TOTAL DISSOLVED SOLID CALCULATIONS SENSITIVITY ANALYSIS USING NUMERIC WELL LOG SIMULATIONS

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SYNTHETIC EARTH MODEL

Utilizing the modeling software UTAPWeLS, an earth model of interlayered sand, limestone, dolomite (each 50 feet thick), and shale (each layer 25 feet thick) was created to investigate the accuracy of different logging tools and total dissolved solid (TDS) calculation methods. The software simulates each geophysical logging tools of interest, and a sensitivity analysis of TDS calculations is performed by manually reading values from the simulated curves and applying the various calculation methods.

The model assumptions for the base case scenario are: Clean, isotropic, fully water saturated aquifers with only NaCl. Borehole diameter is 12.25 inches. For Archie's equation, values for 'a' and 'm' are 1 and 2, respectively. Mud filtrate salinity is 3,000 mg/L NaCl. Mudcake porosity, permeability, and thickness are 0.35, 0.03 md, and 0.4 inches. Table 1 summarizes the input parameters for the synthetic model base case.

Table 1. Input parameters for the synthetic model base case

Layer	Depth (ft)	Lithology	*k* (md)[a]	Ø[b]	*T* (°F)[c]	Salinity (ppm NaCl)[d, e]
1	500	Shale	0.001	0.25	79.23	100,000
2	525	Dolomite	300	0.15	80.03	1,000
3	575	Shale	0.001	0.25	80.47	100,000
4	600	Sandstone	300	0.15	80.91	3,000
5	650	Shale	0.001	0.25	81.34	100,000
6	675	Limestone	300	0.15	81.71	9,000
7	725	Shale	0.001	0.25	82.14	100,000

TDS CALCULATION METHODS

The following TDS calculation methods were tested for their accuracy using the synthetic earth model and synthetically generated log curves:

Archie's equation (Rwa method) $R_w = R_t \left[\frac{\emptyset^m}{a}\right]$

Resistivity ratio (Alger-Harrison method) $R_w = \frac{R_t}{R_{xo}} R_{mf}$

Spontaneous potential $SSP = SP_{log} - SP_{shale}$ $\quad C_w = C_{mf} 10^{-SSP/K_{SP}}$

Cw = NaCl concentration in ppm

INDUCTION LOG VS LATEROLOG

For a simple case with no mud invasion, Figure 1 demonstrates that the deep induction and laterolog tools have significant error in low TDS formation water simply from tool effects, with up to 28% error for TDS of 1,000 mg/L. The induction log is the most reliable in high TDS formation water with an error of 3% at TDS of 9,000 mg/L. Note that the peak resistivity of the induction log in freshwater is barely resolved in a 50 foot thick bed, and therefore the accuracy for low TDS will be worse in thin beds.

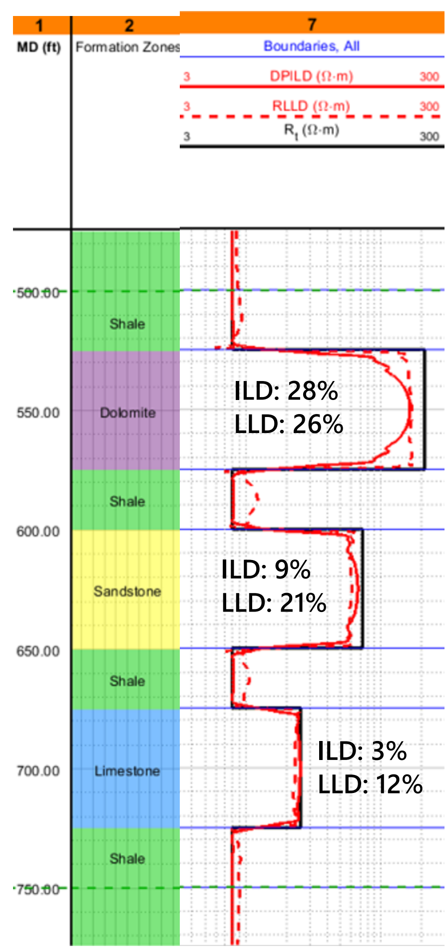

Figure 1. Synthetic log responses for deep induction log (DPILD) and deep laterolog (RLLD), compared to the true formation resistivity (Rt). Percent error from calculated TDS using the Rwa method is annotated for each zone.

EFFECTS OF MUD INVASION, POROSITY, AND FORMATION FACTOR

Figure 2 shows the base case of synthetic logging tool responses assuming moderate mud invasion (2.5 feet, visualized by the formation resistivity in track 8) and equal porosity and 'm' values. The addition of mud invasion significantly reduces the accuracy of the resistivity tools. Table 2 compares the results for various TDS calculation methods. The induction tool overall has greater accuracy than the laterolog, and the Rwa method is overall more accurate than the resistivity ratio method, while the SP method is the most accurate in fresh groundwater. The resistivity ratio method using a laterolog has a 71% error in a freshwater formation. Other analyses show that deeper mud invasion (5 feet) increases the error of the resistivity tools in excess of 90%, but does not affect the SP. Increasing values of 'm' increases formation resistivity, causing greater error in the induction log, whereas the laterolog remains mostly unchanged. The induction log has error in excess of 87% in a freshwater, highly resistive formation in the moderate mud invasion scenario. The effects of porosity are proportional to its effect on mud evasion, where increased porosity results in less mud invasion and increased accuracy, whereas decreased porosity results in more mud invasion and decreased accuracy.

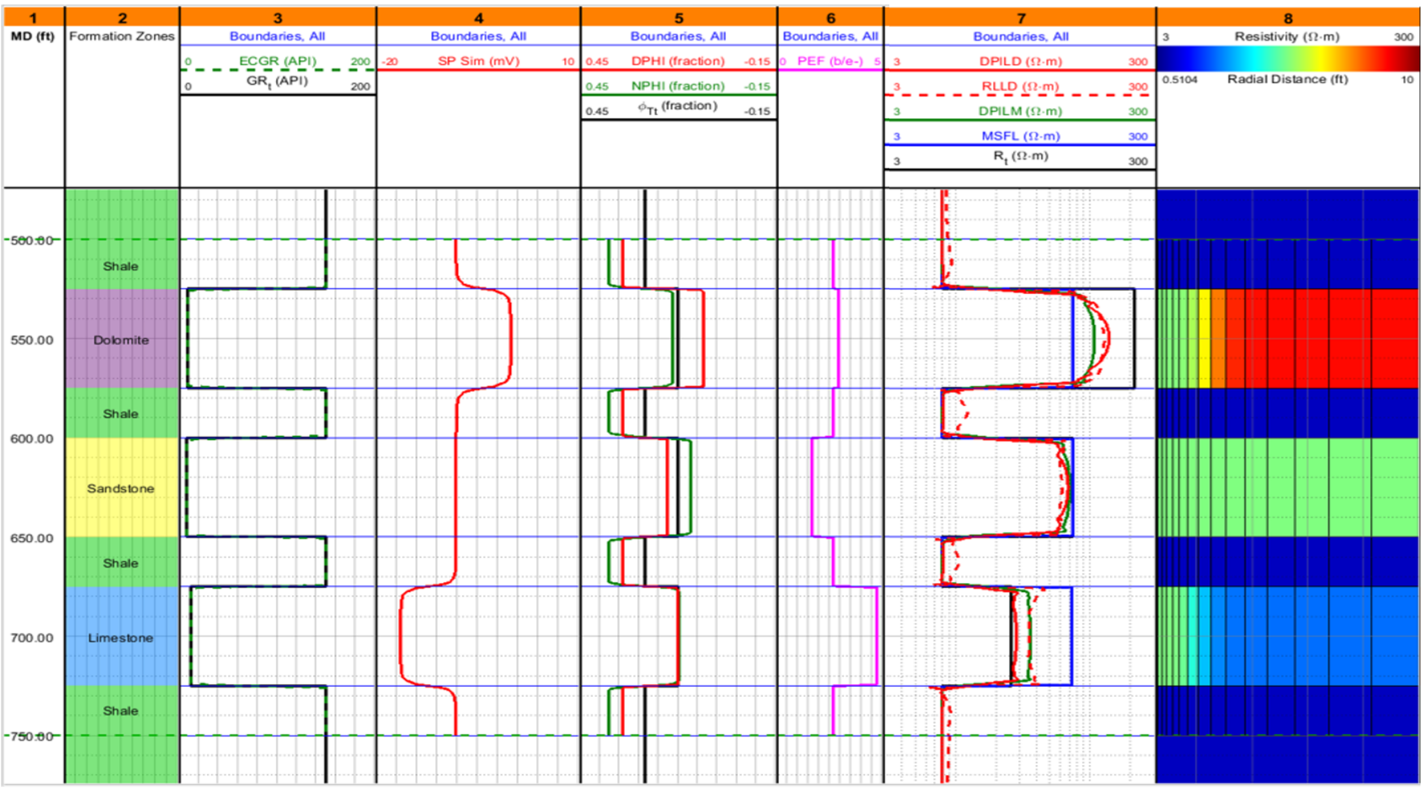

Figure 2. Synthetic log results from the base case of moderate mud invasion and equal values of porosity and 'm'.

Table 2. Water quality calculation results from different methods and logging tools from the base case.

Layer	T(°F)[a]	R_{mf}[b]	R_w[c]	Salinity (ppm NaCl)[d, e]	Method	Error (%)
			4.7005	1,000	Simulation	0.0
			3.1275	1,534	Archie's Equation IL[f]	53.4
2	80.03	1.654	3.0650	1,567	Resistivity Ratio IL[f]	56.7
			2.8800	1,673	Archie's Equation LL[g]	67.3
			2.8224	1,709	Resistivity Ratio LL[g]	70.9
			6.0188	771	Spontaneous Potential	22.9
			1.6372	3,000	Simulation	0.0
			1.5525	3,173	Archie's Equation IL[f]	5.8
4	80.91	1.637	1.5265	3,230	Resistivity Ratio IL[f]	7.7
			1.3950	3,552	Archie's Equation LL[g]	18.4
			1.3717	3,616	Resistivity Ratio LL[g]	20.5
			1.6122	3,049	Spontaneous Potential	1.6
			0.5756	9,000	Simulation	0.0
			0.6300	8,173	Archie's Equation IL[f]	9.2
6	81.71	1.622	0.6139	8,402	Resistivity Ratio IL[f]	6.6
			0.8100	6,255	Archie's Equation LL[g]	30.5
			0.7893	6,430	Resistivity Ratio LL[g]	28.6
			0.4518	11,666	Spontaneous Potential	29.6