Log Normalization, a Very Important Task in the Petrophysical Evaluation for La Peña and Tundy Fields
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Abstract
The well logs available in the La Peña and Tundy fields have been logged for different service companies from the 60’s (the oldest wells) up to the present time. The logging tool generations go from the oldest (Neutron in cps, Density gamma gamma, Microlog, Resistivity) to the modern technology (PI, CDL, CN, NMR, ect). This wide variety of logging tools technology made the normalization a critical step before getting into any Petrophysical Evaluation. Some logs corrections such as depth shift, wrong values corrections and eliminations, SP base line and others, were also applied before normalization. The main task of normalization was to obtain an homogeneous log data set because an important number of log traces showed signs of differing calibration and scaling. This became most apparent when the logs were displayed in cross sections and also when cross plots were compared with each other for different wells. This publication shows the importance, benefits and follows the log normalization procedure applied to 79 wells from La Peña field and the 9 wells from Tundy field. Once log normalization was performed, the wireline log data base obtained was displayed in cross sections and also when cross plots were interpreted during a field study. The logs were submitted to a rigorous log quality control, loading the digital log data into a workstation system and plotting out the digital data on the same scales as the original paper logs and then overlaying them on a light table.

Introduction
The La Peña field consists of about 82 wells (the wells lpñ-80, lpñ-81 and lpñ-82 were not included in the log normalization procedure because they were drilled after this job). The related, but hydraulically isolated Tundy field is to the north of the La Peña field and actually there are 11 wells, two of them are horizontals. In the two horizontal wells, only directional logs were recorded.

These oil fields are located east of Santa Cruz - Bolivia and are on the eastern edge of the Andes orogenic influence (Fig. 1). The Tundy field has one producing horizon in the Carboniferous San Telmo formation. The La Peña field has multiple producing horizons on the Carboniferous San Telmo and Escarpment formations. The producing horizons are lithologically complex and are generally considered to have been deposited in both fluvial and marine environments (Fig. 2).

The Gulf and Oil company discovered the La Peña field in 1965, the total Oil Cumulative Production is 35.5 MMBBLS. from the reservoirs La Peña and Bolivar. The Tundy field was discovered in 1992 for the National Bolivian Oil Company YPFB and the total Oil Cumulative Production is over 2 MMBBLS. only from the La Peña sand.

As a part of the Petrophysical Analysis for these fields, the previous log normalization was a very important task in providing an homogeneous and consistent log data set. All the effort employed in performing log normalization was rewarded with reliable values of Sw, Effective Porosity, Permeability, Gross and Net Hydrocarbon Thickness to be used as input data in the simulation model and reserves calculations.

Log Data Preparation
There are several stages of wireline preprocessing that are required before wireline log data can be normalized and interpreted during a field study. The logs were submitted to each one of these vital stages described below:

Log Digitalization and Quality Control
Were not digital log files provided by the client in these fields. It was necessary to build a digital log data base which includes the open hole resistivity, acoustic, radioactive and spectrometry logs. In order to have a complete data base, all the available paper logs were collected, even several cased hole GR and Neutron logs were sent to be digitized and submitted to a rigorous log quality control, loading the digital log data into a workstation system and plotting out the digital data on the same scales as the original paper logs and then overlaying them on a light table.
Log Edition. Once the log data base was completed in ASCII format files, all the digital log data including the header logs parameters (Rmf, Rm, Rmc, KB, DF, BS, BHT, mud density and surface locations) were loaded into the petrophysical interpretation software. The logs were displayed graphically to be checked and several log editions procedures were applied such as:

**Neutron Conversion from cps to Porosity Units.** For 13 wells of the La Peña field the Neutron log was recorded in cps by the old Neutron tool. All these curves were transformed in porosity units (PHIN) using the following equation:

\[
\text{PHIN} = 45 - 42 \ast \left( \frac{\log(\text{Neut}/\text{Neut}_{\text{min}})}{\log(\text{Neut}_{\text{max}}/\text{Neut}_{\text{min}})} \right)
\]

The Neut_{min} and Neut_{max} values were picked from a frequency plot considering the averages minimum and maximum values.

**RHOB Log Generation.** The Density log for 35 wells of the La Peña field and 8 wells for the Tundy field was expressed in porosity units (PHID) in paper log copies. The widely known equation:

\[
\text{RHOB} = \rho_{ma} - (\text{PHID} \ast (\rho_{ma} - pfl))
\]

was used to transform the recorded PHID curve to Bulk Density RHOB.

**Data Correction and Elimination.** During the logs reviewing process it was noticed that some of the curves especially the porosity logs (Density and Neutron) showed anomalous values due to bad hole conditions (washouts and roughness). All these spikes of erratic values were removed when this problem was really dramatic. The DT curve was smoothed or removed when cycle skipping was observed. The false data acquired before the logging tools “picked up” from the bottom of the hole was also edited out.

This type of correction was very helpful in having coherent answer in the model.

**SP Base Line.** The SP curve was recorded with serious deviation problems along the whole log interval. For 83 wells the SP curve was straightened to the base (shale) line. The mechanical displacement problem was also corrected with this procedure.

**Depth Shift.** The tools trips into the hole may not be exactly on depth with each other. Log depth matching was needed for consistent depth correlations. The reference was the resistivity tool, the one which the depths are properly corrected for cable stretch since this is the first run in the borehole. All the others (GR, Density, Neutron, Natural gamma ray espectrometry, Sonic) tools were depth matched referenced to this tool.

**Environmental Corrections.** Environmental corrections were applied to correct the logs readings due to pressure, temperature, hole size, mud weight and mud salinity effects. In the interpretation software the appropriate log correction chart was used for each different logging tool. This corrections were very important and necessary to be made, before getting into the log normalization and to provide accurate interpretations.

**Log Normalization**

When logs data were displayed and plotted out in x-sections and cross plots (Fig. 3 and 4), some differences in logging tools calibrations and curve scaling was noticed, specially when log data was compared for each well against the other.

Log normalization is a vital procedure in La Peña and Tundy field before getting into any log evaluation in order to have a reliable petrophysical analysis. When log normalization is performed the logs readings will be similar in the same interval (sandstones or shales) for the different logging tools, minimizing tool calibrations and scaling differences, therefore the log data set would be homogeneous and consistent for all the wells included in the analysis.

Normalization at know homogeneous facies (marine environmental shale, a tight limestone, anhydrite layer, etc.) is preferable as the reference data. In the La Peña and Tundy fields two shales are present on top of the interest zone which were named Shale A (upper) and Shale B (lower) (Fig. 5).

During the job execution, it was supposed that shale A was fluvial, which it is present only in the northern area of the field. At the same time, B was supposed to be marine and it is areally present in the entire fields (Fig. 6). The normalization for La Peña and Tundy fields was made taken the shale B because is in the whole of both fields and is more homogeneous and continuous than A.

The log normalization was made following the next steps:

**Step 1.** A master data set was chosen for comparison with all the other wells. The well LPN-75 was picked for some advantages respect to the others well:  
- The strategic geographical location (central area of the field) (Fig. 6).
- The well was drilled through the two interest reservoirs, the La Peña and Bolivar sandstones, even the base of the Bolivar was reached.
- The logging data set is one of the most complete (SP, GR, Induction, Density, Neutron, Sonic, TH, K, U) respect to the other wells.

**Step 2.** With all the edited and environmentally corrected log data, several X-plots types were printed out for each well. This plots were built as shown in Table 1, then the high and low curve values (minimum and maximum olds values) were selected out from this plots.

**Step 3.** Each plot was compared with the master plot (LPN-75) and the differences between the high and low curve values of each well respect to the master were recorded in a spreadsheet. All the differences were added up (considering the exceptions noted in the Table 1) and divided by the number of wells used to make up the total to find the average deviation from the master data set.

**Step 4.** The average then needed to be added to the master well (LPN-75). This produced a minimum and maximum value for each curve type in the key well. These values then became the “New minimum.” and “New maximum” values for the rescaling of each well. This could be done using the
rescaling function in the interpretation software or by applying a linear equation of the form:

$$C_{new} = A \cdot C_{old} + B$$

All but the resistivity and sonic curves were normalized at their high and low end range of values (hence the slope, A and the offset, B parameters of the above equation). The resistivity was only normalized at the shale value and no attention was paid to normalize the high resistivities values as they are not very continuous across the field. In the case of the sonic log, it was normalize only for the DT low (shale) values in order to avoid variations in the sandstones porosity.

The problems of washout and bad hole conditions caused difficulties in choosing parameters for the cross plots with neutron and density curves. Great care was taken to avoid using the washout affected points to find the best fit of the patterns in the plots.

Since the SP is often reversing in the interval where San Telmo and Escarpment formations reside, there was little point in spending effort to normalize this curve. Most of the wells have a gamma ray (even if it is from a cased hole log) and so the SP was not so essential. As an example the (Fig. 7) shows the GR curve from the lpñ-20 well before and after the normalization in wich the similarity of the normalized curve about the master can be observed.

**Comments**

A latter geological study determined that shale A is a fluvial shale and confirmed that B is a marine shale. As a result, the top of San Telmo formation now is taken at the top of shale B.

**Conclusions**

1. Log edition and environmental corrections are very important and recommended to do before getting into the log normalization task, with the objective of removing some recording errors and to compensate environmental effects.

2. When logs are from different vintages (From the 1960s to the present in the case of La Peña field), are of different types, or require different scales and presentations, then the task of correlation and log evaluation becomes difficult, therefore for multi well fields the normalization step is absolutely vital.

3. It is preferable to use a marine shale as reference data because is more homogeneus and bigger in thickness than a fluvial shale.

4. Normalization of GR curves was significant, 25 API units were defined for clean sand and 120 and 130 API units, for clay. Corrections for resistivity and porosity curves were less significant.

5. The time and effort employed in the log normalization is rewarded with an homogenous and consistent log data set as the input for a reliable petrophysical evaluation.

**Nomenclature**

- $GR$ = gamma ray, API units
- $SP$ = spontaneous potential, mv
- $PHIN$ = neutron porosity, v/v
- $PHID$ = density porosity, v/v
- $RHOB$ = bulk density, gr/cc
- $DT$ = transite time, μsec/ft
- $TH$ = thorium, ppm
- $K$ = potassium, dimensionless
- $U$ = uranium, ppm
- $Neut_{min}$ = minimum neutron value, cps
- $Neut_{max}$ = maximum neutron value, cps
- $Neut$ = neutron value, cps
- $ρma$ = matrix density, gr/cc
- $ρfl$ = fluid density, gr/cc

**Subscripts**

- $cps$ = counts per second
- $PI$ = phasar induction
- $CDL$ = compensate density log
- $CN$ = compensate neutron
- $NMR$ = nuclear magnetic resonance
- $Sw$ = water saturation
- $Rmf$ = mud filtrate resistivity
- $Rm$ = mud resistivity
- $Rmc$ = mud cake resistivity
- $KB$ = Kelly bushing
- $DF$ = derrick floor
- $BS$ = bit size
- $BHT$ = bottom hole temperature
- $Cnew$ = new curve value
- $Cold$ = old curve value

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**References**


**Appendixes-Curve Rescaling Calculations**

**New GR values calculation**

GR averages values:
\[ GR_{\text{minimum}} = -0.88 \]
\[ GR_{\text{maximum}} = -10.7 \]

GR values from the master well LPÑ-75:
\[ GR_{\text{old minimum}} = 25 \]
\[ GR_{\text{old maximum}} = 119 \]

then the new GR minimum and maximum values are:
\[ GR_{\text{new minimum}} = 25 + (-0.88) = 24.12 \]
\[ GR_{\text{new maximum}} = 119 + (-10.7) = 108.3 \]

**New Rt value calculation**
The Rt average value was just taken in the shale zone.
Rt average value = 0.6
Rt value from the master well LPÑ-75:
\[ Rt_{\text{old minimum}} = 4.75 \]

then the new Rt minimum value is:
\[ Rt_{\text{new minimum}} = 4.75 + 0.6 = 5.35 \]

**New Rxo value calculation**
The Rxo average value was just taken in the shale zone.
Rxo average value = -0.61
Rxo value from the master well LPÑ-75:
\[ Rxo_{\text{old minimum}} = 4.15 \]

then the new Rxo minimum value is:
\[ Rxo_{\text{new minimum}} = 4.15 - 0.61 = 3.54 \]

**New PHIN and RHOB values calculations**
PHIN and RHOB averages values:
\[ PHIN \min = -0.42 \]
\[ PHIN \max = 0.08 \]
\[ RHOB \min = -0.02 \]
\[ RHOB \max = -0.03 \]

PHIN and RHOB values from the master well:
\[ PHIN_{\text{old min}} = 17.4 \]
\[ PHIN_{\text{old max}} = 30.6 \]
\[ RHOB_{\text{old min}} = 2.16 \]
\[ RHOB_{\text{old max}} = 2.485 \]

the new minimum and maximum PHIN and RHOB values are:
\[ PHIN_{\text{new min}} = 17.4 - 0.42 = 16.98 \]
\[ PHIN_{\text{new max}} = 30.6 + 0.08 = 30.68 \]
\[ RHOB_{\text{new min}} = 2.16 - 0.02 = 2.14 \]
\[ RHOB_{\text{new max}} = 2.485 - 0.03 = 2.455 \]

**New DT values calculation**
For rescaling the DT curve it was just necessary to add the registered difference shale low value, obtained from the comparison of each well respect to the master, as shown in the following equation:
\[ DT_{\text{new}} = DT + \text{Difference \_ value} \]

**New K and TH values calculation**
K and TH averages values:
\[ K_{\text{min}} = -0.19 \]
\[ K_{\text{max}} = 0.83 \]
\[ TH_{\text{min}} = -0.4 \]
\[ TH_{\text{max}} = -0.2 \]

K and TH averages values from the master well:
\[ K_{\text{old min}} = 0.4 \]
\[ K_{\text{old max}} = 3.5 \]
\[ TH_{\text{old min}} = 0.8 \]
\[ TH_{\text{old max}} = 9.6 \]

then the new minimum and maximum values were:
\[ K_{\text{new min}} = 0.4 - 0.19 = 0.21 \]
\[ K_{\text{new max}} = 3.5 + 0.83 = 4.33 \]
\[ TH_{\text{new min}} = 0.8 - 0.4 = 0.4 \]
\[ TH_{\text{new max}} = 9.6 - 0.2 = 9.4 \]
### TABLE 1 - CROSS PLOTS TYPES FOR LOG NORMALIZATION

<table>
<thead>
<tr>
<th>Order</th>
<th>X-plot</th>
<th>Curves to normalize</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GR vs. RT</td>
<td>GR, RT</td>
<td>Use only open hole GR to determine average values</td>
</tr>
<tr>
<td>2</td>
<td>GR vs. RXO</td>
<td>RXO</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>GR vs. DT</td>
<td>DT</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>PHINSS vs. RHOB</td>
<td>PHINSS, RHOB</td>
<td>Use only wells with compensated neutrons to determine average values</td>
</tr>
<tr>
<td>5</td>
<td>GR vs. RHOB</td>
<td>RHOB</td>
<td>For the wells with density but no neutron only</td>
</tr>
<tr>
<td>6</td>
<td>TH vs. K</td>
<td>TH, K</td>
<td>Only on spectral gamma ray wells</td>
</tr>
</tbody>
</table>

Fig. 1—Location of the La Peña and Tundy fields in Santa Cruz, Bolivia.
Fig. 2—Geological Sequence and Stratigraphic cross section of the producing sandstones in the La Peña and Tundy fields.

Fig. 3—Cross section showing the differences in calibration and curves scaling. The GR clean in LPÑ-20 well is reading about 80 °API, additionally the LPÑ-19, LPÑ-14 and LPÑ-9 wells show a very tenuos GR in the shale zones, related to LPÑ-75 master well.
Fig. 4—GR vs. RT cross plot from LPÑ-75 and LPÑ-20. Note the big difference for the GR low and high values. This is a clear scaling problem example.

Fig. 5—North to South cross section. Note the continuity of shale B about to shale A which disappear to the southern area of the field.
Fig. 6—Base Map of La Peña and Tudy fields showing the areal distribution of shale A and B, and the geographical location of the master well LPÑ-75.

Fig. 7—See the GR curve from well LPÑ-20 before and after the normalization. Observe how the Gr values after normalization are similar to the Gr values of the master well.