Journal of Zankoy Sulaimani
Part-A- (Pure and Applied Sciences)
http://jzs.univsul.edu.iq

Reservoir Rock Properties of the Upper Cretaceous Shiranish Formation in Taq Taq Oilfield, Iraqi Kurdistan Region

Dler H. Baban[1*], Fuad M. Qadir[1], Aram R. Mohammed[1]

[1] *Department of geology, College of Science, University of Sulaimani, Sulaimani, Kurditan Region – Iraq,*
**Corresponding author's e. mail: dler.mohamad@univsul.edu.iq*

Article info

Original: 7 March 2020
Revised: 18 April 2020
Accepted: 17 May 2020
Published online: 20 June 2020

Key Words:
Shiranish Formation, Taq Taq Oilfield, Reservoir Units, Petrophysics

Abstract

Reservoir rock properties of the tight carbonate of Upper Cretaceous Shiranish Formation was studied in three selected wells in Taq Taq Oilfield/ Iraqi Kurdistan Region. The penetrated thickness of the formation by the studied wells of TT-04, TT-20, and TT-21 were 249, 290.8, and 236m respectively. The available logs and core test data were mainly dependant in characterizing the formation. The dominant limestone lithology of the formation was identified using Neutron-Density and M-N crossplots. The shale content, as calculated from the Gamma ray log, appeared to be highest in the lower part of the formation with about 15-30%. The shale content of Shiranish Formation are mainly consists of Glauconite, Illite, and Micas with a little contribution from other kinds of clay minerals like Montmorillonite.

The total porosity of Shiranish Formation is generally less than 10% whereas the lower part of the formation has the lowest porosity (less than 5%).

The calculated permeability through Multiple Regression Analysis method and by using the available core test data showed that The formation is generally of less than 10mD permeability. The lower part of the formation (at the two wells of TT-20 and TT-21) has relatively higher permeability compared to the middle and upper part of the formation. Three distinctive reservoir units were identified in this study in Shiranish Formation depending on variations in the shale content, porosity, and permeability. Reservoir unit (RU-1) at the upper part of the formation in the well TT-21is considered to be of the best reservoir property among the identified reservoir units in the three studied wells. The expected contribution of minor and large fractures in enhancing the permeability of the formation approved through output of the existed Formation Micro Image log for the lower part of the formation in the well TT-21.

Introduction

The Upper Campanian - Maastrichtian Shiranish Formation is considered as an imperative fractured carbonate reservoir in northern Iraq [1]; however, it is not productive when not fractured. Oil is produced from fractured limestone of the Shiranish Formation in the Taq Taq Field as one of the main pay zones [2]. Oil has also been produced from the fractured Shiranish Formation in the Ain Zalah and Butmah fields and from the Baba dome of the Kirkuk Field in northern Iraq [3] [4].

Taq Taq Oilfield is located in the Low Folded Zone of the Iraqi physiographic subdivisions and structurally consists of a longitudinal, asymmetrical anticline of about 29 km long and about 11 km wide [5] (Fig. 1A). The anticline is clearly visible at the surface, where Miocene sandstones crop out forming ridges in an elliptical shape approximately 13 km long and 7 km wide.

In this study, the petrophysical properties of Shiranish Formation in Taq Taq Oilfield will be discussed using the data gathered from the available logs and core test of three selected wells.

Geologic setting and Stratigraphy

The Cretaceous sedimentary succession of the NE Arabian Plate was deposited in a structural setting described as narrow extensional basins, a wide foreland basin close to the thrust front and stable palaeo-highs [6]. A regional unconformity caps the Late Cretaceous progression and a several hundred meters of sedimentary section may be eroded and removed particularly from anticlinal crests in northern Iraq [3] [6].

Accordingly, the Latest Maastrichtian sedimentary units are commonly missing with some exceptions [6]. As the foreland basin was created in northern Iraq, general subsidence resulted in an open marine basin in which primarily carbonates were deposited [1] [3] [6]. Shallow-marine shelf limestones and detrital carbonates have numerous reservoirs in the Zagros basin in Iraq and Iran [7].

The stratigraphy comprises (from the top): red beds, fluvial clastics and conglomerates of the Lower Fars (Fatha) Formation of Miocene–Pliocene age; limestones and dolomites of the Pila Spi Formation of Eocene age, which form a minor reservoir at the crest of the structure.

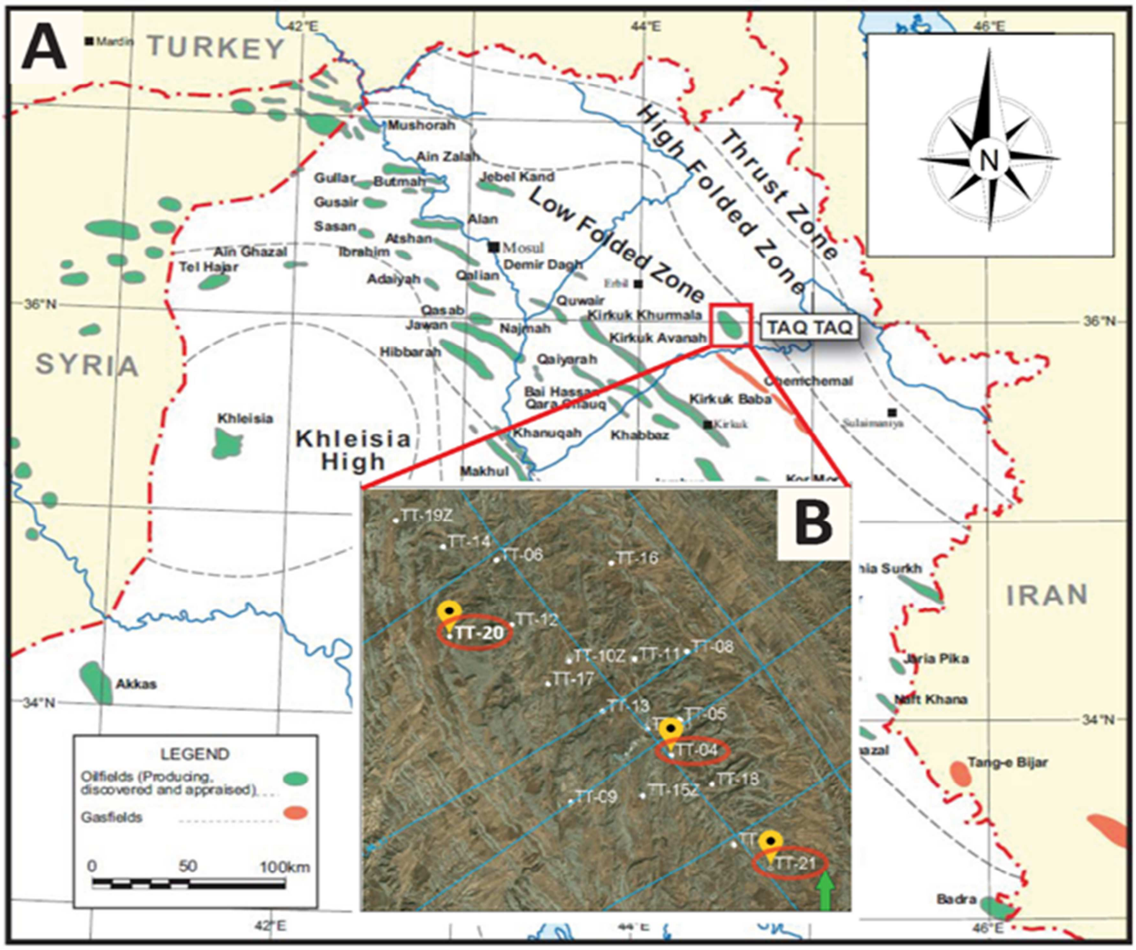


Figure 1: A: Map of northern Iraq showing the location of Taq Taq and nearby oilfields (after [6]), B: Location of the studied wells in Taq Taq Oil Field (Geophysical survey, Taq Taq Operating Company, TTOPCO).

The shelf and shoal limestones overlying marine clastics of the Kolosh Formation (Paleocene–Eocene) form the main seal to the Cretaceous fractured reservoirs at a depth of approximately 1000m below Sea level (BSL). Source rocks for Taq Taq oil have been shown to be Jurassic in age: this is consistent with regional studies [8]which show the Naokelekan and Sargelu Formation (which are present in Taq Taq) to be the main source rocks in northern Iraq (Fig. 2). These began generating hydrocarbons in the Miocene prior to the main compressional phase of Zagros folding [9].

Shiranish Formation

The Shiranish Formation was defined at northeast of Zakho close to the village of Shiranish Islam from the High Folded Zone of Iraqi Kurdistan by Henson (1940; in [4]).

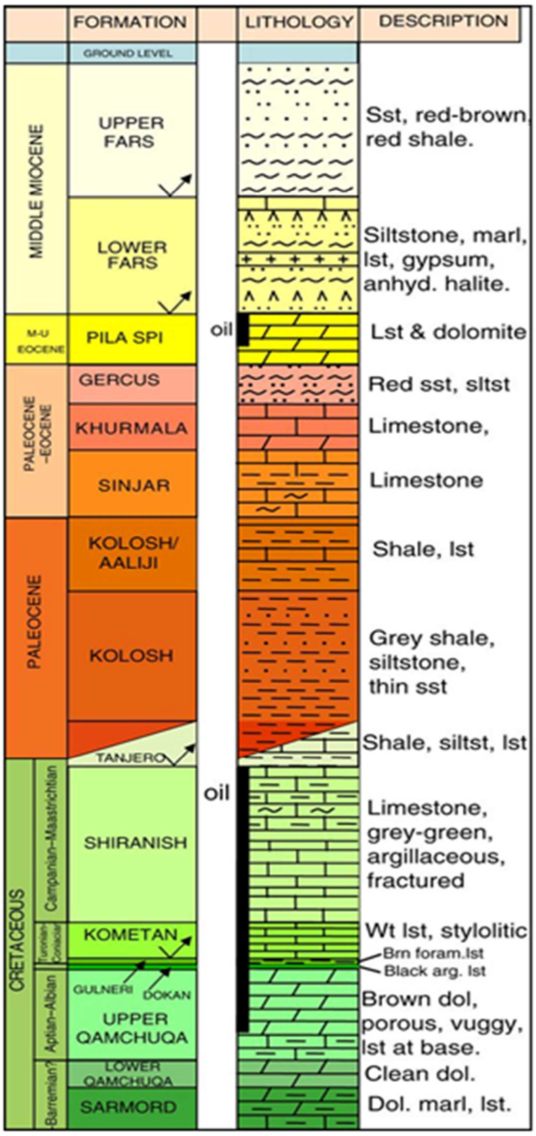


Figure 2: Stratigraphic columnar section of Taq Taq Oil Field (after [2])

The Shiranish Formation represents the lower part of an Upper Cretaceous (Campanian and Maastrichtian) regional transgressive-regressive depositional sequence that flooded about over of Iraq [3]. Abundant fossils confirm that the formation is of Late Campanian– Maastrichtian age [1] and according to [10], the age of Shiranish Formation may be further extended to the Paleocene based on the identified foraminifera's species in Hijran area. Shiranish Formation is composed of fine-grained thin-bedded limestone, with thickness of the individual beds extending from 0.4 to 1.5m. They are deep water marly limestone in the lower part [11]. At the type locality in the Shiranish area, there are several shallow-water intervals within the middle part of the formation [12].

In Mergasur area, the formation mainly consists of mudstone, wackestone, and packstone microfacies that deposited in deep marine, pelagic (open marine) reduced depositional environment [13].

The exposed 228m of the formation on the southwestern limb of the Sarah anticline consists of six main facies reflecting middle shelf to middle bathyal depositional environments [14].

The upper boundary of Shiranish Formation with the overlying Tanjero Formation is conformable and gradational [1]. According to [15], the boundary with the overlying Tanjero Formation and the upper part of the Kometan Formation belong to the same depositional sequence and all deposited in a huge foreland basin that occupied most of the Iraqi territory during the late Cretaceous.

Shiranish Formation is 225m thick in the type section, however differs from 100 to 400m in the other localities [1] and exceptionally the thickness of 1300m for the formation mentioned by [16] for the area between Hemrin and Mandali. The drilled wells in Taq Taq Oilfield generally show thicknesses for Shiranish Formation ranging between 220 and 355m [17].

Data and Methodology

Wireline well logs and core test or analysis are the main data used in characterizing Shiranish Formation in this study.

Three subsurface sections (wells) have been selected in order to study Shiranish Formation in Taq Taq Oilfield, namely TT-04, TT-20 and TT-21 (Fig. 1B). Information about total depth, elevation, and thickness of the penetrated Shiranish Formation in the studied wells are shown in Table 1.

The data used in this study are records of Natural gamma ray, Spectral gamma ray, Caliper, Sonic, Neutron, and Density logs for Shiranish Formation in the three selected wells in addition to the Image log data for the lower part of the formation in well TT-21 only.

Core test data for the depth interval between 1658 and 1665m (7m thickness with 92% recovery) for Shiranish Formation in the well TT-04 also used for determining permeability values for the whole studied sections.

The used softwares for digitizing, plotting, and editing the log data included Neuralog, Geolog, Interactive Petrophysics, LAS File Viewer Java Applet, Adobe Acrobat DC, Nitro pro, and Techlog in addition to the conventional softwares of Excel, Note pad, and 3D Paint.

Table 1: Total depth and elevation of the selected wells with the drilled thickness of the Shiranish Formation in each well.

Studied wells	Total Depth of the well (m)	Elevation (RT-MSL) (m)	Top of Shiranish Fm. (m)	Bottom of Shiranish Fm. (m)	Thickness (m)
TT-04	2286	626.5	1608	1857	249
TT-20	2422	527	1631	1921.8	290.8
TT-21	2370	525	1670	1906	236

Objectives of the study

The main objective of this research is to evaluate the petrophysical properties of Shiranish Formation as a reservoir in Taq Taq Oilfield using the available log and core test data. Accordingly, subdividing the studied formation to distinctive reservoir units and then describing and evaluating each unit will be the way to achieve the objective.

Lithology Determination from Porosity logs

The logging tools respond to the lithology of the beds in different ways. Some of them are seriously affected by certain types of lithology (such as the effect of shale on Neutron log) and some are very effective in determining certain types of lithology. Identification of lithology using log data become more efficient when the data of different tools are combined through applicable equations or crossplots.

The most useful combination of logs were used in this study for determining the lithology of the studied Shiranish Formation is of Neutron, Density, and Sonic logs (porosity logs). Neutron and the Density logs are not easy to be used for lithology identification separately, but when combined, they become probably the best available indicator [18] [19].

The readings of the Density and Neutron logs for the studied Shiranish Formation are plotted on the Neutron-Density crossplot proposed by [20] (Fig.3). The crossplot is essentially constructed for clean, liquid saturated formations and a borehole-filled with a water based mud or just a water. The sufficient separation between quartz, limestone, and dolomite lines in the crossplot indicate good identification for those lithologies as well as the common evaporates such as anhydrite and rock salt can also be easily indicated. The interpretation of the crossplot can be ambiguous when there is more than one mineralogy in the formation like dolomite-cemented sandstone [21].

The distribution of the measured Neutron porosity ($Ø_N$) and bulk density (ρb) on the N-D crossplot showed almost same pattern of distribution for the three studied wells (Fig.3). The lithology appeared to be limestone dominanted; the scattered sample points far from the main lithology lines are due to the very low ρb readings as a result of drilling mud effect in zones of bad borehole conditions (enlargements).

The distortion of the points toward the main line of the dolomite are mainly due to the effect of dolomitization or the effect of shale content as the location of the shale zone in the crossplot is toward the right corner where high values of $Ø_N$ and ρb exist.

In complex mineral mixtures, lithology interpretation is facilitated by using the M-N plot. These plots combine the data of all three porosity logs (Neutron, Density, and Sonic) to provide the lithology-dependent quantities M and N, which are simply the slopes of the lines of each individual lithology on the Density-Neutron and Sonic-Density crossplots, respectively. Thus, M and N are essentially independent of porosity, and the crossplot provides lithology identification [22].

M and N are defined as:

$$M = \frac{\Delta tfl - \Delta t}{\rho fl - \rho b} * 0.01 \quad \text{................................ Eq-1}$$

$$N = \frac{ØNf - ØN}{\rho b - \rho fl} \quad \text{..Eq-2}$$

Where:
Δtfl: interval transit time in the fluid in the Formation
Δt: interval transit time in the Formation (from log)
ρb: Formation bulk density (from log)
ρfl: fluid density (generally, 1.0 for fresh mud and 1.1 for saline mud)
ØNf: neutron porosity of the fluid in the Formation (usually 1.0)
ØN: neutron derived porosity (from log)
The multiplier 0.01 is used to make the M values compatible for easy scaling.

Three pure mineral endpoints of silica, calcite, and dolomite in the M-N crossplot create a lithology triangle that represents a shale-free carbonate zone. Zones which located above the dolomite-calcite-silica line are considered to have secondary porosity development of magnitude represented by the distance from the point to the lithology triangle [23].

The shale or clay content in the unit makes the sample points be plotted in the increasing shale region below the lithology triangle. Rugosity also causes distortion of the sample points toward the direction of increasing shale content [24].

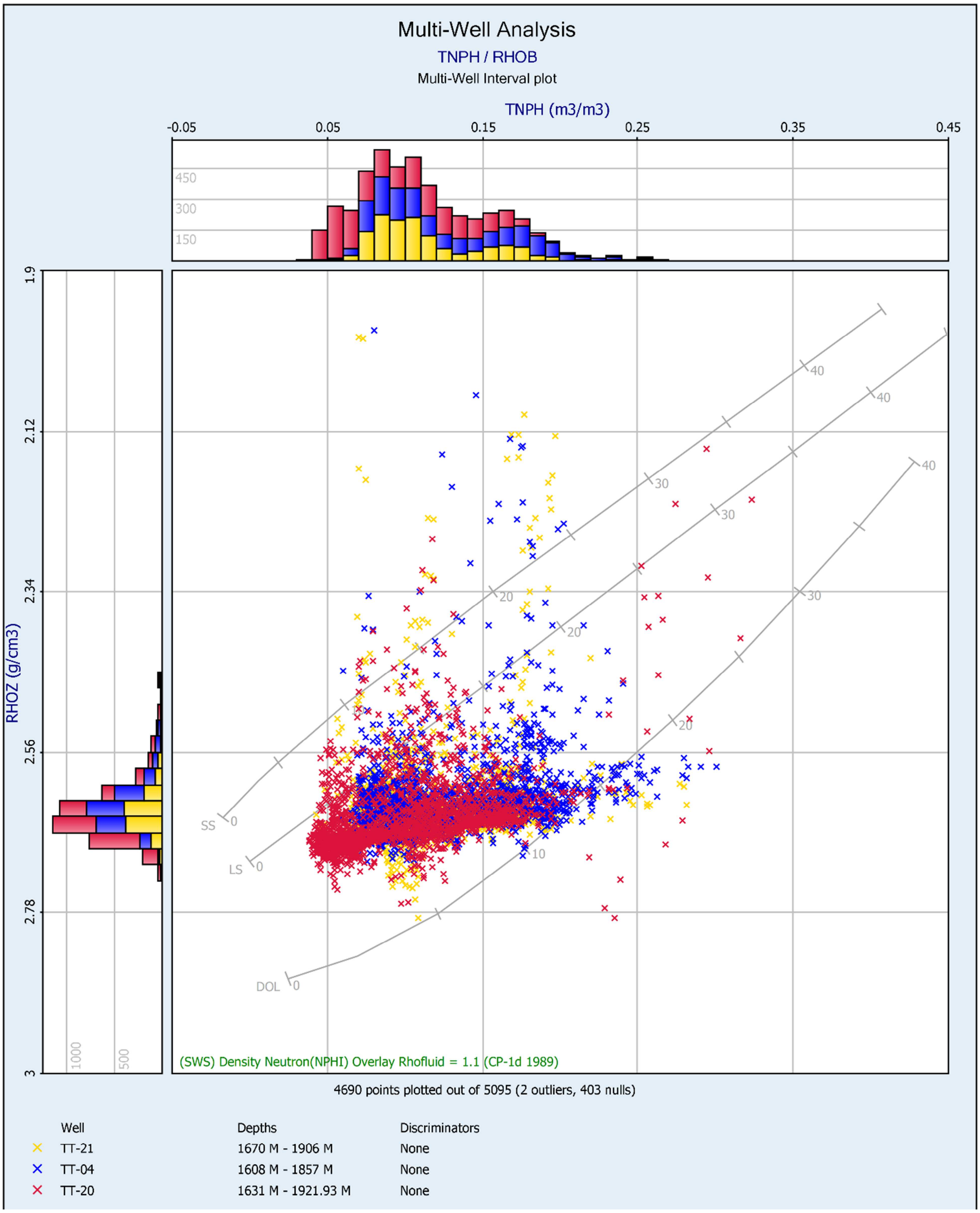


Figure 3: Neutron-Density Crossplot for determining lithology of Shiransih Formation in the studied wells.

The lithologies identified from the M-N crossplot were very similar to those identified from the Neutron-Density crossplot for the studied Shiranish Formation in the three studied wells (Fig. 4). The most important advantage of M-N crossplot over Neutron-Density crossplot is good identification of the secondary porosity in the studied intervals as in M-N crossplot, sonic log also contributes in addition to Neutron and Density logs.

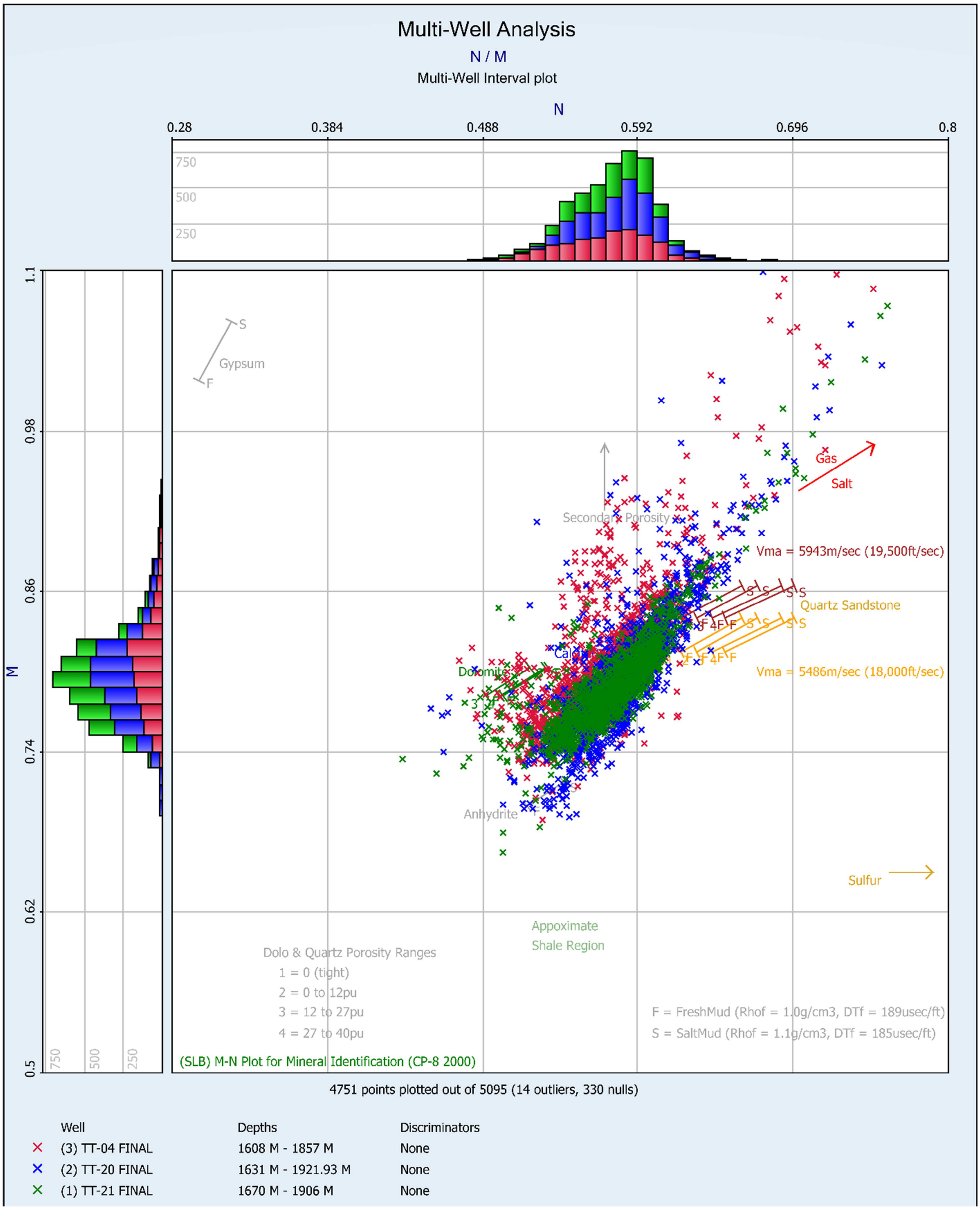


Figure 4: M-N Crossplot for determining lithology of Shiransih Formation in the studied wells.

The identification of fractures have been mostly done when M factor shows high values due to the low readings of Density log (ρb) in the fractured or vuggy zones. Sonic log is not affected by the fractures or vugs and the recorded Δt readings will represent the time needed by the sonic wave to pass through the rock and through the fluid exist in the primary matrix porosities of the rock.

As in the previous N-D crossplot, lithology is easily identified for Shiranish Formation in the wells TT-04, TT-20 and TT-21 using the M-N crossplot. The concentration of the M-N points in the limestone field signs clearly to domination of this lithology in Shiranish Formation.

Shale content and distribution

Shale volume determined for Shiranish Formation depending on the data of the gamma ray log and using the equations of Gamma Ray Index (Eq.3) and shale volume calculation of [25] for consolidated rocks older than Tertiary (Eq.4).

$$IGR = \frac{(GRlog-GRmin)}{(GRmax-GRmin)} \quad \text{....................Eq.3}$$

Where:

IGR: Gamma Ray Index
GR_{log}: (gamma ray log) relates to the desired depth.
GR_{min}: the minimum value at non-shale formation (clean)
GR_{max}: the value that is read at a 100% shale Formation

$$Vsh = 0.33\ [2^{(2*IGR)} - 1.0] \quad \text{................. Eq.4}$$

The obvious notes about the determined volume of the shale are firstly, the lower part of the formation contains a relatively higher percentage of shale (more than 10%) than the middle and the upper parts (Fig.5), and secondly, the shale content of the Shiranish Formation in the well TT-04 is relatively higher than in the other two studied wells of TT-20 and TT-21 and exceeds 30% in some horizons at the lower part of the formation.

The calculated shale content in this study is in total agreement with the results obtained by [26] about the calcite and clay content percentages of Shiranish Formation in the Euphrates graben in Syria.

The mode of the shale distribution determined for the formation based on the crossplot proposed by [27] and depending on the data of the density and neutron logs (Fig.6). The shale content in the Shiranish Formation appeared to be mostly distributed as dispersed type. In such a shale distribution mode, a relatively low neutron and density porosity records are mostly expected.

Dispersed shale distribution type in any reservoir affects both porosity and permeability values. The effective porosity of the formation (when removing the impact of shale) showed values generally less than 10% for the formation (Fig.6).

In this study, the data of the natural gamma ray spectroscopy was available for Shiranish Formation at the well TT-21 only (Fig. 7). The values of the recorded U, Th, and K are listed in the Appendix A.

The relatively high U value at the lower part of the formation is an indication to high organic carbon content (as organic matter has ability of adsorbing U) or deposition of uranium salts in the fractures [28].

The researcher tried his best to recover information as much as possible from the data of the spectroscopy gamma ray log through applying special crossplots and graphs established to be used for such a purpose.

The crossplot of K versus Th (Fig. 8) shows that most of the clay minerals formed the shale content consist of Glauconite, Illite, and Micas with a little contribution from other kinds of clay minerals like Montmorillonite. The other crossplot used for the same purpose, depending on the data of PEF and Th/K ratio (Fig. 9), showed a distribution for the sample points close to the regions of the Glauconite, Illite, and Montmorillonite with being also not far from the fields of Micas (Biotite and Muscovite).

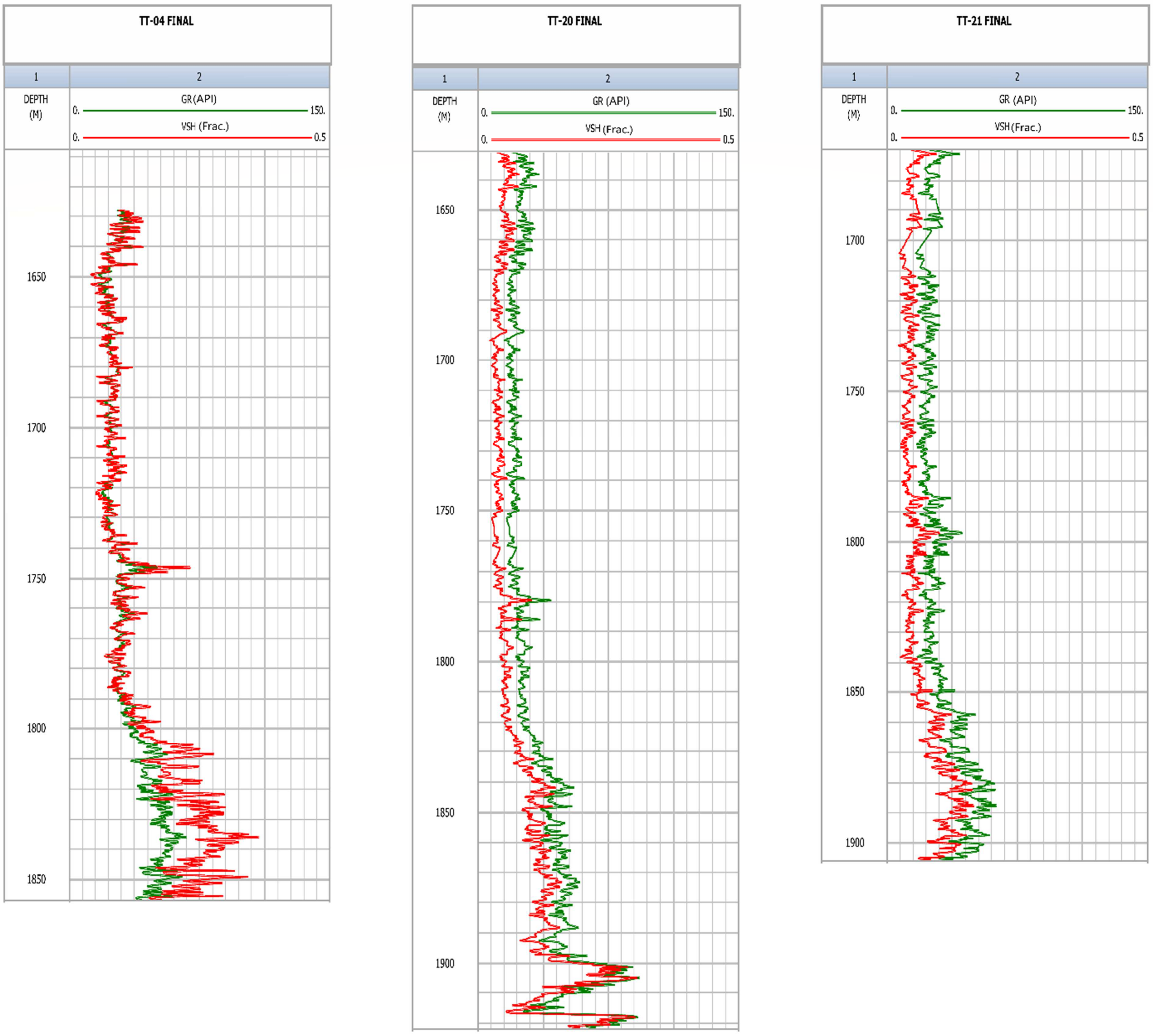


Figure 5: The record of the Gamma ray log and the calculated shale volume for the Shiranish Formation in the studied wells.

Porosity

Porosity for Shiranish Formation was calculated in this study using records of the Density and Neutron logs. The recorded bulk density (ρb) was converted to density porosity ($Ø_D$) using equation Eq.5.

$$ØD = \frac{\rho ma - \rho b}{\rho ma - \rho fl} \text{……………………..Eq.5}$$

Where:

$Ø_D$: the porosity calculated from data of Density log

ρma: matrix density in gm/cm³

ρb: bulk density in gm/cm³ (the record of the tool in any depth)

ρfl: the density of the mud filtrate in gm/cm³

Correction of the effect of shale content done for the calculated density porosity and the recorded neutron porosity for the whole formation in the studied sections using Eqs. 6 and 7 of [29] although in most parts of the formation the shale content doesn't exceed 10%.

$$Ø_{D\text{-shale corrected}} = Ø_D - (V_{sh} * Ø_{Dsh}) \text{………………………..Eq.6}$$

$$Ø_{N\text{-shale corrected}} = Ø_N - (V_{sh} * Ø_{Nsh}) \text{………………………..Eq.7}$$

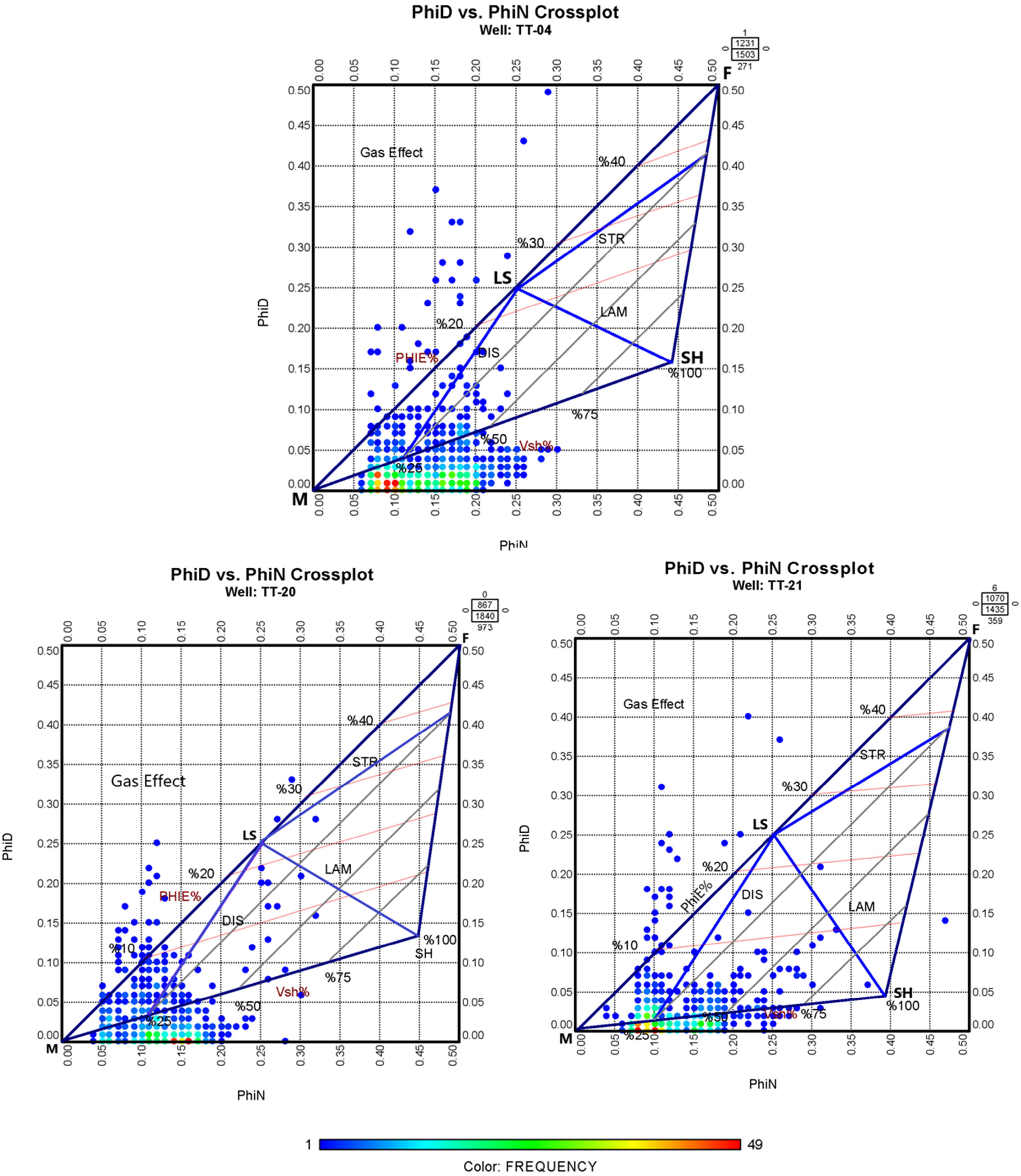


Figure 6: Mode of shale distribution type based on [27] crossplot for Shiransih Formation in the studied wells.

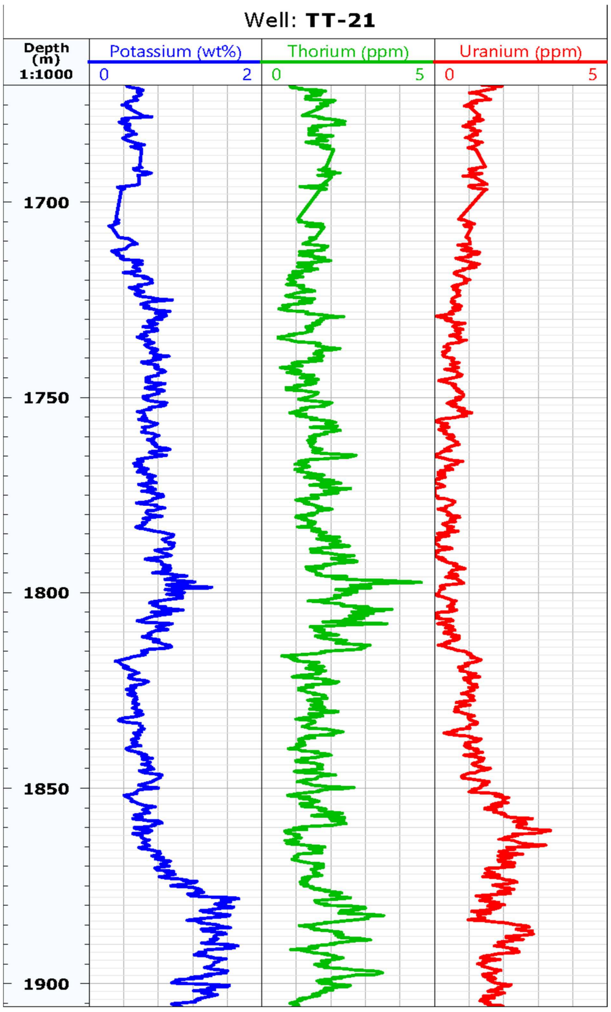


Figure 7: Potassium (K), Thorium (Th), and Uranium (U) curves of the Spectroscopy Gamma ray log for Shiranish Formation at the well TT-21.

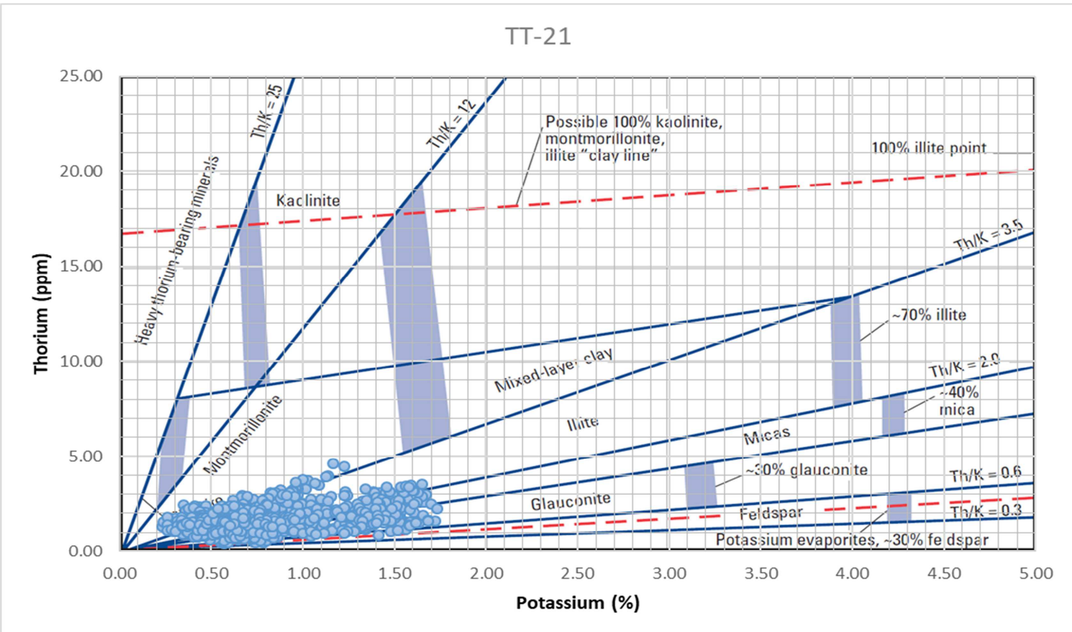


Figure 8: Thorium-Potassium crossplot for clay mineral identification for Shiranish Formation at the well TT-21 (the crossplot is after [30]).

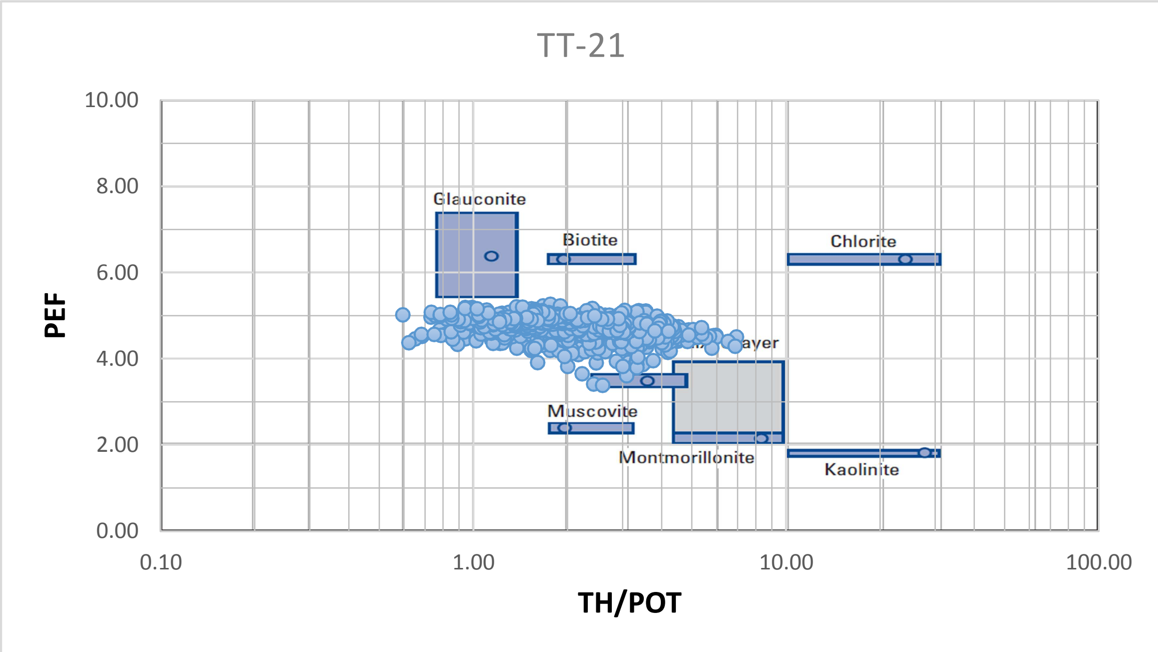


Figure 9: PEF - Th/K crossplot for clay mineral identification in Shiranish Formation at well TT-21 (the crossplot is after [30]).

Where:

$Ø_{D\text{-shale corrected}}$: corrected density porosity from effect of shale
$Ø_{N\text{-shale corrected}}$: corrected neutron porosity from effect of shale
$Ø_{D}$: uncorrected calculated density porosity
$Ø_{N}$: uncorrected recorded neutron porosity
V_{sh}: calculated volume of shale in any depth
$Ø_{Dsh}$: calculated density porosity at the shale zone
$Ø_{Nsh}$: recorded neutron porosity at the shale zone

Eq.8 depended in evaluating Shiranish Formation in this study.

$$Ø_{N\text{-}D} = \frac{ØNcorr + ØDcorr}{2} \text{........................Eq.8}$$

Where:
$Ø_{N\text{-}D}$: combination neutron-density corrected porosity
$Ø_{Ncorr}$: corrected neutron porosity
$Ø_{Dcorr}$: corrected density porosity

Figure 10 shows the plot of the calculated uncorrected and corrected $Ø_{ND}$ along with the calculated the shale volume.

The formation (as mentioned above) appeared generally to be own less than 10% porosity with the upper part being of relatively higher porosity than the middle and the lower part. The porosity showed values less than 5% in the lower part of the formation where which the highest shale content is observed.

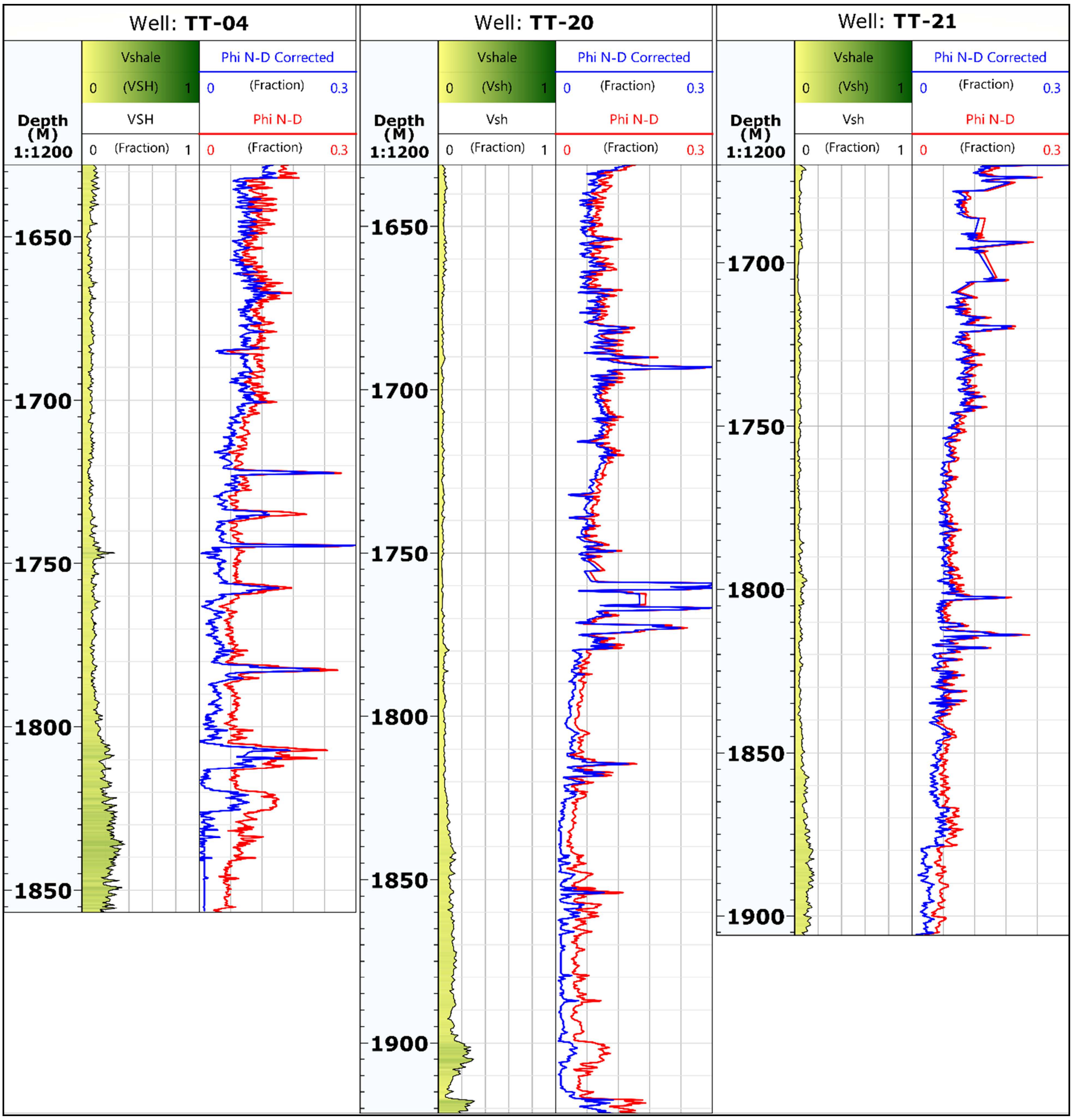


Figure 10: Uncorrected and corrected Neutron - Density combination porosity and shale volume curves for Shiranish Formation at wells of TT-04, TT-20 and TT-21.

Permeability

Greater porosity usually corresponds to greater permeability, but this is not always the case. Pore size, shape, and continuity, as well as the amount of porosity, influence formation permeability [22]. Permeability can be indirectly estimated using wireline logging and pressure transient methods, or directly through core analysis techniques. Indirect methods often prove to be unreliable; however, integration of methods at all scales yields the best estimate of reservoir permeability.

In this study, the available permeability values from core test analysis for Shiranish Formation from well TT-04 were used with the log data of gamma, sonic, neutron, and density to apply the Multiple Regression Analysis (MRA) method in order to formulate the best equation representing the relationship between permeability and the mentioned log responses.

The equation Eq-9 appeared to be best representing the depended permeability values and the independent well log data.

$$\log K = 73.549 + (0.0755 * \Delta t) + (-0.267 * GR) + (19.3289 * \varnothing_N) + (-28.2389 * \rho b) \quad \text{..........Eq.9}$$

Where:
K: permeability
GR: gamma ray
Δt: interval transit time
$\varnothing_N$: neutron porosity
ρb: bulk density

Through applying Eq.9 on the available log data for the Shiranish Formation in the three studied wells; permeability values are determined for the whole section of Shiranish Formation in the three mentioned wells (Fig. 11).

The calculated permeability for Shiranish Formation showed that the formation generally has less than 10mD permeability. The lower part of the formation appeared to be of higher permeability than the middle and upper parts, although the lower part is relatively of higher shale content.

A lot of intercalated permeable and impermeable horizons were detected in the middle and upper parts of the formation indicating anisotropy in permeability and non-homogeneous nature of the lithology. Such a condition was not observe in the lower part of the formation. The relatively higher permeability of the lower part of the formation (especially at wells of TT-20 and TT-21) may be attributed to existence of fractures as secondary porosity providing easier passages for flow.

Reservoir Units

In order to distinguish between the horizons of different reservoir capacity, Shiranish Formation in the studied wells was subdivided to different reservoir units depending on variations in the three main rock properties of shaleness, porosity, and permeability.

Such a subdivision to different reservoir units shows firstly the variation in the storage capacity of the different parts (units) of the formation (depending on values of shaleness and porosity) and secondly aids in detecting preliminarily the flow capacity of each unit (depending on shaleness and permeability) regardless of the type of the produced fluid.

The Figures 12-14 show the division of the Shiranish Formation to three reservoir units based on the mentioned parameters at the studied three wells. The Tables 2 and 3 summarize the minimum, maximum and average values of the mentioned three parameters for the distinguished reservoir units of Shiranish Formation at the studied wells of TT-04, TT-20, and TT-21 respectively. The tables also show the depth interval of each unit within the studied wells.

Shiranish Formation, in the studied wells, did not show distinguishable lateral variations in its lithological properties, so the same reservoir units were observed in the three studied wells.

This also means that even no diagenetic processes affected the formation laterally in such a different way leading to changing the reservoir properties of the formation among the wells. Below is description and evaluation of each reservoir unit.

Reservoir Unit 1 (RU-1)

This unit represents the upper part of Shiranish Formation with about 97m thickness at TT-04, 94m at TT-20, and 80m at TT-21. The average shaleness of this reservoir unit ranges between 4% and 8% and the average porosity is ranges from 9 to 11%. Permeability of this reservoir unit, on the other hand, is ranging between 1.15 to 1.39mD resulting partly from micro fractures. This unit is lithologically composed mainly of limestone and slightly marly limestone in the three studied wells.

Reservoir Unit 2 (RU-2)

This unit has about 95m thickness at the well TT-04, 100m at TT-20, and 90m at TT-21 and consists of limestone with average shale content between 5 and 9.7%.

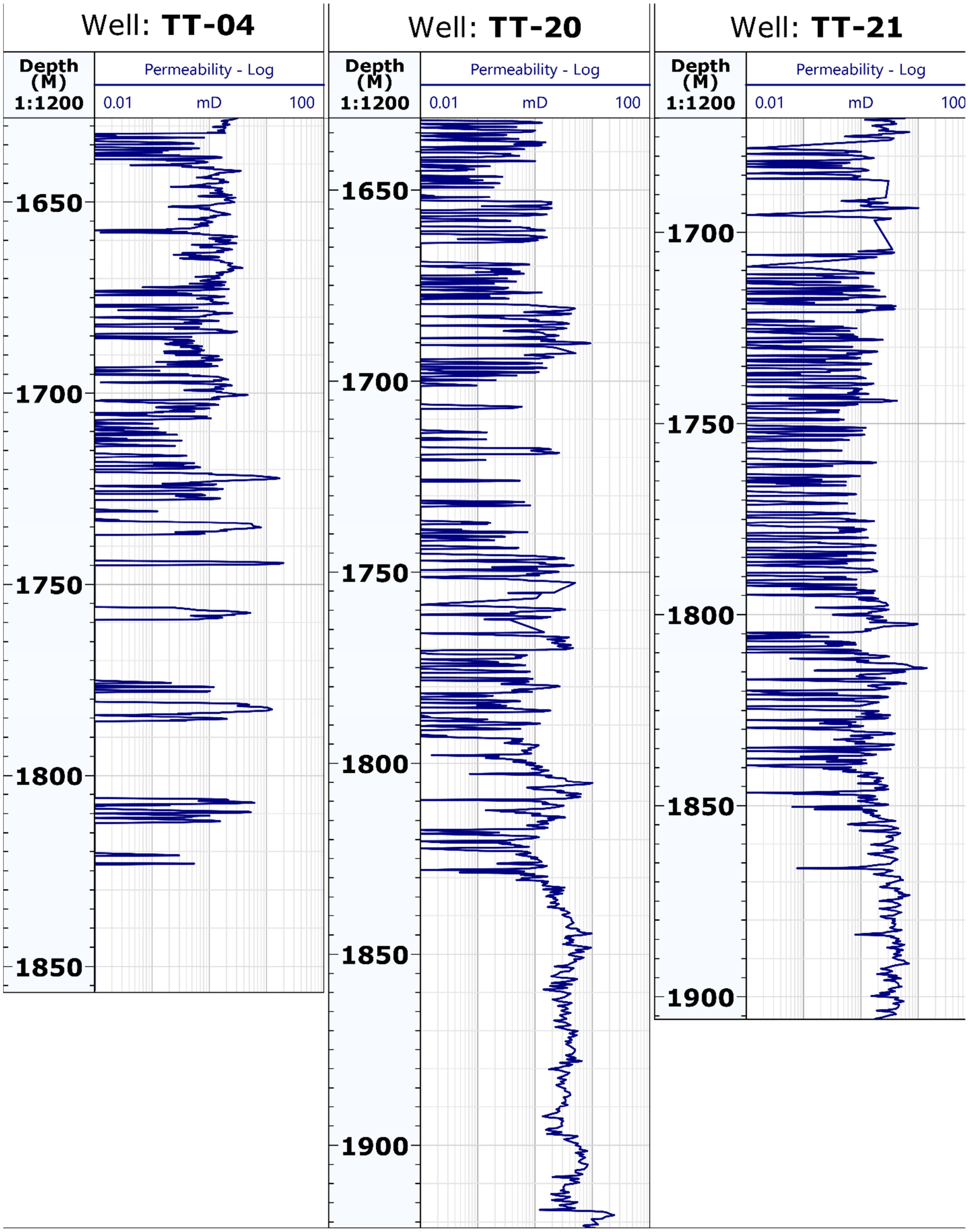


Figure 11: The calculated permeability through applying MRA method and using log data for the studied Shiranish Formation at the wells TT-04, TT-20, and TT-21.

The porosity is ranging as average between 5 and 7%, whereas the permeability is ranges between 0.01 and 1.51mD. The lithology of this reservoir unit is mainly limestone in the three studied wells.

Reservoir Unit 3 (RU-3)

This unit represents the lowermost 10m of Shiranish Formation which is mainly composed of marly limestone in all of the three studied wells. This unit is characterizes by average shale content ranging between about 10% and 23% with an average porosity ranging between about 2 to 4%. The average permeability ranges between about 1.57 to 4.37mD indicating the possibility of micro-fractures existence that has enhanced the permeability.

Figure 15 shows a correlation between the identified three reservoir units in the three studied wells. Although the same reservoir units are identified in the three wells, but the thicknesses of the reservoir units (and the total thickness of the formation) is greater at the well TT-20 than in the other two wells of TT-04 and TT-21. Such a variation in the thickness is mostly due to the paleodepositional condition of the formation.

Generally regardless of hydrocarbon saturations, RU-1 at the well TT-21 has the best reservoir properties among the identified reservoir units within Shiranish Formation in the studied wells as it owns the highest average porosity and acceptable permeability. The reservoir unit RU-3 at the well TT-20 is of the lowest reservoir properties compared to other identified reservoir units as it's of about 14% average shale content and of a low porosity (about 2%) although relatively high average permeability was calculated for this unit (average 4.37mD).

The available Formation Micro Image log (FMI) for the lower part of the formation (RU-3) in the well TT-21(Fig.16) may aid in recognizing the different kinds of the fractures in the formation.

As shown in the Figure 16, the almost horizontal shaly beds of the formation has occasionally suffered from fracturing. Open fractures can be observed in the section through the shade of the color darkness of the image log (open fractures appear as dark colors). Open and filled minor fractures (fractures ended within the frame of the well) and open with partially open large fractures (fractures passing across the diameter of the well) all exist in this unit. The large fractures look to have different dip amount and directions. At least two sets of large fractures can be recognized in Figure 16, as those noticed around the depth 1900m.

Induced fractures, on the other hand, can also be seen in this unit especially in its upper part. Accordingly, fractures seem to be continuously in enhancing the permeability of the formation.

[17] Observed in their study for selected cores from Shiranish Formation in Taq Taq Oilfield that the fractures in the formation are either unfilled joints or veins partly cemented with calcite. They also mentioned that the largest extensional fractures and faults are of steeply dipping and are continuous across the core samples. [2] On the other hand, stated that the upper part of the formation contains mostly shear type fractures. The fracture intensity decreases and diminishes upwards towards the top of the Shiranish Formation [17].

Conclusions

Below are a summary for the main conclusions that this study came out with:

- The shale content in the limestone and marly limestone of Shiranish Formation is highest in the lower part of the formation and reaches to about 30% in some horizons, whereas the middle part contains the lowest shale content (less than 10%).
- The type of the shale distribution in the formation is mainly dispersed type which has affected both porosity and permeability of the formation.
- The shale content of Shiranish Formation mainly consists of Glauconite, Illite, and Micas with a little contribution from other kinds of clay minerals like Montmorillonite.
- The porosity of Shiranish Formation is generally less than 10% with the lower part being of the lowest porosity (less than 5%).

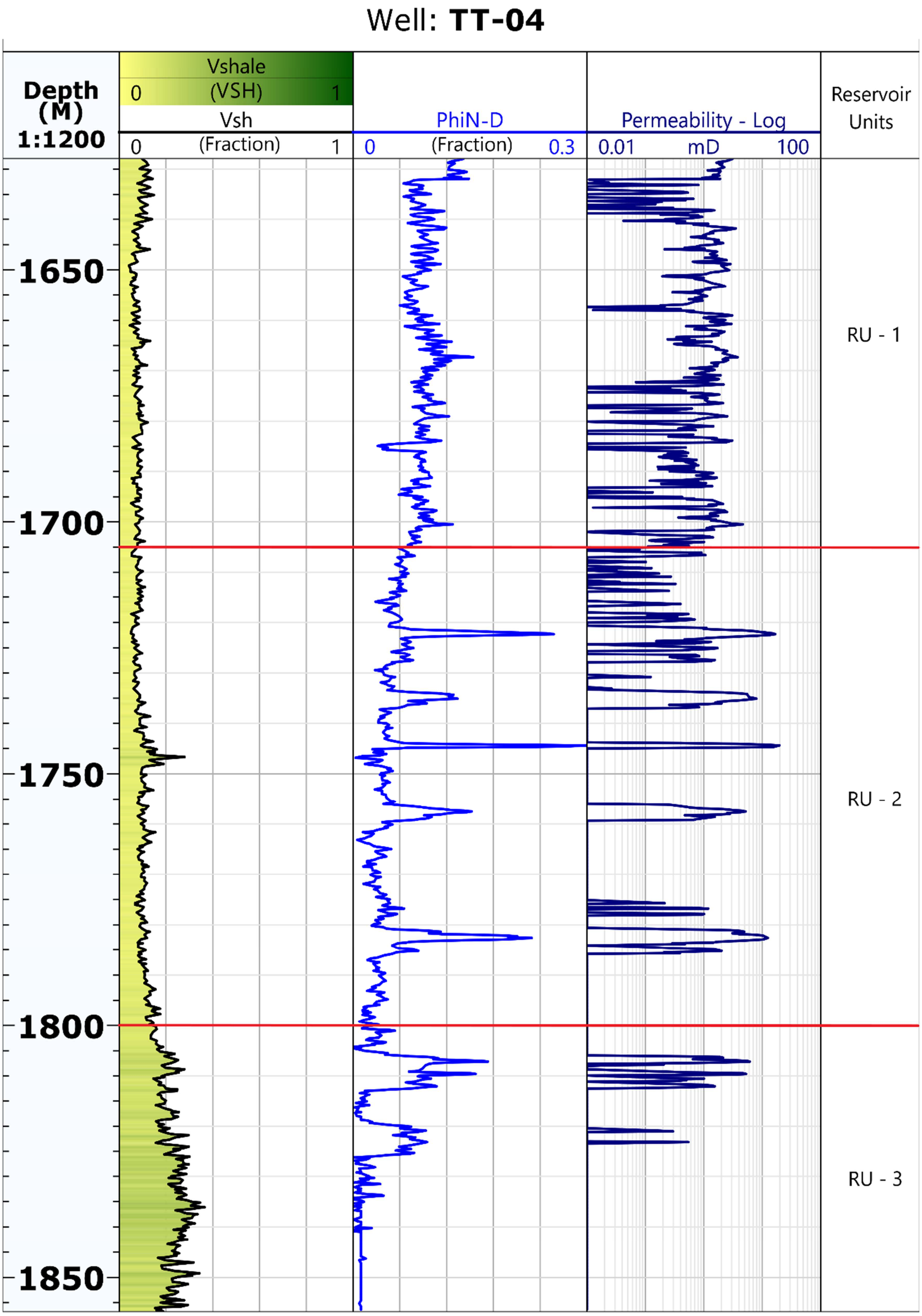


Figure 12: Identified reservoir units based on shale content, porosity, and permeability for Shiranish Formation at the well TT-04.

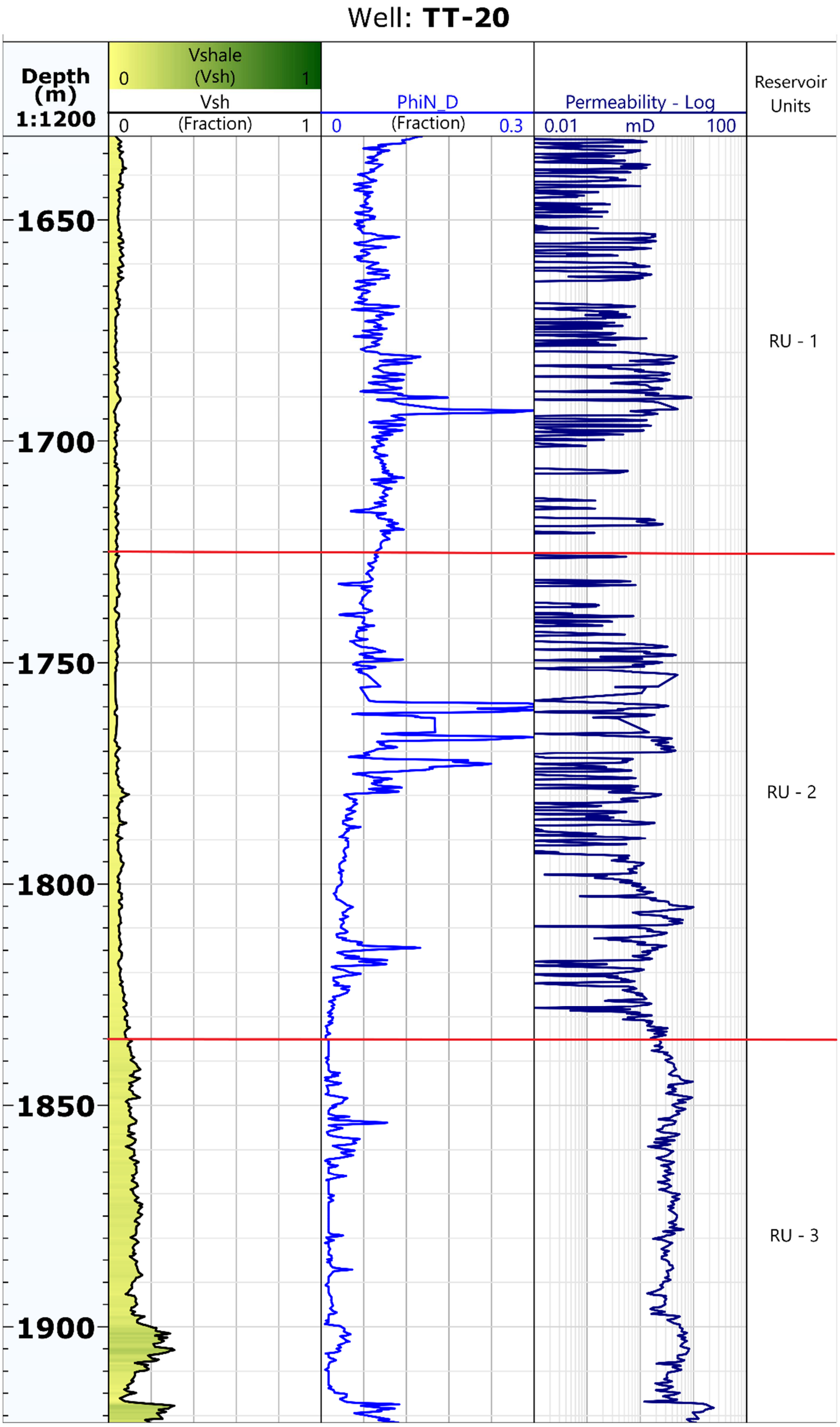


Figure 13: Identified reservoir units based on shale content, porosity, and permeability for Shiranish Formation at the well TT-20.

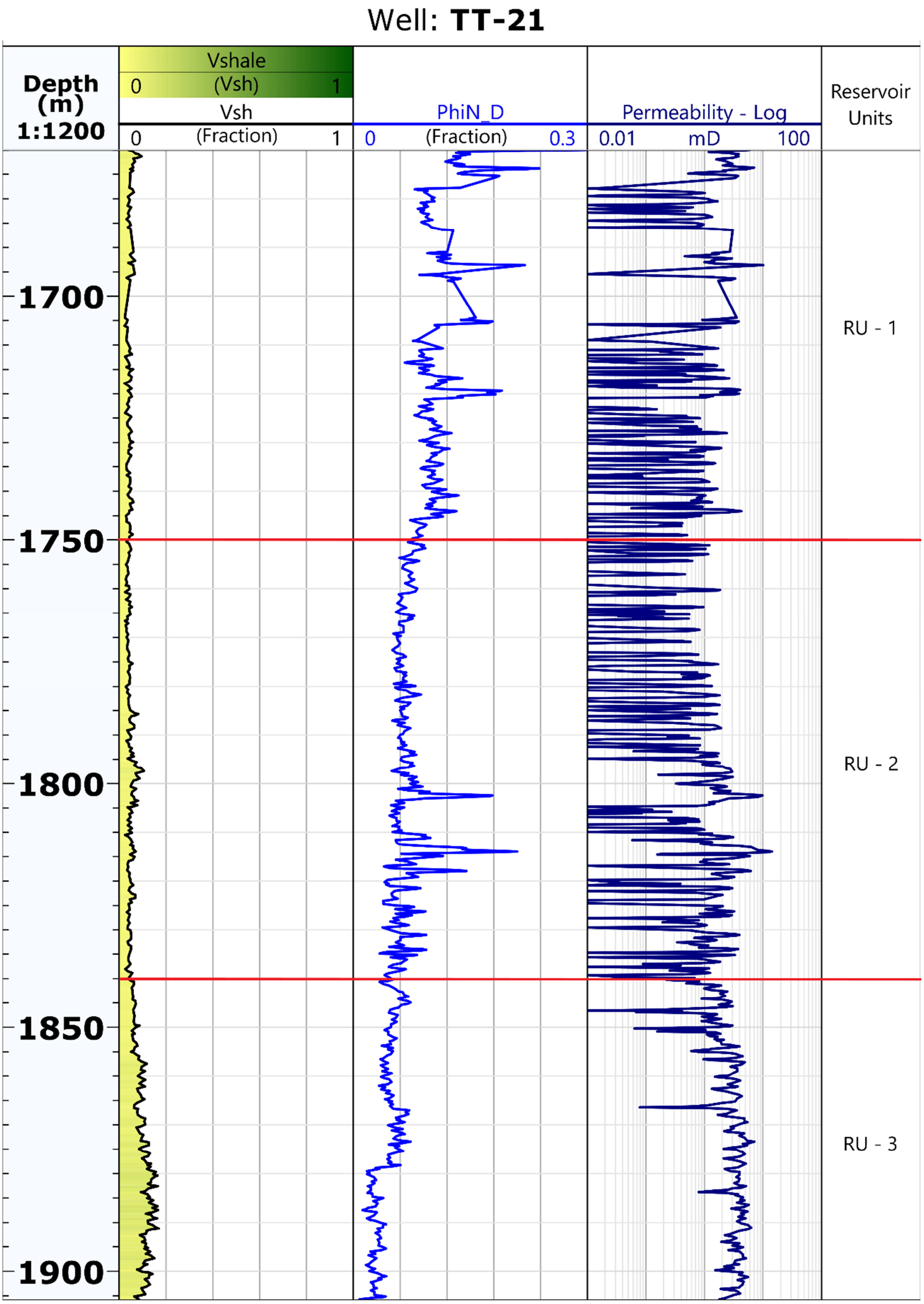


Figure 14: Identified reservoir units based on shale content, porosity, and permeability for Shiranish Formation at the well TT-21.

Table 2: Minimum, maximum, and average values of shale content, porosity, and permeability for the distinguished reservoir units of Shiranish Formation in the well TT-04.

Reservoir Units	*Depth Interval (m)*	*Statistics*	*Vsh (%)*	*Porosity (%)*	*Permeability (md)*	*Main Lithology*
RU - 1	*1608 - 1705*	*Min*	*4*	*3*	*0.0002*	*Limestone and Slightly marly Limestone*
		Max	*15*	*15*	*4.66*	
		Average	*8*	*9*	*1.17*	
RU - 2	*1705 - 1800*	*Min*	*5*	*0.32*	*0.004*	*Limestone*
		Max	*28*	*30*	*19.72*	
		Average	*9.7*	*5*	*0.01*	
RU - 3	*1800 - 1857*	*Min*	*13*	*0.03*	*0.02*	*marly Limestone*
		Max	*36*	*17*	*6.09*	
		Average	*23*	*4*	*1.57*	

Table 3: Minimum, maximum, and average values of shale content, porosity, and permeability for the distinguished reservoir units of Shiranish Formation in the well TT-20.

Reservoir Units	*Depth Interval (m)*	*Statistics*	*Vsh (%)*	*Porosity (%)*	*Permeability (md)*	*Main Lithology*
RU - 1	*1631 - 1725*	*Min*	*2*	*4*	*0.01*	*Limestone and Slightly marly Limestone*
		Max	*8*	*35*	*9.20*	
		Average	*4*	*8*	*1.15*	
RU - 2	*1725 - 1835*	*Min*	*2*	*1*	*0.01*	*Limestone*
		Max	*11*	*44*	*10.51*	
		Average	*5*	*6*	*1.32*	
RU - 3	*1835 - 1922*	*Min*	*5*	*1*	*1.20*	*marly Limestone*
		Max	*31*	*11*	*24.00*	
		Average	*14*	*2*	*4.37*	

Table 4: Minimum, maximum, and average values of shale content, porosity, and permeability for the distinguished reservoir units of Shiranish Formation in the well TT-21.

Reservoir Units	*Depth Interval (m)*	*Statistics*	*Vsh (%)*	*Porosity (%)*	*Permeability (md)*	*Main Lithology*
RU - 1	*1670 - 1750*	*Min*	*2*	*7*	*0.01*	*Limestone and Slightly marly Limestone*
		Max	*10*	*31*	*10.07*	
		Average	*4*	*11*	*1.39*	
RU - 2	*1750 - 1840*	*Min*	*2*	*3*	*0.02*	*Limestone*
		Max	*11*	*21*	*14.14*	
		Average	*5*	*7*	*1.51*	
RU - 3	*1840 - 1906*	*Min*	*4*	*1*	*0.06*	*marly Limestone*
		Max	*17*	*7*	*7.17*	
		Average	*10*	*4*	*3.16*	

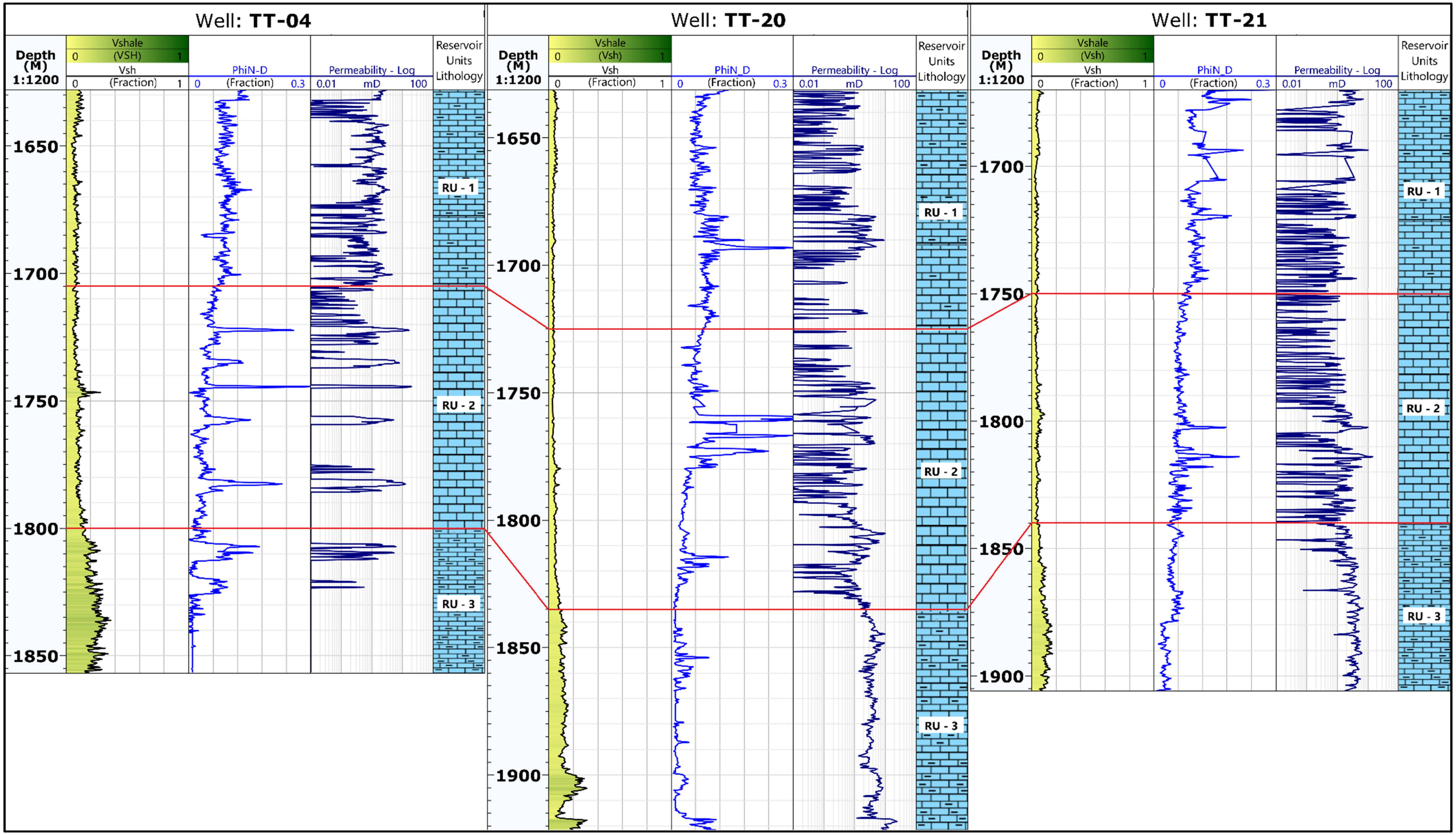


Figure 15: Correlation between the identified reservoir units of Shiranish Formation at the studied wells.

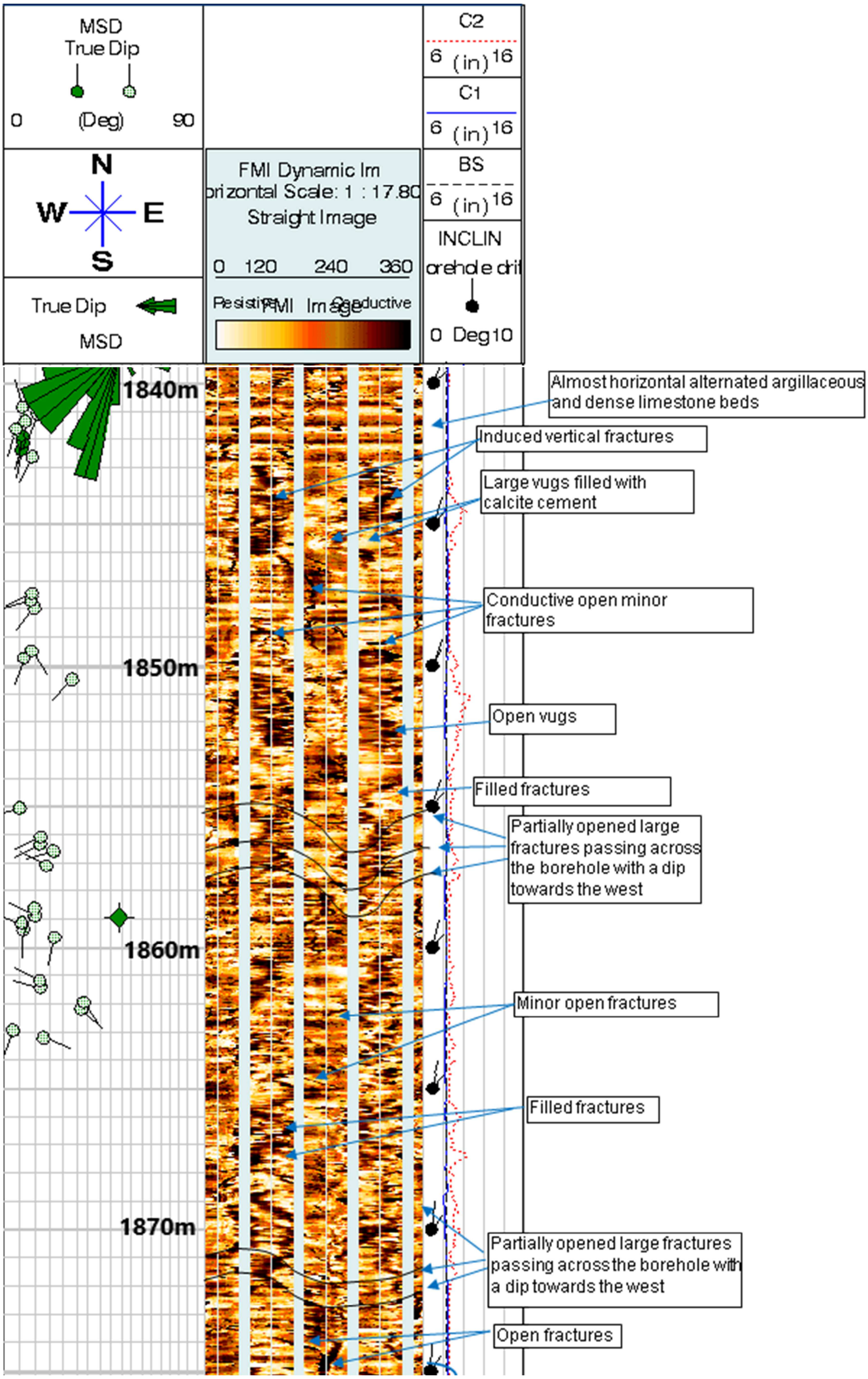
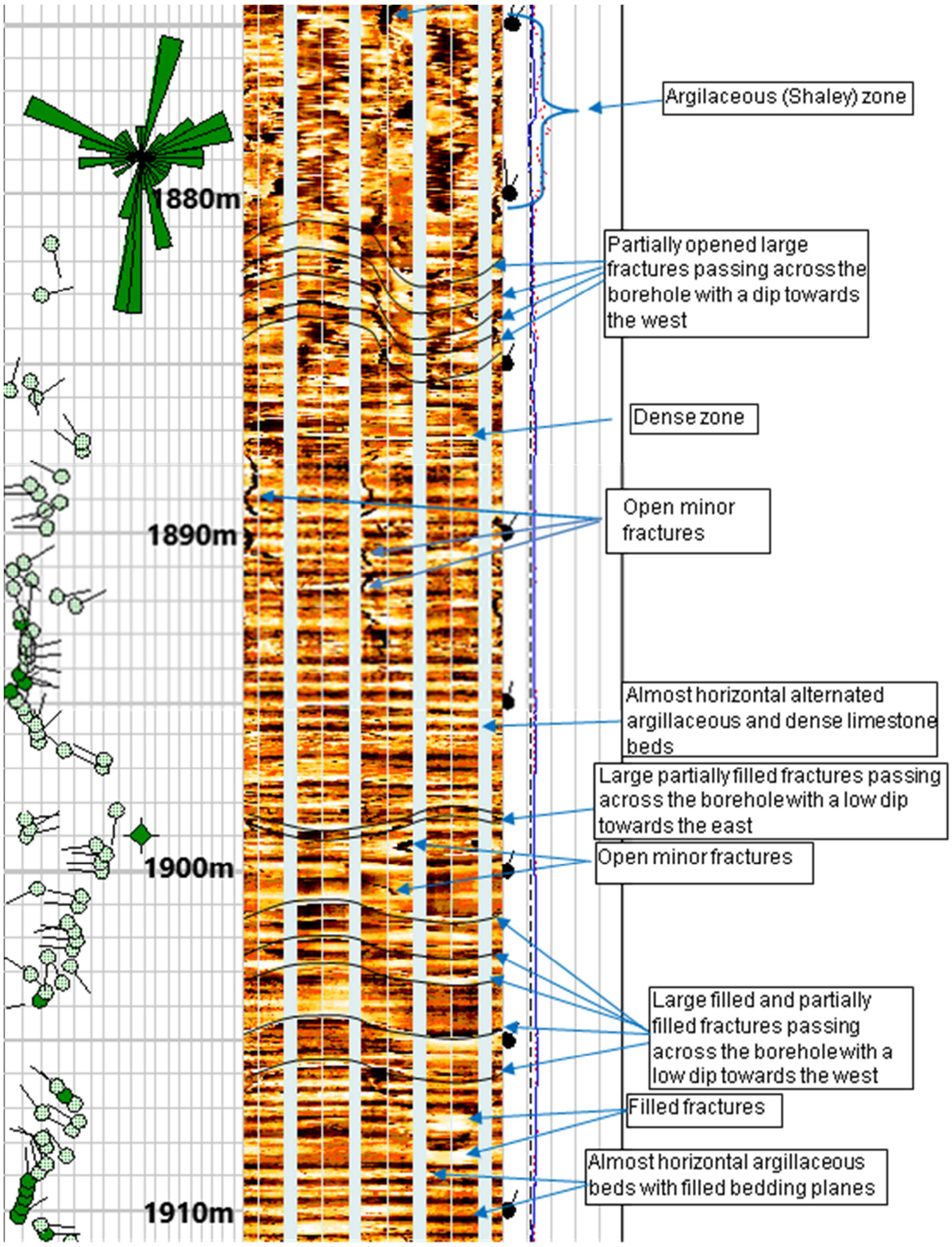


Figure 16: Formation Micro Image log for the lower part of Shiranish Formation (RU-3) in the well TT-21.



Continued…

- The formation is generally of less than 10mD permeability with the lower part of formation (at the two wells of TT-20 and TT-21) being of relatively higher permeability in comparison to the middle and upper part of the formation.
- The formation can be subdivided to three reservoir units depending on the variations in the shale content, porosity, and permeability.
- The reservoir unit RU-1 at the upper part of the formation in the well TT-21 is of the highest reservoir quality with an average shale content of about 4%, average porosity of about 11%, and average permeability of about 1.39mD.
- The reservoir unit RU-3 in the well TT-20 is considered of the lowest reservoir quality with an average shale content about 14% and average porosity of only 2% although more than 4.37mD average permeability calculated for this unit.

- Large and minor fractures has contributed in enhancing the permeability of the formation especially in its lower part.

Acknowledgments

The authors would like to acknowledge the Ministry of the Natural Resources in the Iraqi Kurdistan Region for providing the data used in this study.

References

[1] Jassim, S.Z., Goff, J.C. "*Geology of Iraq*". Dolin, Prague and Moravian Museum, Czech Republic, 341p. (2006).

[2] Garland, C.R., Abalioglu, I., Akca, L., Cassidy, A., Hiffoleau, Y., Godail, L., Grace, M.A.S., Kader, H.J., Khalek, F., Legarre, H., Nazhat, H.B., and Sallier, B. "*Appraisal and development of the Taq Taq field, Kurdistan Region, Iraq*". Petroleum Geology Conference Series. Vol. 7, pp.801-810. (2010).

[3] Dunnington, H.V. *"Generation, migration, accumulation and dissipation of oil in northern Iraq*". In: Weeks L.G. (ed.) Habitat of Oil. AAPG (Special Publications) Vol. 18, pp. 1194–1251. (1958).

[4] Bellen, R.C.Van., Dunnington, H.V., Wetzel, R., and Morton, D. "*Lexique Stratigraphique International*." Asia, Fscicule 10a, Iraq, Paris, 333p. (1959).

[5] Baban, D.H. and Ranyayi, K.S. "*Potentiality of Paleocene source rocks and their contribution in generating the accumulated oil in the Eocene Pila Spi Reservoir in Taq Taq Oil Field, Kurdistan Region, Iraq*". Arab J. Geosci. Vol. 6, No. 11, pp. 4225–4237. (2013).

[6] Aqrawi, A.A.M., Goff, J.C., Horbury, A.D., and Sadooni, F.N. "*Petroleum Geology of Iraq*". Scientific press Lt., Beaconsfield, Bucks HP9 1NS, UK, 424p. (2010).

[7] Ziegler, M.A. "*Late Permian to Holocene paleofacies evolution of the Arabian Plate and its hydrocarbon occurrences*". GeoArabia. Vol. 6, pp. 445–504. (2001) .

[8] Pitman, J.K., Steinshouer, D.W., and Lewan, M.D. "*Generation and Migration of Petroleum in Iraq: Modeling Study of Jurassic Source Rocks*". US Geological Survey Open-File Report. (2003).

[9] Ameen, M.S. "*Alpine Geowarpings in the Zagros-Taurus range: influence on hydrocarbon generation, migration and accumulation*". J. Pet. Geol. Vol. 14, pp. 417–428. (1991).

[10] Hammoudi, R.A. "*High resolution biostratigraphy of the K/T boundary in the Hijran Section, Shaqlawa Area, Northern Iraq*". Iraqi National Journal of Earth Sciences. Vol. 11, No. 1, pp. 23−48. (2011).

[11] Saadooni, F. N. "*Stratigraphic and lithological characteristics of upper Cretaceous carbonates in central Iraq*". J. Pet. Geol., Vol. 19, Issue 3, pp. 271-288. (1996).

[12] Al-Qayim, B. "*Bioturbated rhythmiticity of Shiranish Formation type locality NW Iraq*". Jour. Geol. Soc. Iraq, Vol. 25, No. 1, pp. 185–194. (1992).

[13] Abdula, R.A., Balaky, S., Khailani, R., Miran, A., Muhammad, M., and Muhamad, C. "*Sedimentology of the Shiranish Formation in the Mergasur area, Iraqi Kurdistan*". Bull Geol Soc Malays Vol. 65, pp.37– 43. (2018).

[14] Malak, Z.A. "*Sequence stratigraphy of Shiranish Formation in Dokan area, Northern Iraq*", Arab J. Geosci, Vol. 8, No. 11, pp. 9489–9499. (2015).

[15] Karim, K.H., Ismail, K.M., and Ameen, B.M. "*Lithostratigraphic study of the contact between Kometan and Shiranish Formations (Cretaceous) from Suleimaniya Governorate, Kurdistan Region, NE Iraq".* IBGM. Vol. 4, pp. 16–27. (2008).

[16] Homci, H.A.L. "*Isopach maps of Tithonian to Base of Tertiary".* Manuscript report, No. FWR 9-RG 53, INOC Library, Baghdad. (1975).

[17] Awdal, A.H., Braathen, A., Wennberg, O.P., and Sherwani, G.H. "*The characteristics of fracture networks in the Shiranish Formation of the Bina Bawi Anticline; comparison with the Taq Taq Field,*

Zagros, Kurdistan, NE Iraq". Petroleum Geoscience, Vol. 19, pp. 139–155. (2013).
[18] Schlumberger, "*Log Interpretation/Charts*". Schlumberger Well Services, Inc 1, Houston, USA. (1972).
[19] Rider, M. "*The Geological Interpretation of Well Logs*". Second Edition, Rider French Consulting Ltd., Aberdeen and Sutherland. (2002).
[20] Shlumberger, "*Log Interpretation Charts"*. Schlumberger Educational Services, USA. (1988).
[21] Halliburton, "*Basic Petroleum Geology and Log Analysis"*. Sperry-Sun, Halliburton Company. (2001).
[22] Schlumberger, "*Log Interpretation Principles/Applications"*. Sguard Land, Texas, USA. (1989).
[23] McCary, L.M. Interpretation of well logs in a carbonate aquifer, U.S. Geological Survey Open-File Report. (1978).
[24] Burke, J.A., Schmidt, A.W., and Campbell, R.L. "*The litho-porosity cross plot*". Log Analyst. Vol. 10, No. 3, pp. 25-43. (1969)
[25] Larionov, V. V. "*Borehole Radiometry*". Moscow, U.S.S.R., Nedra. (1969).
[26] Ismail, N.R. "*Evaluation of Limestone and Marl of Shiranish Formation (Cretaceous) for Cement Industry, Koya Area, NE Iraq*". International Journal of Engineering Technology, Management and Applied Sciences Vol. 4, No. 3, pp44-53. (2016).
[27] Thomas, E.C. and Steiber, S.J. "*The Distribution of Shales in Sandstones and Its Effect upon Porosity*". Transactions of the 16th Annual SPWLA Logging Symposium, paper T. (1975).
[28] Serra, O., Balwin, J. and Quirein, J., "*Theory, Interpretation and Practical Application of Natural Gamma Ray Spectroscopy*" Paper presented at the 21st Society of Professional Well Log Analysts, Logging Symposium. (1980).
[29] Dewan, J.T. "*Essentials of modern open-hole log interpretation*". Tulsa, Oklahoma, Penn Well publishing company, 361p. (1983).
[30] Schlumberger, "*Log Interpretation Charts*" Sugar Land, Texas, 293p. (2009).