Formation Evaluation by Analysis of Hydrocarbon Ratios

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Introduction

Mud logging was first offered commercially in Aug., 1939. This logging method quickly gained favor among many operators because the type of fluid in the formation could be determined within minutes after the formation was drilled. The presence and magnitude of the methane show was and is the most important factor in mud log interpretation. However this magnitude in some instances was improperly understood, and as a consequence some operators still do not use mud logging, even though the early technique frequently made the difference between a successful well and an abandoned hole. Both the "hot wire" log of gas combustibles in the sample and the percent-of-gas log obtained with the conventional gas trap and the gas chromatograph indicate only that the reservoir in question contains hydrocarbons. These methods do not necessarily indicate the quantitative amounts of the various hydrocarbons in the mud.

The addition of a new Steam Still-Reflux gas sampling system to gas chromatography enables accurate determination of the composition of the mud gas sample. A knowledge of gas composition makes it possible to establish the relationship of methane to the heavier hydrocarbon shows. An awareness of this relationship led to a new, additional mud log interpretative technique that permits relating the quantitative amounts of methane (C_1), ethane (C_2), propane (C_3), butane (C_4), and pentane (C_5) to in-place reservoir fluid content.

A long-accepted premise is that as formations are drilled, the drilling mud filtrate partially flushes the formation fluid ahead of the bit. It was generally thought that the formations were flushed to an irreducible minimum — generally considered to be about 30 percent of in-place fluid. Experience in mud logging, however, has shown that this rarely happens. This partial flushing does not prevent mud logging from successfully determining productive or nonproductive formations. Experienced logging engineers, in possession of quantitative gas analyses, make interpretations that take into account the flushing that results in rocks of various permeabilities, the effect of overbalanced mud weight and the effect of initial filtrate loss.

Method

Ordinarily, when formation cuttings are drilled they retain much of the formation pore fluid. This fluid is released to the mud column as the cuttings travel up the annulus. Most of the formation fluid in the cuttings will be "produced" into the drilling mud during the top 500 ft of hole travel. Conventionally, a mud sample is diverted to a mechanically operated gas trap to obtain a sample of the gas in the mud. The efficiency of this trap is from 15 to 70 percent, depending upon the gel strength of the mud, the amount of mud flowing through the trap and the rotation speed of the trap impeller. The magnitude of the conventional

The ratio of methane to the heavier hydrocarbon components — ethane, propane, butane, and pentane — is indicative of gas, oil and water productive potential. The Steam Still-Reflux Unit, used in conjunction with mud logs and gas chromatographs yields a quantitative analysis from which this ratio can be plotted.

gas show is, therefore, quantitative only to the air-gas sample obtained. The sample is accurately analyzed by the gas chromatograph; but, because the sample furnished by the conventional gas trap represents only a fraction of the gas present in the mud, and because that fraction is not representative of the total gases in the mud, the results are still only qualitative.

When the Steam Still-Reflux Unit is used to obtain the gas sample, the gas sample will represent almost 100 percent of the hydrocarbon fractions C_1 through C_5 that were in the mud sample. This enables the chromatograph analysis to be related quantitatively to the mud, and the readings to be reported as parts per million of each hydrocarbon vapor (C_1 through C_5) to mud volume.

Because the cuttings from a particular formation "produce" the gas they contain into the drilling mud, it was reasonable to assume that this same formation, if completed, would produce gases of a similar composition. This assumption led to a comparison of ppm Logs of hydrocarbon vapors with similar data from producing wells. Plots were made of the ratio of methane to each of the heavier hydrocarbons from many analyses of wellhead samples. These plots were compared with plots, made from ppm Logs, of gas in mud. Both groups of plots showed definite patterns between (1) the magnitude of the ratios of methane to each of the heavier hydrocarbons, and (2) the slope of the lines of the plotted ratios. These, in turn, indicate productive potential and reservoir permeability.

The Steam Still-Reflux Unit consists of a small steam boiler, mud-injection port, mud-steam mixing chamber, Reflux-Condensing Unit and a gas-extraction port. Five ml of mud are injected into the purged mud-steam mixing chamber. The mud is rolled with 2,000 to 4,000 volumes of steam. The hydrocarbons (C_1 through C_5) extracted from the mud are collected at the Reflux-Condensing Unit, withdrawn with a syringe, diluted to the standard chromatograph sample size and injected into the chromatograph for analysis. The Reflux-Condensing Unit removes only the lighter paraffin series hydrocarbons from the mud sample tested. For example, if the mud contains diesel oil, the more complex hydrocarbons — C_6 and above — condense and drop back into the mud-steam mixing chamber. Therefore, regardless of whether the fluid phase of the mud is oil or water, the gas sample analyzed contains only the light fractions through C_5, and the analysis is representative of the formation gas.

The full importance of determining formation gas composition has not always been apparent. At first it was observed that if the magnitude of butane in the mud was greater than the magnitude of either propane or ethane, the zone in question would produce water and hydrocarbons. Later, the ratios of methane to each of the heavier hydrocarbon components were plotted on semilog paper. Hydrocarbon ratio plots obtained from ppm Logs and available data from wellhead gas sample analyses were compared. The comparison of the plots from ppm Logs and wellhead gas analysis data showed a striking correlation. The correlation demonstrated that ppm Logs made with Steam Still-Reflux samples could be interpreted in terms of in-place formation content.

The magnitude of the methane-to-ethane ratio determines if the reservoir contains gas or oil or if it is nonproductive. The slope of the line of the ratio plot of C_1/C_2, C_1/C_3, C_1/C_4, and C_1/C_5 indicates whether the reservoir will produce hydrocarbons or hydrocarbons and water. Positive line slopes indicate production; negative slopes indicate water-bearing formations. An undersaturated reservoir may show a negative slope, but such occurrences are rare. The ratio plots may not be definitive for low permeability zones, but unusually steep plots indicate tight zones.

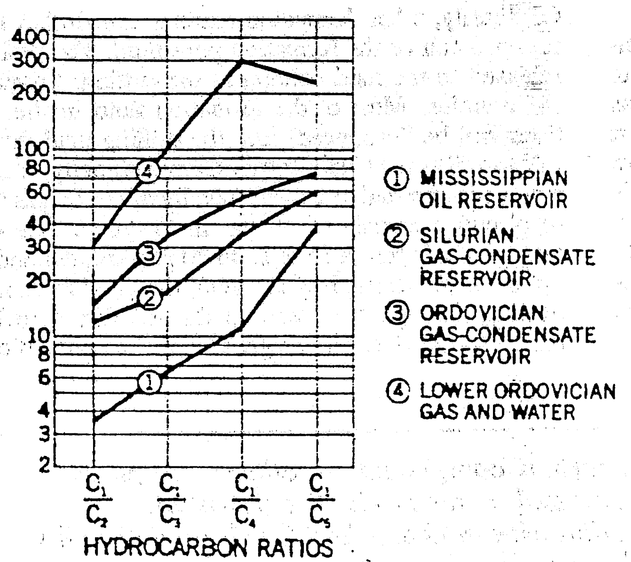


Fig. 1—Hydrocarbon ratio plots obtained from wellhead sample analyses data, limestone reservoirs, Rocky Mountain area.

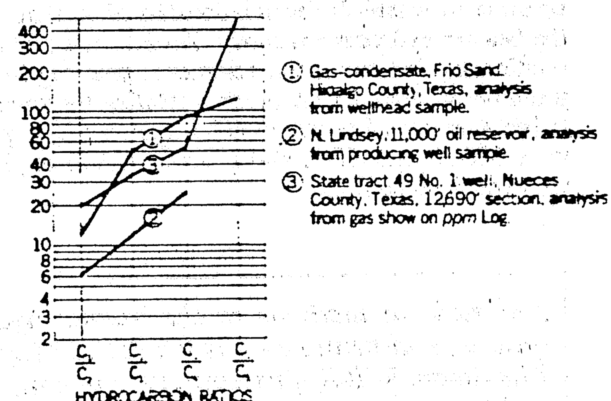


Fig. 2—Hydrocarbon ratio plots, productive reservoirs, South Texas.

A ratio of C_1/C_2 between 2 and 15 indicates oil. A ratio of C_1/C_2 between 15 and 65 indicates gas. The lower the C_1/C_2 ratio, the richer the gas or the lower the oil gravity. If the ratio of C_1/C_2 is below about 2 or above about 65 the zone is nonproductive.

Field Examples

Fig. 1 shows average hydrocarbon ratio plots from limestone reservoirs in the Rocky Mountain area. Plot 1 is derived from analyses of gases from Mississippian oil-producing reservoirs. The C_1/C_2 ratio is 3.5. The slope of the line is positive and not steep. Plot 2 was obtained from analyses of gases from wells producing gas-condensate from the Silurian. The C_1/C_2 ratio is 12; the line slope is again positive and not steep. Plot 3 is from gas-condensate wells producing from the Ordovician. The C_1/C_2 ratio is 15 and, again, the slope of the line is not steep; all three plots show slopes favorable for production. Plot 4 shows ratios obtained from an analysis of gas from the Lower Ordovician, which produced gas and water. The plot shows a negative slope of the section from the C_1/C_4 ratio to the C_1/C_5 ratio. Many tests have verified the fact that if a ratio plot shows a negative slope, the zone in question is water-bearing.

Fig. 2 shows plotted hydrocarbon ratios for productive reservoirs in South Texas. Plot 1 was made from an analysis of a wellhead sample of gas-condensate produced from a Frio sand, Hidalgo County. The production is rich in liquid hydrocarbons as indicated by the low C_1/C_2 ratio. Plot 2 is from an analysis of a wellhead gas sample from an 11,000-ft oil reservoir, North Lindsey field. The pentane was not reported, but the low C_1/C_2 ratio indicates oil production. Plot 3 was obtained from a gas show at 12,690 ft on the ppm Log of the State Tract 49 No. 1 Well, Nueces County, Tex. Formation tests resulted in gas production.

Experience shows that if the C_1/C_2 ratio is above 65 the zone is too tight for commercial production. Fig. 3 shows the ratio plots obtained from ppm Logs on Texas Gulf Coast wells that were nonproductive in the zones of interest. Plot 1 is from the ppm Log of the R. A. Tally No. 1 Well, Victoria County, Tex. The C_1/C_2 ratio was 470. The zone was tested extensively but it was a low permeability reservoir that could not be commercially completed. Plots 2 and 3 are from the State Tract 49 No. 1 Well, Nueces County, Tex. Plot 2 was from a sand encountered at about 8,060 ft. The relatively high ratios of C_1/C_2, C_1/C_3, C_1/C_4, and C_1/C_5 indicated that the zone was nonproductive because of the low permeability. This was subsequently verified by testing. Plot 3 was obtained from a sand at 9,130 ft. The negative slope of the ratio plot, C_1/C_2 to C_1/C_3, indicated that the zone was water-bearing. Subsequent formation tests showed water and non-commercial amounts of gas.

Plot 4 was obtained from the ppm Log of the Kovar No. 1 Well, Victoria County, Tex. The sand encountered from which the plot was made is at 10,120 ft. The gas show appeared to be good, but a negative slope of the C_1/C_3 ratio to the C_1/C_4 ratio was positive identification of a water-bearing formation.

Evaluation Technique

It is apparent that with this evaluation system, potential production can be accurately predicted. The only significant time lapse between penetration of the formation and evaluation of its productive possibilities is the time required to pump the mud from the bottom of the hole to the surface and analyze it by the Steam Still-Reflux and Chromatograph method. Fig. 4 shows the evaluation technique, which may be described as follows.

First, record the net increase of each gas component over the background gas; next, plot the ratios

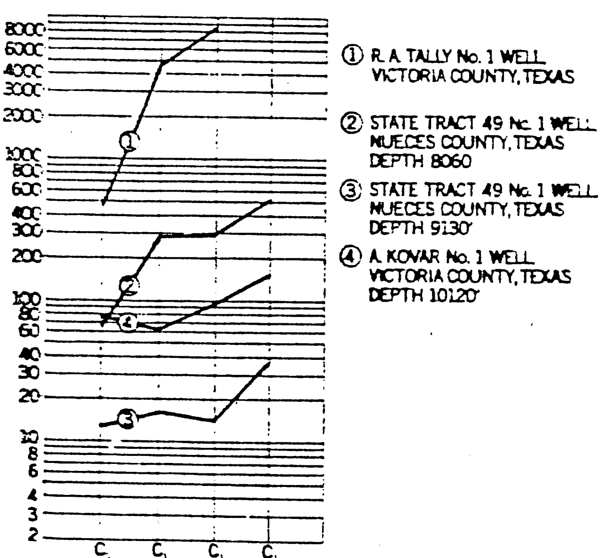


Fig. 3—Hydrocarbon ratio plots, nonproductive reservoirs. South Texas—analyses from gas shows on ppm Logs.

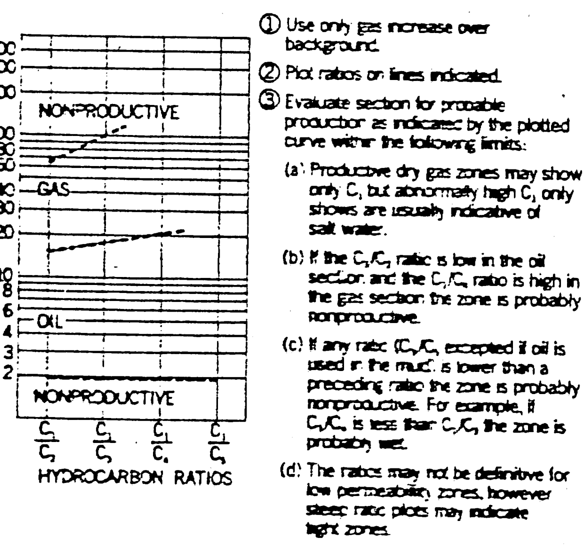


Fig. 4—ppm Log and report form for evaluation of show.

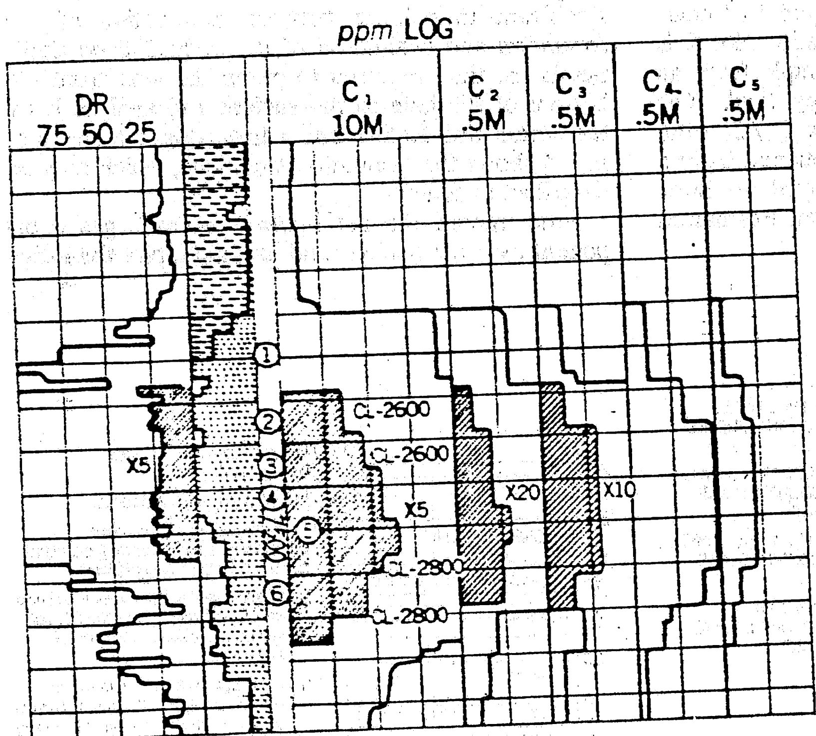
C_1/C_2, C_1/C_3, C_1/C_4, C_1/C_5 on the ratio lines as indicated. Then evaluate, within the following limits, the section in question for probable production as indicated by the plotted curve:

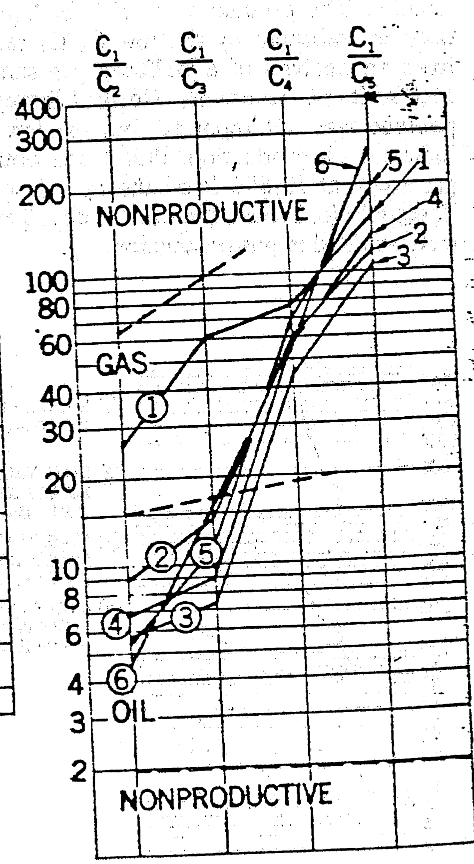
1. Productive dry gas zones may show only C_1, but abnormally high shows of C_1 only are usually indicative of salt water.
2. If the C_1/C_2 ratio is low in the oil section and the C_1/C_4 ratio is high in the gas section the zone is probably nonproductive.
3. If any ratio (C_1/C_5 excepted if oil is used in the mud) is lower than a preceding ratio, the zone is probably nonproductive. For example, if C_1/C_4 is less than C_1/C_3, the zone is probably water-bearing.
4. The ratios may not be definitive for low permeability zones; however, steep ratio plots may indicate tight zones.

Application

The ppm Log is only one of many tools that are ordinarily used for formation evaluation. But in many instances, the ppm Log has furnished the vital information necessary to make the final decision on a well. One well drilled in inland waters of Louisiana had what appeared on the ppm Log to be a good sand body, but the ppm Log showed only a nominal increase in gas. After the sand was penetrated and the well deepened, hole trouble was encountered. No other information of interest was available on the sand. The cost of the side-tracking to investigate the sand was sizable. Tight hole conditions and the low magnitude of the gas show indicated that the sand had good permeability and that possibly formation hydrocarbons had been flushed ahead of the bit. A plot of the hydrocarbon ratios indicated oil production. Therefore, at considerable expense, the sand was investigated and a new oil field was found.

An interesting well recently drilled in St. Martin Parish, La., was the No. 1 St. Martin Bank and Trust located on the southeast flank of the Anse La Butte Dome. A good sand encountered at about 8,000 ft showed oil, but the negative slope of the ratio plot indicated that the sand was water-bearing. The well was deepened to approximately 9,600 ft. One of the partners, a successful independent with a talent for finding oil by "feel" and by prudent use of the latest technology, decided that the formations in which the well was being drilled were tilted to almost vertical.





HYDROCARBON RATIOS

PLOT	C_1/C_2	C_1/C_3	C_1/C_4	C_1/C_5
1	26	62	78	155
2	8.6	14	59	118
3	5.6	7.4	46	106
4	6.8	9.1	56	130
5	5.4	11	70	193
6	4.5	15	54	254

Fig. 5—ppm Log and hydrocarbon ratio plots, No. 1 St. Martin Bank and Trust Well, St. Martin Parish, La.

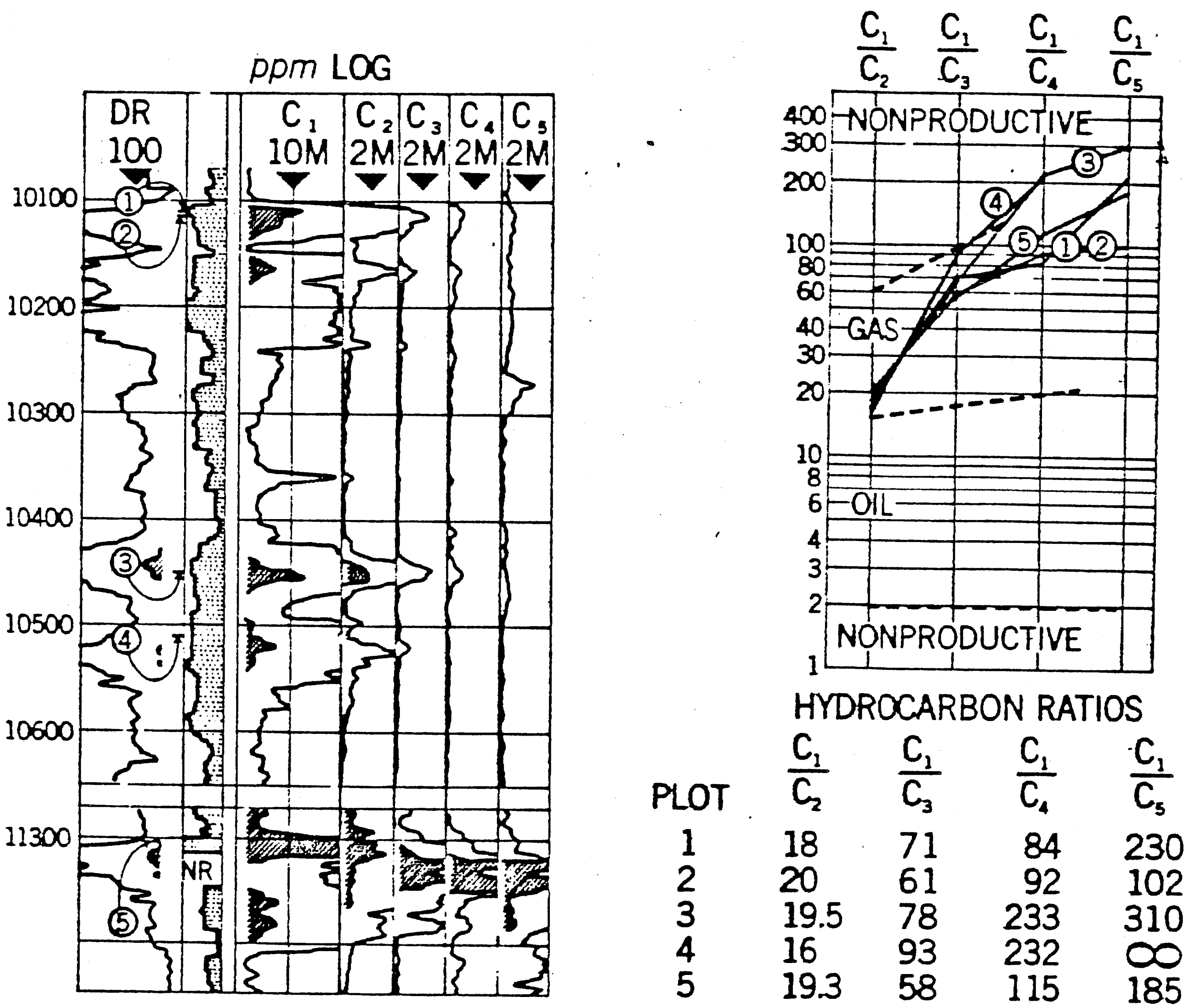
On his recommendaion the well was plugged back to about 7,000 ft and sidetracked. The sand that was drilled at 8,000 ft in the first hole was encountered in the directional hole at approximately 7,400 ft and the entire sand was hydrocarbon saturated.

The ppm Log and the ratio plots from the sand in the sidetrack hole are shown in Fig. 5. Table 1 shows the mud gas components related to percent of total gas. In actual practice the ppm gas shows obtained from the ppm Log are not converted to percent of total gas; but note the general decrease in percent methane in the lower section of the sand compared with that in the upper section. The magnitude of the gas show in the straight hole and in the sidetrack hole was significant. An accurate determination, however, of the composition of the gas in both cases led to correct conclusions on the potential productivity of the sand at the different depths in each hole. Note that the ratio Plot 1 at the top of the sand indicates a gas cap. As shown in Table 1, the gas was 93.1 percent methane. Subsequent plots indicated that production would be oil. In each of these cases the C_1/C_2 ratio was less than 9. The lowest ratio, 4.5, is shown in Plot 6, which was made from the show at the bottom of the sand.

TABLE 1—MUD GAS COMPONENTS, PERCENT OF TOTAL GAS

Depth (ft)	C_1	C_2	C_3	C_4	C_5
7,460	93.1	3.6	1.5	1.2	0.6
7,475	82.4	9.6	5.9	1.4	0.7
7,485	74.4	13.3	10.0	1.6	0.7
7,490	78.0	11.4	8.6	1.4	0.6
7,500	77.0	14.3	7.2	1.1	0.4
7,515	76.1	17.1	5.1	1.4	0.3

Another example of the application of the ppm Log is No. 1 State Tract 198 Well, Aransas County, Tex. Many sands were encountered showing the presence of hydrocarbons. The logging crew submitted more than 60 ratio plots to the operator during the drilling of the well. In almost all instances subsequent information verified the logging engineers' predictions of probable productivity based on the ratio plots. Fig. 6 shows a section of the ppm Log and the ratio plots for this well. The gas composition relating the percent of each gas component to the total gas is shown in Table 2. Gas condensate production is indi-



PLOT	C_1/C_2	C_1/C_3	C_1/C_4	C_1/C_5
1	18	71	84	230
2	20	61	92	102
3	19.5	78	233	310
4	16	93	232	∞
5	19.3	58	115	185

Fig. 6—ppm Log and hydrocarbon ratio plots, No. 1 State Tract 198 Well, Aransas County, Tex.

TABLE 2—MUD GAS COMPOSITION, PERCENT OF TOTAL GAS

Depth (ft)	C_1	C_2	C_3	C_4	C_5
10,110	92.0	5.2	1.3	1.1	0.4
10,115	92.0	4.6	1.5	1.0	0.9
10,450	93.3	4.8	1.2	0.4	0.3
10,520	92.8	5.8	1.0	0.4	0.0
11,305	92.3	4.8	1.6	0.8	0.5

cated by the ppm Log and ratio plots as shown. The zones are tight marine deposits — especially the 10,520-ft zone. Plot 4 has the steepest line slope; pentane was not present. The slope of Plot 3 is steep. Plots 2 and 5 show more favorable (less steep) line slopes. The electric log and subsequent formation tests made of each zone indicated probable production. The well was completed as a gas condensate producer in the 11,300-ft section, which is the section plotted as No. 5.

Conclusions

Only qualitative shows of hydrocarbons in the mud can be derived from conventional mud logs. If chromatography is used, only a general indication of in-place gas composition is obtainable. Such hydrocarbon shows may be reported as units of gas or percent hydrocarbons or parts per million of gas in the air-gas mixture tested. Only the presence in relative amounts, not the actual quantity, of hydrocarbons in mud is indicated, and other supplemental information may be necessary to evaluate the formation in terms of potential productivity. However, if the composition of the gas sample obtained from the mud is representative of the in-place formation gas, then the gas analysis is accurate. The use of the Steam Still-Reflux Unit makes possible a report of formation gas composition on the ppm Log. Meaningful ratio plots of gas composition can then be made. Even though many factors affect the amount of reservoir fluid released to the drilling mud, reservoir potential productive capabilities can be determined by a study of the ratio of methane to each of the heavier hydrocarbon components. The hydrocarbon ratio plot is a unique technique and provides the operator with new information for evaluating productive possibilities of exploratory wells.

Computer programs involving percent gas in mud (ppm Log) and gas composition are being used in special cases to determine reservoir potential production. The use of computers in mud log interpretation, although new, will contribute significantly towards a better application of the data shown on the ppm Log.

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