RELATION OF ELECTRIC LOG RESISTIVITIES IN LIMESTONE TO OIL PRODUCTION

WILLIAM P. MILNE
University of Oklahoma, Norman

HYPOTHESIS: Oil productivity can be correlated with the deviation from the apparent parallelism of the second and third resistivity curves exhibited on the electrical log diagrams in limestones.

Apparent parallelism means here that the second and third resistivity curves would be identical if their scales were the same. In Fig. 1, the Mississippi Limestone shows this exceedingly well. The values on the third curve are approximately three times those of the normal curve. The difference in scale measurement is an approximate relationship between the two spacings.

All of the current writers on electric log interpretation demonstrates the effect of the contact between two different formations on the electric log diagram. They show that it produces boundary figures, one of which is illustrated in the basal portion of the Mississippi Limestone in Fig. 1.

Another cause for the deviation from the apparent parallelism is mud invasion. However, in the area studied the mud invasion was so small as to be negligible. Its effect can be corrected graphically, in some cases, even though the invasion is pronounced.

The fourth cause of the deviation is the fluid content. Salt water tends to give a negative deviation, whereas oil, being more resistant, gives a positive deviation. Since major interest is in estimating the production of oil and because other authors have worked out the oil-water ratio effect on the electric log diagram, concentration will be on the correlation of the deviations with productivity.

To do this, an arbitrary variable, Φ, will be defined here as the average deviation divided by the square root of the quantity, the average square of the deviation minus the deviation squared.

$$\Phi = \bar{d}/S_d = \sum_{i=1}^{n} d_i \Big/ n \sqrt{\frac{1}{n} \Sigma d_i^2 - \bar{d}^2}$$

Where d_i = deviation

$\Sigma d_i^2 = d_1^2 + d_2^2 + d_3^2 + \dots + d_n^2$

n = number of observations

The n in the equation may be found by simply counting the number of measured deviations or the number of operations. The deviation, d, is a little more involved. First, the resistivity side of the electric log must be plotted graphically on a convenient continuous scale. (Fig. 1.) Because of the electrode arrangement and the fact that oftentimes no scale alignment method is used in making the electric log, it is necessary to shift the second curve to match the boundary figures of the third curve. The amount of shift in the diagrams is related to both the electrode arrangement and spacing. (Fig. 2.)

Third, as was indicated earlier, the second curve must be expanded to a scale comparable to that of the third curve. The difference between the two curves is related to the difference in spacing. (Fig. 3.) This difference may be adjusted by using small whole numbers like two, three, and four (as yet two and four have not been used) to expand the second curve. The

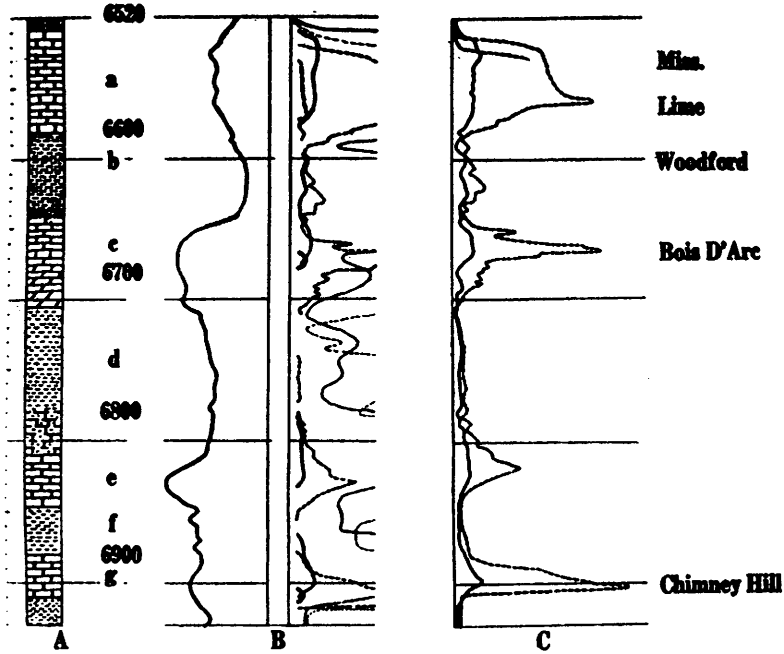

FIGURE 1

selection of the scale multiplier will depend on matching the slopes of the figure at the top and bottom of the formation.

Finally, the deviations are actually measured. It does not matter whether these deviations are measured in inches feet, miles or centimeters because by the definition of Φ the investigator is permitted to use any units whatsoever, just so long as the units are consistent throughout one given formation. Paul G. Hole, in his text *Elementary Mathematical Statistics*, has shown that it is permissible to compare samples measured in different units as long as the samples are converted to standard units. That has been done by the definition of the variable, Φ.

The Phillips No. 2 Kosar Well 4-14N-4W was used to test this method of approach. (Figs. 1 and 4.) The scale alignment correction was ten feet. The scale correction factor was three. Figure 4 shows the values of the deviation measured every two feet in the Bois D'Arc and Chimney Hill producing horizon of the Hunton in the West Edmond Pool. By referring to the formula, it is seen that the sum of the deviations, the sum of the squares of the deviations, and the number of observations are needed. It will be noticed that a Φ value must be worked out for each formation. The values

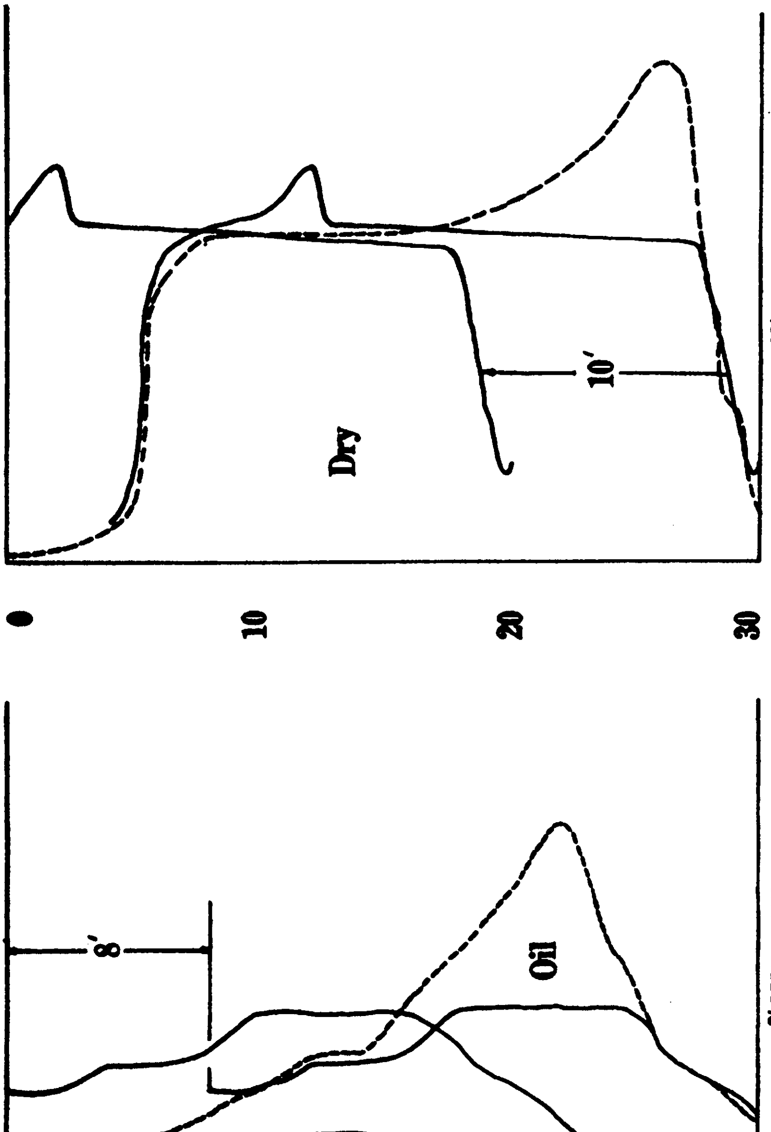

FIGURE 2. Graphic Alignment

are substituted in the formula as illustrated and a ϕ value for the Bois D'Arc and Chimney Hill is obtained.

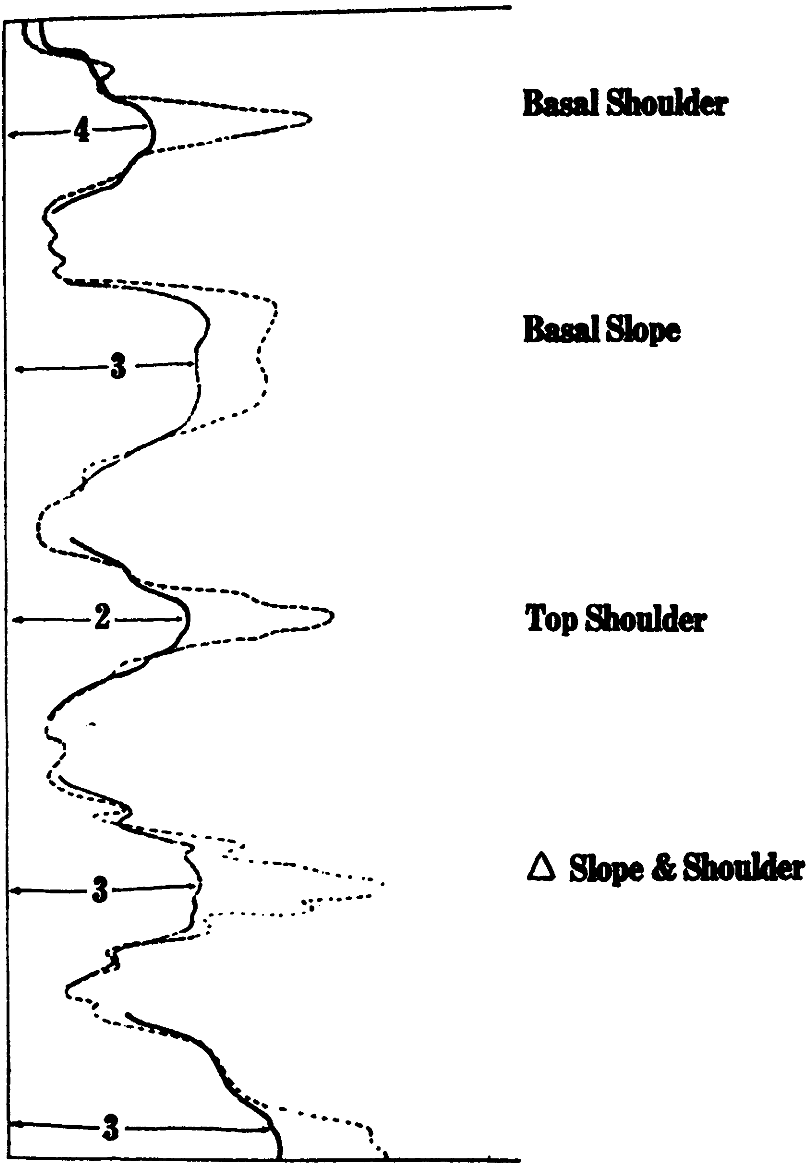

FIGURE 3. Scale Adjustment

$$\Phi = \bar{d}/S_d = \frac{1}{n}\sum_{j=1}^{n} d_j \Big/ \left(\frac{1}{n}\sum_{j=1}^{n} d_j^2 - \bar{d}^2\right)^{1/2}$$

$$\bar{d} = \frac{1}{n}\sum d_j = \frac{1}{n}(d_1 + d_2 + d_3 + \dots + d_n)$$

n = no. of d_j = ½ thickness of zone in feet

d	d^2	
0	0	$n = 8$ $\bar{d} = 14.0$
3	9	
13	169	
33	1089	$\Phi = \frac{\frac{1}{8}(111)}{\left[\frac{1}{8}(3309) - (14)^2\right]^{\frac{1}{2}}}$
43	1849	
12	144	
7	49	
0	0	
$\Sigma d = 111$	$\Sigma d^2 = 3309$	$\Phi = 0.9491$

Bois D'Arc $\Phi = 0.9491$ $p = 21^{bbl}/_{hr}$ ½" choke

d	d^2	
0	0	$n = 9$ $\bar{d} = 24.65$
5	25	
15	225	$\Phi = \frac{\frac{1}{9}(220)}{\left[\frac{1}{9}(10942) - (24.65)^2\right]^{1/2}}$
31	961	
45	2025	
59	3481	$\Phi = 1.023$
65	4225	
10	100	
0	0	
$\Sigma d = 220$	$\Sigma d^2 = 10942$	

Chimney Hill $\Phi = 1.023$ $p = 23^{bbl}/_{hr}$ ½" choke

FIGURE 4. Computation of ϕ

Before the ϕ value can be correlated with the productivity, production from a well must be related to a standard size choke (a ½" choke is suggested here). Fig. 5-A shows the experimental graphs for which the information was obtained from actual production tests through various sized chokes from a number of wells in the West Edmond Pool. Fig. 5-B shows a theoretical curve found by using basic physics formulas. Production from each well then for this work was related to the production through a ½" choke and the ϕ values were then plotted against the production values thus obtained. These results are shown in Figure 6. Continuing with our example, the ϕ value for the Bois D'Arc in the Kosar Well is found to be 0.95 which would indicate a production of 21 barrels per hour through a ½" choke, while the Chimney Hill with a ϕ value of 1.02 would have an indicated production of 23 barrels of oil per hour, a total of 44 barrels per hour. The well was completed for 55 barrels per hour. The calculated figure is well within the variation limits illustrated in Fig. 6.

Limitations of this method are many. Since only sixteen wells were used, the reliability of this particular correlation chart may be good for only a small area. Second, because of the method of investigation, one well in twenty is expected to fall outside of the limits. In addition, one well in one hundred is expected to fall excessively outside the limits. Third, these results indicate only that further work is justified and that in the future when the results of a much larger investigation are available, prediction should be considerably more reliable.

A correlation should be made for each formation and for the same formation where there is considerable variation in physical properties. After

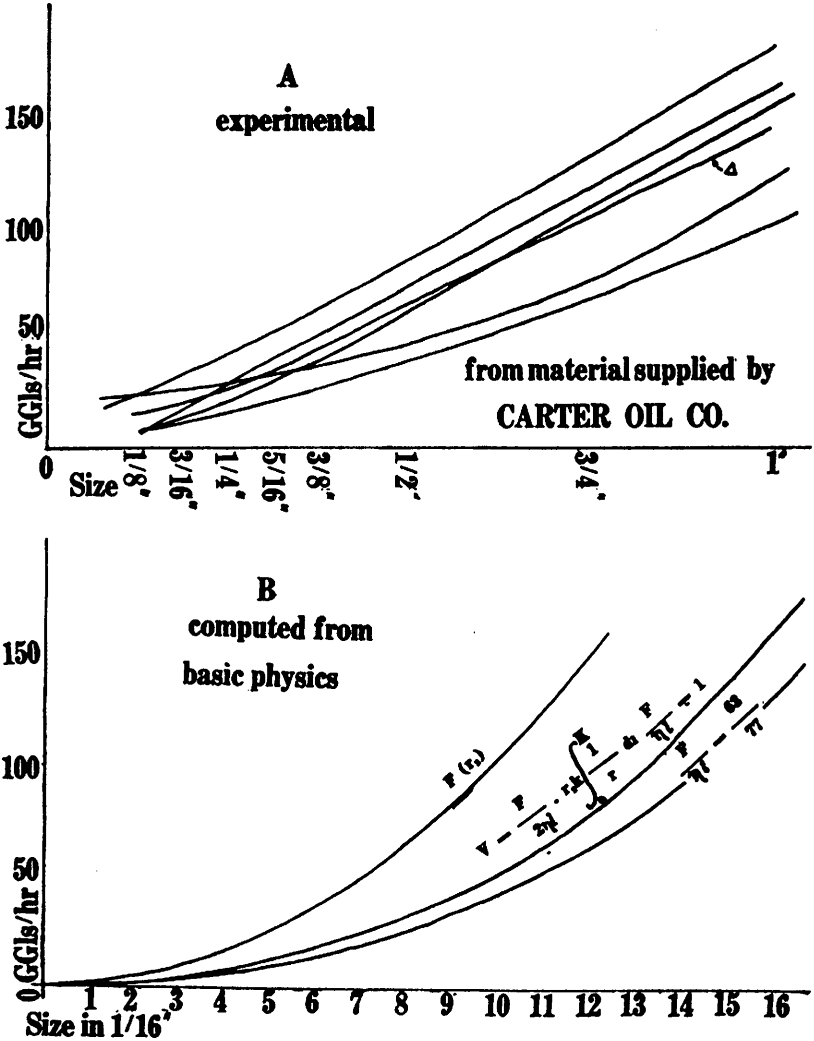

FIGURE 5. Flow Through Chokes

such correlation has been carried on, over, say, a hundred wells each, it may be possible to combine the various correlation charts. Further, the varied methods employed by the different companies engaged in electrical well logging require a separate correlation chart for each.

It might well be asked whether the time necessary to conduct an analysis of a well might prohibit the use of this type of prediction of a new well as an indication of its productiveness. It should be pointed out that the total time spent in representation graphically of the Kosar Well, computation of the

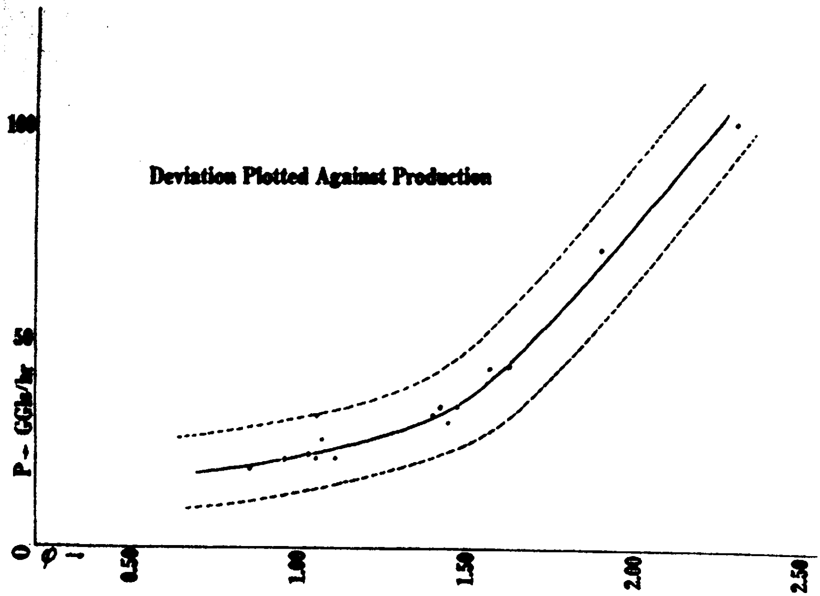

FIGURE 6.

variable, etc. required only forty minutes. It therefore seems evident that this type of analysis of the electric log diagram of the new well will be sufficiently accurate to eliminate to some degree the necessity of further testing. Further, it would give a new basis for proration in the West Edmond Pool. From the preceding it is evident that the possibilities of this type of investigation as a new tool for the interpretive geologist are unlimited. Finally, as an extreme example of the possibilities of this type of investigation it may in the future be possible, with modification of the present electrical geophysical methods, to predict fluid contents in advance of drilling.
