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Analysis of Conventional Geophysical Well Logs for Identification of Coal Layer - A Case Study

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Abstract

Identification of the coal layer is the primary technical issue that guides CBM exploration and development. Conventional well logs are now generally used by mining geoscientist for identification of coal layer. The aim of this study is to identify coal layers and investigate physical properties by cross-plot and qualitative inspection of log curves methods in 9 wells from Ordos basin, China. The result confirmed that Gamma ray and density logs are most sensitive followed by neutron, resistivity and acoustic logs to the coal formation in the Ordos Basin. Combining the information from multiple conventional geophysical log types can provide important information, in terms of understanding coal litho-units in the area for its future exploitation.

Keywords: *Geophysical well log analysis; Coal layer identification; Log cross-plot.*

1. Introduction

Diversification of energy is necessary to resolve the energy deficiency in China. One of the sources of new energy is methane gas. Methane gas reservoir occurred as unconventional gas in coal layer. Coal is one of the most abundant fossil fuel in China. It is mainly used in the iron and steel industry, and in thermal power plants to produce electricity. Coal is expected to play an important part in meeting the short to long-term energy needs of China.

Coal is a combustible sedimentary rock made from the decomposition of organic matter which has been consolidated among other rock layers and changed by the joined effects of pressure, heat, and microbial action over a large time age [1]. Due to growing demand and the deficiency of natural gas in China, unconventional gas has come to be an important as a substitute for conventional gas, which is harder to discover. This substitution of conventional natural gas for unconventional gas was not difficult, since China has a massive Coalbed Methane formation (CBM). Over the last 20 years, CBM has become a very important energy resource and natural gas in the world. According to the results of Chinese national oil and gas resources evaluation, China's CBM methane resources within 2000m of buried depth are approximately 36.8 trillion m^3, equivalent to the amount of conventional natural gas resources, the third largest coal seam after Russia and Canada reserve country [2]. In the late 1980s, China commenced drilling survey boreholes for CBM. In following years, as exploration progressed, the CBM industry goes into commercial production [3]. This rapid progress can be explained by research and innovation in CBM methods.

Coal reservoirs are identified during exploration phase. Modern coal exploration usually involves extensive geophysical methods use, including seismic method to provide detailed information on the geology, to characterize the coal layers; and downhole logging investigation gives a possibility to verify the expected structure, to determine coal quality and thickness. Note that all coal has methane gas however not all coal can be produced economically [4]. Now, well logging technique in coal reservoir assessment is reflected as a very significant method in the CBM study. It is the most cost effective approach reliable, which makes it an irreplaceable method in the process of exploration and development of the CBM [5-6]. Well logging takes measurements along the rock surrounding the drill hole in terms of physical proprieties. A lithology may be characterized by physical properties that are measured by a well logging tool. In this manner, the geologic section surrounding the drill hole must be interpreted by utilizing more than one kind of borehole log to scrupulously identify individual coal layer.

Conventional well logs are now generally used by mining geoscientist during the exploration phase, to provide an overall view of site geology. It is therefore very important for CBM's resources exploration and development to improve research on the accuracy of the evaluation and the interpretation of the exploitation of the CBM deposit. Well logs response change in coal layer according to the layer characteristics. In this way, a deduction for the coal characteristics could be made from the coal exploration well logs signature [7].

In this study, a representative case study from the HH Oilfield in China based on conventional geophysical logs interpretation for identification of coal layer to allow for accurate extraction of Methane gas is presented.

The HH Oilfield is located in the Ordos Basin which is exceptional with rich and diverse hydrocarbon resources. In recent years, several new results have been achieved in the hydrocarbon exploration. Many of these accomplishments were made in research activities focusing on shale oil, tight oil, and, tight gas within the basin [8-9].

The main objective of this paper is to (1) is to review the reported examples of coal log interpretation;(2) Identify coal layers and investigate physical properties by using cross-plot technique. The following cross plots were utilized: Density-Gamma ray, Gamma ray-Resistivity, Gamma ray-Neutron porosity, Density-Acoustic, Density-Resistivity, and Gamma ray–Acoustic; (3) Identify Coal layers, their depth, and their thickness by visual inspection of conventional well logs curves. The results confirm that the main sensitive well logs to coal layer are: gamma-ray and density, followed by resistivity, neutron, and acoustic.

Combining the information from multiple log types can provide important information, in terms of understanding subsurface formations.

2. Data and methodology

Well data was obtained from 9 wells (HH#25, HH#32, HH#33, HH#42, HH#44, HH#53, HH#54, HH#55 and HH#57) of HH Oilfield at the Tianhuan Synclinal, Ordos Basin, and the wells HH#32, HH#42, and HH#57 were selected as the reference boreholes for this study. The raw well log data were first edited (cleaning) and corrected for environmental effects as recommended by [10]; then the log curves were interpreted to determine the characteristics of the coal layers. Lithology interpretation from well geophysical measurements is based on the fact that different rock types exhibit characteristic physical properties that can be measured by the tools. Cross plotting and multitrack log display are used to examine relationships between multiple log type readings in order to understand subsurface formations. Both allow the well log interpreter to visualize the data more successfully than observing at each log individually. These methods are widely used in lithology identification [11-15]. As mentioned by [16], if numerous log curves are available, the coal commonly can be recognized with sureness even though other rock strata with similar log signatures in the sequence. The following conventional well logs from HH Oilfield are discussed here: gamma-ray, density, neutron porosity, acoustic velocity, and resistivity. These conventional well logs were choose because there are the most common geophysical logs which have been, and continue to be used in coal deposit investigation [1,7,16-30].

3. Review of coal log interpretation

3.1. Natural gamma log (GR)

As mentioned by [18], coal largely displays low GR. However, a number of coals show slight or no thorium or potassium content, which make low GR. It is vital to highlight that high GR does not usually display the absence of coal. A number of coals show significant contain of uranium, making GR response high [30]. According to [22], anthracite coals show GR value of range 10-30API; Bituminous coals make the GR responses in between 20-45API; Sub-bituminous exhibit GR value 20API; while Lignite coals have GR value comprise from 0 to 25API.

3.2. Density log (DEN)

The DEN is a radioactivity probes, which is based on the rock response to induced, medium-energy gamma rays. The consequence is an estimated measurement of rock bulk density. In a number of cases, coal exhibits low DEN as compared to adjacent rocks. According to [22], the DEN value of anthracite range in the interval of 1.4-1.8 g/cm^3; lignite DEN reading shows 0.7-1.5g/cm^3; whereas those of bituminous coals are in between 1.2-1.5 g/cm^3. Referring to [18], sub-bituminous and bituminous coals commonly show the lowest response value on the DEN, averaging less than 1.6 g/cm^3. DEN depends on the ash content [31]. The DEN reading of sedimentary rocks is related to grain density and porosity. Clay and Shale display low DEN in 2.2- 2.5 g/cm^3, that sandstone exhibit an intermediate DEN range from 2.5 to 2.65 g/cm3, whereas limestone exhibits a high DEN (2.7-2.9 g/cm^3). The DEN is talented of recognizing detailed variations in the density of rocks. Consequently, DEN is an outstanding tool for coal layer recognition. DEN should be utilized in combination with other logs to avoid mistaking false low density responses for coal.

3.3. Acoustic log (AC)

The acoustical log, records the time for a sound wave to travel through a definite length of formation. Referring to [16], the AC is influenced by the lithology and the porosity of the rock type being drilled. A decrease in velocity (increase in interval transit time) can be understood to be the consequence of an increase in porosity. Coal normally displays a low velocity as compared to adjacent rocks; since AC can record velocity variations in great detail.

3.4. Neutron porosity log (CNL)

Referring to [16-18], CNL is generally called the porosity index and respond primarily to the hydrogen amount of saturated formations. Hydrogen plays the most effective role in slowing or moderating neutrons in formation. CNL show high reading adjacent to permeable fluid-filled rocks because of their high hydrogen contents, but it also exhibit high adjacent to a coal layer because of its high carbon content. Coal shows a low neutron count ratio for its high hydrocarbon content [21]. Clay with high-moisture content will also show high reading on CNL curve. Therefore, high-moisture clay adjacent to a coal layer can obscure the contact between the clay and coal and exhibit a false thickness of coal.

3.5. Resistivity logs

According to [16-18], electric logs can be used to support radioactive logs, however are seldom utilized alone. This can be demonstrated by the fact that most coal beds are highly resistant to the flow of an electric current compared with most adjacent rocks, resistivity curves usually display a large deflection opposite a coal bed. However, in wells coal is difficult to differentiate from several rock types. Shale has a low resistivity compared to a lot of rock, while both coal and sandstone have a high resistivity value and may be mistaken for coal. Consequently, based only on the resistivity, it is difficult to dissociate the coal to sandstones. According to [22], lignite show resistivity value in between 2-10000 Ohm-m; that Bituminous is in 50-200 Ohm-m; while Anthracite exhibits resistively reading range of 2-8 Ohm-m. However, Reeves [32] mentioned that bituminous show higher resistivity while anthracite and lignite may display low values. Consequently, resistivity must be utilized with attention due to its large interval of variation.

4. Results and discussions

4.1. Cross plot analysis

Figure 1a shows GR plotted against the AC from Well#HH57. From Figure 1a, shale, coal and sandstone can be separated by the GR vs AC, despite the fact that the sandstone seems to be still in the shale. GR value of coal is lower than that of sandstone (moderate) and shale (higher). Coal contains very little clay content, which makes GR value very low response [4-30]. GR helps distinguish high radioactivity from low radioactivity [15]. GR showed consistent log curve to differentiate coal to shale and sandstone. This can be additionally seen in cross-plot of GR vs other logs from Well#57 in Figure 1 as well as in the GR plotted against other logs from Well#HH32 and Well#HH42 in Figure 2 and Figure 3 respectively.

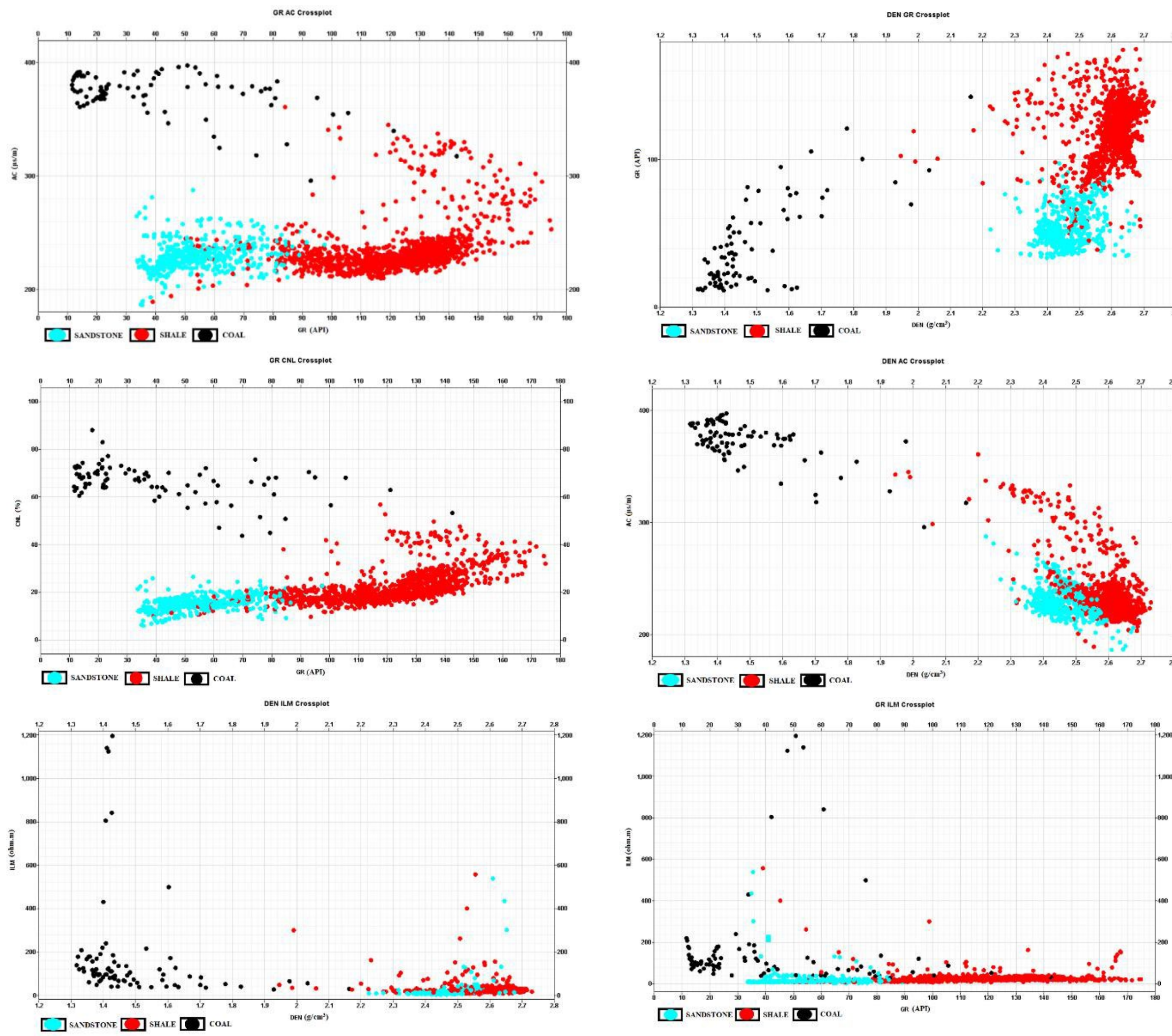


Figure1.The cross-plots of geophysical logs data from Well# 57: (a) GR against AC, (b) DEN against GR, (c) GR against CNL, (d) DEN against AC, (e) DEN against Resistivity, (f) GR against Resistivity.

As the coal is rich in hydrogen, it can be recognized on the neutron logs [21]. Interestingly, In GR-CNL cross-plot (Figure 1), there is a clear distinction between the different lithologies, despite the fact that sandstone seems to be slightly in the shale. In Figure1, the cross plot in the DEN-AC cross-plot as well as the DEN-ILM also shows a similar result as that of GR-CNL plot. Based on the aforementioned, coal shows lower DEN and resistivity, and higher AC and CNL values as compared to sandstone and shale. DEN, CNL, ILM and AC are also consistent log curve to differentiate coal to other lithologies. This performance of DEN, ILM and AC can be additionally seen in Well#HH32 and Well#HH42 from Figure 2 and Figure 3 respectively.

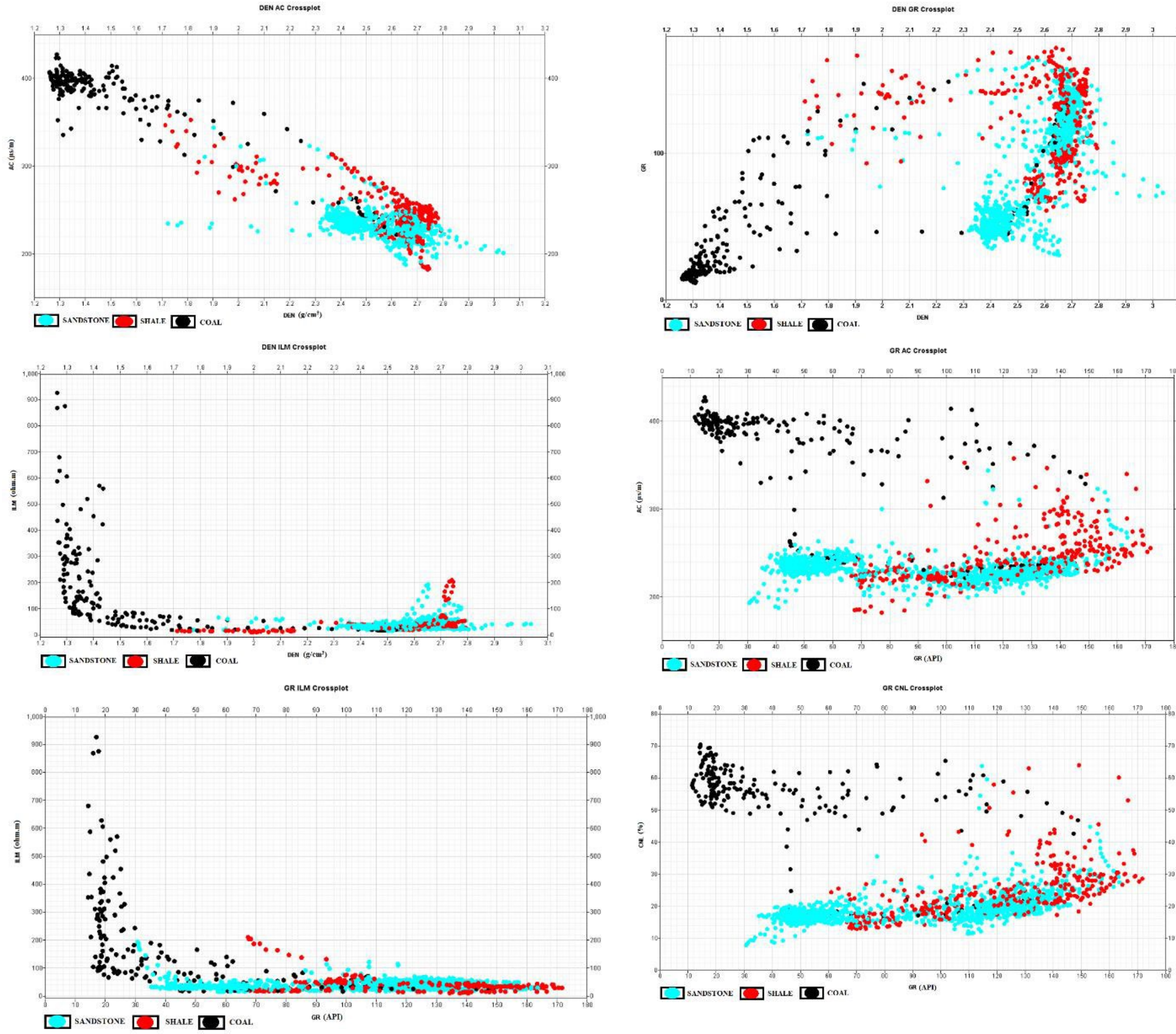
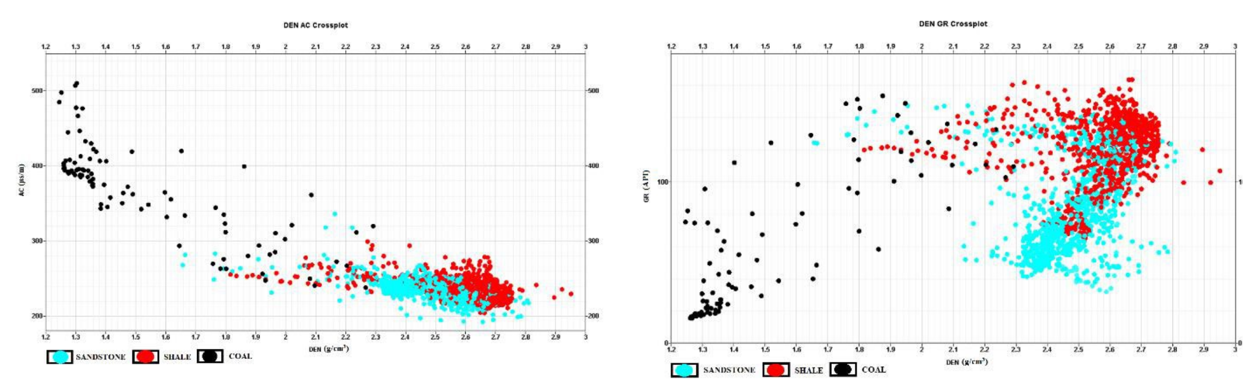


Figure 2. The cross-plots of geophysical logs data from Well# 42: (a) DEN against AC, (b) DEN against GR, (c) DEN againstResistivity, (d) GR against AC, (e) GR against Resistivity, (f) GR against CNL



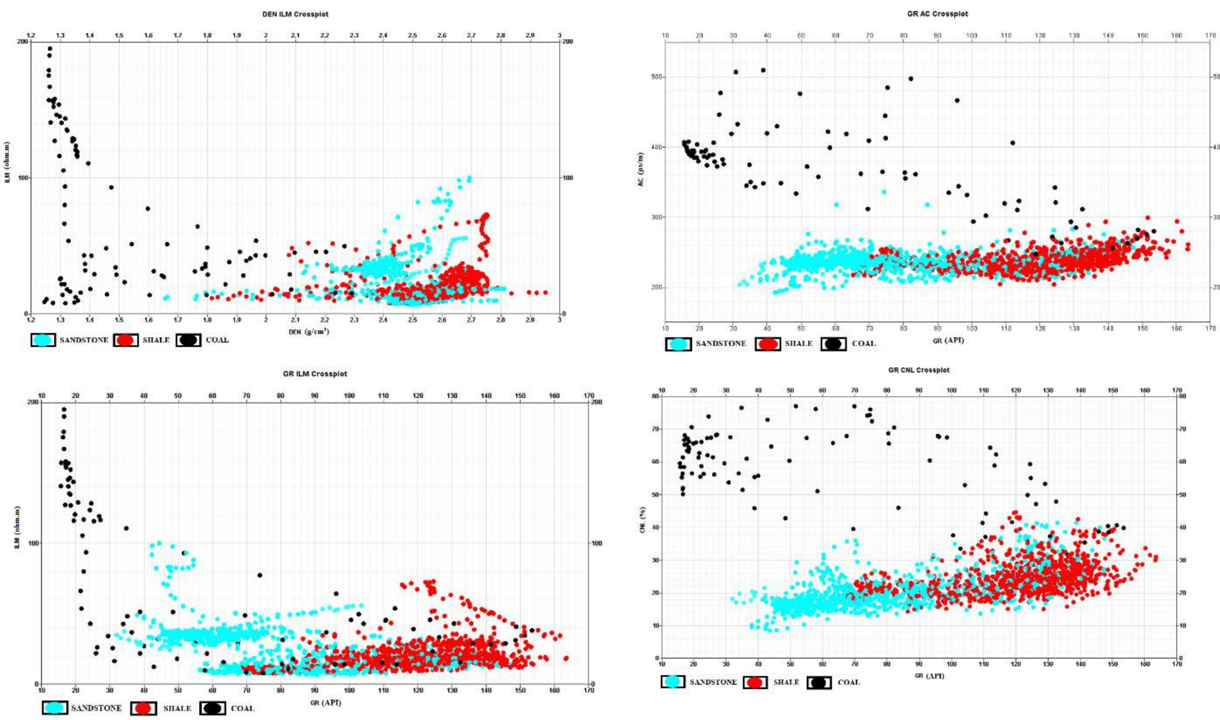


Figure 3. The cross-plots of geophysical logs data from Well# 42: (a) DEN against AC, (b) DEN against GR, (c) DEN against Resistivity, (d) GR against AC, (e) GR against Resistivity, (f) GR against CNL

By analyzing the above undertaken, it can be said that the GR and DEN followed by ILM, AC, CNL are the reliable log to differentiate coal to sandstone and shale. In the study area, logs can be used to distinguish lithologies. Therefore, cross plot method to identify the lithologies is appropriated in the area.

It is important to note that, the low value of GR, and DEN showed coal bed methane has been reported by several authors [4-25-26]. Meanwhile**,** AC and Resistivity values must be utilized with attention due to their large range of variation, depending among other factors upon the environment and conditions under which coal was deposited. A study carried out by [25], on the identification of coal layers base on well log data from Auranga Coalfied in India had reported very high value of resistivity for coal layer. Similar high resistivity value was also found by [26].

4.2. Identification of coal layers from Well Log curves

Multi-well log interpretation methods are applied to examine the shape of the various log curves or combination of well log responses that best characterize a coal layer. All the coal layers of 9 exploratory wells, namely, 9 wells (HH#25, HH#32, HH#33, HH#42, HH#44, HH#53, HH#54, HH#55 and HH#57) were recognized from combined signatures of GR, DEN, resistivity, AC, and CNL logs versus coal layers. Table 1 displays the coal layers depth and thickness of 9 wells. Table 2 shows the response interval of each conventional log to coal layer. Analysis of conventional log curves in the study area allowed to distinguish logs from coal layers. Figure 4 and 5 show the conventional log curves of Coal layer in the well#HH42 and well#HH57 respectively.

Table 1. Coal layer in HH Oilfield

No.	Well	Coal layer	Depth Interval(m)	Thickness (m)
1	HH25	1#	1722.1-1723.3	1.2
		2#	1727.8-1728.9	1.1
		3#	1736.8-1739.4	2.6
2	HH32	1#	1647.2-1649.9	2.7
		2#	1654.0-1657.3	3.3
		3#	1676.3-1682.0	5.7
3	HH33	1#	1729.3-1731.1	1.8
		2#	1733.1-1735.9	2.8
		3#	1764.0-1770.3	6.3
4	HH42	1#	1368.7-1370.3	1.6
		2#	1374.9-1378.0	3.1
		3#	1422.9-1430.4	7.5
		4#	1453.0-1459.5	6.5
5	HH44	1#	2090.6-2094.2	3.6
		3#	2119.1-2125.1	6
		4#	2152.5-2154.5	2
6	HH53	1#	1628.3-1630.1	1.8
		2#	1638.2-1640.7	2.5
		3#	1678.2-1685.0	6.8
		5#	1688.7-1690.9	2.6
7	HH54	1#	1731.6-1733.1	1.5
		2#	1741.4-1743.0	1.6
		3#	1781.4-1790.4	9
8	HH55	1#	1688.6-1690.7	2.1
		2#	1696.4-1699.9	3.5
		3#	1745.9-1754.9	9
9	HH57	1#	1633.3-1634.6	1.3
		2#	1642.1-1643.3	1.2
		3#	1670.4-1676.7	6.3

Table 2. Conventional log curves response characteristics in the coal layer

Type of data	DEN (g/cm^3)	ILM (Ω.m)	GR (API)	AC (μs/m)	CNL (%)
Coal layer	1.25-1.67	91-2000	15-45	328.57-428.57	45.71-75.71

Coal layer in the well#HH42 (Zones 3&4#) in Figure 4 are located at a depth of 1422-1430.4.30m and 1430.9~1434.10 m, with a thickness 7.50m and 3.2m respectively. The statistical analysis shows that the values of the following logs: GR varies from 11.5-25.3 API and 17.9-29.6 API, with an average value of 16.6API and 20.2API respectively; Resistivity value are in between 340-16577Ω.m and 199-1269.3 Ω.m, with an average value 2967.6Ω.m and 647.9Ω.m respectively. AC value are from 380.6-427.1 μs/m and 384.2-408μs/m with an average 399.7 μs/m and 398.8μs/m respectively; CNL are in between 51.7-70.4 and 55-65.1%, with an average of 61.6 and 59.3% respectively. DEN varies between 1.26-1.35 g/cm^3 and 1.29-1.31 g/cm^3 with an average of 1.29 g/cm^3 and 1.30 g/cm^3 respectively. This Coal layer is located in Yan'an formation (J1-2y).

Coal layer in the well#HH57 (Zone 3#) in Figure 5 is located at a depth of 1670.30m-1676.60m, with a thickness of 6.3m. The statistical analysis shows that the values of the following logs: GR varies from 11.6-23.3 API with an average value of 17.3. Resistivity value is in between 66.8 Ω.m-132.2Ω.m, with an average value of 98 Ω.m. AC value is from 362 μs/m -391μs/m with an average 377.6 μs/m. CNL varies between 60.6%-88.1 % and an average of 68.9 %. DEN varies between 1.32 g/cm^3-1.62 g/cm^3 with an average of 1.49 g/cm^3. This Coal layer is located in the formations of the Jurassic, Yan'an formation (J1-2y).

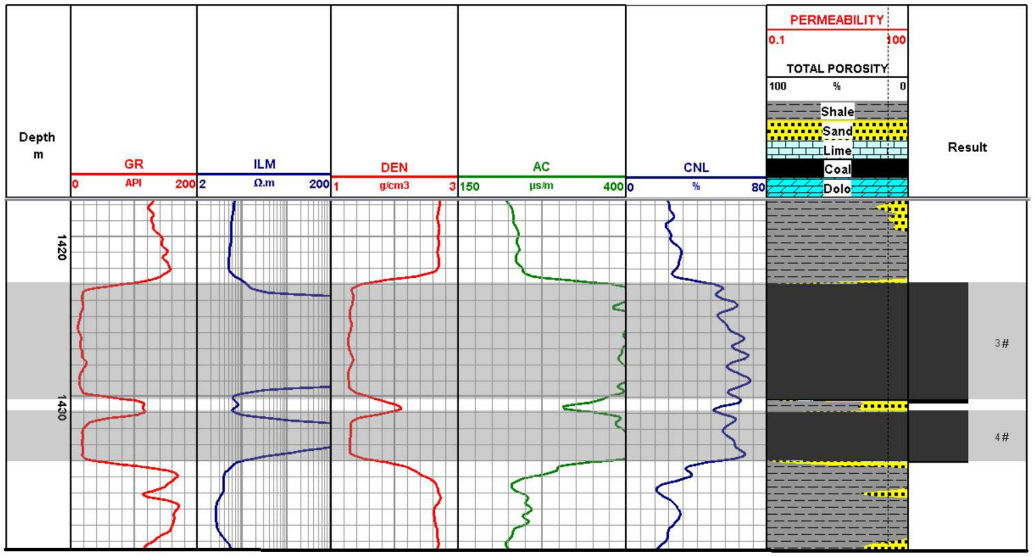


Figure 4. Well logging curve of coal layer in the well #HH42

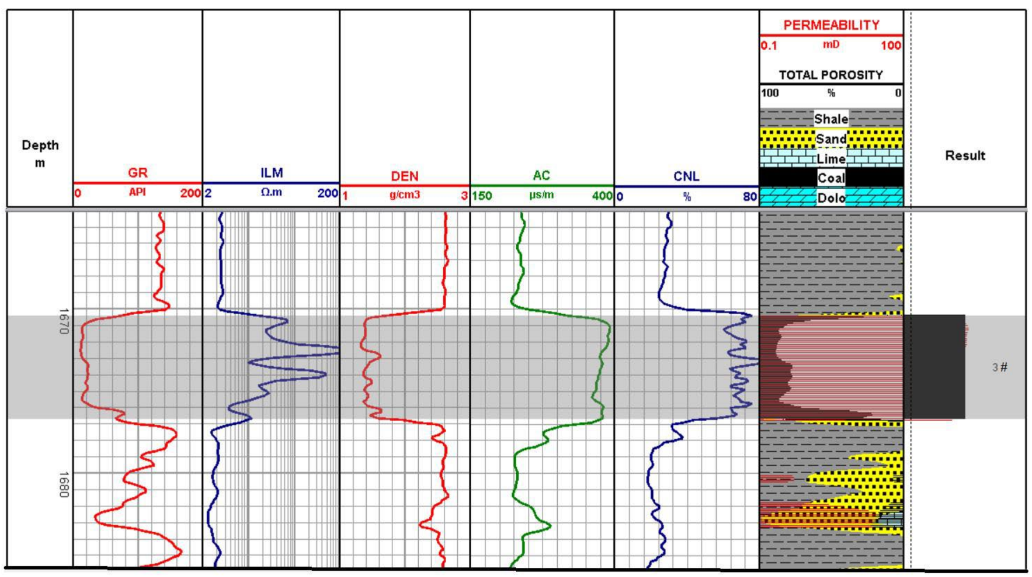


Figure 5. Well logging curve of coal layer in the well #HH57

5. Conclusion

This paper analyses the ability to utilize conventional well logs to allow for accurate identification of the coal layer located in HH Oilfield, Ordos basin, to accurate extraction of methane gas. Cross plots and visual inspections of log curves methods were applied and discussed here. The result indicated GR and DEN logs followed by resistivity, AC, and CNL logs in the study area are sensitive curve for lithology recognition. Additionally, the cross-plot method confirmed the presence of sandstones and shale in the reservoir. The analysis of the behavior of log curves, allowed us to recognize well sensitive curves to the coal reservoir. In most cases, the log response characteristics of coal reservoir is low GR, DEN and resistivity, and high AC and CNL values. So, these logs curves can be used to effectively identify and classify coal layers. However, for the Ordos Basin, the interpretation techniques established in this study are only of reference significance, there are differences between different environment and different coal layers. In this manner, some log curves such as resistively log values must be utilized with caution due to their large range of variation.

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