

Establishing Petrophysical Benchmark for the Burgan Field in Kuwait - A Case Study*

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Abstract

A field-wide petrophysical re-evaluation project was carried out for the Greater Burgan Field of Kuwait ([Figure 1](#)). The evaluation covered Early Cretaceous Burgan Sands and the platform carbonates of the Mauddud as well as Late Cretaceous Wara and Ahmadi sequences. The aim of the project was four-fold. First, a comprehensive open hole well log database was constructed to serve as the foundation for the subsequent work. Second, standardized and auditable log processing and normalization procedures were prepared to facilitate the petrophysical interpretation. Third, a core calibrated petrophysical model was generated for each reservoir in the analyzed interval. Finally, a consistent process was implemented to evaluate new wells in the field.

The 1000 wells processed in the study were divided based on old and modern vintages ([Figure 2](#)). The old vintage of wells (nearly 400 wells) in the Burgan Field were processed to derive shale volume, porosity and water saturation estimates. A consistent Neutron counts to porosity index conversion algorithm was implemented for the old vintage Neutron tools. The petrophysical properties distribution in the old vintage wells were validated against modern well data in offset wells. A Potassium Chloride correction workflow was introduced in the processing of the modern wells that included quantitatively estimating and then removing the borehole and invasion effect. For consistency, complete set of environmental corrections were performed on Gamma Ray, Neutron Porosity and Bulk Density logs. The key well study was performed on 46 wells in the field, incorporating all core and advanced log data. Thorough examination of XRD and integration with thin-section data revealed formation complexity and heterogeneity which was studied in detail. Other core data including core grain density, porosity, permeability and critical saturation from SCAL data in addition to advanced logs including capture spectroscopy and magnetic resonance log data was used for model validation. The validation process was implemented at each step of the workflow to reduce the results uncertainties. The modern wells that were processed using defined workflows from the study showed consistent results when integrated with new core and dynamic data such as production logs. The results of the new and improved petrophysical analysis would fulfill the first ever reservoir rock typing and the next generation full field static model requirements for the Greater Burgan Field.

Three culminations constitute the Greater Burgan Field: Burgan, Magwa, and Ahmadi. These three culminations are located near the crest of the north-south-trending Kuwait Arch (Fox, 1961; Adasani, 1965; Brennan, 1990b; Carman, 1996). The first well in the Burgan Field was drilled in 1938. The stratigraphic interval ranges from Albian to Cenomanian, and consists predominantly of siliciclastic intervals (Burgan and Wara formations) with an interbedded carbonate interval (Mauddud Formation). With over 1000 wells drilled in the field over seven decades, the wealth of data needed to be present in a consistent framework along with traceable and auditable workflows for formation evaluation.

Objectives

The Burgan Field well by well petrophysics project was conceived to address four key objectives. They were:

- 1) To establish a comprehensive well log database for the Greater Burgan field
- 2) Standardized and auditable log processing and normalization procedures
- 3) Core calibrated formation evaluation for multiple reservoirs (Ahmadi – Shuaiba)
- 4) Propose a consistent process/workflow to evaluate new wells in the field

To address the objectives, the project was divided into three phases.

Phase 1

This early phase of the project was aimed at creating a fresh project where the raw log data was loaded. It was ensured that all necessary parameters and constants are loaded and preserved as this has been a point of concern in the past where important parameters were not kept and stored. Formation tops, well header information and well deviation surveys were provided by KOC at the start of this phase. The second but the most important part of this phase was the key well study. Suitable wells with extensive log and core data showing good aerial distribution were pre-selected for this task. It was ensured that the final petrophysical model defined is consistent with core data measurements in all aspects. The task was critical as subsequent population of the workflow and parameters was dependent on the robustness of this key well study.

Phase 2

The second phase of the project comprised of log processing work. This entailed QC, log data preparation and performing basic editing, depth matching and environmental corrections on selected logs. All procedures pertinent to log formatting, loading, editing, depth matching and environmental corrections were established prior to performing the log processing. Calculations of borehole properties such as borehole/bottom hole temperatures, pressure mud properties were performed using standard modules. Environmental corrections were only performed on Gamma Ray and Neutron logs. A second task of this phase was to establish processing workflow for old vintage wells. Digitized log data was available for all old vintage wells which were gathered and utilized for processing. The field prints of these old wells were already available in digital scans which were used for the QC purpose.

Phase 3

The final phase of the project covered implementation of the finalized workflows for log normalization and petrophysical evaluation which was performed on all Burgan wells. Petrophysical evaluation was performed to determine shale volume, effective and total porosity and water saturation logs for all wells in the field. Confidence logs were generated to aid in establishing interpretation qualifiers. The goal of the new petrophysical evaluation was not only to utilize it into the next generation full field geological modelling and simulation but also helps in establishing a benchmark to process newly drilled wells in the field.

Phase 1 - Database

The database was divided into vintage and modern wells. Old vintage wells were the first 400 wells drilled in the Burgan Field prior to 1971. Typical logs in the old vintage included SP, Gamma Ray (OH/CH), Neutron (majority with count rates) and Resistivity logs (majority with Electrical Survey and Induction). The inventory of the tools was extracted from the raw field print headers. A data inventory for 602 modern wells in the field revealed logging services ranging from simple Resistivity/Sonic to Triple Combo and Quad Combo services. 47 wells in the modern vintage had Quad Combo, Spectroscopy, NMR and core data. These 47 wells were hence selected as the key wells.

Phase 1 - Key Well Study

In order to carry out the interpretation, a key wells study needed to be performed to establish the correct workflow, parameters and ascertain the uncertainties. The requirement for performing normalization and environmental corrections was also established from the key well studies. Both these topics are discussed in the subsequent sections. The key well selection process was based on the following criterion:

- a) Presence of core data
- b) Presence of advanced logs
- c) Spatial distribution of wells

Core data Review

All the available core data was reviewed extensively to determine the most prevalent mineralogy ([Figure 3](#)). For the petrophysical properties, due diligence was imparted to understand the core drying procedure and hence the porosity it represented. It was established after detailed review that the core porosity was generally in closer agreement with the total porosity derived from wireline log analysis.

Shale Volume, Porosity and Saturation

Different shale models were tested on the data and it was found that the Steiber 3 model best fit the data. It was also established that the Gamma Ray log, as a stand-alone measurement, was not sufficient to obtain an accurate estimate of shale volume. A combination of Gamma

Ray based shale volume and a Neutron-Density based shale volume provided the most accurate estimate as shown in [Figure 4](#). Special logic to account for the bad hole conditions was simultaneously introduced in the workflow.

The porosity workflow was designed following the Bateman-Konen algorithm (Bateman, 1978). The workflow calculates a shale and hydrocarbon corrected density-neutron porosity where hydrocarbon correction is based on the density of the hydrocarbon, and its saturation in the flushed zone ([Figure 5](#)). The core porosity, after overburden corrections, was compared to the log derived porosity for validation. To establish the saturation, the first step performed was to ascertain the Archie parameters. All SCAL FRF data was analyzed per reservoir to generate these parameters. Different Sw models were tested across the shaly sand intervals and it was established that the Dual Water Model was giving the best results when compared to SCAL data.

Phase 2 - Data Processing, Corrections and Vintage Wells

The data qc, editing, depth matching, environmental corrections and normalization were performed on a well by well basis ([Figure 6](#)). Consistent datasets following an agreed naming convention were prepared.

The environmental corrections and normalization were handled in detail to get the most consistent log responses. A major challenge encountered in this work was to deal with considerable number of wells drilled with Potassium Chloride (KCL) muds and handling log response in shales which were severely affected by borehole washouts.

Environmental Corrections

The Gamma Ray correction is performed in two steps ([Figure 7](#)). The first step was to remove any background radioactivity associated with KCL mud. The second step was aimed at applying the Mud Weight and Hole Size corrections. To remove the background radioactivity, the 5th percentile of the GR reading was calculated and stored across BM1/BM3 (clean sands) and Mauddud (clean carbonate) intervals. This P05 value was then compared with reference values of Gamma Ray response across the same formations in non KCL wells. A shift was applied on the Gamma Ray to match the reference values across these formations. The KCL corrected Gamma Ray was subsequently corrected for hole size and mud weight. The significance of Neutron log environmental correction was evident from the fact that variation in environmental conditions prevailing in different wells would yield a spread of ~3.5 p.u across typical “wet sands” if the EC’s on Neutron are not implemented. Considering this variation, hole size, temperature, pressure, borehole salinity, mud weight and (nominal) standoff corrections were implemented in the EC module.

Vintage Wells

Challenges pertaining to vintage well log evaluation falls in two broad categories. First one is related to specific elements for the log preparation of the vintage wells for e.g. depth matching, parameters setting, SP baseline shifting and Neutron conversion from counts to porosity. The second challenge pertains to formation evaluation of old vintage logs to enable Volume of Shale calculation in the absence of Density-Neutron logs, porosity estimation from a single porosity measurement, synthetic porosity and porosity combination, etc. Shale Volume

from SSP was calculated using transforms generated for VSH using GR log in modern wells during the Key Well Study. The final shale volume was a combination of VSH_GR and VSH_SSP with VSH_GR getting priority. The neutron transforms to porosity were generated using the historical charts. The porosity output in each vintage well was validated against a nearby modern well for validation ([Figure 8](#)). A confidence log was also generated for each well to highlight the overall level of confidence in the petrophysical analysis carried out.

Phase 3 - Key Normalization, Evaluation and Validation

Normalization

The key element in normalization is to find a consistent log response across the entire data set that can be used as reference ([Figure 9](#)). The challenge is to define a reference that is consistent to avoid introducing a bias in the normalized data set and remove existing properties variations. Gamma Ray normalization was done using a 2-point method to get a consistent response across the low and high end of the distribution. The KCL correction, as described above, helped in getting the low end of the distribution handled well. The high end was characterized by getting reference values across shale markers in the key wells. The Neutron normalization was based on an offset that considers density and neutron porosities equal in good hole, clean and wet sands. BM3/BM1 intervals of the Burgan massive sands were given priority due to absence of shale. A 3-step process was adapted. Step 1 was to get the neutron density response across clean water sands. Step 2 was to get the mean of the difference in response between density porosity and neutron porosity in this zone to ascertain the offset. Step 3 was to apply the offset on the neutron to get the normalized response. In case of insufficient log data samples across in gauge clean water sands, no normalization was performed (the offset is set to zero).

Evaluation and Validation

Once the evaluation was completed, blind testing on randomly selected wells with core data was performed. VSH methods were compared with various references including: Core permeability, WCLA from spectral data, XRD clay fractions. Computed VSH was input in porosity computations to check for validity against core porosity. Porosity model showed consistent results compared to core porosity. Some variability was observed related to vertical resolution in thin beds, under correction for light hydrocarbon effect in gas zones and some porosity deficit compared to core but matching NMR. Comparison of Water Volume from Saturation equations was made with NMR (Clay and capillary bound water) and SCAL_Swc (from RI, PC (Oil-Brine or MICP) and Kr core tests).

Conclusions

This article describes the steps followed in developing a consistent and auditable database and petrophysical workflow for the Burgan Field. It also describes the challenges faced, along with the proposed solutions. For the very first time, a consistent and complete open hole log and core database was constructed in the asset preserving the entire audit trail for any future referencing. This was specifically done to ensure easy data handling, transfer and overall utilization of petrophysical data for years to come. Several methods for shale volume estimation were tested and compared, whenever applicable, to core data and Neutron Induced Spectroscopy results.

The Porosity calculation was based on well-known and industry accepted Bateman Konen method (Bateman, 1978). Use of crossplots and histograms per well enabled determining the endpoints. The resulting porosity calculations were validated against core porosity (at NOB) and NMR porosity. Cementation and Saturation exponents selected were based upon a thorough review of all available electrical SCAL data. A bimodal response in the measured drainage 'N' values is believed to be related to a combination of lab operator, lab location as well as a possible correlation to height above FWL and the difficulty to clean the core samples. Further analysis was recommended to investigate possible changes in reservoir wettability with HAFWL. The Dual Water and Archie Saturation equations were compared and found to give very similar results mainly due to the high salinity of the formation water (160 ppk). Due to a better control on total porosity it is recommended to use the total water saturation calculations as the main reference. The resulting saturation calculations were validated against SCAL PC data and NMR bound fluid volume above the OWC. The established workflows from the project have now become the gold standard for petrophysical evaluation within the asset team. The scripts, with their efficient setup, are utilized to generate results with shortest turnaround time to facilitate in making key decisions such as completions and workovers.

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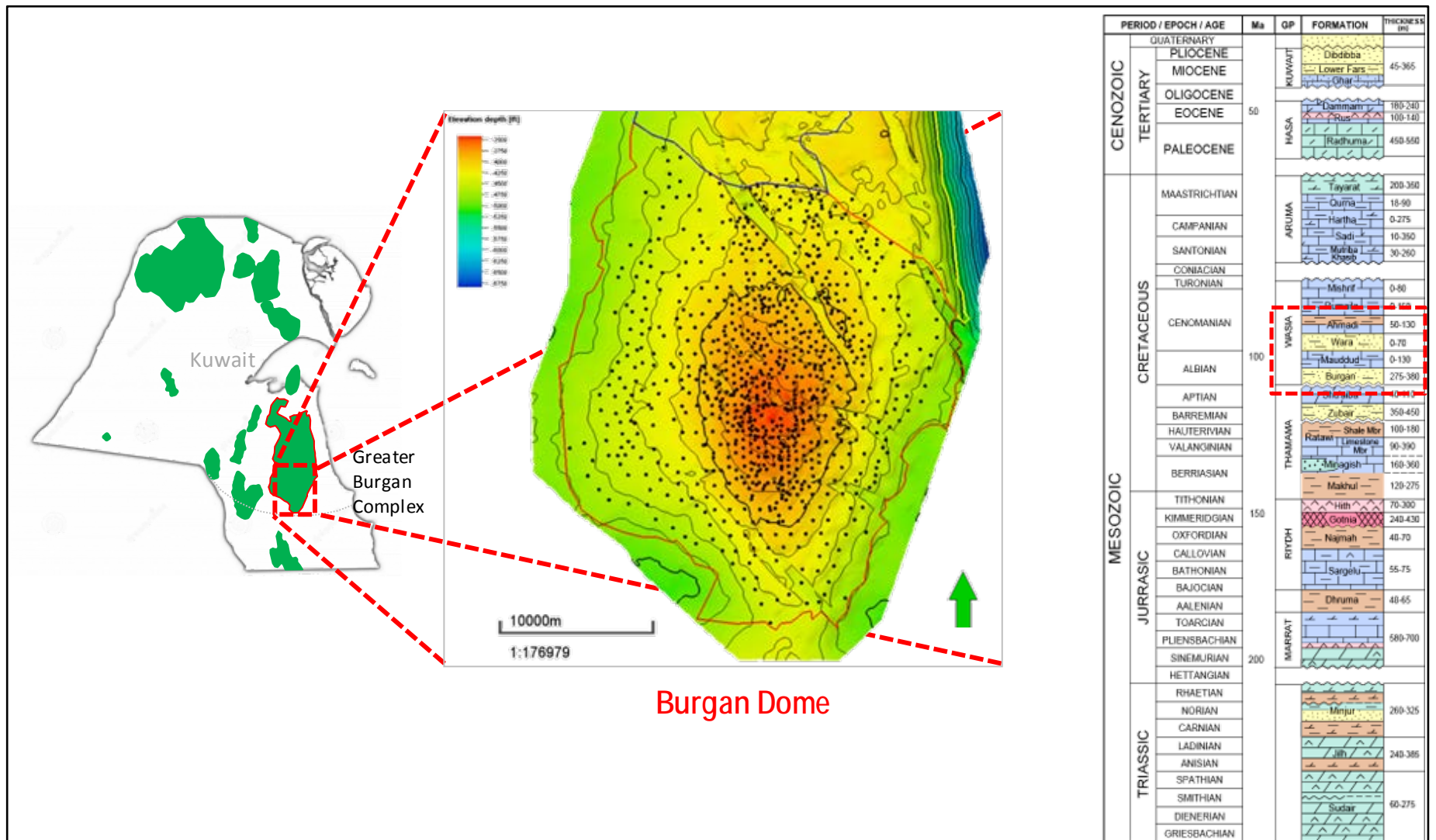


Figure 1. The Greater Burgan Field, discovered in 1938, is one of the largest clastic fields in the world.

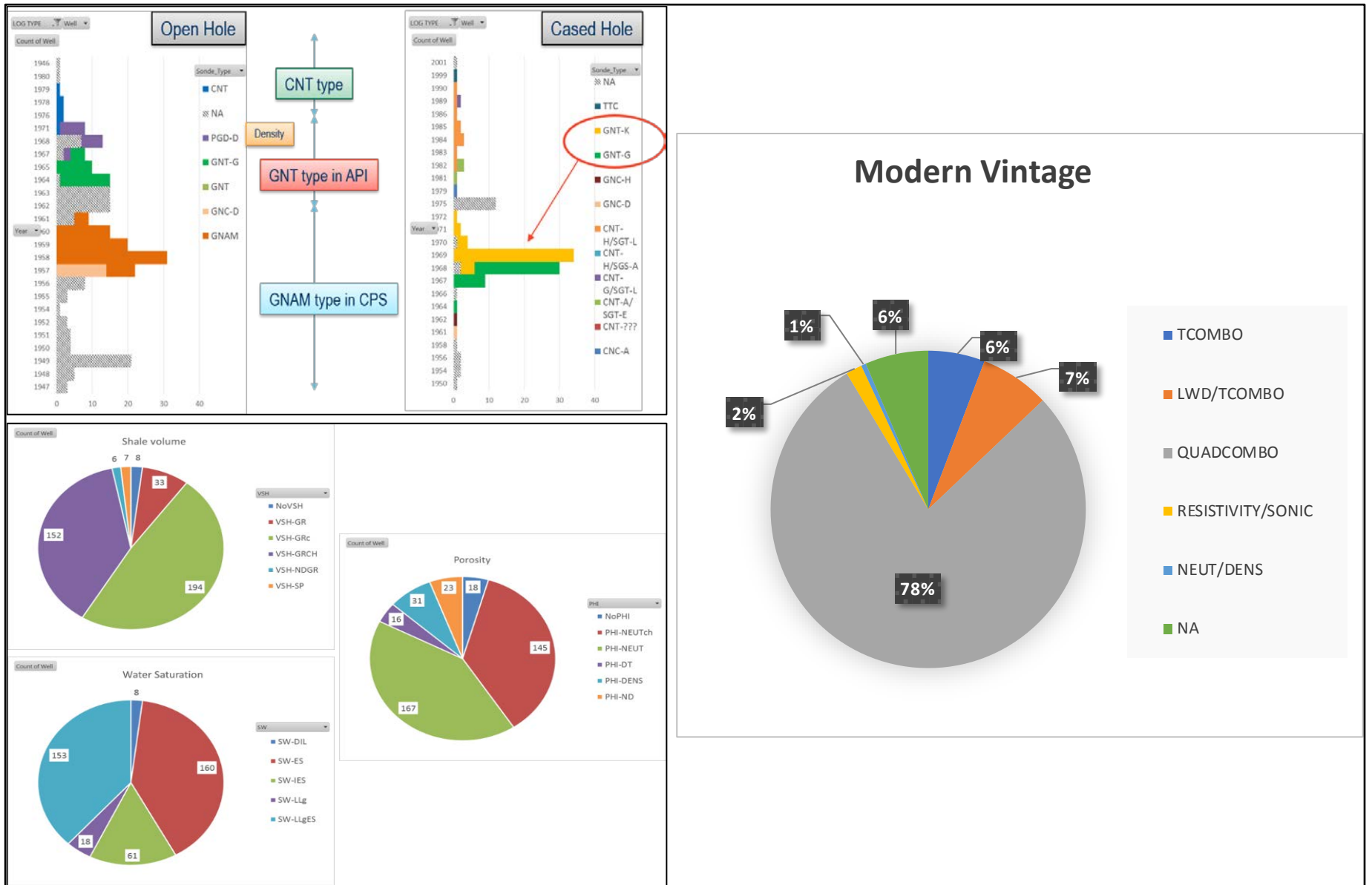


Figure 2. Top left picture shows the inventory of the vintage of neutron tools. The bottom left picture shows the solutions and methods available for the vintage wells. The right figure shows the data inventory for the modern wells.

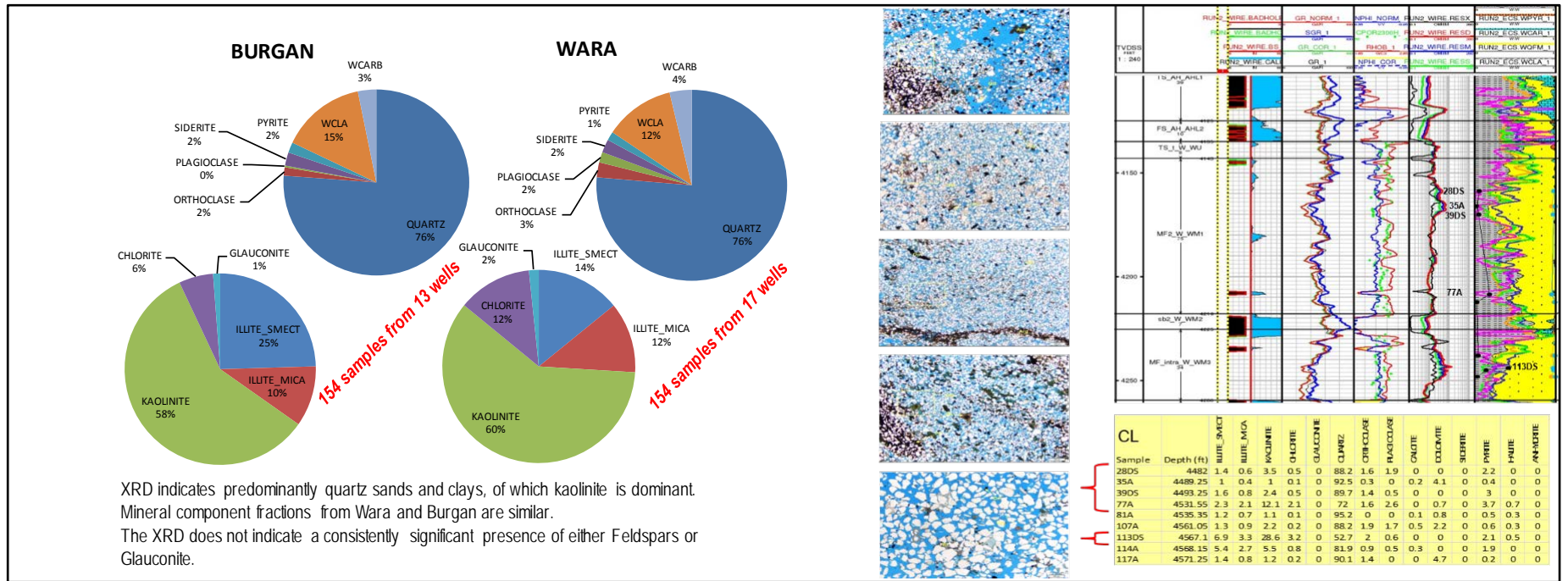


Figure 3. The core data helped establish the mineralogy per zone and the log responses to the dominant minerals

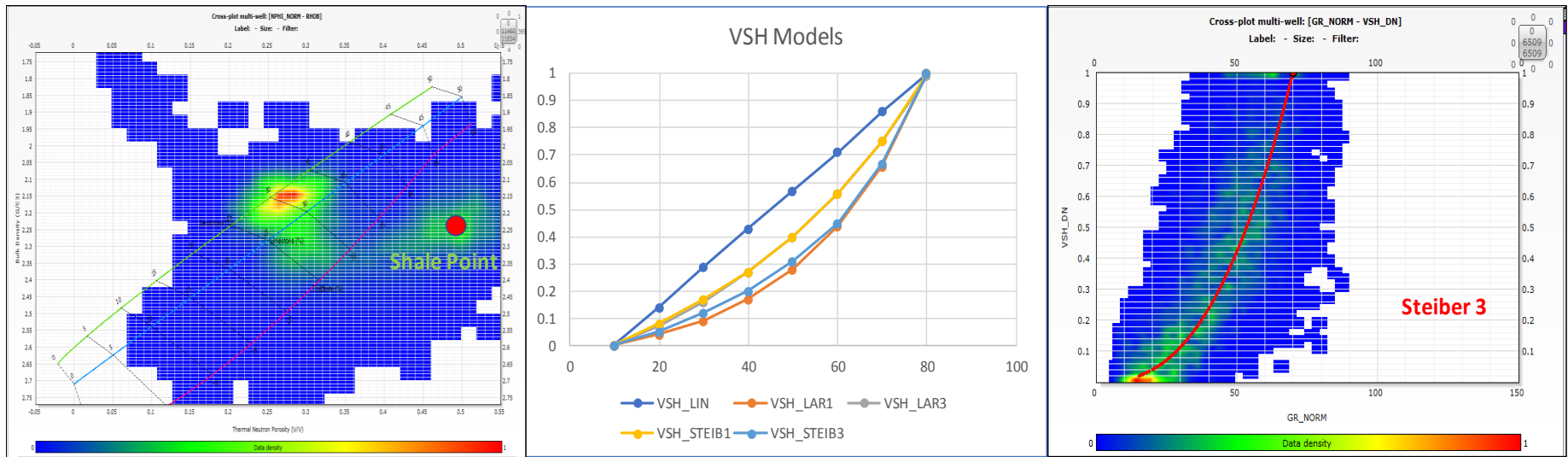


Figure 4. The Steiber 3 model represents the best fit for the Gamma Ray shale volume transform when compared to neutron density based shale volume estimation.

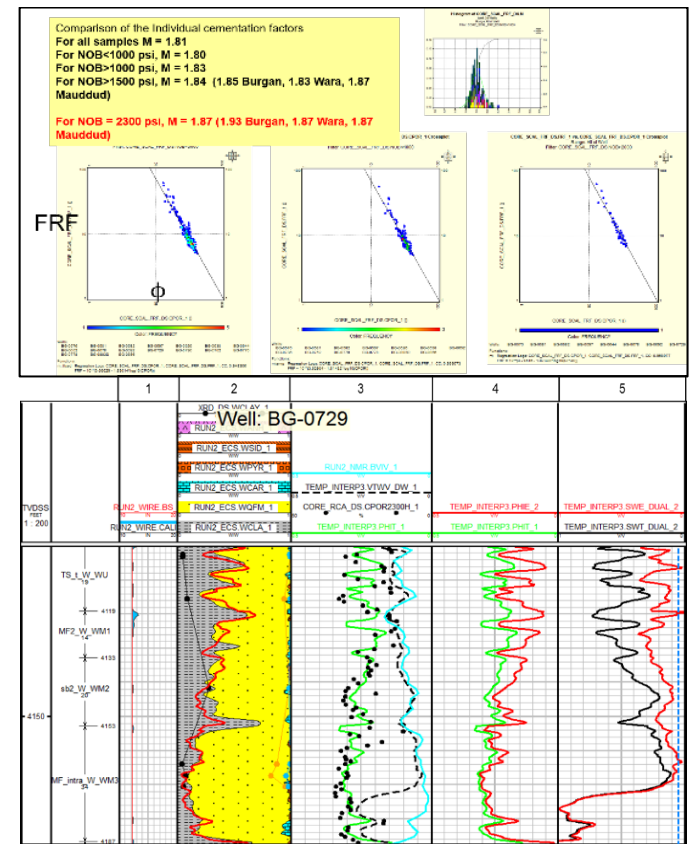
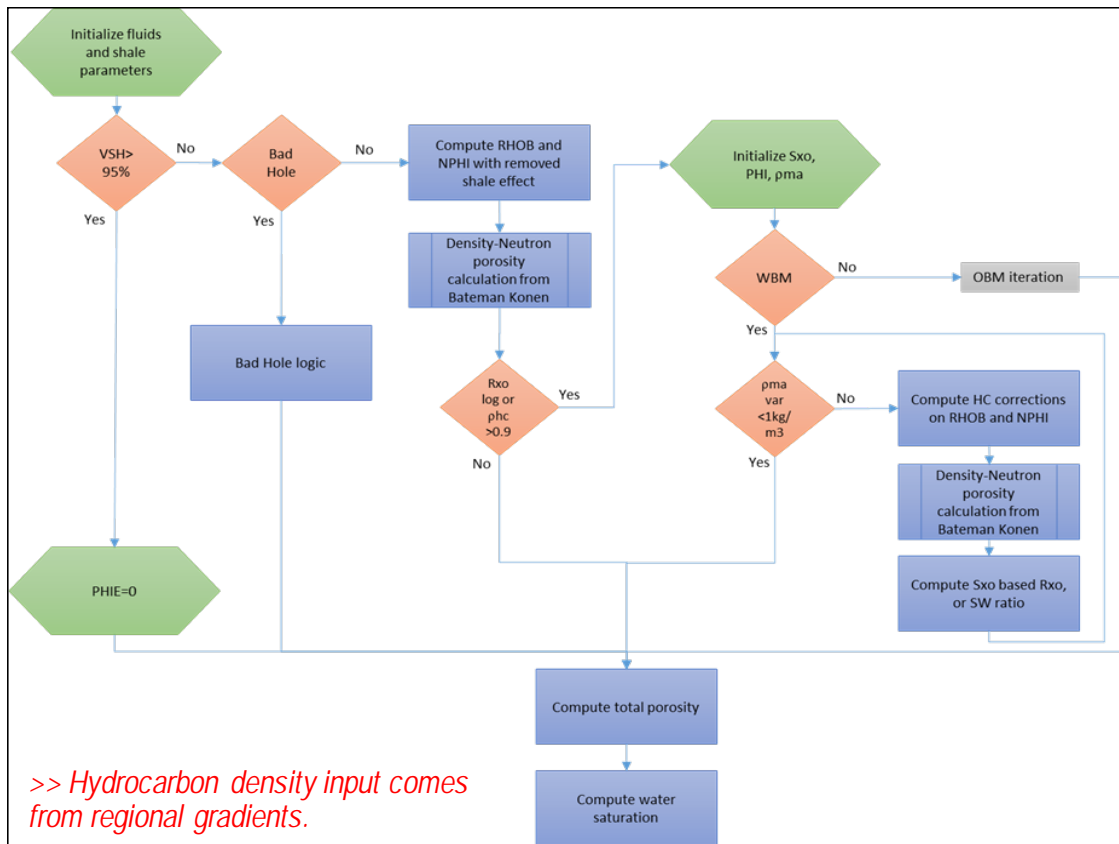


Figure 5. The flow chart shows the workflow to derive porosity and saturation. The top right figure shows the SCAL data used to derive the Archie parameters, while the bottom right shows the validation of porosity and saturation.

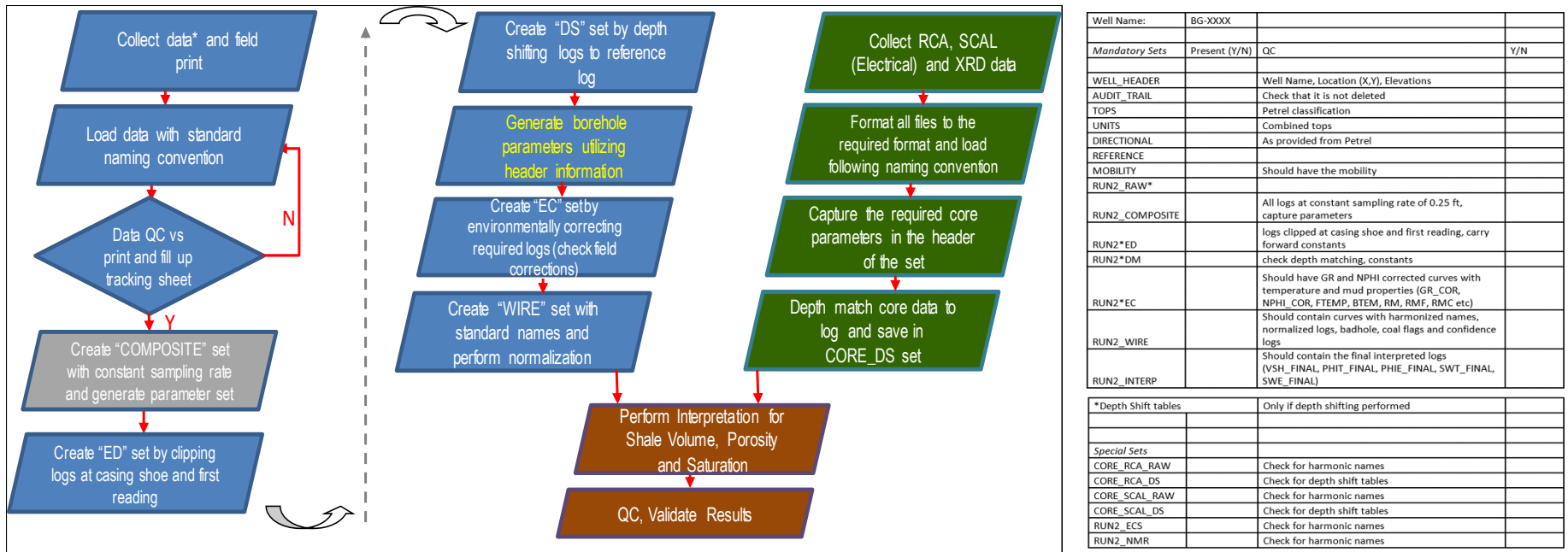


Figure 6. The flow chart shows the workflow followed in the project. The blue boxes represent the data preparation, green boxes represent the core data workflow while the brown boxes represent the interpretation. The right table shows the naming convention followed for datasets.

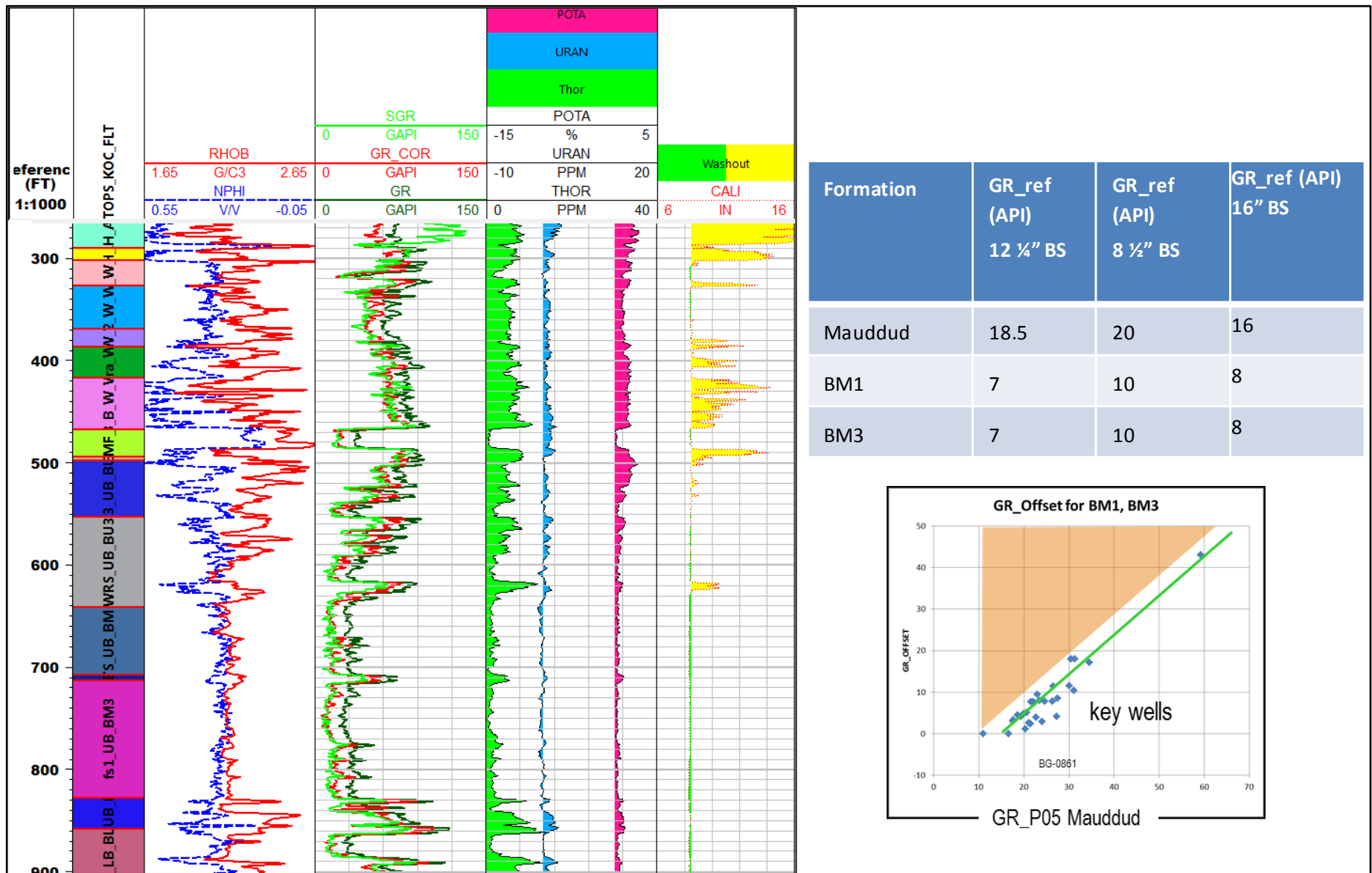


Figure 7. The left figure shows the corrected GR (GR_COR) along with the raw GR (GR) and the spectral GR (SGR). After the KCL correction the SGR (corrected for KCL) was compared with GR_COR to see the validity of the correction. The table on the top right shows the reference values and the bottom right figure shows the GR offset required in key wells.

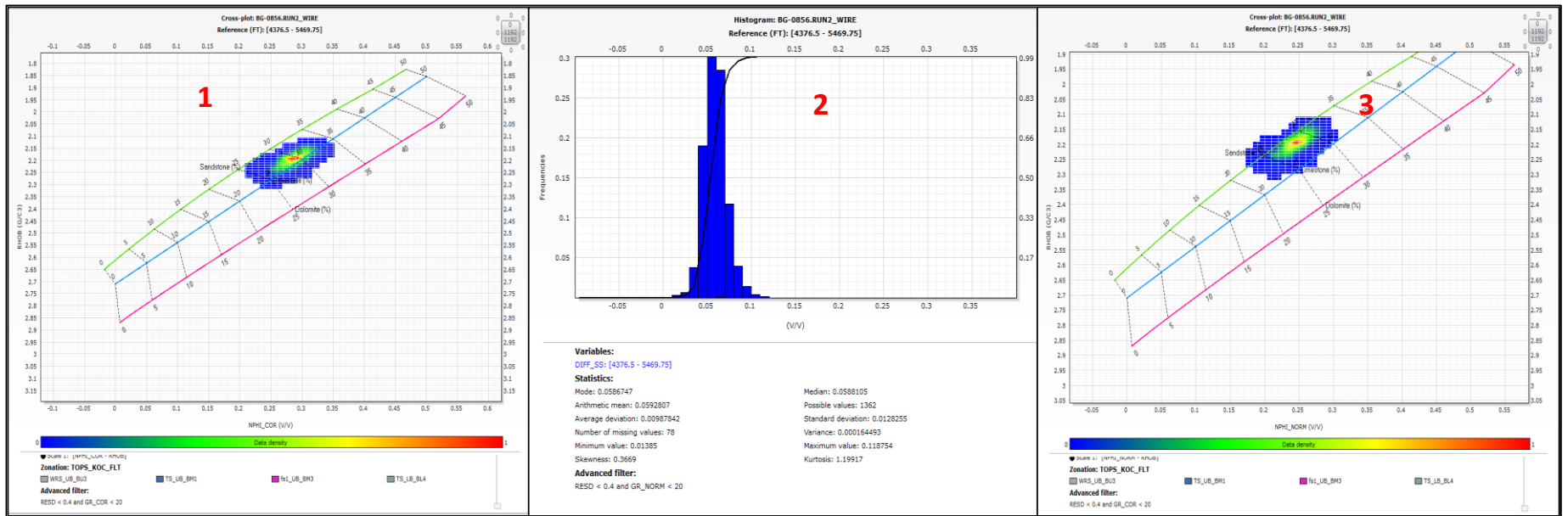


Figure 9. The left figure shows the neutron density response across a clean wet sand prior to normalization. The histogram in the middle shows the difference in density porosity and neutron porosity across this interval. The mean of the histogram is used to apply a shift in the neutron to obtain the normalized response which is shown in [Figure 3](#).