SPE 362

OIL MUD LOGGING ON THE GULF COAST

by H. C. Robinson

Schlumberger Well Surveying Corporation
Beaumont, Texas

ABSTRACT

Effective logging programs are available for wells drilled with non-conductive oil muds. The basic log in such a program is the simultaneously-recorded Gamma Ray-Induction Survey. This log provides the primary means for correlation, depth control, and for determination of resistivity values for qualitative and quantitative interpretation.

The Sonic Log, used in conjunction with the resistivity values from the Induction Log, serves as an excellent detector of hydrocarbon-bearing zones.

Determination of porosity is best accomplished with the Formation Density Log. In addition to supplying reliable values of effective porosity, this is the most accurate logging means of determining the lithology of the sand-shale sequences, found in this area.

The use of Induction, Sonic, and Formation Density Logs provides data for complete interpretation of water saturation, effective porosity, and shale content.

Other wireline tools, such as Neutron, Dipmeter, Sidewall Coring, and Wireline Formation Testing, are effective in oil muds.

OIL MUD LOGGING ON THE GULF COAST

by H. C. Robinson
Schlumberger Well Surveying Corp.
Beaumont, Texas

Effective logging programs are available for wells drilled with non-conductive oil muds. Many of the logs are obtained with the same tools that are recommended for water-base mud logging. The interpretation techniques are also very similar. However, the fact that such oil muds are not electrically conductive requires some variations in both the services run and the interpretation methods used.

During the past year the frequency of drilling with oil muds has increased in the area of the upper Texas Gulf Coast. The formations in this area are relatively unconsolidated sand and shale series. While many of the points covered in this paper are broadly applicable, the examples and discussion are based exclusively on experience in this particular area.

For the purposes of this paper, oil muds are those in which a non- conductive fluid is the continuous phase. Thus, oil, oil-base, and inverted emulsion muds fall into this category. Regular oil emulsion muds, in which water is the continuous phase, are not included since such muds will conduct electrical current.

Basic Log

The basic log for oil muds is the simultaneously recorded Gamma Ray-Induction Log as shown in Figure 1. The role of this particular log is essentially the same as that of the Induction-Electrical Survey in water base muds. Correlation, depth control, and resistivity measurements for both qualitative and quantitative interpretation are afforded by this combination log. For correlation, the gamma ray is used in liew of the SP, and the induction conductivity curve is an excellent replacement for the short normal. The Induction Log reliably indicates true formation resistivity; there is no conductivity signal from the borehole. Experience in this

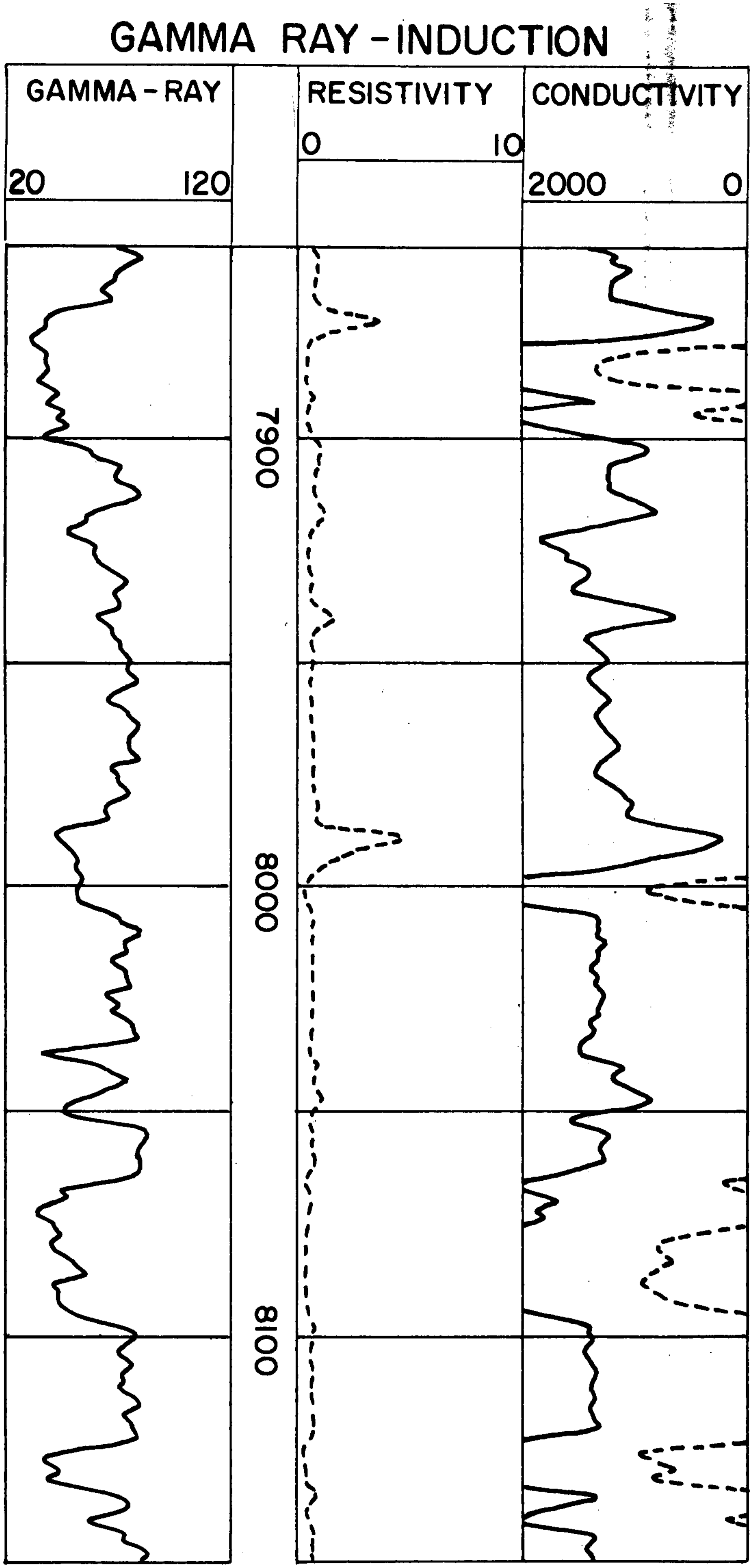

FIGURE 1 - GAMMA RAY-INDUCTION SURVEY . . . Simultaneously recorded in oil mud.

area indicates that there is little invasion of the beds by the oil.

The lack of an SP curve is the greatest shortcoming of the oil mud logging program. Since these muds are non-conductive, there is no spontaneous potential to record. In water-base mud logging, the SP curve is used for correlation and to identify sands and shales. It is one of the most effective means for determining the resistivity of formation water. In oil muds there is no comparable curve for determination of water resistivity; while the value may be computed through measurement of resistivity and porosity in a water sand, it is very helpful to have data on water resistivity from the logs or production of nearby wells. The other major application of the SP, differentiation between sands and shales, is handled by the gamma ray curve. In most cases, the shales are recognizably more radioactive than the sands. In such cases the Gamma Ray Log supplies adequate lithological control. However, in some cases the sands are almost as radioactive as the shales. To guard against mistakes thus caused in the identification of sands, other services are available and will be discussed.

Logging speeds in oil muds must be less than those normally used in water muds; the recording of the gamma ray curve makes this necessary. While the gamma ray may be recorded faster than normal, the quality of the recording deteriorates rapidly at speeds in excess of those recommended. Along the Gulf Coast the recommended logging speed is approximately 2000 feet per hour, or one third the normal logging speed for the Induction-Electrical Survey in water-base muds. Electrode-type resistivity tools, such as the short normal or the microlog, cannot be used in oil muds. These devices require a mud that will conduct electrical current to the formations. However, since there is little or no invasion of formations by oil muds, the main necessity for shorter spacing resistivity devices is eliminated.

Porosity Control

In water base muds, the Sonic Log provides supplementary formation data to help detect oil or gas zones, and to compute values of porosity and water saturation. The Sonic Log is also effective in oil muds. Previously published interpretation techniques for the sonic-resistivity methods apply equally well in oil muds.

In the example shown on Figure 2, the Rwa plot, as computed from Sonic and Induction Logs (Table I), readily indicates the productive intervals. The hard streak at 8610' is recognized as such with the Sonic Log; with only the induction and gamma ray curves this point might easily have been considered productive.

TABLE I

Depth	R_{IL}	Δt	R_{wa}	Interpretation
8503	3.30	155	1.30	Hydrocarbon
8508	2.30	170	1.30	Hydrocarbon
8517	0.59	130	0.11	Shale
8540	0.87	110	0.08	Water
8554	0.60	118	0.08	Water
8564	0.66	124	0.10	Shale
8568	0.84	110	0.08	Water
8597	0.84	110	0.08	Water
8603	0.66	123	0.10	Shale
8610	2.10	93	0.09	Water - tight
8620	1.50	133	0.30	Hydrocarbon
8629	0.90	120	0.12	Shaly - Hydrocarbon
8634	1.00	124	0.15	Shaly - Hydrocarbon
8646	0.62	115	0.07	Shaly - Water
8652	0.59	133	0.12	Shaly - Hydrocarbon
8657	0.76	114	0.09	Shale
8667	0.76	117	0.09	Shaly - Hydrocarbon
8672	1.50	125	0.24	Hydrocarbon
8687	0.62	127	0.10	Shale
8702	1.25	137	0.28	Hydrocarbon
8713	5.30	135	1.20	Hydrocarbon
8719	1.90	140	0.43	Hydrocarbon
8726	0.36	116	0.04	Water
8744	0.90	70	0.01	Limy
8750	0.51	93	0.02	Limy
8762	1.00	79	0.02	Limy

Simultaneously with the recording of the sonic curve, both a gamma ray and a caliper may be recorded. The presence of the gamma ray on both Sonic and

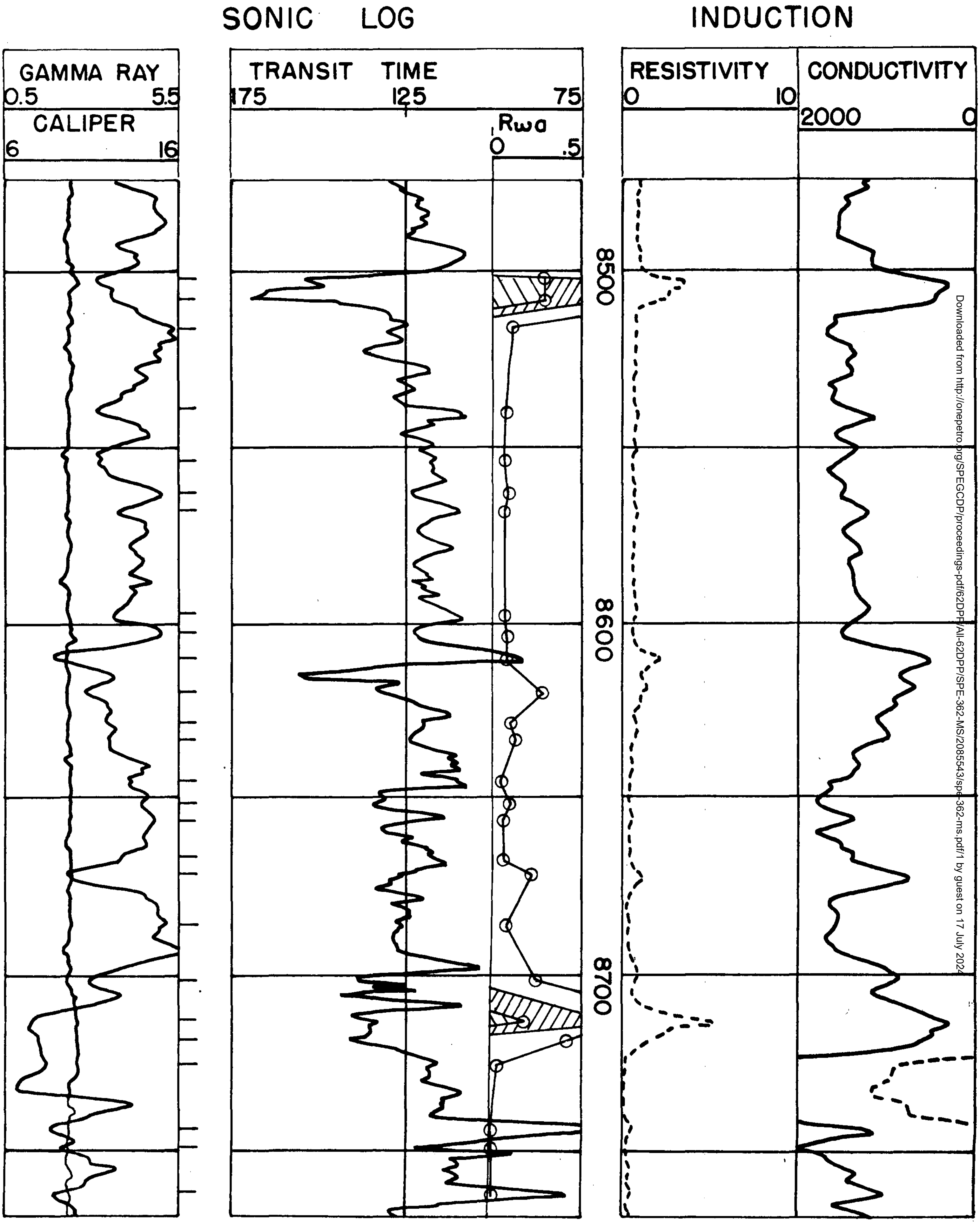

FIGURE 2 - SONIC-GAMMA RAY-CALIPER LOG . . . Shown with Induction Log and R_{wa} plot.

Induction Logs facilitates the positive matching of depths. Experience in logging wells along the upper Texas Gulf Coast indicates that the wells drilled with oil muds tend to remain close to bit size; there is very little evidence on the caliper curves of hole enlargement.

Another technique for determining porosity and computing water saturations makes use of the Formation Density Log. The particular device (shown in Figure 3) used in these studies has only recently been introduced in the Gulf Coast area. Essentially, it is engineered to measure the bulk density of formations. The principle of operation of the tool is as follows: a radioactive source and a detector are mounted in a skid that is pressed against the wall of the hole; gamma rays emitted by the source are scattered in the formation -- some reach the detector and are counted; the lower the density of the formation the greater will be the number of gamma rays reaching the detector.

The formation density curve is scaled in standard counts per second. The chart shown in Figure 4 is used to convert the count rate to bulk density; the latter is expressed in grams per cubic centimeter. This particular chart is appropriate for liquid-filled holes in which no wall cake is present. Similar charts are available for wells drilled with mud or with air.

Figure 4 shows that the counting rate is affected, to a slight degree, by hole size. A caliper curve is recorded simultaneously with the density log to provide this information on hole size. It is also important that the skid be against the wall of the hole; if the skid is not against the wall, as in the case of a caved zone, high counting rates will result.

Once the bulk density of the formation is determined, porosity may be computed through the use of the following expression:

$$\phi = \frac{\rho G - \rho B}{\rho G - \rho F}$$

where ϕ = Porosity

ρB = Bulk density as obtained from the log,

ρG = Grain density; 2.65 gm/cc for sand, and

ρF = Density of fluid in the formation.

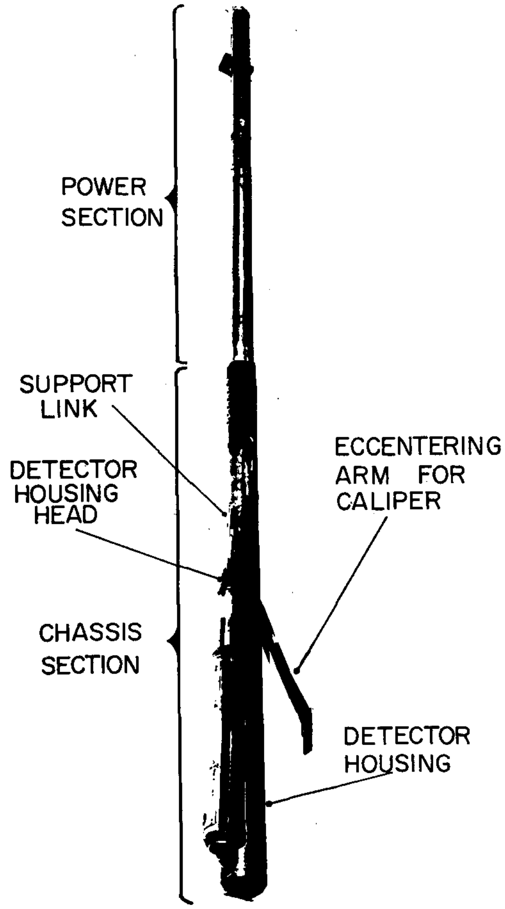

Fig. 3 - FORMATION DENSITY TOOL

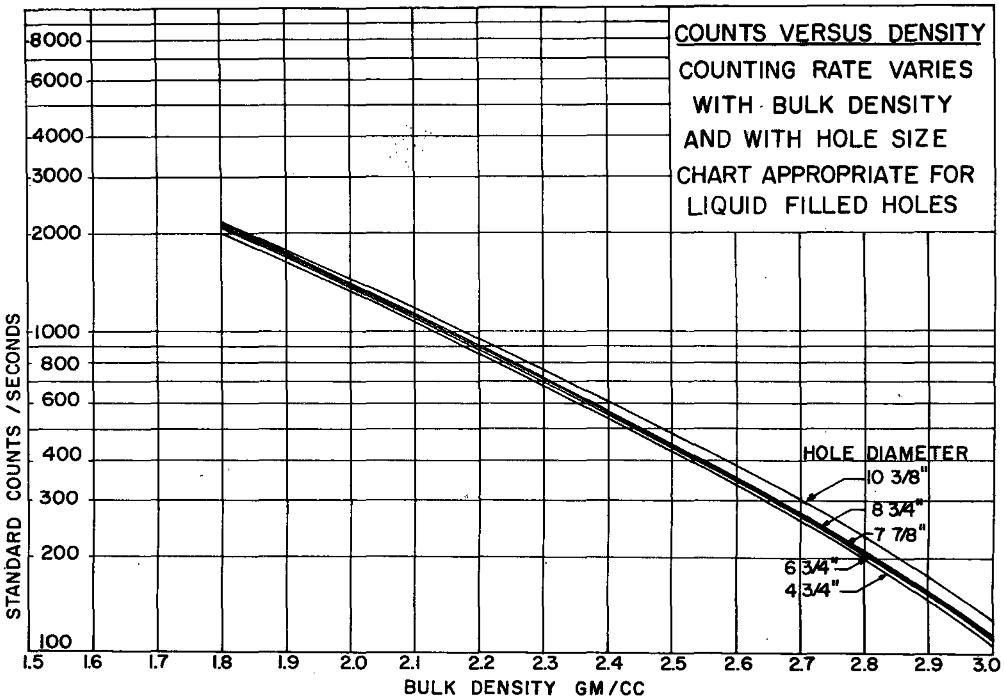

FIGURE 4

The density of formation water will depend upon the temperature, salinity, and pressure. The value will normally range between 0.95 and 1.10 gm/cc. For purposes of computation of porosity the water density is normally considered to be 1.00 gm/cc. Errors resulting from such an assumption are small, for water-bearing sands.

Both oil and gas have lower densities than water. Therefore, in productive intervals it is usually necessary to correct the erroneously high values of porosity that are obtained by solution of the formula. For oil sands good results have been obtained by multiplying the computed porosity by a factor of 0.9. In low-pressure gas sands, particularly at shallow depths, the correction is more severe. Reasonable agreement with known formation porosity has been obtained using a multiplying factor of 0.7 in gas sands. These corrections are incorporated in the chart of Figure 5. These same correction factors, 0.9 for oil and 0.7 for gas, are normally used in correcting Sonic-derived porosities in pay zones that have only shallow invasion.

A comparison of bulk density versus resistivity, similar to the sonic-resistivity methods, is very helpful in identifying hydrocarbon zones. Figure 6 shows Formation Density and Gamma Ray-Induction Logs run in an oil-mud well. Values of resistivity and bulk density, taken at the indicated points, clearly distinguish between oil and water zones when plotted on the chart shown in Figure 7. In this case the Ro line, corresponding to 100% water saturation, was computed on the basis of a grain density of 2.65 gm/cc and a formation water resistivity (Rw) of 0.046 ohm-meters. The formation water resistivity was obtained from measurements of water produced from nearby wells. Points 1 and 6 plot near the Ro line. The points corresponding to the productive intervals at 2, 3, 5, 7, and 8 plot well below the 100% Sw line. The plot graphically indicates that these intervals are productive. In clean sands the productive intervals are easily distinguished from water zones.

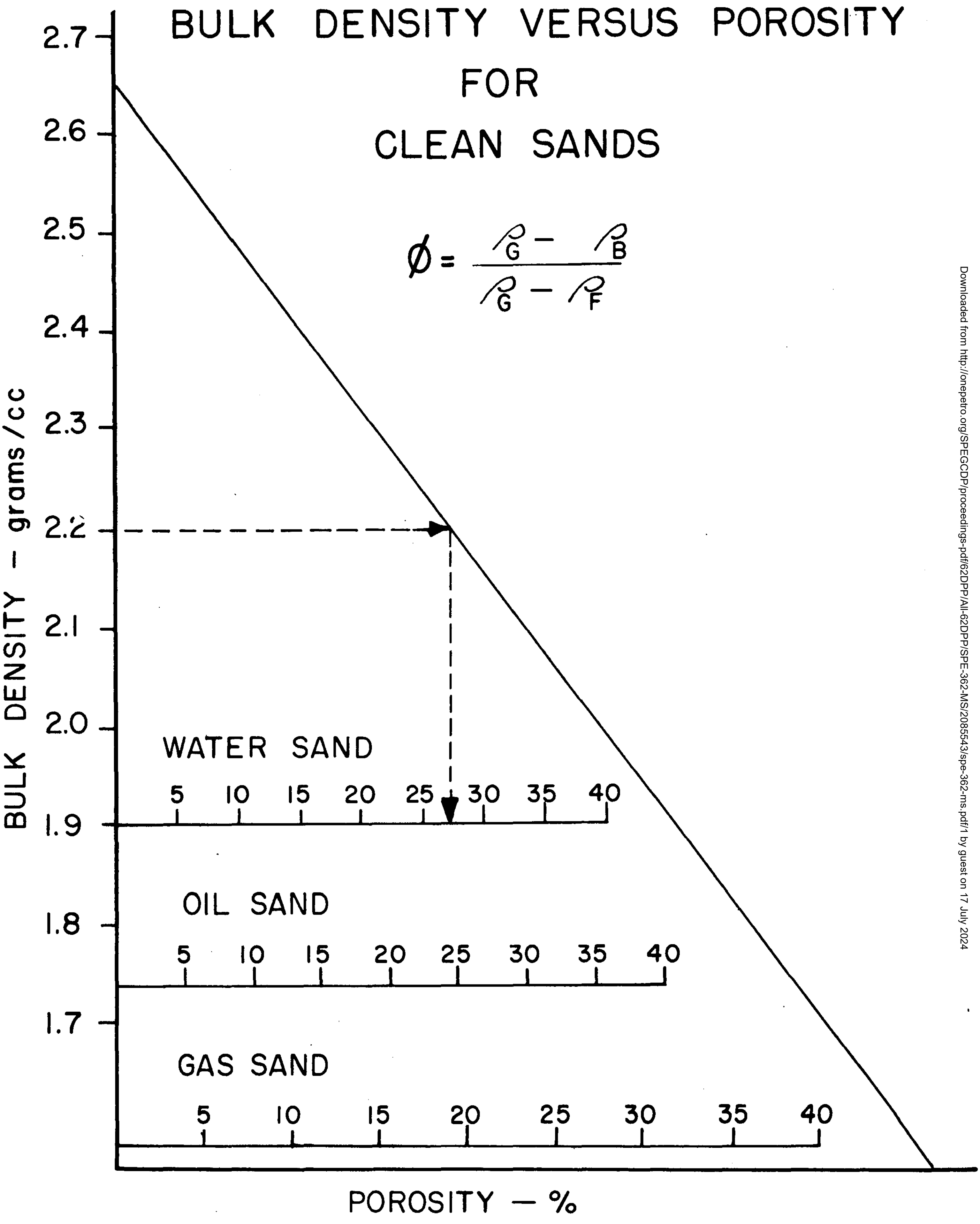
BULK DENSITY VERSUS POROSITY
FOR
CLEAN SANDS
$\phi = \frac{\rho_G - \rho_B}{\rho_G - \rho_F}$
BULK DENSITY - grams/cc
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
WATER SAND
5 10 15 20 25 30 35 40
OIL SAND
5 10 15 20 25 30 35 40
GAS SAND
5 10 15 20 25 30 35 40
POROSITY — %

FIGURE 5

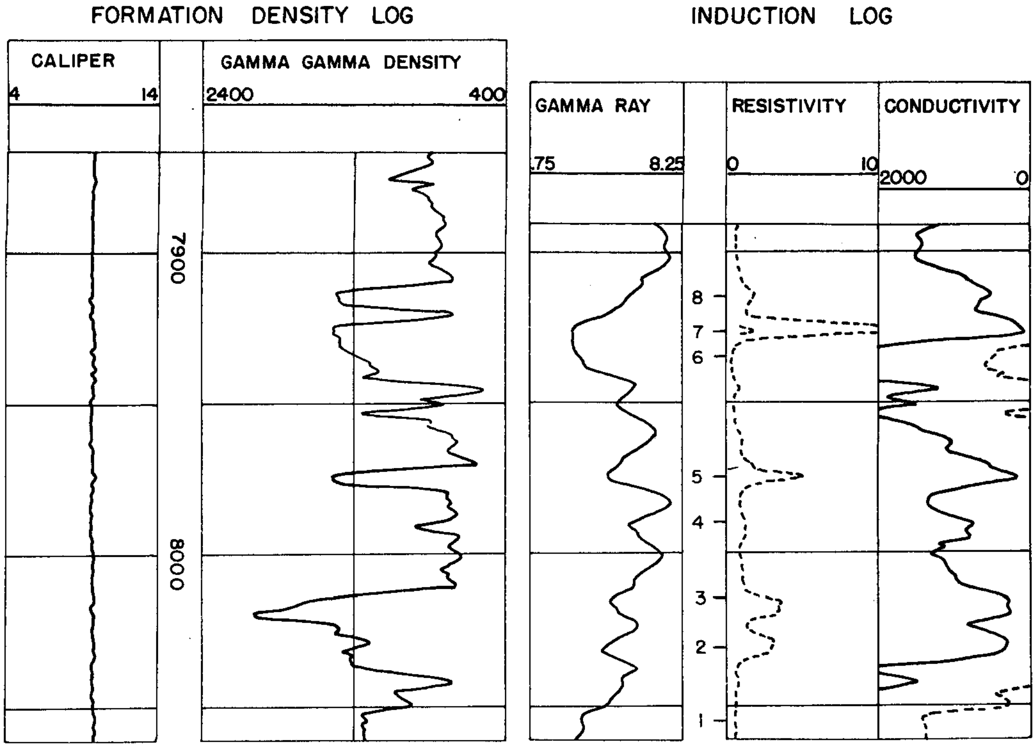

FIGURE 6 - FORMATION DENSITY LOG . . . Shown with Gamma Ray-Induction Log. Caliper curve indicates hole diameter remains close to bit size of 9-7/8".

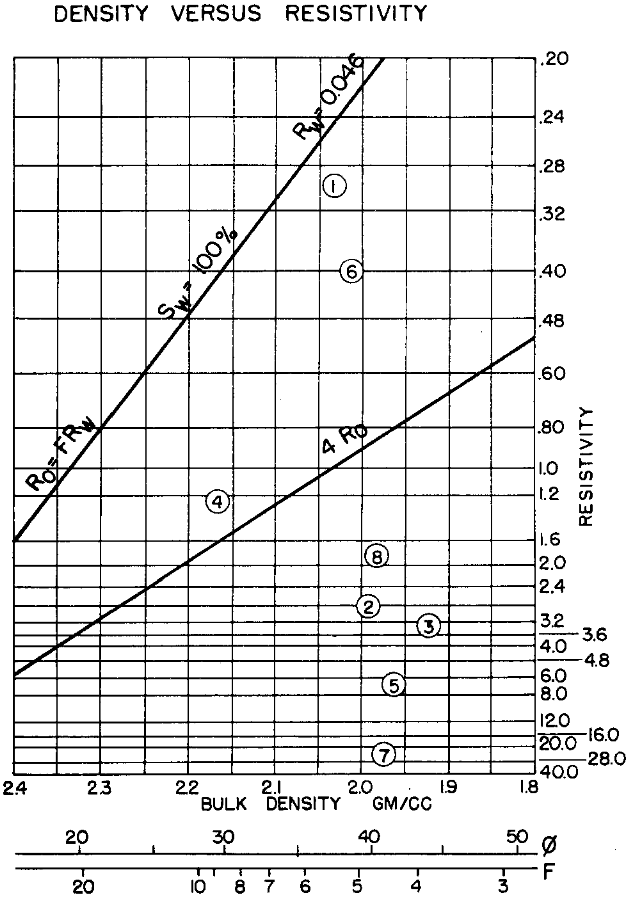

FIGURE 7 - PLOT OF DENSITY VERSUS RESISTIVITY . . . . data from example shown in Figure 6.

The presence of shale in a sand serves to reduce its effective porosity. This reduction is apparent on the Formation Density Log. The shaly oil sand at point 4 plots to the left and above the cleaner productive zones. The presence of the shale has increased the bulk density and decreased the resistivity. It can be seen that a shaly oil zone is not so readily identified by this method.

Though not shown on Figure 7, shale zones would be found to plot on or near the Ro line. For example, the shale at 7983 feet (Figure 6) has a Formation Density Log reading of 750 cps, corresponding to a bulk density value of 2.29 gm/cc. The Induction Log at this point indicates the shale resistivity to be 0.74 ohm-meters. The plot of this point falls on the Ro line. This tendency for shales to plot on or near the Ro line suggests that an estimate of the water resistivity may thus be obtained.

One of the major advantages of the Formation Density Log is its ability to furnish effective porosity values. Here, along the Gulf Coast, the formations are almost exclusively sand and shale. The shales customarily have a higher bulk density than the porous reservoir sands. Thus, the Formation Density Log is an excellent indicator of lithology. As previously mentioned, the gamma ray curve is not always effective in distinguishing between sand and shale. Figure 8 illustrates a case in which a water sand with relatively high radioactivity (2952 to 2969 feet) is well defined by the density log. The gamma ray curve fails to identify the zone as sand.

The similarity between the Formation Density Log and an SP curve is illustrated in Figure 9. The density log was recorded in a well drilled with oil mud. The SP curve was recorded in an offset well drilled with fresh water mud. The sand anomalies are amplified by the sensitive scale of the density log, but they are readily correlatable with the SP anomalies. The efficiency of the density curve in defining lithology is a strong recommendation for its use in oil muds.

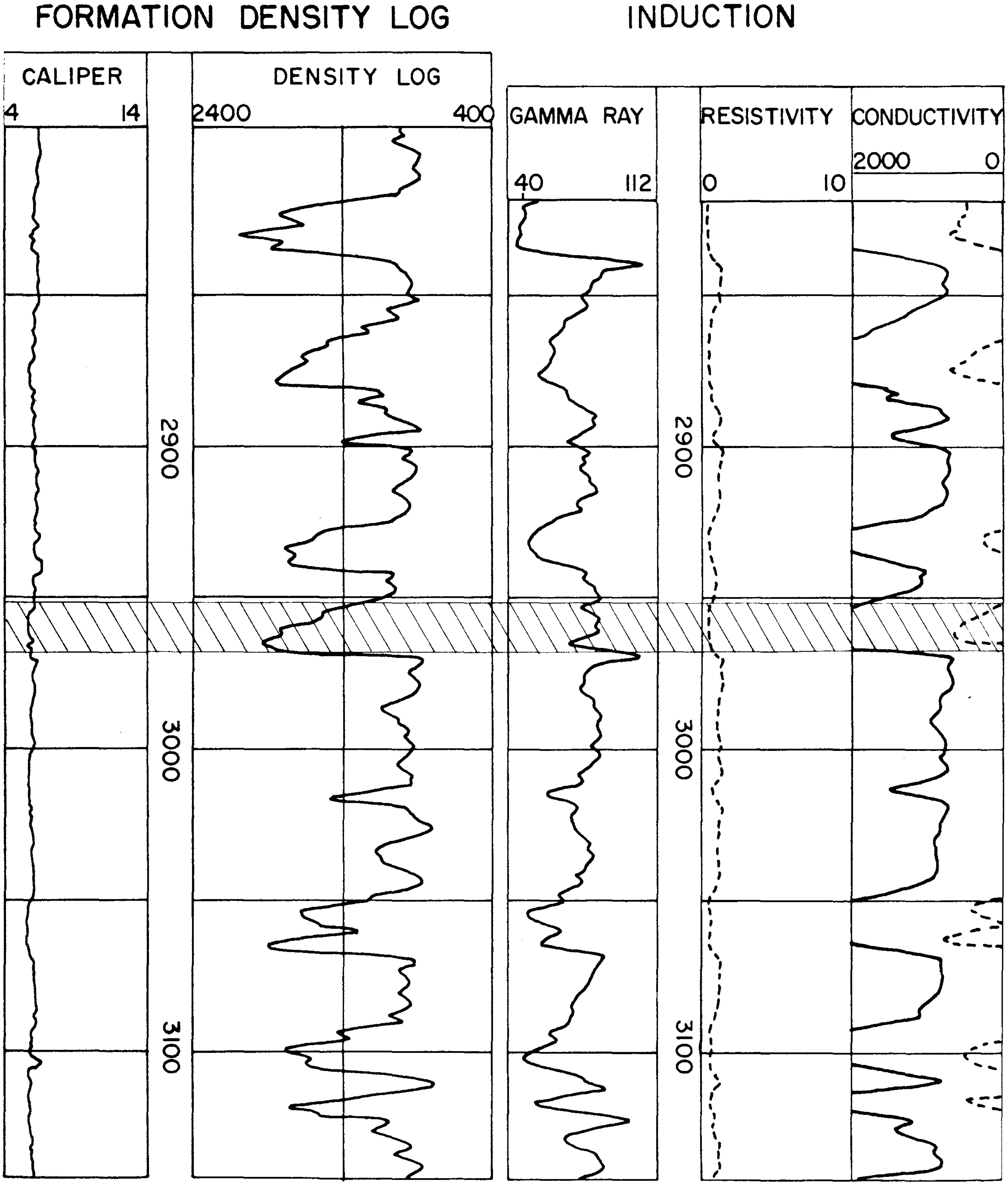

Figure 8 - Formation Density Log identifies sand (2952-2969 feet) that is abnormally radioactive.

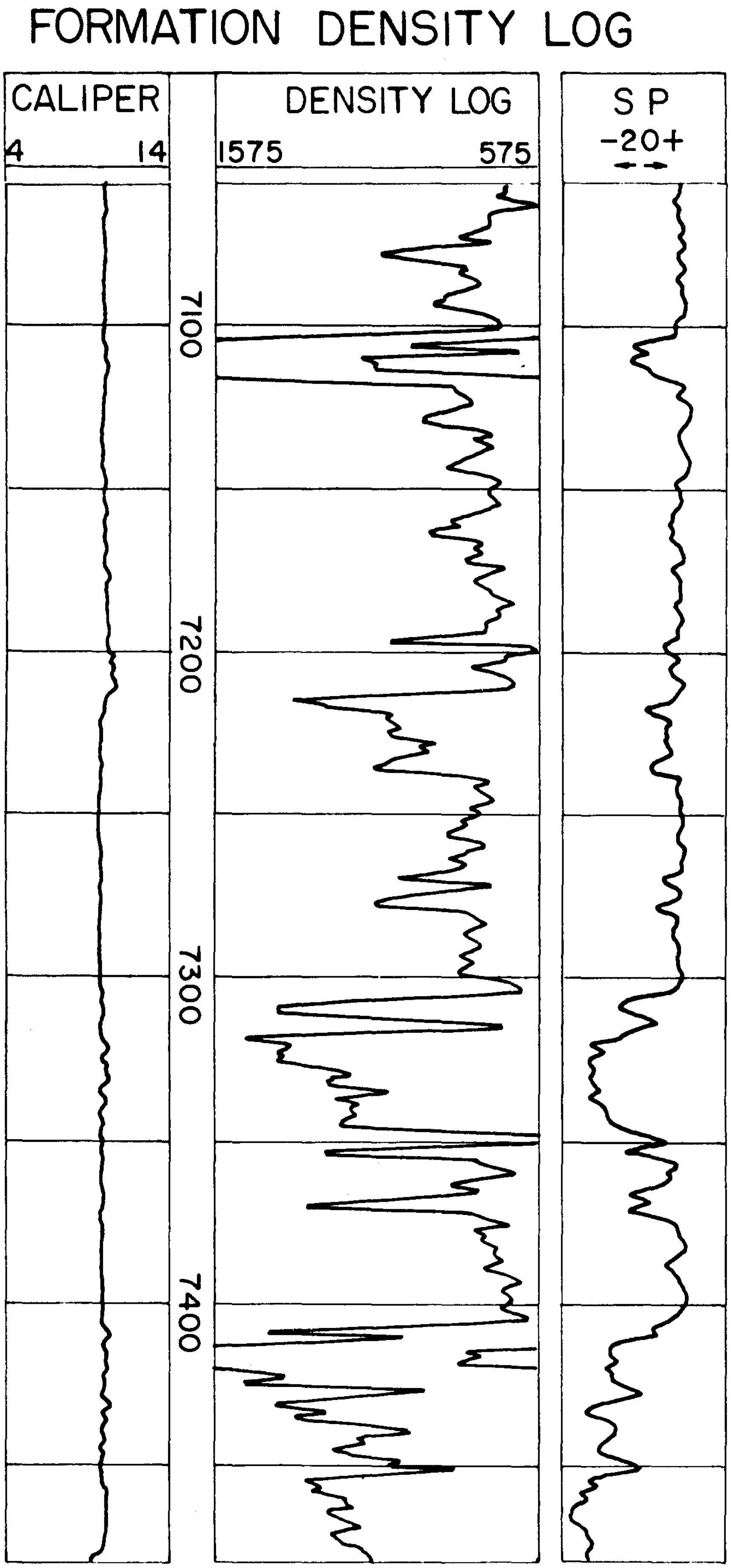

FIGURE 9 - COMPARISON OF FORMATION DENSITY LOG AND SP CURVE . . . The SP was recorded in an offset well drilled with water-base mud.

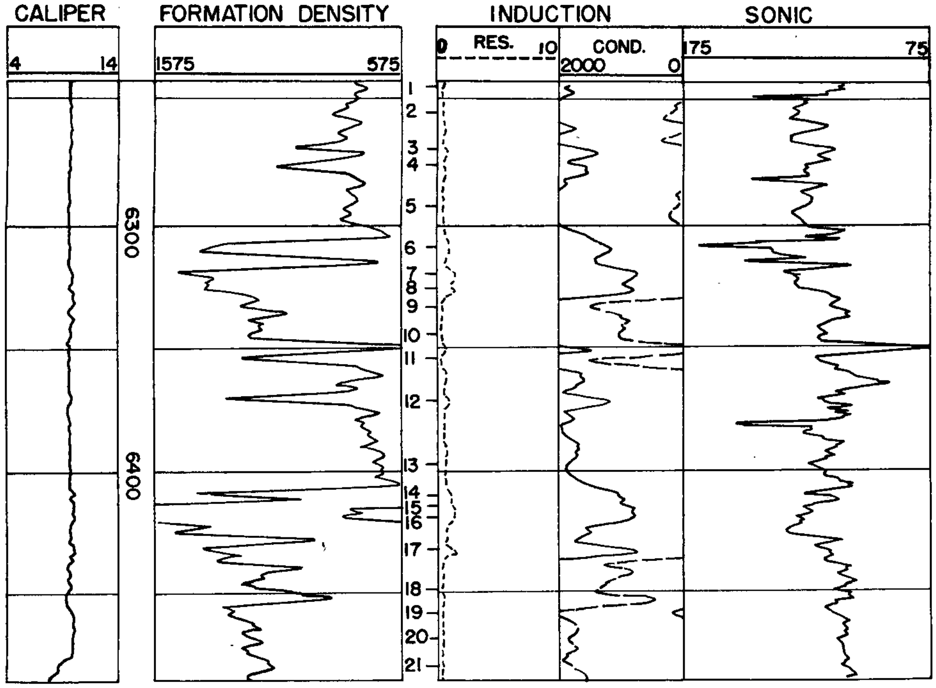

FIGURE 10 - FORMATION DENSITY, INDUCTION, AND SONIC LOGS . . . recorded in oil-mud.

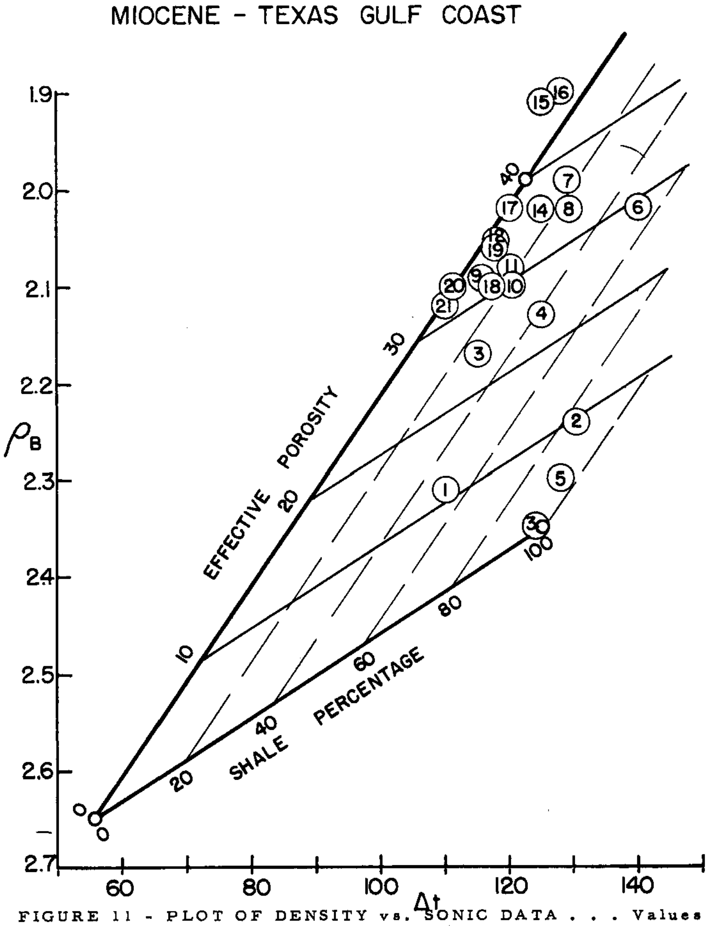

FIGURE 11 - PLOT OF DENSITY vs. SONIC DATA . . . Values taken from examples in Figure 10.

Sonic and Density

When both Sonic and Formation Density Logs are available, greater confidence can be placed in the results of interpretation. These two porosity devices permit safer identification of productive intervals and afford better lithological determination. The Sonic Log does not reliably differentiate between sand and shale, and, as previously indicated, the gamma ray is sometimes misleading. The problem of identifying sands, and evaluating their shale content, is greatly facilitated if a Formation Density Log is available.

Figure 10 presents the Sonic, Density, and Induction Logs as recorded on an Upper Gulf Coast well. The well was drilled with oil mud.. Figure 11 is an example of the method of using the Sonic and Formation Density Logs to determine both lithology and effective porosity. The construction of this chart is based upon three points; for 100% shale, the log values of $\Delta t_{sh} = 125$ and $\rho_{sh} = 2.35$ are used; the zero-porosity, clean sand is plotted according to the normally accepted matrix values of $\Delta t_m = 55.5$ and $\rho_G = 2.65$; the values for the third point, that of a clean water sand with 40% porosity, are computed using $\rho_G = 2.65$, $\rho_F = 1.00$, and $\Delta t_m = 55.5$, $\Delta t_F = 189$, and $c\Delta t_{sh} = 125$. The solution of the customary formulas, using this latter data, provides values of $\Delta t = 122$ and $\rho_B = 1.99$. Once the basic chart is constructed, the values of Δt and ρ_B in the interesting zones are read from the logs and plotted on the chart. Clean water sands will plot on or near the line described by the two clean sand points. Shaly sands will plot to the right of the clean sand line. The shalier the sands are, the closer they will approach the plot of the 100% shale point. It is considered that the relative displacement from the clean sand line toward the shale point is a measure of the percent of shale in the zone. The effective porosity of the zone, including the shale, may be read by interpolating between the lines parallel to that described by the 100% sand matrix and the 100% shale points.

In the case of sand-shale laminations, the porosity of the sand streaks may be determined by extending a line from the 100% shale point, through the plotted point for the zone, to the clean sand line. The sand porosity is then read from the scale on this clean sand line.

Gas sands will occasionally plot to the left of the clean sand line. Such a plot is normally experienced in clean, gas sands of relatively high porosity.

Once these values of effective porosity for the zone, percent shale, and porosity in the sand streaks are determined, the usual methods for determination of water saturation and permeability may be employed.

The density-resistivity method, alone, lacks the necessary resolution for identifying production in shaly sands. The shaly oil sand, point 4 on Figure 6, plotted disturbingly close to the 100% water saturation line on Figure 7. While the Sonic Log may fail to reliably distinguish between shale and sand, it does help to locate pay zones in both clean and shaly sands. With the Sonic Log, the shaly sand at point 4 would be identified as productive; the Formation Density Log then provides the important data on effective porosity and relative shale content.

With both the sonic and density measurements, the oil finding efficiency of the sonic-resistivity method is augmented by the porosity determinations from the Formation Density Log. A more positive interpretation is possible.

Other Services

In addition to the logs already discussed, many other services are available for wells drilled with oil muds. The Neutron Log, for example, is very useful for identifying gas-liquid contacts when compared with either the Sonic or Formation Density Logs. Dipmeter Logs can be run with special knife-blade pads; results from such logs in this area are excellent.

Both sidewall cores and wireline formation tests may be taken in oil muds. Positioning of these devices is accomplished with a gamma ray tool. Determinations of porosity and permeability from the sidewall cores are just as effective as in the case of water-mud wells; however, in some instances the fluid saturations may not be obtainable. Experience in this area has shown that the better condition of holes drilled with oil reduces the possibility of sticking the tools. In addition, the very shallow invasion by oil muds permits tests that are representative of formation fluids.

CONCLUSIONS

The use of oil muds in the Gulf Coast drilling programs has required a change in the types of logging services used, in order to obtain the maximum amount of information. In addition to the basic Gamma Ray-Induction Log, the Sonic and Formation Density Logs provide porosity and saturation data.

Other useful services which can be run in oil muds include the Neutron Log and the Dipmeter. Sidewall Cores still furnish porosity and permeability data even though they may be contaminated with the drilling oil.

Wireline Formation Tests are usually better in oil-mud holes, because of shallow invasion, than in water-base mud wells.

Thus, when it is advantageous to drill with such oil muds, an effective logging program is available to adequately provide the means for correlation, depth control, and interpretation.

ACKNOWLEDGMENTS

The author is indebted to R. P. Alger, L. L. Raymer, R. L. Morris, and W. P. Biggs for their assistance in the preparation of this paper. Thanks are extended to the various oil companies who permitted the use of their logs.

REFERENCES

R. P. Alger, "Modern Logging Programs and Interpretation Methods", Schlumberger Well Surveying Corporation, 1961.

Tixier, M. P., Alger, R. P., and Doh, C. A., "Sonic Logging", Trans. AIME (1959) 216, 106.

Tixier, M. P., Alger, R. P., and Tanguy, D. R., "New Developments in Induction and Sonic Logging", Journal Petroleum Technology, May, 1960, p. 79.

Burton, R. P., "New Log Interpretation Techniques for the Gulf Coast", 9th Annual Convention of GCAGS and the 1959 Fall Regional Meeting of AAPG, Houston, November 11-13, 1959.

Phillips, H. C., and Petty, L. Jr., "Development and Interpretations of Formation Testing on Logging Cable", API Meeting, February 26, 1958.

Rodermund, R. P.,Alger, R. P., and Tittman, J., "Empty Hole Logging", Oil and Gas Journal, June 12, 1961.