

Unconventional Reservoir Formation Evaluation of Visean organic rich formation with limited logging dataset in Dnipro-Donets Basin, Eastern Ukraine.

*S. Iuras (Subbotin Institute of Geophysics of National Academy of Sciences of Ukraine, Petrophysical consultant), M. Orlyuk, V.Karpyn (Subbotin Institute of Geophysics of National Academy of Sciences of Ukraine), S. Levoniuk (JSC Ukrgazvydobuvannya)

Summary

The Visean unconventional formation in Dnipro-Donets Basin (DDB) is characterized by the high total organic carbon (TOC) content and has quite visible signs in well logging data. The main target formation Rudov bed (V-23) is related to XIIa Microfaunistic horizon and represents it quite clearly. Underlying Visean Carbonate platform (V-24-25) in DBB on well logs data also shows radioactivity increasing and it does not always correspond to clay or dolomites. Usually, the reservoirs and rock properties change across the basin, and common geological and petrophysical instruments do not work very well in every case. For estimating TOC in cases with limited logging dataset DlogR approach is usually used, but it does not work very accurately everywhere in DDB. This talk will present comparison of several methods of TOC estimations and propose own equations and workflow for evaluation of TOC with limited logging data using multilinear regression approach. Additionally, we improved and proposed new equations for main mineralogy components and porosity estimation for such complicated type of reservoirs in our area of study with not advanced and quite cheap logging dataset (Gamma Ray, Deep Resistivity, Sonic and Neutron Log).

Our results show that individual approach for evaluating main shale gas reservoirs petrophysical properties has consistent better correlation with elemental spectroscopy data and SCAL analysis data than the other methods. It looks very robust in case where we have limited logging dataset especially from old drilled wells. The applied equations can be use not only in black hot shale reservoirs, but also in carbonate formations with organic rich layers.

Introduction

Ukraine's Dnipro-Donets Basin (DDB) is a first-rank Super Basin with total discovered reserves exceeding 1.6 BBO of liquids and 59 TCF of natural gas (11.4 billion barrels of oil equivalent). Recent studies have collectively pointed to a promising unconventional play residing within a thick succession of Visean marine source rocks. Mean recoverable resource estimates of 56.5 TCF (9.4 billion barrels of oil equivalent) represent an incremental target large enough to convert Ukraine into a significant natural gas exporter to Europe (Levoniuk et. al., 2023).

Dnipro-Donets Basin originated as a Late-Devonian failed arm of a triple junction located between the Eastern European Craton and Voronezh Massif in Eastern Ukraine. Recent exclusive research highlighted two potential unconventional play fairways within the DDB, the North-West Play (NWP) and the Southern Flank Play (SFP) (Figure 1), geographic distribution of which are controlled by basin tectonic and depositional events (Orlyuk et.al., 2018; Levoniuk et. al., 2023). DDB has world-class source rocks both shales and carbonates that can be unconventional reservoirs with high potential in Visean formations. There are 5 landing targets, which are characterized by different facies types layered within the entire gross "stack" of source rocks. In this paper, we will focus on the 2 most promising ones - V-23 siliciclastic (NWP) and carbonate-rich (SFP) radioactive black shale with measured TOC values commonly ranging 4-10% (weight percentage); in the underlying upper V-24 carbonate-dominated mudstone facies TOC values

commonly range from 1 to 4%. The depth of zone interests is mostly 4-5 km with decreasing in SE part of Southern Flank Play to 2.5-3.5 km. In our study we will provide a general overview of the work flow, methodologies, results of derived equations for main petrophysical properties of DDB unconventional formations and conclusion of the petrophysical component of the investigation.

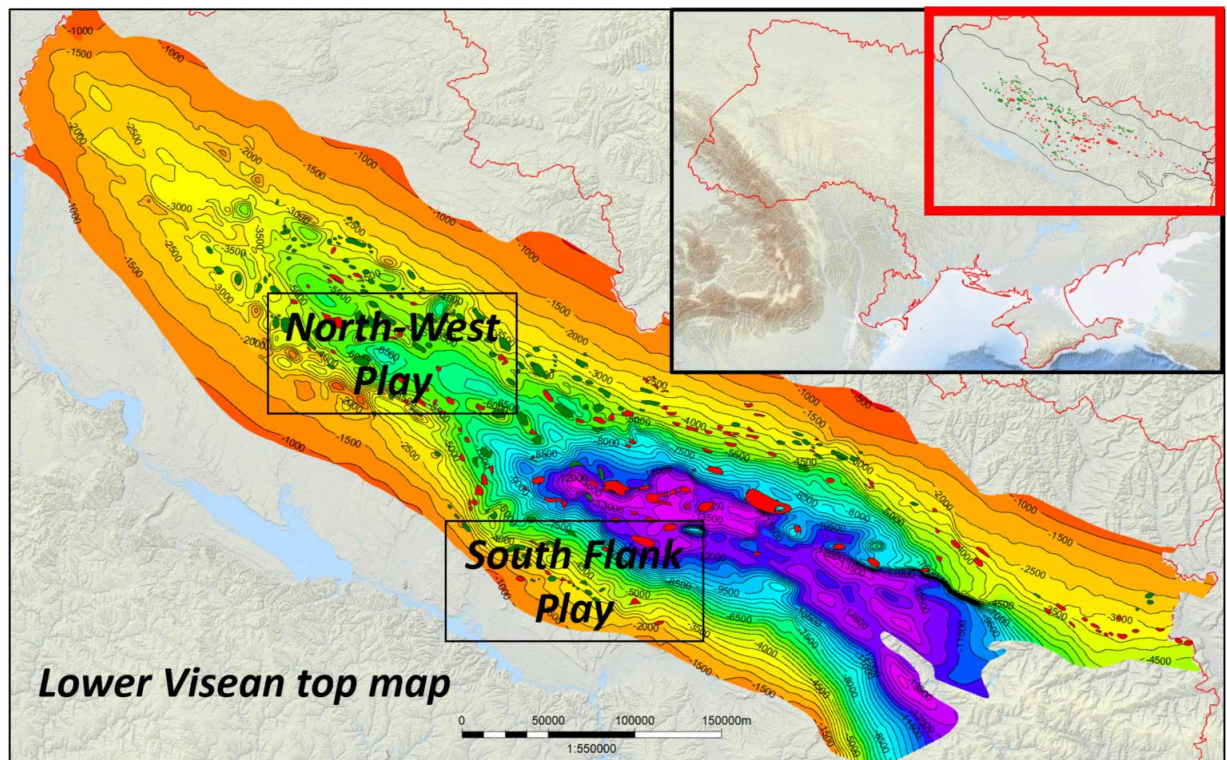


Figure 1. - Dnipro-Donets Basin Lower Visean structural map

Theory / Method / Workflow

The main organic rich unconventional reservoir parameter as known is TOC. Correct determination of TOC is important for kerogen content characterization and has relation with total porosity. Surely, the recrystallized rock matrix porosity has impact on total porosity. According to Peters classification, if we have source rock with TOC >1 %, it corresponds to good potential of target reservoirs. Recent experience of hydrocarbon production in the world shows that this cut off is TOC >2 %. It is very important to estimate TOC of target formations accurately. Due to limited presence of core samples/cuttings and not continuous core data in big intervals it is not possible to fully cover zone of interest for precise studies. Moreover, to do a lot of coring is very expensive for operators. In that case, it is very important to apply well logging data and their interpretation precisely. Such modern logging methods for TOC, mineralogy and porosity estimation like geochemical/ elemental spectroscopy logs, spectral gamma ray or nuclear magnetic resonance with density log combination are very robust solution. In old wells when we have typical logging data set like gamma ray, deep resistivity and sonic logs it makes TOC estimation much more complicated. The minerals computation is more complicated with such data due to limitation for probabilistic formation evaluation. A similar situation appears with porosity estimation when you are not sure in matrix properties.

One of the first who began to study the organic matter rocks and TOC determinations in details was geologist-petrophysicist Q.R. Passey. While working at Exxon Mobil, he analyzed data from hundreds of wells in North American fields. This technique is one of the most famous methods of TOC estimation for geoscientists, because we need to have only typical logging dataset. Ukrainian geoscientists also use it quite often. In such case, we need to choose calibrated baseline points (water wet clays) and to know LOM (level of maturity) which can be taken from vitrinite reflectance data, Ro% (Rock-Eval pyrolysis or microscope analysis). Visually we can see intervals with high TOC in crossover on logs between sonic and resistivity. High compressional slowness and high resistivity corresponds with high organic matter interval (Figure 1). In our case according to Rock-Eval pyrolysis data (Iuras et. al., 2023.) our targets are in late oil window, and we choose LOM= 9.

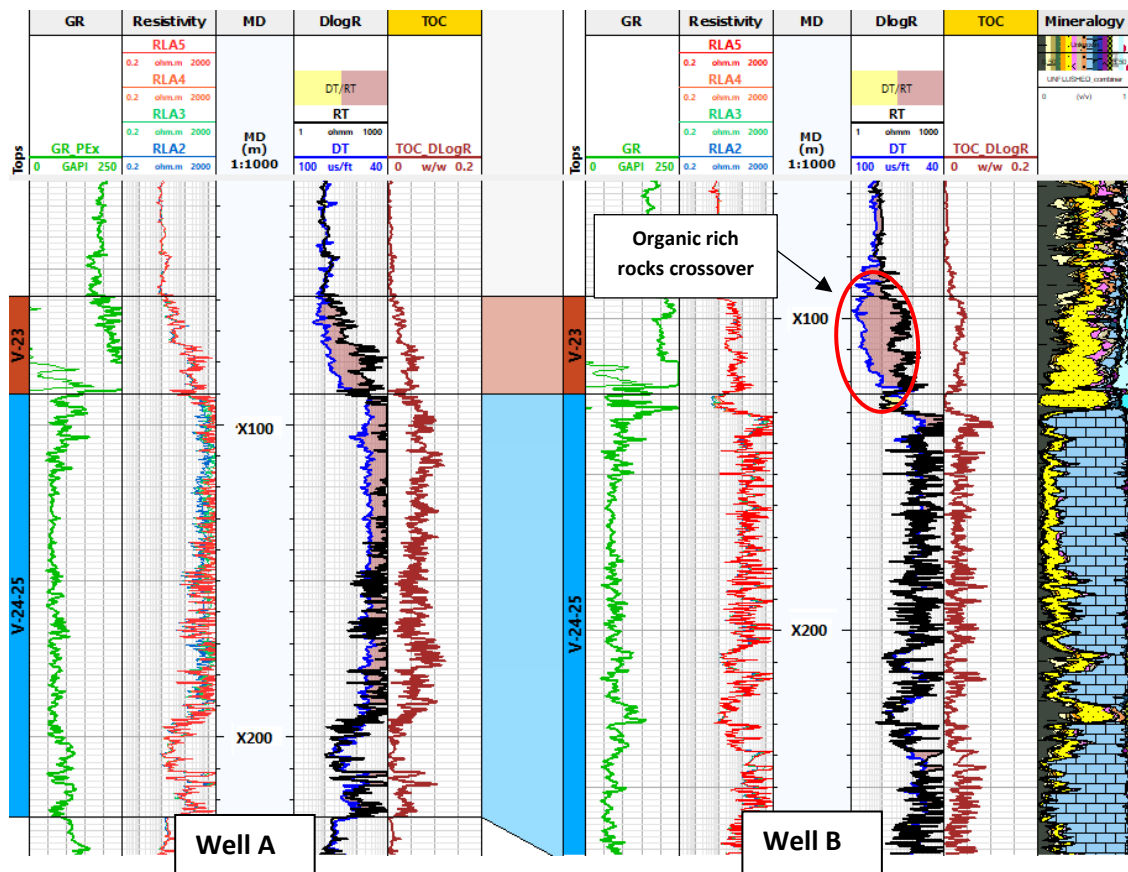


Figure 1. Well logs data and interpretation of wells A, B. Tracks: 1 - Gamma Ray ($\mu\text{R}/\text{h}$), 2 – Multilateral log resistivity ($\text{ohm}\cdot\text{m}$), 4- Depth (m), 5 - DT and Deep Resistivity crossover, 6 - DlogR TOC estimated from sonic and resistivity logs (w/w), 7 - mineralogy model QElan

One of the direct geophysical methods for TOC calculations is spectral gamma ray (SGR). This method can determine three main isotopes – Uranium ($\text{U}238$), Thorium ($\text{Th}232$) and Potassium ($\text{K}40$). Specifically, Uranium directly depends on kerogen accumulations in the formations and it highlights the presence of source rock formations or other geological environments, which corresponds to $\text{U}238$. Sometimes these tools can be used also in cased hole environments.

Recently, advanced service companies and their engineers did huge progress with tool construction and developing technologies. It also refers to radioactive methods such as elemental spectroscopy. One of them has pulsed neutron generator, two LaBr₃:Ce gamma ray detectors, and a deep YAP (YAlO₃) detector. The acquisition scheme was optimized to record time and energy domain data simultaneously. In the time domain, formation Sigma and neutron porosity are self-compensated for the wellbore environment. From energy domain we can build accurate minerals model and determine matrix properties. Additionally, TOC can be obtained by subtracting the inorganic carbon (from carbon rich minerals) from the measured total carbon (Figure 4). This technology can provide measurements both in open hole and cased hole. Numerous scientific papers show good correlation between modern log (elemental spectroscopy, NMR) and SCAL data (Gonzalez et al., 2013; Craddock et al., 2021).

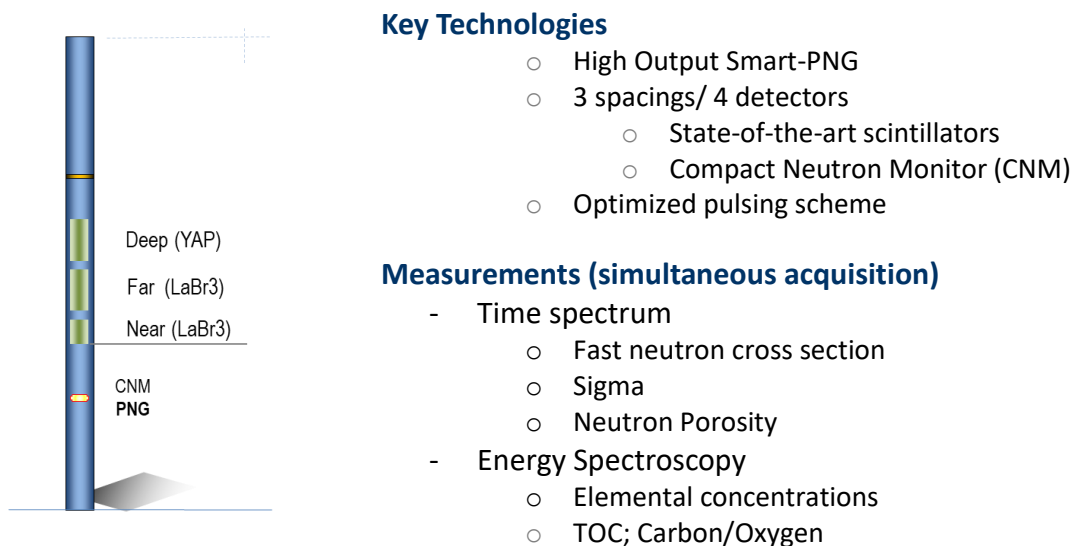


Figure 4 An example of pulsed-neutron elemental-spectroscopy tool and main outputs (Pulsar, SLB)

Results, Observations, Conclusions

In well B, we had a chance to compute most accurate TOC estimation methods and to compare those results with special core analysis data (LECO TOC), Figure 5. In our study, we had analyzed 49 core samples and 12 mud cuttings samples from zones V-23 and V-24-25. The results at log panel show that not all log methods match very well with laboratory analysis TOC data results. The elemental spectroscopy TOC and NMR_TOC have the best correlations with core measurements. The biggest mismatching is with DlogR technique TOC for these target formations. It can lead to underestimation of TOC for such shale gas reservoirs in DDB and their hydrocarbon potential. The data from SGR shows better correlation with core data in carbonate intervals, but in V-23 it matches only partially. We would like to highlight that core samples data are more reliable and have better depth shift samples than cuttings. For depth matching all core samples from Well B were logged by Gamma Ray tool in the laboratory [Iuras et al. 2023]. When full logging data suite is available, the petrophysicists and geoscientists can properly estimate TOC without big challenges, but for limited logging datasets, which we usually deal with in old wells they can have problems with it. As we observed the DlogR is not robust solution for Viséan formations. For situation when we do not have big bunch of SCAL data in the area of study

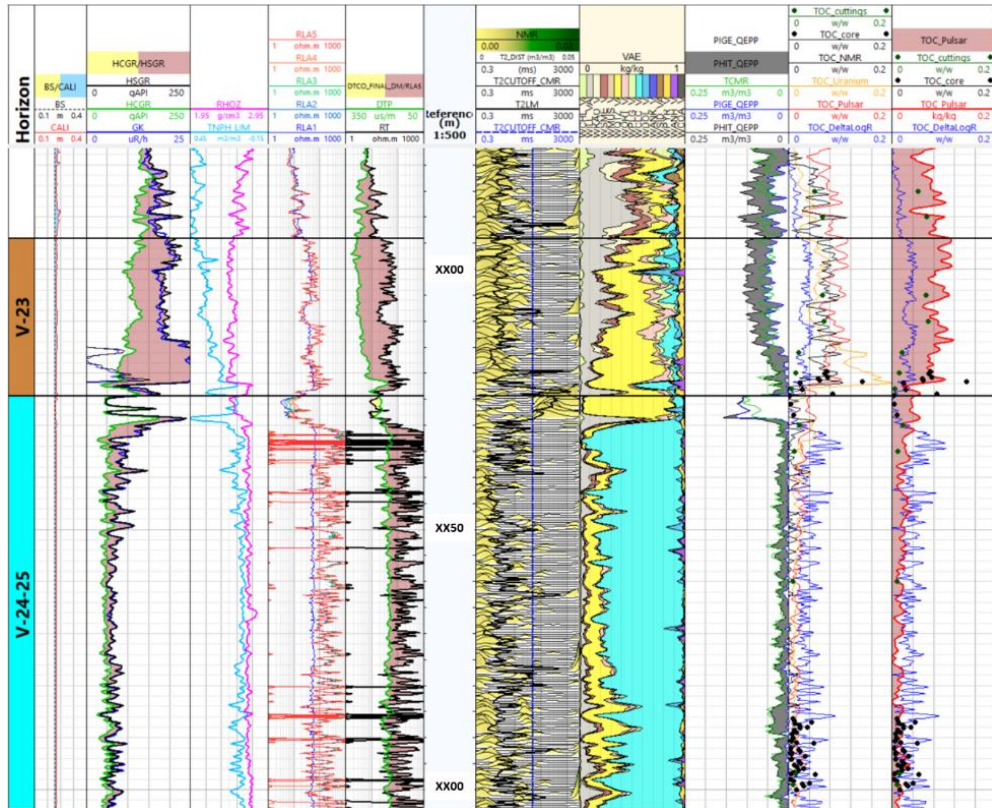


Figure 5 Modern log data from Well B and different TOC estimations methods and comparing them with LECO TOC core (black dots) and cutting data results (green dots).

and after reviewing international experience results, we have decided to build multilinear regression between logging data. Also, due to quite robust matches between elemental spectroscopy TOC and core data from Well B we built multilinear regression between both logging data. In this case, we have used elemental spectroscopy TOC and gamma ray, formation resistivity and compressional slowness logs. Finally, we have computed the equation for TOC estimation in the organic rich rocks (V-23 and V-24-25) of North West Play in DDB (Figure 6). After reviewing and comparing TOC_ML values results with real advanced logs data we received very good correlation between them ($R^2=0.825$).

The same approach was applied to mineralogy and porosity estimation of target unconventional formations. The advanced open hole data, especially pulsed neutron elemental spectroscopy and nuclear magnetic resonance data with checking points of SCAL (XRD) analysis data (Figure 7) were used as calibration points. In this case, additionally we included the neutron porosity as input logging method that makes our model and result equations more accurate. Finally, we have computed equations for Vshale, Vcarb, Vqtz and total porosity. **Vshale** = $-0.000735024 * GR + 1.66798 * NPHI + 0.08147911$; GR (gAPI), NPHI (v/v); **Vcarb** = $-1.518274 * NPHI - 0.0005688319 * GR - 0.001894639 * DTP + 1.161073$; GR (gAPI), NPHI (v/v), DTP (us/m); **PHI_ML** = $0.0002825747 * DTP + 0.09433695 * NPHI - 0.03513782$; NPHI (v/v), DTP (us/m). **Vsand** = $1 - Vsh - Vcarb - PHI$. The pyrite content in our case was not included due limitation of needed inputs log data.

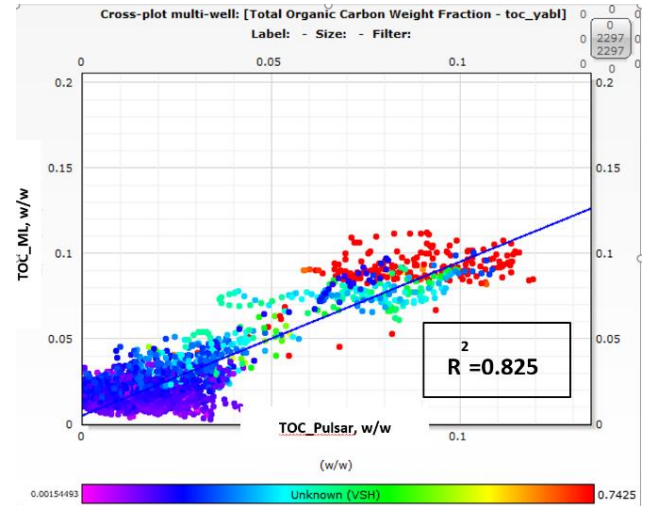
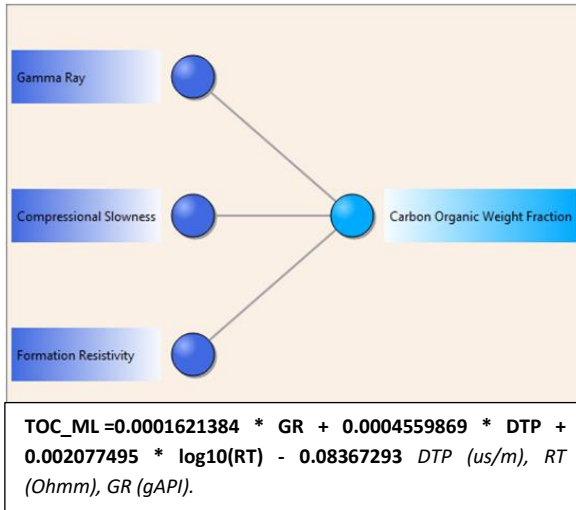


Figure 6 Left - TOC_ML own equation with multilinear regression approach (GR, RT and DTP vs TOC from elemental spectroscopy). Right – correlation between log TOC_ML and TOC_Pulsar data.

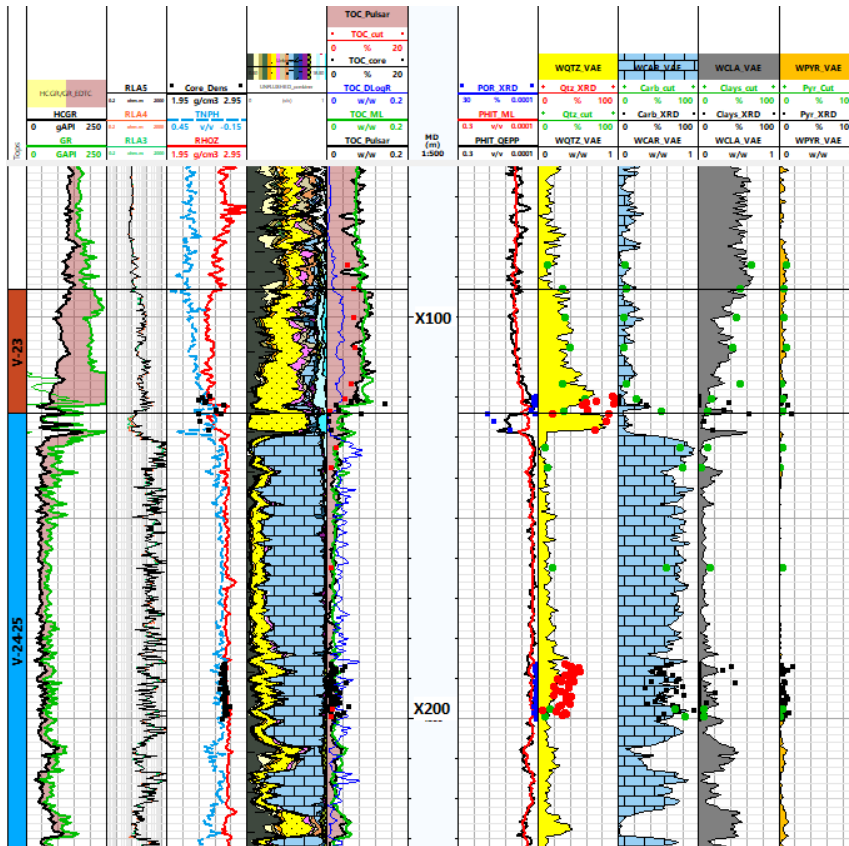


Figure 7 - Evaluated petrophysical parameters show a good correlation between TOC, XRD derived mineralogy, Core Porosity. Green dots cuttings laboratory analysis data, calibration well B.

These equations were applied in the wells South flank Play of DDB where it was not possible to run elemental-spectroscopy or other advanced well logging methods. The results were compared with SCAL analysis data in few wells (Figure 8). You can see quite good matches of evaluated TOC, main mineralogy and porosity.

The received results of our study are very important not only for estimating reservoir properties of the target formations, but also for building robust geomechanical and rock physics models, which will be used for multistage fracking modeling and seismic QI. It can have impact on the final results but not very significant in our case.

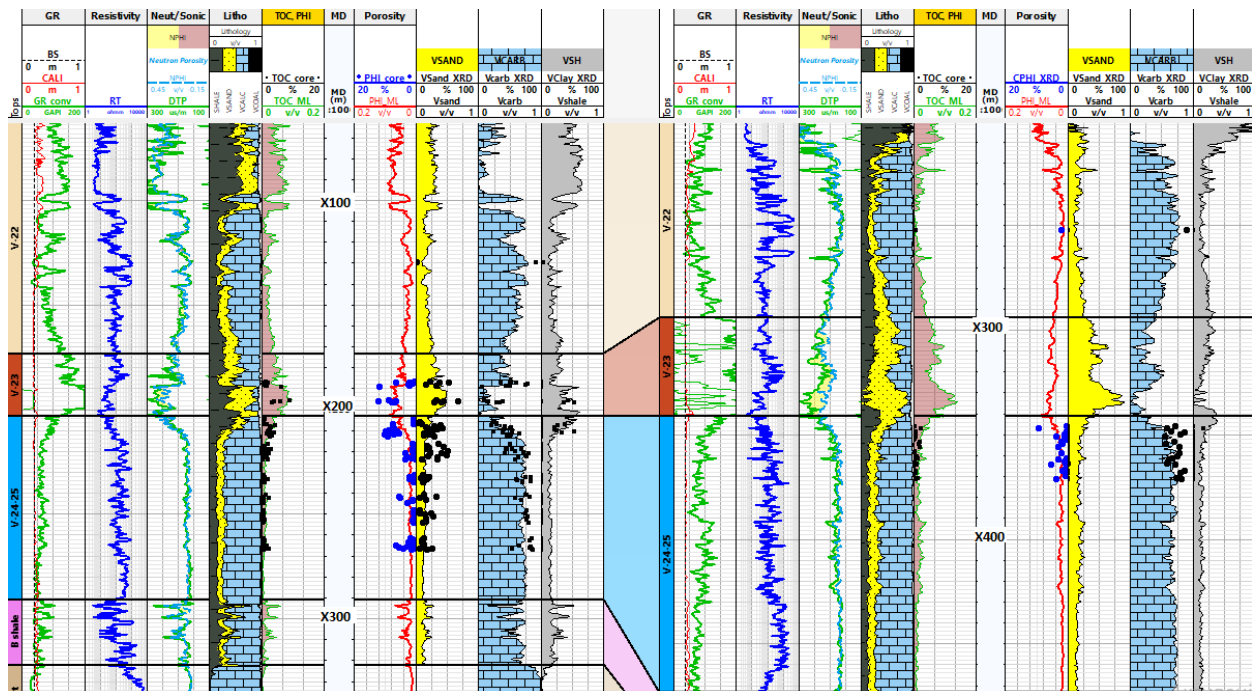


Figure 8 - Petrophysical model with using own local equations for evaluation and SCAL analysis data in wells E and D with more higher calcareous content from South Flank Play of DDB.

Novel/Additive Information

In our research, we have used different approaches for TOC calculation and petrophysical evaluation of main reservoir parameters in Viséan target formations with using modern log and SCAL data. Total organic carbon content obtained from elemental spectroscopy and NMR logs show the best matching between core and log data. Well-known DlogR technique showed less accurate results in our case. After applying multilinear regression technique, we have evaluated and proposed equation of TOC estimation for wells with limited logging datasets (GR, RT and DTP). The correlation between TOC computed from equation was proposed by us and real modern logging data (two wells) is very good and has robust correlation coefficient 0.825. It is very useful for cases when we have old wells logging data and it can help better understand potential of unconventional shale gas reservoirs in DDB. The mineralogy model and porosity estimation with using our proposed equations show good matches not only in North-West Play of DDB, but also in more calcareous formations in South Flank Play. It confirms that in cases with

“old style” datasets we can apply such approach for interpretation and receive quite accurate evaluation of the high-organic rich unconventional reservoirs properties and their potential for producing hydrocarbons. Additional advanced logging and coring data in South Flank Play can improve equations derived by us and increase the accuracy of petrophysical model, which is essential for successful assessment potential of an unconventional resource.

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