The Use of the Thermal Neutron Decay Time Log in West Texas

RALPH C. BRUTON
Schlumberger Well Services

INTRODUCTION

The Thermal Neutron Decay Time Log (TDT, a trademark of Schlumberger) is a pulsed neutron log that is used to locate hydrocarbons behind casing. The downhole equipment generates high-energy neutrons that penetrate the formation opposite the tool. These neutrons lose their energy as they collide with various atoms in the formation. The neutrons are captured by these atoms when they reach a thermal neutron energy level. The capturing atoms then emit gamma-rays which are counted by a downhole detector. The surface equipment computes the rate at which these neutrons are being captured.[1]

The rate at which neutrons are captured in the formation primarily depends on the amount of chlorine present. Since chlorine is a major constituent of salt water, the measurement can be related to the absence or presence of salt water. Then, when the porosity is known, the absence or presence of hydrocarbons can be inferred.

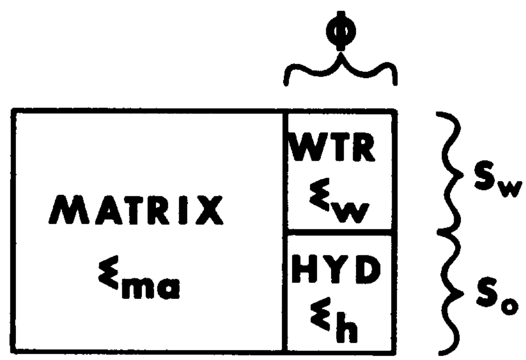
MACROSCOPIC CAPTURE CROSS SECTION (Σ) FOR SELECTED COMMON AND RARE ELEMENTS

COMMON ELEMENTS	Σ (in c.u.)
Chlorine	570.
Hydrogen	200.
Nitrogen	83.
Potassium	32.
Iron	28.
Sodium	14.
Sulfur	9.8
Calcium	6.6
Aluminum	5.4
Phosphorus	3.9
Silicon	3.4
Magnesium	1.7
Carbon	.16
Oxygen	.01
RARE ELEMENTS of Large Capture Cross Section	Σ (in c.u.)
Boron	45,000.
Cadmium	18,000.
Lithium	6,200.
Mercury	1,100.
Manganese	150.

TABLE 1

INTERPRETATION

All elements have a certain ability to capture thermal neutrons. This ability is expressed as the macroscopic capture cross section of that element (designated by the Greek symbol Σ). The unit of measurement used is the "capture unit". Table 1 lists various elements and their capture cross section.



$$\Sigma_{log} = (1-\Phi)\Sigma_{ma} + \Phi \cdot S_w \cdot \Sigma_w + \Phi(1-S_w)\Sigma_h$$

FIGURE 1

Figure 1 represents the volume of a typical clean formation composed of rock matrix, formation water, and hydrocarbons. The capture cross section of this formation would be the summation of the volume fraction of each element times the capture cross section of that element. The formation capture cross section would thus be:

$$\Sigma = (1-\phi)\,\Sigma_{ma} + \phi S_w \Sigma_w + \phi(1-S_w)\,\Sigma_{hc} \qquad (1)$$

ϕ is the porosity of the formation (open hole or cased hole logs).

Σ_{ma} is the capture cross section of the rock matrix (local matrix knowledge or TDT log).

Σ_w is the capture cross section of the formation water (chemical analysis, resistivity measurements or local knowledge).

Σ_{hc} is the capture cross section of the hydrocarbons (oil or gas).

S_w is the water saturation (percent water in the pore volume).

The formation capture cross section is obtained directly from the TDT log. Figure 2 solves Eq. 1 graphically for water saturation.[2] This method of interpretation works quite well in a high-porosity and high-water-salinity situation.

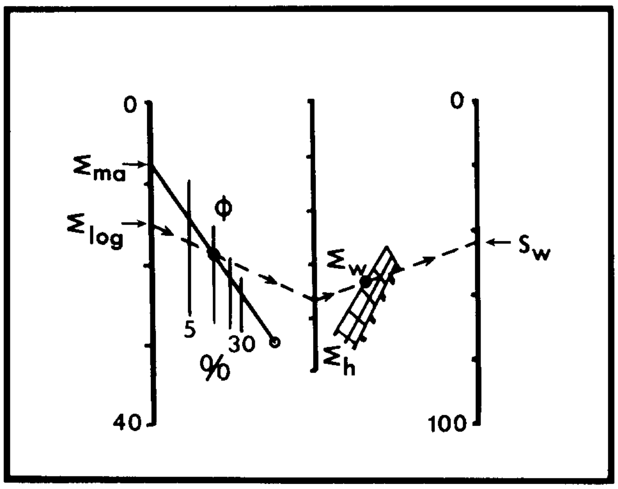


FIGURE 2

A good porosity value is absolutely essential for TDT log interpretation. Good porosity logs recorded before casing was set are preferable in most cases. Unfortunately, such open-hole logs are not available in many wells. The new Compensated Neutron Log (CNL, a trademark of Schlumberger) is an excellent log to use under these circumstances, as it provides accurate values of porosity through the casing. If necessary a high quality conventional neutron such as the GNT may be used.

Since the accuracy of the TDT log interpretation diminishes as the porosity is reduced, it becomes critical to establish the variables in Eq. 1 or Fig. 2 as accurately as possible.

The capture cross section of the formation water to use in Eq. 1 or Fig. 2 is difficult to ascertain. Since the capture cross section of water and NaCl salinity are directly related, a water sample can be measured (resistivity or chemical analysis) to determine the actual value. Many times, a measured actual value is too low to use because of trace elements present in the water which have a high capture cross section. Also, the measured log value and the true value of formation capture cross section may differ because of diffusion which alters the normal capture process.[3]

For these reasons an ***apparent*** water salinity or capture cross section should be used in Eq. 1 or Fig. 2. This ***apparent*** salinity may be as high as 2.5 times the measured salinity. It is very difficult to determine accurately.

An overlay method of interpretation is a refined approach which can be used to determine the ***apparent*** salinity. It also is an excellent visual technique for distinguishing between water-bearing and hydrocarbon-bearing formations.

In the overlay method, the porosity information and TDT information must be on a compatible scale so that a direct comparison can be made.

Equation 1 can be reduced by assuming that the water saturation is 100 percent (S_w=1.0) in all zones. Equation 1 can then be written:

$$\Sigma_{log} = (1-\phi)\,\Sigma_{ma} + \phi\,\Sigma_w \qquad (2)$$

An apparent water-filled TDT porosity can then be computed:

$$\phi_{TDT} = \frac{\Sigma_{log} - \Sigma_{ma}}{\Sigma_w - \Sigma_{ma}} \qquad (3)$$

A ***porosity*** overlay technique is one method of continuous interpretation. The apparent water-filled TDT porosity and an independent true porosity are compared on a linear scale. In a clean water-bearing zone, the apparent water-filled TDT porosity and the true porosity should coincide, since S_w is equal to 100 percent. In a hydrocarbon-bearing zone when S_w is less than 100 percent, the apparent water-filled TDT porosity will be too low. The amount of divergence between the two curves is a function of water saturation if the other parameters (ϕ, Σ_{hc}, and Σ_w) were chosen correctly. Shaliness tends to reduce the amount of separation and should be considered qualitatively. The accuracy of the water saturation determination diminishes as the porosity and water salinity decrease.

An alternate approach to the porosity overlay technique is the ***formation factor*** overlay technique. Both the apparent water-filled TDT porosity and the true porosity are converted to a formation factor by Archie's relationship:

$$F = \frac{1}{\phi^2} \quad (4)$$

The sensitivity of the curves is thus expanded by a factor of two. The formation factor values are then printed out on a $\log_{10}$ grid. The porosity can be read directly from a scale that is incorporated on each log. A formation factor of 100 is equivalent to a porosity of 10 percent. The porosity increases from right to left. The divergence between the curves still is a function of water saturation if the other parameters were chosen correctly.

The main advantage of the overlay technique, aside from being a "quick look" log, is that if the various parameters ($\Sigma_w, \Sigma_{ma}, \phi, \Sigma_{hc}$) are not well known, a good interpretation can still be made by "fitting" the two curves.

Figure 3 is a typical formation factor overlay log. Note the various responses opposite the different formations.

APPLICATIONS IN WEST TEXAS

The following examples demonstrate some of the applications of the Thermal Neutron Decay Time Log and the formation factor overlay techniques.

Figure 4

This is a chert and dolomite Devonian section in Crane County. The well had originally pro-

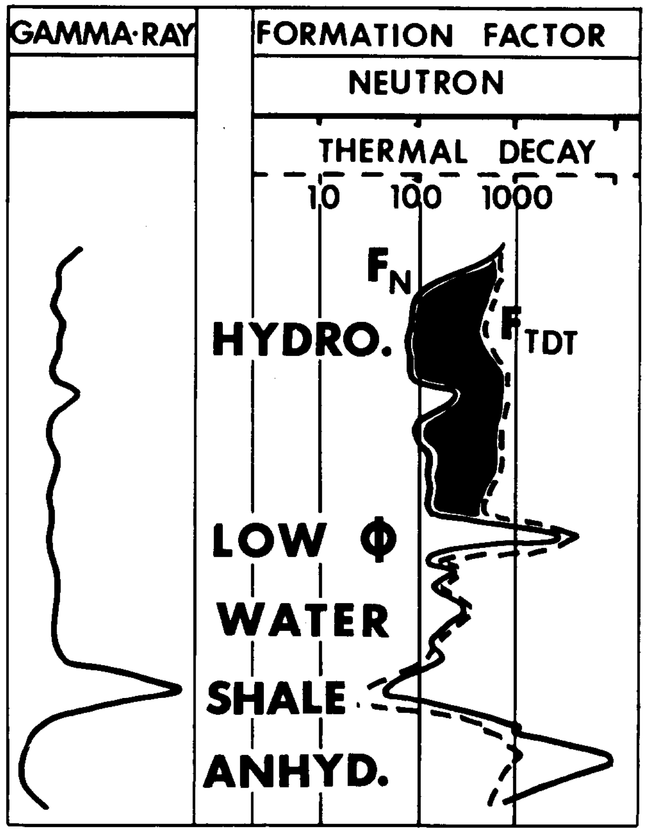


FIGURE 3

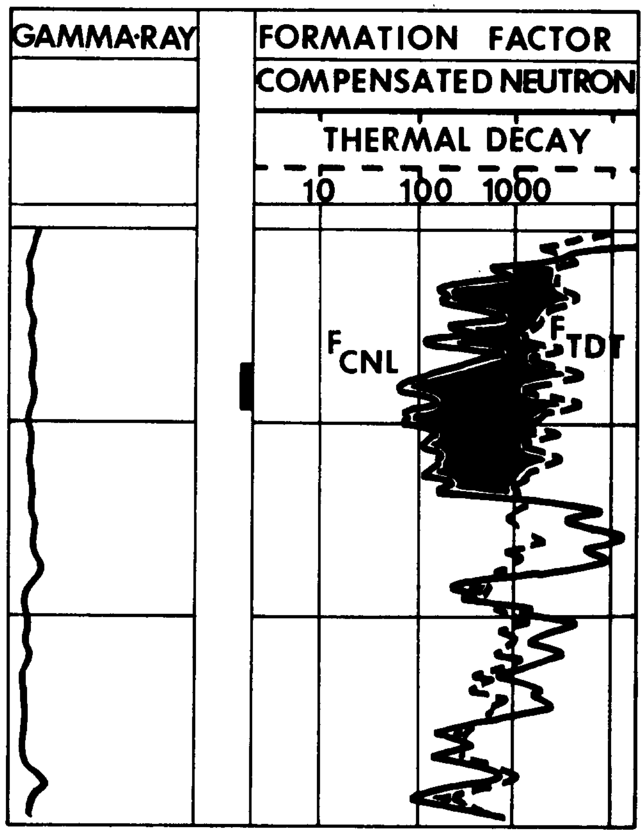


FIGURE 4

duced from a zone several hundred feet deeper than the Devonian. The Compensated Neutron Log was used to determine the true porosity. The formation factor overlay log showed that the average water saturation was approximately 10 percent through the most porous interval (lowest formation factor). Perforations were made through the section indicated in the depth track. The production gained was 133 BOPD and 0 BWPD.

Figure 5

This log is from a well through the Penn Reef section in Motley County. The well had produced a top allowable of 111 BOPD with no water after it was originally completed. Some years later the production had declined to 53 BOPD and 264 BWPD. Before logging, zone C had been squeezed and reperforated twice with no change in water production.

The TDT log was used with a conventional neutron to compute the overlay log. Zone C had a water saturation of about 45 percent which would indicate a high water-cut. This verified that the produced water was coming from zone C rather than through a channel in the cement.

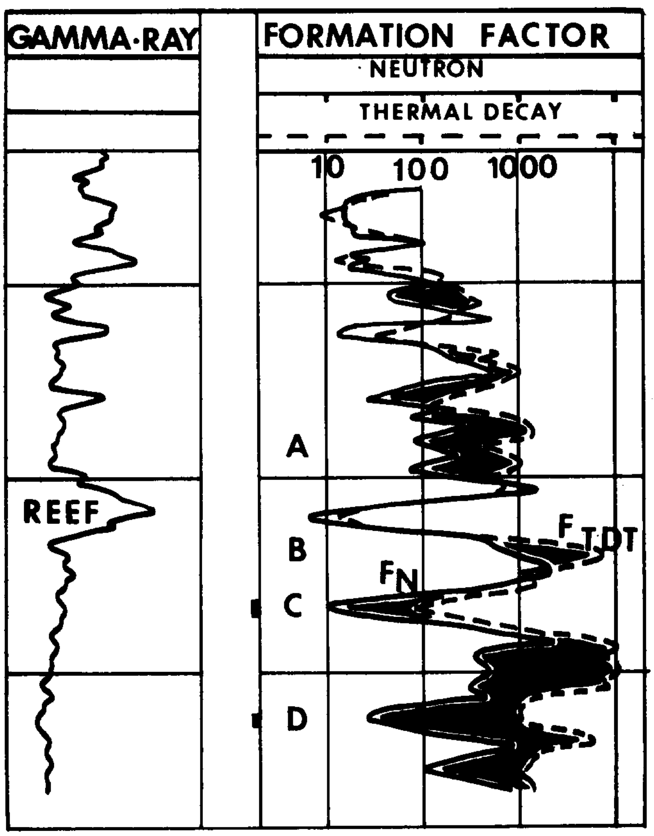


FIGURE 5

Zone D showed a water saturation of 10 percent. This interval was perforated as shown in Fig. 5 and potentialed for 147 BOPD with no water.

The formation factor overlay log indicated that the Strawn limestone stringer (zone A) above the Penn Reef had some potential for later production.

The information obtained through these logs refuted the belief that this reef was homogeneous and should drain through the uppermost porous interval.

Figure 6

This log is from a well in the same field as Fig. 5. The perforated interval in zone C had originally produced top allowable oil, but had dropped to 61 BOPD and 3 BWPD. The TDT log was run in an attempt to find another zone that would bring this well back up to top allowable.

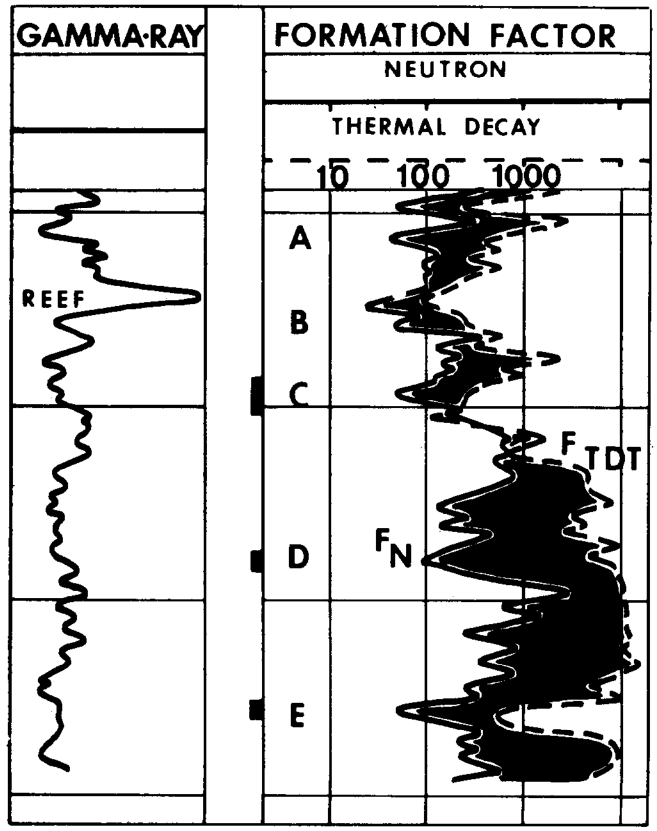


FIGURE 6

Zones D and E indicated good porosities from the conventional neutron, as well as low water saturation from the formation factor overlay log. Zone E was chosen to perforate since it was deeper than zone D. The well produced 106 BOPD and 5 BWPD from this interval for several months before the water production became excessive. It had produced 13,600 barrels of oil that might have been lost if the TDT log had not been run.

Zone D was then perforated for 100 BOPD and no water.

The Strawn limestone stringers (zone A) once again have future potential.

Figure 7

This is a log from a well through the Tubb dolomite in Crane County. It had formerly produced from a deeper formation (not shown). A drop in production from the deeper horizon had made the well uneconomical to operate.

The formation factor overlay log showed very low water saturations in the upper portions of the interval. This zone was perforated as indicated in Fig. 7 and yielded 500 MCFGPD and 55 BOPD with no water. Note that a sonic log was available for porosity information.

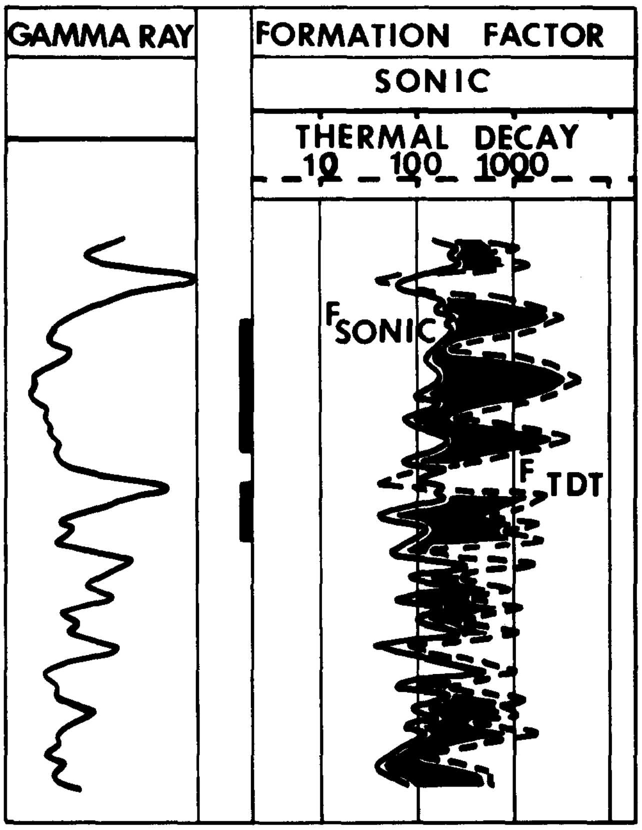


FIGURE 7

Figure 8

This log shows the Delaware Mountain carbonaceous sand in a well in Ward County. The well had originally produced from the much deeper Ellenburger formation.

Well conditions were quite adverse at the time the TDT was recorded. The hole size was 15-16 in. as recorded from the open-hole caliper, and there was no cement behind the 9-5/8 in. casing.

An open-hole sonic log was available to use for porosity information.

The formation factor overlay log showed water saturations that would indicate production in the upper 20 ft of the formation. This interval was perforated after squeezing for a potential of 5.4 MMCFGPD.

An offset well was drilled to this interval because of the excellent results in this well.

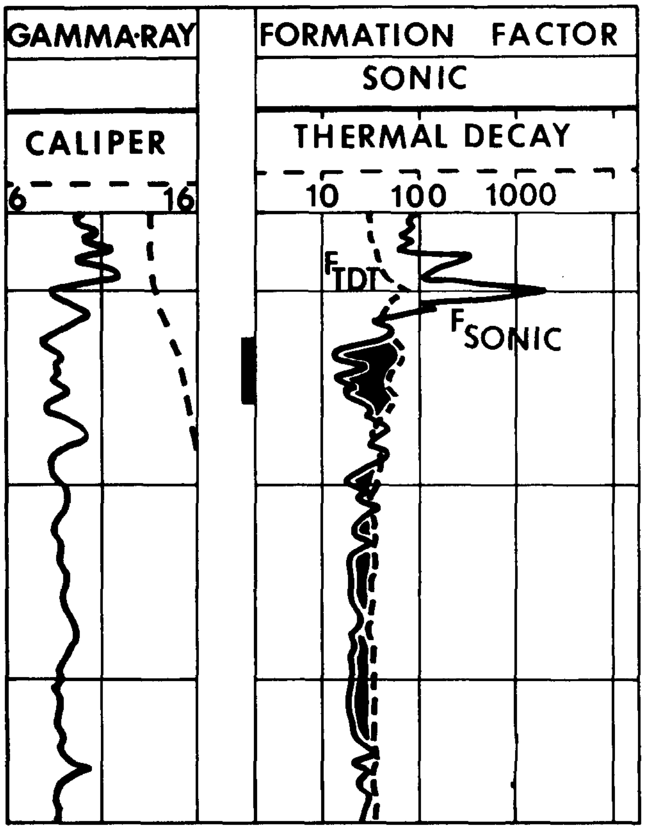


FIGURE 8

Figure 9

This is a log through the Grayburg-San Andres dolomite section in Crane County. The well was producing 4.0 MMCFGPD through the perforations shown in Fig. 9 on the right side of the depth track.

The TDT log was run to determine if some of the untested zones could add to the production. The well was killed with brine water prior to logging. The brine water probably entered the open perforations and flushed the gas back away from the bore. This would account for the high water saturations observed through the perforated intervals.

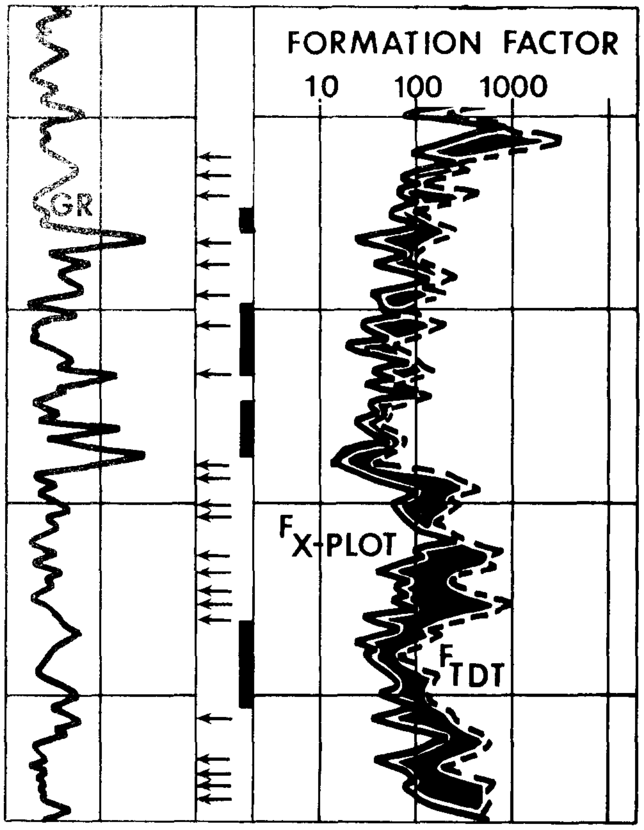


FIGURE 9

Information from an open-hole sonic and density log was used to derive a crossplot porosity, since these logs were available.

The formation factor overlay log showed low water saturations through the lower portion of this interval, which indicated production.

Perforations were added as shown by the arrows in Fig. 9. The well then produced 7.0 MMCFGPD, which was an increase of 3.0 MMCFGPD.

CONCLUSIONS

The Thermal Neutron Decay Time Log has done an outstanding job of finding hydrocarbons behind casing in West Texas. Many wells are being plugged—and—abandoned because the known pay zone is no longer economically feasible to produce. In many instances, unknown hydrocarbons could be located in the shallower zones with a minimum of workover costs by logging a TDT before plugging is considered.

The TDT log can be used to increase production or solve production problems as well as find new hydrocarbon zones.

The formation factor overlay technique is used as a continuous visual "quick look" log for distinguishing between water-bearing and hydrocarbon-bearing zones. It is also important in defining some of the unknown parameters so that an accurate interpretation can be made.

Many successful examples of the TDT log in West Texas attest to its value in solving problems in old wells.

REFERENCES

1. Clavies, D., Hoyle, W. R. and Meunier, D.: Quantitative Interpretation of TDT Logs, SPE of AIME, Denver, Sept. 28-Oct. 1, 1969.
2. Log Interpretation Charts, Schlumberger Limited, 1969.
3. Wahl, J. S., Nelligan, W. B., Trentrop, A. H., Johnstone, C. W. and Schwartz, R. J.: The Thermal Neutron Decay Time Log, SPE of AIME, Houston, Sept. 29-Oct. 2, 1968.