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Advanced Reservoir Characterization and Hydrocarbon Potential Assessment of the Chanda Oilfield, Kohat Basin, Pakistan Using Wireline Logs

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Abstract
This research paper aims to provide with the analysis of wireline logs for reservoir characterization of the Chanda oil field, which is located in Shakardara, Kohat basin, Khyber Pakhtunkhwa, Pakistan. Kohat sub-basin is considered the most prolific area in the Upper Indus Basin. Kohat sub-basin is a structurally complex area characterized by a series of complex structures. The Chanda oil field is located at Chanda structure which is characterized by an imbricate thrust structure. Producing reservoirs in the Chnada oil field include Datta Formation of Jurassic age and Kingriali Formation from Triassic age. Petrophysical investigations has depicted that the Chanda oilfield has multiple reservoirs from Jurassic to Paleocene & has greater potential to serve the future energy requirements of Pakistan. Determination of porosity, water saturation and clay volume has been done through petrophysical analysis of wireline well logs. The petrophysical analyses of well logs has revealed that by the use of advance logging tools, advance interpretation techniques and unconventional exploitation methods there could be a better productivity that led to better results regarding improved hydrocarbon production.

Keywords: Reservoir characterization, wireline logs, Chanda deep wells, Kohat basin and hydrocarbon production, Improved Hydrocarbon Production.

Introduction

In the Kohat sub-basin of Indus Basin, the Chanda oilfield (Fig.1) is located which is considered to be most prolific area of the Upper Indus Basin. In the Kohat sub-basin, the Kohat range comprises of Jurassic to Paleocene age rocks and structurally, the Kohat basin is more deformed than its eastern counterpart sub basin that is Potwar Basin. In the eastern part of the study area where Kohat Formation is exposed has more duplex structures whereas; the western part of the study area is more tectonically deformed as compared to the eastern part of the Kohat region.

Among the earlier geological studies, Gee (1945) determined the age and stratigraphic connection of the salts in the Kohat and the deposits of the Salt Range Formation. Detailed work done by Eames (1951); Fatmi (1973) and Meissner et al., (1974 and 1975) focused on stratigraphic nomenclature, geological mapping and determining of the lithological units of the Kohat Basin where they defined the different lithological and stratigraphic successions exposed in the Kohat Basin. Moreover, the geological mapping and section measurements of the

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southern portion of Kotal Pass and then segmenting them into different physical domains by (Ghauri et al. 1983) and proposing a model for tectonic reconstruction of Early Eocene Kohat Sub Basin by (Latif and Iqbal, 1986) are of worth mention. The structural work, then reported by (McDougal and Hussain, 1991) where he prepared a balanced cross section through the eastern Foreland of Kohat Basin and Surghar Range to describe the lateral extent of thrusts and folds in the Kohat Basin.

The studied wells Chanda deep-01, Chanda-01, Chanda -02 are developmental wells in the Chanda oil field operated by OGDCL, located in Shakardara, District Kohat, Khyber Pakhtunkhwa. The Chanda structure is characterized by an imbricate thrust system with series geometries where the Chanda oil field is located. The producing reservoirs in the Chanda oil field include the Jurassic Datta Formation and the Triassic Kingriali Formation in the form of wells Chanda deep -01(Oil), Chanda-01(Oil & Gas), Chanda-02 (Oil & Gas), Chanda-03 (Suspended), and some of the reservoirs like Lockhart, Hangu, and Lumshiwal formation are depleted. In the study area, the subsurface succession above the Eocene and the surface outcrops have undergone more deformation compared to the lower Eocene competent package. Previously, the reservoir zone testing has been ignored; this is where the new technique turns out to add value in current productivity enhancement of the reservoir and to enhance the life of the any oilfield in future.

This study is aimed to infer hydrocarbon potential of Chanda oil field by estimating the values of porosity, shale volume, water saturation through well logs of Chanda -1, Chanda- 2 and Chanda Deep- 1 to find out some new and ignored prospective zones. According to the log response within the Chanda oil field wells, the Datta formation is divided into three zones: Datta 1, Datta 2 and Datta 3. Data 1 cross over shows gas response and Datta 3 shows oil response. Datta 2 has been acting as a barrier.

Methodology

The employed methodology involves getting access to the public domain data of the wells of the Chanda deep 01, Chanda-01 & Chanda -02 and these well data was used as input to carry out the current study. Petrophysical parameters, such as shale volume, permeability, porosity, water saturation, hydrocarbon saturation was calculated from well logs using Schlumberger Techlog Software. The employed logs in hand of the wells were Spontaneous potential, Gamma ray, Neutron porosity, Density, Resistivity, Caliper, Sonic and Photoelectric effect log (PEF). To develop an accurate lithological model for petrophysical interpretation all available geological and mineralogical data provided was used together with different cross-plotting techniques. Different X-Plot techniques were used for lithology calculation, like neutron-density x-Plot, M-N x-Plot and ZU vs. Density Matrix x-Plot. Porosity is calculated using neutron-density x-Plot-technique and porosity is calculated using neutron-density x-Plot-technique coupled with Neutron and density logs.

General Geology of the area

The study area is the part of the Kohat sub basin, and the Chanda oilfield located in the Shakardarra area is a prolific area of the Upper Indus Basin. The Shakardara area lies south of the Himalaya and Karakuram, within the Kohat Foredeep belt, which also includes the Potwar Foredeep (Western Sub-Himalaya). The Kohat Potwar Depression constitutes the northern most part of the Indus Basin and is bounded to the north by the Parachinar-Kalachita folded belt through a system of faults and to the southwest, it is bounded by the Salt Range composite orocline, and to the east and west, it is bounded by Kalabagh and Kurram faults respectively (Fig. 1).

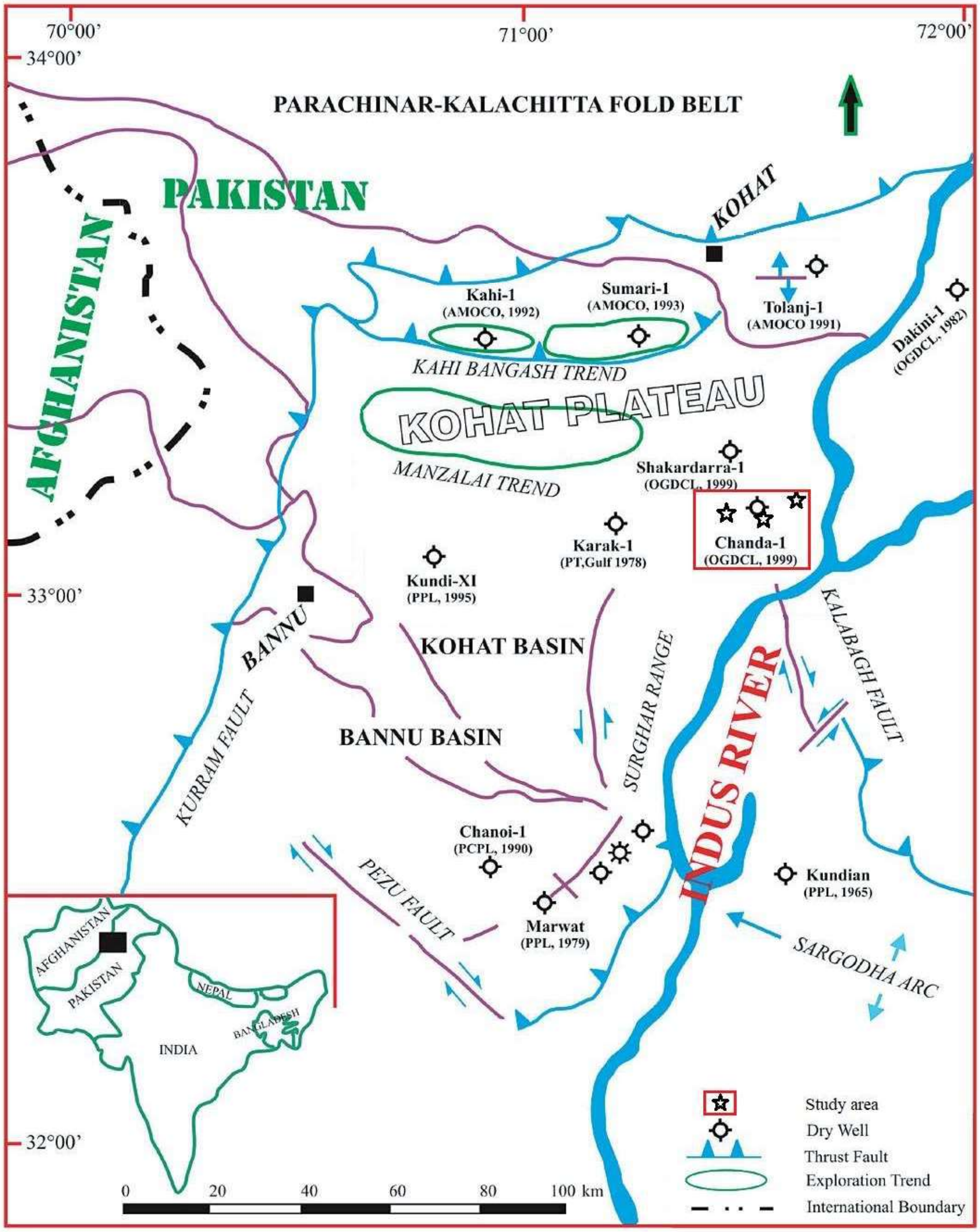

Figure 1. Location map of the drilled well in Kohat Plateau (modified after Paracha W, 2004)

Finally, the depression is separated from the Sulaiman Depression by Pezu Wrench Fault. The Kohat Potwar Depression is comprised of the three major elements, the Potwar Plateau, the Kohat Plateau and the Salt Range Composite Orocline. The area located west of the Indus River forms the Kohat Plateau which consists of a northern uplift (Kohat Salt Zone) and a southern depression (Bannu Depression). The Bannu Depression is an alluvial plain and its geology is completely marked by the alluvial cover. The Shakardara Concession is a part of the Kohat sub-basin in Khyber Pakhtunkhwa and covers the southernmost part of the Kohat Basin, north of the Surghar Range.

In the study area of Shakardarra, the stratigraphy exposed is of Eocene succession till Pliocene rocks (Fig. 2). The Kohat sub-basin encompasses the exposed stratigraphic succession that ranges from Jurassic to Paleocene age rocks. Structurally, the Kohat basin is more deformed than its eastern counterpart sub basin that is the Potwar Basin and as a result of rotational activity in the northern and northwestern area of Kohat consists of tighter and deformed structures compared to the southern and southeastern areas. In the study area, structural complexity increases towards the north and the folds are mostly plunging in nature. Similarly to the Potwar region, the Kohat region is characterized by imbricate wrench faults that are steeper than those in the Potwar region which are gentler in nature.

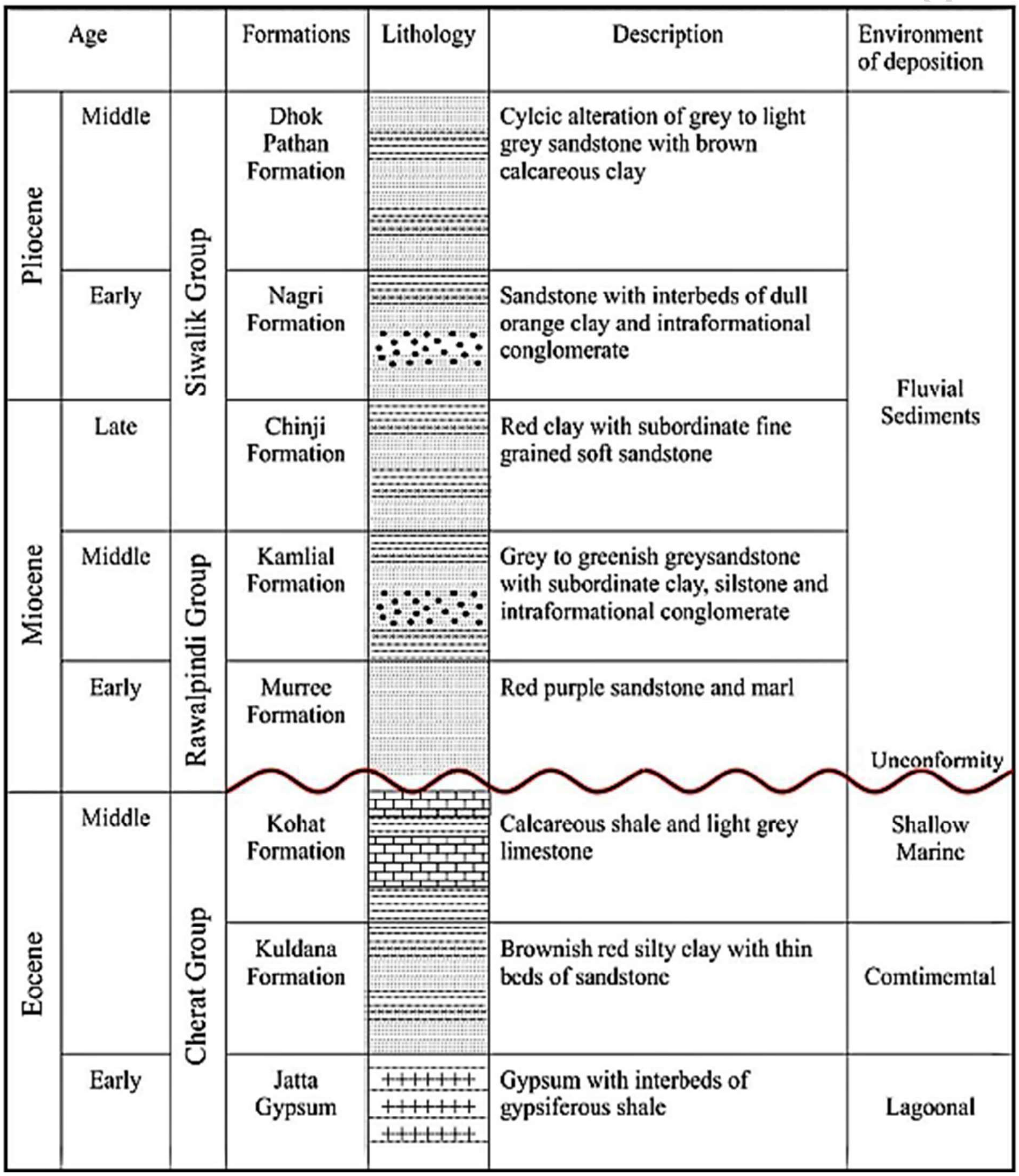

Figure 2. The stratigraphic column of Chakardarra area (modified after Meissner et al. 1974)

Petrophysical Analysis

Petrophysical analysis also known as formation evaluation is the method of processing, calculating analyzing and interpretating various borehole measurements to gather information on several petrophysical parameters of reservoir rocks, lithology, porosity, saturation and permeability.

The studied wells of Chanda deep- 01, Chanda-01 and Chanda -02 were analyzed petrophysically to obtain information about reservoir lithology (matrix and shale), porosity and water saturation and such petrophysical interpretation was performed using Techlog software. Two important properties of reservoir rock for characterization are porosity and permeability (Asquith & Gibson, 1997). Step wise interpretation was carried out like lithological identification, shale volume calculation and porosity determination. Both quantitative and qualitative analyses of Chanda deep- 01, Chanda-01 and Chanda -02 wells are conducted to identify reservoir intervals in these wells. Petrophysical analyses are done by evaluating shale volume, water and hydrocarbon saturation, porosities, water resistivity and gas effect by interpreting suits of wireline logs, i.e., self-potential, dual induction focused (ILD & ILM), gamma ray, neutron, density, and resistivity logs. The neutron porosity (ϕN), density porosity (ϕD), total porosity (ϕT) and effective porosity (PHIE / ϕE) were calculated using the following formulas (Rider, 1996; Asquith & Gibson, 1982; Crain, 1986);

$\phi N = (1.02 \times \phi N\ log) + 0.0425$

$\phi\ density = \rho matrix - \rho log / \rho matrix - \rho fluid$

$\phi T = (\phi D + \phi N) / 2$

$\phi E = \phi T \times (1 - Vsh)$

Matrix = Density of matrix, ρlog = Density reading from the log curve, $\rho fluid$ = Density of the fluid, Vsh = Volume of shale

The volume of shale (Vsh) was calculated using the gamma ray log by first determining the gamma ray index (IGR) with the following equation (Schlumberger, 1974);

IGR= GRlog – GRmin / GRmax – Grmin,

IGR= Gamma ray index,

GRlog = Gamma ray reading at the depth of interest

GRmin = Minimum gamma ray reading (Usually the mean minimum through a clean sandstone or carbonate formation).

GRmax = Maximum gamma ray reading (Usually the mean maximum through a shale or clay formation).

After calculating IGR, the values can be used to calculate the volume of shale using the following formulae (Larionov, 1969).

$V = 0.083 \times (23.7 \times IGR - 1)$ for the tertiary rocks sh and $V = 0.33 \times (22 \times IGR - 1)$ for older rocks, sh the saturation for a pore fluid (Sw and Sh) was determined using Archie's (1942) equation, first by finding the saturation for water (Sw) as;

$S = [(a/ \phi\ m)$ __ $\times (Rw/Rt)]1/n$ (Archie,1942) and putting water saturation in the following formula.

Sh = (100 – Sw) % (Schlumberger, 1996).

Further, the bulk volume of water was calculated as follows.

$Vbw = \phi\ e \times Sw$ (Asquith & Gibson, 1982; Crains, 1986).

The gas effect, in a gas bearing zone can be calculated as follows.

Gas effect $= A^* \phi D + (1-A) * \phi N / A$ (2) (Asquith & Gibson, 1982).

Rw = Water resistivity (calculated through SP method)

Rt = True resistivity, Sw = Water saturation, Sh = Hydrocarbon saturation, Vbw = Bulk volume of water, a = Tortousity factor, m = Cementation exponent, n = Saturation exponent

A= Gas correction factor.

The lithology was determined using the bulk density (RHOB) and neutron porosity (NPHI) curves (Schlumberger, 1996).

Results and discussion

The two imperative reservoir parameters of the wells were interpreted are porosity and permeability. The threshold minimum values for porosity in terms of percentage include 8% for oil and 6% for gas. Based on the neutron-density cross plot, the lithologies encountered in Chanda-01 are mainly dolomite followed by sandstone with very rare limestone. In Chanda deep-01 the main lithology is sandstone and followed by limestone and very rare dolomite. In Chanda-02, the main lithology is limestone followed by sandstone (Fig. 3). Porosity is based on neutron-density x-Plot-technique, and based on the effective porosity histogram, the three of wells fall in tight porosity zone (Fig. 4). The saturation of water remains variant in three of the wells (Fig.5). Table 1 shows the statistical interpretation results for Chanda-deep-01 with porosity cut-off (2%), cut-offs for VSH is 30 %, for SW is 60 %, and remains the same. Table 2 shows the statistical interpretation results for the Chanda-01 well for porosity cut-off (2%), cut-offs for VSH is 30 %, for SW is 60 %. It is clear that this zone shows very good gas saturation. Table 3 shows the statistical interpretation results for Chanda-02 well for porosity cut-off (2%), cut-offs for VSH is 30 %, for SW is 60 % remains the same. The logs of the Chanda deep-01, Chanda-01 and Chanda-2 have been given in Figure 6, 7 and 8 respectively. The crossover formed by ND log, with comparable sonic values depicted the presence of hydrocarbon in sand packages.

Chanda oil field located in Shakardara, characterized by the compressional regime with both gas & oil window. Petrophysical analysis revealed that crossover formed by ND log, with comparable sonic values demonstrate the existence of hydrocarbon in sand packages and it is further depicted that the Datta and Kingriali formations also contain hot sands which can be clearly seen on Neutron Density log responses where it is showing high readings on GR logs. Based on the petrophysical results, the Chanda oilfield has multiple reservoirs within the Kingriali, Datta formations of the Kohat sub-basin and such a field of Chanda will have prolific results by employing the advance techniques and tests.

Table 1. A summarized table of Datta 1, 2 and 3 & Kingriali formation of Chanda deep-01 well

30%Vclay, 2%Porosity, 60% SW										
Well	**Zones**	**Flag Name**	**Top**	**Bottom**	**Gross**	**Net**	**Net to Gross**	**Av_Shale Volume**	**Av_Porosity**	**Av_Water Saturation**
Chanda Deep - 1	Datta-3	ROCK	4650	4684	34	18.87	0.555	0.097	0.043	0.493
		RES	4650	4684	34	12.95	0.381	0.032	0.062	0.491
		PAY	**4650**	**4684**	**34**	**11.12**	**0.327**	**0.019**	**0.066**	**0.459**
	Datta-2	ROCK	4684	4736	52	36.601	0.704	0.083	0.036	0.357
		RES	4684	4736	52	27.899	0.537	0.042	0.047	0.354
		PAY	**4684**	**4736**	**52**	**25.759**	**0.495**	**0.041**	**0.047**	**0.333**
	Datta-1	ROCK	4736	4814	78	53.92	0.691	0.062	0.052	0.358
		RES	4736	4814	78	46.949	0.602	0.043	0.059	0.354
		PAY	**4736**	**4814**	**78**	**44.52**	**0.571**	**0.042**	**0.06**	**0.341**
	Kingriali	ROCK	4814	4864	50	33.38	0.668	0.101	0.013	0.603
		RES	4814	4864	50	8.379	0.168	0.034	0.033	0.465
		PAY	**4814**	**4864**	**50**	**6.1**	**0.122**	**0.031**	**0.035**	**0.393**

Table 2. A summarized table of Datta-3 Sandstone Chanda -01 well

30% vclay, 2%Porosity, 60%Sw										
Well	**Zones**	**Flag Name**	**Top**	**Bottom**	**Gross**	**Net**	**Net to Gross**	**Av_Shale Volume**	**Av_Porosity**	**Av_Water Saturation**
Chanda-01	Datta-3	ROCK	4751	######	45.64	40.7	0.892	0.046	0.056	0.22
		RES	4751	######	45.64	37.03	0.811	0.035	0.06	0.216
		PAY	**4751**	**######**	**45.64**	**#####**	**0.781**	**0.032**	**0.062**	**0.207**

Table 3. A summarized table of Datta 1, 2 and 3 & Kingriali formation of Chanda-02 well

Well	**Zones**	**Flag Name**	**Top**	**Bottom**	**Gross**	**Net**	**Net to Gross**	**Av_Shale Volume**	**Av_Porosity**	**Av_Water Saturation**
Chanda -2	Datta-3	ROCK	4791	4820	29	#####	####	0.087	0.06	0.252
		RES	4791	4820	29	8.839	####	0.038	0.078	0.249
		PAY	**4791**	**4820**	**29**	**8.839**	**####**	**0.038**	**0.078**	**0.249**
	Datta-2	ROCK	4820	4855	35	19.31	####	0.053	0.052	0.27
		RES	4820	4855	35	#####	####	0.026	0.063	0.267
		PAY	**4820**	**4855**	**35**	**15.85**	**####**	**0.025**	**0.063**	**0.265**
	Datta-1	ROCK	4855	4902	47	#####	0.62	0.082	0.078	0.447
		RES	4855	4902	47	#####	####	0.063	0.088	0.442
		PAY	**4855**	**4902**	**47**	**#####**	**0.47**	**0.052**	**0.092**	**0.403**
	Kingriali	ROCK	4902	4979	77	73.8	####	0.043	0.037	0.239
		RES	4902	4979	77	#####	####	0.016	0.054	0.231
		PAY	**4902**	**4979**	**77**	**#####**	**####**	**0.015**	**0.054**	**0.229**

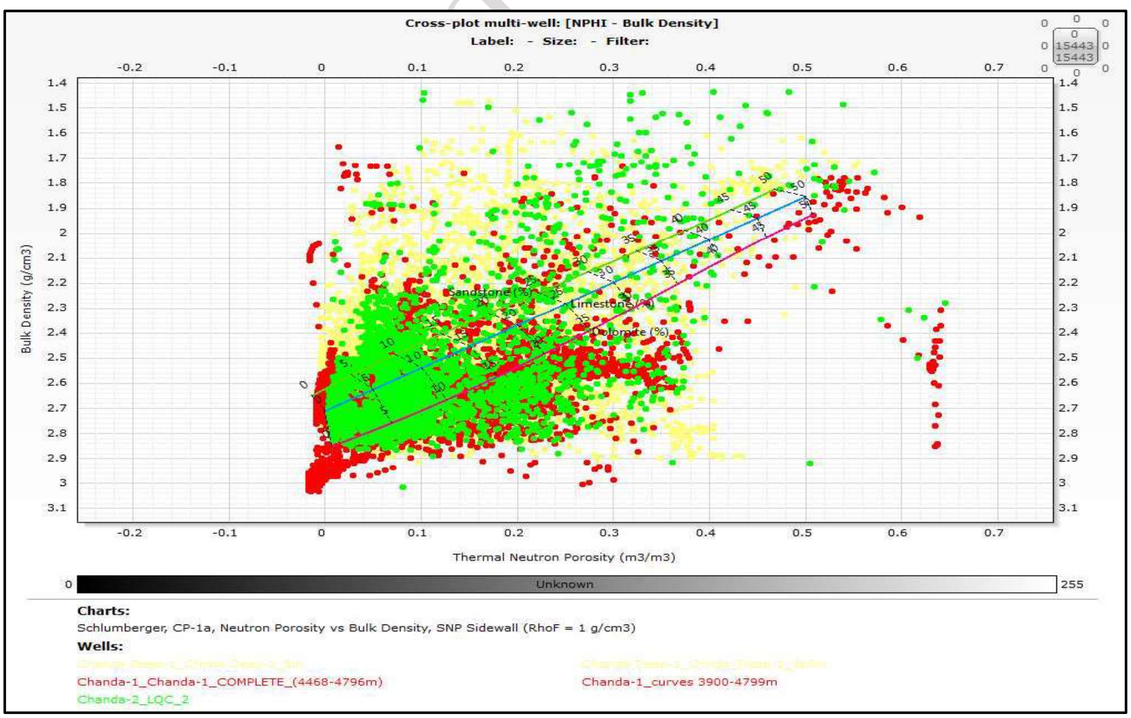

Figure 3. Neutron density cross plot for lithology

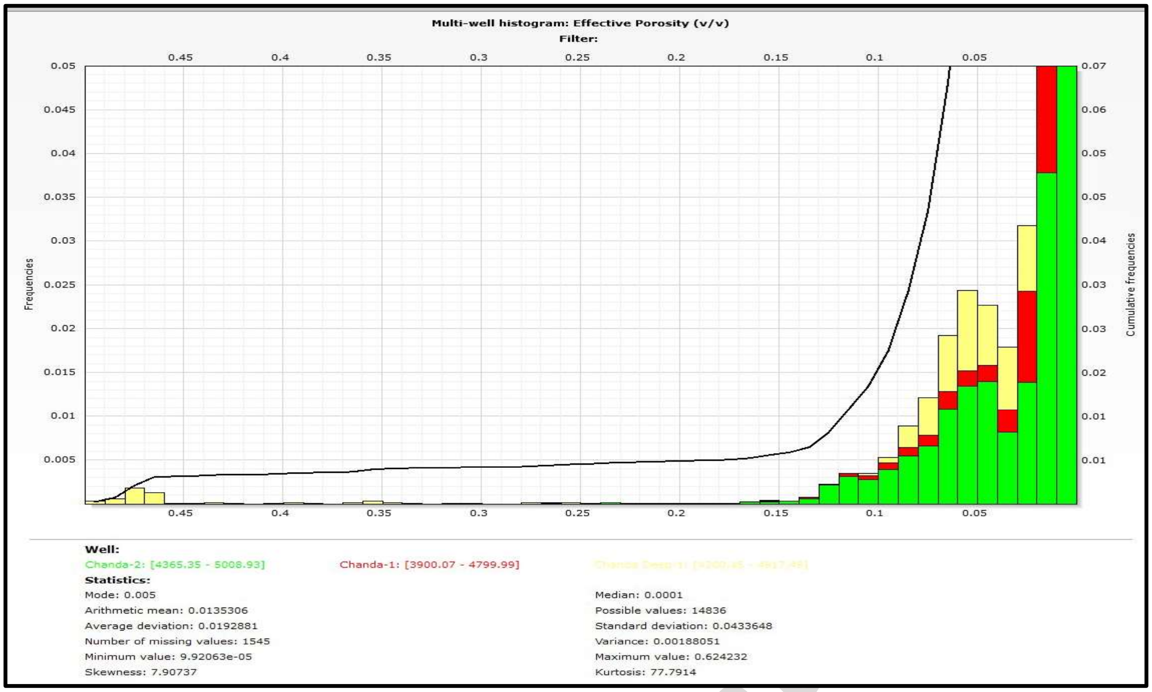

Figure 4. A histogram of the effective porosity shows variation within the well, major data falls in tight porosity zone

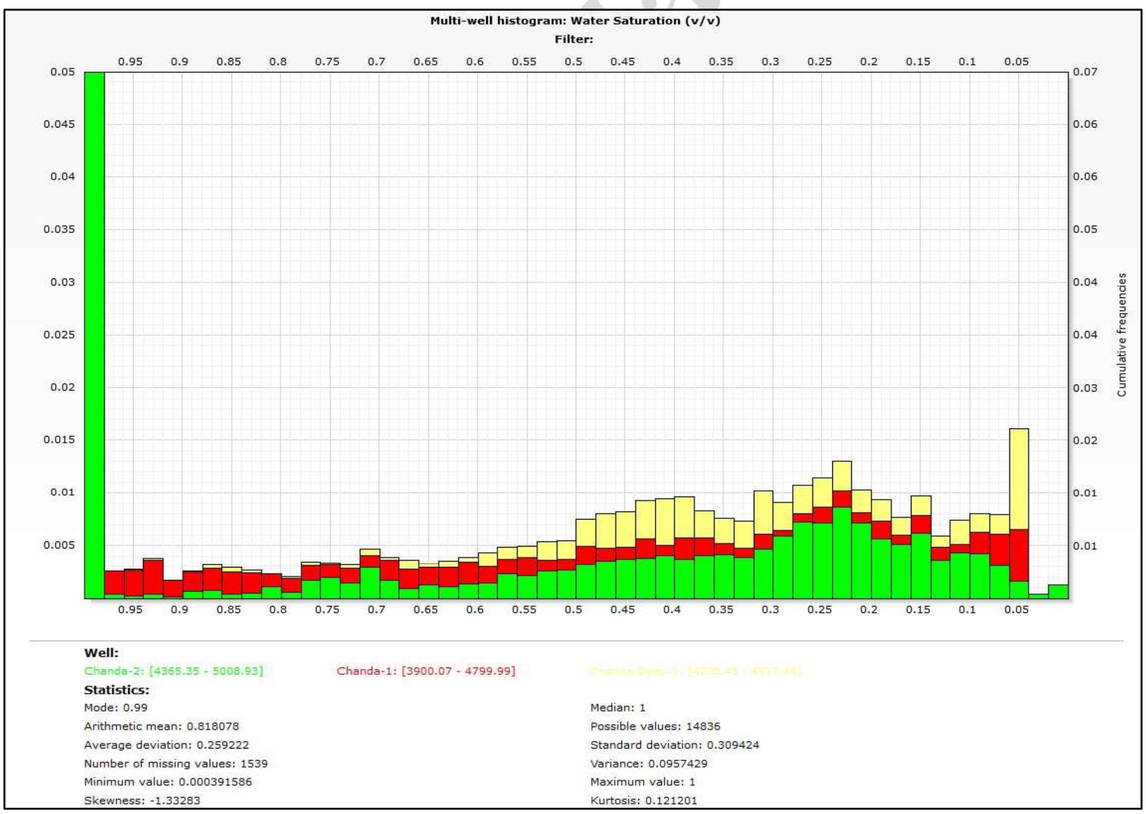

Figure 5. A histogram showing water saturation variation in the wells within Chanda field

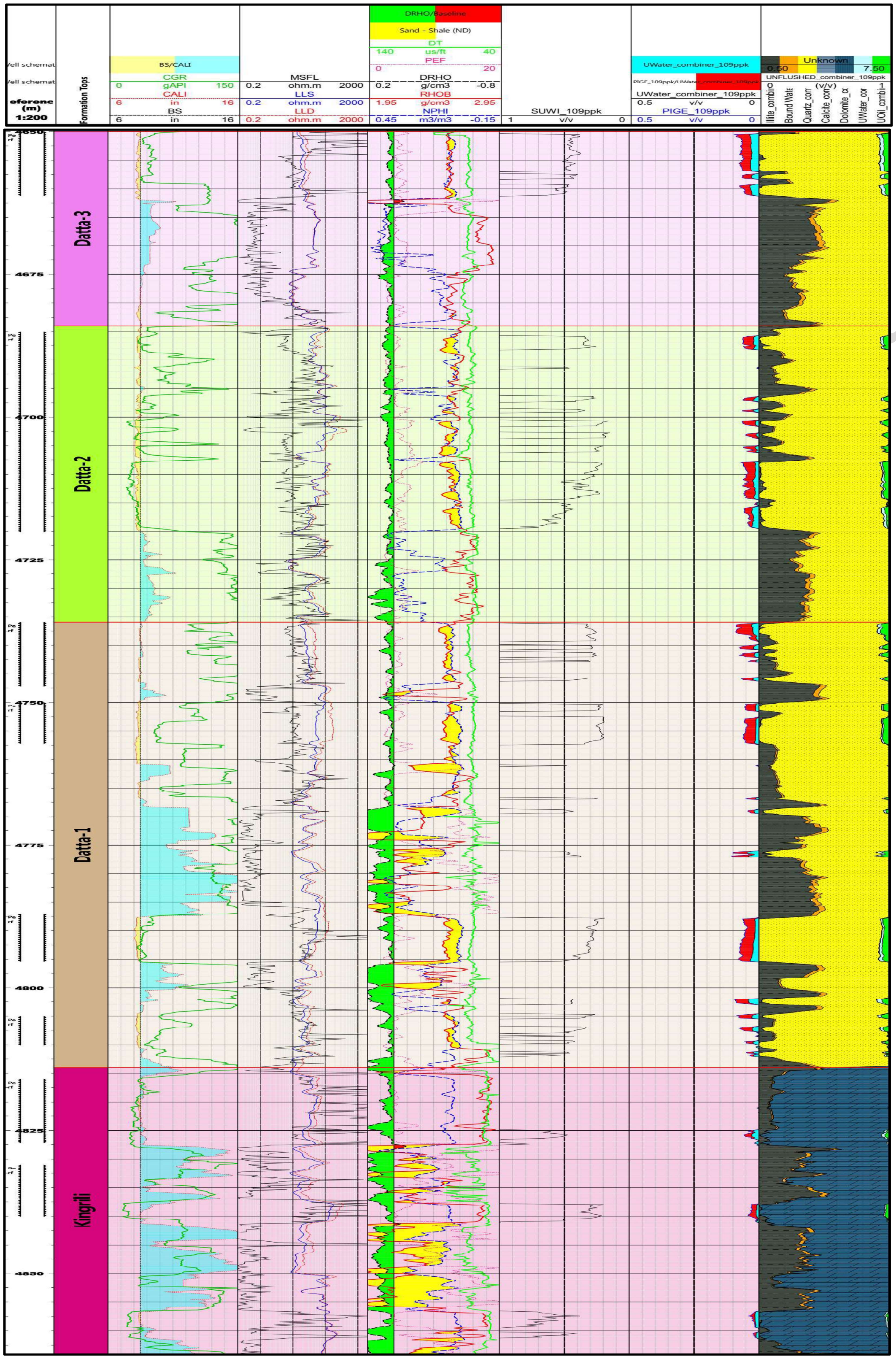

Figure 6. Elan of Datta sandstone and Kingriali dolomite in Chanda deep-01 well

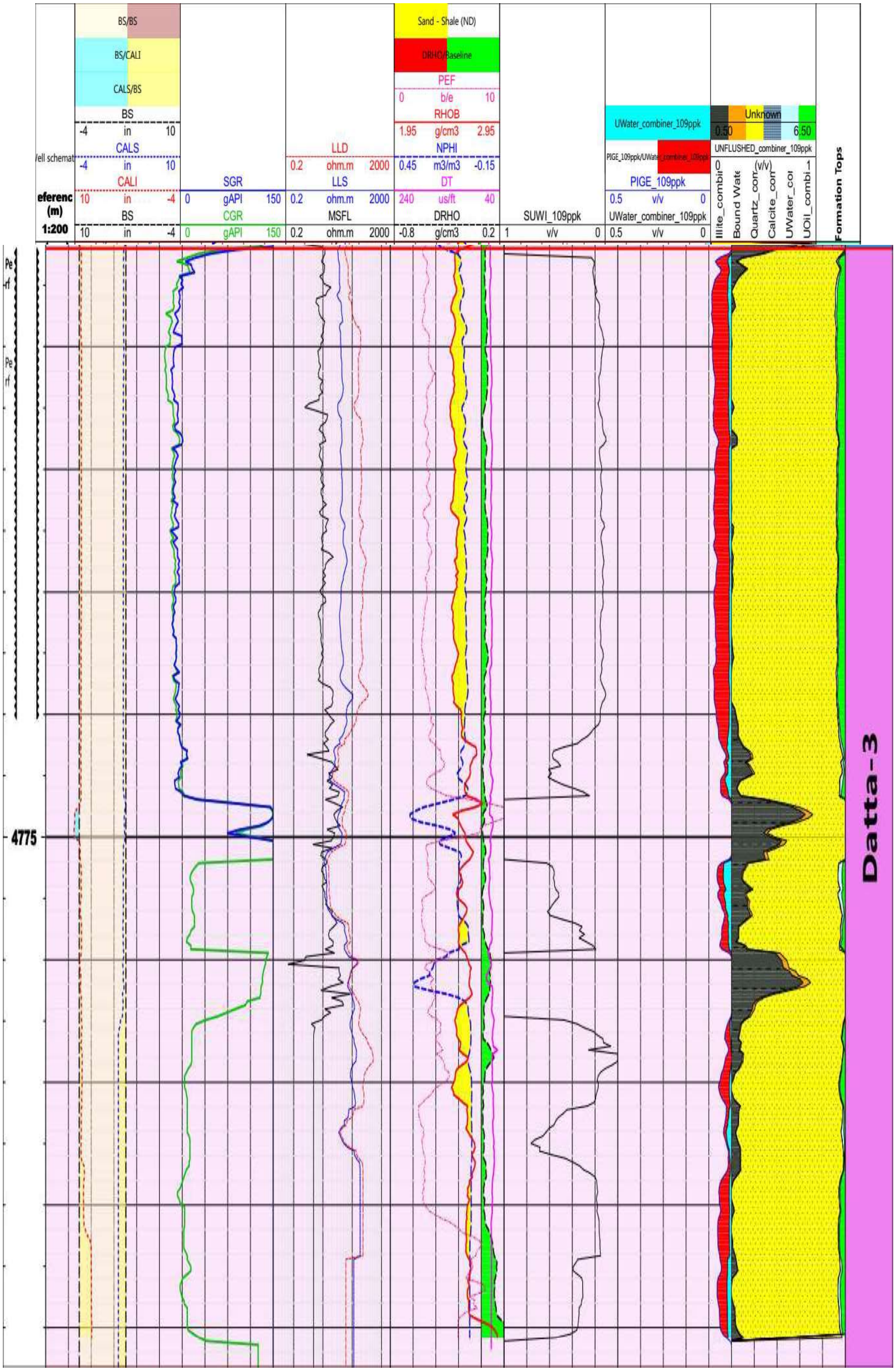

Figure 7. Elan of Datta sandstone in Chanda-01 well

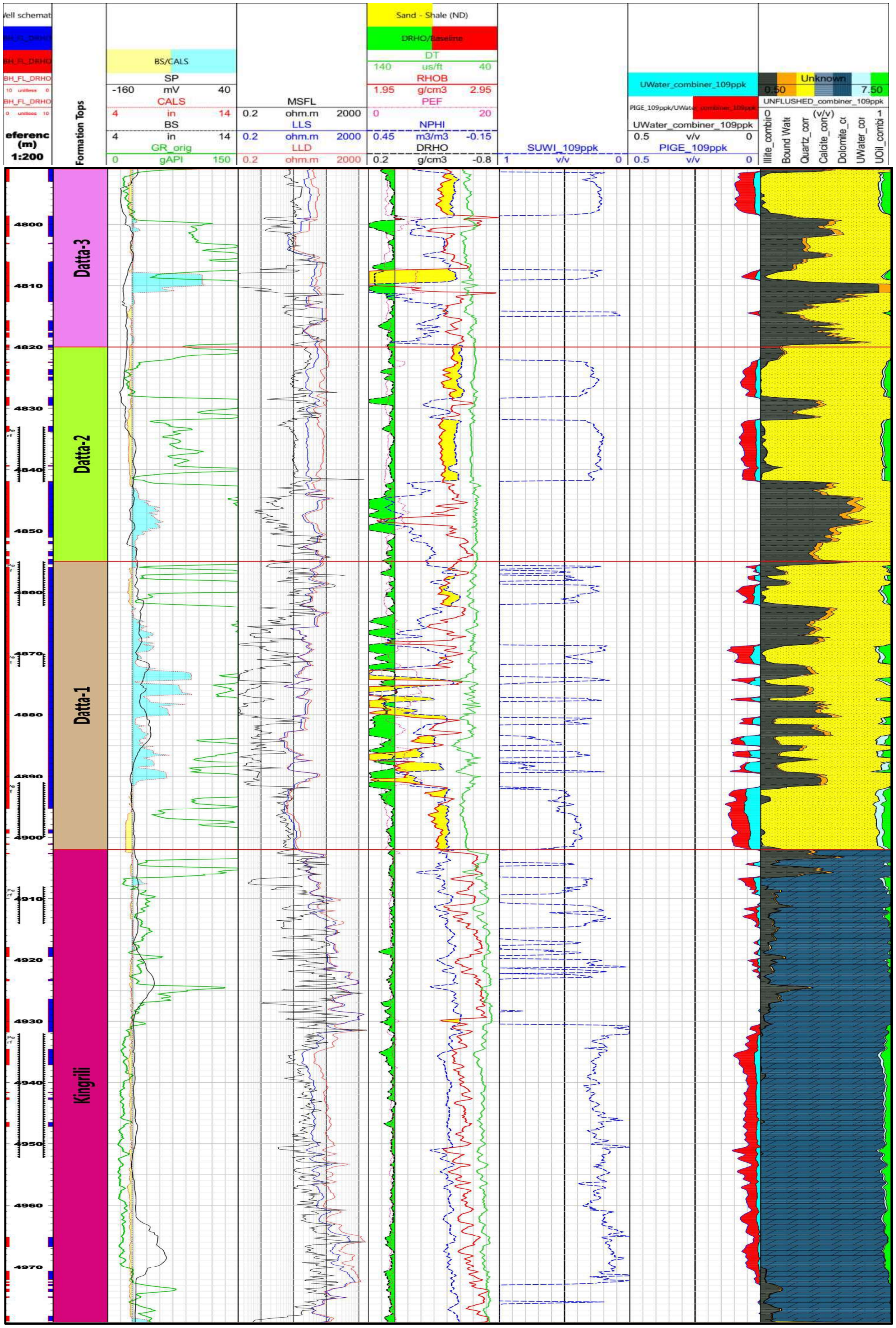

Figure 8. Elan of Datta Sandstone and Kingriali dolomite in Chanda-02 well

Conclusions

The Chanda oil field located in Shakardara, is characterized by a compressional system with both gas & oil window. Based on the Petrophysical interpretation of three wells, reservoir sand packages at the Datta sand level were identified. Petrophysical analysis revealed the crossover formed by ND log, with comparable sonic values demonstrate the existence of hydrocarbon in sand packages and it is further depicted that the Datta and Kingriali formations also contain hot sands which can be clearly seen on Neutron Density log responses where it is showing high readings on GR logs. Two zones of interest were identified based on well log curves. The Datta Formation is a sandstone with porosity ranging from 0.687% to 0.758%, calculated from Neutron Density and an average water saturation ranging from 20%-40%. The Kingriali Formation is a dolomite with primary porosity which is ranging from 0.01 % to 0.05%. Based on available data and petrophysical analysis the formation is hydrocarbon bearing with Sw ranging from 20% to 40%. The formation also has secondary porosity (fractures) which is also playing its role in HC recovery from the field. Reaching the Kingriali Formation is always a challenge because of its presence at deep level in the basin.

Acknowledgements

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References

Asquith, G., Gibson, C., 1982. Basic well log for Geologists. American Association of Petroleum Geologist, Tulsa Methods in Exploration, 216.
Eames, F.E., 1951. A contribution to the study of the Eocene in western Pakistan and western India: A. The geology of standard sections in the western Punjab and in the Kohat district.
Fatmi, A.N., 1973. Lithostratigraphic units of the Kohat-Potwar province, Indus basin, Pakistan. Geological Survey of Pakistan
Gee, E.R., 1945. The age of the Saline series of the Punjab & of Kohat: National Academy of Sciences of India, Proceedings, section B, 14 (6): 269-310.
McDougal, J.W., Hussain, A., 1991. Fold & thrust propagation in the western Himalayan based on balanced cross section of Surghar range & Kohat Plateau, Pakistan. Bull. Amer. Assoc. Petrol. Geol., 75: 463-478.
Meissner, C.R., Hussain, M., Rasheed, M.A., Sethi, U. B., 1975. Geology of Parachinar quadrangle, Pakistan. U. S. Geol. Surv., Prof. Paper 716-G, 20 p.
Meissner, C.R., Master, J.M., Rasheed, M.A., Hussain, M., 1974. Stratigraphy of Kohat quadrangle, Pakistan. U. S. Geol. Surv., Prof. Paper 717: 30.
Paracha, W., 2004. Kohat Plateau with Reference to Himalayan Tectonic General Study. CSEG Recorder, 46-52.
Quarterly Journal of the Geological Society, 107(1-4): 159-171.
Schlumberger, C., Schlumberger, M., Leonardon, E. G., 1996. Log Interpretation Chart Book, Houston, 201