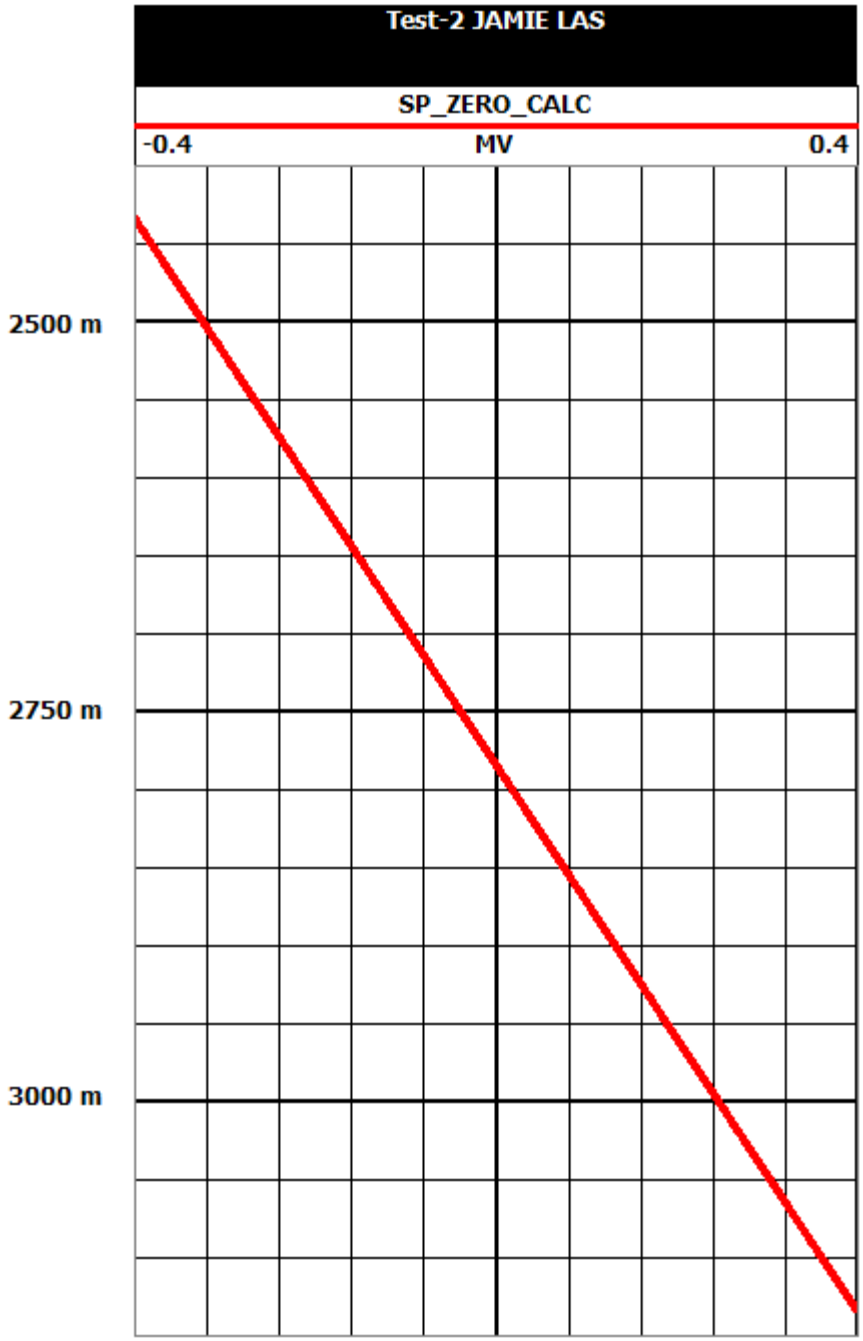
PLOT SP ZERO,

Using the formula SP_ZERO = [Log (RMF/RW) * (-1)*(61+0.133*TEMP_DEGF)]+X

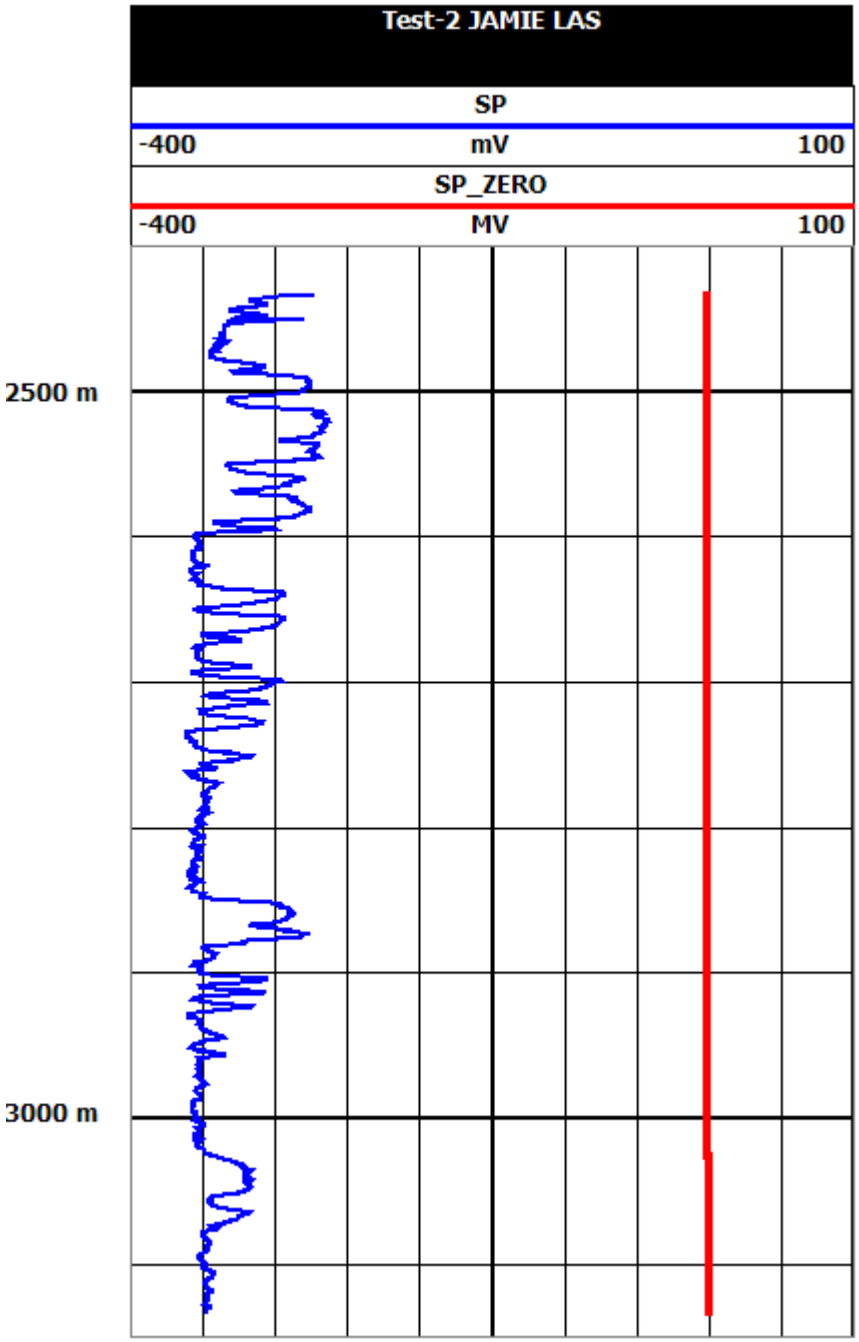
Start with X=0



Start with x = 0 and Average the Min-Max values of 11.5 to 12.4mv shown above. Now subtract 11.9925 (-X) to make the Default Scale to the same absolute value, for left and Right in this case -4 to +4.



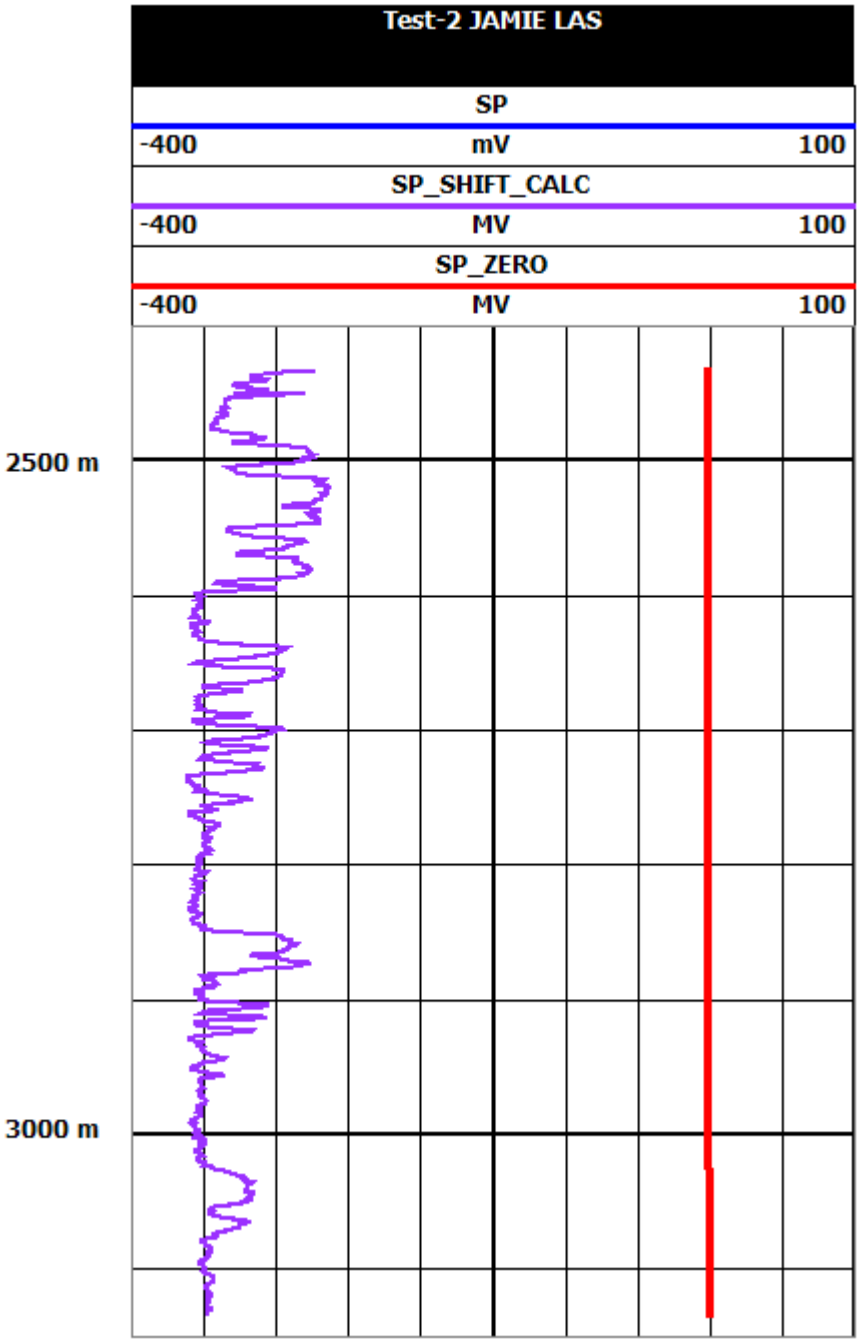
Rename to SP_ZERO and plot on same scale as SP



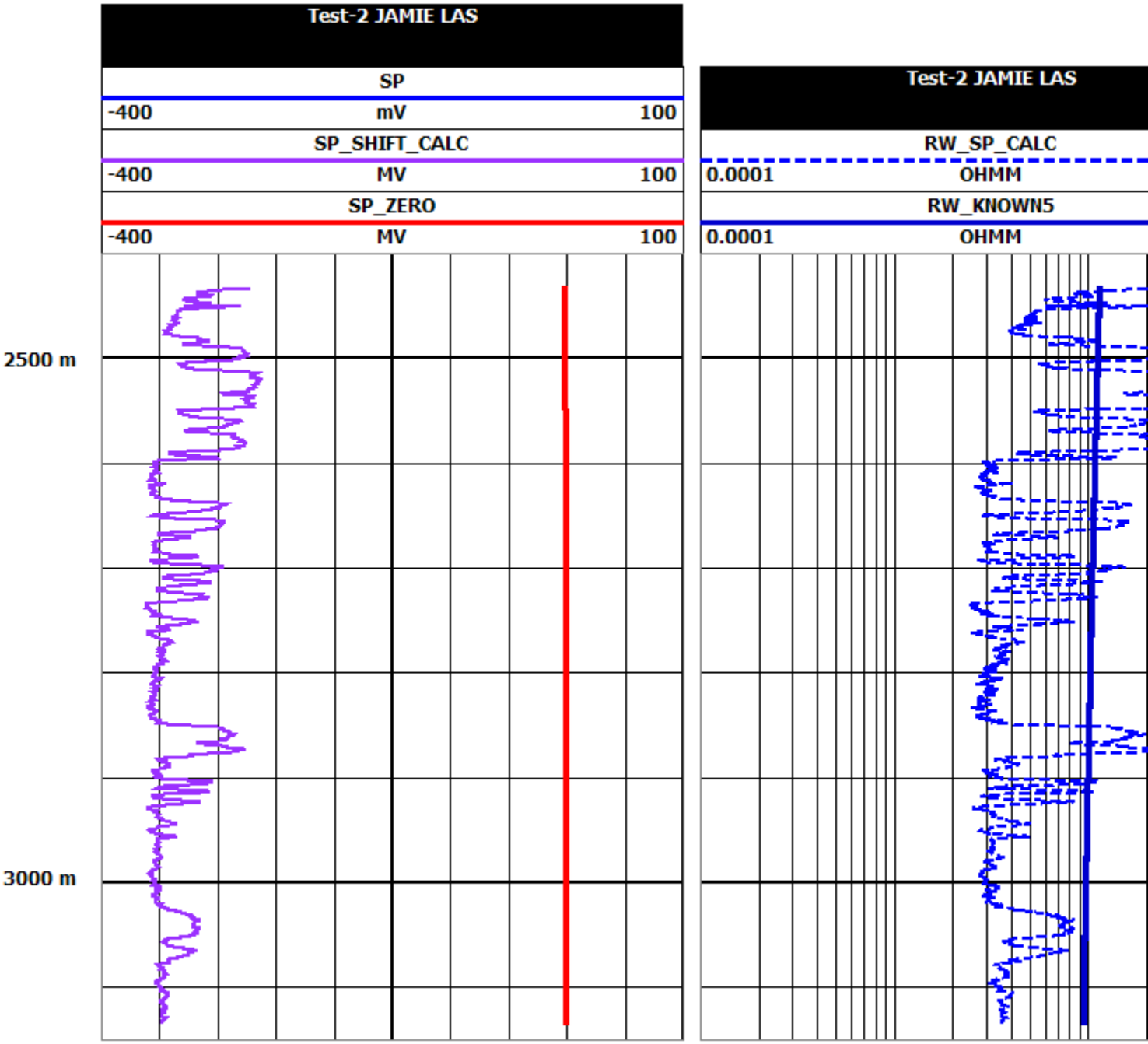
Plot SP_SHIFT

Using the formula: SP_SHIFT = SP + Z ; Start with Z = 0

This results in an SP_SHIFT_CALC that is the same as the SP



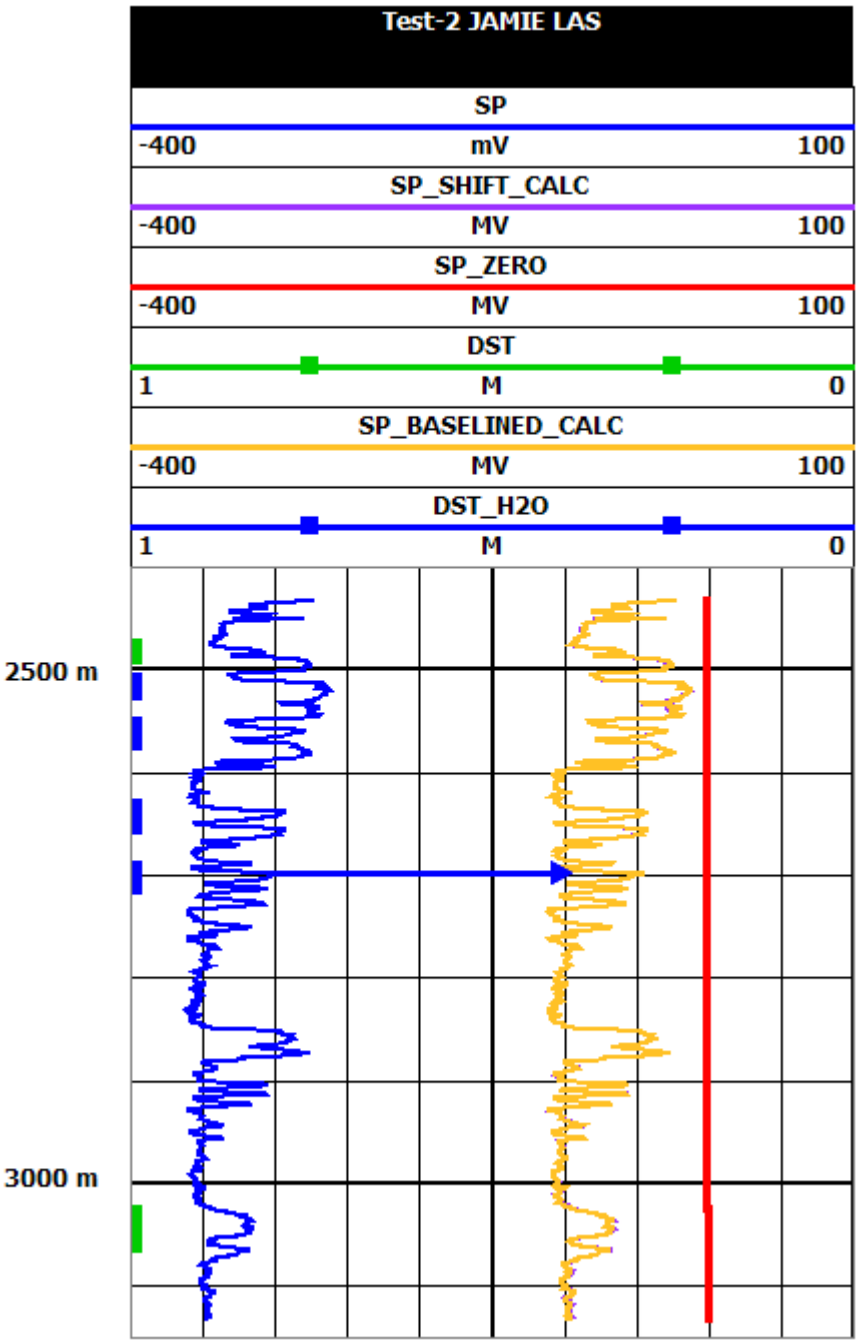
Calculate SP_BASELINED_CALC (first try)



The dashed RW_SP_CALC is too low, relative the the known value from DST 5 (straight line, corrected for temperature); Move the second try of RW_SP_CALC to the right by replacing Z (in SP_SHIFT_CALC) with 250 and the resulting SP_BASELINED will give an RW_SP. Note we have changed the scale of the resisitivity track and changed the colour of DST5 RW_KNOWN5 to brown, to accommodate the revised Rw_SP

PLOT SP BASE LINE

SP_BASELINED = SP_SHIFT - SP_ZERO



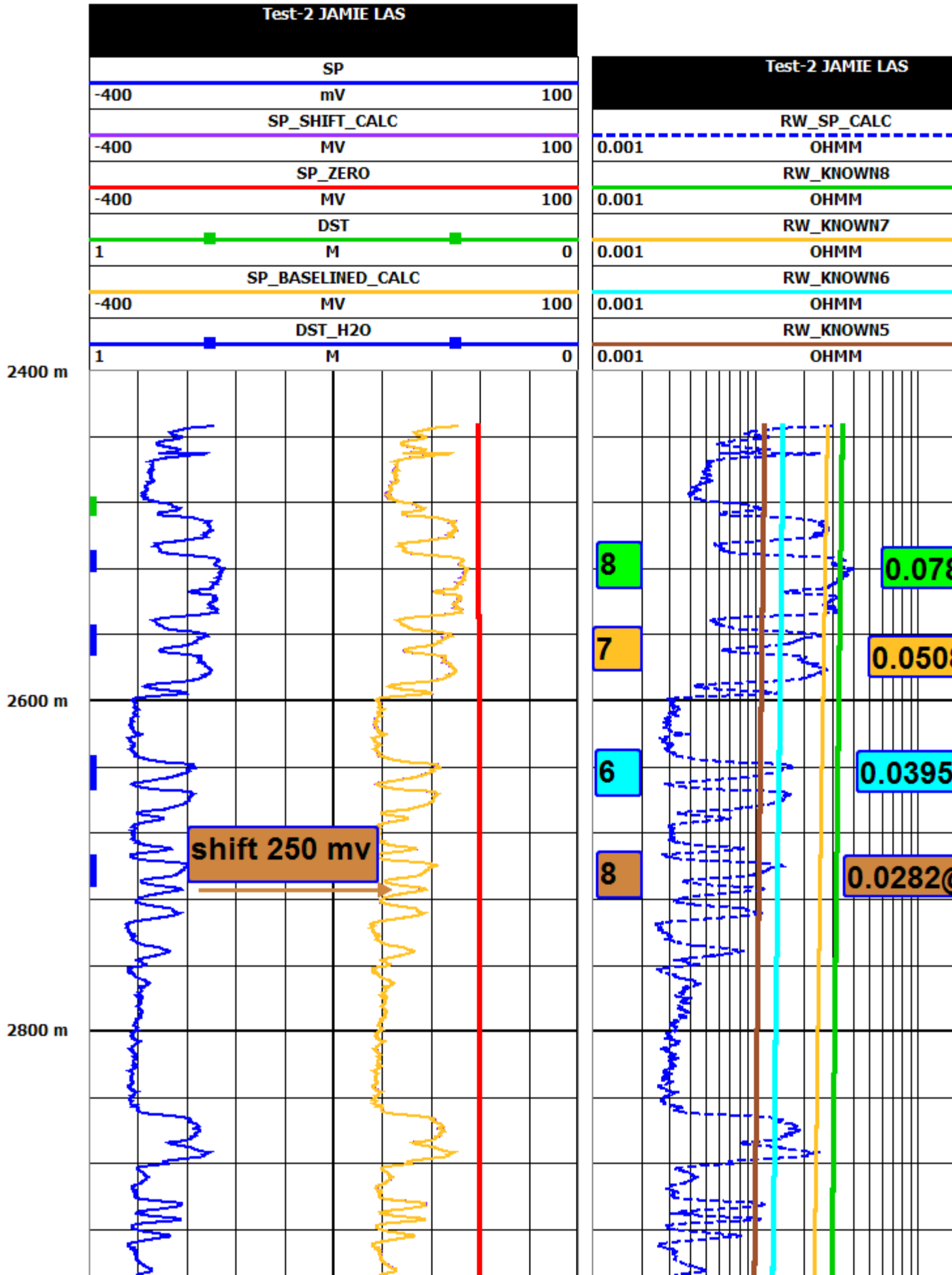
PLOT RW_SP

Using the following formula:

RW_SP = RMF /[Antilog (SP_BASELINED/(1*(61+0.133*TEMP_DEGF))]

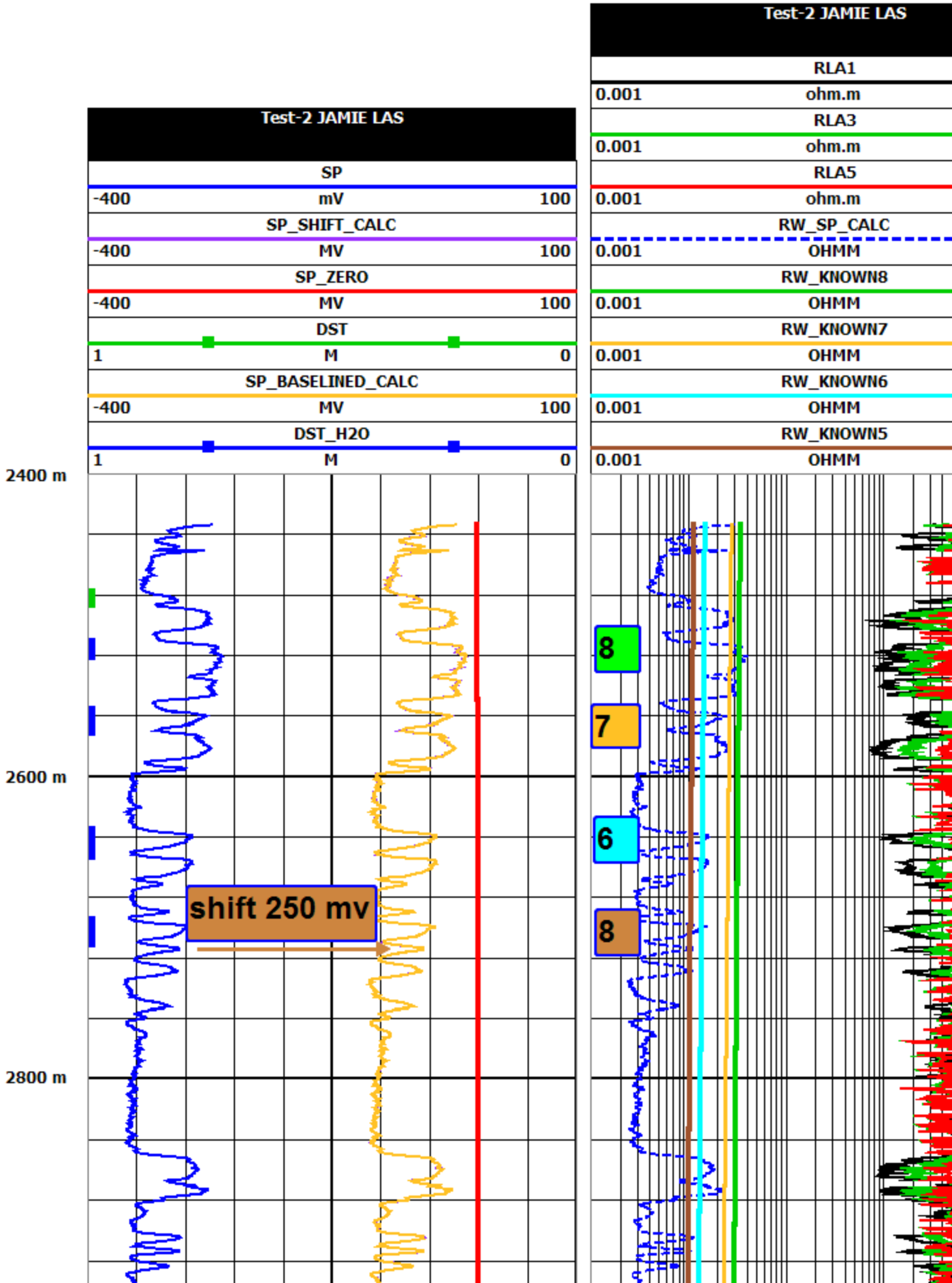
Plot RW_SP and see where it falls relative to SP_KNOWN (e.g. RW for #5 = 0.0282 @78.98 F). After some iterations adding 250 in the SP_SHIFT formula makes it agree with the

RW_KNOWN5. The SP changes as it comes uphole, changing the Rw and susequently verifying that the Rw agrees with the rest RW_KNOWNs.


Test-2 JAMIE LAS
SP
-400
mV
100
SP_SHIFT_CALC
-400
MV
100
SP_ZERO
-400
MV
100
DST
1
M
0
SP_BASELINED_CALC
-400
MV
100
DST_H2O
1
M
0
Test-2 JAMIE LAS
RW_SP_CALC
0.001
OHMM
RW_KNOWN8
0.001
OHMM
RW_KNOWN7
0.001
OHMM
RW_KNOWN6
0.001
OHMM
RW_KNOWN5
0.001
OHMM
2400 m
2600 m
2800 m
shift 250 mv
8
7
6
8
0.078
0.050
0.0395
0.0282@

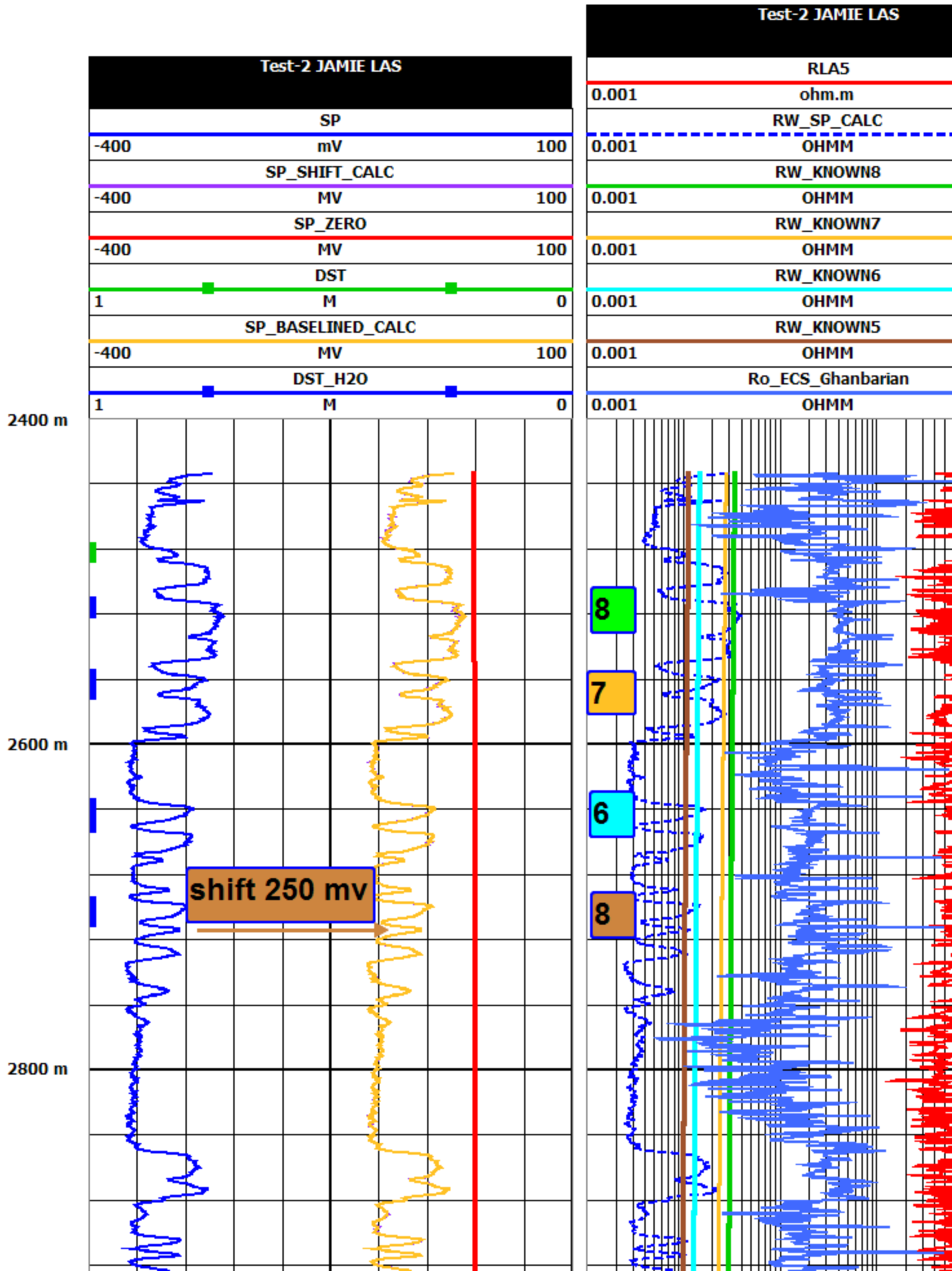
Notice that the RW_SP agrees with all the RW_samples at depths. In short, setting the Rw_SP on one test value results in being calibrated for the rest as you check up or down the well.

Plot the Rla5, Rla3 and Rla1 to show invasion from their separation


Test-2 JAMIE LAS
SP
-400
mV
100
SP_SHIFT_CALC
-400
MV
100
SP_ZERO
-400
MV
100
DST
1
M
0
SP_BASELINED_CALC
-400
MV
100
DST_H2O
1
M
0
Test-2 JAMIE LAS
RLA1
0.001
ohm.m
RLA3
0.001
ohm.m
RLA5
0.001
ohm.m
RW_SP_CALC
0.001
OHMM
RW_KNOWN8
0.001
OHMM
RW_KNOWN7
0.001
OHMM
RW_KNOWN6
0.001
OHMM
RW_KNOWN5
0.001
OHMM
2400 m
2600 m
2800 m
shift 250 mv
8
7
6
8

For quality control purposes, check if (Ro_ECS_Ghanbarian) falls less than Rla5. If it does not, we need to adjust the Rw_SP. If it does, Then Rw_SP is OK. This check is often crucial in detecting an incorrect Rw from the SP.

By now, you have figured out we are dealing with a salt mud. This is a challenging environment when the Rw ~ Rmf. However, in this well, Rmf<Rw, so there is some contrast on the SP deflection and on Rw_SP.


Test-2 JAMIE LAS
SP
-400
mV
100
SP_SHIFT_CALC
-400
MV
100
SP_ZERO
-400
MV
100
DST
1
M
0
SP_BASELINED_CALC
-400
MV
100
DST_H2O
1
M
0
Test-2 JAMIE LAS
RLA5
0.001
ohm.m
RW_SP_CALC
0.001
OHMM
RW_KNOWN8
0.001
OHMM
RW_KNOWN7
0.001
OHMM
RW_KNOWN6
0.001
OHMM
RW_KNOWN5
0.001
OHMM
Ro_ECS_Ghanbarian
0.001
OHMM
2400 m
2600 m
2800 m
shift 250 mv
8
7
6
8

Conclusions

In general, one must calculate an SP_ZERO to get the SP_BASELINED that gives a correct RW_SP. The SP_ZERO is based on an RMF (from log header) and an Rw (from DST or Water Catalog or Rw of 0.05@308F), then calculate the SP using the conventional SP formula (SP_zero = -k log Rmf/Rw). This gives a straight line that moves with temperature; whatever value this comes out to is shifted by adding or subtracting to get the "correct" SP-Baselined. The SP baselined is correct when the calculated RW_SP matches the Known Rw or a water test salinity. Once the SP is calibrated to one salinity, it is calibrated for the entire interval.

In this method, all you need is one approximately-known Rw (from water Catalog or DST sample or Rw of 0.05@308F) for a Formation depth, cross-check it with Ro<=Rt and the resulting Rw will be good for all the Formations available in the well. This method can be applied regardless of the availability of clean, wet zone.

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We have a Petrophysics Designed to Honour Core working group that contributed to this paper.

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