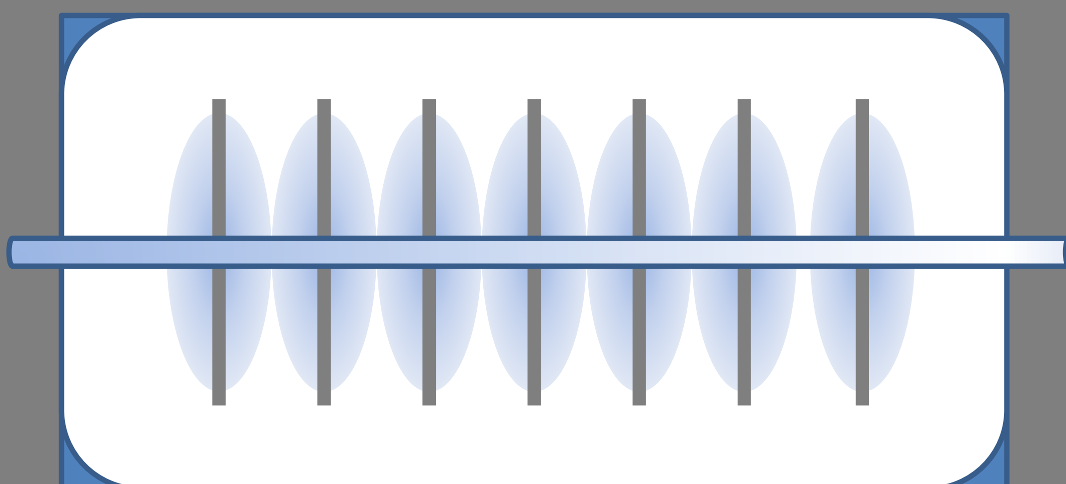
Petroleum Engineering & Economics Essentials

Tools and Techniques to Evaluate Unconventional (and Conventional) Wells and Reservoirs



Quick Log Analysis

Don LeBlanc, PEng

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Disclaimer

Although every effort has been made to ensure that the programs that are a part of PE^2 Essentials work as expected by checking them against historical models that have been built and used in the past, the author does not warrant any of the programs for accuracy.

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Quick Log Analysis Tool

There are numerous log analysis books available. The definitive reference for log analysis techniques is Crain. E. R., The Log Analysis Handbook, Volume 1, Quantitative Log Analysis Methods, PennWell Publishing Company, 1986. In addition, some of the techniques and equations presented here were also published in LeBlanc, D. P., “Enhanced Shaly Sands and Carbonate Analysis on the HP-41c”, Canadian Well Logging Society Journal, December, 1983 and LeBlanc, D. P., “Shaly Sands and Carbonate Analysis on the HP-41c”, Canadian Well Logging Society Journal, December, 1982.

PE² Essentials ‘Quick Log Analysis’ tool (Figure QLA-1) is a basic log analysis tool that can be used to evaluate up to five log intervals and includes a pressure-depth analysis module.

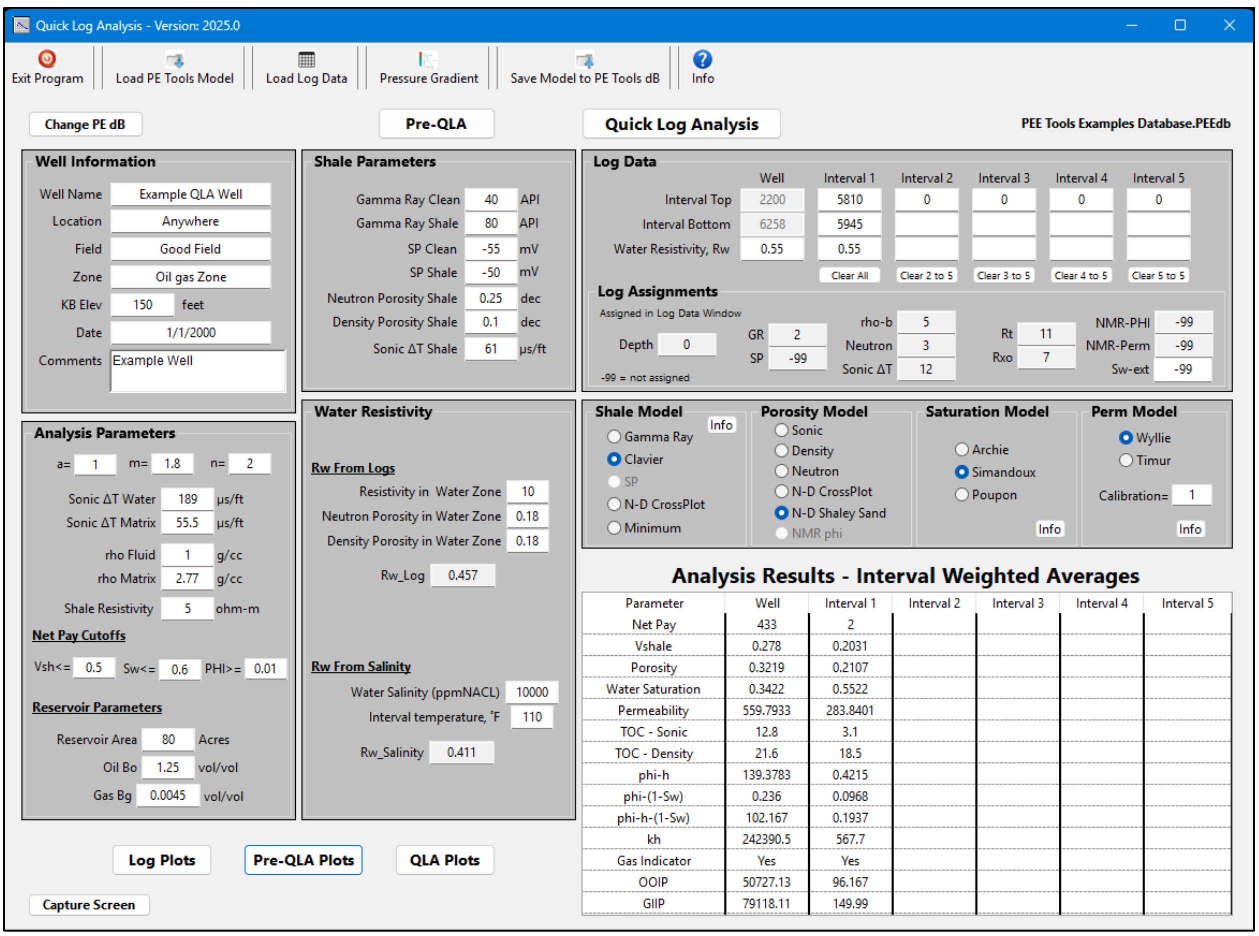


Figure QLA-1: PE² Essentials Quick Log Analysis Tool

The QLA tool can load raw log data into the system, either through a LAS file or from Excel, prior to performing log analysis on an interval basis. The purpose of the Quick Log Analysis tool is to be able to perform a quick analysis of potential reservoir intervals from the log data and presents the weighted averaged analysis results for each interval.

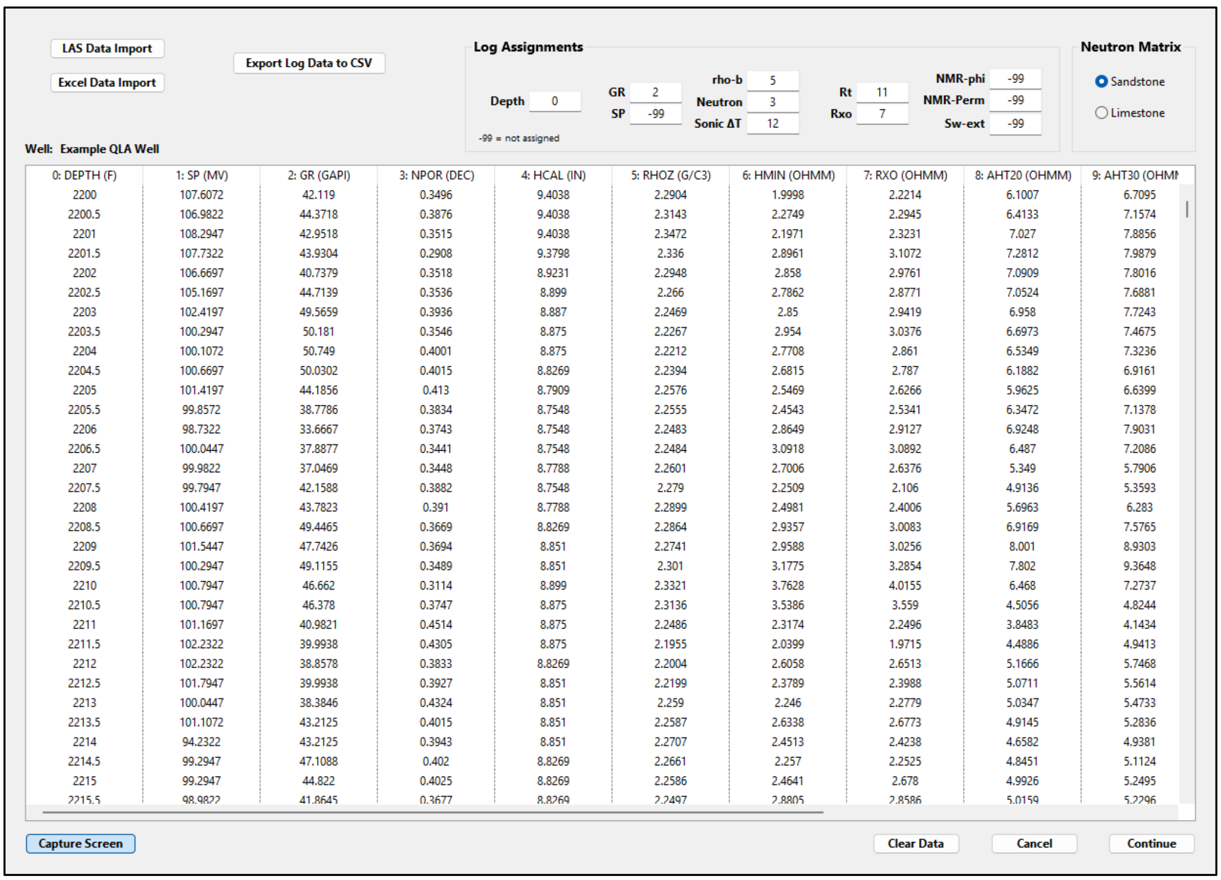
QLA.1 Importing Log Data

There are two options available for importing log data: LAS files; or Excel files. Refer to the "PE Essentials 2025\Example Input Files\QLA Files" directory for example files.

QLA.1.1 LAS Files

Log Ascii Standard (LAS) files are the most common ascii file format available for log data. There is also a binary file format called DLIS, but this is not implemented in the PE² Essentials Quick Log Analysis tool.

QLA can read, and write, LAS files as long as they conform to the version 2.0 LAS standard. If the available data is in a different format, then an Excel file can be used to import the data. To load a LAS file, click the "Load Log Data" menu item. Choose "LAS Data Import" and select the LAS file. Figure QLA-2 shows the load results.



0: DEPTH (F)	1: SP (MV)	2: GR (GAPI)	3: NPOR (DEC)	4: HCAL (IN)	5: RHOZ (G/C3)	6: HMIN (OHMM)	7: RXO (OHMM)	8: AHT20 (OHMM)	9: AHT30 (OHMM
2200	107.6072	42.119	0.3496	9.4038	2.2904	1.9998	2.2214	6.1007	6.7095
2200.5	106.9822	44.3718	0.3876	9.4038	2.3143	2.2749	2.2945	6.4133	7.1574
2201	108.2947	42.9518	0.3515	9.4038	2.3472	2.1971	2.3231	7.027	7.8856
2201.5	107.7322	43.9304	0.2908	9.3798	2.336	2.8961	3.1072	7.2812	7.9879
2202	106.6697	40.7379	0.3518	8.9231	2.2948	2.858	2.9761	7.0909	7.8016
2202.5	105.1697	44.7139	0.3536	8.899	2.266	2.7862	2.8771	7.0524	7.6881
2203	102.4197	49.5659	0.3936	8.887	2.2469	2.85	2.9419	6.958	7.7243
2203.5	100.2947	50.181	0.3546	8.875	2.2267	2.954	3.0376	6.6973	7.4675
2204	100.1072	50.749	0.4001	8.875	2.2212	2.7708	2.861	6.5349	7.3236
2204.5	100.6697	50.0302	0.4015	8.8269	2.2394	2.6815	2.787	6.1882	6.9161
2205	101.4197	44.1856	0.413	8.7909	2.2576	2.5469	2.6266	5.9625	6.6399
2205.5	99.8572	38.7786	0.3834	8.7548	2.2555	2.4543	2.5341	6.3472	7.1378
2206	98.7322	33.6667	0.3743	8.7548	2.2483	2.8649	2.9127	6.9248	7.9031
2206.5	100.0447	37.8877	0.3441	8.7548	2.2484	3.0918	3.0892	6.487	7.2086
2207	99.9822	37.0469	0.3448	8.7788	2.2601	2.7006	2.6376	5.349	5.7906
2207.5	99.7947	42.1588	0.3882	8.7548	2.279	2.2509	2.106	4.9136	5.3593
2208	100.4197	43.7823	0.391	8.7788	2.2899	2.4981	2.4006	5.6963	6.283
2208.5	100.6697	49.4465	0.3669	8.8269	2.2864	2.9357	3.0083	6.9169	7.5765
2209	101.5447	47.7426	0.3694	8.851	2.2741	2.9588	3.0256	8.001	8.9303
2209.5	100.2947	49.1155	0.3489	8.851	2.301	3.1775	3.2854	7.802	9.3648
2210	100.7947	46.662	0.3114	8.899	2.3321	3.7628	4.0155	6.468	7.2737
2210.5	100.7947	46.378	0.3747	8.875	2.3136	3.5386	3.559	4.5056	4.8244
2211	101.1697	40.9821	0.4514	8.875	2.2486	2.3174	2.2496	3.8483	4.1434
2211.5	102.2322	39.9938	0.4305	8.875	2.1955	2.0399	1.9715	4.4886	4.9413
2212	102.2322	38.8578	0.3833	8.8269	2.2004	2.6058	2.6513	5.1666	5.7468
2212.5	101.7947	39.9938	0.3927	8.851	2.2199	2.3789	2.3988	5.0711	5.5614
2213	100.0447	38.3846	0.4324	8.851	2.259	2.246	2.2779	5.0347	5.4733
2213.5	101.1072	43.2125	0.4015	8.851	2.2587	2.6338	2.6773	4.9145	5.2836
2214	94.2322	43.2125	0.3943	8.851	2.2707	2.4513	2.4238	4.6582	4.9381
2214.5	99.2947	47.1088	0.402	8.8269	2.2661	2.257	2.2525	4.8451	5.1124
2215	99.2947	44.822	0.4025	8.8269	2.2586	2.4641	2.678	4.9926	5.2495
2215.5	98.9822	41.8645	0.3677	8.8269	2.2497	2.8805	2.8586	5.0159	5.2296

Figure QLA-2: Log Data Import

The data import is presented in a table with numbers assigned to each log. Prior to exiting this screen, the Log Assignments must be made. This indicates which LAS data is assigned to specific logs. This is required to ensure the analysis is valid.

It should be noted that the QLA tool uses bulk density, not density porosity. This ensures that the final density porosity is presented using the correct matrix density which is entered on the main screen.

Finally, the matrix under which the Neutron log was recorded (sandstone or limestone) must be specified. This is required since the QLA tool will correct the Neutron log to the matrix density that has been entered on the main screen.

After the parameters have been set, a plot of the well log data is presented (Figure QLA-3).

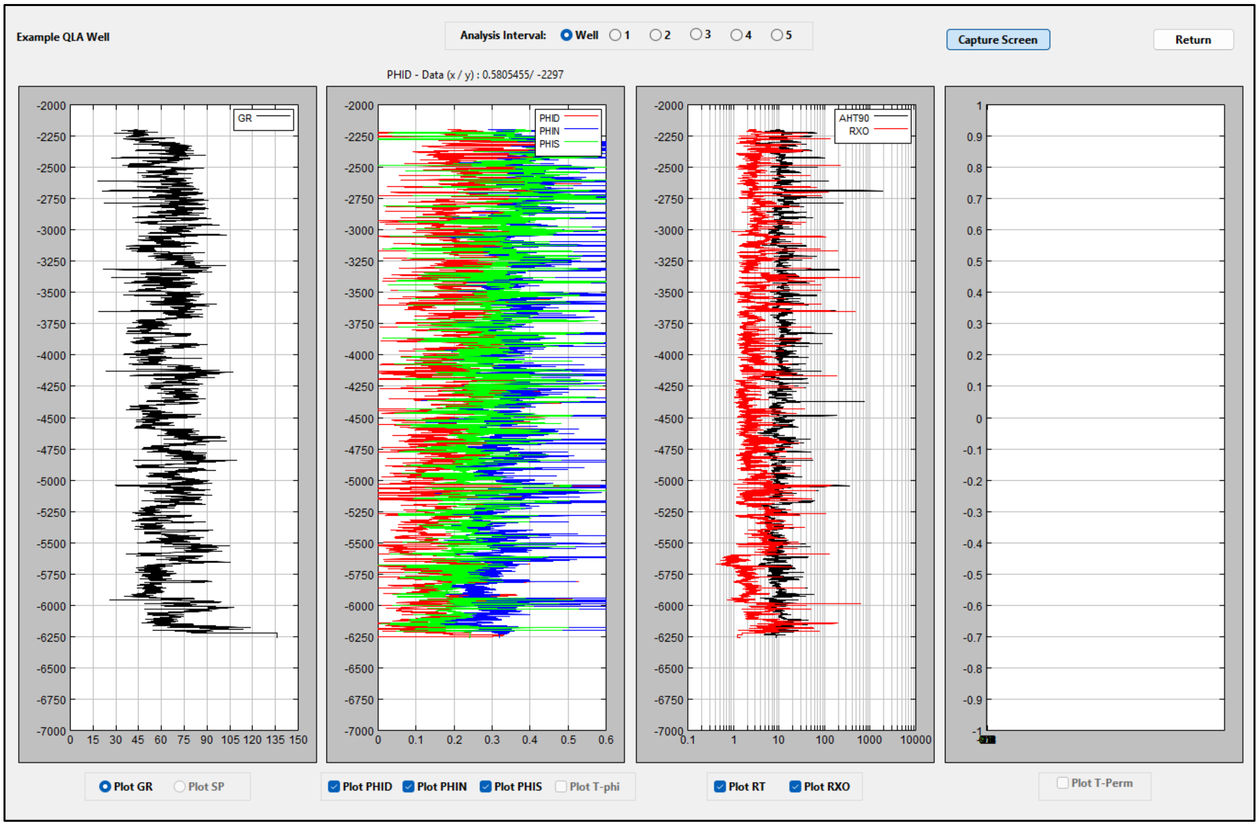


Figure QLA-3: Log Data Plot

The log plot can be used to ensure the data has been imported and for log quality control.

QLA.1.2 Excel Files

If a version 2.0 LAS file is not available, an Excel file can be used to import the data. Figure QLA-4 shows the Excel format that must be used to import the log data. Refer to “PE Essentials 2025\Example Input Files\QLA Files\Log Data.xlsx” for an example Excel log data input file.

To import from an Excel file, the Excel file must be open and the data worksheet selected.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	LogData													
2	QLA2025 Example													
3	DEPTH	SP	GR	NPOR	HCAL	RHOZ	HMIN	RXO	AHT20	AHT30	AHT60	AHT90	DT	GR2
4	F	MV	GAPI	DEC	IN	G/C3	OHMM	OHMM	OHMM	OHMM	OHMM	OHMM	US/F	GAPI
5	2200	107.6072	42.119	0.3496	9.4038	2.2904	1.9998	2.2214	6.1007	6.7095	8.1753	8.7193	103.8466	46.1331
6	2200.5	106.9822	44.3718	0.3876	9.4038	2.3143	2.2749	2.2945	6.4133	7.1574	8.6445	9.2221	105.2436	42.552
7	2201	108.2947	42.9518	0.3515	9.4038	2.3472	2.1971	2.3231	7.027	7.8856	9.7654	10.3563	106.6206	40.3401
8	2201.5	107.7322	43.9304	0.2908	9.3798	2.336	2.8961	3.1072	7.2812	7.9879	9.6571	10.0797	107.1082	32.1246
9	2202	106.6697	40.7379	0.3518	8.9231	2.2948	2.858	2.9761	7.0909	7.8016	9.5192	9.7497	107.1549	33.2305
10	2202.5	105.1697	44.7139	0.3536	8.899	2.266	2.7862	2.8771	7.0524	7.6881	9.4983	9.5026	106.2107	34.8104
11	2203	102.4197	49.5659	0.3936	8.887	2.2469	2.85	2.9419	6.958	7.7243	9.5311	9.5469	104.8097	37.0223
12	2203.5	100.2947	50.181	0.3546	8.875	2.2267	2.954	3.0376	6.6973	7.4675	9.1662	9.2365	104.4829	38.5495
13	2204	100.1072	50.749	0.4001	8.875	2.2212	2.7708	2.861	6.5349	7.3236	8.9779	8.9115	103.69	41.7094
14	2204.5	100.6697	50.0302	0.4015	8.8269	2.2394	2.6815	2.787	6.1882	6.9161	8.3404	8.5134	104.1057	40.7614
15	2205	101.4197	44.1856	0.413	8.7909	2.2576	2.5469	2.6266	5.9625	6.6399	7.9585	8.2994	104.9029	42.1833
16	2205.5	99.8572	38.7786	0.3834	8.7548	2.2555	2.4543	2.5341	6.3472	7.1378	8.7854	9.1509	105.24	37.1276
17	2206	98.7322	33.6667	0.3743	8.7548	2.2483	2.8649	2.9127	6.9248	7.9031	10.1098	10.6115	106.2572	39.0235
18	2206.5	100.0447	37.8877	0.3441	8.7548	2.2484	3.0918	3.0892	6.487	7.2086	8.8559	9.317	103.3474	39.4975
19	2207	99.9822	37.0469	0.3448	8.7788	2.2601	2.7006	2.6376	5.349	5.7906	6.8048	7.0941	99.2786	42.6573
20	2207.5	99.7947	42.1588	0.3882	8.7548	2.279	2.2509	2.106	4.9136	5.3593	6.2926	6.5478	99.8895	46.9757
21	2208	100.4197	43.7823	0.391	8.7788	2.2899	2.4981	2.4006	5.6963	6.283	7.5535	7.8499	101.4309	47.6077
22	2208.5	100.6697	49.4465	0.3669	8.8269	2.2864	2.9357	3.0083	6.9169	7.5765	9.4021	10.1438	104.0155	47.6077
23	2209	101.5447	47.7426	0.3694	8.851	2.2741	2.9588	3.0256	8.001	8.9303	11.4411	12.6717	109.1727	41.0774
24	2209.5	100.2947	49.1155	0.3489	8.851	2.301	3.1775	3.2854	7.802	9.3648	11.8535	13.1708	108.6076	38.1282
25	2210	100.7947	46.662	0.3114	8.899	2.3321	3.7628	4.0155	6.468	7.2737	8.8288	9.665	107.094	37.4963
26	2210.5	100.7947	46.378	0.3747	8.875	2.3136	3.5386	3.559	4.5056	4.8244	5.4376	5.7816	106.3998	41.92
27	2211	101.1697	40.9821	0.4514	8.875	2.2486	2.3174	2.2496	3.8483	4.1434	4.7849	4.9704	106.5485	42.0253
28	2211.5	102.2322	39.9938	0.4305	8.875	2.1955	2.0399	1.9715	4.4886	4.9413	5.9373	6.2519	106.4089	41.13
29	2212	102.2322	38.8578	0.3833	8.8269	2.2004	2.6058	2.6513	5.1666	5.7468	6.9322	7.4567	107.0675	45.2378
30	2212.5	101.7947	39.9938	0.3927	8.851	2.2199	2.3789	2.3988	5.0711	5.5614	6.6143	7.1804	109.1971	49.9775

Figure QLA-4: Log Data Input from an Excel File

Following input of the log data from Excel, the table and plot presented in Figures QLA-2 and QLA-3 will be presented.

QLA.2 Pre-QLA

The Pre-QLA module is designed to enable picking intervals and performing a pre-analysis of the data.

Pre-analysis encompasses picking intervals form the log for analysis. The top and bottom depth of the intervals are set on the main screen and each interval can be selected Pre-QLA Plot (Figure QLA-5) for in-depth review.

Once an interval is set and chosen (Figure QLA-6) the Pre-QLA module enables the setting of the shale parameters and shale model; setting the porosity parameters and choosing a porosity model; and evaluating R_{wa} within the interval. R_{wa} can be used to estimate the water resistivity and is also termed a quicklook parameter for finding hydrocarbon zones.

It is possible to export the Pre-QLA results for the selected interval to a CSV file by clicking the "Export preQLA Data to CSV" button.

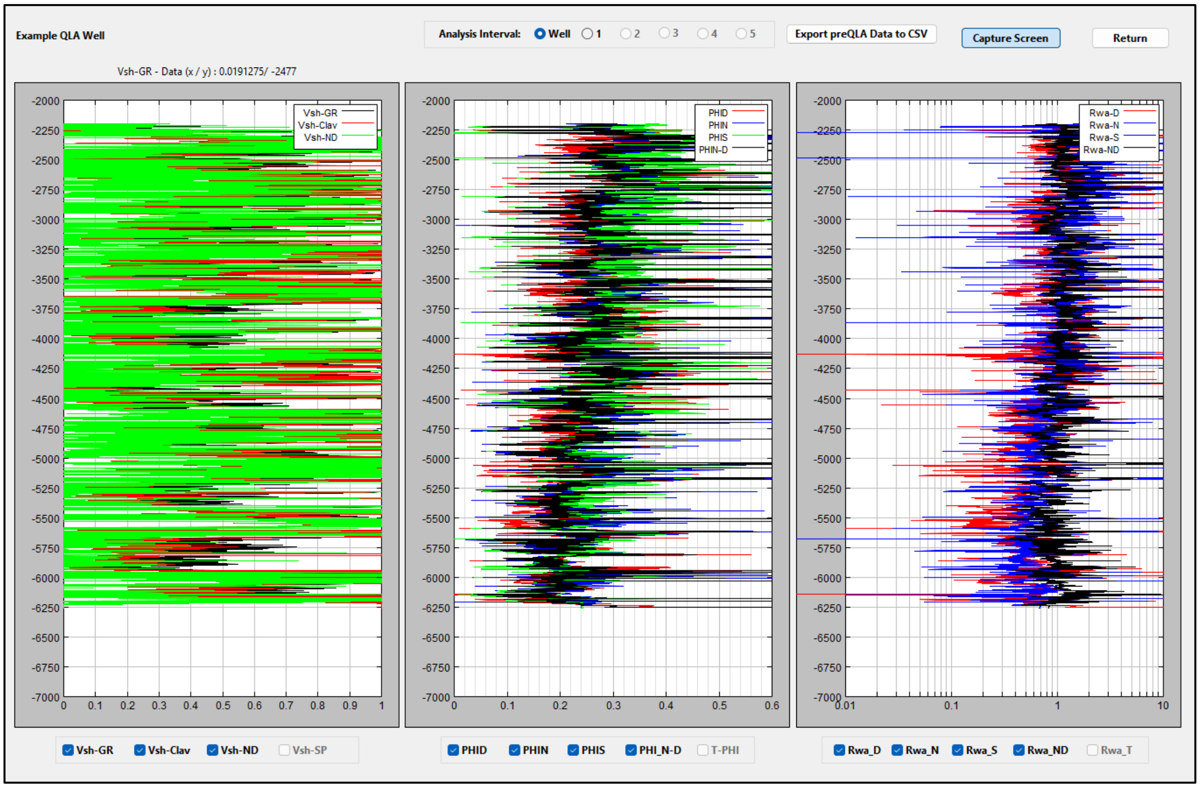


Figure QLA-5: Pre-QLA Plot

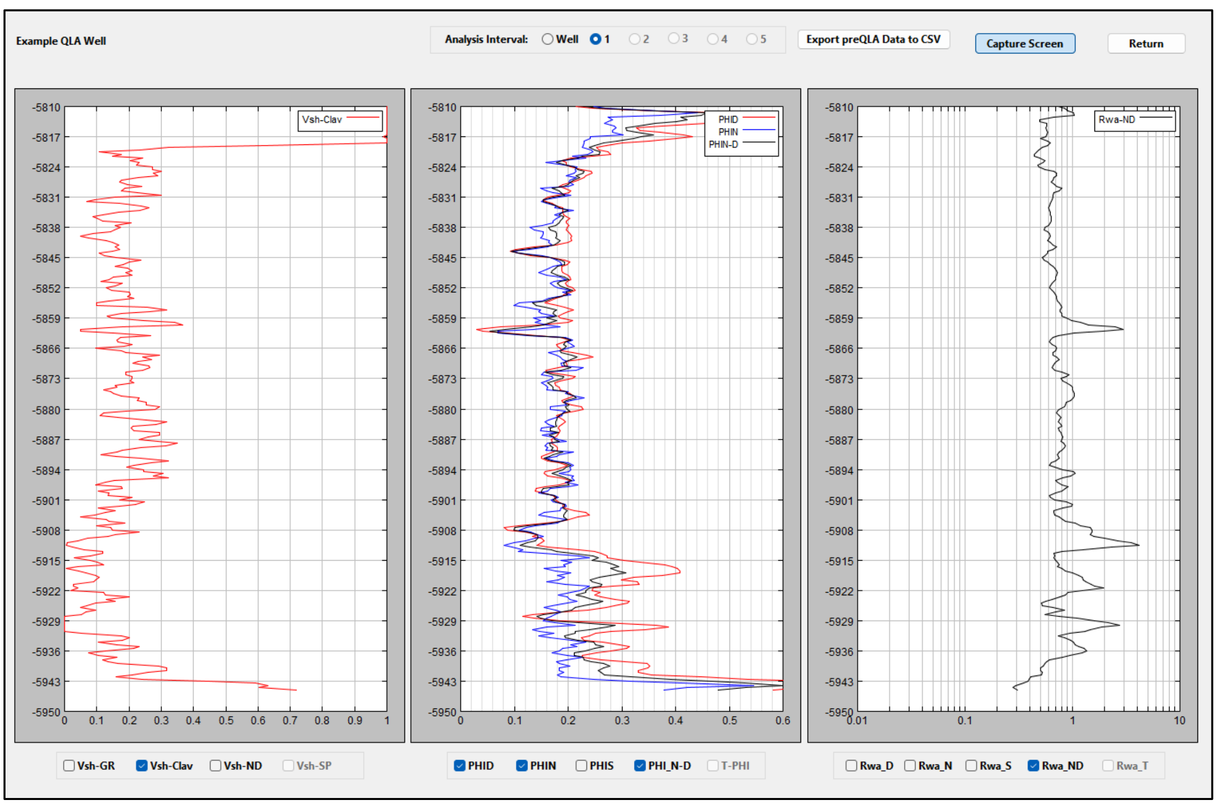


Figure QLA-6: Pre-QLA Plot – Interval 1

QLA.3 Log Analysis Models

A number of petrophysical models make up a log analysis system. PE² Essentials Quick Log Analysis tool includes models for shale, porosity, water saturation and permeability (Figure QLA-7).

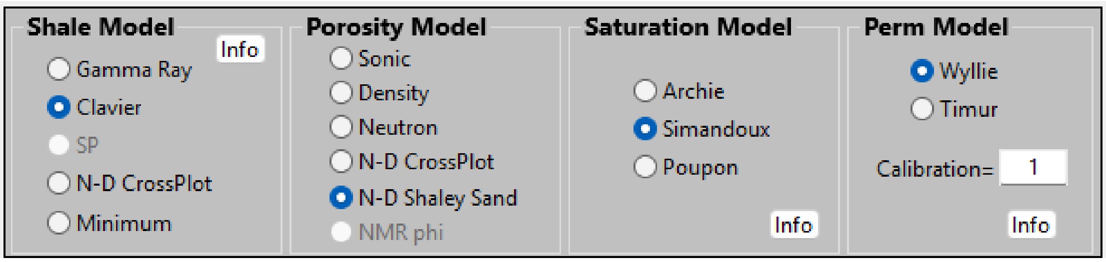


Figure QLA-7: PE² Essentials Quick Log Analysis Tool - Model Options

Although there are many models and techniques available, the included models are some of the most commonly used models for log analysis.

QLA.3.1 Shale Models

Shale volume is required to correct porosity and water saturation results for the effects of shale. Shale volume is also an indicator of reservoir quality and is used to indicate net pay.

The most common models used to calculate shale volume are based on the Gamma Ray (GR) log, the Spontaneous Potential (SP) log, and the Neutron-Density logs (Figure QLA-3).

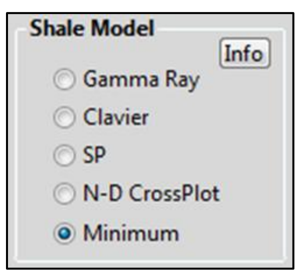


Figure QLA-8: Shale Model Options

The 'Gamma Ray' and 'Clavier' options both use an index (I_{SH}) calculated from the GR log.

For the 'Gamma Ray' option, the assumption is that the shale volume, V_{sh}, follows a linear relationship from the clean GR value, GR_0, to the 100% shale GR value, GR_{100}.

$$I_{SH} = (GR_{log} - GR_0) / (GR_0 - GR_{100}) \quad \text{(QLA-1)}$$

$$V_{sh} = I_{GR} \quad \text{(QLA-2)}$$

Shlumberger and Dresser-Atlas (now Baker-Hughes) published optional equations that changed the V_{sh} calculation to a non-linear function of I_{GR}. Shlumberger's equation is included as the "Clavier" option as follows.

$$V_{sh} = 1.7 - (3.38 - (I_{SH} + 0.7)^2)^{0.5} \qquad \text{(QLA-3)}$$

The Dresser-Atlas equations are as follows.

$$V_{sh} = 0.083\ (2^{3.7 I_{SH}} - 1) \quad \text{:Tertiary Rocks} \qquad \text{(QLA-4)}$$

$$V_{sh} = 0.33\ (2^{2 I_{SH}} - 1) \quad \text{:Older Rocks} \qquad \text{(QLA-5)}$$

Note that the Dresser-Atlas equations are not included in the PE^2 Essentials Quick Log Analysis model.

The 'SP' option is similar to the Gamma Ray option in that the assumption is that the shale volume, V_{sh}, follows a linear relationship from the clean SP value, SP_0, to the 100% shale SP value, SP_{100}.

$$I_{SH} = (SP_{log} - SP_0) / (SP_0 - SP_{100}) \qquad \text{(QLA-6)}$$

$$V_{sh} = I_{SH} \qquad \text{(QLA-7)}$$

The 'N-D CrossPlot' option uses the Neutron (ϕ_N) and Density (ϕ_D) logs to determine V_{sh}.

$$V_{sh} = (\phi_{Nlog} - \phi_{Dlog}) / (\phi_{NSH} - \phi_{DSH}) \qquad \text{(QLA-8)}$$

The V_{sh} calculated by N-D crossplot may be impacted by the assumed value of the rock matrix, the existence of gas and the rugosity of the borehole.

Choosing the 'Minimum' option will choose the minimum V_{sh} calculated using all models.

QLA.3.2 Porosity Models

There are three basic porosity logging tools – sonic, density and neutron. Each tool can be used as an independent indicator of porosity or the Neutron (ϕ_N) and Density (ϕ_D) logs can be used simultaneously (crossplotted) to determine the porosity (Figure QLA-9).

Porosity calculated from logs without applying a shale correction is termed apparent or total porosity. Effective porosity is the resulting porosity after applying a shale correction.

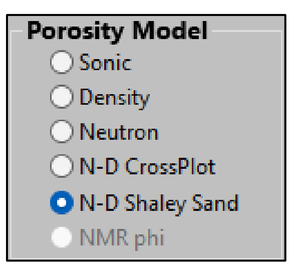


Figure QLA-9: Porosity Model Options

The sonic log records the sonic travel time, Δt, of a small interval of rock. The equation for sonic porosity, ϕ_s, is as follows.

$$\phi_s = (\Delta t_{log} - \Delta t_{ma}) / (\Delta t_w - \Delta t_{ma}) \qquad \text{(QLA-9)}$$

The equation for sonic-based porosity, with shale correction is as follows.

$$\phi = (\Delta t_{log} - ((1 - V_{sh})\ \Delta t_{ma}) - (V_{sh}*\Delta t_{sh})) / (\Delta t_w - \Delta t_{ma}) \qquad \text{(QLA-10)}$$

Where: ϕ is the porosity in decimal, Δt_{log} is the sonic log reading in the interval of interest, V_{sh} is the volume of shale, Δt_{ma} is the rock matrix travel time (Table QLA-1), Δt_{sh} is the sonic travel time in 100% shale and Δt_w is the sonic travel time in water.

Lithology	Δt	
	µsec/ft	µsec/m
Fresh Water	200	656
Salt Water	188	617
Shale	60 - 150	197-492
Granite	50	164
Sandstone	55.5	182
Limy sandstone	52	171
Limestone	47.3	155
Limy Dolomite	46	151
Dolomite	44	144
Anhydrite	50	164
Coal	95+	312+
Salt	66.7	219

Table QLA-1: Sonic Δt Values

One caution to be kept in mind is what is termed as the 'sonic compaction factor', C_p. This is only an issue if Δt_{sh} is greater than 100µsec/ft (328µsec/m), which could occur for depths less than 3000ft (1000m).

$$C_p = \Delta t_{sh} / 100 \text{ or } C_p = \Delta t_{sh} / 328 \qquad \text{(QLA-11)}$$

$$\phi = \phi_s / C_p \qquad \text{(QLA-12)}$$

The Quick Log Analysis tool assumes that C_p is one; i.e. no compaction correction applied to ϕ_s.

The density log measures the bulk density, ρ_b, of the rock and records either the density, ρ_b, or the density porosity, ϕ_D. The equation for density porosity is as follows.

$$\phi_D = (\rho_{ma} - \rho_b) / (\rho_{ma} - \rho_f) \qquad \text{(QLA-13)}$$

The equation for density-based porosity, with shale correction is as follows.

$$\phi = \phi_D - V_{sh}\ \phi_{Dsh} \qquad \text{(QLA-14)}$$

$$\phi_{Dsh} = (\rho_{ma} - \rho_{sh}) / (\rho_{ma} - \rho_f) \qquad \text{(QLA-15)}$$

Where: ϕ is the porosity in decimal, ϕ_D is the density porosity, V_{sh} is the volume of shale, ϕ_{Dsh} is the density porosity of 100% shale, ρ_b is the recorded log bulk density, ρ_{ma} is the rock matrix density (Table QLA-2), ρ_{sh} is the density of 100% shale and ρ_f is the density of mud filtrate (water).

Lithology	ρ	
	g/cc	kg/m³
Fresh Water	1	1000
Salt Water	1.1	1100
Shale	2.5 - 2.83	2500-2830
Chlorite	2.6 - 2.96	2600-2960
Kaolinite	2.6 - 2.68	2600-2680
Montmorillonite	2.2 - 2.7	2200-2700
Granite	2.75	2750
Sandstone	2.65	2650
Limy sandstone	2.68	2680
Limestone	2.71	2710
Limy Dolomite	2.83	2830
Dolomite	2.87	2870
Anhydrite	2.95	2950
Coal	1.5 - 2.35	1500-2350
Salt	2.03	2030

Table QLA-2: Density Values

The existence of gas may cause the calculated porosity to be too high because a low bulk density is recorded. This can be corrected by modifying ρ_f as follows.

$$\rho_f = (1 - S_{xo})\rho_g + S_{xo}\rho_{mf} \qquad \text{(QLA-16)}$$

Where: S_{xo} is the water saturation in the invaded zone, ρ_g is the gas density and ρ_{mf} is the density of the mud filtrate.

Note that this correction is not incorporated into the Quick Log Analysis model.

The neutron log measures hydrogen index of the rock and presents it as the neutron porosity, ϕ_N, of the rock.

The caveat for the neutron log is the matrix on which the log is recorded. Most analysis and interpretation charts assume that the neutron log is recorded on a limestone matrix. For this situation, the neutron porosity can be corrected to a different lithology. As an example, for Schlumberger CNL logs the following corrections apply.

- Limestone to sandstone: $\phi_{Nss} = 0.222\phi_{NLS}^2 + 1.021\phi_{NLS} + 0.039$ (QLA-17)
- Limestone to dolomite: $\phi_{Ndol} = 1.4\phi_{NLS}^2 + 0.389\phi_{NLS} - 0.01259$ (QLA-18)

In general, if the neutron porosity is presented on a limestone scale, add 0.04 to the log reading to yield neutron porosity for a sandstone matrix, and vice-versa.

The equation for neutron-based porosity, with shale correction is as follows.

$$\phi = \phi_N - V_{sh}\,\phi_{Nsh} \qquad \text{(QLA-19)}$$

Where: ϕ is the porosity in decimal, ϕ_N is the neutron porosity, V_{sh} is the volume of shale and ϕ_{Nsh} is the neutron porosity of 100% shale.

The existence of gas may cause the neutron porosity read too low because of the reduced hydrogen index in the gas. This effect is not a constant and is a function of the density and wetness of the gas. Dry, low-pressure and high temperature gases have larger impact on the neutron porosity. Shale will reduce the gas effect since shale ϕ_{Nsh} tend to be high values.

If the existence of gas is suspected, using the neutron-density crossplot model is preferred to calculate porosity. The 'N-D CrossPlot' model will take an average of the neutron and density log porosities.

$$\phi = (\phi_N + \phi_D) / 2 \qquad \text{(QLA-20)}$$

If the neutron porosity is more than 0.02 less than the density porosity, a gas effect is assumed to exist and the porosity calculation is as follows.

$$\phi = ((\phi_N^2 + \phi_D^2) / 2)^{0.5} \qquad \text{(QLA-21)}$$

This weights the porosity towards the density porosity and is valid in a clean sandstone or a carbonate reservoir.

The 'N-D Shaly Sand' model takes an average of the shale-corrected neutron and density porosities.

$$\phi = (\phi_{Nc} + \phi_{Dc}) / 2 \qquad \text{(QLA-22)}$$

$$\phi_{Nc} = \phi_N - V_{sh}\,\phi_{Nsh} \qquad \text{(QLA-23)}$$

$$\phi_{Dc} = \phi_D - V_{sh}\,\phi_{Dsh} \qquad \text{(QLA-24)}$$

If the shale-corrected neutron porosity is more than 0.02 less than the shale-corrected density porosity, a gas effect is assumed to exist and the porosity calculation is as follows.

$$\phi = ((\phi_{Nc}^2 + \phi_{Dc}^2) / 2)^{0.5} \qquad \text{(QLA-25)}$$

This weights the porosity towards the density porosity.

QLA.3.3 Water Saturation Models

There are two shaly sand water saturation models as well as the Archie water saturation model included in the Quick Log Analysis model (Figure QLA-10).

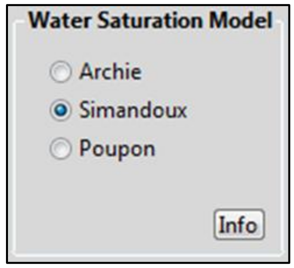


Figure QLA-10: Water Saturation Model Options

The Archie water saturation model is the original standard used by the oil industry but is now only used for clean sandstones or carbonates. The equation is as follows.

$$S_w = (a\ R_w / \phi^m\ R_t)^{1/n} \quad \text{(QLA-26)}$$

Where: a is the tortuosity factor (1 for carbonate and 0.62 for sandstone), m is the cementation exponent (2 for carbonate and 2.15 for sandstone), n is the saturation exponent (ranges from 1.8 to 2.5, normally set equal to 2), R_w is the formation water resistivity and R_t is the true formation resistivity.

For the flushed zone, the Archie equation is as follows.

$$S_{xo} = (a\ R_{mf} / \phi^m\ R_{xo})^{1/n} \quad \text{(QLA-27)}$$

Where: R_{mf} is the mud filtrate resistivity and R_{xo} is the flushed zone resistivity.

If the value for S_{xo} is greater than the value for S_w, this may be an indication that movable hydrocarbons exist in the reservoir.

The Archie equation is inaccurate when shale is present in the reservoir. One of the most commonly used shaly sand water saturation model is the Simondoux model.

The Simondoux water saturation equation is as follows.

$$S_w = [(A^2 + B)^{0.5} - C]^{2/n} \quad \text{(QLA-28)}$$

$$A = [(1 - V_{sh})\ V_{sh}\ aR_w/2\phi^m R_{sh}]$$

$$B = (1 - V_{sh})\ aR_w/\phi^m R_t$$

$$C = 0.5(1 - V_{sh})\ V_{sh}\ aR_w/\phi^m R_{sh}$$

Where: a is the tortuosity factor (1 for carbonate and 0.62 for sandstone), m is the cementation exponent (2 for carbonate and 2.15 for sandstone), n is the saturation exponent (ranges from 1.8 to 2.5, normally set equal to 2), R_w is the formation water, R_{sh} is the resistivity of the shale, and R_t is the true formation resistivity.

An alternative shaly sand model is the empirical Poupon-Leveaux model, also referred to as the Indonesian model. The Poupon-Leveaux water saturation equation is as follows.

$$S_w = [(A + B)^2 R_t]^{-1/n} \quad \text{(QLA-29)}$$

$$A = [V_{sh}^{(2-Vsh)} / R_{sh}]^{0.5}$$

$$B = (\phi^m / aR_w)^{0.5}$$

Where: a is the tortuosity factor (1 for carbonate and 0.62 for sandstone), m is the cementation exponent (2 for carbonate and 2.15 for sandstone), n is the saturation exponent (ranges from 1.8 to 2.5, normally set equal to 2), R_w is the formation water, R_{sh} is the resistivity of the shale, and R_t is the true formation resistivity.

QLA.3.4 Permeability Models

There are two permeability models included in the Quick Log Analysis model (Figure QLA-6).

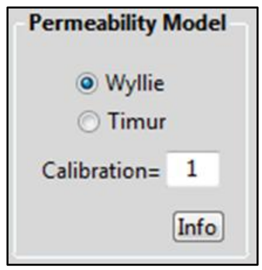


Figure QLA-11: Permeability Model Options

The Wyllie-Rose permeability model is the original method used to calculate permeability from logs. It is accurate when calibrated to core data. The equation is as follows.

$$k = 65000Cor\ \phi^6 / S_w^2 \quad \text{(QLA-30)}$$

Where: k is permeability in md, Cor is the correlating parameter equal to 1 for oil and 0.1 for gas.

The Timur permeability model is similar to the Wylie-Rose formulation but incorporates different constants. The equation is as follows.

$$k = 3400Cor\ \phi^{4.4} / S_w^2 \quad \text{(QLA-31)}$$

Where: k is permeability in md, Cor is the correlating parameter equal to 1 for oil and 0.1 for gas.

The Cor constant is entered as the ‘Calibration’ input on the main screen. This factor can also be used to calibrate the log reading to the core data.

QLA.4 Log Analysis Parameters and Results

A number of parameters are required in order to generate a log analysis. Formation water resistivity, R_w, is one of the main parameters required for all water saturation models. There are two main techniques to derive R_w; calculate directly from a water bearing interval, or estimate the value based on water salinity (Figure QLA-12).

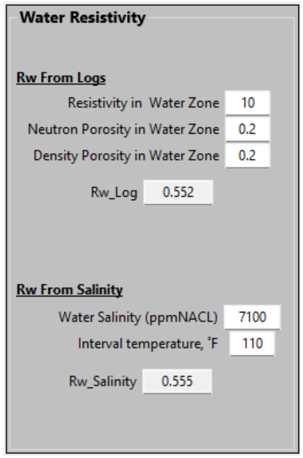


Figure QLA-12: Input Formation Water Resistivity

Estimating R_w from a water zone is done using the Archie equation with input R_t and ϕ. For this calculation the a, m and n parameters need to be entered as well (Figure QLA-13). To estimate R_w based on salinity, the ppm NACL and the temperature have to be entered. If both calculations are performed, then the R_w to be used in the water saturation calculations has to be specified.

The net pay cutoffs and the reservoir parameters are optional inputs but are normally entered so that net reservoir and hydrocarbon (oil and/or gas) volumes can be calculated.

Input of shale parameters are required if shaly sand analysis is to be performed (Figure QLA-14).

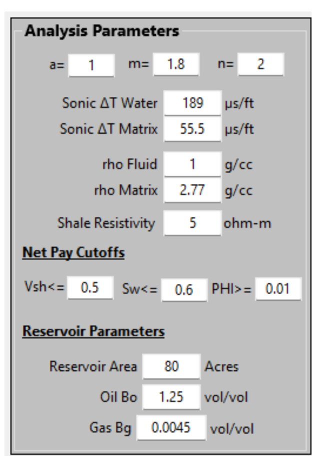


Figure QLA-13: Input Analysis Parameters

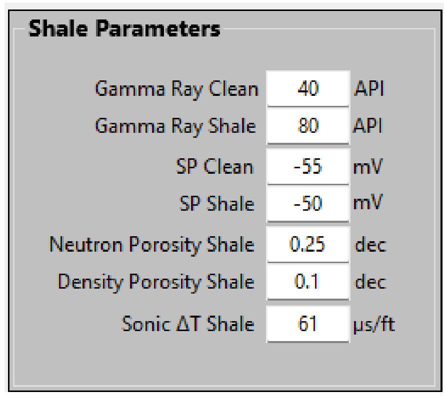


Figure QLA-14: Input Shale Parameters

Once all the model/analysis parameters are entered, log analysis is initiated by clicking the ‘Run Log Analysis’ button. Figure QLA-15 shows the analysis results for a water zone in the example well (note all zones in the well are wet).

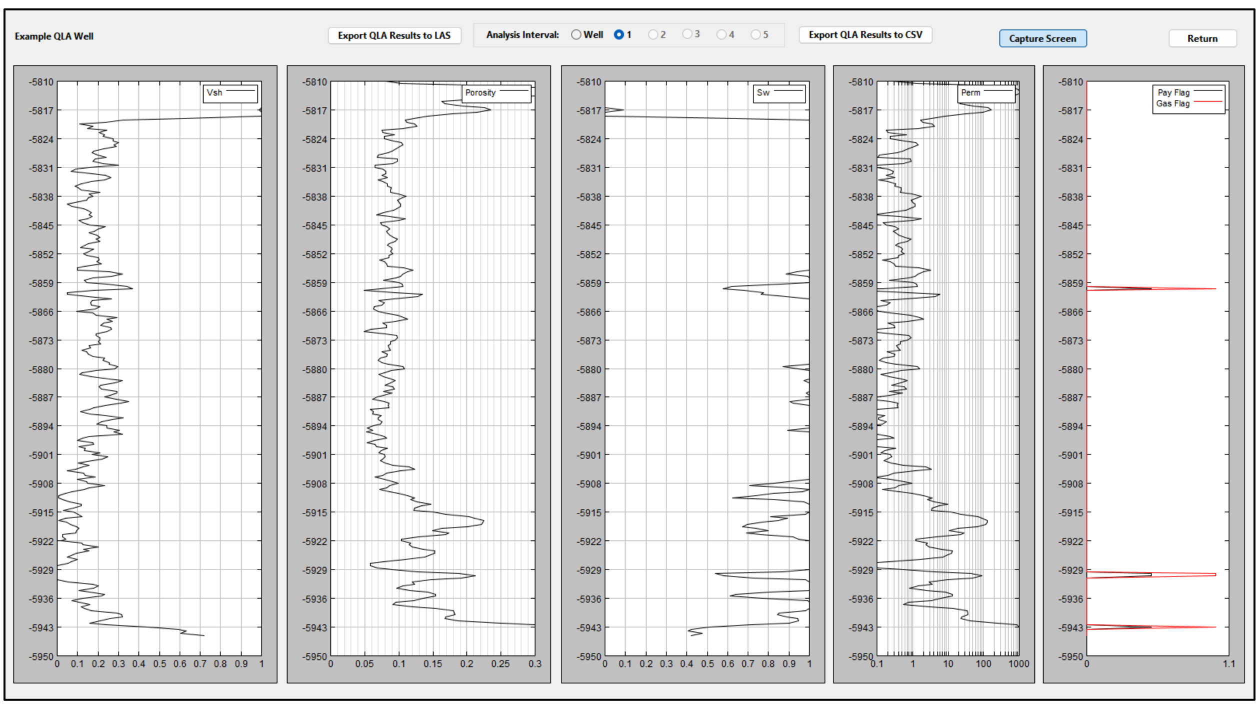


Figure QLA-15: Log Analysis – Water Zone

The log analysis results for each interval are averaged and presented in the results table (Figure QLA-16)

Analysis Results - Interval Weighted Averages

Parameter	Well	Interval 1	Interval 2	Interval 3	Interval 4	Interval 5
Net Pay	433	2				
Vshale	0.278	0.2031				
Porosity	0.3219	0.2107				
Water Saturation	0.3422	0.5522				
Permeability	559.7933	283.8401				
TOC - Sonic	12.8	3.1				
TOC - Density	21.6	18.5				
phi-h	139.3783	0.4215				
phi-(1-Sw)	0.236	0.0968				
phi-h-(1-Sw)	102.167	0.1937				
kh	242390.5	567.7				
Gas Indicator	Yes	Yes				
OOIP	50727.13	96.167				
GIIP	79118.11	149.99				

Figure QLA-16: Output Log Analysis Results

The log analysis results for each interval includes a sonic-based and density-based total organic carbon (TOC) calculation. These calculations are purely qualitative estimates and should be used for comparative purposes only. The TOC's are calculated as follows (ref: https://spec2000.net/11-vshtoc.htm).

Sonic: $$TOC = 0.234 * (\Delta t + 59.433\log(R)) - 31.86 \quad \text{(QLA-32)}$$

Density: $$TOC = 45.14 - 142.9(\rho - 1.014)/(\log(R) + 4.122) \quad \text{(QLA-33)}$$

Where: Δt sonic travel time in µsec/ft, R is the resistivity and ρ is bulk density in g/cc.

The analysis results also include a summation of the hydrocarbon volumes contained in the intervals identified as net pay.

To disable either the oil volume calculation or the gas volume calculation, enter zero for the 'Oil Bo' or the 'Gas Bg'.

QLA.5 Pressure-Depth Analysis

The Pressure Gradient Analysis tool is accessed from the main menu (Figure QLA-17). Data is loaded into the tool by clicking 'Load Data'.

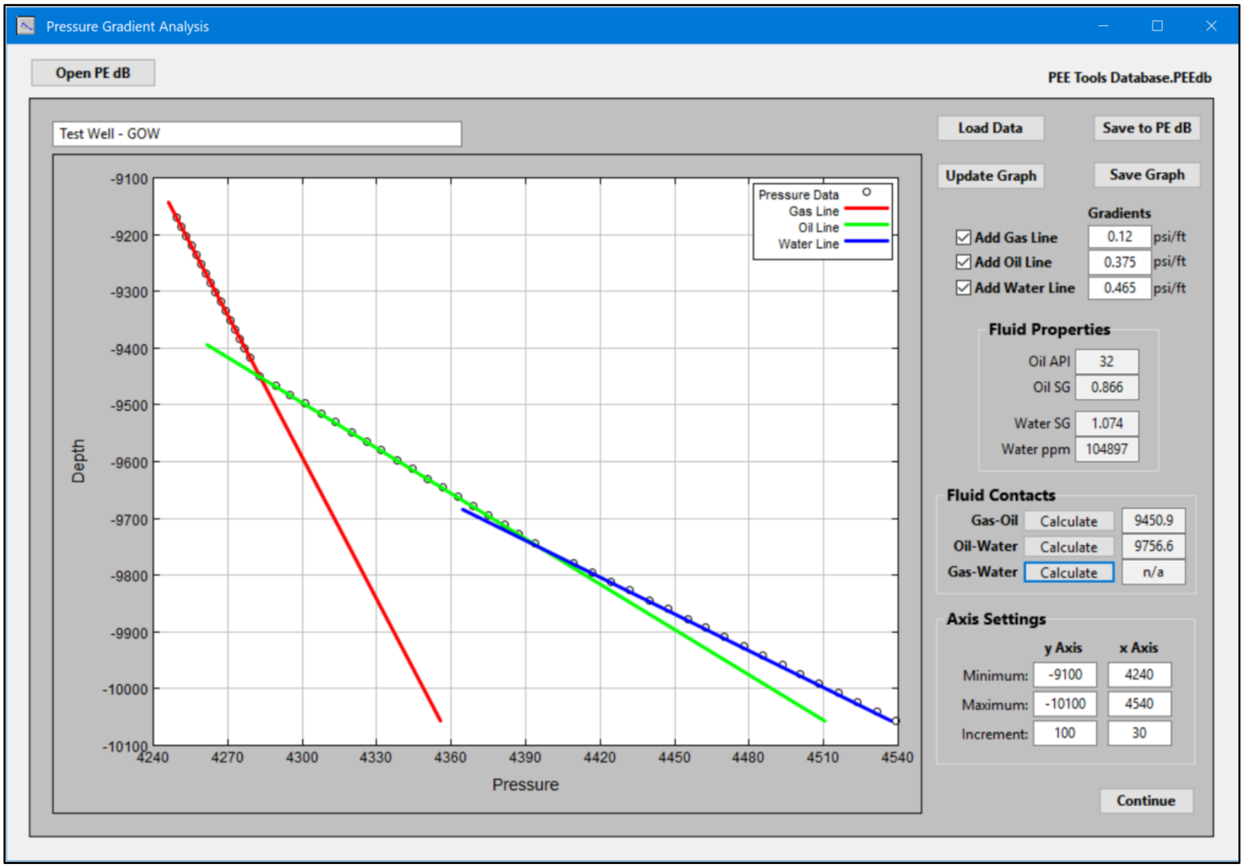


Figure QLA-17: Pressure-Depth Analysis

Data can be entered manually in the Depth/Pressure table; imported from a PE Tools database file ('Load PE db Data'), Figure QLA-18; or imported from an Excel file ('Excel Import'), Figure QLA-19. The data in the figures is from 'Gradient Data.xlsx' included in the 'Example Input Files\Excel Files' directory.

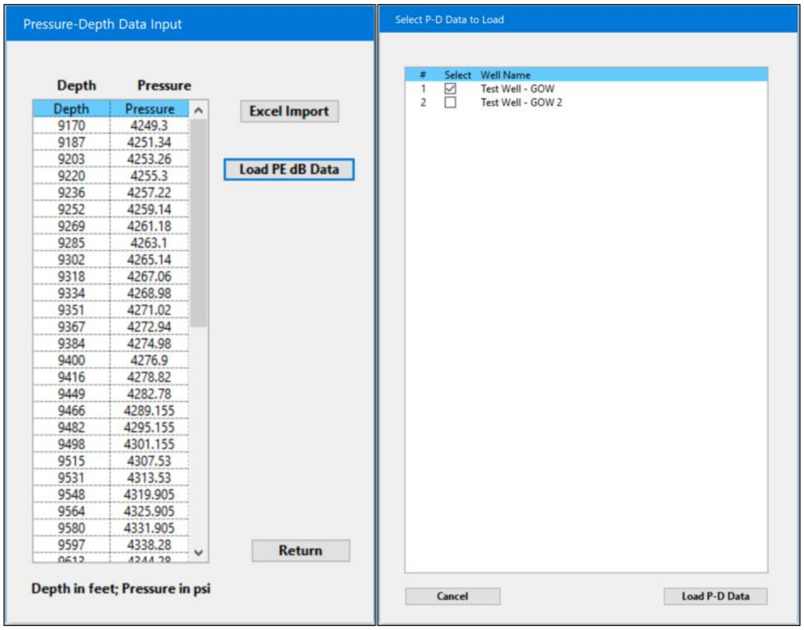


Figure QLA-18: Pressure-Depth Analysis, Database Import

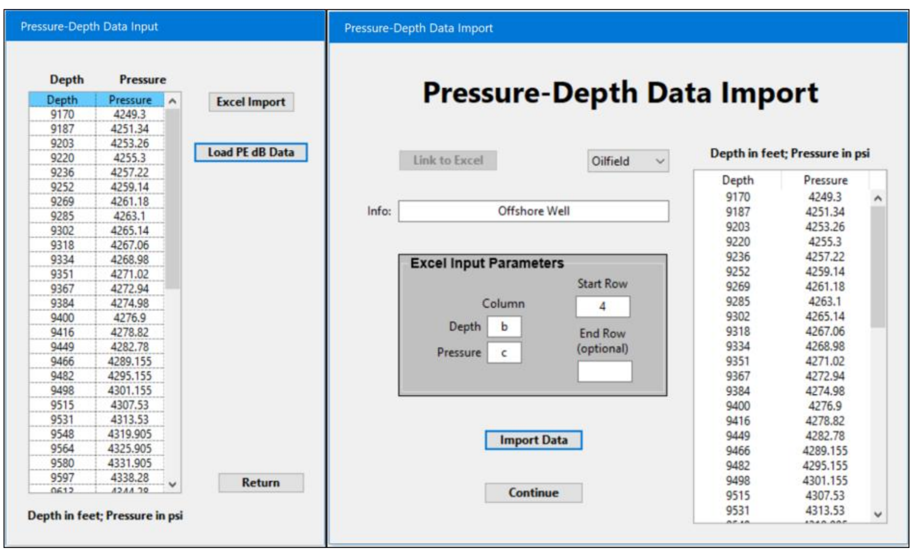


Figure QLA-19: Pressure-Depth Analysis, Excel Import

After the data is loaded, it can be saved to the PE Tools database with “Save to PE db” (Figure QLA-17). The database model will also contain the analysis parameters for the well.

This tool can be used to estimate fluid properties and fluid contacts.

Gas/water/oil gradient lines can be added to the plot. The line can be moved by clicking on the upper left end of the line and moving it to the desired location. The gradient is then modified to get the best fit. The equivalent reservoir fluid property, at reservoir conditions, is calculated for the given gradient and presented in the 'Fluid Properties' box (Figure QLA-20).

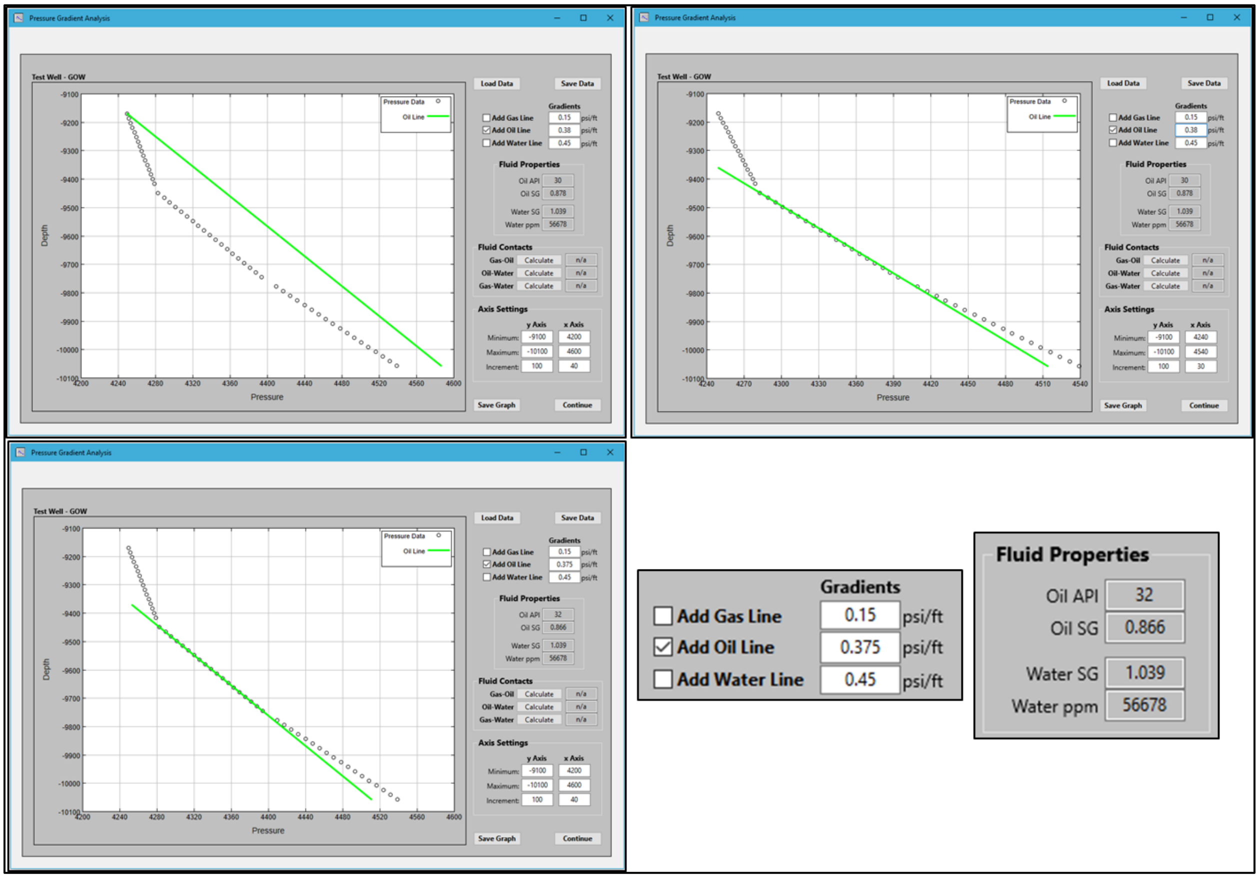


Figure QLA-20: Pressure-Depth Analysis Example

If more than one gradient line is included on the plot, the fluid contact - GOC, OWC or GWC – can be determined by clicking the appropriate 'Calculate' button.