Application of mud gas analysis for reservoir evaluation

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Abstract

Mud gas, which is usually used for monitoring the safety of the wells while drilling, can also be used as a formation evaluation tool. This study aims to analyse mud gas ratios and compare them with the traditional formation evaluation tools, such as resistivity. The analysis of four wells, either exploration or development wells, located in differing geological settings, shows that qualitatively, mud gas can be robustly used as a formation tool to show the identity of fluids in the reservoir zones.

1.0 Introduction

While drilling oil and gas wells, data is collected by mud logging contracted companies. This data includes cutting descriptions and measurements of gas from the drilling mud. Mud gas data has been analysed on the wellsite for a long time, mainly for safety reasons, and has not been used extensively for formation evaluation (Blanc *et al.*, 2003). This is because the older gas extraction systems were unreliable; in many ways, for example, the gas volume collected was not constant (Blanc *et al.,* 2003; Capone *et al.,* 2012).

This drilling gas data analysis can be used as a formation evaluation tool to identify fluid types and fluid contacts (Zhou *et al.,* 2009). Furthermore, formation characteristics like permeability and water saturation can be estimated using gas ratios (Pinna *et al.,* 2008). (Mode *et al.,* 2014) compared gas ratio analysis and resistivity values in three wells in the Congo basin, and both methods confirmed oil zones in the wells.

The gas ratio methods mainly used are the Haworth gas ratios (Haworth *et al.,* 1985) and the Pixler gas ratios (Pixler,1969). Gas chromatograph analysis also has a resolution that makes it a geo-steering tool in horizontal wells (Hawker, 2001).

Logging of wells using downhole geophysical tools is the conventional method for formation evaluation, albeit at a higher cost than mud logging (Pinna, 2012). In the last decade, there have been improvements in gas extractors, analytical detectors, and mud gas analysis quality control (Pinna, 2012). Data from recent mud gas systems can be applied more reliably to inform about the reservoir fluids (Melo *et al.,* 2016).

This project aims to evaluate the application of mud gas ratios as a reliable formation evaluation tool for reservoir fluids characterisation, including identifying fluid types, fluid zonation, production potential, flow barrier and reservoir connectivity.

2.0 Literature Review

2.1 Mud Gas System

The mud gas system is composed of three parts, namely the gas trap, which extracts the gas from the mud, the lines, which transport the gas to the mud logging unit, where we have the third part of the gas system, which is the gas detection system.

Advanced gas extraction systems whereby a constant volume of gas is obtained from the mud have increased efficiency and more reliable data (Pinna *et al.,* 2008; Breviere *et al.,* 2012). The reliability of the gas extraction system is increased when the line transporting the gas is thermally insulated and made of a material that is not chemically reactive with the hydrocarbon gases (Ferroni *et al.,* 2012).

The gas detection system comprises a total hydrocarbon detector and a gas chromatograph, preferably with FID (Flame Ionisation Detection) technology, as this has been found through experiments to be suitable for hydrocarbon detection (Ferroni *et al*., 2012).

2.2 Gas Ratios

Chromatographic gas analysis at the wellsite is for lighter alkanes (from methane to Pentane); heavier alkanes remain in a liquid state at the surface temperature (Hawker, 1999). The gas detection system analyses the individual gas components; these can be used to show the hydrocarbon-bearing zones or calculated as gas ratios, which gives more information about the fluid character in the hydrocarbon-bearing zone.

This study will use the following gas ratios to interpret the reservoir zones' fluid character.

- Haworth gas ratio, which includes Wetness ratio, Balance ratio and character ratio.
- Pixler gas ratios, which include C1/C2.
- Oil indicator ratio/inverse oil indicator ratio.

(Haworth *et al.* 1985) "Wetness" method gas ratios have three components, which are shown below. Each of the ratios is calculated using the formula shown beside it.

(a)Wetness ratio (Wh) = [C2+C3+C4+C5]/[C1+C2+C3+C4+C5] * 100

(b) Balance Ratio (Bh) = [C1+C2]/ [C3+C4+C5]

(c) Character Ratio (Ch) = [C4 + C5]/C3

The table below, which is modified after (Haworth et al., 1985), shows the interpretation guidelines. (Haworth *et al.* 1985) His experiments found that using the wetness and balance ratios together gave the most consistent results.

Balance Ratio	**Wetness Ratio**	**Fluid Character**
>100		very light, dry gas
<100	<0.5	light dry gas
Wh<Bh<100	0.5 – 17.5	gas, increasing in wetness as the curves are closer together
<Wh	0.5 – 17.5	very wet gas or condensate or high gravity oil with high GOR (Bh<Wh indicates liquid, but Wh still indicates gas)
<Wh	17.5 - 40	oil with decreasing gravity as the curve separation increases
<< Wh	17.5 - 40	low gravity, low gas saturation oil
	>40	Very low gravity oil or residual oil

Table 1: Modified after (Haworth et al, 1985).

Character ratio (Ch) is used to clarify the interpretation of fluid character, where wetness and balance ratio indicate lighter fluid due to high C1 readings. (Haworth *et al.*1985)

The interpretation of Ch is then as follows. Ch< 0.5, then gas confirmed. Ch> 0.5, the gas indicated by wetness and balance ratios is associated with oil.

Pixler gas Ratio Method uses the ratios of methane to ethane, propane, butane, and pentane. (Pixler, 1969) proposed using these ratios to indicate the production potential of the hydrocarbons from the reservoir zone where they are liberated.

C1/C2 Ratio	**Fluid Type**	**Gravity**
<2	Non-productive residue oil	
2-4	Low-gravity oil	API 10-15
4-8	Medium gravity oil	API 15-35
8-15	High gravity oil	API>35

10-20	Gas condensate	
15-65	Gas	
>65	Light gas, non-productive	
C1 only	Saltwater	

Table 2: Modified after (Pixler, 1969).

The oil indicator ratio (also plotted as Inverse Oil Indicator) is useful in indicating the reservoir's hydrocarbon fluid. Its origin is unknown; hence, it is not explained why C2 is omitted in the formula. (Hawker, 1999). The formula is O=C3+C4+C5/C1. Inverse = C1/C3+C4+C5.

Oil Indicator	**Inverse oil indicator**	**Interpretation**
0.01 – 0.07	100 – 14.3	Dry gas
0.07 – 0.10	14.3 - 10	Condensate – light oil with high GOR
0.10 – 0.40	10 - 2.5	Oil (unsaturated)
0.40 – 1.0	2.5 - 1	Residual oil

Table 3: modified after (Hawker,1999)

2.3 Geophysical Well Logs

Geophysical well logs, also called well logs, are the most used and trusted methods of evaluating reservoirs in wells (Rider *et al.,* 2011). These logs measure different formation parameters, and the measurements are then used to infer the fluid character in the reservoirs, porosity, permeability, and rock types. Two methods are used to obtain the logs. (a) By LWD (logging while drilling), the logging tools are connected to the drilling string, sending data through the drilling mud or string. (b) Wireline logging is when a wireline inserts the tools into the borehole after the drilling tools have been pulled out. In practice, companies run some tools, e.g. gamma by LWD and other logging tools by wireline, though to cut costs and when not many types of logs are required, logs can only be run by the LWD (logging while drilling) method.

Some of the logs used for formation evaluation include.

- Gamma ray log records gamma ray emissions from the formation and is used qualitatively for lithology identification and stratigraphy correlation (Rider *et al.,* 2011). Shaly formations will generally have higher gamma rays than sandy formations.
- Resistivity logs measure the conductivity of the formation; their primary use is to detect hydrocarbons (Rider *et al.,* 2011). Hydrocarbons are not conductive, hence they will have higher resistivity values than saline formation water zones.
- Density log measures the bulk density of the formation; it is used quantitatively to calculate porosity (Rider *et al.,* 2011).

- Neutron log records formation reaction to neutron bombardment, which is influenced by the hydrogen nuclei in the formation; it is used qualitatively to discriminate between gas and oil. (Rider *et al.* 2011). Gas having interspersed hydrogen ions will have a lower neutron porosity reading than oil zones.

3.0 Methodology

Gas data was accessed from mudlogging reports of the selected wells. These wells were chosen from different petroleum basins. The well names and locations are made anonymous for data privacy purposes.

The gas ratios were calculated using the Excel software using the gas ratio formulas in the section above.

The ratios were then exported to Petrel software in the well template window, where they will be displayed along geophysical well logs. The reservoir sections of the wells were then interpreted using the gas ratio logs and complemented by geophysical logs obtained by wireline tools and/or LWD (logging while drilling tools) and well tests and sampling reports.

4.0 Results

4.1 Field A

4.1.1 Petroleum System

This oil field is in the Gulf of Guinea in West Africa. The well analysed is hereby called AB. This development well was drilled to drain the channel complex's central region, which has been producing oil for some years.

The geological structure is a snake-like channel complex comprising stacked channels. The Source rock from which the hydrocarbons are charging is an oil-prone type 2 marine shale of Upper Albian to Cenomanian age. The reservoir is three stacked channels here called A-sst-1, A-sst-2, and A-sst-3 of Turonian age. The reservoir's rock type is sandstones, which are well sorted in the axis of the channels, interbedded with shales and silts in some parts, and in the fringes of the channels, the sandstones are of good quality with porosities of between 16% and 22%. The trapping structure is stratigraphic, with a water leg at lower levels and a small gas cap pinching out at higher levels. The seal is a thick regional shale of Coniacian age.

4.1.2 Well Interpretation

Four gas peaks have their readings analysed here to inform about the reservoir fluid type. The gas analysis in this development well aims to evaluate if the gas ratios can inform about the reservoir connectivity to other producing wells and whether the gas ratios and the geophysical logs indicate similar fluid types.

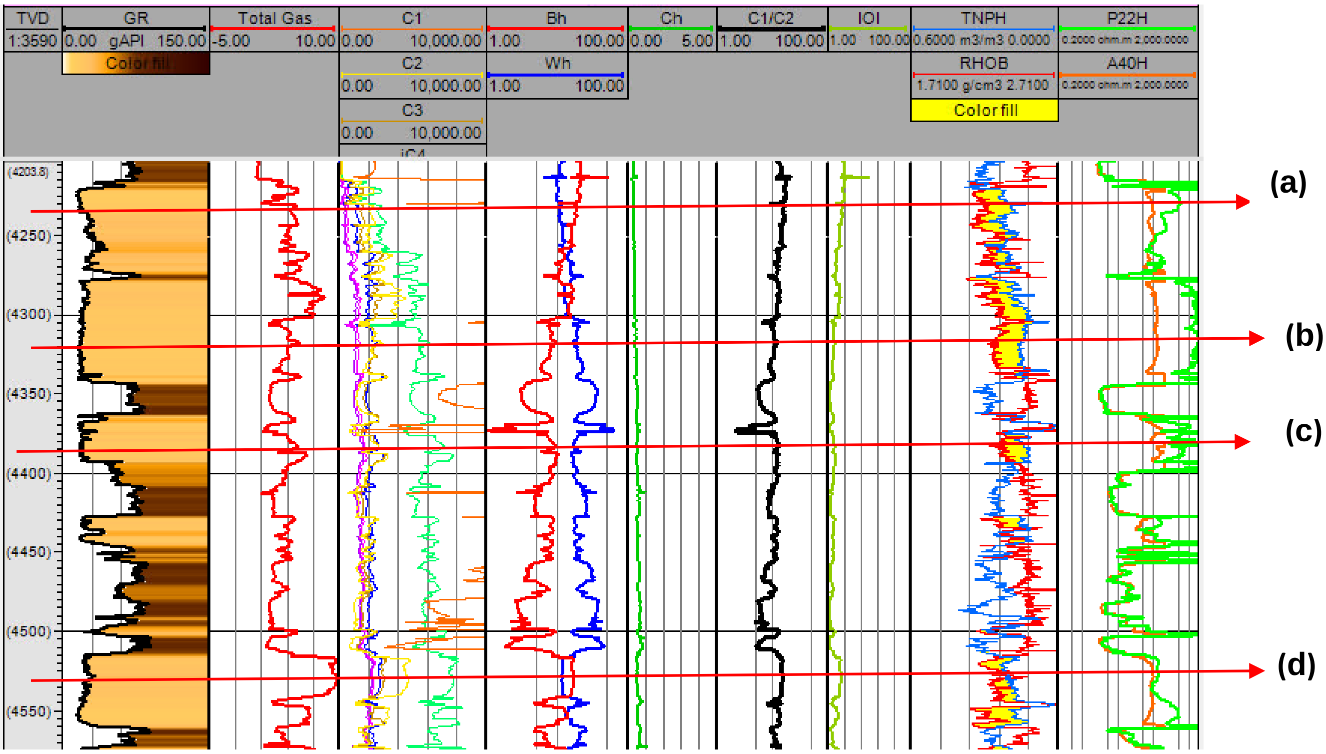

Figure 1: Well AB logs; GR is gamma ray, total gas in %, gas chromatographs from C1 to C5, BH is Balance ratio, WH is wetness ratio, CH is character ratio, C1/C2 ratio, IOI is inverse oil indicator ratio, RHOB is density, TNPH is neutron porosity, P22H is phase resistivity (shallow) and A40H is attenuation resistivity (deep).

Well AB				
Depth	**4225m (a)**	**4320m (b)**	**4385m (c)**	**4530m (d)**
Interpretation	All the gas ratios indicate gas. An increase in resistivity indicates hydrocarbon.	All gas ratios indicate oil. Resistivity logs indicate hydrocarbons and show separation.	Gas ratios indicate high GOR oil. Resistivity logs indicate hydrocarbons and some separation.	Wh and Bh indicate gas; Ch indicates the gas is associated with oil. Resistivity logs indicate hydrocarbons.

Table 4: Well AB peak readings and interpretation.

The top reservoir (A-sst-1), represented by peaks (a) and (b), is showing fluid fractionation, with the upper part indicating gas instead of oil; this is a secondary gas cap that has formed. This confirms that this reservoir is connected to other producing wells in the field, and it is depleting. Reservoir A-sst-2 (c) is also depleting and has high GOR oil. Reservoir A-sst-3 (d) also shows fluid fractionation and depletion character; the upper part of this reservoir indicates gas character, and the lower zone has oil character.

Resistivity logs show separation between the shallow and deep zones, where the gas logs indicate oil, and no separation where the gas ratios indicate gas. Neutron and density show higher porosities in the upper parts of A-ss-1 (a) reservoir, with higher depletion and lower porosities in the lower part of the same reservoir (b).

Soon after the well went into production, it was confirmed to have remarkably high GOR oil and produced much less than anticipated. Wells in the field also concurrently started producing water. Soon after, this field was confirmed to decline in oil production quickly and could not produce the estimated volumes.

4.2 Field B

4.2.1 Petroleum System

This field is in the Suriname-Guyana basin in South America. Two exploration wells are drilled to determine the presence and type of hydrocarbons. The wells are hereby called BA and BB, located 25 km apart. The structure targeted is a shelf-terrace-slope. The petroleum system has been proven in this area by oil discoveries in the neighbouring block, and oil is shown in the cuttings of offset wells. They are of similar play type: Tertiary channel turbidites. The source rock charging the wells is regionally extensive type 2 marine shales of Albian-Cenomanian-Turonian age. Transgressive shales seal the two channels.

BA well targeted an Eocene age canyon turbidite lobe with a good DHI (Direct Hydrocarbon Indicator). An up-dip truncation traps the reservoir.

BB well was a shallower prospect, targeting Pliocene channel turbidite with a strong DHI, with class 3 AVO (Amplitude Versus Offset).

4.2.2 Wells Interpretation

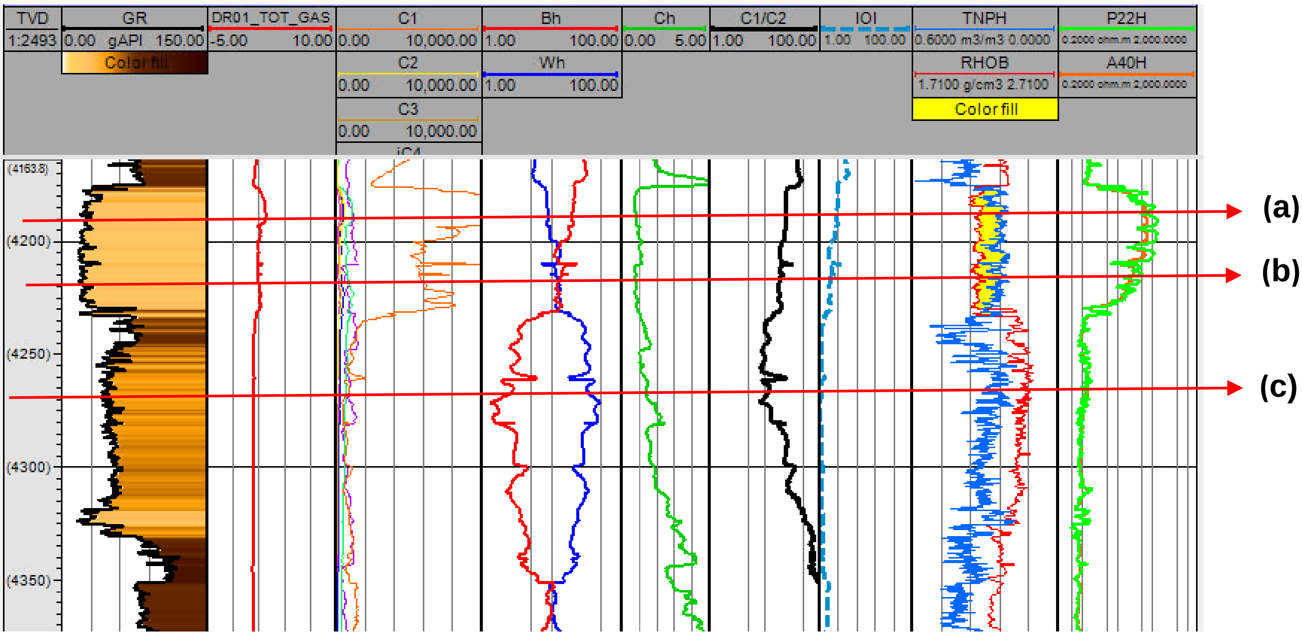

Figure 2: Well BA well logs; GR is gamma ray, total gas in %, gas chromatographs from C1 to C5, BH is Balance ratio, WH is wetness ratio, CH is character ratio, C1/C2 ratio, IOI is inverse oil indicator ratio, RHOB is density, TNPH is neutron porosity, P22H is phase resistivity (shallow) and A40H is attenuation resistivity (deep).

WELL: BA			
Depth	**4190m (a)**	**4220m (b)**	**4270m (c)**
Interpretation	Wh and Bh ratios indicate gas; Ch indicates the gas is associated with oil. IOl shows it is a dry gas. Resistivity logs indicate hydrocarbons.	Wh and Bh indicate very wet gas or condensate, and Ch shows that the gas is associated with oil. Resistivity logs indicate hydrocarbons.	Gas ratios indicate the residual oil zone. Resistivity logs indicate no hydrocarbons.

Table 5: Well BA peak interpretation.

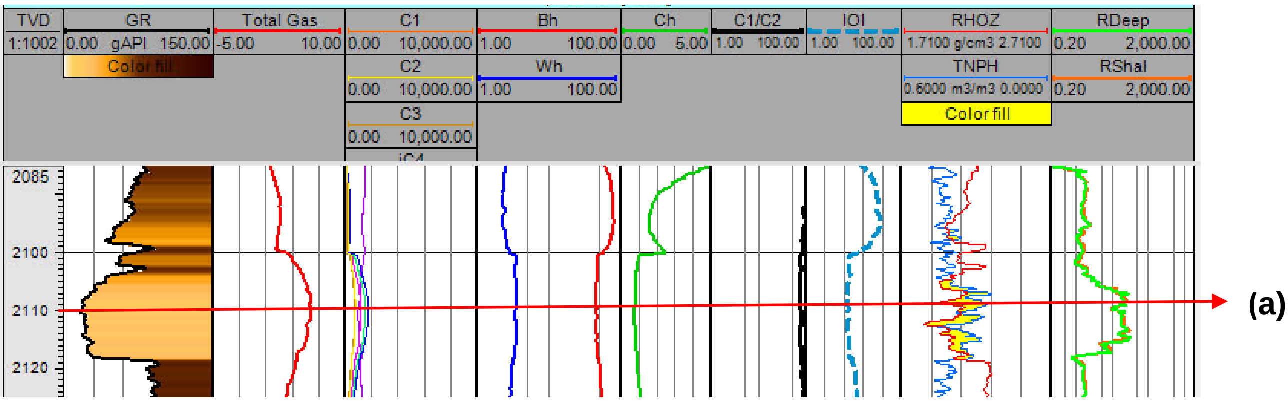

Figure 3: Well BB logs; GR is gamma ray, total gas in %, gas chromatographs from C1 to C5, BH is Balance ratio, WH is wetness ratio, CH is character ratio, C1/C2 ratio, IOI is inverse oil indicator ratio, RHOZ is density, TNPH is neutron porosity, RDeep is deep resistivity and RShal is shallow resistivity.

WELL: BB	
Depth	**2110m (a)**
Interpretation	Wh and Bh indicate light gas; Ch indicates the gas is associated with oil. C1/C2 indicates that the gas is non-productive. Increased resistivity indicates hydrocarbons in the reservoir.

Table 6: Well BB peak interpretation.

The tests on the fluid type from these wells showed that both wells have high-density oils. Well, BA and BB samples showed the heavy oil to have a density of 12 to 13 API. These samples confirm the oil has undergone alteration. The gas ratios could not identify this as there was exceedingly high C1 compared to the other light gases, but they pointed out the fluid type's ambiguity. Neutron-density logs only indicated the good porosity, and resistivity indicated the presence of hydrocarbons, but did not highlight the ambiguity of the fluids in the reservoir.

The conclusion is that the oil in the reservoirs has undergone deasphalting biodegradation due to the later influx of methane gas into the reservoir, which the sample test results can confirm, showing remarkably high asphaltenes. Well BB shows a gas character, which is explainable by its shallower location in the basin, which results in a greater methane gas influx. Alteration by deasphalting involves a later gas charge into the reservoir whereby precipitation of asphaltenes occurs and the initial oil becomes heavy crude (Allen *et al.*, 2013).

4.3 Field C

4.3.1 Petroleum System

Field C is in the East African Rift Valley. The basin itself is a half-graben of tertiary age. Well CA analysed here was an exploration well drilled to test the prospectivity of the basin. The structure targeted is a three-way dip closure against the rift bounding fault. The source rock charging the basin is an oil-prone lacustrine shale. The primary method of migration from the source rock is through faults. A basin-wide thick shale seals the main reservoirs, which are stacked sandstones separated by thin shale beds.

4.3.2 Wells Interpretation

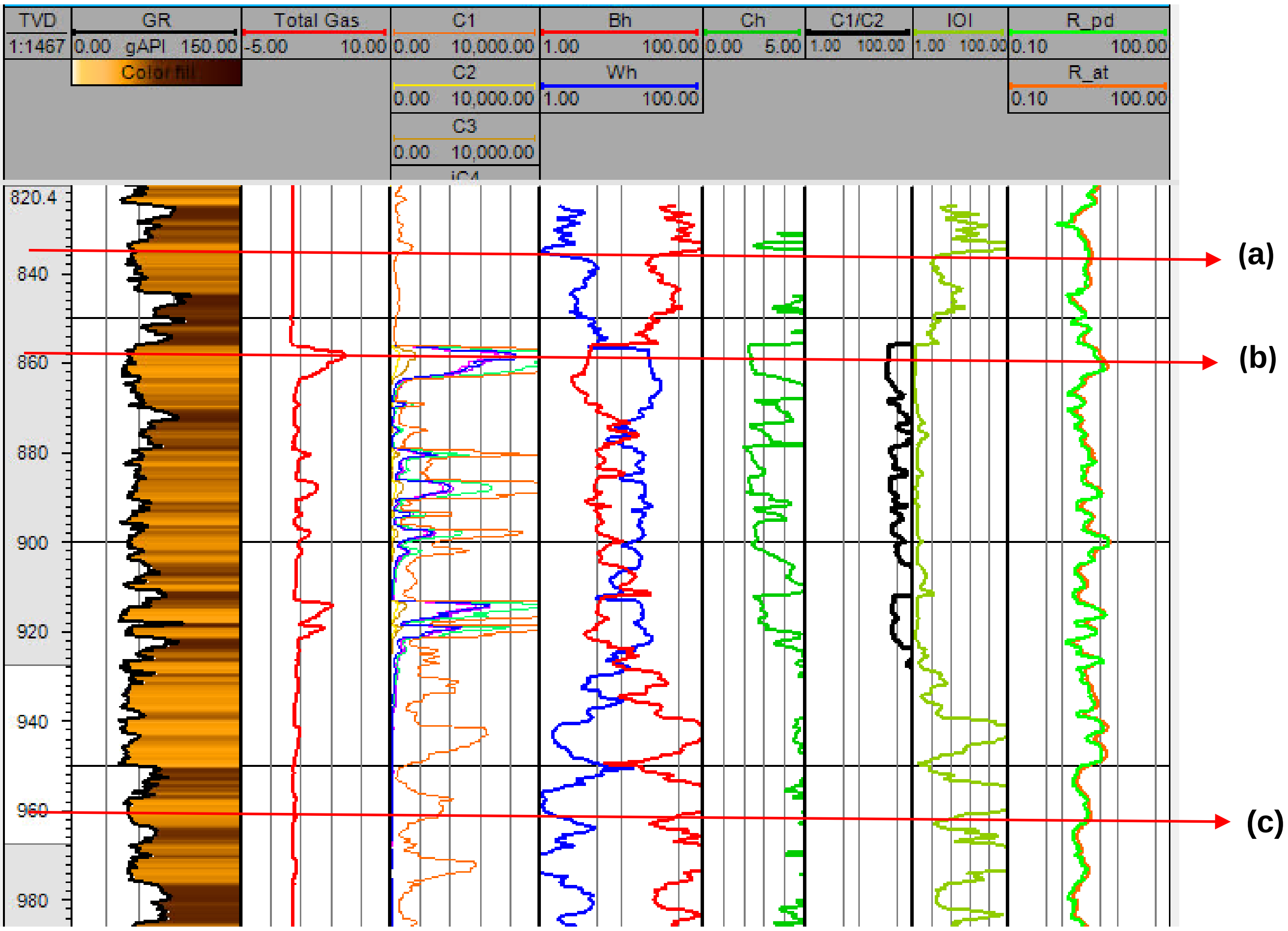

Figure 4: Well CA logs; GR is gamma ray, total gas in %, gas chromatographs C1 to C5, WH-wetness ratio, BH-balance ratio, CH-character ratio, C1/C2 ratio, IOI-inverse oil indicator ratio and resistivity logs; R-pd is phase (shallow) resistivity and R-at is attenuation (deep) resistivity.

WELL: CA			
Depth	**834m (a)**	**858 (b)**	**960 (c)**
Interpretation	Gas ratios indicate the water zone.	Gas ratios and a slight increase in resistivity logs indicate an oil zone.	Gas ratios indicate a water zone; there is a decrease in resistivity logs.

Table 7: Well CA interpretation from logs.

The gas ratio readings in this well show fluid types and zonation in different sands. This was confirmed by well sampling and tests done. In this field, the formation water is not saline. Therefore, the resistivity logs' variation between oil-bearing and water zones is very slight; in some cases, no difference is seen. This is because fresh formation water is non-conductive like hydrocarbons. Gas logs, therefore, become an important, inexpensive way of fluid characterisation. Gas logs can help choose the sampling points and well tests in this case. Not only will they guide one to sample hydrocarbon-bearing zones, but they will also help in saving cost, as fewer points and less time can be used.

5.0 Discussion/Conclusion

With the modern advanced gas mud systems with a constant gas volume trap, gas ratios can be used more confidently in characterising the formation fluids. This study concludes that gas ratios can be used as a qualitative formation tool. This study recommends using a combination of three or four gas ratios for the most reliable interpretation.

In exploration wells, such as field B and C above, gas ratios indicate hydrocarbon-bearing zones; they can show fluid zonation in the reservoirs. In field B, gas logs and resistivity logs both indicated hydrocarbon-bearing zones. Resistivity logs could not qualitatively give information about the heavy crude in the reservoir; they just indicated hydrocarbon presence. The gas ratio logs in Field B indicated ambiguity in interpreting the fluid type in the reservoirs. With the use of gas ratio logs, reservoirs like these can be flagged for further tests, and the usefulness of the gas ratio logs is in flagging the anomaly.

In production wells, as in field A above, gas ratios indicated depleting zones in the reservoir and informed of the connectivity of the reservoirs in the field. Neutron-density logs indicate the high porosity zones. The resistivity log pattern in this well matched the gas ratio log; zones indicated oil-bearing zones by gas ratios had a separation character between the deep and shallow resistivity. Meanwhile, zones indicated that the gas-bearing zones had two resistivity logs showing no separation. This concludes that the gas ratios are as good as resistivity logs, indicating fluid character change. It can be argued that gas ratios add more information to the fluid characterisation in this case, as the resistivity logs character can be interpreted.

Where geophysical logging has failed or is unavailable, gas ratio logs can be used as a formation evaluation tool. Furthermore, they can be used with geophysical logs to clarify ambiguity in formation fluid type and select sampling and testing points in the well. Gas ratio logs are as good or even better in some cases when evaluating formation fluids in the reservoirs. For this purpose, they should be given equal attention to the geophysical logs.

6.0 References

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